A Hybrid Monte Carlo Generator for Ultra High Energy Cosmic Rays from their Sources to the Observer

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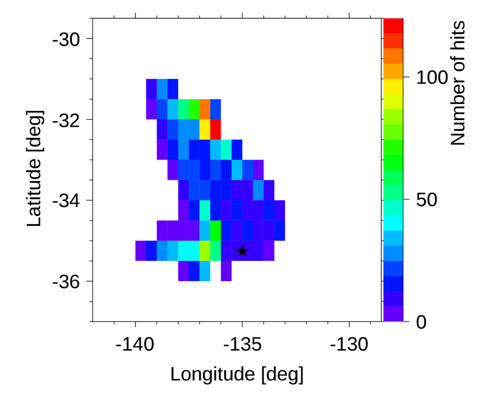
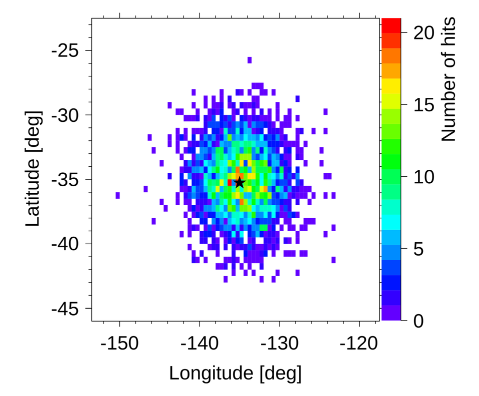
We identify three different propagation regimes for the propagation of UHECRs: our Galaxy, the local universe out to 110 Mpc (359 ly), and the distant universe. For each regime we apply a different propagation method. Finally we combine all three using probability maps.

1. Distant Universe: Parameterized Propagation

Simulations through a turbulent magnetic field suggest that for distant sources the angular distribution can be parameterized by a Fisher distribution. Continuous energy loss approximations and the effects of the expanding universe (redshift) are considered as well.



Source at 28 Mpc



Source at 250 Mpc

2. Local Universe: Forward Tracking

Propagate individual particles through a realistic large scale structure.

Computational Challenges

- Low hit ratio: huge distances (universe) and tiny target (Earth)
- Up to 600 GB of memory for the magnetic field data
- Huge statistics required for analyses.

Technologies

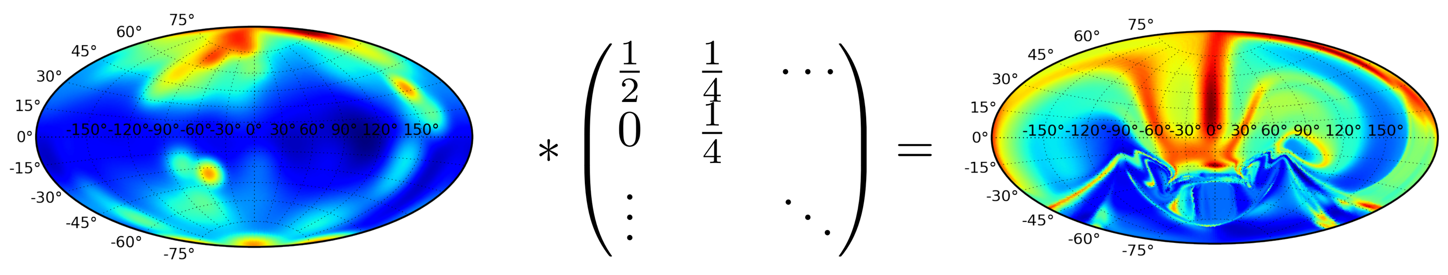
- CRPropa tracking software[1]
- Large scale simulation data[2]
- Approximations: increase observer size, limit propagation time
- High degree of parallelization: per particle and spatial partitioning

Many nodes (Grid)

Many cores ('Fat Node')

3. Galaxy: Lensing

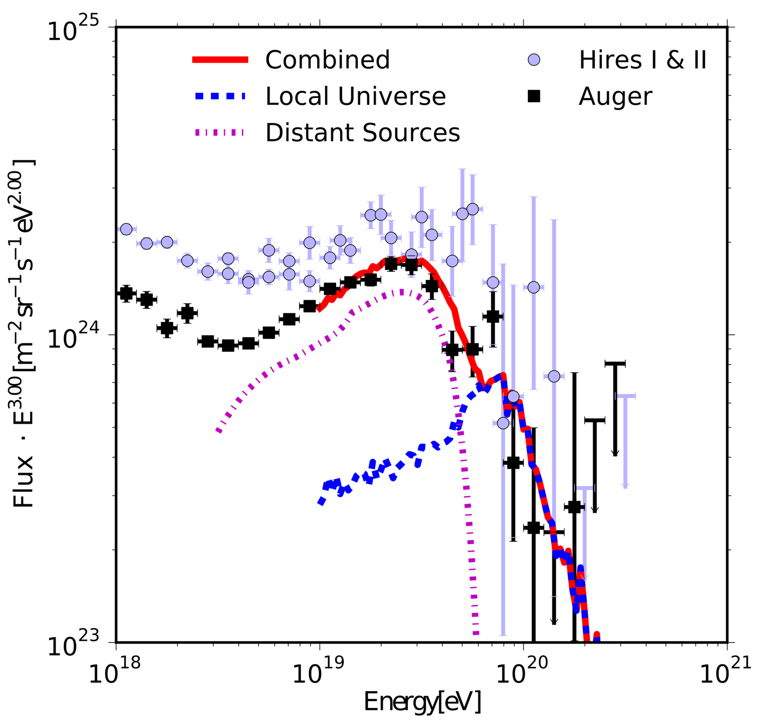
The energy loss in the Galaxy is negligible. Use antiparticles for backtracking[3] from Earth to the edge of Galaxy. Create 50k x 50k (sparse) transformation matrix **M** for probability maps (HEALPix[4]).



Galaxy Earth

Compare with Measurements

The synergy of the presented propagation types offer a quantitative simulation of UHECRs in the universe. Finally, simulations are compared to experimental data to constrain astrophysical parameters such as the strength of extragalactic magnetic fields.



Compare the energy spectrum of HiRes[5] and Auger[6] with simulations.

References

[1] G. Sigl et al., Astropart. Phys. 28, 463-471
[2] K. Dolag et al., Journal of Cosmology and Astroparticle Physics, 2005
[3] M. Sutherland et al., Astropart. Phys. 34, 198-204
[4] K. M. Górski et al., ApJ 622, p759 (http://healpix.jpl.nasa.gov)
[5] HiRes Collaboration (2008) Physical Review Letters 100, 1011
[6] The Pierre Auger Collaboration (2010) Physics Letters B 685, 239–246.

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