RCW 86 as the remnant of a calcium-rich core-collapse supernova explosion

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in collaboratiom with

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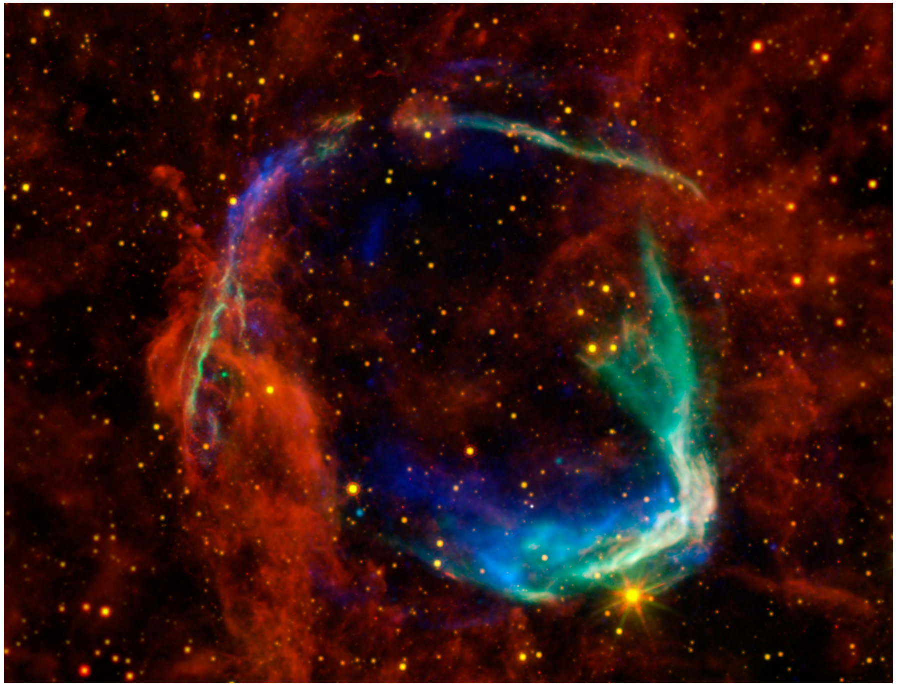
Supernova remnant RCW 86

age: ~ few 1000 yr

distance: ≈2.3 kpc

diameter: 40′ or ≈26 pc

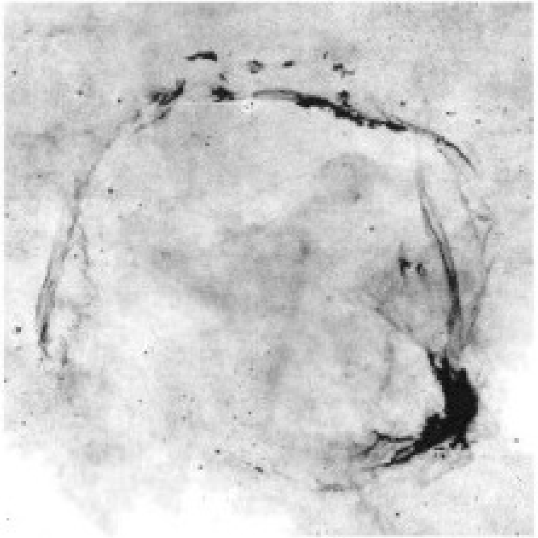


XMM-Newton/Chandra (blue & green)

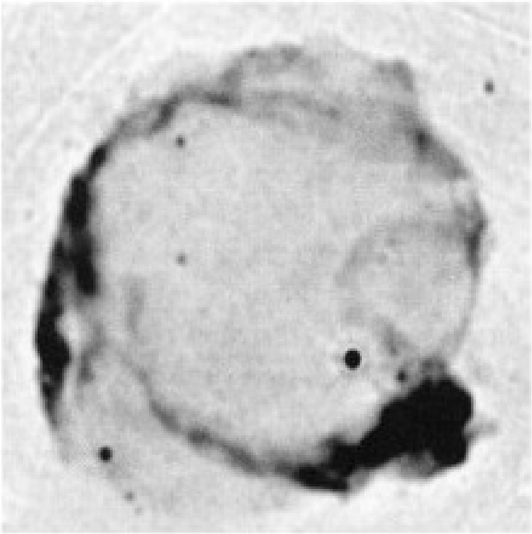
WISE/Spitzer (yellow & red)

Supernova remnant RCW 86

X-ray



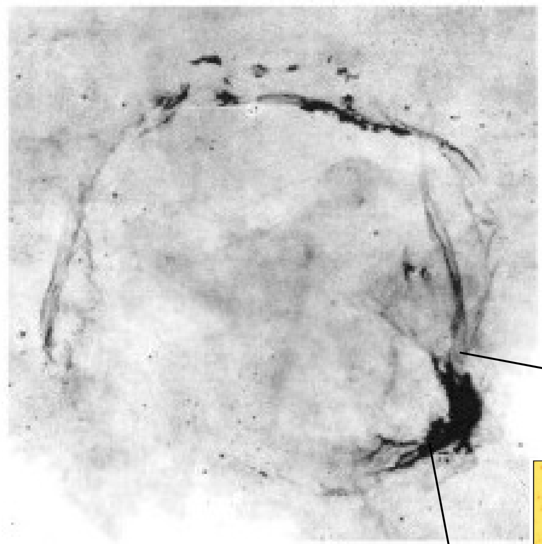
Hα

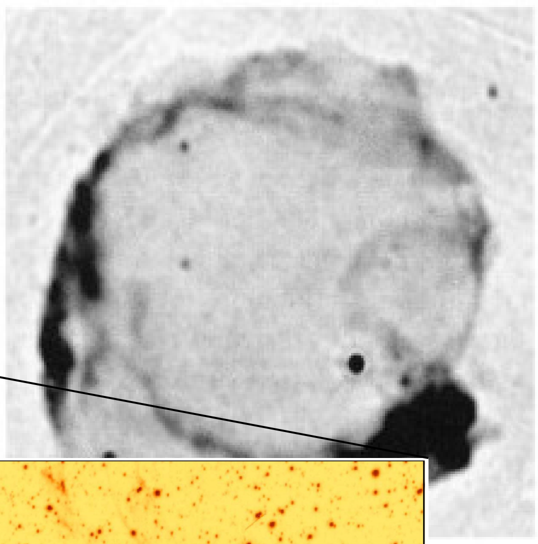


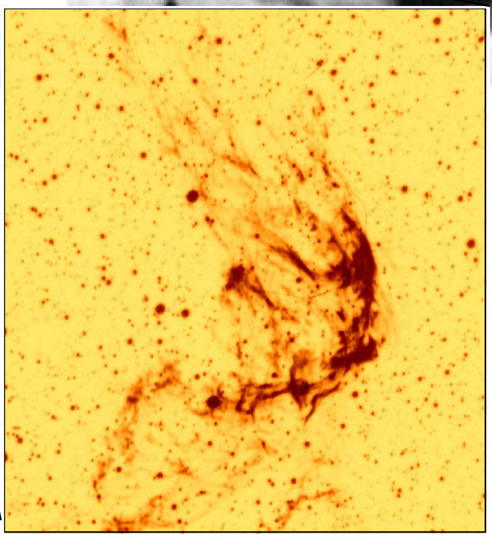
radio

(Smith 1997)

Supernova remnant RCW 86







X-ray

Hα

radius ≈2′ or 1.1 pc

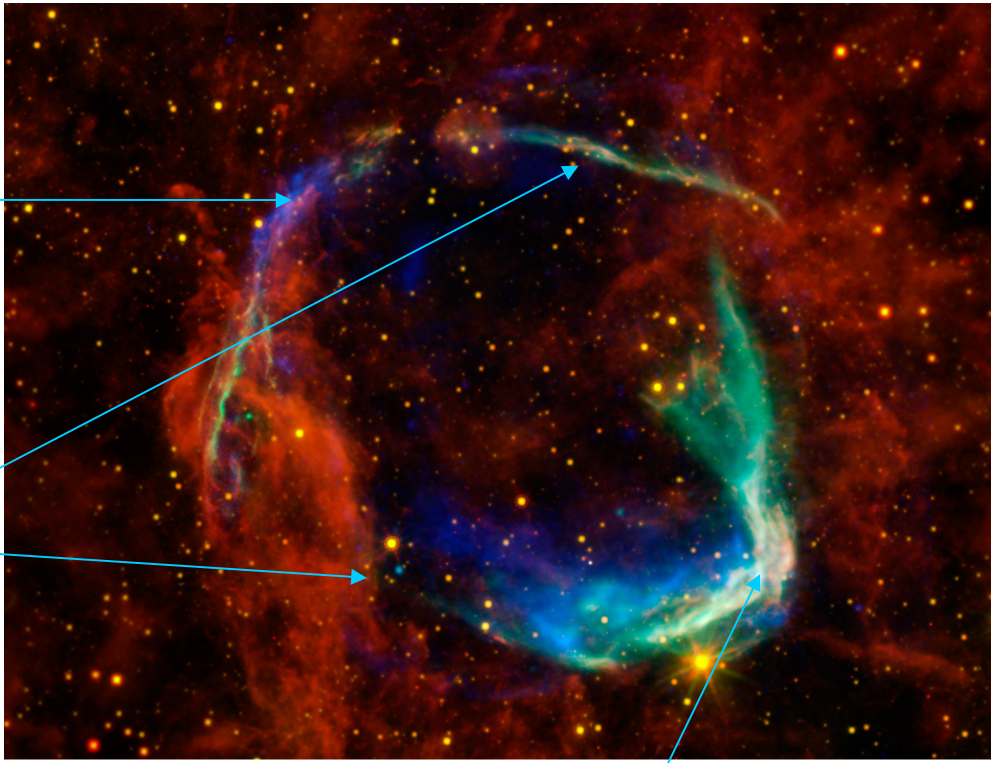
Supernova remnant RCW 86

3000 km/s

(Yamaguchi et al. 2016)

500–600 km/s

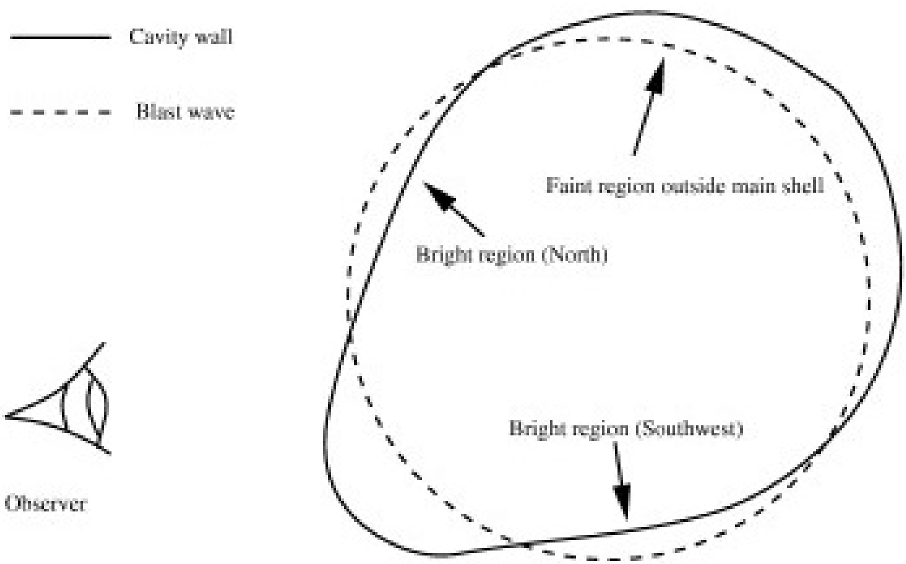
(Long & Blair 1990)



~100 km/s (Ruiz 1981)

RCW 86: cavity supernova explosion

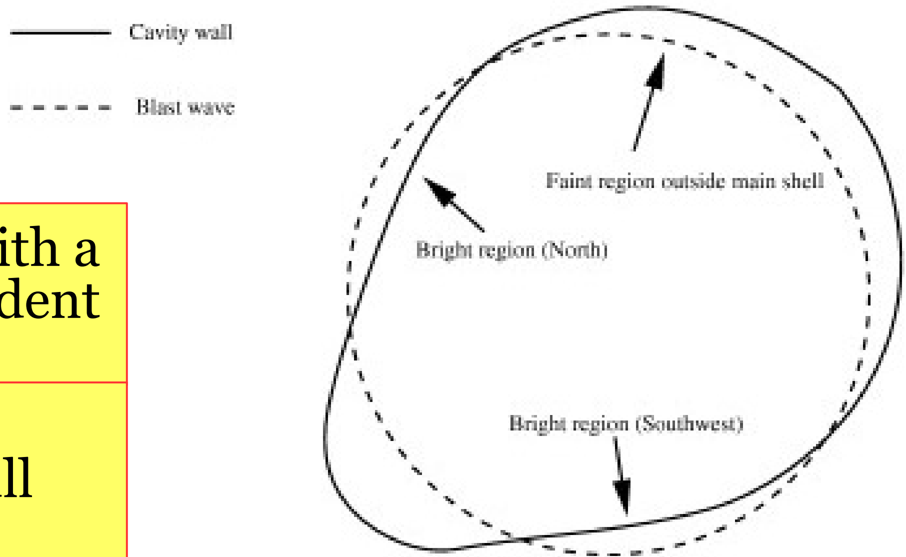
- stellar wind of the supernova progenitor created a low-density bubble
- density gradient in the ISM => elongated bubble
- optical arc in the south-west is the result of interaction between the blast wave and a dense cloudlet
- stellar remnant (neutron star) should be near the centre of RCW 86



(Vink et al. 1997)

RCW 86: cavity supernova explosion

- stellar wind of the supernova progenitor created a low-density bubble
- density gradient in the ISM => elongated bubble
- but: interaction of the blast wave with a cloudlet should result in a concave dent in the shell, not in a protrusion
- searches for a neutron star in the central region of RCW 86 gave a null result => type Ia supernova



(Vink et al. 1997)

Wind-driven bubble: static star

R_1 , R_2 – shock waves

R_c – contact discontinuity

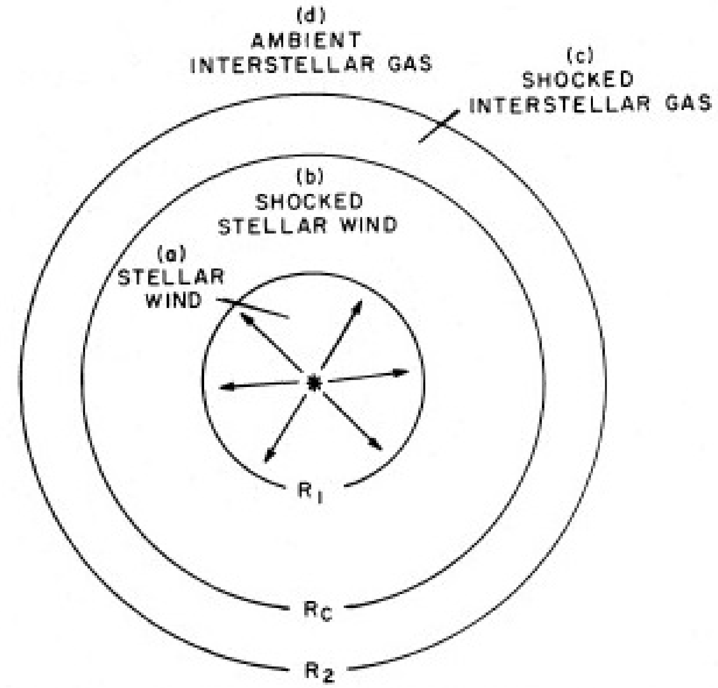


FIG. 1.—Schematic sketch indicating the regions and boundaries of the flow.

(Weaver et al. 1977)

Wind-driven bubble: moving star

No. 2, 1977 INTERSTELLAR BUBBLES 391

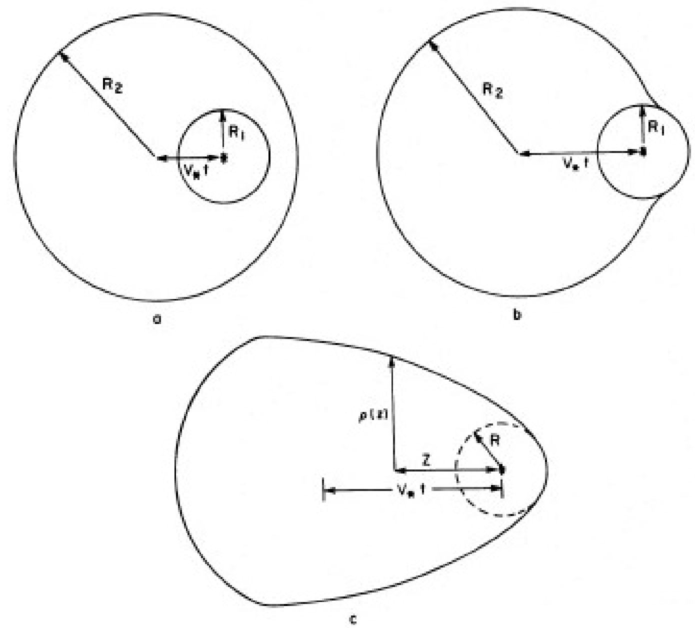
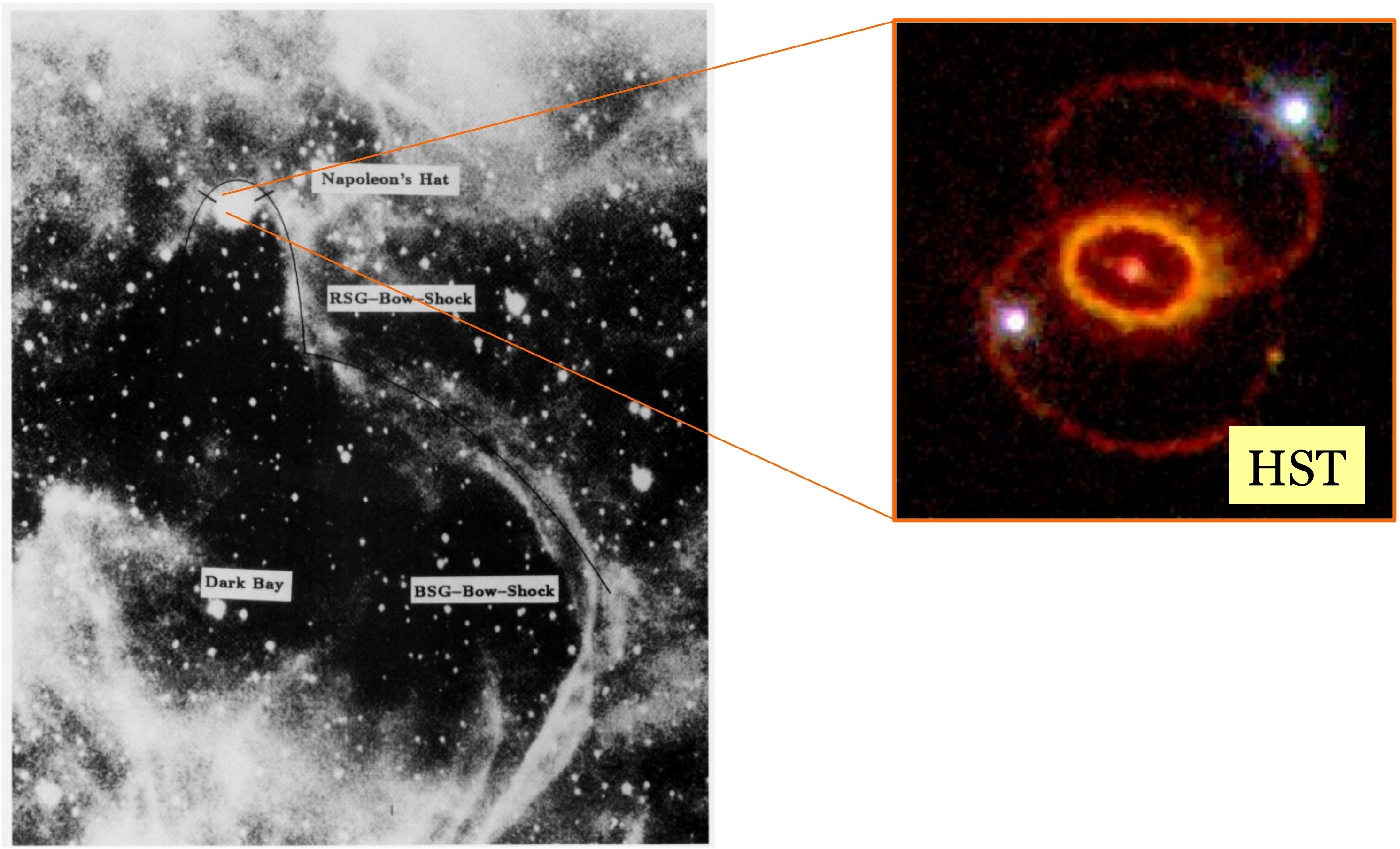


FIG. 7.—Schematic illustration of the effect of stellar motion on the structure of a bubble: (*a*) at early times when $V^*t < R_2 - R_1$; (*b*) at intermediate times for a star that has large velocity with respect to its ambient interstellar medium; (*c*) at extremely advanced times. Note that the scale of this figure changes—i.e., we have kept $R_2(t) \approx$ constant.

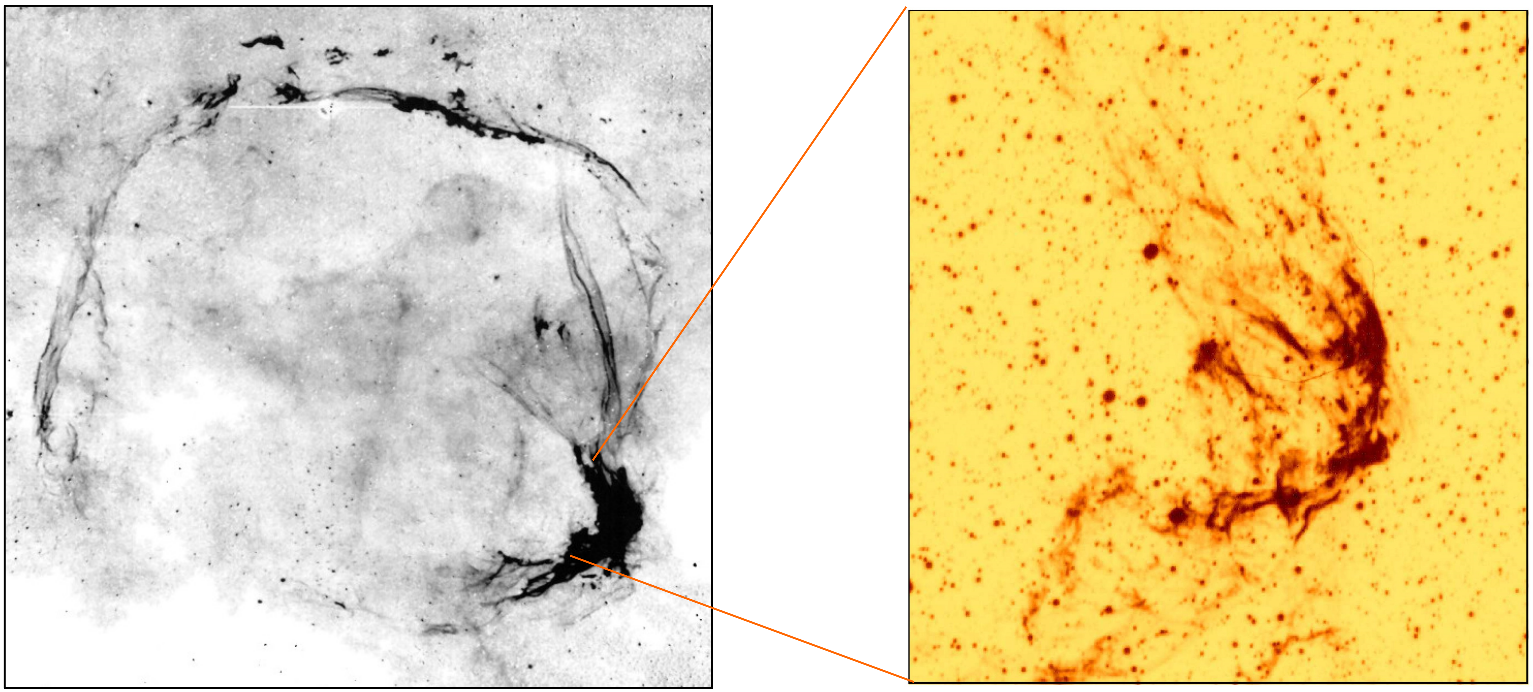
(Weaver et al. 1977)

Bubble around SN 1987A



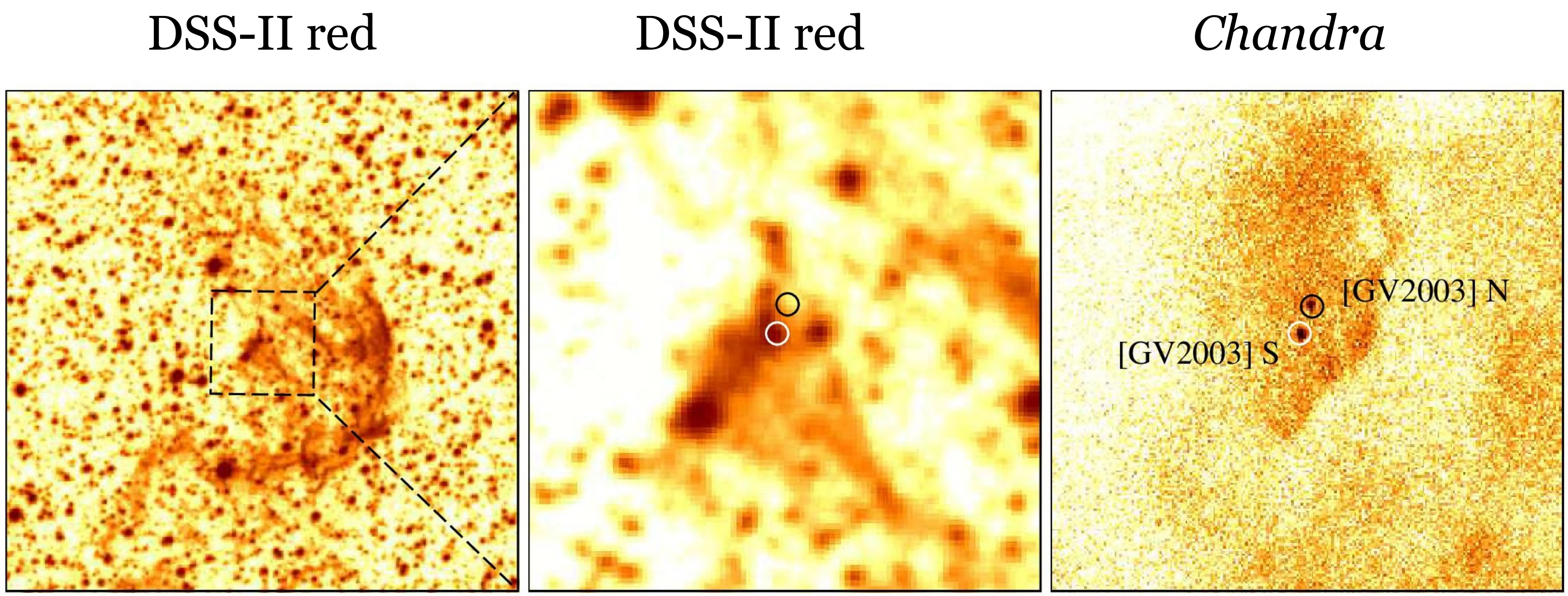
(Wang, Dyson & Kahn 1993)

RCW 86: supernova explosion near the edge of a wind bubble?



(Gvaramadze 2001)

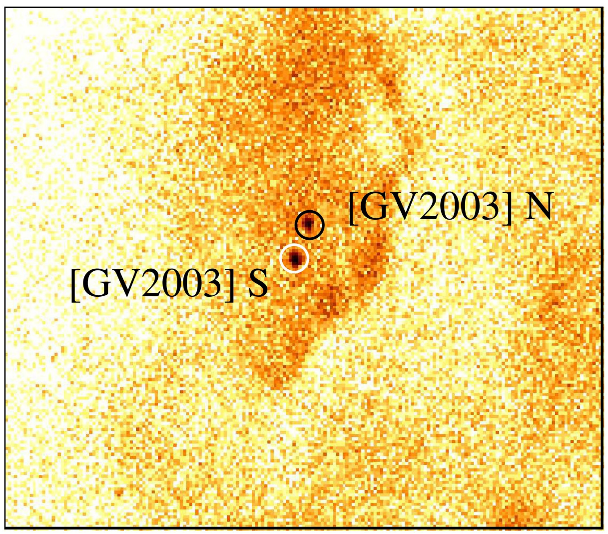
RCW 86: supernova explosion near the edge of a wind bubble?

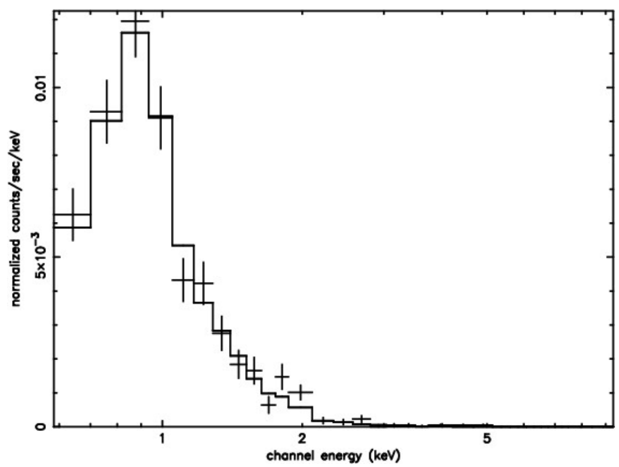


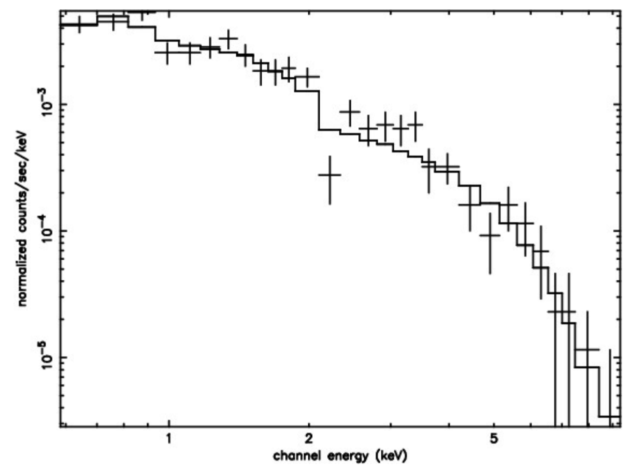
[GV2003] S: V=14.4 mag, [GV2003] N: V=???

(Gvaramadze & Vikhlinin 2003)

RCW 86: supernova explosion near the edge of a wind bubble?







[GV2003] S

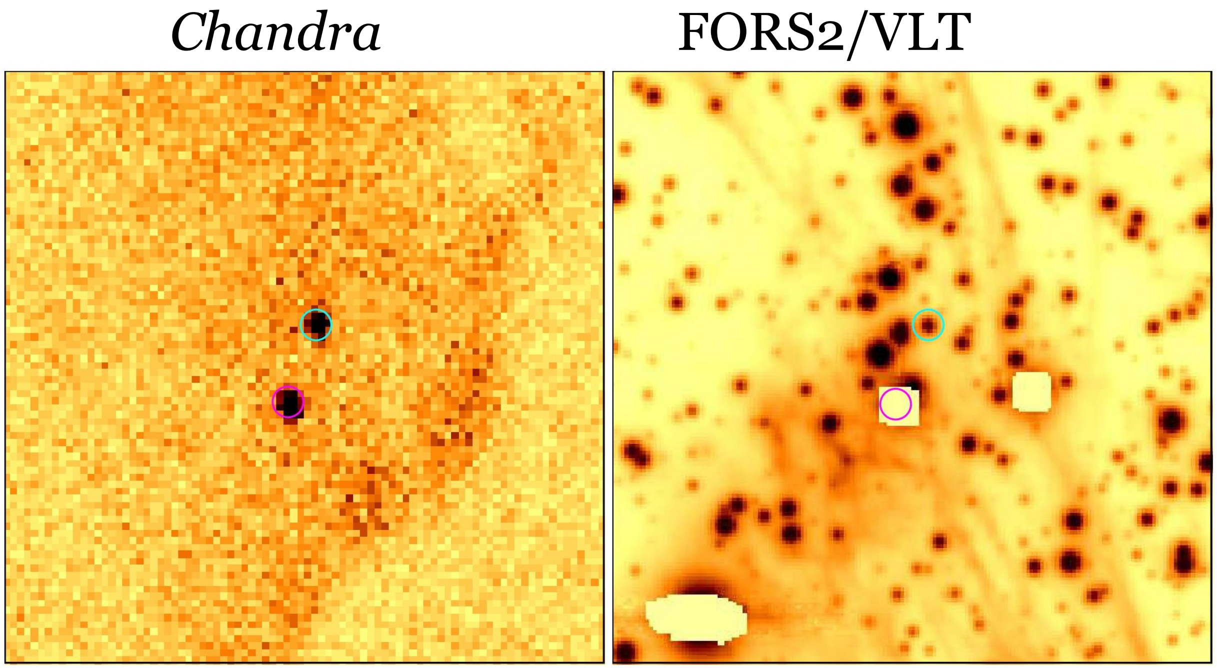
(late-type active star)

[GV2003] N

(neutron star?)

(Gvaramadze & Vikhlinin 2003)

[GV2003] N: neutron star?



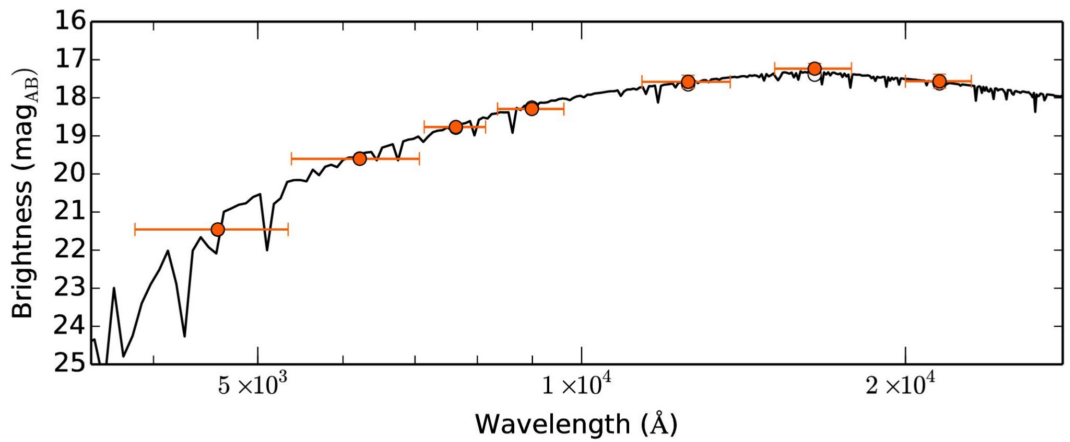
If [Gv2003] N is a neutron star, then $F_X/F_{opt} > 100$ => $V > 28$ mag

2010: FORS2/VLT => [GV2003] N: V=20.7 mag

(Gvaramadze et al. 2017)

[GV2003] N: neutron star?

seven-channel imager GROND (g', r', i', z', J, H, K_s)



2013: GROND => T_{eff} = 5200 K, $E(B\text{-}V)$ = 0.9 mag

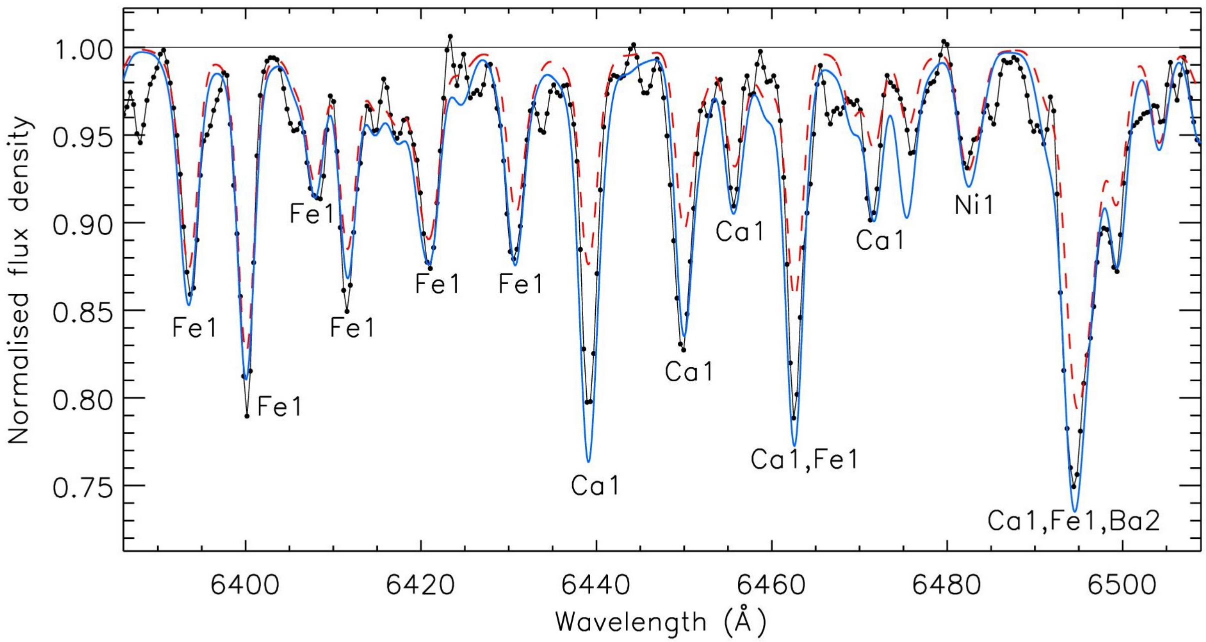
- solar-type star (G star) at a distance comparable to that of RCW 86
- the X-ray luminosity of [GV2003] N (~10^{32} erg/s) is too high for a G star => X-ray and optical emission originates in different objects!

binary system: neutron star + G star?

(Gvaramadze et al. 2017)

[GV2003] N: neutron star!

portion of the FORS2/VLT spectrum of the optical star

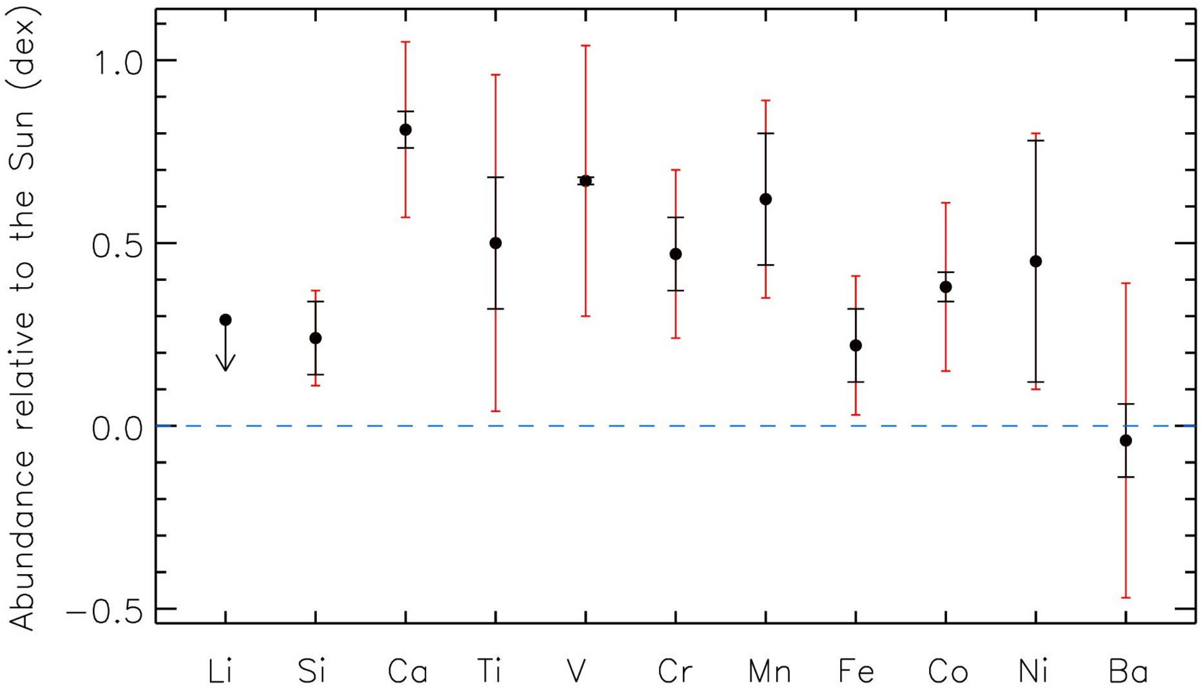


2015 April-May: four spectra => G star !

(Gvaramadze et al. 2017)

[GV2003] N: neutron star!

elemental abundances of the G star



(Gvaramadze et al. 2017)

[GV2003] N: neutron star!

14.04.2015: RV= -71±2 km/s

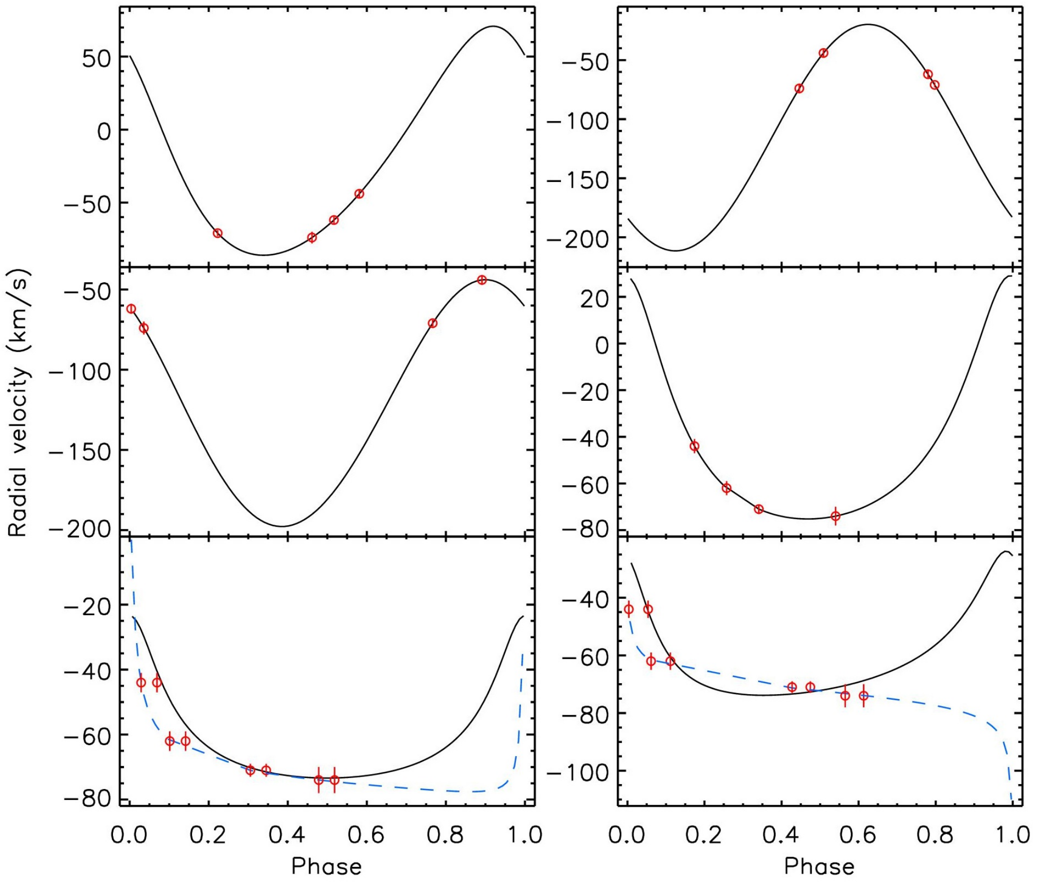
21.04.2015: RV= -74±4 km/s

13.05.2015: RV= -44±3 km/s

16.05.2015: RV= -62±3 km/s

eccentric orbit

$P_{orb} < 40$ d



(Gvaramadze et al. 2017)

Several conclusions

The detection of the strongly polluted binary G star at the position of

[GV2003] N supports the idea that this X-ray sources is a neutron star

The large overabundance of Ca in the G star suggests that the SN that produced RCW 86 might belong to the rare type of Ca-rich SNe – the fast and faint transients with strong Ca lines in their spectra

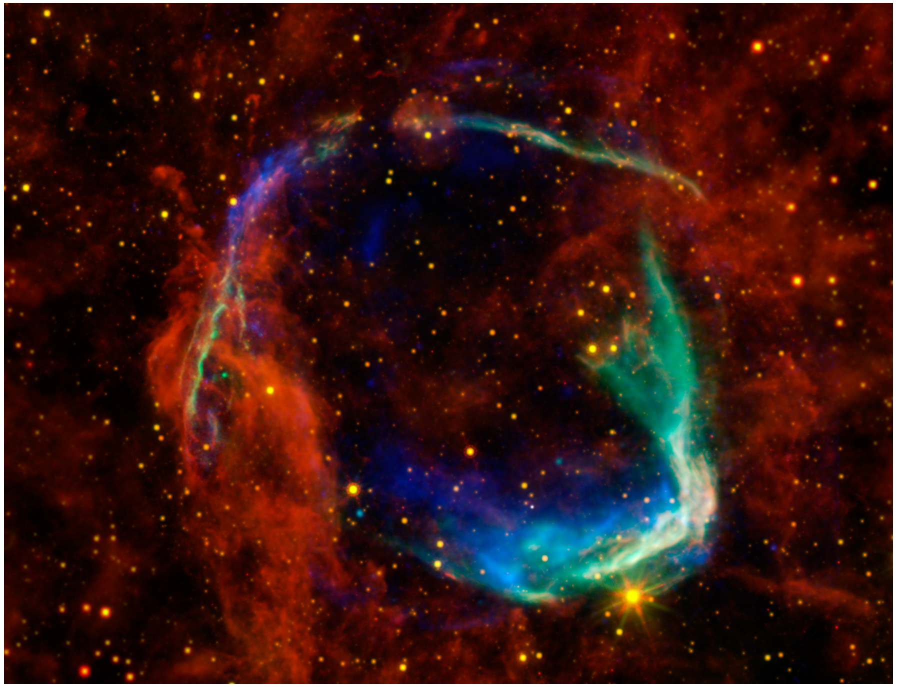
$M_G = 0.9\ M_{sun}$, $M_{NS} = 1.4\ M_{sun}$ => $M_{ej} < 2.3\ M_{sun}$, $M_{pre\text{-}SN} < 3.7\ M_{sun}$
=> $M_{in} \approx 10\text{-}12\ M_{sun}$ => common-envelope ejection ($\approx 5\text{-}7\ M_{sun}$)

=> arc in the southwest of RCW 86 is composed of the common-envelope ejecta

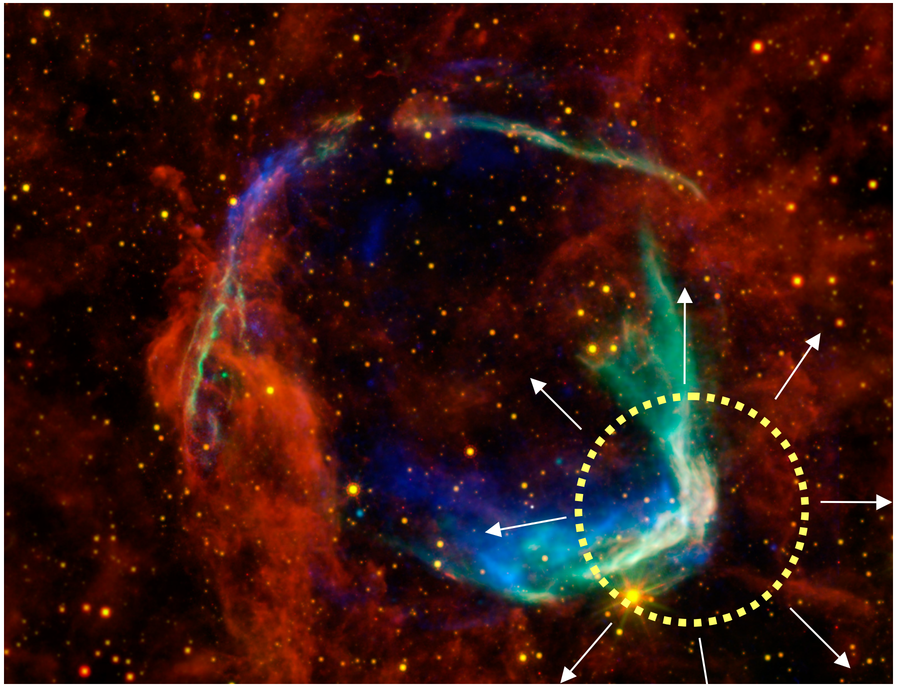
The inferred short orbital period of the binary system means that this system will evolve into a low-mass X-ray binary (LMXB) within its nuclear time-scale ($\sim 10^{10}$ yr)

=> [GV2003] N is the first example of a pre-LMXB within a SNR

What will happen with RCW 86 after ~10 000 yr?

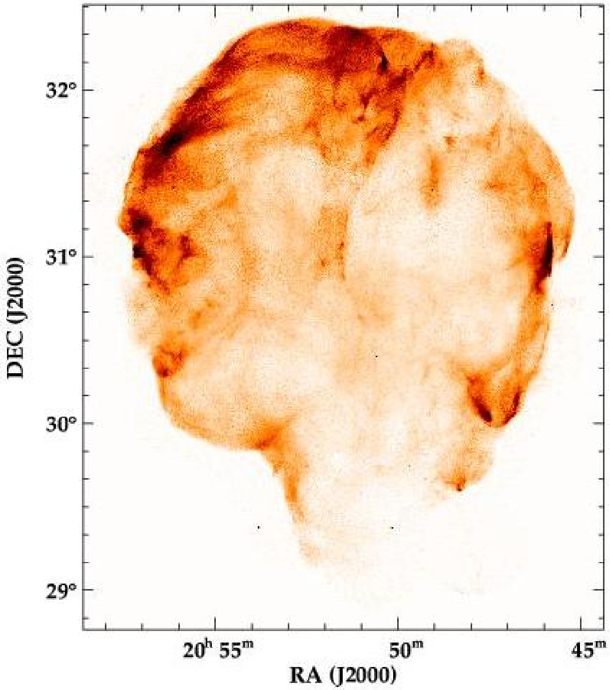


What will happen with RCW 86 after ~10 000 yr?

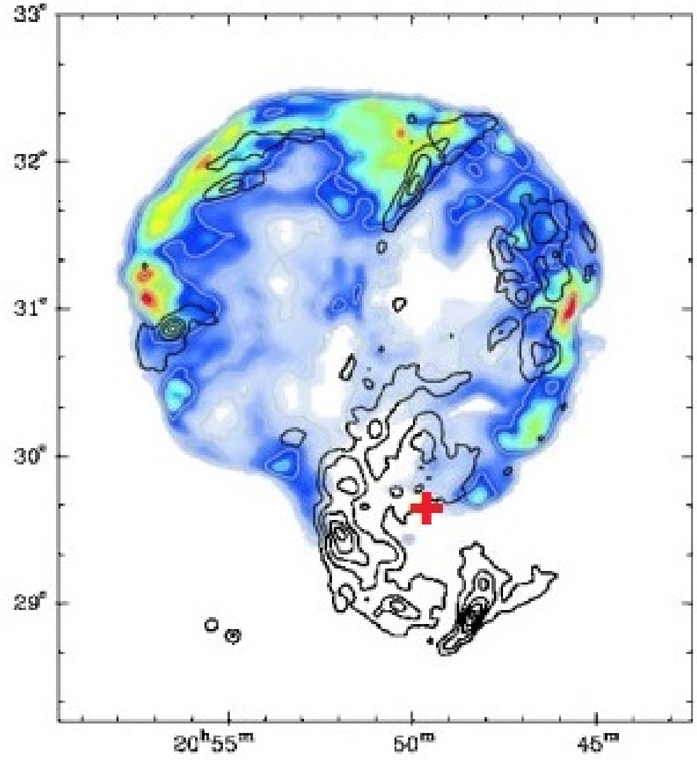


two-shell supernova remnant!

Cygnus Loop supernova remnant



(Levenson et al. 1997)



(Uyaniker et al. 2002)

Thank you!