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Constraints of age, distance and progenitor of the supernova remnant RX J0852.0-4622/GRO J0852-4642

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Abstract. The discovery of the nearest young supernova remnant RX J0852.0-4622 / GRO J0852-4642 in the Galaxy by ROSAT and COMPTEL has been reported recently. Age and distance are determined to ~680 years and ~200 pc by the X-ray diameter and the γ-ray line flux of radioactive ^{44}Ti. Here we discuss the implications of the X-ray spectra and of the fact that 1.8 MeV γ-ray line emission from the decay of ^{26}Al has been measured from the Vela region with a certain fraction possibly associated with the new SNR. We estimate an uncertainty of the age of $\pm$ 100 yrs for a fixed yield of ^{44}Ti. The highest values of ^{44}Ti yield provided by current supernova explosion models give worst case upper limits of 1100 yrs for the age and of 500 pc for the distance. Also the unknown ionization stage of ^{44}Ti adds to the uncertainty of age and distance which is at most another 35% on top. Both the energy balance compiled for the remnant and yield predictions for ^{44}Ti and ^{26}Al by supernova models favour a core-collapse event. Two point sources have been found in the vicinity of the explosion center, either one of these might be the neutron star left by the supernova. If there is a neutron star the X-ray count rates of the two point sources provide an upper limit of the blackbody surface temperature, which is very unlikely to exceed 3×10^5 K. The supernova might have been observed some 700 $\pm$ 150 yrs ago, but based on the data of SN 1181, e.g., there is a realistic chance that it has been missed if the supernova was sub-luminous.

Key words: shock waves – ISM: individual objects: RX J0852.0-4622 – ISM: supernova remnants – X-rays: general – X-rays: ISM

1. Introduction

Recently, we have published our discoveries of a previously unknown galactic supernova remnant (SNR) (Aschenbach 1998, Iyudin et al. 1998). The X-ray image obtained in the ROSAT all-sky survey shows a disk-like, partially limb brightened emission region of 2° in diameter, which is the typical appearance of a shell-like SNR (cf. Fig. 1). The PSPC X-ray spectra reveal rather high temperatures of $> 3\times10^7$ K, which indicate that RX J0852.0-4622 is a young object. Combining the low age and the 2° angular extent it is concluded that RX J0852.0-4622 is relatively close-by. Comparison with historical SNRs limits the age to about $\sim$ 1500 yrs and the distance to <1 kpc. The case of RX J0852.0-4622 being an SNR was clinched by the detection of γ-ray line emission from ^{44}Ti, which is a titanium isotope exclusively produced in supernovae. The centre of the ^{44}Ti source, called GRO J0852-4642, is off-set from the center of RX J0852.0-4622 by 0.4°, but this is significantly less than the angular resolution of the COMPTEL instrument, so that RX J0852.0-4622 and GRO J0852-4642 are considered to be the same object. Using a weighted mean lifetime of ^{44}Ti of 90.4 yrs, the angular diameter and adopting a mean expansion velocity of 5000 km s^{-1} as well as a ^{44}Ti yield of 5×10^{-5} $M_\odot$ age and distance are uniquely determined to ~680 yrs and ~200 pc, respectively. Therefore, RX J0852.0-4622/GRO J0852-4642 could be

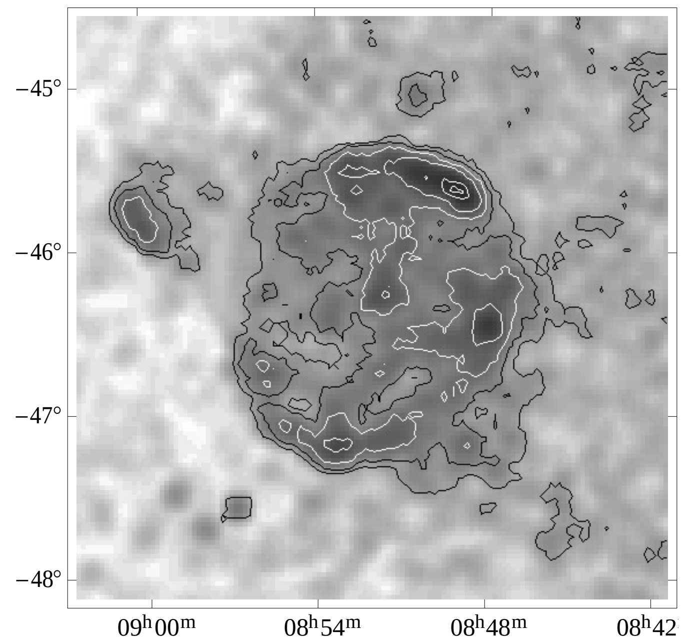

Fig. 1. Grey scale image of RX J0852.0-4622 for E > 1.3 keV. Coordinates are right ascension, declination of epoch 2000.0. Contour levels are (in black) 1.5, 2.3, (in white) 3.5, 5.2, 8.2, 9.2 in units of 10^{-4} PSPC counts s^{-1} arcmin^{-2}.

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the nearest supernova to Earth to have occured during recent human history.

The discovery of RX J0852.0-4622 and the interpretation as an SNR was made by one of us (BA) in early 1996. During the time which followed it was attempted to associate some fraction of the ^{26}Al γ-ray line emission from the Vela SNR region measured by COMPTEL (Oberlack et al. 1994, Diehl et al. 1995) with RX J0852.0-4622. The results have not been conclusive basically because of the unknown distance of RX J0852.0-4622 (Oberlack 1997). The discovery of ^{44}Ti γ-ray line emission, however, made it clear that RX J0852.0-4622 is indeed a nearby object, so that we could take up again the discussion of the association of ^{26}Al emission with RX J0852.0-4622. For example the combination of just the ^{26}Al and ^{44}Ti data allow to derive a distance independent estimate of the age of GRO J0852-4642. Furthermore, if a major fraction of the Vela ^{26}Al mass would be associated with the SNR, a type Ia supernova is excluded within the framework of current explosion models. Under the assumption of adiabatic expansion (Sedov-like) of the SNR we give an estimate of the supernova explosion energy E_0 related to the progenitor star and the ambient matter density n_0. The uncertainties in the determination of age and distance by exploiting the X-ray spectra are discussed to come up with a time span in which to search for the historical supernova event.

In a recent paper Chen & Gehrels (1999) conclude that RX J0852.0-4622 was created by a core-collapse supernova of a massive star. Their analysis is based on the X-ray data and γ-ray data published published earlier by us (Aschenbach 1998, Iyudin et al. 1998). We discuss their approach and conclusions in the relevant section.

2. Age and distance

Basis for the determination of the age and distance of the new SNR is the law of radioactive chain-decay $^{44}\mathrm{Ti} \rightarrow\ ^{44}\mathrm{Sc} \rightarrow\ ^{44}\mathrm{Ca}$, for which we have

$$f = \frac{1}{4\pi d^2}\ \frac{Y_\mathrm{A}}{m_\mathrm{A}\cdot(\tau_\mathrm{A}-\tau_\mathrm{B})}\ [exp(-t/\tau_\mathrm{A}) - exp(-t/\tau_\mathrm{B})] \quad (1)$$

with the definitions: *f* photon flux density, *d* distance, Y_A mass yield of the element A, m_A its atomic mass, τ_A its mean life time and *t* the age. For the ^{44}Ti decay chain $\tau_\mathrm{Ti} >> \tau_\mathrm{Sc}$, so that we can neglect τ_B and the second exponential term of Eq. 1. The data available suggest $\tau_\mathrm{Ti} \approx 90$ yrs, which we adopt for the following. This value is also close to the result of (87.7 ±1.7) yrs recently published by Ahmad et al. (1998). *f* is the flux of the 1.157 MeV line which has been measured by Iyudin et al. (1998) to $(3.8\pm0.7)\cdot10^{-5}$ photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. Apart from the statistical error a systematic error should be added, which is estimated to ± 20%.

2.1. ^{44}Ti and X-ray data

The range of d, t and Y_A of Eq. 1 can be constrained by introducing the X-results. The angular radius $\theta = 1^\circ$ is related to d and t by $\theta = v \cdot t\ /\ d$, with v the mean expansion velocity of the SNR. By substituting d or t of Eq. 1 by v a quantitative relation between $Y_{^{44}\mathrm{Ti}}$ and t or $Y_{^{44}\mathrm{Ti}}$ and d can be derived with v as a parameter. An estimate of v can be obtained from the X-ray spectra. The analysis of the ROSAT X-ray spectra is affected by the presence of the low energy emission of the Vela SNR, which is aggravated by the large size of RX J0852.0-4622. But an archival ROSAT PSPC pointing observation centred on the southeastern limb of the Vela SNR with an exposure of 11000 s happens to contain the northern limb section of RX J0852.0-4622. The number of counts is sufficient to extract a small section of the limb as well as a small section of the Vela SNR offset by just 10 arcmin to create both uniform source and background spectra. Limiting the analysis to these small regions, each 10 arcmin $\times$ 10 arcmin in size, reduces the impact of any spectral and spatial non-uniformity across the source and the background. Fits to the residual northern limb spectrum were performed with a two component, optically thin thermal emission equilibrium model (Raymond-Smith model) with $kT_{l,1} = 0.21^{+0.14}_{-0.09}$ keV, $kT_{l,2} = 4.7^{+4.5}_{-0.7}$ keV and an absorption column density of $N_{H,l,T} = [2.3^{+1.5}_{-1.5}]\times10^{21}$ cm^{-2}. We note that the data can be fit equally well ($\chi^2_\mathrm{red} < 1$) with a straight power law with index $\alpha = -2.6^{+0.3}_{-0.4}$ and absorption column density $N_{H,l,\alpha} = [1.2^{+7.3}_{-1.2}]\times10^{20}$ cm^{-2}. The spectrum of the rest of the SNR can be obtained only from the ROSAT all-sky survey data and because of the relatively low exposure the spatial region selected for analysis needs to be large which increases the uncertainty in assessing the background level from the Vela SNR. For the full remnant excluding the bright northern limb an acceptable fit with $\chi^2_\mathrm{red} < 1$ is obtained 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 and $N_{H,r,T} = [4.0^{+1.5}_{-3.5}]\times10^{21}$ cm^{-2}.

The matter density of the shock-wave heated SNR plasma can be derived from the observed X-ray flux F_x via the relation $F_x = \frac{4}{3}\ \theta^3\ d\ n_\mathrm{e}\ n_\mathrm{H}\ \Lambda(kT)$. $\Lambda(kT)$ is the cooling function for the best-fit values of kT; n_e is the electron number density and n_H is the number density of the un-shocked matter, intitially uniformly distributed in a sphere. Furthermore, a factor of four has been used for the density jump at the shock. The low and high temperature components are associated with densities of $n_{\mathrm{H},1} = 0.6\times d_2^{-0.5}$ cm^{-3} and $n_{\mathrm{H},2} = 0.06\times d_2^{-0.5}$ cm^{-3}, respectively, with d_2 measured in units of 200 pc. Despite the acceptable spectral fit the value of $n_{\mathrm{H},1}$ and the column density are quite uncertain, as the low temperature component could be significantly affected by the Vela SNR radiation, which is, however, not the case for $n_{\mathrm{H},2}$.

As usual for thermal SNRs two components with different temperatures are needed for equilibrium models to fit the observed spectrum. If the plasma is far from ionization equilibrium the low temperature component appears as an artifact because of the under-ionization. The time-scale to reach ionization equilibrium is about 10^{12} s cm^{-3}/n_e, with n_e the electron density of the radiating plasma in units of cm^{-3}. With t = 680 yrs and the densities given above 1.5×10^9 s cm^{-3} $< n_e\cdot t < 1.5\times10^{10}$ s cm^{-3}, which demonstrates that RX J0852.0-4622 departs significantly from ionization equilibrium. Clearly the high temperatures observed are closer to the real electron temperature. But even the high temperatures may underestimate the average temperature of the electrons and ions if the electrons are heated mainly by Coulomb collisons with the ions, which occurs on a timescale similar to that of reaching ionization equlibrium.

The X-ray temperatures which have been produced by shock wave heating can be used to estimate the velocity v_s of the shock wave: $kT = \frac{3}{16}\ \mu\ \mathrm{m_p} v_s^2$; $\mathrm{m_p}$ is the proton mass and μ is the mean molecular weight, which is 0.6 for a fully ionized plasma of cosmic abundances. Again, this relation is for a density jump of a factor of four at the shock. Discarding the low temperature components as argued above the X-ray temperatures stretch from 1.8 keV $\leq \mathrm{kT_2} \leq$ 9.2 keV including $\pm$1-σ errors. The mean $\mathrm{kT_2}$, which is consistent at the same significance level with both the radiation from the bulk of the SNR and its northern limb section, taking the thermal option, is $\mathrm{kT_2}$ = 4.4 keV. The corresponding best estimates of the minimal and maximal shock velocities using the relation above are 1940 km s^{-1}, 1240 km s^{-1} and 2800 km s^{-1}, respectively. The current shock velocity v_s is related to the mean expansion velocity v by the past temporal evolution of the SNR. With the limited observations available we are forced to rely on what is known about historical remnants. The compilation of Strom (1994) provides both maximal internal shock velocity and mean expansion velocity and the ratio v/v_s is 1.5 for the Crab Nebula and Cas A, 2.5 for SN 1006 and 3.5 for the Kepler and Tycho SNRs. For a purely adiabatic expansion in a uniform medium of constant matter density (the Sedov description) v/v_s = 2.5. As Strom has pointed out the observed maximal internal velocities may not be strictly related to v_s but they provide a reasonable estimate. More recently measurements of the expansion rate in the X-ray band have become available by comparing images obtained with the EINSTEIN and ROSAT observatories or even just the ROSAT images taken at different epochs. Both Koralesky et al. (1998) and Vink et al. (1998) have found an expansion rate of Cas A of 0.002% yr^{-1} which corresponds to a factor of $\sim$ 1.55 for the ratio of mean expansion rate over current expansion rate. Hughes (1996) has found a similar value for the Tycho SNR. In each of these cases, however, the current expansion velocities, using reasonable distance estimates, are significantly larger than the X-ray spectra and temperatures indicate. Therefore a factor of 1.5 for v/v_s is a very conservative lower limit to estimate v from X-ray spectra.

For a worst case estimate we define a velocity range for RX J0852.0-4622 applying factors of 1.5, 2.5, 3.5 to the minimal, best-estimate and maximal v_s, respectively, which leads to a best-estimate expansion velocity v_b = 5000 km s^{-1} bracketed by a minimal expansion velocity of v_{min} = 2000 km s^{-1} and a maximal expansion velocity v_{max} = 10000 km s^{-1}; the values have been rounded off slightly. Since we don't know whether the X-ray temperatures are associated with either the blast wave heated ambient medium or the progenitor ejecta heated by reverse shocks, the expansion velocities derived may even be lower limits. Similarly, the values are too low if the electrons have not reached thermal equilibrium with the ions. For the discussion of the impact of the expansion velocity on age and distance we note that the ^{44}Ti line appears to be broadened (Iyudin et al. 1998), the origin of which is unknown. In the most extreme case that the width is exclusively attributed to Doppler broadening the associated velocity is (15300$\pm$3700) km s^{-1} with an upper limit of v_γ = 19000 km s^{-1}. We include v_γ for the sake of completeness, but we stress that the use of v_γ for constraining the type of progenitor is overinterpretating the γ-ray data and it is essentially misleading. Nevertheless, we add that Nagataki (1999) quotes ^{44}Ti expansion velocities $\geq$12000 km s^{-1} for sub-Chandrasekhar mass models of SNe Ia.

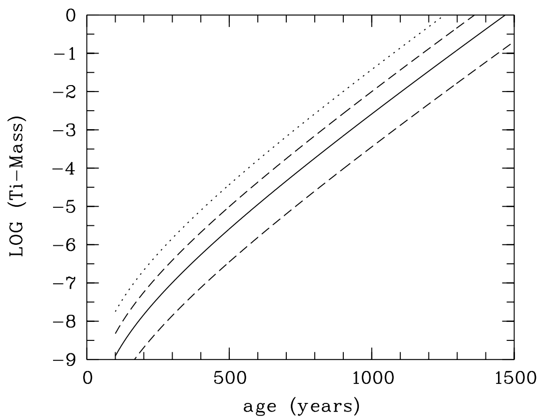

Fig. 2. Logarithm of ^{44}Ti yield in solar masses vs. age. Lines are for v_b = 5000 km s^{-1} (solid), v_min = 2000 km s^{-1} and v_max = 10000 km s^{-1} (dashed) and v_γ = 19000 km s^{-1} (dotted).

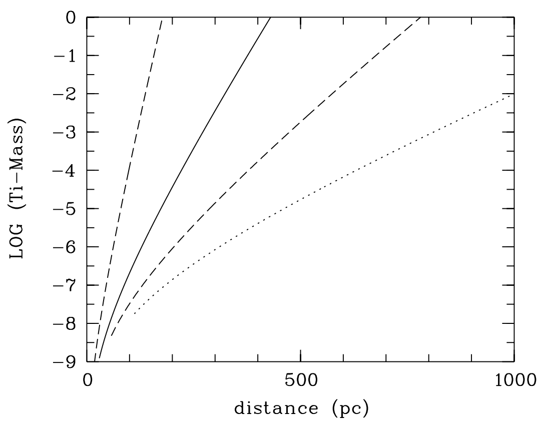

Fig. 3. Logarithm of ^{44}Ti yield in solar masses vs. distance. Lines are for v_b = 5000 km s^{-1} (solid), v_min = 2000 km s^{-1} and v_max = 10000 km s^{-1} (dashed) and v_γ = 19000 km s^{-1} (dotted).

Fig. 2 shows the relation between $Y_{^{44}\mathrm{Ti}}$ and the age t of RX J0852.0-4622 parametrized by v. Despite the large uncertainty of v, t is determined to within $\pm$ 100 yrs for fixed $Y_{^{44}\mathrm{Ti}}$ using v of the X-ray data. For $Y_{^{44}\mathrm{Ti}}$ = 5$\times$10^{-5} $\mathrm{M_\odot}$ and v = v_b, t = 680 yrs and d = 200 pc (c.f. Fig. 3). Age and distance are rather insensitive to the exact value of the ^{44}Ti γ-ray line flux. A total error of the flux of $\pm$40%, which is the sum of the statistical error and the systematic error, broadens the range of t by $\pm$40 yrs and that of d by $\pm$ 10 pc. If RX J0852.0-4622 is expanding as fast as v_γ indicates the age would be as low as $\sim$500 yrs. Model calculations provide a range for $Y_{^{44}\mathrm{Ti}}$, which runs for symmetric core-collapse supernovae from 1.4×10^{-5} $M_\odot$ to 2.3×10^{-4} $M_\odot$, depending on progenitor mass (Woosley & Weaver 1995, Thielemann et al. 1996). Within this range (t, d) is within (500 yrs, 400 pc) and (950 yrs, 80 pc). Nagataki et al. (1998) have pointed out that $Y_{^{44}\mathrm{Ti}}$ could be much higher in an axisymmetric collapse-driven supernova. For example, in their model with the highest degree of asymmetry they obtain $Y_{^{44}\mathrm{Ti}}$ = 5.1×10^{-4} for $Y_{^{56}\mathrm{Ni}}$ = 0.07 $M_\odot$. This value of $Y_{^{44}\mathrm{Ti}}$ would allow an age of up to 1000 yrs. For type Ia supernovae we find 7.9×10^{-6} $M_\odot \leq Y_{^{44}\mathrm{Ti}} \leq 4.7\times10^{-5}$ $M_\odot$ for carbon deflagration models (Nomoto et al. 1984, Iwamoto et al. 1999), which do not significantly differ from the core-collapse SNe, and accordingly the range for (t, d) is not affected. Values of $Y_{^{44}\mathrm{Ti}}$ as high as 2×10^{-3} $M_\odot$ are obtained in He-detonation models (Woosley & Weaver 1994). This would allow (t, d) to lie between (850 yrs, 500 pc) and (1100 yrs, 100 pc). In summary, for any $Y_{^{44}\mathrm{Ti}}$ given by current models the upper limit of the distance of RX J0852.0-4622 is 500 pc and 1100 years for the age.

Chen & Gehrels (1999) have also used the X-ray temperature to derive age and distance, although in a slightly different manner. They use the temperature derived from the ROSAT data for the central region (Aschenbach 1998) which might not be representative for the current expansion velocity at the rim, why we prefer a somewhat higher velocity consistent with the apparently higher temperature observed at the limb. For the mean expansion velocity, which should be higher than the current expansion velocity by some factor, Chen & Gehrels derive a range of 2000–5000 km s^{-1}, whereas we propose a range of 2000 km s^{-1} to 10000 km s^{-1} by comparison with observational data obtained for the historical remnants. For given velocity and $Y_{^{44}\mathrm{Ti}}$ our results agree with those obtained by Chen & Gehrels, but our estimates allow a wider range of age and distance.

2.2. ^{44}Ti ionization

^{44}Ti decays by electron capture, which means that lifetime depends on ionization stage, in particular to what extent the K shell is populated. The ^{44}Ti lifetime of $\approx$ 90 yrs is the mean lifetime for two electrons in the K-shell irrespective of the number of electrons in the higher shells. For just one electron in the K-shell, the hydrogen-like state $^{44}\mathrm{Ti}^{+21}$, the lifetime is expected to be about twice as long, and for the fully ionized atom $^{44}\mathrm{Ti}^{+22}$ the lifetime is $>> \tau_{\mathrm{Ti}}$. Eq. 1 gives the decay rate for the ionic fraction $X(^{44}\mathrm{Ti}^{+22})$ = 0 (full ionization), $X(^{44}\mathrm{Ti}^{+21})$ = 0 (one electron in the K-shell) and $X(^{44}\mathrm{Ti}^{\leq+20})$ = 1. For $X(^{44}\mathrm{Ti}^{\leq+20}) < 1$ Eq. 1 is modified by introducing the ionic fraction $X(^{44}\mathrm{Ti}^{\leq+20})$ with τ = 90 yrs and $X(^{44}\mathrm{Ti}^{+21})$ with $\tau = 2 \times 90$ yrs; the impact of $X(^{44}\mathrm{Ti}^{+22})$ has been neglected because of its comparatively low contribution to f. The solution for t of Eq. 1 for either the 'ionization' or the 'no-ionization' case is done with the same f. As before also d and t are not independent of each other but constrained by θ and v, which means that not only t but also d is to change for the 'ionization' case compared to the 'no-ionization' case. So the comparison is done with the same v but not with the same d. Furthermore v is constrained by the X-ray spectra and the impact of the uncertainty of v on d and t has been given in the previous section. If $t = t_0$ for $X(^{44}\mathrm{Ti}^{\leq+20})$ = 1 and $t = t_1$ for $X(^{44}\mathrm{Ti}^{\leq+20}) \neq 1$ Eq. 2 describes the change of the age in terms of $q = t_1/t_0$.

$$q^2 = X(^{44}\mathrm{Ti}^{\leq+20}) \exp[-\mathrm{t_0}/\tau_{\mathrm{Ti}} \cdot (1-\mathrm{q})] + \frac{1}{2} \cdot X(^{44}\mathrm{Ti}^{+21}) \exp[-\mathrm{t_0}/\tau_{\mathrm{Ti}} \cdot (1-\mathrm{q}/2)] \quad (2)$$

The ionization stage of ^{44}Ti of GRO J0852-4642 is not yet known, but a case study is useful to demonstrate quantitatively the impact of the ionization on the estimate of t and d. If ^{44}Ti would have been heated to around kT = 4.4 keV like the X-ray emitting plasma, e.g. by a reverse shock propagating in the ejecta and if ^{44}Ti is in ionization equilibrium the ionic fractions can be extracted from literature. Titanium has not been tabulated so far but the distributions of the ionic fraction of calcium and iron are available, which are taken as case representative examples. Arnaud & Rothenflug (1985), for instance, computed $X(\mathrm{Ca}^{\leq+18})$ = 0.086, $X(\mathrm{Ca}^{+19})$ = 0.339 and 57.5% of Ca completely ionized for log T = 7.8. Using Eq. 2 t_0 = 680 yrs increases to t_1 = 930 yrs as does d by the same factor of q. For iron, which has $X(\mathrm{Fe}^{\leq+24})$ = 0.686 and $X(\mathrm{Fe}^{+25})$ = 0.269 at log T = 7.8, t_1 = 900 yrs, which is very close to the result obtained for Ca, despite a significantly different distribution of the ionic fractions. For higher temperatures, e.g. log T = 8.5, $X(\mathrm{Ca}^{\leq+18})$ = 0, $X(\mathrm{Ca}^{+19})$ = 0.0465 and 95.4% of Ca is completely ionized. For this ionic fraction distribution q = 1 and t and d are unchanged although only 4.65% of the total $Y(^{44}\mathrm{Ti})$ decays radioactively. For even lower values of $X(^{44}\mathrm{Ti}^{+21})$, i.e. a larger fraction of totally ionized ^{44}Ti, $q < 1$ or the age becomes even lower. Using the distribution of the ionic fractions of iron at log T = 8.5, q = 1.28. Clearly, the ionization of Ti has an impact but of moderate size. Values of t and d may be underestimated by some 30% when the ionization starts to affect the K-shell population and they may be even unchanged if only some 10% or less of the Ti has just one electron in the K-shell but is otherwise completely ionized.

Quite recently Mochizuki et al. (1999) have modelled the heating and ionization of ^{44}Ti by the reverse shock in Cas-A, for which they report the possibility of a currently increased ^{44}Ti activity. With respect to RX J0852.0-4622 / GRO J0852-4642 they find that the reverse shock does not heat the ejecta to sufficiently high temperatures to ionize ^{44}Ti because of the low ambient matter density. Future X-ray spectroscopy measurements may answer the question of ionization. But independent of the outcome this section shows that even if ionization were significant it does not change the conclusion that RX J0852.0-4622 / GRO J0852-4642 is a young nearby SNR.

2.3. Explosion energy E_0

The Sedov relation $R \propto (E_0/\rho_0)^{1/5} \cdot t^{2/5}$, which has been adopted for describing the adiabatic expansion of an SNR of radius R in a homogenous medium of matter density ρ_0, has been used quite often in the past to estimate the explosion en-

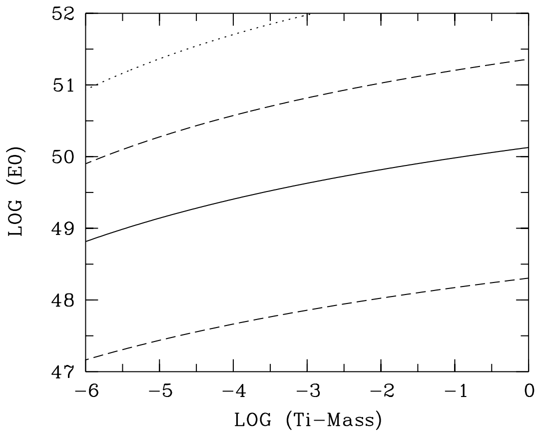

Fig. 4. Logarithm of supernova explosion energy E_0 in ergs vs. logarithm of ^{44}Ti yield in solar masses. Lines are for $v_{\rm b}$ = 5000 km s^{-1} (solid), $v_{\min}$ = 2000 km s^{-1} and $v_{\max}$ = 10000 km s^{-1} (dashed) and v_γ = 19000 km s^{-1} (dotted).

ergy E_0 associated with the supernova (Winkler & Clark 1974, Pfeffermann et al. 1991). The limitations of this approach are well known. The X-ray spectra provide $k\,T$, from which v is derived, the X-ray flux is proportional to $\rho_0 \cdot\ d^{-0.5}$ via $\Lambda(k\,T)$ (cf. Sect. 2.2) and the X-ray image shows the angular extent θ. With the Sedov relation E_0 is not yet uniquely determined but can then be expressed as a function of a single variable, for instance t. Since for RX J0852.0-4622 t can be related to $Y_{^{44}{\rm Ti}}$ via Eq. (1), E_0 is a function of $Y_{^{44}{\rm Ti}}$. In contrast to the relation $E_0(t)$, $E_0(Y_{^{44}{\rm Ti}})$ is constrained because of the limited range of $Y_{^{44}{\rm Ti}}$, at least towards the higher end. Fig. 4 shows $E_0(Y_{^{44}{\rm Ti}})$ for various v, because v is not uniquely determined by the X-ray spectra.

For the reference values of $Y_{^{44}{\rm Ti}}$ = 5×10^{-5} M$_\odot$ and $v = v_b$ = 5000 km s^{-1}, E_0 = 2.6×10^{49}, which is a factor of about 40 less than the canonical E_0 = 10^{51} erg. With v = 5000 km s^{-1} this value can not be reached with a realistic $Y_{^{44}{\rm Ti}}$; even a value of E_0 = 10^{50} erg is hardly consistent with reasonable $Y_{^{44}{\rm Ti}}$ values at v = 5000 km s^{-1}. It is interesting to note that a similarly low value of E_0, i.e. $E_0 >$ 4.4×10^{49} erg s^{-1} have been derived by Willingale et al. (1996) for the SNR of SN 1006, with which RX J0852.0-4622 shares a number of other similarities like the X-ray appearance and the ratio of radio to X-ray surface brightness (Aschenbach 1998). For the reference value of d = 200 pc the total swept-up mass of RX J0852.0-4622 is less than one solar mass, which means that the slow-down of the remnant expansion may not be dominated by ρ_0, so that the applicability of the Sedov relation may be questioned. The radial evolution depends then on the details of the explosion rather than just on E_0. For instance, most of the kinetic energy of the SN may be in matter which does not radiate in X-rays.

E_0 could be raised by increasing ρ_0. The slow down could have occurred at times $<\ t_0$ when regions of higher density might have been passed by the shock wave, e.g. if the progenitor star had produced a strong stellar wind. For a mass loss rate of 10^{-5} M$_\odot$·yr^{-1} and a wind velocity of 1000 km s^{-1} the wind number density would exceed 10^4 cm^{-3} within a radius of about 6×10^{15} cm and X-rays would have been emitted from this region. Lower wind velocities like those typical of red supergiants would increase the size accordingly. The emission region would expand to a measurable size over the 700 yrs but both radiative cooling and adiabatic expansion are likely to have reduced the flux below the detection limit. Nevertheless, we point out that the ROSAT image shows weak but enhanced emission from the central 15′ diameter region (c.f. Fig. 1).

For higher values of v, e.g. for $v = v_{max}$ = 10000 km s^{-1} and $Y_{^{44}{\rm Ti}}$ = 5×10^{-5}M$_\odot$, E_0 = 2.9×10^{50} erg is relatively close to the canonical E_0, but the swept-up, X-ray radiating mass is still just 1 M$_\odot$. Basically, because of the low F_x and the maximal value of d consistent with $Y_{^{44}{\rm Ti}}$ the swept-up, X-ray radiating mass never exceeds a few solar masses.

In summary, E_0 is not very sensitive to $Y_{^{44}{\rm Ti}}$ (c.f. Fig. 4) but instead to the mean expansion velocity v. Taking the full range of v indicated by the X-ray spectra it follows that 10^{49} erg $<$ E_0 $<$ 3×10^{50} erg for a Sedov-type expansion.

The energy budget made of E_0 and the kinetic and thermal energy observed can be used to constrain the mass of the progenitor. The total energy E_x of the X-ray radiating mass, i.e. the sum of the kinetic energy and the thermal energy, amounts to E_x = 4×10^{48} erg s$^{-1}\cdot v_{s,1}^2 \cdot d_2^{2.5}$ with $v_{s,1}$ in units of 1000 km s^{-1}. Since the maximum velocity of the ejecta should not exceed the uniform expansion velocity *v*, which for the adiabatic case is 2.5×v_s, a lower limit of the ejecta mass M_{ej} is $M_{ej}\ \geq 100 \cdot (E_{0,51} \cdot v^{-2} - 6.4 \times\ 10^{-4}\ d_2^{2.5})$ with M_{ej} in M$_\odot$ and $E_{0,51}$ in 10^{51} erg. For $v = v_b$ = 5000 km s^{-1} $M_{ej}\ \geq$ 4 M$_\odot$, i.e. a massive progenitor is required for $E_{0,51}$ = 1, whereas a low mass progenitor with $M_{ej}\ \geq$ 0.9 M$_\odot$ is consistent with the data for v = v_{max} = 10000 km s^{-1}. A more massive progenitor is required if the bulk of the ejecta mass is moving at significantly lower velocities.

Another approach to constrain the progenitor and the supervova type has been taken by Chen & Gehrels (1999). They have used the shock wave velocity indicated by the X-ray temperature observed in the central region of the SNR and used this as the current expansion velocity. By comparison of this velocity with that predicted by SN explosion models and their subsequent evolution into an ambient medium of constant matter density, they conclude that the likely progenitor of the SNR was a massive star of 15 M$_\odot$ with a type II explosion, solely based on the relatively low value of the current expansion velocity v_s inferred from the X-ray temperature. Lower mass progenitors like those leading to a SN of type Ia are supposed to have significantly higher ejecta velocities and according to Chen & Gehrels an ambient matter density $\geq$ 500 cm^{-3} is required to decelerate the explosion wave from initially 11000 km s^{-1} to the current value of 1300 km s^{-1}, using the relation $v_s \propto t^{-2/5}$ (Chen & Gehrels, 1999). If we use the standard Sedov-Taylor relation of $v_s \propto t^{-3/5}$ instead, i.e. the asymptotic limit of the evolution into a uniform medium of constant matter density, a much lower ambient density of 1.4 cm^{-3} is sufficient to reduce the ejecta speed from 11000 km s^{-1} to v_s = 3900 km s^{-1} (the upper limit of v_s estimated by Chen & Gehrels) in 1000 years for an ejecta mass of one solar mass and E_0 = 10^{51} erg. Although this ambient density still exceeds the observed value by a factor of ∼30 it is not unreasonable in comparison with other SNRs and ISM densities. Different ejecta mass, explosion energy and non constant density distributions, in particular, might reduce the required matter density further. In contrast to Chen & Gehrels we are therefore very reluctant to rule out a SNIa for RX J0852.0-4622 based on just the X-ray temperature.

2.4. ^{44}Ti, ^{26}Al and the supernova type

After the discovery of its X-ray emission in early 1996 it was attempted to identify RX J0852.0-4622 as a source contributing to the 1.8 MeV ^{26}Al γ-ray line emission from the Vela region, which had been mapped with the COMPTEL instrument (Oberlack et al. 1994, Diehl et al. 1995). Because of its identifaction as an SNR and because of its apparently low distance RX J0852.0-4622 was considered a good candidate to provide a measurable amount of the ^{26}Al γ-ray line emission. 1.8 MeV γ-ray lines are emitted in the radioactive decay of ^{26}Al, which is processed and released in supernovae but in other sources as well. The 1.8 Mev Vela source appears to be extended with a significant peak at about lII = 267.4°, bII = -0.7°. Oberlack (1997) has used the ROSAT X-ray map of the Vela region to model the 1.8 Mev γ-ray map, taking into account the full size of the Vela SNR, the Vela SNR explosion fragments (Aschenbach et al. 1995), RX J0852.0-4622 and other potential sources. He found two "COMPTEL point-like" sources which could contribute significantly to the γ-ray peak, which are the Vela SNR fragment D/D′ and RX J0852.0-4622. The peak position and the center position of RX J0852.0-4622 agree within the 2-σ localization accuracy of COMPTEL, and the 1.8 Mev point source flux is $f_{\rm Al,m}$ = (2.2±0.5)·10^{-5} photons cm^{-2} s^{-1} out of the total Vela flux of $f_{\rm Al,tot}$ = (2.9±0.6)·10^{-5} photons cm^{-2} s^{-1}. Recently, Diehl et al. (1999) reported a 2-σ upper limit of 2·10^{-5} photons cm^{-2} s^{-1} for a contribution of RX J0852.0-4622 to the overall Vela emisson. This result is not really in conflict with the result of Oberlack, which we are going to use in the present paper. As we show below most of the our conclusions do not depend on the precise value of $f_{\rm Al}$ anyway. If $f_{\rm Al,m}$ is to be attributed to a single SNR with a representative yield of $Y_{^{26}{\rm Al}}$ = 5×10^{-5} M$_\odot$ it follows from Eq. (1) that the distance of the source would be (160 ± 20) pc using a mean lifetime of $\tau_{\rm Al}$ = 1.07×10^6 yrs. Because this excitingly low distance for an SNR was not supported by any other measurements at that time and because of other competing ^{26}Al sources like the Vela SNR fragment D/D′ the results were not published.

But after the discovery of the ^{44}Ti emission, which immediately implies a low age because of its short lifetime and a correspondingly low distance because of the X-ray angular diameter, the situation has changed and both the ^{44}Ti and the ^{26}Al flux may indeed come from a single supernova now visible as the RX J0852.0-4622 SNR. Because of the uncertainty of the amount of $f_{\rm Al}$ actually to be attributed to RX J0852.0-4622 we discuss two cases in the following chapters: a.) $f_{\rm Al,m}$ is entirely from RX J0852.0-4622; b.) $f_{\rm Al,m}$ is not entirely associated with RX J0852.0-4622 but then the COMPTEL data provide a firm upper limit of $f_{\rm Al,ul}$ = 3.5×10^{-5} photons cm^{-2} s^{-1}, which is the total flux observed for the entire Vela region.

Eq. 1 can be used to compute the age $t_{\rm Al,Ti}$ of RX J0852.0-4622 by using the fluxes of just the two radionuclides, making use of $\tau_{\rm Ti} << \tau_{\rm Al}$:

$$t_{\rm Al,Ti} = \tau_{\rm Ti} \cdot \ln({\rm Y}_{^{44}{\rm Ti}}/{\rm Y}_{^{26}{\rm Al}} \cdot 26/44 \cdot \tau_{\rm Al}/\tau_{\rm Ti} \cdot {\rm f_{Al}}/{\rm f_{Ti}}) \quad (3)$$

Interestingly, the age determination does not require knowledge of the distance, and it depends only on the ratio of the mass yields of the two elements considered, which might be useful for further searches for young SNRs. For $f_{\rm Al}$ = $f_{\rm Al,m}$ and $Y_{^{44}{\rm Ti}}/Y_{^{26}{\rm Al}}$ = 1, $t_{\rm Al,Ti}$ = (750 ± 25) yrs. This age agrees remarkably well with the age $t = t_0$ = 680 yrs which has been derived from the ^{44}Ti data and the X-ray measurements, and it appears to support the identification of RX J0852.0-4622 being the source of both the ^{44}Ti and the ^{26}Al emission. Furthermore the value of $t_{\rm Al,Ti}$ is not very sensitive to the precise value of $f_{\rm Al,m}$; even if only one fifth of $f_{\rm Al,m}$, e.g., is actually associated with RX J0852.0-4622, $t_{\rm Al,Ti}$ is reduced by just 145 yrs.

Some interesting conclusions can be drawn about the type of the supernova by making use of model produced values of $(Y_{^{44}{\rm Ti}}, Y_{^{26}{\rm Al}})$. The core-collapse models of Woosley & Weaver (1995) give 0.1 ≤ $Y_{^{44}{\rm Ti}}/Y_{^{26}{\rm Al}}$ ≤ 4.1 for progenitor masses between 11 M$_\odot$ and 40 M$_\odot$ for initial solar metallicity, excluding their models with $Y_{^{44}{\rm Ti}} < 10^{-8}$ M$_\odot$. This leads to $t_{\rm Al,Ti}$ = (540–880) yrs ±30 yrs. Fig. 5 shows the $(Y_{^{44}{\rm Ti}}, Y_{^{26}{\rm Al}})$ – plane of the core-collapse model data (S-sequence of solar metallicity) of Woosley & Weaver (1995); pairs of $(Y_{^{44}{\rm Ti}}, Y_{^{26}{\rm Al}})$ with $Y_{^{26}{\rm Al}}$ greater than the values cut by the line of fixed v are not consistent with $f_{\rm Al,ul}$. Fig. 5 demonstrates that the models of Woosley & Weaver (1995) are consistent with relatively low expansion velocities, most of them with $v <$ 5000 km s^{-1}, which fits nicely the expansion velocity estimated from the X-ray temperature. For increasingly lower metallicity, $Y_{^{26}{\rm Al}}$ of the Woosley & Weaver computations decreases and eventually the data of all the Z = 0 models are above the v = 5000 km s^{-1} cut, except the models for which $Y_{^{44}{\rm Ti}}$ <10^{-8} M$_\odot$. We note that the data of the models S18A, S19A and S25A describing the explosion of the progenitor with a mass of 18 M$_\odot$, 19 M$_\odot$ and 25 M$_\odot$, respectively, are closest to the v = 5000 km s^{-1} line. This appears to be in rather good agreement with the conclusion which has been derived from the energy balance described in Sect. 2.3.

The core-collapse models of Thielemann et al. (1996) for masses between 13 M$_\odot$ and 25 M$_\odot$ show similar values of $Y_{^{44}{\rm Ti}}$ but significantly lower values of $Y_{^{26}{\rm Al}}$ because only the yields of the explosively produced elements are given (Thielemann, private communication, 1999). Therefore $Y_{^{26}{\rm Al}}$ is to be treated as lower limit, and the applicability to RX J0852.0-4622 remains unanswered at this stage.

Interestingly, Woosley & Weaver (1995) have also calculated the yields of models with very little output of ^{56}Ni, from which the supernova power is being drawn after a possible plateau phase. Models with a small yield of ^{56}Ni, which may explain the sub-luminous supernovae after the early phase, also have low $Y_{^{44}{\rm Ti}}$ but relatively high values of $Y_{^{26}{\rm Al}}$, which is pro-

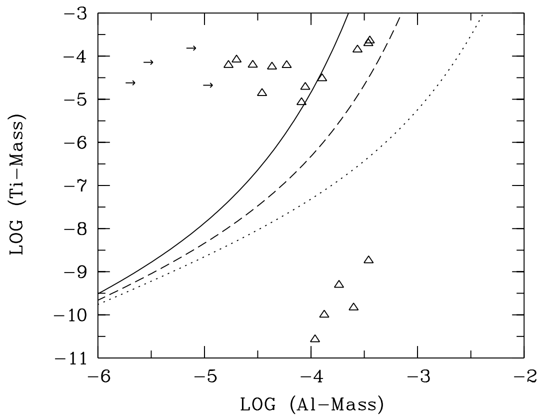

Fig. 5. Logarithm of ^{44}Ti yield in solar masses vs. logarithm of ^{26}Al yield in solar masses. Lines are for v = 30000 km s^{-1} (dotted), v = 10000 km s^{-1} (dashed) and v = 5000 km s^{-1} (solid). Arrows are for core-collapse model data of Thielemann et al. (1996), triangles for model data (S-sequence) of Woosley & Weaver (1995).

duced predominantly in the upper envelope by ordinary burning. The yields predicted by Woosley & Weaver for solar metallicity are shown in Fig. 5 as well. Clearly, the ratio of $Y_{^{26}\mathrm{Al}}/Y_{^{44}\mathrm{Ti}}$ is very high and it is too high to be consistent with the observations. Given the low value of $Y_{^{44}\mathrm{Ti}}$, $Y_{^{26}\mathrm{Al}}$ is simply too large. Such large values have to be checked against $f_{\mathrm{Al,ul}}$. $f_{\mathrm{Al,ul}}$ requires a minimal d for a given $Y_{^{26}\mathrm{Al}}$, which in turn requires a maximal t to be consistent with $Y_{^{44}\mathrm{Ti}}$. Minimal d and maximal t define a minimal expansion velocity for the angular diameter not to exceed θ. Fig. 5 shows that the Woosley & Weaver models require very large values of v Such high mean expansion velocities after some 700 yrs are unlikely and it is evident that these models cannot explain the RX J0852.0-4622 measurements primarily because they are inconsistent with the upper limit of the ^{26}Al flux. Furthermore, the models of Woosley & Weaver show a signficant gap for $Y_{^{44}\mathrm{Ti}}$, which covers the range $3{\times}10^{-8}$ M$_\odot$ $< Y_{^{44}\mathrm{Ti}} < 10^{-5}$ M$_\odot$. This gap might be artificial and further model calculations are required to check, whether the fall-back of matter towards the center of the explosion chokes the production of the high-Z elements to the extent shown by the current explosion models. Models with somewhat lower values of both $Y_{^{44}\mathrm{Ti}}$ and $Y_{^{26}\mathrm{Al}}$ would be consistent with the observations, and a lower value of $Y_{^{44}\mathrm{Ti}}$ might mean a low value of ^{56}Ni as well, which allows for a sub-luminous supernova although the connection between low $Y_{^{56}\mathrm{Ni}}$ and low kinetic energy and luminosity is not yet well established.

Models for type Ia supernovae predict a much higher ratio of ($Y_{^{44}\mathrm{Ti}}/Y_{^{26}\mathrm{Al}}$); Iwamoto et al. (1999) predict 16$<$ $Y_{^{44}\mathrm{Ti}}/Y_{^{26}\mathrm{Al}}$ $<$ 470 and the sub-Chandrasekhar models of Woosley & Weaver have 280$<$ $Y_{^{44}\mathrm{Ti}}/Y_{^{26}\mathrm{Al}} <$ 930. These values correspond to a relatively large t (Eq. 3) and a low d with f_{Al} = $f_{\mathrm{Al,m}}$, which results in a relatively low value of the mean expansion velocity, i.e. 50 km s^{-1} $< v <$ 275 km s^{-1} for the models of Iwamoto et al. and 180 km s^{-1} $< v <$ 1060 km s^{-1} for the models of Woosley & Weaver. These values are well below the lower limit velocity of v_s = 1240 km s^{-1} and are therefore inconsistent with the X-ray temperature measurements. It appears that the type Ia model predictions are in serious conflict with the measurements, thus excluding type Ia models from explaining RX J0852.0-4622. But this conclusion hinges on the assumption that f_{Al} = $f_{\mathrm{Al,m}}$ is actually associated with RX J0852.0-4622. If only a minor fraction of $<$ 1% of $f_{\mathrm{Al,m}}$ is due to RX J0852.0-4622, also type Ia models may be reconsidered. For this case d and t are given in Sect. 2.1.

3. A compact remnant?

In contrast to type Ia supernovae core-collapse supernovae are expected to leave a neutron star or a black hole initially close to the explosion center. Here we restrict the discussion to a neutron star. If borne with a significant kick-velocity the neutron star will travel a distance from the centre given by the kick-velocity. Kick-velocities as large as 1000 km s^{-1} have been reported for pulsars, and for RX J0852.0-4622 with a mean expansion velocity of v = 5000 km s^{-1} any putative neutron star should be within a radius of about 12′ around the center. The ROSAT all-sky survey data of this area have been searched for point sources and two candidate sources have been found. Excess emission has been detected at RA(2000) = 8$^{\mathrm{h}}$ 52′ 3″, DEC(2000) = $-46°$ 18′ 36″, which is off-set from the explosion center by 3.4′. With the nominal value of v and t derived above the separation corresponds to 283 km s^{-1} for the transverse component of the kick-velocity or a proper motion of 0.3″ yr^{-1}. The center of the explosion has been determined by the circle matching best the SNR outer boundary. The uncertainty in the center position is estimated to be about $\pm$1.5′. This point-like source and the implications concerning a compact remnant have already been reported and discussed (Aschenbach, 1998). Here we report excess emission from a second point-like source inside the suspected area at RA(2000) = 8$^{\mathrm{h}}$ 51′ 58″, DEC(2000) = $-46°$ 21′ 33″. This source has been detected in the low energy ROSAT image of the Vela SNR created from the counts which have been recorded in the central 40′ diameter field of the PSPC. Compared to the full field of 2° this procedure improves the spatial resolution considerably and thereby the sensitivity of detecting point sources above the diffuse background. The 17 source counts per 40″×40″ pixel exceed the mean background level of 4.4 counts (40″×40″)$^{-1}$ by 6-σ. The source count rate is 0.12 counts s^{-1}. No spectrum and no information about interstellar absorption is available. But the flux can be used to estimate the size of the X-ray emitting area as a function of temperature T_{bb} for a black-body with the interstellar absorption as parameter, which is shown in Fig. 6.

If the source is a black-body radiating neutron star of 10 km radius with emission from the entire surface, there is an upper limit of T_{bb} = 1.2×10^6 K imposed by the 5-σ upper limit of N_{H} = 10^{22} cm^{-2}. But more realistical is a much lower value of N_{H} $<$ 10^{20} cm^{-2}, which is typical for the southeastern section of the Vela SNR. Then, Fig. 6 implies that $T_{\mathrm{bb}} \approx 3{\times}10^5$ K. If just a fraction of the full surface is radiating the temperature may be slightly higher by about a factor of two, for instance, if the area of the radiating spot is about 1% of the full neutron star

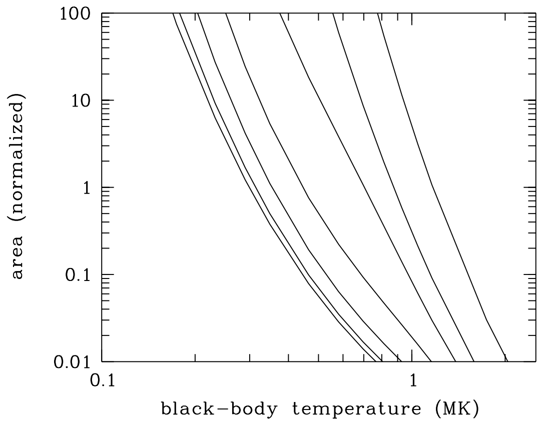

Fig. 6. Black-body surface area normalized to a full size 10 km radius neutron star vs. temperature in units of 10^6 K. Lines are for different interstellar absorption, which is 10^{19}, $3{\cdot}10^{19}$, 10^{20}, $3{\cdot}10^{20}$, 10^{21}, $3{\cdot}10^{21}$, 10^{22} in units of cm^{-2} from left to right.

surface area. For a full size area radiating neutron star, which is just 700 yrs old, $T_{\rm bb}$ would be surprisingly low. Furthermore, if the supernova left a neutron star somewhere else the black-body surface temperature would be even lower because of a lower X-ray count rate, unless the column density to the putative neutron star should be even higher.

4. A historical event?

A supernova going off at a distance of 200 pc should have been a spectacular sight for the contemporaries in the 13th or 14th century. (If we take into account the full band of our age determination also the 12th and the 15th century should not be excluded.) Just how spectacular this event was depends on the absolute visual magnitude M_V. For a bright supernova of type Ia with $M_V \leq -19.0$ the burst of light would have been as bright as the full moon. For a type II, Ib or Ic which are intrinsically fainter the light output can be orders of magnitude less. For the sub-luminous or ultra-dim SNe recently discussed (Schaefer 1996, Hatano et al. 1997, Woltjer 1997) $M_V = -13.0 \pm 2$. Examples quoted are SN 1181 with $M_V = -12.68 \pm 1.41$ and Cas A with $M_V = 13.03 \pm 2.69$. Taking a somwewhat extreme position with $M_V = -11.5$ the SN associated with RX J0852.0-4622 would still have been brighter than Venus. Taking the other extreme position of a type Ia the SN is a candidate to be recognized even in daylight. In any case it should have been seen.

Records of astronomical events including the epoch of the supernova proposed by us were taken by the far-east astronomers of China, Japan and Corea (Clark & Stevenson 1977, Ho Peng Yoke 1962). Their observatories were typically located at a geographical latitude of $\sim$35° north (Clark & Stevenson 1977), within $\pm 5°$ north or south, so that the SN of RX J0852.0-4622 would have risen above the horizon after sun-set by up to 11° from middle of December to end of March. If the SN of RX J0852.0-4622 would have exploded say in late March it would have re-appeared in the northern hemisphere during night after more than 250 days with significantly lower brightness. The light curve of the sub-luminous SN 1997D (Turatto et al. 1998) provides an estimate of $\Delta m_v \sim 5$ at ~ 250 days after outburst, which appears rather little compared with other SNe which show $\Delta m_v \sim 8$ like SN 1994W (Sollerman et al. 1998). With $M_V = -11.5$, $\Delta m_v = 5$ and a distance modulus of 6.5 the SN of RX J0852.0-4622 then had $V = 0$ and it is not unlikely to have escaped the attention of the medieval far-east observers. Even with the M_V of SN 1181 the chances to miss it would not have been low. Furthermore, within this scenario, that only the tail of the light curve had been caught, the SN may have not been noticed as a "guest star" because the change was only against a pattern observed more than 200 days before. The light curve of SN 1997D also demonstrates that even if the SN went off in the December–March time frame the detection might have been prevented by a rather short peak/plateau period, and sky visibility conditions become important. For SN 1997D this period probably lasted for ≤ 60 days (Turatto et al.), over which the brightness decreased by $\Delta m_v \sim 3$.

The above exercise demonstrates with realistic data that it is indeed possible that the SN of RX J0852.0-4622 was not bright enough, despite its proximity. This sort of physical explanation requires a sub-luminous SN. The peak luminosity and the early lightcurve are determined by the ejecta mass, E_0, pre-SN radius, the structure of the outer layers, $Y_{^{56}\rm Ni}$ and its distribution. As shown by Chugai & Utrobin (1999) in their model for SN 1997D it appears that $Y_{^{56}\rm Ni}$ is rather low for this class of sub-luminous SNe, and it remains to be seen whether these SNe can actually produce enough ^{44}Ti (but c.f. Figs. 2, 3 for the minimum amount). We stress that we cannot exclude that the SN was indeed much brighter and even a daylight object. Observers located much further south, like the people of the Incas, the Aztecs or in Middle- and South-Africa, should have had better visibility and their traditions are recommended to be searched for an event pointing to a SN. In this context it is interesting to note that the records of the far-east observers as published by Ho Peng Yoke (1962) appear to be incomplete. The compilation shows three gaps, which are suspiciously long and statistically inconsistent with the mean rate of entries. These periods include the years of 773–814, 1245–1264 and 1277–1293, the latter two of which are relevant for RX J0852.0-4622.

Finally, we point out that there is a chance that the progenitor star of RX J0852.0-4622 is shown in ancient star charts if it happened to be a massive star. Up to now just one progenitor star of a supernova has been identified, which is the progenitor of SN 1987A, the B3 Ia blue supergiant Sanduleak $-69\,202$ with $M_V = -6.8$ (West et al. 1987). At a distance of 200 pc the apparent unreddened visual magnitude would have been $V = -0.3$, which would have made the star the brightest star in the Vela constellation located between γ Vel and λ Vel. A Wolf-Rayet type progenitor star would have been less bright with $V \approx +2.5$, but still comparable with the other bright stars in Vela. This opens up an interesting explanation for the apparent absence of a historical record, which admittedly is a speculation. If the progenitor star had been so bright the supernova might not have been noted down as a "guest star". The existing star would just have become brighter. And if the short peak of the outburst had been missed of whatsoever reason and only the tail of the supernova lightcurve has been observed the change of brightness might not have been spectacular, and the star would have disappeared slowly over a couple of years.

5. Conclusions

An estimate of the age t and distance d of the supernova remnant RX J0852.0-4622 / GRO J0852-4642 can be obtained by combining the ROSAT X-ray and COMPTEL γ-ray data. Assuming a ^{44}Ti yield of the supenova of 5×10^{-5} $M_\odot$ and an expansion velocity of 5000 km s^{-1} t = 680 yrs and d = 200 pc are obtained. Actually, the expansion velocity is constrained by the X-ray data to lie in the range of 2000 km s^{-1} $<$ v $<$ 10 000 km s^{-1} yielding an uncertainty of the age of $\pm$ 100 years for a fixed ^{44}Ti yield. For the highest ^{44}Ti yield given by current supernova models, a firm upper limit of the distance is 500 pc and 1100 years for the age.

The determination of the age depends to some extent on the ionization state of ^{44}Ti because ^{44}Ti decays by electron capture. The values quoted above have been obtained under the assumption that the K-shell is fully populated. If the K-shell contains only one electron, the ^{44}Ti mean lifetime is estimated to increase by a factor of two. But the age of the SNR will not increase by the same factor because of the angular diameter, and therefore distance constraint. Adopting the same mean expansion velocity t and d can change by about 35% at most and for a very strong ionization t and d may be even lower than the "nominal" estimate. Future X-ray spectroscopy measurements are needed to search for Ti X-ray emission lines to determine the ionization state of ^{44}Ti and further constrain t and d.

The X-ray surface brightness of RX J0852.0-4622 is rather low and implies a rather low matter density of the shock wave heated plasma if the radiation is thermal. A formal analysis of the X-ray data in terms of a Sedov-type evolution of the SNR using the standard conversion of X-ray temperature in shock velocity turns out a rather low value of a few times 10^{49} erg for the explosion energy E_0, which can be raised only significantly if the mean expansion velocity v would exceed 10000 km s^{-1}. But if v is closer to 5000 km s^{-1} as the X-ray data indicate then the bulk of E_0 resides still in kinetic energy of the ejecta, not radiating in X-rays, which means that any reverse shock has not yet penetrated deep into the ejecta, and that the titanium is not highly ionized. In this case a lower limit for the mass of the progenitor star of 25 $M_\odot$ is estimated from the energy balance.

There is evidence for ^{26}Al 1.809 MeV line emission from RX J0852.0-4622, which has been measured by COMPTEL towards the Vela region. Admittedly this has still to be confirmed. But if a non-neglible part of this 1.809 MeV line flux is coming from RX J0852.0-4622 a similar age of 600-750 yrs for the SNR is obtained for similar yields of ^{26}Al and ^{44}Ti. Since t depends only on the logarithm of the yields and the fluxes t will not change significantly even for large changes of the ^{26}Al flux. It is more a matter of whether or not there is ^{26}Al emission. If the ^{26}Al line flux is about what is indicated by the COMPTEL data the existing type Ia supernova models can be ruled out for the progenitor explosion because they predict a ratio of the ^{26}Al and ^{44}Ti yield which is by far too large. They could be reconsidered only if less than 1% of the ^{26}Al line flux from Vela in total is associated with RX J0852.0-4622. Explosion models of core-collapse supernovae (Woosley & Weaver, 1995) are in general in agreement with the observations, i.e. the measurements of v, ^{44}Ti line flux and ^{26}Al line flux, judging from their prediction of the yields of ^{44}Ti and ^{26}Al. Their models with $Y_{^{44}\mathrm{Ti}} < 10^{-8}$ $M_\odot$ and $Y_{^{26}\mathrm{Al}} > 10^{-4}$ $M_\odot$ can definitely be excluded because the yield of ^{26}Al predicted is inconsistent with even the upper limit of the ^{26}Al line flux measured for the Vela region in total. In summary, both the energy balance and the yield predictions of the currently available explosion models point towards a core-collapse event.

Within the vicinity of the explosion center two point-like X-ray emission regions have been found, either of which could be the manifestation of a neutron star. Spectra are not available, but if the radiation is assumed to be black-body emisson, the X-ray flux indicates a surface temperature of $\approx 3 \times 10^5$ K, which is surprisingly low for a 700 years old neutron star. If neither one of these two sources is a neutron star and the neutron star hides somewhere else with an even lower X-ray count rate or if only a fraction of the radiation observed from the point-like objects is due to thermal radiation the surface temperature of the neutron star could be even lower.

In principle, the supernova could have been seen from the far-east astronomers of China, Corea or Japan or from geographical latitudes further south. The supernova could have been very bright and then there are records expected to exist, which should be searched for. If the supernova would have been of the subluminous class with a brightness as low as that of SN 1181 and a short peak-plateau duration it could have been missed. There is some chance that the progenitor star was sufficiently bright and could have been seen by the naked eye. Then the stellar pattern of Vela was different in ancient times and the astronomers who monitored the sky might not have noted the supernova as a "guest star" or a "new" star, because the star was existing and just brightening and eventually fading away.

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