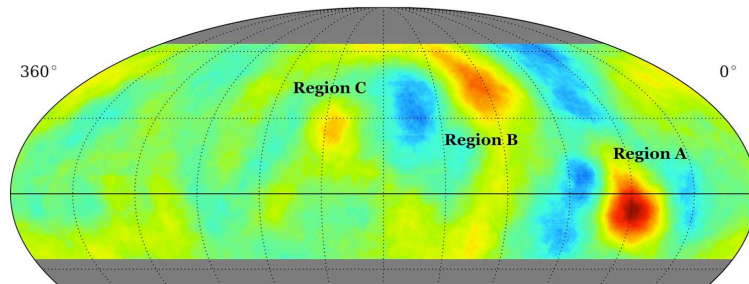


Cosmic-ray anisotropy with the HAWC Observatory



*Daniel Fiorino (Wisconsin-Madison)
for the HAWC Collaboration*



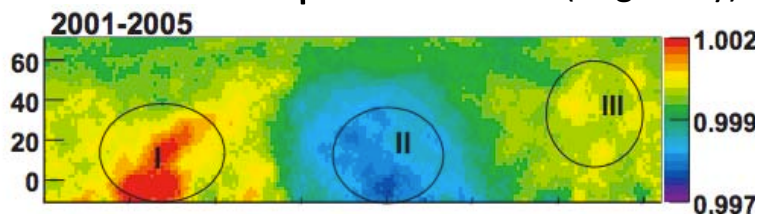
Motivation



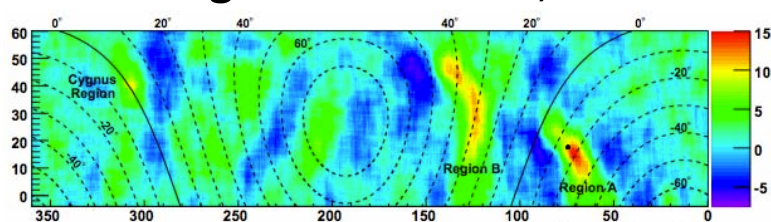
Experiment 1 sky map / year

Theory 2 papers / month

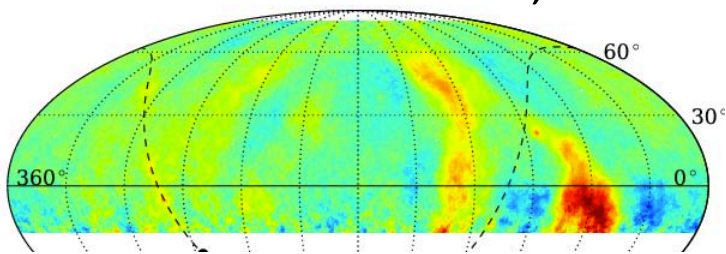
1 – Tibet-Asy 2005 (large only)



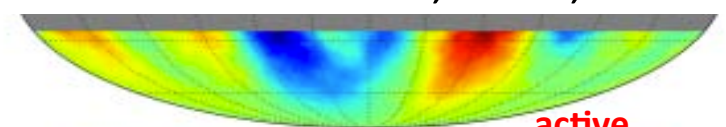
2 – Milagro 2008, 2009



3 – ARGO-YBJ 2009, 2013



4 – IceCube 2010, 2011, 2012



active
Southern hemisphere

Diffusive propagation of cosmic rays

from supernova remnants in the Galactic environment

Understanding TeV-band cosmic-ray anisotropy

Martin Pohl^{1,2}, David Eichler³

The Milagro anticenter hot spots: cosmic rays from the Geminga supernova?

Local Magnetic Turbulence and TeV–PeV Cosmic Ray Anisotropies

Gwenael Giacinti^{1,2,3} and Günter Sigl¹

¹ II. Institut für Theoretische Physik, Universität Hamburg, Germany

² Institut for fysikk, NTNU, Trondheim, Norway and

³ AstroParticle and Cosmology (APC), Paris, France

In the energy range from $\sim 10^{12}$ eV to $\sim 10^{15}$ eV, the Galactic cosmic ray flux has anisotropies of 0.1%, and on scales between $\approx 10^\circ$ and $\approx 10^\circ$. With a diffusion coefficient inferred from an approximation predicts a dipolar anisotropy scale anisotropies. We demonstrate here that arise from the local concrete realization of the ring length. We show how such anisotropies arise from the concrete realization of the ring length.

ANISOTROPY OF TEV COSMIC RAYS AND THE OUTER HELIOSPHERIC BOUNDARIES

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Department of Astronomy, University of Wisconsin, Madison, WI 53706
Draft version October 30, 2012

ABSTRACT

Cosmic-ray diffusion in collisionless plasmas including pressure anisotropy

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J. Peralta-Ramos

Departamento de Física, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires and IAFI-CONICET, Ciudad Universitaria, Buenos Aires 1281, Argentina

Abstract

Using a hybrid kinetic magnetohydrodynamic formalism incorporating the effects of pressure anisotropy, we simulate the evolution of a turbulent collisionless plasma in six different models covering the sub-/super-Alfvénic and sub-/super-Alfvénic regimes. Based on the power spectrum of the simulated magnetic field, we compute the particle diffusion coefficients for protons with kinetic energy in the 50–500 MeV range, and compare them to those obtained within standard magnetohydrodynamics. Our results show that the differences in the statistical properties of the magnetic field, generated by pressure anisotropy and its associated kinetic instabilities, have an appreciable impact on the diffusion coefficients of energetic protons. Moreover, the values of the diffusion coefficients that we obtain within each of the six models considered vary significantly.

Keywords: cosmic rays; diffusion; collisionless space plasmas; pressure anisotropy

The problem of small angular scale structure in the cosmic ray anisotropy data

L. O’C. DRURY

Dublin Institute for Advanced Studies
School of Cosmic Physics
31 Fitzwilliam Place
Dublin 2
Ireland

Global Anisotropies in TeV Cosmic Rays Related to the Sun’s Local Galactic Environment from IBEX

N. A. Schwadron^{1,2,*}, F. C. Adams³, E. R. Christian⁴, P. Desiati⁵, P. Frisch⁶, H. O. Funsten⁷, J. R. Jokipii⁸,

D. J. McComas^{2,9}, E. Moebius¹, G.P. Zank^{1,10}

Cosmic Ray Anisotropy as Signature for the Transition from Galactic to Extragalactic Cosmic Rays

¹Southwest
Arbor, MI 4
nsin, IceCut
tment of As
Science anc
ces, Tucson
of Alabama,

G. Giacinti,^{a,b} M. Kachelrieß,^a D. V. Semikoz,^{c,d} G. Sigl^b

^aInstitut for fysikk, NTNU, Trondheim, Norway

^bII. Institut für Theoretische Physik, Universität Hamburg, Germany

^cAstroParticle and Cosmology (APC), Paris, France

^dInstitute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia

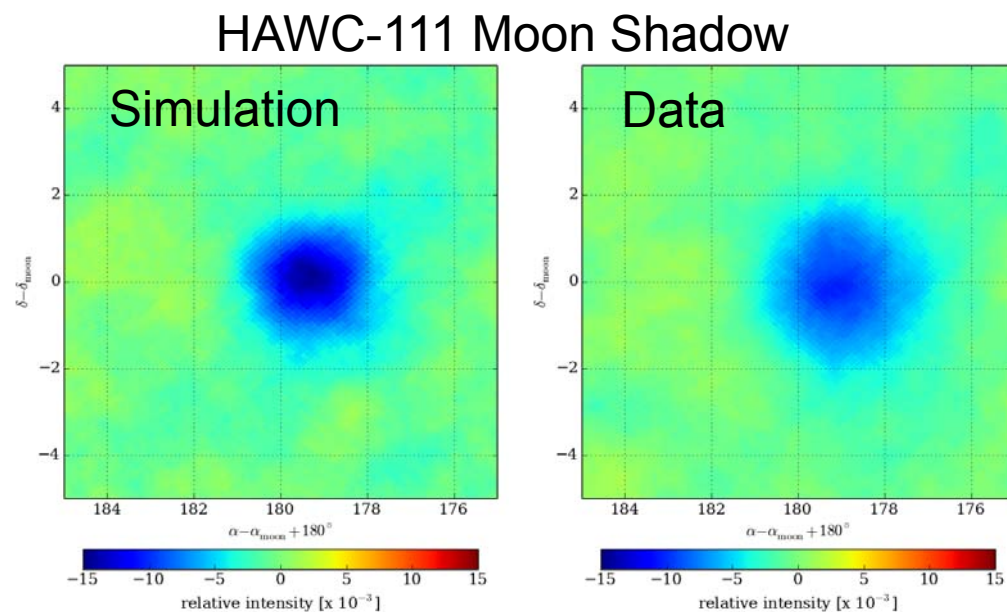
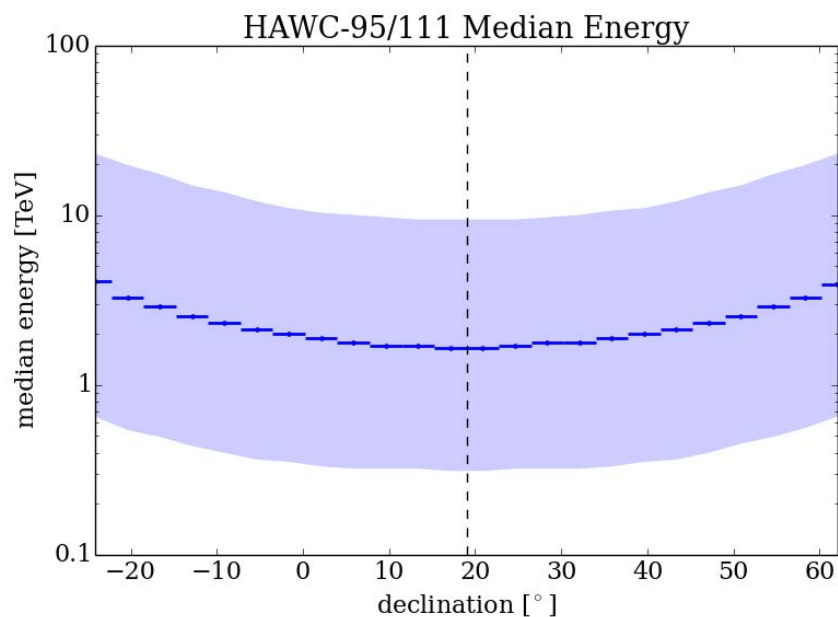
Data Set

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



Full Sky Map

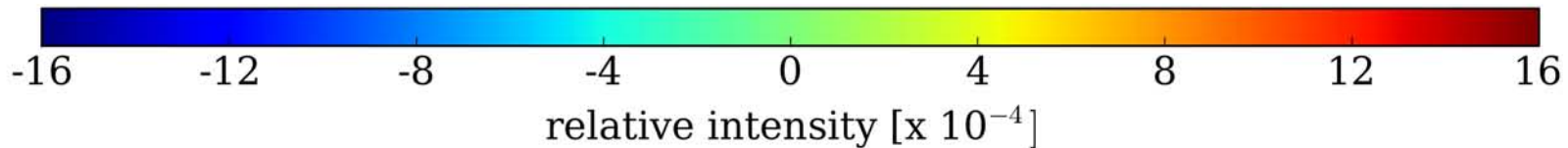
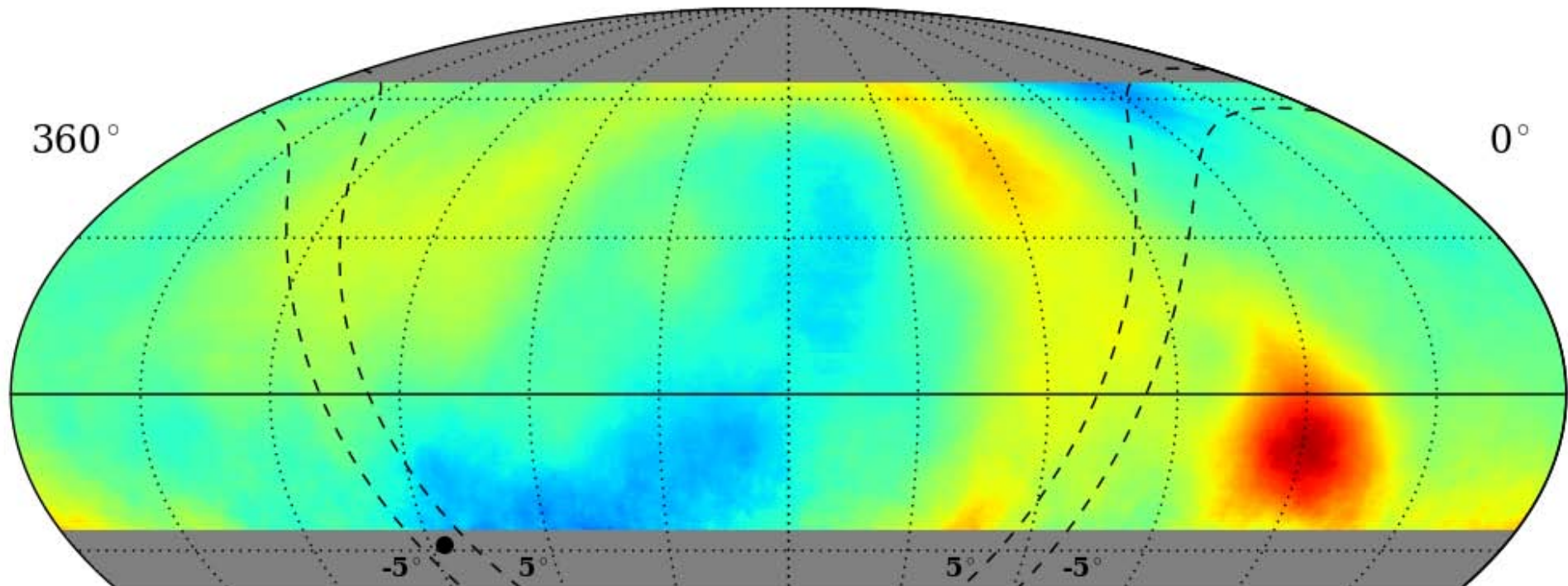


Shows features of all angular scales (24 hr background estimation)

Smoothed 10°

Dipole deficit is consistent with previous observations (1×10^{-3} @ $ra=200^\circ$, dec)

Brightest region sits in region of general excess ($ra=60^\circ$, $dec=-10^\circ$)



1.8 TeV median

HAWC \neq 1 full year

Power Spectrum of CR Anisotropy



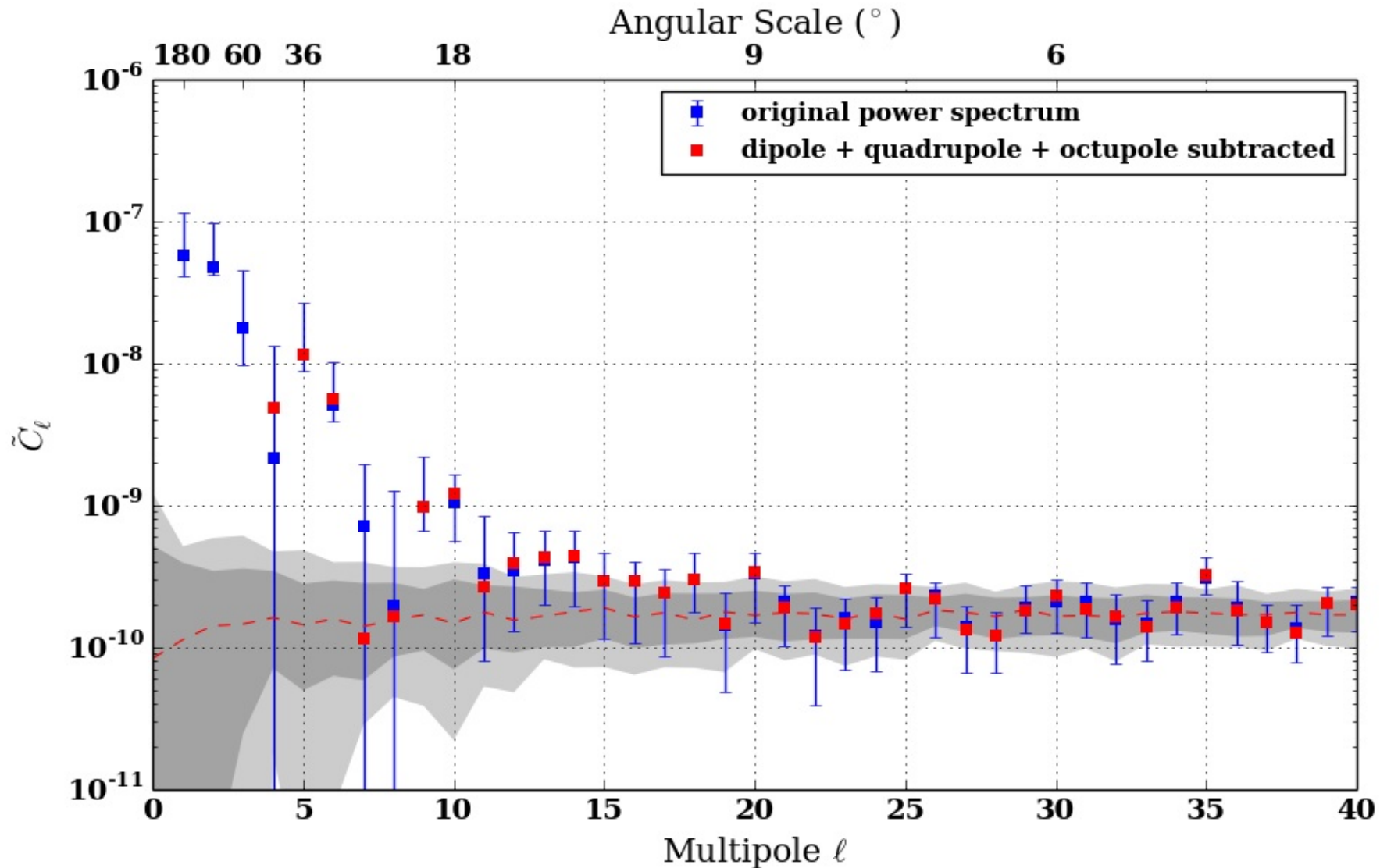
Original (24h bkg est)

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"

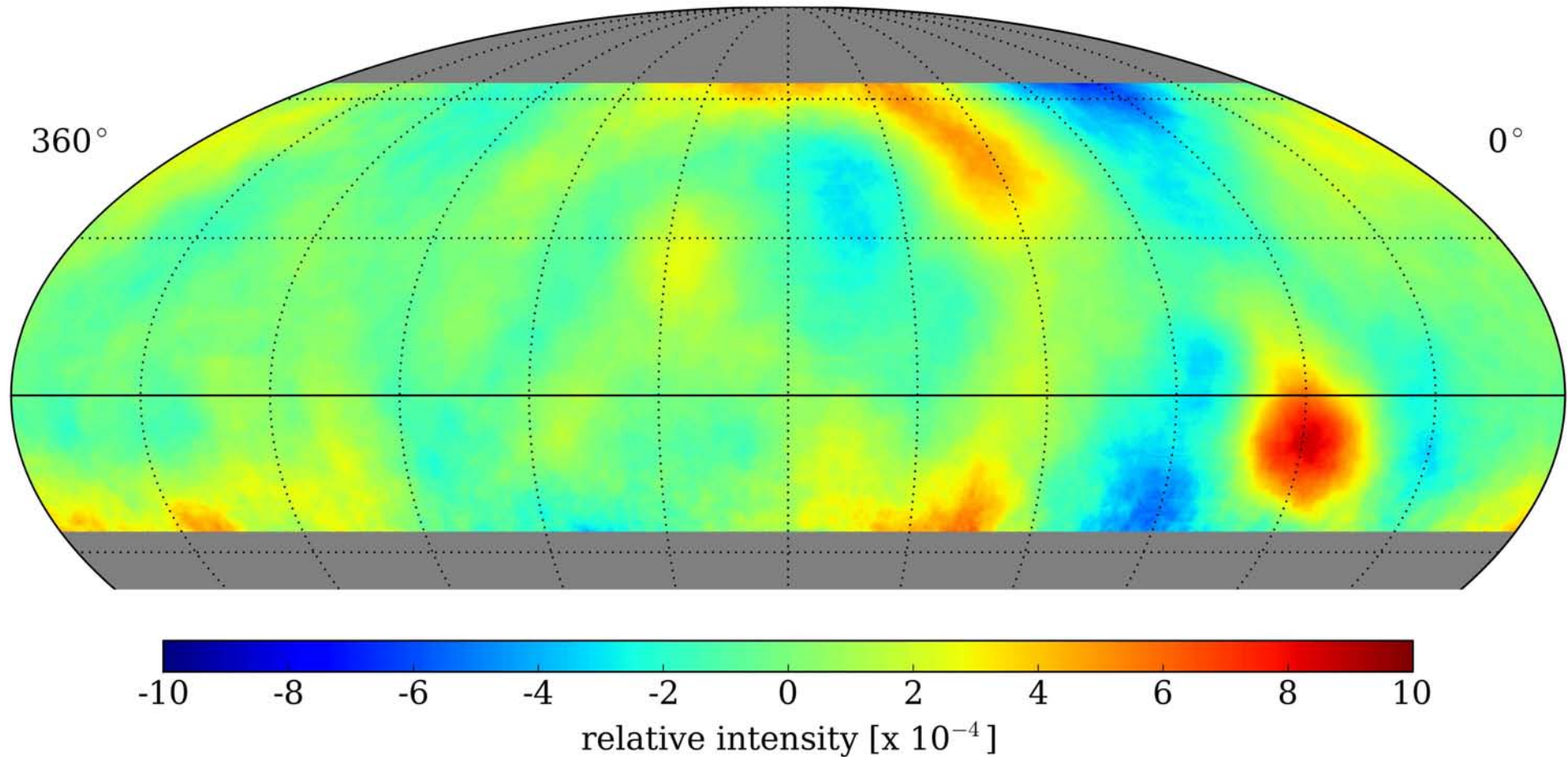
<http://arxiv.org/pdf/1105.2326.pdf> (section 3.3)



Small-Scale Anisotropy

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

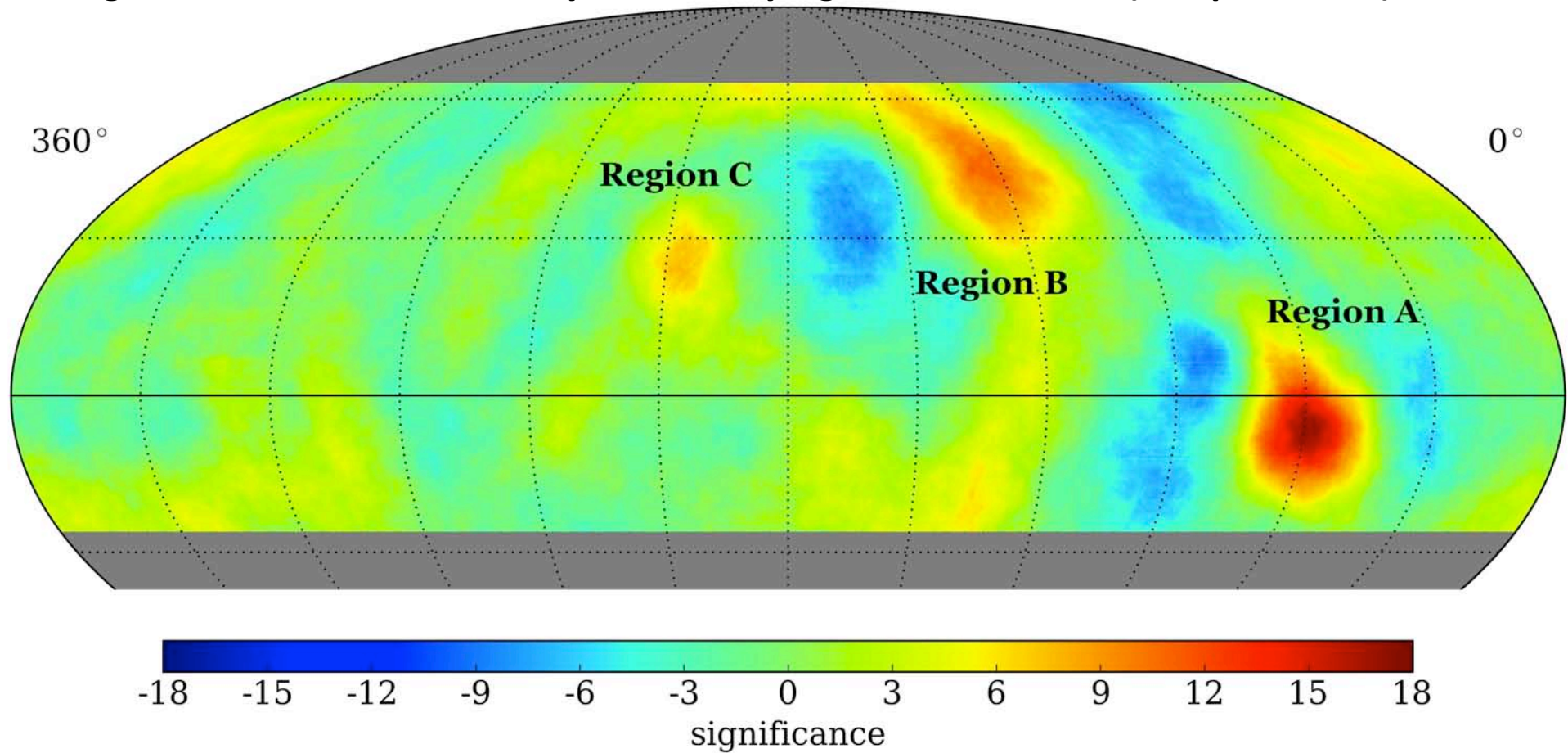
$\pm 1.0 \times 10^{-4}$ $\delta = 64^\circ$ $\delta = -26^\circ$ $\pm 0.6 \times 10^{-4}$ $\delta = -10^\circ$ $\delta = 50^\circ$ $\pm 0.4 \times 10^{-4}$ $\delta = 20^\circ$



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 ($>5\sigma$ post-trials)

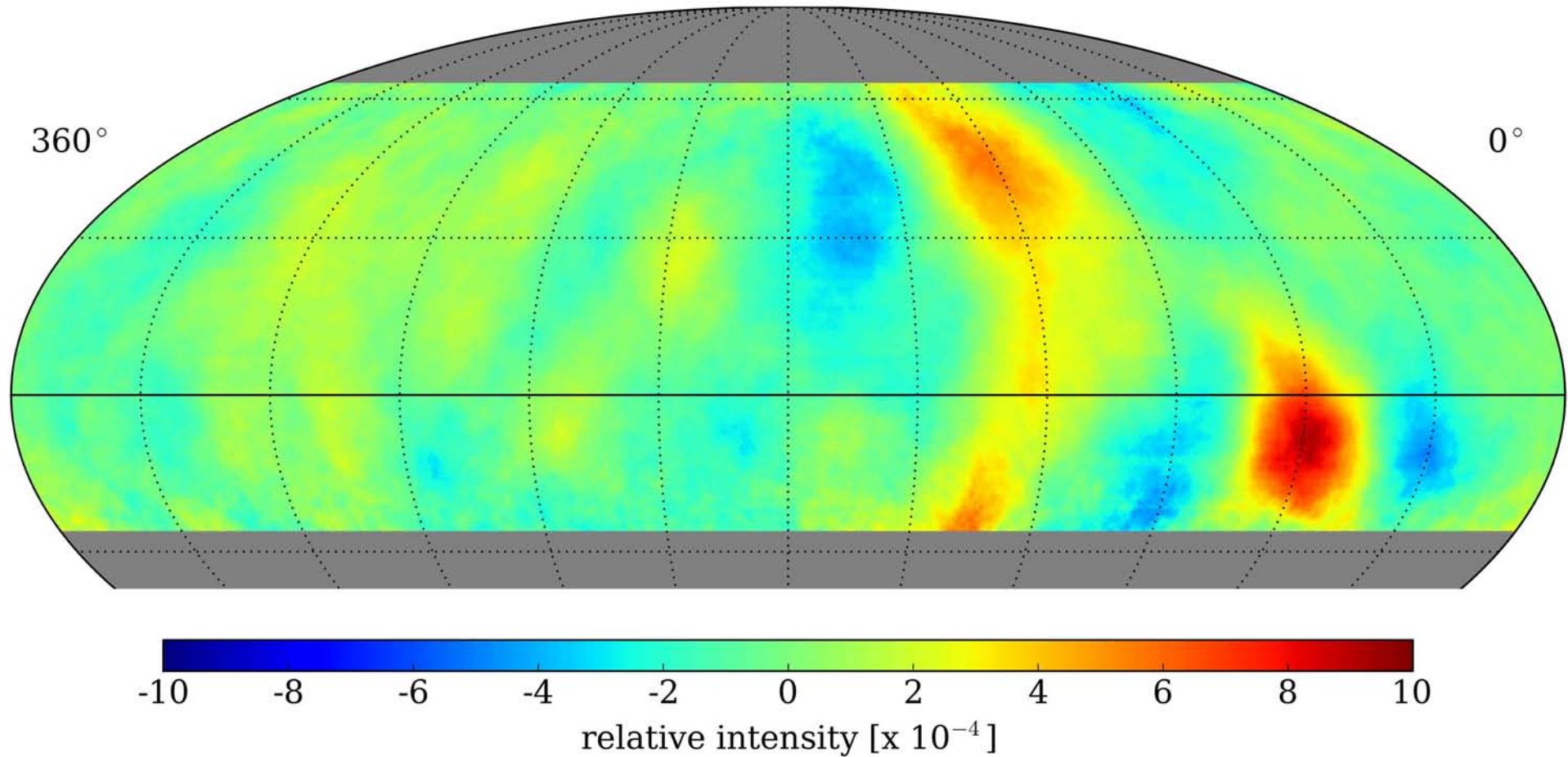


Small-Scale Anisotropy



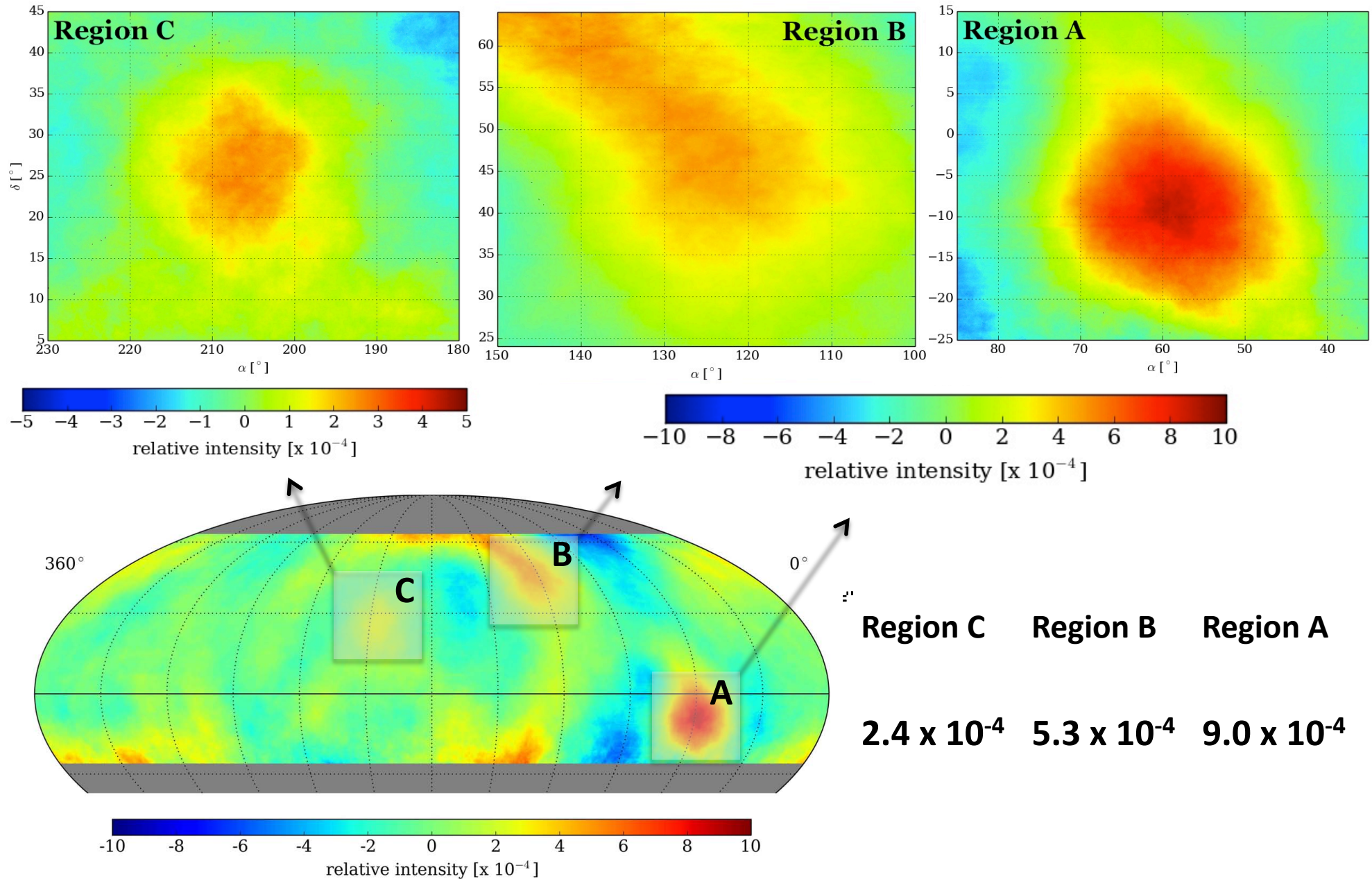
4 hr background estimation

Shows features $\sim 60^\circ$. Background fits to any features larger than that

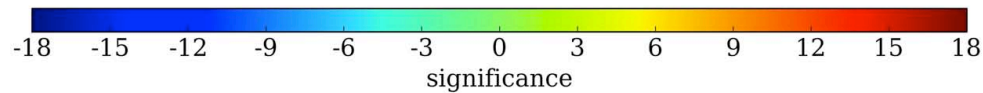
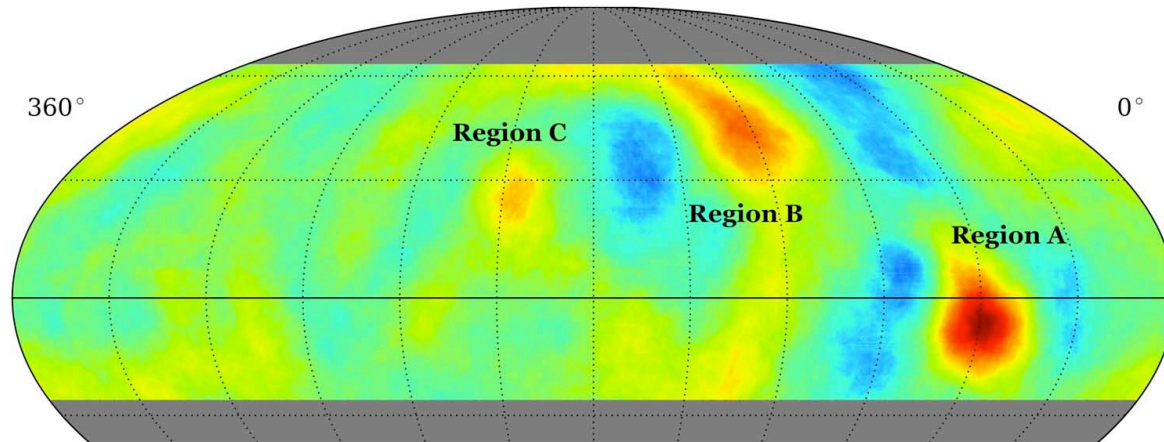
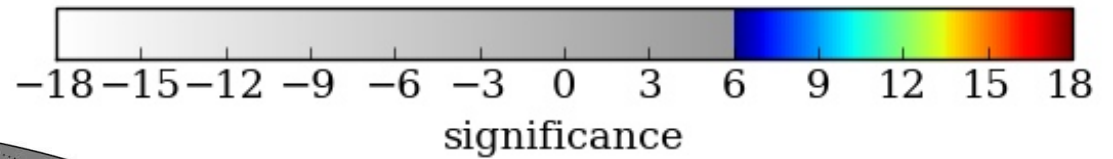
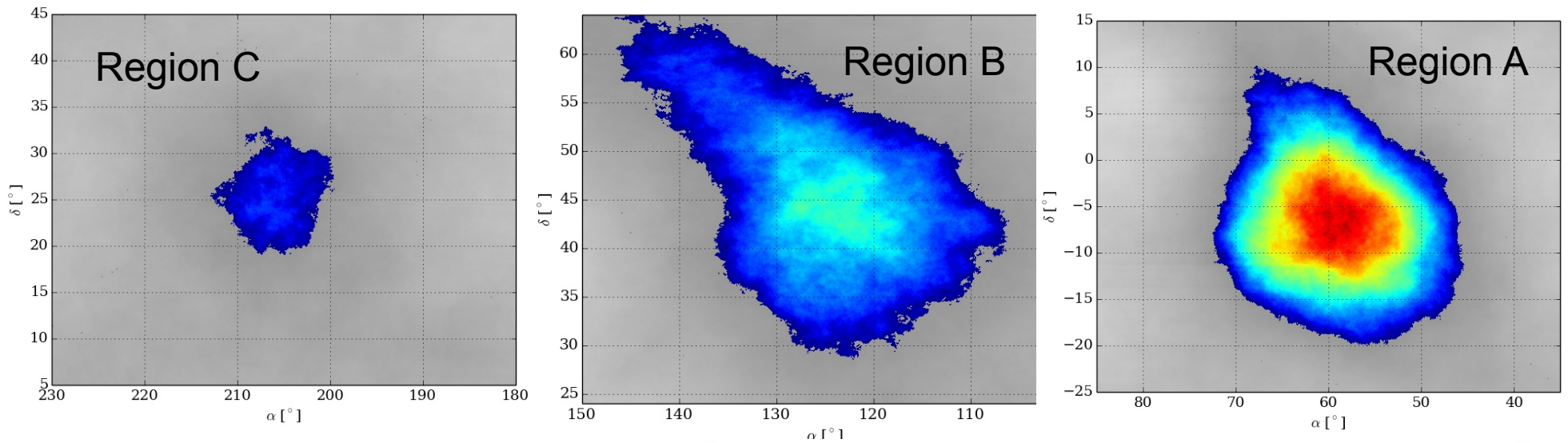


1.8 TeV median

Small-Scale Anisotropy



Small-Scale Anisotropy



	Region C	Region B	Region A
Significance	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).

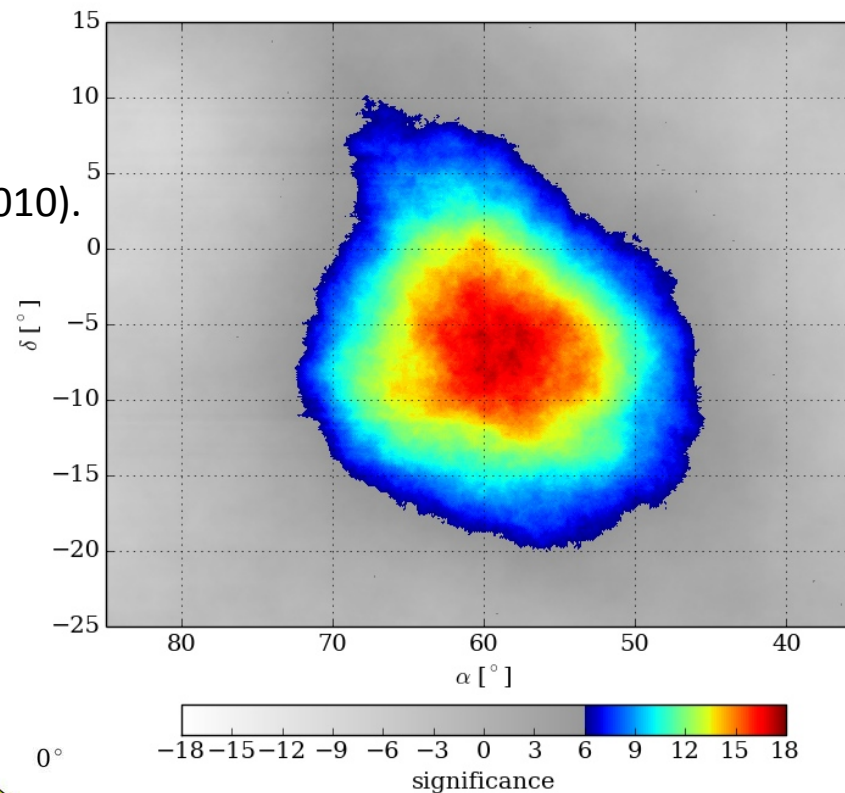
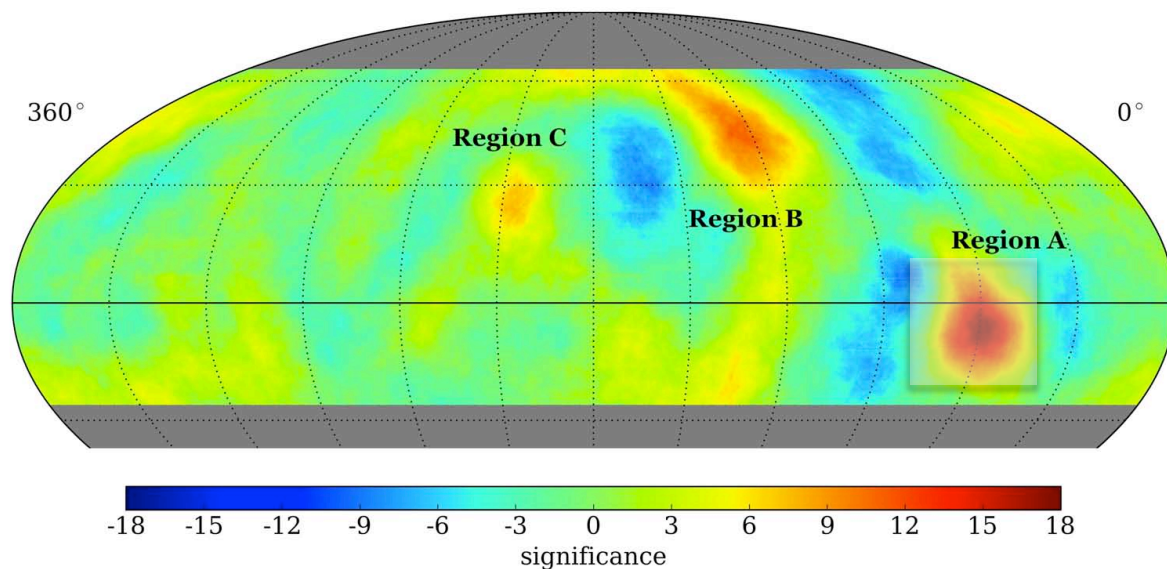
A. Lazarian and P. Desiati, *Astrophys. J.* 722, 188 (2010).

Magnetic bottle

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

Dark Matter interpretation

P. Harding arXiv:1307.6537

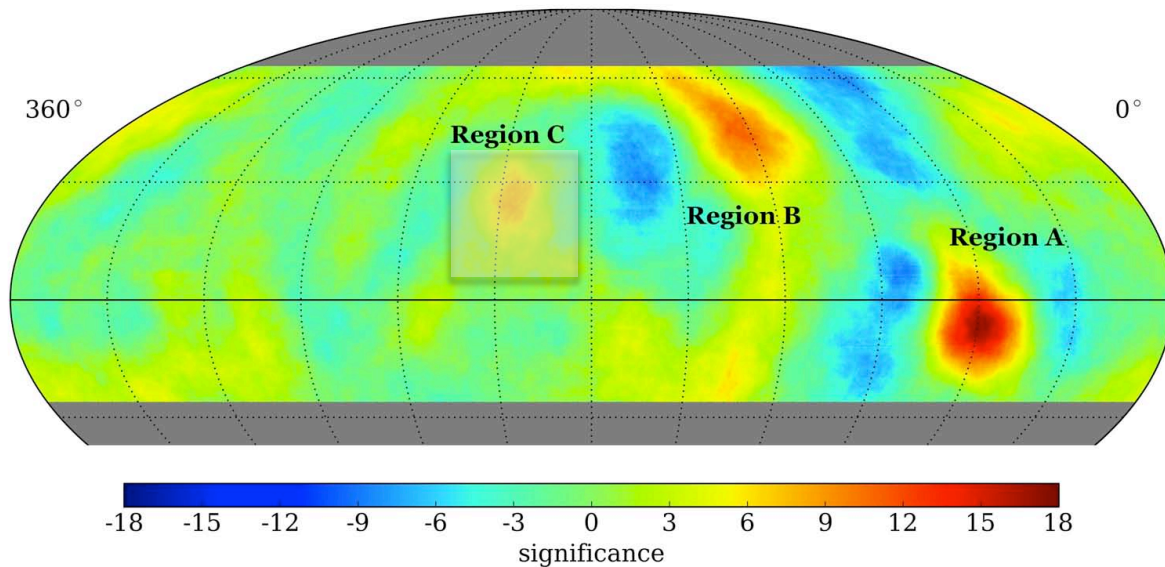
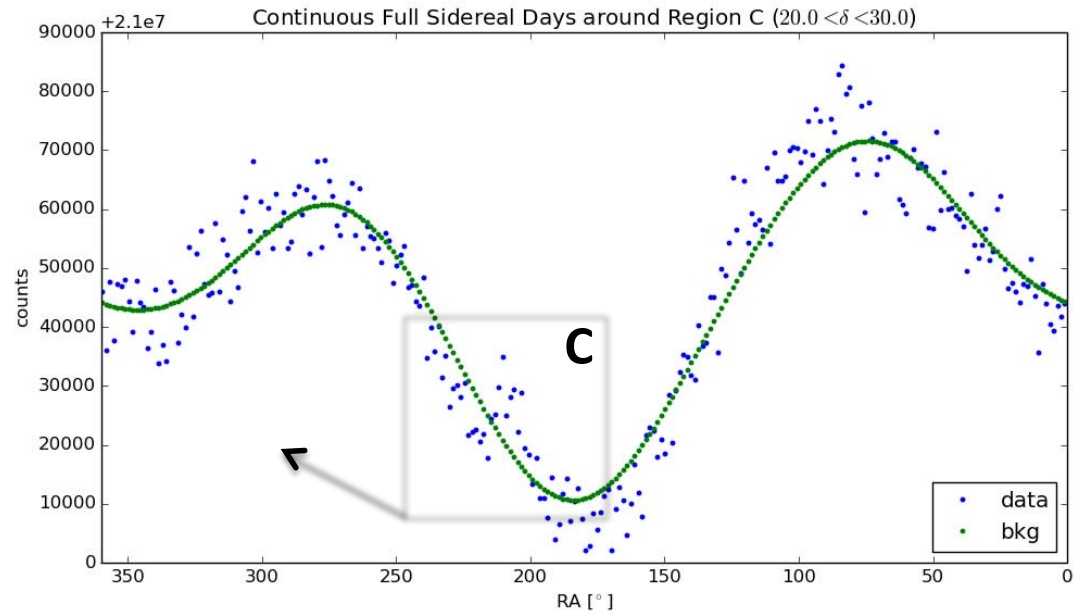
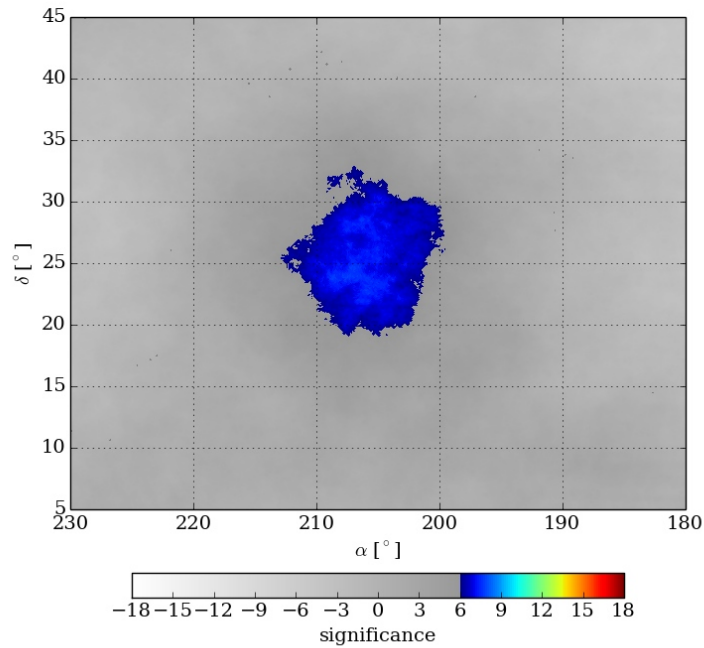


Far south for Milagro and ARGO
(35°N and 30°N latitude)

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

Milagro saw cutoff at $\sim 4 - 20$ TeV

Region C



Consistent with excess seen in ARGO
 Not present in Milagro

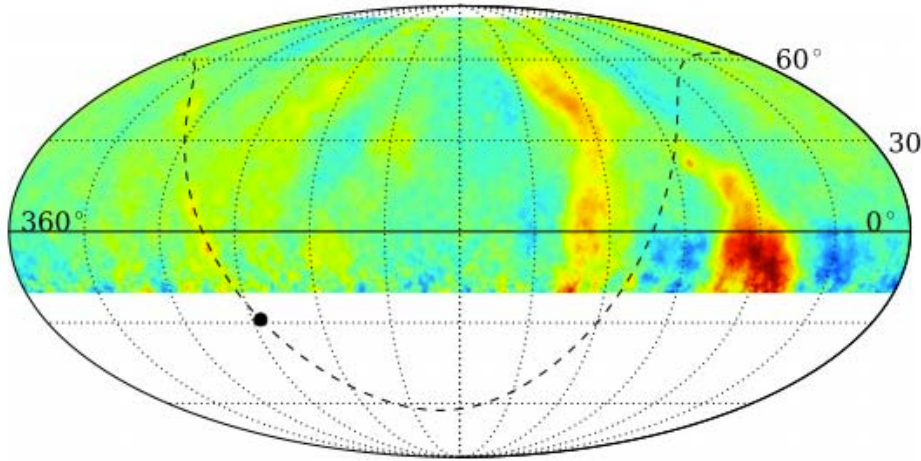
Sits in large-scale minimum

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

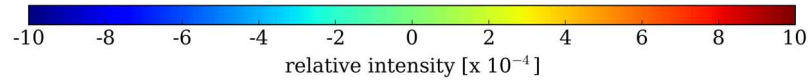
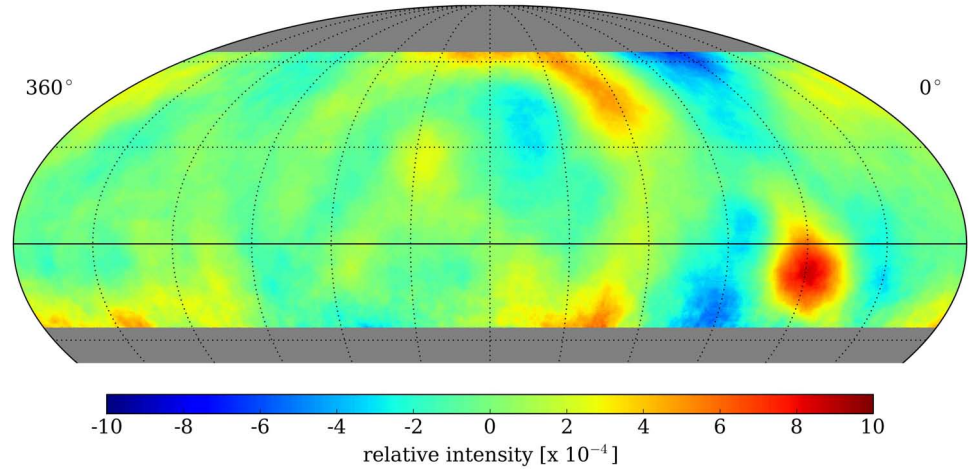
7.9σ pre-trials ($> 5\sigma$ post-trials)

Comparisons

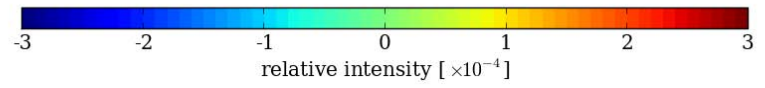
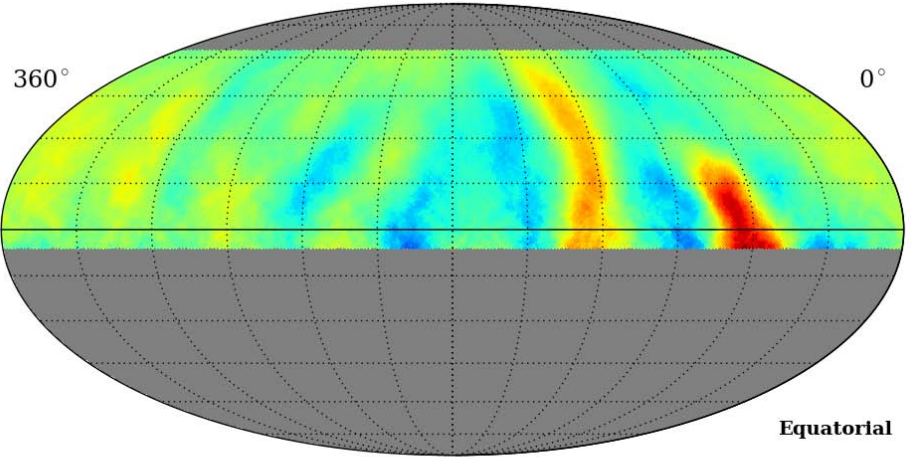
ARGO



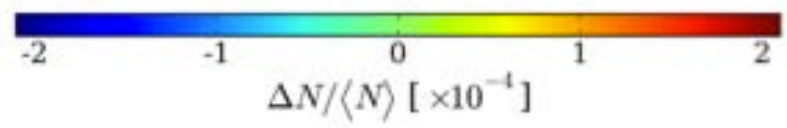
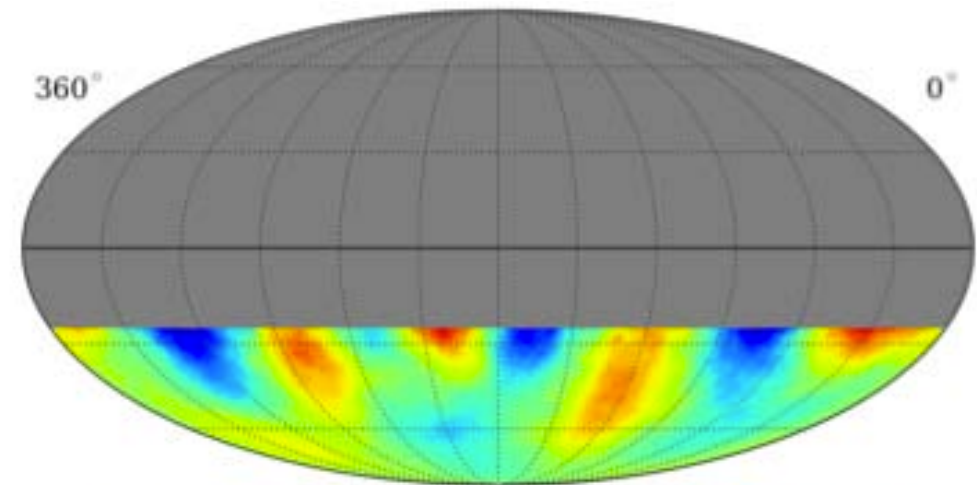
HAWC

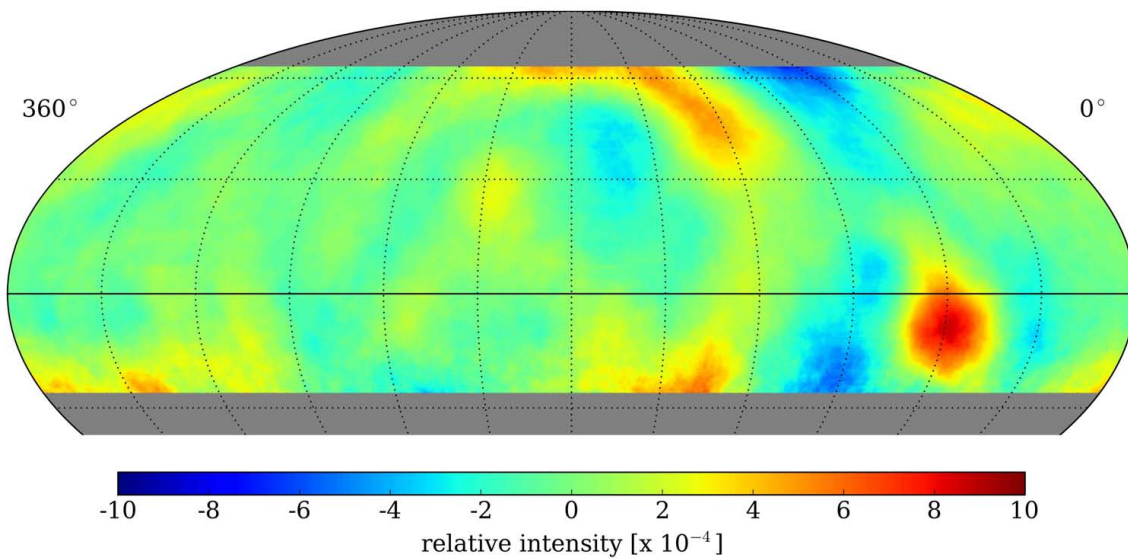


Milagro

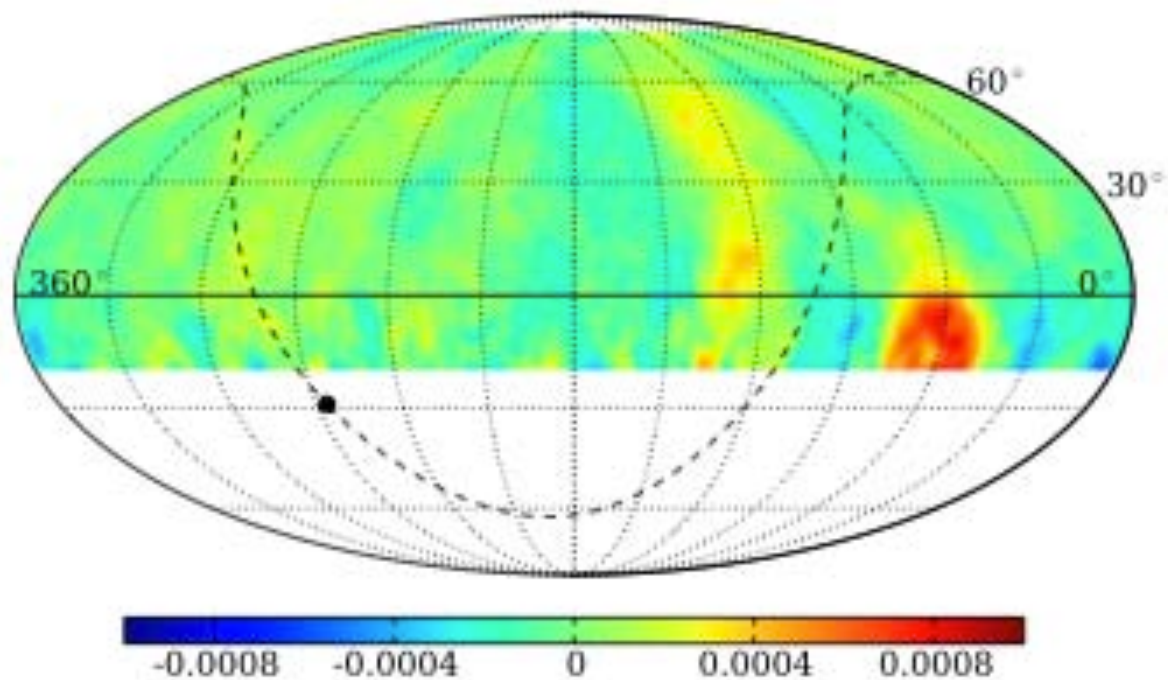


IceCube





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

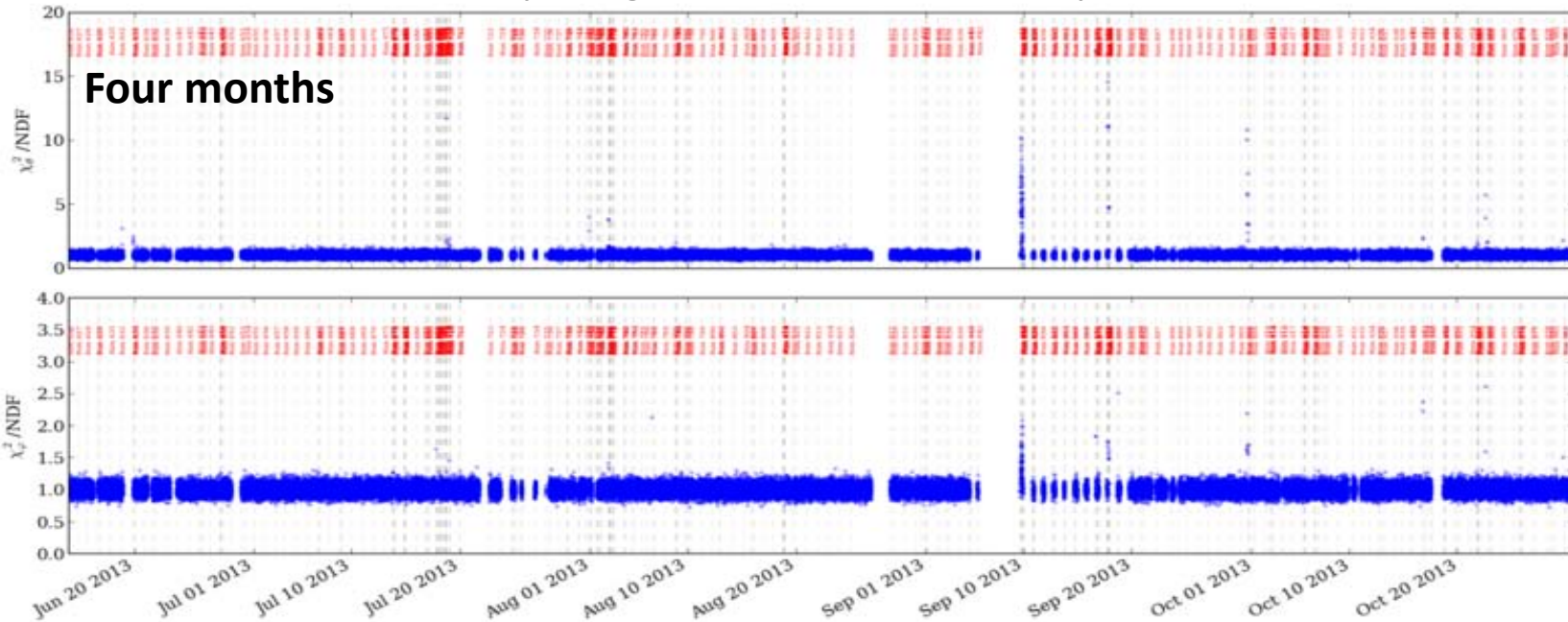
Energy-dependent study is coming soon

Begin back-up slides

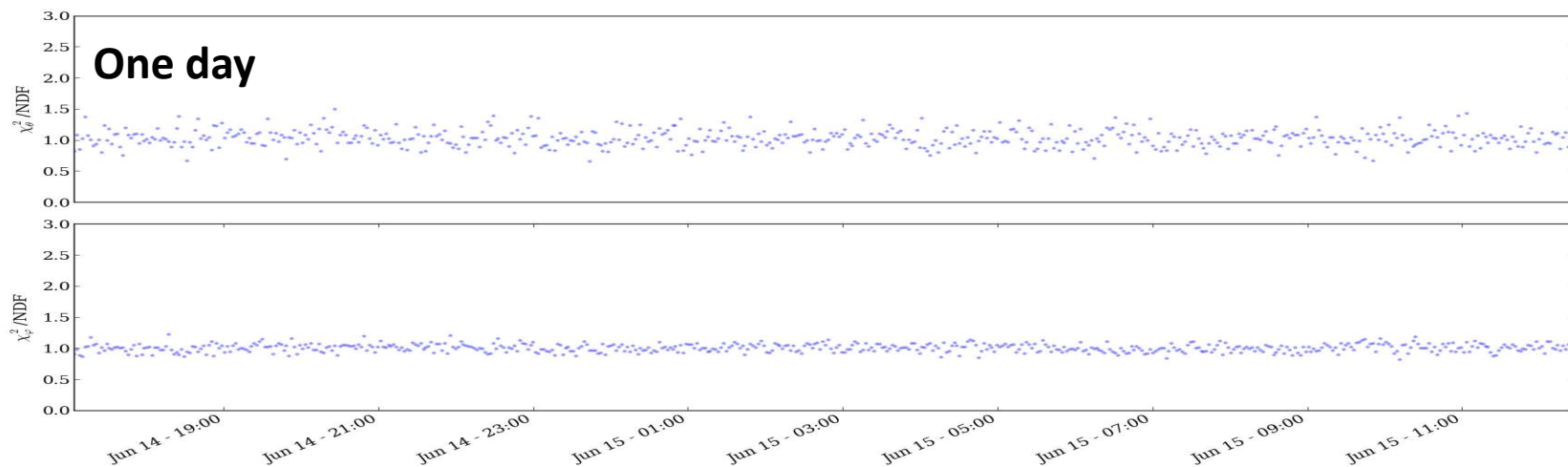
Data Stability

Reduced Chi-Squared Comparing subrun of data to the previous

Zenith
Angle
Distrib.

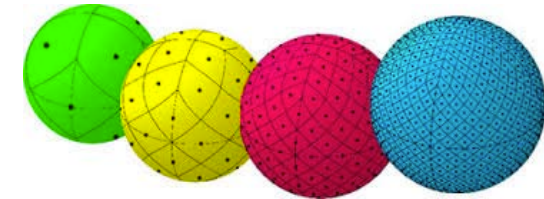


Azimuth
Angle
Distrib.



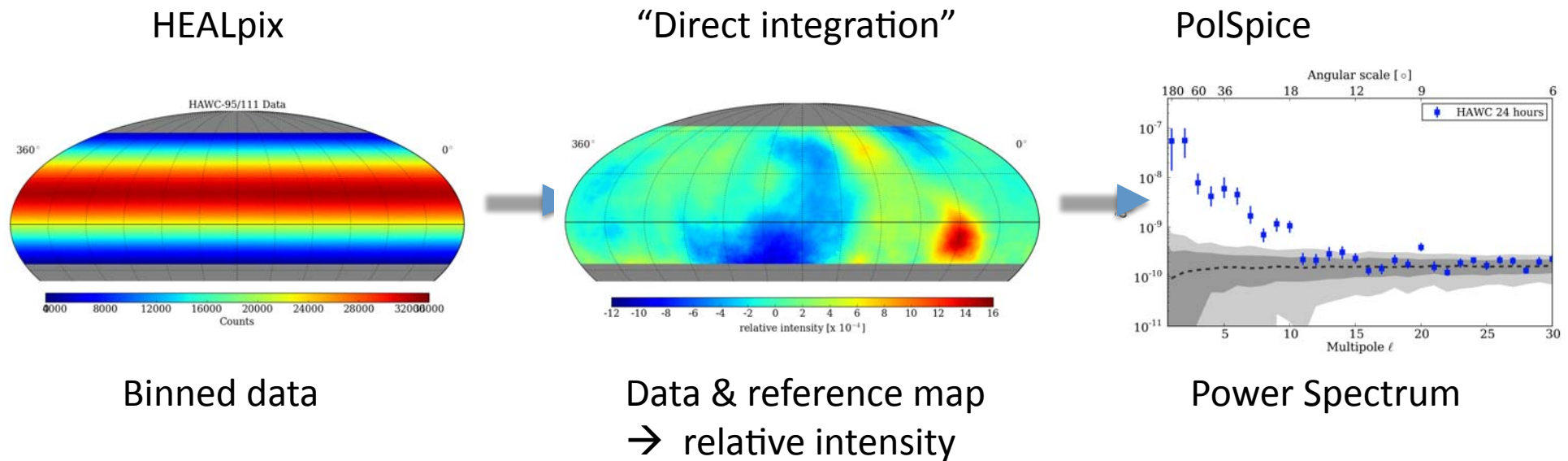
Analysis Technique

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



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*

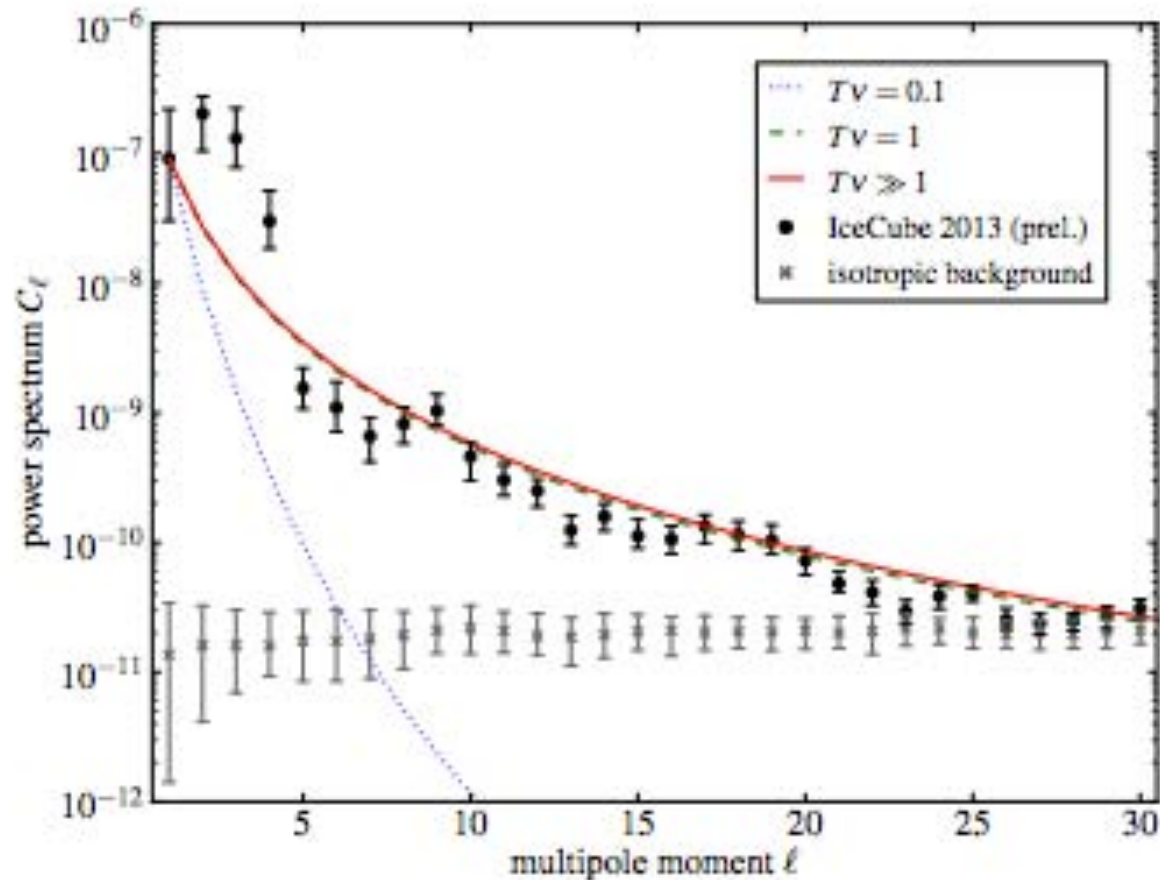
Phys. Rev. Lett 112, 021101 (2014) [arXiv:1310.5712](#)

Energy-depedent
small-scale

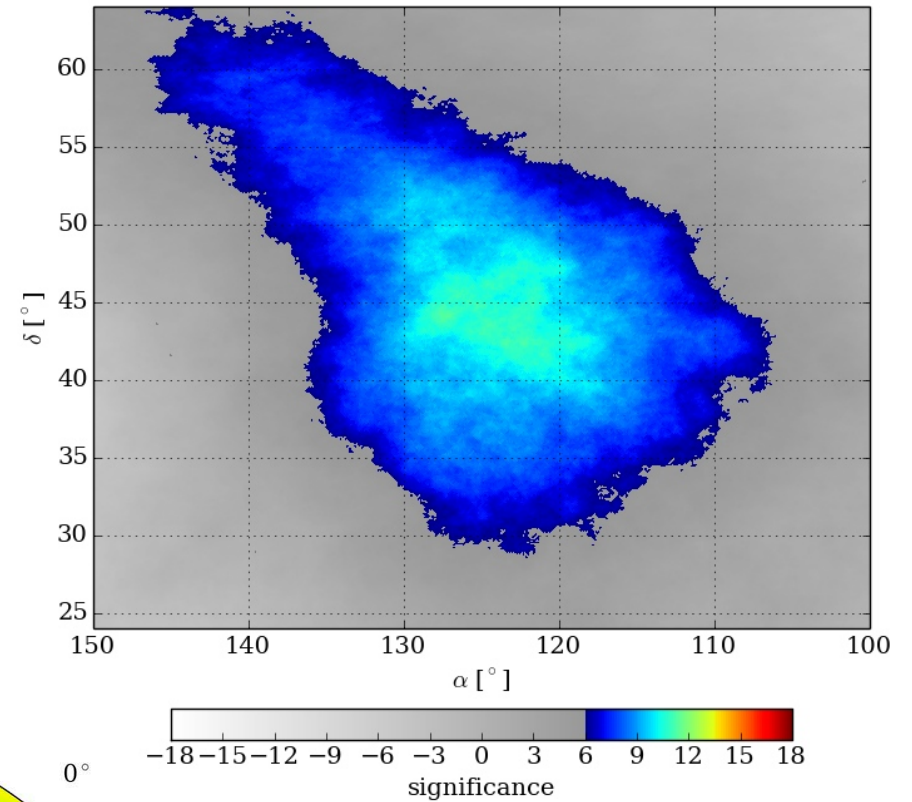
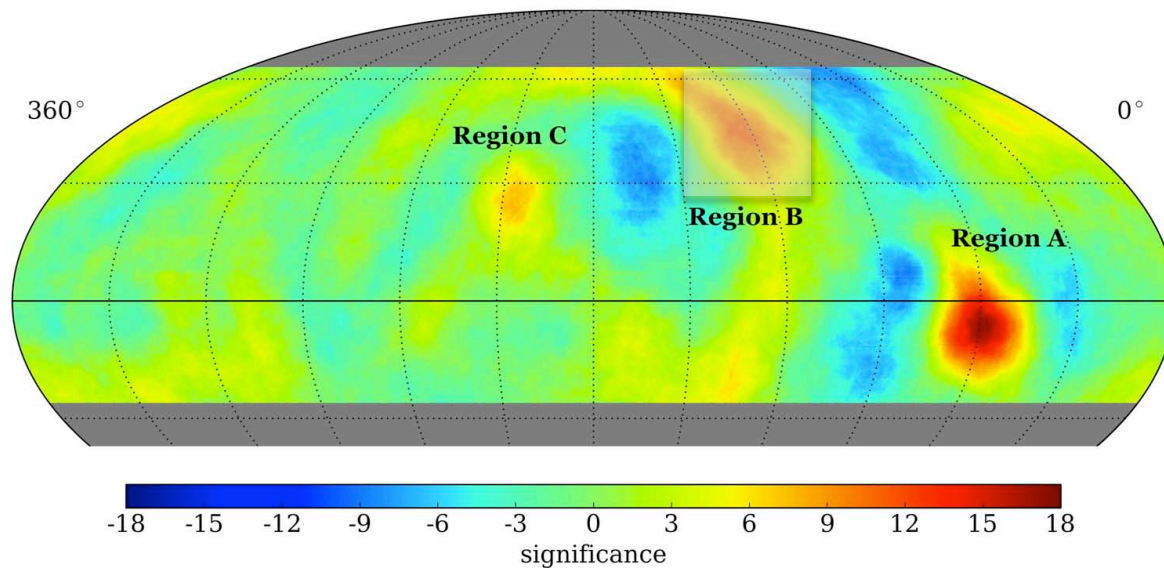
Calculation is best tied
to strength of dipole

HAWC \neq 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