SNIa supernova remnant with M dwarf companion

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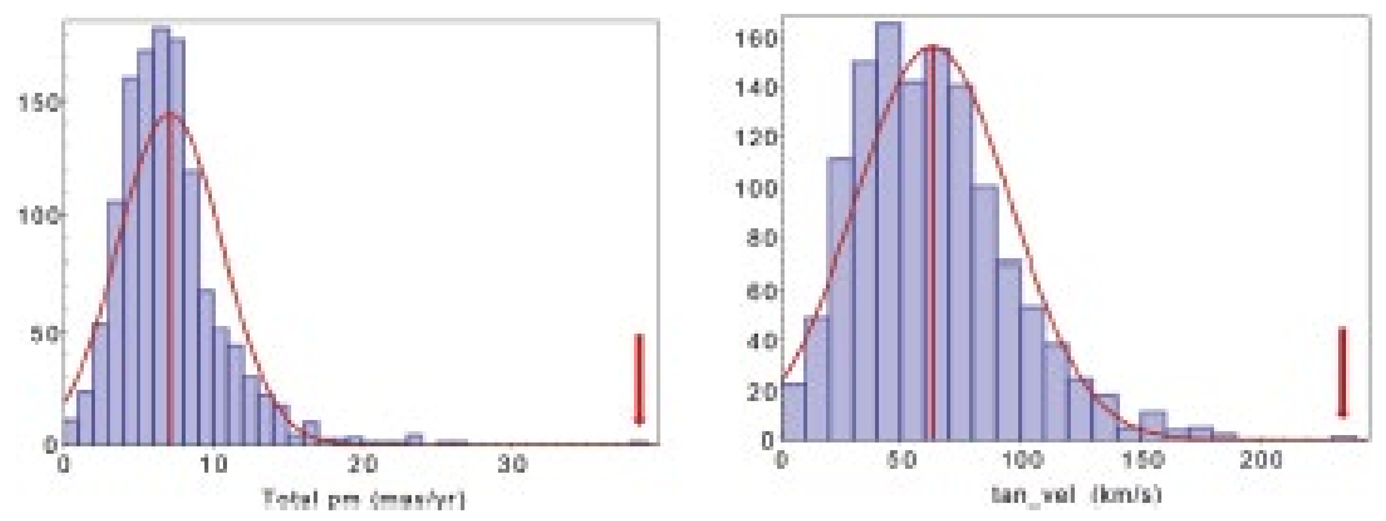
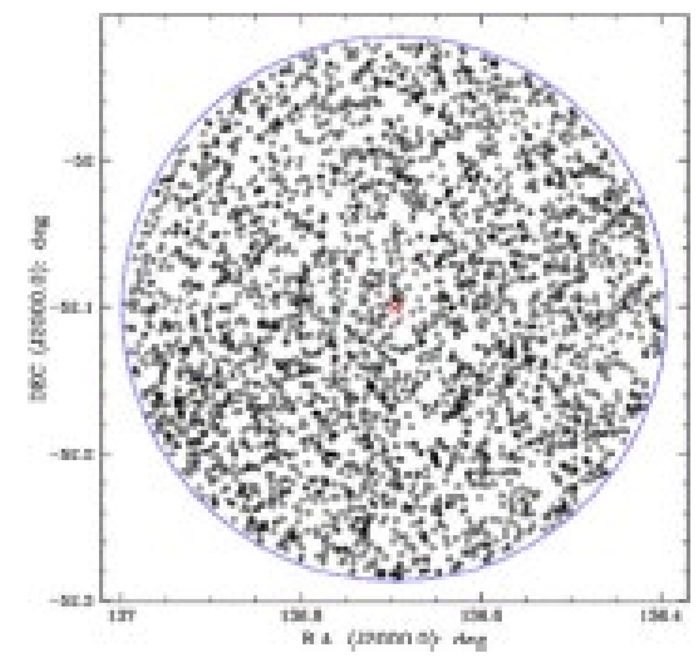
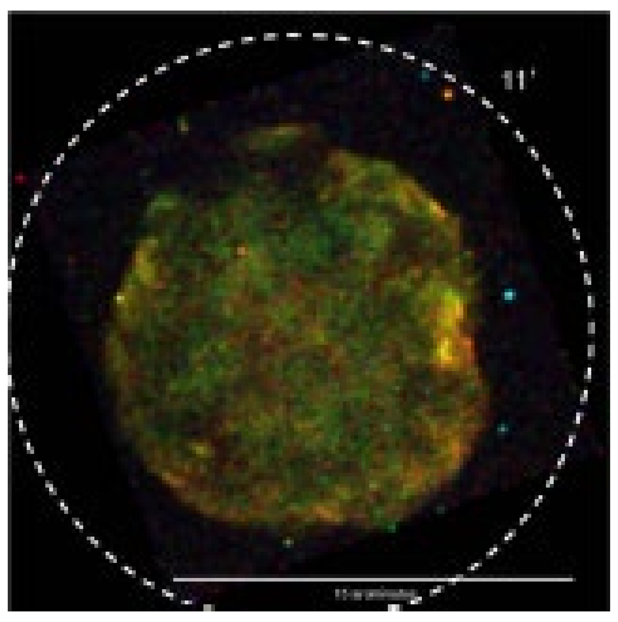
Abstract

We use the Gaia EDR3 to explore the Galactic supernova remnant (SNR) G272.2-3.2, produced by the explosion of a Type Ia supernova (SN Ia) about 7500 yr ago, to search for a surviving companion. From the abundances in the SNR ejecta, G272.2-3.2 is a normal SN Ia. The Gaia parallaxes allow us to select the stars located within the estimated distance range of the SNR, and the Gaia proper motions allow us to study their kinematics. From the Gaia EDR3 photometry, we construct the H-R diagram of the selected sample, which we compare with the theoretical predictions for the evolution of possible star companions of SNe Ia. We can discard several proposed types of companions by combining kinematics and photometry. We can also discard hypervelocity stars. We focus our study on the kinematically most peculiar star, Gaia EDR3 5323900215411075328 (hereafter MV-G272), an 8.9σ outlier in proper motion. It is of M1–M2 stellar type. Its trajectory on the sky locates it at the center of the SNR, 6000–8000 yr ago, a unique characteristic among the sample. Spectra allow a stellar parameter determination and a chemical abundance analysis. In conclusion, we have a candidate to be the surviving companion of the SN Ia that resulted in SNR G272.2-3.2. It is supported by its kinematical characteristics and its trajectory within the SNR. This opens the possibility of a single-degenerate scenario for an SN Ia with an M-type dwarf companion. Recent simulations of the impact of SN Ia ejecta on such companion support the possibility of having an objet like MV-G272 after ~8000 yr

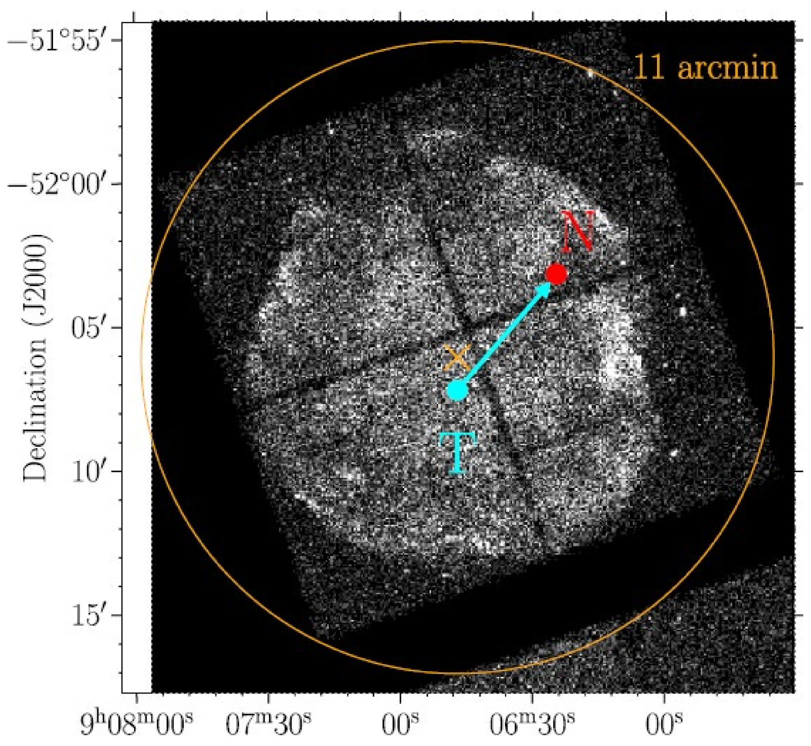


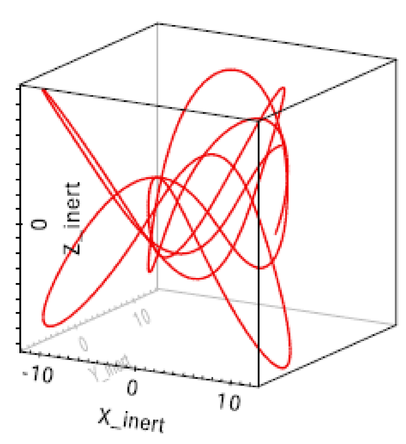
Distribution of the total proper motions (left) and of the velocities perpendicular to the line of sight (right). Star MV-G272 is a 8.9σ outlier in PM

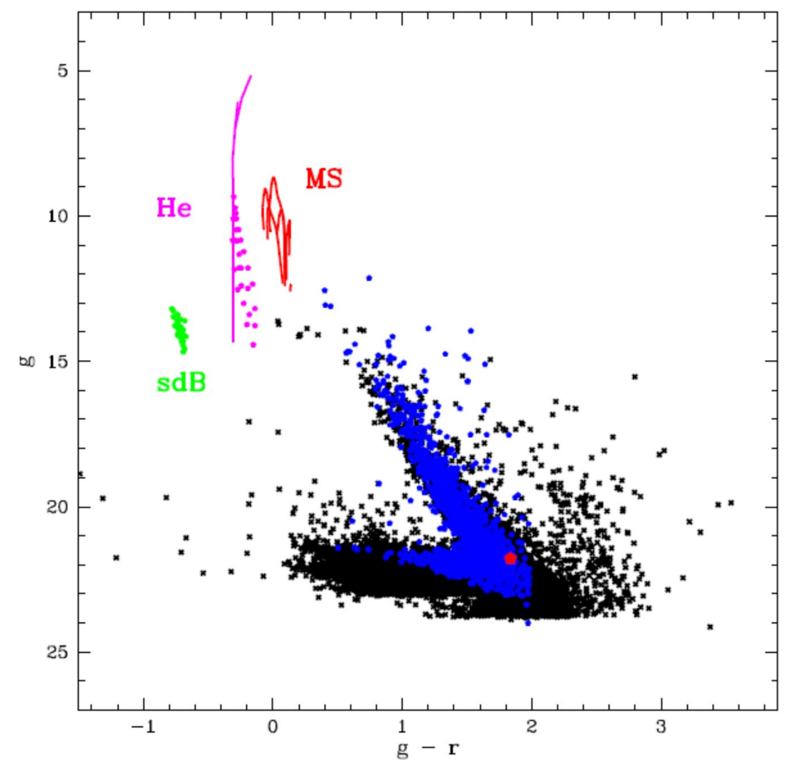
Explored región around the G272.2-3.2 Type Ia supernova remnant, comprising 3082 stars within 11′ radius and distances 1 kpc ≤ d ≤ 3 kpc

Present position of star MV-G272 (red dot) and its position 8000 yr ago (blue dot), based on its proper motion. The centroid of the SNR is marked with a yellow cross





3D orbit of the star MV-G262



Magnitude-color diagram of the sampled stars, compared with predictions of the post-impact evolution from different models. Star MV-G272 is marked with a red dot. All assumed companions are twice as massive, at least, than this star

Table 1: Characteristics of star MV-G272

μ_α^* (mas/yr)	...	-22.79
μ_δ (mas/yr)	...	30.60
μ (mas/yr)	...	38.15
μ_l^* (mas/yr)	...	-37.96
μ_b (mas/yr)	...	3.85
d (kpc)	...	$1.32^{+1.00}_{-0.39}$
$v_{\rm tan}$ (km s^{-1})	...	239^{+181}_{-70}
v_r (km s^{-1})	...	77.2± 0.5 (LSR)
v_r (km s^{-1})	...	92.6±05 (barycentric)
$v_{\rm tot}$ (	...	256^{+181}_{-65}
G mag	...	19.85
G_{BP} mag	...	21.03
G_{RP} mag	...	18.77
Spectral type	...	M1-M2
Luminosity class	...	V
$[Fe/H]$	...	-0.32±0.04
M ($M_\odot$)	...	0.44-0.50
R ($R_\odot$)	...	0.446-0.482
$T_{\rm eff}$ (K)	...	3,600-3850
log g	...	$4.46^{+0.10}_{-0.11}$
log$(L/L_\odot)$	...	-1.54/-1.39

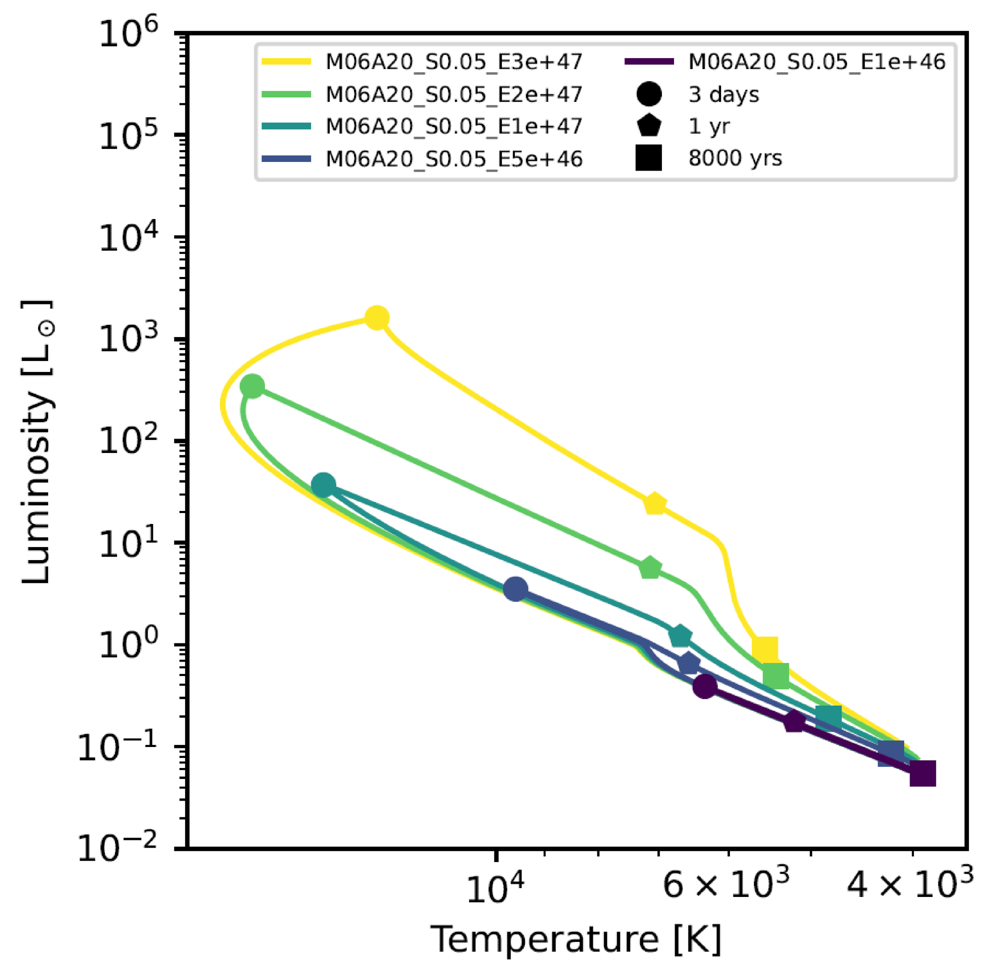
Is it posible to have a surviving companion that looks as a M1-M2 star ~8000-10000 yr after the explosion?

Model Name	M $[M_\odot]$	R $[R_\odot]$	A $[R_\odot]$	$M_{\rm f}$ $[M_\odot]$	$v_{\rm kick}$ [km s^{-1}]	$v_{\rm orb}$ [km s^{-1}]	$v_{\rm linear}$ [km s^{-1}]
M05A15	0.5	0.446	1.5	0.184	152	419	446
M05A20	0.5	0.446	2.0	0.432	102	363	377
M05A30	0.5	0.446	3.0	0.489	45	296	300
M06A15	0.6	0.564	1.5	< 0.07	–	419	> 419
M06A17	0.6	0.564	1.7	0.312	143	394	419
M06A18	0.6	0.564	1.8	0.370	134	383	405
M06A20	0.6	0.564	2.0	0.447	117	363	381
M06A30	0.6	0.564	3.0	0.571	57	396	301
M07A20	0.7	0.654	2.0	0.498	117	363	381
M07A30	0.7	0.654	3.0	0.650	61	296	302

Standard simulations of the post-impact evolution of the low-mass models above give objects similar to MV-G272 but only after ~10^6 yr, due the long thermal timescale for energy dissipation. A possible solution is to have the energy deposition limited to a shallower zone. We then use an artificial heating formula:

$$\dot{\epsilon}(m) = \frac{\Delta E_{heat}}{\tau_{heat}\sqrt{\pi\sigma/2}} \exp\left(-\frac{(m-1)^2}{\sigma}\right)$$

where ΔE_{heat} is the amount of heating, τ_{heat} = 3 days, σ describes the depth of the heated zone and m is the normalized mass



Then we can have, for instance, for different models and varying amounts energy, with a fixed σ= 0.05, post-impact evolutions fast enough to produce M-dwarf stars after a time of ~8000 yr only

Conclusions

Kinematically, star MV-G272 has all the characteristics of a companion star of the WD whose explosion gave rise to the G272.2-3.2 SNR. We find that there are models of the post-impact evolution of low-mass companions that produce objects analogous to MV-G272, ~8000 yr after the explosion. The energy deposition by the supernova ejecta should have occurred at the surface of the companion.

References

Ruiz-Lapuente, P., González Hernández, J.I., Cartier, R., et al. 2023, ApJ, 947, 90. Hiray, R. & Yamada, S. 2015, ApJ, 805, 170. Pan, K.C. & Ruiz-Lapuente, P. 2024, in preparation