Cosmic Ray anisotropy with HAWC

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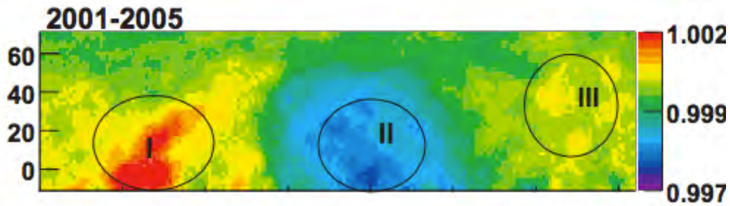
HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

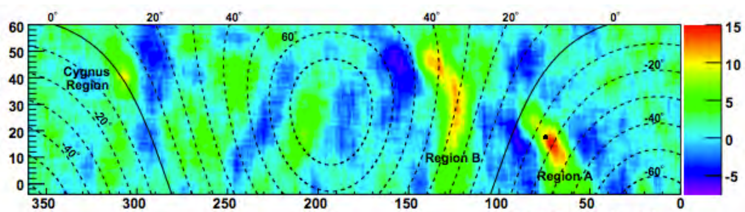
Motivation

Observations

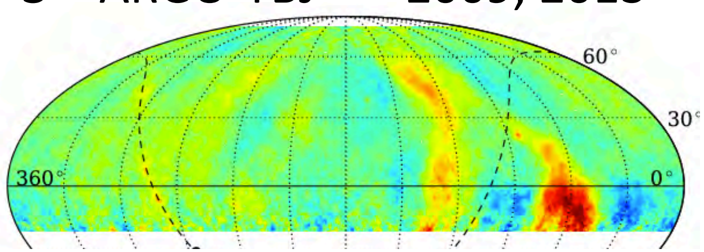
1 – Tibet-ASγ 2005 (large only)



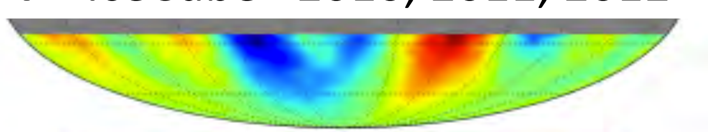
2 – Milagro 2008, 2009



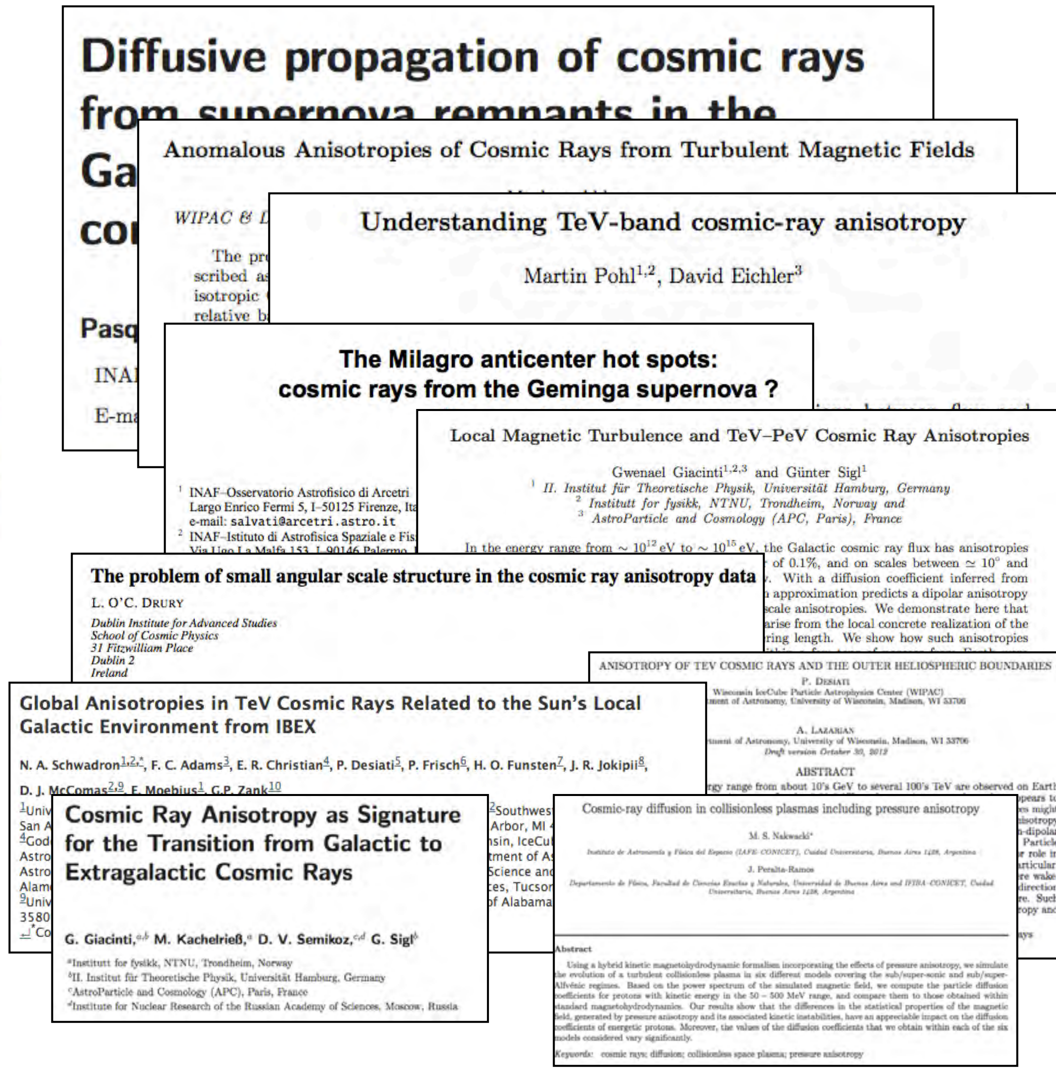
3 – ARGO-YBJ 2009, 2013



4 – IceCube 2010, 2011, 2012



Theory

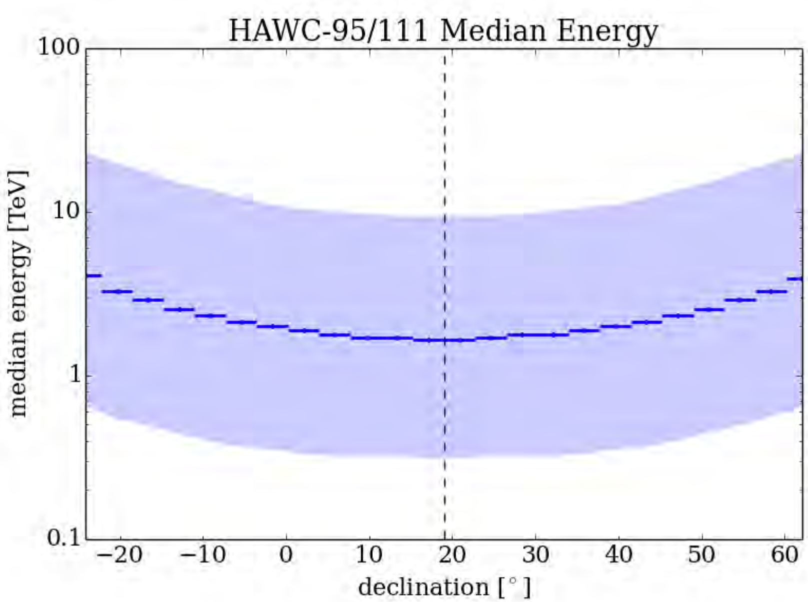


Data Set

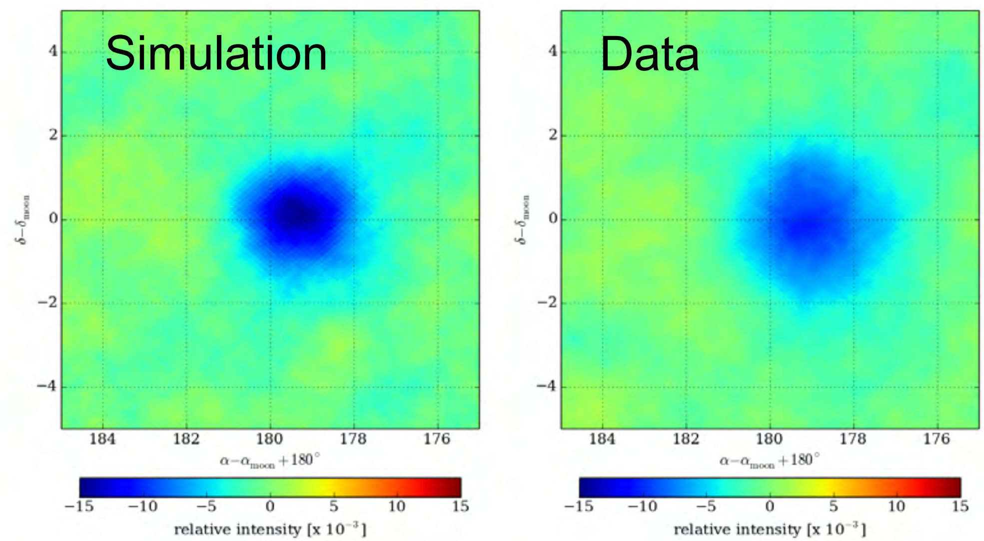
Using HAWC-95 and HAWC-111

June 2013 – February 2014
114 full sidereal days

50 billion events,
1.2° median ang. res.,
1.8 TeV median energy



HAWC-111 Moon Shadow



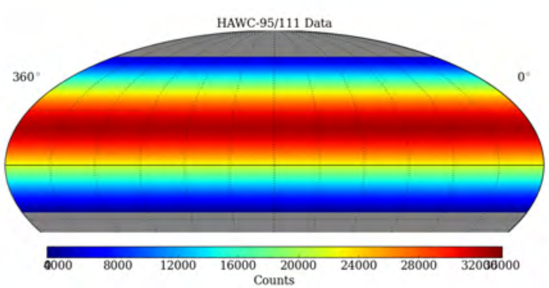
Analysis Technique

HEALpix (K.M. Gorski et al., Astrophys. J., 2005, 622, 759)
Equal-area binning of the sphere

"Direct Integration" (R.Atkins et al., Astrophys. J., 2003, 595, 803.)
Method to estimate background using the data themselves

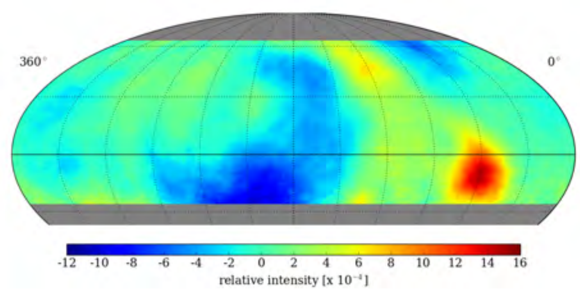
PolSpice (I. Szapudi et al. 2001, Astrophys. J., 548, L115)
Software to compute power spectrum with partial sky coverage

HEALpix



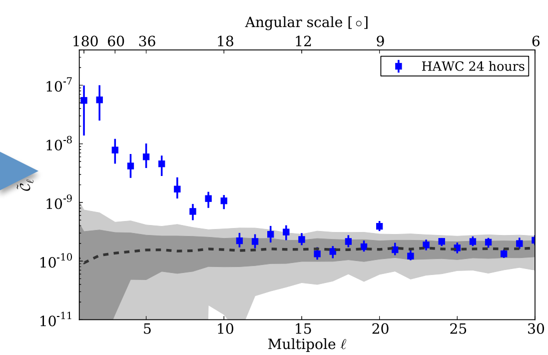
Binned data

"Direct integration"



Data & reference map
→ relative intensity

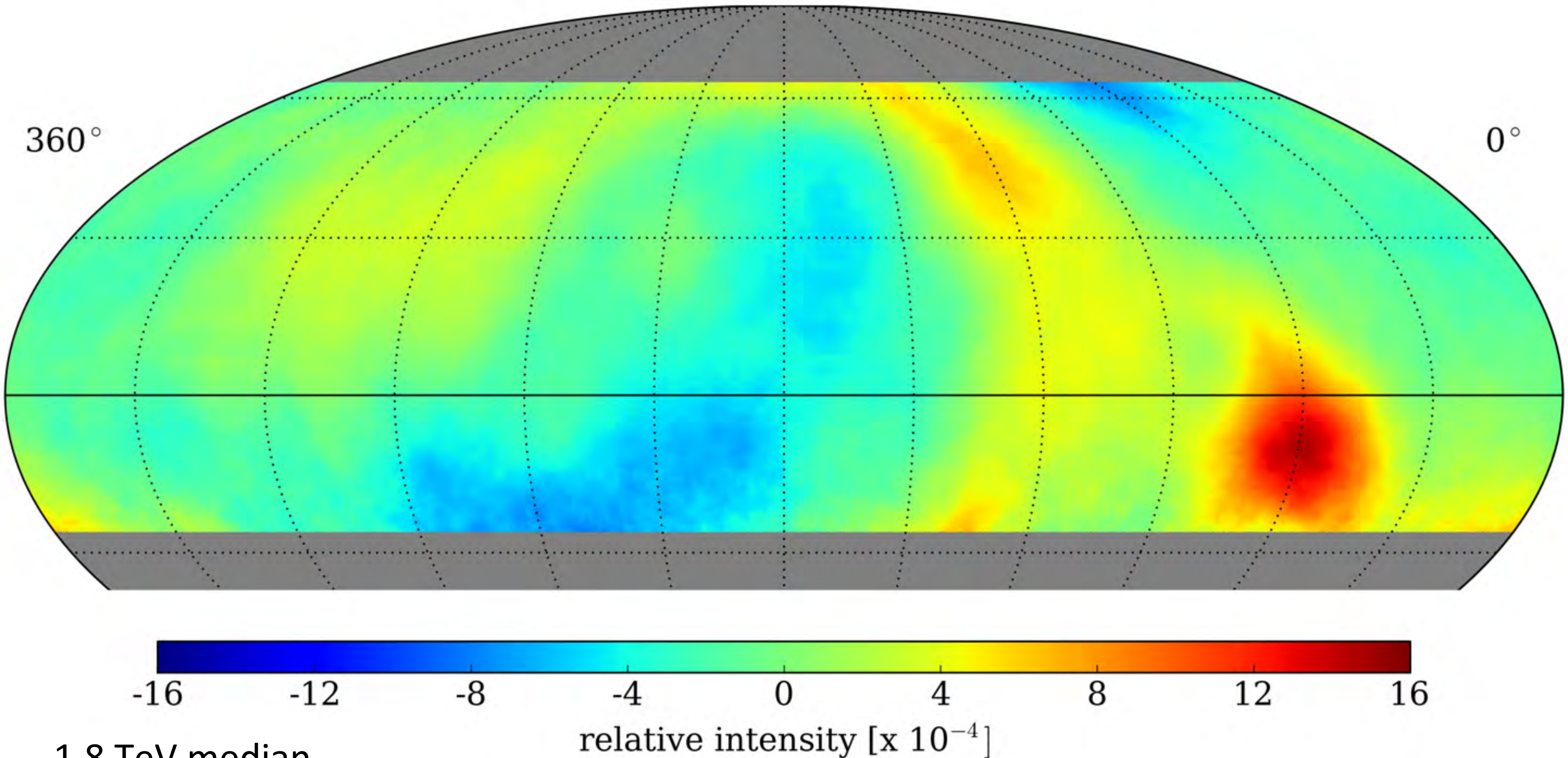
PolSpice



Power Spectrum

Large Scale Anisotropy

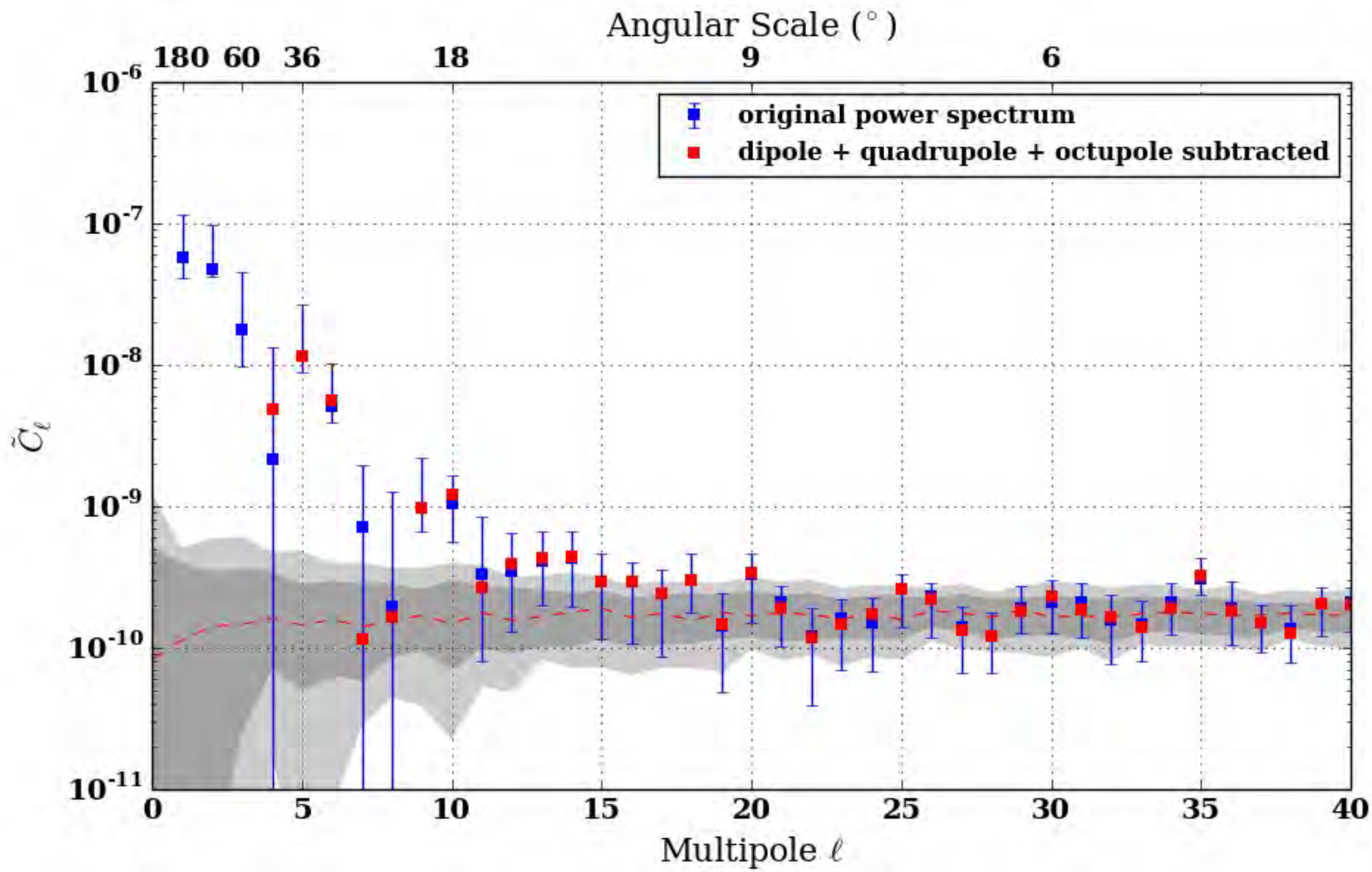
Shows largest accessible features (24 hr background estimation)
Smoothed 10°
Dipole deficit is consistent with previous observations (1 x 10^{-3} @ ra=200°, dec)
Brightest region sits in region of general excess (ra=60°, dec=-10°)



1.8 TeV median

Power Spectrum

Power spectrum of Large-Scale (24h bkg est). Strong dipole + quadrupole



Power Spectrum

Local Magnetic Turbulence and PeV-TeV Cosmic-Ray Anisotropies
G. Giacinti and G. Sigl, Phys. Rev. Lett. 109, 071101 (2012) arXiv:1111.2536

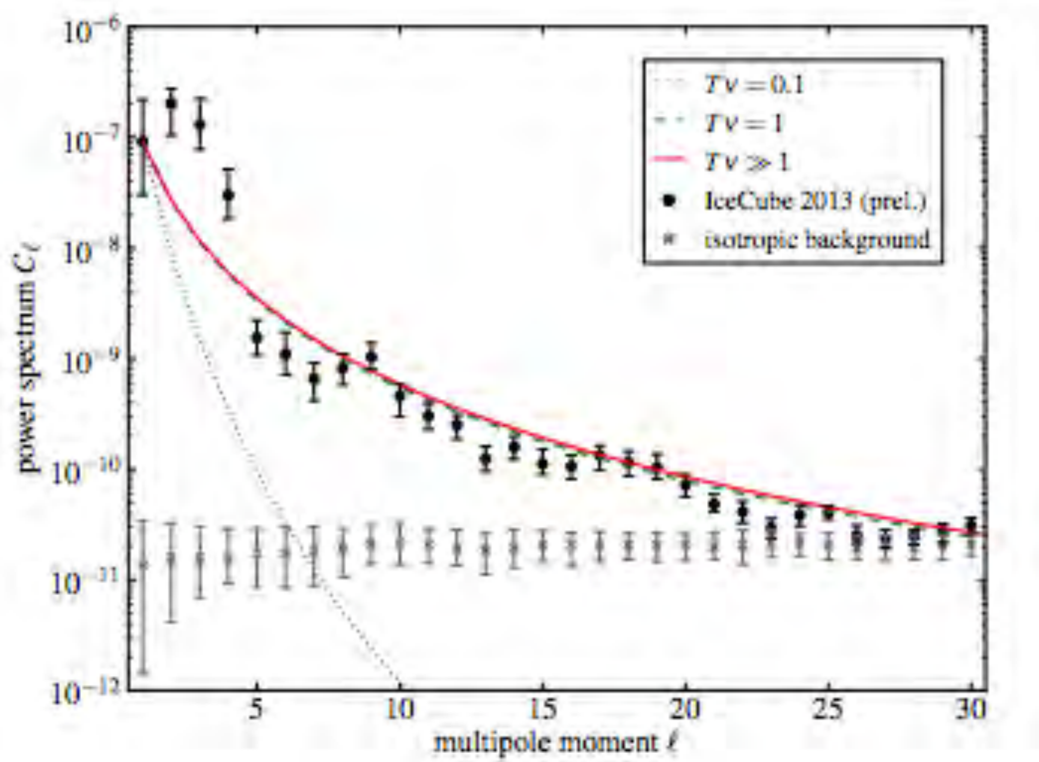
Anomalous Anisotropies of Cosmic Rays from Turbulent Magnetic Fields
M. Ahlers, Phys. Rev. Lett 112, 021101 (2014) arXiv:1310.5712

Energy-dependent small-scale

Calculation is best tied to strength of dipole

HAWC ≠ 1 full year

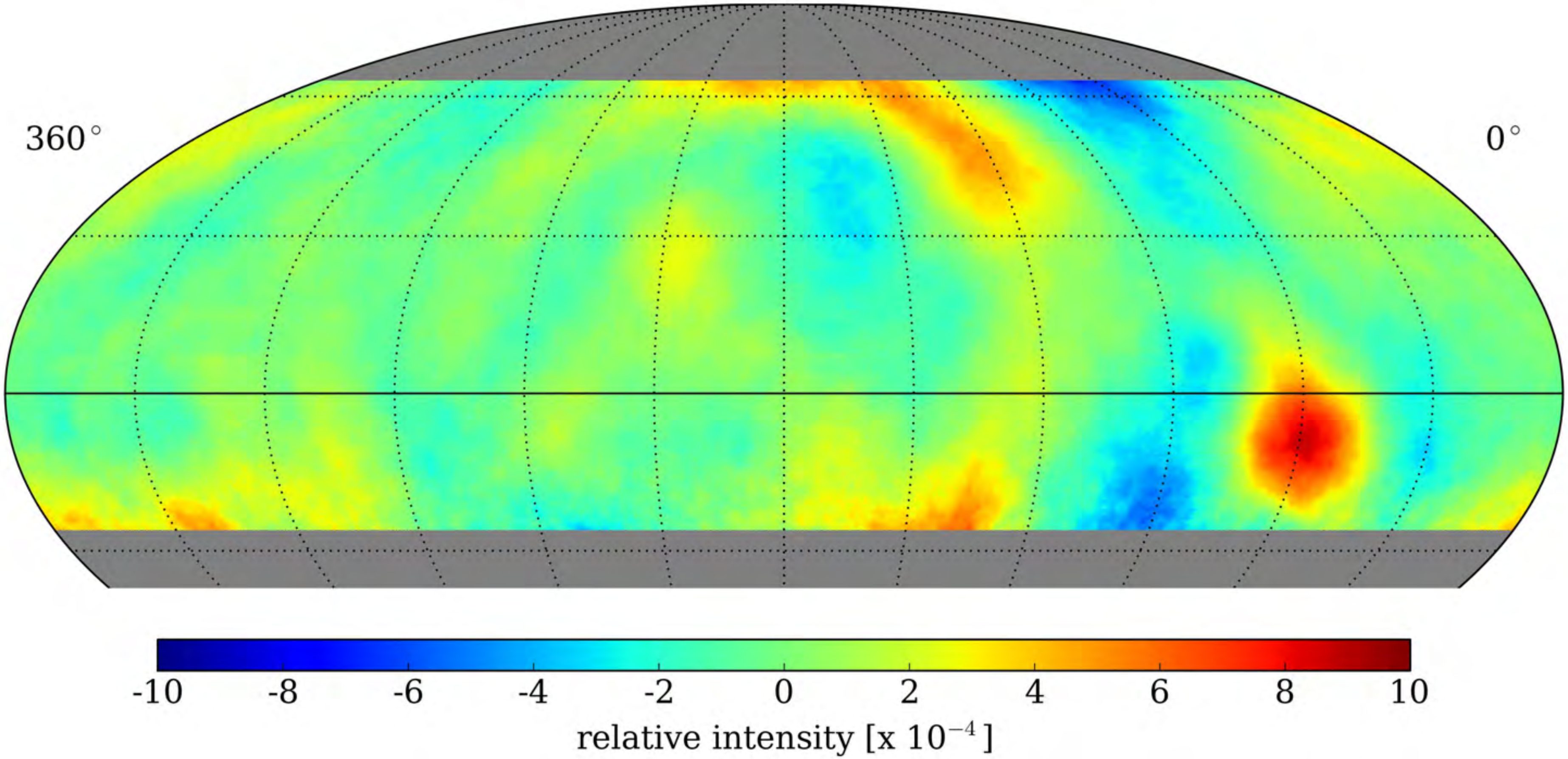
Solar dipole contamination



Small Scale Anisotropy

Fit dipole+quadrupole to map for 24-hr background estimation

Subtracted fit relative intensity from 24-hr map



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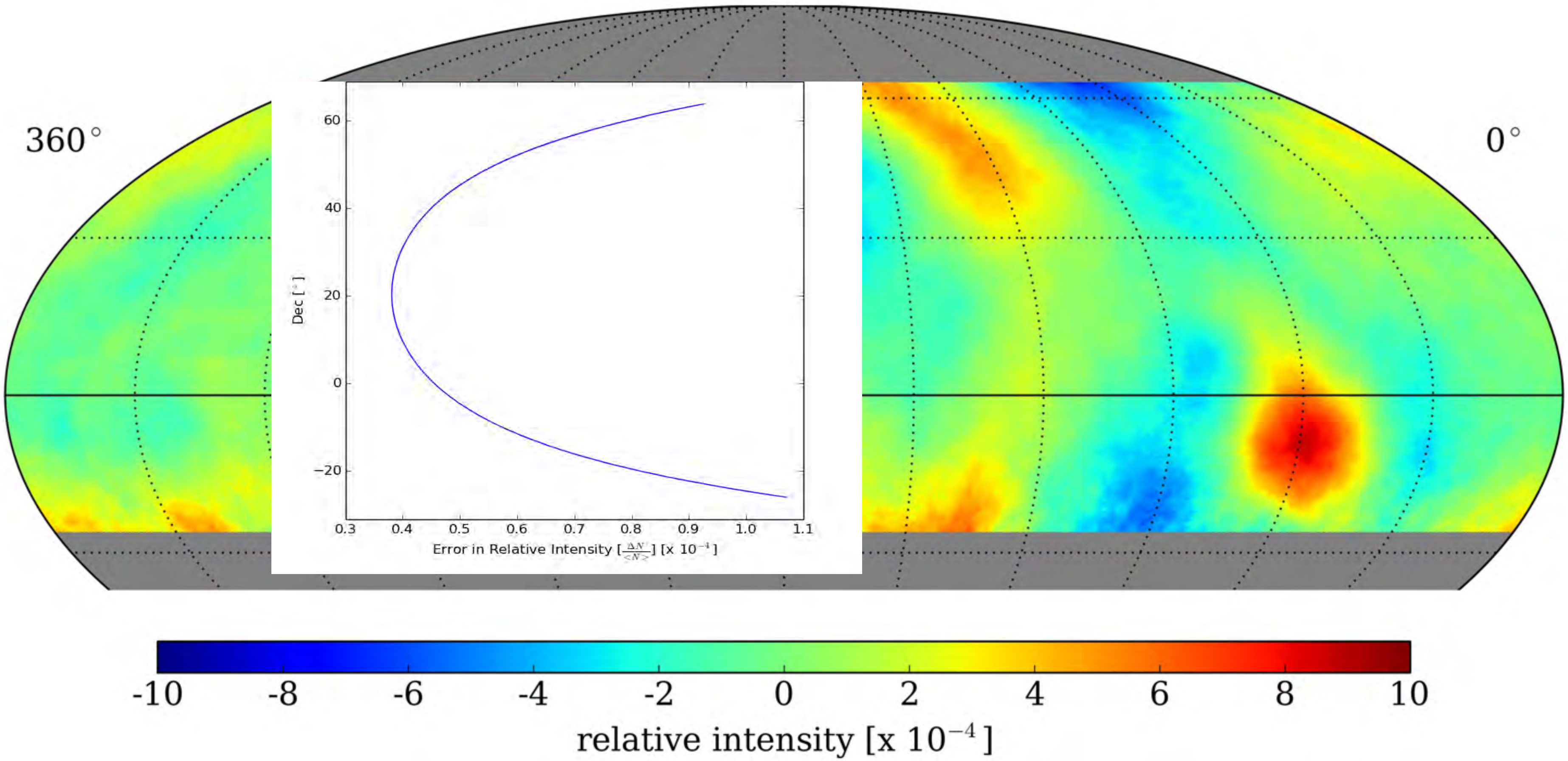

Small Scale Anisotropy

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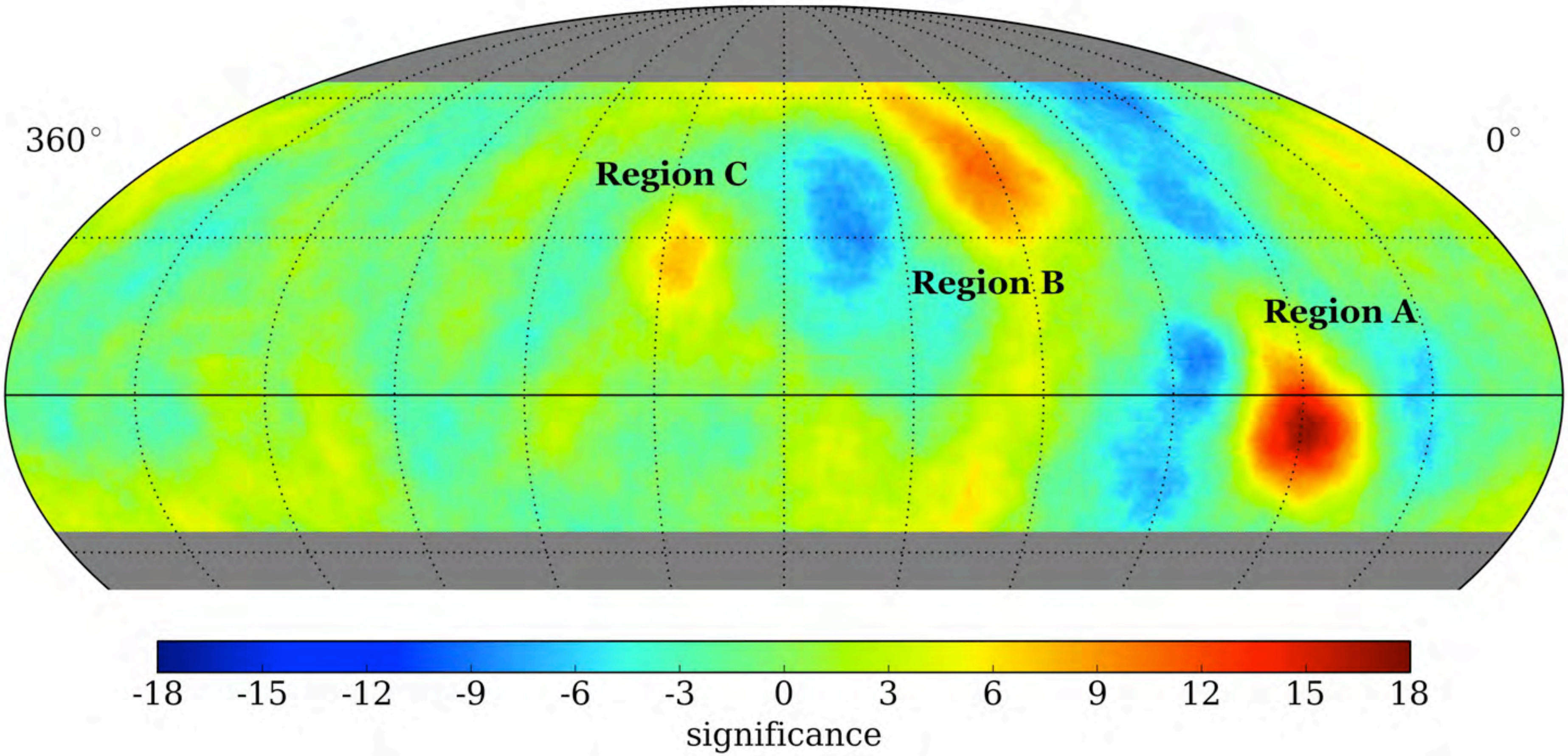
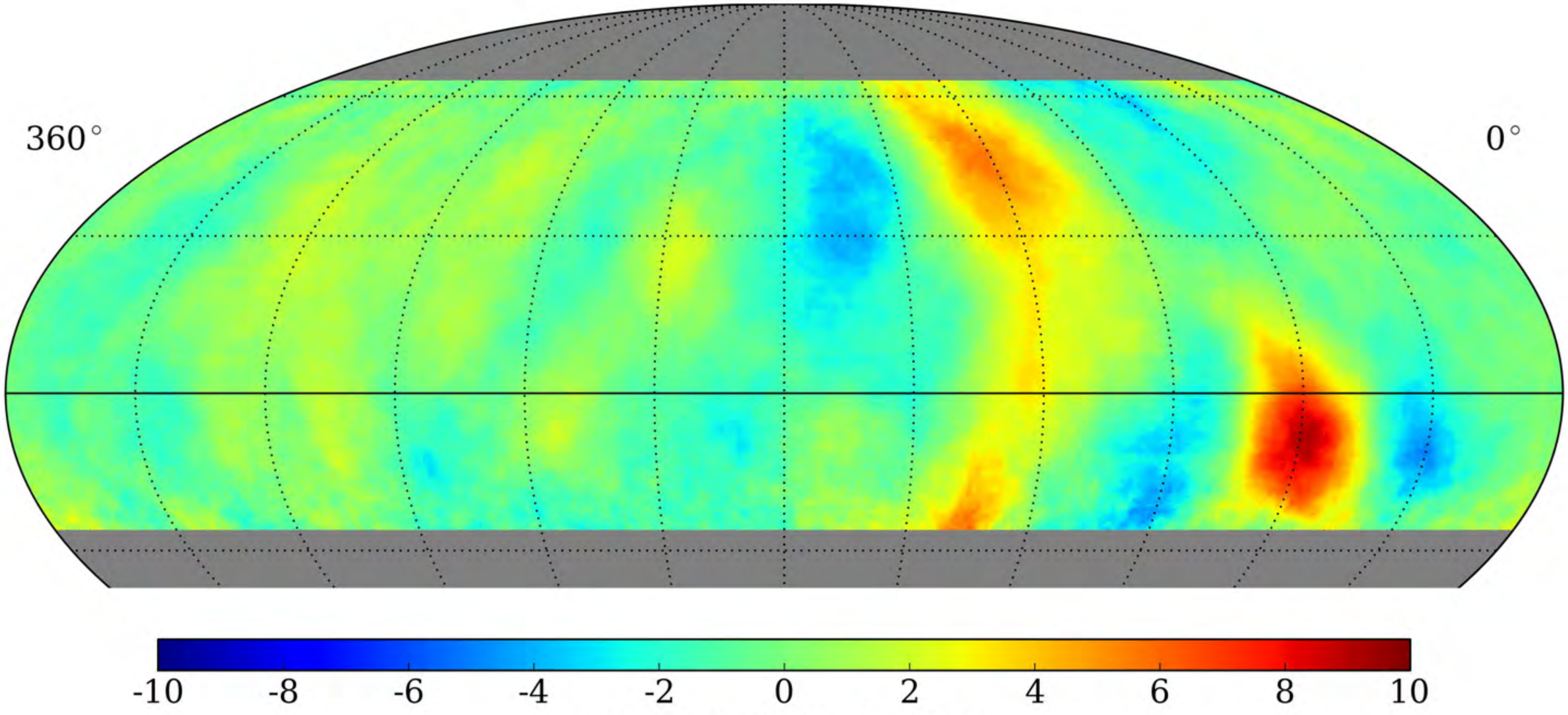


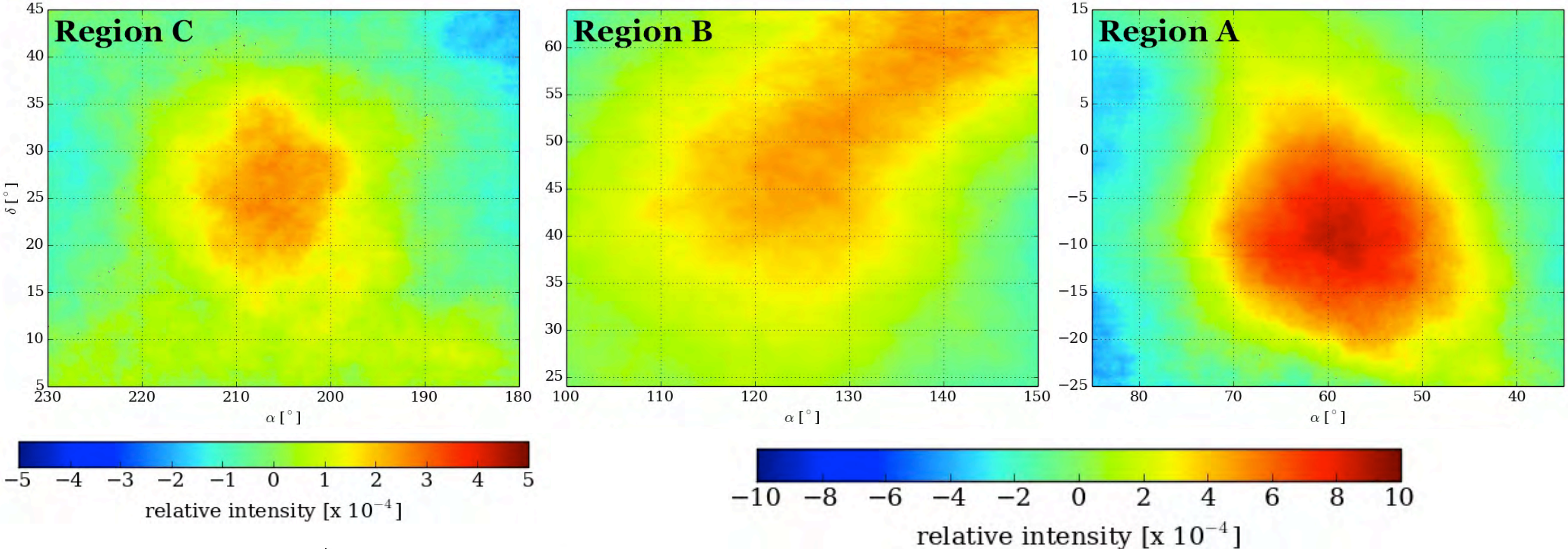
Small Scale Anisotropy

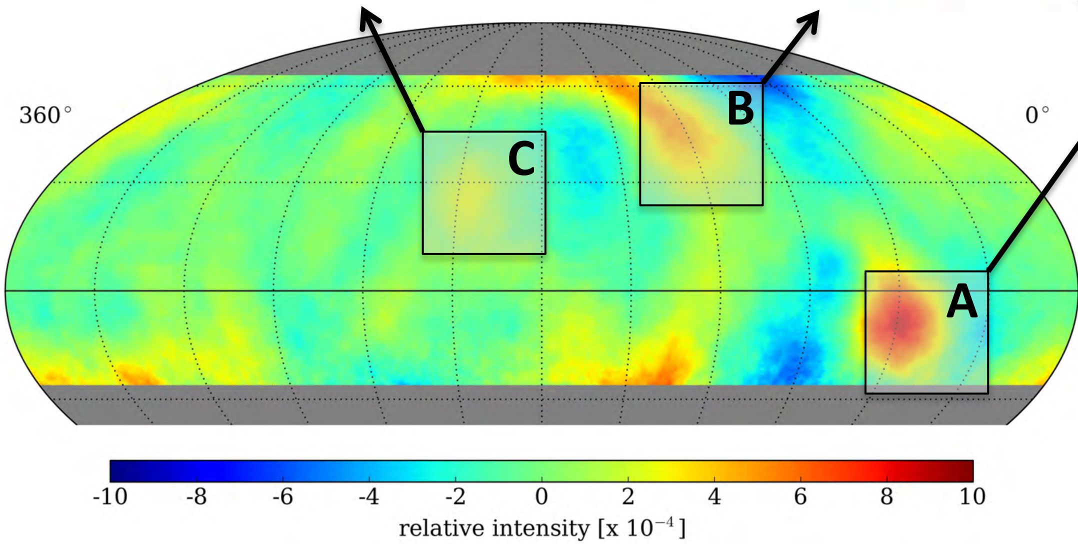
4 hr background estimation
Shows features ~ 60°. Background fits to any features larger than that
Regions A, B and C are the only statistically significant excesses (>5σ post-trials)



1.8 TeV median

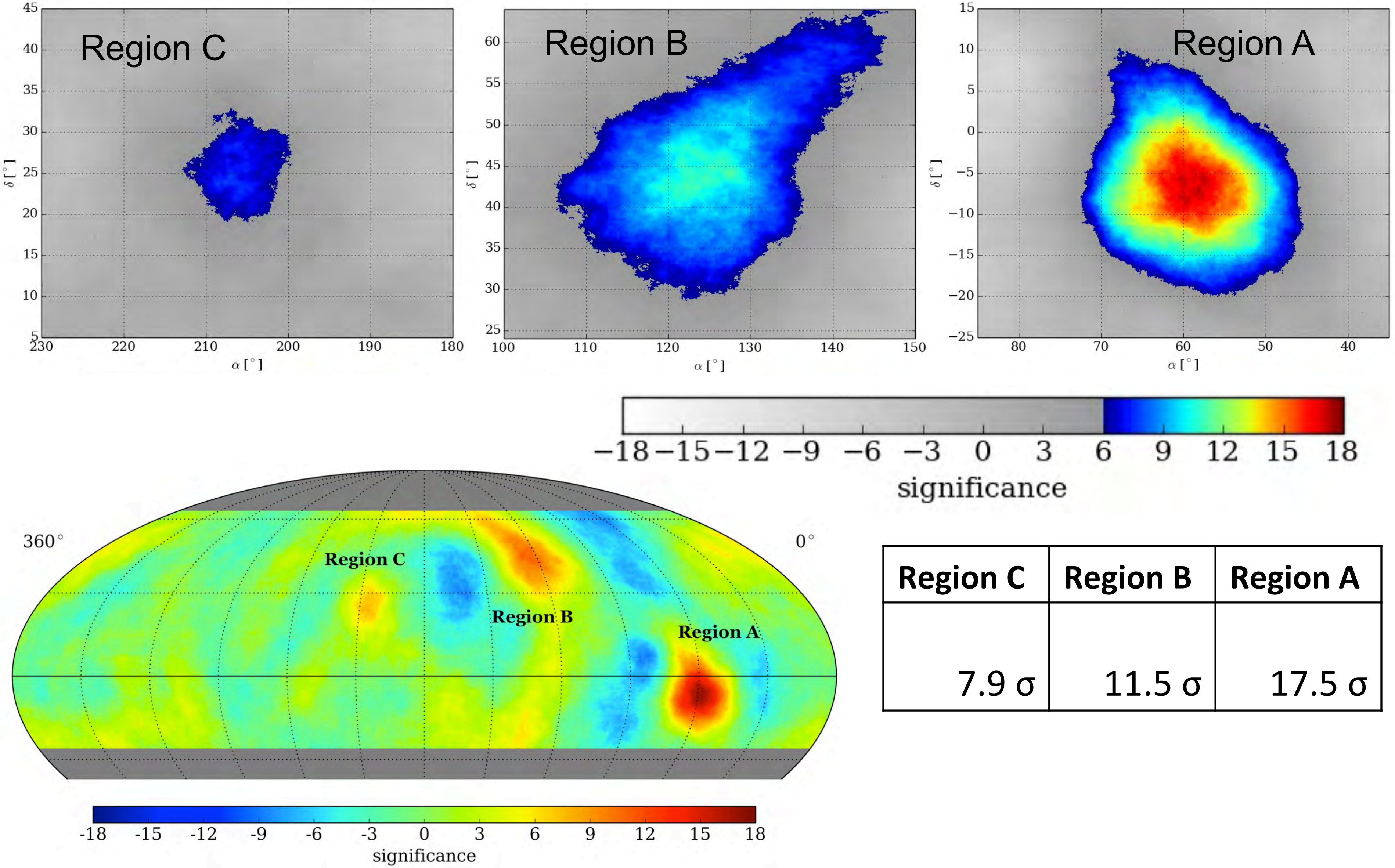
Small Scale Anisotropy





Region C	Region B	Region A
2.4×10^{-4}	6.0×10^{-4}	9.0×10^{-4}

Small Scale Anisotropy



Region C	Region B	Region A
7.9 σ	11.5 σ	17.5 σ

Region A

Explanations for localized excess?

Local interstellar magnetic fields

M. Amenomori et al., Astrophys. Space Sci. Trans. 6, 49 (2010).

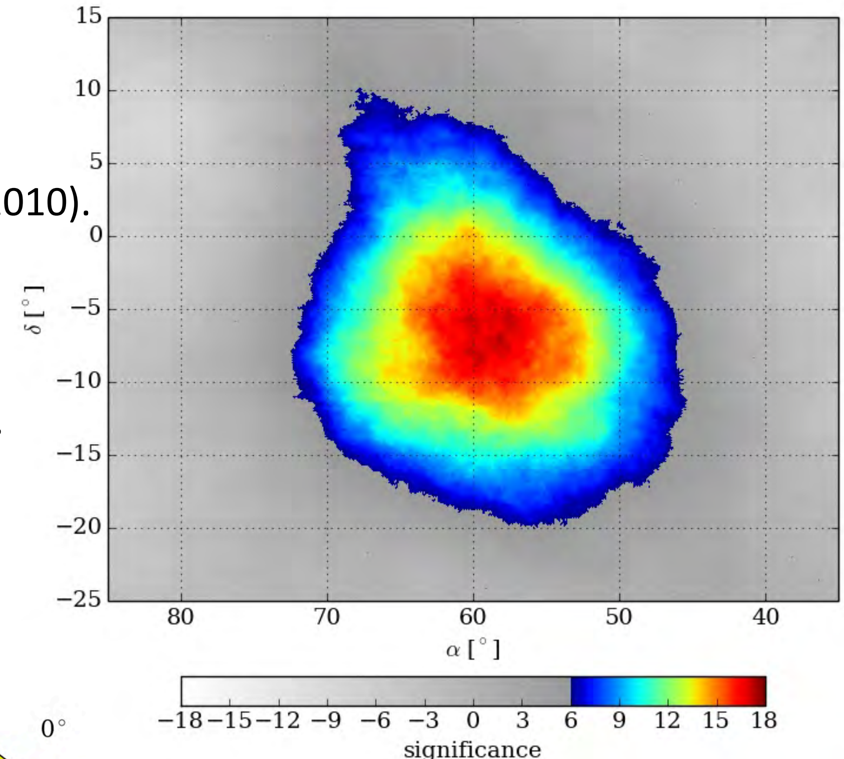
A. Lazarian and P. Desiati, Astrophys. J. 722, 188 (2010).

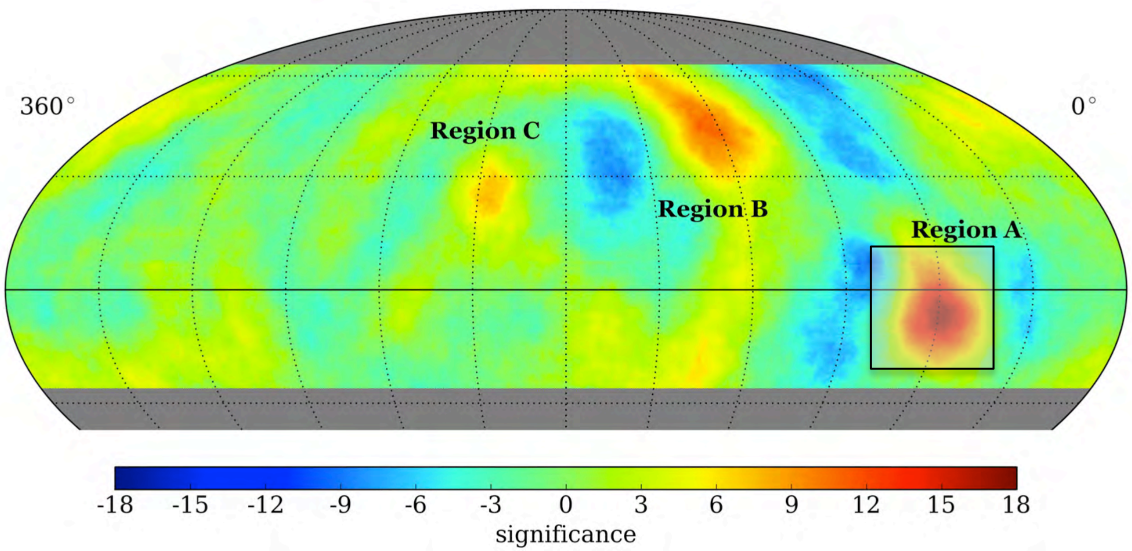
Magnetic bottle

L. Drury and F. Aharonian, Astropart. Phys. 29, 420(2008).

Dark Matter interpretation

J. Harding arXiv:1307.6537





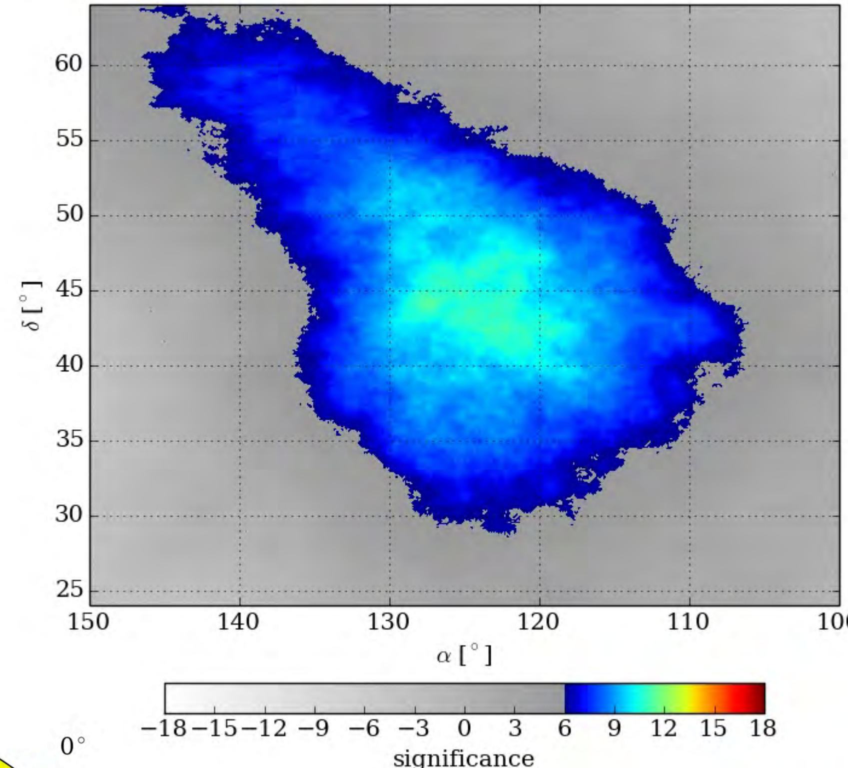
Far south for Milagro and ARGO
(35°N and 30°N latitude)

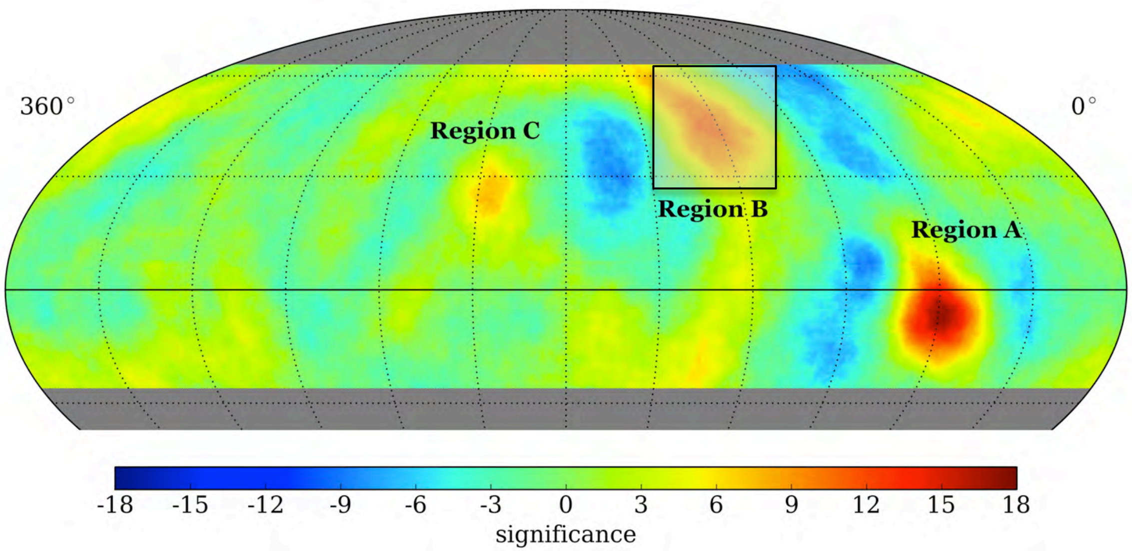
Sits on large-scale maximum

$(8.9 \pm 0.6) \times 10^{-4}$ excess

Milagro saw cutoff at ~ 4 – 20 TeV

Region B



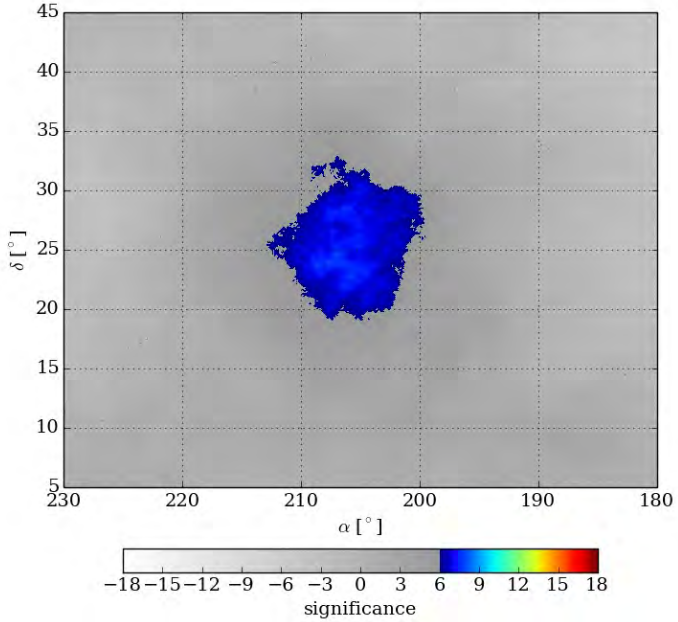


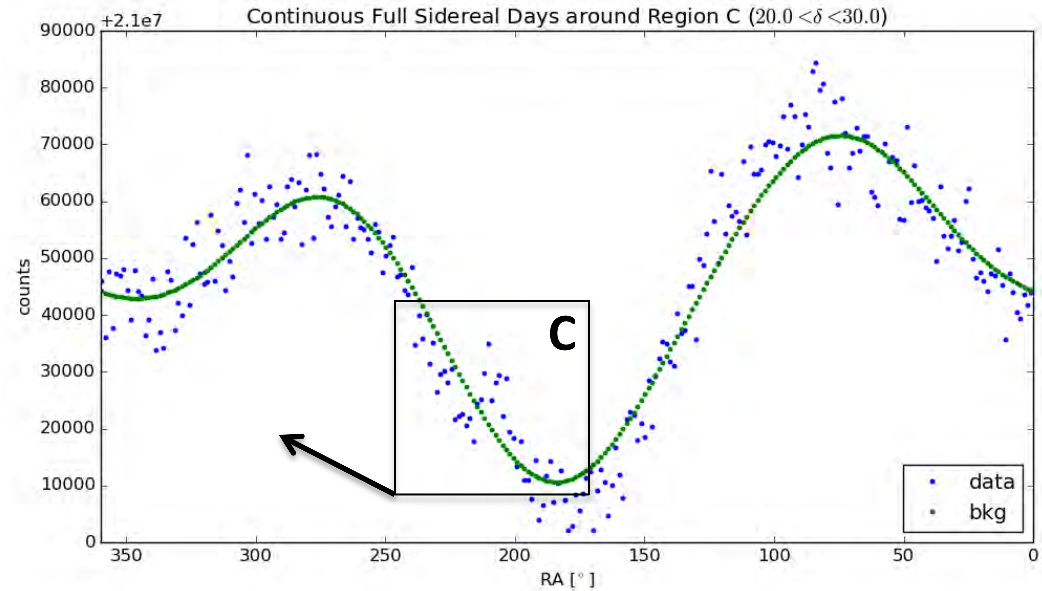
Extends full FOV in declination
Sits at edge of large-scale maximum

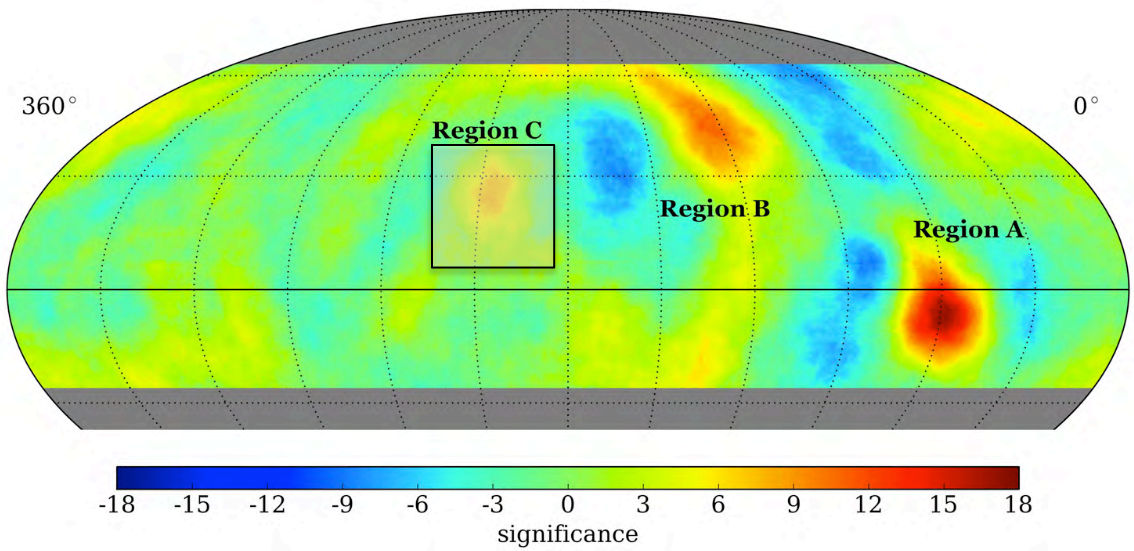
(5.3 ± 0.6) x 10^{-4} excess

Milagro: same spectrum as bkg

Region C







Consistent with excess seen in ARGO
Not present in Milagro

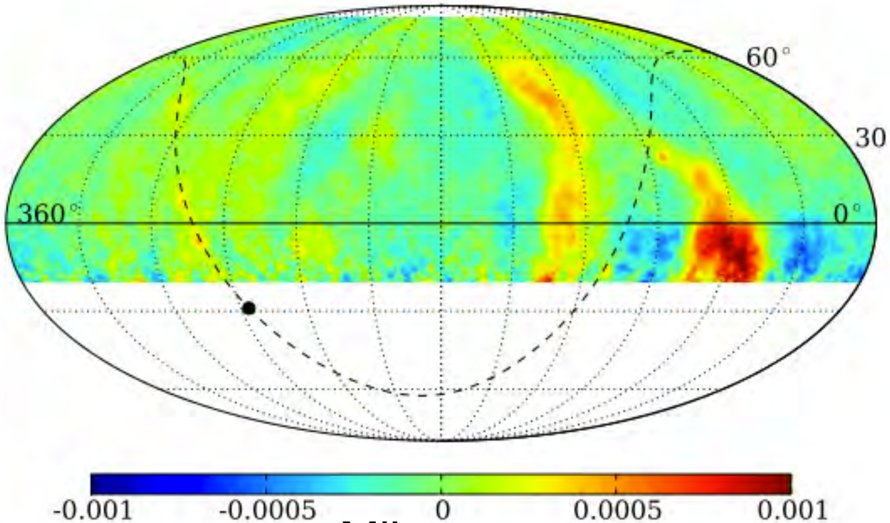
Sits in large-scale minimum

$(2.8 \pm 0.4) \times 10^{-4}$ rel. int.

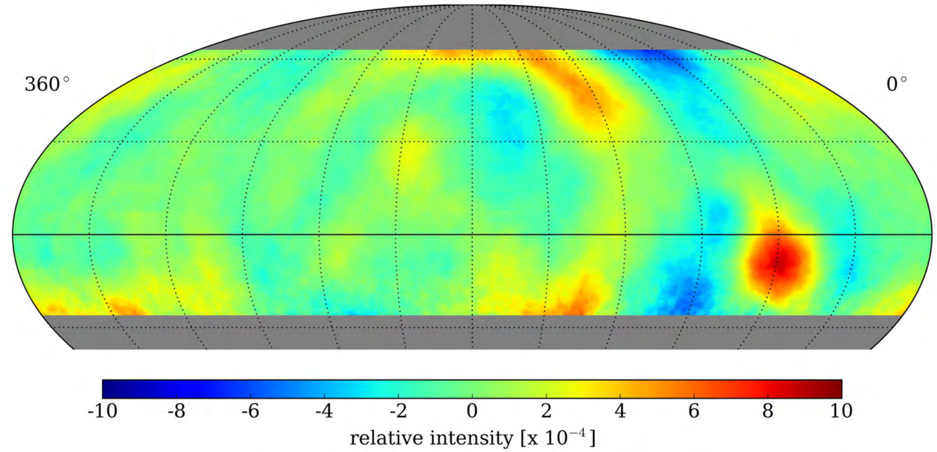
7.9σ pre-trials (> 5σ post-trials)

Comparisons

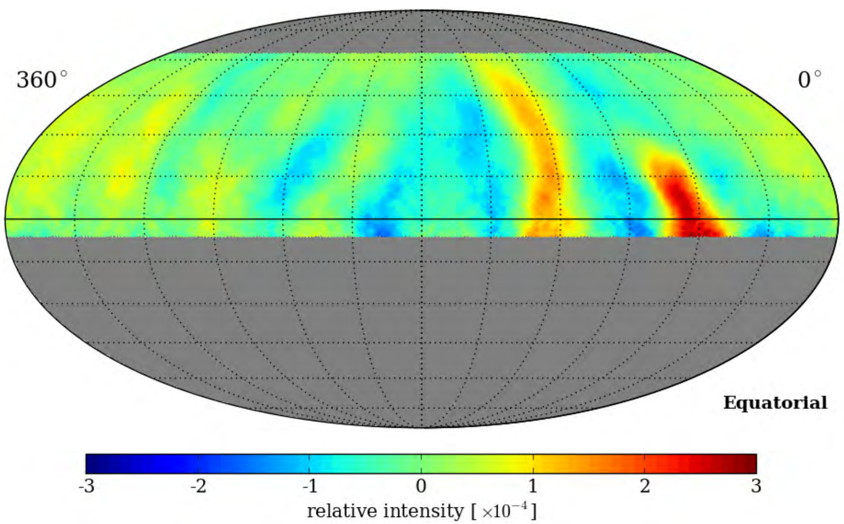
ARGO



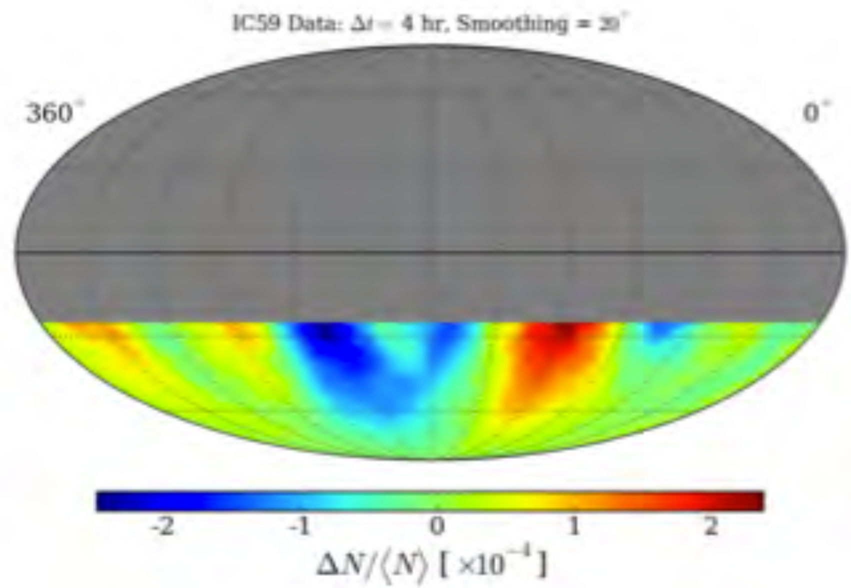
HAWC



Milagro



IceCube



Conclusions

HAWC detected 3 regions of cosmic-ray excess
- 2 previously discovered (Region A & B)
- 1 newly discovered (Region C)

Consistency with ARGO observations

Energy-dependent study is promising and getting better