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

V.V. Gvaramadze
(Sternberg Astronomical Institute,
Moscow State University)

in collaboration with
N. Langer, L. Fossati,
D.C.-J. Bock, N. Castro, I.Y. Georgiev, J. Greiner,
S. Johnston, F. Rau & T.M. Tauris
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

Ha

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 $\Rightarrow$ 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

(Weaver et al. 1977)
Wind-driven bubble: moving star

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?

DSS-II red  DSS-II red  Chandra


(Gvaramadze & Vikhlinin 2003)
RCW 86: supernova explosion near the edge of a wind bubble?

(Gvaramadze & Vikhlinin 2003)

[GV2003] S
(late-type active star)

[GV2003] N
(neutron star?)
If \([\text{GV2003}]\) N is a neutron star, then \(\frac{F_x}{F_{\text{opt}}} > 100\) => \(V > 28\) mag

2010: FORS2/VLT => \([\text{GV2003}]\) 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 => $T_{\text{eff}} = 5200$ K, $E(B-V) = 0.9$ mag

- solar-type star (G star) at a distance comparable to that of RCW 86
- the X-ray luminosity of [GV2003] N ($\sim 10^{32}$ 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)
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: $RV = -71 \pm 2$ km/s
21.04.2015: $RV = -74 \pm 4$ km/s
13.05.2015: $RV = -44 \pm 3$ km/s
16.05.2015: $RV = -62 \pm 3$ km/s

eccentric orbit

$P_{\text{orb}} < 40$ 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 source is a neutron star

\[ M_G = 0.9 \ M_{\text{sun}}, \ M_{\text{NS}} = 1.4 \ M_{\text{sun}} \Rightarrow M_{\text{ej}} \leq 2.3 \ M_{\text{sun}}, \ M_{\text{pre-SN}} < 3.7 \ M_{\text{sun}} \]

\[ \Rightarrow M_{\text{in}} \approx 10-12 \ M_{\text{sun}} \Rightarrow \text{common-envelope ejection (} \approx 5-7 \ M_{\text{sun}} \text{)} \]

\[ \Rightarrow \text{arc in the southwest of RCW 86 is composed of the common-envelope ejecta} \]

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

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 (~10^{10} yr)

\[ \Rightarrow [\text{GV2003}] \ N \text{ is the first example of a pre-LMXB within a SNR} \]
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!