# The True Interstellar Anisotropy of 13 TeV Cosmic Rays


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## INTRODUCTION

Cosmic rays (CRs) are high-energy particles; bare atomic nuclei, with varying origins and energy levels. Research in this field is focused on identifying potential origins, understanding transport mechanisms faced on their journey to Earth, and interpreting the angular structure of incident CRs.

One obstacle of this research is the trajectory modulation induced by the heliosphere during the CRs' journey. In this work we employ a method to reconstruct the properties of CRs as they were at the local interstellar medium (LISM) by means of a non-linear model fit to the map at Earth. Another obstacle is the time-averaging used to collect this data, which eliminates latitudinal sensitivity of measurements.

## METHODS

This study relies on data from the IceCube collaboration, focusing on the dataset with median energy level of 13 TeV. In order to undo the effects introduced by the heliosphere and the latitudinal averaging, we utilize the Liouville Mapping Method. To this end the following are utilized:

- Fortran backpropagation on FL Tech's HPC Cluster,
- University of Alabama's Multi-scale Fluid Kinetic Simulation Suite.

Then, the optimal number of parameters in our model is chosen via a Python K-fold cross-validation method. That model is then fit to the measurement map at the Earth, the structure of this model allows inference of the map at the LISM. This process also allows the retrieval of latitudinal sensitivity.

## REFERENCES


Zhang, M., et al. 2020, ApJ, 889, 97

IceCube Collaboration. 2025, The Astrophysical Journal, 981, 182.

Maalal, N. D., & Zhang, M. 2025, The Astrophysical Journal, 992, 46.

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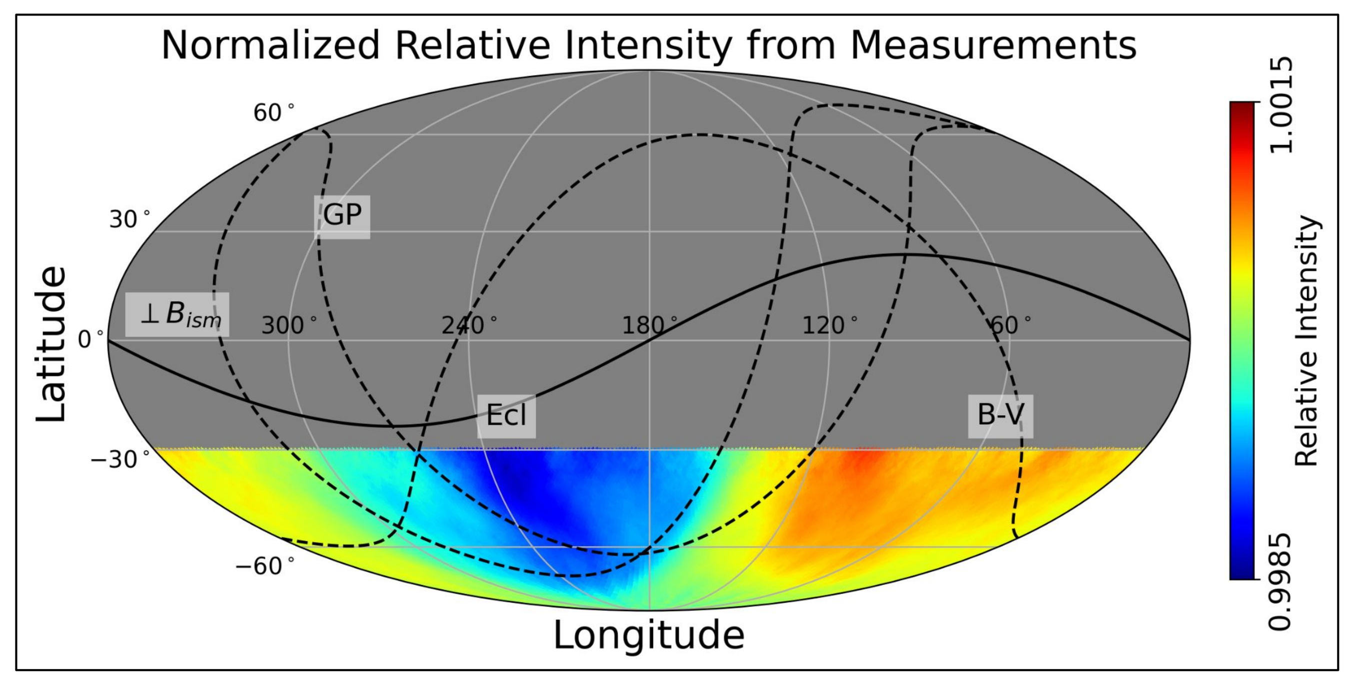
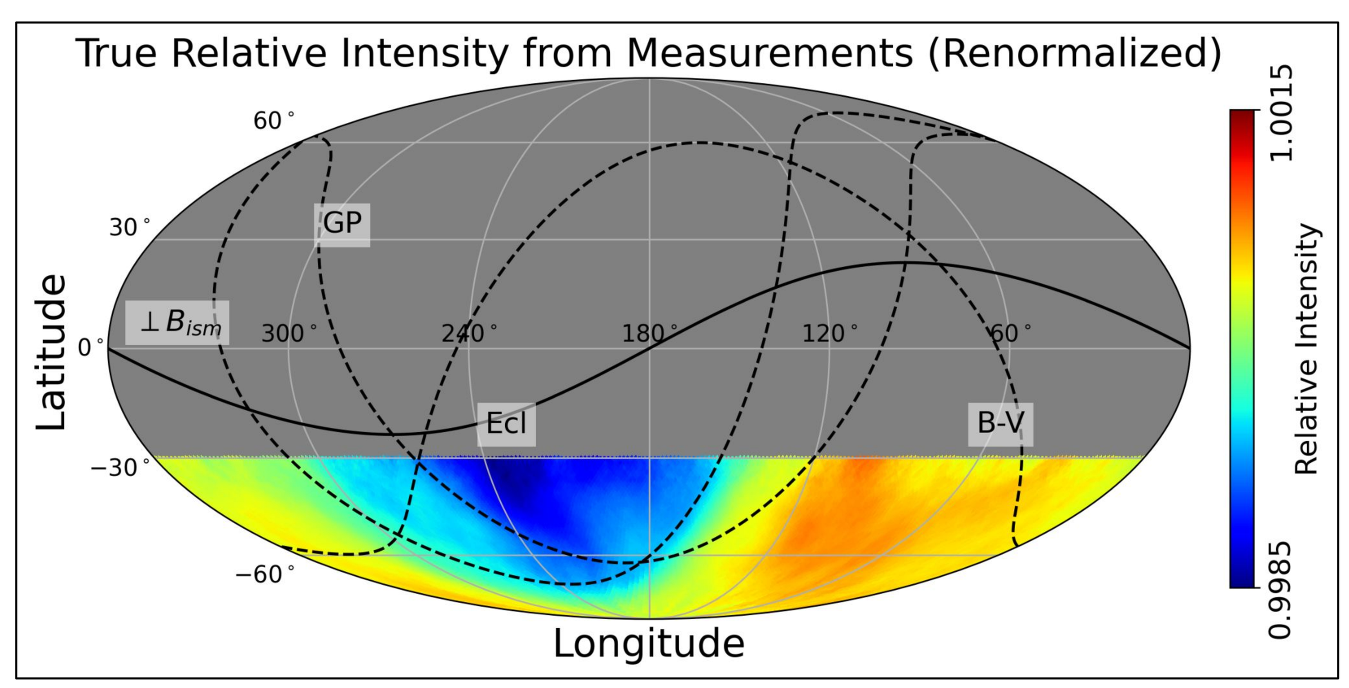
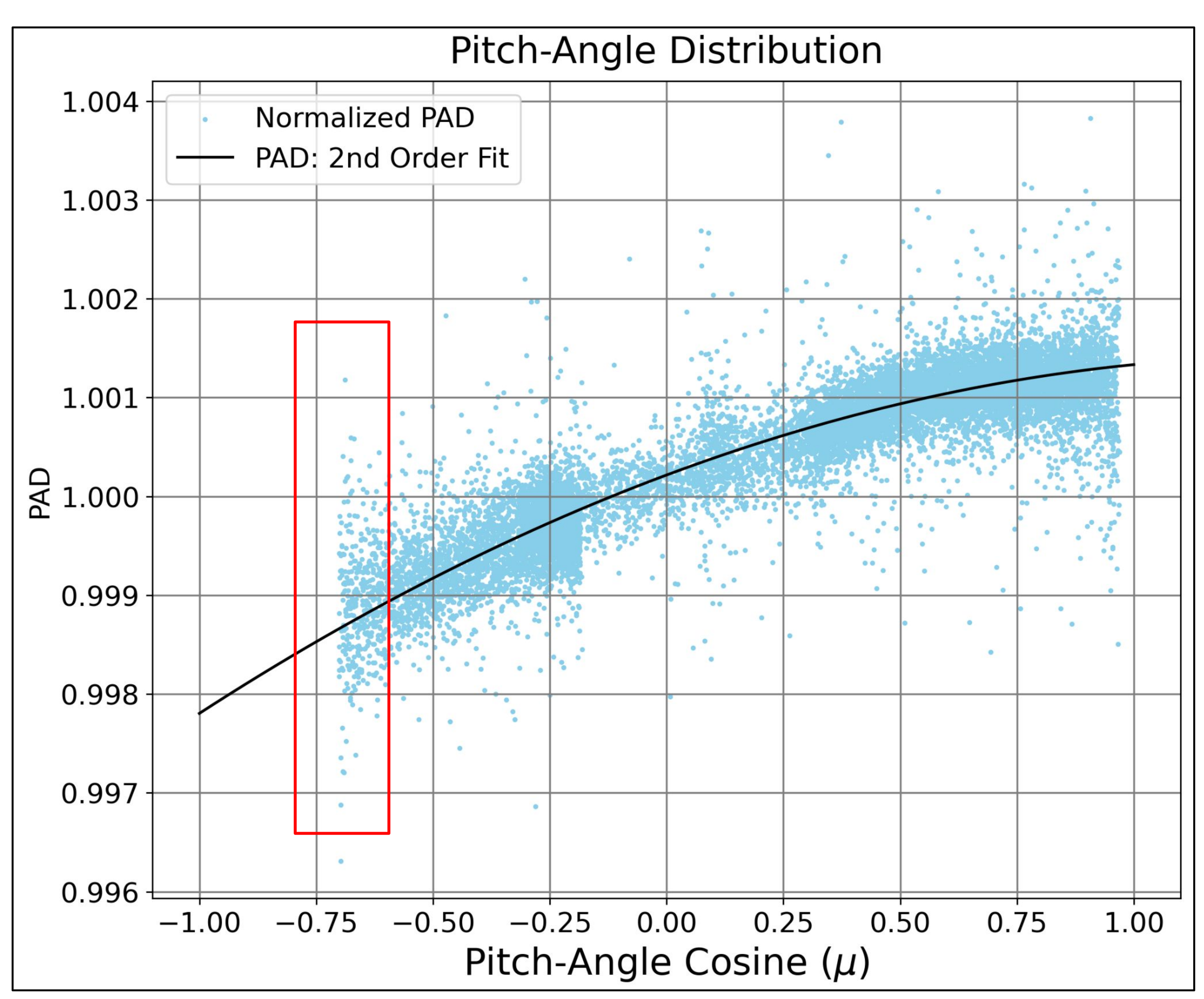
Then the final results are retrieved:

- Measurement, model, and "true" maps,
- Pseudo-power spectra,
- Pitch-angle flux distribution.



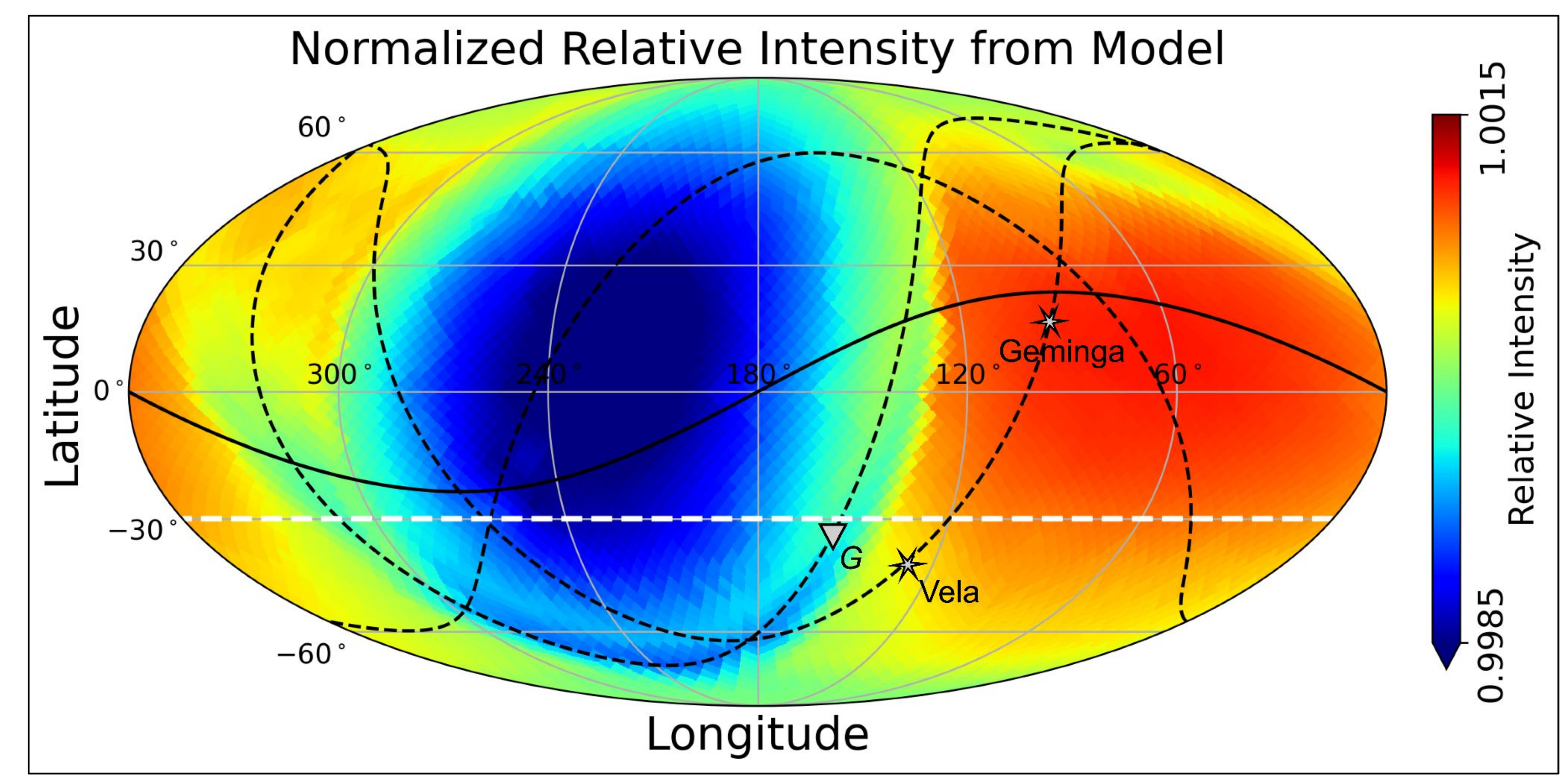




There is a clear cut-off at μ = -0.70.

## RESULTS

This study produced the following results:

- This dataset is best described by a simple dipole.
- Latitudinal averaging obscures angular structure of intensity.
- The pitch angle distribution curves downwards, whereas it is expected to curve upwards.
- CR density gradient suggests Vela as a likely origin of CRs.




The unexpected curve of the pitch-angle distribution suggests that there is a lack of magnetic focusing in the IceCube FOV, and could explain why the model fails to recognize the northern hemisphere hotspot.

Beyond a certain pitch-angle, the CRs are blocked by the surface of the Earth, this is related to the alignment between the Earth's axis of rotation and the LISM magnetic field. It is estimated to be roughly 44.4°.

In sum, this research suggests southern hemisphere maps are lacking information about CR anisotropy and cannot be trusted. Future research should focus on full-sky maps to accurately interpret the angular structure of anisotropy.

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