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

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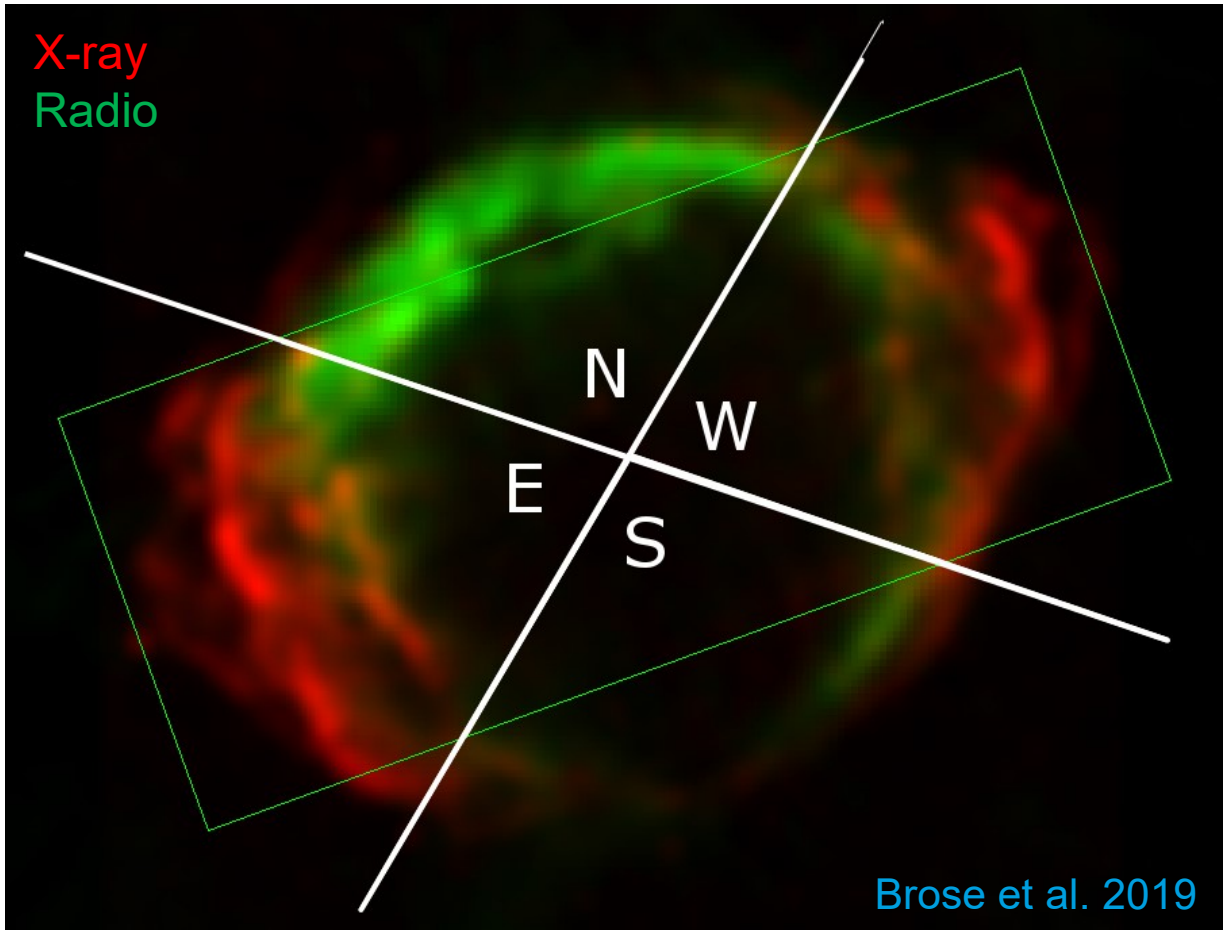
DESY

Why G1.9+0.3?

Overview

General Properties

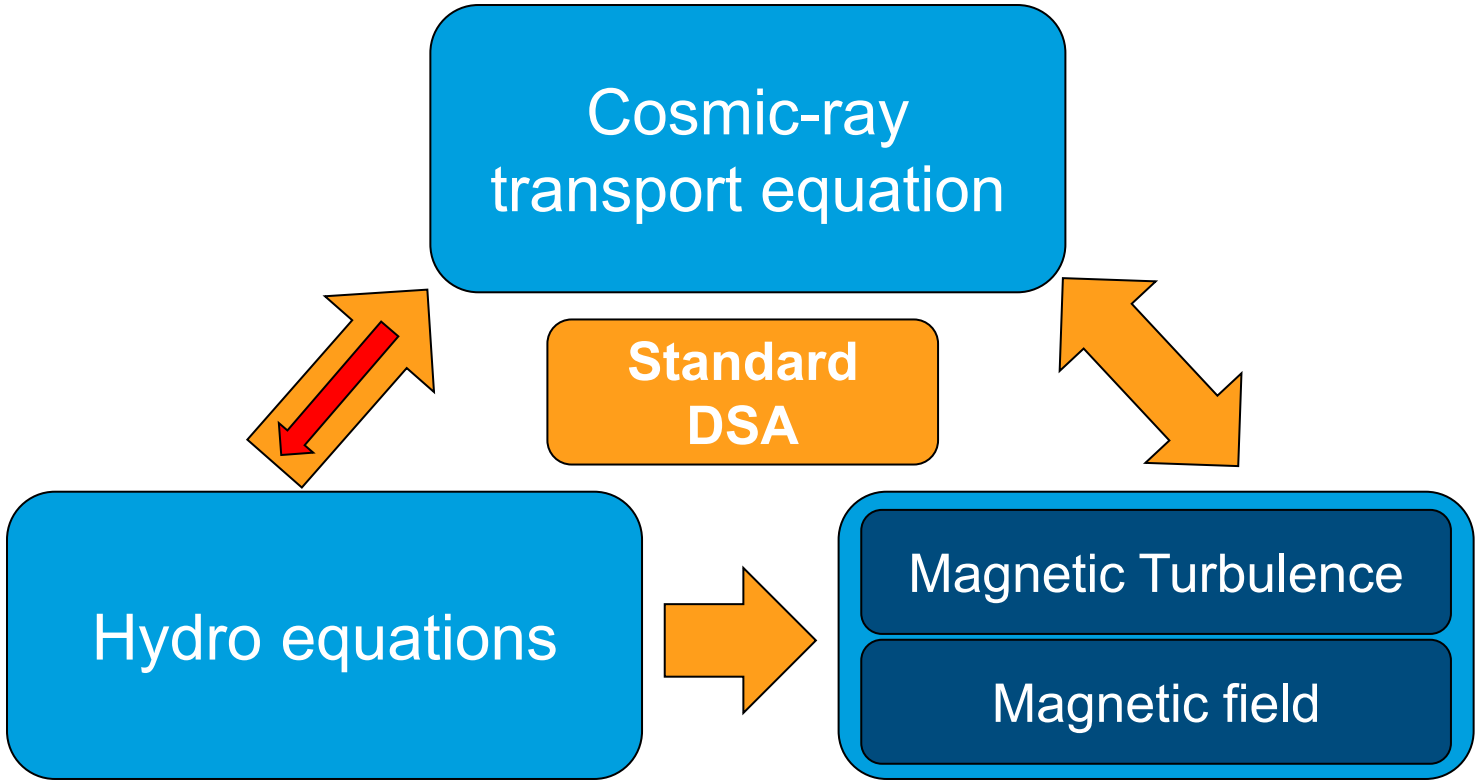
- No detection in gamma rays yet
- Located near the galactic center
- Radius of around 2pc (difference between radio and x-rays)
- Age of about 100yrs
- Shock speed of about 14.000km/s
- Probably a type1a supernova



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

Fermi acceleration

Coupled equations



Feedback effects are negligible for G1.9+0.3

Standard DSA

Non-linear DSA

Fermi acceleration

Transport equation for cosmic rays

$$\frac{\partial N}{\partial t} = \underbrace{\nabla D_r \nabla N}_{\text{Diffusion}} - \underbrace{\nabla v N}_{\text{Advection}} - \frac{\partial}{\partial p}\left(\underbrace{N\dot{p}}_{\text{Cooling}} - \underbrace{\frac{v}{3} N p}_{\text{Acceleration}}\right) + \underbrace{Q}_{\text{Injection}}$$

The equation is solved:

- One dimensional
- Assuming spherical symmetry
- Including Synchrotron cooling for electrons
- On a comoving, expanding grid → no free escape boundary

Fermi acceleration

Transport equation for magnetic turbulence

$$\frac{\partial E_W}{\partial t} = -\underbrace{(v\nabla_r E_W + c\nabla_r v E_W)}_{\text{Advection + Compression}} + \underbrace{k^3 \nabla_k D_k \nabla_k \frac{E_W}{k^3}}_{\text{Cascading}} + \underbrace{2(\Gamma_g - \Gamma_d)E_W}_{\text{Growth + Damping}}$$

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

$$\frac{\partial}{\partial t}\begin{pmatrix}\varrho\\ \boldsymbol{m}\\ E\end{pmatrix}+\nabla\begin{pmatrix}\varrho\boldsymbol{v}\\ \boldsymbol{m}\boldsymbol{v}+P\boldsymbol{I}\\ (E+P)\boldsymbol{v}\end{pmatrix}=\begin{pmatrix}0\\ 0\\ \Lambda\end{pmatrix}$$

$$\frac{\rho\boldsymbol{v}^2}{2}+\frac{P}{\gamma-1}=E$$

- Free parameter: ambient density

Fermi acceleration

Two dimensional effects

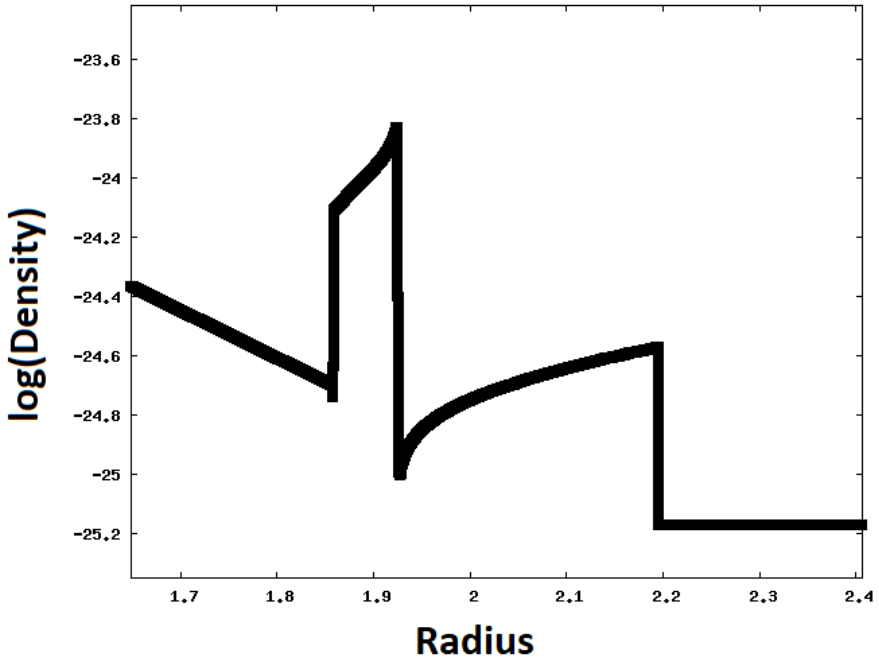
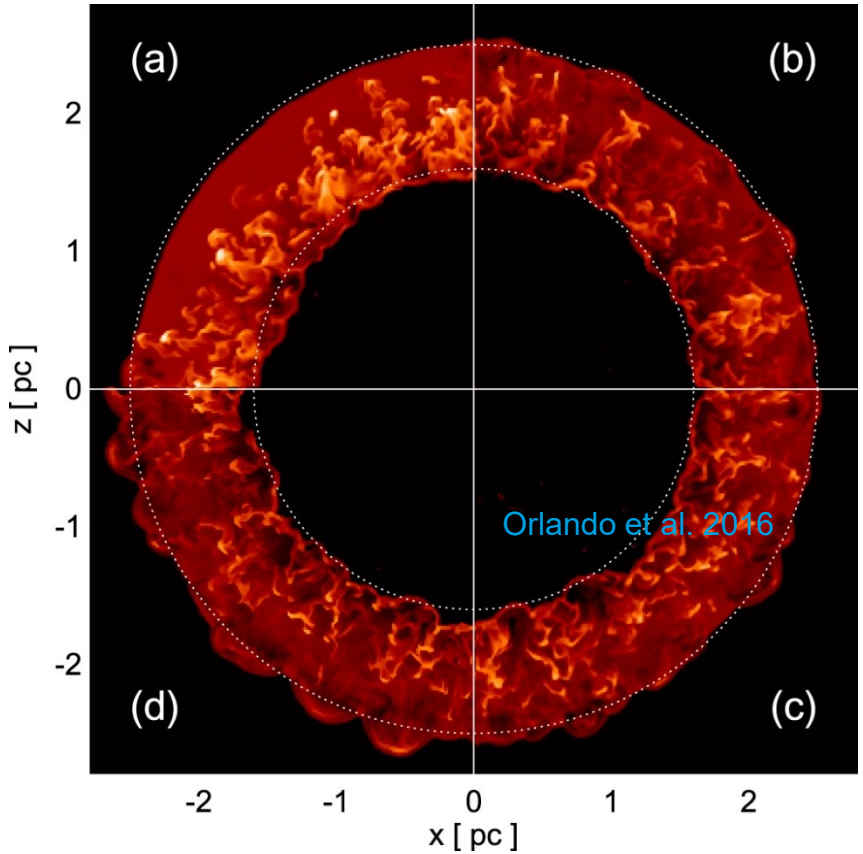


Figure: Plasma density in 1D simulations

Figure: Plasma density in 2D simulations



MHD instabilities might drive magnetic field amplification at both shocks

→ Additional field downstream at both shocks included

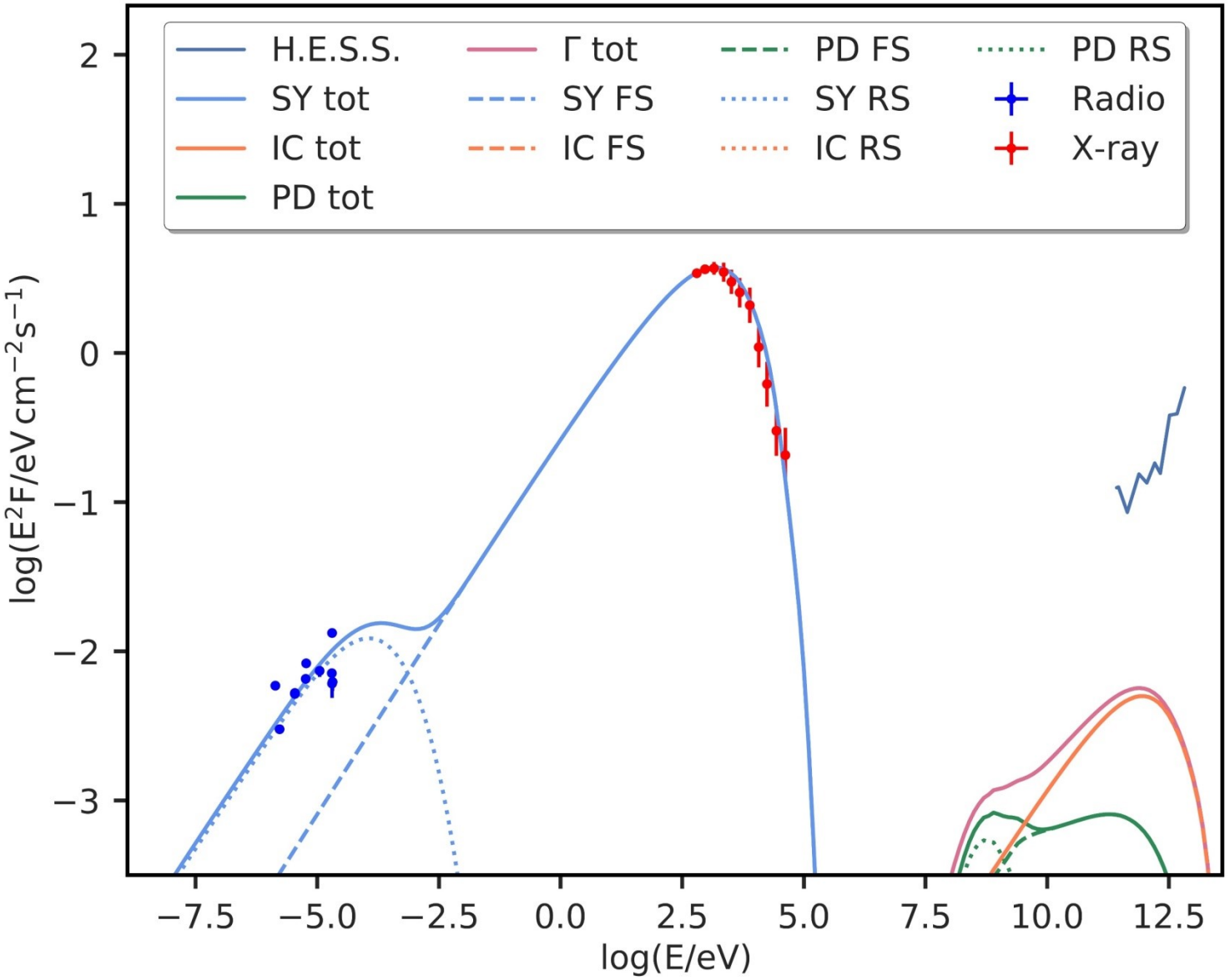
Results

Forward and reverse shock model: Spectral energy distribution

- 0.75% of the thermal energy density at both shocks transferred into magnetic field:
  B_d = 180μG (FS)
  B_d = 120μG (RS)

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

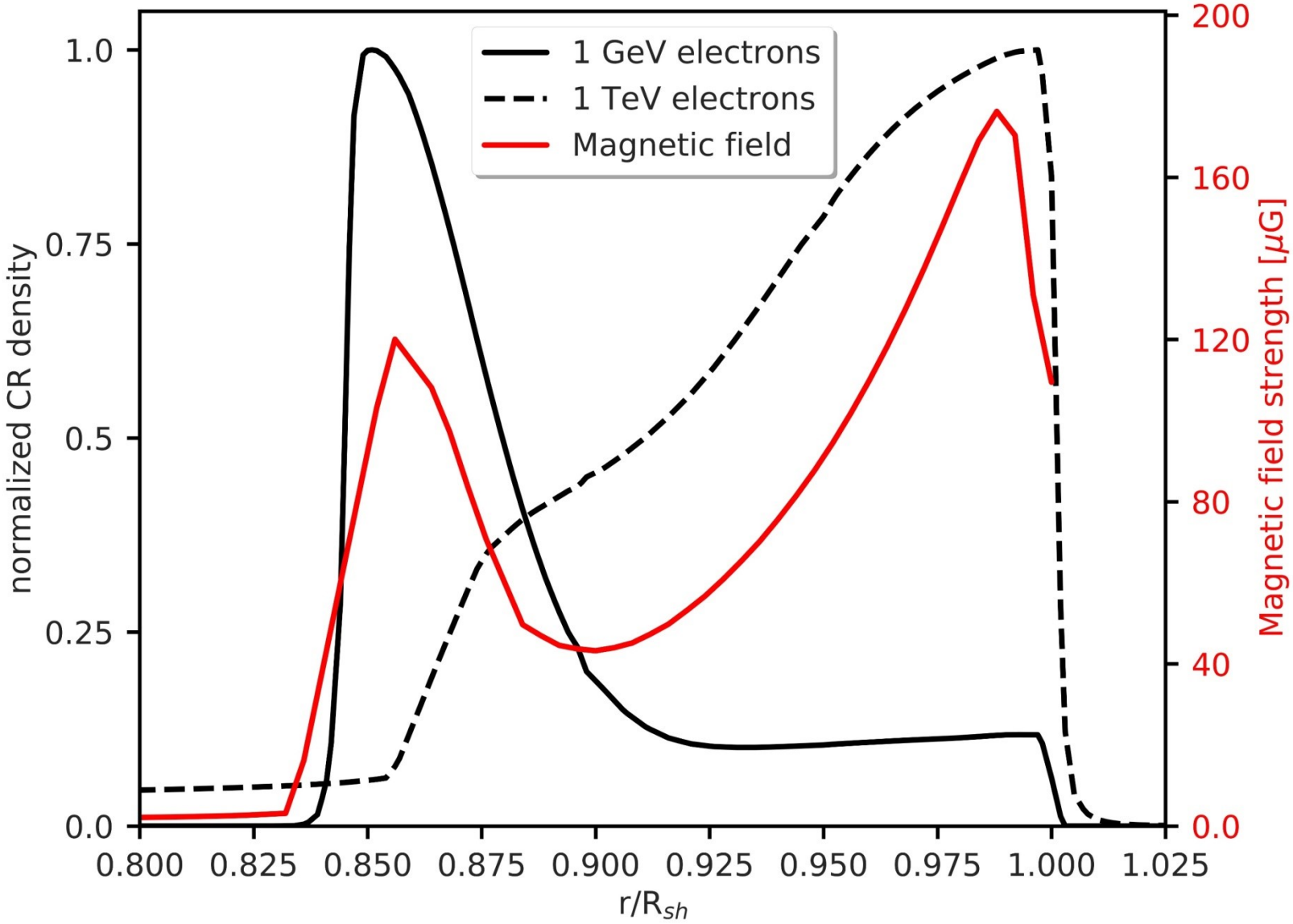
- TeV dominated by forward shock IC emission



Results

Magnetic field and particle distribution

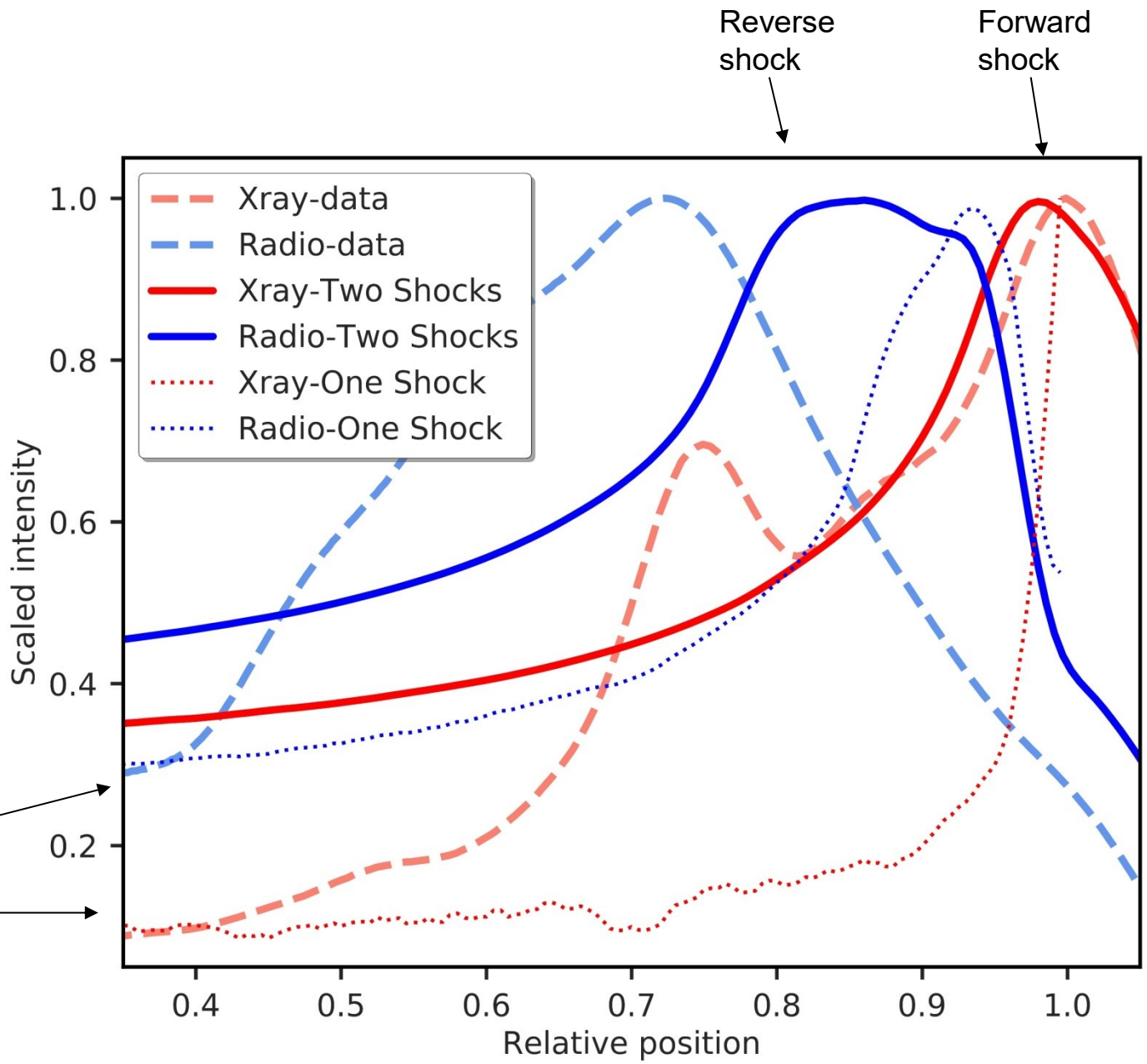
- Similar magnetic fields but higher CR density at low energies makes the reverse shock bright in Radio and GeV gamma-rays



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

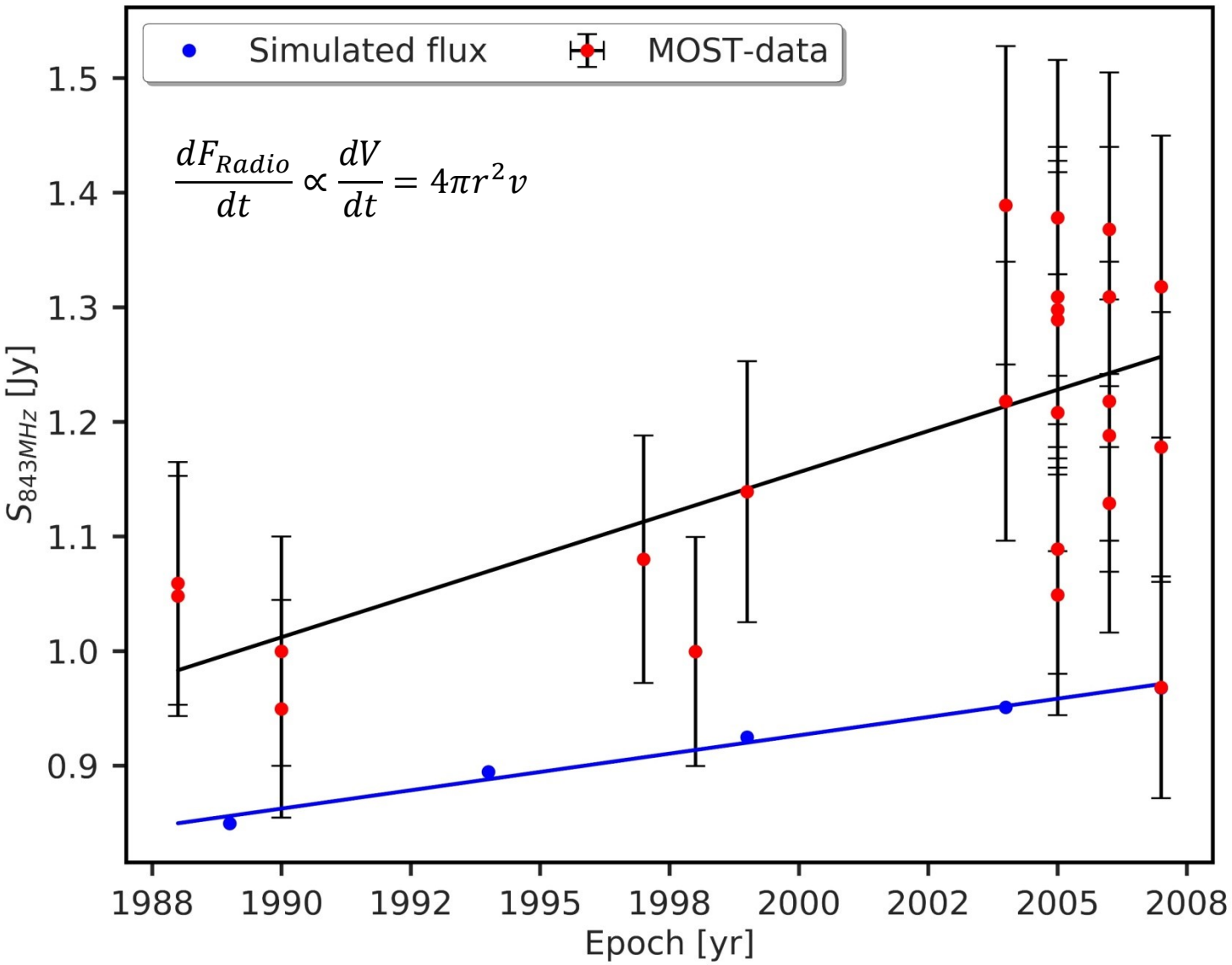


Results

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

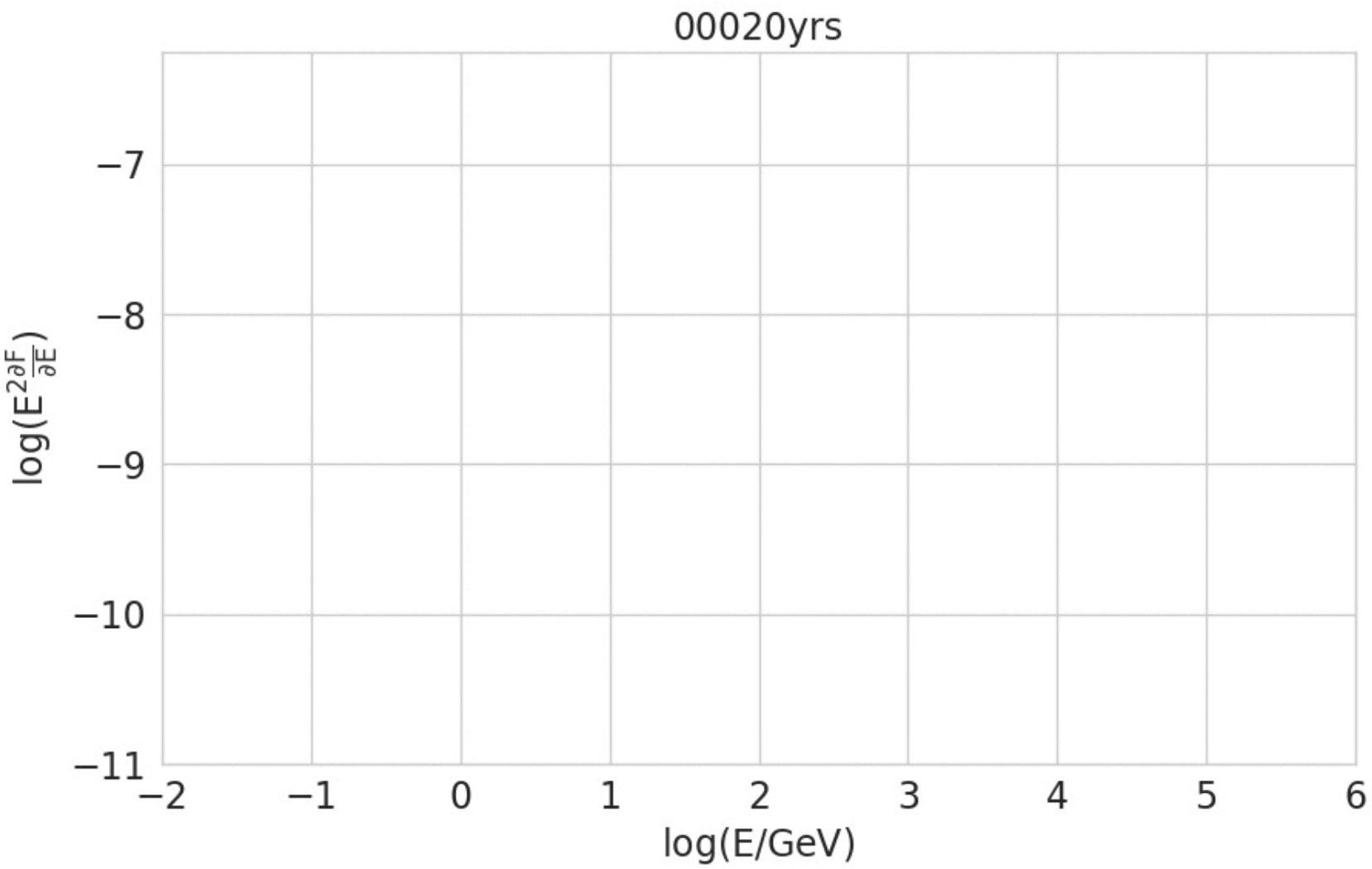
What is the spectral evolution during the lifetime of the SNR?



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 fom 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 ($s \approx 2.7$)