Gamma-rays from young SNRs in dense circumstellar environments

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Introduction

Supernova remnants (SNRs) are considered as possible sources of the Galactic cosmic-rays (CRs). So far, no indications of PeV-particles – the highest energetic particles observed in Galactic CR-spectrum - from SNRs have been found.

Here, we investigate if SNR-shocks expanding in dense winds of Type-IIP and Type-IIn SN-progenitors are able to reach the relevant energies. Further, we check the detectability of these events with current and next-generation gamma-ray instruments.

Model

Radiation **A**cceleration **T**ransport **Pa**rallel **C**ode (RATPaC) – a numerical toolset to study particle acceleration in SNRs [1]

Hydrodynamics:

- Gasdynamical equations solved in 1D for core-collapse SNRs in a free-expanding wind
- Luminous blue variable (LBV) and Red Supergiant (RSG) progenitors

$\dot{M}_{LBV} = 10^{-2} M_{Sol}/yr$ $\dot{M}_{RSG} = 8 \cdot 10^{-5} M_{Sol}/yr$
$v_{LBV} = 100 km/s$ $v_{RSG} = 15 km/s$

Cosmic rays:

- Kinetic test-particle approach; 1D spherical symmetry
- Synchrotron and IC-cooling for electrons

- **Magnetic turbulence:**
  Passively transported large-scale field
- Large-scale ambient field following
- Self-consistent amplification of Alfvenic turbulence

Thermal X-ray emission

- Predicted X-ray luminosities match reasonably well the experimental data
- Absorption relevant for LBV-progenitors

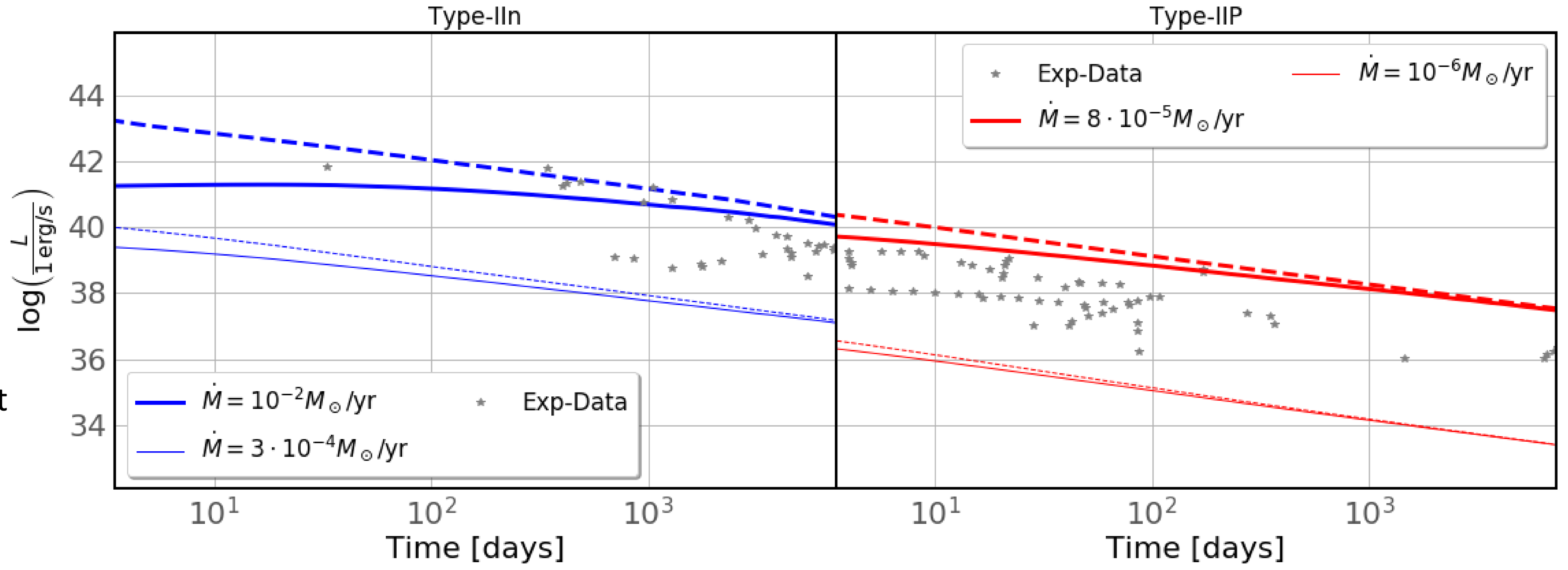


Figure 2: Thermal X-rays from two very young SNRs. The solid lines represent the predicted thermal X-ray continuum luminosity including local absorption while the dashed lines represent the intrinsic/unabsorbed X-ray luminosity. Thin lines represent models for modest mass-loss rates. The experimental data is taken from [2].

Gamma-ray emission

- ϒϒ-absorption significantly reduces the observed luminosity in the first months after the explosion
- The peak-flux has to be expected 15-30 days after explosion

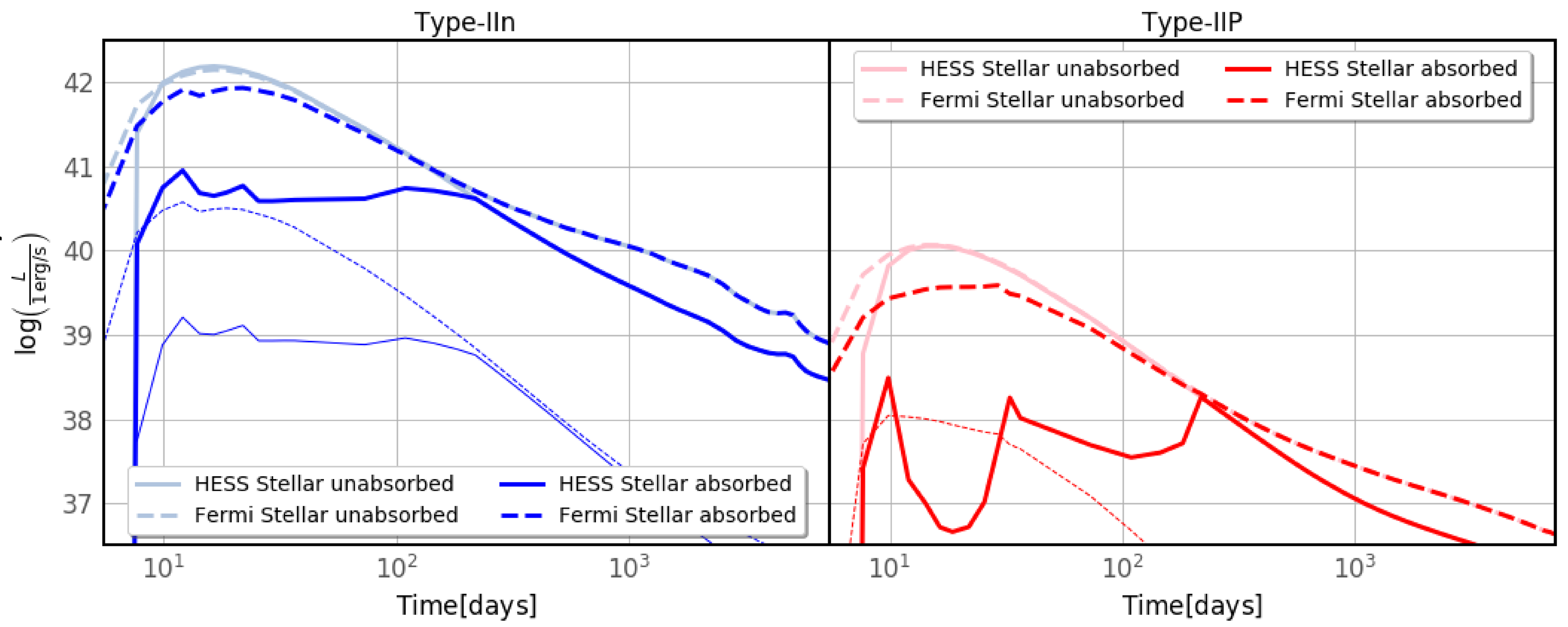
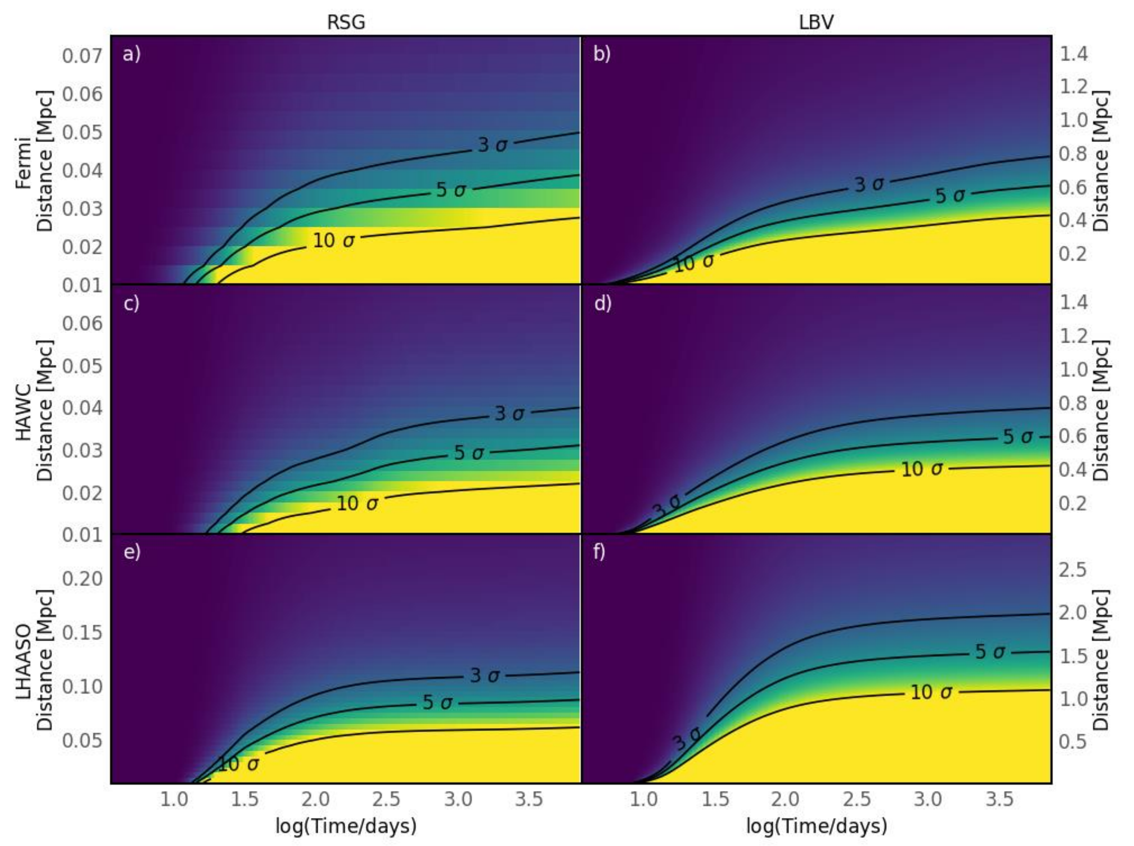


Figure 1: The luminosities for hadronic gamma-ray emission for a LBV (left) and a RSG (right) progenitor. Solid lines correspond the 1-10TeV band and dashed lines to 1-300GeV. Strong colors show the ϒϒ-absorbed flux and light colors the unabsorbed flux. The thin lines denote the cases with modest mass-loss rates.

Detectability

- No detection of a SNR by gamma-ray instruments has to be expected up-to-now
- The detection-horizon ranges from ~100kpc (RSG) to ~2Mpc (LBV)
- Best detection prospects for IACTs tens of days after the explosion
- "Survey-like" instruments should detect close-enough SNRs within ~100days after the explosion



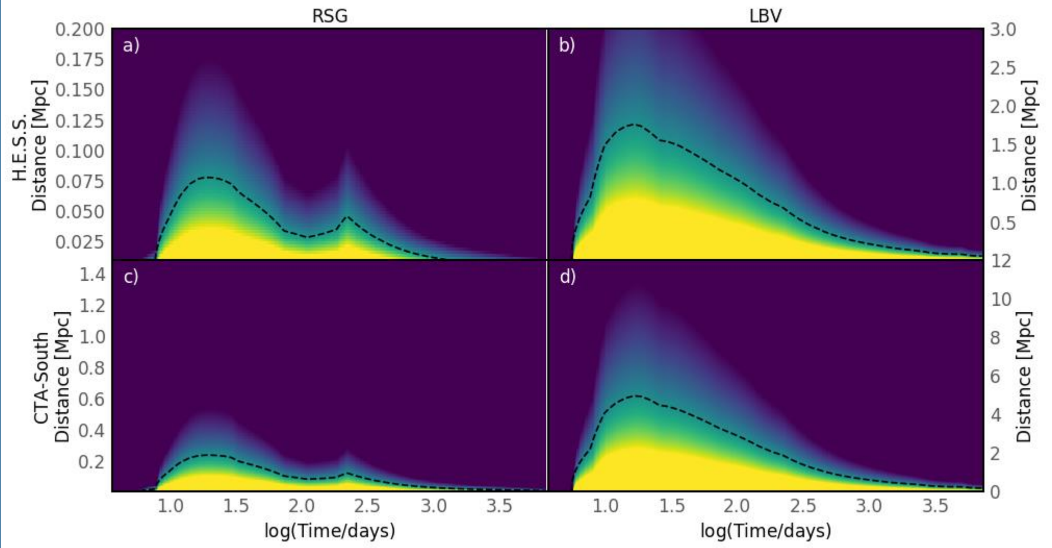


Figure 4+5: The detectability of the gamma-ray flux of a LBV/Type-IIn and RSG/Type-IIP SNR by various instruments. The left plot shows the culminated detectability by survey-like instruments and the right-side for Imaging Air Cherenkov Telescopes. The dashed lines represent the flux detectable within 50h of observations [4]

Maximum energy

- The maximum energy is limited to ~600TeV for high mass-loss rates and ~250/70TeV for modest mass-loss rates
- A combination of limited growth time (no saturation of the turbulent field) and damping by turbulence-cascading is limiting the maximum energy

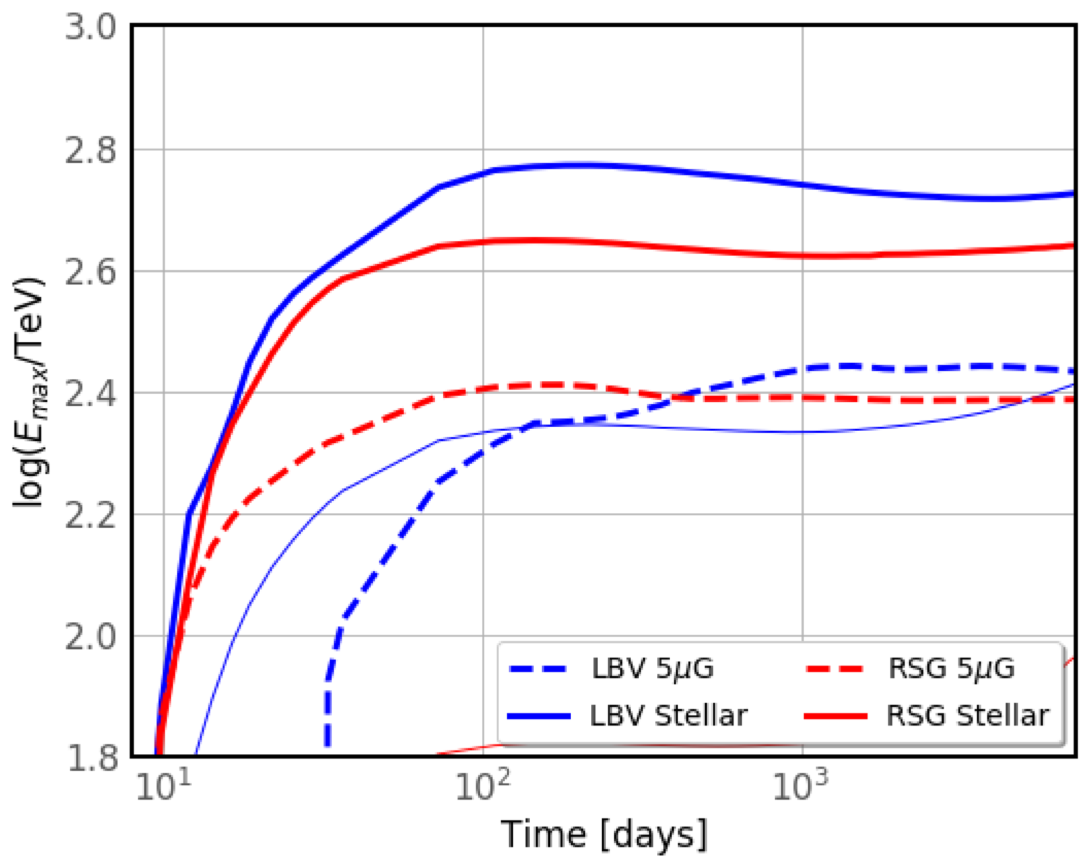


Figure 3: The maximum enegies for a LBV (blue) and a RSG (red) progenitor. Solid lines represent cases with a strong field in the progenitors wind and dashed lines a uniform 5μG field around the SNR. Thin lines represent the cases with a modest mass-loss rates.

Radio emission

- Good agreement between simulation and observations
- Slight hint of additional magnetic-field component

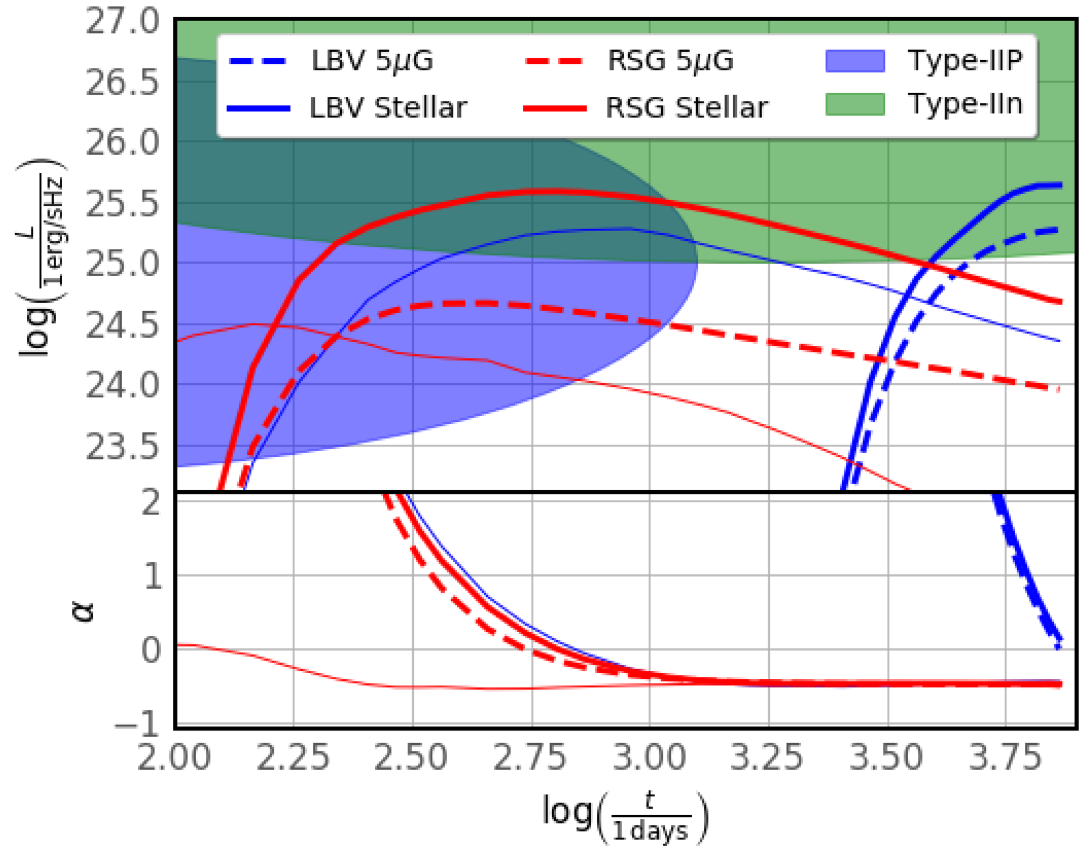


Figure 6:
Top-panel: Radio-luminosity of our models compared to the population averages from [3]
Bottom-panel: Radio spectral-index evolution. Color-coding as in Figure 3.

Conclusions and Outlook

- Peak maximum energy reached months after explosion
- No PeVatrons

- Future: Account for the structure around RSGs and LBVs → dense photoionization shells and shells from previous high mass-loss can enhance the radio/X-ray/gamma-ray luminosities years after the explosions

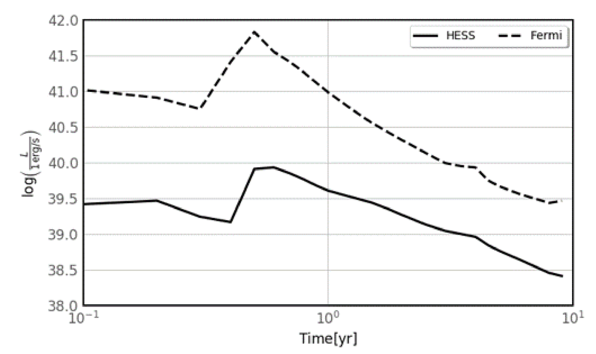


Figure 4: Gamma-ray luminosity for a "structured" ambient medium

Selected Publications

1. Brose, R., Telezhinsky, I., & Pohl, M. 2016, A&A, 593, A20
2. Dwarkadas, V. V. 2014, MNRAS, 440, 1917
3. Bietenholz, M. F.et al., 2021, ApJ, 908, 75
4. Vernetto S., LHAASO Collaboration, 2016, Journal of Physics Conference Series

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