The Radio-Gamma Correlation In Starburst Galaxies

Link to the publication

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1 The Leaky Box Approach

Starburst galaxies are generally extremely bright at infrared wavelengths showing a distinct **FIR-radio correlation** that enables to estimate the star formation rate (SFR) in these galaxies. The high SFR suggests a high density of target particles $N_t \gg 1\,\mathrm{cm}^{-3}$ as well as a magnetic field strength B in the order of a few $10\,\mu$G up to a few mG.

Do recent observations in the γ-ray band enable to draw further conclusions on the physics of starburst galaxies?

Shock acceleration by supernovae (SNe) commonly represent the source of the relativistic particles in starburst galaxies. In the case of relativistic electrons, the spectral index α of the resulting energy spectrum is supposed to steepen to $\alpha - 1$ at $\gamma > \gamma_B$ due to the competing inverse Compton (IC) losses. Subsequently, the relativistic particles propagate through the galaxy and emit synchrotron and gamma radiation, so that we account for:

- SN rate determines proton source rate $q_p(\gamma) \to q_e(\gamma)$ due to **quasi-neutrality** (see Fig. 1a);
- **Diffusive particle transport** with escape timescale $\tau_{diff}^{e,p}(\gamma) \propto \gamma^{-1/3}/l_{e,p}$ vs. **advection losses** with $\tau_{adv} \simeq R/v_{adv}$ by the galactic wind;
- **Continuous energy losses** $|\dot{\gamma}|_{e,p}$ due to synchrotron (e), IC (e), Bremsstrahlung (e), ionization (e,p) and hadronic pion production (p).

Hence, the relativistic particle density of electrons and protons $n_{e,p}(\gamma)$ in the innermost region of a spherical symmetric starburst galaxy is described by

$$0 = \frac{\partial}{\partial \gamma}\left(|\dot{\gamma}|_{e,p}\, n_{e,p}\right) - \frac{n_{e,p}}{\tau_{diff}^{e,p}(\gamma)} - \frac{n_{e,p}}{\tau_{adv}} + q_{e,p}(\gamma)\,,$$

and a corresponding solution is shown in Fig. 1b.

2 Radio & Gamma Spectrum & Secondary Particles

- The **synchrotron radiation** $F_{syn}(\nu)$ from the primary and secondary relativistic electrons are supposed to describe the steep part of the observed radio spectrum between $1\,\mathrm{GHz} \lesssim \nu \lesssim 10\,\mathrm{GHz}$ (see Fig. 1c).
- The **gamma radiation** $\Phi_\gamma(E_\gamma)$ from non-thermal Bremsstrahlung, IC collisions and hadronic pion production (π^0 decay) is considered to describe the observed spectrum above $100\,\mathrm{keV}$ (see Fig. 1d).
- **Secondary particles** like electrons and neutrinos result from hadronic pion production ($\pi^\pm$ decay).

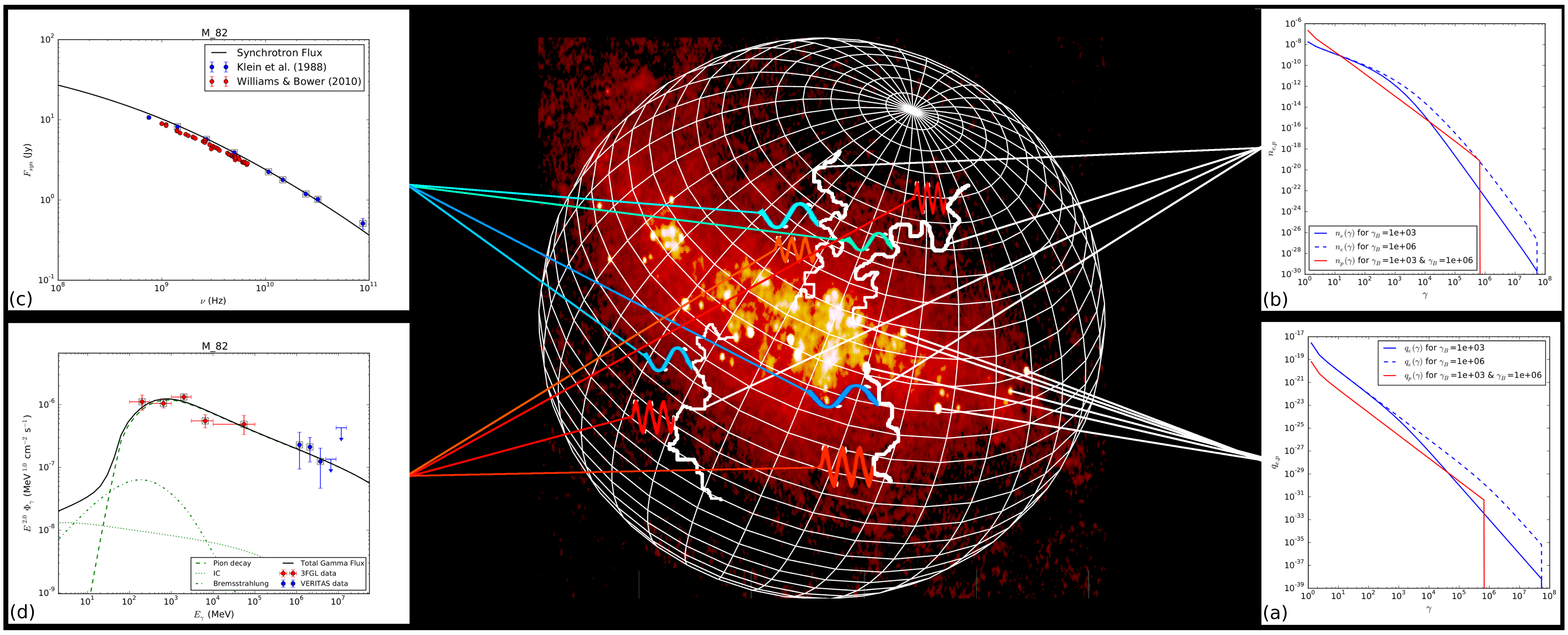
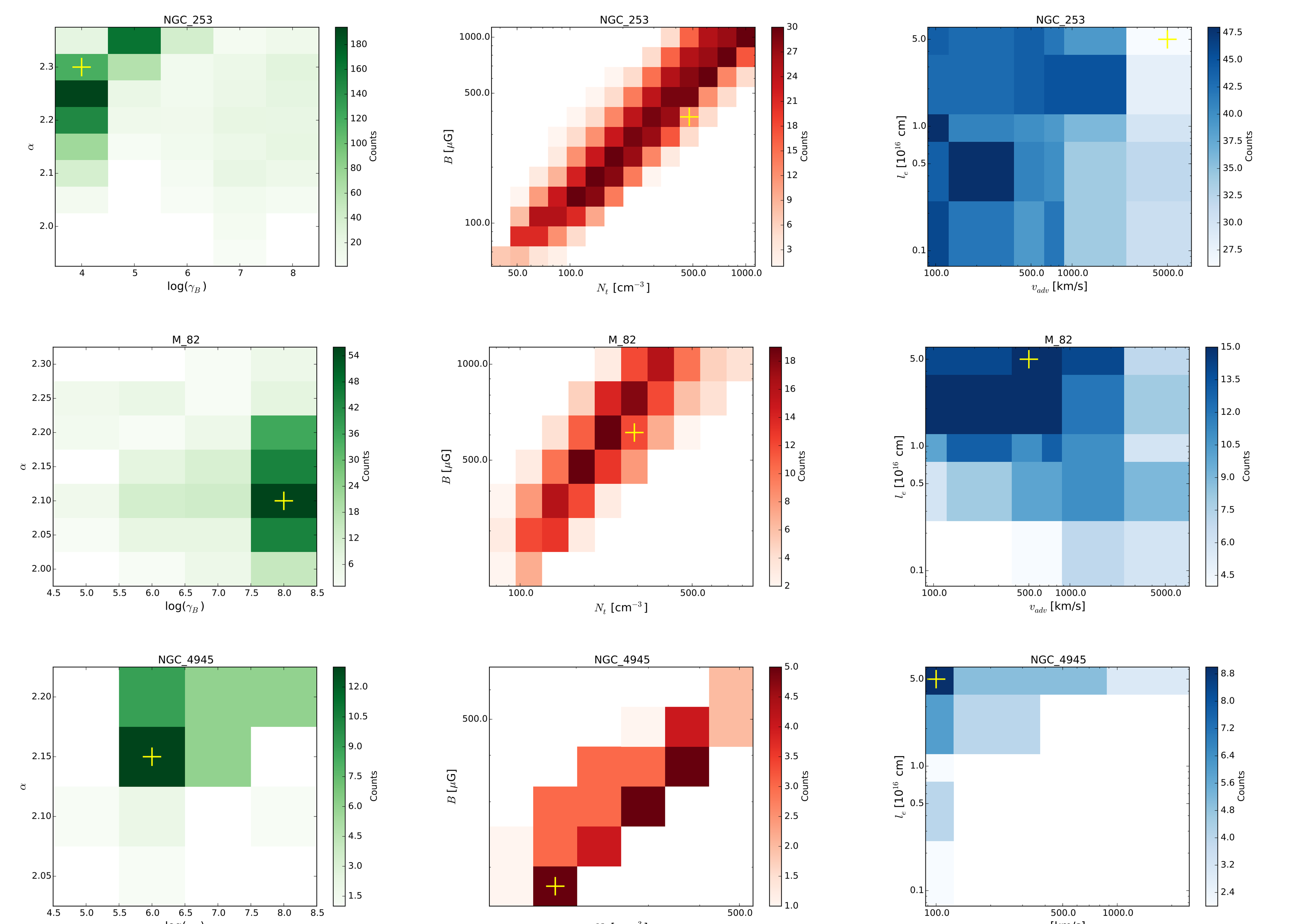


Fig.1 : Relativistic particle transport with the radio and γ-ray emission of M82 (underlying image shows a combined MERLIN/VLA radio image of M82).

3 The Results

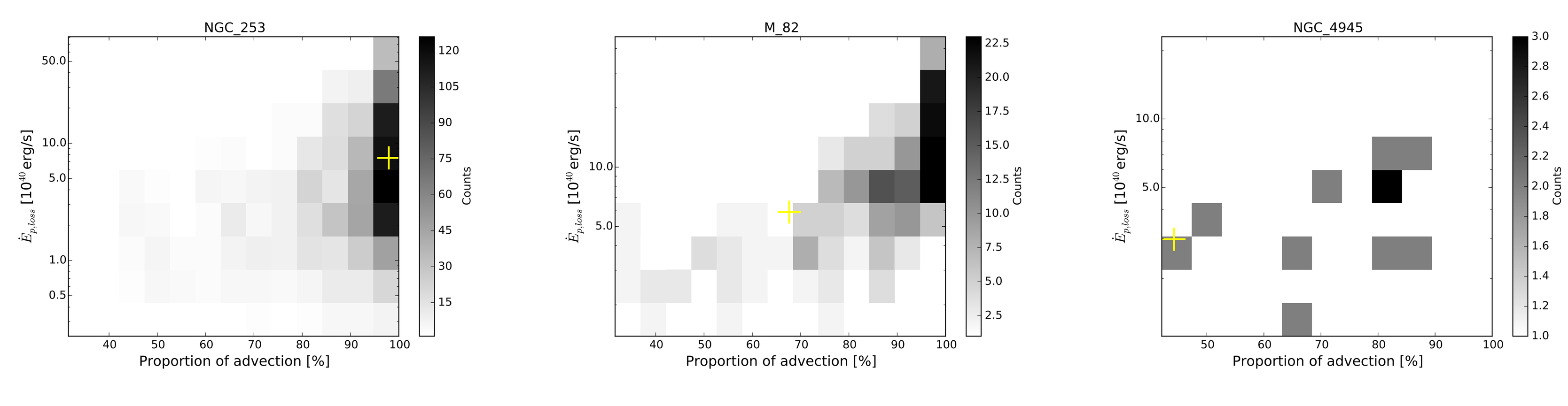
The data of **M82, NGC 253 and NGC 4945 is well described** (for M82 see Fig. 1c,d) by our model (γ-ray flux is dominated by hadronic pion production) yielding several parameter sets $(N_t,\, B,\, \alpha,\, \gamma_B,\, l_e,\, v_{adv})_i$ within 2σ of the best-fit model (marked by a yellow cross):



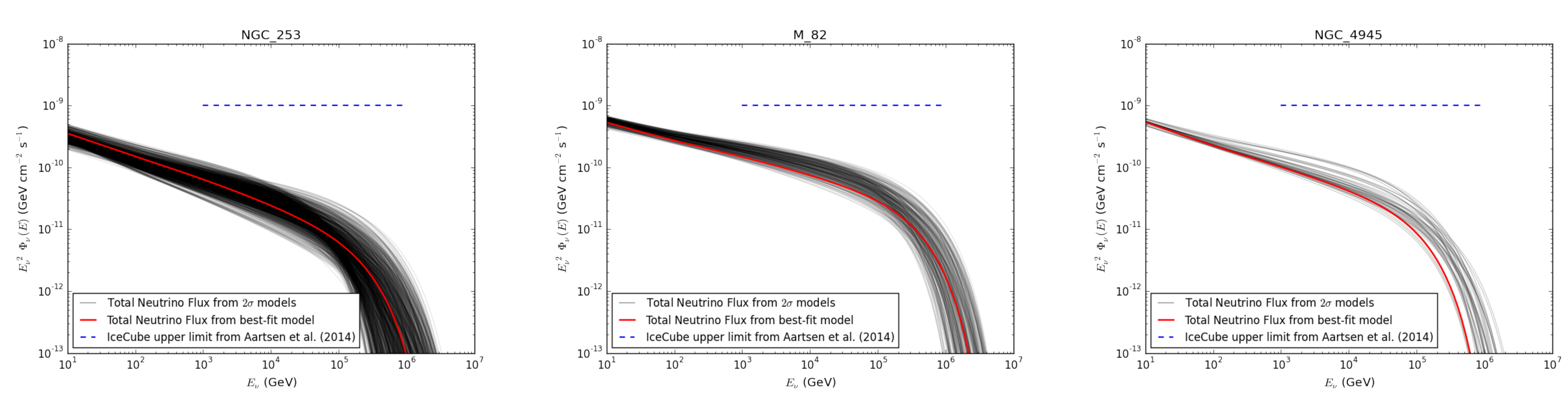
(i) No mandatory need for an initial broken power-law spectrum and an **agreement with the common acceleration approach** for a strong shock according to γ_B.

(ii) **Supernovae are the dominant particle accelerators for NGC 253, M82 and NGC 4945**, but not in the case of NGC 1068.

(iii) All considered starburst galaxies are **poor proton calorimeters** in which for NGC 253 the escape is predominantly driven by the galactic wind, whereas the **diffusive escape can dominate in NGC 4945 and M82** (at energies $> 1\,\mathrm{TeV}$):



(iv) **Secondary electrons from hadronic pion production are important** to model the radio flux ($50^{+30}_{-10}\,\%$ in NGC 253 and $75^{+5}_{-25}\,\%$ in M82, NGC 4945, respectively), but the associated **neutrino flux is below the current observation limit**:



For further information please look at the publication (Eichmann & Tjus, 2016, ApJ, 821) or contact: eiche@tp4.rub.de