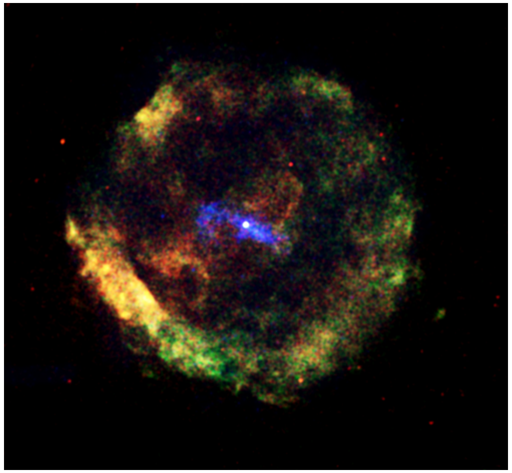
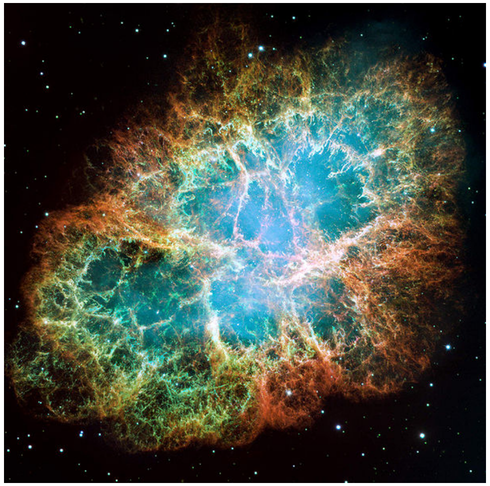
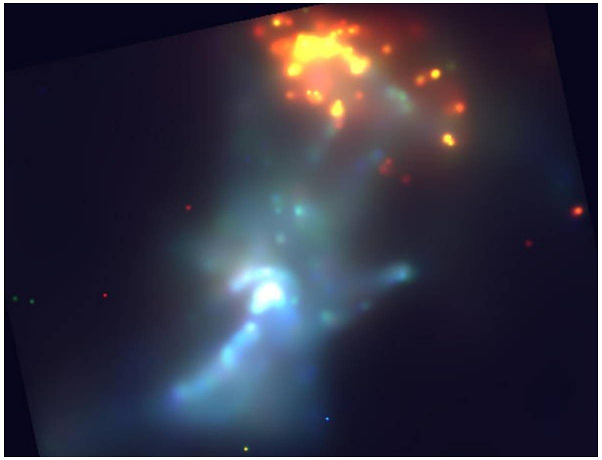
MODELLING THE EVOLUTION OF PULSAR WIND NEBULA







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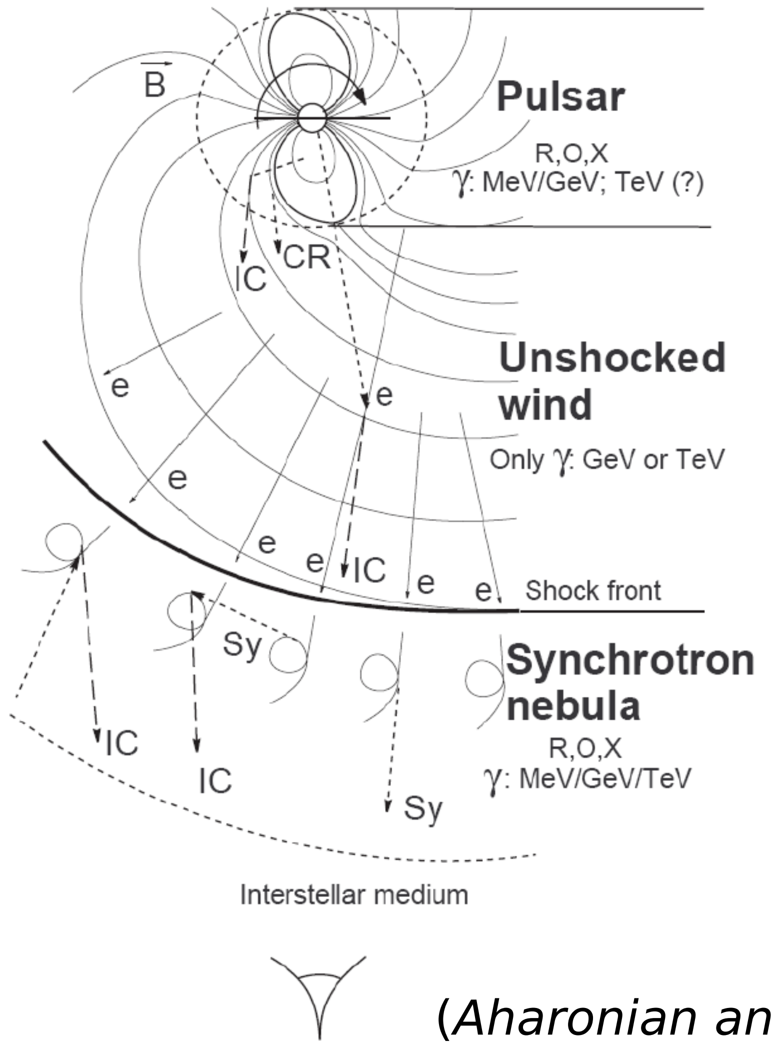
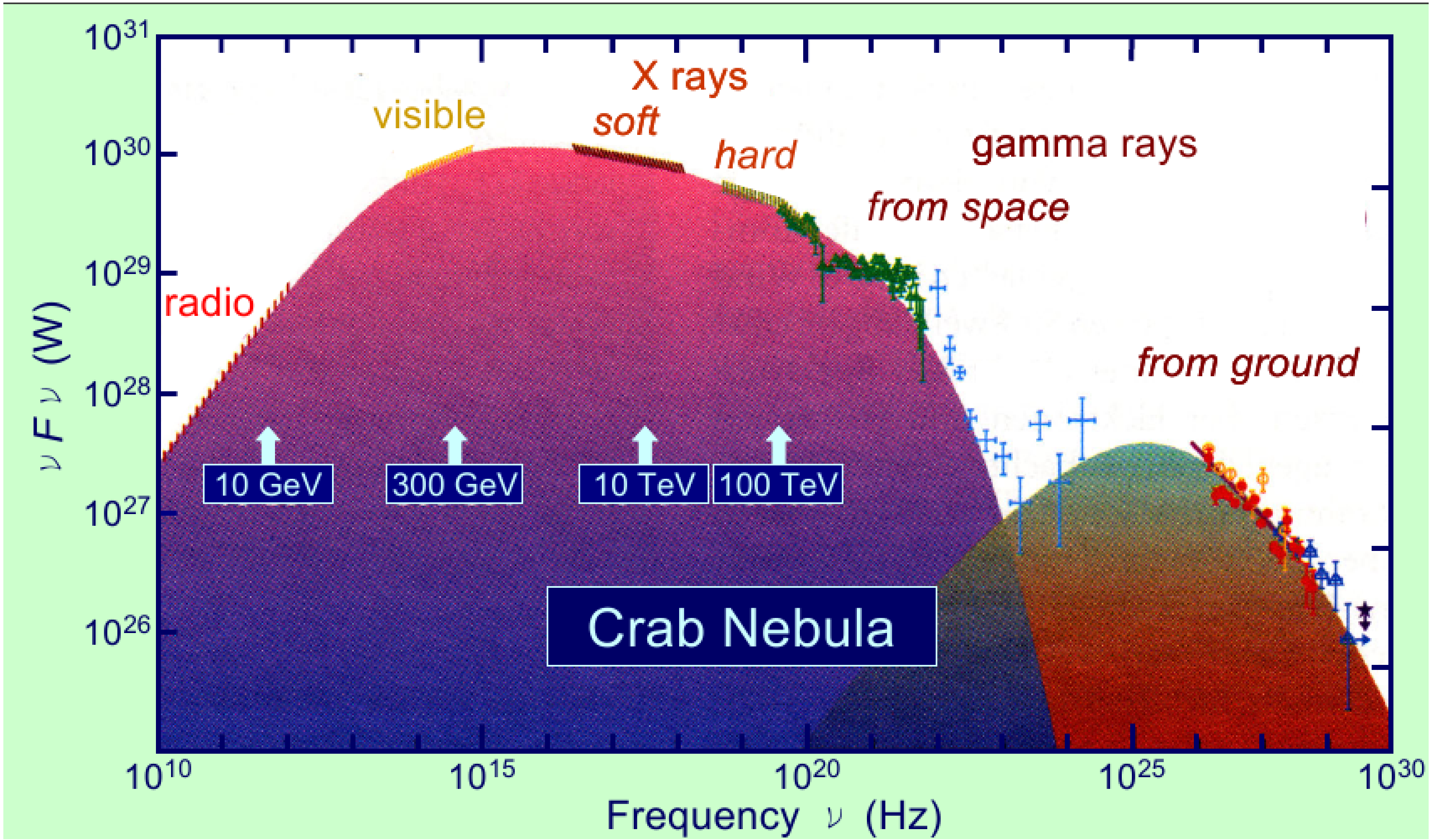
Pulsar Wind Nebulae

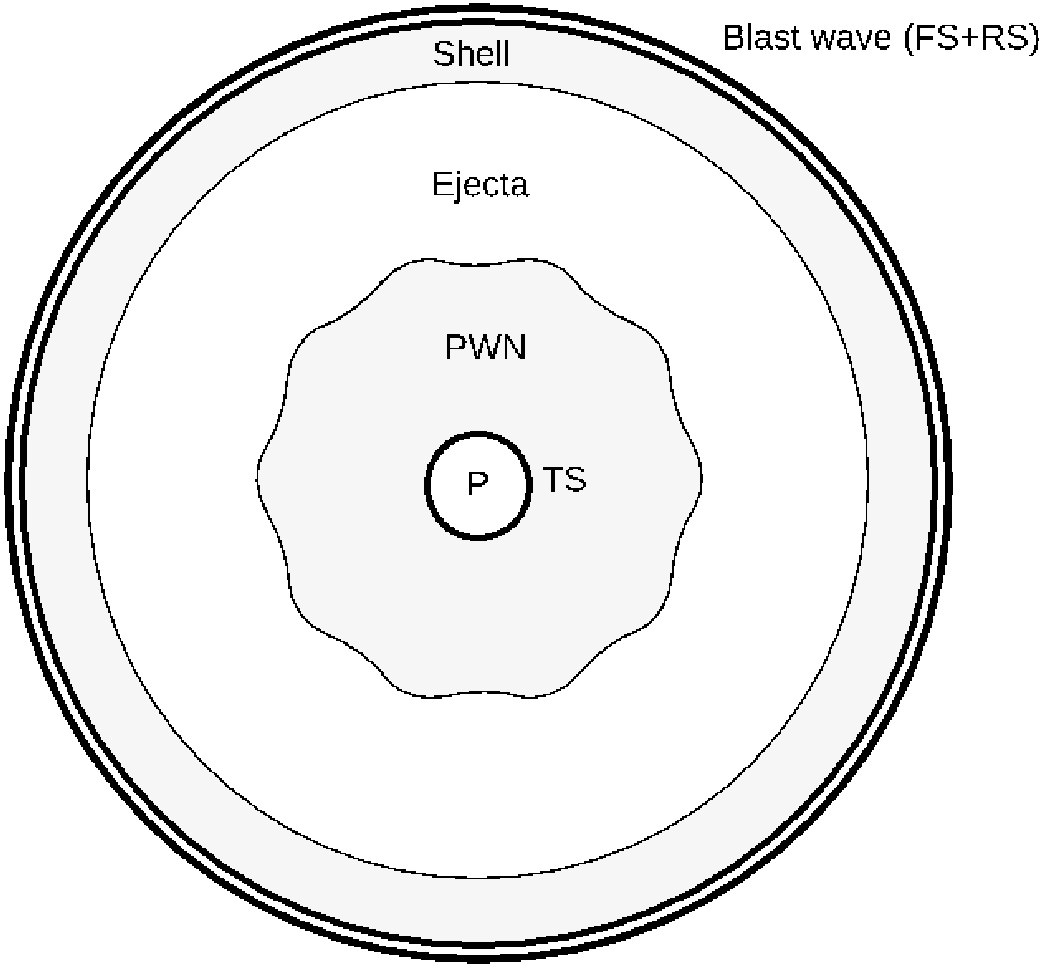


(*Aharonian and Bogovalov*, 2003)

Non-thermal spectra



Evolution of PWN’e



(Magneto)hydrodynamic Modelling

- Euler equations

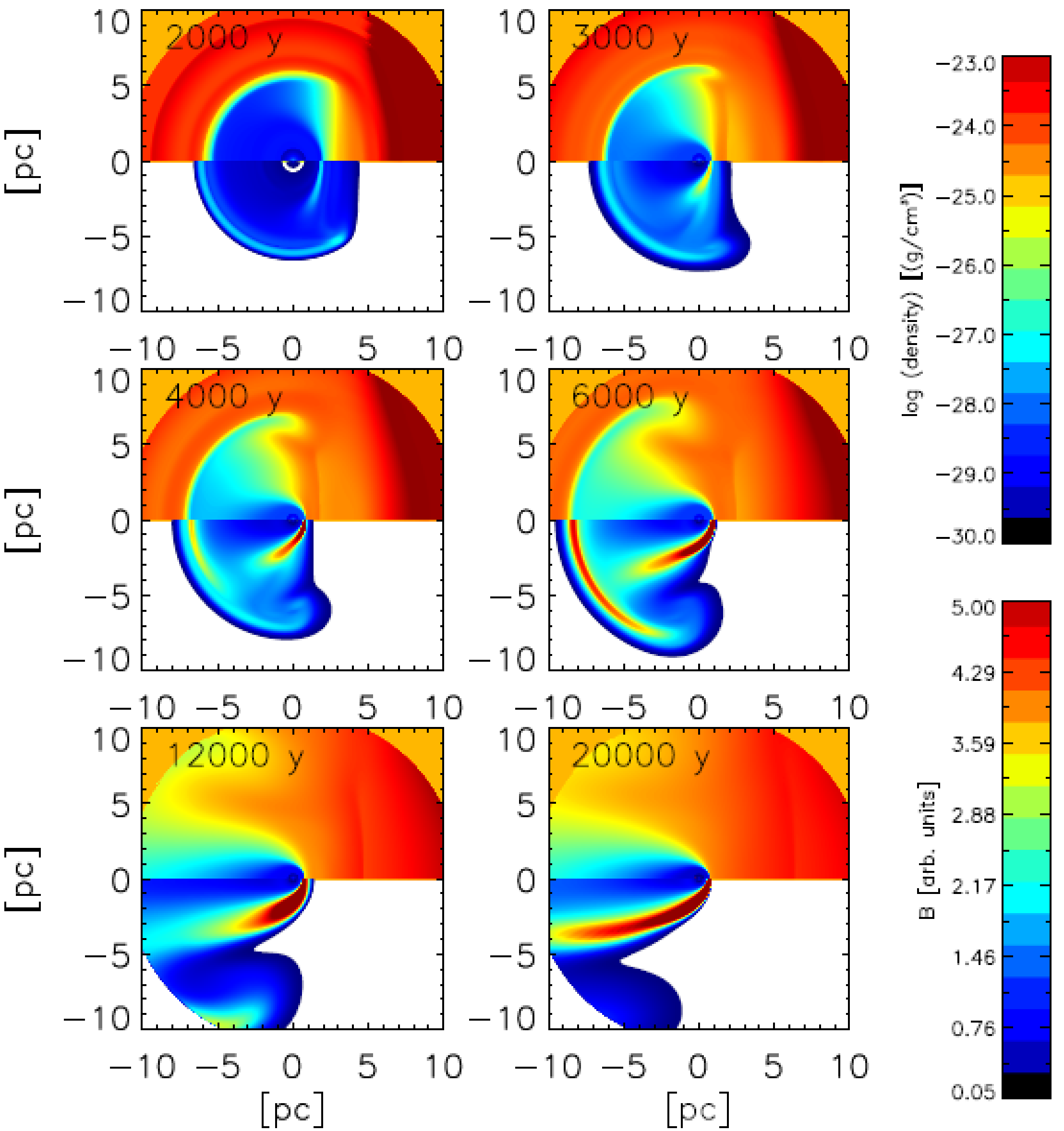
$$\frac{\partial}{\partial t}\rho + \nabla \cdot (\rho \mathbf{v}) = 0,$$

$$\frac{\partial}{\partial t}(\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v}\mathbf{v} + P\mathbf{I}) = 0,$$

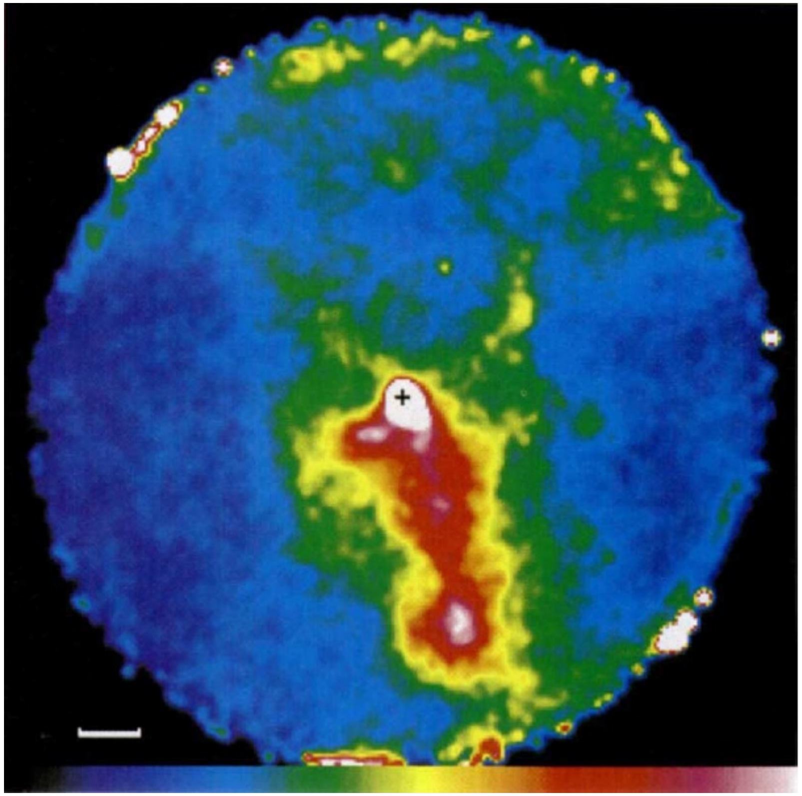
$$\frac{\partial}{\partial t}(\frac{\rho}{2}\mathbf{v}^2 + \frac{P}{\gamma - 1}) + \nabla \cdot (\frac{\rho}{2}\mathbf{v}^2\mathbf{v} + \frac{\gamma \mathbf{v} P}{\gamma - 1}) = 0$$

- Kinematic B-field

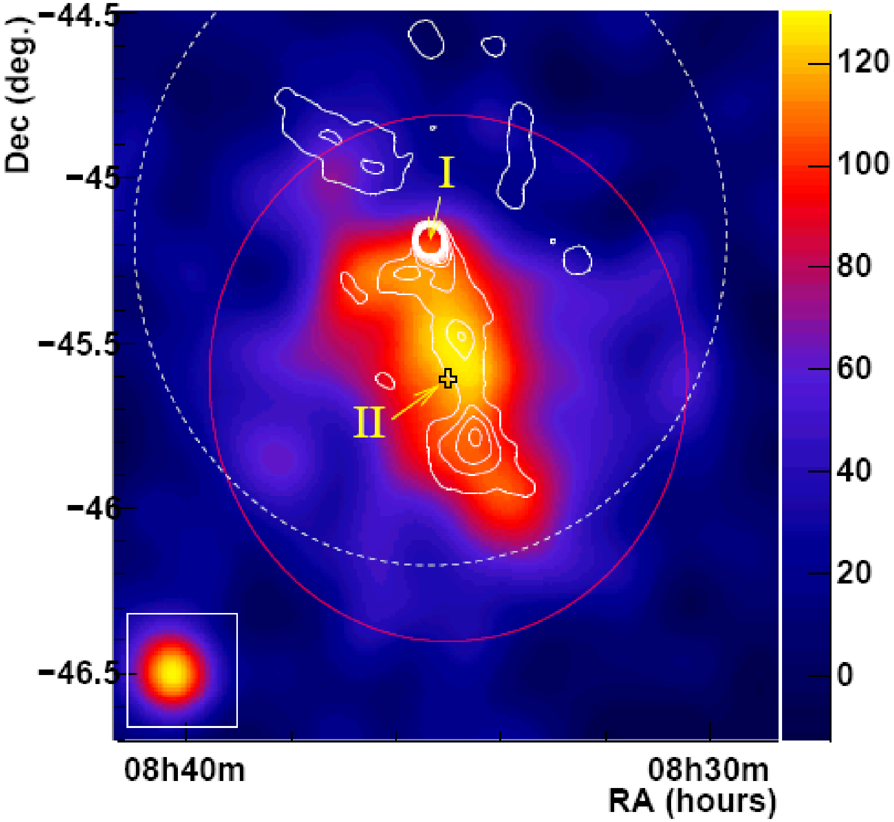
$$\frac{\partial \mathbf{B}}{\partial t} + \nabla \times (\mathbf{v} \times \mathbf{B}) = 0$$



2000 y
3000 y
4000 y
6000 y
12000 y
20000 y
[pc]
log (density) [(g/cm³)]
B [arb. units]

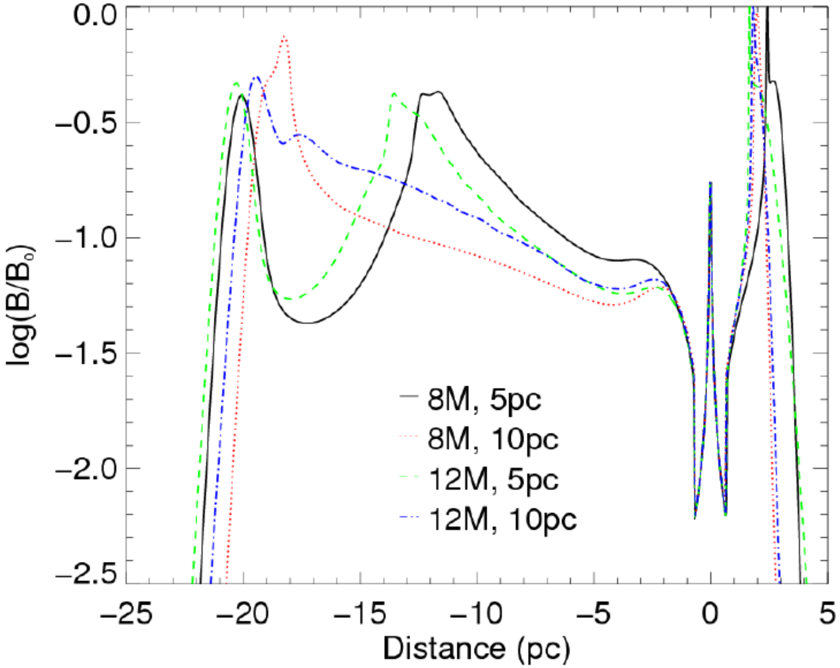


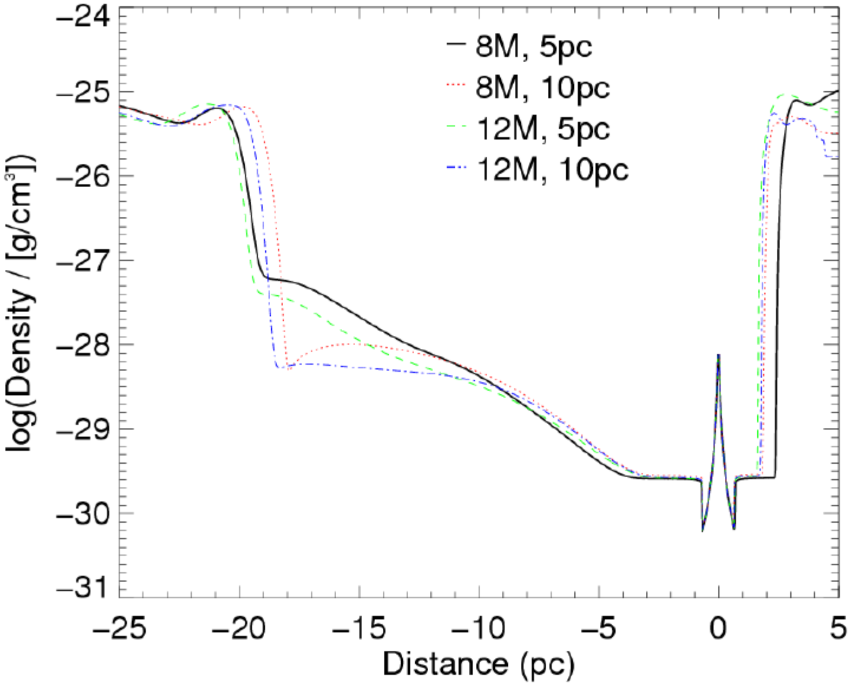
(*Markwardt and Ögelman*, 1995)



(*Aharonian et al.*, 2006)

Non-uniform evolution: radial profiles after 12 000 years





The Particle Transport Equation

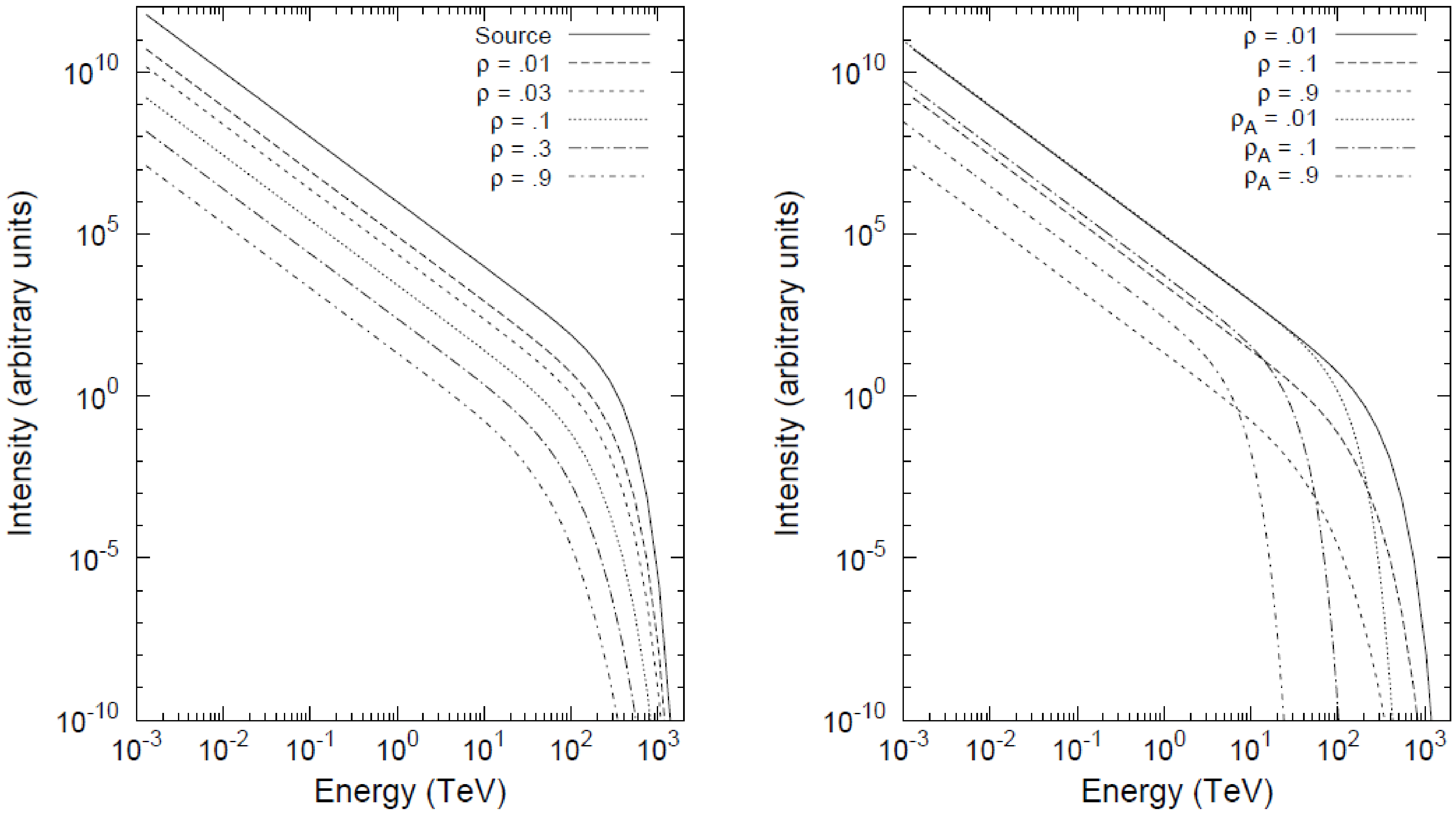
$$\frac{\partial f}{\partial t} - Q = \nabla \cdot [\underline{\mathbf{K}} \cdot \nabla f - \mathbf{v} f] + \frac{1}{p^2} \frac{\partial}{\partial p} \left[\dot{p} p^2 f + \frac{(\nabla \cdot \mathbf{v})}{3} p^3 f \right]$$

$$\dot{p} = \frac{4}{3} \sigma_{\mathrm{T}} \frac{1}{8\pi} \frac{B^2 p^2}{(m_0 c)^2}$$

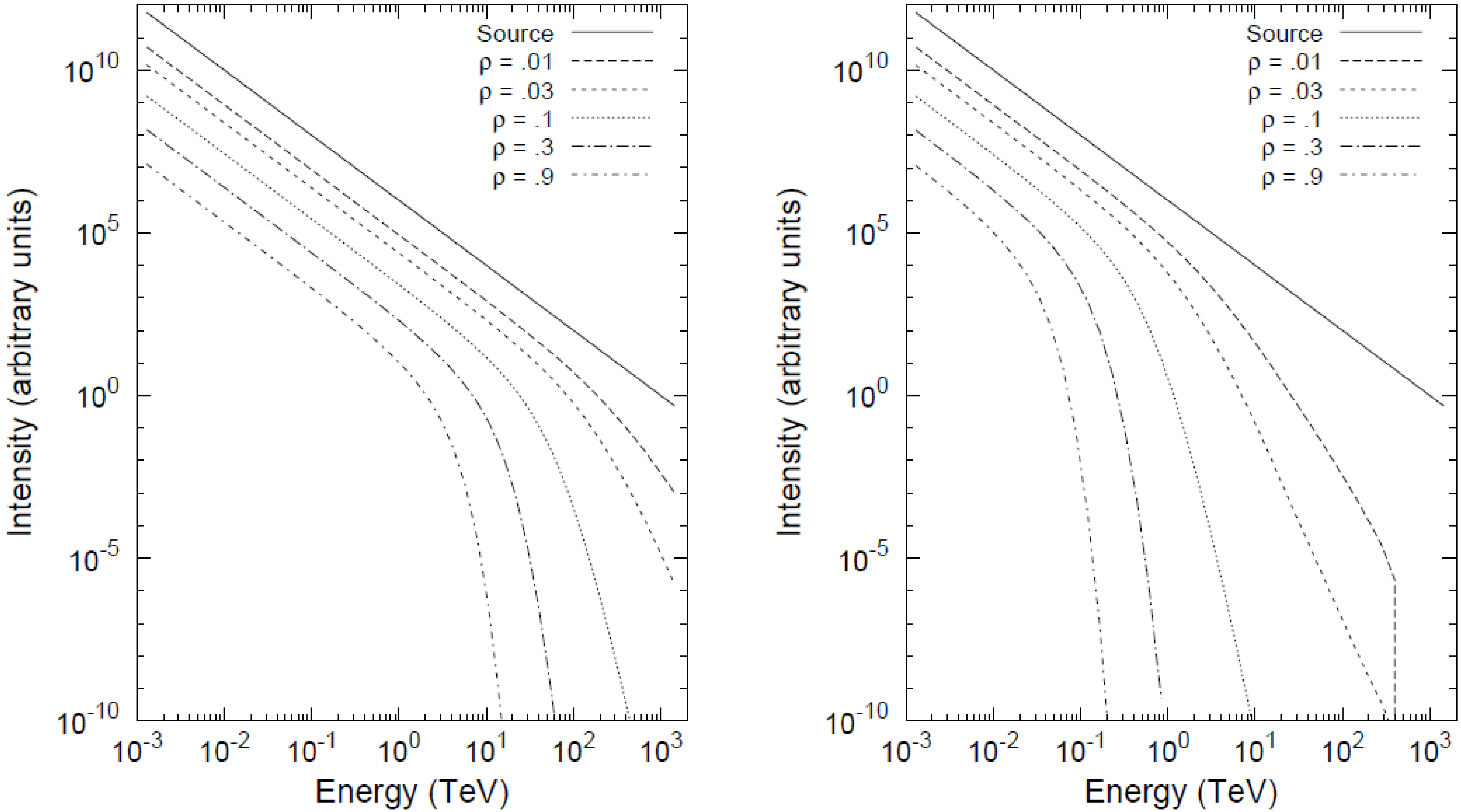
- Spherically symmetric:

$$\frac{\partial f}{\partial t} = \kappa_r \frac{\partial^2 f}{\partial r^2} + \left[\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 \kappa_r \right) - v_r \right] \frac{\partial f}{\partial r} + \frac{1}{3} \left[\frac{1}{r^2} \frac{\partial}{\partial r} \left(r^2 v_r \right) + 3kB^2 p \right] \frac{\partial f}{\partial \ln p} + 4kB^2 p f + Q\left(r, p, t \right) .$$

Time-independent: adiabatic losses



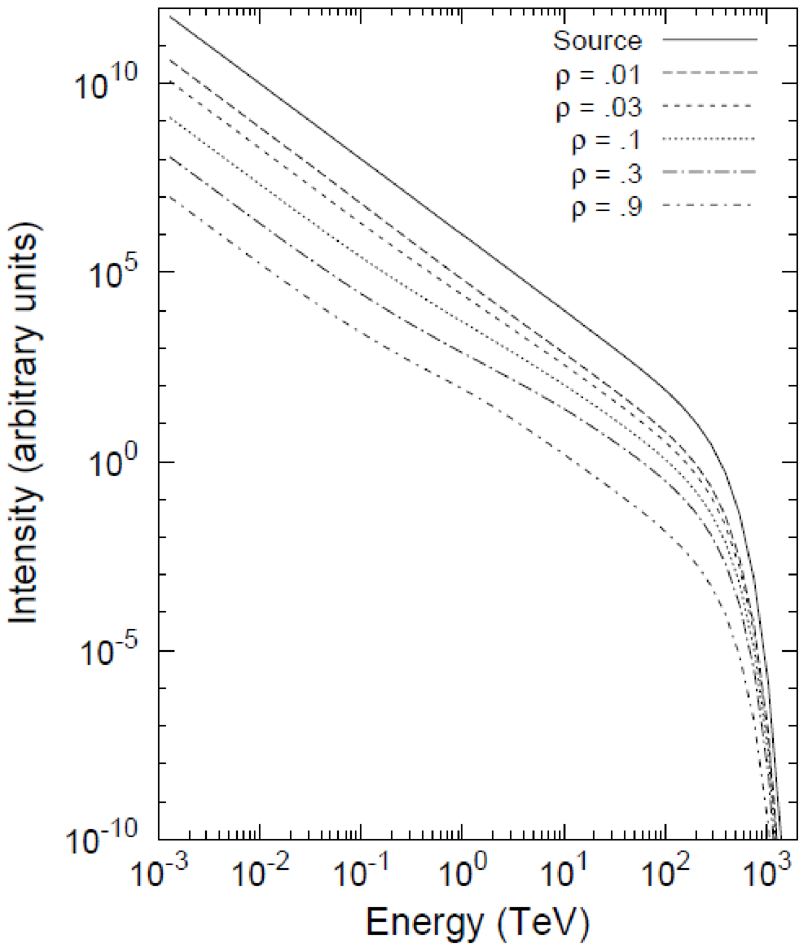
Time-independent: synchrotron losses



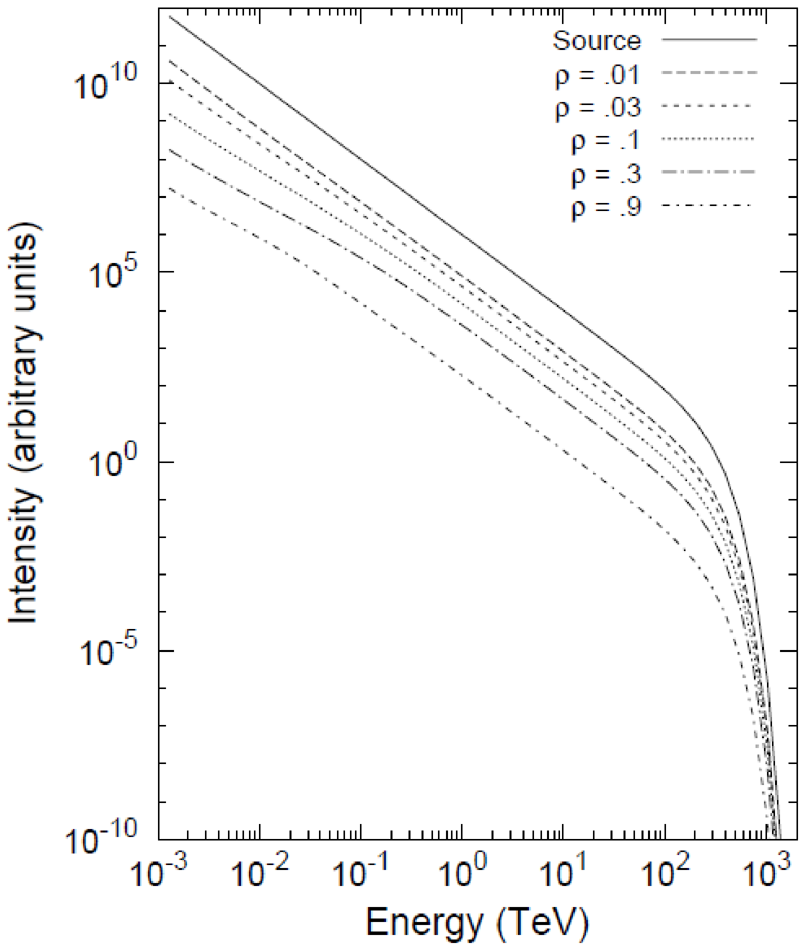
(a) Synchrotron losses for $B = 100\ \mu$G

(b) Synchrotron losses for $B = 1000\ \mu$G

Time-independent: diffusion



(a) Spectra calculated with the diffusion coefficient set to $\varkappa = 0.01\xi$.



(b) Spectra calculated with the diffusion coefficient set to $\varkappa = 1\xi$.

Conclusions

- (M)HD model
  - results agree with observations
- Transport model
  - hyperbolic/parabolic nature of problem
  - diffusion can explain observed break in synchrotron spectrum