ABSTRACT BOOK

Scientific Organizing Committee:
P. Boumis (Greece, co-chair)
P. Slane (USA, co-chair)
E. Amato (Italy)
W. Blair (USA)
G. Dubner (Argentina)
R. Fesen (USA)
C. Fryer (USA)
J. Hughes (USA)
H. Lee (Japan)
D. Milisavljevic (USA)
J. Raymond (USA)
S. Safi-Harb (Canada)

Local Organizing Committee:
P. Boumis (Greece, co-chair)
A. Bonanos (Greece, co-chair)
D. Abartzi (Greece)
A. Chiotellis (Greece)
S. Derlopa (Greece)
M. Kopsacheili (Greece)
I. Leonidaki (Greece)
A. Manousakis (UAE)
G. Maravelias (Greece)
E. Paraskeva (Greece)
M. Pliatsika (Greece)
Z.T. Spetsieri (Greece)
M. Yang (Greece)

Venue: Minoa Palace Resort & Spa (Imperial Main Hall)

A conference organized by the National Observatory of Athens, Greece

PROGRAM

Sunday June 02

16:00 – 18:30	Registration	
20:30 – 00:00	**Welcome Reception** @ beach area of Minoa Palace Resort	

Monday June 03

07:45 – 08:30	Registration	

Morning Session (Chair: G. Dubner)

08:30 – 08:40	P. Boumis/P. Slane	Welcome
08:40 – 09:20	J. Raymond	(Opening Plenary) Understanding SNRs and Galaxies

Session 1: Observations and Classifications of SNe and SNRs

09:20 – 10:00	D. Patnaude	What do we learn from X-ray observations of SNe and SNRs
10:00 – 10:20	R. Fesen	The velocity and dynamical effects of Cas A's reverse shock
10:20 – 10:40	P. Plucinsky	The expansion of the forward shock of 1E 0102.2-7219 in X-rays
10:40 – 11:00	F. Sutaria	A deep, UV, imaging study of the Cygnus SNR
11:00 – 11:30	**Coffee Break & Poster Viewing**	
11:30 – 12:10	M. Modjaz	SN classification and diversity: the case of Stripped CCSNe
12:10 – 12:30	T. Holoien	Insights into the Local SN population from ASAS-SN
12:30 – 12:50	G. Terreran	Very late-time observations of stripped envelope SNe and evidences for the presence of a PWN
12:50 – 13:10	F. P. A. Vogt	Revealing the environment of central compact objects with optical integral field spectroscopy: E0102, Vela Jr., and friends
13:10 – 14:40	**Lunch**	

Afternoon Session (Chair: W. Blair)

14:40 – 15:00	N. Hurley-Walker	27 new SNRs found using the Murchison Widefield Array

Session 2: SN/SNR Progenitors: Models and Observations

15:00 – 15:40	N. Smith	The diversity in pre-SN evolution and mass loss of massive stars
15:40 – 16:00	K. Nomoto	Pre-SN mass ejections in pulsational pair-instability SNe and electron-capture SNe, and connections to super- luminous SNe and fast-evolving luminous transients
16:00 – 16:20	D.A. Howell	Pulsational and non-pulsational pair-instability SNe and their remnants
16:20 – 16:50	**Coffee Break & Poster Viewing**	
16:50 – 17:30	J. Murphy	Toward predicting and constraining the explosions of massive stars
17:30 – 17:50	A. J. Ruiter	Type Ia SN subclasses and their progenitors
17:50 – 18:10	P. Ruiz-Lapuente	Search of possible surviving companions in SNe Ia remnants to determine the nature of the explosions
18:10 – 18:30	20 Poster Presentations - Sessions 1 & 2	

Tuesday June 04

Morning Session (Chairs: H. Lee / C. Fryer)

Special Session: JWST – SNRs/SNe

09:00 – 09:40	W. Blair	JWST is on the Horizon: Is our community ready?

Session 2: SN/SNR Progenitors: Models and Observations

09:40 – 10:00	J. Anderson	A meta analysis of core-collapse SNe ^{56}Ni masses
10:00 – 10:20	B. Barna	Chemical stratification of type Iax SNe

Session 3: Supernova Explosion Mechanisms

10:20 – 11:00	H.-T. Janka	3D core-collapse SN modeling and applications to Cas A and other SNRs

11:00 – 11:30	**Coffee Break & Poster Viewing**	
11:30 – 12:10	M. Bersten	Hydrodynamical models of core-collapse SNe and shock breakout
12:10 – 12:30	S. Gronow	A sub-Chandrasekhar mass white dwarf as possible progenitor for a thermonuclear explosion
12:30 – 12:50	S.-C. Leung	Extracting type Ia SN explosion mechanisms by its nucleosynthesis yields
12:50 – 13:10	R. Sawada	Nucleosynthesis constraints on the energy growth timescale of a core-collapse SN explosion
13:10 – 14:40	**Lunch**	

Afternoon Session (Chair: S. Reynolds)

Session 4: Shock Physics and Particle Acceleration in SNRs

14:40 – 15:20	D. Caprioli	Acceleration at SNR shocks: state of the art and challenges
15:20 – 15:40	M. Miceli	Measuring the post-shock temperatures of heavy ions in SN 1987A
15:40 – 16:00	R. Bandiera	Interplay between physics and geometry in Balmer filaments
16:00 – 16:20	N. Tsuji	Constraint on diffusion coefficient at SNR shock using nonthermal X-ray and gamma-ray observations
16:20 – 16:50	**Coffee Break & Poster Viewing**	
16:50 – 17:30	A. Bamba	Observational study of nonthermal phenomena on SNR shocks
17:30 – 17:50	J. Vink	The strange behavior of the reverse shock of Cas A
17:50 – 18:10	D. Castro	The expansion and width of the synchrotron filaments associated with the forward shock of Cas A
18:10 – 18:30	20 Poster Presentations - Sessions 2, 3, 4 & 5	

Wednesday June 05

Morning Session (Chairs: D. Milisavljevic / P. Slane)

Session 5: Supernova Ejecta and Dust

09:00 – 09:40	B. Williams	What we can learn from ejecta in SNRs

09:40 – 10:00	M. Arias	The unshocked ejecta in Cas A and Tycho through low-frequency radio absorption
10:00 – 10:20	A. Wongwathanarat	A three-dimensional core-collapse SN model resembling Cas A
10:20 – 10:40	I. Seitenzahl	Type Ia SNR tomography
10:40 – 11:00	P. Ghavamian	Rings of metal-rich ejecta in Puppis A: hints of a SN interaction in a binary?

11:00 – 11:30 **Coffee Break & Poster Viewing**

11:30 – 12:10	M. Barlow	(on behalf of H. Gomez) Supernova dust factories
12:10 – 12:30	M. Matsuura	ALMA, VLT and SOFIA observations of SN 1987A
12:30 – 12:50	F. Schmidt	Hydrodynamic simulations of SNRs: Dust destruction by the reverse shock
12:50 – 13:10	H. Chawner	Dusty SNRs in our Galactic plane

Session 6: Pulsar Wind Nebulae

13:10 – 13:50	T. Temim	Progenitors and evolution of composite SNRs

13:50 – 14:00 **Conference Photo**

15:30 – 22:30 **Excursion #1: Tour to the Ancient Olive Tree of Vouves, Karavitakis Winery & Phalasarna beach**

15:30 Buses depart from Minoa Palace & Euphoria Resorts

22:30 Buses arrive to Minoa Palace & Euphoria Resorts

Thursday June 06

Morning Session (Chairs: P. Slane / S. Safi-Harb)

09:00 – 09:40	M.-H. Grondin	Gamma-ray observations of PWNe
09:40 – 10:00	M. Kerr	The tail of PSR J0002+6216 and the SNR CTB1
10:00 – 10:20	J. D. Gelfand	Probing extreme physics with PWNe
10:20 – 10:40	M. Filipovic	Discovery of a Pulsar-powered Bow Shock Nebula in the SMC SNR DEM S5
10:40 – 11:00	B. Guest	Spectral index maps of PWNe

11:00 – 11:30 **Coffee Break & Poster Viewing**

Session 7: SNRs and Their Galaxies

11:30 – 12:10	K. Long	What are we learning from SNR samples in nearby galaxies?
12:10 – 12:30	M. Kopsacheilli	Study of extragalactic SNRs

12:30 – 12:50	S. K. Sarbadhicary	Observational tests of momentum feedback by SNRs in M31
12:50 – 13:10	R. Diesing	Effect of cosmic rays on SNR evolution
13:10 – 14:40	**Lunch**	

Afternoon Session (Chairs: S. Safi-Harb / J. Vink)

14:40 – 15:20	I. Leonidaki	SNR populations in our Galaxy and beyond: bridging the gap

Session 8: Magnetic Fields in SNRs and PWNe

15:20 – 16:00	B. Olmi	Modeling PWNe and their magnetic fields
16:00 – 16:20	P. Velazquez	MHD simulations of SNRs in magnetized medium
16:20 – 16:50	**Coffee Break & Poster Viewing**	
16:50 – 17:30	S. Reynolds	Magnetic fields in SNRs: observational inferences
17:30 – 17:50	S. Loru	New high-frequency radio observations of the Cygnus Loop SNR
17:50 – 18:10	R. Kothes	Revealing the nature of the unusual PWN CTB87
18:10 – 18:30	20 Poster Presentations - Sessions 6, 7, 8, 9 & 10	
20:00	Buses depart from Minoa Palace Resort to Neorio Moro, Venetian Port of Chania	
20:30 – 23:30	**Conference Banquet** @ Neorio Moro Restaurant	
23:30	Buses depart from Neorio Moro to Minoa Palace Resort	

Friday June 07

Morning Session (Chairs: R. Fesen / J. Raymond)

Session 9: Jets and Asymmetries in SNe and Their Remnants

09:00 – 09:40	L. Lopez	The morphologies and kinematics of SNRs
09:40 – 10:00	C. Law	A three-dimensional kinematic reconstruction of SNR N132D's high-velocity, oxygen-rich ejecta
10:00 – 10:20	T. Holland-Ashford	Asymmetries of heavy elements in Cas A
10:20 – 10:40	A. Picquenot	Revisiting the ejecta asymmetries in Cas A with a novel method for component separation in X-rays

10:40 – 11:00	T. Kasuga	Doppler velocity measurement of Fe ejecta in Kepler's SNR
11:00 – 11:30	**Coffee Break & Poster Viewing**	
11:30 – 12:10	S. Orlando	Investigating asymmetries of SNRs through 3D long-term SN-SNR simulations

Session 10: SNe and SNRs with circumstellar interactions

12:10 – 12:50	R. Margutti	Changing look Supernovae
12:50 – 13:10	J. Larsson	HST observations of SN1987A in its early thirties
13:10 – 14:40	**Lunch**	

Afternoon Session (Chair: J. Raymond)

14:40 – 15:20	S. Katsuda	SNRs interacting with circumstellar medium
15:20 – 15:40	A. Chiotellis	On the interaction of type Ia SNRs with PNe
15:40 – 16:00	C. Fransson	The circumstellar media of superluminous SNe
16:00 – 16:20	B.-C. Koo	Dense circumstellar knots in the Cas A SNR
16:20 – 16:50	**Coffee Break & Poster Viewing**	
16:50 – 17:10	K. E. Weil	The optically inferred circumstellar environment of Cas A
17:10 – 17:30	M. Dopita*	Calibrating interstellar abundances using SNR radiative shocks - *In his memory, who passed away on Dec 22, 2018 - by I. Seitenzahl
17:30 – 18:10	R. Chevalier	(Closing Plenary) SNR research: Where do we stand?
18:10 – 18:30	P. Slane	Closing Remarks

Saturday June 08

08:30 – 20:00	**Excursion#2: Full-day excursion to Exotic Elafonisi beach & to Cretan Brewery "Charma"** Buses depart/arrive from/to Minoa Palace/Euphoria Resort

END OF CONFERENCE

CONFERENCE POSTERS

Session 1: Observations and Classifications of SNe and SNRs

S1.1	C. Braun	An X-ray Imaging and Spectroscopic Study of the Supernova Remnant RCW 103 Using Chandra and XMM-Newton
S1.2	J. Devin	Fermi-LAT observations of the surprising SNR G150.3+4.5
S1.3	R. Fesen	Discovery of Extensive Optical Emission from the Extremely Radio Faint Galactic Supernova Remnant G182.4+4.3
S1.4	M. Filipovic	Supernova Remnants in the Multi-Messenger Era
S1.5	V. Fragkou	Deep Optical Study of the Supernova Remnant G132.7+1.3
S1.6	D. Green	An updated catalogue of Galactic SNRs and some statistics
S1.7	É. J Harvey	Supernovae with the New Robotic Telescope
S1.8	N. Hurley-Walker	GaLactic and Extragalactic All-sky MWA Survey - eXtended
S1.9	A. Ingallinera	ASKAP observations of known and new Galactic SNRs
S1.10	P. Kostić	Test observations of galactic supernova remnant G67.7+1.8 with 1.4m telescope Milanković at Astronomical Station Vidojevica, Serbia
S1.11	J. A. Kypriotakis	Mapping the Physical Properties of Supernova Remnants in our Galaxy
S1.12	C. D.-J. Lin	Searching for Balmer-Dominated Type Ia SNRs in M33
S1.13	D. Milisavljevic	Evidence for a Pulsar Wind Nebula in the Type Ib Peculiar Supernova SN 2012au
S1.14	I. Moumen	3D Optical Spectroscopic Study of NGC 3344 with SITELLE: I. Identification and Confirmation of Supernova Remnants
S1.15	D. Onic	Revealing the radio continuum and X-ray properties of the Galactic supernova remnant G5.9+3.1 with Murchison Widefield Array and XMM-Newton
S1.16	P.-S. Ou	Structures of M33 Supernova Remnants Revealed by Broad-Band HST Images
S1.17	E. Paraskeva	Early high-cadence monitoring of supernovae: key to identifying the progenitors
S1.18	A. Rest	Light Echoes of Ancient Transients
S1.19	A. M. Ritchey	Physical Conditions in Shocked Interstellar Gas Interacting with the Supernova Remnant IC 443
S1.20	M. Rosado	Optical counterparts of Galactic Supernova Remnants and their kinematic distances
S1.21	S. Safi-Harb	A New Version of SNRcat: the High Energy Catalogue of Supernova Remnants
S1.22	Z. Spetsieri	Supernovae, transients and high amplitude variables in the Hubble Catalog of Variables
S1.23	K. E. Weil	The Cygnus Loop's Distance, Properties & Environment Driven Morphology
S1.24	J. West	G182.5-4.0: A new supernova remnant near the Crab nebula

S1.25	P. Zhou	Asymmetric Type-Ia supernova origin of W49B as revealed from spatially resolved X-ray spectroscopic study

Session 2: SN/SNR Progenitors: Models and Observations

S2.1	J. Anderson	The lowest metallicity type II supernova from the highest mass red supergiant progenitor
S2.2	B. Barna	Spectral signs of ^{56}Ni in the outer ejecta of SNe Ia
S2.3	F. Bocchino	A Virtual Reality environment for scientific exploitation of 3D MHD Astrophysical Simulations
S2.4	P. Chandra	Electron Cyclotron Maser Emission revealed in magnetic massive stars
S2.5	C.-H. Chen	Searching for Fast Runaway Massive Stars in Core-Collapse SNRs in the LMC
S2.6	M. Diaz-Rodriguez	Progenitor Mass Distribution for Core-Collapse Supernova Remnants
S2.7	J. I. Gonzalez-Hernandez	Searching for stellar companions of Galactic type-Ia Supernovae with HST and Gaia
S2.8	T. Jacovich	A Grid of Core Collapse Supernova Remnant Models Evolved from Massive Progenitors
S2.9	A. Yalinewich	The Signature of a Windy Radio Supernova Progenitor in a Binary System
S2.10	J. Kuuttila	Excluding SSSs as progenitors for four Type Ia supernovae in the LMC
S2.11	S.-H. Lee	Cradle-to-grave models for core-collapse supernova remnants and machine learning
S2.12	C.-J. Li	Searching for Surviving Companions of Type Ia SNe in Five Balmer-Dominated SNRs in the LMC
S2.13	W. Li	Constraints on the ejecta properties of SN 2018oh with early excess emission from K2 Observation
S2.14	G. Maravelias	Identifying massive stars in nearby galaxies, in a smart way
S2.15	P.-S. Ou	Is There a Critical Metallicity of Mass Loss in Massive Star Evolution?
S2.16	R. Ouchi	Constraining massive star activities in the final years through properties of supernovae and their progenitors
S2.17	L. Sun	Spatially Resolved X-Ray Spectroscopy of Kepler's Supernova Remnant: Distinct Properties of the Circumstellar Medium and the Ejecta
S2.18	A. Tutone	3D MHD simulations from the onset of the SN to the full-fledged SNR: role of ejecta clumps on matter mixing
S2.19	M. Yang	Evolved Massive Stars at Low-metallicity: A Source Catalog for the Small Magellanic Cloud

Session 3: Supernova Explosion Mechanisms

S3.1	D. Alp	X-Ray and Gamma-Ray Emission from 3D Neutrino-Driven SN Simulations and Comparisons With Observations of SN 1987A
S3.2	C. Fryer	Radioactive Isotopes in Core-Collapse Remnants
S3.3	F. Lach	Type Iax Supernovae from Deflagrations of Chandrasekhar Mass White Dwarfs
S3.4	S. Nagataki	From the (thermonuclear) supernova to the supernova remnant
S3.5	T. Takiwaki	Simulation of an Ultra-stripped Type Ic Supernova

Session 4: Shock Physics and Particle Acceleration in SNRs

S4.1	F. Acero	Understanding gamma-ray emission of RX J1713.7-3946
S4.2	B. Arbutina	Non-linear diffusive shock acceleration: A recipe for electron injection
S4.3	A. Bohdan	Physics of nonrelativistic perpendicular shocks of young supernova remnants: electron injection, energy redistribution and magnetic turbulences
S4.4	P. Dell'Ova	Stellar and interstellar content of the region interacting with cosmic rays in IC443G
S4.5	V. Domček	Synchrotron radiation in Cas A: the non-linear connection
S4.6	P. Kostić	Hydrodynamical simulations of supernova remnant in fractal interstellar medium: morphology of the shock-wave
S4.7	M. Lemoine-Goumard	Efficient particle acceleration from HESS J1640.6-4633 and the PeVatron candidate HESS J1641.0-4619
S4.8	N. Maxted	The gas structure towards supernova remnants suspected of cosmic-ray acceleration
S4.9	M. Pais	Constraining the coherence scale of the interstellar magnetic field using TeV gamma-ray observations of supernova remnants
S4.10	A. Pellizzoni	Challenging electron populations, magnetic fields and acceleration models in Supernova Remnants shocks through high-frequency single-dish radio observations
S4.11	H. Sano	Shock-cloud interactions in young gamma-ray supernova remnants: Evidence for cosmic-ray acceleration
S4.12	J. Shimoda	Polarized Balmer line emission from SNR shocks: on the effects of cosmic-ray acceleration
S4.13	I. Sushch	The impact of the circumstellar magnetic field of progenitor stars on the resulting gamma-ray spectrum of supernova remnants
S4.14	I. Sushch	Non-thermal emission from the reverse shock of the youngest galactic Supernova remnant G1.9+0.3
S4.15	H. Suzuki	A systematic study on escaping of cosmic rays from SNR shocks through observations of thermal X-ray plasmas
S4.16	M. Vučetić	Proper motion of Cygnus loop filaments

S4.17	R. Yamazaki	Toward the generation of magnetized collisionless shocks with high-energy lasers
S4.18	V. Zekovic	Quasi-parallel collisionless shock (re)formation and particle acceleration by (non)resonant micro-instabilities
S4.19	H. Zeng	Evolution of high-energy particle distribution in Supernova Remnants
S4.20	X. Zhang	Is Supernova Remnant Cassiopeia A a PeVatron?

Session 5: Supernova Ejecta and Dust

S5.1	F. Acero	Beyond the non-thermal emission of RX J1713.7-3946: first results from the XMM-Newton Large Program
S5.2	M. Barlow	Massive Amounts of Cold Dust in Small Magellanic Cloud Supernova Remnant 1E 0102-7219
S5.3	A. Bevan	Dust formation rates and locations in interacting supernovae
S5.4	F. Bocchino	Ejecta fragments and protrusions in and around SN1006
S5.5	E. Greco	Studying the radiative recombination continua in the X-ray spectra of pure ejecta and of overionized plasmas
S5.6	F. Kirchschlager	Dust destruction by the reverse shock in Cas A
S5.7	Y.-H. Lee	Near-Infrared Multi-Object Spectroscopy of the Outer Ejecta Knots in Cassiopeia A
S5.8	M. Niculescu-Duvaz	Spatially resolved models of the dust in Cassiopeia-A using DAMOCLES
S5.9	F. D. Priestley	Revisiting the Crab Nebula's dust and synchrotron radiation from the infrared to radio domain
S5.10	F. D. Priestley	The survivability of newly-formed dust grains in supernova remnants
S5.11	J. Slavin	Survival of Dust Created in Cas A Supernova Remnant
S5.12	L. Shingles	Late-phase radiative transfer of Type Ia supernovae
S5.13	R. Wesson	Dust in the remnant of SN 1995N

Session 6: Pulsar Wind Nebulae

S6.1	Y. Bao	Interpreting the GeV-TeV Gamma-ray Emission of the Vela X Pulsar Wind Nebula
S6.2	G. Castelletti	A new radio look of the pulsar wind nebula 3C 58
S6.3	Y. A. Gallant	Pulsar Wind Nebulae observed in TeV gamma-rays and their Galactic environments
S6.4	E. Giacani	New X- ray observations towards the pulsar PSR J1826-1256
S6.5	S. Hattori	NuSTAR Properties of G21.5-0.9
S6.6	J. Lee	Rapid X-Ray Variations of the Geminga Pulsar Wind Nebula
S6.7	B. Olmi	Middle aged PWNe: Hints on the reverberation process
S6.8	C. Omand	Submillimetre Constraints on the Pulsar-Driven Supernova Model

S6.9	S. Park	Spectral Nature of Quiescent X-ray Emission from SGR 0526-66 in the LMC
S6.10	S. Safi-Harb	The X-ray Evolution of the PWN in the SNR Kes 75
S6.11	S. Tanaka	Dynamics of Pulsar Wind Nebula with Magnetic Dissipation and Turbulence

Session 7: SNRs and Their Galaxies

S7.1	W. P. Blair	The Fireworks Galaxy, NGC 6946: Looking at the Fading Embers
S7.2	J. Bruursema	A UKIRT [FeII] Study of M33 and its Supernova Remnants
S7.3	B.-C. Koo	Supernova Remnants and Supernova Feedback
S7.4	D. Leahy	Applying models with reverse shocks to Galactic supernova remnants in the VGPS survey.
S7.5	D. Leahy	Using MHD simulations to construct analytical models for supernova remnant evolution
S7.6	M. Michałowski	What can we learn about SNe from atomic gas in their environments?
S7.7	I. Moumen	O CEASAR: The Optical Catalogue of ExtrAgalactic SupernovA Remnants
S7.8	H. Sano	ALMA view of the molecular clouds associated with the Magellanic SNRs
S7.9	S. Sarbadhicary	Deep, systematic radio-based surveys of supernova remnants in M31 and Magellanic Clouds

Session 8: Magnetic Fields in SNRs and PWNe

S8.1	A. Moranchel-Basurto	Asymmetries in the emission from young supernova remnants: The case of Tycho
S8.2	P. Slane	X-ray Polarization in Supernova Remnants

Session 9: Jets and Asymmetries in SNe and Their Remnants

S9.1	E. Greco	Discovery of a jet-like structure with overionized plasma in the SNR IC 443
S9.2	M. Millard	Measuring Ejecta Velocities in Tycho's and Kepler's Supernova Remnants with the Chandra HETGS
S9.3	T. Nagao	An extended aspherical explosion of a core-collapse supernovae
S9.4	A. Suzuki	Supernova ejecta with a powerful central engine
S9.5	S. Ustamujic	Three-dimensional MHD modeling of SNR IC 443: effects of the inhomogeneous medium in shaping the remnant morphology
S9.6	F. Vogt	Exploring the scientific potential of Virtual Reality for observational astrophysics with SNR 1E 0102.2-7219

Session 10: SNe and SNRs with circumstellar interactions

S10.1	C. Abate	What is the role of wind mass transfer in the progenitor evolution of Type Ia Supernovae?
S10.2	M. Arias	The Circumstellar and Interstellar Environment of VRO 42.05.01, A Peculiar Mixed Morphology SNR
S10.3	P. Boumis	Optical study of the peculiar SNR G 166+4.3 (VRO)
S10.4	A. Chiotellis	VRO 42.04.01: A supernova remnant resulting by a supersonically moving Wolf Rayet progenitors star
S10.5	S. Derlopa	SNR VRO (G 166.0 +4.3) 3-D morpho-kinematical model
S10.6	P. Chandra	Revealing inhomogeneities in supernovae shocks and their environments via low frequency radio observations
S10.7	É. J. Harvey	A recurrent nova super-remnant in the Andromeda galaxy
S10.8	M. Katsuragawa	Time-dependent hydrodynamic model of X-ray emitting plasma in evolved SNRs for high resolution X-ray spectroscopy
S10.9	H.-G. Lee	Near-infrared imaging and spectroscopic observations of supernova remnants in M33
S10.10	Q.-C. Liu	Investigation of the Interstellar Environment of SNR CTB 87
S10.11	H. Matsumura	Suzaku X-ray Observations of Galactic Supernova Remnants to Understand the Formation Process of Recombining Plasmas
S10.12	T. Matsuoka	Millimeter Emission from SNe in the Very Early Phase: Implications for Dynamical Mass Loss of Massive Stars
S10.13	N. Maxted	Upper Limits on Very-High-Energy Gamma-ray Emission from Supernovae Observed with H.E.S.S.
S10.14	M. Miceli	Fe K-alpha emission from the southwestern limb of SN 1006
S10.15	O. Mogawana	Radio Predictions Of Core-Collapse Supernovae
S10.16	A. P. Ravi	The Latest Evolution in the X-ray Remnant of SN 1987A
S10.17	P. Saha	A study of Kepler supernova remnant: angular power spectrum estimation from radio frequency data
S10.18	J. Y. Seok	Unbiased Spectroscopic Study of the Cygnus Loop with LAMOST
S10.19	H. Yasuda	Time evolution of broadband non-thermal emission from SNRs in different circumstellar environments
S10.20	G.-Y. Zhang	Non-equilibrium ionization in mixed-morphology SNRs
S10.21	P. Zhou	Molecular Gas toward Supernova Remnant Cassiopeia A

Special Session: JWST – SNRs/SNe

S.S.1	E. Regos	Detection of SNe beyond redshift of 2 with the JWST

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Opening Plenary

Understanding Supernova Remnants and Galaxies

Invited Plenary Talk

John Raymond

Harvard-Smithsonian Center for Astrophysics, USA

Abstract

Supernova remnants play many key roles in the evolution of galaxies.They dominate the chemical evolution; they generate the turbulence;they produce cosmic rays; they supply the hot phase of the ISM; and,they govern the destruction of dust grains. Models of galaxy formation and evolution simplify all this to a few adjustable parameters, but a reliable foundation is needed for the models to have predictive power. There have been major advances in the observations of SNRs in recent years, at wavelengths from gamma-rays to radio, and there have been corresponding improvements on the theoretical side including shock wave physics, the mechanisms of supernova explosions, and sophisticated numerical simulations. I'm looking forward to a conference that explores many of these topics.

Session 1.

Observations and Classifications of SNe and SNRs – Oral Talks

The Velocity and Dynamical Effects of Cas A's Reverse Shock

Oral Talk

Robert Fesen[1], Dan Patnaude[2], Dan Milisavljevic[3], and Kathryn Weil[1]

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[2]Smithsonian Astrophysical Observatory, Harvard, USA
[3]Purdue University, USA

Abstract

Using ground-based and HST images taken in the optical and NIR of the Cassiopeia A supernova remnant covering the time period 1951 to 2019, together with moderate dispersion optical spectra of selected filaments, we present an investigation of the remnant's reverse shock velocity and the dynamical effects it has on the remnant's expanding metal-rich ejecta. Proper motion measurements of optical features all around the remnant's main emission shell indicate Cas A's reverse shock front is fragmented due to the clumpy nature of the ejecta but can be in some areas seen as a nearly continuous, although highly corrugated in places, shock front. In areas of the remnant's main emission shell exhibiting relatively small radial velocities, we find the reverse shock to be roughly stationary in terms of proper motion in the sky reference frame, exhibiting a small transverse motion toward the remnant's center of -500 to 0 km/s. This implies a reverse shock velocity with respect to the ejecta roughly nearly equal to the ejecta's expansion velocity of 5000 – 5500 km/s. In addition, we find strong dynamical effects of the reverse shock on the morphology of the ejecta visible both in HST images and in moderate resolution ground-based optical spectra. These data reveal the formation of extended mass ablated trailing emission 'tails' on scales of $0.1'' - 1.0''$ following passage of the reverse shock, with decelerated velocities as high as 1000 km/s.

Insights into the Local Supernova Population from ASAS-SN

Oral Talk

Thomas Holoien

The Observatories of the Carnegie Institution for Science, USA

Abstract

The last major census of the supernova population in the local Universe was the Lick Observatory Supernova Search (LOSS), whose sample was biased by the survey strategy and methodology. The All-Sky Automated Survey for Supernovae (ASAS-SN) surveys the entire visible sky nightly to a depth of $g \sim 18.5$, and since beginning operations in 2013 we have discovered over 1000 bright, nearby supernovae. Using this population, we are constructing an unbiased volume-limited sample of supernovae to a redshift of $z = 0.02$, allowing us to build upon the results from LOSS and perform population and rate studies that were not previously possible. In this talk I will discuss the early results of these rate and population studies, and how these results can inform the classification and further study of supernovae. In particular, the results from ASAS-SN will be highly applicable to studying supernova populations at higher redshifts with future survey projects such as LSST.

27 new SNRs found using the Murchison Widefield Array

Invited Talk

Natasha Hurley-Walker

Curtin University, International Centre for Radio Astronomy Research, Australia

Abstract

95% of all supernova remnants (SNRs) have been discovered via their radio emission. Most surveys have been restricted to a small field-of-view, reducing the area surveyed. Interferometric surveys may resolve out large-scale objects and underestimate the brightness of extended features, while the low resolution of single-dish surveys often leads to confusion and a difficulty understanding the morphology of SNRs. In the case of single-frequency surveys, discriminating between thermal and non-thermal emission can be difficult, leading to false identification of candidates. The field is on the threshold of change with the advent of wideband, widefield, low-frequency radio telescopes, driven by the upcoming Square Kilometer Array (SKA). Using images from the Galactic and Extragalactic All-sky Murchison Widefield Array (GLEAM; MWA) survey, I have discovered 27 SNRs via their non-thermal emission at low radio frequencies. Some of these are quite unusual objects with very low surface brightness, or steep spectral indices, while others were simply hidden from view due to confusion between thermal and non-thermal emission at higher radio frequencies. For six candidates I have suggested pulsar associations and can derive physical characteristics. I will conclude the talk with future prospects for further discoveries using upcoming surveys by the low-frequency SKA and its precursors.

SN classification and diversity: the case of Stripped CCSNe

Invited Talk

Maryam Modjaz

New York University, USA

Abstract

I will review the field of SN classification and observed diversity for the case of Stripped Envelope Core-Collapse SNe.

What Do We Learn From X-ray Observations of Supernovae and Supernova Remnants?

Invited Talk

Daniel Patnaude

Smithsonian Astrophysical Observatory, Harvard, USA

Abstract

At different times, the X-ray emission from supernovae and supernova remnants will encode a wealth of information about the properties of the explosion, the progenitor, and its environment. In this talk I will present recent observations of supernova remnants and young supernovae, and discuss how they inform us about how stars both evolve and end their lives. In particular, I will detail how multi-epoch observations of young supernovae provide clues about progenitor mass loss properties and allow us to understand the evolution of supernova central engines. I will also review how X-ray spectra of supernova remnants provide clues to the explosion physics and can potentially aid us in assigning a supernova remnant to a particular supernova subtype. Finally, I will discuss recent efforts to use machine learning to connect the properties of supernova remnants back to their progenitors in order to classify remnants in terms of their progenitor properties.

The Expansion of the Forward Shock of 1E 0102.2-7219 in X-rays

Oral Talk

Paul Plucinsky[1], Long Xi[2], Terrance J Gaetz[1], John P. Hughes[3] and Daniel J. Patnaude[1]

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Abstract

We measure the expansion of the forward shock of the Small Magellanic Cloud supernova remnant 1E 0102.2-7219 in X-rays using Chandra X-Ray Observatory on-axis Advanced CCD Imaging Spectrometer (ACIS) observations from 1999–2016. We estimate an expansion rate of 0.025±0.006 yr^{-1} and a blast-wave velocity of $1.61 \pm 0.37 \times 10^3$ km s^{-1}. Assuming partial electron-ion equilibration via Coulomb collisions and cooling due to adiabatic expansion, this velocity implies a post shock electron temperature of 0.84±0.20 keV which is consistent with the estimate of 0.68±0.05 keV based on the X-ray spectral analysis. We combine the expansion rate with the blast wave and reverse shock radii to generate a grid of one-dimensional models for a range of ejecta masses (2-6 $M_\odot$) to constrain the explosion energy, age, circumstellar density, swept-up mass, and unshocked-ejecta mass. We find acceptable solutions for a constant density ambient medium and for an r^{-2} power-law profile (appropriate for a constant progenitor stellar wind). For the constant density case, we find an age of 1700 yr, explosion energies 0.87-2.61× 10^{51} erg, ambient densities 0.85-2.54 amu $^{-3}$, swept-up 22-66 $M_\odot$, and unshocked-ejecta masses 0.05-0.16 $M_\odot$. For the power-law density profile, we find an age of $\sim$ 2600 yr, explosion energies 0.34-1.02× 10^{51} erg, densities 0.22-0.66 amu cm^{-3} at the blast wave,swept-up masses 17-52 $M_\odot$, and unshocked-ejecta masses 0.06-0.18 $M_\odot$. Assuming the true explosion energy was 0.5-1.5 × 10^{51} erg, ejecta masses 2-3.5 $M_\odot$ are favored for the constant density case and 3-6 $M_\odot$ for the power-law case. The unshocked-ejecta mass estimates are comparable to Fe masses expected in core-collapse supernovae with progenitor mass 15.0-40.0 $M_\odot$, offering a possible explanation for the lack of Fe emission observed in X-rays.

A deep, UV, imaging study of the Cygnus Supernova Remnant

Oral Talk

Firoza Sutaria[1], K. P. Singh[2], Jayant Murthy[1] and N.K. Rao[1], and A. Ray[3]

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Abstract

The x-ray, UV, and optically bright Cygnus supernova remnant provides a unique opportunity to characterize the interaction of a supernova shock, and the ejecta with any historical circumstellar medium (CSM) ejected by the progenitor, as well as the local ISM. Using the F154W, F169M, F172M, and the N279N filters on the Astrosat/UVIT instrument, we provide the most complete FUV and NUV imaging study of this SNR to date. Combined with archival IUE slit-spectra, we trace nebular emission regions of C IV (1550 Å), HeII (1640 Å) and N IV (1468 Å). The further inclusion of Galex NUV broad-band (1693-3007 Å) images of the same regions allows us to isolate emission features of Mg II UV doublet (2795 / 2803 Å) from the NUV continuum. Finally, we use simultaneous Astrosat/SXT soft x-ray (0.3-10 keV) spectra fitted to multicomponent thermal plasma models, to isolate the thermal characteristics of the same regions. Combined with archival XMM/Newton and Chandra spectra, and some archival optical data, we study the interaction of supernova blast wave with (mainly) the progenitor's CSM, and better constrain the CSM properties, thus providing an insight in to the nature of the remnant's progenitor.

Very late-time observations of stripped-envelope SNe and evidences for the presence of a Pulsar Wind Nebula

Oral Talk

Giacomo Terreran[1], Raffaella Margutti[1], Deanne Coppejans[1] and Dan Milisavljevic[2]

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Abstract

Late-time observation of supernovae have already proven to be an invaluable source of information, providing a privileged insight to the innermost region of the ejecta, and therefore on the core of the progenitor star. By waiting long enough for the ejecta to be completely optically thin, we could in principle reveal the compact remnant left by the explosion. Very late-time observations of a handful of stripped-envelope SNe are starting to show indirect evidences for the presence of the compact object left there by the stellar collapse (e.g. Milisavljevic et al., 2018). Optical spectra taken more than a decade after explosion appear to be dominated by forbidden emission of oxygen and sulfur, with velocities of 2500 km/s. These could result from the heating of the ejecta by a inner source, like a pulsar wind nebula. This is also supported by an enhancement of the X-ray and radio fluxes, possibly originated by the highly magnetized compact object. We present very very-late observations of SNe at t 6-16 years and discuss our findings into the context of pulsar wind nebulae inflated by the compact object.

Revealing the environment of Central Compact Objects with optical integral field spectroscopy: E0102, Vela Jr., and friends.

Oral Talk

Frédéric P.A. Vogt[1], Ivo R. Seitenzahl[2], Parviz Ghavamian[3], Elizabeth S. Bartlett[1], Ashley J. Ruiter[2]

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Abstract

Last year, integral field spectroscopic observations of SMC SNR E0102 with MUSE at the VLT revealed a peculiar, pc-scale, ring-shaped structure visible primarily in optical recombination lines of Ne I and O I. An X-ray point source, with a spectral signature consistent with the Central Compact Object (CCO) found in Cas A, was subsequently identified at the center of the ring in reprocessed archival Chandra observations. In this talk, I will discuss the observational efforts undertaken by our team in the wake of this discovery, focusing on the potential of optical emission lines for studying the immediate environment of galactic CCOs. I will describe our ongoing MUSE survey of these systems which was initiated in 2018, and present the first scientific outcome. In particular, MUSE is allowing us to settle the mysterious nature of the nebulosity spatially coincident with the CCO in the Vela Jr. SNR, that shines primarily in the lines of [N II] 6548,6584Å. We also find evidence of an outflow from the nearby emission-line star Wray 16-30 that unambiguously connects it with the near-by (pc-scale) Hα nebulosity.

Session 1.

Observations and Classifications of SNe and SNRs – Posters

An X-ray Imaging and Spectroscopic Study of the Supernova Remnant RCW 103 Using Chandra and XMM-Newton

Poster

C. Braun[1], S. Safi-Harb[1] and C. Fryer[2]

[1] University of Manitoba, Canada
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Abstract

RCW 103 is a Galactic supernova remnant (SNR) with a bilateral morphology and hosting the peculiar central compact object (CCO) 1E 161348-5055. We present a Chandra and XMM-Newton imaging and spectroscopic study of RCW 103 with the goal to determine the intrinsic properties of the SNR including the explosion energy, ambient density, age, distance and progenitor mass. XMM-Newton data were used to construct equivalent width images for the Fe L, Mg, Si, and S lines to map the distribution of the ejecta and to extract spectra from the low-surface brightness regions of the remnant. Chandra data were used to perform a spatially resolved spectroscopic study with 54 regions spanning the entire remnant. These regions were best characterized by a two-component thermal model, VPSHOCK+APEC. The hard component (kT$\sim$0.6 keV) is best fit by the VPSHOCK non-equilibrium ionization model with an ionization timescale in the range of 10^{11}–10^{12} cm^3 s and slightly enhanced abundances. The soft component (kT$\sim$0.2 keV) is best fit by the APEC model, describing plasma in collisional ionization equilibrium with abundances consistent with solar values. We discuss the nature of the SN explosion and its progenitor mass by comparing the fitted abundances with the most recent core-collapse nucleosynthesis models, including with different explosion energies.

Fermi-LAT observations of the surprising SNR G150.3+4.5

Poster

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Abstract

G150.3+4.5 has been detected as a faint radio supernova remnant with an angular size of 3 degrees (Gao & Han, 2014), suggesting an old or a nearby SNR. Extended gamma-ray emission spatially coincident with the radio morphology has been reported in the Fermi-LAT Galactic Extended Sources catalog (FGES, Ackermann et al., 2017), revealing a hard spectral index from 10 GeV to 2 TeV. A dedicated Fermi-LAT data analysis from 5 GeV to 500 GeV confirmed the hard spectral shape (Gamma $\sim$ 1.88, Mysore et al. 2015), similar to that observed in young shell-type SNRs such as RX J1713.7-3946 or RCW 86. However, no non-thermal X-ray emission from G150.3+4.5 has been reported, challenging our understanding on the origin of the emission. Using 10 years of Fermi-LAT data, we investigate the morphology and the spectral properties of the SNR G150.3+4.5, from 1 GeV to 1 TeV, to constrain the origin of the emission. This newly discovered SNR may be one of the closest GeV gamma-ray SNRs and one of the best SNR candidates, as a bright TeV object, that could be observed with the next generation of Cherenkov telescopes (CTA, Cherenkov Telescope Array).

Discovery of Extensive Optical Emission from the Extremely Radio Faint Galactic Supernova Remnant G182.4+4.3

Poster

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Abstract

Wide-field Hα images of the radio faint Galactic supernova remnant G182.4+4.2 reveal a surprisingly extensive and complex optical emission structure with an unusual series of broad and diffuse filaments along the remnant's southwestern limb. Deep [O III] images reveal no appreciable remnant emission with the exception of a single filament coincident with the westernmost of the broad southwest filaments. The near total absence of [O III] emission suggests the majority of the remnant's optical emission arises from relatively slow shocks (< 80 km/s). Low-dispersion optical spectra of several regions in the remnant's main emission structure confirm a lack of appreciable [O III] emission and indicate [S II]/H*alpha* line ratios of 0.75 - 1.03, consistent with a shock-heated origin. We propose that G182.4+4.2 is a relatively large (d ∼50 pc at 4 kpc) and much older (age ∼40 kyr) supernova remnant than previously estimated, whose weak radio, X-ray and optical emissions are related to its age and location in a low density region some 12 kpc out from the Galactic center.

Supernova Remnants in the Multi-Messenger Era

Poster

Miroslav Filipovic[1], Nigel Maxted[1], Gavin Rowell[2], Manami Sasaki[3], Frank Haberl[4], Dejan Urosevic[5], Maitra, Pierre Maggi[6], Rami Alsaberi[1] and Patrick Kavanagh[7]

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Abstract

This is an exciting time for the discovery of supernova remnants (SNRs) in our and other nearby galaxies. SNRs reflect a major process in the elemental enrichment of the ISM. The study of this interaction in different domains including gamma-ray, radio, optical, IR and X-ray, allow a better understanding of these objects and their environments. Nearby galaxies offer an ideal laboratory, since they are near enough to be resolved, yet located at relatively known distances. The emission from non-thermal MeV to GeV electrons makes SNRs bright radio sources, while non-thermal X-rays have been confirmed for a number of young Galactic SNRs indicating the existence of TeV electrons. Similarly, highly relativistic particles have been detected in superbubbles (e.g., 30 Dor C), which are interstellar structures created by the combination of stellar winds of massive stars and their supernovae. However, the underlying physics such as particle injection, magnetic field configuration and amplification, and the escape of particles from the shock regions requires further investigation. Magnetic fields in SNRs and superbubbles are most likely a complex mixture of interstellar magnetic fields, relic fields of the progenitor, fields modified and enhanced by turbulence in the shock regions, and fields excited by relativistic particles. Therefore, various high spatial resolution, high sensitivity, and high spectral resolution observations are necessary to address these issues. SKA pathfinders' observations in radio at low frequencies with high sensitivity will detect new SNRs in our Galaxy

and the MCs, which are either old and too faint, young and too small, or located in a too confusing environment and have thus not been detected yet. In addition, the SKA pathfinders' observations will also allow high-resolution polarimetry and are key to the study of the energetics of accelerated particles as well as the magnetic field strength and configurations. Gamma-ray studies provide answers to the long-standing question in high energy astrophysics: Where do cosmic rays come from? The gamma-ray emission seen from some middle-aged SNRs is now known to be from distant populations of cosmic-rays (probably accelerated locally) interacting with gas, but there is still much work to be done in accounting for the Galactic cosmic-ray flux. Young PeV gamma-ray supernova remnants require different techniques to address the question of cosmic-ray acceleration. The CTA will allow us to do this. I will present an overview of our ongoing multi-wavelength studies of the young (and some not-so-young) SNRs: LMCSNR0509-69, N103B, RX J1713.7-3946, HESSJ1731-347, Vela Jr, HESS J1534-571, G23.1+0.2 and others. Finally, I will present our strategies for the next 10 years on how to observe SNRs with the next generation of instruments – from ASKAP/MWA2 via eROSITA to CTA.

Deep Optical Study of the Supernova Remnant G132.7+1.3

Poster

V. Fragkou[1], P. Boumis[1], A. Chiotellis[1], S. Derlopa[2,3], S. Akras[4], E. Harvey[4], J. Alikakos[2] and I. Leonidaki[6]

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Abstract

G132.7+1.3 is one of the most extended supernova remnants is our Galaxy. In this work we explore its optical emission with $H\alpha$ + $[N_{II}]$, $[S_{II}]$ and $[O_{III}]$ imaging, which we compare with its emission in other wavelengths, and spectral data for its brightest filaments. We find that its optical structure matches these of its infrared and X-ray morphologies and that its radio emission in 330 MHz forms a nearly complete shell. Our data suggest that the detected emission originates from shock-heated gas. Our calculated reddening and distance agree within the errors with those estimated from previous studies and we found an electron density upper limit of 300 km^{-3} and a column density larger than 3.95×10^{-21}.

An updated catalogue of Galactic SNRs and some statistics

Poster

Dave Green

Cavendish Laboratory, Cambridge, UK

Abstract

This year I will produce an updated version on my catalogue of Galactic SNRs. This contains about three hundred remnants, plus there are many other possible and probable remnants reported in the literature that require further observations to clarify their nature. I will review the recent revisions to the catalogue, and present some statistical analyses, particularly: 1) the selection effects that apply to the identification of Galactic SNRs, and 2) their Galactocentric distribution.

Supernovae with the New Robotic Telescope

Poster

Eamonn Harvey, Chris Copperwheat, Helen Jermak, Iain Steele and Doug Arnold

Astrophysics Research Institute, LJMU, UK

Abstract

We are entering a new era of synoptic surveys where alerts for young transients are increasing at a rate faster than they can be followed up. The bottle-neck is related to spectroscopic follow-up, with the problem getting worse as surveys get wider and deeper, moving towards the LSST era. To remedy this dearth of spectral follow-up we are building a fast-slewing, fully robotic 4m class telescope on La Palma, to be known as the New Robotic Telescope. The workhorse instrument is to be a medium resolution, high-throughput IFU spectrograph. The aim of being on target 30 seconds following an alert will allow us to explore a previously difficult to observe parameter space. Many areas of transient physics will be positively impacted by fast and frequent spectral follow-up of transients at early times. For example, the relative frequency of the ever-increasing zoo of exotic supernova subtypes can be addressed and their unusual environments probed. The new facility will work in parallel with the synoptic surveys by not only providing object classification, thanks to the broad spectral range to be covered, but will also better observe the high velocity features in early time SN Ia spectra. Early spectral observations will help to pin down contested issues like deflagration and detonation models; the single/double progenitor question and spectral evolution of rare supernova subclasses. Other key science drivers include gravitational wave counterpart follow-up and gamma-ray bursts. The advantages of having a fully robotic observatory is that both down-time and time-to-target are significantly reduced.

GaLactic and Extragalactic All-sky MWA Survey - eXtended

Poster

Natasha Hurley-Walker

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Abstract

Following the success of the original Murchison Widefield Array (MWA) flagship survey, the GaLactic and Extragalactic All-Sky MWA (GLEAM) survey, we have successfully proposed for observations of a follow-up survey using the new extended baselines of the upgraded MWA. This will increase the survey resolution by a factor of two, its depth by an order of magnitude, and greatly enhance its scientific utility. In the original survey, 27 SNRs of diameters > 5' were detected; the doubled resolution and order of magnitude lowered noise of the extension will allow us to find fainter and smaller SNR, particularly those with the steepest spectra.

ASKAP observations of known and new Galactic SNRs

Poster

Adriano Ingallinera

INAF, Osservatorio Astrofisico di Catania, Italy

Abstract

The Australian SKA Pathfinder (ASKAP), one of the three SKA precursors, entered its early-science phase in late 2017 and it is now approaching the full-regime period. During these last months many scientific programs have been carried out for commissioning purposes. Beside the technical value of reducing and analyzing these data, a surprisingly high scientific return also occurred. In the wide context of the preparation for the EMU survey, one of the large programs approved for ASKAP and planned to start by mid-2019, we used ASKAP in January and December 2018 to observe at 0.9 and 1.6 GHz the "SCORPIO field", a patch of about 40 square degrees on the Galactic plane, previously imaged with the Australia Telescope Compact Array to serve as validation for ASKAP. ASKAP is proving formidable in imaging Galactic fields, providing simultaneously a high resolution (20 arcsec) and a good sensitivity to extended structures (with a largest angular scale around 40 arcmin). Thanks to these features we were able to observe several tens of Galactic objects and in particular supernova remnants (SNRs). We detected all the 17 SNRs known from literature lying in our field. For these objects ASKAP data are allowing us to derive a very accurate flux density, disentangling the remnants from nearby sources (especially in particularly crowded regions), make a comparison with infrared images at about the same resolution, and build radio spectral index maps. The ASKAP images are also revealing several other previously undetected or unclassified sources that we are proposing as SNRs, highlighting in this way also the discovery capability of the instrument. We finally remark that the study of SNRs in SCORPIO is also part of the Italian project 'Gamma-prop' aimed at studying cosmic accelerators (including SNRs and pulsar wind nebulae) in view of the construction of the CTA and SKA and their synergetic use.

Test observations of galactic supernova remnant G67.7+1.8 with the 1.4m telescope Milankovic at Astronomical Station Vidojevica, Serbia

Poster

Petar Kostic, Ana Vudragovic, Branislav Vukotic

Astronomical Observatory, Belgrade, Serbia

Abstract

We present the optical photometric observations of a galactic supernova remnant to test the possibilities of telescope Milankovic at Astronomical Station Vidojevica, Serbia, for observing supernova remnants. The selected SNR, G67.7+1.8, first observed by Mavromatakis et al. (2001), is observed through optical narrow-band filters Hα, Hα continuum and [SII]. The observations are carried out with the telescope Milankovic, a 1.4m Nasmyth reflector with 10.5 m focal length, and CCD camera ANDOR iKonL, 2048$\times$2048 pixels (13.5$\times$13.5 μm/pix), with $\sim 8' \times 8'$ field of view at the telescope.

Mapping the Physical Properties of Supernova Remnants in our Galaxy

Poster

John Andrew Kypriotakis, Andreas Zezas and Ioanna Leonidaki

University of Crete, Department of Physics, Greece

Abstract

The study of supernova remnants is crucial, not only for uncovering the physics behind the evolution of the remnants themselves, but also the physics of the explosions, the shock waves and the interaction with the interstellar medium. The commonly used method for studying the supernova remnants is to measure their physical parameters from their spectra. In this contribution, we present a method to recover maps of the shock wave velocity, and the corresponding uncertainties. This is achieved by means of narrow-band imaging in diagnostically useful spectral lines. We apply this method on the Galactic supernova remnants G65.8-0.5 and G67.8+0.5. In this context we also redefine the standard $\frac{[S_{II}]}{H_\alpha}$ shock-excitation diagnostic in order to account for the contamination of the H_α line by the $[N_{II}]$ emission. Finally, we compare those results with measurements from long-slit spectra in selected regions of the SNRs.

Searching for Balmer-Dominated Type Ia SNRs in M33

Poster

Chris Ding-Jyun Lin, Po-Sheng Ou, Chuan-Jui Li and You-Hua Chu

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Abstract

Conventional optical emission-line surveys of SNRs in M33 used the [S II]/Hα line ration to diagnose SNR candidates. Type Ia SNe most frequently occur in a mostly neutral interstellar medium (ISM) and the SNR shocks are collisionless, producing Balmer-dominated spectra in optical wavelengths. Lacking forbidden lines, young Type Ia SNRs would escape detection in the conventional optical surveys of SNRs. Young Type Ia SNRs in the Large Magellanic Cloud (LMC) provide excellent template for us to search for similar SNRs in more distant galaxies. The LMC has 5 Balmer-dominated Type Ia SNRs, and they share a common X-ray characteristic: thermal X-ray emission with luminosity greater than $\sim 10^{36}$erg/s. We have taken advantage of the Chandra X-ray source catalog of M33 and found 13 X-ray sources with thermal spectra and luminosities $> 10^{36}$ erg/s. We have examined their optical counterparts, and find that 7 of them are known SNRs, 3 are known foreground stars, 1 has a possible stellar counterpart, and 2 have no optical counterparts. For the 7 known SNRs, we have examined their 4m emission-line images and Hubble Space Telescope images, and concluded that none of them is Balmer-dominated.The total stellar mass of M33 is about 3 times that of the LMC. While the LMC has 5 Balmer-dominated Type Ia SNRs, M33 has none. This result is puzzling. We will discuss the implications in terms of star formation history and physical conditions of the general ISM.

Evidence for a Pulsar Wind Nebula in the Type Ib Peculiar Supernova SN 2012au

Poster

Dan Milisavljevic[1], R. Chevalier[2], R. Fesen[3], R. Margutti[4], D. Patnaude[5] and R. Raymond[5]

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Abstract

We present optical and X-ray observations of the slow-evolving and energetic Type Ib SN2012au obtained more than six years post-explosion that offer fresh insight into the suspected link between supernovae (SNe), superluminous supernovae (SLSNe), and broad-lined SNe associated with gamma-ray bursts (GRBs). Our optical spectra show forbidden transition emission lines of oxygen and sulfur with expansion velocities of 2300 km/s that are dramatically different from those observed in spectra obtained one year post explosion. H Balmer lines are not detected and Chandra observations reveal no X-ray emission down to a luminosity of $< 2 \times 10^{38}$ erg/s (0.5-10 keV), suggesting that interaction with circumstellar material does not contribute significantly to the emission. We conclude that the dominant source of the observed late-time emission is photoionization of O zone gas that has been shocked by a high-pressure pulsar wind nebula (PWN) and subjected to instabilities, similar to the Crab Nebula. Our discovery marks the first time a PWN signature has been detected in a verified extragalactic SN Ib and support the notion that SN2012au belongs to a subset of SLSNe, GRB-SNe, and SNe Ib/c that are relatedly influenced by magnetized compact objects on a wide range of energy scales. Consequently, we anticipate that other members of this family of SNe harboring influential pulsar/magnetar wind nebulae will evolve into a late-time phase dominated by forbidden oxygen transitions, if observed long enough after explosion and with sufficient depth. We also predict that optical emission line widths in these objects observed post-transformation should remain constant or broaden upwards of a few percent per year due to acceleration of ejecta by the pulsar/magnetar bubble. It remains unclear what key aspects of the progenitor systems unite these SNe that span absolute magnitudes of $22 < M_B < 17$.

3D Optical Spectroscopic Study of NGC 3344 with SITELLE: I. Identification and Confirmation of Supernova Remnants

Poster

Ismael Moumen[1,2], C. Robert [1], D. Devost[2], R. P. Martin[3], L. Rousseau-Nepton[2], L. Drissen[1] and T. Martin[1]

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Abstract

We present the first optical identification and confirmation of a sample of Supernova Remnants (SNRs) in the nearby galaxy NGC 3344. Using high spectral and spatial resolution data, obtained with the CFHT imaging Fourier transform spectrograph SITELLE, we identified 128 SNR candidates based on four criteria that include the well known emission lines flux ratio $\frac{[S_{II}]}{H_\alpha} \geq 0.4$. Emission lines of $[O_{II}]\,\lambda 3727$, H_β, $[O_{III}]\,\lambda\lambda 4959$, 5007, H_α, $[N_{II}]\,\lambda\lambda 6549$, 6584, and $[S_{II}]\,\lambda\lambda 6717$, 6731 have been measured to study the ionized gas properties of the SNR candidates. We adopted a self-consistent spectroscopic analysis, based on Sabaddin plots and BPT diagrams, to confirm the shock-heated nature of the ionization mechanism in the candidates sample. With this analysis, we end up with 35

Confirmed SNRs, 20 Probable SNRs, and 73 Less likely SNRs. Using shock models, the Confirmed SNRs seems to have shock velocities below 250 km/s and a metallicity somewhat equivalent or higher to the LMC. We do not find correlations between the size of the confirmed SNRs (with a diameter between 40 and 120 pc) and their emission lines ratios, but we see a gradient within the galaxy for the ratios $\frac{[N_{II}]}{H_\alpha}$ and $\frac{[S_{II}]}{H_\alpha}$.

Revealing the radio continuum and X-ray properties of the Galactic supernova remnant G5.9+3.1 with Murchison Widefield Array and XMM-Newton

Poster

Dusan Onic[1], M. D. Filipovic[2], I. Bojicic[2], N. Hurley-Walker[3], B. Arbutina[1], T. G. Pannuti[4], C. Maitra[5], D. Urosevic[1], F. Haberl[5], N. Maxted[2],[6], G. F. Wong[2],[6], G. Rowell[7], M. E. Bell[8], J. R. Callingham[9], K. S. Dwarakanath[1]0, B.-Q. For[1]1, P. J. Hancock[3], L. Hindson[1]2, M. Johnston-Hollitt[3], A. D. Kapinska[1]1, E. Lenc[1]3, B. McKinley[1]4, J. Morgan[3], A. R. Offringa[9], L. E. Porter[4], P. Procopio[1]5, L. Staveley-Smith[1]1, R. B. Wayth[3], C. Wu[1]1, Q. Zheng[1]6

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Abstract

We will present the radio continuum and X-ray analysis of Galactic supernova remnant G5.9+3.1. The radio spectral energy distribution obtained with the Murchison Widefield Array, together with the surveys at other radio continuum frequencies is discussed. In addition, we have also examined an archival XMM-Newton observation which allowed us to detect an X-ray emission from this remnant for the first time. Finally, a detailed X-ray spectral analysis will be presented.

Structures of M33 Supernova Remnants Revealed by Broad-Band HST Images

Poster

Po-Sheng Ou, You-Hua Chu and Chris Lin

Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan

Abstract

Ground-based optical surveys have suggested $\sim$ 200 supernova remnants (SNRs) or SNR candidates in M33, and further classified them as core-collapse (CC) or Type Ia SNRs by their nebular morphologies and stellar environments. At M33's distance of $\sim$ 820 kpc, 1" corresponds to $\sim$ 4 pc and small SNRs are not well resolved by ground-based images. Hubble Space Telescope (HST) resolution is needed; however, narrow-band nebular line images of M33 are available only for the giant HII region NGC 604. The recent HST panoramic imaging survey of M33 (PI: Dalcanton) has provided broad-band images of the bright main part of this galaxy, where $\sim$ 80 SNRs or SNR candidates reside. Using these broad-band HST images, we find that dense regions of SNRs can be detected and resolved because some nebular lines are strong and are transmitted through the broad-band filters. As the exposure times of broad-band images are usually short, only the brightest/densest regions of a SNR can be detected. This poster reports the structures of SNRs in M33 as revealed by the HST broad-band images, and compare them to those of SNRs in the Large Magellanic Cloud (LMC). A subset of these SNRs are reported in a poster by Lin et al. in search for Balmer-dominated young Type Ia SNRs.

Early high-cadence monitoring of supernovae: key to identifying the progenitors

Poster

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Abstract

High-cadence photometry on the early evolutionary stage of supernova light curves has the potential to provide a better understanding of nearly every aspect of SNe, from their explosion physics to their progenitors and the circumstellar environment. Given the increasing rate of discovery of bright supernovae before their maximum brightness from modern time-domain optical surveys, we have the opportunity to capture their intraday behavior near the time of their explosions. We present results of monitoring the optical light curves of $\sim$ 6 bright SNe, primarily using the 2.3m Aristarchos telescope and 1.2m Kryoneri telescope. The supernovae were observed over several nights during the early and late evolution with a cadence of 30-120s and high precision differential aperture photometry was derived. Differential light curves with respect to all comparison stars available on each night, as well as reconstructed light curves after implementing the Trend Filtering Algorithm (TFA; Kovacs et al. 2005) are presented. We derive the decline slope of each supernova on each night and quantify the precision of our photometry and variability in the light curves, after accounting for sources of systematic error. We encourage further high-cadence photometric monitoring of bright SNe with the goal of identifying explosion mechanisms, binary-star interaction, progenitor channels, or properties of the explosion environment.

Light Echoes of Ancient Transients

Poster

Armin Rest

Space Telescope Science Institute, Baltimore, USA

Abstract

Our discovery of light echoes of Tycho's SN, Cas A, Eta Car's Great Eruption, and 3 SNRs in the LMC has given us the unique opportunity to directly observe the light of long gone ancient events. Furthermore, multiple light echoes allow us to see the same explosion from different directions, providing the only way to directly probe asymmetry. In favorable cases, we can even obtain a spectrophotometric time-series, e.g., for Eta Car's eruption and Tycho's SN. We also found a new application of light echoes: the distance measurement to these historic transients using recently available E(B-V) 3D map of Green et al.(2015). I will discuss how we have used all these tools to make connections between the underlying explosion physics, the observed transients, and their remnants. In addition, I will show the results of our search for new light echoes associated with SNRs in the Southern Hemisphere.

Physical Conditions in Shocked Interstellar Gas Interacting with the Supernova Remnant IC 443

Poster

Adam M. Ritchey[1], Edward B. Jenkins[2], Steven R. Federman[3], Johnathan S. Rice[3],Damiano Caprioli[4] and George Wallerstein[5]

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[4]University of Chicago, USA
[5]University of Washington, USA

Abstract

We present the results of a detailed investigation into the physical conditions in interstellar material interacting with the supernova remnant IC 443. Our analysis is based on an examination of high-resolution HST/STIS spectra of two stars probing predominantly neutral gas located both ahead of and behind the supernova shock front. The pre-shock neutral gas is characterized by densities and temperatures typical of diffuse interstellar clouds, while the post-shock material exhibits a range of more extreme physical conditions, including high temperatures ($> 10^4$ K) in some cases, which may require a sudden heating event to explain. The ionization level is enhanced in the high-temperature post-shock material, which could be the result of enhanced radiation from shocks or from an increase in cosmic-ray ionization. The gas-phase abundances of refractory elements are also enhanced in the high-pressure gas, suggesting efficient destruction of dust grains by shock sputtering. Observations of highly-ionized species at very high velocity indicate a post-shock temperature of 10^7 K for the hot X-ray emitting plasma of the remnants interior, in agreement with studies of thermal X-ray emission from IC 443.

Optical counterparts of Galactic Supernova Remnants and their kinematic distances

Poster

Margarita Rosado[1], Patricia Ambrocio-Cruz[3], Mnica Snchez-Cruces[3], Diego Trejo

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Abstract

Distances to Galactic supernova remnants are important to determine their actual location in our Galaxy, as well as the energetics and age and some possible association with compact objects. However, for many Galactic supernova remnants there are no clues on this important quantity. In the case of supernova remnants with optical counterparts this task is possible when we can detect line emission from the SNR shock. We have undertaken a project of finding optical counterparts to Galactic SNRs in order to study their kinematics and to obtain kinematical distances to those objects. I will show the power of this method with some examples.

A New Version of SNRcat: the High Energy Catalogue of Supernova Remnants

Poster

Samar Safi-Harb[1], Michael Ramsay[1], G. Ferrand[2] and Jennifer West[3]

[1]University of Manitoba
[2]strophysical Big Bang Laboratory (ABBL), RIKEN, Japan
[3]Dunlap Institute for Astronomy and Astrophysics, University of Toronto, Canada

Abstract

SNRcat, the High-Energy Catalogue of Supernova Remnants (SNRs), is the first public database of high-energy (X- and gamma-ray) observations of all known Galactic SNRs. The catalogue has been widely used by the community worldwide. We present an updated version of the online catalogue which includes an imaging component (all SNR images in the radio and X-ray bands), Galaxy maps (top down and plane views), as well as a new interface for the website. A demo will highlight the website features and tools. Data will be downloadable. Feedback and requests on further updates are welcome.

Supernovae, transients and high amplitude variables in the Hubble Catalog of Variables

Poster

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Abstract

We present an exceptionally deep catalog of supernovae, transients and high-amplitude variables included in the Hubble Catalog of Variables (HCV). The HCV contains all variable objects detected through a robust variability search of the light curves of all sources included in the Hubble Source Catalog version 3 (Whitmore et al. 2016). Taking this work one step further, we queried the HCV to detect all variable sources with an amplitude of variability > 1 mag, in more than one filter of observations. We cross-matched the sources with catalogs in CDS to check whether the high-amplitude variable sources were previously reported. We proceeded to classify the newly identified high-amplitude variables based on their magnitude, light curve shape and position on the color magnitude diagram. The high-precision astrometry extracted from the HSC for all sources combined with the deep HST observations makes our catalog a powerful tool for further research on the environments and properties of high-amplitude variables observed by the Hubble Space Telescope. This work was supported by the European Space Agency (ESA) under the "Hubble Catalog of Variables" program, contract No. 4000112940.

The Cygnus Loop's Distance, Properties & Environment Driven Morphology

Poster

Kathryn Weil[1], Robert A. Fesen[1], William P. Blair[2], John C. Raymond[3]

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Abstract

The Cygnus Loop is among the brightest and best studied evolved Galactic supernova remnants. However, its distance has remained uncertain thus undermining quantitative understanding about many of its fundamental properties. Here we present moderate-dispersion spectra of stars with projected locations toward the remnant. Spectra of three stars revealed Na I 5890, 5896Å and Ca II 3934Å absorption features associated with the remnant's expanding shell, with velocities ranging from -160 to +240 km/s. Combining Gaia DR2 parallax measurements for these stars with other recent observations, we find the distance to the Cygnus Loop's centre is 735 ± 25 pc, only a bit less than the 770 pc value proposed by Minkowski some 60 years ago. Using this new distance, we discuss the remnant's physical properties including size, SN explosion energy, and shock velocities. We also present multi-wavelength emission maps which reveal that, instead of being located in a progenitor wind-driven cavity as has long been assumed, the Cygnus Loop lies in an extended, low density region. Rather than wind-driven cavity walls, these images reveal in unprecedented clarity the sizes and locations of local interstellar clouds with which the remnant is interacting, giving rise to its large-scale morphology.

G182.5-4.0: A new supernova remnant near the Crab Nebula

Poster

Jennifer West[1], Roland Kothes[2] and Samar Safi-Harb[3]

[1]University of Toronto, Canada
[2]Dominion Radio Astrophysical Observatory, Canada
[3]University of Manitoba, Canada

Abstract

We present new radio observations from the Dominion Radio Astrophysical Observatory Synthesis Telescope (DRAO-ST) made as part of a project to observe a complete sample of faint high-latitude supernova remnants in the outer Galaxy. We report a probable new supernova remnant, located near the Crab Nebula. This object is polarized at 1.4 GHz and has a unusual shape with a very compressed, thin, and straight shell.

Asymmetric Type-Ia supernova origin of W49B as revealed from spatially resolved X-ray spectroscopic study

Poster

Ping Zhou and Jacco Vink

Anton Pannekoek Institute, University of Amsterdam, Netherlands

Abstract

The composition and distribution of ejecta in supernova remnants (SNRs) provides crucial information on the nucleosynthesis products and explosion geometry, and therefore, can be used to probe supernova explosion mechanism and to type SNRs. The type and the origin of the asymmetry of SNR W49B have been a matter of debate: is it produced by a rare jet-driven core-collapse (CC) supernova, or by a normal supernova that is strongly shaped by its dense environment? We have performed spatially resolved X-ray spectroscopy of W49B using the adaptively binning methods. This allows us to obtain a detailed distribution of the metal elements and other parameters. Asymmetric Type-Ia explosion of a Chandrasekhar-mass white dwarf (WD) well- explains the abundance ratios and metal distribution of W49B, whereas a jet-driven explosion and normal CC models fail to describe the abundance ratios and large masses of iron-group elements. A model based on a multi-spot ignition of the WD can explain the observed high M_{Mn}/M_{Cr} value (0.8−2.2). The bar-like morphology is mainly due to a density enhancement in the center, given the good spatial correlation between gas density and X-ray brightness. W49B is likely a Type-Ia SNR, which suggests that Type-Ia supernovae can also result in mixed-morphology SNRs. It also indicates that some of Type-Ia supernovae can be born in a dense medium.

Session 2.

SN/SNR Progenitors: Models and Observations – Oral Talks

A Meta Analysis of Core-Collapse Supernovae ^{56}Ni Masses

Oral Talk

Joseph Anderson

European Southern Observatory, Vitacura, Chile

Abstract

A fundamental property determining the transient behaviour of core-collapse supernovae (CCSNe) is the amount of radioactive ^{56}Ni synthesised in the explosion. Using established methods, this is a relatively easy parameter to extract from observations. Here, I present a meta analysis of all published ^{56}Ni masses for CCSNe. Collating a total of 258 literature ^{56}Ni masses I compare distributions of the main CC SN types: SNe II; SNe IIb; SNe Ib; SNe Ic; and SNe IcBL. On average, stripped-envelope SNe (SE-SNe: IIb; Ib; Ic; and Ic-BL) have much higher values than SNe II. These observed distributions are compared to those predicted from explosion models. While the SN II distribution follows model predictions, the SE-SNe have a significant fraction of events with ^{56}Ni masses much higher than predicted, implying significant differences in the progenitor structures and/or explosion properties between SNe II and SE-SNe. However, such distinct progenitor and explosion properties are not currently favoured in the literature. Alternatively, the popular methods used to estimate ^{56}Ni masses for SE-SNe may not be accurate. I discuss possible issues with these methods and the implications of true ^{56}Ni mass differences on progenitor properties of different CC SNe.

Chemical stratification of Type Iax Supernovae

Oral Talk

Barnabás Barna[1], Tamas Szalai, Yssavo Camacho-Neves, Saurabh W. Jha

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Abstract

Modeling of supernova (SN) spectra obtained at different epochs allows us to scan through the optically thin region of the atmosphere and provides the abundance distribution of the ejecta. If we fit not only a single spectrum, but a whole time series, we can map the chemical and physical properties of the ejecta. Constraining the chemical abundances with this technique called abundance tomography could allow a powerful tool to test the different explosion scenarios. However, the large number of free parameters and their degeneracy caused by the overlapping spectral lines challenge the analysis, which require carefully chosen spectral samples and fitting strategy. The members of the Type Iax SN subclass are peculiar thermonuclear explosions showing low peak absolute brightness and expansion velocities. Because of their narrow spectral lines and the extremely wide range of physical properties, SNe Iax offer excellent possibilities to perform abundance tomography and to test different explosion scenarios. In order to do that, we define a multi-layer atmosphere structure, where the fractions of the chemical elements are fitting parameters in each velocity shell. The fitting process was carried out using the 1D MC radiative transfer code TARDIS. Here we present the results from our abundance tomography analysis of several Type Iax SNe sampling well the diverse subclass. Based on the best-fit model maps, we discuss a possible correlation between the physical parameters and the chemical distribution. The fitting of the early spectra contradicts with the abundances in the outermost layers predicted by pure deflagration models, describing a promising explosion scenario for SNe Iax. Moreover, the peculiar nature of this subclass may allow us to extend the abundance tomography technique to later epochs and deeper layers. The mapping of the whole ejecta structure could also reveal the double-nature of the flux source observed in the late-time spectra of Type Iax SNe.

Pulsational and non-Pulsational Pair-Instability Supernovae and their Remnants

Oral Talk

D. Andrew Howell

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Abstract

iPTF14hls is the strangest supernova ever observed. It has a lightcurve spanning years, with at least 5 peaks, ejecta in the tens of solar masses, and has evidence for multiple eruptive episodes at supernova-level energies spanning back to at least 1954. It may be the first evidence of the theorized class of pulsational pair-instability supernovae – SNe from 70-140 $M_{\odot}$ progenitors, which have multiple explosions over years to millennia, ultimately resulting in a terminal core-collapse explosion producing a black hole. More massive stars, up to about 260 $M_{\odot}$ are expected not to pulsate, and instead produce a pair-instability supernova – a thermonuclear supernova that leaves no compact remnant. SN 2007bi was claimed as evidence of the first pair-instability supernova, but our more recent observations of similar SNe indicate they probably do not belong to this class. The presence of pair-instability supernovae should result in a lack of black holes in a certain mass range that there is hope of probing from LIGO-Virgo observations. I will discuss these and other implications for supernova remnants for PI and PPI SNe.

Constraints on Core-Collapse Supernova Theory

Invited Talk

Jeremiah Murphy

Florida State University, Tallahassee, USA

Abstract

Core-collapse supernova theory predicts that some massive stars explode and some fail to explode forming black holes. In this talk, I will summarize the theory of CCSN explosions and present observational constraints. In particular, we compare the inferred explosion energies from simulations and observations. We find that the simulations are a factor of 2 to 10 times less energetic than the observations. However, both the simulations and observations are biased, and we discuss way to mitigate this bias. In addition, we age-date the stars around 300 SNRs in M31, M33, and M83. From these ages, we infer the progenitor masses for the stars that exploded. With hundreds of progenitor masses, we infer basic parameters of the progenitor distribution. We infer the minimum mass for explosion to be 7.3 ± 0.1 solar masses, the maximum mass is greater than 59 solar masses, and the power law distribution between these limits is $-2.95^{+0.45}_{-0.25}$.

Presupernova Mass Ejections in Pulsational Pair-Instability Supernovae and Electron-Capture Supernovae, and Connections to Superluminous Supernovae and Fast-Evolving Luminous Transients

Oral Talk

Kenichi Nomoto

Kavli IPMU, University of Tokyo, Tokyo, Japan

Abstract

We first report our calculations of the evolution of 80-140 $M_{\odot}$ stars that undergo pair-instability pulsations during oxygen burning. We find that the presupernova mass ejection caused by pulsations is quite extensive. Some ejecta are as much as 20 $M_{\odot}$, which include a large amount of C+O core materials. We calculate the subsequent evolution through Fe core-collapse and construct explosion models including circumstellar interaction. We discuss their connections to a certain type of superluminous supernovae, and the maximum mass of black holes to compare with the gravitational wave observations. Secondly, we report our calculations of circumstellar interactions in electron-capture supernovae from 8-10 $M_{\odot}$ Super-AGB stars and the successful modelling of Fast-Evolving Luminous Transients (FELT).

Type Ia Supernova Subclasses and their Progenitors

Oral Talk

Ashley Ruiter

University of New South Wales Canberra, Canberra, Australia

Abstract

It has become quite clear over the last decade that the progenitors of Type Ia supernovae (SNe Ia) originate from at least 2 (probably more) formation channels. However, it is still uncertain what the different SN Ia progenitors are in terms of exploding white dwarf mass, nature of the mass-losing companion star, and how these are connected to the observed sub-classes of SNe Ia (e.g. normal, sub-luminous, Type Iax, etc.). Binary evolution modelling can constrain the ages (delay times), birthrates, and evolutionary channel origin of SNe Ia and other thermonuclear transients. I will discuss how metallicity and other evolutionary factors influence the rate of Chandrasekhar mass (single degenerate) vs. sub-Chandrasekhar mass explosions among different stellar populations. In particular, the single degenerate scenario involving a hydrogen-stripped, helium-burning star donor appears to be more favourable than the canonical hydrogen-rich donor channel in certain metallicity regimes.

Search of Possible Surviving Companions in SNe Ia Remnants to Determine the Nature of the Explosions

Oral Talk

Pilar Ruiz-Lapuente

ICCUB U. Barcelona/IFF CSIC, Barcelona, Spain

Abstract

Type Ia supernovae (SNe Ia) arise as thermonuclear explosions of white dwarfs (WDs) in close binary systems, brought about by mass gain of the WDs from their companion star. The nature of that companion star can be either a main sequence, subgiant, red giant, AGB, He star or another WD. The explosion as SNe Ia can occur through steady accretion of material, through merging or through collision depending on the nature of the binary system. The detection of a surviving companion or the lack of such detection in SNe Ia remnants discriminates the nature of the progenitor systems and also the mode of explosion. For more than a decade, our group has explored the remnannts of Galactic SNe Ia in search of possible surviving companions. In this talk, I would like to present the most recent results and also the prospects for expanding those explorations to other Galactic SNe Ia remnants.

The Diversity in pre-Supernova Evolution and Mass Loss of Massive Stars

Invited Talk

Nathan Smith

University of Arizona, Tucson, USA

Abstract

Observational work in the past decade has made it very clear that normal, relatively steady, radiation-driven wind mass loss typically discussed for single massive stars is inadequate to explain the diverse inferred properties of pre-supernova (SN) mass loss. Normally observed mass-loss rates for dust-driven winds of red/yellow supergiants and line-driven winds of blue supergiants and Wolf-Rayet stars cannot achieve the circumstellar density needed to explain the observed diversity of SNe that interact with dense circumstellar material (CSM). Impulsive/explosive mass-loss and/or violent binary interaction events occurring over a variety of timescales preceding core collapse are likely needed to account for the observed CSM properties. This dense CSM and the resulting shock interaction span a wide range in circumstellar mass. The diversity includes cases where the typical signatures of shock interaction are fleeting or easily overlooked, meaning that this type of shock interaction applies to more than just 10% of core collapse events. This episodic pre-supernova mass loss paints a picture of dynamical changes in the cores of many massive stars as they approach death. Our lack of theoretical understanding of the mass loss mechanisms makes it challenging to map observed SN subtypes to progenitor initial masses, and may influence our understanding the core collapse explosion itself.

Session 2.

SN/SNR Progenitors: Models and Observations – Posters

The Lowest Metallicity Type II Supernova from the Highest Mass Red Supergiant Progenitor

Poster

Joseph Anderson

European Southern Observatory, Vitacura, Chile

Abstract

Red supergiants have been confirmed as the progenitor stars of the majority of hydrogen-rich type II supernovae. However, while such stars are observed with masses >25 $M_\odot$, detections of >18 $M_\odot$ progenitors remain elusive. Red supergiants are also expected to form at all metallicities, but discoveries of explosions from low-metallicity progenitors are scarce. Here, we report observations of the type II supernova, SN 2015bs, for which we infer a progenitor metallicity of <0.1 Zsun from comparison to photospheric-phase spectral models, and a Zero Age Main-Sequence mass of 17-25 $M_\odot$ through comparison to nebular-phase spectral models. SN 2015bs displays a normal plateau light-curve morphology, and typical spectral properties, implying a red supergiant progenitor. This is the first example of such a high mass progenitor for a normal type II supernova, suggesting a link between high mass red supergiant explosions and low-metallicity progenitors.

Spectral signs of ^{56}Ni in the outer ejecta of SNe Ia

Poster

Barnabás Barna

Institute of Physics, University of Szeged, Szeged, Hungary

Abstract

Despite the decade-long, intense studies, the exact origin of the thermonuclear supernovae (SNe) is still a mystery. There are several theories that broadly reproduce the observables of SNe Ia but differ in details. Such competing explosion models are the ones assuming deflagration to detonation transition (DDT), or, double detonation (DD). Constraining the distribution of the chemical elements in the studied SN ejecta could allow us to test the predictions of these models. In this study, we focus on the appearance of radioactive material in the outer layers of the analyzed SNe. We performed abundance tomography analysis carried out by TARDIS radiative transfer code. We define a multi-layer synthetic atmosphere, where the fractions of the chemical elements are fitting parameters in each velocity shell. The modelling of the SN spectra obtained at different epochs allows us to scan through the optically thin region of the atmosphere and provides the abundance distribution of the ejecta.We present the spectral model fitting for three normal SNe Ia. SNe 2013dy and 2014lp show different levels of UV suppression, while SN 2011fe does not. Best-fit models from our abundance tomography analysis indicate a significant mass fraction of radioactive nickel in the outermost regions in order to reproduce the flux suppression below 3500 A. Such abundance feature may originate from the ignition of the helium layer in a DD scenario. Our results are tested against the predicted abundance profiles of several different DD and DDT hydrodynamical simulations. We also discuss the flux contribution of the outer radioactive material to the light curves calculated by the MC code TURTLS.

A Virtual Reality Environment for Scientific Exploitation of 3D MHD Astrophysical Simulations

Poster

Fabrizio Bocchino, S. Orlando, I. Pillitteri, M. Miceli, G. Peres

INAF-Osservatorio Astronomico di Palermo, Palermo, Italy

Abstract

Virtual Reality (VR) hardware and software are now routinely used in several fields for public outreach and education with excellent feedback. For this purpose, YouTube and online multimedia digital stores have several VR titles of great impact in the Astrophysics and Space categories of their catalogues. However, scientific use of VR environments are still at their beginning. Fully 3D Magneto-hydrodynamical simulations of astrophysical phenomena represent a challenge in standard data visualization for scientific purposes, for the amount of processed data and the wealth of scientific information they contain. In this poster, we present a VR platform based on Oculus Rift for data visualization of 3D MHD models of Supernova Remnants and Young Stellar Objects developed at INAF-Osservatorio Astronomico di Palermo. We show that fully immersive space-walks inside properly configured datacubes may be of great importance to study the distribution of hot plasmas, cold materials and the magnetic fields of these environments.

Electron Cyclotron Maser Emission Revealed in Magnetic Massive Stars

Poster

Poonam Chandra

National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Pune, India

Abstract

As per current understanding, massive OB stars are the progenitors of most of the supernovae. However, magnetism in massive stars, which is rare and seen only in 10% of these stars, have important consequences in their rotational properties, mass-loss rates, thus their final fate as supernovae. While gyro-synchrotron emission, a consequence of magnetic fields in these stars, have been seen in a substantial fraction of magnetic OB stars, evidence of electron cyclotron maser emission (ECME) was seen only in one star, CU-Vir (Trigilio et al. 2000), until 2015, when we found evidence of ECME in another B-type star HD 133880 via our low frequency Giant Metrewave Radio Telescope (GMRT) observations. Since then we are carrying out a survey of magnetic massive stars and have found ECME phenomenon in 4 more stars. The ECME is a directional emission, seem to occur at the magnetic nulls of the stars. ECME appears to be a property at low frequencies, while the same stars show gyro-synchrotron emission at high radio frequencies. In this talk, we will discuss the detection of ECME, their implications in these stars final demise as supernovae.

Searching for Fast Runaway Massive Stars in Core-Collapse SNRs in the LMC

Poster

Chen-hung Chen, You-Hua Chu

Institute of Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan

Abstract

Massive stars are often formed in binary systems. When the more massive binary component explodes as a supernova (SN), the less massive component will run away due to the disappearance of gravitational attraction from its exploding companion. The runaway velocity depends on the separation and mass ratio of the two binary components. If a runaway star is identified in a core-collapse supernova remnant (SNR), it will be a promising candidate for the binary companion of the SN progenitor and its mass and velocity may provide constraints to the properties of the SN progenitor. The Large Magellanic Cloud (LMC) at a distance of 50 kpc hosts a large number of core-collapse SNRs, and massive stars are bright enough for Gaia DR2 to provide proper motion measurements with errors of a few tens km/s, comparable to the velocities observed in most runaway stars. This level of errors prohibits the identification of run-of-the-mill runaway massive stars, but fast runaway stars with proper motions >100 km/s can be identified. We have thus used Gaia DR2 data to search for fast runaway stars in core-collapse SNRs in the LMC. During the course of this work, we find that several stars with very larger proper motions, >100 km/s, are resolved by HST images into multiple stars, and the large proper motions are most likely spurious. Preliminary results of our search for fast runaway stars in core-collapse SNRs will be presented in this poster.

Progenitor Mass Distribution for Core-Collapse Supernova Remnants

Poster

Mariangelly Diaz Rodriguez[1], Jeremiah W. Murphy[1], David A. Rubin[2], Andrew E. Dolphin[3], Benjamin F. Williams[4], Julianne J. Dalcanton[4]

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[2]Space Telescope Science Institute, Baltimore, USA
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[4]University of Washington, Seattle, USA

Abstract

We infer the progenitor mass distribution for 100 core-collapse supernovae. In particular, we infer the age of stellar populations surrounding 94 supernova remnants (SNRs) in M31 and M33. From these ages, we infer the progenitor mass distribution. Assuming each progenitor evolved as a single star, we find that the minimum mass is $M_{min} = 7.33^{+0.02}_{-0.16}$ $M_\odot$, the slope of the progenitor distribution is $\alpha = -2.96^{+0.45}_{-0.25}$, and the maximum mass is greater than $M_{max} > 38$ $M_\odot$. The accuracy on the minimum mass may provide tight constraints on stellar evolution. The steep distribution suggests that the most massive stars are either not exploding with the same frequency as the stars near the minimum mass, or SNR catalogs are biased against the youngest SF regions. If there is a bias on the SNR catalogs, it will most likely only affect the slope. This bias will not affect the minimum mass or the lower limit on the maximum mass. In the future, we will infer the progenitor ages and masses for thousands of SNRs, placing unique and robust constraints on which stars explode as CCSNe.

Searching for stellar companions of Galactic type-Ia Supernovae with HST and Gaia

Poster

Jonay Gonzalez Hernandez, Pilar Ruiz-Lapuente, Luigi Bedin, Ramn Canal, Javier Mndez, Roger Mor, Merc Romero-Gmez, Nria Miret-Roig, Francesca Figueras, Llus Galbany, John Pritchard, Hugo M. Tabernero, David Montes

Instituto de Astrofisica de Canarias, Santa Cruz de Tenerife, Spain

Abstract

Type Ia supernovae (SNe Ia) are the best known cosmological distance indicators at high redshifts. Their use led to the discovery of the currently accelerating expansion of the universe. These SNe are thought to occur when a white dwarf (WD) made of carbon and oxygen accretes sufficient mass to trigger a thermonuclear explosion. The explosion could occur via accretion from a companion star (single-degenerate (SD) channel), or via merging of two white dwarfs (double-degenerate (DD) channel) or via merging of a WD with stellar core (CD channel). Our group has been searching for companions of progenitors of historical Galactic SN Ia with the aim of clarifying the origin of these cosmological candles, using high-resolution spectroscopic data taken with Keck I (Hawaii, USA) and VLT (Paranal, Chile) together with the astrometry from the Hubble Space Telescope (HST) and Gaia, to characterize the stars close to the geometrical center of the supernova remnants, and obtain their chemical and kinematical properties. We discuss in detail several aspects of the search for the companions in Tycho Brahe's SN 1572, SN 1006 and Kepler SN 1604.

A Grid of Core Collapse Supernova Remnant Models Evolved from Massive Progenitors

Poster

Taylor Jacovich[1], D. Patnaude[1], C. Badenes[2], S. H. Lee[3], P. Slane[1], S. Nagataki[4], D. Milisavjevic[5], D. Ellison[6]

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[3]Kyoto University, Kyoto, Japan
[4]RIKEN, Tokyo, Japan
[5]Purdue University, West Lafayette, USA
[6]North Carolina State University, Raleigh, USA

Abstract

We present preliminary results from modeling core-collapse supernovae evolved from pre-main sequence models with wind-driven mass loss. We construct a software pipeline to follow the massive star evolution beginning with modelling up to iron core collapse with MESA. We then use the Supernova Evolution Code (SNEC) to explode the star and follow the evolution of the ejecta with the cosmic ray hydro (ChN) code. ChN allows us to model the remnants dynamics and broadband spectrum as a function of age. We quantify the impact of progenitor evolution on the bulk observable characteristics of the remnant, including its dynamics and spectral properties.

Excluding SSSs as progenitors for four Type Ia supernovae in the LMC

Poster

Jere Kuuttila[1], M. Gilfanov[1], I. R. Seitenzahl[2], T. E. Woods[3], F. P. A. Vogt[4]

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[2]University of New South Wales Canberra, Canberra, Australia
[3]University of Birmingham, Birmingham, UK
[4]European Southern Observatory, Santiago, Chile

Abstract

Type Ia supernovae are vital to our understanding of the Universe due to their use in measuring cosmological distances and their significance in enriching the interstellar medium with heavy elements. They are understood to be the thermonuclear explosions of white dwarfs, but the exact mechanism(s) leading to these explosions remains unclear. The two competing models are the single degenerate scenario, wherein a white dwarf accretes material from a companion star and explodes when it reaches the Chandrasekhar limit, and the double degenerate scenario, wherein the explosion results from a merger of two white dwarfs. Here I report results which rule out hot and luminous progenitors consistent with the single degenerate scenario for four young Type Ia supernova remnants in the Large Magellanic Cloud. Using the integral field spectrograph WiFeS, we have searched these remnants for relic nebulae ionized by the progenitor, which would persist for up to 10^5 years after the explosion. No such nebula was detected around any of the observed remnants. By comparing the upper limits from the observations with photoionization simulations performed using Cloudy, we have placed stringent upper limits on the luminosities of the progenitors of these supernova remnants. Our results add to the growing evidence disfavouring the single degenerate scenario.

Cradle-to-Grave Models for Core-Collapse Supernova Remnants and Machine Learning

Poster

Shiu-Hang (Herman) Lee, Daniel Patnaude

Kyoto University, Kyoto, Japan

Abstract

We generate an exhaustive grid of hydrodynamical models for core-collapse SNRs to follow their evolution from progenitors to a few 1000 yr after explosion. By coupling the MESA, SNEC and CR-hydro-NEI codes, we explore a large number of CCSNR models with different progenitor mass, pre-SN mass loss history, explosion energy and ejecta profile, from which their dynamical evolution and characteristics in their electromagnetic signals are investigated. To do this, we develop a preliminary machine learning algorithm to train a predictive model based on the outputs from the model grid, including the detailed time-evolving X-ray spectra. This ML methodology will allow for a robust interpretation of future spectroscopic data of CCSNRs in terms of their progenitor nature, surrounding CSM environment and evolution history.

Searching for Surviving Companions of Type Ia SNe in Five Balmer-Dominated SNRs in the LMC

Poster

Chuan-Jui Li, You-Hua Chu

Institute of Astronomy and Astrophysics, Academia Sinica, Taipei, Taiwan

Abstract

We have been searching for surviving companions of Type Ia SNe in five young Type Ia SNRs in the LMC in order to assess their explosion mechanism. These young Type Ia SNRs are characterized by shells whose optical spectra are dominated by hydrogen Balmer lines. These Blamer-dominated spectra result from collisionless shocks moving into a partially neutral ambient medium. The five SNRs are 0509-67.5, 0519-69.0, 0548-70.4, DEM L71, and N103B. Only N103B is known to contain a dense circumstellar medium interior to the SNR shell, suggesting a single-degenerate nature of its SN progenitor. We have used HST photometry of stars projected within the above five youngType Ia SNRs to produce color-magnitude diagrams (CMDs) and compare the stars to the post-impact evolution tracks of surviving companions from Pan et al. (2014) to identify candidates of surviving companions. We have also used VLT/MUSE observations of 0519-69.0, DEM L71, and N103B to extract spectra of stars projected within their SNR shells in order to use stellar radial velocities to identify candidates of surviving companions. In both methods, we find stars with unexpected behaviors that could be candidates of surviving companions of the SN progenitors. We also find intriguing dense nebular knots inside 0519-69.0 and DEM L71. These nebular knots will also be discussed.

Constraints on the Ejecta Properties of SN 2018oh with Early Excess Emission from K2 Observation

Poster

Wenxiong Li[1], Xiaofeng Wang[1], Jozsef Vinko[2], Griffin Hosseinzadeh[3], David Sand[4]

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Abstract

Supernova (SN) 2018oh (ASASSN-18bt) is the first spectroscopically-confirmed type Ia supernova (SN Ia) observed in the *Kepler* field. The *Kepler* data revealed an excess emission in its early light curve, allowing to place interesting constraints on its progenitor system (Dimitriadis et al. 2018, Shappee et al. 2018b). Here, we present extensive optical, ultraviolet, and near-infrared photometry, as well as dense sampling of optical spectra, for this object. SN 2018oh is relatively normal in its photometric evolution, with a rise time of 18.3±0.3 days and $\Delta m_{15}(B) = 0.96\pm0.03$ mag, but it seems to have bluer $B-V$ colors. We construct the "uvoir" bolometric light curve having peak luminosity as 1.49×10^{43}erg s^{-1}, from which we derive a nickel mass as $0.55\pm0.04M_\odot$ by fitting radiation diffusion models powered by centrally located ^{56}Ni. Note that the moment when nickel-powered luminosity starts to emerge is +3.85 days after the first light in the Kepler data, suggesting other origins of the early-time emission, e.g., mixing of ^{56}Ni to outer layers of the ejecta or interaction between the ejecta and nearby circumstellar material or a non-degenerate companion star. The spectral evolution of SN 2018oh is similar to that of a normal SN Ia, but is characterized by prominent and persistent carbon absorption features. The C II features can be detected from the early phases to about 3 weeks after the maximum light, representing the latest detection of carbon ever recorded in a SN Ia. This indicates that a considerable amount of unburned carbon exists in the ejecta of SN 2018oh and may mix into deeper layers.

Identifying massive stars in nearby galaxies, in a smart way

Poster

Grigoris Maravelias[1], Alceste Z. Bonanos[1], Ming Yang[1], Frank Tramper[1], Stephan A. S. de Wit[1], Paolo Bonfini[1,2]

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Abstract

To better understand supernova remnants we need a good perception of their progenitor stars. Important insights can only be acquired through the systematic study of these populations in different host galaxies. However, luminous massive stars can remain undetected, as they can be embedded in thick circumstellar environments due to their strong and sometimes eruptive mass-loss. To address this we have used the largest optical (e.g. Pan-STARRS, OGLE) and IR (e.g. 2MASS, Spitzer) photometric datasets to compile the most complete samples of massive stars for a number of nearby galaxies (e.g. the Magellanic Clouds, M31, M33). By taking advantage of different machine-learning techniques (i.e. Support Vector Machines, Random Forests, Convolutional Neural Networks) we have developed an algorithm that classifies supergiant stars with a success ratio of 90% for the training samples. By applying this to the available photometric datasets, we can uncover previously unclassified sources, which will become our prime candidates for spectroscopic follow-up aiming to confirm their nature and our approach.

Is There a Critical Metallicity of Mass Loss in Massive Star Evolution?

Poster

Po-Sheng Ou, Ke-Jung Chen

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Abstract

Stellar winds inject mass and energy into the interstellar medium, playing an important role in stellar feedback. Mass loss of progenitor stars also affects their supernova types. However, the amount of mass lost and energy released during stellar evolution are highly uncertain. Especially, for low-metallicity stars in the early and local universe, while mass loss is thought to be weak, its role is still unknown. To investigate mass loss quantitatively, we include wind recipes based on empirical laws in the MESA code and perform 1D simulations of stellar evolution. We use a grid of initial masses and metallcities in our simulations, and systematically study their effects on mass loss. Our results show a critical metallicity Zc$\sim$0.001 as a transition of mass loss. At the Z>0.001, the fractions of mass lost become large, and remain similar at different Z>Zc. Whether the stars can successfully evolve to the red supergiant phase is the crucial reason that makes such a difference in mass loss. Nevertheless, the boundary of the two regimes is not well defined, as large variations in mass loss exist near Zc through different masses. Furthermore, we calculate the kinetic energy released by stellar winds. The mass loss histories from our 1D MESA models can be used to build up as realistic initial conditions for 2D and 3D simulations of stellar winds in the future.

Constraining Massive Star Activities in the Final Years through Properties of Supernovae and their Progenitors

Poster

Ryoma Ouchi, Keiichi Maeda

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Abstract

Recent observations of supernovae (SNe) just after the explosion suggest that a good fraction of SNe have the confined circumstellar material (CSM) in the vicinity, and the pre-SN enhanced mass loss may be a common property. The physical mechanism of this phenomenon is still unclarified, and the energy deposition into the envelope has been proposed as a possible cause of the confined CSM. In this work, we have calculated the response of the envelope to various types of sustained energy deposition starting from a few years before the core collapse. We have further investigated how the resulting progenitor structure would affect appearance of the ensuing supernova.While it has been suspected that a super-Eddington energy deposition may lead to a strong and/or eruptive mass loss to account for the confined CSM, we found that such a super-Eddington energy injection into the envelope changes the structure of the progenitor star substantially, and the properties of the resulting SNe become inconsistent with usual SNe. This argument constrains the energy budget involved in the possible stellar activity in the final years to be at most sub-Eddington. Such a sub-Eddington energy generation however would not dynamically develop a strong wind in the time scale of a few years. We therefore propose that a secondary effect (e.g., pulsation or binary interaction) of the moderate envelope inflation, which is caused by sub-Eddington energy injection should induce the mass loss.

The Mass Loss Properties of Supernova Progenitors

Poster

Daniel Patnaude

Smithsonian Astrophysical Observatory, Cambridge, USA

Abstract

The mass loss history of massive stars is one of the least understood yet fundamental aspects of stellar evolution. How and when do massive stars shed their hydrogen envelopes? Is there a relationship between the expulsion of the stellar envelope and core collapse? Is there a fundamental relationship between late time mass loss and supernova classification? In this talk, I will present results from a recent Chandra program to perform followup observations of a sample of young and nearby SNe, in order to probe the evolutionary properties of the progenitor. Studying the evolution of a supernova shock as it interacts with its environment, over timescales of years and decades after core collapse, provides insight into how much mass was lost and perhaps most importantly, when it was lost. X-ray emission from the shocked gas probes the dynamics of the interaction, and when combined with multiwavelength observations, constrains properties of the surrounding circumstellar gas and thus the later stages of the progenitor's evolution.

Spatially Resolved X-Ray Spectroscopy of Kepler's Supernova Remnant: Distinct Properties of the Circumstellar Medium and the Ejecta

Poster

Lei Sun, Yang Chen

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Abstract

Kepler's supernova remnant (SNR) is believed to result from a Type Ia supernova, but to be interacting with dense circumstellar material (CSM), which makes its progenitor system a mystery. Using the Chandra ACIS-S 741 ks effective exposure data and an advanced adaptive binning algorithm, we analyse the spectra from tessellated regions in Kepler's SNR. For the first time, we map out the detailed spatial distributions of emission measure (EM), electron temperature, ionization parameter, and metal abundances for both the low- and high-temperature plasma components. The low-temperature plasma diverges into two branches in the temperature v.s. ionization parameter diagram, which appear to be spatially associated with the warm CSM dusts and the Si- and S-rich ejecta, respectively. We construct the probability distribution functions of abundance ratios of O and Mg to L-shell emitting Fe ($[\mathrm{O}]/[\mathrm{Fe}]_\mathrm{L}$ and $[\mathrm{Mg}]/[\mathrm{Fe}]_\mathrm{L}$), and fit them with double Gaussians. Thereby, we distinguish the CSM from the ejecta: the CSM is characterized by $[\mathrm{O}]/[\mathrm{Fe}]_\mathrm{L} = 0.77^{+0.30}_{-0.23}$ and $[\mathrm{Mg}]/[\mathrm{Fe}]_\mathrm{L} = 1.11^{+0.46}_{-0.32}$, while the ejecta by $[\mathrm{O}]/[\mathrm{Fe}]_\mathrm{L} = 0.31^{+0.17}_{-0.10}$ and $[\mathrm{Mg}]/[\mathrm{Fe}]_\mathrm{L} = 0.38^{+0.36}_{-0.19}$. We estimate the total hydrogen mass of the shocked CSM as $\sim 1.4\ \mathrm{M}_\odot$ and the EM-weighted mean $[\mathrm{Mg}]/[\mathrm{O}] = 1.14 \pm 0.49$, which can be reproduced with an asymptotic giant branch donor star with initial mass of $\sim 4\ \mathrm{M}_\odot$. The abundance ratios from the shocked ejecta are well compatible with the predicted results from spherical delayed-detonation models for Type Ia supernovae. We also find that the two 'ears' of the remnant are dominated by Si- and S-rich ejecta, thus favoring a pre-explosion jets scenario.

3D MHD Simulations from the Onset of the SN to the Full-fledged SNR: Role of Ejecta Clumps on Matter Mixing

Poster

Antonio Tutone[1], Salvatore Orlando[2], Marco Miceli[3]

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[2]INAF-Osservatorio Astronomico di Palermo, Palermo, Italy
[3]Universit degli studi di Palermo, Palermo, Italy

Abstract

The physical properties and the morphology of supernova remnants (SNRs) partially reflect the structure of the stellar progenitor and possible asymmetries developed soon after their parent supernova (SN) explosions. The aim of this work is to bridge the gap between SNe and their remnants by investigating how the various chemically homogeneous layers at the time of the explosion map into the resulting abundance pattern observed when the remnant is fully developed. To this end, we have performed three-dimensional magneto-hydrodynamical simulations starting soon after the SN and following the interaction of the SN ejecta with the CSM (consisting in the wind of the stellar progenitor), obtaining the physical scenario of a SNR. As stellar progenitor, we have considered the case of a 19 $\mathrm{M}_\odot$ red supergiant. We investigated how the evolution of a post-explosion large-scale anisotropy in the ejecta and the role of its initial parameters (position, dimension, density and velocity contrast) can affect the ejecta distribution and the matter mixing of heavy elements in the remnant, covering 5000 years of evolution.

The Signature of a Windy Radio Supernova Progenitor in a Binary System

Poster

Almog Yalinewitz[1], Simon Portegies Zwart[2]

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[2]Leiden Observatory, Leiden, Netherlands

Abstract

Type II supernova progenitors are expected to emit copious amounts of mass in a dense stellar wind prior to the explosion. When the progenitor is a member of a binary, the orbital motion modulates the density of this wind. When the progenitor explodes, the high-velocity ejecta collides with the modulated wind, which in turn produces a modulated radio signal. In this work we derive general analytic relations between the parameters of the radio signal modulations and binary parameter in the limit of large member mass ratio. We use these relations to infer the semi major axis of SN1979c and a lower bound for the mass of the companion. We also perform numerical simulations using the AMUSE framework of the progenitor binary system including the wind and the gravitational effect of a companion star. The simulation output is compared to the observed radio signal in supernova SN1979C. We find that it must have been a binary with an orbital period of about 2000 years. If the exploding star evolved from a $\sim$18 $M_\odot$ zero-age main-sequence at solar metallicity, we derive a companion mass of 5 to 12 $M_\odot$ in a roughly circular orbit.

Evolved Massive Stars at Low-metallicity: A Source Catalog for the Small Magellanic Cloud

Poster

Ming Yang[1], Alceste Z. Bonanos[1], Bi-Wei Jiang[2], Jian Gao[2], Panagiotis Gavras[3], Grigoris Maravelias[1], Yi Ren[2], Shu Wang[4], Meng-Yao Xue[5], Frank Tramper[1], Zoi T. Spetsieri[1], Ektoras Pouliasis[1], and Stephan A. S. deWit[1]

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Abstract

We present a clean, magnitude-limited (IRAC1 or WISE1$\leq$15.0 mag) multiwavelength source catalog for the Small Magellanic Cloud (SMC) with 45,466 targets in total, intending to build an anchor for future studies, especially for the massive star populations at low-metallicity. The catalog contains data in 50 different bands including 21 optical and 29 infrared bands, retrieved from SEIP, VMC, IRSF, AKARI, HERITAGE, Gaia, SkyMapper, NSC, Massey et al. (2002), and GALEX, ranging from the ultraviolet to the far-infrared. Additionally, radial velocities and spectral classifications were collected from the literature, as well as the infrared and optical variability information retrieved from WISE, SAGE-Var, VMC, IRSF, Gaia, NSC, and OGLE. The catalog was essentially built upon a 1" crossmatching and a 3" deblending between the Spitzer Enhanced Imaging Products (SEIP) source list and Gaia Data Release 2 (DR2) photometric data. Further constraints on the proper motions and parallaxes from Gaia DR2 allowed us to remove the foreground contamination. We estimated that about 99.5% of the targets in our catalog were most likely genuine members of the SMC. By using the evolutionary tracks and synthetic photometry from MESA Isochrones & Stellar Tracks and the theoretical J-Ks color cuts, we identified 1,405 red supergiant, 217 yellow supergiant and 1,369 blue supergiant candidates in the SMC in five different color-magnitude diagrams (CMDs). We ranked the candidates based on the intersection of different CMDs. A comparison between the models and observational data shows that the lower limit of initial masses of the RSGs population may reach down to 7 or even 6 $M_\odot$, making RSGs a unique population connecting the evolved massive and intermediate stars, since stars with initial mass around 6 to 8 $M_\odot$ are thought to go through a second dredge-up to become asymptotic giant branch stars. We encourage the interested reader to further exploit the potential of our catalog.

Session 3.

Supernova Explosion Mechanisms – Oral Talks

Hydrodynamical models of Core-Collapse Supernovae and Shock Breakout

Invited Talk

Melina Bersten[1]

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Abstract

A very active area of research in the field of core-collapse supernovae (SNe) is the study of their progenitors, in particular the processes of mass loss. Direct progenitor identification using pre- and post-SN images is a powerful method but it can only be applied to the most nearby events. An alternative method is the hydrodynamical modeling of SN light curves and expansion velocities, which can serve to characterize the progenitor (e.g. mass and radius) and the explosion itself (e.g. explosion energy and radioactive yields). Models show that the first hours/days of the SN evolution provide key information of the outer progenitor structure. Large observational efforts are being done with the aim of detecting SNe at ever earlier stages, even at the initial phase of the shockwave emergence the shock breakout. I will review the power and prospects of studying the shock-breakout emission using hydrodynamical models.

A sub-Chandrasekhar mass white dwarf as possible progenitor for a thermonuclear explosion

Oral Talk

Sabrina Gronow[1], **Friedrich Röpke**[1,2]

[1]Heidelberger Institut für Theoretische Studien, Germany
[2]Universität Heidelberg, Germany

Abstract

For Type Ia supernovae, neither the progenitor system nor the details of the explosion mechanism are known. Various scenarios are being investigated in the context of different progenitor evolution channels. In the double detonation scenario a sub-Chandrasekhar mass carbon-oxygen white dwarf has accreted material from a companion resulting in a helium shell. Instabilities develop and lead to a helium detonation at the base of the shell. Following this, a second detonation can be triggered in the carbon-oxygen core. We simulate this explosion mechanism with a particular focus on studying the propagation of the helium shell detonation and the ignition of the core detonation. This is enabled by using new numerical techniques. Our simulations show a detonation ignition mechanism which previously received little attention. We show that the success of this mechanism and the nucleosynthesis yields in the helium shell detonation ejecta depend sensitively on how the core-shell interface is modeled.

3D core-collapse Supernova modeling and applications to Cas A and other Supernova Remnants

Invited Talk

Hans-Thomas Janka

Max Planck Institute for Astrophysics, Ludwig Maximilians University Munich, Germany

Abstract

First three-dimensional, first-principle simulations of core-collapse supernovae have become possible in the recent past. They demonstrate the basic viability of the neutrino-driven mechanism for powering the explosions of the majority of supernova progenitors. Although a number of open questions remain to be settled, the explosion models are now sufficiently mature to strive for detailed comparisons against observations, for example considering well studied, nearby supernovae and young supernova remnants. This talk will review our basic understanding of the explosion mechanism and report some results of such observational tests.

Extracting Type Ia Supernova Explosion Mechanisms by their Nucleosynthesis Yields

Oral Talk

Shing-Chi Leung[1], Ken′ichi Nomoto[1]

[1]Kavli IPMU, The University of Tokyo, Japan

Abstract

A type Ia supernova is the thermonuclear runaway of a carbon-oxygen(-neon) white dwarf. However, the detailed explosion mechanisms of Type Ia supernovae such as the nature of turbulent flame and details of the deflagration-detonation transition, and its evolutionary path before explosion (the single degenerate versus double degenerate scenario and its exact chemical composition) remain outstanding scientific questions. In fact, the chemical abundance patterns derived in the explosion can provide constraints on these theoretical uncertainties. In this talk, I will present our recent parameter surveys for Type Ia supernovae using near-Chandrasekhar mass and sub-Chandrasekhar mass white dwarfs as the progenitors using multi-dimensional hydrodynamics simulations with nucleosynthesis. I will first discuss their characteristic nucleosynthesis yields. Then I will demonstrate how to use the chemical abundance patterns obtained from supernova light curves (e.g. SN 2011fe, SN 2012cg and SN 2014J), spectra from supernova remnants (e.g. 3C 397), and in low-mass white dwarfs (e.g. LP 40 -365) to derive constraints on the explosion mechanisms and on their possible progenitors. At last, I will discuss how the galactic chemical evolution can provide clues to the Type Ia supernova progenitors.

Nucleosynthesis Constraints on The Energy Growth Timescale of a Core-Collapse Supernova Explosion

Oral Talk

Ryo Sawada[1], **Keiichi Maeda**[1]

[1]Kyoto University, Japan

Abstract

The details of the explosion mechanism of core-collapse supernovae (CCSNe) are not yet fully understood. There are an increasing number of numerical examples by ab-initio core-collapse simulations leading to an explosion. Most, if not all, of them represent a 'slow' explosion in which the 'observed' explosion energy ($\sim 10^{51}$ ergs) is reached in a time scale of $\sim$1 second, or even longer. On the other hand, traditionally the SN explosive nucleosynthesis has been studied assuming an instantaneous explosion. In this work, we investigate how the nucleosynthesis products are affected by the energy growth time scale ($t_{\rm grow}$; the timescale in which the explosion energy is reached to 10^{51} ergs from start of explode). We employ one-dimensional hydrodynamic and nucleosynthesis simulations above the iron core, by parameterizing the nature of the explosion mechanism by $t_{\rm grow}$. The results are then compared to various observational constraints; the masses of ^{56}Ni derived for typical CCSNe, the masses of ^{57}Ni and ^{44}Ti observed for SN 1987A, and the abundance patterns seen in metal-poor stars. We find that these observational constraints are consistent with the 'rapid' explosion ($t_{\rm grow} \lesssim 200$ ms), and especially the best match is found for a nearly instantaneous explosion ($t_{\rm grow} \lesssim 10$ ms). On the other hand, the slow mechanism ($t_{\rm grow} \gtrsim 400$ ms) does not satisfy these constraints. Note that multi-dimensional effects in the explosion may also be a key in the synthesis of ^{44}Ti; for example, a jet-like explosion is suggested to increase the amount of ^{44}Ti. For example, the jet-like explosion can lead to the high ratio of ^{44}Ti to ^{56}Ni, but the mass of ^{44}Ti itself tends to decrease as a decreasing amount of ^{56}Ni. However, these effects would not be sufficiently strong to remedy the large discrepancy we find here. Our finding places a strong constraint on the explosion mechanism; the rapid growth of the explosion energy, at most in $\sim$ 200 ms, should be realized in typical CCSNe.

Session 3.

Late Stages and endpoints – Posters

X-Ray and Gamma-Ray Emission from 3D Neutrino-Driven SN Simulations and Comparisons With Observations of SN 1987A

Poster

Dennis Alp[1], Josefin Larsson[1], Claes Fransson[2], Keiichi Maeda[3], Annop Wongwathanarat[4], Hans-Thomas Janka[4], Michael Gabler[4], Anders Jerkstrans[4]

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[2]Stockholm University, Sweden
[3]Kyoto University, Japan
[4]Max Planck Institute for Astrophysics, Germany

Abstract

During the first few hundred days, core-collapse supernovae (SNe) strongly emit down-scattered X-rays and gamma-rays originating from radioactive line emissions, primarily from the ^{56}Ni → ^{56}Co → ^{56}Fe chain. We use SN models based on three-dimensional neutrino-driven explosion simulations (Wongwathanarat et al. 2013, 2015) to compute this emission and compare the predictions to observations of SN 1987A. First, we use the 3D models to investigate the effects of 3D structure and asymmetries on the escaping emission. The main effect of asymmetries is to vary the flux normalization by a factor of ∼2, while the spectral shapes and shapes of the light curves are relatively insensitive to the viewing angle. Additionally, properties such as the time of the first X-ray emission and direct line fluxes are very sensitive to the ejecta structure. These effects combined allows for strong constraints on the models.The overall spectral shapes are in good agreement with observations. In particular, the soft X-ray cutoff is determined by the metallicity of the progenitor and the comparisons show that the metallicity of the SN 1987A progenitor is similar to the LMC metallicity. The first escape of emission around 200 days almost matches data. This indicates that the neutrino-driven mechanism is capable of self-consistently producing sufficient mixing to match the early emergence of the X-rays and gamma-rays for certain progenitor properties. However, there are differences that cannot be matched by a suitable choice of viewing angle. The discrepancies relative to the best-fitting model (B15) indicate that only slightly more mixing and minor modifications to the distribution of the bulk of ^{56}Ni are needed. This can almost certainly be achieved by minor differences in the progenitor structure, especially considering the uncertainties related the progenitor evolution. We will also present predictions from models based on the merger progenitors of Menon & Heger (2017), and compare these with the single-star predictions.We study other progenitors that are not designed to match SN 1987A to extend our results to more common types of SNe and to serve as a reference for future observations. Red supergiants are similar to SN 1987A progenitors in the predicted observables, but stripped-envelope SNe are substantially more luminous and evolve faster. Future *NuSTAR* observations should detect the down-scattered continuum and low-energy photoabsorption cutoff of future (non-)stripped SNe up to distances of (2)8 Mpc. Observations of the soft X-ray cutoff could potentially constrain the progenitor surface metallicity. The detection limits for the direct lines by *INTEGRAL* are (0.2)2 Mpc for (non-)stripped SNe.

Radioactive Isotopes in Core-Collapse Remnants

Poster

Chris Fryer[1], Aimee Hungerford[1], Oleg Korobkin[1], Sam Jones[1], Samar Safi-Harb[2]

[1]Los Alamos National Laboratory, USA
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Abstract

NuSTAR observations of ^{44}Ti have demonstrated the power radioactive nuclei have in constraining aspects of the supernova engine. Radioactive nuclei have the potential to probe core-collapse remnants (and neutron star mergers) over a range of ages. Radioactive decays produce photons both in the gamma-rays and, through de-excitation, X-rays. Because these decay photons do not rely on shock heating, they provide a clean probe of the yields (probing the progenitor and the explosion mechanism) that, in some cases, have the potential to be observed 0.1-1 million years after the explosion. Here I discuss the potential of radioactive isotopes to probe these explosions and the physics behind them, focusing on ^{60}Fe, and ^{26}Al in core-collapse and r-process elements in neutron star mergers.

Type Iax Supernovae from Deflagrations of Chandrasekhar Mass White Dwarfs

Poster

Florian Lach[1], Friedrich Röpke[1,2], Markus Kromer[1,2]

[1]Heidelberg Institute for Theoretical Studies, Germany
[2] Zentrum für Astronomie der Universität Heidelberg, Germany

Abstract

In addition to the bulk of normal Type Ia supernovae a variety of subclasses exist. The largest of these is the subclass of Type Iax supernovae. The corresponding events are fainter than normal Type Ia supernovae, they lack the characteristic second maximum in the near-infrared light curves and their ejectastructure is well mixed. Moreover, their spectra show only weak features of intermediate mass elements but signs of iron group elements at early times and lack a transition to the nebular phase at very late times.It has been demonstrated that these features can largely be reproduced by deflagrations in Chandrasekhar-mass carbon-oxygen white dwarfs. These kinds of explosion predict the existence of a bound remnant. This hypothesis is also supported by observations. However, it has not been studied yet whether this scenario can cover the wide ranges of properties of Type Iax supernovae such as the large spread in peak luminosities and thus explain the entire subclass.We present the results of state-of-the-art full star simulations of deflagrations in carbon-oxygen white dwarfs exploring the parameter space of the progenitor, i.e.its metallicity, its central density and the number, size and location of theignition kernels. For this purpose, we employed the hydrodynamics code LEAFS to simulate the explosion phase as well as the nuclear network code YANN to evaluate detailed nucleosynthesis yields in a postprocessing step. Finally, radiative transfer calculations using the ARTIS code were used toassess whether the models match observed spectra and light curves of Type Iax supernovae.

From the (thermonuclear) supernova to the supernova remnant

Poster

Shigehiro Nagataki[1], Gilles Ferrand[1], Don Warren[1], Masaomi Ono[1], Friedrich Röpke[2,3], Ivo Seitenzahl[4]

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[2]Universität Heidelberg, Germany
[3]Heidelberg Institute for Theoretical Studies, Germany
[4]University of New South Wales, Syndey

Abstract

Recent progress in the simulation of supernovae (SNe) has shown the importance of turbulence and asymmetries in successful explosions, which prompts us to revisit the subsequent phase, the supernova remnant (SNR). Can we use the SNR morphology as a probe of the explosion mechanism? Recent work by Orlando et al has shown the interest of this approach for a core-collapse SNR like Cas A. Here we argue for the case of a Type Ia SNR like Tycho. Our project is making the link between two communities, the one studying the explosion and the one studying the remnant. We have run 3D simulations of a SNR starting from the output of a 3D simulation of the thermonuclear explosion of a carbon-oxygen white dwarf. By analyzing the wavefronts we have quantified the imprint of the explosion on the remnant over time. Assuming a uniform ambient medium, we find that the impact of the SN on the SNR may still be visible after hundreds of years. And interestingly, the newly simulated maps look more realistic than in previous works based on spherically symmetric ejecta profiles.

Simulation of an Ultra-stripped Type Ic Supernova

Poster

Tomoya Takiwaki[1]

[1]National Astronomical Observatory Of Japan, Japan

Abstract

Using neutrino radiation hydrodynamic simulation, I will discuss our model of ultra-stripped type Ic supernova.

Session 4.

Shock Physics and Particle Acceleration in SNRs – Oral Talks

Observational study of Non-thermal phenomena on SNR shocks

Invited Talk

Aya Bamba

University of Tokyo, Japan

Abstract

Shocks of supernova remnants (SNRs) are widely believed as the main accelerator of Galactic cosmic rays. However, quantitative studies are still on beginning, such as the maximum energy of accelerated particles, acceleration efficiency, and so on. It is another open issue, how to escape particles from acceleration sites to be cosmic rays. Observations of SNRs in X-rays and gamma-rays are one strong tools to untangle these problems. Accelerated particles emits X-rays and gamma-rays via synchrotron, inverse Compton, and pi-0 decay. Plasmas heated by the strong shock up to ∼MK emit strong bremsstrahlung and characteristic X-ray lines, which include plenty of information of the environment of acceleration sites such as density, temperature, time scale, and so on. In this talk we introduce the recent progress and future prospective of observations of SNRs.

Interplay between Physics and Geometry in Balmer filaments

Oral Talk

Rino Bandiera[1], Giovanni Morlino, Sladjana Knezevic, John C. Raymond

[1]INAF - Osservatorio Astrofisico di Arcetri, Italy

Abstract

The comparison between observations and models of Balmer-dominated emission in supernova remnants may represent a powerful way to gather information on the physical conditions in their shocks, like on their structure, on the ambient medium properties, on the cosmic-ray acceleration efficiency. We will focus here on the importance of disentangling physical and geometrical effects for a correct interpretation of the data. To this purpose we have developed a rather general scheme, which is particularly useful for data with enough spatial resolution to resolve the structure of the Balmer-emitting transition region of the shock. We have applied this technique to re-analyze very high quality data of an area located along the northwestern limb of the remnant of SN 1006, and we have shown how some observed features can be interpreted rather naturally when also geometrical effects are taken into account. By this analysis we have derived new constraints on physical quantities in that region, like the ambient density, the upstream neutral fraction, the level of face-on surface brightness variations and the typical scale lengths related to such variations. An optimal use of this scheme, for SN 1006 as well as for a few other nearby Balmer-dominated remnants, will require future data in which a superbe spatial resolution is combined with detailed spectral information on the emission line structure.

Acceleration at SNR shocks: state of the art and challenges

Invited Talk

Damiano Caprioli

University of Chicago, USA

Abstract

I review the recent developments in the theory of diffusive shock acceleration (DSA) by using both first-principle kinetic plasma simulations and analytical theory based on the solution of the convection/diffusion equation. In particular, I discuss the conditions for efficient particle acceleration, the generation of magnetic fields, and the spectra of the accelerated particles, highlighting agreement and discrepancies between theory and multi-wavelength observations of SNRs.

The expansion and width of the synchrotron filaments associated with the forward shock of Cas A

Oral Talk

Daniel Castro[1], Jacco Vink[2], Dan Patnaude[1], et al.

[1]Harvard-Smithsonian Center for Astrophysics, USA
[2]University of Amsterdam, The Netherlands

Abstract

X-ray observations of Cas A have revealed filamentary non-thermal rims tracing the forward shock of the supernova remnant (SNR). These structures have been identified as synchrotron radiation from shock-accelerated electrons with TeV energies, interacting with the compressed, and probably amplified, local magnetic field. Magnetic field amplification (MFA) is broadly believed to result from, and contribute to, cosmic ray acceleration at the shocks of SNRs. Using data from the long term Chandra program studying the evolution of Cas A, we have estimated the expansion of the non-thermal rims at the forward shock of the SNR, as well as the width of these filaments. Since the size of the synchrotron filaments places constraints on the magnetic field strength, this study allows us to establish a connection between the shock velocity and the characteristics of the particle acceleration process.

Measuring the post-shock temperatures of heavy ions in SN 1987A

Oral Talk

Marco Miceli[1], S. Orlando[2], F. Bocchino[2], S. Park[3], A. Pazhayath Ravi[3], D. Burrows[4], K. Frank[5], C, Argiroffi[1], G. Peres[1], E. Greco[1], O. Petruk[6]

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Abstract

The shock waves originated from supernova explosions provide crucial information on the physics of shock heating. Astrophysical shocks are typically collisionless and electrons, protons, and ions are expected to be heated at different temperatures, but the actual dependence of the post-shock temperature on the particle mass is still debated. We tackle this long standing issue through the analysis of high-resolution observations of SN 1987A, made with the Chandra X-ray telescope in 2007 and 2011, and we also include the latest 2018 observation in our analysis. We study the observed spectra in close comparison with a dedicated full 3-D hydrodynamic simulation. The simulation is able to reproduce self-consistently the whole broadening of the spectral lines of many ions altogether. We could therefore measure the post shock temperature of protons and selected ions. We found that the ion to proton temperature ratio is always significantly higher than one and increases linearly with the ion mass for a wide range of masses. Thanks to the new 2018 deep observation we are also able to further extend our results for a wide range of shock parameters.

Constraint on diffusion coefficient at SNR shock using nonthermal X-ray and gamma-ray observations

Oral Talk

Naomi Tsuji[1], Yasunobu Uchiyama[1], Dmitry Khangulyan[1], and Felix Aharonian[2]

[1]Rikkyo University, Japan
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Abstract

The motion of the cosmic rays (CRs) is characterised by the diffusion coefficient. It is a key factor for acceleration of CRs at the shock of supernova remnants (SNRs). Both the absolute value and the energy dependence of the diffusion coefficient are important to determine the efficiency of acceleration and the wave spectrum of turbulent magnetic field, which is not fully understood. It has been proposed that the diffusion coefficient can be measured from the cutoff shape of the electron energy distribution, and the corresponding synchrotron X-ray spectrum. We apply this to nonthermal X-ray observations of several synchrotron-dominated SNRs. We estimate the diffusion coefficient in the case of Bohm-type, that is widely accepted for acceleration at the SNR shock, and non-Bohm-type diffusion, such as Kolmogorov type. Assuming that the diffusion coefficient is larger than Bohm limit, the constraint becomes tighter. For example, the diffusion is close to the Bohm-limit regime, and Kolmogorov-type diffusion is excluded for RX J1713.7-3946. On the other hand, G1.9 shows that the absolute value of the diffusion coefficient (or so-called gyro factor) is about one order of magnitude higher than that of Bohm limit both in the case of Bohm and Kolmogorov diffusion. We report the results from the systematic analysis of synchrotron-dominated SNRs, and discuss about the relation between the diffusion coefficient and the evolutional phase. We also test the application to the cutoff shape of the gamma-ray spectra using TeV gamma-ray observations, and report the result.

The strange behaviour of the reverse shock of Cas A

Oral Talk

Jacco Vink, Daniel Patnaude, Daniel Castro, et al.

University of Amsterdam, The Netherlands

Abstract

The dynamics of the reverse shock of Cas AAs part of an ongoing long term Chandra program to study the evolution of Cassiopeia A, we analysed both the expansion of the forward shock regions and the regions shocked each split in 36 sectors. For our measurements we use an updated version of the code used in Vink 2008, in that several epochs can be fitted simulteneously, which reduces the systematic errors, as it allows for better separation of brightness changes version proper motions. In this presentation we focus on the reverse shock, for which we incorporate knowledge about the reverse shock position from radio (Arias et al. 2018) and X-rays (Helder & Vink 2008). We confirm previous findings (e.g. Helder & Vink 2008, Sato et al. 2018) that, contrary to theoretical expectations, the reverse shock in the western half is stationary or inward moving in the observer frame. This is contrary to model predictions such as the analytical models of Truelove & McKee and its extensions and the numerical hydrodynamical modelling by Orlando et al. (2016). The models are consistent with the reverse shock motion in the eastern half of the remnant. We will present the results of the expansion measurements and place them in the context of the hydrodynamical models, but also observational evidence (radio and X-rays) that the reverse shock is shifted to the West with respect to the centre. A byproduct of this is that the reverse shock velocity in the frame of the ejecta is much slower in the eastern part ($\sim$ 1500 km/s), where the reverse shock moves outward and the free expansion velocity of the ejecta is lower due to the smaller reverse radius, than in the western region, where the shock speed may be as high as 7800 km/s. This large contrast explains why only in the Western part of the remnant the reverse shock is identified with X-ray synchrotron emitting filaments.

Session 4.

Shock Physics and Particle Acceleration in SNRs – Posters

Understanding gamma-ray emission of RX J1713.7-3946

Poster

Fabio Acero, Jean Ballet

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Abstract

RX J1713.7-3946 is the brightest TeV supernova remnant, so it is an important test case for cosmic-ray acceleration. The absence of ambient thermal X-ray emission (together with only moderate absorption) indicates that the gas is tenuous. Since a Central Compact Object sits at the center of the remnant, the mainstream view is that the SNR develops into the wind of its high-mass progenitor and now reaches a shell of denser gas around, observed in CO. The gamma rays are well correlated with the X-ray emission, which is dominated by synchrotron emission from accelerated electrons, but the correlation is very non-linear (approximately $F_\gamma \propto \mathrm{Sqrt}(F_X)$). In that context, the most natural model is that gamma-rays are dominated by inverse Compton emission (leptonic). The X to gamma ray ratio is modest, implying a low magnetic field. We have obtained deep full coverage of RX J1713.7-3946 with XMM-Newton (PI F. Acero). Together with the good HESS map, it allows testing the gamma/X correlation into the faint areas, in particular the external boundary of the SNR where the HESS collaboration reported gamma-ray emission beyond the X-ray border, which could be due to escape of cosmic-ray protons. I will discuss whether the better X-ray data could explain the gamma-ray map in a purely leptonic model. I will also discuss how the gamma-ray spectral shape, which has a break around 10 GeV, could be due to the decrease of the magnetic field as the shock develops in the wind.

Beyond the non-thermal emission of RX J1713.7-3946: first results from the XMM-Newton Large Program

Poster

Fabio Acero[1], Satoru Katsuda[2]

[1]CEA-Saclay, DAp/AIM, [2]Saitama Univ.

Abstract

RX J1713.73946 is the poster-child of cosmic-ray accelerator and is among the brightest X- and gamma-ray non- thermal emitters. While the dominant X-ray synchrotron emission has been heavily studied in the past, there is still much to learn about the ejecta properties and the surrounding medium by studying the faint thermal emission. While previous XMM-Newton programs focused their attention on a few regions, other parts of the remnant were only observed for 10 ks and some outer and fainter regions were never observed. With a diameter of 1°, a 700 ks LP, completed in 2018, was necessary to obtain a deep exposure (80 ks) across the remnant. Here I will present the first results of this program focusing on the thermal emission of a bright clump in the SNR (shocked circumstellar material ?), and a detailed study of a direct shock-cloud interaction region. In addition, thanks to a new blind source analysis technique, we were able to obtain the first image of the faint thermal component across the entire remnant and I will discuss its nature, spatial properties and impact in terms of SN progenitor.

Non-linear diffusive shock acceleration: A recipe for electron injection

Poster

Bojan Arbutina, Vladimir Zekovic

Department of Astronomy, Faculty of Mathematics, University of Belgrade, Serbia

Abstract

Prescriptions for the electron injection into the diffusive shock acceleration process are required in many practical considerations of the cosmic-ray astrophysics, particularly in modeling of the synchrotron emission of astrophysical sources. Inspired by the results of our particle-in-cell shock simulations, we assumed that the injection parameter xi = pinj/pth is the same for both, protons and electrons. We applied the Blasis semi-analytical model of the non-linear diffusive shock acceleration in order to obtain the particle spectra and the electron-to-proton ratio Kep at high energies. By using the shock jump conditions which also include the electron heating, for the Mach number $\sim$ 100 we find that the ratio for the Galactic cosmic rays is Kep $\sim$ 1:100 in the test particle case.

Physics of nonrelativistic perpendicular shocks of young supernova remnants: electron injection, energy redistribution and magnetic turbulences

Poster

Artem Bohdan, Martin Pohl, Jacek Niemiec, Takanobu Amano, Masahiro Hoshino, Yosuke Matsumoto

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Abstract

It is generally assumed that the most part of galactic cosmic rays is produced by supernova remnants through diffusive shock acceleration (DSA). To be involved in DSA particles should be picked up from thermal pool. This issue is known as injection problem and still remains unresolved. Here we present results of 2D3V particle-in-cell simulations of nonrelativistic perpendicular shocks for the parameters applicable for supernova remnants. Physics of such shocks is governed by ions, part of which reflected back upstream by shock potential. That leads to the excitation of the electrostatic Buneman instability in the shock foot and to the formation of magnetic filaments in the shock ramp, resulting from the ion-beam-Weibel instability. Injection of electrons occurs in three different ways, namely, shock surfing acceleration, magnetic reconnection and stochastic Fermi-like acceleration. However efficiency of these processes strongly depends on shock parameters, such as Alfven Mach number and ion-to-electron mass ratio. Weibel instability in the shock transition also leads to redistribution of ion bulk kinetic energy into ion thermal, electron thermal, magnetic field energies and formation of turbulent magnetic field in the shock downstream. These results are used to approximate the electron injection efficiency in shocks with realistic physical parameters.

Stellar and interstellar content of the region interacting with cosmic rays in IC443G

Poster

Pierre Dell'Ova, Antoine Gusdorf, Maryvonne Gerin

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Abstract

Context. Supernova remnants (SNRs) represent a major feedback source of stars on the interstellar medium of galaxies. During the latest stage of supernovae explosions, shock waves produced by the initial blast modify the chemistry of gas and dust, inject kinetic energy in the surroundings, and may enhance or trigger star formation. Simultaneously, cosmic rays accelerated in the early stages interact with the ambient gas, generating gamma ray photons.

Aims. We study the properties of the gas and stars in IC443, an evolved shell type SNR at a distance of 1-1,5 kpc, with an estimated age of 30k years. We aim to fully characterize the stellar and interstellar content of the extended G region, which corresponds to the peak of gamma ray emission detected by VERITAS and *Fermi*.

Methods. We performed 10' $\times$ 10' mapped observations of CO(1-0), CO(2-1) and CO(3-2) transitions obtained with IRAM 30m and APEX telescopes over the whole extent of the gamma ray peak to reveal the molecular structure of the region. First, we inferred the optical depths of these transitions from the emission of the isotope ^{13}CO. Then we used an excitation diagram analysis and/or LVG analysis to measure the column density, mass and kinetic temperature of the gas. We used complementary data (stars, gas and dust at multiple wavelengths) to further characterize the region and understand its association with the peak of gamma emission.

Results. Our observations revealed three molecular structures: one already known shocked molecular clump associated with an emission lines extending between -30 km/s and 20 km/s, one quiescent, denser cloud associated with a linewidth of 2 km/s, and a narrow ring-like structure associated with a linewidth of 1 km/s. The masses we measured for the different structures are the following: [100-150] $M_\odot$, [150-220] $M_\odot$ and [120-170] $M_\odot$ respectively for the shocked clump, dense cloud and ring-like structure. Our results show that the presence of the ring-like structure and quiescent cloud cannot be overlooked when quantifying the interaction of cosmic rays with the dense local medium. Additionally, the presence of numerous possible protostars in the region might contribute to the injection of cosmic rays, which must also be taken into account in the interpretation of gamma ray observations in this region.

Synchrotron radiation in Cas A: the non-linear connection

Poster

Vladimir Domček[1,2,3], Jacco Vink[1,2,3], Ping Zhou[1,3], Maria Arias[1,3]

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Abstract

One of the most important themes in research of supernova remnants (SNRs) over the last 10-20 years has been cosmic-ray acceleration by SNR shocks. The detection of synchrotron emission from radio up to X-rays has proved that young SNRs can accelerate electrons up to energies of 10-100 TeV. It was also shown that SNR should be capable of converting $\sim$10% of their kinetic energy into cosmic rays. This means that accelerated particles cannot be treated separately from the plasma flow, but instead can alter the plasma properties around the shock and the power-law shape of the resulting spectra. A prediction of efficient acceleration is that electron cosmic-ray spectra should flatten toward higher energies before eventually cutting off. We test this hypothesis by spatially investigating the spectral index in the Cas A remnant by comparing radio and mid-infrared data. We find indeed

evidence throughout the remnant that the spectral index flattens from radio to infrared. The overall flattening spectrum also puts an upper limit on any cooling break, which puts an upper limit on the magnetic field strengths. A possible exception is the southeastern region, where we find a hint of a cooling break.

Hydrodynamical simulations of supernova remnant in fractal interstellar medium: morphology of the shock-wave

Poster

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Abstract

We present a 3D hydrodynamical simulation of supernova remnants in adiabatic phase, based on the MUSCL-Hancock finite volume scheme. The remnants are evolved in uniform as well as in fractally structured interstellar medium. The fractal medium is modelled as fractally distributed ensemble of clumps of matter. The morphological features of calculated synchrotron radiation from the shock-wave region resemble the X-ray synchrotron emission readily observed in well studied supernova remnants. This implies that these remnants are likely to evolve in a similar non-uniform environment, although their spherical appearance might suggest that they are evolving in a highly uniform medium.

Efficient particle acceleration from HESS J1640.6-4633 and the PeVatron candidate HESS J1641.0-4619

Poster

Marianne Lemoine-Goumard, A. Mares

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Abstract

There are only a few PeVatron candidates known in our Galaxy which might contribute particles up to the knee of the cosmic-ray spectrum. HESS J1641.0-4619, a gamma-ray source located in the Galactic plane and detected by H.E.S.S. above 4 TeV, is one of them. Characterized as a point source with a hard spectral index, HESS J1641.0-4619 remains unidentified but is coincident with a radio SNR G338.5+0.1 and the dense HII region G338.4+0.0. With an angular extent of only 0.25°, the high energy gamma-ray source HESS J1640.6-4633, coincident with the composite SNR 338.3-0.0 and the pulsar PSR J1640-4631, was originally classified as an extremely powerful SNR. In this context, the escape of cosmic-ray protons accelerated by G338.3-0.0 colliding with the ambient dense gas would be able to produce the emission of HESS J1641.0-619, providing a self-consistent explanation for the gamma-ray emission of both sources. Using 9 years of Fermi LAT pass 8 data, we analyzed these two sources from 100 MeV to 800 GeV. Our extensive morphological and spectral analyses provide new constraints on the origin of the gamma-ray emission as well as the efficiency of these two H.E.S.S. sources to accelerate protons and contribute to the galactic cosmic-ray flux around the knee.

The gas structure towards supernova remnants suspected of cosmic-ray acceleration

Poster

Nigel Maxted[1], Gavin Rowell[2], Miroslav Filipovic[3], Catherine Braiding[4], Michael Burton[5] (Armagh Observatory), Fabien Voisin[2], Graeme Wong[4]

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[3]Western Sydney University, Australia
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[5]Armagh Observatory, UK

Abstract

Gamma-ray astronomy may offer answers to a long-standing question of high energy astrophysics: Where do cosmic rays come from? The gamma-ray emission seen from some middle-aged supernova remnants is now known to be from distant populations of cosmic-rays interacting with gas, but there is still much work to be done in accounting for the Galactic cosmic-ray flux. I will present analyses of the interstellar medium gas surrounding young and middle-aged Galactic supernova remnants such as W28, RX J1713.7-3946, HESSJ1731-347, Vela Jr, HESS J1534-571 and others using data from the Mopra radio telescope. By making the connection between supernova remnant high energy emission and gas, as traced by molecules such as CO, CS and NH3, we can test the potential of these objects to accelerate hadrons beyond TeV energies.

Constraining the coherence scale of the interstellar magnetic field using TeV gamma-ray observations of supernova remnants

Poster

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Abstract

Galactic cosmic rays are believed to be accelerated at supernova remnant (SNR) shocks. In the hadronic scenario the TeV gamma-ray emission from SNRs originates from decaying pions that are produced in collisions of the interstellar gas and cosmic rays. Using cosmic ray magnetohydrodynamic simulations performed with the code AREPO, we show that magnetic obliquity-dependent shock acceleration is able to reproduce the observed TeV gamma-ray morphology of SNRs solely by varying the magnetic field topology. This allows us to constrain the magnetic coherence scale in the cases of SN1006 and Vela Jr shown here respectively to $>200^{+10}_{-60}$ pc and 8^{+15}_{-6} pc.

Challenging electron populations, magnetic fields and acceleration models in Supernova Remnants shocks through high-frequency single-dish radio observations

Poster

Alberto Pellizzoni[1], Sara Loru[2], Elise Egron[1], Simona Righini[3], Noemi Iacolina[4], Sara Mulas[5], Adriano Ingallinera[2], Andrea Melis[1], Raimondo Concu[1], Patricia Reich[6], Wolfgang Reich[6]

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Abstract

Supernova Remnants are among the most important probes for the study of the ambient interstellar medium and the physics of Cosmic-Rays acceleration and shocks. Despite high-resolution continuum and polarimetric images at frequencies above 510 GHz are still surprisingly lacking, our pioneering early science observations of middle-aged SNRs with the 64-m single-dish Sardinia Radio Telescope (SRT) shed new light on spectral features and breaks up to 27 GHz. Synchrotron cutoff differences between different SNR complexes could be related to still poorly understood different primary and secondary (from hadron interactions) electron energy distributions and/or magnetic fields, accordingly to local shock conditions arising from different interacting structures in the ISM. In particular, we provided, for the first time, single-dish deep imaging at 7 GHz and 21.4 GHz of the IC443 and W44 complexes coupled with spatially resolved spectra, and observations of the well known Tycho SNR as a calibration cross-check for our pioneering K-band observations. A wide physical parameter scatter among different SNR regions was observed: a flat spectrum from the brightest SNR regions at the shock, and steeper spectral indices in fainter cooling regions, disentangling in this way different populations and spectra of radio/gamma-ray-emitting electrons. In their early phase, young SNRs such as Tycho typically do not show a spectral break in the radio band due to very efficient acceleration conditions. In fact, our flux density measurement on Tycho obtained with SRT at 21.4 GHz confirms the non-thermal synchrotron as the dominant emission process, ruling out any spectral curvature up to high radio frequencies. On the other hand, a spectral index steepening is expected at radio frequencies in evolved SNRs as W44, and IC443 wherein the particle acceleration mechanisms are less efficient. In fact, for the first time we provided direct evidence of a spectral break in the radio spectral energy distribution of W44 at an exponential cutoff frequency of 15+/-2 GHz. This important result constrains the maximum energy of the accelerated CR electrons in the range 613 GeV, in agreement with predictions indirectly derived from AGILE and Fermi-LAT gamma-ray observations. On the other hand, for the case of IC443, we did not observe any spectral break, while the presence of a significant dust emission bump at 2070 GHz seems confirmed by our observations at 21.4 GHz. Our on-going projects involves high-frequency and polarimetric investigations on a wider population sample of young and middle-aged SNRs that could clarify the origin of the observed spectral differences among targets. Precise modelling of region-dependent spectra correlated with polarimetric and X-ray/gamma-ray information will allow us to obtain Cosmic-Ray acceleration maps and to disentangle magnetic enhancement processes from spectral variation contributions due to different primary and secondary electron populations.

Shock-cloud interactions in young gamma-ray supernova remnants: Evidence for cosmic-ray acceleration

Poster

Hidetoshi Sano[1], Yasuo Fukui[1]

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Abstract

In young supernova remnants (SNRs; $\sim$ 2000 yrs old), interactions between the shockwave and interstellar neutral gas play a key element in understanding the origin of cosmic rays and their high-energy radiation. Fukui et al. (2012) demonstrated good spatial correspondence between the TeV gamma rays and total interstellar gas in the young SNR RX J1713.7−3946. This gives one of the essential conditions producing the hadronic gamma rays, and evidence for acceleration of cosmic ray protons up to 100 TeV. Subsequent studies showed similar results for young SNRs HESS J1731−347 (Fukuda et al. 2014), Vela Jr. (Fukui et al. 2017), and RCW 86 (Sano et al. 2019). For cosmic ray electrons, Sano et al. (2010, 2013) revealed the synchrotron X-ray enhancement toward the dense molecular clouds in RX J1713.7−3946. Owing to interactions between the shock and inhomogeneous gas distribution—dense gas ($\sim 10^3$ cm^{-3}) clumps in low-density environments (~ 0.01 cm^{-3})—the magnetic field strength is significantly enhanced up to $\sim$ 1 mG via the strong turbulent motion around the dense gas clumps. The X-ray hard spectra are reported toward the regions in which the shock-cloud interactions are strongly occurred, indicating that cosmic rays are efficiently accelerated to the higher maximum energy (Sano et al. 2015; Babazaki et al. 2018). In this talk, we introduce our recent studies of shock-cloud interactions toward the young SNRs bright in both the TeV gamma rays and synchrotron X-rays.

Polarized Balmer line emission from SNR shocks: on the effects of cosmic-ray acceleration

Poster

Jiro Shimoda, Yutaka Ohira; Ryo Yamazaki; J. Martin Laming; Satoru Katsuda

Tohoku University, Japan

Abstract

Linearly polarized Balmer line emissions from supernova remnant shocks are studied taking into account the energy loss of the shock owing to the production of cosmic-rays. The polarization degree depends on the downstream temperature and the velocity difference between upstream and downstream regions. The former is derived once the line width of the broad component of the H emission is observed. Then, the observation of the polarization degree tells us the latter. At the same time, the estimated value of the velocity difference independently predicts adiabatic downstream temperature that is derived from Rankine-Hugoniot relations for adiabatic shocks. If the actually observed downstream temperature is lower than the adiabatic temperature, there is a missing thermal energy which is consumed for particle acceleration. It is shown that a larger energy-loss rate leads to more highly polarized Hα emission. Furthermore, we find that polarized intensity ratio of Hβ to Hα also depends on the energy-loss rate and that it is independent of uncertain quantities such as electron temperature, the effect of Lyman line trapping and our line of sight.

The impact of the circumstellar magnetic field of progenitor stars on the resulting gamma-ray spectrum of supernova remnants

Poster

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[2]University of Potsdam, Germany

Abstract

Supernova remnants (SNRs) are widely believed to be one of the main candidates for the origin of Galactic cosmic rays. The observed very-high-energy gamma-ray emission observed from a number of SNRs suggests that particles are indeed accelerated to high energies at the shock of the remnants. However, it is extremely difficult to determine which particles are responsible for this emission as both protons (through hadronic interactions and subsequent pion decay) and electrons (through inverse Compton scattering on ambient photon fields) can potentially generate gamma-ray photons. Recent detection of the abrupt cut-off at lower energies in the gamma-ray spectra of two SNRs, IC 443 and W44, with the Fermi-LAT provided a strong evidence that cosmic-ray protons are indeed accelerated in SNRs based on the interpretation of this cutoff as a characteristic pion-decay feature. However, it cannot be firmly excluded that a similar spectral feature can be formed also in the leptonic scenario as a result of some spatial or temporal variability of properties of the ambient medium. SNRs created in core-collapse explosions expand inside the stellar wind bubble blown up by a progenitor star. The magnetic field in the wind medium follows a 1/r profile with high values at the surface of the star up to 10-100 G. This means that at early stages of its evolution the remnant interacts with a very strong magnetic field, which results in a synchrotron cooling feature in the electron spectrum, which in turn shows up in the gamma-ray spectrum as a break at similar energies as a pion-decay signature.

Non-thermal emission from the reverse shock of the youngest galactic Supernova remnant G1.9+0.3

Poster

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[1]DESY, Zeuthen, Germany
[2]University of Potsdam, Germany

Abstract

The youngest galactic Supernova remnant G1.9+0.3 has been only detected in the radio and the X-ray bands, but its young age and inferred shock speed of 14,000 km/s could make it an efficient particle accelerator and an interesting target for next generation gamma-ray observatories. We modelled the observed radio, X-ray, and gamma-ray spectra together with the morphology of the remnant. At the same time, we evaluated the prospects of its detection with the Cherenkov Telescope Array, CTA.We performed spherical symmetric 1-D simulations with the RATPaC code, in which we simultaneously solve the transport equations for cosmic rays and magnetic turbulence and the hydrodynamical equations for the gas flow. The distributions of the particles accelerated at the forward and the reverse shock are then used to calculate the spectra of synchrotron, inverse Compton, and pion-decay radiation from the source. The emission from G1.9+0.3 can be self-consistently explained within the test-particle limit. We find that the X-ray flux is dominated by emission from the forward shock while most of the radio emission originates near the reverse shock, which makes G1.9+0.3 the first remnant with non-thermal radiation clearly detected from the reverse shock. The flux of very-high-energy gamma-ray emission from G1.9+0.3 is expected to be close to the sensitivity threshold of CTA. The limited time available to grow large-scale turbulence restricts the maximum energy of particles to values below 100 TeV, hence G1.9+0.3 is not a PeVatron.

A systematic study on escaping of cosmic rays from SNR shocks through observations of thermal X-ray plasmas

Poster

Hiromasa Suzuki, Aya Bamba, Hirokazu Odaka, Ryo Yamazaki, Hiroya Yamaguchi, Yutaka Ohira

The University of Tokyo, Japan

Abstract

Galactic cosmic rays are thought to originate from supernova remnants (SNRs). However, it is still poorly understood how they escape from SNR shock regions. Here we propose a new idea to measure timescale of proton escaping (Suzuki et al. 2018, PASJ, 70, 75). Recent studies have indicated that most of the SNRs emitting hadronic GeV gamma-rays are interacting with molecular clouds (MCs) (e.g. Ackermann et al. 2013). Interestingly, such SNRs often contain rapidly-cooled plasmas (RCPs: plasmas with unusually low electron temperatures), likely due to thermal conduction into MCs (e.g. Matsumura et al. 2018). Therefore, thermal X-ray properties can be the key to understanding the processes of proton escaping. We conducted a systematic analysis of all the identified RCP SNRs associated with GeV-emission, in order to study proton escaping by utilizing thermal X-ray properties. We discovered a positive correlation between elapsed time after therapid cooling (RCP age) and spectral softness in the GeV energy band (Suzuki et al. 2018), and a negative correlation between the RCP ages and cut-off energies in the GeV spectra. These results imply that the maximum energy of the accelerated protons gradually decreases along with the RCP ages, which is consistent with the scenario that the collision between the SNR shocks and MCs causes both proton escaping and rapid cooling of the plasma. In this analytical model, time evolution of proton escaping was calculated assuming several parameter sets of the shock velocities and environments of an SNR. We discuss the physical parameters that naturally explain the observational correlations.

Proper motion of Cygnus loop filaments

Poster

Milica Vučetić[1], Dušan Onić[1], Dejan Urošević[1]; John Raymond[2]

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Abstract

In this paper we determine the shock velocities in the Cygnus Loop supernova remnant, using proper motions of the filaments in the remnant. The proper motions were measured by comparing the Hα images of the remnant observed in two epochs: in 1993 (obtained at Kitt Peak National Observatory), and in 2018 (obtained at National Astronomical Obsevatory Rozhen, Bulgaria). Then the shock velocities were derived using the most recent distance estimate of Cygnus Loop based on Gaia DR2 parallax measurements of several stars. The velocities of both nonradiative and radiative filaments were obtained and compared. Radiative filaments were selected as those that are visible in [SII] images of the remnant.

Toward the generation of magnetized collisionless shocks with high-energy lasers

Poster

Ryo Yamazaki

Aoyama Gakuin University, Japan

Abstract

There are still unsolved issues on collisionless shocks such as particle acceleration and plasma heating. Recently, laboratory astrophysics has developed, reproducing the collisionless shocks in the laboratory, where physical parameters are controllable. Although this potential ability of the laboratory experiment is attractive, the methodology of experiments or the data analysis techniques have not been well established so far. We will introduce our recent effort to excite collision less shocks propagating into magnetized plasma.

Quasi-parallel collisionless shock (re)formation and particle acceleration by (non)resonant micro-instabilities

Poster

Vladimir Zekovic, Bojan Arbutina

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Abstract

We present a theoretical model and simulations of quasi-parallel magnetized collisionless shock (re)formation and consequential particle acceleration. The two counter-streaming plasmas of comparable densities can excite the resonant instability. By using Particle-In-Cell simulations, we analyze the role of this strong-beam instability in shock triggering and subsequent formation of the initial return current. Consequently, this current excites a weak-beam instability ahead of the forming shock, which quickly becomes non-linear and starts to reform the shock. We find that ions reflected from the reforming shock barrier, begin to bounce between the approaching upstream instability and its part that is compressed and slowed down at the shock. Ions are thus accelerated in successive resonant reflections. Electrons experience the same acceleration mechanism, however, their reflections are due to the conservation of the magnetic moment. This DSA-like mechanism can contribute not only to the formation of supra-thermal part of the particle spectra, but it can also build up the non-thermal tail.

Evolution of high-energy particle distribution in Supernova Remnants

Poster

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Abstract

Supernova remnants (SNRs) have been considered as the dominant contributors to Galactic cosmic rays (CRs). However, the relation between high-energy particles accelerated in SNRs and cosmic rays observed at the Earth remains obscure. We fit the spectral energy distributions of 35 SNRs with a simple one-zone emission model and find some correlations of model parameters which can uncover the evolution of high-energy particle distribution in SNRs. We also comment on the implications of these results on the SNR origin of Galactic cosmic rays.

Is Supernova Remnant Cassiopeia A a PeVatron?

Poster

Xiao Zhang, Siming Liu

Nanjing University, China

Abstract

Cassiopeia A, a well-observed young core-collapse supernova remnant (SNR), is considered as one of the best candidates for studying very high-energy particle acceleration up to PeV via the diffusive shock mechanism. Recently, MAGIC observations revealed a gamma-ray spectral cutoff at $\sim$3.5 TeV, suggesting that if the TeV gamma-rays have a hadronic origin, SNR Cas A can only accelerate particles to tens of TeV. Here, we propose a two-zone emission model for regions associated with the forward (zone 1) and inward/reverse shocks (zone 2). Given the low density in zone 1, it dominates the high-frequency radio emission, soft X-ray rim via the synchrotron process and TeV gamma-ray via the inverse Comptonization. With a relatively softer particle distribution and a higher cut-off energy for electrons, emissions from zone 2 dominate the low-frequency radio, hard X-ray via the synchrotron process and GeV gamma-ray via hadronic processes. There is no evidence for high-energy cutoffs in the proton distributions implying that Cas A can still be a PeVatron. Hadronic processes from zone 1 dominate very high-energy gamma-ray emission. Future observations in hundreds of TeV range can test this model.

Session 5.

Supernova Ejecta and Dust – Oral Talks

The Unshocked Ejecta in Cas A and Tycho through Low-Frequency Radio Absorption

Oral Talk

Maria Arias de Saavedra Benitez

Anton Pannekoek Institute, University of Amsterdam, The Netherlands

Abstract

Young supernova remnants (SNRs) can have a reservoir of internal, cold stellar ejecta that have not yet been heated by the reverse shock. These can be traced in few ways: through the decay of radioactive elements (if the remnant is still very young), through infrared line emission (which can be faint), or through low-frequency radio absorption (as the cold, photoionised material can absorb part of the emission from the synchrotron shell). In our work, we use the powerful LOw Frequency ARray (LOFAR) telescope in order to probe unshocked material with the third method. LOFAR goes as low in frequency as 30 MHz, almost the ionospheric cutoff of the radio window, and its Low Band Antenna (LBA) has a bandwidth of 50 MHz. This combination is ideal for not only noticing the effects of low-frequency absorption on the spectral index, but, for high signal-to-noise sources, it also allows us to fit for curvature, and hence to constrain some of the physical parameters of the absorbing source.Cassiopeia A (Cas A) is one of such high signal-to-noise sources. In our recent work we used a gallery of narrow-band LOFAR maps to fit for the effect of absorption as a function of frequency in the radio spectrum of the synchrotron shell. This allowed us to conclude that there is a large amount of unshocked material in Cas A: three solar masses for the temperature and ionisation conditions that describe its interior. The mass estimate can be changed if one considers different physical conditions in the interior of the remnant. More importantly, if the ejecta are highly clumped, the mass estimate can be significantly lowered. Having said that, our measurements are difficult to reconcile with many state-of-the-art models of Cas As evolution that predict almost no mass in unshocked material. This could have implications for the pre-explosion mass of Cas As progenitor star.The LOFAR method for probing unshocked ejecta requires sources that are bright, young, and Northern. This limits the sample of sources we can analyse. One of the sources that we can study, though, is Tychos supernova remnant. We expect Tycho to have a decent amount of unshocked mass, since the explosion that originated it is thought to have produced 0.5-0.8 $M_{\odot}$ of iron, and Tychos SNR shows less iron in its spectrum than other of its type Ia counterparts, suggesting that an important amount of it has not yet been heated to X-ray emitting temperatures.We are currently analysing recent LOFAR LBA observations of this source, and will present some preliminary results on the unshocked stellar ejecta in Tycho, including a mass estimate. The effects of absorption also allow us to trace the rim of Tychos reverse shock, which has, until now, only been done with X-ray observations. Our experience with Cas A taught us that the reverse shock as determined through radio absorption can give a more unbiased estimate of the reverse shock radius.

Dusty SNRs in our Galactic Plane

Oral Talk

Hannah Chawner[1], Haley Gomez[1], Mikako Matsuura[1], Andrea Papageorgiou[1], Phil Cigan[1], Loretta Dunne[1], Jeonghee Rho[2], Alberto Noriega-Crespo[3], Ilse De Looze[4], Mike Barlow[4], Ken Marsh[5]

[1]Cardiff University, UK [2]SETI Institute and SOFIA Science Center, USA [3]Space Telescope Science Institute, USA [4]University College London, UK [5]IPAC, Caltech, USA

Abstract

There is still on-going debate as to how much dust has been formed and destroyed by supernovae and supernova remnants. A systematic search for dust in supernova remnants is an effective way to resolve this issue. We have completed a search for far-infrared counterparts of 190 known supernova remnants across the entire Galactic plane at 70, 160, 250, 350, and 500 μm using the Herschel Infrared Galactic Plane Survey (Hi-GAL). We detect FIR dust emission from 39 of our sample, including 12 sources where we observe dust in the inner ejecta region, indicating that dust can survive the destructive processes of a supernova remnant. In particular we find evidence of ejecta dust heated by pulsar wind nebulae. Using point process mapping we analyse the dust mass distribution across three sources at various temperatures and values of dust emissivity, at the resolution of the Herschel 70 micron maps. This indicates a significant mass of ejecta dust within each supernova remnant, between 0.29 and 0.64 solar masses, which is warmer than that of the ISM (15–20 K), at temperatures between 20 and 45 K. We expect that pulsar wind nebulae can heat SNR dust, increasing the temperature above that of the surrounding interstellar medium. We also find marginal evidence for one SNR that there may be a variation in the dust emissivity between the SNR material compared to that of the ISM, suggesting that there is a different dust composition within the SNR.

Rings of metal-rich ejecta in Puppis A: hints of a supernova interaction in a binary?

Oral Talk

Parviz Ghavamian, I. Seitenzahl, F. Vogt, A. Ruiter

Towson University, USA

Abstract

Near the center of the oxygen-rich supernova remnant Puppis A, a highly unusual structure exists consisting of multiple irregular rings of metal-rich material propagating at high radial velocities, was detected 30 years ago. These structures have thus far only been detected at visible wavelengths, and appear to be associated with the Puppis A supernova. Here we present new integral field data of the ring structure from the Wide Field Integral Spectrograph (WiFeS) which reveals the rings to be kinematically distinct from one another. The rings occur at nearly quantized velocity intervals of -350, -750 and -1300 km/s and exhibit a range of metal-rich compositions including Nitrogen-rich/S-rich and O-rich material. It has been speculated that the rings originate in a second supernova explosion within Puppis A. However, our new observations suggest another possible scenario, wherein the rings originated from interaction of the supernova shock from one member of a massive binary with the outer atmosphere of the other member.

Supernova Dust Factories

Invited Talk

H. Gomez

Cardiff University, UK

Abstract

In the last decade, observations of supernovae and supernova remnants in the infra-red and submillimetre have revealed that core collapse supernovae are prolific dust factories. In agreement with some theoretical models of dust formation, there is now strong observational evidence that 0.05-0.7 $M_\odot$ of dust can be formed within the ejecta after the explosion. Here, I will discuss our changing view on supernovae as interstellar dust sources, reviewing the observational evidence and showing that dust seems to be particularly common in pulsar wind nebulae. Although there is little evidence (as yet) for significant dust production in Type Ia supernova ejecta, there is no longer any question that dust (and molecule) formation is efficient after some supernova events, though it is not clear how much of this dust survives over longer timescales nor how the dust mass evolution changes in general. Now that the Herschel Space Observatory is no longer operational, new methods and instrumentation will be needed to pin down the role of supernovae in the interstellar dust budget of galaxies at all epochs.

ALMA, VLT and SOFIA observations of SN 1987A

Oral Talk

Mikako Matsuura

Cardiff University, UK

Abstract

Supernova (SN) 1987A is the closest supernova explosion detected in the past 400 years. It is an ideal target to investigate how the supernova evolved in time and to search for footprints of the supernova explosion imprinted in the expanding gas. SN 1987A has two major components: ejecta and the circumstellar equatorial ring. The SN ejecta expands with a speed of 2000 km s-1, and can be clearly resolved with high angular resolution telescopes, such as HST and ALMA. Whereas the slowly expanding (100 km s-1) ring is composed with circumstellar material that had been expelled by the progenitor when it was a red supergiant, about 20,000 years ago.After identifying the cold (20 K) dust and the CO and SiO molecules in the ejecta of SN 1987A from early ALMA observations, we now move onto deeper and even higher-angular resolution (10 milarcsec scale) imaging of SN 1987A. High angular resolution of ALMA images reveal dust, CO, SiO and HCO+ structures that are highly clumpy, and in general, different molecules are distributed at slightly different locations within the ejecta. The presence of clumpy ejecta is consistent with the predictions that Rayleigh-Taylor instabilities occurred at the time of the SN explosion and broke the ejecta gas into clumps. Spatial anti-correlation was found between the CO and dust emission, which implies that carbonaceous dust was formed by dissociating CO. This is the first time that a specific chemical path to form dust in supernovae is suggested.The fastest part of the blast waves has been colliding with the circumstellar ring. Collisionally heated 300 K dust and synchrotron emission has been detected from the ring, which has been monitored for over 20 years. Recently, the waves are now about to exist the ring, as found by HST Halpha images in 2014 (Fransson et al. 2015). A change in morphology also started appearing in ALMA synchrotron images, too. Around that timing, the Very Large Telescope (VLT) and SOFIA captured some colder (∼70K) dust emissions appearing from the ring. We will discuss whether ring dust might have been destroyed by blast waves or not.

Hydrodynamic Simulations of Supernova Remnants: Dust Destruction by the Reverse Shock

Oral Talk

Frandziska Schmidt[1], Florian Kirchschlager[1], Erica Fogerty[2], Antonia Bevan[1], Felix Priestley[1], Michael Barlow[1]

[1]University College London, UK [2]LANL, USA

Abstract

Sub-millimetre observations of galaxies at redshift z > 6 have revealed dust masses of up to 10^8 solar masses. As such systems are too young for significant dust enrichment by asymptotic giant branch stars to have occurred, core-collapse supernovae (CCSNe) have been suggested as possible alternative dust producers. This is supported by the recent discovery of dust in young remnants of such supernovae using Herschel.Once formed, the dust grains in the remnant are subjected to various erosion processes such as sputtering and grain-grain collisions due to the reverse shock generated by interactions between ejecta and circumstellar material. This can result either in the complete destruction of the grains or in a size reduction.The predicted dust survival rates vary greatly from study to study and models tend to treat dust destruction during post-processing.In this study, we investigate the survival rates of dust produced in CCSN remnants using hydrodynamic simulations carried out with the publicly available AMR code AstroBEAR. For this purpose, we have developed the Dusty Gridmodel which allows us to incorporate the dust and the dust destruction mechanisms directly into the MHD code. Our simulation setup is an extension of the Cloud Crushing model from Silvia et al. (2010) featuring a collection of dense gas clumps embedded in a less dense ambient medium through which a shock propagates. As the shock travels through the computational domain, it collides with the clumps and accelerates, compresses and heats the gas contained within. The dust grains then gain velocity of their own as a result of the gas movement and are henceforth subjected to dust processing routines that result in a redistribution of grain sizes.We present our preliminary results featuring the Dusty Grid model combined with an extended Cloud Crushing setup and an oxygen cooling function tailored to replicate the conditions in Cassiopeia A.

Type Ia supernova remnant tomography

Oral Talk

Ivo Seitenzahl[1], P. Ghavamian[2], J. M. Lamin[3] , F. P. A. Vogt[4]

[1]University of New South Wales, Canberra, Australia [2]Towson University, USA [3]U.S. Navy Research Laboratory, USA [4]European Southern Observator, Germany

Abstract

The last decade has witnessed a remarkable expansion of our knowledge of the chemistry occuring in the huge envelopes surrounding supergiants. The development of highly sophisticated infrared - submillimeter telescopes was crucial for this progress due their potential to detect gas-phase and solid-state species. Instruments such as Herschel, ISO, IRAM, APEX, SMA, etc. were key for these discoveries. The opening of ALMA end 2011 heralded the start of a new era thanks to an increase in sensitivity and spatial resolution of ca. 2 orders-of-magnitude. Although some supergiants have now been studied in quite some detail, a comprehensive understanding of the main chemical routes and the impact of some dominant physical processes is still lacking. In this talk, I give an overview of the current knowledge on the molecular and dust content in shells around supergiants. I discuss the importance of some chemical formation routes and their relation with some dynamical process. I end the talk with some suggestion for future research.

What We Can Learn from Ejecta in Supernova Remnants

Invited Talk

Brian Williams

NASA Goddard Space Flight Center, USA

Abstract

The ejecta in supernova remnants is the most direct link to information about the progenitor system of the pre-supernova star. The abundances of various elements, the spatial velocity of the ejecta blobs, the temperature of the reverse-shocked plasma; all of these are important diagnostics from the ejecta. In this talk, I will give an overview of how we can use studies of the ejecta in SNRs to learn about the evolutionary stage of the remnant and the connections to the progenitor system. I will highlight recent results and discuss avenues for future study with upcoming missions such as JWST, XRISM, and Athena.

A three-dimensional core-collapse supernova model resembling Cassiopeia A

Oral Talk

Annop Wongwathanarat

Max-Planck Institute for Astrophysics, Germany

Abstract

In this talk, a three-dimensional core-collapse supernova simulation of a progenitor star that has its hydrogen envelope stripped is discussed. The explosion is triggered by means of a parametric neutrino engine. Large-scale explosion asymmetries seeded by small-scale random perturbations develop during the stalled shock phase by hydrodynamic instabilities. These asymmetries later manifest themselves in the distributions of radioactive ^{56}Ni and ^{44}Ti synthesized during the explosion. Our simulation result shows that the distributions of these elements remarkably resemble the observed morphology in Cassiopeia A supernova remnant. They are mostly ejected in the hemisphere opposite to the neutron star recoil direction, hinting for a neutron star kick by the gravitational tug-boat mechanism.

Session 5.

Supernova Ejecta and Dust – Posters

Massive Amounts of Cold Dust in Small Magellanic Cloud Supernova Remnant 1E 0102-7219

Poster

M. Barlow[1], Ilse De Looze[2]

[1]University College London, UK, [2]Ghent University, Belgium

Abstract

We present an estimate for the dust mass in supernova remnant (SNR) 1E 0102.2-7219 (E0102), and show that for some grain species this may supply enough dust to satisfy the dust budget crisis for early Universe galaxies. Currently, the primary source of interstellar dust is a subject of debate. Observations of distant quasars suggest that they contain massive reservoirs of dust, 10^8-$10^9\,M_\odot$. Such evidence challenges models that rely on evolved asymptotic giant branch stars which introduce a significant delay in dust accumulation. This delay is difficult to rectify with constraints placed by the age of the Universe at high redshifts. However, core collapse supernovae (CCSNe) have a much shorter lifecycle and are a plausible alternative for dust production in early Universe galaxies. Estimates suggest that each SNR would need to generate 0.1-1$M_\odot$ of interstellar grains if CCSNe are indeed the major sources of dust. Numerous reports exist for warm dust masses several orders of magnitude below the 0.1-1$\,M_\odot$ range, but some recent studies incorporating longer wavelength data show large masses of low temperature dust from remnants such as CasA and the Crab Nebula. Here, using data from Spitzer Space Telescopes MIPS instrument with PACS and SPIRE data from Herschel Space Observatory, we detected massive amounts of cold dust in E0102, a 1000 year old oxygen rich remnant at a distance of 62.1kpc in the Small Magellanic Cloud (SMC). After removing SMC background signals, a polynomial interpolation was applied across an annulus of pixels surrounding the remnant to construct a map of local noise and to extract the residual signal attributed to E0102 alone. Due to possible contamination from the adjacent N76 emission nebula, only the non-adjacent half of the remnant was considered when calculating the remnant SED. We then applied a Bayesian SED model to fit remnant dust emission to warm and cold dust components for a variety of grain species.

Dust formation rates and locations in interacting supernovae

Poster

A. Bevan[1], R. Wesson, M. J. Barlow, I. De Looze, J. E. Andrews, G. C. Clayton, K. Krafton, M. Matsuura and D. Milisavljevic

[1]University College London, UK

Abstract

The source of the very large masses of dust observed in some very early Universe galaxies at redshifts z< 6 has been much debated. Core-collapse supernovae (CCSNe) have been predicted to be efficient producers of dust but the majority have only had small masses of warm dust ($< 0.001M_\odot$) detected in their ejecta during their early phases (t< 3yr), based on fits to their near-IR and mid-IR SEDs. Observations in the far-IR with Herschel and ALMA have revealed far higher cold dust masses but there are currently no instruments capable of detecting cold SN dust in emission at extra-galactic distances. Dust formation in CCSNe often induces a red-blue asymmetry in the optical and NIR line profiles since redshifted radiation emitted from the receding half of the SN must traverse a higher column depth of dust to reach us. We present Monte Carlo radiative transfer models of dust-induced asymmetries in the optical and NIR line profiles of three interacting supernovae. We have used the Bayesian radiative transfer code DAMOCLES (Bevan & Barlow 2016; Bevan 2018) to model the Balmer and HeI lines of SN 2005ip, SN 2010jl and SN 1995N to determine the rate of dust formation and the current dust mass. We additionally constrain the clumping structure of the ejecta and properties of the dust grains. We compare our results to radiative transfer models of the optical-IR SEDs and consequently isolate the relative contributions to the IR flux from pre-existing circumstellar dust and newly-formed dust in the ejecta or cool, dense shell.

Ejecta fragments and protrusions in and around SN1006

Poster

F. Bocchino

INAF-Osservatorio Astronomico di Palermo, Italy

Abstract

The remnant of SN1006 is well known to be a cosmic-ray accelerating supernova remnant, with two bright limbs dominated by non-thermal emission. However, in the soft X-ray band the emission is dominated by a thermal component filling al the remnant, which was traditionally associated to the shocked stellar ejecta fragments. Some of this emission is shaped as fragments with bow-shock-like morphologies, already noted in the literature, which is located both inside and ouside the rim (protrusions). In this poster, we will review the ejecta fragments and protrusions and discuss their origin through the comparison with numerical simulations including ejecta clumpiness.

Studying the radiative recombination continua in the X-ray spectra of pure ejecta and of overionized plasmas

Poster

E. Greco[1], Jacco Vink, Marco Miceli, Vladimir Domcek, Ping Zhou, Salvatore Orlando, Giovanni Peres, Fabrizio Bocchino

[1]Universita di Palermo - Dipartimento di Fisica e Chimica, Italy

Abstract

Several Supernova Remnants (SNRs) show signatures of over ionization. A plasma is over ionized when its ionization state is higher than that expected from its electron temperature, namely when it is non-equilibrium of ionization and in recombining phase. The physical origin of over ionized plasma in SNRs is largely debated in the literature. The characteristic feature of a recombining plasma in the X-rays is the presence of prominent Radiative Recombination Continua (RRC), associated with electron recombining with ions. However, the intensity of the RRCs in the X-rays also increases with the plasma metallicity. We here present a thorough spectral study to investigate whether the bright RRC originating from a pure ejecta plasma in collisional ionization equilibrium can mimic that of an over ionized plasma in non-equilibrium of ionization. We performed series of spectral simulations in the X-rays, by exploring different values of temperature, emission measure, and chemical abundances. We also considered spectra emerging from a combination of interstellar medium and pure ejecta and compared them against actual observations of recombining SNRs. We present here some preliminary results and discuss in which conditions pure ejecta plasma in collisional ionization equilibrium might mimic features usually attributed to over ionized plasma in non-equilibrium of ionization.

Dust destruction by the reverse shock in Cas A

Poster

F. Kirchschlager[1], Franziska Schmidt[1], Michael Barlow[1], Erica Fogerty[2], Antonia Bevan[1], Felix Priestley[1]

[1]University College London, UK, [2]Los Alamos, USA

Abstract

It is well known that dust grains form in the ejecta of Population III supernovae. However, due to interactions with the circumstellar and interstellar medium, reverse shocks will traverse the ejecta which could potentially destroy large amounts of the newly formed dust material. Impinging gas particles evoke thermal and non-thermal sputtering of the dust grains but can lead also to grain growth by gas accretion. In addition, grain-grain collisions occur which can result in shattering or vaporisation of one or both colliding grains and to a redistribution of the initial grain size distribution. In order to determine dust survival rates, we performed spatially highly resolved hydrodynamical simulations using the grid-based code AstroBEAR to model a shock wave interacting with clumpy supernova ejecta. The resulting density, temperature and velocity of the gas is utilised to calculate dust trajectories and the dust destruction using our dust post-processing code PAPERBOATS. Collisional and plasma drag are considered as well as a comprehensive model for the grain charging, sputtering and grain-grain collisions. We determined the dust destruction rate for the supernova remnant Cas A as a function of initial dust properties, considering grain sizes from nanometre to several micrometre, and found that narrow size distributions around 0.5 micrometre of graphite grains have the highest probability to survive the passage of the reverse shock. The surviving rate of silicate grains is slightly below the one of carbon grains. Our results show that grain-grain collisions and sputtering are synergetic and that grain-grain collisions have to be considered in dust destruction simulations in supernova remnants.

Near-Infrared Multi-Object Spectroscopy of the Outer Ejecta Knots in Cassiopeia A

Poster

Y.-H. Lee[1], B.-C. Koo[1], J.-J. Lee[2]

[1]Seoul National University, S. Korea, [2]Korea Astronomy and Space Science Institute, S. Korea

Abstract

Cassiopeia A (Cas A) is the youngest ($\sim$340 yr) confirmed core-collapse supernova remnant (SNR) in the Milky Way, where we can observe the fine details of the imprints of the supernova (SN) explosion. The complex spatial distribution of the SN ejecta material in the remnant, such as the jet-like structure of X-ray emitting Si material and O/S-rich optical knots outlying the bright ejecta shell, suggests violent explosion with an inversion of chemical layers. We have performed near-infrared multi-object spectroscopy of the SN ejecta knots in the northeastern (NE) jet and eastern (E) outer regions of the remnant using MMIRS attached on MMT 6.5 m telescope. The spectra of 67 ejecta knots have been obtained. By analyzing their spectra, we have found that the knots in the NE jet emit strong [S II], [S III], and [Fe II] lines but little or no [P II] line, indicating that the jet was launched from a S-rich; region near the progenitor's core. In the E outermost region, there are knots emitting only [Fe II] lines with/without He I line. These dense Fe-rich; knots appear to be embedded in diffuse X-ray emitting Fe ejecta, suggesting that the initial density distribution of Fe ejecta was inhomogeneous. In this talk, we discuss the nature of the different types of outer ejecta knots and their implications on the SN explosion.

Spatially resolved models of the dust in Cassiopeia-A using DAMOCLES

Poster

M. Niculescu-Duvaz[1], A. Bevan, M. J. Barlow, D. Milisavljevic

[1]University College London, UK

Abstract

Large quantities of dust have been discovered in a number of high-redshift (z>6) galaxies and quasars. One hypothesis is that this dust is mainly formed in the ejecta of core-collapse supernovae (CCSNe). For this to be the case, it has been estimated that each CCSN would need to produce >0.1 $M_\odot$ of dust (e.g. Morgan and Edmunds 2004; Dwek et al. 2007). Determinations of the masses of dust present in CCSN ejecta and remnants are therefore needed.Newly formed dust can produce red-blue asymmetries in optical emission lines of CCSNe ejecta (Lucy et al. 1989), which can be modelled using the Monte-Carlo code DAMOCLES (Bevan and Barlow 2016). We have developed DAMOCLES so it is capable of modelling spatially resolved datasets of CCSN remnants, so instead of only returning a global dust mass estimate, it can also determine the 3D distribution of this dust.We model the [OIII] 4959,5007 line doublet in the spatially resolved dataset of the supernova remant Cassiopeia A presented in Milisavljevic et al. 2013, retrieved from 94 long slit spectra taken with the MDM Modular spectrograph, on the Hiltner 2.4m telescope. We have corrected this dataset for interstellar extinction using the De looze et al. (2016) map of the dust in the interstellar medium in the sightline to Cas A . We use the spherical shell geometry of Bevan et al. 2017 for the [OIII] 4959,5007 $\AA$ emitting gas distribution for our model.Cassiopeia A is the ideal object to test our new technique, as it has been studied in detail, with estimates of its dust mass ranging from 0.6-1.1 $M_\odot$ (Priestley et al. 2018, De Looze et al. 2016, Bevan et al. 2017). In this study we present a map of the dust distribution in Cas A, as well as an estimate of the dust mass.

Revisiting the Crab Nebulas dust and synchrotron radiation from the infrared to radio domain

Poster

F. D. Priestley[1], M. J. Barlow[1], R. Bandiera[2], A. Bevan[1], M. F. Bietenholz[3,4], H. Chawner[5], H. L. Gomez[5], M. Matsuura[5], F. Priestley[1], R. Wesson[1]

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[4]York University, Toronto, Canada
[5]Cardiff University, UK

Abstract

The large reservoirs of dust observed in some high redshift galaxies have been hypothesised to originate from dust produced by supernovae (SN). Theoretical models predict that core-collapse SN can be efficient dust producers (0.1-1 M_{odot}) potentially responsible for most of the dust production in the early Universe. Observational evidence for this dust production efficiency is however currently limited to only a few remnants (e.g., SN 1987A, Cas A) that confirm this scenario. I will revisit the dust mass produced in the Crab Nebula relying on a spatially resolved analysis of its infrared to radio observations. The Crabs supernova dust mass is estimated to range between 0.024 and 0.054 M_{odot} (for amorphous carbon grains) with an average dust temperature $T_{textdust}$ of 42 K. This revised dust mass is up to ten times lower than some previous estimates, which can be attributed to our different interstellar dust corrections, lower submm fluxes, and higher dust temperatures. The dust is predominantly found in dense filaments south of the pulsar, with an average V band dust extinction of A_{textV}= 0.200.26 mag, consistent with recent optical dust extinction studies. The modelled synchrotron power-law spectrum is consistent with a radio spectral index $alpha_{textradio}$=-0.29, a spectral break long-wards of break=1 mm, and an infrared spectral index $alpha_{textIR}$=-0.42. We have identified a millimetre excess emission in the Crabs spectrum, and argue that this mm-wave bump most likely results from the pile up of energetic electrons just below the spectral break in the Crabs central regions. We conclude that the Crabs efficient dust condensation (6-13%) is consistent with predictions from theoretical dust condensation models and provides further evidence for a scenario where supernovae provide non-negligible contributions to the interstellar dust budgets in galaxies.

The survivability of newly-formed dust grains in supernova remnants

Poster

F. D. Priestley[1], M. J. Barlow[1], I. De Looze[1,2]

[1]University College London, UK, [2]Ghent University, Belgium

Abstract

The amount of ejecta dust which can survive into the interstellar medium (ISM) is a key factor in the ability of core-collapse SNe to resolve the dust budget crisis in high-redshift galaxies. We present physical models of the dust emission from two nearby supernova remnants, Cassiopeia A (Cas A) and the Crab Nebula, which allow greater insight into the location and properties of the dust than commonly used modified blackbody fits. In Cas A, we fit the observed spectral energy distribution (SED) with four dust emission components, corresponding to different phases of the shocked and unshocked gas. We find that the majority of the dust mass ($\sim 0.6\,\mathrm{M}_\odot$) is located in the unshocked ejecta, confirming previous results based on the spatial distribution of the emission, while $\sim 10\%$ is in clumped material which has passed through the reverse shock. Based on gas mass estimates for each component, up to 50% of the initially present dust may have survived in the clumps, while grains in the diffuse shocked material appear to have been largely destroyed. For the Crab Nebula, we fit the observed SED with emission models for multiple sizes of dust grain, determining a grain size distribution with no prior assumptions about its intrinsic shape. Our models suggest $0.03 - 0.08\,\mathrm{M}_\odot$ of carbon dust is present in the ejecta, with the majority of the mass concentrated in micron-size grains, independent of modelling assumptions. The overall size distribution is well-fit by a power law with a somewhat shallower slope than the typically-assumed ISM value. The presence of large grains, which are more resistant to destruction by sputtering, and the indication that clumped dust can survive being processed by a reverse shock, suggest that dust formed in SNe may be more resilient than has previously been assumed.

Survival of Dust Created in Cas A Supernova Remnant

Poster

J. Slavin[1], Eli Dwek[2], Mordecai-Mark Mac Low[3], Alex Hill[4]

[1]Harvard-Smithsonian CfA, USA, [2]NASA Goddard Space Flight Center, USA, [3]AMNH, USA, [4]Space Telescope Science Institute, USA

Abstract

Supernovae are known creators of dust in their dense cold ejecta. However it is still uncertain how much of that dust survives and is injected into the interstellar medium. I will present the results of new hydrodynamical simulations using the FLASH code in which we model the evolution of the clumpy ejecta in the Cas A supernova remnant (SNR) as an exemplar of such dust creating SNRs. Along with the hydrodynamical evolution of the clumpy ejecta, we model the processing of the dust grains created in the ejecta. We do this by following the trajectories of the grains as they are eroded and experience drag after the ejecta are decelerated and the grains decouple from the gas. Our goal is to trace the evolution of dust from the ejecta clumps in order to assess the fraction of the dust mass that survives the interaction with the reverse shock and ends up finally in the interstellar medium.

Late-phase radiative transfer of Type Ia supernovae

Poster

L. Shingles[1], S. A. Sim, M. Kromer, K. Maguire, M. Bulla, C. Collins, C. P. Ballance, A. S. Michel, C. A. Ramsbottom, F. K. Ropke, I. R. Seitenzahl, and N. B. Tyndall

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Abstract

Type Ia supernovae are well-studied objects, largely because of their usefulness as precise distance indicators for cosmology and their role in the production of Fe-peak elements for chemical evolution. However, while Type Ia supernovae almost certainly involve the thermonuclear explosion and unbinding of a carbon-oxygen white dwarf, understanding the possible role of a binary companion and the mechanism of explosion remain open problems in supernova research. Multi-band observations including radio and X-ray have placed deep upper limits on the density of the surrounding medium and disfavour most scenarios involving a non-degenerate companion. Several other scenarios remain, and thanks to theoretical developments in the last decade, we now have a variety of 3D hydrodynamic explosion models available. These can can be tested with nucleosynthesis and radiative transfer simulations to compare to observational light curves and spectra. We present recent work to improve the physics of the ARTIS radiation transport code to extend its validity to late times (>100 days in the nebular phase) for application to existing 3D explosion models. The code developments are initially tested with 1D models, including the well-known W7 fast-deflagration model, and then applied to sub-Chandrasekhar mass detonation models that account for the effect of gravitational settling in the progenitor white dwarf. We also outline the next step to three-dimensional radiative transfer simulations of 3D hydrodynamic explosion models.

Dust in the remnant of SN 1995N

Poster

R. Wesson, A. Bevan, M. J. Barlow

University College London, UK

Abstract

The Type IIn supernova 1995N was discovered about 10 months after its likely explosion date, at a distance of about 24Mpc in the galaxy MCG-02-38-17. It is a bright and long-lived X-ray and radio source, indicating strong interaction between its ejecta and the pre-existing circumstellar medium (CSM). The supernova was detected as an infrared point source in Spitzer and WISE observations about 15 years after its explosion. This emission has been attributed to 0.12Mo of CSM dust illuminated by the supernova flash and thermally echoing. We argue, however, that a CSM echo is unlikely given the required geometry of the echoing material. We propose that the emission is due to about 0.2Mo of newly formed dust in the supernova ejecta, heated externally by the interaction of the ejecta with the CSM. We present radiative transfer models of the spectral energy distribution, and of asymmetric emission lines, which support this scenario.

The evolution of dust in SN ejecta

Poster

E. Dwek[1], A. Sarangi, R.G. Arendt, & E. Micelotta

[1]NASA Goddard Space Flight Center, USA

Abstract

Supernovae are very efficient producers of interstellar dust. Infrared (IR) observations of SN1987A show the presence of 0.5-1.0 $M_\odot$ of dust 20 years after the explosion. Theoretical calculation of the chemical reactions and nucleation processes following the explosion suggest the rapid formation formation of dust in the ejecta. Dust formation models suggest that most of the dust is formed within 2-3 years after the explosion. In contrast, IR observations of SN1987A and several other SNe around that time period show the presence of only a small fraction, about 0.001, of the total mass of the condensible elements in the ejecta at that time. In this poster I will address the origin of this discrepancy.

Session 6.

Pulsar Wind Nebulae – Oral Talks

Discovery of a Pulsar-powered Bow Shock Nebula in the Small Magellanic Cloud Supernova Remnant DEM S5

Oral Talk

Miroslav Filipovic[1], **Rami Alsaberi**[1] **et al.**

[1]Western Sydney University, Australia

Abstract

We report the discovery of a new Small Magellanic Cloud Pulsar Wind Nebula (PWN) at the edge of the Supernova Remnant (SNR) DEM S5. The pulsar powered object has a cometary morphology similar to the Galactic analog PSR B1951+32 as well as the PWN. It is travelling supersonically through the ISM. We estimate the kick velocity is in the range of 7002000 km/s for an age between 2810 kyr. The radio spectral index for this SNR-PWN-pulsar system, is flat (0.29) consistent with other similar objects. Also, we infer that the putative pulsar has a radio spectral index of 1.8, which is typical for Galactic pulsars. We searched for dispersion measures (DMs) up to 1000 cm^{-3} pc but found no convincing candidates with a S/N greater than 8. We produce a polarisation map for this PWN at 5500 MHz and find a mean fractional polarisation of P$\sim$23%. The X-ray power-law spectrum ($\Gamma \sim$2) is indicative of non-thermal synchrotron emission as is expected from PWN-pulsar system. Finally, we detect DEM S5 in Infrared (IR) bands. Our IR photometric measurements strongly indicate the presence of shocked gas which is expected for SNRs. However, it is unusual to detect such IR emission in a SNR with a supersonic bow-shock PWN. We also find a low-velocity HI cloud of 107 km/s which is possibly interacting with DEM S5. SNR DEM S5 is the first confirmed detection of a pulsar-powered bow shock nebula found outside the Galaxy.

Probing Extreme Physics with Pulsar Wind Nebulae

Oral Talk

Joseph Gelfand[1], **Samayra Straal**[1], **Soichiro Hattori**[1], **Pat Slane**[2], **Daniel Castro**[2], **Tea Temim**[3]

[1] NYU Abu Dhabi, United Arab Emirates
[2]CfA, Cambridge, MA, USA
[3] STScI, USA

Abstract

Pulsar wind nebulae (PWNe) result from the interaction between the relativistic outflow powered by a neutron star's rotational energy and the material ejected in the progenitor core-collapse supernova. Therefore, its properties can be used to study how neutron stars are produced in these explosions, how electrons and positrons are generated in their magnetosphere, and how these particles are then accelerated to extremely energies. In this talk, I will present initial results on these topics from modeling a sample of PWNe – which suggest a surprising diversity of both neutron stars progenitors and particle acceleration mechanisms.

Gamma-ray observations of Pulsar Wind Nebulae

Invited Talk

Marie-Helene Grondin[1,2]

[1] Centre de Etudes Nuclaires de Bordeaux-Gradignan, France
[2]Université de Bordeaux, France

Abstract

Since 2003, the continuous observations of the Galactic Plane by Atmospheric Cherenkov Telescopes and Extended Air Shower Arrays at TeV energies have yielded the detection of more than 130 Galactic sources. Among them, Pulsar Wind Nebulae (PWNe) are the dominant class with 35 sources firmly identified plus a new population of gamma-ray halos. In the GeV range, deep observations have been made mainly possible through the launch of AGILE in 2007 and the Fermi-Large Area Telescope operating since 2008 in the band between 20 MeV and more than 300 GeV. During the last 10 years, the Fermi-LAT has detected high energy emission from several PWNe, including the Crab Nebula, MSH 15-52, Vela or HESS J1825-137. In addition, upper limits derived on famous PWNe have brought new constraints on the physical properties of these objects.In this presentation, I will review the recent results obtained and give a general overview of the gamma-ray population of Pulsar Wind Nebulae.

Spectral Index Maps of Pulsar Wind Nebulae

Oral Talk

Ben Guest[1], A. MacMaster[1], S. Safi-Harb[1]

[1]University of Manitoba, Canada

Abstract

Pulsar wind nebulae are non-thermal objects. Observing variability within them has therefore been limited to cases of significant brightening, or the few instances where transient features are interpreted in terms of intrinsic motion. Jet and torus morphology are also only visible in cases of differing brightness with respect to the surrounding nebula and favourable alignment with our line of sight. Spectral map analysis involves binning observations with an adaptive algorithm to meet a signal limit and colouring the results based on the desired model parameter fits. Minute changes in spectral index become therefore apparent even in cases with relatively few photon counts. This technique reveals previously hidden structures, and changes in the emitting particle spectrum where traditional RGB and brightness images have provided little insight. We present an X-ray study of several PWNe with the Chandra X-ray Observatory, contrast our new spectral map results with those found from the traditional methods, and discuss the implications for understanding the physics at the heart of these fascinating objects.

The Tail of PSR J0002+6216 and the Supernova Remnant CTB 1

Oral Talk

Matthew Kerr[1], **Frank Schinzel**[2], **Dale Frail**[2], **Sanjay Bhatnagar**[2], **Urvashi Rao**[2]

[1]US Naval Research Laboratory, USA
[2] National Radio Astronomy Observatory (NRAO), USA

Abstract

Sensitive, widefield VLA observations have revealed a striking bow-shock pulsar wind nebula trailing the 115-ms gamma-ray and radio pulsar J0002+6216. The narrowly collimated, non-thermal emission stretches at least $7'$; and, at a position angle of 113 deg, points to the geometric center of the supernova remnant CTB 1 about $28'$; away. A timing analysis of data collected with the Fermi LAT indicates the pulsar has a proper motion of 115 ± 33 mas/yr at a position angle of 121 ± 13 deg. The direction and magnitude of the proper motion support the claim that PSR J0002+6216 was born from the same supernova that produced CTB 1 about 10,000 years ago. In this scenario, PSR J0002+6216 was born spinning near its current frequency, and its high velocity (>1000 km/s) suggests an unusually asymmetric supernova. Recent C- and X-band observations with the VLA confirm that the PWN has an unusually steep spectrum, and their good angular resolution allows measurement of the bow shock collimation and constraint of the position of the Mach disk and model parameters. We discuss both these new results and the overall implications for pulsar birth periods, asymmetric supernova explosions, and mechanisms for pulsar natal kicks.

Progenitors and Evolution of Composite Supernova Remnants

Invited Talk

Tea Temim

STScI, Baltimore, USA

Abstract

Supernova remnants (SNRs) that host pulsar wind nebulae (PWNe) undergo distinct evolutionary stages marked by the interaction of the pulsar wind with the ejected supernova (SN) material and the SNR reverse shock. In very young systems, the PWN drives a shock into the innermost SN material, giving rise to low-excitation lines and a continuum from heated dust grains. These observational signatures make it possible to cleanly measure the properties of the deepest ejecta layers and newly formed dust that can, in turn, provide constraints on the SN progenitor. Meanwhile, during the later phases of evolution, the SNR reverse shock modifies the morphology and spectral signatures of the PWN. Observationally-constrained modeling of this process offers insight into the explosion properties and the structure of the surrounding ambient medium. I will discuss recent multi-wavelength observations and modeling of PWNe in various stages of evolution and their implications on our understanding of composite SNRs and their progenitors.

Session 6.

Pulsar Wind Nebulaes – Posters

Interpretting the GeV-TeV Gamma-ray Emission of the Vela X Pulsar Wind Nebula

Poster

Yiwei Bao[1], Yang Chen[1], Siming Liu[2]

[1] Nanjing University, China
[2]PMO, China

Abstract

The two-peaked gamma-ray spectral distribution and spatial deviation of the GeV-TeV regions of the Vela X pulsar wind nebula (PWN) as revealed by Fermi and HESS observations remain perplexing. Based on Slane et al. 2018) hydrodynamic simulation of the PWN, we suggest that the TeV-gamma-ray emitting electrons are impulsively injected when the cocoon is formed due to the interaction between the SNR reverse shock and the PWN. Because of the reverberation phase experienced in the evolution of the relic PWN or the extended radio nebula (ERN), in which the magnetic field was enhanced and high energy electrons were burnt off, the gamma-ray photons of the ERN are produced below 100 GeV. We have thus reproduced the broadband spectral SED of the ERN and the SED, the surface brightness profile, and the spatial index distribution of the TeV nebula.In the model, we constrain the diffusion coefficient of TeV-gamma-ray emitting electrons and positrons, leading to a value over three orders of magnitude lower than that in the interstellar medium, in agreement with a constraint recently obtained from HAWC observations of a TeV nebula associated with the Geminga pulsar. Such a slow diffusion can hardly transport the positrons below 100 TeV out of the Vela SNR.

A new radio look of the pulsar wind nebula 3C 58

Poster

Gabriela Castelletti

Institute of Astronomy and Space Physics, Argentina

Abstract

We report on new full-synthesis imaging of intensity and linear polarization structure of the radio emission from 3C 58, one of the most beautiful and interesting pulsar wind nebula known to date. The observations, acquired with the Karl G. Jansky Very Large Array in the 2-8 GHz wide range of frequencies, cover a much wider spectral bandwidth than any other used in previous studies of this iconic object. We used the new data to revisit the distribution of the magnetic field and investigate the spectral transition in the individual pulsar wind nebula features.

Pulsar Wind Nebulae observed in TeV gamma-rays and their Galactic environments

Poster

Yves A. Gallant[1], Michelle Tsirou[1], Zakaria Meliani[2]

[1]LUPM, UMR5299, CNRS/IN2P3, U. Montpellier, France
[2]LUTh, Obs. Paris, France

Abstract

Pulsar Wind Nebulae (PWNe) constitute the largest class of identified Galactic sources of TeV gamma-rays, as revealed by the Galactic Plane Survey with the HESS telescopes. This survey allowed a systematic study of a large number of PWNe in TeV gamma-rays, which revealed properties that could only be hinted at previously. In particular, there is a weak but significant trend for the gamma-ray luminosity to decrease with age, and apparently to depend on Galactic location. Furthermore, older PWNe are often significantly offset from the associated pulsar, with separations larger than may be readily explained solely by pulsar proper motion. After reviewing the above properties of TeV-emitting PWNe, we investigate possible explanations in terms of their respective Galactic environments. In particular, we review recent models of the photon density in the Galaxy and its spiral arms, and study their possible influence, in a leptonic (inverse Compton) model, on the observed contrasts in luminosity. We also discuss an explanation of the offsets which relies, in addition to the pulsar proper motion, on density heterogeneity in the surrounding medium. We examine this scenario by means of relativistic magneto-hydrodynamic numerical simulations. We outline the prospects for the next-generation TeV gamma-ray observatory, CTA, to shed light on these issues.

New X- ray observations towards the pulsar PSR J1826-1256

Poster

Elsa Giacani[1], G. Castelletti, A. Petriella, L. Supan

Institute of Astronomy and Space Physics, Argentina

Abstract

We present the results of XMM-Newton observations in direction to the pulsar PSR J1826-1256, which lies at 5.4 arcmin from the centroid of the TeV source HESS J1826-130. These data reveal an elongated nebula with the pulsar located in the northern border and a trail towards the peak of the very high energy source. The spectral analysis shows a nonthermal nature for the X-ray emission and a clear softening of the photon index with increasing distance from the pulsar. We discuss the connection among the pulsar, its nebula, and the HESS source.

NuSTAR Properties of G21.5-0.9

Poster

Soichiro Hattori[1], Samayra Straal[1], Joseph D. Gelfand[1], Patrick O. Slane[2], Tea Temim[3], Emily Zhang[4]

[1]New York University, Abu Dhabi
[2]CfA, USA
[3]STScI, USA
[4]Columbia, USA

Abstract

Powered by a rapidly rotating and highly magnetized neutron star, pulsar wind nebulae (PWNe) are known to produce very high energy particles. However, the acceleration mechanism of particles to such high energies in PWNe is poorly understood. As a portion of these high energy particles emit synchrotron radiation in the X-ray band, studying such emissions provide clues in understanding the underlying acceleration mechanism. Hence, we present a comprehensive reanalysis of the archival *NuSTAR* X-ray spectra (3-45 keV) of PWN G21.5-0.9, incorporating an additional ∼190 ks of previously unused observations. We find that the difference in the calculated flux between data from the two detectors onboard *NuSTAR* (FPMA and FPMB) during the same observation exceed the expected ∼5% fluctuation and also find that the flux from FPMB is consistently higher across all observations. However, we still find a higher power-law photon index compared to the photon index in the soft X-ray band (0.5-8 keV) as measured by *Chandra*, indicating spectral softening in the X-ray band. Preliminary modelling using a one-zone model suggests that the spectral softening is not due to synchrotron cooling. We also find that the synchrotron emission from the highest energy particles peaks in the hard X-ray (*NuSTAR*) band. We will discuss the implications of these results for particle production and acceleration in G21.5-0.9.

Rapid X-Ray Variations of the Geminga Pulsar Wind Nebula

Poster

Jongsu Lee[1], A.K.H. Kong, P.H.T. Tam, J. Takata, K. S. Cheng, Dongsu Ryu

[1]Chungnam National University, Korea

Abstract

We have observed Geminga pulsar wind nebula (PWN) by using Chandra X-ray Observatory. In comparison with previous studies of this system, a number of new findings have been reported, and we found that these suggest the possible variabilities in various components of this PWN. This motivates us to carry out a dedicated search for the morphological and spectral variations of this complex nebula. We have discovered variabilities on timescales from a few days to a few months from different components of the nebula. The morphological variation of the tail that trace the pulsars motion resemble those resulted from magnetic reconnections. The fastest change occurred in the circumstellar environment at a rate of 80% of the speed of light. One of the most spectacular results is the wiggling of a half light-year long tail as an extension of the jet, which is significantly bent by the ram pressure. The jet wiggling occurred at a rate of about 20% of the speed of light. This twisted structure could possibly be a result of a propagating torsional Alfven wave. We have also found evidence of spectral hardening along this tail for a period of about nine months.

Middle aged PWNe: Hints on the reverberation process

Poster

Barbara Olmi[1], Niccolo Bucciantini[1], Rino Bandiera[2], Diego F. Torres[3]

[1]INAF OAA, Italy, [2]ICE-CSIC, Spain, [3]IEEC, Spain

Abstract

Pulsar Wind Nebulae (PWNe) are powered by a neutron star that loses part of its rotational energy in the form of a relativistic, magnetized and cold wind. The interaction of this wind with the surrounding material ejected in the supernova explosion induces the formation of a termination shock, at which the wind is slowed down and heated. The downstream plasma can be then revealed thanks to non-thermal processes as a PWN. The evolution of middle aged systems, and their emitting properties, will strongly depend on a relatively short phase of their evolution, the so called reverberation phase. At a certain point the reverse shock generated by the supernova explosion, which travels back to the center of the remnant, will interact with the contact discontinuity of the PWN, giving rise to this reverberation period. Depending on the properties of the pulsar, of the remnant and of the way the interaction between the shocks arises, this could produce the compression of the nebula down to considerably smaller radii, with the consequent increase of the magnetic field in the nebula, that may be revealed as a huge variation in the emitting of the PWN itself. We will present here a way to model this complex interaction phase, which at present was not addressed with details with hydrodynamic models.

Submillimetre Constraints on the Pulsar-Driven Supernova Model

Poster

Conor Omand[1]

[1]University of Tokyo, Japan

Abstract

It has been widely argued that Type-I super-luminous supernovae (SLSNe-I) are driven by powerful central engines with a long-lasting energy injection after the core-collapse of massive progenitors. One of the popular hypotheses is that the hidden engines are fast-rotating pulsars with a magnetic field of $B{\sim}10^{13} - 10^{15}$ G. Murase et al. (2016) and Omand et al. (2018) proposed that non-thermal pulsar wind nebula (PWN) emission could be detected in certain SLSN remnants at submillimetre wavelengths at $\sim$ 1-3 years after the explosion. We observed two SLSNe, SN2015bn and SN2016ard, in two bands with ALMA and one SLSNe, SN2017egm, in one band with NOEMA; all to a flux below the lower limit of our model. We did not detect any sources consistent with SN2015bn or SN2016ard, and while we detected emission from the host galaxy of SN2017egm, there was no significant signal from the SN remnant. I discuss the implications of these non-detections, as well as the recent detection of 6 GHz emission from PTF10hgi (Eftekhari et al. 2019), on the pulsar-driven SN model.

Spectral Nature of Quiescent X-ray Emission from SGR 0526-66 in the LMC

Poster

Sangwook Park[1], Oleg Kargaltsev[2], Patrick Slane[3] and Jayant Bhalerao[1]

[1]University of Texas at Arlington, USA
[2]George Washington University, USA
[3]SAO, USA

Abstract

SGR 0526-66 is the first-identified magnetar, and is projected within the supernova remnant N49 in the Large Magellanic Cloud. Based on our 50 ks NuSTAR observation, we detect ∼200 counts in the 10-30 keV band (L∼ 5.4 x 10^{34} erg/s) from the quiescent X-ray counterpart. The detected NuSTAR spectrum is consistent with the spectral extrapolation from the power law model (photon index = 2.5) which previously fitted the hard component Chandra spectrum of 0526-66. Our results could be interpreted as synchrotron radiation from the neutron stars magnetosphere for the origin of the hard component X-ray spectrum of 0526-66 rather than thermal emission from hot spots (a blackbody with kT ∼ 1 keV) which alternatively fitted the hard component Chandra spectrum of 0526-66. We discuss preliminary results from our joint spectral analysis of 0526-66 based on our NuSTAR and the archival Chandra data.

The X-ray Evolution of the PWN in the SNR Kes 75

Poster

Samar Safi-Harb

[1]University of Manitoba, Canada

Abstract

We present coeval XMM-Newton and NuSTAR X-ray observations of the pulsar wind nebula (PWN) in the supernova remnant (SNR) Kes 75. The PWN is powered by PSR J1846-0258, a highly energetic (Edot = 8.1×10^{36} erg/s) rotation-powered pulsar with the youngest spin-down age (Pdot/2P ∼ 728 yr). The inferred magnetic field of the pulsar, Bs = 4×10^{13} G, is the largest known for such an object, and is likely responsible for the past flare and burst activity, suggesting a transition to a magnetar state. We use new and archival X-ray observations to study the broadband spectrum of the pulsar, PWN, and SNR and consider the spectral evolution of this system. Our study reveals hard X-ray emission from the remnant for the first time and suggests that the flux of the PWN is decreasing.

The geometry and dynamics of mass-loss at milli-arcsecond scales of massive stars in transition

Poster

Shuta Tanaka[1]

[1]Aoyama Gakuin University, Japan

Abstract

Pulsar wind nebulae (PWNe) are composed of relativistic magnetized plasma wind supplied from their central pulsars, called pulsar wind. Based on standard ideal magnetohydrodynamics model of PWN, magnetization of the pulsar wind is much less than unity in order to explain the observed slow expansion of the PWN. On the other hand, the pulsar wind is Poynting dominated at its base. This is called σ-problem. Here, we introduce our recent study extending the standard ideal MHD model by Kennel; Coroniti. Including the effects of magnetic dissipation and turbulence, requirement of low-magnetization from the dynamics of PWNe is relaxed.

Session 7.

SNRs and Their Galaxies – Oral Talks

Effect of cosmic rays on supernova remnant evolution

Oral Talk

Rebecca Diesing[1], Damiano Caprioli[1]

[1]University of Chicago, USA

Abstract

Using a semi-analytic approach based on the thin-shell approximation, we calculate the long-term evolution of supernova remnants (SNRs) while also accounting for the cosmic rays (CRs) accelerated at their blast waves. Our solution reproduces the results of state-of-the-art fluid simulations across the adiabatic and radiative stages for the gas-only case, and it predicts that typical CR acceleration efficiencies (≈10%) can boost SNR momentum deposition by a factor of 2-3. This enhancement can become as large as an order of magnitude in environments in which the gas experiences more severe radiative losses. This result may have a crucial impact on modeling the effect of supernova feedback on star formation and galaxy evolution.

Study of Extragalactic Supernova Remnants

Oral Talk

Maria Kopsacheili[1], Andreas Zezas[1], Ioanna Leonidaki[1]

[1]University of Crete/FORTH, Greece

Abstract

Studies of populations of supernova remnants (SNRs) in different galaxies provide a more representative picture of their importance for feedback and metal enrichment in a wide variety of galactic environments. We present our results on the SNRs populations in a sample of nearby spiral galaxies, based on deep narrow-band Hα and [S II] images. We derive the Hα and excitation distributions of the SNRs, both of which are proxies of the energy deposition on the galactic interstellar medium (ISM). In our analysis we develop methods to account for selection effects that allow us to directly compare results between different galaxies. We compare our results with similar studies in irregular galaxies and we discuss the effects of recent star-forming activity and the morphology and physical conditions in the ISM on the SNR populations and their physical properties. We also present a new, efficient, diagnostic tool for identifying SNRs and measuring their shock velocities based on narrow-band imaging. Through the effective differentiation from H II regions this diagnostic provides more complete samples of SNRs including those in later evolutionary phases with slower shocks.

SNR populations in our Galaxy and beyond: bridging the gap

Invited Talk

Ioanna Leonidaki

IESL/FORTH, Greece

Abstract

I will outline the updated demographics on multi-wavelength surveys of extragalactic Supernova Remnant (SNR) populations in order to probe their properties (e.g. line ratios, luminosities, densities, temperatures) and their connection. With these studies we are allowed to cover a wider range of environments and Interstellar Medium (ISM) parameters than our Galaxy, providing us a more complete and representative picture of SNR populations. However, most of these studies are hampered by limited sensitivity and low resolution not allowing the detailed study of their multi-wavelength emission, excitation and interplay with the ISM. Galactic SNRs on the other hand are an ideal laboratory to probe their structure, their evolution and their interaction with their ambient medium because, due to their proximity, can be observed in parsec scales. Although a census of 294 Galactic SNRs is available in the radio band, surprisingly no study has been conducted so far to investigate the multi-wavelength properties of Galactic SNRs as a population. Therefore, we have embarked on creating for the first time a complete optical narrow-band atlas of the entire SNR population in our Galaxy. I will present the first results of this very promising campaign: the morphology, the excitation / shock-velocity maps, and the integrated emission of optically observed Galactic SNRs. Comparison with existing maps in the X-ray and radio bands will allow us for the first time to probe how their observational characteristics correlate with their age, and therefore their evolution. This project will also shed light on how SNRs energize the ISM and remedy the inherent biases of extragalactic SNR surveys.

What are We Learning from Supernova Remnant Samples in Nearby Galaxies?

Invited Talk

Knox S. Long

Space Telescope Science Institute, USA

Abstract

More than four times as many supernova remnants (SNRs) have been found in other galaxies than are known in our Galaxy. Most of these were discovered as optical emission nebulae with elevated [SII]:Ha ratios compared to HII regions, unlike Galactic SNRs which were mostly discovered as extended, non-thermal radio sources. Although we know much more about individual SNRs in the Galaxy, the extragalactic samples arguably provide more information about SNRs as a class of objects than the Galactic sample, as the SNRs in a nearby galaxy are all effectively at the same distance and in most cases suffer relatively less internal absorption. Here, I will review the information we have collected about these samples, beginning with a brief mainly historical overview of the properties of SNRs in the Large Magellanic Cloud. I will then describe what we are learning from samples in three nearby spiral galaxies, M33, M83, and NGC6946, where substantial numbers of SNRs have been detected not only optically, but also as X-ray and radio sources, and where stellar populations studies are being used to suggest which SNRs arise from core-collapse explosions and which do not. As an example, in M33, where 155 of the 217 optical candidates have been detected at radio wavelengths and 112 in X-rays, we are learning that the dispersion in radio to X-ray luminosity is not easily interpretable with the current generation of theoretical models. To address this and other difficulties, I will argue that it is less important to identify SNRs in completely unexplored galaxies than it is to improve with deeper and different observations the samples we have in galaxies that have already been surveyed.

Observational Tests of Momentum Feedback by Supernova Remnants in M31

Oral Talk

Sumit Sarbadhicary[1], Enrico Ramirez-Ruiz, Davide Martizzi, Katie Auchettl, Carles Badenes

[1]Michigan State University, USA

Abstract

Momentum feedback from supernova remnants (SNRs) is a key ingredient in numerical simulations of galaxy formation. However, the mass and spatial scales of SNRs are much smaller than/barely resolved in such simulations, making a self-consistent prediction of feedback unfeasible. The alternative has been "sub-grid" models, where some prescription for the cumulative feedback per resolution unit is assumed, and tuned to reproduce bulk observations of galaxies. With the large variety of sub-grid models used by different groups, this poses a major uncertainty in our theoretical understanding of galaxy formation. In this talk, I will discuss efforts by our group to observationally constrain hydrodynamic models of momentum feedback from SNRs (Martizzi et al 2015) using the exquisite, resolved observations of M31. As observational constraints, we use maps of star formation histories derived from detailed photometry by the HST PHAT group, maps of ISM densities and velocity dispersions from 21 cm observations, and existing constraints on the SN delay-time distribution. We find that 1D models of feedback under-predict the velocity dispersion in the star-forming ring of M31, and we discuss the possible role of more complex physics in 3D shock models, clustering of SNe, and/or other systematic factors.

Session 7.

SNRs and Their Galaxies – Posters

The Fireworks Galaxy, NGC 6946: Looking at the Fading Embers

Poster

William P. Blair[1], K. S. Long[2], P. F. Winkler[3], C. K. Lacey[4]

[1]Johns Hopkins University, USA
[2]STScI, USA
[3]Middlebury College, USA
[4]Hofstra University, USA

Abstract

NGC 6946 is a relatively nearby (6.7 Mpc), face-on spiral galaxy with active star-formation activity throughout, including a bright nuclear starburst. NGC 6946 holds the record for production of observed supernovae, with some 10 in the last century (and four just since the turn of the millennium). Hence, it is a prime galaxy to in which to study global SN remnant populations. As part of our ongoing multiwavelength program to find and characterize the supernova remnant (SNR) populations and their progenitors in nearby galaxies, we have recently concentrated on this NGC 6946. Finding and characterizing SNRs in nearby galaxies is enhanced by having both ground-based and HST optical imaging data. The former are typically more sensitive to lower surface brightness and somewhat extended objects, while the latter are far superior for deriving diameter and morphology information and finding objects that are in relatively confused regions of emission. (Note: $1''= 33$ pc.) We have recently published a new optical ground-based SNR survey of NGC 6946 and cataloged 147 SNR candidates where only 27 were known previously (Long et al. 2019). We also presented optical ground-based spectroscopy with Gemini-N and GMOS, confirming some 89 out of 102 objects observed to have elevated [S II]:Hα ratios (the normal criterion for shock heating). Interestingly, we still find that many of the brighter SNRs do not have corresponding radio counterparts (Lacey & Duric 2001), which has been a long-standing problem for NGC 6946 compared with other nearby galaxies and one we are trying to understand. We have just recently obtained HST WFC3 UVIS Hα and [S II] imaging and IR imaging at [Fe II] 1.64 μm for much of NGC 6946; these add new diagnostic power for studying the SNRs. The [Fe II] data allow us to find objects in dusty regions as well as confirming many of the optical SNRs. The HST optical data will permit meaningful diameter measurements of most of the catalog, and allow us to study the global properties of the sample. We will report our initial analysis of these new data. We are currently using published X-ray and radio data to add the multiwavelength diagnostics at least for the brighter objects.

A UKIRT [FeII] Study of M33 and its Supernova Remnants

Poster

Justice Bruursema

United States Naval Observatory, Flagstaff Station, USA

Abstract

Supernova remnants (SNRs) are generally identified and studied at optical, X-ray or radio wavelengths. However, studies of supernova remnants in the infrared have shown that SNRs are linked to strong [Fe II] emission which originates from gaseous iron produced when a supernova shock wave destroys dust in the interstellar medium. This study furthers an attempt to develop [Fe II] observations as a detection and diagnostic tool for extragalactic SNRs. Using the United Kingdom Infrared Telescope (UKIRT) Wide Field Camera (WFCAM), deep imaging of M33 has been obtained in broad bands H and K and narrow bands 1.64 μm [Fe II] and 2.141 μm H_2. M33 is a spiral galaxy less than 1 Mpc away and has a long history of SNR studies, however a detailed map of narrow-band infrared emission has never been made until now. Analysis of [Fe II] emission throughout the galaxy is examined as well as infrared emission from previously identified supernova remnants and supernova remnant candidates.

Supernova Remnants and Supernova Feedback

Poster

Bon-Chul Koo[1], Chang-Goo Kim[2,3]

[1]Seoul National University, South Korea
[2]Princeton University/Flatiron Institute, USA
[3]Sangwook Park/ UT Arlington, USA

Abstract

Supernova (SN) is a major feedback mechanism driving large-scale turbulence in the interstellar medium (ISM), which regulates star formation in galaxies. In recent years, it has become possible to directly simulate SN feedback in realistic multiphase ISM in full three dimensions with high resolution. Although there is an emerging consensus from these theoretical works on the evolution of supernova remnants (SNRs) and the momentum/energy input from a SN event to the ISM, observational constraints are still lacking and necessary to validate the theoretical understanding. In this presentation, we review the observations of SNRs in radiative phase in the Milky Way. There are eight SNRs where we can observe fast-expanding radiative shells in HI 21 cm line. The shell momentum is in the range of (0.5-4.5)$\times 10^5$ $M_\odot$ km/s. Some of the SNRs are core-collapse SNRs interacting with molecular clouds, and they provide a template for the coupling of SN explosion energy and momentum to the inhomogeneous ISM. In two SNRs (W44 and IC 443), expanding molecular shells with momentum comparable to that of the atomic SNR shells have been also observed. We compare the observed momentum and kinetic/thermal energy of these eight SNRs with the results from 1D numerical simulations and discuss the implications.

Applying models with reverse shocks to Galactic supernova remnants in the VGPS survey

Poster

Denis Leahy[1], Sujith Ranasinghe[1]

[1]University of Calgary, Canada

Abstract

We apply SNR interior structure models to Galactic supernova remnants (SNR) in the VGPS survey to obtain properties of the Galactic SNR population. The models include the evolution of SNR interior structure for both forward and reverse shocks, and calculate forward and reverse shock X-ray emission measures at any time. By applying the models to SNRs with measure X-ray spectra, we obtain estimates of explosion energy, age and ejecta mass for a significant set of SNRs.

Using MHD simulations to construct analytical models for supernova remnant evolution

Poster

Denis Leahy[1], Yuyang Wang

[1]University of Calgary, Canada

Abstract

We use numerical MHD simulations, run with the public PLUTO code (Mignone et al. 2012), to follow the evolution of supernova remnants. We consider the full evolution from days after explosion to late in the adiabatic phase. For these calculations we consider spherically symmetric evolution. For power-law ejecta profile, and before the reverse shock encounters the ejecta core, the early evolution agrees with the Chevalier self-similar results. For the late evolution there are significant differences from the standard Sedov model, cause by finite ejecta mass.

What can we learn about SNe from atomic gas in their environments?

Poster

Michal Michalowski[1]

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Abstract

I will present the result of an observational campaign to map atomic gas in host galaxies of long gamma-ray bursts (GRB) and supernovae (SN). For GRBs and a relativistic type Ic-BL SN we found off-centre gas concentrations close to the GRB/SN positions and irregular velocity fields. This suggests a recent gas inflow. This is consistent with GRB/SN progenitors being born when a galaxy accretes metal-poor gas from the intergalactic medium, and opens a possibility to use GRB/SN hosts to study gas accretion. On the other hand, the host galaxy of the unusual transient AT 2018cow does not exhibit such features, which suggests that its progenitor may not have been a massive star.

O CEASAR: The Optical Catalogue of ExtrAgalactic SupernovA Remnants

Poster

Ismael Moumen[1,2], C. Robert[1], D. Devost[2], R. P. Martin[3], L. Rousseau-Nepton [2], D. Patnaude [4], L. Drissen[1], T. Martin[1]

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[2]CFHT, Canada
[3]University of Hawaii at Hilo, USA
[4]Smithsonian Astrophysical Observatory, USA

Abstract

We present O CAESAR, the Optical CAtalogue of Extragalactic SupernovA Remnants. O CAESAR will provide the largest homogenous optical survey of extragalactic SNR candidates taken by the same telescope (Canada-France-Hawaii Telescope, CFHT), the same instrument (SITELLE), and in similar observation parameters. SITELLE, the imaging Fourier transform spectrograph of the CFHT, offers a large field of view (11'x11'), complete spatial coverage, and a high spatial resolution

(0.32" limited by the seeing), which are ideal to cover the whole disk of nearby galaxies. Using three filters, we are able to measure the strong emission lines [OII]λ3727, Hβ, [OIII]1$\lambda\lambda$4959,5007, Hα, [NII]$\lambda\lambda$6548,6583, and [SII]$\lambda\lambda$6716,6731. The spectral resolution is variable and depends on the scientific goal. Our sample is volume limited (D $\leq$10 Mpc) and will include the galaxies of SIGNALS survey ($\sim$40 galaxies) in addition to other galaxies that will be proposed specifically for our project to include different ranges of types, masses, and metallicities. Identification of the SNR candidates will be done automatically and will be based on the emission line criterium [SII]/H$\alpha \geq 0.4$. The shock-excited nature of SNR candidates will be confirmed using the whole set of emission lines available with our SITELLE data.

ALMA view of the molecular clouds associated with the Magellanic SNRs

Poster

Hidetoshi Sano[1], Yumiko Yamane[1], Hideaki Matsumura[2], Kazuki Tokuda[3], Miroslav D. Filipovic[4], Gavin Rowell[5], Manami Sasaki[6], Kengo Tachihara[1], Yasuo Fukui[1]

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[2]The University of Tokyo, Japan
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[4]Western Sydney University, Australia
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Abstract

The Large Magellanic Cloud (LMC) is among the best laboratories for studying various astronomical objects and their physics because of its almost face-on inclination to us, and a well-known distance ($\sim$ 50 kpc). Supernova remnants (SNRs) in the LMC were well studied by radio continuum, optical, and X-ray observations (e.g., Bozzetto et al. 2017 and references therein). By contrast, very few attempts have been made to observe molecular clouds associated with the LMC SNRs (Banas et al. 1998). Sano et al. (2017a,b) observed 25 X-ray bright LMC SNRs using the Mopra 22-m and ASTE 10-m radio telescopes with a spatial resolution of $\sim 6 - 11$ pc. At least twelve of them were shown to have giant molecular clouds that have a good spatial correspondence with X-ray shells; this indicates that shock-cloud interactions may have occurred. Subsequently, we observed four SNRs using the Atacama Large Millimeter/ submillimeter Array (ALMA) with a spatial resolution of $\sim 0.4 - 0.7$ pc. We spatially resolved clumpy molecular clouds associated with the LMC SNRs for the first time (N49, Yamane et al. 2018; N103B, Sano et al. 2018; N63A, Sano et al. 2019; and in the superbubble 30 Doradus C, Yamane et al. 2019 in preparation). We are therefore entering a new age in studying the Magellanic SNRs yielding a spatial resolution comparable to what had been possible only for Milky Way SNRs. For N49, the synchrotron radio emission is clearly enhanced around molecular clouds, suggesting that the magnetic field amplification occurred via shock-cloud interactions. For the Type Ia SNR N103B, molecular clouds nicely trace the X-ray shell boundary, which shows an expanding gas motion in the position-velocity diagram with an expansion velocity of ~ 5 km s^{-1}. The expanding gas motion was possibly created by accretion winds from a single-degenerate progenitor system. For N63A, we spatially resolved clumpy molecular clouds embedded within both the shock-ionized and photoionized optical nebulae, indicating that the molecular clouds have started to be ionized by shock waves and UV-radiation. In this talk, we report our latest results of CO studies in the X-ray bright LMC SNRs using the Mopra, ASTE, and ALMA.

Deep, systematic radio-based surveys of supernova remnants in M31 and the Magellanic Clouds

Poster

Sumit K. Sarbadhicary[1], Jessica Maldonado, Danny Huizenga, Jay Strader, Carles Badenes

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[2]Universite Montpellier II, Vendome, France
[3]Laboratoire d/Astrophysique de Marseille, Marseille, France
[4]Universidad de Valparaiso, Valparaiso, Chile
[5]Centro de Astrofisica da Universidade do Porto, Porto, Portugal

Abstract

This is a poster detailing our group's efforts to survey the supernova remnant population using deep VLA mosaic images of M31, and ATCA images of the Magellanic Clouds. Along with White et al (2019), this will complete the next-generation, deep limit, systematically assembled survey of radio supernova remnants of the Local Group. We use a proper source-extraction algorithm and uniform selection criteria to pick out genuine radio sources from our deep images, and assign each source (point and extended) a "probability" of being a supernova remnant (as opposed to AGN, HII regions) using their radio spectral index and optical spectroscopy from SOAR. These surveys are expected to have abundant sources (particularly in M31) with well-defined completeness, which will be essential for statistical studies of supernova rates and progenitor models, as well as individual case-studies of supernova remnants.

Session 8.

Magnetic Fields in SNRs and PWNe – Oral Talks

Revealing the nature of the unusual PWN CTB87

Oral Talk

Roland Kothes[1], Wolfgang Reich[2], Samar Safi-Harb[3], Benson Guest[3]

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[2]Max-Planck-Institut für Radioastronomie, Germany
[3]University of Manitoba, Canada

Abstract

We present a thorough radio continuum and linear polarization study of the unusual pulsar wind nebula CTB87. The supernova most likely exploded inside a stellar wind bubble close to its edge in the vicinity of a molecular cloud complex about 30,000 years ago. There are two PWN components; one is still dispersing freely inside the wind bubble and the other is a relic PWN, resulting from the interaction of the pulsar wind with the SN reverse shock generated in the molecular clouds. A kinematic and evolutionary study of the two components reveals the most likely location of the to date missing SNR shell and why we cannot easily detect it. We will also show a radio shell candidate towards the molecular clouds, only detectable in polarized radio emission.

New high-frequency radio observations of the Cygnus Loop Supernova Remnant

Oral Talk

Sara Loru[1], Alberto Pellizzoni[1], Elise Egron[1], Simona Righini[2], Noemi Iacolina[3], Sara Mulas[4], Adriano Ingallinera[1], Andrea Melis[1], Raimondo Concu[1], Patricia Reich[5], Wolfgang Reich[5]

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[3]Agenzia Spaziale Italiana, Italy
[4]University of Cagliari, Italy
[5]Max-Planck-Institut für Radioastronomie, Germany

Abstract

Thanks to its large size, its location well out of the Galactic plane, and its high brightness, the middle-age SNR Cygnus Loop is well suited for observations across the entire electromagnetic spectrum. In the radio band, this SNR presents a very characteristic morphology with a large northern circular shell and a bubble-like shell located in the southern part. The radio studies showed substantial differences between these two regions, which suggested that the Cygnus Loop consists of two interacting supernova remnants. Indeed, the northern part of the remnant would seem governed by the compression of the magnetic field due to the SN explosion shock, while the southern part results most likely from shock acceleration that is thought to act in young remnants. Furthermore, a possible spectral steepening above 2.7 GHz is still debated.Despite this scientific interest, sensitive flux density measurements are missing at higher frequencies (above $\sim$ 5 GHz), due to the technical difficulties in performing radio continuum observations of a so large sources. These arguments made Cygnus Loop a challenging and very interesting target to observe with the Italian radio telescopes. With this aim, we observed Cygnus Loop with the Medicina radio telescope at 8.3 GHz, obtaining the highest-frequency map so far with a single-dish radio telescope. In this image we detected the two prominent shells and the central filament, which constitute the northern remnant, as well as the southern remnant. Our measurement rules out any global spectral steepening up to 8.3 GHz.At the light of these results, we included Cygnus Loop in our 2018 observing project with the Sardinia Radio Telescope (SRT). The project is focused on the high-frequency and polarimetric comparative investigations on a wider sample of middle-aged and young SNRs in order to perform a precise modelling of the region-dependent continuum spectral indices and to disentangle magnetic enhancement processes from spectral variation contributions. Spectro-polarimetric observations have been performed

with SRT at 6.9 GHz and in the range 18.6−24.5 GHz on two interesting regions of Cygnus Loop: the northern-bright filament and the southern remnant. These observations are crucial to study region-dependent variations on spectral indices and polarisation properties above $\sim$ 5 GHz, which are attributable to different acceleration mechanisms acting in these regions.

Modeling PWNe and their magnetic fields

Invited Talk

Barbara Olmi and Niccolo Bucciantini

INAF OAA, Italy

Abstract

Pulsar Wind Nebulae (PWNe) and bow shock PWNe, their aged counterparts, are fascinating systems. Indeed they show a large variety of emission properties, evidence for particles accelerated to extreme energies and puzzling signatures indicating efficient particles escape and diffusion from the nebulae. Due to the very complex physics involved, their modeling has been for years a real challenge. The complex physics of acceleration, transport and emission in these systems is strongly dependent on the magnetic field structure and evolution. In the last few years, the availability of 3D models has allowed us to investigate the properties of the plasma flow and magnetic fields in PWNe, leading to a big step forward in the solution of some of the puzzles, like for instance the long standing “sigma-problem” highlighted from the modeling of the non-thermal emission of the Crab Nebula and other young PWNe. In recent works, also the signatures of the magnetic field geometry on the overall morphology of bow shock PWNe have been investigated, with a particular focus on X-ray emission properties and particle escape mechanisms. All the above aspects will be discussed in this talk by reviewing the latest results from 3D models of PWNe.

Magnetic fields in supernova remnants: observational inferences

Invited Talk

Stephen P. Reynolds

North Carolina State University, USA

Abstract

Synchrotron radiation from shell supernova remnants can serve as a diagnostic of the strength and order properties of magnetic fields. Radio polarization observations give information on the orientation and degree of order in the magnetic field on the scales to which they are sensitive, but can say little about strengths. Observations of X-ray synchrotron emission in the dozen or so remnants in which it is firmly detected can provide additional information: ”thin rims” require strong and/or decaying magnetic fields, while rapid variability constrains electron acceleration and loss times. If gamma-ray emission is detected as well, broadband spectral-energy distribution (SED) models can give magnetic-field strengths. Time variability can provide (model-dependent) estimates. As additional cases of X-ray synchrotron emission are identified, and as further cases of GeV-TeV emission from SNRs are found, more determinations or estimates of magnetic-field strength become available. I shall review the current status of this field, with particular attention to correlations of magnetic-field strength estimates with other remnant properties. This information is essential to constrain theoretical models of magnetic-field amplification in strong shock waves.

MHD simulations of Supernova Remnants in a magnetized medium

Oral Talk

Pablo Velazquez[1], Alejandro Avila-Aroche[1]

[1]Instituto de Ciencias Nucleares, UNAM, Mexico City, Mexico

Abstract

We have carried 3D MHD simulations of a supernova remnant expanding into an ISM, which has a magnetic field with a random component. From our numerical results, we have performed synthetic maps of the linearly polarized synchrotron emission. The idea is to analyze how the random t component of the ISM magnetic field affects the morphology of the linearly polarized emission, and thus have a better understanding of what mechanism of acceleration is actually taking place in the shock wave of the remnant.

Session 8.

Magnetic Fields in SNRs and PWNe – Posters

Asymmetries in the emission from young supernova remnants: The case of Tycho

Poster

A. Moranchel Basurto[1], P. F. Velázquez[1], E. M. Schneiter[2], A. Esquivel[1]

[1]ICN-UNAM, Mexico
[2]IATE, Argentina

Abstract

We have developed three-dimensional MHD numerical simulations using the "Guacho" code, in order to explore the scenario in which the initial mass distribution of a Supernova (SN) explosion is anisotropic. The idea is to analyze if this scenario can explain the radio-continuum emission and the expansion observed in young supernova remnants (SNRs), such as the case of Tycho's SNR. From our numerical results, synthetic polarized synchrotron emission maps were computed. Additionally with our results an expansion study was carried out. We have found a good agreement of this expansion study with previous observational results applied to the Tycho's SNR. We found that both the observed morphology and the brightness distribution are well reproduced.

X-ray Polarization in Supernova Remnants

Poster

Patrick Slane

Harvard-Smithsonian Center for Astrophysics, USA

Abstract

The fast shocks in supernova remnants are known to accelerate particles to extremely high energies. The acceleration process is closely tied to the magnetic field structure in the shock region. This, in turn, can be modified considerably by the shock. Synchrotron emission from the shock regions provides crucial details about the magnetic field strength and orientation through its polarization. Radio polarization studies of several SNRs have provided important maps of the field orientation, and these provide clues about the connection with particle acceleration. Due to the rapid losses of the highest-energy particles, however, X-ray polarization measurements provide magnetic field information from particles much closer to the acceleration sites. Here I discuss how X-ray polarization observations can be used to investigate the magnetic fields in SNRs in order to address questions about acceleration efficiency dependence on shock obliquity, levels of turbulence in the fields, and acceleration of particles at the reverse shock.

Session 9.

Jets and Asymmetries in SNe and Their Remnants – Oral Talks

Asymmetries of Heavy Elements in Cassiopeia A

Oral Talk

Tyler Holland-Ashford[1], Laura Lopez[1], Katie Auchettl[2]

[1]The Ohio State University, USA
[2]Niels Bohr Institute, Denmark

Abstract

Supernova remnants offer the means to study supernovae long after the original explosion and can provide a unique insight into the mechanism(s) that govern these energetic events. Recently, observations and simulations have suggested that the anisotropic distribution of expanding ejecta in these remnants is closely tied to the physical processes that occur during explosion, as opposed to soley a result of interaction with inhomogenous interstellar medium. In this work, we examine the X-ray morphologies of different elements (from oxygen to iron) found in the youngest known core-collapse supernova remnant in the Milky Way, Cassiopeia A. We find a linear relationship where the heaviest elements exhibit the highest levels of asymmetry, which we relate to the burning process that created the elements and their proximity to the likely center of explosion. Our findings support recent theories that the mechanism(s) governing a supernova explosion is highly asymmetric in nature, and ejects the material closest to the source of explosion with the most asymmetry. In addition, we find that the heaviest elements–formed closest to the center of explosion–are moving in an opposite direction to the neutron star at angles greater than those of lighter elements. This provides further evidence that NS kicks are generated via ejecta asymmetries, as opposed to neutrino asymmetries.

Doppler Velocity Measurement of Fe Ejecta in Keplers Supernova Remnant

Oral Talk

Tomoaki Kasuga[1], Toshiki Sato[2,3,4], Koji Mori[5], Hiroya Yamaguchi[6], Aya Bamba[7]

[1]The University of Tokyo, Japan
[2]RIKEN, Japan
[3]NASA Goddard Space Flight Center, USA
[4]University of Maryland Baltimore County, USA
[5]University of Miyazaki, Japan
[6]ISAS, JAXA, Japan
[7]The University of Tokyo, Research Center for the Early Universe, School of Science, Japan

Abstract

We present asymmetric kinematics of the hot Fe ejecta in Kepler's SNR, the remnant of the SN Ia observed in 1604, revealed using Doppler velocity measurement (Kasuga et al. 2018, PASJ, 70, 5, 88). The ejecta kinematics of young SNRs is an important clue to understanding the explosion mechanism of their progenitors. The line-of-sight velocity of the shock-heated ejecta can only be measured by the Doppler shift of emission lines in the X-ray band. Using Chandra $\sim$ 741-ksec observations, we discovered significantly red shifted bulk Fe ejecta near the center of the SNR together with several blue shifted Fe clumps. This suggests possible asymmetricity of the progenitor explosion particularly at the hot dense core. Another SN Ia remnant Tycho, on the other hand, shows more symmetric expansion structure (e.g., Williams et al. 2017, Sato & Hughes 2017), suggesting variety in SN Ia progenitor system and/or explosion mechanism.

A Three-Dimensional Kinematic Reconstruction of Supernova Remnant N132D's High-Velocity, Oxygen-Rich Ejecta

Oral Talk

Charles Law[1], Dan Milisavljevic[2], Paul Plucinsky[1], Daniel Patnaude[1]

[1]Harvard-Smithsonian Center for Astrophysics, USA
[2]Purdue University, USA

Abstract

Observations of young, Galactic oxygen-rich supernova remnants (SNRs) have revealed prominent asymmetries in their expanding ejecta at spatial scales impossible to investigate from most extragalactic supernova observations. The three-dimensional velocity structure of these remnants provides a direct probe of core-collapse explosion dynamics, explosive mixing in the progenitor star, and ejecta interaction with the surrounding circumstellar and interstellar medium. Unfortunately, only a few such sources have been mapped with high-resolution. I will present a 3D Doppler reconstruction of optically-emitting, oxygen-rich knots in SNR N132D that showcases its distorted torus geometry in new detail. I will discuss the observed morphology in the context of its X-ray emission as well as the kinematic structure of other well-studied O-rich SNRs. In particular, morphological similarities with the prototypical O-rich SNR Cas A call into question previous interpretations of the relative influence of intrinsic explosion dynamics versus ISM/CSM interaction in shaping the stellar ejecta. The presence of a spatially-separated, high-velocity runaway knot of O-rich material that is coincident with a Si-enriched, bright compact X-ray source provides tantalizing evidence that a jet-like outflow may have participated in the core-collapse explosion that produced N132D.

The Morphologies and Kinematics of Supernova Remnants

Invited Talk

Laura Lopez

Ohio State University, USA

Abstract

I will review the major advances in using the morphologies and kinematics of supernova remnants (SNRs) to probe their explosive origins, evolution, and interactions with their surroundings. Simulations of SN explosions have improved dramatically over the last few years, and SNRs can be used to test models through comparison of predictions with SNRs' observed large-scale compositional and morphological properties as well as the three-dimensional kinematics of ejecta material. In particular, Galactic and Magellanic Cloud SNRs offer an up-close view of the complexity of these events. I will summarize the progress tying SNRs to their progenitors' explosions through imaging and spectroscopic observations, and I will discuss exciting future prospects for SNR studies, such as X-ray microcalorimeters.

Investigating asymmetries of SNRs through 3D long-term SN-SNR simulations

Invited Talk

Salvatore Orlando

INAF - Osservatorio Astronomico di Palermo, Italy

Abstract

The structure and morphology of supernova remnants (SNRs) reflect the properties of the parent supernovae (SNe) and the characteristics of the inhomogeneous environments through which the remnants expand. Thus establishing a link between asymmetries and features observed in SNRs and anisotropies developed during their parent SNe can be essential to obtain key information on many aspects of the explosion processes associated with SNe. Nowadays, our capability to study the SN-SNR connection has been largely improved thanks to multi-dimensional models describing the long-term evolution from the SN to the SNR as well as to observational data of growing quality and quantity across the electromagnetic spectrum which allow to constrain the models. In this talk, I will review recent advances in the modeling of young to middle-aged SNRs, focusing on investigations aimed to link asymmetries and features observed in the remnants to their parent SN explosions. I will discuss the role of post-explosion anisotropies vs. inhomogeneous environments in the shaping of SNRs, highlighting the importance to disentangle the two effects when interpreting observations of SNRs. Finally, I will discuss future prospects in view of upcoming missions and possible improvements of current models.

Revisiting the ejecta asymmetries in CasA with a novel method for component separation in X-rays

Oral Talk

Adrien Picquenot, Fabio Acero, Jérôme Bobin

CEA, France

Abstract

In the X-ray emission of supernovae remnants, the shocked interstellar medium, the shocked ejecta and the synchrotron possess a different spatial and spectral signature, but are closely entangled. Extracting the intrinsic spatial and spectral information of the individual components from this data is a challenging task. Current analysis methods do not fully exploit the 2D-1D (x,y,E) nature of the data, as the spatial and spectral information are considered separately. Here we investigate the application of a blind source separation algorithm (the General Morphological Component Analysis; GMCA) that jointly exploits the spectral and spatial signatures of each component in order to disentangle them. The performance of the GMCA on X-ray data is tested using Monte-Carlo simulations of Cassiopeia A-like toy models, designed to represent typical science cases. We find that the GMCA is able to separate highly entangled components in X-ray data even in high contrast scenarios, and can extract with high accuracy the spectrum and morphological maps of each physical component. Applying the algorithm to the deep Chandra observations of Cassiopeia A, we are able to produce detailed maps of the synchrotron emission at low energies (0.6-2.2 keV), and of the red/blue shifted distributions of a number of elements including Si, S, Ar, Ca and Fe K. These maps, besides highlighting the asymmetries of some elements distribution in the ejecta of Cassiopeia A, exhibit their spatial distributions with a level of details never attained before. We were also able to retrieve, for the first time, an image of the Oxygen distribution.

Session 9.

Jets and Asymmetries in SNe and Their Remnants – Posters

Discovery of a jet-like structure with overionized plasma in the SNR IC 443

Poster

Emanuele Greco, Marco Miceli, Salvatore Orlando, Giovanni Peres, Eleonora Troja, Fabrizio Bocchino

INAF - Osservatorio Astronomico di Palermo, Italy
Università degli Studi di Palermo - Dipartimento di Fisica e Chimica, Italy

Abstract

IC 443 is a supernova remnant (SNR) located in a complex environment and interacting with nearby clouds. Indications for the presence of overionized plasma have been found though the possible physical causes of overionization are still debated. Moreover, because of its peculiar position and proper motion, it is not clear if the pulsar wind nebula (PWN) within the remnant is the relic of the IC 443 progenitor star or just a rambling one seen in projection on the remnant. We addressed the study of the IC 443 X-ray emission in order to investigate the relationship between the PWN and the remnant, the presence of overionization and its origin. We identified an elongated (jet-like) structure with Mg-rich plasma in overionization. The head of the jet is interacting with a molecular cloud and the jet is aligned with the position of the PWN at the instant of the supernova explosion. Interestingly, the direction of the jet of ejecta is somehow consistent with the direction of the PWN jet. Our discovery of a jet of ejecta in IC 443 enlarge the sample of core-collapse SNRs with collimated ejecta structures. IC 443's jet is the first one which shows overionized plasma, possibly associated with the adiabatic expansion of ejecta. The match between the jet's direction and the original position of the PWN strongly supports the association between the neutron star and IC 443.

Measuring Ejecta Velocities in Tycho's and Kepler's Supernova Remnants with the Chandra HETGS

Poster

Matthew Millard[1], Jayant Bhalerao[1], Sangwook Park[1], Toshiki Sato[2,3], John Hughes[4,5], Patrick Slane[6], Daniel Patnaude[7], David Burrows[8], Carles Badenes[9,10]

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Abstract

We report measurements of the bulk radial velocity from a sample of small, X-ray emitting metal-rich ejecta knots in Kepler's and Tycho's supernova remnants (SNRs). We measure the Doppler shift of the Si K line center energy in the spectra of these knots from our *Chandra* High-Energy Transmission Grating Spectrometer (HETGS) observations to estimate their radial velocities. Our preliminary results on the analysis of Tycho's SNR show radial velocities up to $v_r \sim 5{,}000$ km s^{-1} in several ejecta knots. In Kepler's SNR, we estimate high radial velocities of up to $v_r \sim 9{,}000$ km s^{-1}. We also measure proper motions for these ejecta knots based on the archival Advanced CCD Imaging Spectrometer (ACIS) data of Kepler's SNR taken in 2000, 2004, 2006, and 2014. The fastest moving knots showed proper motions of up to ~ 0.2 arcseconds per year. A few knots with the highest radial velocities also exhibit large proper motions, indicating that they are nearly freely expanding. Assuming that these high velocity ejecta knots are freely expanding near or beyond the main SNR shell, we estimate a distance to Kepler of $d \sim 5$ to 8.5 kpc. The ejecta knots in our sample have an average space velocity of $|v_s| \sim 5{,}000$ km s^{-1} (at a distance of 6 kpc) in Kepler's SNR. Eleven out of these 15 ejecta knots from our sample show a redshifted spectrum, suggesting an asymmetry in the ejecta distribution in Kepler's SNR along the line of sight. This work has been supported in part by NASA *Chandra* Grants GO6-17060X, GO7-18061X, and AR7-18006X.

An extended aspherical explosion of a core-collapse supernovae

Poster

T. Nagao[1], A. Cikota[2], F. Patat[1], M. Bulla[3], T. Faran[4], S. Taubenberger[5], D. J. Sand[6], S. Valenti[7], J. E. Andrews[6], D.E. Reichart[8]

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[8]University of North Carolina at Chapel Hill, USA

Abstract

Unvealing the explosion geometry of core-collapse supernovae helps to understand the explosion mechanism of massive stars. The most reliable evidences for asymmetry in the explosion have been provided by spectropolarimetric observations. Type IIP SNe, which belong to the most common class of core-collapse SNe, show a rapid increase in continuum polarization just after entering the nebular phase. This time-evolution in polarization can be explained by a highly asymmetric helium core, which is exposed when the ejected material becomes transparent. Since only few SNe IIP are intensely observed with spectropolarimetry, it is not clear whether the aspherical geometry is common for all SNe IIP. Here we report spectropolarimetry of SN 2017gmr, which shows an unusually early rising of the polarization ($\gtrsim$ 30 days before starting the nebular phase). This implies that SN 2017gmr is the most extended aspherical SN IIP explosion observed so far, i.e., asymmetries exist not only in the helium core but also in a significant part of the hydrogen envelope, and also that there is intrinsic diversity in the aspherical geometry of the SN explosions. Our observations provide new constraints on the explosion mechanism of core-collapse SNe, i.e., proposed explosion models must produce such extended asphericity and also account for the diversity in the aspherical structure.

Supernova ejecta with a powerful central engine

Poster

Akihiro Suzuki

National Astronomical Observatory of Japan, Japan

Abstract

The origin of luminous supernova (SNe), such as SNe associated with gamma-ray bursts and superluminous SNe, are still debated despite a lot of theoretical and observational studies. It is claimed that such luminous SNe harbor powerful "engines" at their centers. In the central engine scenario, a rotating magnetized proto-neutron star, a black accretion disk, or whatever is left in the supernova ejecta and serves as a power source for luminous thermal emission. The energy injection at the center of SN ejecta create a hot bubble or a nebula, similar to pulsar wind nebulae, and its impact on the SN ejecta is non-negligible when considering sufficiently powerful engine realizing superluminous SNe. We are investigating the effect of such powerful central energy source on the dynamical evolution of SN ejecta by using (radiation-)hydrodynamics simulations in 2D and 3D. In this presentation, we report the results of our past and ongoing studies on numerical modeling of SN ejecta with a powerful central energy source.

Three-dimensional MHD modeling of SNR IC 443: effects of the inhomogeneous medium in shaping the remnant morphology

Poster

S. Ustamujic[1], S. Orlando[1], E. Greco[1,2], M. Miceli[1,2], F. Bocchino[1], G. Peres[1,2]

[1]INAF - Osservatorio Astronomico di Palermo, Italy
[2]Università degli Studi di Palermo - Dipartimento di Fisica e Chimica, Italy

Abstract

In this study we aim at investigating the effects of the inhomogeneous medium in shaping the remnant morphology of IC 443 after the supernova (SN) explosion. The distribution of the interstellar medium in the vicinity of the supernova remnant (SNR) plays a fundamental role for our understanding of the morphology and later evolution. In particular, IC443 is a SNR located in a quite complex environment: it interacts with a molecular cloud in the northwestern and southeastern areas and with an atomic cloud in the northeast. We have developed a 3D MHD model for SNR IC 443 describing the interaction of the SNR with the environment, parametrized in agreement with the results of the multiwavelength data analysis. In this poster we present our preliminary results.

Exploring the scientific potential of Virtual Reality for observational astrophysics with SNR 1E 0102.2-7219

Poster

Frederic Vogt and Enrico Baracaglia

European Southern Observatory

Abstract

To aid in the analysis of the 3D structure of the oxygen-bright ejecta in SNR 1E 0102.2-7219 in the SMC (reconstructed from MUSE observations), we assembled a dedicated Virtual Reality (VR) application: "E0102-VR". With it, we identify a (7.0±0.5) pc-long funnel structure on the far-side of the remnant. The base of the funnel is spatially coherent with the Central Compact Object in the system. This strongly suggests that the supernova explosion site is to be found in the general vicinity (on-sky) of the Central Compact Object, and offset by $\sim 10'' \equiv 3$ pc from the center of symmetry of the X-ray emission of the system. The E0102-VR application, albeit experimental, demonstrates the benefits of using human depth perception for a rapid and accurate characterization of complex 3D structures. Given the implementation costs (time-wise) of a dedicated VR application like E0102-VR, we conclude that the future of VR for observational astrophysics lies in the development of a robust, generic application dedicated to the exploration and visualization of 3D observational datasets, akin to a "ds9-VR".

Session 10.

SNe and SNRs with circumstellar interactions – Oral Talks

On the interaction of Type Ia supernovae with Planetary Nebulae

Oral Talk

A. Chiotellis[1], P. Boumis [1], C. Abate[2]

[1]National Observatory of Athens, Athens, Greece
[2]Argelander-Institute fur Astronomie, Universitat, Bonne

Abstract

Type Ia supernovae (SNe Ia) are believed to result from the thermonuclear combustion of carbon oxygen white dwarfs that get destabilized by mass accretion from a companion star. However, despite decades of research, the nature of SNe Ia remains largely unknown. One promising method that attempts to put insights on the unknown nature of SNe Ia is the search of traces from the interaction of the SN ejecta with circumstellar structures formed by the progenitor system. These traces can be found either at the early SN phase or at the subsequent phase of the supernova remnant (SNR). However, from the current observations of SNe Ia and their SNRs are extracted ambiguous conclusions about the existence and the properties of the surrounding circumstellar medium (CSM) and up to date there is no any model able to explain all the observables at the same time. In this work we present an alternative progenitor model according to which SNe Ia occur in the center of, and substantially interact with, Planetary Nebulae (PNe) formed by one or both the progenitor stars. We show that the diverse observables of the CSM around SNe Ia and SNRs reveal intriguing similarities with the overall properties of PNe. We preform 2D hydrodynamic simulations and we study the results of a SN Ia-PN interaction on the properties of the resulting SNR. We show that such a model can explain self-consistently the overall properties of well-studied SNRs e.g. Kepler's and Tycho's SNR.

On the interaction of Type Ia supernovae with Planetary Nebula

Oral Talk

Michael A. Dopita[†], Ivo Seitenzahl

University of New South Wales, Canberra, Australia

Abstract

Using integral field data we extract the optical spectra of shocked interstellar clouds in Kepler's supernova remnant located in the inner regions of our Galaxy, as well as in the Large Magellanic Cloud, the Small Magellanic Cloud, NGC 6822, and IC 1613. Using self-consistent shock modeling, we make a new determination of the chemical composition of the interstellar medium in N, O, Ne, S, Cl, and Ar in these galaxies and obtain accurate estimates of the fraction of refractory grains destroyed in the shock.

[†]In his memory, who passed away on December 22, 2018 - by I. Seitenzahl.

The Circumstellar Media of Superluminous Supernovae

Oral Talk

Claes Fransson

Dept. of Astronomy, Stockholm University, Sweden

Abstract

I will discuss observations and modeling of the circumstellar media of superluminous supernovae. Recent observations of several superluminous Type I SNe, as well as Type Ibn SNe, show strong evidence for dense circumstellar media of these stripped SNe. This may be seen as either direct interaction or as light echoes. I will in particular discuss the case of iPTH16eh, where a resonance line echo in the Mg II 2800 doublet provides direct estimates of the velocity, distance and time scale of the ejection of a narrow shell a few decades years before the SN. This is consistent with the predicted eruptions of a pulsation pair instability SN with a progenitor mass of about 110 $M_\odot$.

The Circumstellar Media of Superluminous Supernovae

Invited Talk

Satoru Katsuda

Saitama University, Japan

Abstract

There is now substantial evidence that progenitors of some supernovae (SNe) undergo enhanced or extreme mass loss prior to explosion. Mass-loss influences the stellar environments, forming the circumstellar medium (CSM) around the progenitor star. The CSM will be excited by the collision with the SN ejecta, and emits intense radiation in various wavelengths, allowing us to reveal the mass-loss history of the progenitor. In this talk, I will present recent studies of supernova remnants (SNRs) that are interacting with the CSM. Specifically, I will focus on very young extragalactic SNRs originating from Type IIn SNe, evolved Galactic SNRs exhibiting recombining plasmas, and relatively young Type Ia SNRs interacting with the CSM.

Dense Circumstellar Knots in the Cassiopeia A Supernova Remnant

Oral Talk

Bon-Chul Koo[1], Hyun-Leong Kim[1], Yong-Hyun Lee[1], John C. Raymond[2], Heeyoung Oh[3], Jae-Joon Lee[3]

[1]Seoul National University, South Korea
[2]Harvard-Smithsonian Center for Astrophysics, USA
[3]KASI, South Korea

Abstract

The young supernova remnant Cassiopeia A is currently expanding into circumstellar medium (CSM). From the early optical studies, dense, slowly-moving, N-rich "quasi-stationary flocculi" (QSFs) have been known. These are probably dense CNO-processed circumstellar knots that have been swept-up by the supernova (SN) blast wave. The QSF knots as such have clues about the mass loss history of the progenitor system immediately prior to the explosion. Recently, we have obtained a long-exposure (10 hr), narrow-band image centered at 1.644 μm. The passband contains [Fe II] 1.644 microns and [Si I] 1.645 microns lines, and our "deep [Fe II]+[Si I] image" provides an unprecedented panoramic view of Cas A, showing both shocked and unshocked SN ejecta, together with shocked circumstellar medium at subarcsecond ($\sim$0.7" or 0.012 pc) resolution. The structure of the optically invisible western area is clearly seen for the first time. From an analysis of the image, we have identified 130 QSFs, 68% of which are newly identified. The comparison with previous optical plates indicates that the lifetime of most QSFs is $\geq$ 60 yr. In this talk, we will present the results from the analysis of the deep [Fe II]+[Si I] image together with the preliminary results of our follow-up high-resolution (R$\sim$40,000) NIR spectroscopic observations of QSF knots.

The Circumstellar Media of Superluminous Supernovae

Oral Talk

Josefin Larsson

KTH Royal Institute of Technology, Sweden

Abstract

The evolution of the nearby SN 1987A has been monitored with the Hubble Space Telescope (HST) for more than 25 years. These observations allow us to resolve the asymmetric ejecta and follow the evolution to the remnant phase as the ejecta interact with the circumstellar ring. In this talk I will discuss the late-time evolution of the ring and ejecta in SN 1987A, as probed by recent HST observations. The ring is currently being destroyed by the shocks and it has been fading for the last $\sim$10 years. This has been accompanied by new "hot-spot" and a rim of diffuse emission appearing outside the ring, showing that the blast wave is now propagating beyond the ring. The new emission is gradually revealing the mass-loss history of the progenitor star. Finally, the brightening of the inner ejecta has levelled off, responding to changes in the X-ray flux from the ring. As all the optical emission is fading, the remnant is moving towards a more X-ray dominated phase.

Changing Look Supernovae

Invited Talk

Raffaella Margutti

Northwestern University/CIERA, USA

Abstract

I will briefly review the effects of strong interaction of the SN shock with a thick medium on the SN appearance and I will discuss the implications of the presence of a thick medium in the immediate vicinity of SNe from the point of view of massive stellar evolution.

The optically inferred circumstellar environment of Cas A

Oral Talk

Kathryn E. Weil[1], Robert A. Fesen[1], Daniel J.Patnaude[2], John C. Raymond[2], Dan Milisavljevic[3], Christopher L. Gerardy[4]

[1]Dartmouth College, USA
[2]Harvard-Smithsonian Center for Astrophysics, USA
[3]Purdue University, USA
[4]University of North Carolina, USA

Abstract

Cassiopeia A is one of the best studied young Galactic supernova remnants, yet questions remain about its progenitor. We present an optical study of the circumstellar environment around Cas A to investigate the pre-supernova mass-loss history of the progenitor star. We find clumpy, filamentary Hα emission concentrated some 10' to the north, first described by Minkowski. This emission is distinctly different from surrounding diffuse nebular emission. Spectra of this filamentary emission show unusually strong [N II] 6548 & 6584 Å and [S II] 6717 & 6731 Å relative to Hα compared to H II regions. We interpret this clumpy emission to be the progenitor's red-supergiant mass-loss that accumulated against a large extended H II region located north and northwest of the remnant. Combining these results with prior X-ray observations, we suggest that Cas A's progenitor was an O or B star with mass-loss from a fast main-sequence wind, a slower clumpy red-supergiant wind, followed by a brief Wolf-Rayet wind just prior to explosion.

Session 10.

SNe and SNRs with circumstellar interactions – Posters

What is the role of wind mass transfer in the progenitor evolution of Type Ia Supernovae?

Poster

C. Abate

Alexander von Humboldt Foundation IPMU, Italy

Abstract

It is believed that Type Ia supernovae (SNe Ia) are thermonuclear explosions of carbon-oxygen white dwarfs (WDs) that accrete mass from a binary companion, which can be either an other carbon-oxygen WD that merges with the first one (double-degenerate scenario) or a non-degenerate star such as a main sequence star or a giant that transfers part of its mass to the WD (single-degenerate scenario). Both scenarios have severe problems in explaining the observed properties of SNe Ia. One of these problems is that population-synthesis models typically predict rates of SNe Ia explosions several times lower than the observations. In these models, the contribution of asymptotic giant branch (AGB) stars is marginal, for two reasons. First, because Roche-lobe overflow from AGB donor stars is mostly unstable, AGB stars do not efficiently transfer mass on to WDs in the single-degenerate channel. Second, in the double-degenerate scenario only an AGB star in a narrow range of separations can form a WD in such a close-enough orbit that the two WDs merge within a Hubble time. Consequently, binary systems with an AGB companion of a carbon-oxygen WD are considered unlikely progenitors of SNe Ia. However, most population-synthesis models assume spherically-symmetric winds and low wind accretion efficiencies, as predicted by the canonical Bondi-Hoyle-Lyttleton model. In contrast, recent hydrodynamical simulations of binary systems with AGB donors show that AGB winds can be very efficiently accreted by the companions, and that the expelled material can carry a significant amount of angular momentum, in some cases shrinking the orbit significantly.In my presentation I will show the results of a population-synthesis study which investigates the impact of these two effects, namely the high wind-accretion efficiencies and the strong angular-momentum losses, on the SNe Ia rate, and I will discuss the role of AGB stars as progenitors of SNe Ia.

The Circumstellar and Interstellar Environment of VRO 42.05.01. A Peculiar Mixed Morphology SNR

Poster

M. Arias

Anton Pannekoek Institute, Netherlands

Abstract

The most noticeable thing about mixed-morphology supernova remnant (MM SNR) VRO 42.05.01 is its shape, with a round shell of emission and a broad triangular wing that intersect in a sharp line. This puzzling shape has been attributed to the presence of an ambient medium with two densities: a dense medium in which the explosion occurred, and a cavity into which the larger wing broke out. In the X-rays, the remnant has a centre-filled morphology, and, like some other MM SNRs, it shows gamma-ray emission. We do not have a clear scenario for the formation of MM SNRs, but, since they are typically located in dense environments, it stands to reason that a dense environment could trigger an early reverse shock, and the reverse shock could heat the ejecta while they are still concentrated in the centre of the remnant. We recently carried out a LOw Frequency ARray (LOFAR) study of VRO 42.05.01 at 150 MHz, in which we discovered that the sources flat spectrum (typical of MM SNRs) steepened at low radio frequencies, and that the steepening happened preferentially in the brighter regions of the remnant. We suggested that the steepening might be due to the radiative shocks having high compression ratios. Since electrons of different energies probe different length scales across the shocks, they sample regions of different compression ratios, which results in a curved spectrum that

steepens at low frequencies. High compression ratio shocks would be yet another indicative of a high post-shock density. We observed the CO environment of VRO 42.05.01 with the IRAM 30m telescope, and instead found that VRO 42.05.01 is in a surprisingly diffuse environment. There is little molecular gas, it is inhomogeneously distributed, and the $^{12}CO\ J = 2-1$ to $^{12}CO\ J = 1-0$ ratios and line widths suggest that the molecular clouds have not been shock-heated. These observations defy all the proposed scenarios that could conceivably explain VRO 42.05.01s unlikely shape. More profoundly, they challenge the idea that a mixed morphology requires a dense environment. What we did find in our observations is that one of the molecular clouds has been swept by what is likely the wind of VRO 42.05.01's progenitor star. From the wind's radius and velocity we find wind parameters that are consistent with a progenitor mass of 15-20 $M_\odot$. We find that the shock has not yet reached the edge of the wind bubble, and so expect the post-shock density to be rather low. We propose that the early triggering of the reverse shock could have been due to mass-loss episodes in the progenitors pre-supernova stage, giving rise to a patchy environment with large density gradients. Perhaps it is the circumstellar environment of the source, rather than its ISM, that is responsible for VRO 42.05.01's morphology.

Optical study of the peculiar supernova remnant VRO 42.05.01 (G 166+4.3)

Poster

P. Boumis

IAASARS, National Observatory of Athens, Greece

Abstract

We present optical images of the VRO 42.05.01 (G 166.0+4.3) supernova remnant in Hα+[N II], [O III] 5007 and [S II] at a moderate angular resolution. Low and high-dispersion spectroscopy and high-resolution imaging were also performed at selected areas around this extended remnant. Diagnostic diagrams of the line intensities from the present spectra and the new kinematical observations both confirm the supernova origin. Taking into account our results (i.e. shock velocities, morphological characteristics etc.) together with observations at other wavelengths (i.e. radio) and modeling, we provide new significant information on (a) it's formation and (b) the interaction between this SNR and the surrounding Interstellar medium (ISM).

VRO 42.05.01: A supernova remnant resulting by a supersonically moving Wolf Rayet progenitor star

Poster

A. Chiotellis

IAASARS, National Observatory of Athens, Greece

Abstract

VRO 42.05.01 is Galactic supernova remnant (SNR), which reveals an intriguing morphology consisted of two major components: a $\sim$ 30' diameter semicircle shell at NE (a.k.a. 'the shell') and a much larger bow shaped (almost triangular) shell at the SW (a.k.a. 'the wing'). The SN ejecta and ambient medium properties that formed VRO 42.05.01 current morphology is a subject of speculation for several decades and up to date remains unknown. In this work we present a model of VRO 42.05.01 according to it the SNR resulted by a supersonically moving Wolf Rayet progenitor star. The strong stellar wind of the Wolf Rayet progenitor was asymmetric enhanced at the equatorial plane of star. The systemic motion of the Wolf Rayet star in combination with its asymmetric outflows excavated an extended wind cavity that revealed similar morphological characteristics with these of VRO. Subsequently, the interaction of the SN ejecta with the surrounding wind bubble resulted to the current morphology of VRO. We present two-dimensional hydrodynamical simulations of both the wind bubble formation and the SNR evolution. The results of our hydrodynamic modeling are in very good agreement with the VRO properties being able to reproduce in sufficient detail its overall morphology and kinematics.

SNR VRO 42.05.01 (G 166.0 +4.3) 3-D morpho-kinematical model

Poster

S. Derlopa[1,2], P. Boumis[1], A. Chiotellis[1], W. Steffen[3], S. Akras[4]

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[4]Instituto de Matemática, Estatística e Física, Universidade Federal do Rio Grande, Rio Grande 96203-900, Brazil

Abstract

We present the first 3-dimensional (3-D) morpho-kinematical model of a supernova remnant (SNR), using as a study case the Galactic SNR VRO 42.05.01 (G 166.0 +4.3). Its 3-D representation provides us with the information in the third dimension, which is completely absent in the 2-D imaging data. This will significantly contribute to our understanding of its evolutionary history which still remains unknown. For the purpose of our model, the astronomical code "SHAPE" was employed in which low and high resolution imaging and spectroscopic data were utilized. We assume that the VRO's current morphology was shaped by the interaction of the remnant with a bow-shaped wind bubble. In the framework of this model, the SNR comprises by three basic components: a hemisphere in the NE region ("shell"), an elongated structure from SE to NW ("wing") and a smaller hemisphere in the SW area ("hat"). We found that in our model: a) The synthetic Position Velocity (PV) diagrams created with "SHAPE" and correspond to the produced 3-D structure of the remnant, are in very good agreement with the observational PVs deduced from the spectroscopic analysis. b) The systemic velocity of the remnant is within the range of -15 km s^{-1} to -25 km s^{-1}. c) The "wing" component of the SNR has lower expansion velocities than the "shell" and "hat" counterparts.

Revealing inhomogeneities in supernovae shocks and their environments via low frequency radio observations

Poster

P. Chandra

National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, India

Abstract

Low frequency radio observations are crucial in revealing the inhomogeneities in the radio emitting supernovae shocks, as well as in the medium surrounding them. In this talk, we present radio observations of a stripped-envelope Type Ib supernova Master OT J120451.50+265946.6 (SN J1204) taken with the Giant Metrewave Radio Telescope (GMRT) as well as the Very Large Array (VLA). Our low frequency GMRT data taken when the SN was in the optically thick phase, interpreted along with the VLA data and non-detection in X-ray bands, reveal inhomogeneities in the structure of the radio emitting region. We suggest a model in which the inhomogeneities of the magnetic field distribution give rise to optical depths of different opacities, and superposition of those lead to a flatter spectral index in the optically thick region, seen in SN J1204. Our model predicts that the inhomogeneities should smooth out at late times, which will be tested via ongoing 325 MHz GMRT observations. In addition, our observations also indicate that the shock is crossing through a dense shell starting around 50 days after the explosion, for around a month in duration. This reveals a non-smooth mass-loss history of the progenitor star. I will discuss the implication of our findings and discuss this in context of other radio bright stripped-enveloped supernovae.

A recurrent nova super-remnant in the Andromeda galaxy

Poster

É. J. Harvey

LJMU, United Kingdom

Abstract

The accretion of hydrogen onto a white dwarf star ignites a classical nova eruption - a thermonuclear runaway in the accumulated envelope of gas, leading to luminosities up to a million times that of the Sun and a high-velocity mass ejection that produces a remnant shell (mainly consisting of insterstellar medium). Close to the upper mass limit of a white dwarf (1.4 $M_\odot$), rapid accretion of hydrogen (about 10^{-7} $M_\odot$ yr^{-1}) from a stellar companion leads to frequent eruptions on timescales of years to decades. Such binary systems are known as recurrent novae. The ejecta of recurrent novae, initially moving at velocities of up to 10,000 kilometres per second, must 'sweep up' the surrounding interstellar medium, creating cavities in space around the nova binary. No remnant larger than one parsec across from any single classical or recurrent nova eruption is known, but thousands of successive recurrent nova eruptions should be capable of generating shells hundreds of parsecs across. Here we report that the most frequently recurring nova, M31N 2008-12a in the Andromeda galaxy (Messier 31 or NGC 224), which erupts annually, is indeed surrounded by such a super-remnant with a projected size of at least 134 by 90 parsecs. Larger than almost all known remnants of even supernova explosions, the existence of this shell demonstrates that the nova M31N 2008-12a has erupted with high frequency for millions of years.

Time-dependent hydrodynamic model of X-ray emitting plasma in evolved SNRs for high resolution X-ray spectroscopy

Poster

M. Katsuragawa

Kavli IPMU/The University of Tokyo, Japan

Abstract

We have developed a new simulation framework to generate X-ray spectral models of SNRs with arbitrary ages including evolved remnants that have interacted with dense ISM that surrounds them. Our model treats dynamical evolution of the expanding remnants and their plasma conditions, which has never been considered by spectral models conventionally used in X-ray observations, and clearly illustrates that recombination-dominant plasma (not in ionization equilibrium) can be naturally formed in an old SNR as suggested by X-ray observations. Recent observations have found that the recombining plasmas coincide with associations of the SNRs with molecular or atomic clouds. This suggests that the evolution of SNRs are considered to be deeply related to the environment of the ambient gas. Our model calculates the time evolution of ionization states of major elements and temperatures of electrons and ions in SNRs from 20 yr to a few 10^4 yr based on a one-dimensional Lagrangian hydrodynamic simulation. We include physical processes of shock heating, energy exchange by Coulomb interaction, radiative cooling, and evolution of ionization states. The spectrum consists of bremsstrahlung and emissions by atomic transitions of the major elements calculated from atomic properties provided by AtomDB. Our models can be applied to analyze XRISM and Athena data with high energy and position resolutions. We characterize X-ray spectra by the electron temperature and ionization temperature, which is an indicator of describing the ionization state represented in temperature. We apply our model with the ISM densities nISM = 1, 3, 10, and 30 cm^{-3} to several Suzaku observations of evolved SNRs that have recombination-dominant plasma, including IC 443 and W44. As a result of comparing these temperatures of our model with the observations, we successfully demonstrate that the time evolution of ionization and recombination are in excellent agreement with the observed values. The recombination-dominant plasma can be explained by the combination of simple processes: hydrodynamic processes including the shock heating and adiabatic cooling, energy exchanges between ions and electrons via Coulomb interactions, and collisional ionizations and recombinations of ions. We obtain slightly higher electron temperatures by the calculation than the observations, implying an additional cooling mechanism, which is also discussed in this talk.

Near-infrared imaging and spectroscopic observations of supernova remnants in M33

Poster

H.-G. Lee

Korea Astronomy and Space Science Institute, Republic of Korea

Abstract

We present near-infrared imaging and spectroscopic observations of supernova remnants (SNRs) in M33. We detect bright [Fe II] and H2 line-emitting SNRs from UKIRT [Fe II] 1.64 and H2 2.12 μm narrow-band images of M33. The H2-emitting SNRs are also detected in [Fe II] images, while their spatial distributions are different. For these SNRs, we perform follow-up spectroscopic observations using GNIRS on Gemini. The detection of H2 emission suggests that the SNRs are interacting with surrounding molecular clouds and significantly impact their environments. Additional observations including high-resolution integral field unit spectroscopy and ALMA molecular line observations will be interesting to reveal the detailed conditions of the SNRs and their environments.

Investigation of the Interstellar Environment of SNR CTB 87

Poster

Q.-C. Liu

Nanjing University, China

Abstract

We present a new millimeter CO-line observation toward supernova remnant (SNR) CTB 87, which was regarded purely as a pulsar wind nebula (PWN), and an optical investigation of a coincident surrounding superbubble. The CO observation shows that the SNR delineated by the radio emission is projectively covered by a molecular cloud (MC) complex at $V_{LSR} = -60$ to -54 km s^{-1}. Both the symmetric axis of the radio emission and the trailing X-ray PWN appear projectively to be along a gap between two molecular gas patches at -58 to -57 km s^{-1}. Asymmetric broad profiles of ^{12}CO lines peaked at -58 km s^{-1} are found at the eastern and southwestern edges of the radio emission. This represents a kinematic signature consistent with an SNR - MC interaction. We also find that a superbubble, $\sim 37'$ in radius, appears to surround the SNR from H I 21 cm ($V_{LSR} \sim -61$ to -68 km s^{-1}), WISE mid-IR, and optical extinction data. We build a multi-band photometric stellar sample of stars within the superbubble region and find 82 OB star candidates. The likely peak distance in the stars' distribution seems consistent with the distance previously suggested for CTB 87. We suggest the arc-like radio emission is mainly a relic of the part of the blast wave that propagates into the MC complex and is now in a radiative stage while the other part of the blast wave has been expanding into the low-density region in the superbubble. This scenario naturally explains the lack of X-ray emission related to the ejecta and blast wave. The SNR - MC interaction alsofavors a hadronic contribution to the γ-ray emission from the CTB 87 region.

Suzaku X-ray Observations of Galactic Supernova Remnants to Understand the Formation Process of Recombining Plasmas

Poster

H. Matsumura

Kavli IPMU/ The University of Tokyo, Japan

Abstract

In a supernova remnant (SNR), a plasma reaches a collisional ionization equilibrium (CIE) after about 10^5 yr. Since most of SNRs have an age of less than a few 10^4 yr, SNR plasmas are naturally expected to have an ionization degree below the equilibrium and to be in an ionization-dominant state. Recent observations with the Suzaku satellite, however, revealed peculiar plasmas in some SNRs, which are in a recombination-dominant state, and thus called recombining plasmas (RPs). Such plasmas are not anticipated in the standard picture of the SNR plasma evolution described above. Although some scenarios are proposed to explain the RPs, the formation process of the RP is not fully understood yet. In any scenario, a key seems to be interactions between the SNR and ambient dense gas. To understand the formation process of RPs, we perform spatially resolved spectroscopic analyses of X-ray emissions from the Galactic SNRs, G166.0+4.3, IC 443, W44, and W49B with Suzaku. We compare spatial variations of physical parameters of the RPs with distributions of the ambient gas. In all the remnants, the spectral analyses reveal good correlations between locations of plasmas with lower electron temperatures and those of surrounding dense molecular clouds. The lower electron temperatures of the RPs can be explained well by the thermal conduction between an SNR plasma and a molecular cloud.

Millimeter Emission from Supernovae in the Very Early Phase: Implications for Dynamical Mass Loss of Massive Stars

Poster

T. Matsuoka

Department of Astronomy, Kyoto University, Japan

Abstract

Recent high-cadence transient surveys and rapid follow-up observations have revealed that some massive stars dynamically lose their own mass within decades before supernovae (SNe). Such a mass-loss forms confined circumstellar medium (CSM); a high density material distribution only in small radius ($\lesssim 10^{15}$ cm with the mass-loss rate of $0.01 \sim 10^{-4}$ $M_{\odot}\mathrm{yr}^{-1}$). While the SN shock triggers particle acceleration and magnetic field amplification in the confined CSM, synchrotron emission may be masked in centimeter wavelengths due to the free-free absorption; the millimeter range can however be a potential new window. We investigate the time evolution of synchrotron radiation from the system of red supergiant surrounded by the confined CSM, relevant to typical type II-P SNe. We have revealed that synchrotron millimeter emission is generally detectable, and the signal can be used as a sensitive tracer of the nature of the confined CSM; it traces different CSM density parameter space than in the optical. Furthermore, our simulations show that the confined CSM efficiently produces secondary electrons and positrons through proton inelastic collisions, which can become main contributors to the synchrotron emission in several ten days since the SN. We predict that the signal is detectable by ALMA, and suggest that it will provide a robust evidence of the existence of the confined CSM.

Upper Limits on Very-High-Energy Gamma-ray Emission from Supernovae Observed with H.E.S.S.

Poster

N. Maxted

UNSW Canberra, Australia

Abstract

Supernova remnants (SNRs) have been proven to be able to accelerate cosmic rays (CR) up to $\sim$ 1014 eV. There is however no observational evidence so far that they can accelerate particles up to the "knee" of the CR spectrum at 1015 eV (= 1 PeV). Some recent theoretical studies of supernovae (SNe) indicate that particles with PeV energies and beyond shall be produced as the SN shock propagates in a very dense environment and this may result in measurable gamma-ray emission.We searched for gamma-ray emission from ten supernovae observed with the High Energy Stereoscopic System (H.E.S.S.) within a year of the supernova event. Nine type II supernovae were observed serendipitously in the H.E.S.S. data collected between December 2003 and December 2014. In addition we observed SN 2016adj as a target of opportunity in February 2016 for 13 hours. No significant gamma-ray emission was detected for any of the objects, and upper limits on the > 1 TeV gamma-ray flux of the order of $\sim 10^{-13}$ $cm^{-2}s^{-1}$ are derived. These values are used to place model-dependent constraints on the mass-loss rates of the progenitor stars, implying upper limits between 2 x 10^{-5} and 2 x 10^{-3} $M_{\odot}\mathrm{yr}^{-1}$ under reasonable assumptions on the particle acceleration parameters.

Fe K-α emission from the southwestern limb of SN 1006

Poster

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Abstract

The bilateral supernova remnant SN 1006 shows X-ray (and radio) synchrotron emission associated with ultrarelativistic electrons accelerated at its northeastern and southwestern limbs, which also emit in the GeV and TeV gamma-ray bands. The southwestern limb is interacting with an atomic cloud which is almost 2 orders of magnitude denser than the ambient medium in its central part. We here present the analysis of a deep NuSTAR observation of the southwestern limb of SN 1006 which suggests the presence of Fe K-α emission from the unshocked cloud, likely associated with the diffusion of cosmic rays accelerated at the remnant shock front and propagating in the cloud core. We obtain estimates of the energy content of the cosmic-rays and discuss them in the framework of multi-wavelength observations and hydrodynamic models of this region.

Radio Predictions of Core-Collapse Supernovae

Poster

O. Mogawana

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Abstract

We present theoretical predictions of radio supernovae (RSNe) in preparation for the upcoming next-generation facilities, e.g., MeerKAT and SKA which due to their ultra-sensitivity and high spatial resolution will further probe these transient events. Using the cutting edge massively parallel, multi-method multi-physics magneto-hydrodynamics and gravity code (GIZMO), we simulate the interaction of the blast wave with the circumstellar medium (CSM) and examine the behaviour of hydrodynamic characteristics (i.e. density, expansion velocity) in the interaction region under various geometrical configurations and various initial densities of the CSM. We discuss the existing efforts and our approach to investigating the source of variability from a handful of well studied, bright RSNe. With the advent of SKA capabilities, this work will open up a systematic study of a larger population of RSNe.

The Latest Evolution in the X-ray Remnant of SN 1987A

Poster

A. P. Ravi

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Abstract

Based on our continuing Chandra observations, we present the latest evolution of the X-ray remnant of SN 1987A. We present updated X-ray light curves and the radial expansion rate of the remnant as of 2018 September. The soft-band (0.5 - 2 keV) X-ray flux remained constant from 2012 (day $\sim$ 9500 since the explosion) till $\sim$ 2017 (day $\sim$ 11000), but showed signs of decrease (by $\sim$ 15%) in September 2018 (at day $\sim$ 11500). The hard band X-ray flux continues to increase monotonically. While the X-ray remnant has been expanding at a similar rate (v $\sim$ 1600 km/s) to that reported by Frank et al. (2016) for the last several years, we find indications for an increase in the expansion rate from the data taken in 2018. Continued Chandra observations will be essential to verify (or dispute) these intriguing developments in the light curves and expansion rate of1987A. Based on our new deep (340 ks) Chandra HETG observation(taken in March 2018), we report on some initial results from our high resolution dispersed spectroscopic study of 1987A. Our preliminary analysis shows that the Kα to Ly α line flux ratios for several ions have decreased considerably(e.g., by $\sim$ 40% for Si and Mg lines) between 2011 and 2018. Our initial results from the spectral model fits to the broadband dispersed spectrum of SN 1987A indicate significant changes in the thermal condition of its X-ray emitting hot gas. We briefly discuss physical implications of these results in terms of 1987A's evolution in the past seven years.

A study of Kepler supernova remnant: angular power spectrum estimation from radio frequency data

Poster

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Abstract

Supernova remnants (SNRs) have a variety of overall morphology as well as rich structures over a wide range of scales. Quantitative study of these structures can potentially reveal fluctuations of density and magnetic field originating from the interaction with ambient medium and turbulence in the expanding ejecta. We have used 1.5 and 5 GHz VLA data to estimate the angular power spectrum C_ℓ of the synchrotron emission fluctuations of the Kepler SNR. This is done using the novel, visibility based, Tapered Gridded Estimator of C_ℓ. We have found that, for $\ell = (1.9 - 6.9) \times 10^4$, the power spectrum is a broken power law with a break at $\ell = 3.3 \times 10^4$, and power law index of -2.84 ± 0.07 and -4.39 ± 0.04 before and after the break respectively. The slope -2.84 is consistent with 2D Kolmogorov turbulence and earlier measurements for the Tycho SNR. We interpret the break to be related to the shell thickness of the SNR (0.35 pc) which approximately matches $\ell = 3.3 \times 10^4$ (i.e. 0.48 pc). However, for $\ell > 6.9 \times 10^4$, the estimated C_ℓ of L band is likely to have dominant contribution from the foregrounds while for C band the power law slope -3.07 ± 0.02 is roughly consistent with 3D Kolmogorov turbulence like that observed at large ℓ for Cas A and Crab SNRs.

Unbiased Spectroscopic Study of the Cygnus Loop with LAMOST

Poster

J. Y. Seok

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Abstract

We present a spectroscopic study of the Galactic supernova remnant (SNR) Cygnus Loop using the fifth Data Release (DR6) of LAMOST. The LAMOST (Large Sky Area Multi-Object Fiber Spectroscopic Telescope) features both a large field-of-view (about 20 deg^2) and a large aperture ($\sim$4 m in diameter), which allow us to obtain 4000 spectra simultaneously.Its wavelength coverage ranges from $\sim$ 3700 Å to 9000 Å with a spectral resolution of $R \approx 1800$.The Cygnus Loop is a prototype of middle-aged SNRs, which has advantages of being bright, large in angular size ($\sim 3.8\,\mathrm{deg} \times 3\,\mathrm{deg}$), and relatively unobscured by dust. Along the line of sight to the Cygnus Loop, 2747 LAMOST DR5 spectra are found in total, which are spatially distributed over the entire remnant. Among them, 778 spectra are selected based on the presence of emission lines (i.e., [O III] λ5007, Hα, and [S II] $\lambda\lambda$6717, 6731) for further visual inspection. About half of them (368 spectra) show clear spectral features to confirm their association with the remnant, 234 spectra show stellar features only, and 176 spectra are ambiguous and need further investigation. For those associated with the remnant, we identify emission lines and measure their intensities. Spectral properties considerably vary inside the remnant, and we compare them with theoretical models to derive physical properties of the SNR such as electron density, temperature, and shock velocity. While some line ratios are in good agreement with model prediction, others cannot be explained by simple shock models with a range of shock velocities but are consistent with our model calculations taking incompleteness of shock into account. Finally, we highlight the powerfulness of the LAMOST data to investigate spatial variations of physical properties of the Cygnus Loop.

Time evolution of broadband non-thermal emission from supernova remnants in different circumstellar environments

Poster

H. Yasuda

Kyoto University, Japan

Abstract

Supernova remnants (SNRs) are thought to be one of the major acceleration sites of galactic cosmic rays (CRs) and an important class of objects for high-energy astrophysics. SNRs produce multi-wavelength, non- thermal emission via accelerated particles at collisionless shocks generated by the interactions between the SN ejecta and the circumstellar medium (CSM). Although it is expected that the rich diversities observed in supernovae (SNe) and their CSM can result in distinct very-high-energy (VHE) electromagnetic signals in the SNR phase, there are only a handful of SNRs observed in both GeV and TeV γ-rays so far. A systematic understanding of particle acceleration at SNRs in different ambient environments is therefore limited. Here, we explore non-thermal emission from SNRs in various circumstellar environments up to 5000 yrs from explosion using hydrodynamical simulations coupled with efficient particle acceleration. We find that time-evolution of emission characteristics in the VHE regime is mainly dictated by two factors; the number density of the target particles and the amplified magnetic field in the shocked medium.

Non-equilibrium ionization in mixed-morphology SNRs

Poster

Gao-Yuan Zhang

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Abstract

Mixed morphology supernova remnants (MMSNRs) comprise a substantial fraction of observed remnants but their origin remains puzzling. Recently, a clue to their nature arose from X-ray evidence of recombining plasmas in some MMSNRs. Recent calculations of remnant evolution in a cloudy interstellar medium that included thermal conduction but not non-equilibrium ionization (NEI) showed promise in explaining observed surface brightness distributions but could not determine if recombining plasmas were present. We present numerical hydrodynamical models of MMSNRs in 2D and 3D including explicit calculation of NEI effects done via an efficient eigenvalue method.Both the spatial ionization distribution and temperature-density diagrams from the simulations show recombining plasmas created both by adiabatic expansion and thermal conduction, albeit in different regions. Features created by the adiabatic expansion stand out in the spatial and temperature-density diagrams, but thermal conduction also plays a role.Simulated observations from XRISM, Athena, and Lynx with both spatial and spectral input from various regions will also be presented along with initial results on how well the underlying physics can be uncovered from spectral analyses.

Molecular Gas toward Supernova Remnant Cassiopeia A

Poster

P. Zhou

Anton Pannekoek Institute, Netherlands

Abstract

We performed molecular line observations toward Cas A and its environment with IRAM 30m telescope, aiming to answer the following questions: Is the SNR interacting with MCs? What are the properties of the MCs? The molecular clouds (MCs) along the line of sight of Cas A do not show optically thin, shock-broadened 12CO lines, or high-temperature features from shock heating. Therefore, we suggest that there is no physical evidence to support that the SNR is impacting the molecular gas. All the detected MCs are likely in front of Cas A, as implied by the HCO+ absorption line detected in the same velocity ranges. These MCs result in absorption in the west, south, and center of the SNR, respectively. The 20 K warm gas at VLSR $\sim$ -47 km/s is distributed along a large-scale molecular ridge in the south of Cas A. Part of the gas is projected onto Cas A, providing a foreground H2 mass of $\sim$200(d/3 kpc)^2 $M_\odot$, consistent with the mass of cold dust (15-20 K; 2-4 $M_\odot$) found in front of the SNR. We suggest that the 20 K warm gas is heated by background cosmic rays with an ionization rate $\sim 2\times10^{-16}$ s^{-1}. The cosmic rays and X-ray emission from Cas A are excluded as the heating sources of the clouds.

Special Session

JWST – SNRs / SNe

JWST is on the Horizon: Is Our Community Ready?

Invited Talk

W. Blair[1]

[1]Harvard-Smithsonian Center for Astrophysics, USA

Abstract

The James Webb Space Telescope is a 6.5 meter IR-sensitive telescope planned for launch in early 2021. JWST is often described as the follow-on to Hubble, but with a primary wavelength range of 1 - 28 microns, it is really more relevant to consider JWST as a huge step forward from the 1 meter Spitzer Space Telescope.The launch date seems far away, but the relevant date to be thinking about is January 2020, when the Call for Proposals is expected to be released, with proposals due several months later. It is not too early to be familiarizing yourselves with the capabilities of the suite of instruments that will be available on JWST and start thinking about how to apply this incredible observatory to the scientific interests of our community. And yes, there will be a significant learning curve for the tools you will need to use to plan your proposals, so you should plan ahead. I will provide an overview of the instruments and their capabilities, the planning tools, and describe the proposal process and schedule expected for Cycle 1 observations. I will then present some prototype science ideas as a way of promoting further discussion of the possibilities for SNR science with JWST.

Detection of Supernovae beyond Redshift of 2 with the James Webb Space Telescope

Poster

E. Regos[1], **Jozsef Vinko**[1,2,3]

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[2]Department of Optics and Quantum Electronics, University of Szeged, Hungary
[3]Department of Astronomy, University of Texas at Austin, USA

Abstract

Future time-domain surveys for transient events in the near- and mid-infrared bands will significantly extend our understanding about the physics of the early Universe. We study the implications of a deep (27 mag), long-term (3 years) survey with the James Webb Space Telescope within its Continuous Viewing Zone, aimed at discovering luminous supernovae beyond $z \sim 2$ redshift. We explore the possibilities for detecting Superluminous Supernovae (SLSNe) as well as Type Ia supernovae at such high redshifts and estimate their expected numbers within a relatively small survey area. We show that it is possible to get relatively accurate photometric redshifts for Type Ia SNe by fitting their Spectral Energy Distributions, redshifted into the observed near-IR bands, with SN templates. This can extend the Hubble-diagram of Type Ia SNe beyond redshift 2 up to $z \sim 4$. Such high-z SNe Ia can provide new observational constraints for their progenitor scenario.We use radiation hydrodynamical simulations of the near-infrared signals of Pop III pair-instability supernovae in realistic circumstellar environments with Lyman absorption by the neutral intergalactic medium. We find that our 4 colour JWST survey will detect these events from the first generation of stars. SNe.

Closing Plenary

Supernova remnant research: Where do we stand?

Invited Plenary Talk

Roger Chevalier

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Abstract

I will summarize progress on the meeting topics since SNR I and comment on future prospects.


SUPERNOVA REMNANTS II
AN ODYSSEY IN SPACE AFTER STELLAR DEATH
3-8 June 2019, Chania, Crete, Greece
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