Morphology of SNRs and their halos

R. Brose[1,2], M. Pohl[2,3], I. Sushch[3,4,5]

1 Dublin Institute for Advanced Studies, D02 XF86 Dublin 2, Ireland
2 University of Potsdam, 14476 Potsdam, Germany
3 DESY, 15738 Zeuthen, Germany
4 North-West University, 2520 Potchefstroom, South Africa
5 Astronomical Observatory of Ivan Franko National University of Lviv, 79005 Lviv, Ukraine

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Institiúid Ard-Léinn Bhaile Átha Cliath | Dublin Institute for Advanced Studies

Introduction and model

Supernova remnants are known to accelerate particles to relativistic energies on account of their non-thermal emission. The observational progress reveals more and more morphological features that need to be accounted for when modeling the emission from those objects.

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 a Type-Ia SNR in a uniform ambient medium

Cosmic rays:

- Kinetic test-particle approach, solved in 1D spherical symmetry
- Synchrotron and IC-cooling for electrons

Magnetic turbulence:

- Passively transported large-scale field
- Self-consistent amplification of Alfvenic turbulence

Morphology

- Initially: shell like for Pion-decay (PD) and inverse Compton (IC) emission
- Shell morphology maintained for PD-emission → target material distribution
- IC-emission center-filled later → diffusion into interior
- From 2kyrs onwards: formation of extensive IC-halo
- Fainter PD-halo of similar extend

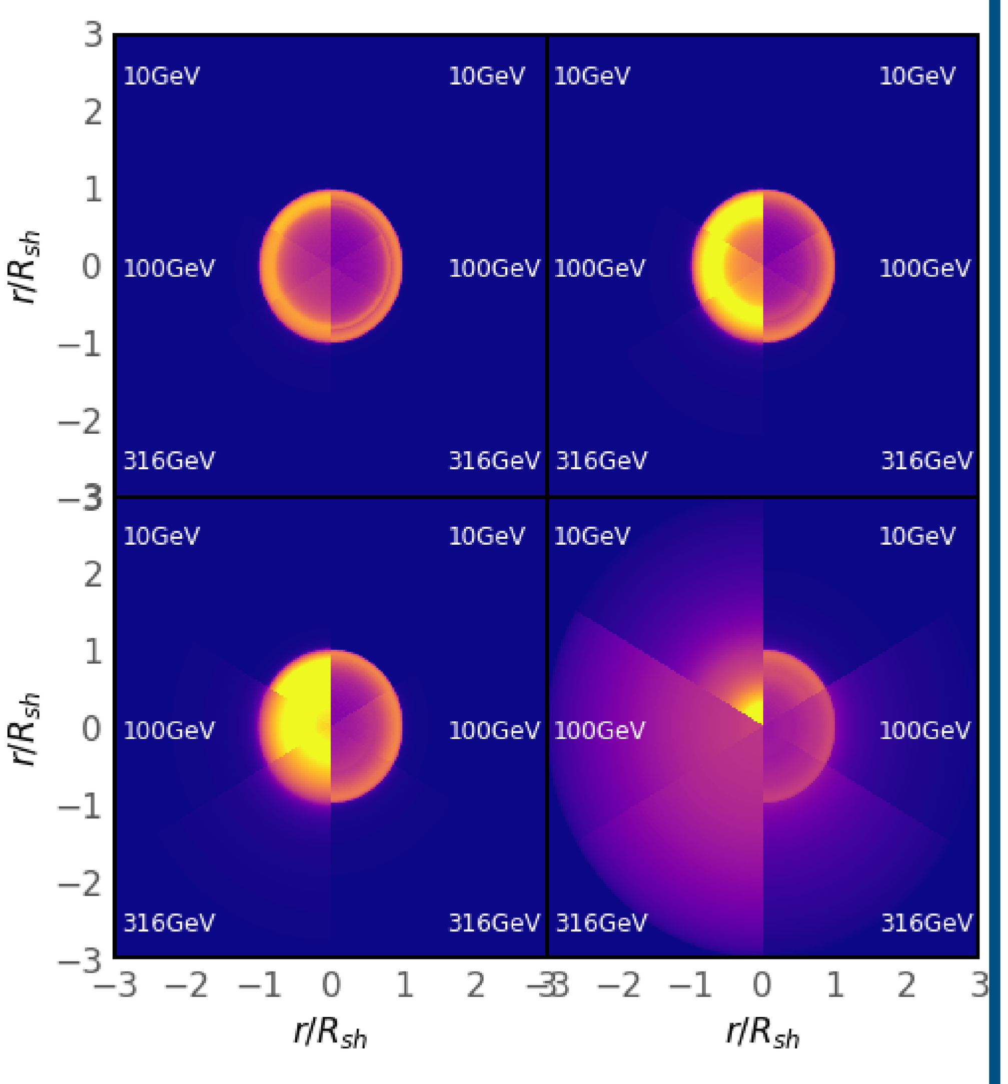
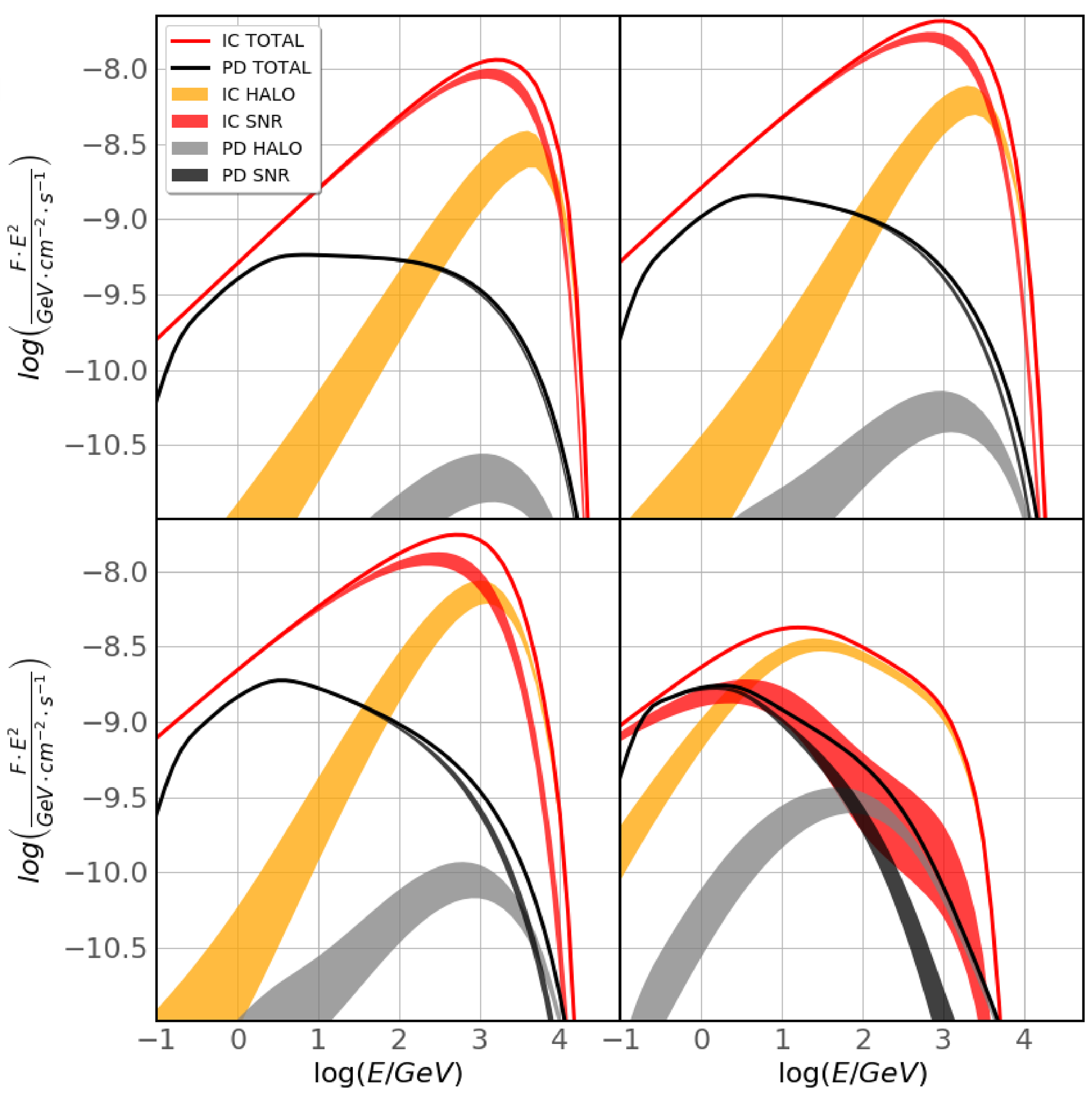


Figure 1: Normalized surface brightness maps of a Type-Ia SNR at 300, 1000, 2000 and 10,000yrs (from top left to bottom right). Left hemispheres are IC emission and right hemispheres PD emission.

Spectral evolution

Figure 2: Comparison of emission-spectra for IC (red) and PD (black) emission. Emission from the SNR is filled-black and filled-red for PD and IC-emission respectively. The halo-emission is filled-orange and filled-gray for IC and PD-emission respectively. Times as in Figure 1. The upper (lower) boundaries of the SNR emission represent spectra including (absent of) the project effect. The situation is inverted for emission from the Halo.



Pion-decay emission:

- PD-spectra soften over time:
  high energetic CRs escape the remnant, leaving low-energy particles trapped inside [2,3]
- Lack of ambient target material → PD-halo fainter than SNR emission

Inverse-Compton emission:

- Synchrotron-cooling important for electrons from 1-2kyrs → visible cooling break afterwards
- Considerably brighter IC-halo compared to PD-halo → uniform target photon-field distribution
- Halo emission fainter by a factor 3-5 compared to SNR-emission up to 2kyrs
- Halo dominates emission later

Observational prospects:

- IC-emission from brightest known SNRs likely to contain halo-contribution
- Halo-spectra are generally harder than spectra from inside the SNR
- Projection effect complicates everything → sources with favorable morphology needed, e.g. SN 1006

Reduced Diffusion Zone

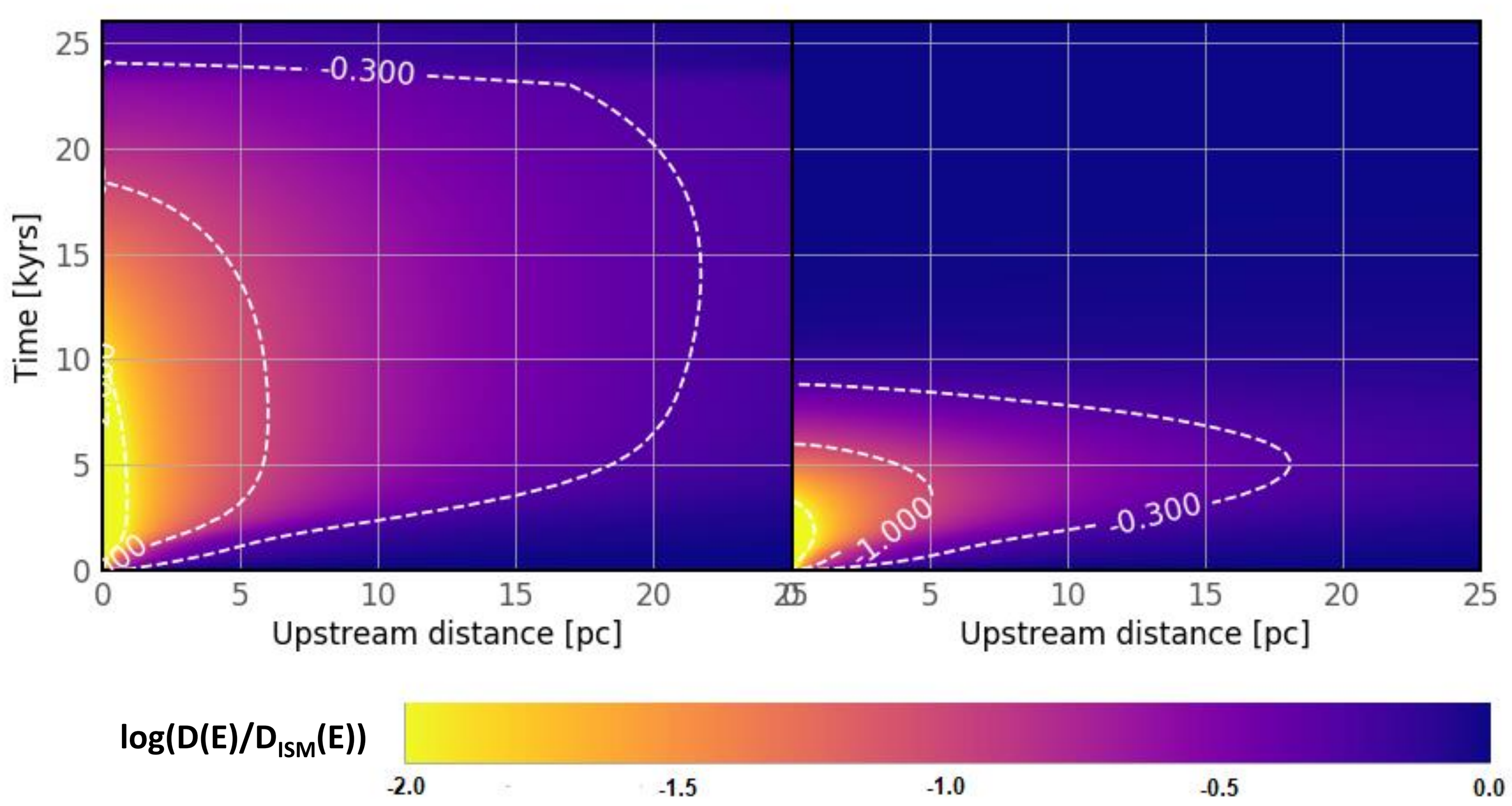


Figure 3: The left panel shows the reduction upstream of the shock for particles with energies of 100 GeV, the right panel the distribution for particles with energies of 3 TeV. The lines correspond to 0.1 %, 1 % and 50 % of D_{ISM}.

- The self-regulated escape creates an extensive zone of reduced diffusion around the SNR
- For the first 5kyrs: diffusion coefficient is reduced by at least a factor of 10 within 5pc of the SNR-shock for 3-TeV-particles.
- 100-GeV-particles are trapped even longer (15kyrs)
- Non-uniform diffusion around the SNR complicates conclusions based on observational data – similar to the situation in PWNs [4]

Conclusions

- PD and IC emission produce different morphologies for evolved remnants
- IC-halos are brighter and more likely to be detected even by current-generation instruments
- The self-generated diffusion coefficient is distributed highly on-uniform around SNRs

Selected Publications

1. Brose, R., Telezhinsky, I., & Pohl, M. 2016, A&A, 593, A20
2. Brose, R., Pohl, M., Sushch, I., Petruk, O., & Kuzyo, T. 2020, A&A, 634, A59
3. Celli, S., Morlino, G., Gabici, S., & Aharonian, F. A. 2019, MNRAS, 490, 4317
4. Evoli, C., Linden, T., & Morlino, G. 2018, Phys. Rev. D, 98, 063017

Learn more about me at:
https://homepages.dias.ie/broserob
broserob@cp.dias.ie

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