Search for Stellar Companions of Galactic type-Ia Supernovae with HST and GAIA

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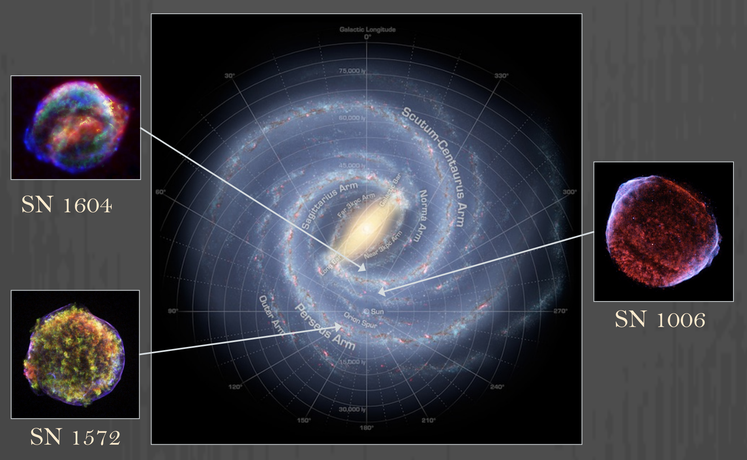
Abstract

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 Ia 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 have been searching for companions of progenitors of historical Galactic type-Ia supernovae with the aim of clarifying their origin, using high-resolution spectroscopic data taken with Keck-I and VLT 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 to derive their chemical and kinematical properties. We present here the study of the Galactic type-Ia supernovae SN1572 (the Tycho Brahe's supernova), SN1006 and SN1604 (the Johannes Kepler's supernova).

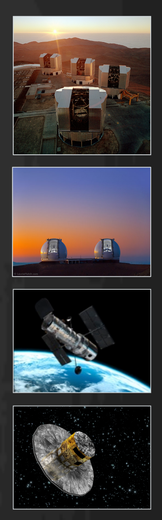
Introduction

The increase in the empirical knowledge of SNe Ia has led to an enormous advance in their cosmological use (Riess et al. 1998; Perlmutter et al. 1999), the understanding of the explosion mechanism still requires careful evaluation (Howell 2011). One way to investigate this is by performing direct survey of the field of Galactic historical SNe Ia. Our group have been trying to search for the companion of the progenitor of historical Galactic SN Ia with the goal of understanding the origin of these cosmological candles (Ruiz-Lapuente 2014).
A high peculiar motion with respect to the stars at the same location in the Galaxy, mainly due to the orbital velocity at the time of the SN explosion, is a basic criterion for the detection of such companions, but also some chemical anomalies of key elements ejected in the SN explosion.

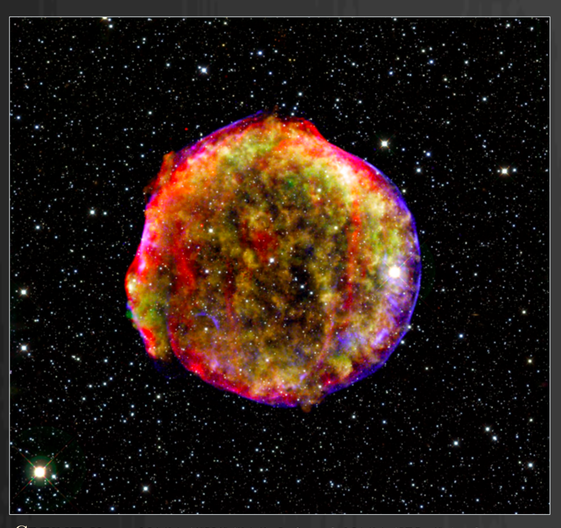


Observations

We have been using high-resolution spectroscopic data taken with HIRES spectrograph at 10m-KeckI telescope (Hawaii, USA) for SN1572 and with UVES spectrograph for SN1006 and FLAMES/GIRAFFE instrument for SN1604 at 8.2m-VLT telescope (Paranal, Chile) to derive radial velocities and to characterize the stars close to the geometrical center of these supernova remnants.
The proper motions of these stars have been also obtained with images at different epochs by astrometry with the Hubble Space Telescope (HST) for SN1572 and SN 1604. More recently, 2e have been using the GAIA data to confirm the proper motions and distances of stars close to the center of the supernova remnants SN 1572.



SN 1572



CREDIT: X-ray: NASA/CXC/SAO; Infrared: NASA/JPL-Caltech; Optical: MPIA/Calar Alto Observatory

The Tycho Brahe's SN remnant SN 1572 is located at a distance of ~2.7±1 kpc (Ruiz-Lapuente et al. 2019) close to the Galatic plane (l=120.1°, b=1.4°) and has a angular diameter of 7.4'. We have searched for surviving companions of the SN1572 within a circle of radius ~ 1' (Ruiz-Lapuente et al. 2004; 2019). We have found a candidate companion stellar companion (Tycho G) to progenitor of SN 1572, (Ruiz-Lapuente et al. 2004). Tycho G is a subgiant star with a effective temperature of ~5900 K, and a metallicity of [Fe/H] ~ -0.1 dex (González Hernández et al. 2009).

We observed Tycho G with HIRES at 10m-Keck-I to derive the stellar parameters and detailed chemical pattern (see Fig.1). We have found a slightly peculiar [Ni/Fe] abundance ratio compared to the [Ni/Fe] trend in Galactic thin disk stars (González Hernández et al. 2009). Tycho G shows a distance compatible with that of the SN 1572 remnant.

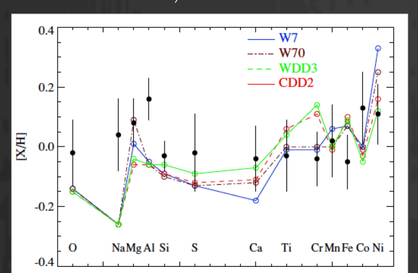


FIG. 1: chemical abundances of Tycho G compared to SNIa modes (Iwamoto et al. 1999)

We used archival and new HST data to derive accurate proper motions of stars in the field of SN 1572 (Bedin et al. 2014). We confirm that Tycho G shows an anomalous proper motion (see Fig. 2) as compared with other stars in the field of SN 1572 with respect to the Besançon model of the Galaxy (Robin et al. 2003).

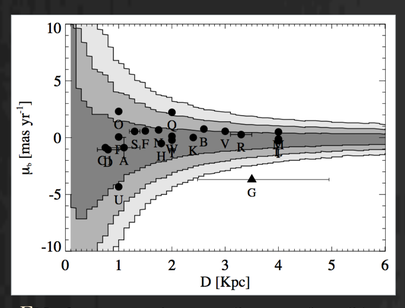


FIG. 2: proper motion μ_l vs. distances of candidate stars of the field of the SN 1572 vs Besançon model

We have revisited the Tycho's supernova using the Gaia DR2 data to derive proper motions and distances with an unprecedented accuracy (Ruiz-Lapuente et al. 2019). We evaluate kinematical properties of all stars (see Fig. 3) and conclude that Tycho B is not a good candidate (see Kerzendorf et al. 2018) and Tycho G remains the only candidate for the single-degenerate scenario.

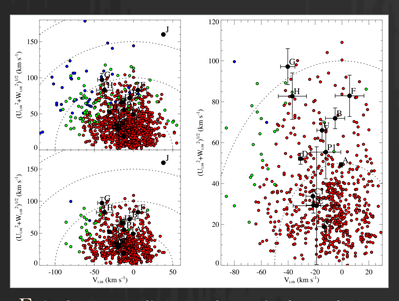
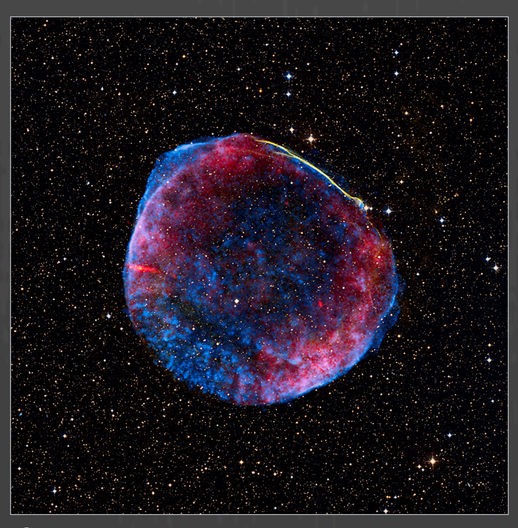


FIG. 3: Toomre diagram of stars in the Tycho's field compared to thin disk (red), thick disk (blue), and transition thin-thick disk (green) stars

SN 1006



CREDIT: X-ray: NASA/CXC; Radio: NRAO/AUI/NSF/GBT/VLA; Optical: Middlebury College/NOAO/AURA/NSF/CTIO Schmidt & DSS

The supernova remnant SN 1006 is located at a distance of ~2.18±0.08 kpc (Winkler et al. 2003) close to the Galatic plane (l=327.6°, b=14.6°) and has a angular diameter of ~15'.

We selected a sample of stars close to the geometrical center of the remnant of SN 1006 (see Fig. 4). For these stars we carried out high resolution spectroscopic observations with UVES at the 8.2m-VLT telescope to derive the stellar parameters: effective temperature, surface gravity and metallicity, and radial velocities of these stars.

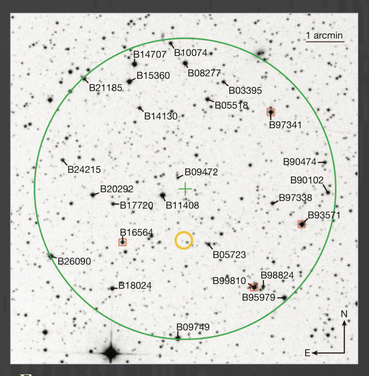


FIG. 4: field of the SN 1006 in the DSS R-band

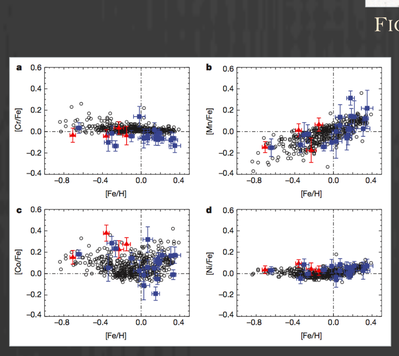


FIG. 5: abundance ratios of Fe-peak elements of giant (red) and dwarf/subgiant (blue) stars in the field of the SN 1006 compared to those in Galactic disk stars

The high resolution spectroscopic data of these stars were used to determine the detailed chemical abundance patterns of the targeted stars (see Fig. 5). We did not see any peculiarity among the targeted stars in the field of SN1006 (González Hernández et al. 2012). Kerzendorf et al. (2012, 2018) did not find either any candidate companion to SN 1006.

We derived the distances of the targeted stars and compared them with the very accurate distance to the SN remnant of SN 1006 (see Fig. 6). Only the giant stars are compatible with the distance to SN 1006, and these normal red giants are not expected to survive the SN explosion (e.g. Marietta et al. 2000), this suggests the double degenerate scenario as the origin of SN 1006.

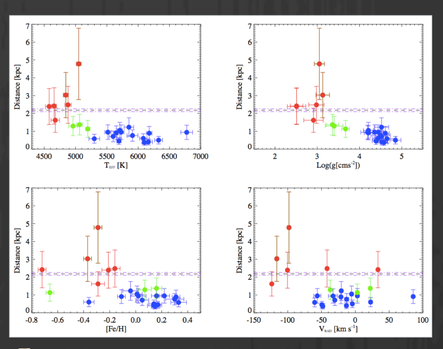
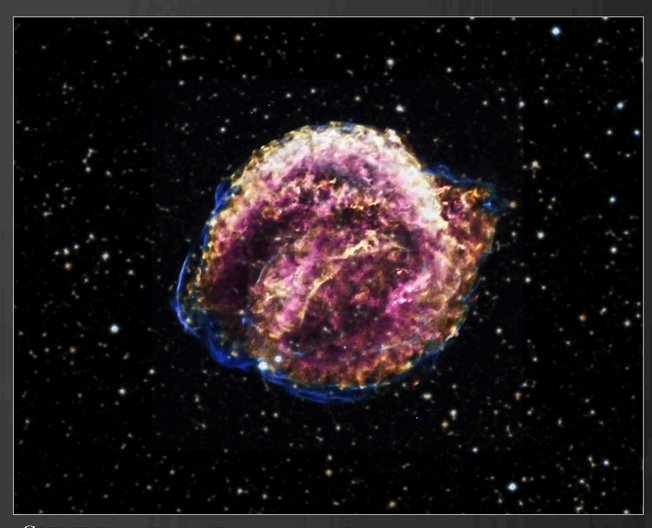


FIG. 6: distances of dwarf (blue), subgiant (green) and giant (red) stars of stars in the field of SN 1006, compared to the very accurate distance to SN 1006

SN 1604



CREDIT: X-ray: NASA/CXC/SAO; Optical: DSS

The Johannes Kepler's remnant SN 1604 is located at a distance of ~5.0±0.7 kpc (Ruiz-Lapuente et al. 2017) close to the Galatic plane (l=4.5°, b=6.8°) and has a angular diameter of 3.75'.

We selected from HST images (see Fig. 7) a sample of stars close to the geometrical center of the supernova remnant SN 1604. We carried out observations with FLAMES (UVES and GIRAFFE) at the 8.2m-VLT telescope to determine radial velocities and stellar parameters of the sample.

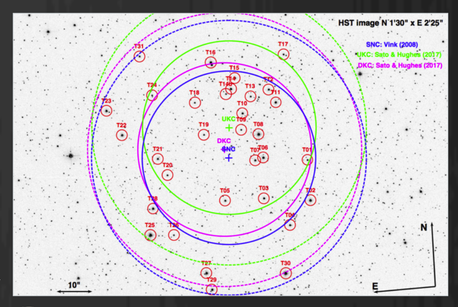


FIG. 7: targeted stars in the field of the Kepler's SN 1604 remnant in the *HST* image for different SN centers.

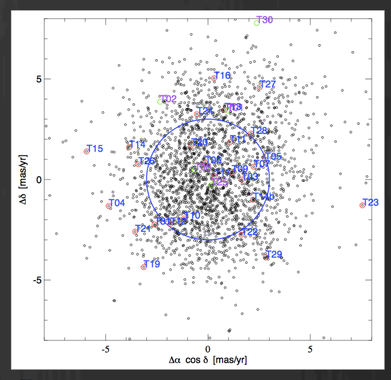


FIG. 8: vector point diagrams of the proper motions of stars targeted in the field of SN1604

To derive the proper motions of the targeted stars we used two epochs separeted by ~10 years (see Fig. 8). Note that most of the field objects are background Galactic bulge stars, with an intrinsic dipersion of ~3mas/yr (e.g. Bedin et al. 2003). Our proper motion precision is significantly superior to this limit.

We compare the kinematical properties of the targeted stars with distances derived from spectroscopy (see Fig. 9). We did not find any peculiar star, which suggests that the SD scenario is not favoured for SN1604, leaving the DD and the CD scenarios the most plausible origin for the Kepler's supernova.

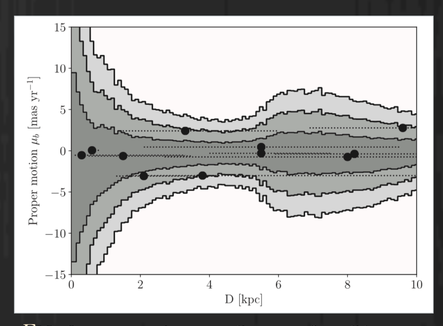


FIG. 9: proper motion μ_b vs. distances of candidate stars of the field of the SN 1604 vs Besançon model

Contact

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