# Search of possible surviving binary companions in SNe Ia remnants

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- Type Ia supernovae are produced by the explosive thermonulear burning of a white dwarf, that resulting from mass accretion of the WD from a close binary companion. **POSSIBILITY OF SURVIVING COMPANION**

- To search for possible surviving companions in recent, nearby SNRs, based on their expected kinematic, photometric and spectrosopic peculiarities was suggested by RL (1997) and actual searches have been carried out in the Galaxy and in the LMC, starting with RL et al. (2004).

# Search of possible surviving binary companions in SNe Ia remnants

Detailed predicitions of the observable charateristics of surviving SNe Ia companions have been made, starting with:

- Marietta et al. (2000): hydrodynamics of the interaction between the SN ejecta and the companion.
- Canal et al. (2001): companion velocities after explosion.
- Podsiadlowski (2003): long-term evolution of the companion after the explosion.

# Search of possible surviving binary companions in SNe Ia remnants

Although with large uncertainties, current simulations generally predict more luminous former companions of SN Ia than anything observed thus far at the centers of recent, nearby SNRs:

- SN 1006 (González Hernández et al. 2012; Kerzendorf et al. 2012; Kerzendorf et al. 2017)
- SN 1572 (Ruiz-Lapuente et al. 2004; González Hernández et al. 2009; Kerzendorf et al. 2009, 2012; Bedin et al. 2014)
- SN 1604 (Kerzendorf et al. 2014; Ruiz-Lapuente et al. 2017)

(SEE ALSO POSTER IN THIS CONFERENCE BY JONAY GONZÁLEZ HERNÁNDEZ et al.)

- SNR 0509-67.5 in the LMC ( Schaefer & Pagnotta 2012)
- SNR 0519-69.0 in the LMC (Edwards, Pagnotta & Schaefer 2012)

# Search of possible surviving binary companions in SNe Ia remnants

- SNR 0505-67.9 (DEM L71) and SNR 0509-68.7 (N103 B) in the LMC (Pagnotta & Schaefer 2015; Li et al. 2017).

- SNR 0548-70.4 in the LMC (Li et al. 2018)

- At a distance of a few Mpc:

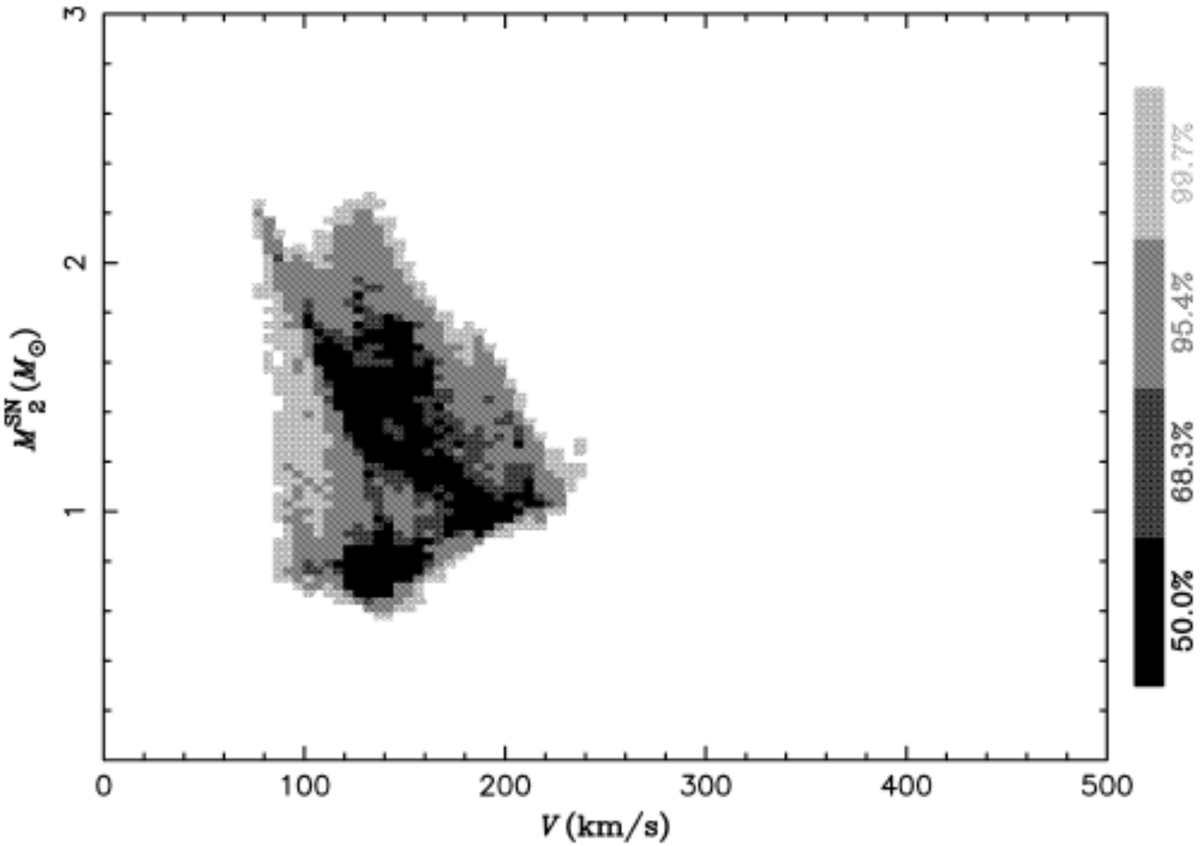
  - SN 2011fe. Li et al. (2011) exclude a red giant as possible companion star

- Other Galactic remnants of SN Ia remain to be explored (G2722-0.2, RCW 86, ...)

## Search of possible surviving binary companions in SNe Ia remnants

- RL (1997) predicted high space velocities for the surviving companions: fastest motions for MS stars and slowest ones for RGs (see also Canal et al. 2001 and Han 2008).

# Search of possible surviving binary companions in SNe Ia remnants

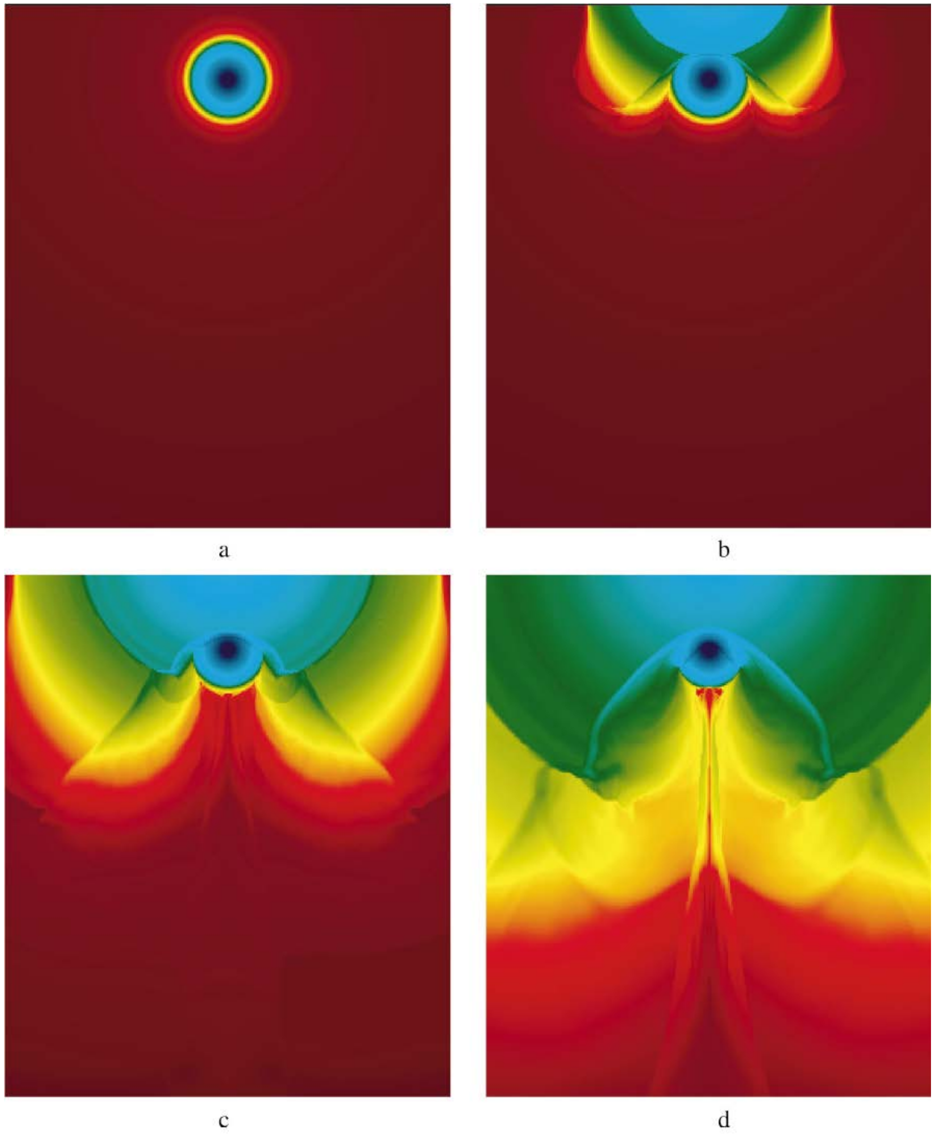



Distribution of companion stars in the plane ($V$, $M_2^{SN}$ ), where $V$ is the orbital velocity and $M_2^{SN}$ the companion mass at the time of the explosion (from Han 2008)

# Opportunities to search for surviving binary companions ot Type Ia supernovae

• Snapshots from the 2D hydrodynamic simulations by Marietta, Burrows & Fryxell (2000) of the impact of the SN Ia ejecta on a main-sequence companion.

• Very high luminosities $L \approx 5000\ L_{\odot}$



# Search of possible surviving binary companions in SNe Ia remnants

• Pan, Ricker & Taam (2012) mapped the final models from their 2D hydrodynamic simulations into a 1D model, followed with the MESA (*Modules for Experiments in Stellar Astrophysics*) code.

• Time steps are made very short initially, to closely follow the evolution when the star is still very far from equilibrium.

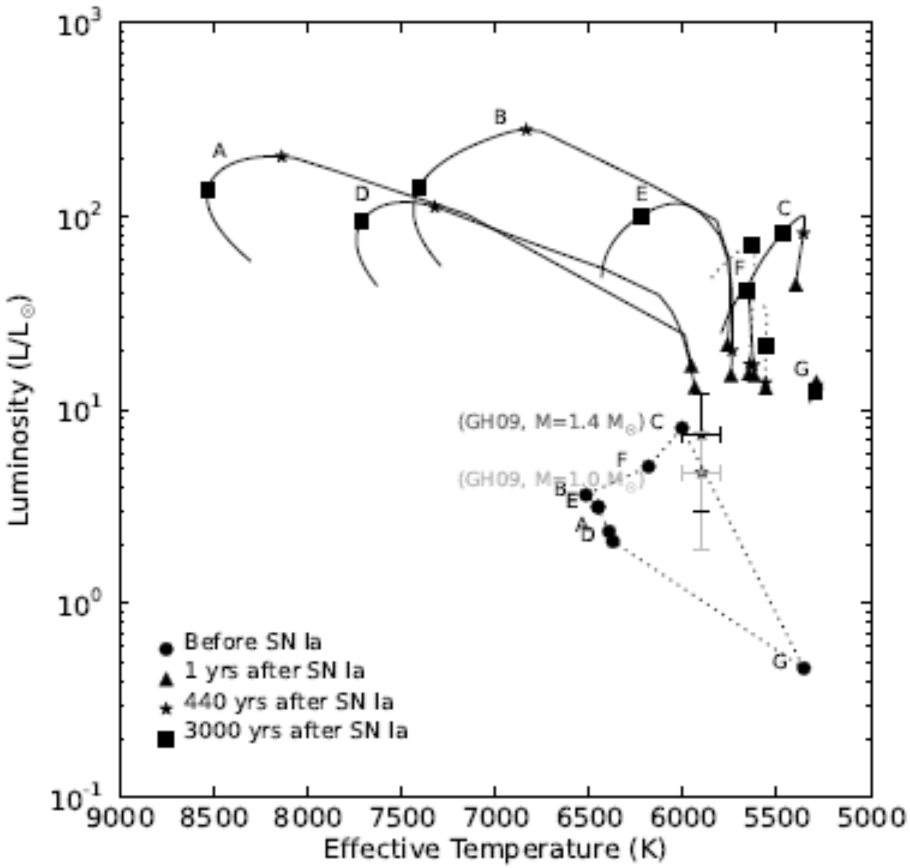
• They suggest that shock compression is an important factor, previously neglected, and criticize the arbitrariness in setting the depth of energy deposition in precedent studies.

# Luminosities and rotation

| Model | $M_i$ | $P_i$ | $R_i$ | $L_i$ | $T_{eff,i}$ | $M_f$ | $P_f$ | $R_f$ | $L_f$ | $T_{eff,f}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | $(M_\odot)$ | (day) | $(R_\odot)$ | $(L_\odot)$ | (K) | $(M_\odot)$ | (day) | $(R_\odot)$ | $(L_\odot)$ | (K) |
| A | 2.51 | 0.477 | 1.83 | 39.2 | 10696 | 1.88 | 0.350 | 1.25 | 2.35 | 6392 |
| B | 2.51 | 0.600 | 2.08 | 42.4 | 10224 | 1.92 | 0.466 | 1.50 | 3.64 | 6516 |
| C | 3.01 | 1.23 | 3.64 | 110.0 | 9800 | 1.82 | 1.09 | 2.63 | 8.06 | 6003 |
| D | 2.09 | 0.472 | 1.67 | 19.2 | 9358 | 1.63 | 0.353 | 1.19 | 2.09 | 6372 |
| E | 2.09 | 0.589 | 1.91 | 20.8 | 8933 | 1.59 | 0.470 | 1.42 | 3.15 | 6450 |
| F | 2.09 | 0.936 | 2.59 | 23.9 | 7934 | 1.55 | 0.770 | 1.97 | 5.09 | 6182 |
| G | 2.00 | 1.00 | 1.70 | 17.6 | 9083 | 1.17 | 0.233 | 0.792 | 0.463 | 5355 |

Parameters of the models used in the calculations of the post-impact evolution of Type Ia supernova companions and their rotational behaviour by Pan, Ricker & Taam (2012). Those at the beginning of Roche lobe overflow are given in columns 2-6. Those at the time of the SN explosion, in columns 7-11.

# Search of possible surviving binary companions in SNe Ia remnants




Evolutionary tracks in the H-R diagram, for the different post-impact companion models. Each track corresponds to the evolution for 104 yr of one of these models. Filled circles mark the conditions of the stars just before the SN explosion. Filled triangles, those 1 yr after explosion. Star symbols, 440 yr after it (the age of Tycho's SN). Filled squares, 3000 yr after explosion. The star symbol with error bars shows the observed luminosity and effective temperature of star G.

## Search of possible surviving binary companions in SNe Ia remnants

- Liu et al. (2013) have made 3D Smoothed Particle Hydrodynamics simulations of the impact of SN Ia ejecta on a 1 $M_\odot$ companion, using the GADGET-3 code (Springel et al. 2001; Springel 2005).

- The evolution of the binary system previous to the explosion was calculated with the 1D code of Eggleton (1973).

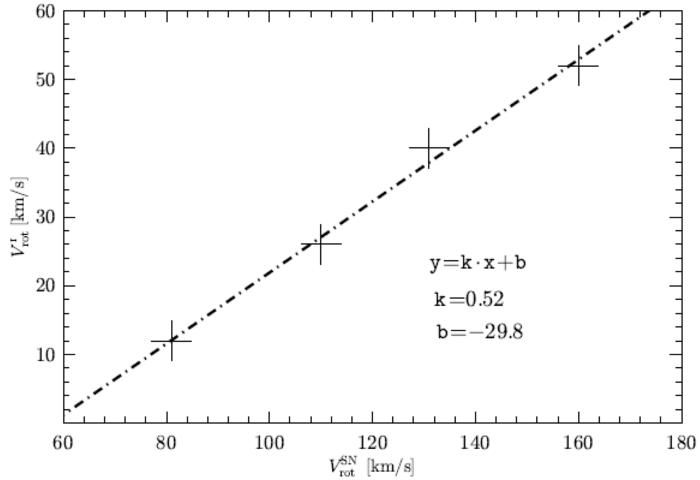
- They study the change in rotational velocity of the companion due to the impact of the ejecta.

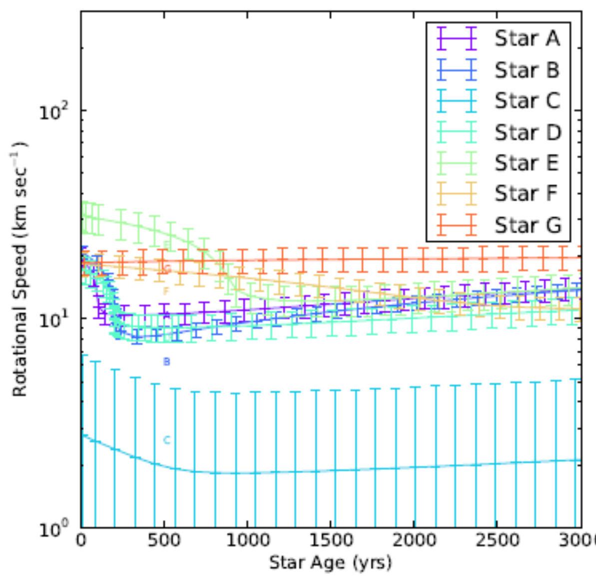
# Search of possible surviving binary companions in SNe Ia remnants

## Rotation

- High rotation velocities were predicted by assuming synchronous rotation (rotation period equal to orbital period) at the time of the explosion (Kerzendorf et al. 2009).

- Subsequent simulations have shown that the companion can lose a large fration of its angular momentum by interaction with the SN ejecta (Pan, Ricker & Taam 2012; Liu et al. 2013).




**Top**: Initial rotational velocity at the time of the SN explosion *vs* rotational velocity after the explosion, for four different models from Liu et al. (2013).

**Bottom**: Evolution of the surface rotational speeds, for the models of Pan, Ricker & Taam (2012).

# Faint companions

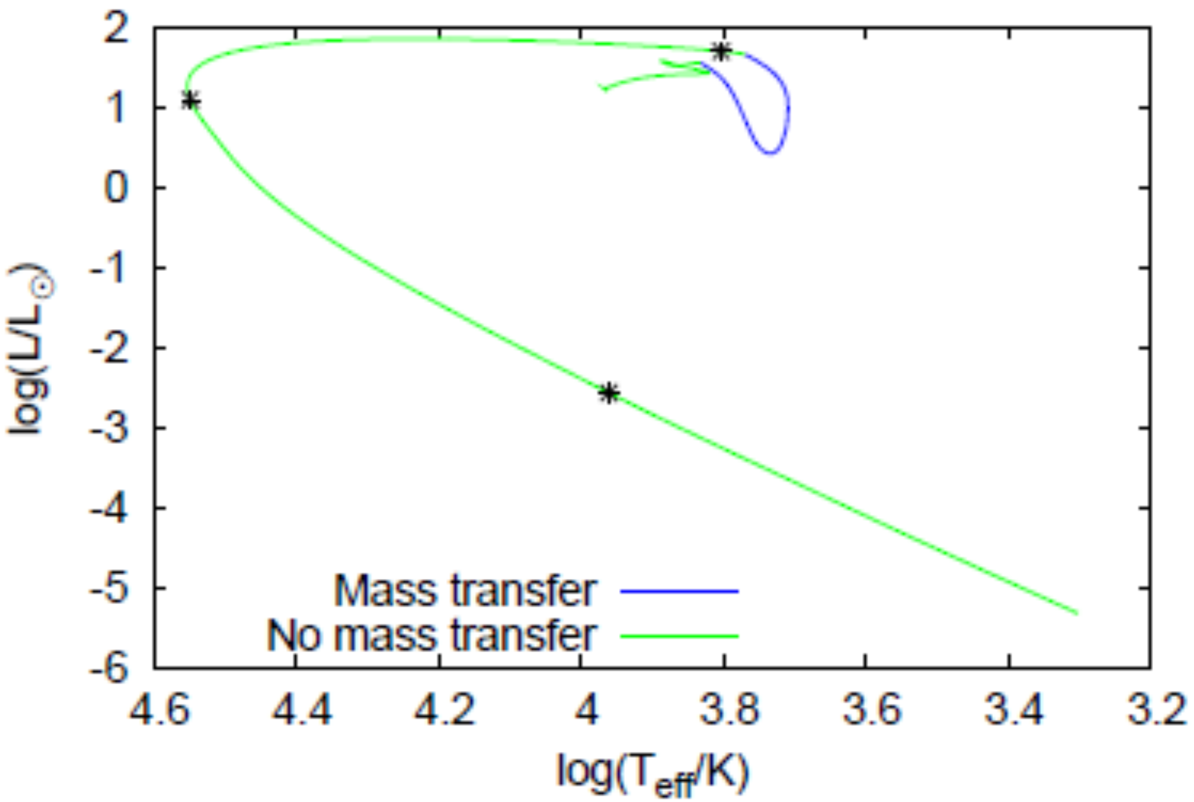
- Mass accretion from a companion should increase, by gain of angular momentum, the rotational velocity of the WD.

- The rotating WD exceeds the Chandrasekhar mass when mass accretion stops. This is the spin-up stage.

- Afterwards, rotation progressively decreases: this is the spin-down stage. Finally, explosion occurs. The time elapsed may allow the companion to evolve to the WD stage.

- Faint companions as survivors of SN Ia explosions from the spin up/spin down mechanism (Di Stefano, Voss & Claeys 2011; Justham 2011). Spin-down times of $10^6$ – $10^9$ yr.

# Search of possible surviving binary companions in SNe Ia remnants

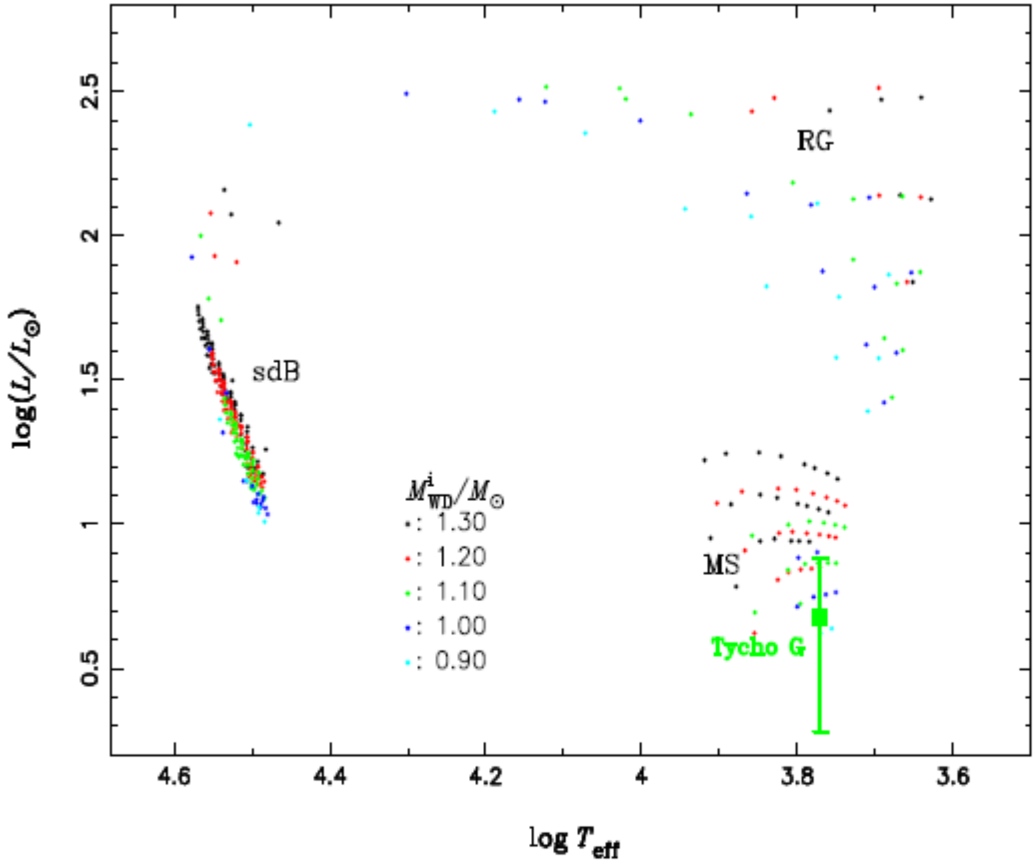



Hertzsprung-Russell diagram of the donor star, for a binary system made of a 0.7 $M_\odot$ WD and a 2 $M_\odot$ MS star and initial orbital period 2.4 days. Mass transfer starts when the donor is in the Hertzsprung gap and continues on the RG branch. Blue indicates that phase. Final system is a WD of ≈ 1.5 $M_\odot$ and a companion of ≈ 0.3 $M_\odot$ which is a He WD. Crosses indicate different times after mass transfer has ceased: $10^6$, $10^7$ and $10^9$ yr (from Di Stefano, Voss & Clays (2011).

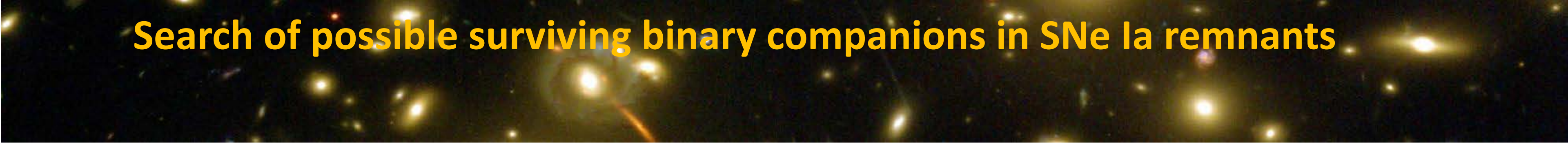
# sdB companions

- New type of surviving companion proposed by Meng & Li (2019): subdwarfs B stars (sdB), based on the common envelope wind model of Meng & Podsidlowski (2017).

- Could be quite luminous (L ~ 10 – 60 $L_{\odot}$), their luminosities peaking in the UV.




Hertzsprung-Russell diagram of the evolutionary status of SN Ia companions at the moment of the SN explosion (from Meng & Li 2019).




# SN 1572 (Tycho's SN)

• First Galactic SNR attributed to a SN Ia to be explored (RL et al. 2004). Several papers since then, by different groups.

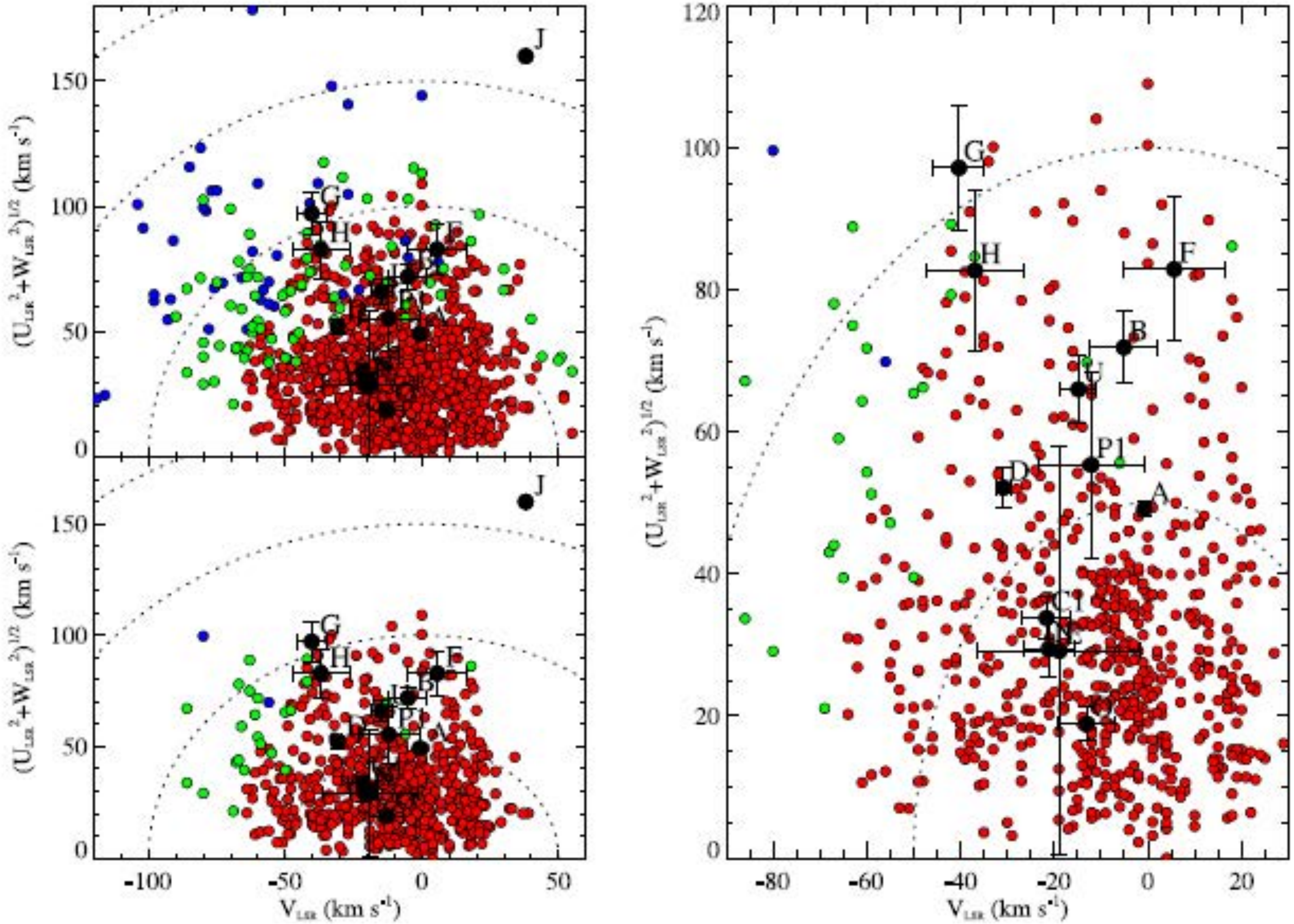
• Proposed candidate (star G), but disagreement about it (starting from Kerzendorf et al. 2009).

• *Gaia* DR2 has provided more acurate distances and confirmed proper motions (RL et al. 2019).

• New data confirm kinematic peculiarity of star G, but are still inconclusive.

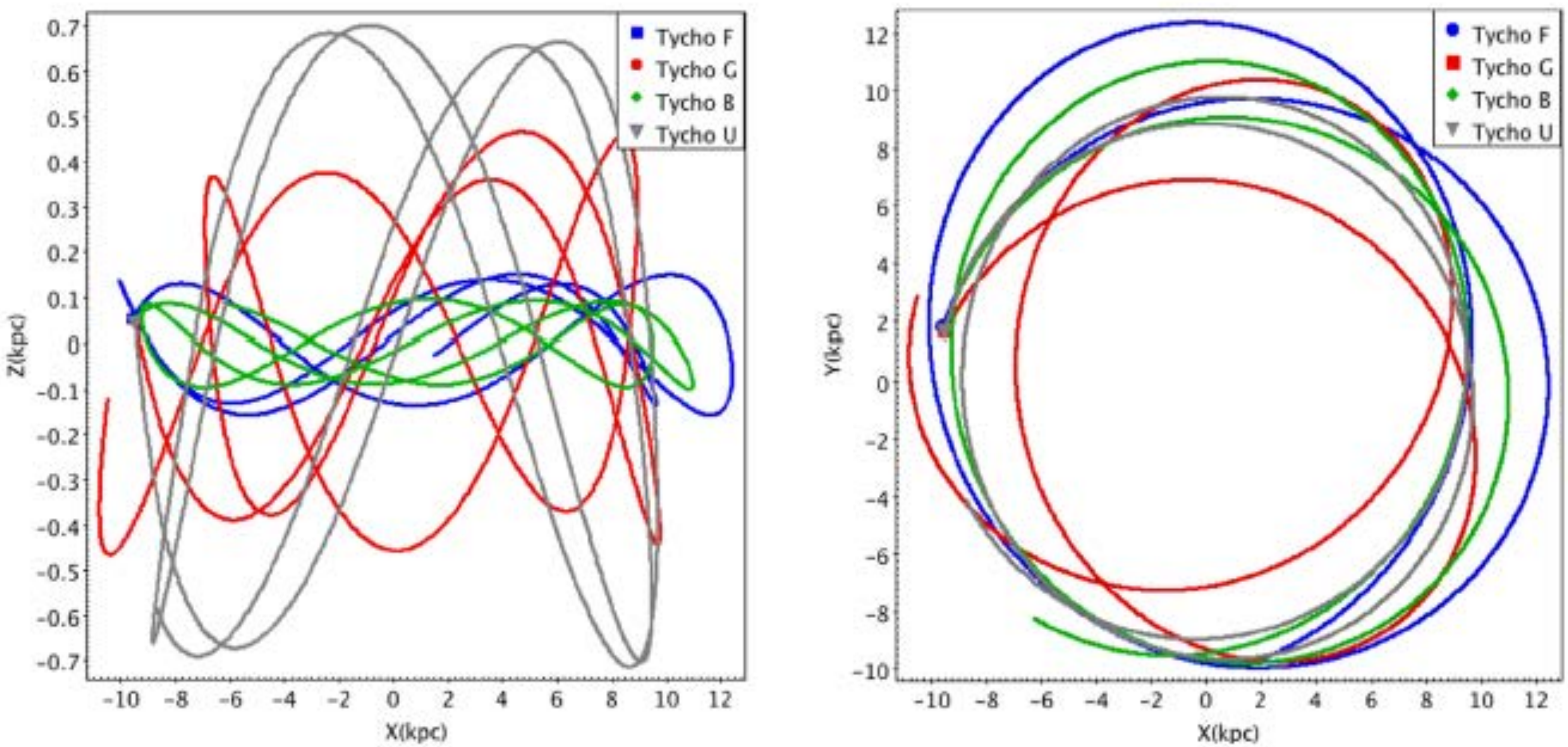
# Search of possible surviving binary companions in SNe Ia remnants

(a)



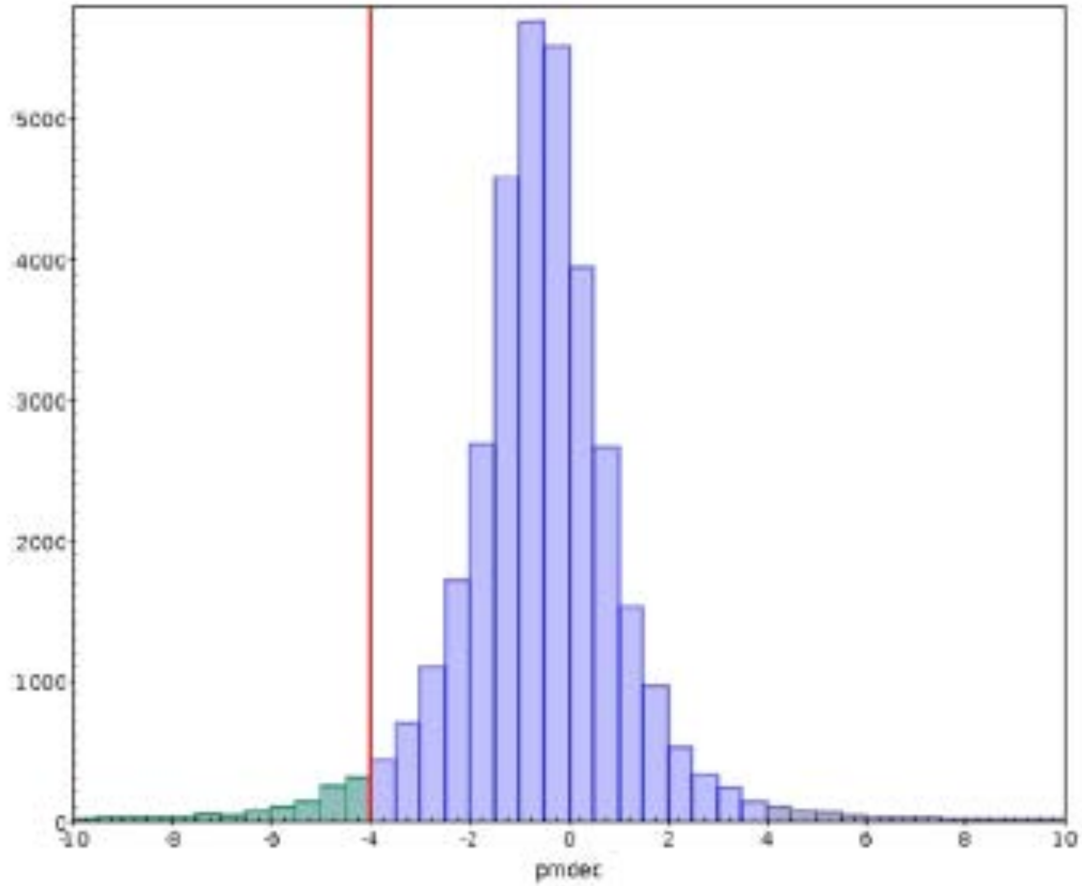

(a): Toomre diagrams for a sample of thin disk, thick disk, and transition thin-thick disk stars, covering a wide range of metallicities, with our stars superimposed (red dots: thin disk stars; green: transition; blue: thick disk stars). (b): Same as (a) but only for stars with metallicities equal or higher than that of star G. (c): Enlargement of (b), without star J.

# Search of possible surviving binary companions in SNe Ia remnants



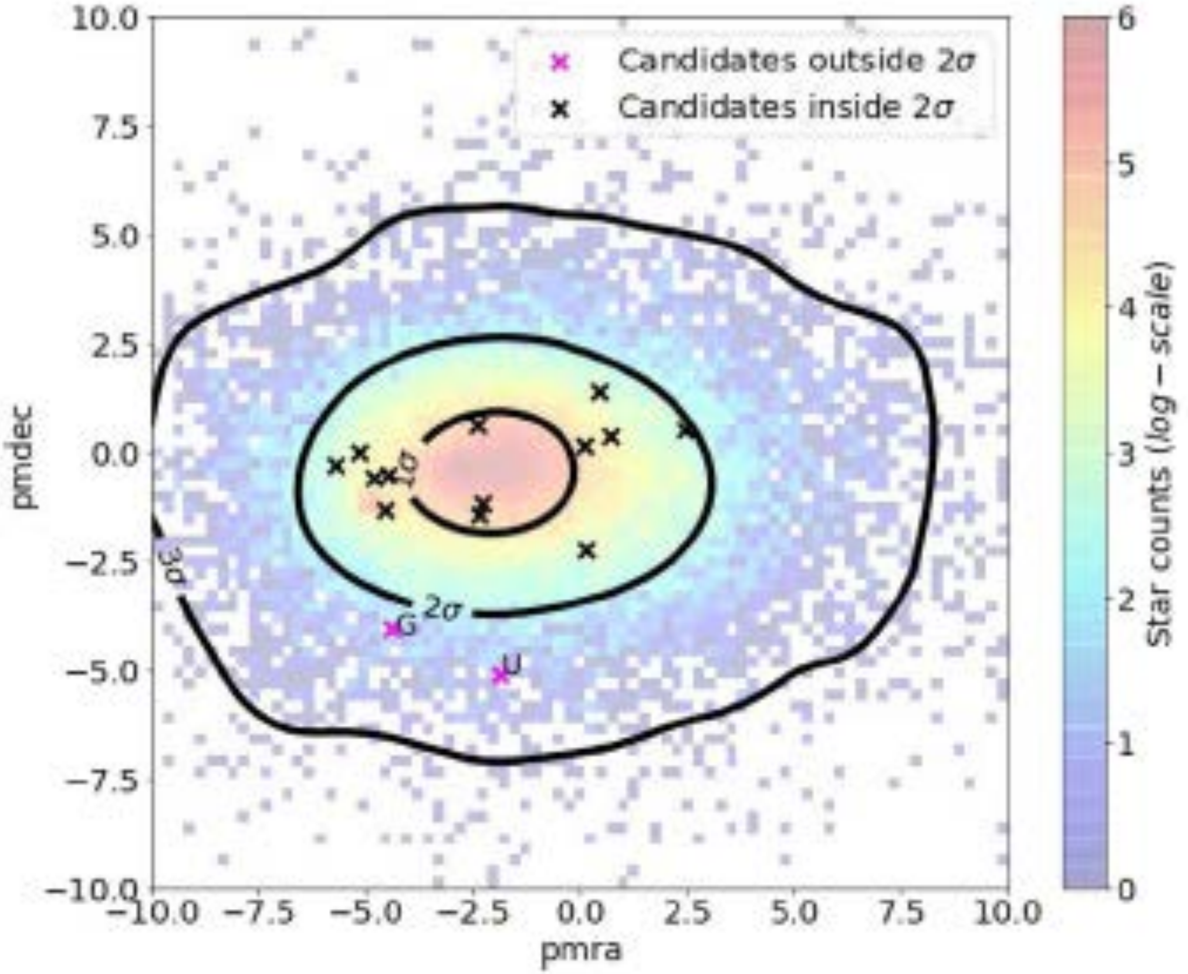

Orbits of stars B (green), G (red), F (blue), and U (gray), projected on the Galactic meridian plane (left) and on the Galactic plane (right), computed forward in time for the next 500 Myr. In the left panel we see that star U reaches the largest distance from the Galactic plane, followed by star G , while stars B and F scarcely depart from the plane. The behavior of the latter stars is typical of the rest of the sample considered here. In the right panel we see that the orbit of star G on the Galactic plane is highly eccentric, while the other stars (including star U) have orbits close to circular. Also here, the behavior of stars B and F is representative of the whole sample.

# Search of possible surviving binary companions in SNe Ia remnants



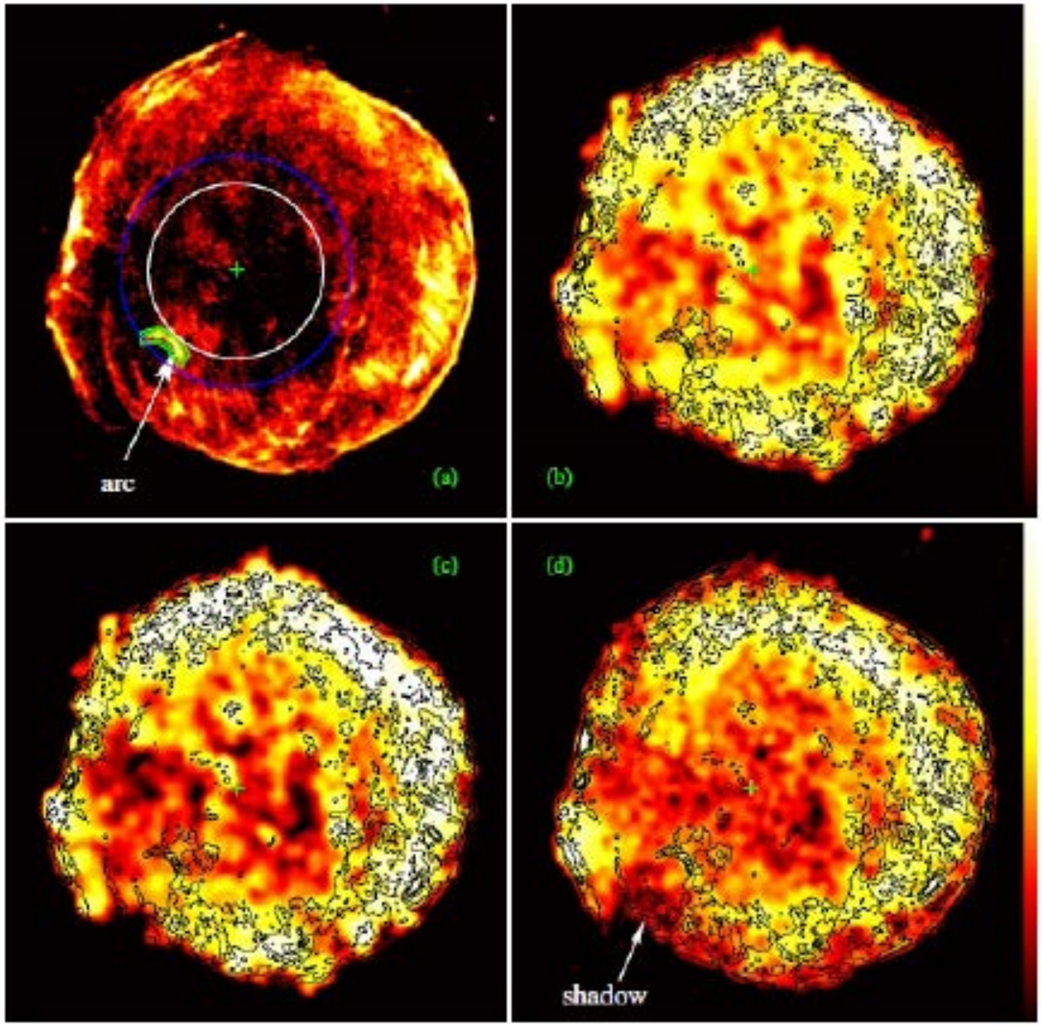

Histogram of the distribution in $\mu_\delta$ (in mas yr$^{-1}$) of the stars within 1° of the geometrical center of Tycho's SNR in the range of distance compatible with SN 1572 (1.7 <d < 3.7 kpc). The data are obtained from Gaia DR2. The red vertical line shows the $\mu_\delta$ of star G.

# Search of possible surviving binary companions in SNe Ia remnants




Proper motions of the candidate stars to companion of SN 1572 plotted over the distribution of all the stars with distance compatible with that of the SNR (1.7 < d < 3.7 kpc) and included within a radius of 1° of the remnant.

# Search of possible surviving binary companions in SNe Ia remnants




*Chandra* X-ray images of Tycho's SNR, in four energy bands. In the first panel, the arch attributed to interaction with the companion is indicated. In the other three, the "shadow" in the emission produced by the companion (Lu et al. 2011).

# SN 1006

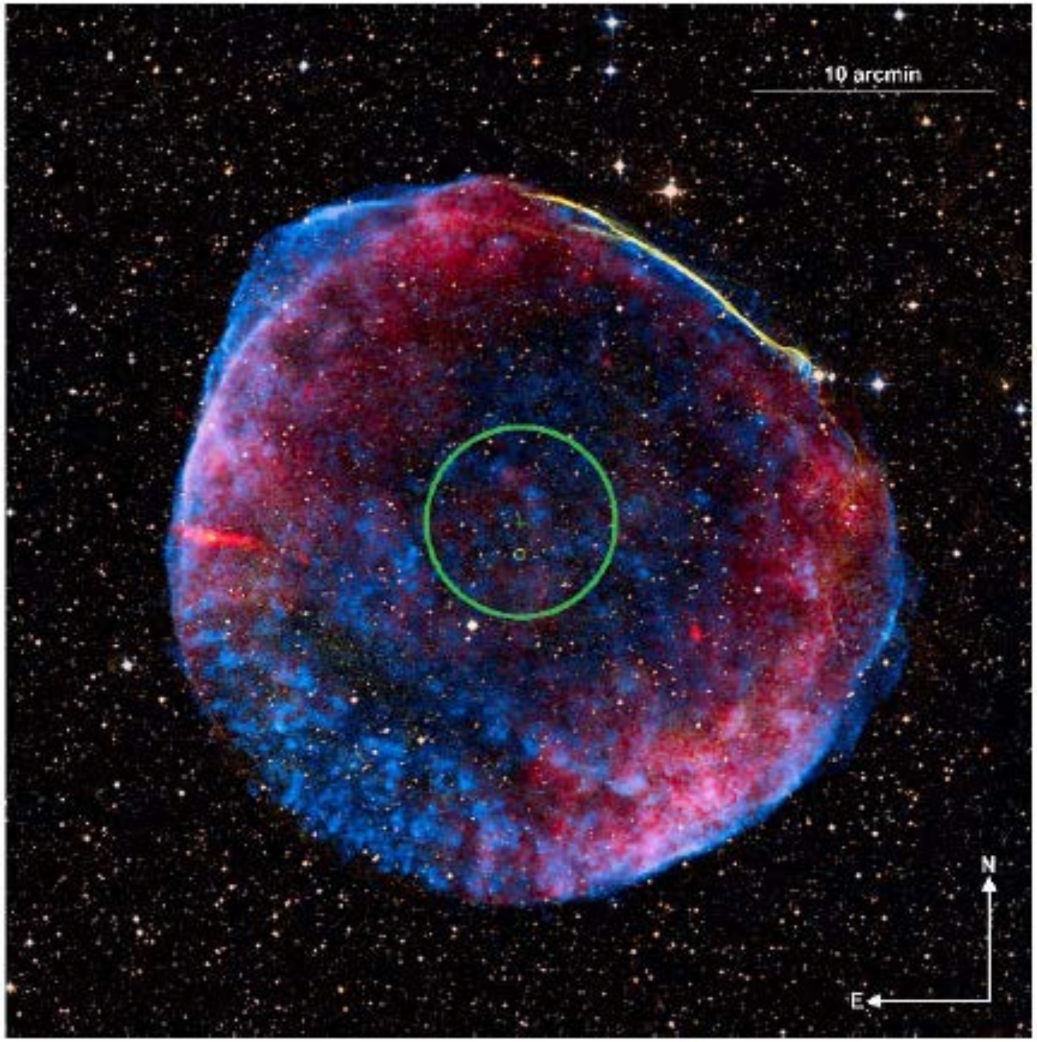
- Second SNR of the Ia type to be investigated (González Hernández et al. 2012; Kerzendorf et al. 2012).

- Survey complete down to stars slightly less luminous than the Sun.

- Only 4 stars (red giants) at distances compatible with that of the SNR. None of them a possible companion to the SN.

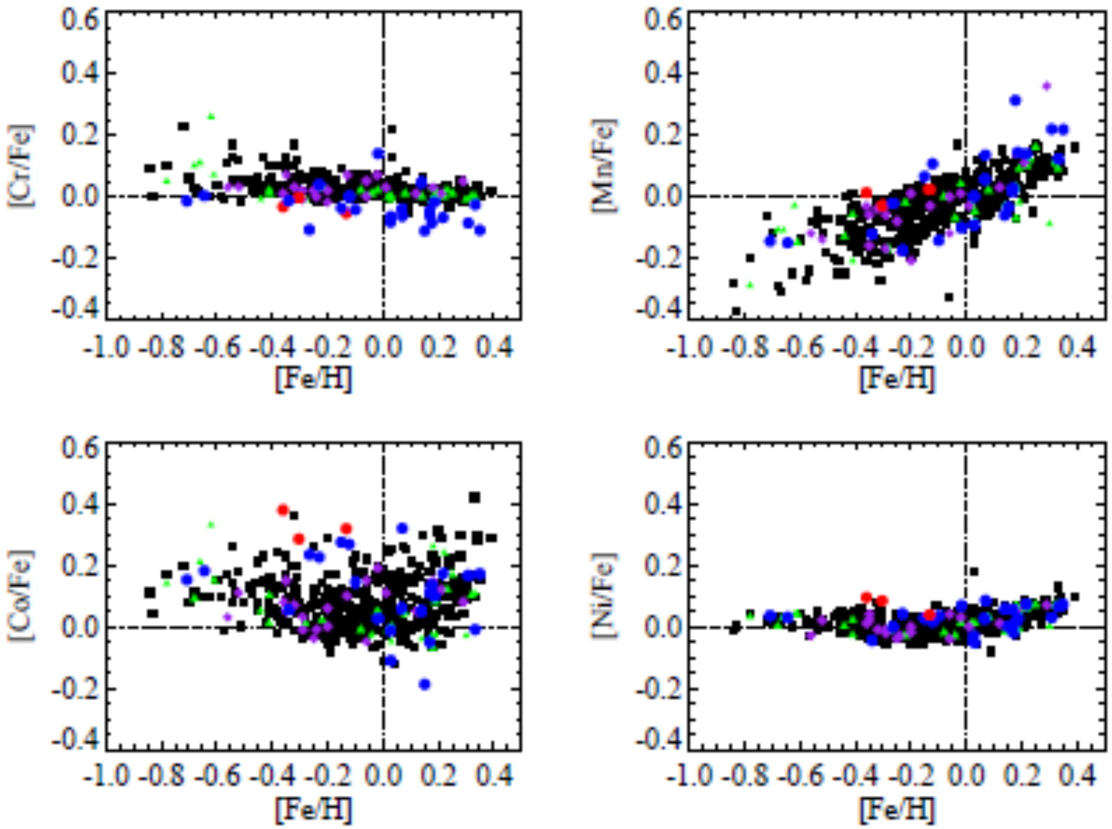
- Recent deep photometric survey (Kerzendorf et al. 2018). Rules out hot WD companions having captured radiactive material from the explosion (Shen & Schwab 2017). Also, cooler WDs resulting from the spin up-spin down mechanism and with cooling times $\leq 10^8$ yr.

# Search of possible surviving binary companions in SNe Ia remnants



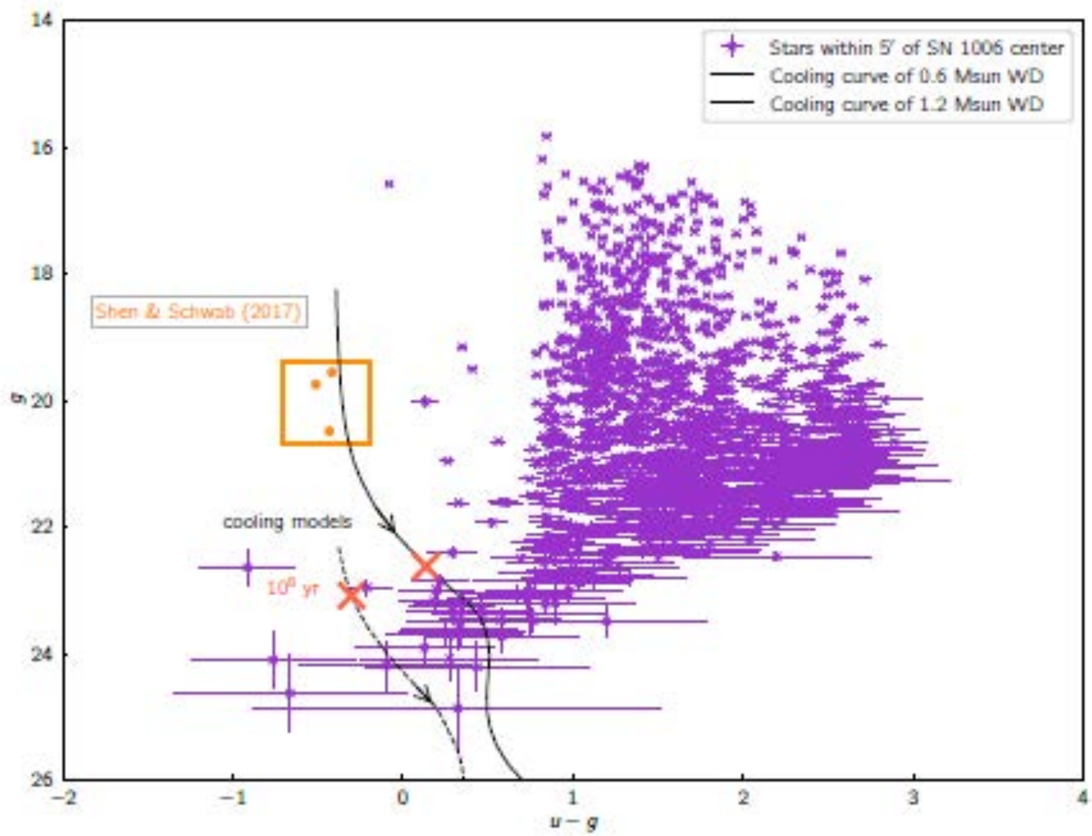

The remnant of SN 1006. The surveyed area is indicated by the large green circle, and the center of the survey with a green cross.

# Search of possible surviving binary companions in SNe Ia remnants




Stellar abundance ratios [X/Fe] of several Fe-peak elements. Red triangles correspond to the four red giants with distances compatible with that of the remnant. Blue squares, to the rest of the stars in the sample of González Hernández et al. (2012).

# Search of possible surviving binary companions in SNe Ia remnants




Color-magnitude diagram of the stars in the sample of Kerzendorf et al. (2018) in SN 1006, together with WD cooling curves (solid: 0.6 $M_\odot$ ; dashed: 1.2 $M_\odot$ ). In orange, the models of Shen & Schawab (2017).

# SN 1604 (Kepler's SN)

• Preliminary photometric and spectroscopic survey by Kerzendorf et al. (2014), with no likely candidates found. Excluded RGs as possible companions.

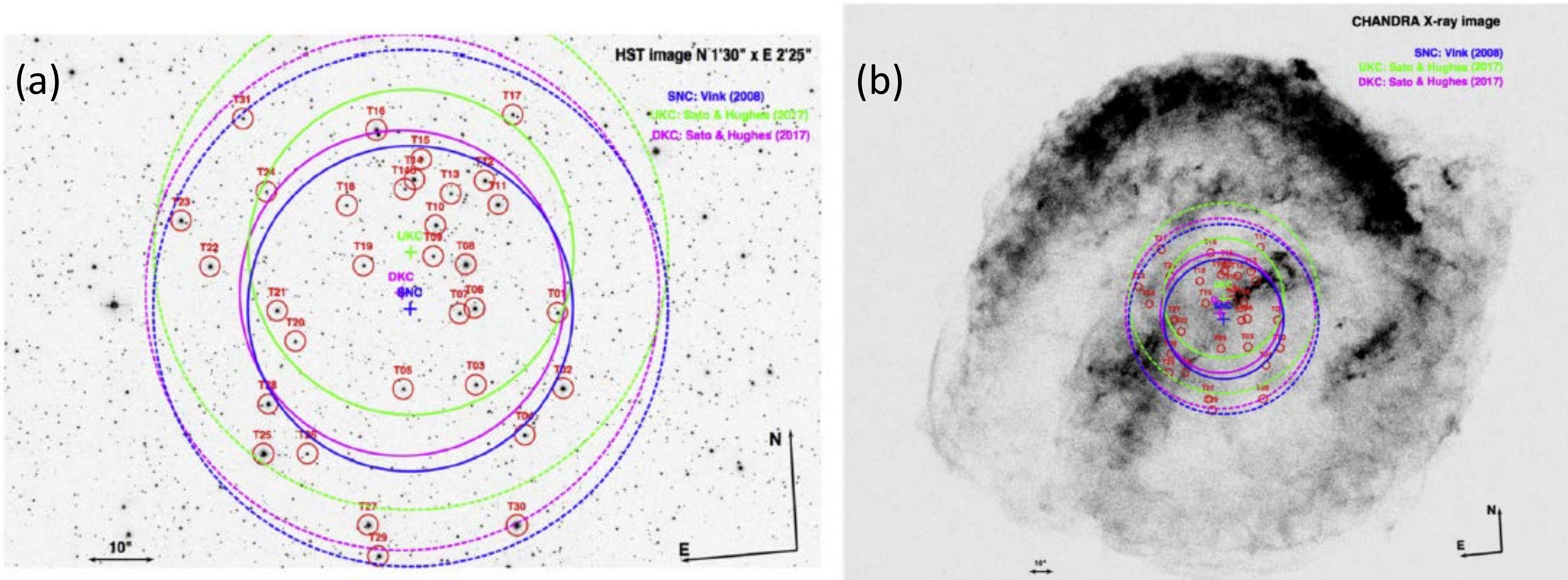
• New survey by RL et al. (2018). ESO VLT spectra and proper motions from the HST. Ordinary mixture of field stars (mostly RGs), some of them being metal-poor.

• Radial and proper motions consistent with the Besançon model of the Galaxy.

• No fast rotators.

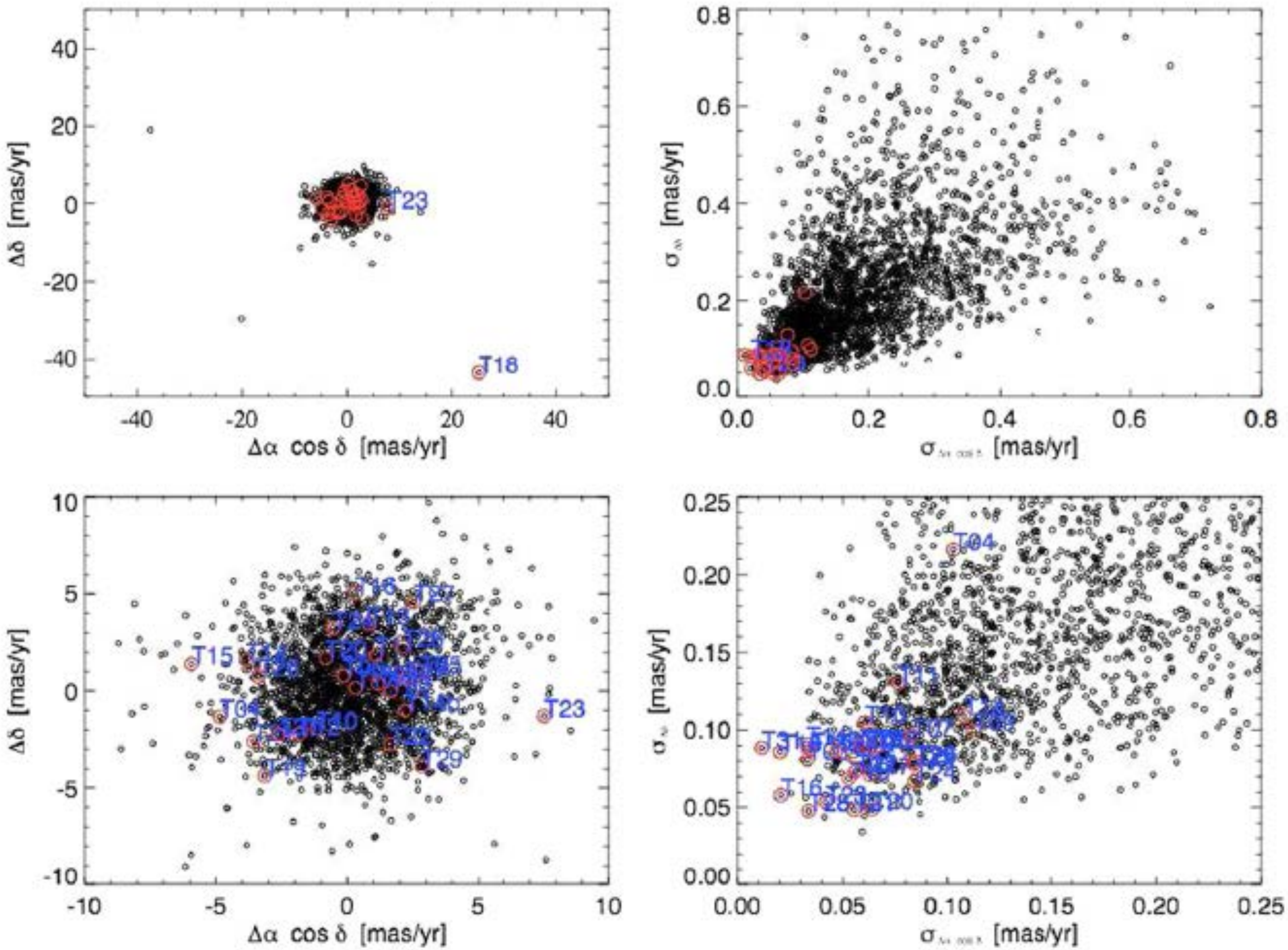
• Given the characteristics of the interstellar medium, a merging of a WD with the electron-degenerate core of a RG, within an AGB envelope (Kashi & Soker 2011), appears as a likely origin of the SN.

# Search of possible surviving binary companions in SNe Ia remnants



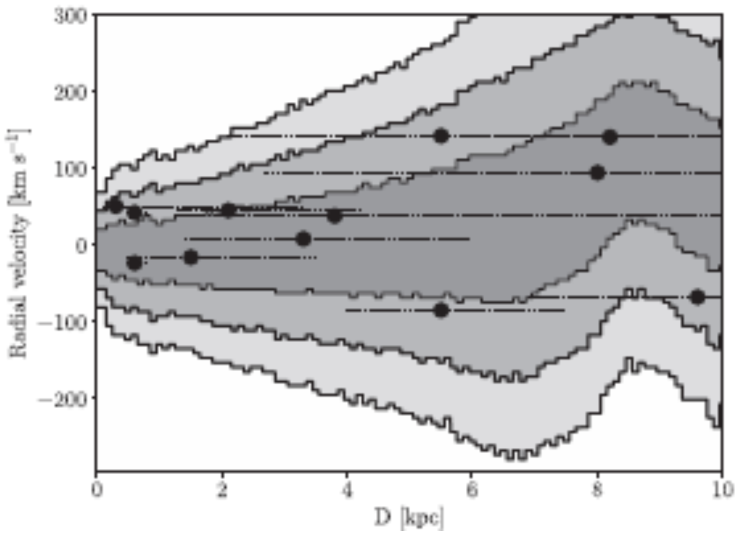

(a) Targeted stars in an image from the HST. Our adopted center of Kepler's SNR is marked with a blue cross. The big (solid line) blue circle corresponds to a radius of 24 arcsec around the center SNC of the SNR, where our primary targets are located. The big (dashed) blue circle (of 38 arcsec) around SNC encompasses our supplementary targets . (b) Chandra X-ray image in the iron-rich 0.7–1.0 keV of SN 1604, with the regions of search and labels as in (a).

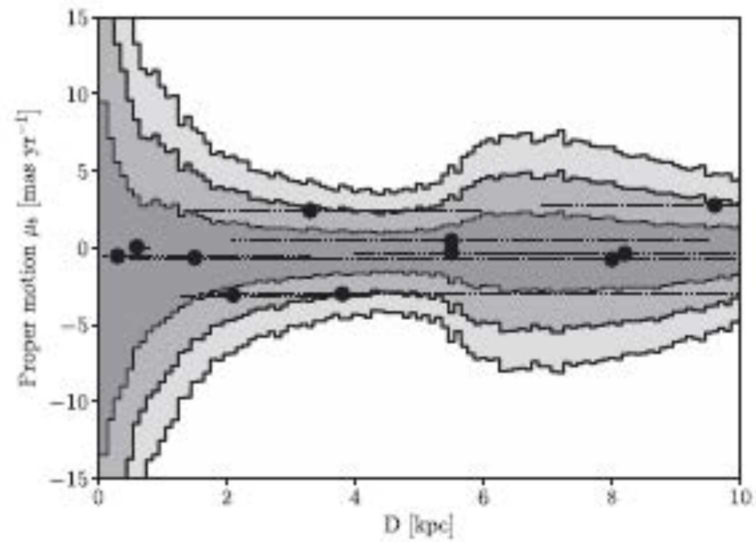
# Search of possible surviving binary companions in SNe Ia remnants




Vector-point diagrams (left panels) of the proper motions measured and their errors (right panels). The lower panels are close-ups of the upper ones.

# Search of possible surviving binary companions in SNe Ia remnants



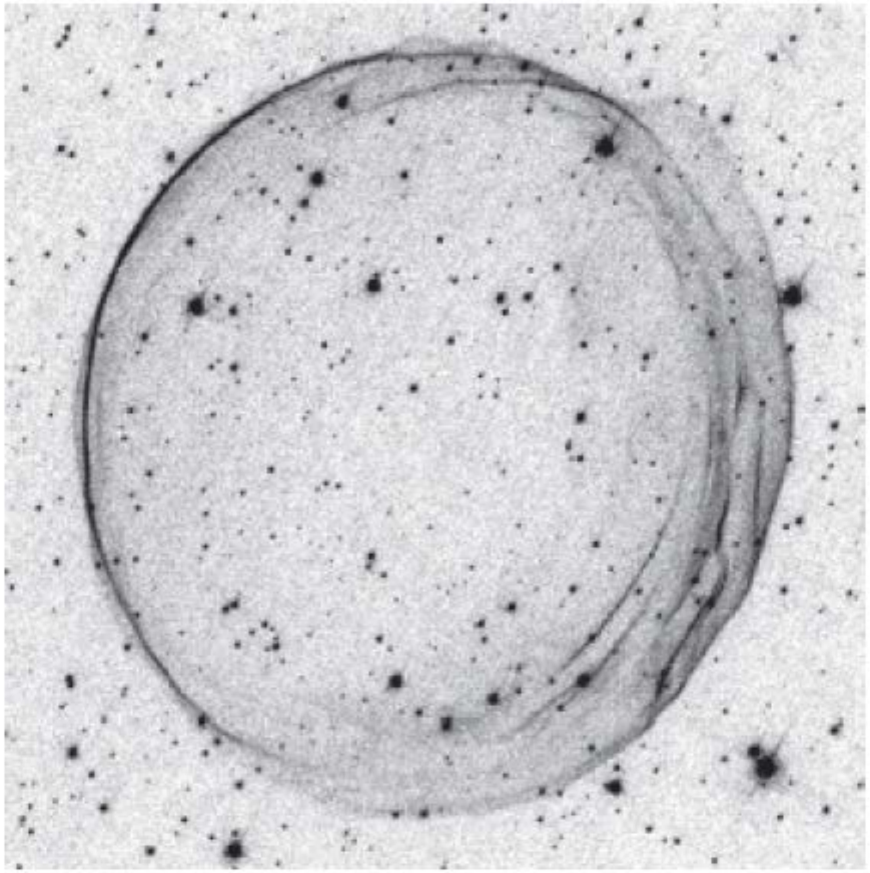

**Left:** Distances and radial velocities of the targeted stars with d <10 kpc, plotted over the distribution given by the Besançon model of the Galaxy.
**Right:** Same, for the proper motions perpendicular to the Galactic plane.

# Search of possible surviving binary companions in SNe Ia remnants

More or less completely explored SNe Ia SNRs in the **LMC**:

- SNR 0509-67.5 ( Schaefer & Pagnotta 2012)
- SNR 0519-69.0 (Edwards, Pagnotta & Schaefer 2012)
- SNR 0505-67.9 (DEM L71) and SNR 0509-68.7 (N103 B) (Pagnotta & Schaefer 2015; Li et al. 2017).
- SNR 0548-70.4 (Li et al. 2018)

# Search of possible surviving binary companions in SNe Ia remnants



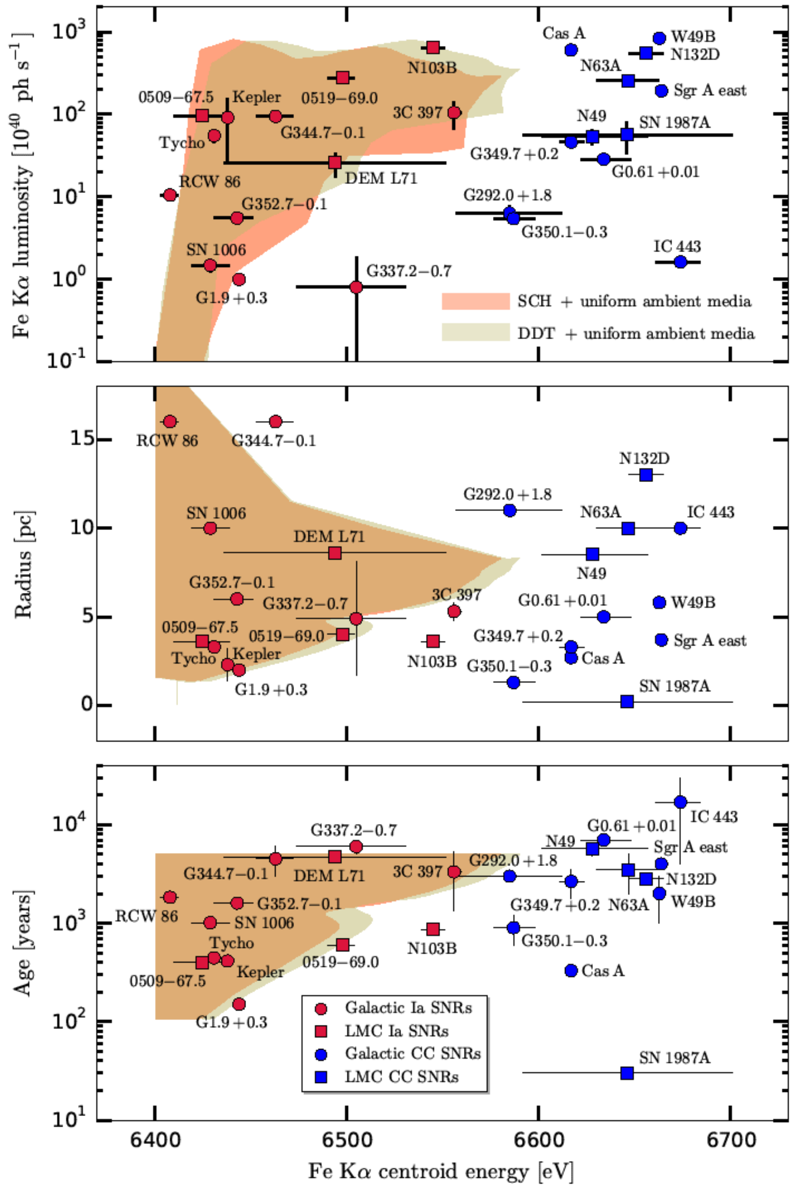
SNR 0509-67.5 in the H filter, obtained by the ACS on board HST (from Hovey, Hughes & Ericksen 2015).

# Opportunities to search for surviving binary companions ot Type Ia supernovae

**Further Galactic SNRs of the Ia type to be explored**

# Opportunities to search for surviving binary companions ot Type Ia supernovae

Fe K luminosity, radius and expansion age as a function of the Fe K centroid energy for Ia (red) and CC (blue) SNRs. The shaded regions depict the predictions from the theoretical MCh (khaki) and sub-MCh (dark orange) models with uniform ISM densities of Martínez-Rodríguez et al. (2018).



# Opportunities to search for surviving binary companions ot Type Ia supernovae

Distances, size and ages of the Ia SNRs

| Name | Distance (kpc) | Size (Radius) (arcmin) | Age (years) |
|---|---|---|---|
| Kepler | $5 \pm 0.7$ | 1.9 | 414 |
| 3C 397 | $6.3 - 9.8$ | 1.7 | $1350 - 1750$ |
| Tycho | $2.83 \pm 0.79$ | 4.3 | 446 |
| RCW 86 | 2.5 | 21 | 1833 |
| SN 1006 | $2.18 \pm 0.08$ | 15 | 1012 |
| G1.9+0.3 | 8.5 | 0.8 | $\sim$150 |
| G272.2-3.2 | $1 - 3.2$ | 10 | 8000 |
| G337.2−0.7 | $2.0 - 9.3$ | 3 | $\sim 5000$ |
| G299.2-2.9 | 5 | 5 | 5000 |
| G344.7−0.1 | $6 - 14$ | 5 | $3000 - 6000$ |
| G352.7−0.1 | 7.5 | 3.5 | $\sim 4700$ |
| N103B | 50 | 0.2 | $\sim 860$ |
| 0509−67.5 | 50 | 0.27 | $\sim 400$ |
| 0519−69.0 | 50 | 0.3 | $\sim 600$ |
| 0548−70.4 | 50 | 0.9 | $10,000$ |
| DEM L71 | 50 | 0.7 | $\sim 4700$ |

# G272.2-3.2

An ongoing project

- SNR discovered in the *ROSAT* All-Sky survey
- Produced by a SN Ia explosion and **~10,000 yr old**
- At a **distance ~2 kpc**
- **Diameter** of the remnant: **20 arcmin**
- Given the old age of the SNR and its short distance, stellar companions might have traveled far, on the sky, from the site of the explosion
- Red-giant companions would move at the lowest velocities (~ 60 km/s), subgiants up to 180 km/s, while main-sequence companions would be the fastest-moving ones (~ 300 km/s)

# Opportunities to search for surviving binary companions ot Type Ia supernovae

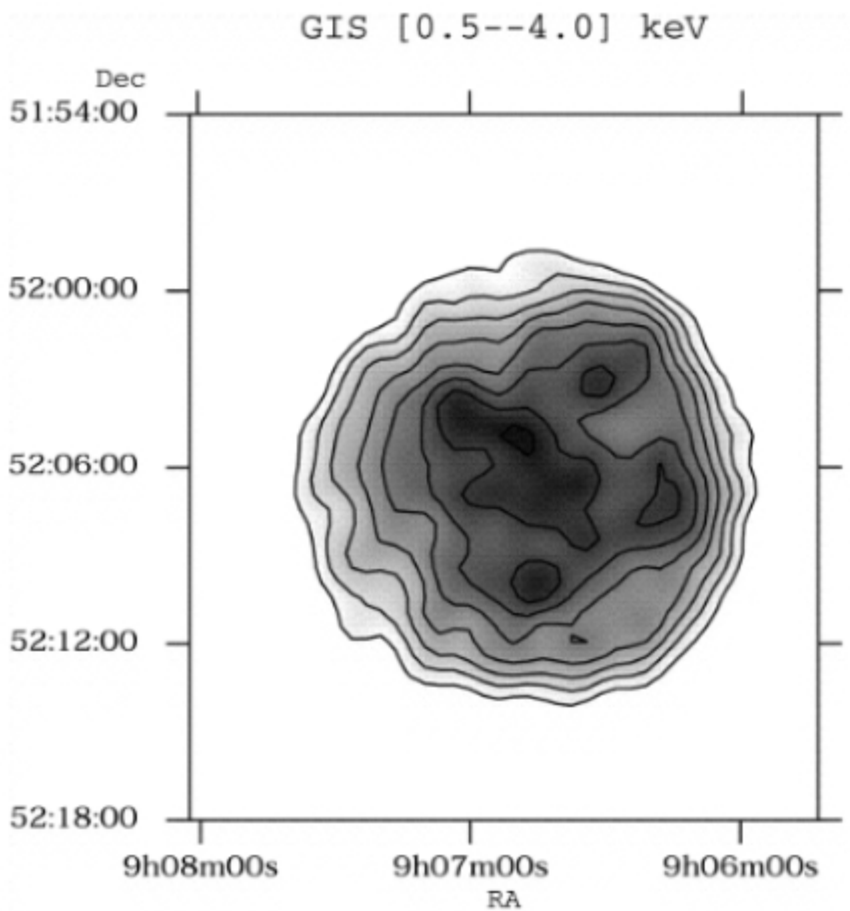



Image of G272.2-3.2 in the 0.5-4.0 keV band, taken with the Gas Imaging Spectrograph (GIS) aboard the Advanced Satellite for Cosmology and Astrophysics (ASCA). Contour values linearly spaced from 30% to 90% of the peak surface brightness (from Harrus et al. 2001).

# Opportunities to search for surviving binary companions ot Type Ia supernovae

- Plan to explore the innermost 32% of the radius (3.2 arcmin), which corresponds to the maximum distance from the explosion site that would be reached by a **subgiant companion** moving perpendicularly to the line of sight (main-sequence companions migh reach up to about half the radius of the SNR)

- $m_R$ **= 18 mag** inside that inner core (the brightness of the Sun at 3.2 kpc, the upper limit to the distance, for an extinction $A_R$ **= 1.28 mag** in the direction of the SNR)

- Down to $m_R$ **= 15.8 mag** (red giants), use FLAMES/UVES
Fainter candidates, with FLAMES/GIRAFFE/IFU

- Same analysis as in the SN 1604 case

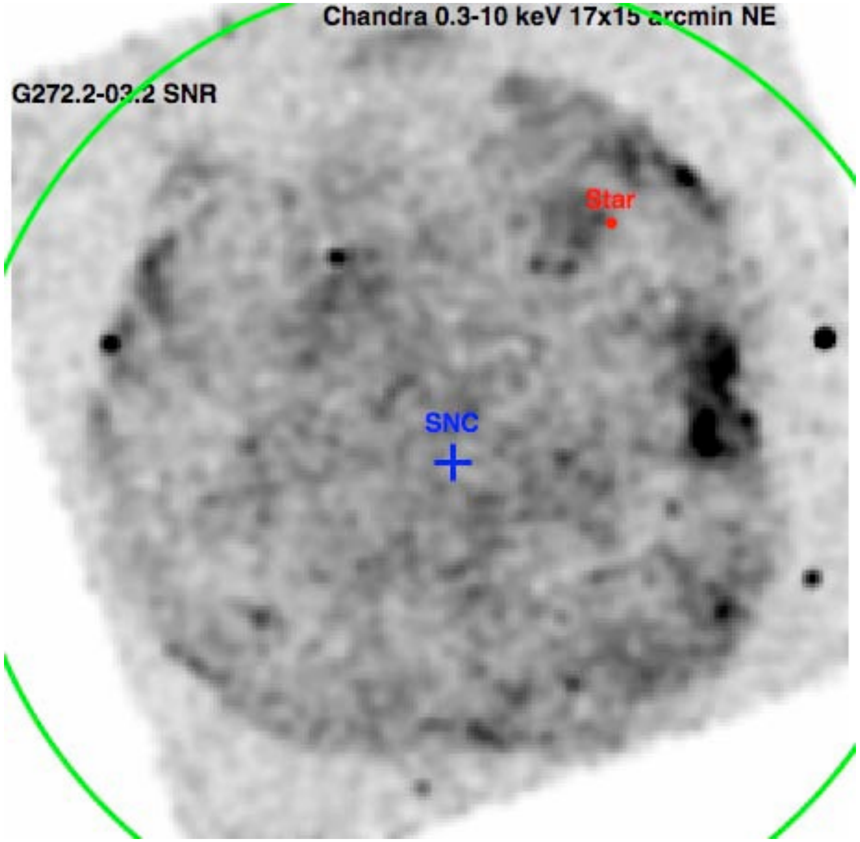
- HST measurements of proper motions of the targeted stars

# Opportunities to search for surviving binary companions ot Type Ia supernovae

- With this observing plan**,** **red-giant** and **subgiant** candidates should be either identified or have their presence excluded

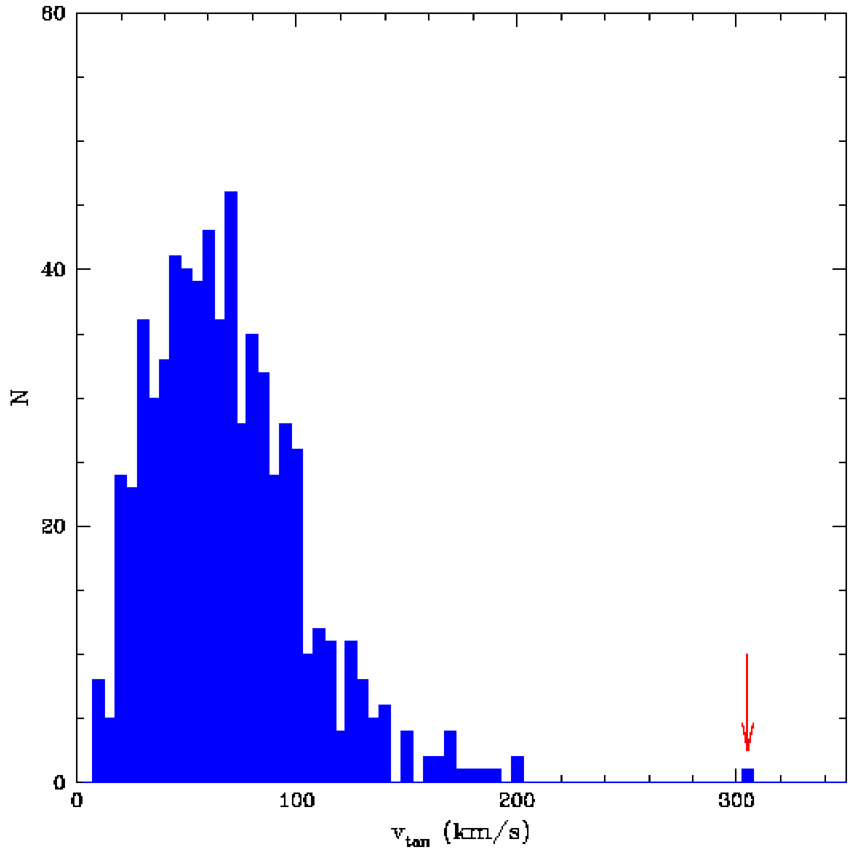
- The absence of **main-sequence** candidates, instead, could not be concluded, since they might be located at longer distances from the center of the SNR

# Opportunities to search for surviving binary companions ot Type Ia supernovae



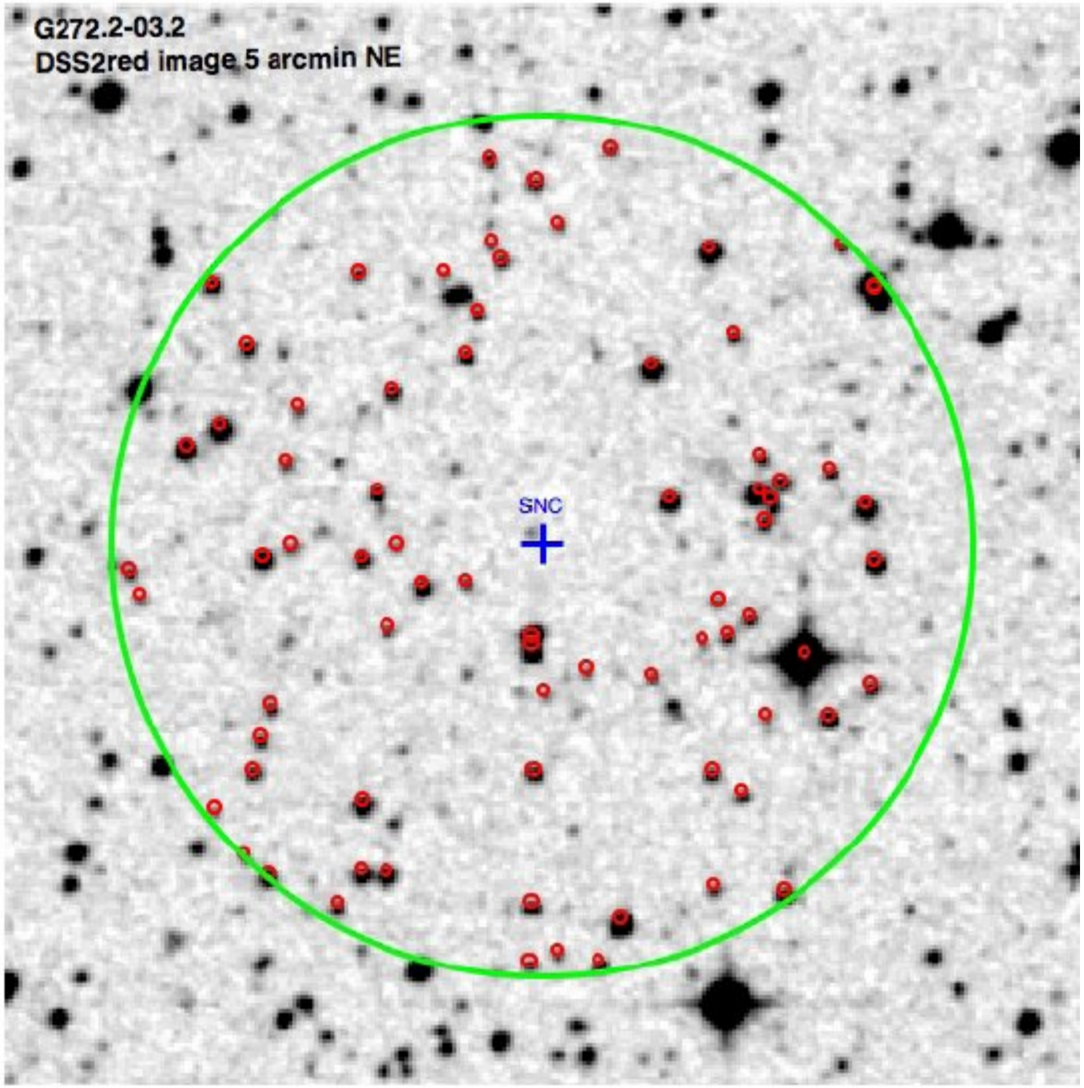

*Chandra* X-ray image of the SNR G272.2-3.2. The centroid of the remanant is marked with a blue cross. An outlier in tangential velocity is marked in red.

# Opportunities to search for surviving binary companions ot Type Ia supernovae




Tangential vel distances
compatible wi he red arrow.

# Opportunities to search for surviving binary companions ot Type Ia supernovae




The central region of **G272.2-3.2**

# G299.2-2.9

- Discovered in the *ROSAT* All-Sky Survey

- Presents an ideal case to test the **core-degenerate scenario** (Ilkov & Soker 2012; Soker et al. 2013)

- The SNR is **asymmetric**, with a diameter of 10 arcmin in the E-W direction and 9.3 arcmin in the N-S direction. The complex structure suggest that the SN exploded in a nonuniform medium

- Distance **d ~ 5 kpc**

- **Age ~ 4500 yr**

# Opportunities to search for surviving binary companions ot Type Ia supernovae

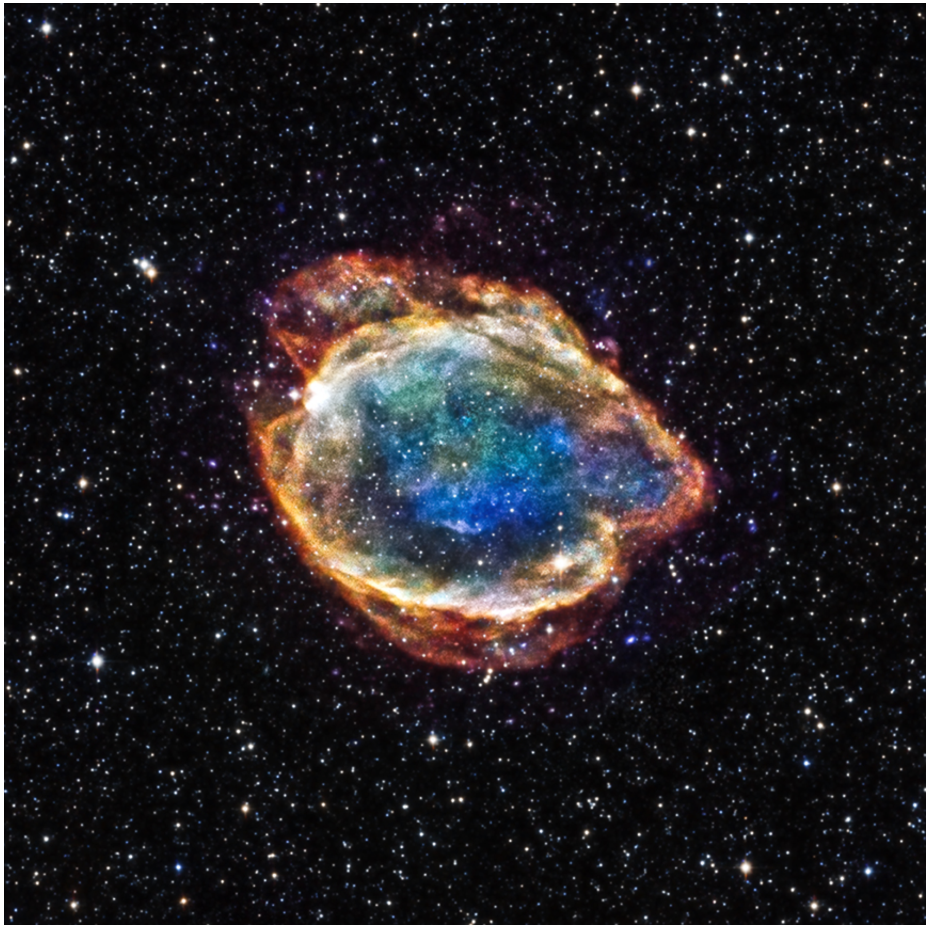


Image of SNR G299.2-2.9 from Chandra. The colors represent soft (red), medium (green) and hard (blue) X-ray emission. The field shown is 24 arcmin in size.

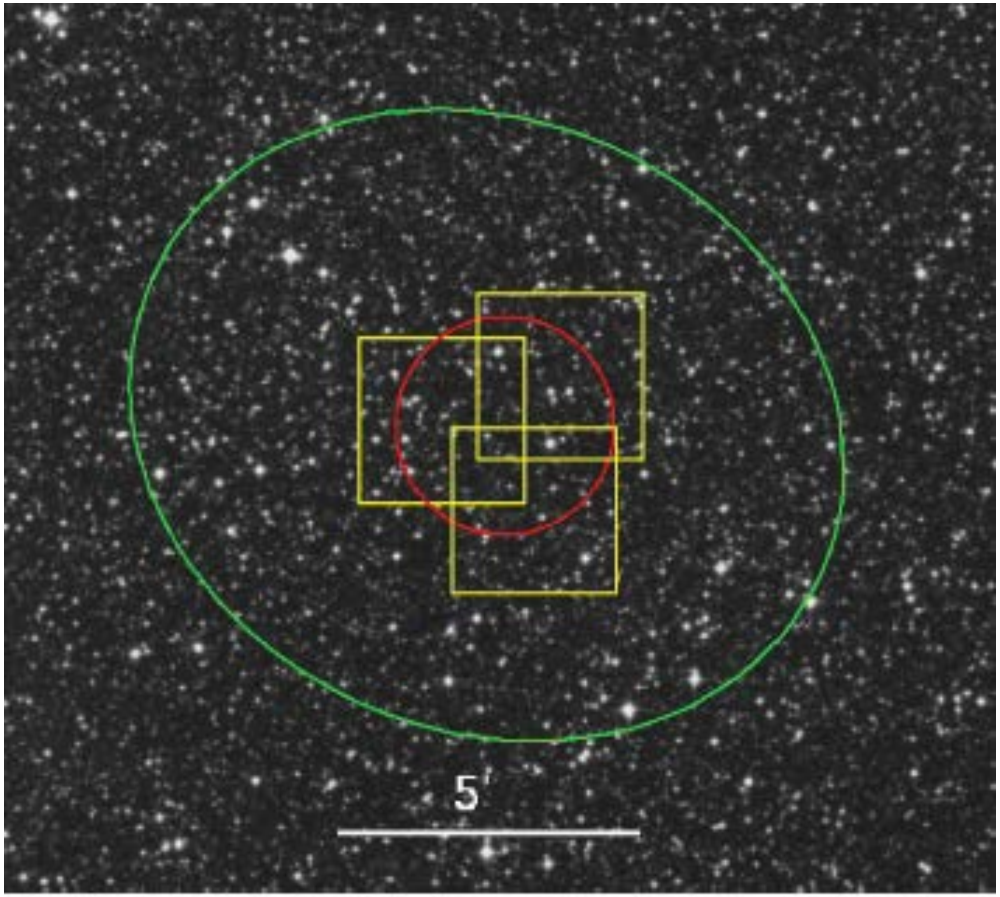
# Opportunities to search for surviving binary companions ot Type Ia supernovae

- It has been suggested (Tsebrenko & Soker 2013) that the asymmetry might be due to bipolar outflows of stellar winds, as seen in planetary nebulae

- A search within a radius of **1.8 arcmin** from the geometrical center of the remnant (20% of the radius of the SNR) would take due account of the asymmetry

- Going down to **$m_R$ = 23** would test all the stars down to **Solar luminosity**

# Opportunities to search for surviving binary companions ot Type Ia supernovae




A DSS image of the region of G299.2-2.9. The green ellipse approximates the main shell of the SNR. The red circle is the primary 1.8 arcmin radius search area to cover. Three WFC3 UVIS fields are shown in yellow to indicate how they cover the search area for the SN companion star.

# G1.9+0.3

Another ongoing project

- Discovered in 2008, and believed to be the remnant of a SN Ia that exploded by around **1900**

- It is at a distance **d = 8.5 kpc** (Carlton et al. 2011). Very close to the Galactic plane (**b = 0.3 deg**) and in the direction of the Galactic center (**l = 1.9 deg**)

- Subtends a **radius** of only **50 arcsec** on the sky

- **Absorption**: ≈ **1.8 mag** in the **K-band** (Reynolds et al. 2008), consistent with the Besançon model of the Galaxy, but still subjected to large uncertainty

- The SN being so recent, a possible companion cannot have moved far away from the site of the explosion (just ≈ 1.2 arcsec, if moving at 300 km/s perpendicularly to the line of sight)

# Opportunities to search for surviving binary companions ot Type Ia supernovae

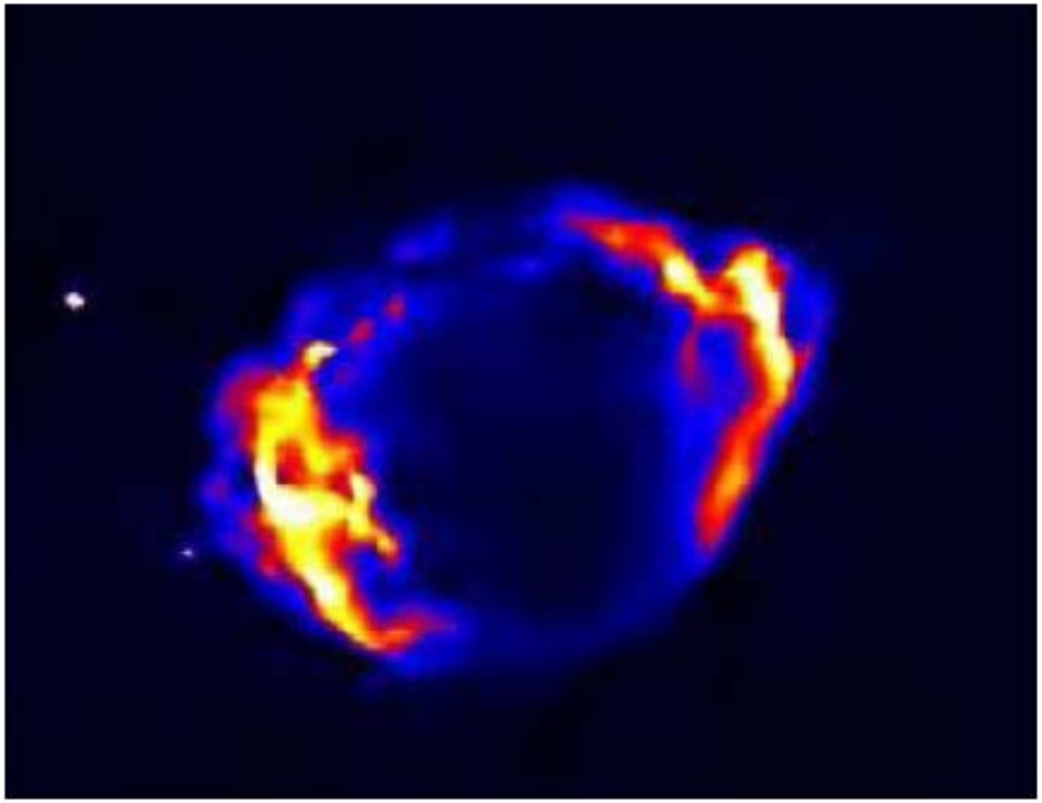


Image in X-rays of G1.9+0.3. It is worth reminding that this image is of a remnant of only 50 arcsec of radius. The search radius could encompass stars within the10 arcsec radius (20% of that of the SNR). Image adapted from Borkowski et al. (2017).

- Given the large extinction, it should be a target for the ***JWST***

# Opportunities to search for surviving binary companions ot Type Ia supernovae

- A search within a radius of **10 arcsec** (20% of the radius) should amply account for any difference , due to the asymmetry of the expansion, between the geometrical center of the SNR and the site of the explosion (Borkowski et al. 2017 estimate that it occurred somewhat NE of that center)

- Thus, the circle to be searched is exceptionally small, and the number of possible companion candidates should be very manageable

- A first step would be to characterize photometrically such candidates. Given the heavy extinction at longer wavelengths, **J, H, and K photometry** is most adequate

Information about the effective temperatures is then obtained and comparison with synthetic colours already gives an idea of whether those stars are main sequence or giants

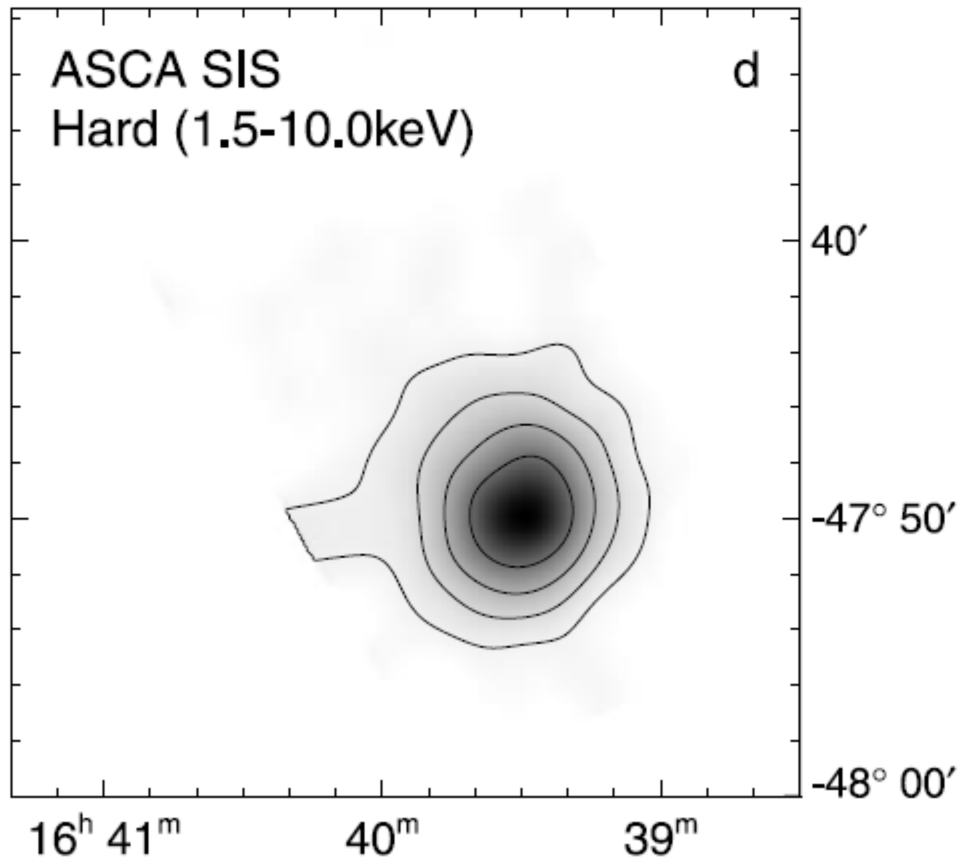
- Given the distance to the SNR, going down to **$m_K = 23$** includes all stars with luminosites down to the **Solar luminosity** (the Sun would only have $m_k = 17.94$ at 8.5 kpc, but with the assumed extinction it goes to $m_K = 19.74$)

# G337.2-07

Another possible project

- Has an **angular diameter** of **~ 6 arcmin**
- **Distance 8.5 kpc**. Very close to the Galactic plane (**b = 0.7 deg**)
- **Age** between **750** and **3500 yr**
- The **abundance ratios** of the chemical elements, in the SN ejecta, are best fitted by **SN Ia models** (Rakowski et al. 2001, 2006)
- Explore a radius of **2 arcmin** from the centroid of the X-ray emission

# Opportunities to search for surviving binary companions ot Type Ia supernovae




X-ray image of **G337.2-0.7**

Rakowski et al. (2001)

# Opportunities to search for surviving binary companions ot Type Ia supernovae

- In fact, at the upper limits on age and distance, a **main-sequence** companion would have traveled only **0.4 arcmin**, at most, from the site of the explosion, and **1.6 arcmin** for the upper limit on age and lower limit on distance (red-giant companions would have traveled 1/5, and subgiant companions less than 2/3 of those distances)

- Due to the low galactic latitude, the extiction is high at short wavelengths, and we should go to the infrared

- As in the case of **G1.9+0.3**, reaching down to **$m_K$ = 23** would, for the given distance, allows to reach down to the **Solar luminosity**, even taking into account the uncertainty concerning extinction.

- Also here, a target for the ***JWST***.

# 3C 397 (G41.1-03)

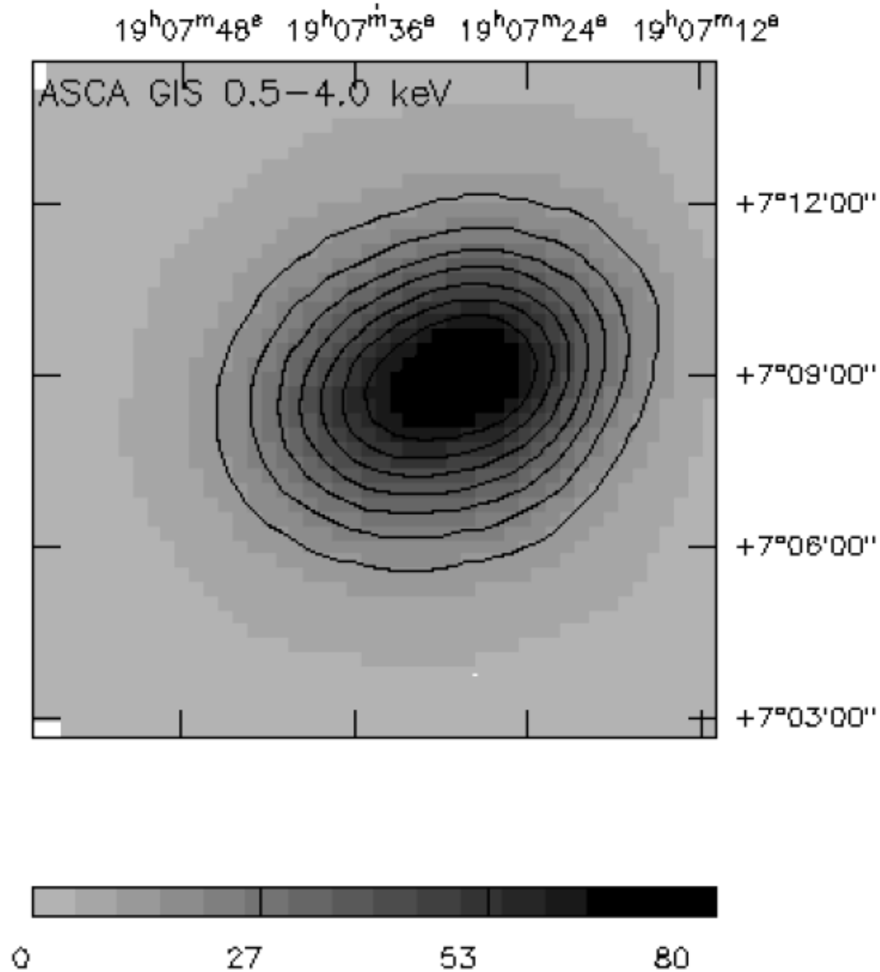
- The explosion of a **white dwarf** with a mass close to the **Chandrasekhar mass** (Yamaguchi et al. 2015), from the degree of neutronization of the ejecta shown by the **high Ni/Fe** and **Mn/Fe mass ratios**

- **Shape** close to elliptical, with a mean angular radius of **≈ 1.8 arcmin**

- **Distance ~ 10 kpc**. Very close to the Galactic plane (**b = -0.3 deg**)

- **Age ≈ 1750 yr** (Safi-Harb et al. 2000)

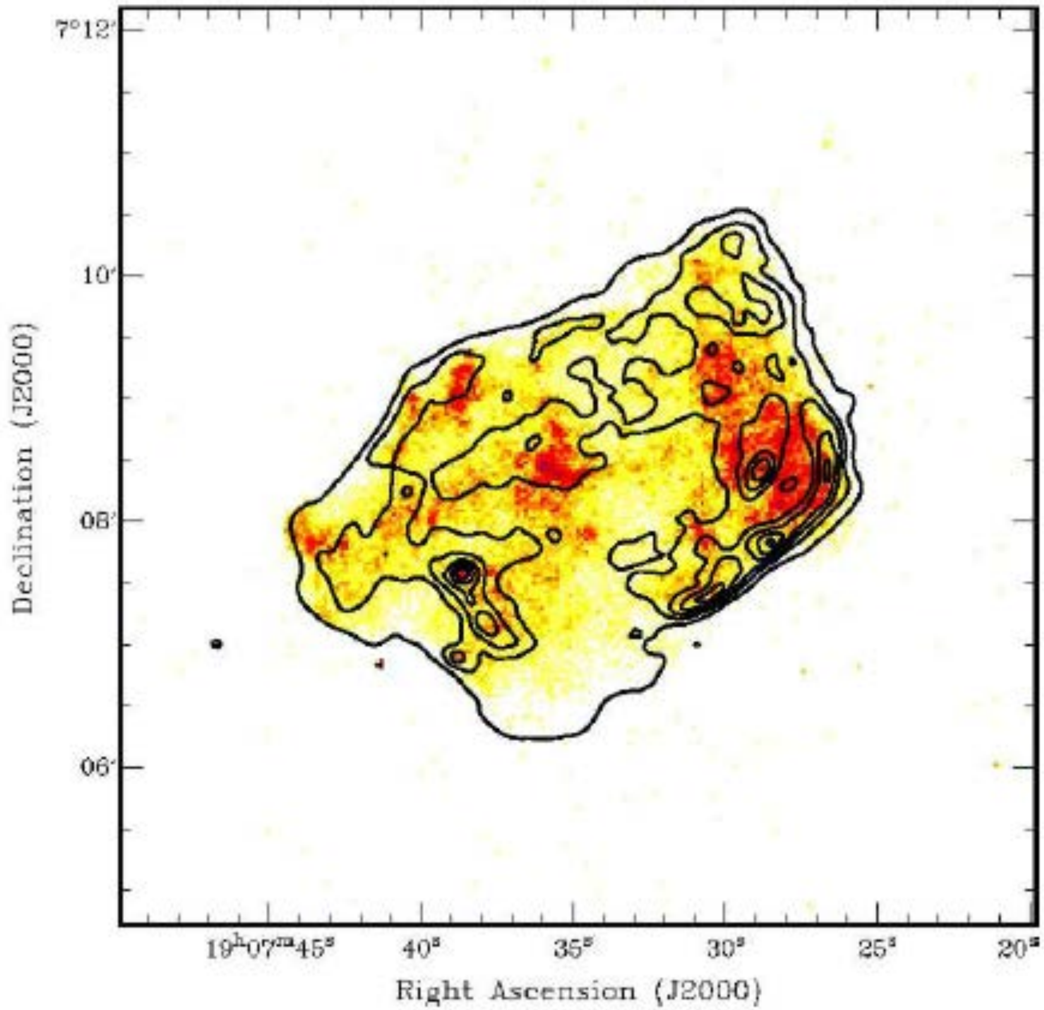
# Opportunities to search for surviving binary companions ot Type Ia supernovae




*ASCA* image of **3C 397**

Safi-Harb et al. (2000)

# Opportunities to search for surviving binary companions ot Type Ia supernovae




Chandra 0.3-10 keV image of the 3C 397 SNIa remnant showing the VLA L-band intensity contours overlaid, from Safi-Harb et al (2005).

# Opportunities to search for surviving binary companions ot Type Ia supernovae

- For that **age** and **distance**, a possible **main-sequence** companion would have moved **0.3 arcmin**, at most, from the site of the explosion

- Explore, however, the region within **1 arcmin** radius from the centroid of the X-ray emission, due to the **asymmetry** of the SNR

- Again, an object at low galactic latitude, which means heavy extinction at short wavelengths

- The **Sun** would have **$m_K$ = 18.3** at that distance (without extinction), so going down to **$m_K$ = 23** ensures reaching down to **Solar luminosity**, allowing for a large error in the extinction.

- Also a case for the ***JWST***.

# RCW86

- Generally assumed to be the remnant of SN 185.

- Very extended and of irregular shape, which makes the location of the explosion site uncertain.

- Recently been studied but no published results yet.

# Opportunities to search for surviving binary companions ot Type Ia supernovae

Combined image of RCW86, from X-rays (XMM Newton and Chandra) and infrared data (Spitzer Space Telescope Observatory and Wide-Field Infrared Survey Explorer). X-rays are in blue and green. Infrared emission, in yellow and red.

# Opportunities to search for surviving binary companions ot Type Ia supernovae

- Three Galactic SNRs have alredy been explored to search for possible surviving binary companions of Type Ia supernovae + five SNRs in the Large Magellanic cloud

- That has not exhausted the numbers of Galactic SNRs that can be explored to the same end

- Instances of the latter are:

**G272.2-3.2**: ~ 10,000 yr old and at a distance ≈ 2 kpc
**G1.9+0.3**: ≈ 100 yr old and at a distance ≈ 8.5 kpc
**G299.2-2.9**: ~ 4,500 yr old and at a distance ≈ 5 kpc
**G337.207**: ≈ 750-3,500 yr old, at distance ≈ 2-9 kpc
**G41.1-0.3**: ≈ 1,750 yr old and at a distance ≈ 10 kpc

# SUMMARY

- Three Galactic SNRs of SN Ia (Tycho, SN 1006 and Kepler), plus other five in the LMC, have been explored, with only one disputed candidate (in Tycho) having been found in the Galaxy and another having been suggested in the LMC.

- Only the very faint companions predicted from the spin up-spin down mechanism (for long enough spin down timescales) could have escaped detection in those cases, plus possible hot subdwarf companions as predicted by Meng & Li (2019).

- There are two good Galactic SNRs still to be explored: G272.2-3.2 and G299.2-2.9. In one of them, *Gaia* DR2 astrometry has singled out a possible SN companion.

- Other Galactic SNRs identified as being of type Ia, the very young G1.9+0.3, 3C397, G344.7-0.1, G352.7-0.1, or G337.2-0.7, due to the strong interstellar extinction in their directions, are targets for the ***JWST***.