High-energy studies of cloud-disc collisions

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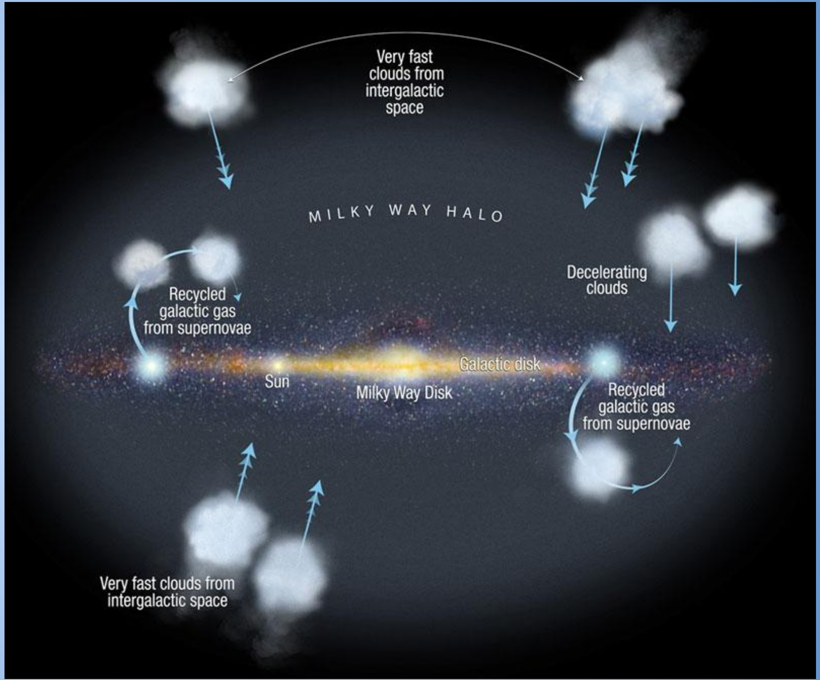
High-velocity clouds

Origin:

- Galactic fountains
- Gas stream (e.g. Magellanic Stream)
- Intergalactic filaments

Properties:

- Velocities: 100 - 500 km s^{-1}
- Neutral hydrogen H I
- Mean density: 0.1 cm^{-3}
- Masses: 10^3 - 10^4 $M_\odot$



Wakker & van Woerden 2013

Collision with the galactic disc

Clouds with inward velocities will inevitable collide with the galactic disc

Time it takes for a cloud to reach the Galactic plane:

$$t_{fall} = z / v_z \sim 69 \, (D / 10 \text{ kpc}) \, (V / 100 \text{ km s}^{-1}) \text{ Myr}$$

10^{47} - 10^{52} erg are released into the ISM per collision

Tenorio - Tagle 1981; van Woeren, Schwarz & Boer 2006; Wakker & van Woerden 2013

Cloud - disc collision

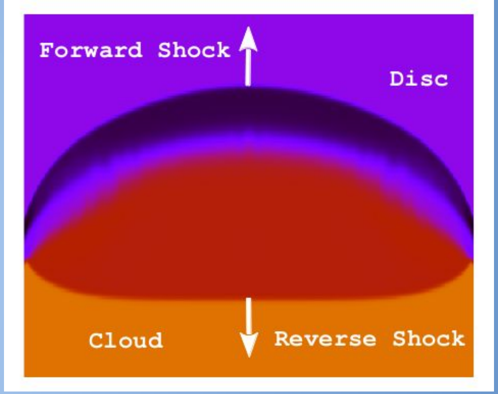
Two shocks:

$$V_{s1} = -\frac{\gamma+1}{2}\frac{\sqrt{\rho_2}}{\sqrt{\rho_1}+\sqrt{\rho_2}}(v_1 - v_2)$$

cloud

$$V_{s2} = \frac{\gamma+1}{2}\frac{\sqrt{\rho_1}}{\sqrt{\rho_1}+\sqrt{\rho_2}}(v_1 - v_2)$$

Disc = 0



e.g., Lee, Kang & Ryu 1996

HVCs sites of particle acceleration in Halo (Hedrick & Cox 1977)

System of shocks

We analysed shocks for different values of:

Galactic disc density n_g: 0.1 - 1.0 cm^{-3}
Cloud density n_c : 1.0 - 0.1 cm^{-3}
Cloud size R_c : 10 - 50 pc
Cloud velocity V_c : 100 - 500 km s^{-1}

Disc thickness W_g : 200 pc

Nature of the shock (Radiative or Adiabatic): t_{cool} / t_{coll}

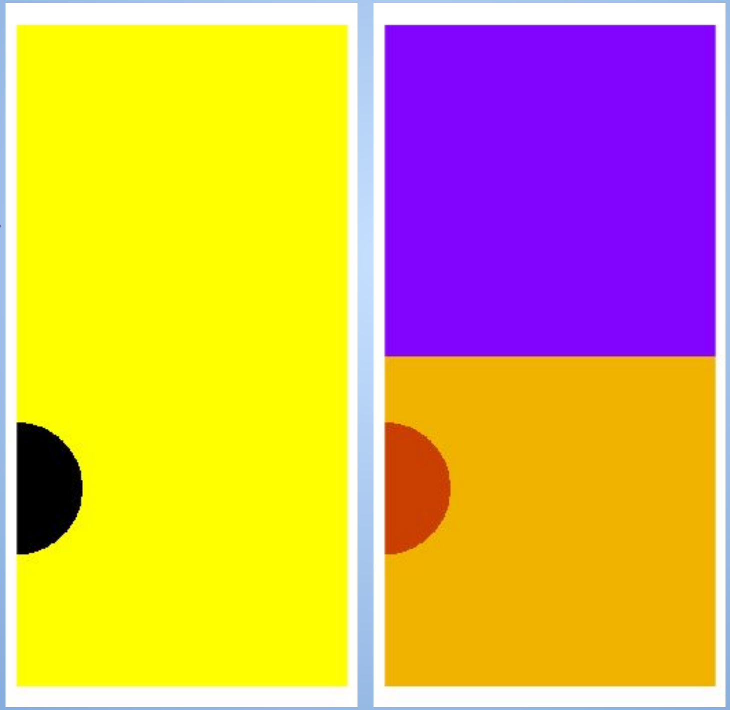
Adiabatic shocks:

- ★ Shock through cloud $n_c = 0.1$ cm^{-3} , $n_g = 1.0$ cm^{-3} and $V_c = 500$ km s^{-1}
- ★ Shock through disc $n_c = 1.0$ cm^{-3} , $n_g = 0.1$ cm^{-3} and $V_c = 500$ km s^{-1}

Collision of light cloud with disc

Parameters:

- V_c = 500 km s^{-1}
- n_c = 0.1 cm^{-3}
- n_g = 1.0 cm^{-3}
- R_c = 10 pc



PLUTO code Mignone et. al 2007

Collision of light cloud with disc

Parameters:

- V_c = 500 km s^{-1}
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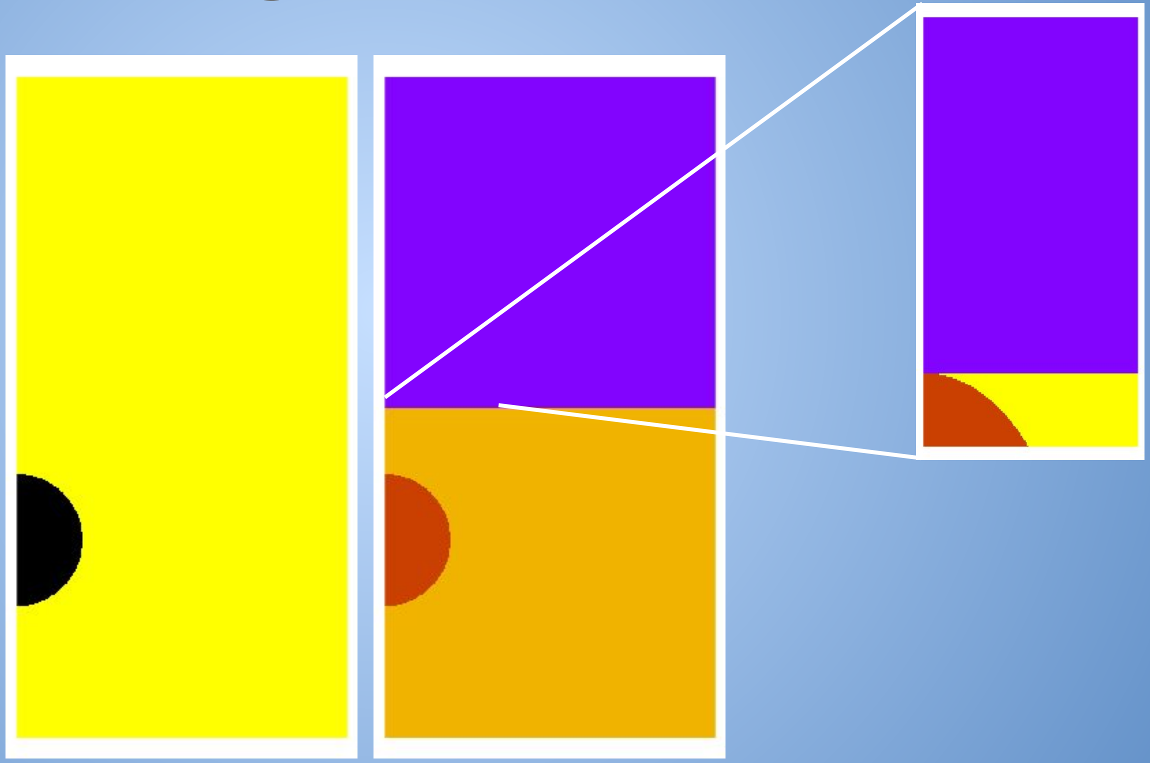
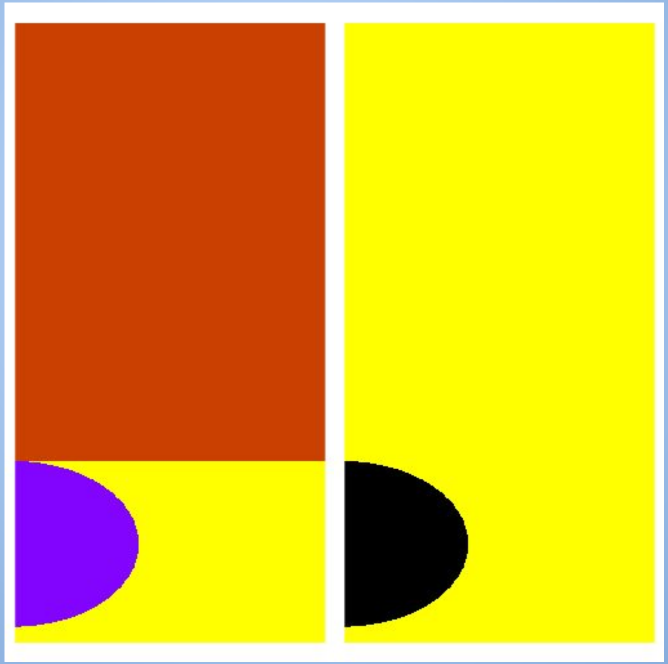


PLUTO code Mignone et. al 2007

Collision of dense cloud with disc

Parameters:

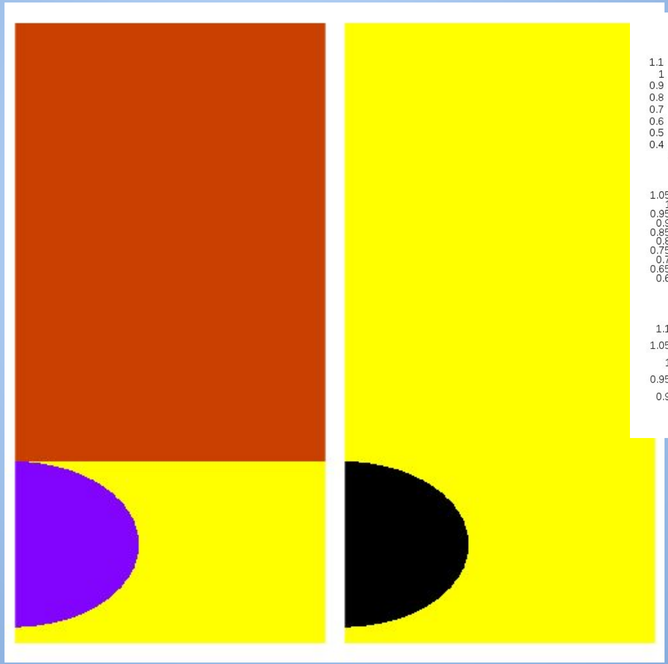
- V_c = 500 km s^{-1}
- n_c = 1.0 cm^{-3}
- n_g = 0.1 cm^{-3}
- R_c = 10 pc

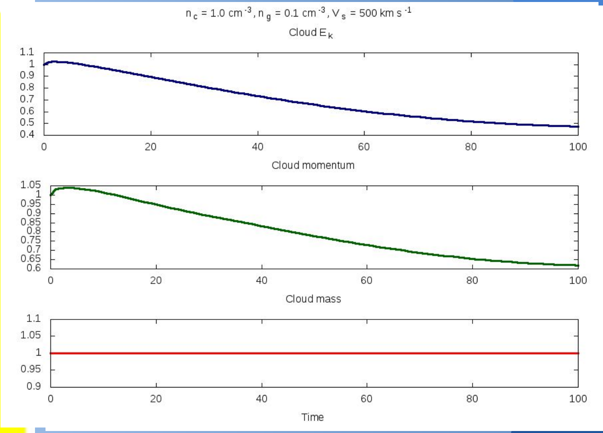


Collision of dense cloud with disc

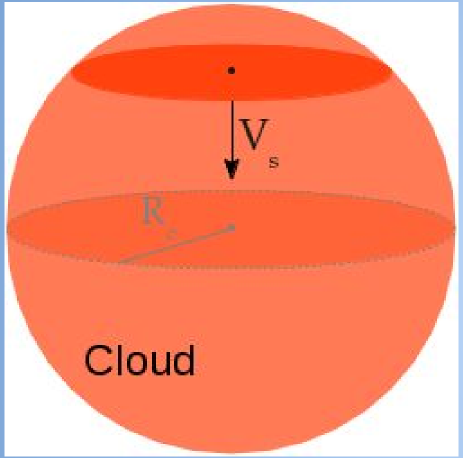
Parameters:

- Vc = 500 km s^{-1}
- nc = 1.0 cm^{-3}
- ng = 0.1 cm^{-3}
- Rc = 10 pc





Shock through cloud

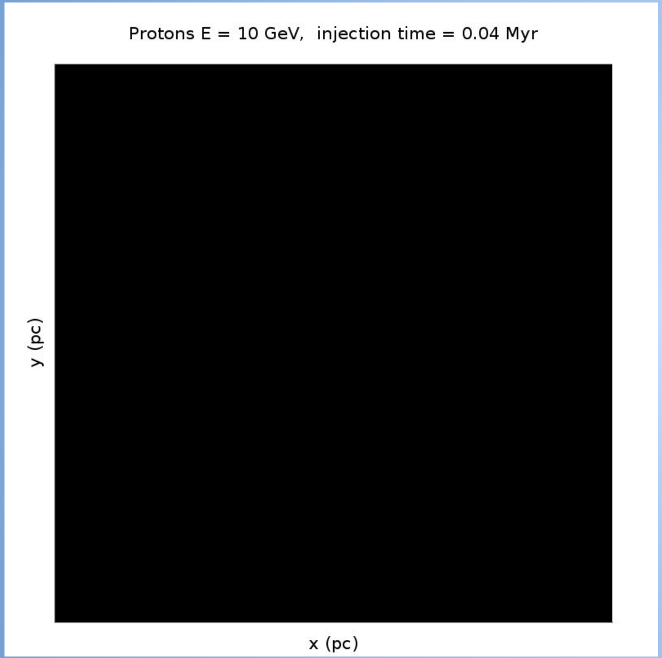


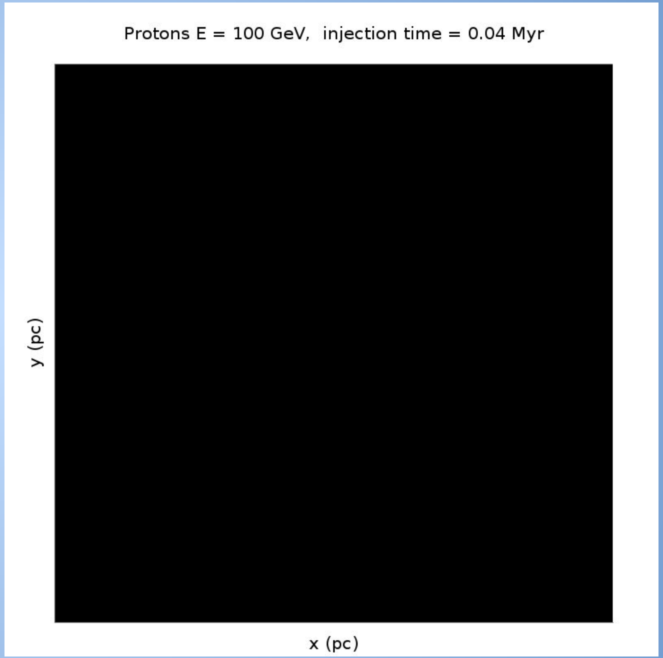
Cloud parameters:
Density: 0.1 cm^{-3}
Magnetic field: 10 μG
Shock velocity: ~ 500 km s^{-1}
Injection time: 0.04 Myr
Power injected in protons: 10^{36} erg s^{-1}
in electrons: 10^{34} erg s^{-1}

Diffusion equation for both protons and electrons:

$$\frac{\partial N_p}{\partial t} = D(E)\left[\frac{1}{R^2}\frac{\partial}{\partial R}\left(R^2\frac{\partial N_p}{\partial R}\right) + \frac{1}{R^2 \operatorname{sen}\theta}\frac{\partial}{\partial\theta}\left(\operatorname{sen}\theta\frac{\partial N_p}{\partial\theta}\right)\right] - \frac{\partial}{\partial E}\left(P(R,\theta,E)\,N_p\right) + Q_p(R,\theta,E,t).$$

Shock through cloud

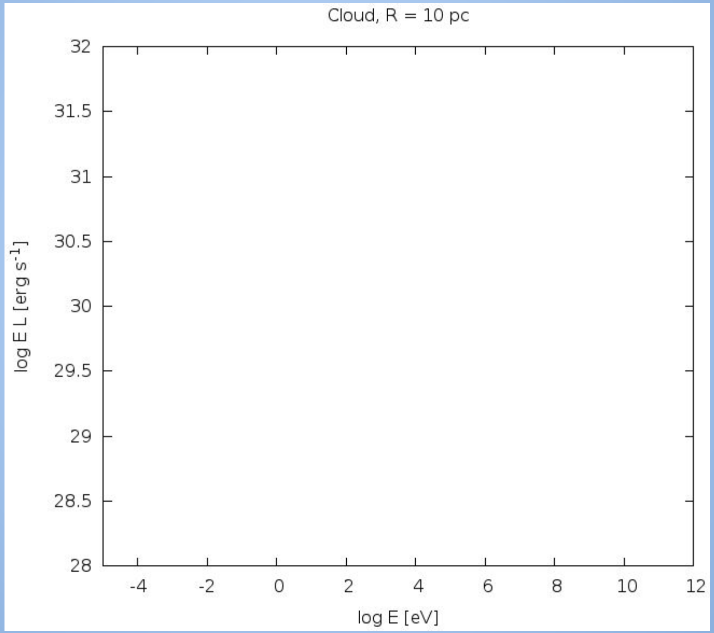




Injection of protons for 10 GeV and 100 GeV

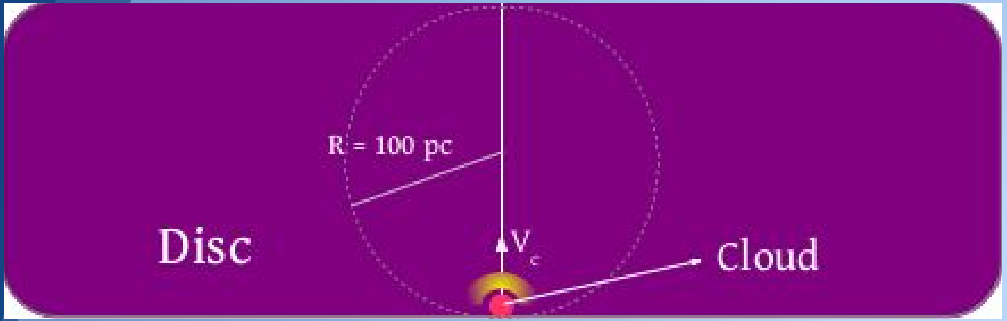
Shock through cloud

Integration time = 0.04 Myr
$\Delta t = 10^{-3}$ Myr



Non - thermal Spectral Energy Distribution

Shock through disc

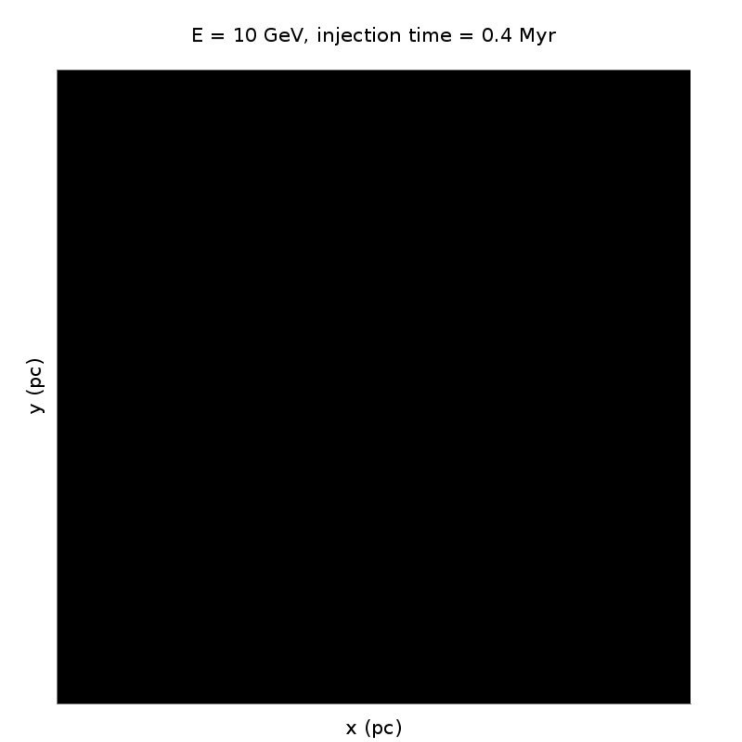


Disc parameters:
Density: 0.1 cm^{-3}
Magnetic field: 1 μG
Shock velocity: ~ 500 km s^{-1}
Injection time: 0.4 Myr
Power injected in protons: 8×10^{36} erg s^{-1}
in electrons: 8×10^{34} erg s^{-1}

Diffusion equation + background cosmic rays

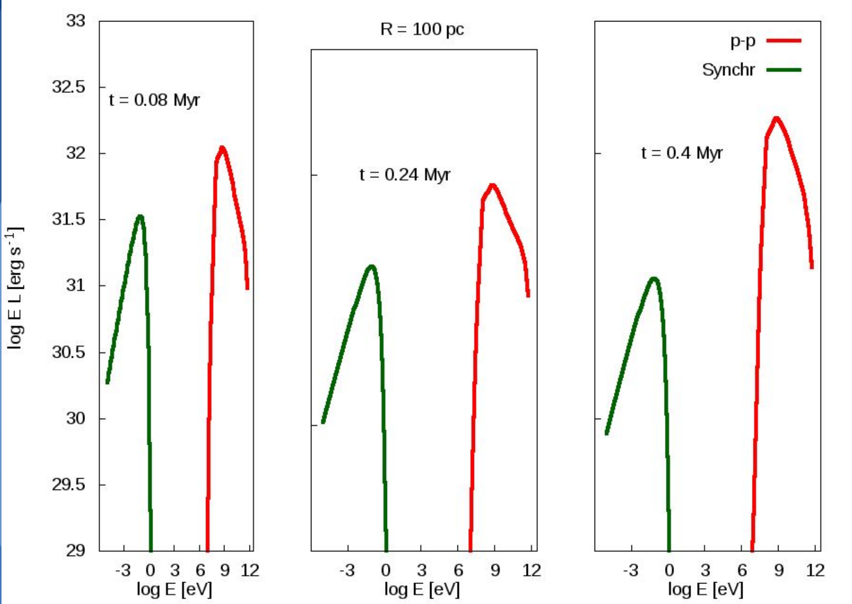
$$J_{\rm RC}^{\rm gal}(E) = 2{,}2\left(\frac{E}{\rm GeV}\right)^{-2{,}75}\ {\rm cm^{-2}\,s^{-1}\,sr^{-1}\,GeV^{-1}}.$$

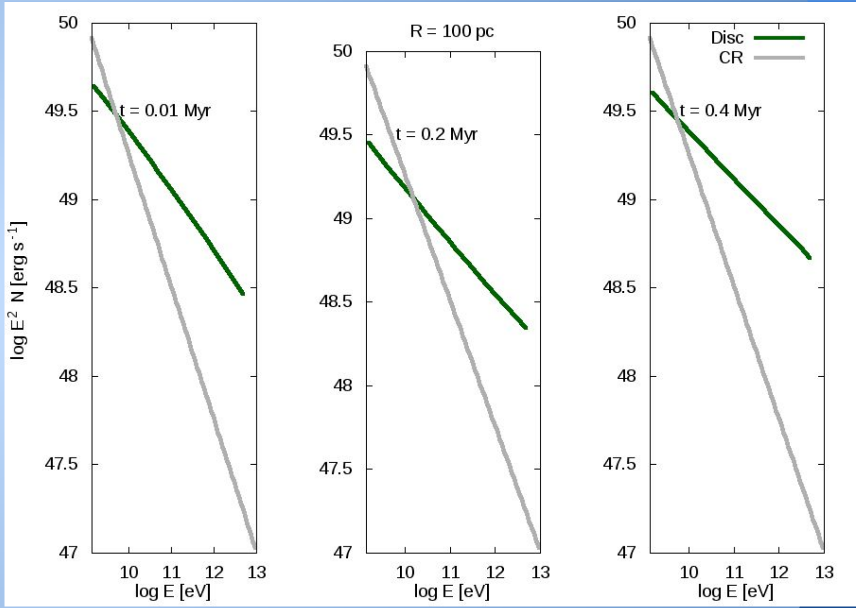
Shock through disc



Injection of protons of 10 GeV

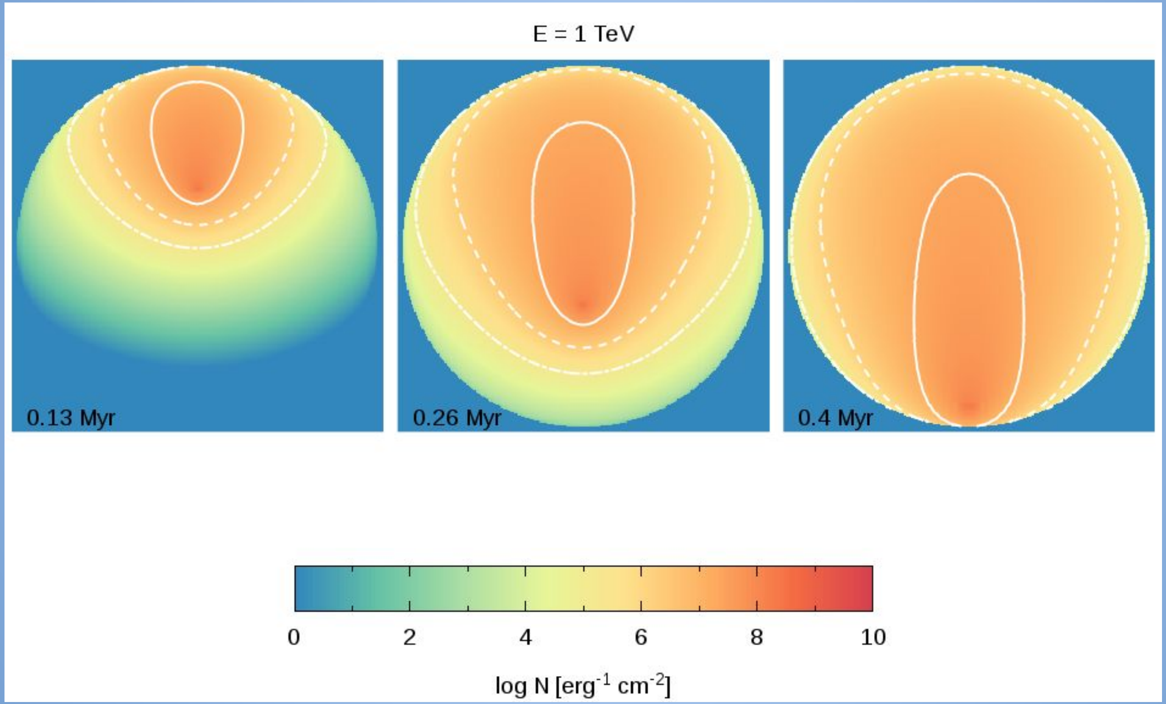
Shock through disc





Non-thermal SED Comparison with background CRs

Shock through disc



Curves

—— 10 f_{pCR}

- - - 1.0 f_{pCR}

. . . . . 0.1 f_{pCR}

Comparison with background CRs (protons)

Conclusions and future work

- Cloud - disc collisions produce strong shocks, adiabatic in some cases
- A strong energy transfer is produced in the collision
- Adiabatic shock in the cloud:
  - Produces significative NT radio emission
  - Protons might diffuse and emit elsewhere
- Adiabatic shock in the disc:
  - Produces significative NT radio and gamma emission
  - Injects protons with E_p from 10 GeV to 10 TeV

Ongoing work:
Studying the radiative, though rapid, shocks
Future work:

➢ Induced star formation
➢ Interaction of a HVC with a denser target (molecular cloud)

Thank you!

Diffusion coefficient

$$D(E) = \chi D_{10} \left(\frac{E}{10\,\mathrm{GeV}} \right)^{\delta}$$

δ: 0.5

χ: 0.1 cloud, 1 disc

D_{10}: $10^{27}\,\mathrm{cm}^2\,\mathrm{s}^{-1}$