MAGNETIC-LENSING DISTORTIONS IN THE PROPAGATION OF COSMIC RAYS THROUGH THE GALAXY

Undergraduate Research Project
Federal University of ABC, Santo André, SP, Brazil

Raissa Bispo Bastos
Advisor - Prof. Dr. Marcelo Augusto Leigui de Oliveira

INTRODUCTION

- Cosmic rays (CRs) are high-energy charged particles that travel through space at nearly the speed of light. Identifying their astrophysical sources remains an open problem.

- Since CRs are electrically charged, their trajectories are deflected by the magnetic fields they encounter, both inside and outside our Galaxy. These deflections make it difficult to reconstruct their original arrival directions and can produce magnetic-lensing effects.

- Studying Galactic magnetic-field models is essential for estimating cosmic-ray deflections, reconstructing their trajectories, and constraining their possible astrophysical sources.

METHODS

- Using Lorentz force and Newton's second law applied to the relativistic case, we obtain:

$$F = qv \times B = \frac{dp}{dt} = \frac{d(\gamma m_0 v)}{dt} = \gamma m_0 a_{cp} = \gamma m_0 \frac{d^2 r}{dt^2}$$

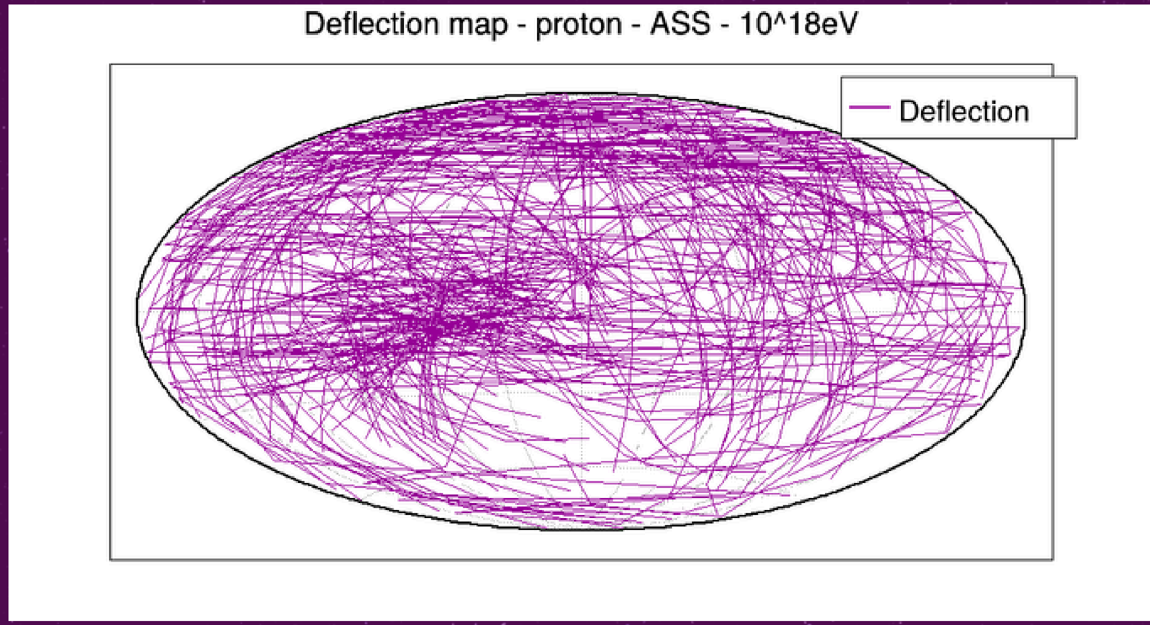
from which we can derive the particle's equations of motion.

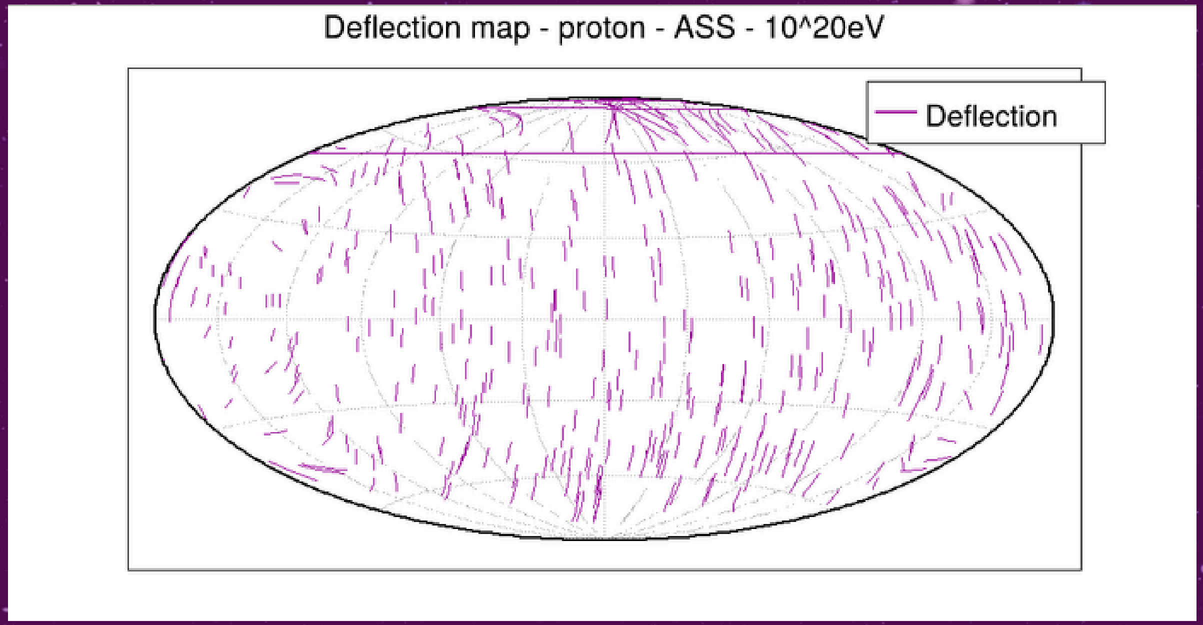
- These equations are invariant under the simultaneous reversal of time and electric charge. Therefore, the spatial trajectory of a particle arriving at Earth can be reconstructed by propagating an antiparticle from Earth with the same energy and the opposite initial velocity.

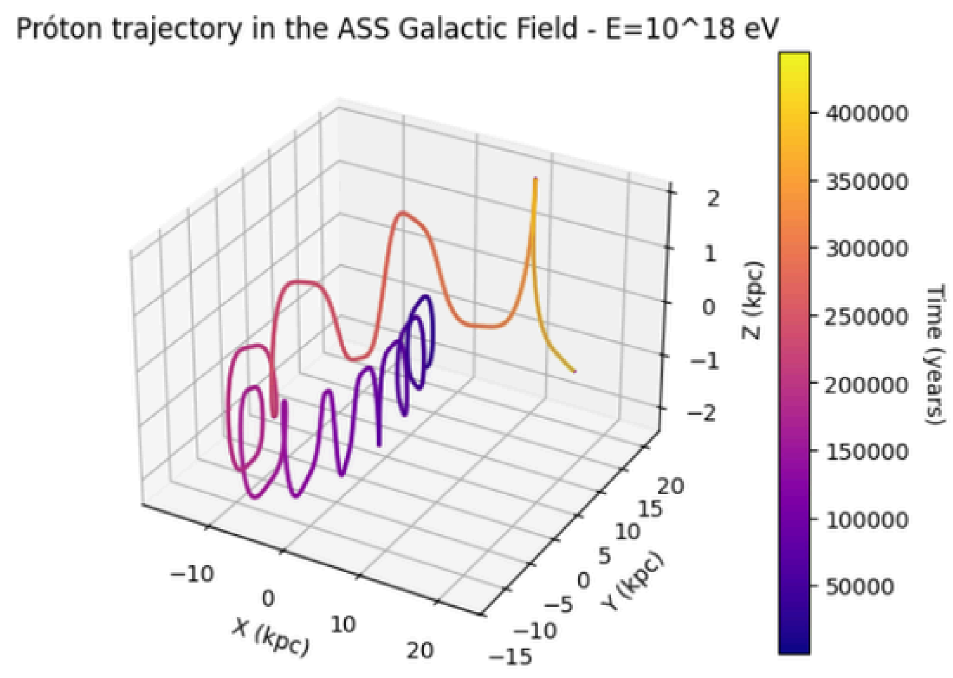
- I applied this backtracking method to the axisymmetric spiral (ASS) and bisymmetric spiral (BSS) models of the Galactic magnetic field, both of which are widely discussed in the literature.

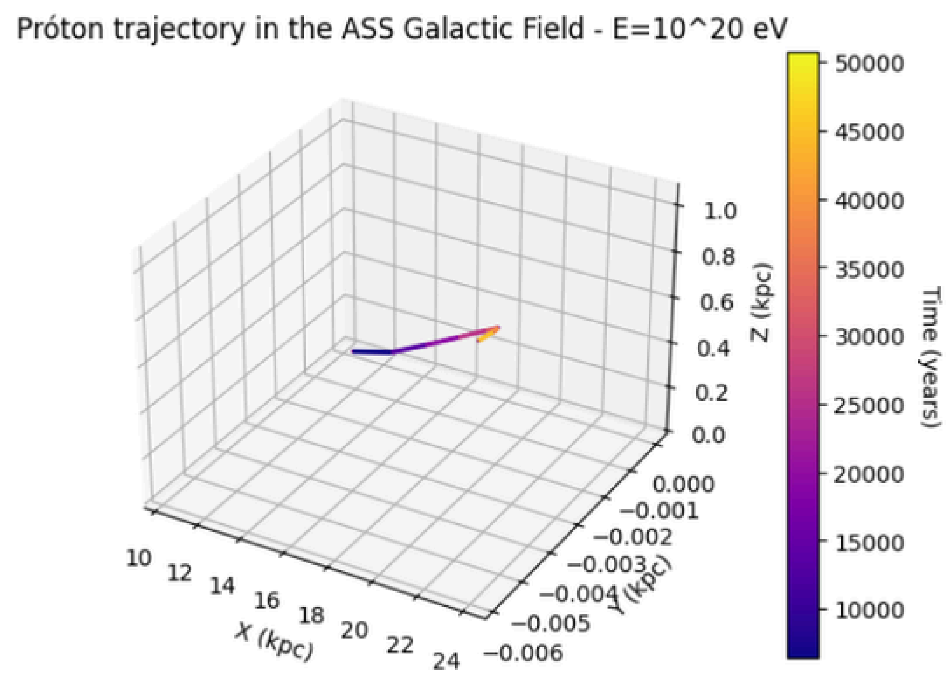
RESULTS

I developed a Python-based computational simulation that numerically integrates the equations of motion and calculates the particle trajectory, the escape time from the Galaxy, and the deflection angle.









RESULTS

CONCLUSION

- For particles with the same mass, the lower energy is related to a greater deflection.
- This result is consistent with theoretical predictions, and obtaining it helps validating the simulation.
- As the next step, I'll run the simulations for different CR nuclei (He, C and Fe) and investigate the BSS model as well. Finally, I will compare the mean deflection angle for each particle and energy with observational results from the Pierre Auger observatory.
- This project allowed me to develop important computational-simulation skills and gain a better understanding of cosmic-ray propagation in Galactic magnetic fields.

REFERENCES

1. J. A. Bittencourt, Fundamentals of Plasma Physics, 3rd ed., Springer, 2004.
2. R. A. Serway and J. W. Jewett Jr., Princípios de Física: Eletromagnetismo, vol. 3, Thomson, 2004.
3. P. Schiffer, Constraining Cosmic Magnetic Fields by a Measurement of Energy-Energy Correlations with the Pierre Auger Observatory, PhD thesis, RWTH Aachen University, 2011.
4. J. L. Han, "Observing Interstellar and Intergalactic Magnetic Fields," Annu. Rev. Astron. Astrophys., vol. 55, pp. 111–157, 2017.
5. R. Jansson and G. R. Farrar, "A New Model of the Galactic Magnetic Field," ApJ, vol. 757, article 14, 2012.
6. X. H. Sun et al., "Radio Observational Constraints on Galactic 3D-Emission Models," A&A, vol. 477, pp. 573-592, 2008.