Modeling non-thermal emission from SN 1987A

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Introduction and model

Supernova remnants are known to accelerate particles to relativistic energies on account of their non-thermal emission. However, evidence for the acceleration to the highest energies is still elusive.

The remnant of SN 1987A is one of the best studies SNRs and understanding its thermal and non-thermal emission is crucial for particle-acceleration models.

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 CC SNR in a structured ambient medium

Cosmic rays:

- Kinetic test-particle approach, solved in 1D spherical symmetry
- Bohm-like diffusion in an amplified field, $B_u = 125\mu G$

Ambient gas density:

- The CSM around SN 1987A shows a high-density "equatorial-ring" region
  - The thermal X-rays are well described by a two-component model [2]:
    - A wide cone with a dense HII-region starting ~0.1pc off-center
    - A narrow cone with a dense HII-region and a very dense equatorial ring starting ~0.16pc off-center

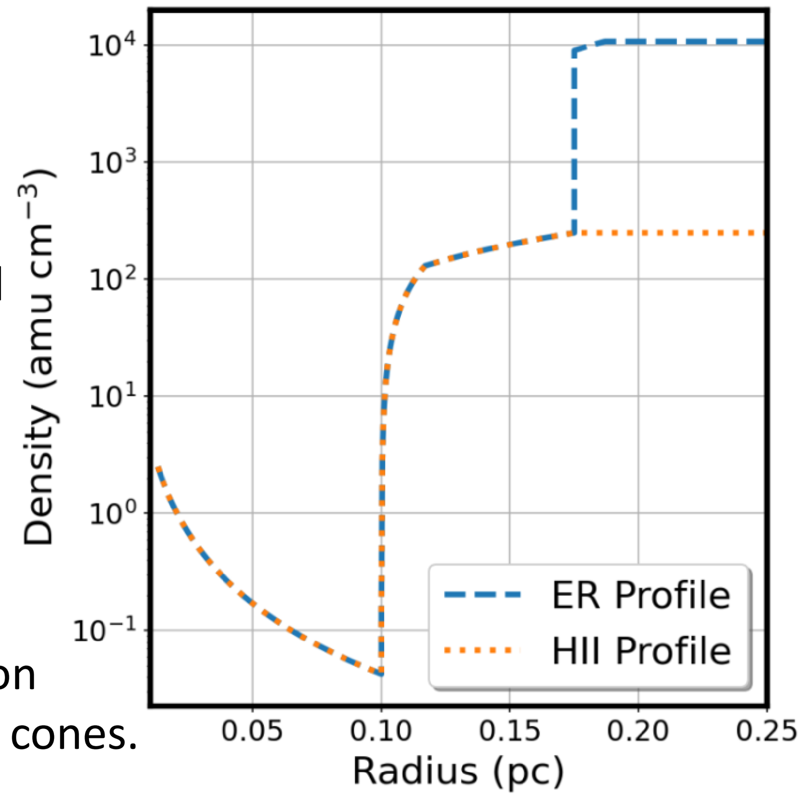

Figure 1: Density distribution around SN1987A using two cones.

X-ray and gamma-ray luminosity

X-ray emission:

- The interaction with the HII-region marks the onset of the thermal X-ray emission
- The interaction with dense ring accelerates the brightening after ~15yrs
- A high-density ring of limited width would halt the X-ray brightening after ~25yrs

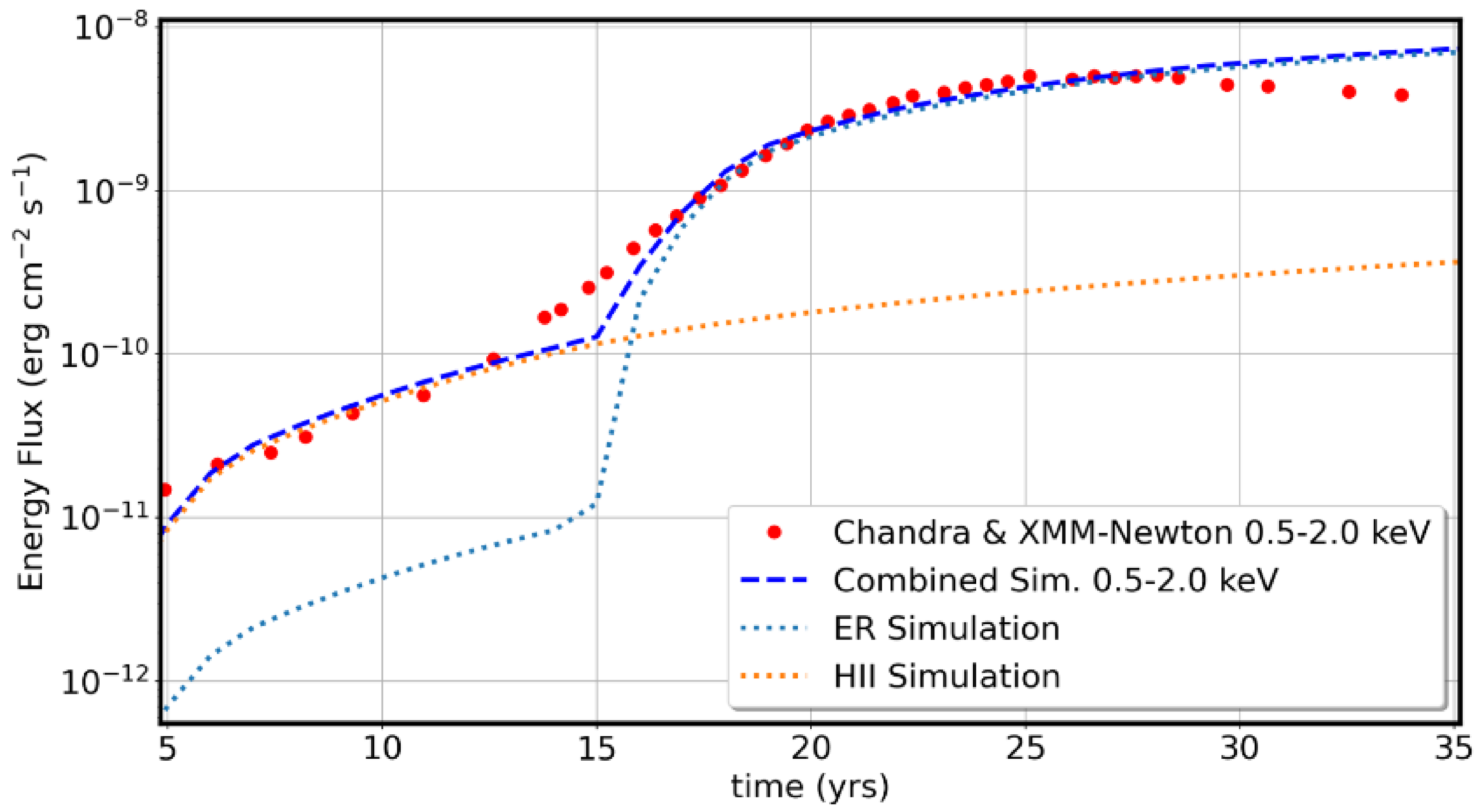

Figure 2: Thermal X-ray luminosity of SN 1987A based on the emission from the two cones, weighted by their surface area vs. Chandra data (red points) [7].

Gamma-ray emission:

- The hadronic gamma-ray emission raises after the collision with ring
- The rise is offset by ~8yrs compared to the rise in the X-ray emission → thermal particles from the ring need to be accelerated
- No density-accelerated brightening at very high-energy gamma-rays yet - steady increase

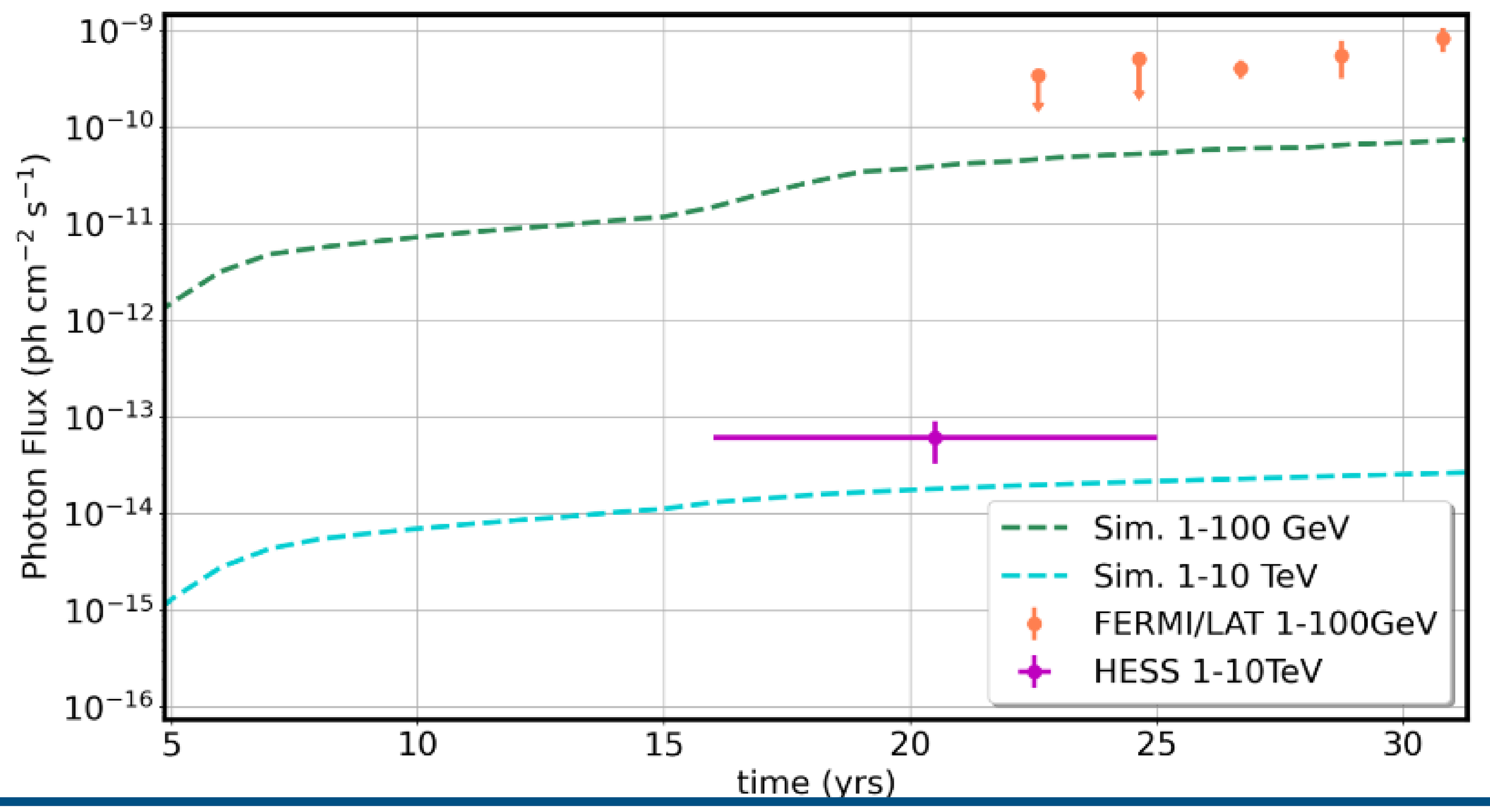

Figure 3: Photon Fluxes in the Fermi-LAT [6] and H.E.S.S. [5] energy ranges.

Gamma-ray spectra

- The interaction with the dense ring significantly increases the emission at low energies → particles from the ring can get accelerated to ~100GeV
- A marginal increase at the highest energies → the slow-down of the shock significantly increases the acceleration time
- The spectra are as soft as s~2.6 beyond ~100GeV transition between low-energy gamma-rays from the dense ring and high-energy gamma-rays from the HII-region
- Dense clumps might enhance GeV-flux further → to be investigated

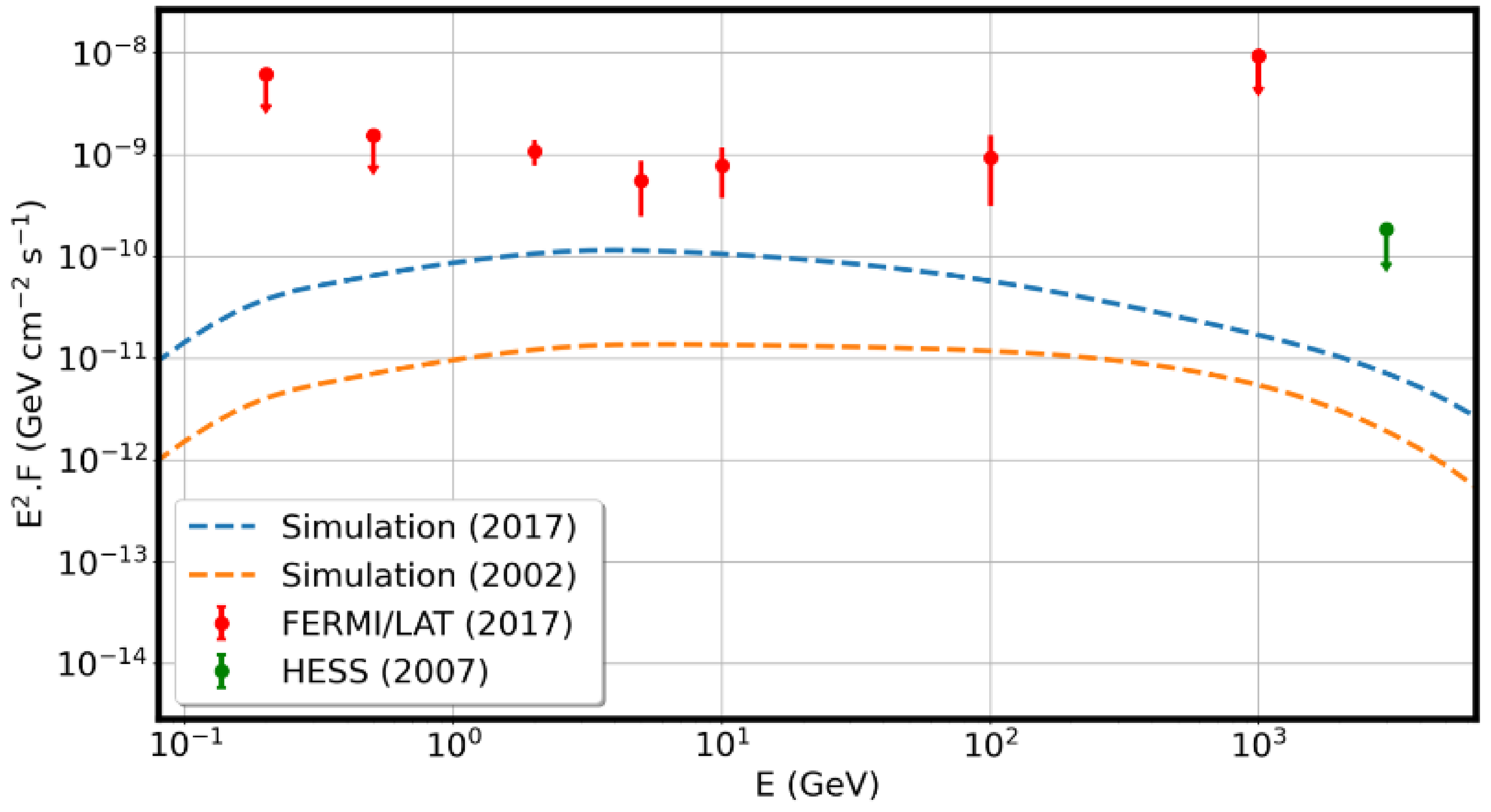

Figure 4: Comparison of the simulated gamma-ray spectra between 2008 and 2017 and Fermi-LAT [6] and H.E.S.S.-observations [5].

Conclusions

- A two-component model for the CSM around SN 1987A reproduces the observed soft X-ray flux
- There is a time-delay between the X-ray brightening and the flux-increase at low-energy gamma-rays
- The high-energy gamma-ray flux steadily increases a detection with H.E.S.S. slightly below the 2012 upper limit might be possible in data taken post ~2015
- Hard X-rays point towards dense clumps in the "ring" → could enhance gamma-ray luminosity further

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Selected Publications

1. Brose, R., Telezhinsky, I., & Pohl, M. 2016, A&A, 593, A20
2. Dewey; D., Dwarkadas, V. V.; Haberl; et al., 2012,ApJ, 752, 103
3. Helder, E. A.; Broos, P. S.; Dewey, D.; et al. 2013, ApJ, 764, 11
4. Mackey, J.; Green, S.; Moutzouri, M.; et al. 2021, MNRAS, 504, 983
5. H. E. S. S. Collaboration,Abramowski, A., Aharonian, F., et al. 2015, Sci-ence, 347, 406
6. Malyshev, D., Pühlhofer, G., Santangelo, A., Vink, J. 2019, arXiv e-prints, arXiv:1903.03045
7. Frank, K. A., Zhekov,S. A., Park, S., et al, 2016,ApJ, 829, 40

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