Cosmic ray acceleration and diffusion by turbulent magnetic reconnection in relativistic jets

From 9 to 40: the SST Telescopes and Gamma-Ray Science with ASTRI and CTAO

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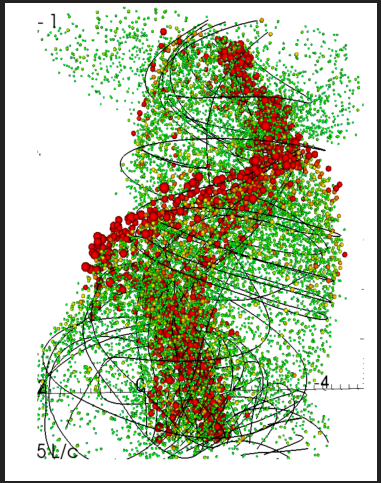
Relativistic jet

Properties

- Magnetically dominated
- Turbulence driven by CDKI
- Turbulent driven reconnection
- 1^{st} order Fermi acceleration
- RMHD-PIC simulation with $B \sim 0.1$ G, $\sigma \sim 1$, $R \sim 2L \sim 10^{-6}$ pc



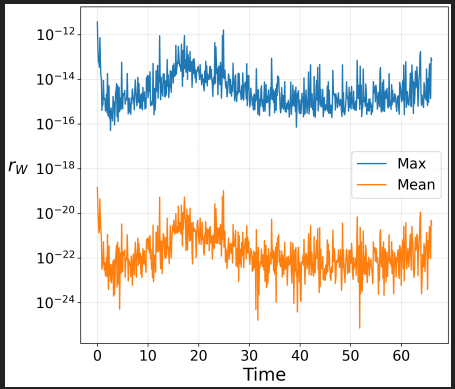
Particle feedback

2 Preliminary results

Particle-jet work ratio

$$W_{\mathrm{CR}} = \boldsymbol{v} \cdot (\boldsymbol{J}_{CR} \times \boldsymbol{B})$$
$$W_{\mathrm{j}} = \boldsymbol{v} \cdot (\boldsymbol{J} \times \boldsymbol{B})$$
$$r_W = \frac{|<W_{\mathrm{CR}}>|}{|<W_{\mathrm{j}}>|}$$

- Effect of particles is dynamically negligible



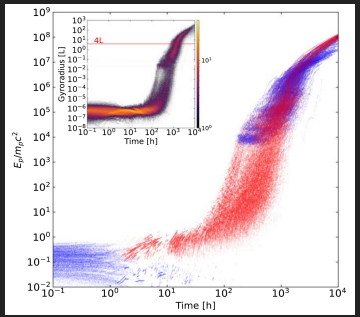
Stefanou & de Gouveia Dal Pino, in preparation

Particle diffusion

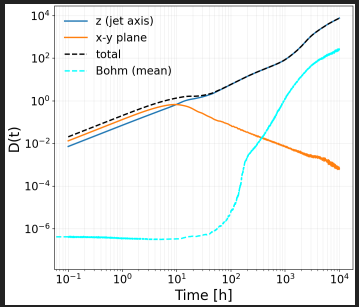
2 Preliminary results

Properties

- Advected along jet axis
- Confined in xy plane
- Behaviour correlates with acceleration
- Trapped in acceleration region until $r_L \sim L$
- Bohm diffusion follows r_L



Medina-Torrejon, de Gouveia Dal Pino et al., ApJ, (2021; 2023)



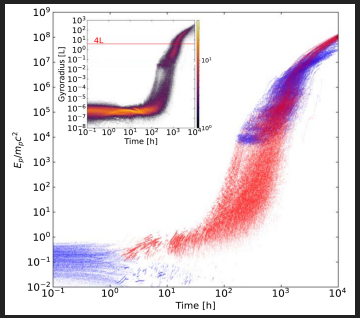
Stefanou & de Gouveia Dal Pino, in preparation

Particle diffusion

2 Preliminary results

Properties

- Similar diffusion parallel and perpendicular to the magnetic field



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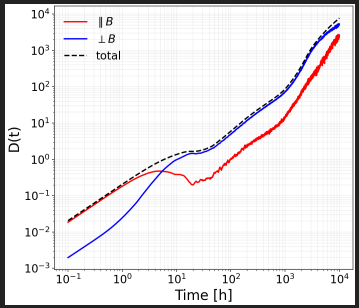

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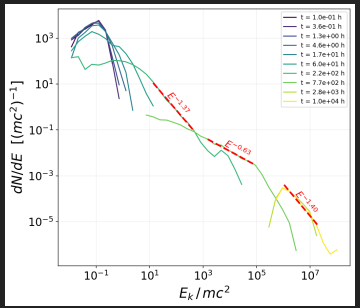
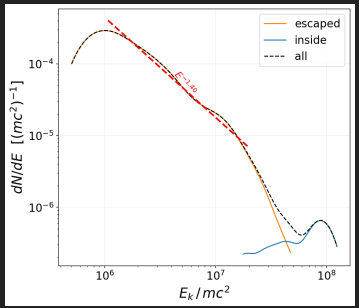
Particle spectra

2 Preliminary results

Properties

- Power law fit for Fermi acceleration
- Particle escape shapes the spectrum
- Radiative losses not taken into account





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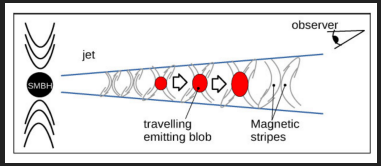
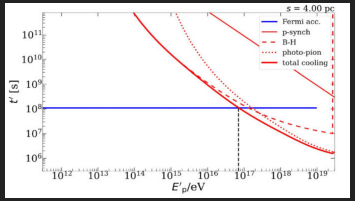
SED for TXS 0506+056

3 Application

Model

- Stripped jet embedded in turbulence
- 1^{st} orderFermi acceleration within TDR layers
- Acceleration region moves in transition zone of decreasing magnetization





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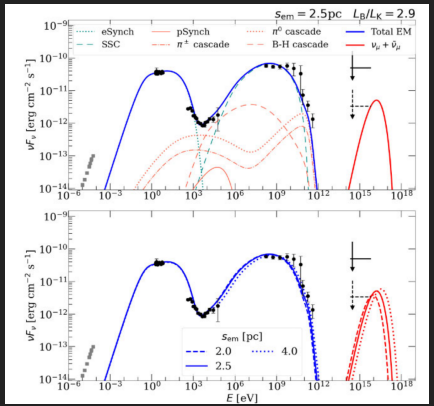
SED for TXS 0506+056

3 Application

Model

- Lepto-hadronic emission
- CR $p^+ \rightarrow$ neutrinos + X-rays + VHE γ-rays, primary $e^- \rightarrow$ HE bump
- Produces neutrinos and VHE γ-rays
- Explains time delay between neutrinos and γ-rays



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Summary and next steps

4 Summary

- TDR in magnetised jets can accelerate cosmic rays to ultra-high energies via 1^{st} order Fermi acceleration within the reconnection layers
- The dynamical feedback of the cosmic rays on the jet is negligible
- Accelerated particles are confined in the jet and only escape when $r_L \sim L$, beyond the maximum energy achieved by Fermi acceleration within reconnection sites
- Particle diffusion coefficient is controlled by transverese confinement
- Resulting particle spectra follow a power law, shaped by acceleration and escape
- Applied to blazar TXS 0506+056: a stripped-jet model with Fermi acceleration in TDR layers and lepto-hadronic emission reproduces the SED and explains the observed neutrino–γ-ray time delay
- Next steps: impact of emission losses on spectrum, radiative transfer and polarization signatures

Thank you!