Telescope Array Hot/Coldspot Study - Intermediate Scale Anisotropy

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Abstract: Indication of an energy dependent intermediate-scale anisotropy has been found in the arrival directions of ultra-high energy cosmic rays with energies above 20 EeV in the northern hemisphere, using 7 years of TA surface detector data. The previously reported "hotspot" excess for E>57 EeV is found to correspond to a deficit, or "coldspot", of events for energies 20<E<57 EeV. At the center of maximum combined significance the excess for energies E>57 EeV has a Li-Ma statistical significance of 4.62σ, and the deficit for energies 20<E<57 EeV a significance of -3.23σ. This combined feature is centered at R.A. = 146°, decl. = 47° (3° degrees from previously reported hotspot) and is 17° from the supergalactic plane. The hot/coldspot feature suggests energy dependent magnetic deflection of the isotropic background and cosmic-rays from a source.

1 Introduction

- Previous Telescope Array hotspot studies showed a 5.1 sigma Li-Ma significance excess - corresponding to a 3.4 sigma post-trial significance.
- At lower energies we find that there is a deficit of events at this location in the sky. The center of maximum combined significance is the Hot/Coldspot.
- This could be a signature of energy dependent magnetic deflection of cosmic rays.

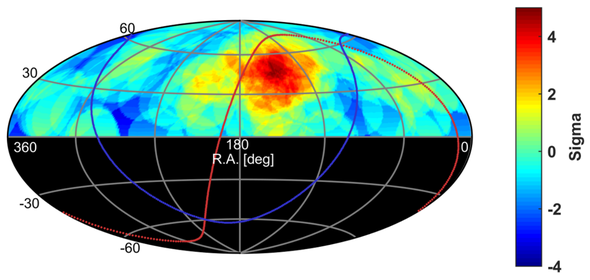

Figure 1: **Hammer-Aitoff projection of ICRC 2015 hotspot (2008 - 2015) in equatorial coordinates using 1.0x1.0 degree oversampling grid and 20° window. Solid curves indicate the galactic plane (GP) and super-galactic plane (SGP). Maximum Li-Ma significance at R.A=148.5°, Dec.=44.5° (shifted from SGP by 17°). Chance probability from isotropy 3.4σ.**

2 Data Summary

- 7 year SD data (ICRC 2015 hotspot). # of good detectors >= 4, Zenith angle < 55°, Pointing Direction Error < 10°.
- Additional cuts (for agreement with theoretical $sin\theta cos\theta$ zenith distribution): Energy >= 20 EeV, Pointing Direction Error < 5°, Boundary Distance > 1.2 km, Lateral Fit χ^2 < 10

Resulting Data: 852 events - 84 with E >= 57 EeV (ICRC 2015 set was 109) .

3 Parameter Summary

- 20 degree spherical cap bin - Used previously by Telescope Array (TA), High Resolution Fly's Eye (HiRes), and Pierre Auger Observatory (PAO).
- 57 EeV Energy Split - Used previously by TA due to PAO AGN correlation.
- 20 EeV low energy cut - Used previously for PAO energy-position correlation study. Also, a theoretical maximum of galactic iron.

4 Data Compared to Isotropic Monte Carlo

- $sin\theta cos\theta$ - theoretical Zenith distribution from detector geometry.
- Flat Azimuthul angle distribution.
- On-time simulated - sampling from 250,000 event times (E > 17.8 EeV).
- Energy interpolated from detector reconstructed HiRes spectrum.

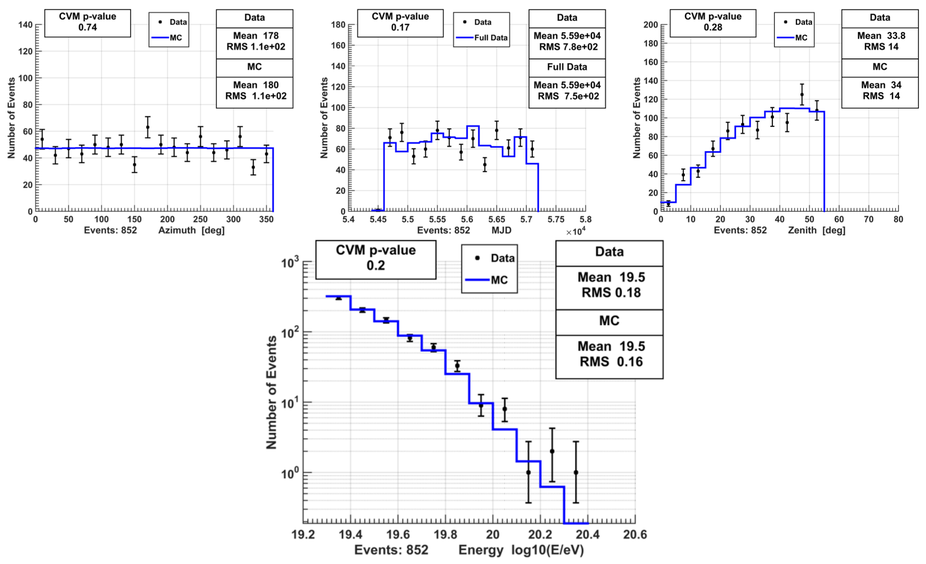

Figure 2: **Data comparisons to Isotropic MC (a) Uniform Azimuthal angle (b) Timing sampled from lower energy threshold data (c) Theoretical Zenith angle distribution ($sin\theta cos\theta$) from detector geometry (d) Reconstructed HiRes Spectrum.**

5 Two Energy Range Li-Ma Statistics

- N_{bg} calculated from 2 million MC events E >= 20 EeV normalized to the # of data events.
- E >= 57 EeV were 144,486 MC events.
- 1.0x1.0 degree oversampling. 20° window.
- Oversampling grid extends down to 0 declination.

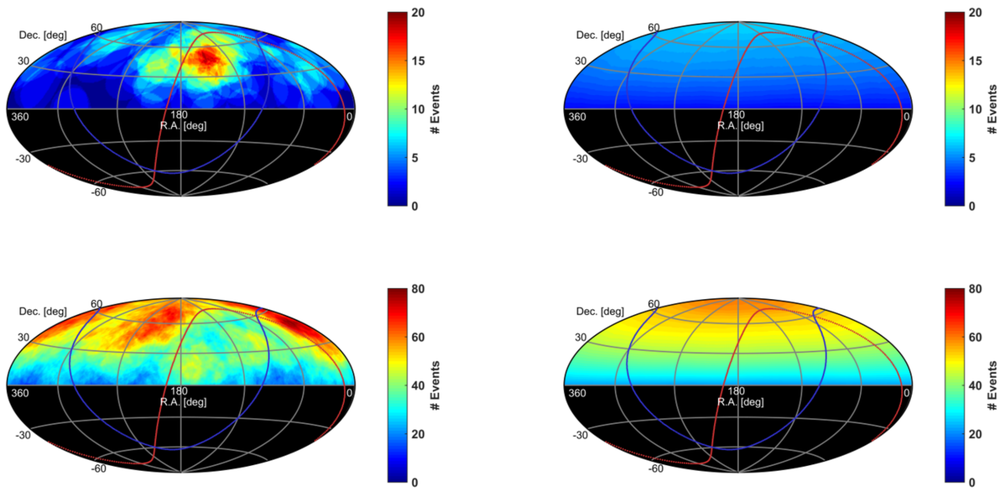

Figure 3: **(a) Data N_{on} E >= 57 EeV (b) MC N_{bg} background E >= 57 (c) Data N_{on} 20 <= E < 57 EeV (d) MC N_{bg} background 20 <= E < 57 EeV**

6 Hot/Coldspot

- Hot/Coldspot is max. significance (preliminary): 146° R.A. 47° Decl.
- 3 degrees from hotspot.
- 17 degrees from supergalactic plane

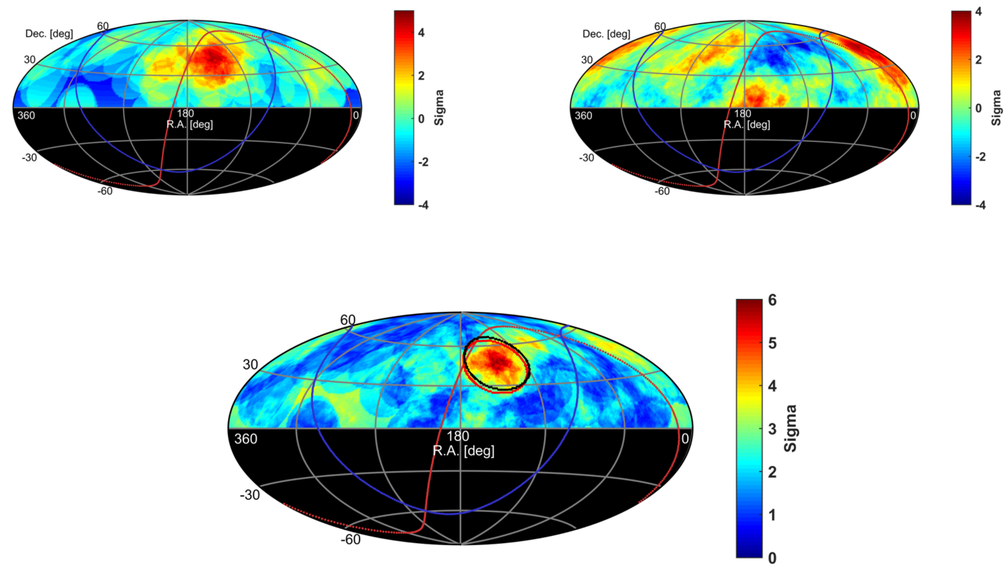

Figure 4: **(a) High energy hotspot excess using current tighter cuts (b) Lower energy coldspot deficit. (c) Combined significance from multiplying probabilities. Red circle is the ICRC 2015 hotspot location and black circle is the hot/coldspot. Maximum has excess > 4.62σ and deficit < -3.23σ.**

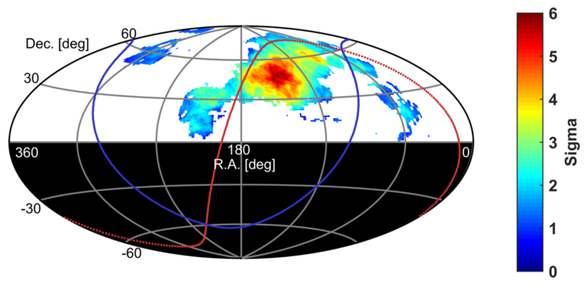

Figure 5: **Locations on the sky where there is a deficit of lower energy events and excess of higher energy events. Maximum combined Li-Ma 5.97σ.**

7 Energy Spectrum

- Data fits reconstructed published spectrum well. As shown in Figure 2c.
- Data inside hot/cold spot does not fit spectrum. Unless hot and cold energy ranges are normalized separately.
- Power laws are consistent, flux is not. Indication of flux enhancement of post-GZK spectrum (currently low statistics).

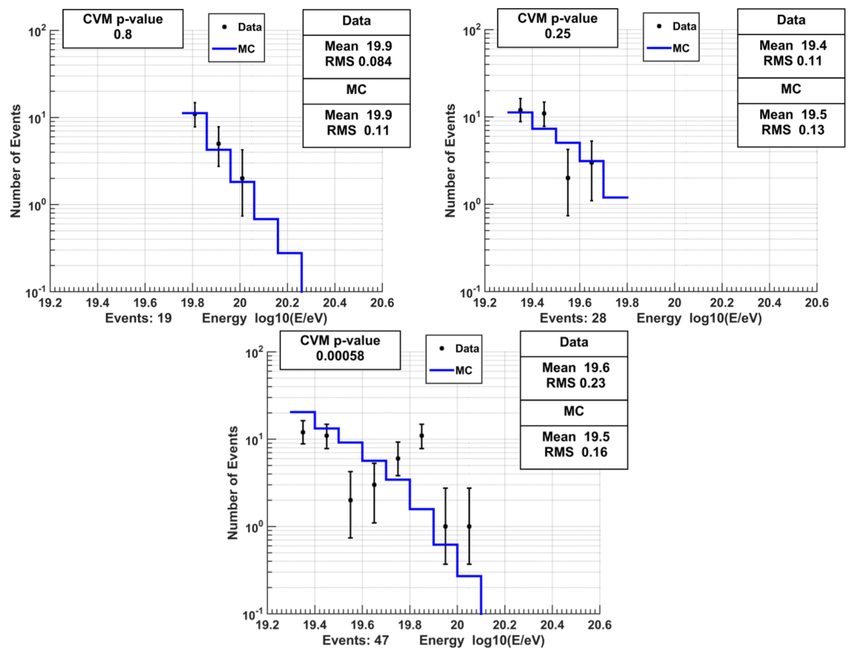

Figure 6: **(a) Inside Hotspot - E >= 57 EeV fits MC well (normalized to 19 events). (b) Inside Coldspot - 20 <= E < 57 EeV fits MC well (normalized to 28 events) (c) Data Vs MC comparison: energy spectrum inside hot/cold spot (normalized to data/MC outside spot) 3.44σ different.**

8 Conclusion

- The previously reported hotspot appears correlated with a deficit of low energy events. This is suggestive of magnetic deflection.
- Hot/Cold spot energy distribution does not appear to be a systematic effect of shifting events from lower to higher energy. It is consistent with flux enhancement of the post-GZK spectrum
- Here is presented pre-trial local Li-Ma results only. Further statistical analysis to account for global fluctuations is in progress.

Full author list and Acknowledgements: http://www.telescopearray.org/images/papers/ICRC2015-authorlist.pdf

References

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