Consequences of Cosmic Ray Acceleration in Supernova Remnants on their Evolution – the Case of RX J0852.0-4622 (Vela Jr.)

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Galactic Cosmic Rays:

electrons (< 100 TeV), protons (< 10^{15} eV)

observation channels:

electrons via hard X-ray synchrotron radiation (> 1 – 2 keV) and
TeV γ-rays by inverse Compton effect (IC)

protons via TeV γ-rays by nuclear collisions with ambient protons
(π^0 decay)

out of > 300 galactic radio SNRs just three objects, i.e.,

SN1006 with spatially limited synchrotron X-rays, (TeV γ-rays ?)

RX 1713.7-3946 with full shell emitting synchrotron X-rays and TeV γ-rays

RX 0852.0-4622 with full shell emitting synchrotron X-rays and TeV γ-rays

Why so few objects?
Special type of supernova?
Special ambient conditions, like ambient density?

Creation of Cosmic Rays

nonlinear diffusion-like acceleration of particles by their interaction with shock waves generated at the front of SNRs (i.e., shell type remnants)

theory shows possible acceleration efficiency such that $E_{CR} > 0.55\ E_{SN}$! ,e.g.,

(Ksenofontov et al., 2005)

This MUST have an effect on the SNR dynamics

The Formalism

$\Delta v_{CR} \sim v_s$ shock acceleration

$\Delta v_{CR} \sim v_s \; \Delta(t^{1/2})$ diffusion –type shock acceleration

$dE_{CR} \sim v_s^2 \, dt$ energy domain

$E_{SN} = E_s + E_{th} + E_{kin} + E_{CR}$ energy conservation

$E_{th} + E_{kin} \sim v_s^2 \sim E_{SN} – E_{CR}$

$dE_{CR} \sim -(E_{CR} – E_{SN}) \, dt$

$E_{CR}/E_{SN} \sim [1 – \exp(-t/t_{CR})]$

E_{cr}/E_{SN} (t => inf) = A $\qquad$ $E_{cr}(t)/E_{SN} = A\,[1 - \exp(t/t_{cr})]$

Modification of Sedov Relation

$r = \text{const}\,(E_{SN}/n)^{1/5}\, t^{2/5}$ => $t_{Sedov} = 2/5\; r/v_s$

$r = \text{const}\,[(E_{SN} - E_{CR}(t))/n]^{1/5}\; t^{2/5}$ with $t = t_{Sedov}/k$

e.g., A = 0.50 k = 1.16

A = 0.70 k = 1.35

A = 0.90 k = 2.22

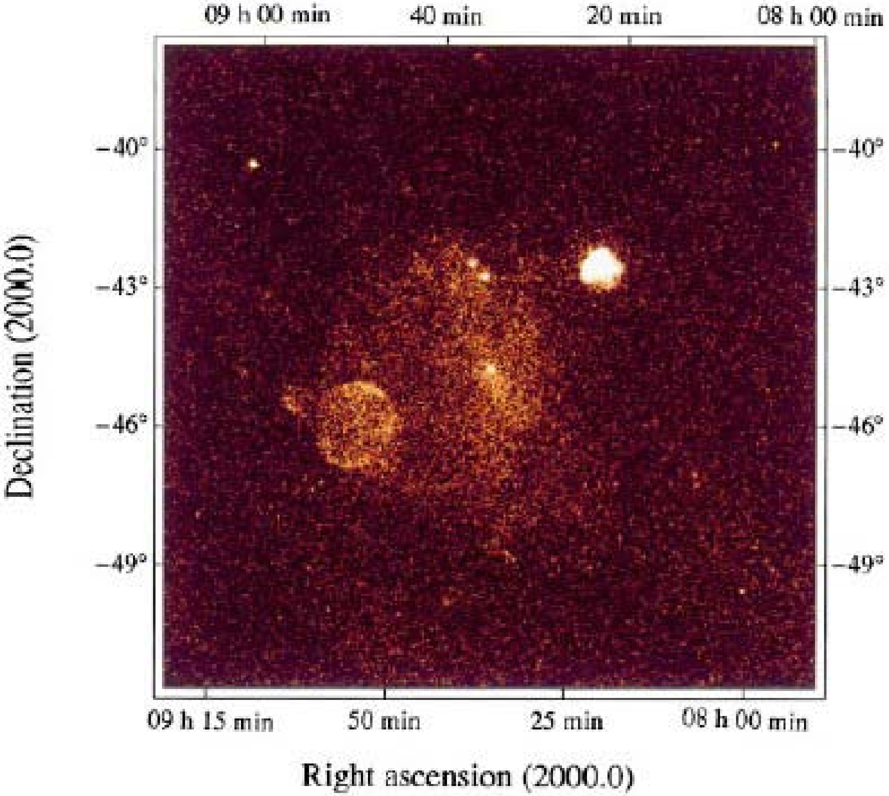
A = 0.95 k = 4.20

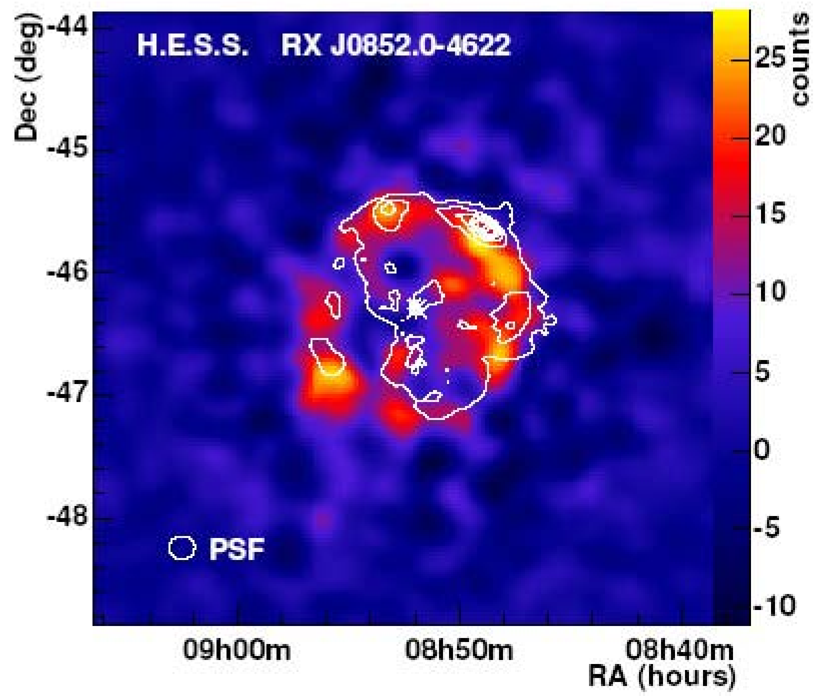
several events suggest a SN around 1271, i.e. ~730 yrs ago

nitrate precipitation in Arctic icecores,
sudden increase in atmospheric radiocarbon,
bright ´star´ reported in Japan (rise of Nichiren Buddhism, comet? Moon anomaly?)
and from Great Zimbabwe monument (settlement of Llemba people)
and from the exodus from the Samoa islands
γ-ray lines of ^{44}Ti ?

RX 0852.0-3946 (Vela Jr.) ?

ROSAT Image (> 1.3 keV), Aschenbach 1998





H.E.S.S. Image (>0.5 TeV), Aharonian, 2007

RX 0852.0-3946 (Vela Jr.)

properties: $r = 1°$ $v_s = 0.84$ arcsec/yr $n \leq 0.029/\sqrt{d_1}$ cm^{-3} (X-rays)

$E_{CR} = 2.5 \cdot 10^{50}$ erg $\cdot\, d_1^{\,2}/n$ TeV γ-rays (if π^0 dominated)

$t_{Sedov} = 1714$ yrs

for $t = 730$ yrs $= t_{Sedov}/k$ $A = 0.91$

solution of modified Sedov relation for $E_{SN} = 10^{51}$ erg (the only free parameter):

$t_{cr} = 338$ yrs $n = 0.0408$ cm^{-3} $d = 385$ pc

what is worth to be noted?

very low ambient density, $n < 0.05\ cm^{-3}$

very high blast wave velocity at early times, $v_s > 40000$ km/s

type of Supernova?

red supergiants ruled out

blue supergiants possible, one example: SN1987A

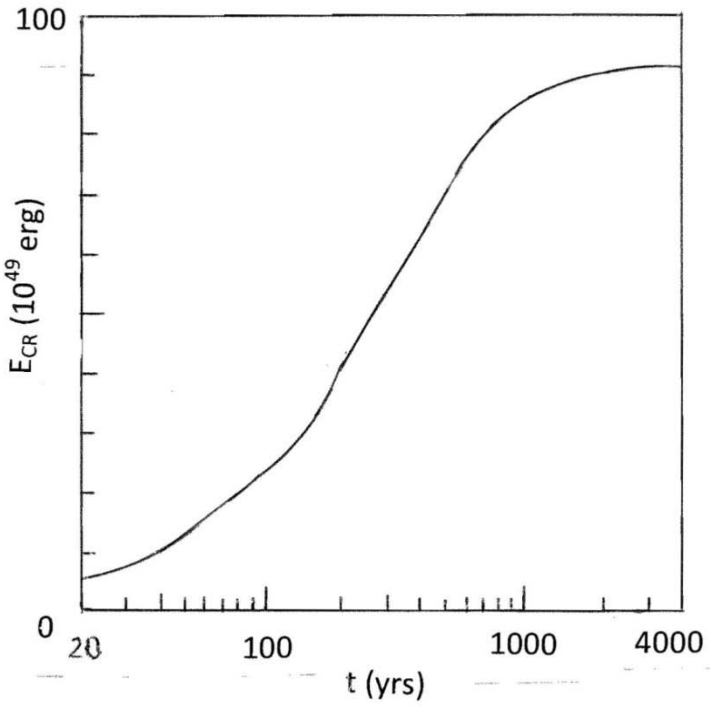
type Ia possible, but with very low residual n (ambient medium evolution?, SN1006?)

A depends on n

$E_S = E_{th} + E_{kin} + E_{CR}$ $E_{th} + E_{kin} \sim n$ but $E_{CR} \sim n^{3/16}$ (Ksenofontov et al., 2005)

high n suppresses cosmic ray acceleration because the blast wave (shock wave energy) is preferentially tranferred to thermal and kinetic energy

Finale



t > 500 yrs : cosmic ray energy production fades rapidly
electrons start to loose energy by synchroton radiation without further supply
remaining lifetime for those producing 1 keV/10 keV X-rays
5800 yrs/1800 yrs for B = 5 μG and
1500 yrs/500 yrs for B = 30 μG (upstream magnetic field)

Non-thermal X-emission and IC TeV γ-emission undetectable after a few thousands years