

Piernik MHD code extension: modelling energy dependent transport of cosmic ray electrons with energy spectrum evolution

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Cosmic Ray Energy SPectrum (CRESP)

- CRESP algorithm is based on Miniati's 2001 COSMOCR code
- Solves CR transport equation (e.g. Skilling 1975, Blandford & Eichler 1987)

$$\frac{\partial f}{\partial t} = -\mathbf{u} \cdot \nabla f + \nabla(\kappa \nabla f) + \frac{1}{3}(\nabla \cdot \mathbf{u})p \frac{\partial f}{\partial p} + \frac{1}{p^2} \frac{\partial}{\partial p} \left[p^2 b_l f + D_p \frac{\partial f}{\partial p} \right] + j$$

- assumes piecewise power-law spectrum to describe CR electrons

$$f(p) = f_{i-1/2} \left(\frac{p}{p_{i-1/2}} \right)^{-q_i}$$

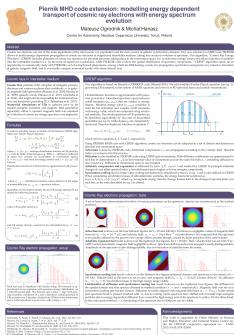
- So far two processes affecting spectrum of CR particles have been implemented:

- Adiabatic compression/expansion:

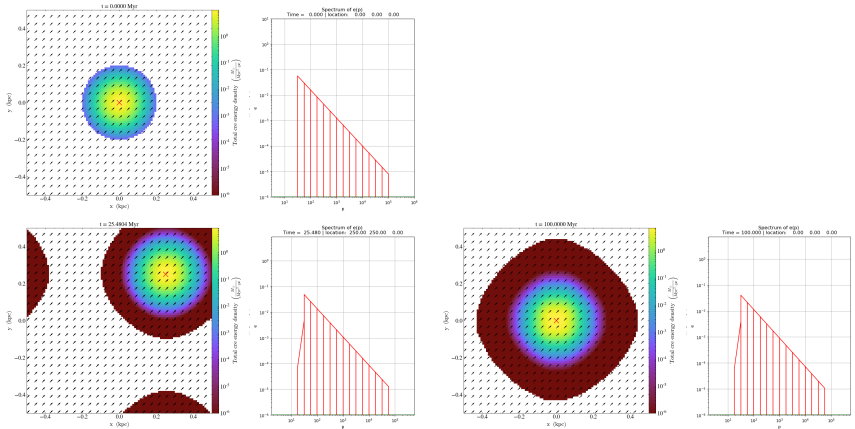
$$\frac{dp}{dt} = b_{ad}(p) \equiv \frac{1}{3}(\nabla \cdot \mathbf{v}) p$$

- synchrotron lossess:

$$\frac{dp}{dt} = b_{syn}(p) \equiv -\frac{4}{3} \frac{\sigma_T}{m_e^2 c} u_B p^2$$

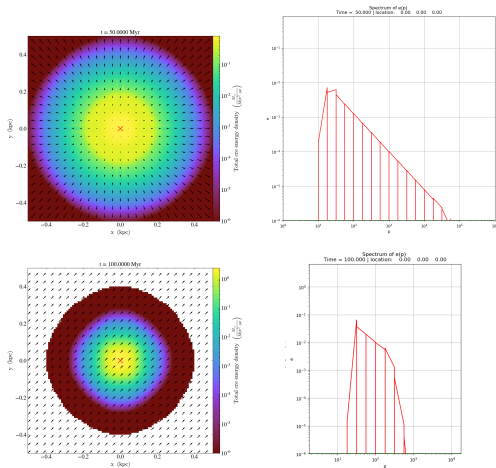


Initial state and advection test



Top: Initial setup – SN remnant with power law spectrum.
Bottom: Domain and spectrum after $t = 25$ and 100 Myr.

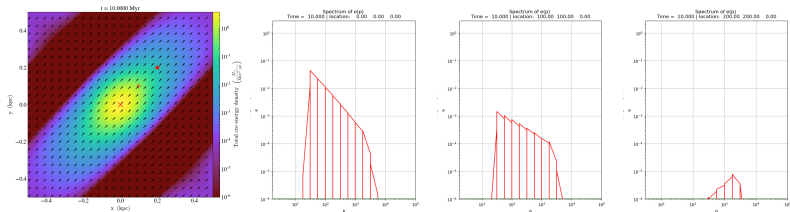
Expansion and synchrotron cooling test



Top: expansion – domain and spectrum after 50 Myr.

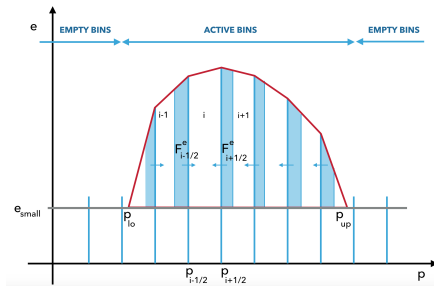
Bottom: synchrotron cooling – domain and spectrum after $t = 100$ Myr.

Diffusion + synchrotron test



Diffusion + synchrotron cooling – domain spectra and spectrum after 10 Myr.

Essential elements of the algorithm



- uniform mesh in $\log p$
- the spectrum (n_i, e_i) extends between p_{lo} and p_{up} (active bins)
- p_{lo} and p_{up} are estimated at the beginning of each timestep
- anisotropic CR diffusion, algorithm by (Hanasz & Lesch A&A 412, 331, 2003),
- $K_{\parallel}(p) \propto p^{0.5}$,
 $K_{\perp}(p) = \text{a few \% of } K_{\parallel}(p)$
- CR spectrum evolution and diffusion steps are executed between MHD steps.
- initial CR spectrum – power law – injected instantaneously in SN remnants.

Thank you!