Relative Fluxes in Backtracked Ultra High Energy Cosmic Rays

Tracking Ultra High Energy Cosmic Rays (UHECRs) through models of the Galactic magnetic field can provide information on both the nature of UHECR sources and properties of the true Galactic magnetic field. Forward tracking UHECRs to the Earth requires significant computational time since most particles generated will not lie on paths intersecting the Earth as such many backtrack particles from Earth. Backtracking, while greatly reducing the required computational time, treats the Earth as a unique point; presented here are the results of simulations studying the effects of small translations of the detector point. The results indicate that small translations of the Earth's position can induce up to a 20% effect on relative fluxes from point sources across the sky.

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Motivation

• Ideally all source hypothesis would be forward tracked from the source (through all intervening fields) to the Earth. Unfortunately this requires an excessive amount of computation time if one wishes to test Galactic Magnetic field models.

• Backtracking greatly reduces the computation time but treats the Earth as an emitting point. The translational invariance of this point is not generally addressed.

• When backtracking, all paths which exit the Galaxy are weighted equally since there is no true flux being emitted (point like source).

• Presented here are results of examining the translational invariance of a specific GMF model and how that effects relative fluxes.
Method

• Pick a direction towards which you want to back track a particle.

• Define the plane perpendicular to this direction.

• Vary the starting point in this plane uniformly and within a given distance (50 pc) from the center.
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- Back track 1M particles through field model for each direction.
- Examine the distribution of the events in the plane normal to the exiting velocity.
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Field Model

- Bisymmetric logarithmic spiral with symmetry across the galactic plane (BSS S). No halo field used.

- Using formulation of Harari, Mollerach, and Roulet (HMR) astro-ph/9906309

- Parameters:
  \( N_\odot = 0.48 \mu \text{G} \)
  \( R_\odot = 8.5 \text{ kpc} \)
  \( \rho_1 = 2 \text{ kpc} \)
  \( \xi_0 = 10.55 \text{ kpc} \)
  \( \beta = -5.67 \)
  \( z_1 = 0.95 \text{ kpc} \)
  \( z_2 = 4 \text{ kpc} \)

\[
|\vec{B}_S(\rho, \theta, z)| = \frac{N_\odot}{B_{sp}(R_\odot, 0)} \cdot B_{sp}(\rho, \theta) \left( \frac{1}{2 \cosh(z/z_1)} + \frac{1}{2 \cosh(z/z_2)} \right)
\]

\[
B_{sp}(\rho, \theta) = B_0(\rho) \cos (\theta - \beta \ln(\rho/\xi_0))
\]

\[
B_0(\rho) = \frac{3R_\odot}{\rho} \tanh^3(\rho/\rho_1)
\]
Results: Towards $l=90 \ b=0$

- Shown are the paths of 100 events as seen from $l=0, b=90$

- All paths appear to follow the same deflection in this projection.
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Results: Towards l=90 b=0

- At 20 EeV we see the distribution on a plane perpendicular to the outgoing direction has been slightly enlarged and offset from x=0, y=0

- There is a hint of variation over the surface which will be quantized later
Results: Towards $l=90 \ b=0$

- At 2 EeV we see the distribution on a plane perpendicular to the outgoing direction has been significantly enlarged and significantly offset from $x=0 \ y=0$

- Variation over the surface is readily apparent to the eye.
Variation of Flux: Towards the Galactic Center

- The variation of the observed flux over a disk at Earth for a uniform extra-galactic flux.
- Only pixels within 1 standard deviation of the mean of all pixels are shown.
- Left shows 20 EeV back tracked towards $l=0,b=0$
- Variations of +/- 5% are apparent.
Variation of Flux: Towards the Galactic Center

- Left shows 2 EeV back tracked towards l=0, b=0

- Variations of +/- 10% are apparent.
Variation of Flux: Towards the Galactic North Pole

- Left shows 20 EeV back tracked towards $l=0, b=90$

- Variations of appear random and uniform.
Variation of Flux: Towards the Galactic North Pole

- Left shows 2 EeV back tracked towards $l=0, b=90$

- Variations of +/- 2% are apparent.
Variation of Flux: Towards $l=90 \ b=0$

- Left shows 20 EeV back tracked towards $l=90, b=0$
- Variations of +/- 15% are apparent.
Variation of Flux: Towards $l=90 \, b=0$

- Left shows 2 EeV back tracked towards $l=90, b=0$
- Variations of +/- 20% are apparent.
Generalizing Across the Sky

Extra-galactic Disk for $0.000 < R_{earth} < 0.029$

- Running 1 M events for densely space points on the sky is too computationally intensive.
Generalizing Across the Sky

Extra-galactic Disk for $0.029 < R_{\text{earth}} < 0.041$

- Running 1 M events for densely space points on the sky is too computationally intensive.
- The simulations show that concentric rings at Earth (at these energies) map to shells on the Extra-galactic disk.
Generalizing Across the Sky

Extra-galactic Disk for $0.041 < R_{\text{earth}} < 0.050$

- Running 1 M events for densely space points on the sky is too computationally intensive.

- The simulations show that concentric rings at Earth (at these energies) map to shells on the Extra-galactic disk.

- Thus we backtrack only the outer ring for each direction.
Variation Across the Sky

• Comparing the area over which we emit from Earth to the area of the Extra-galactic disk gives us the flux enhancement for that direction.

• The flux enchantment across the sky at 2 EeV
Variation Across the Sky

- The flux enchantment across the sky at 20 EeV
- Color scale has changed significantly
Conclusions

• The variation of observed flux over a small region (<50pc) near Earth can be at least +/-20% for some regions of the sky.

• Backtracking particles from a point like source may sample unrepresentative extra-galactic points. That is the flux enhancement varies across the sky but backtracking from a point treats the sky uniformly.

• The impact parameter for extra-galactic sources entering our galaxy on trajectories observable at Earth can be quite large (>10 kpc). This can effect how we should treat nearby sources.