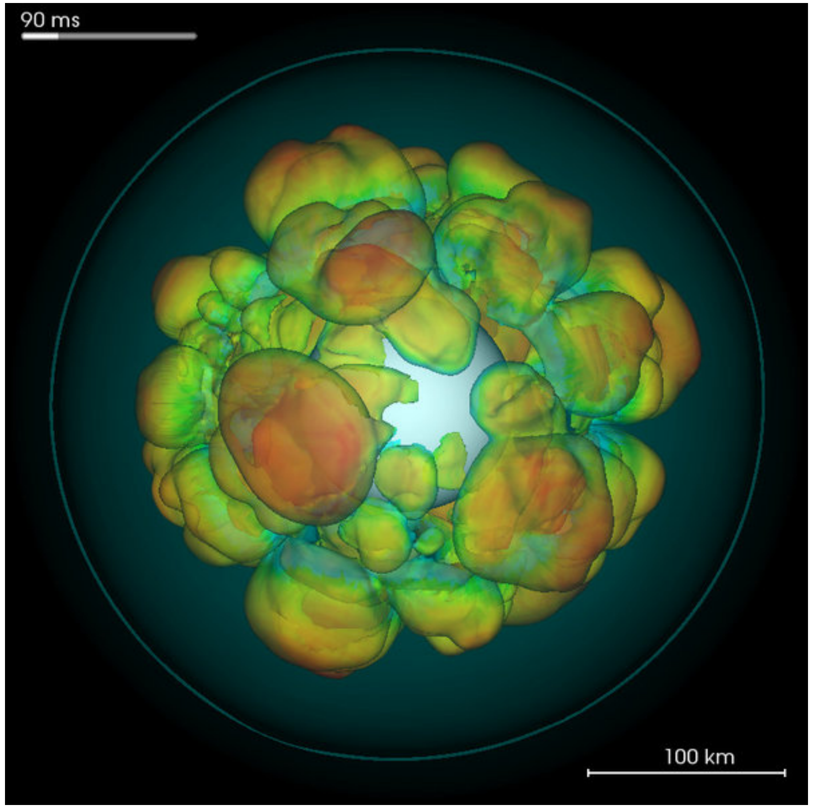
Where do we stand?

Roger Chevalier

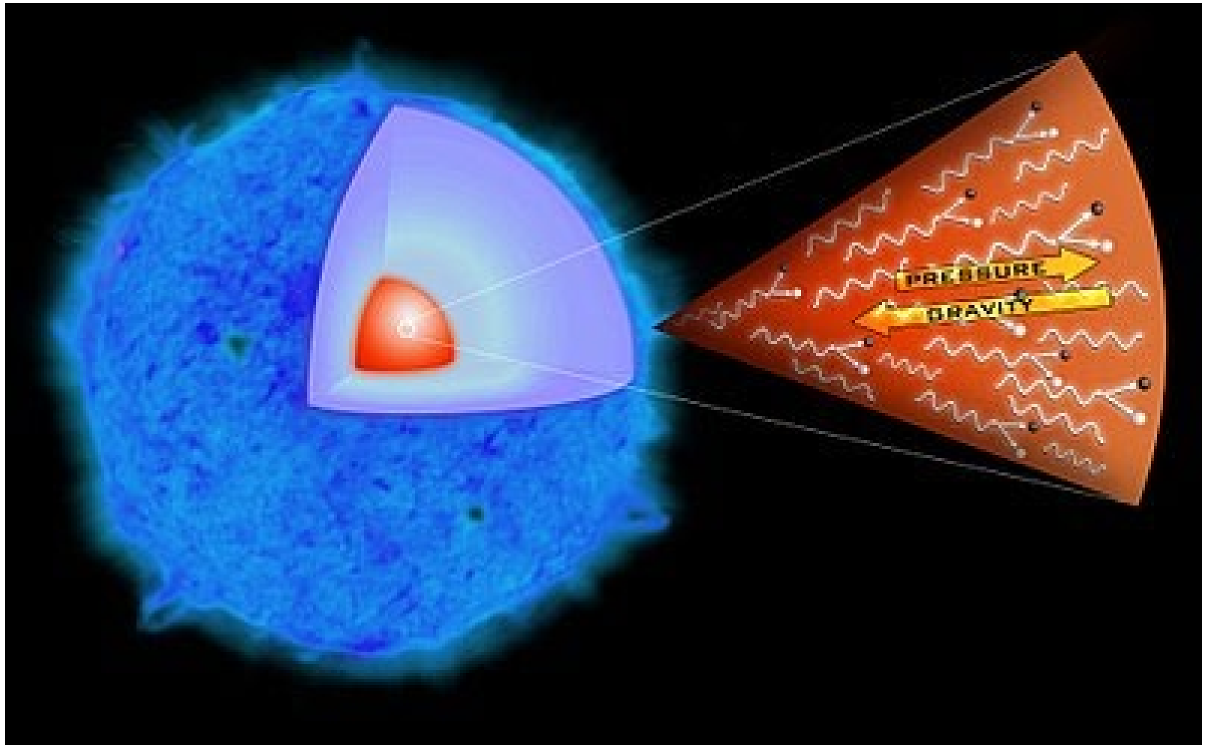
Core collapse

- Growing number of 3-D models that explode (Janka)
  - Need progenitor late burning asymmetry for some explosions, `jets'
  - SN 1987A models better with binary progenitor
  - Promising comparisons to Cas A, 1987A (Wongwathanarat, Alp)
- Approximate models useful for exploring parameter space (Murphy)

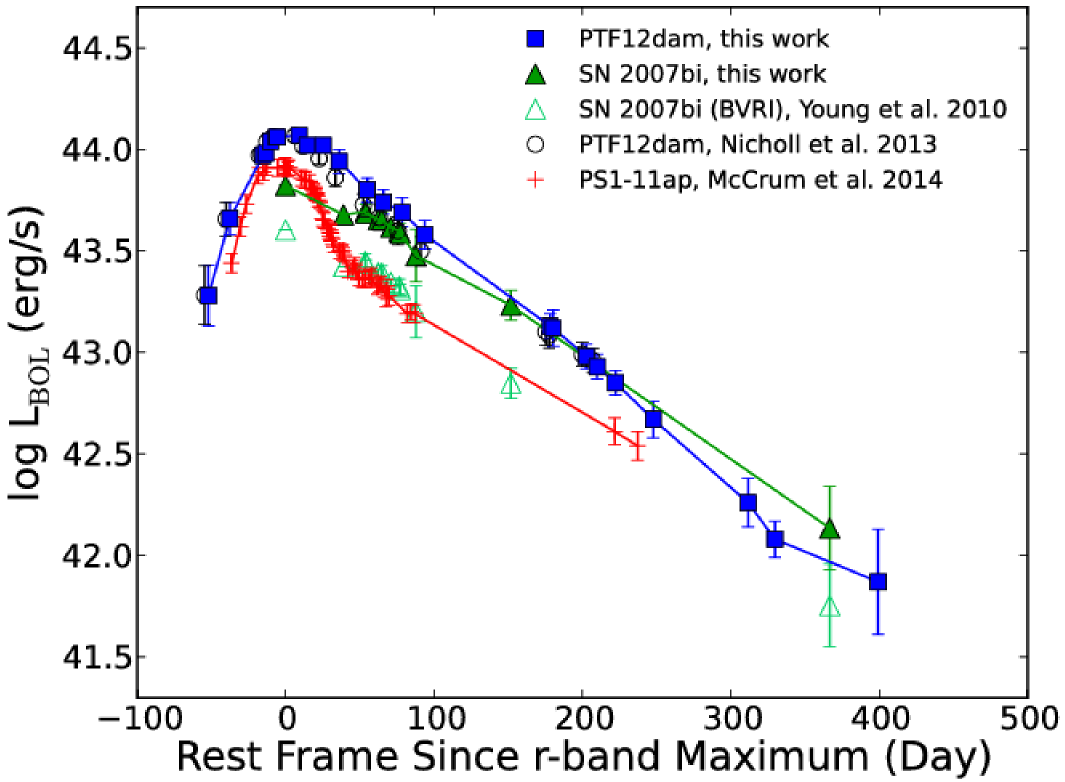


Pair instability

- <100 $M_\odot$: γ-rays do not pair produce; regular SN or BH
- 100 – 130 $M_\odot$: pair produce but do not overcome gravity; pulsations drive mass loss
- 130 – 250 $M_\odot$: pair instability supernova
- >250 $M_\odot$: photodisintegration



- Suggested PISN events have generally not held up, e.g. SN 2007bi (Howell)
- Can lose 10s of $M_\odot$ during the PPI phase (Nomoto)
- Evidence for PPI shell around a superluminous SN (Fransson)

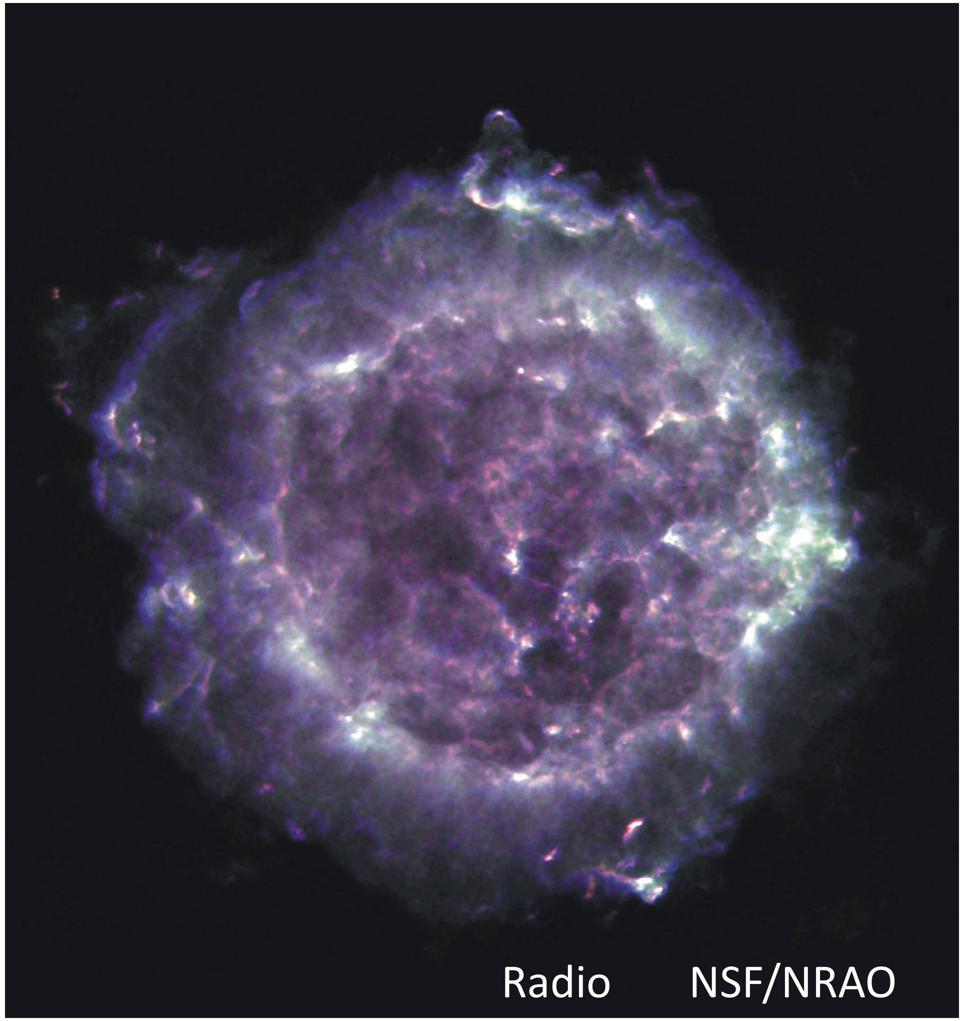


Progenitors of SNe Ia

- SD – single degenerate   vs   DD – double degenerate
- More than one mechanism likely
- For the majority of events (normal), DD now favored (Ruiter)
  - Delay time distribution
  - Peak luminosity distribution
  - Robust explosions
  - Merger rates about right
- Also
  - Limits on late H emission (Holoien, ASAS-SN)
  - SN 2018oh (Kepler field), early deviations from power law (W. Li, Holoien)

Cassiopeia (Cas) A

- Low power neutron star
- Type IIb supernova (Rest, Krause)
- Running into $\rho \sim r^{-2}$ circumstellar matter
- Molecular clouds along line of sight, not interacting (P. Zhou)



Cas A – surprising result

- Reverse shock
  - Optical, often stationary where present (Fesen)
  - X-ray, moving back in W region (Vink)
- Do not see effect on forward shock -> not running into something
- May be moving into low density ejecta regions

Young SNRs: thermonuclear or core collapse SN

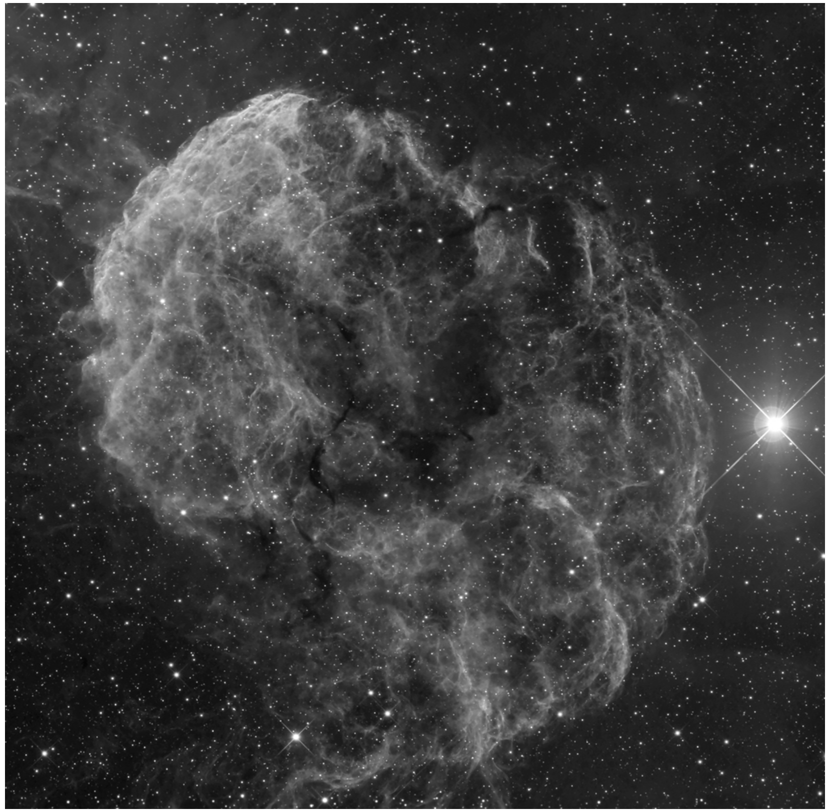
- Compact object -> CC
- Low density ISM, Balmer filaments, generally TN
- High Fe / O from X-ray spectra   -> TN
- More asymmetric -> CC (Lopez)
- Light echoes

- Not always agreement, e.g. W49B (Zhou+)

IC 443 – middle aged remnant

- Main optical shell - v_{sh} ~ 100 km/s, n~10 cm $^{-3}$
- Hydrodynamics (Ustamujic+)
- Highly ionized ions (Si IV,..) seen in absorption in star to the NE (Ritchey+)
  - Broad, blueshifted –620 km/s
  - Shock would give T~ 10^7 K, which is seen in X-ray emitting gas

Churchill



Hα

Cygnus Loop

- Standard view – SNR in a pre-existing bubble
- Now, multiwavelength study shows expansion in low density ISM with IS clouds (Weil+)
- Astrosat study of ultraviolet (Sutaria)

Interstellar medium

- Multiphase, in pressure equilibrium
- Turbulent structure
- Molecular clouds – turbulent structure
- Fractal structure (Kostic)

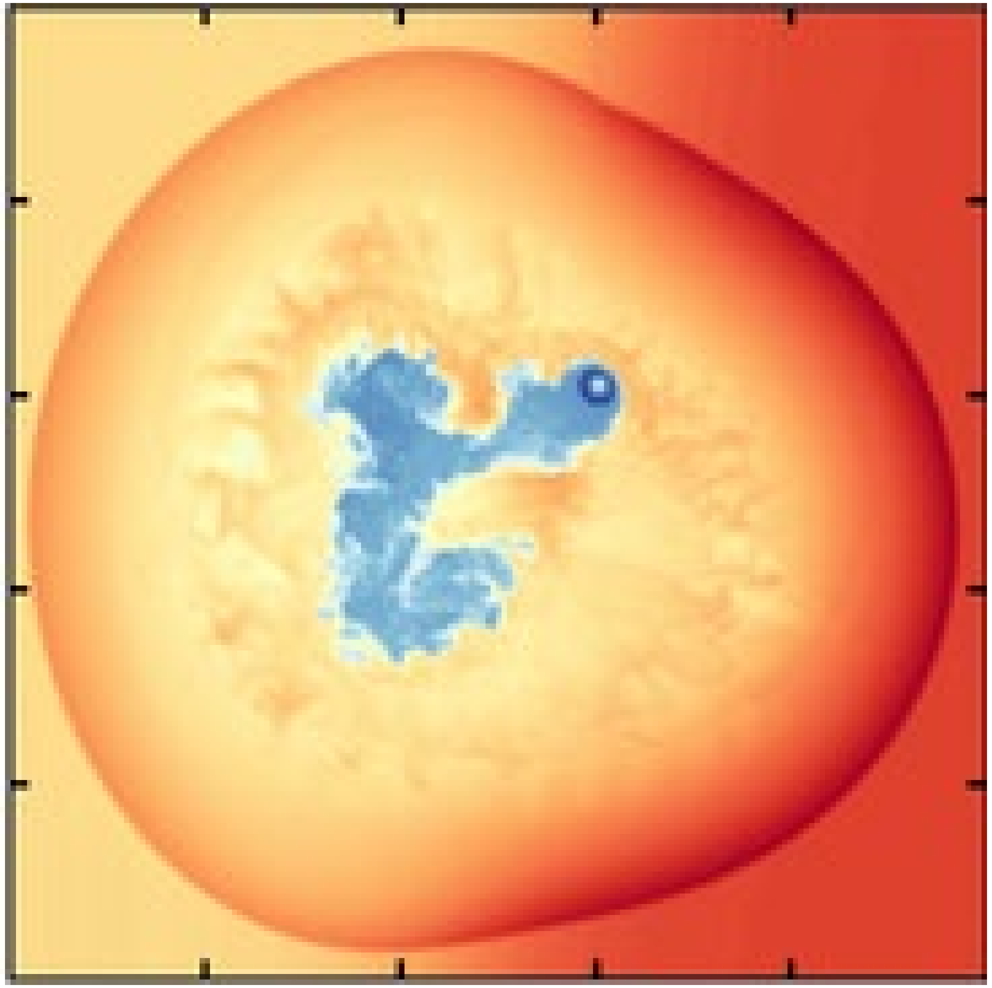
    - Wavy structure in Balmer dominated remnants (Bandiera)

Comprehensive evolutionary models

- CCSN
  - Pre-SN evolution; estimate mass loss
  - Input explosion
  - Follow shock through star into surrounding medium
  - Include cosmic rays
  - Emission: X-rays,…
  - Aim for 3-D
  - (Orlando, Patnaude, Lee,)
- TN (Thermonuclear)
  - Realistic explosion model
  - Surrounding ISM
  - 3-D
  - (Nagataki,..)

Pulsar wind nebulae

- Realistic relativistic MHD models of shocked pulsar winds, 3-D important (Olmi)
- Appearance of crushed PWN determined by asymmetric surroundings, pulsar velocity (Temim)
- PWNe are a dominant class of Galactic TeV sources (Grondin)



Kolb,…Temim 2017 3-D

Population studies

- Optical
  - [S II]/Hα
  - Other (like Cas A, Crab; Balmer dominated)
- Radio
- X-ray
- Stellar population

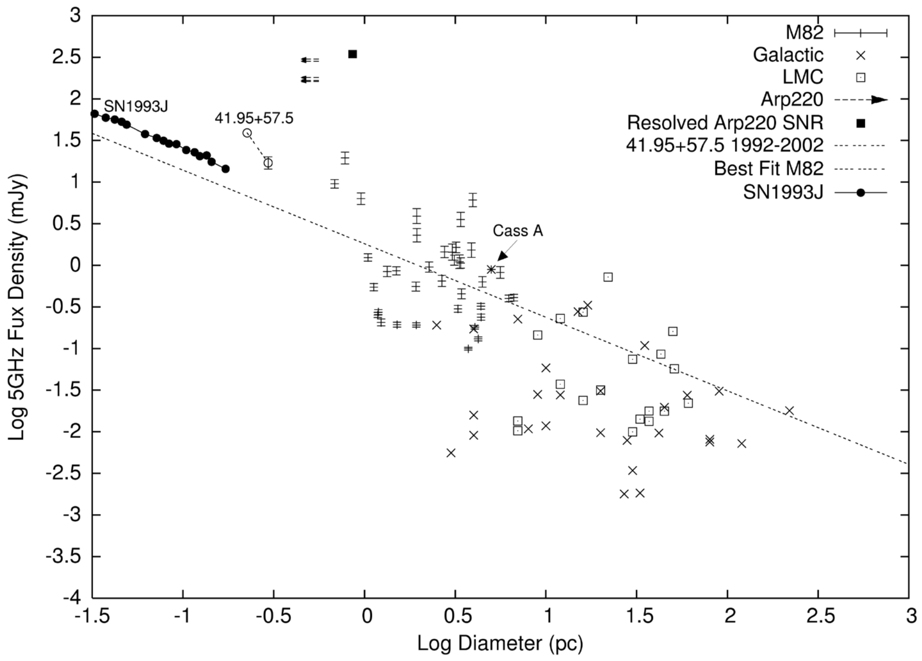
- Galaxy
- Magellanic Clouds
- M31
- M33
- M83
- NGC 6946,….

Results

- No Balmer dominated in M33 (Lin+)
- 27 new Galactic (low radio frequency) (Hurley-Walker)
- > 1500 SNRs   (Long, Kopsacheilli, Leonidaki,…)

- Catalogs
  - Updated Galactic catalog (D. Green)
  - High energy catalog (Safi-Harb)

- Populations depend on the galaxy
  - M82, starburst galaxy, has many objects like Cas A
  - Interstellar pressure could be a factor



M82 radio sources Fenech et al.

SNRs relevant to:

- Explosive nucleosynthesis
- Presupernova mass loss
- Shock wave physics
- Acceleration of relativistic particles, cosmic rays
- Formation of dust grains
- Pulsar winds
- SNR populations
- Interstellar medium
- Galaxy formation models (feedback)

- Theory
  - Importance of 3-D simulations, along with approximate models to enhance understanding

- Observations
  - JWST (Blair)
  - XRISM X-rays
  - CTA (Cherenkov Telescope Array)