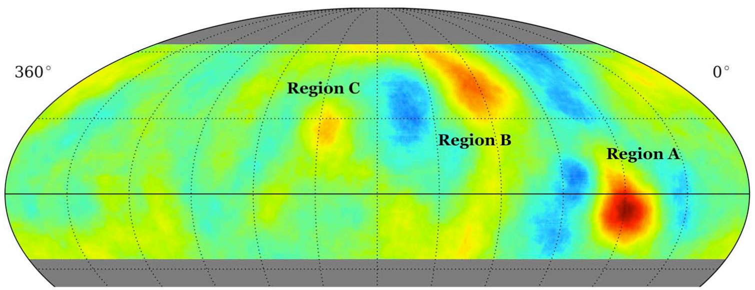
Cosmic-ray anisotropy with the HAWC Observatory

Daniel Fiorino (Wisconsin-Madison)
for the HAWC Collaboration

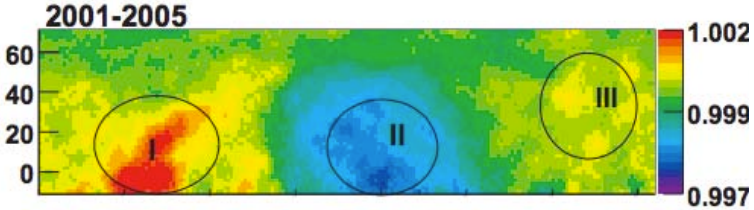


High Altitude Water Cherenkov
Gamma-Ray Observatory

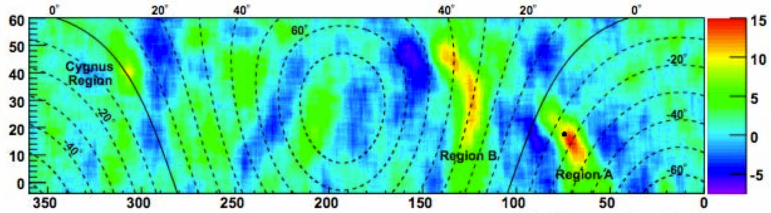
Motivation

Experiment 1 sky map / year

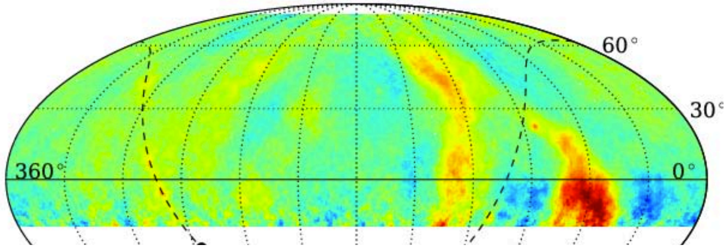
1 – Tibet-Asγ 2005 (large only)



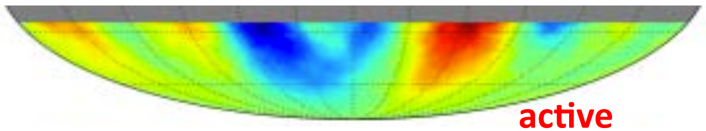
2 – Milagro 2008, 2009



3 – ARGO-YBJ 2009, 2013

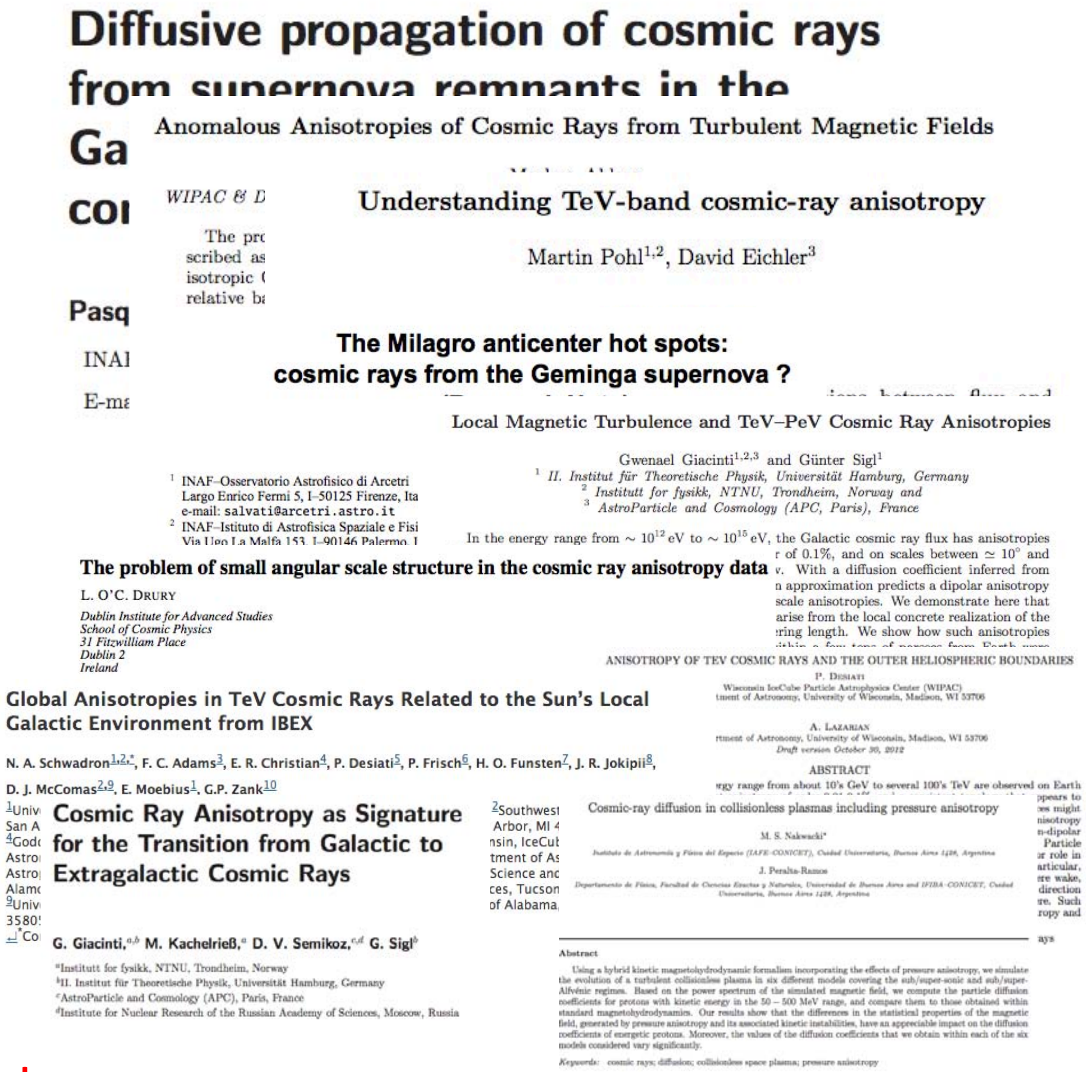


4 – IceCube 2010, 2011, 2012



active
Southern hemisphere

Theory 2 papers / month

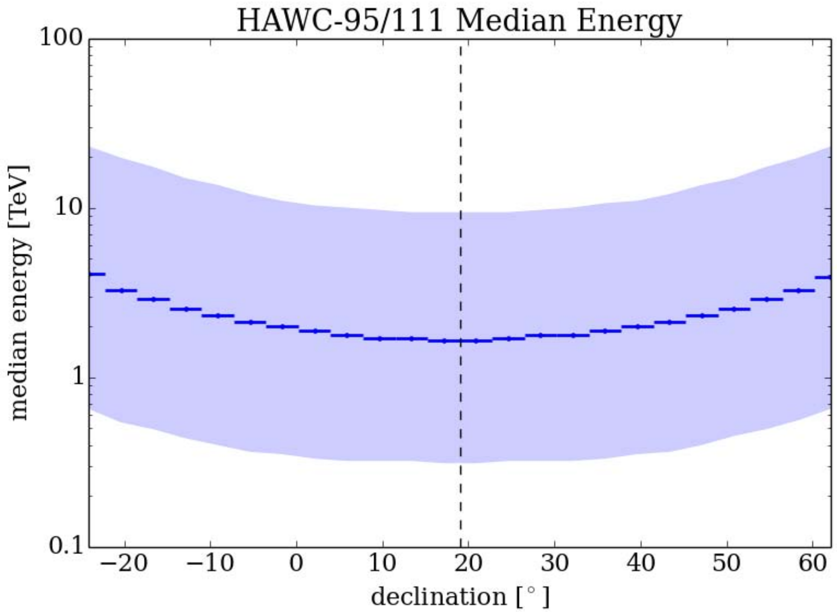


Data Set

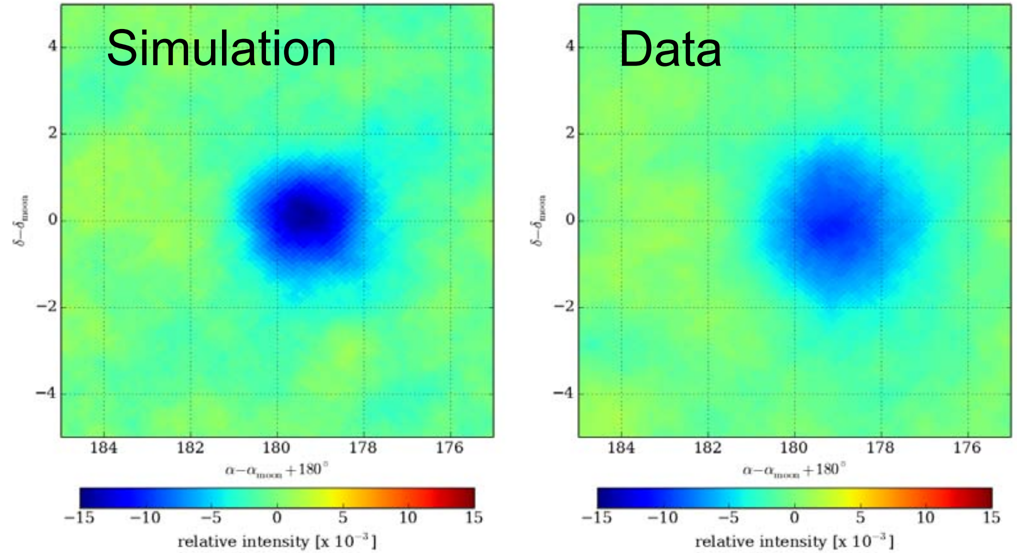
Using HAWC-95 and HAWC-111

June 2013 – February 2014
110 full sidereal days

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

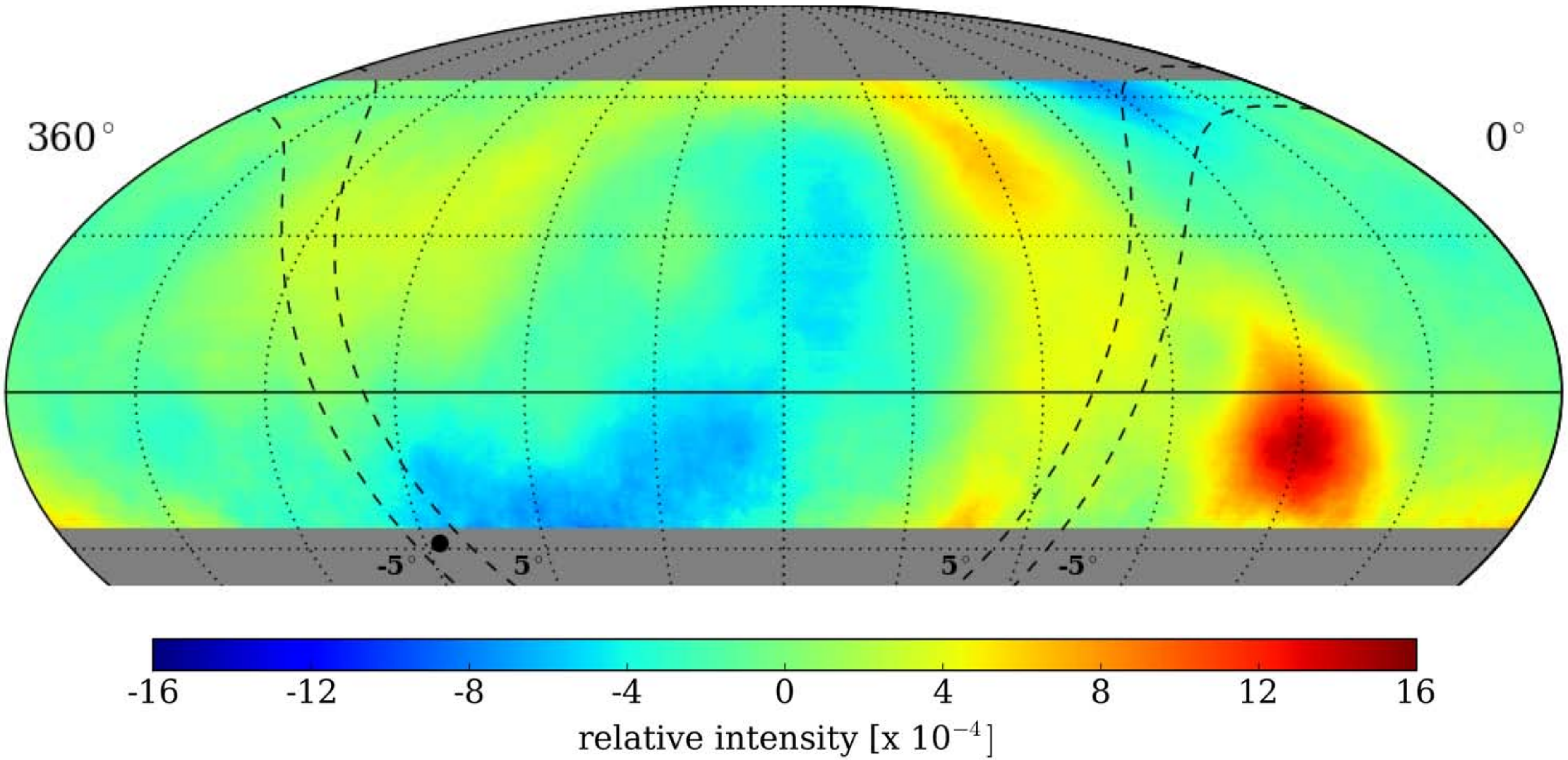


HAWC-111 Moon Shadow



Full Sky Map

Shows features of all angular scales (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

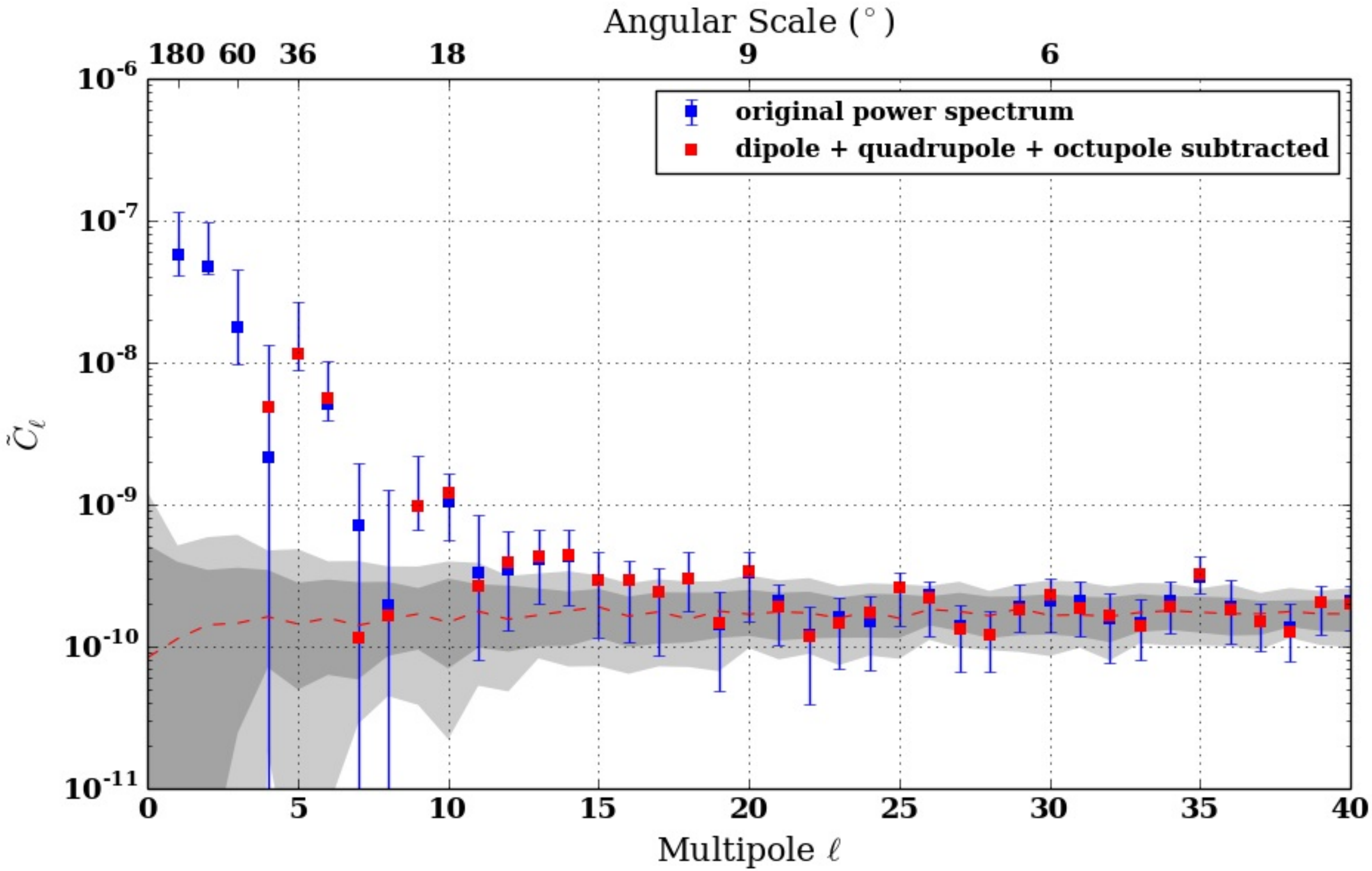
HAWC ≠ 1 full year

Power Spectrum of CR Anisotropy

Original (24h bkg est)

Subtract multipole fit from 24hr map

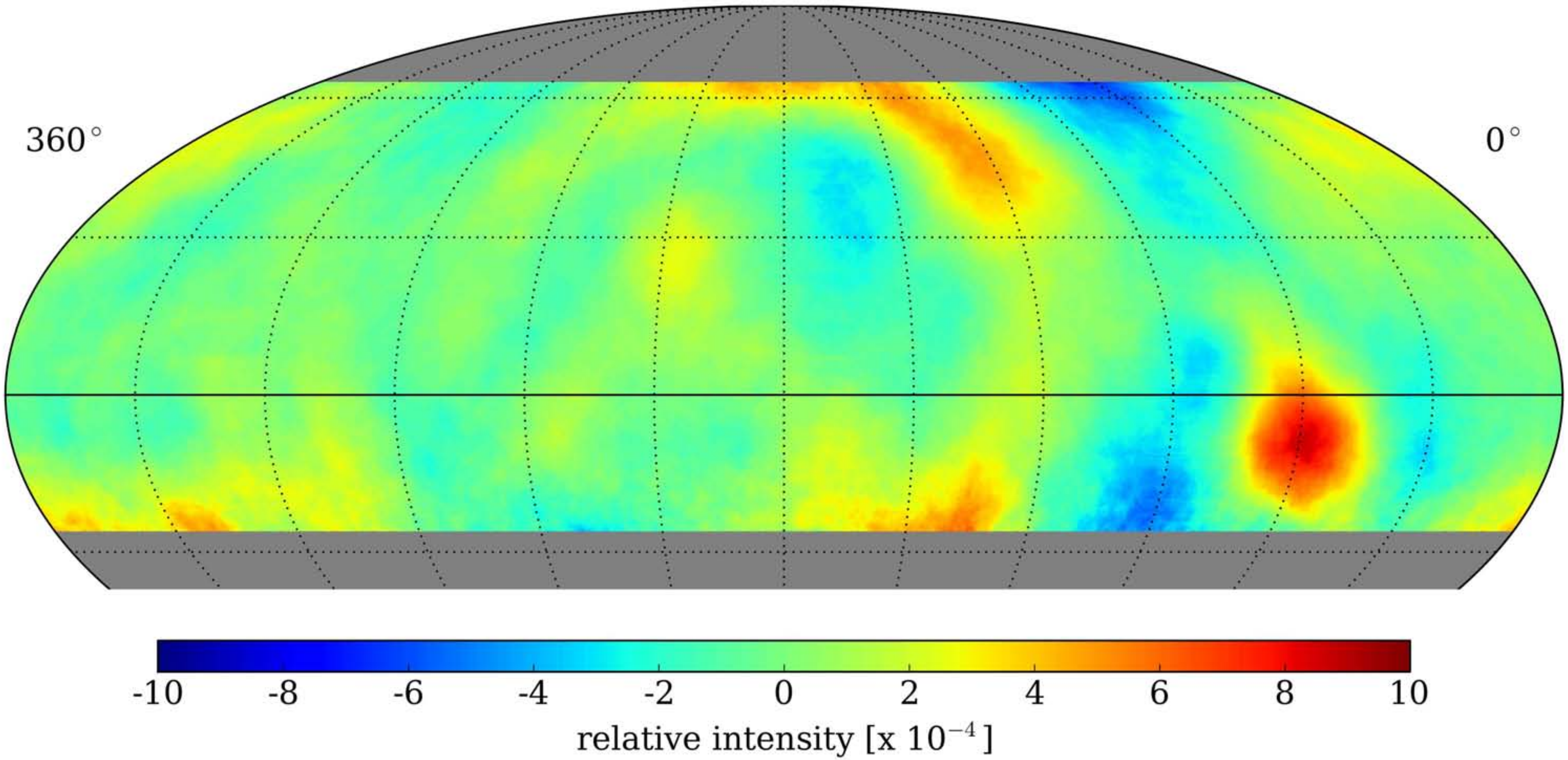
For details of the analysis see:
"Observation of Anisotropy in the Arrival Directions of Galactic Cosmic Rays at Multiple Angular Scales with IceCube"
http://arxiv.org/pdf/1105.2326.pdf (section 3.3)



Small-Scale Anisotropy

Fit dipole+quadrupole+octupole to map for 24-hr background estimation
Subtracted fit relative intensity from 24-hr map

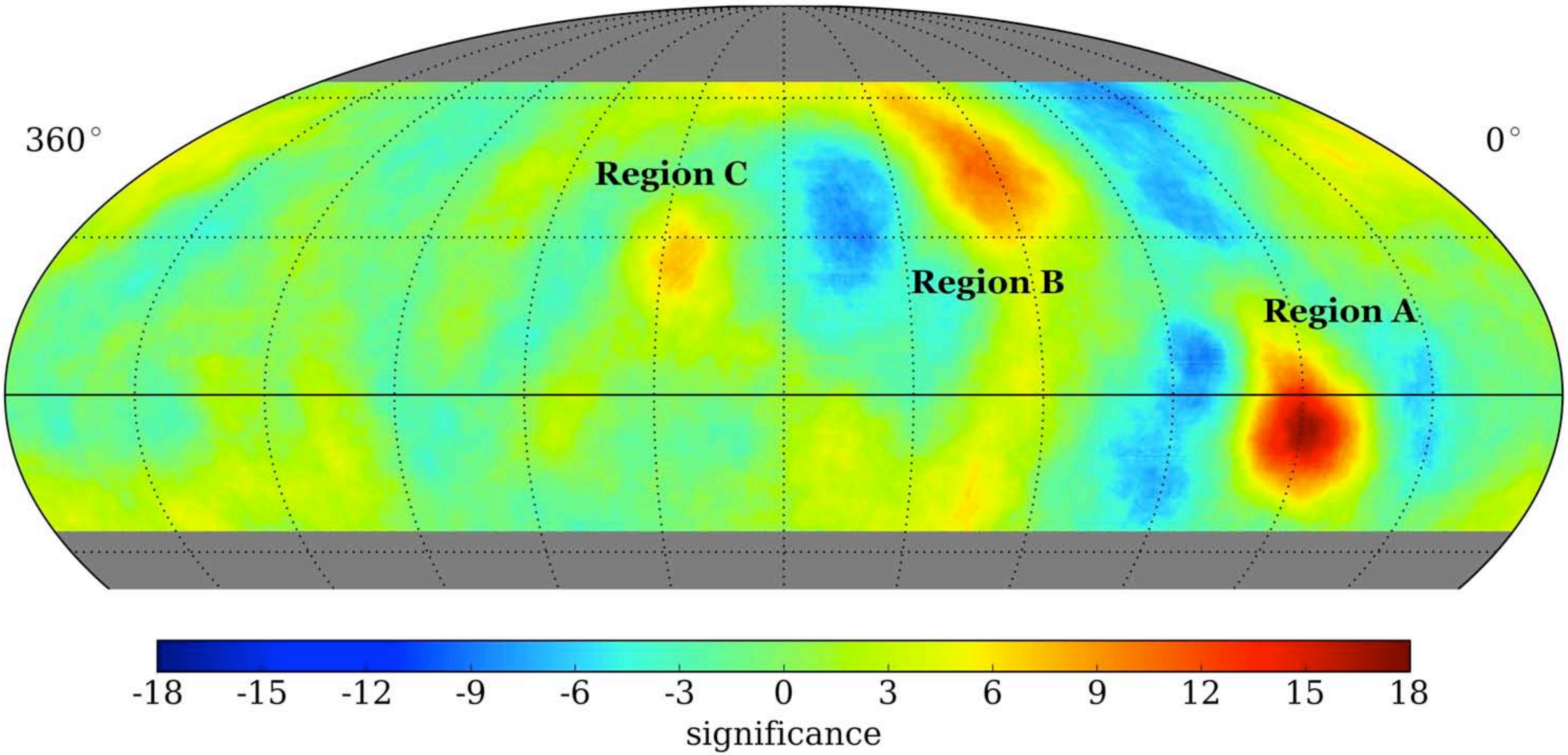
± 1.0 x 10^{-4} ∂= 64° ∂=-26° **± 0.6 x 10^{-4}** ∂=-10° ∂=50° **± 0.4 x 10^{-4}** ∂=20°



Small-Scale Anisotropy

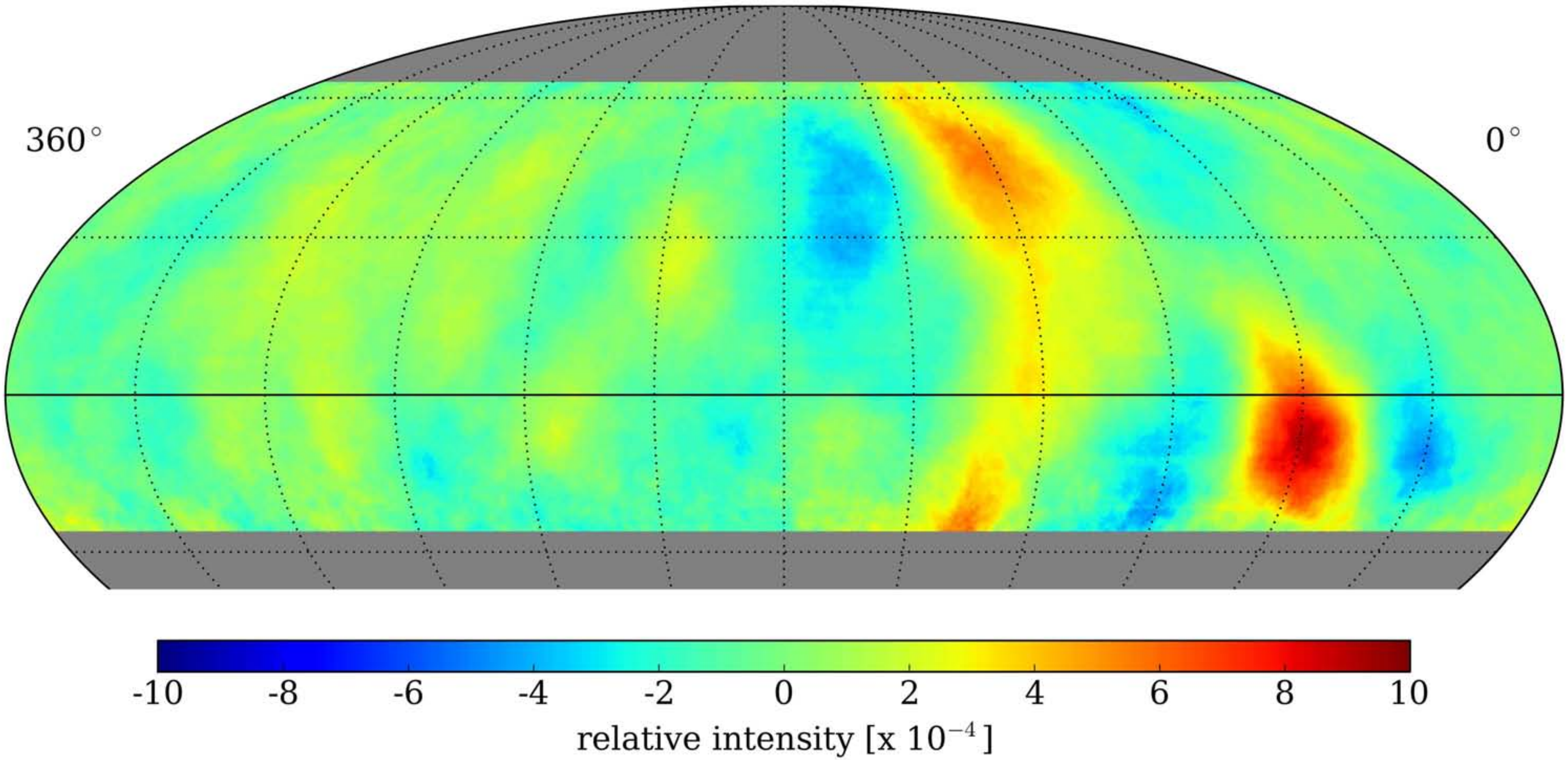
Fit dipole+quadrupole+octupole to map for 24-hr background estimation
Subtracted fit relative intensity from 24-hr map

Regions A, B and C are the only statistically significant excesses (>5σ post-trials)



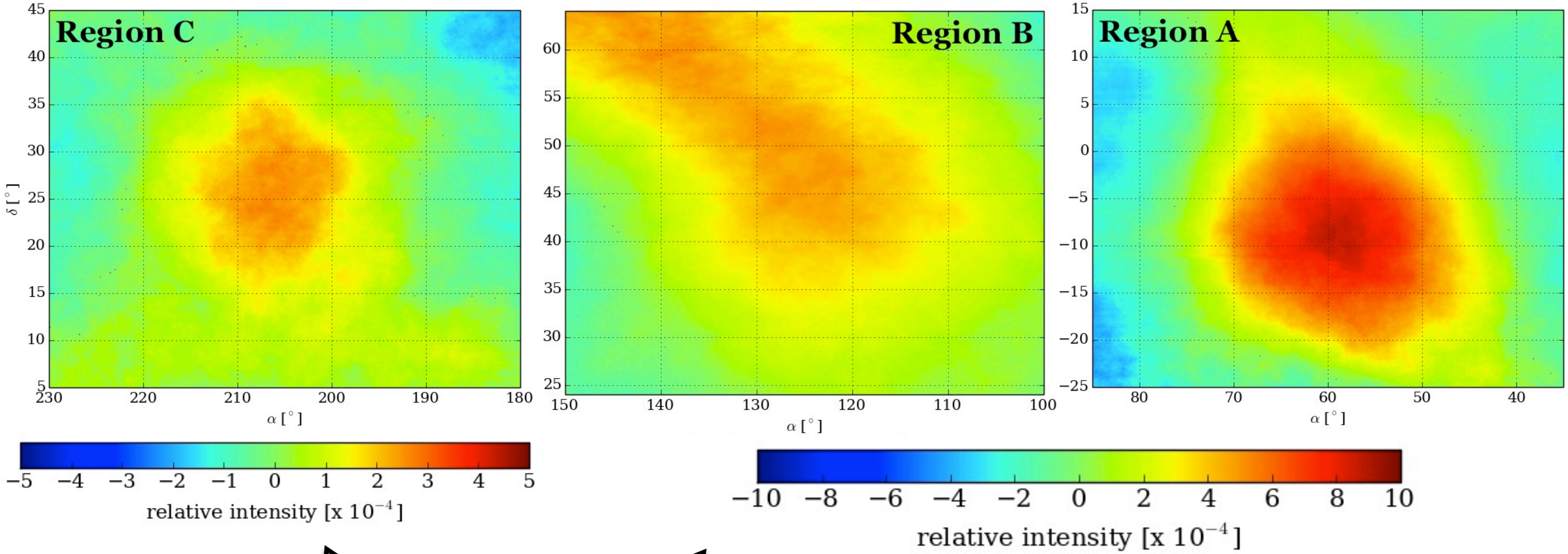
Small-Scale Anisotropy

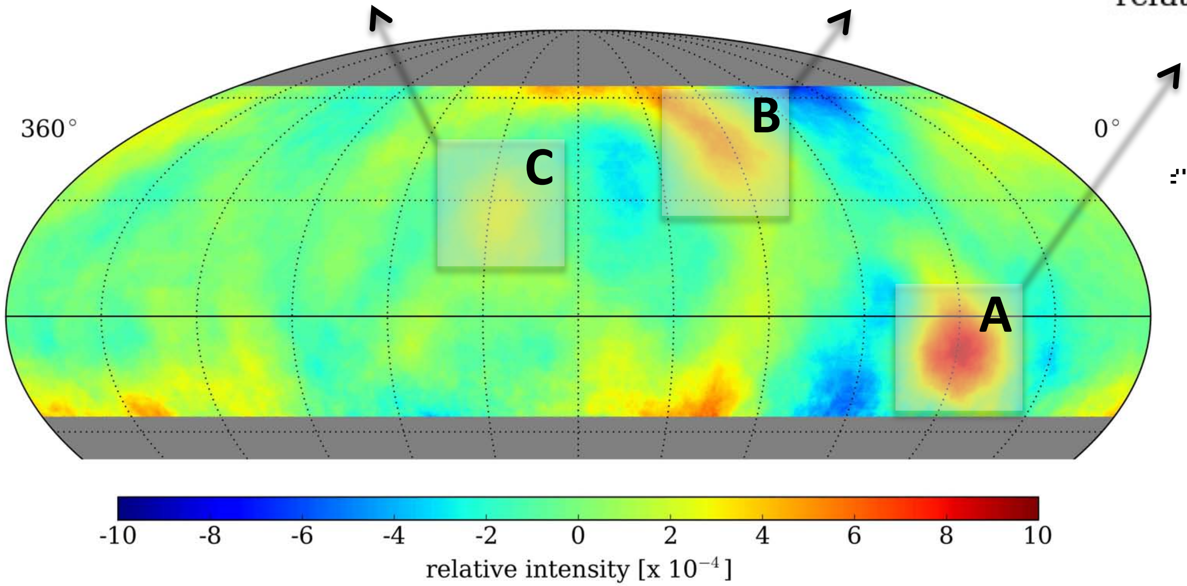
4 hr background estimation
Shows features ~ 60°. Background fits to any features larger than that



1.8 TeV median

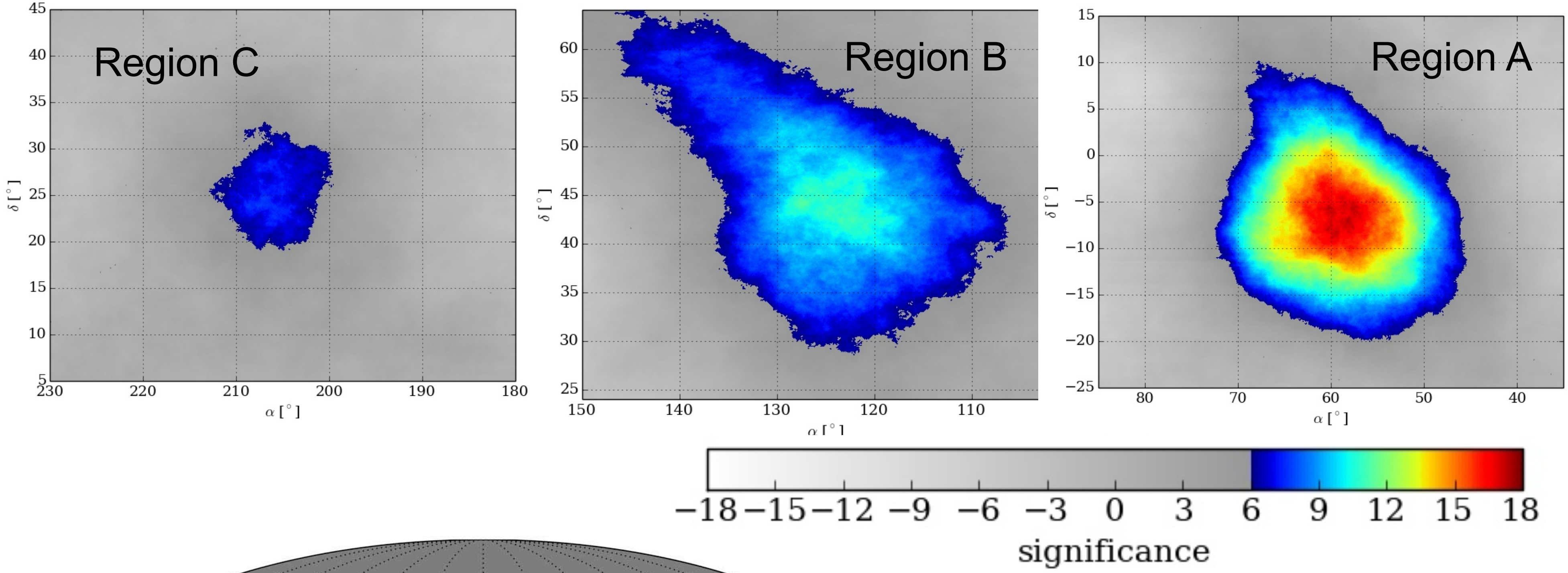
Small-Scale Anisotropy

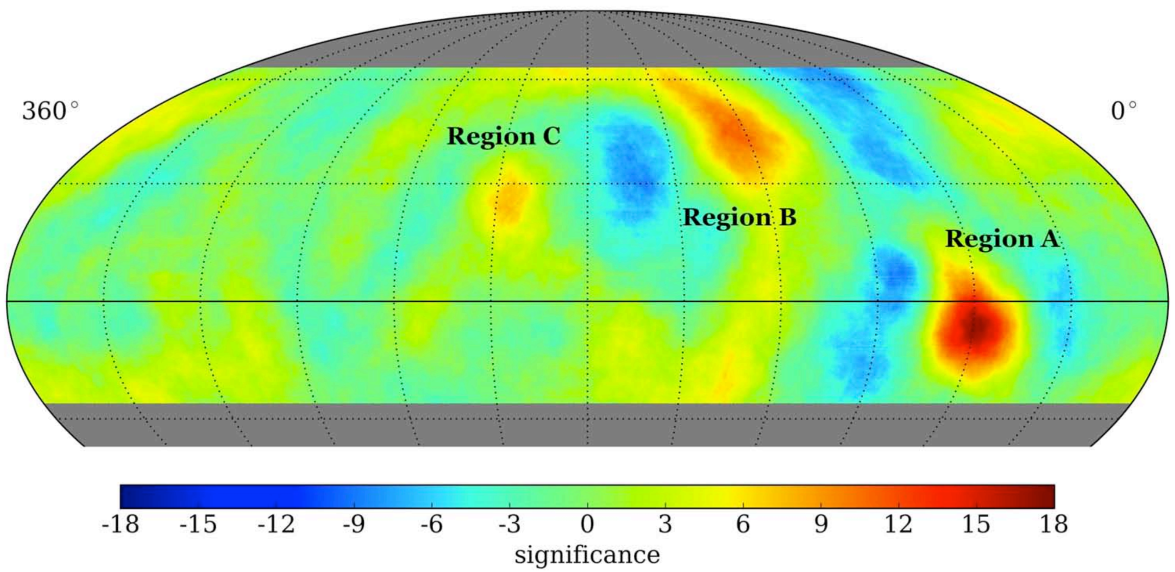




Region C	Region B	Region A
2.4 x 10^{-4}	5.3 x 10^{-4}	9.0 x 10^{-4}

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

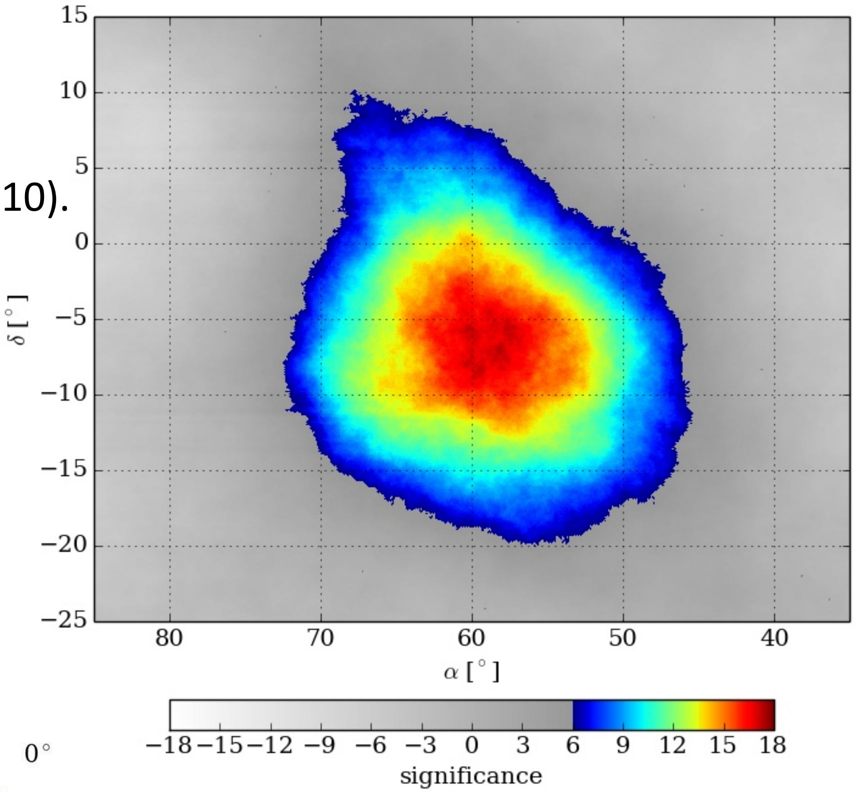
M. Amenomori et al., Astrophys. Space Sci. Trans. 6, 49 (2010).
A.Lazarian and P. Desiati, Astrophys. J. 722, 188 (2010).

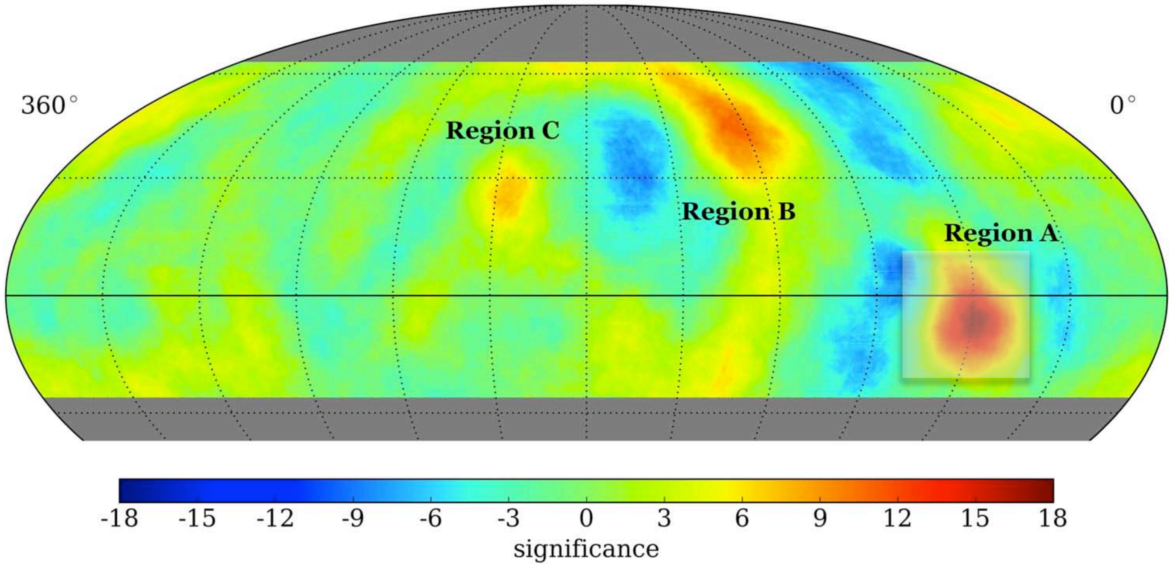
Magnetic bottle

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

Dark Matter interpretation

P. Harding arXiv:1307.6537



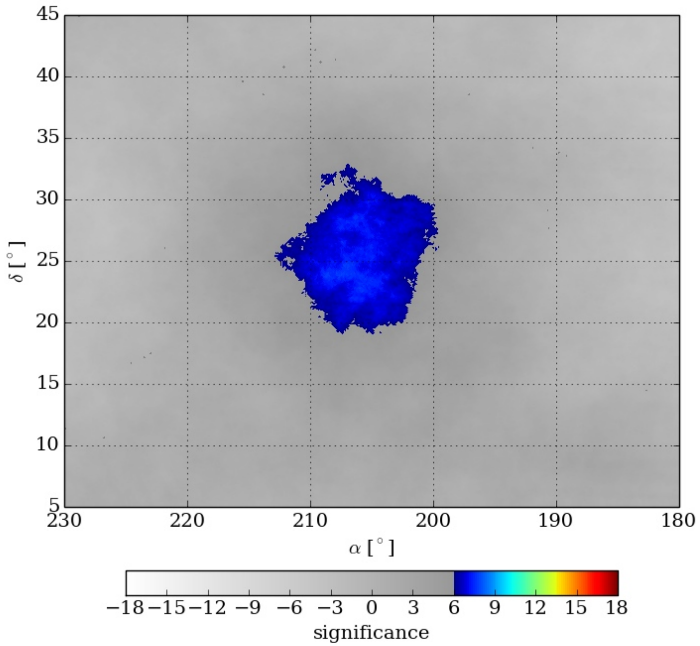


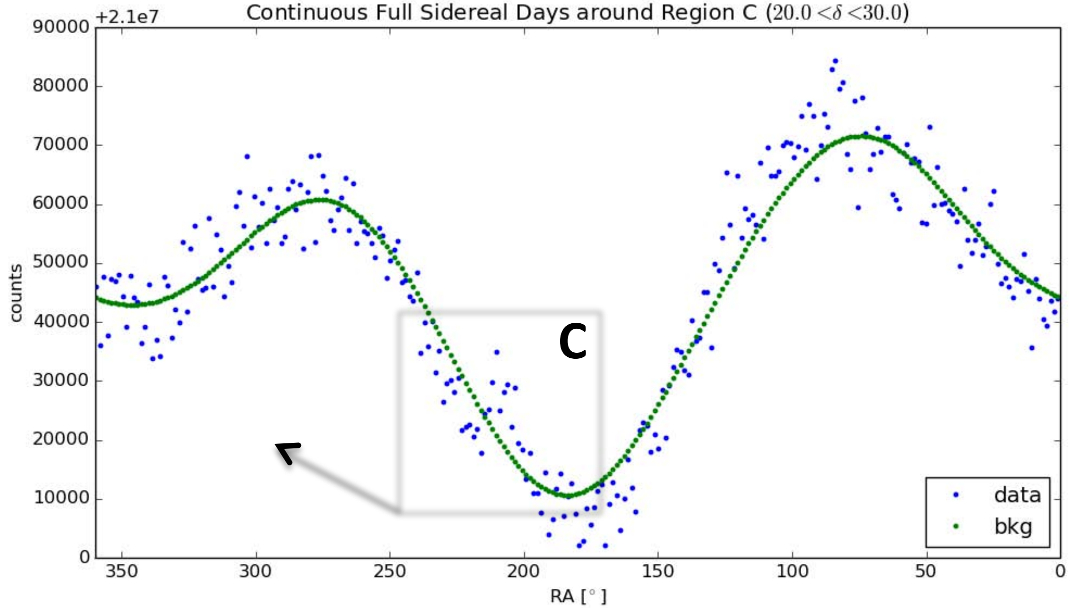
Far south for Milagro and ARGO (35°N and 30°N latitude)

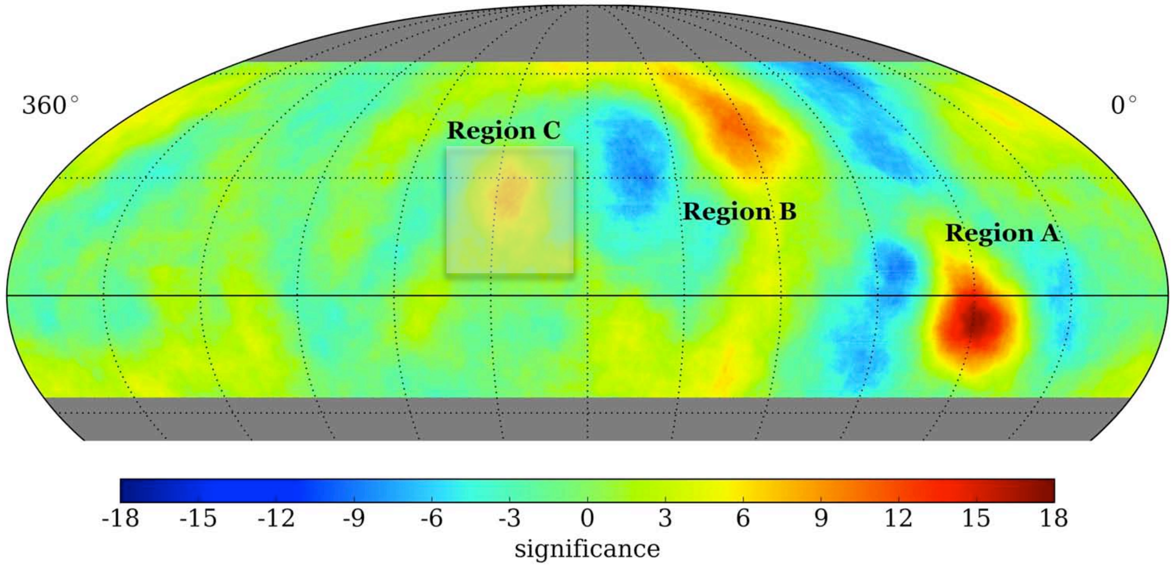
$(8.9 \pm 0.6) \times 10^{-4}$ excess

Milagro saw cutoff at ~ 4 – 20 TeV

Region C







Consistent with excess seen in ARGO
Not present in Milagro

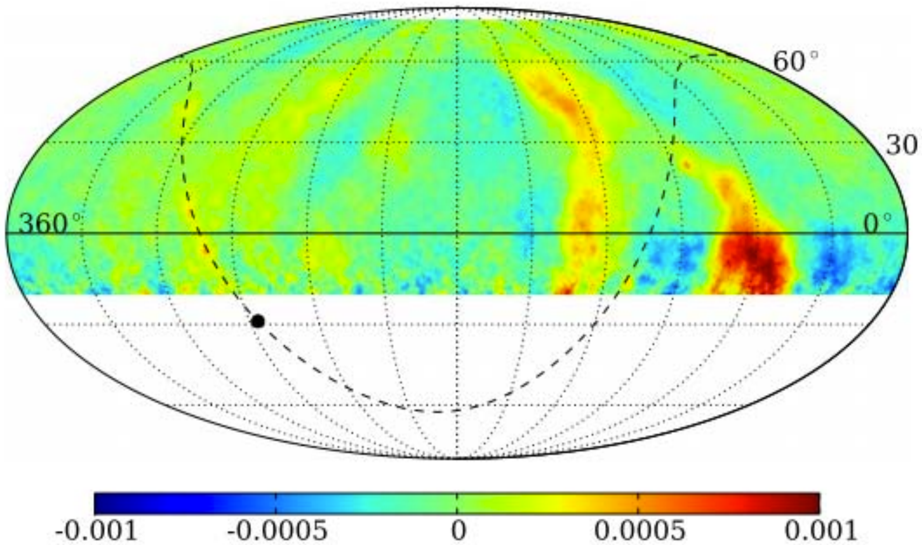
Sits in large-scale minimum

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

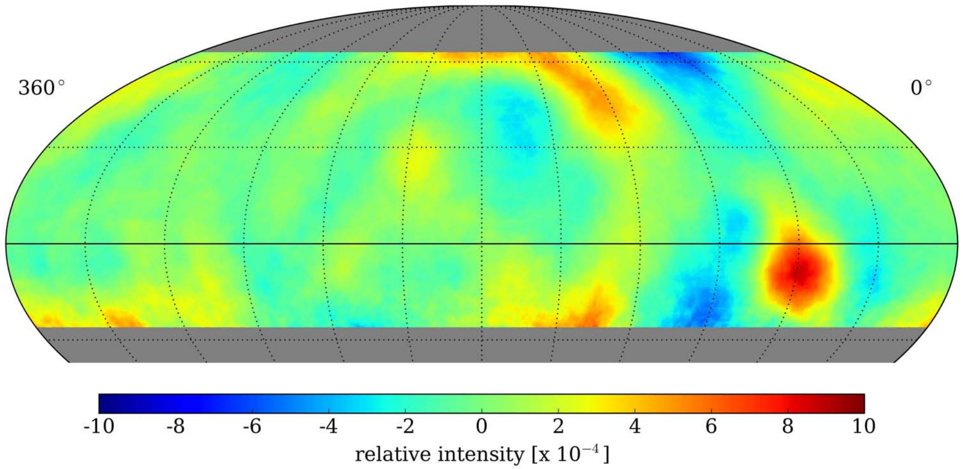
7.9σ pre-trials (> 5σ post-trials)

Comparisons

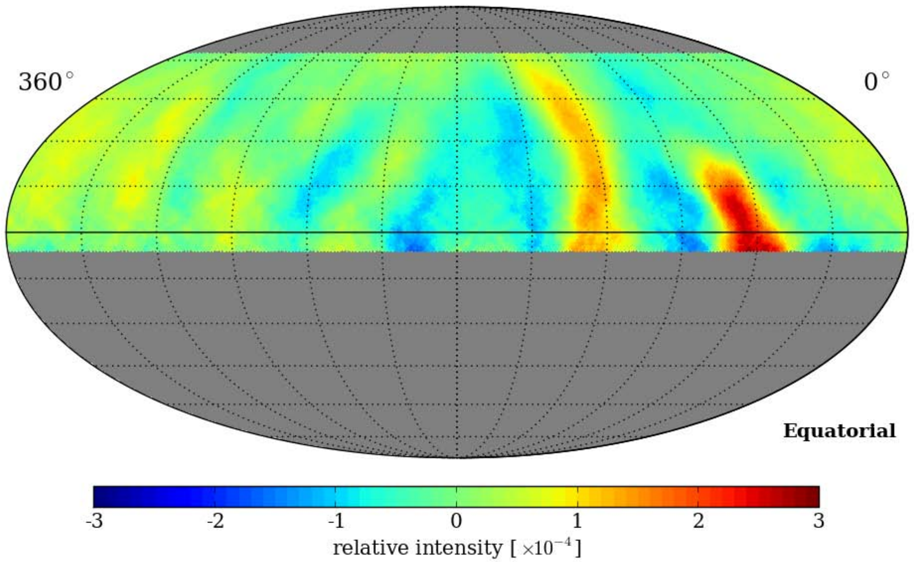
ARGO



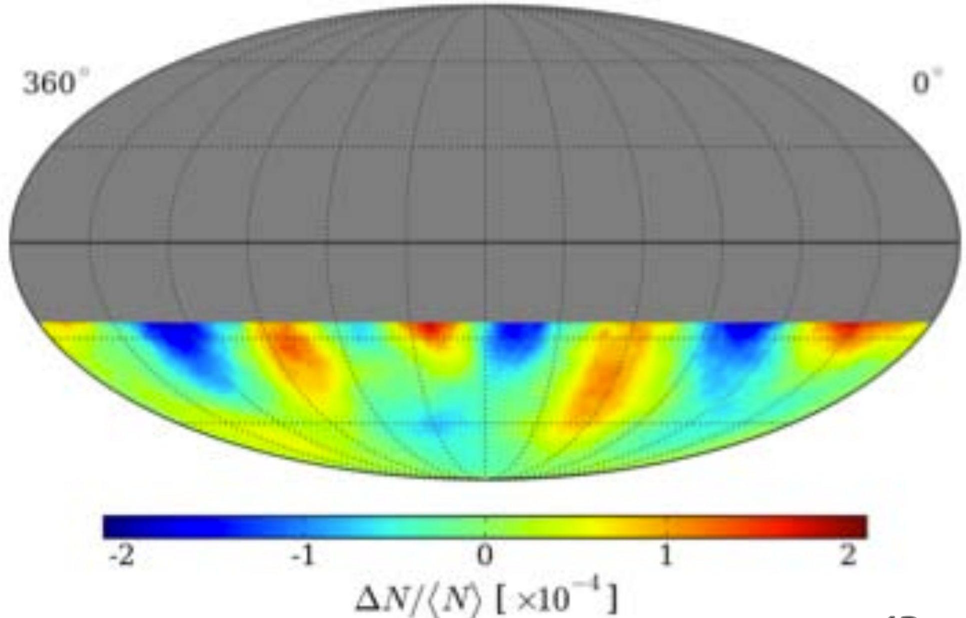
HAWC

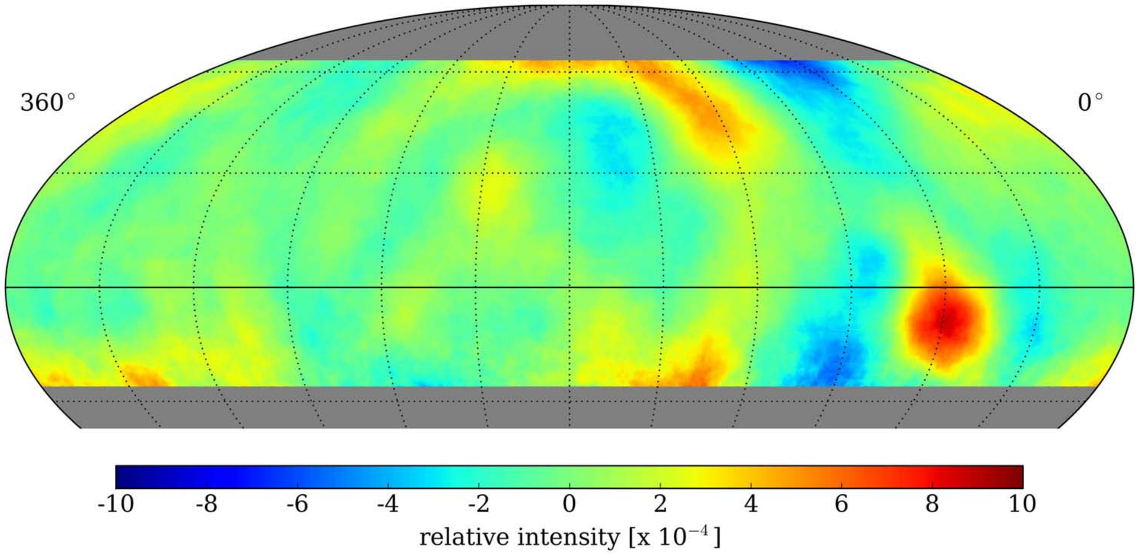


Milagro

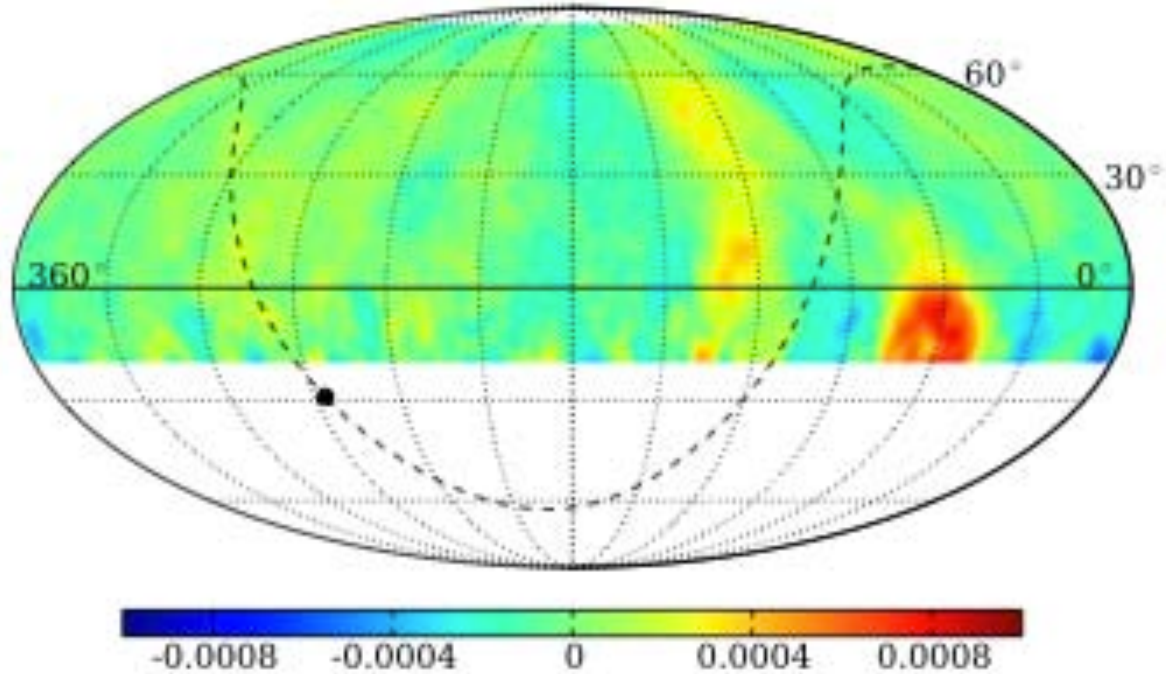


IceCube





HAWC – all data
Median = 1.8 TeV



ARGO– lowest E bin
Median = 0.66 TeV

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 coming soon

Begin back-up slides

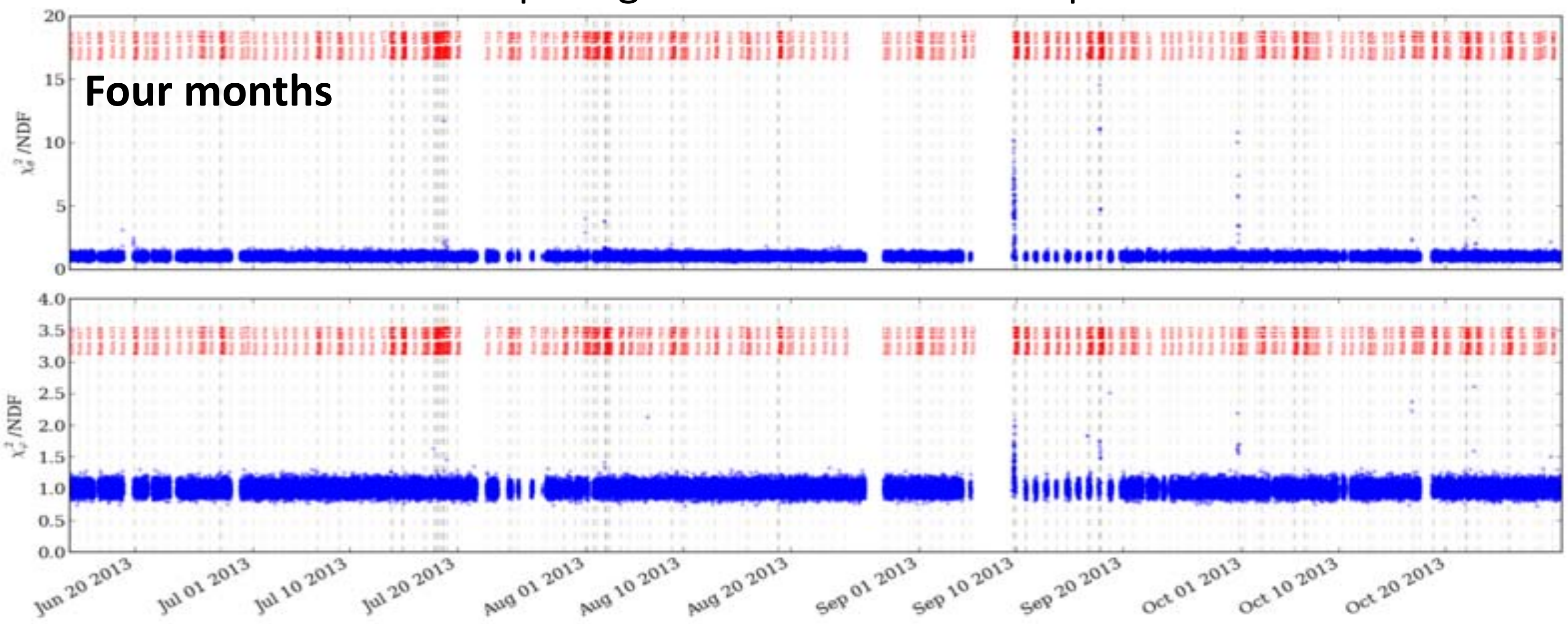
Data Stability

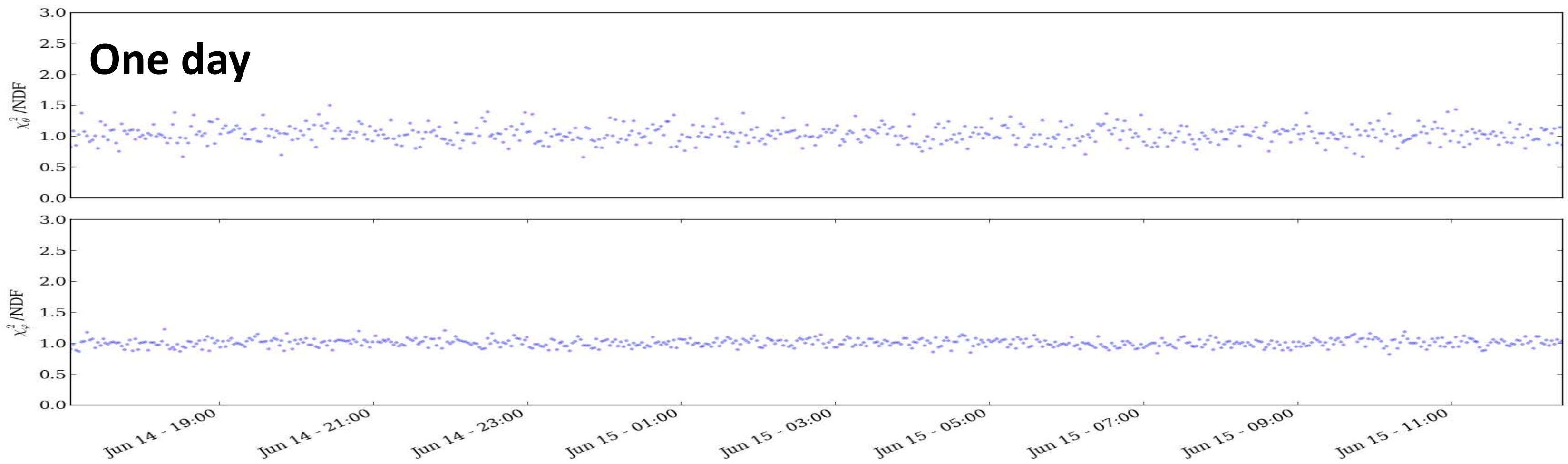
Reduced Chi-Squared

Comparing subrun of data to the previous

Zenith Angle Distrib.

Azimuth Angle Distrib.

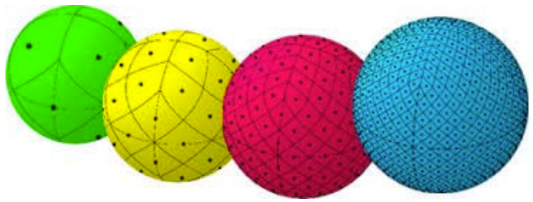




Analysis Technique

HEALpix (K.M. Gorski et al., Astrophys. J., 2005, 622, 759)

Equal-area binning of the sphere



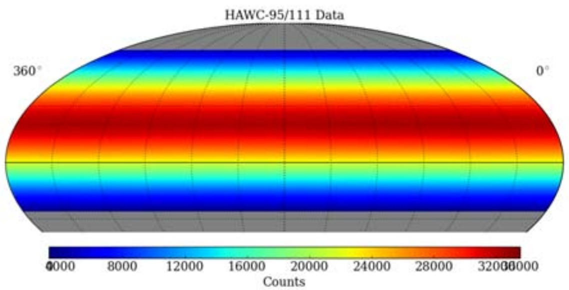
"Direct Integration" (R.Atkins et al., Astrophys. J., 2003, 595, 803.)

Method to estimate background using the data themselves

PolSpice (I. Szapudi et al. 2001, Astrophys. J., 548, L115)

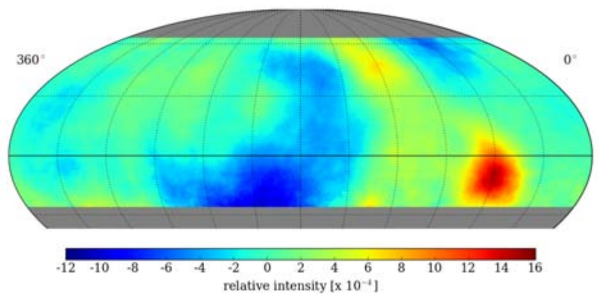
Software to compute power spectrum with partial sky coverage

HEALpix



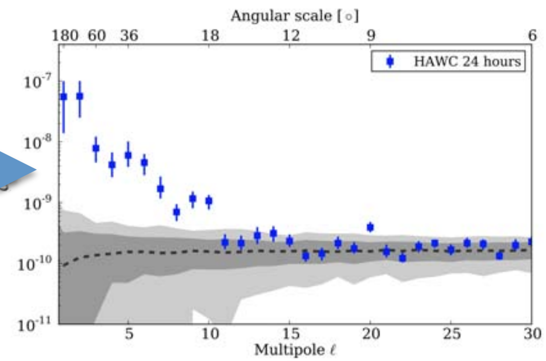
Binned data

"Direct integration"



Data & reference map
→ relative intensity

PolSpice



Power Spectrum

Power Spectrum of CR Anisotropy

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

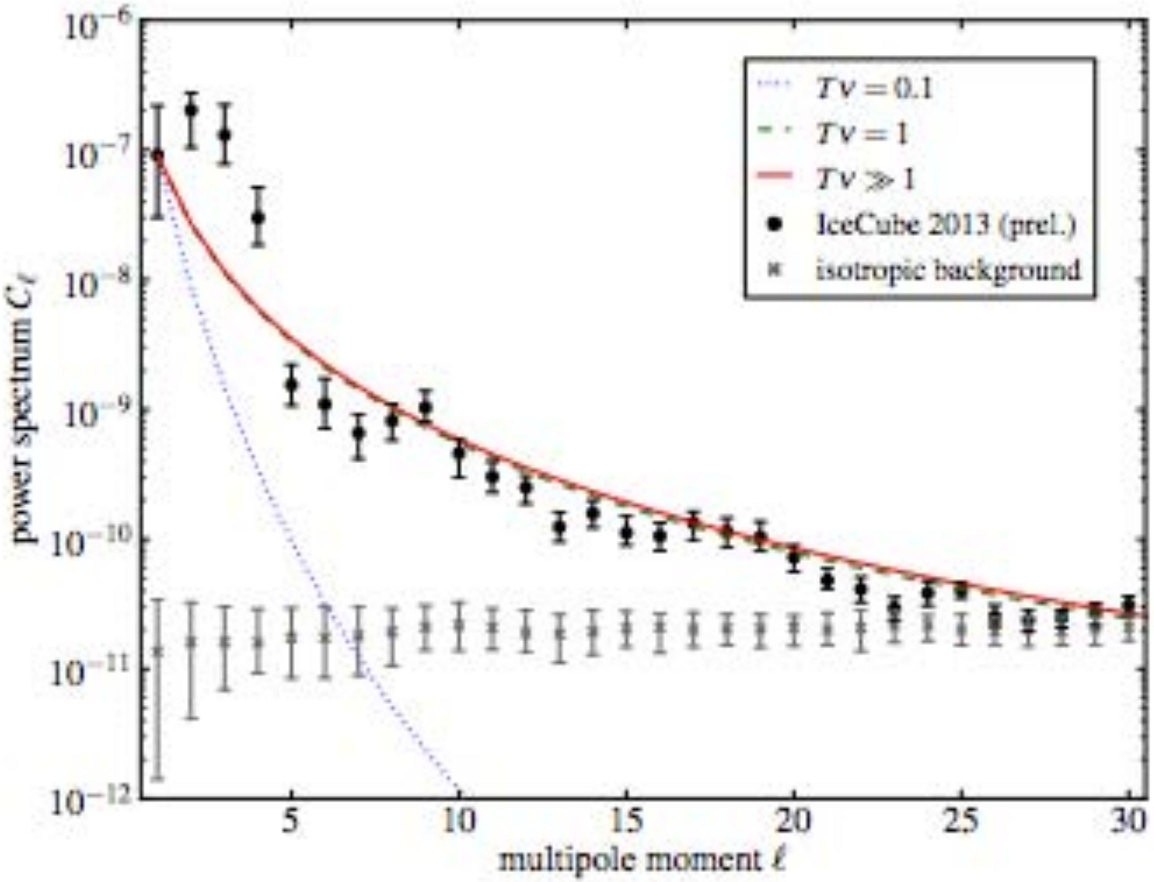
Anomalous Anisotropies of Cosmic Rays from Turbulent Magnetic Fields *M. Ahlers*
Phys. Rev. Lett 112, 021101 (2014) arXiv:1310.5712

Energy-depedent small-scale

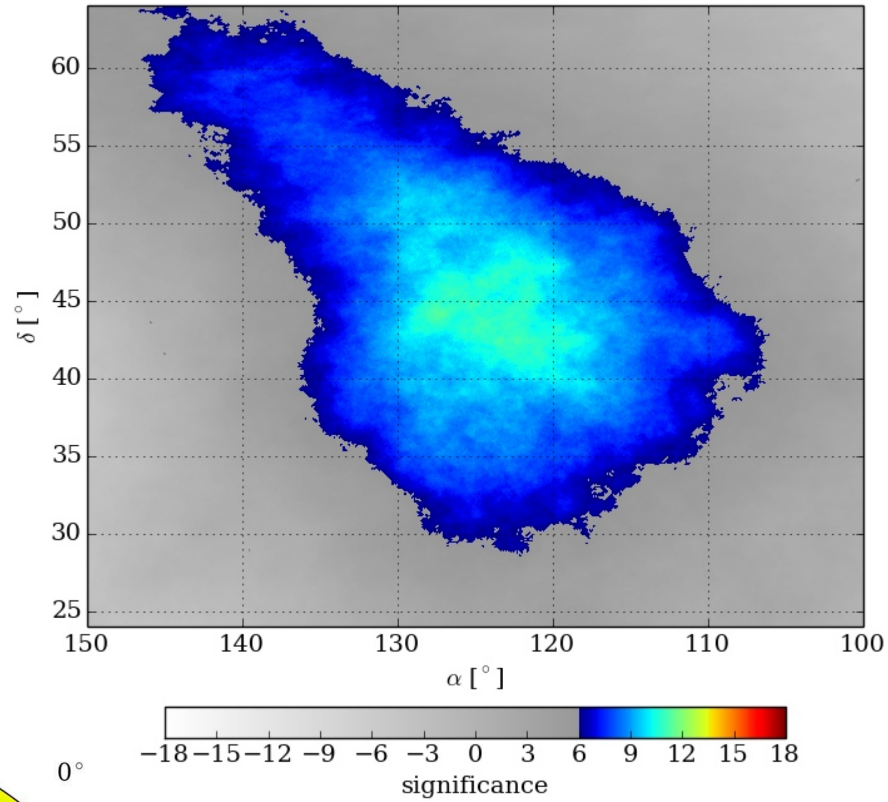
Calculation is best tied to strength of dipole

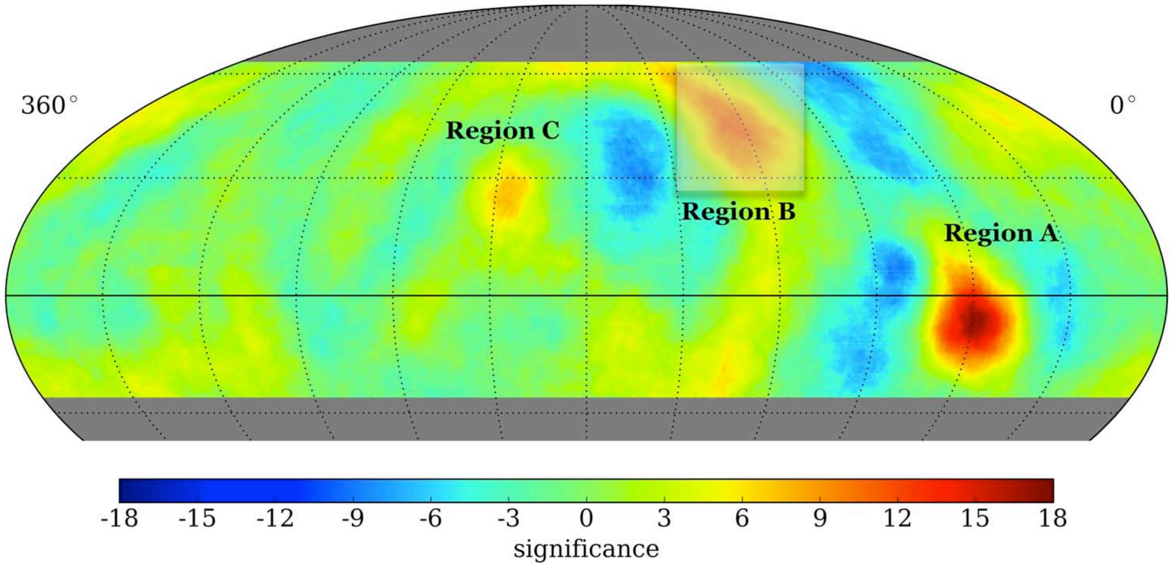
HAWC ≠ 1 full year

Solar dipole contamination



Region B





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

$(5.3 \pm 0.6) \times 10^{-4}$ excess

Milagro: same spectrum as bkg