Discovery of a young nearby supernova remnant

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About 200 supernova remnants have been found in the galaxy[1], six of which are younger than about 1,000 years (ref. 2). Observations of these young remnants are important for understanding of the late phases of supernova evolution, and each new object should add substantially to our knowledge of the processes involved. Here I report the discovery of a supernova remnant (RX J0852.0 − 4622), identified by its X-ray emission, at the southeast corner of the known Vela supernova remnant. The high temperature ($>3\times10^7$ K) indicates an age of less than ~1,500 yr. The observed diameter of the remnant is about 2°, which suggests a distance of less than 1 kpc, based on a comparison with the remnant of the supernova of AD 1006. RX J0852.0 − 4622 may therefore be the nearest supernova to have occurred during recent human history.

The Vela region was mapped in soft X-rays by Rosat in 1990/91. The image obtained for photon energies $E > 0.1$ keV is shown in Fig. 1, left panel. When I used energy bands different from the Rosat standard settings, I discovered an X-ray source which becomes visible only at $E > 1.3$ keV (Fig. 1, right panel) but which is outshone otherwise by the emission of the Vela supernova remnant (SNR). The source, located at the southeast corner of the Vela SNR, displays a circular emission region with a diameter of 2° centred on right ascension (2000) 8 h 52 min 3 s, declination (2000) −46° 22′, which was accordingly named RX J0852.0 − 4622. It is limb brightened in the north and south with a limb width of ~20% of the source radius; the morphology suggests the source to be a previously unknown SNR[1]. No radio counterpart[3,4] showing the same full size has been found, but the northern limb appears to coincide with the 408 MHz emission peak of Vela Z, which is a non-thermal radio source[5]. Recently Vela Z has been mapped and spatially resolved in the 843 MHz MOST survey[6]. Vela Z shows a relatively broad arc-like structure 40 arcmin long, which matches the brightest section of the northern limb of RX J0852.0 − 4622 in position and shape. The association of Vela Z and RX J0852.0 − 4622 supports the identification of the latter as an SNR.

The analysis of the X-ray spectra shows that the emission from the northern limb of RX J0852.0 − 4622 may be thermal with temperatures $T_{l,1}$ and $T_{l,2}$; however, it can also be represented by a power-law spectrum created by synchrotron radiation. In contrast the emission from the rest of the remnant (excluding the northern and the southern limb sections) is clearly of thermal origin with temperatures $T_{r,1}$ and $T_{r,2}$. Independent of whether the northern limb emission is thermal or non-thermal, RX J0852.0 − 4622 is a young SNR because the temperatures observed are high. As heating occurs by shock waves the temperatures $T_{r,2}$ and possibly $T_{l,2}$ correspond to shock wave velocities of 1,500 km s^{-1} and 2,000 km s^{-1}, respectively. Such high internal velocities have so far been observed only in SNRs younger than ~1,500 years (ref. 2).

X-ray synchrotron emission from two limb sectors and thermal emission from the rest of the remnant of SN1006 has been

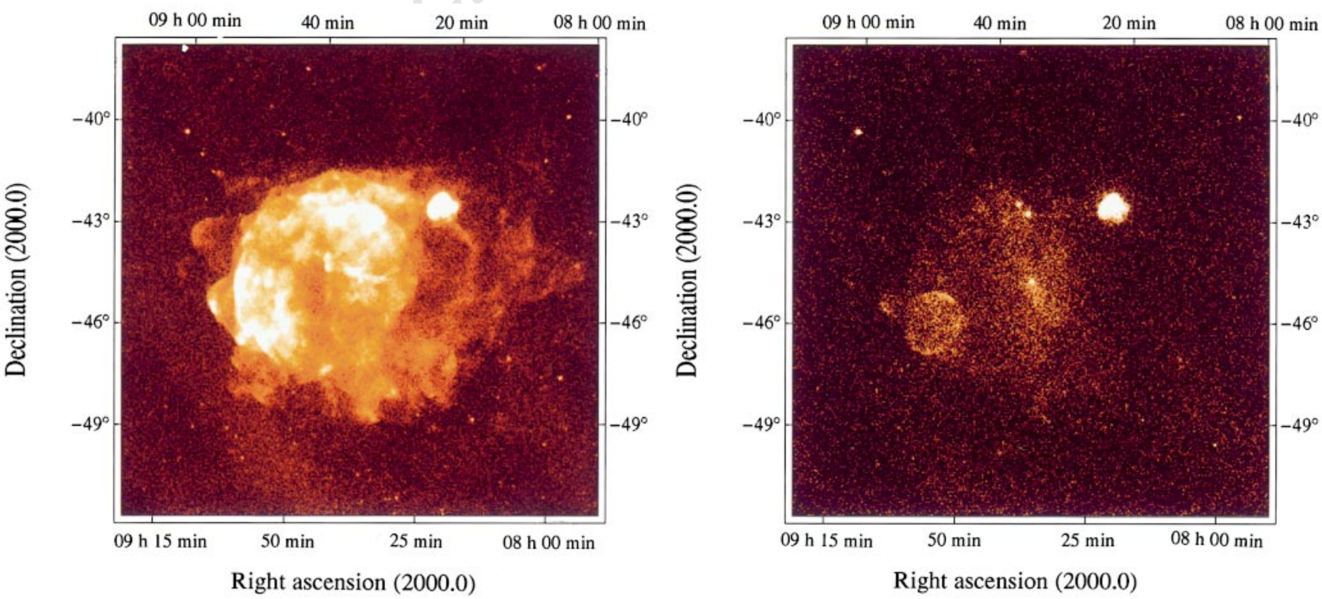

Figure 1 Rosat all-sky survey images of the Vela SNR and its surroundings. Angular resolution is 1 arcmin half-power radius; mean exposure is 993 s. The left-hand image was taken for photon energies $0.1 < E < 2.4$ keV; surface brightness increases from dark yellow to white by a factor of 500. The right-hand image is for photon energies >1.3 keV. Most of the Vela SNR X-ray emission which dominates at low energies had disappeared. At the centre, the synchrotron nebula around the Vela pulsar remains visible as well as the SSW beam-like structure, and at the very northwest (upper right) the bright Puppis-A SNR can be seen. The new shell-type SNR RX J0852.0 − 4622 shows up in the lower left. East of RX J0852.0 − 4622 hard X-ray photons from the D/D′ Vela SNR shrapnels are seen which, however, are associated with a much lower-temperature spectrum than RX J0852.0 − 4622 (ref. 14). For X-ray spectral analysis, RX J0852.0 − 4622 was divided into two regions, one containing the bright northern limb section (l) and the other one (r) excluding the northern and southern limbs. Spectral fits were performed with either power-law models, optically thin thermal emission equilibrium models (Raymond–Smith models) or combinations of both. Solutions with a reduced $\chi^2 < 1$ for region r are obtained only with a two-temperature model with $kT_{r,1} = 0.14^{+0.08}_{-0.03}$ keV, $kT_{r,2} = 2.5^{+4.5}_{-0.7}$ keV. The spectrum of the northern limb can be fitted by either a simple power law with index $\alpha = -2.6^{+0.3}_{-0.4}$ or a two-temperature model with $kT_{l,1} = 0.21^{+0.14}_{-0.09}$ keV, $kT_{l,2} = 4.7^{+4.5}_{-0.7}$ keV. The presence of low-temperature components may partially be due to a residual, uncorrected contribution from the much softer Vela SNR. The total, absorption-corrected flux of the high-temperature components is $F_x(0.1\text{–}2.4\ \text{keV}) = 3\times10^{-10}$ erg cm^{-2} s^{-1}.

reported[7,8]; the spectra of RX J0852.0 − 4622 are similar to these if the power-law-like spectrum of its northern limb section is applied. The X-ray spectral parameters which Willingale *et al.*[8] have obtained for SN1006 and our results for RX J0852.0 − 4622 are basically the same concerning the spectral index α as well as the temperatures $T_{r,1}$ and $T_{r,2}$ of the SNR interior. Furthermore, the X-ray morphology of the two objects is very similar for $E > 1$ keV, they have the same surface brightness for the thermal region within a factor of 1.3. The non-thermal northern limb of SN1006, however, is brighter by a factor of 20. I note that the ratio of energy flux density at 843 MHz ($\sim$10 mJy arcmin^{-2}; D. Bock, personal communication) to that at 1 keV (1.2×10^{-8} Jy arcmin^{-2}) of 8×10^5 is close to that of SN1006 which is 7×10^5 (ref. 9), supporting a synchrotron model but with significantly less non-thermal energy density. Either of the two brightness ratios can be used to estimate the distance d to RX J0852.0 − 4622, assuming brightness proportional to $(\Phi d)^{-3}$, which holds for similar ambient conditions, that is either thermal electron density or relativistic electron density times magnetic energy density. With an angular diameter Φ four times bigger, RX J0852.0 − 4622 is closer by a factor of 1.5–4, which is $d = 500$ pc to 1.4 kpc for $d_{SN1006} = 2$ kpc (ref. 10). If d_{SN1006} is as low as 800 pc (ref. 8), d is reduced to 200–600 pc. Large distances (>1 kpc) can be excluded by the 5σ upper limit of the photoelectrical absorption column density N_H of 8×10^{21} cm^{-2} observed in the X-ray spectra. This limit requires RX J0852.0 − 4622 to lie in front of the Vela molecular ridge, the distance of which is $\sim$1 kpc (ref. 11). From the size and X-ray flux observed in the high-temperature components, an upper limit to the density of the ambient medium in which the progenitor of RX J0852.0 − 4622 exploded can be given as $0.04 d_5^{-0.5}$ cm^{-3} (with d_5 measured in units of 500 pc). This low external density, as well as the low age (which limits the electron acceleration time[9]) may be responsible for the low level of X-ray synchrotron radiation.

I have searched the Rosat all-sky survey data of RX J0852.0 − 4622 for a point-like, compact, stellar remnant. The 5σ upper limit of the 0.1–2.4 keV flux $F_{5\sigma}$ corrected for absorption with $N_H = 2 \times 10^{20}$ cm^{-2} is 3×10^{-12} erg cm^{-2} s^{-1} anywhere except in a 3 arcmin by 3 arcmin region centred on RA(2000) = 8 h 52 min 3 s, Dec(2000 = −46.31°, where an excess count rate F_{point} of 8×10^{-12} erg cm^{-2} s^{-1} was found. But this field includes the B8 IV/Vstar HD76060 with visual magnitude $m_v = 7.9$ and the Be star IRAS08502 − 4606 with $m_v = 13.8$. If the supernova left a pulsar, it is less luminous than the Crab pulsar by about four orders of magnitude for $d_5 = 1$, provided that the pulsar beam crosses the line of sight. A young neutron star is supposed to be hot, radiating X-rays from the black-body surface with a flux (in the 0.1–2.4 keV range) of $F_{ns} = (2 \times 10^{-10}\ \text{erg cm}^{-2}\ \text{s}^{-1}) R_{10}^2 T_{1.7}^4 d_5^{-2}$, with R_{10} the neutron-star radius in units of 10 km and $T_{1.7}$ the surface temperature in units of 1.7×10^6 K, which is expected from standard cooling models for a neutron star $\sim$1,000 years old[12]. The values of $F_{5\sigma}$ and F_{point} seem to rule out the presence of such a neutron star in RX J0852.0 − 4622 by a large factor; however, a neutron star of somewhat lower temperature and smaller radiating surface area could be there. This result does not therefore exclude the possibility that RX J0852.0 − 4622 is the remnant of a core-collapse supernova, but leaves unanswered the question about the supernova type. □

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1. Green, D. A. *A Catalogue of Galactic Supernova Remnants (1996 August version)* (Mullard Radio Astronomy Observatory, Cambridge, UK); available at http://www.mrao.cam.ac.uk/surveys/snrs/.
2. Strom, R. G. "Guest stars", sample completeness and the local supernova rate. *Astron. Astrophys.* **288,** L1–L4 (1994).
3. Haslam, C. G. T., Salter, C. J., Stoffel, H. & Wilson, W. E. A 408 Mhz all-sky continuum survey. II. The atlas of contour maps. *Astron. Astrophys. Suppl.* **47,** 1–143 (1982).
4. Duncan, A. R., Stewart, R. T., Haynes, R. F. & Jones, K. L. The Vela supernova remnant and the Gum nebula: new perspectives at 2.4 GHz. *Mon. Not. R. Astron. Soc.* **280,** 252–266 (1996).
5. Milne, D. K. Radio emission from the supernova remnant Vela-X. *Aust. J. Phys.* **21,** 201–219 (1968).
6. Bock, D. C.-J., Turtle, A. J. & Green, A. J. A high-resolution radio survey of the Vela supernova remnant. *Astron. J.* (accepted).
7. Koyama, K. *et al.* Evidence for shock acceleration of high-energy electrons in the supernova remnant SN1006. *Nature* **378,** 255–258 (1995).
8. Willingale, R., West, R. G., Pye, J. P. & Stewart, G. C. ROSAT PSPC observations of the remnant of SN 1006. *Mon. Not. R. Astron. Soc.* **278,** 749–762 (1996).
9. Reynolds, S. P. Synchrotron models for X-rays from the supernova remnant SN 1006. *Astrophys. J.* **459,** L13–L16 (1996).
10. Winkler, P. F. & Long, K. S. X-ray and optical imagery of the SN 1006 supernova remnant. *Astrophys. J.* **491,** 829–838 (1997).
11. Murphy, D. C. & May, J. Molecular clouds in Vela. *Astron. Astrophys.* **247,** 202–214 (1991).
12. Becker, W., Brazier, K. T. S. & Trümper, J. ROSAT observations of PSR 2334 + 61 in the supernova remnant G 114.3 + 0.3. *Astron. Astrophys.* **306,** 464–466 (1996).
13. Iyudin, A. F. *et al.* Emission from ^{44}Ti associated with a previously unknown Galactic supernova. *Nature* **396,** 142–144 (1998).
14. Aschenbach, B., Egger, R. & Trümper, J. Discovery of explosion fragments outside the Vela supernova remnant boundary. *Nature* **373,** 587–590 (1995).

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Emission from ^{44}Ti associated with a previously unknown Galactic supernova

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Nearly 400 years have passed since a supernova was last observed directly in the Milky Way (by Kepler, in 1604). Numerous Galactic supernovae are expected to have occurred since then[1], but only one (Cassiopeia A) may have been seen[2]. The historical record of supernovae is therefore incomplete, as demonstrated by the spatial distribution of young supernova remnants[3]. The discovery[4,5] of γ-ray emission from the decay of ^{44}Ti nuclei associated with Cassiopeia A, the youngest known remnant, has revealed a new way to search for the remnants of other relatively recent supernovae (less than ~1,000 years old). Here we report the discovery of ^{44}Ti line emission from a previously unknown young supernova remnant, in the direction of the Vela remnant. We estimate a distance of ~200 parsecs and an age of ~680 years for the remnant, making it the closest young remnant to the Earth. Why it was not recorded historically remains unknown.

^{44}Ti is expected to be produced in different types of supernovae[6–9], although with very different abundances (typically $\sim 7 \times 10^{-5} M_\odot$ by type Ia[6]; up to $10^{-4} M_\odot$, depending on the mass of the condensed star-like remnant, for the most frequent types II and Ib[7,8]; and up to $3.9 \times 10^{-3} M_\odot$ for the rare helium white-dwarf detonation[9]; here $M_\odot$ is the solar mass). The Galaxy is almost transparent in the γ-ray band, unlike the situation for optical wavelengths, so that hitherto optically obscured supernovae may become detectable at γ-ray energies. For this purpose, the γ-ray line from the decay-chain of ^{44}Ti at 1.156 MeV is very suitable. Because of the ^{44}Ti lifetime of ~90 yr, this line is the best indicator of young (age ≤1,000 yr) Galactic supernova remnants (SNRs)[10]. In addition, the decay time is comparable to the average time interval between Galactic supernovae, so ^{44}Ti γ-ray line emission should appear as localized sources rather than diffuse emission.

The first detection (that of Cas A) was obtained by COMPTEL[4]. This youngest Galactic SNR was seen in the early phase of the CGRO