Searching for Surviving Stellar Companions of Historical Galactic type-Ia Supernovae

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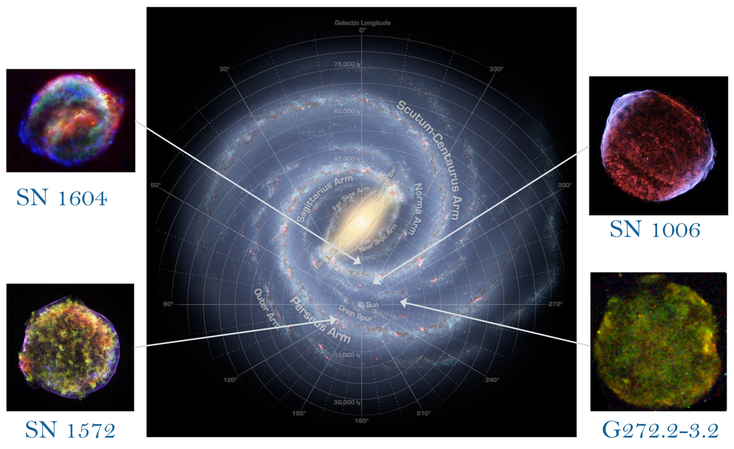
Abstract

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), via merging of two white dwarfs (double-degenerate (DD) channel), or via merging of a WD with electron-degenerate core of an asymptotic giant branch (AGB) star (CD channel).
Our group has been searching for companions of progenitors of historical Galactic type-Ia supernovae with the aim of clarifying their origin. We have been using high-resolution spectroscopic data taken with 10m-Keck-I, 8.2m-VLT and more recently with the 6.5m-Magellan telescope together with astrometry from the Hubble Space Telescope (HST) and GAIA, to characterize the stars close to the geometrical center of supernova remnants (SNRs), and to derive their chemical and kinematical properties. We present here the study of the Galactic type-Ia supernovae SN1572 (Tycho Brahe's supernova), SN1006, SN1604 (Johannes Kepler's supernova), and more recently the SNR G272.2-3.2.

Introduction

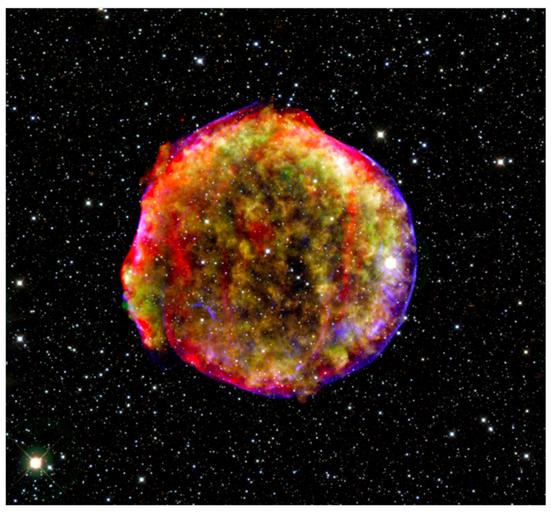
Increasing empirical knowledge of SNe Ia has led to enormous progress in its cosmological use (Riess et al. 1998; Perlmutter et al. 1999), but understanding the explosion mechanism still requires careful evaluation (Howell 2011). One way to investigate this is to conduct a direct study of the fields around and within the supernova remnants of galactic historical SNe Ia. Our group have been trying to search for companions of progenitors of historical Galactic SNe Ia with the goal of understanding the origin of these cosmological candles (Ruiz-Lapuente 2014; 2019). 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, with UVES spectrograph for SN1006, and FLAMES/GIRAFFE instrument for SN1604 at 8.2m-VLT telescope (Paranal, Chile), and with MIKE at 6.5m-Magellan telescope (Las Campanas, 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, we have been using GAIA to confirm and evaluate proper motions and distances of stars close to the center of the supernova remnants SN 1572 and G272.2-3.2.

SN 1572



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The Tycho Brahe's SN 1572 remnant is located at a distance of ~2.7±1 kpc (Ruiz-Lapuente et al. 2019) close to the Galactic plane (l=120.1º, b=1.4º) and has a angular diameter of 7.4'. We have searched for surviving companions of SN1572 within a circle of radius ~ 1' (Ruiz-Lapuente et al. 2004; 2019) around its geometrical center. We have found a candidate stellar companion (Tycho G) of the 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; Bedin et al. 2014). Tycho G shows a distance compatible with that of the SN 1572 remnant.

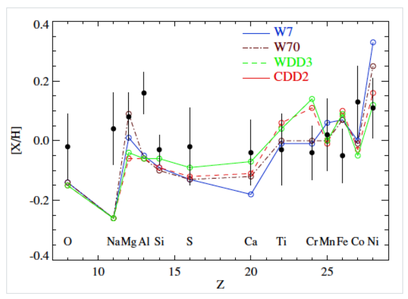


FIG. 1: chemical abundances of Tycho G compared to SNIa models (Iwamoto et al. 1999).

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 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).

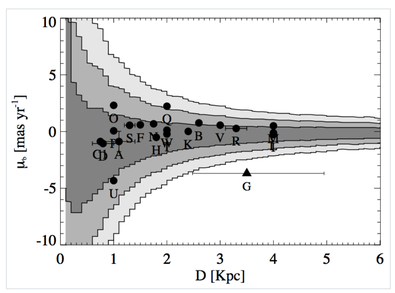


FIG. 2: proper motion μ_b vs. distances of candidate stars of the field of the SN 1572 vs Besançon model.

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.

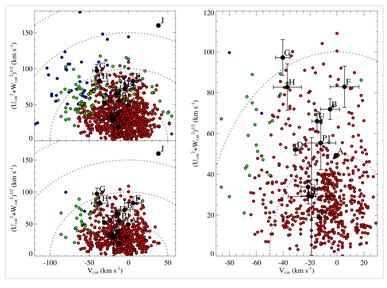
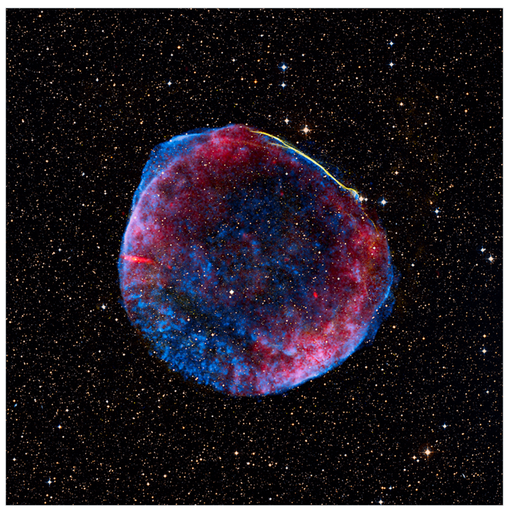


FIG. 3: Toomre diagram of stars in the Tycho's field compared to thin disk (red), thick disk (blue), and transition thin-thick disk (green) stars.

SN 1006



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

The SN 1006 remnant is located at a distance of ~2.18±0.08 kpc (Winkler et al. 2003) close to the Galatic plane (l=327.6º, b=14.6º) and has a angular diameter of ~30' (González Hernández et al. 2012).

We selected a sample of stars close to the geometrical center of the remnant of SN 1006 (see Fig. 4). The radius of search is 4', which is 27% of the 15' radius of the SNR (González Hernández et al. 2012). For these stars we carried out high resolution spectroscopic observations with UVES at the 8.2m-VLT telescope to derive stellar parameters, effective temperature and surface gravity, metallicity, and radial velocities of these stars.

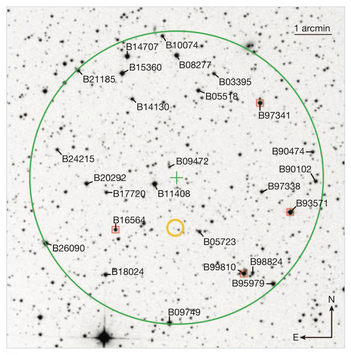


FIG. 4: target stars in the field of the SN 1006 in the DSS R-band, around the SN center.

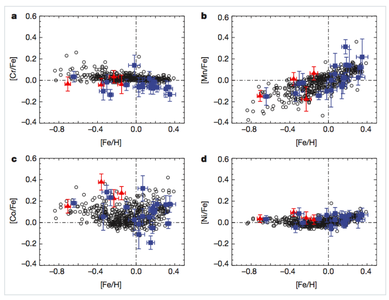


FIG. 5: abundance ratios of Fe-peak elements of giant (red) and dwarf/subgiant (blue) stars in the field of the SN 1006 compared to those in Galactic disk stars.

These UVES high resolution spectroscopic data were used to determine detailed chemical abundances. The chemical patterns of the targeted stars are compared then with stars in the Galactic disk (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 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), therefore this suggests that the double degenerate scenario as the likely origin of SN 1006.

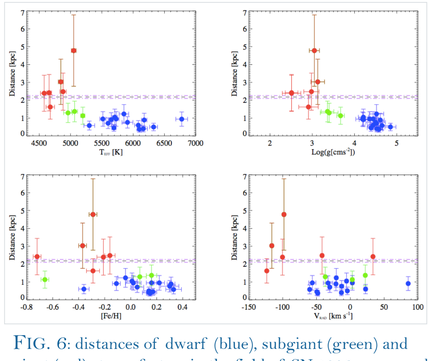
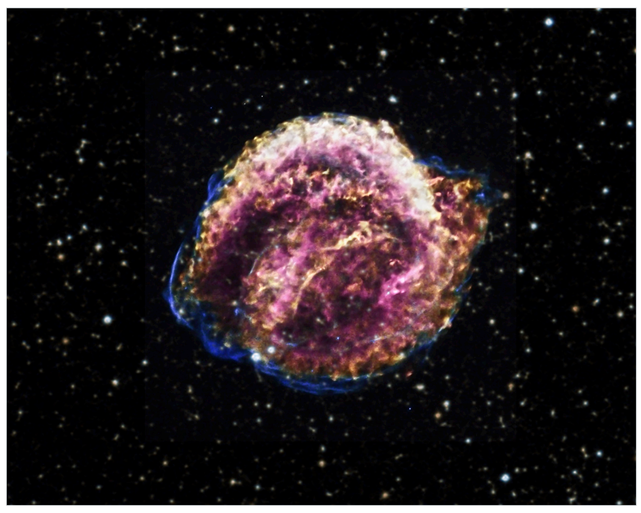


FIG. 6: distances of dwarf (blue), subgiant (green) and giant (red) stars of stars in the field of SN 1006, compared to the very accurate distance to SN 1006.

SN 1604



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

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

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

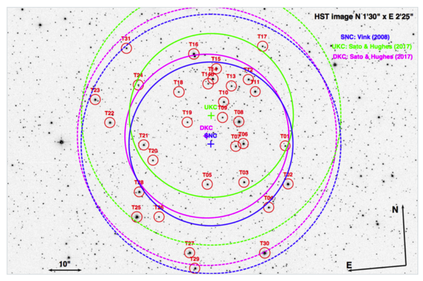


FIG. 7: target stars in the field of the Kepler's SN 1604 remnant in the *HST* image for different SN centers.

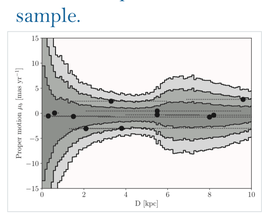
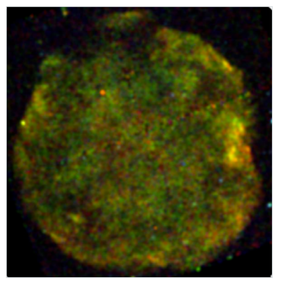


FIG. 8: proper motion μ_b vs. distances of candidate stars of the the SN 1604 vs Besançon model.

We compare the kinematic properties of the target stars with distances derived from spectroscopy (see Fig. 8). We did not find any peculiar stars, suggesting that the SD scenario is not preferred for SN1604, leaving the DD and CD scenarios as the most plausible origin for the Kepler supernova.

G272.2-3.2



The G272.2-3.2 supernova remnant is located at a distance of ~1.8±1.1 kpc (Ruiz-Lapuente et al. 2023) close to the Galactic plane (l=272.2º, b=-3.2º) and has a 15' angular diameter, and an estimated age of 7500 ± 3500 yr.

Using Gaia EDR3, we have found a candidate surviving companion M dwarf star (MV-G272), with a peculiar proper motion (see Fig. 9). Using high-resolution MIKE spectra, we measured stellar parameters, radial velocity and chemical abundances of MV-G272. The trajectory of this peculiar star on sky locates it at the center of the SNR, about 6,000 – 8,000 yr ago, suggesting the SD scenario for SNR G272.2-3.2.

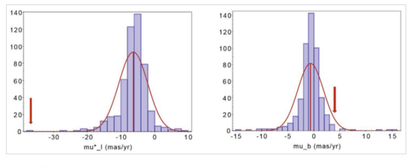


FIG. 9: proper motions μ_l^* and μ_b of M-dwarf stars at distances in 1-2 kpc in the direction of G272.2-3.2 of our sample from Gaia EDR3. Red arrows indicate the candidate surviving M-dwarf companion MV-G272.

Contact

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