The young supernova remnant G1.9+0.3 and the late-time gamma-ray emission from SNR

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Why G1.9+0.3?

Overview

General Properties
• No detection in gamma rays yet
• Located near the galactic center
• Radius of around 2pc (difference between radio and x-rays)
• Age of about 100yrs
• Shock speed of about 14.000km/s
• Probably a type1a supernova

G1.9+0.3 could be an very efficient particle accelerator
Fermi acceleration

Coupled equations

- Cosmic-ray transport equation
- Hydro equations
- Magnetic Turbulence
- Magnetic field

Feedback effects are negligible for G1.9+0.3
Fermi acceleration

Transport equation for cosmic rays

\[
\frac{\partial N}{\partial t} = \nabla D_r \nabla N - \nabla v N - \frac{\partial}{\partial p} \left( N \dot{p} - \frac{v}{3} N p \right) + Q
\]

Diffusion \hspace{1cm} \text{Advection} \hspace{1cm} \text{Cooling} \hspace{1cm} \text{Acceleration} \hspace{1cm} \text{Injection}

The equation is solved:

- One dimensional
- Assuming spherical symmetry
- Including Synchrotron cooling for electrons
- On a comoving, expanding grid \(\rightarrow\) no free escape boundary
Fermi acceleration

Transport equation for magnetic turbulence

\[
\frac{\partial E_W}{\partial t} = - (v \nabla_r E_W + c \nabla_r v E_W) + k^3 \nabla_k D_k \nabla_k \frac{E_W}{k^3} + 2(\Gamma_g - \Gamma_d)E_W
\]

\( E_W \): Energy density in magnetic turbulence per unit logarithmic bandwidth

\( B_{tot} = \sqrt{B_0^2 + 4\pi \int E_W d \ln k} \)

The equation is solved:

- Assuming isotropic, alfvenic turbulence
- 1D and spherically symmetric
- Same spatial grid as for cosmic rays

Turbulence growth at the largest scales takes time and limits \( E_{Max} \)!
Fermi acceleration

Additional ingredients

Hydro modeling:
• Solving the standard gas-dynamical equations
• 1D and spherically symmetric
• Modeled as type1a-explosion in a uniform medium

\[
\frac{\partial}{\partial t} \begin{pmatrix} \rho \\ m/E \end{pmatrix} + \nabla \begin{pmatrix} \rho \mathbf{v} \\ m \mathbf{v} + P \mathbf{I} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \\
\frac{\rho \mathbf{v}^2}{2} + \frac{P}{\gamma - 1} = E
\]

• Free parameter: ambient density
Fermi acceleration

Two dimensional effects

MHD instabilities might drive magnetic field amplification at both shocks

→ Additional field downstream at both shocks included
Results
Forward and reverse shock model: Spectral energy distribution

- 0.75% of the thermal energy density at both shocks transferred into magnetic field:
  \[ B_d = 180\mu G \text{ (FS)} \]
  \[ B_d = 120\mu G \text{ (RS)} \]

- Acceleration at reverse shock inefficient but emission bright in Radio and GeV gamma-rays

- TeV dominated by forward shock IC emission
Results

Magnetic field and particle distribution

- Similar magnetic fields but higher CR density at low energies makes the reverse shock bright in Radio and GeV gamma-rays.
Results

Emission profile

• Reproducing the profile requires a two-shock model

• Different expansion speeds of x-ray (14,000km/s) and radio (9,500km/s) features → consistent with two-shock model (14,000km/s and 11,000km/s)

• Very low intensity in the center → no spherical symmetry
Results

Radio Brightening

- Simulated brightening of 0.75%/yr roughly consistent with measured brightening of 1.2%/yr
- Brightening indicates a magnetic field growth faster than predicted in our model

What is the spectral evolution during the lifetime of the SNR?
Results

Future evolution of the SED

- Time-dependent turbulence amplification limits $E_{max}$ at early times

- The decay of turbulence alters particles spectra at late times → Non-negligible escape of high-energy particles from far downstream leads to softer spectra

- HE electrons escaping past the CD stop being cooled
Summary

- The SED can be reproduced in a two-shock scenario and the emission profile requires two shocks
- The electron-cutoff energy is consistent with the self-consistent amplification of Alfvenic turbulence
- Additional magnetic field generation in the downstream is needed for the emission
- No indication for CR-pressure feedback
- Self-consistent turbulence treatment naturally provides soft particle spectra at late evolutionary phases ($s \approx 2.7$)