ARGO实验大尺度各向异性研究

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LHAASO合作组会议
南开大学，2016.08

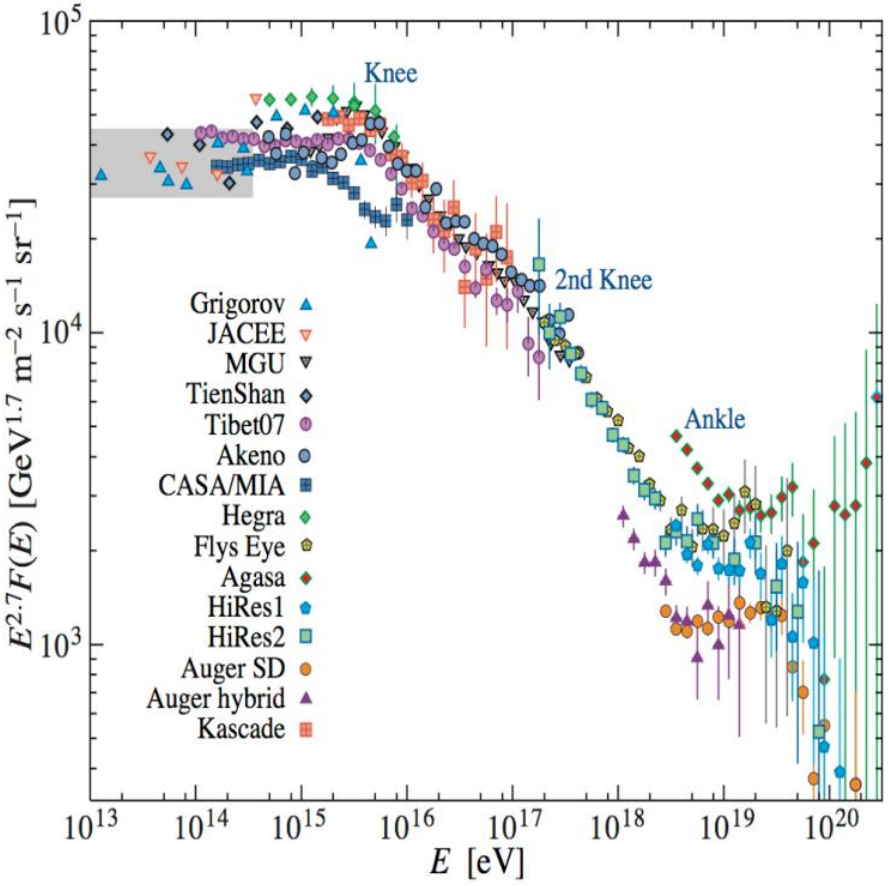
内容介绍

- 实验观测大尺度各向异性进展
- argo实验简单介绍
- 大尺度各向异性观测结果
  - 2008-2009年能量依赖效应
  - 2008-2012年长时间年变化效应
- 中小尺度各向异性测量
- 小结

物理背景

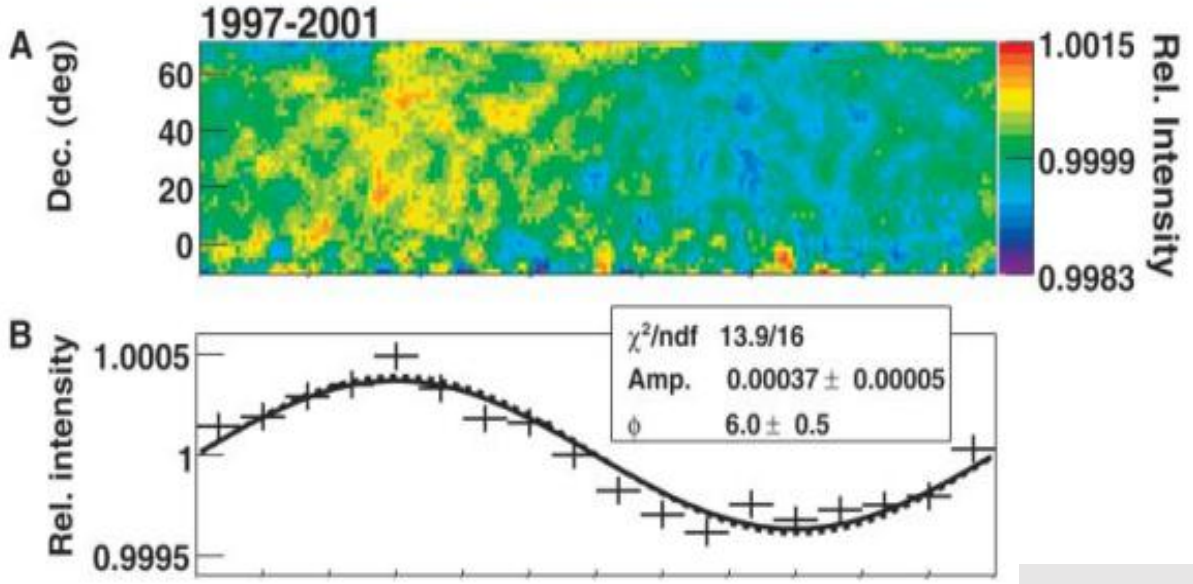
- 宇宙线以带电粒子为主，伴有少量的中性粒子（γ光子，中微子等）
- 宇宙线在很宽的能量范围内呈幂律分布

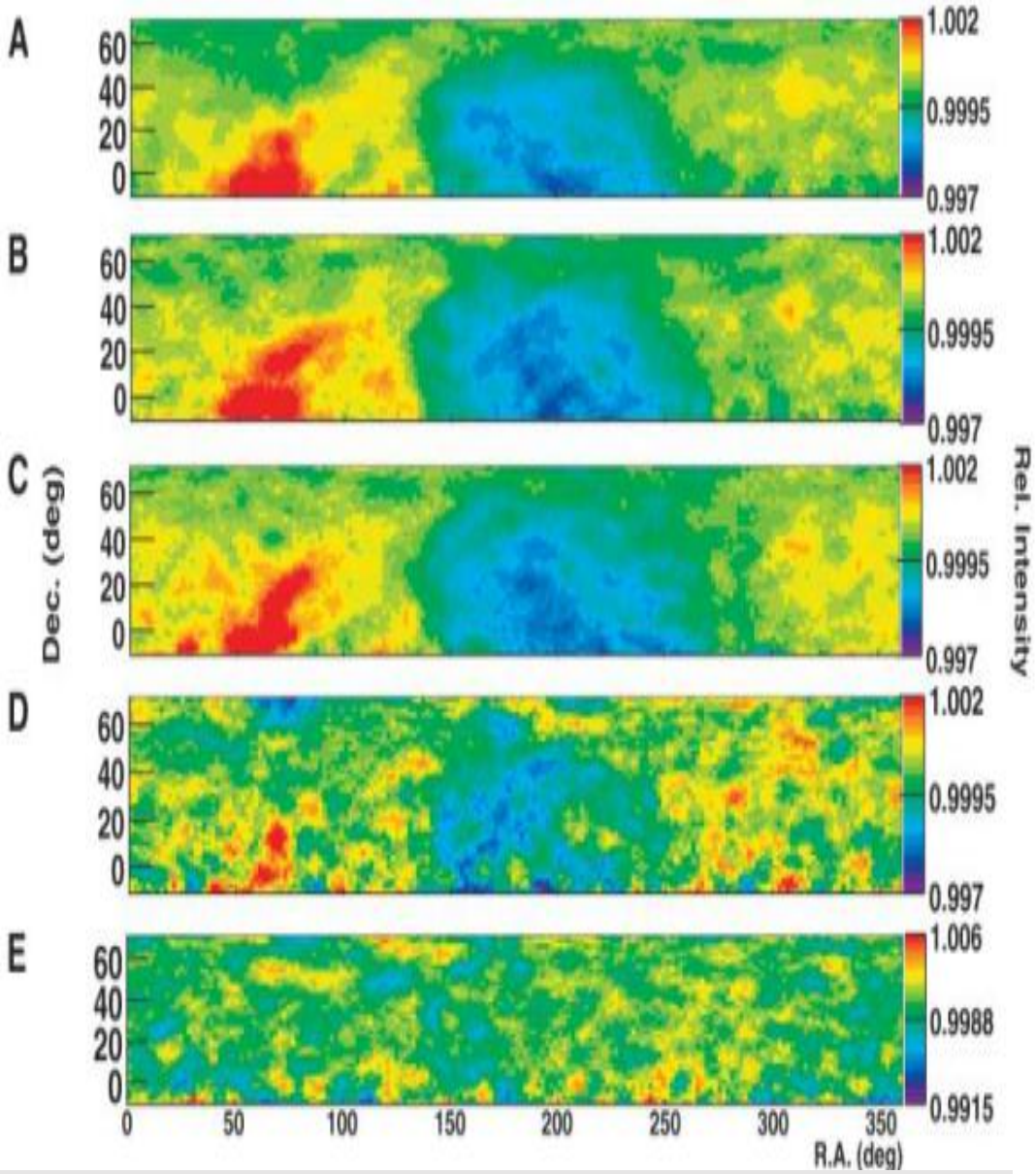
  - 能谱分布联系着宇宙线的起源、加速和传播信息。——负幂律分布：
    - 起源：太阳、超新星（SNR）、脉冲星——河内，AGN、GRB——河外
    - 加速：激波加速、电磁场加速
    - 传播：星际磁场偏转，星际介质相互作用



大尺度各向异性的观测结果

- Tibet ASγ
- Energy~3TeV
- 1997-2005





Amenomori, M., Ayabe, S., Bi, X. J., et al. 2006, Science, 314, 439

Milagro result

- Energy~6TeV
- 2000-2007

The Astrophysical Journal, 698:2121–2130, 2009 June 20

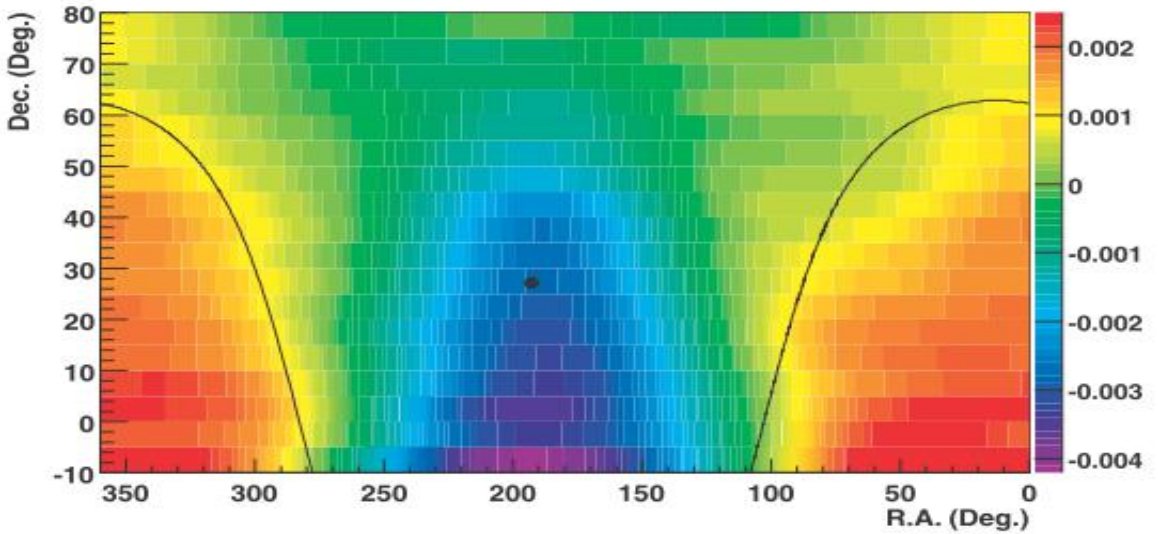
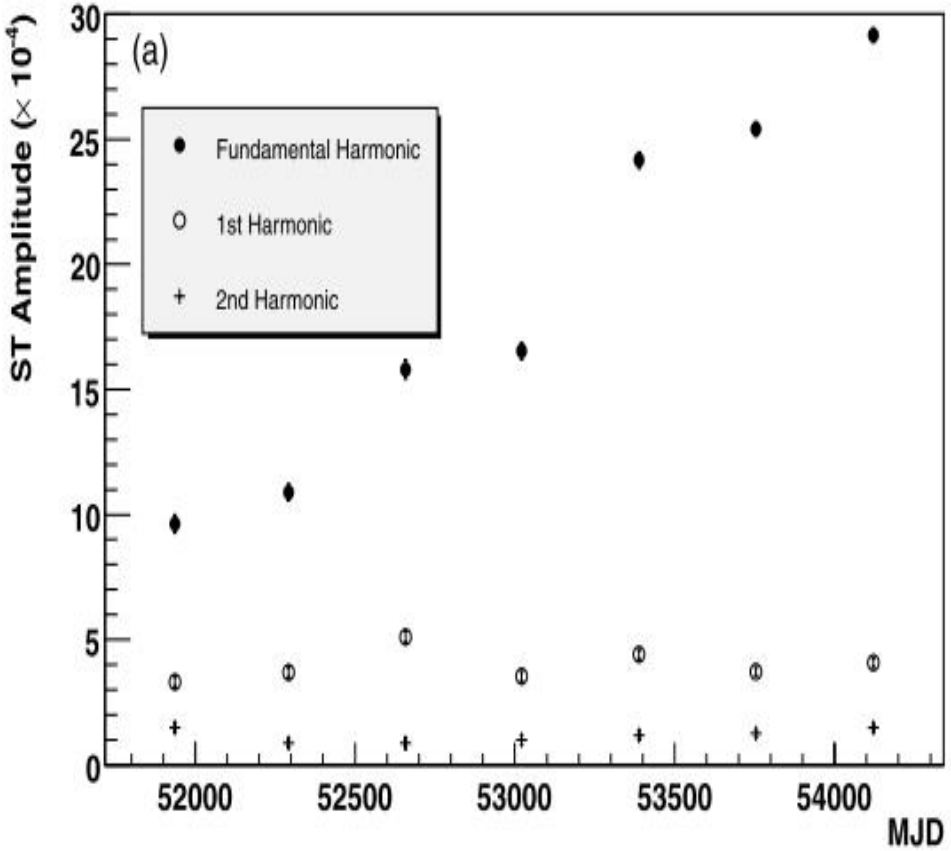


Figure 7. Result of a harmonic fit to the fractional difference of the CR rates from isotropic in equatorial coordinates as viewed by Milagro for the years 2000–2007. The color bin width is 1.0×10^{-4} reflecting the average statistical error. The two black lines show the position of the Galactic equator and the solid circle shows the position of the Galactic north pole. This map is constructed by combining 18 individual profiles of the anisotropy projection in R.A. of width 5° in decl. It is not a two-dimensional map of the sky. The median energy of the events in this map is 6 TeV.



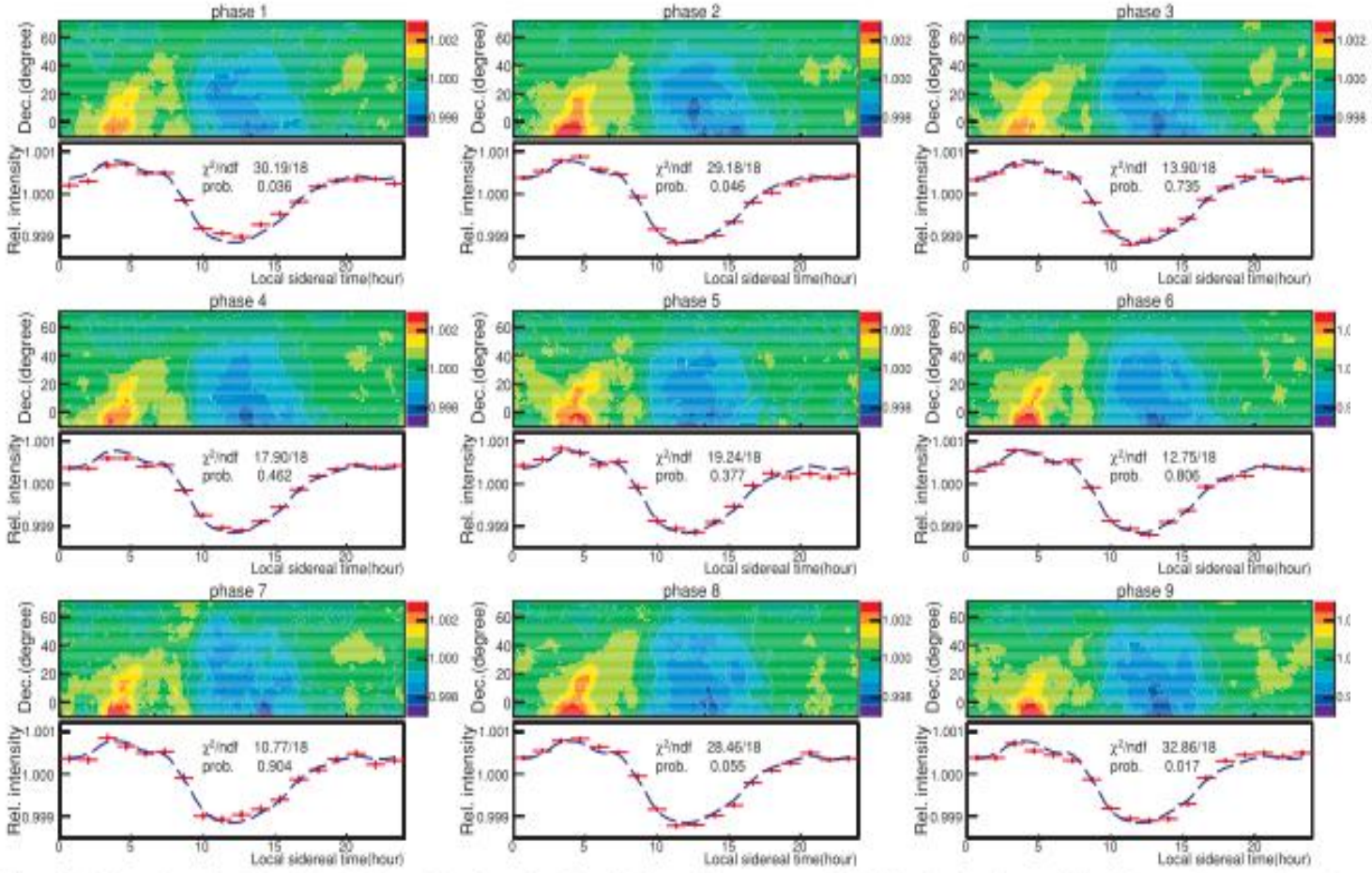
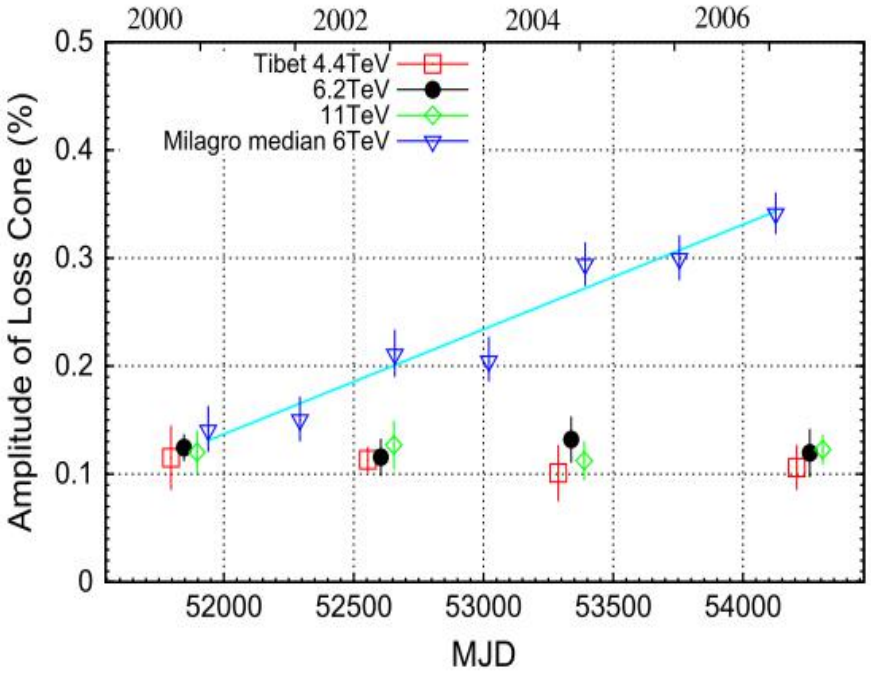


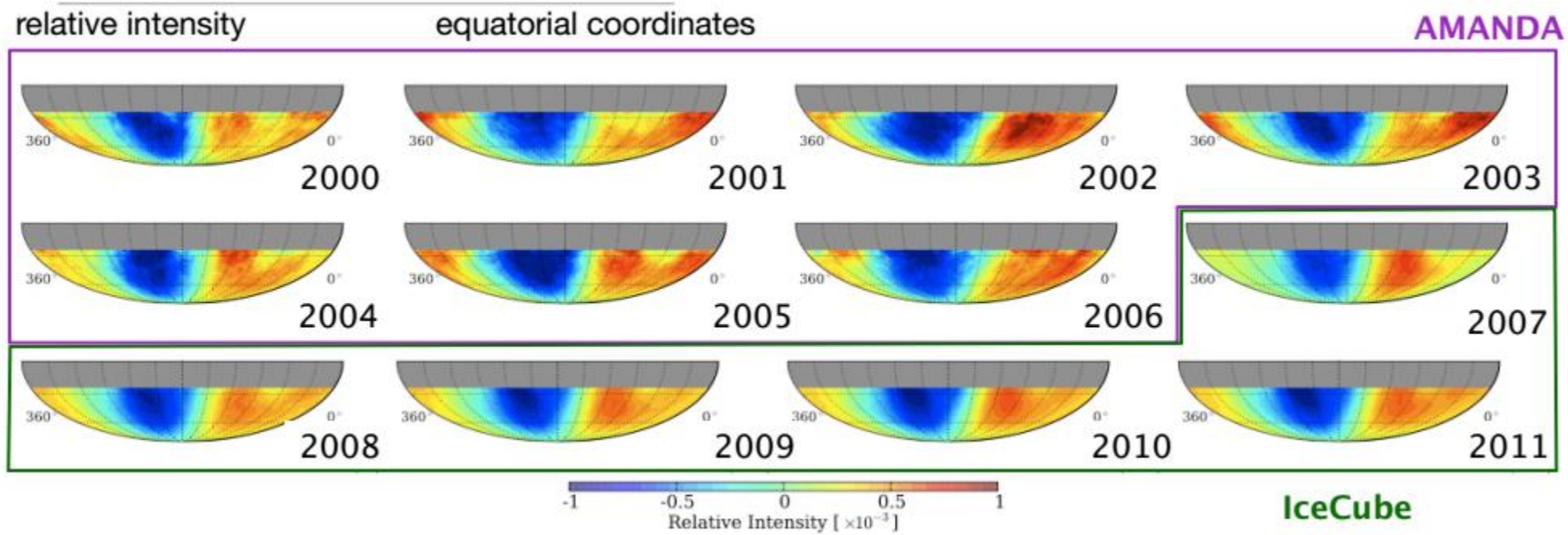
Figure 2. CR intensity variation in the local sidereal time frame for CRs with the modal energy around 5 TeV in the nine phases of Tibet III array. Top: two-dimensio intensity map of each phase; Bottom: one-dimensional projection averaged over all declinations. In bottom plots of each panel, the red crosses in each plot show t intensity variation over each phase respectively, while the dashed blue lines represent the intensity averaged over all nine phases of Tibet III array.

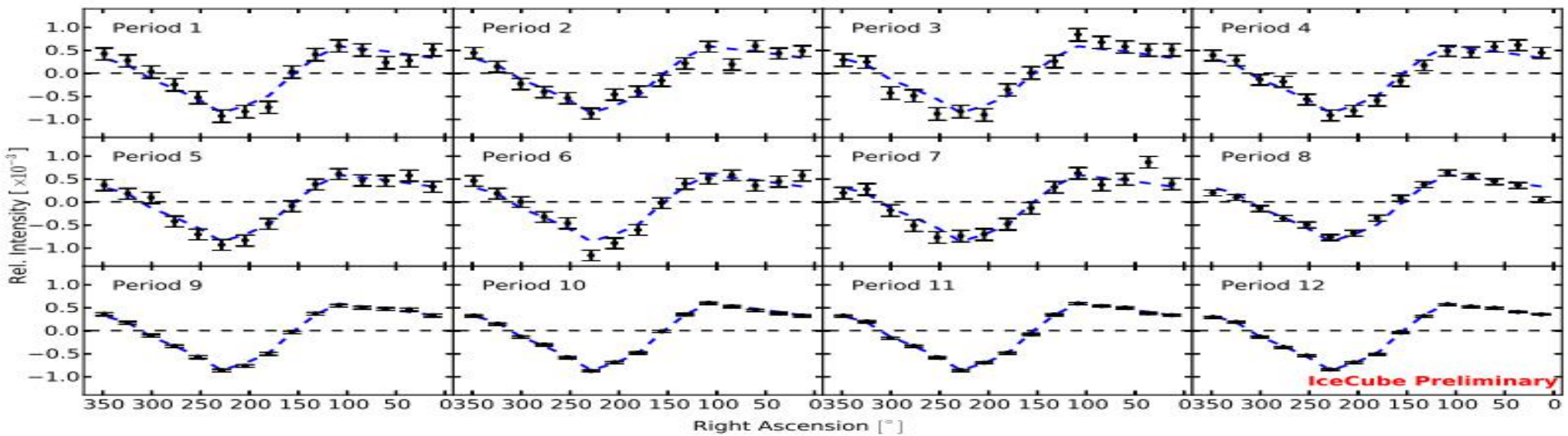
Tibet AS γ 实验结果



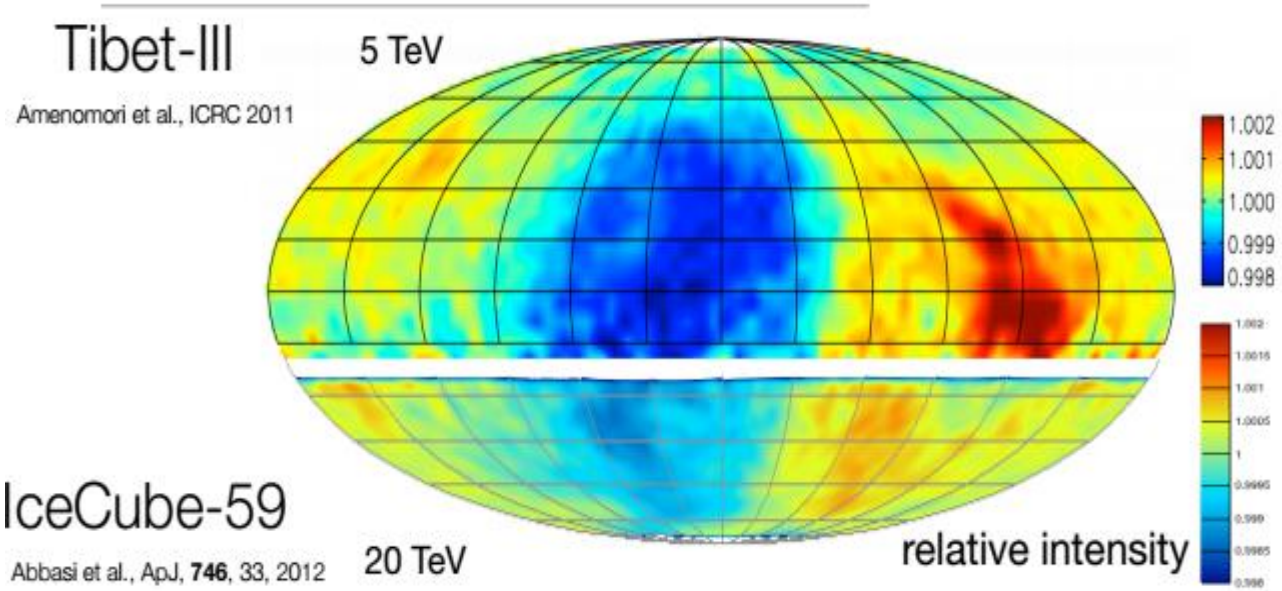
The Astrophysical Journal, 711:119–124, 2010 March 1

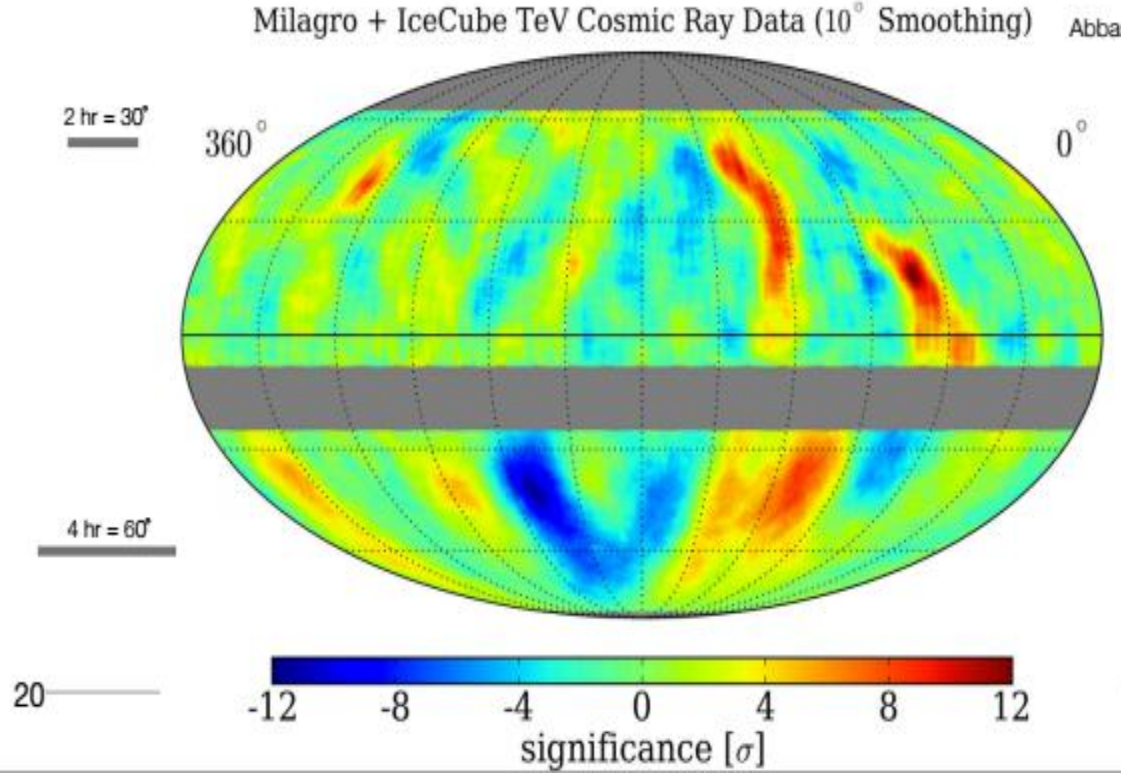
Observation of TeV-PeV cosmic ray anisotropy with IceCube, IceTop and AMANDA(arXiv:1308.0246)





南北半球观测天区各向异性结构相同





Milagro 1 TeV
Abdo et al., PRL, 101, 221101, 2008

IceCube-59 20 TeV
Abbasi et al., ApJ, 740, 16, 2011

南北半球观测天区中等尺度各向异性结构分布略有差异

equatorial coordinates

ICETOP实验结果

ICECUBE实验结果

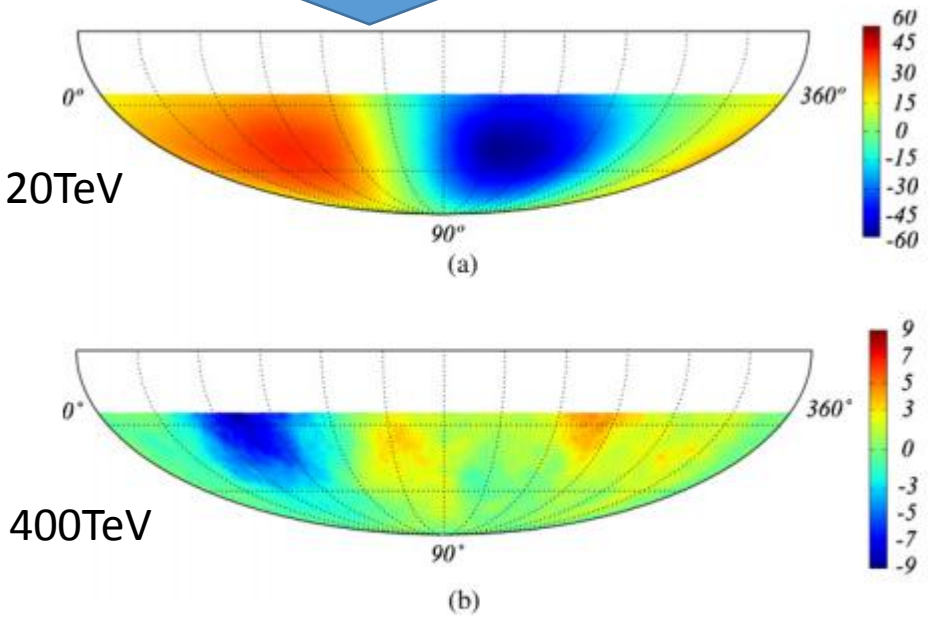


Figure 7. Panel (a) shows the pre-trial significance map for the 20 TeV energy band plotted with 30 deg smoothing. Panel (b) shows the pre-trial significance map for the 400 TeV energy band plotted with 20 deg smoothing.

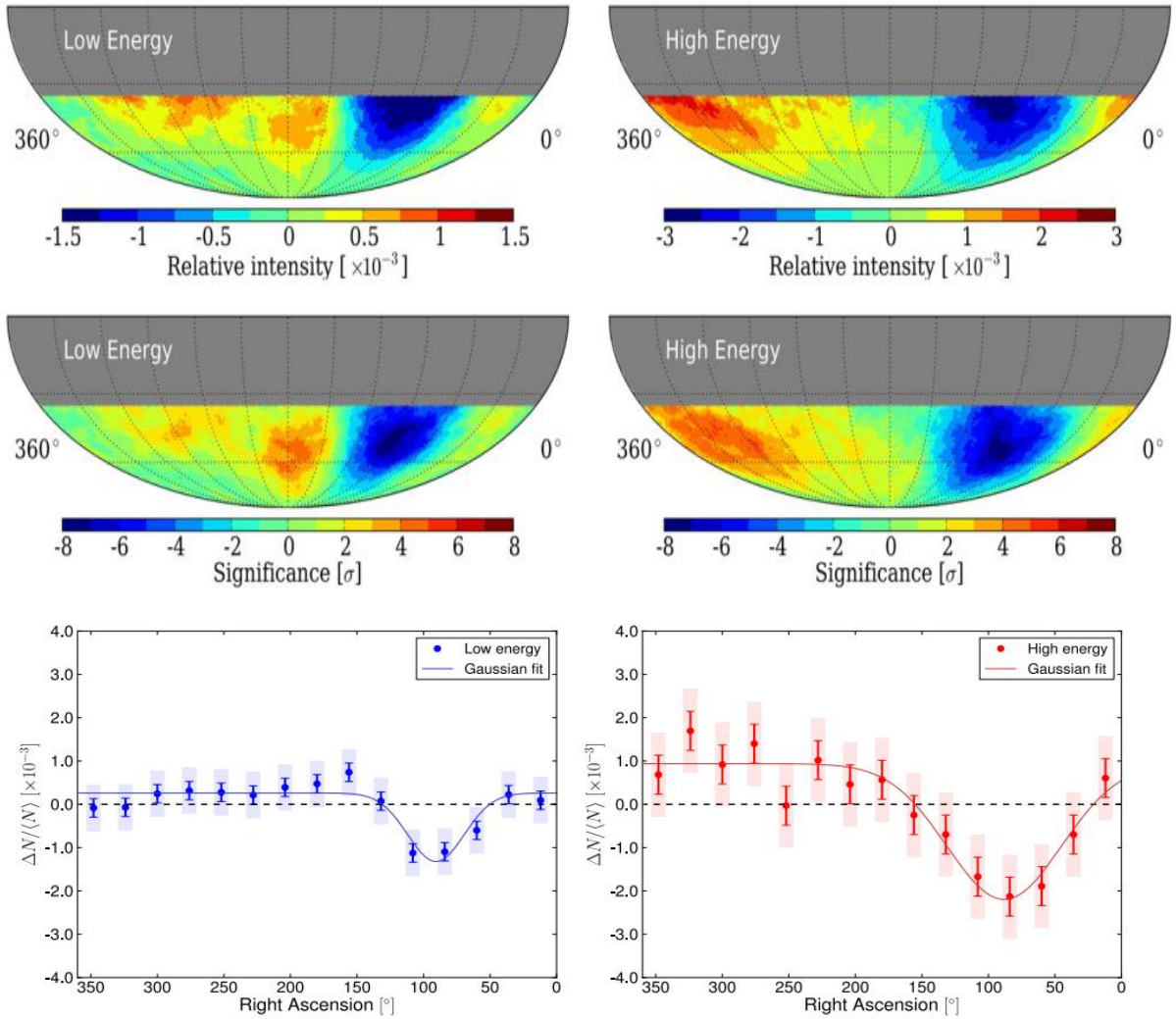
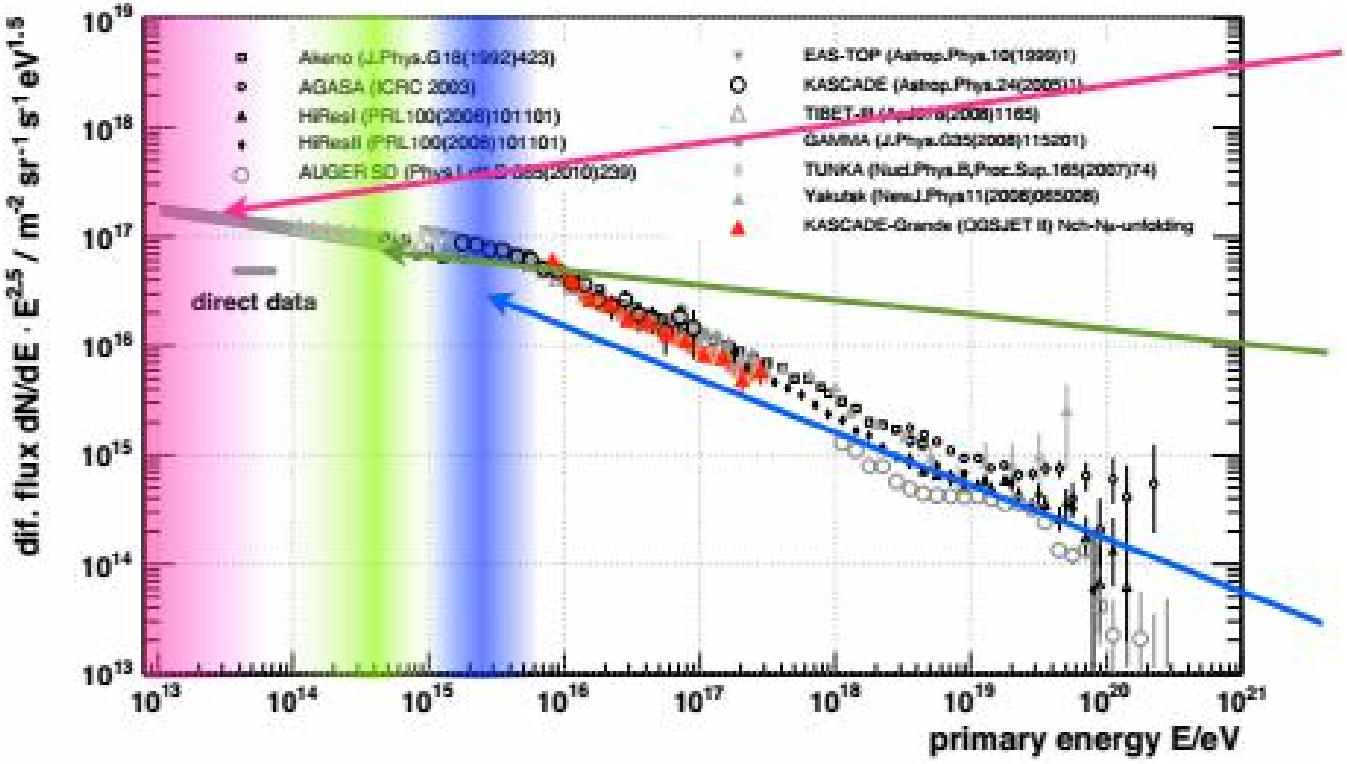


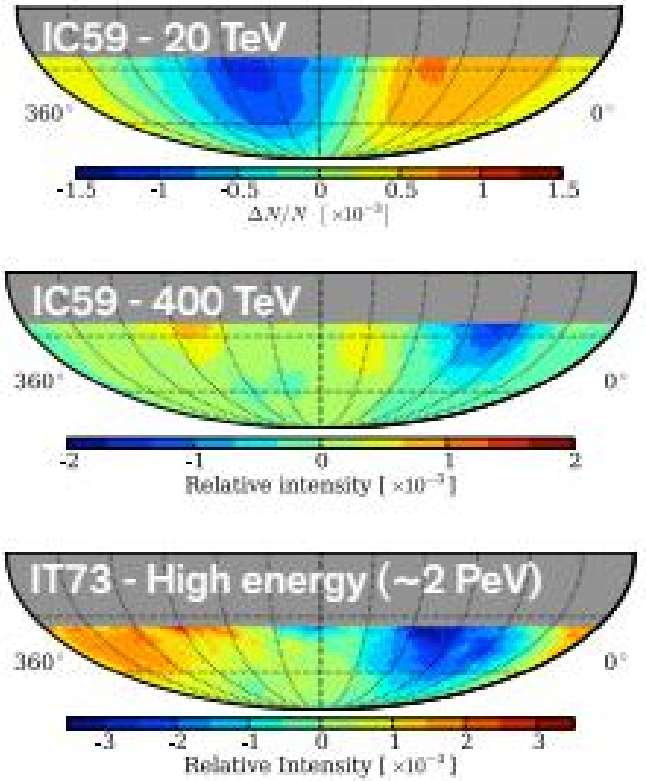
Figure 7. Relative intensity as a function of right ascension for the low-energy (left) and high-energy (right) data samples in the declination band $-75° < \delta < -35°$. The error bars are statistical, while the colored boxes indicate the systematic uncertainty obtained from analyzing the same data in the anti-sidereal time frame (see Section 4 for details). The result of a fit using the Gaussian function given in Equation (3) to both energy bands is also shown.

(A color version of this figure is available in the online journal.)

The Astrophysical Journal, 746:33 (11pp), 2012 February 10

The Astrophysical Journal, 765:55 (9pp), 2013 March 1





- Anisotropy changes in position, size
- Above 400 TeV there's indication of an increase in strength.

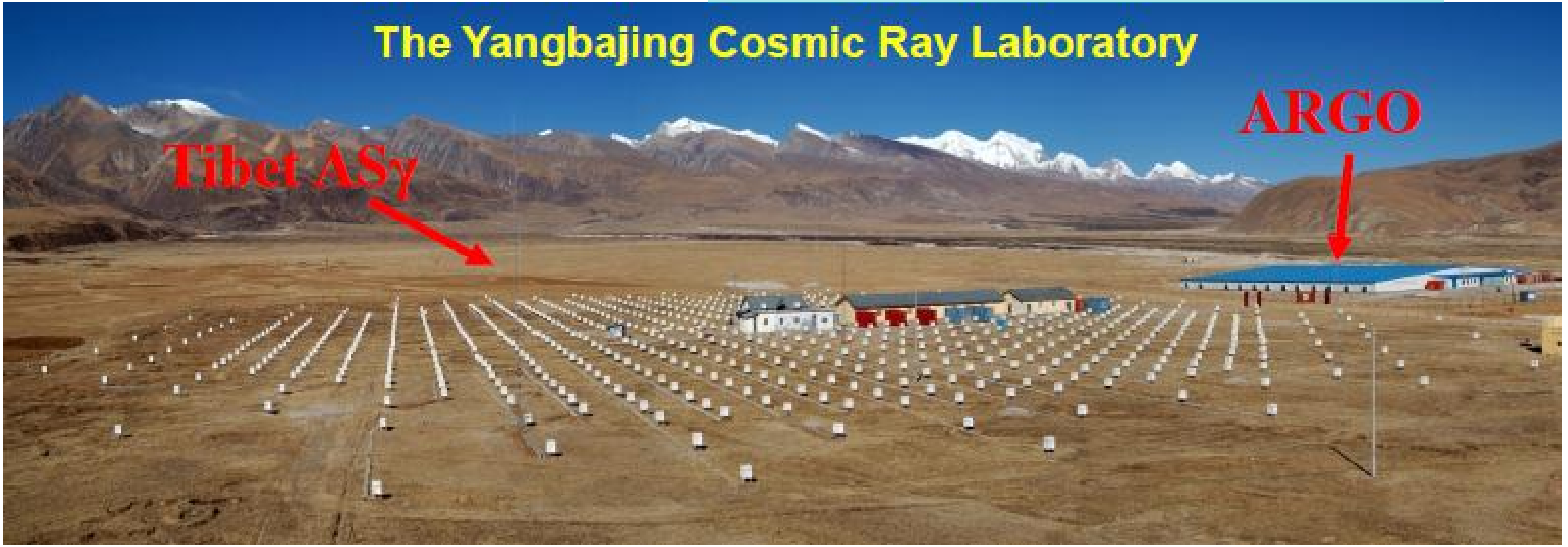
Summary of observed LS anisotropy

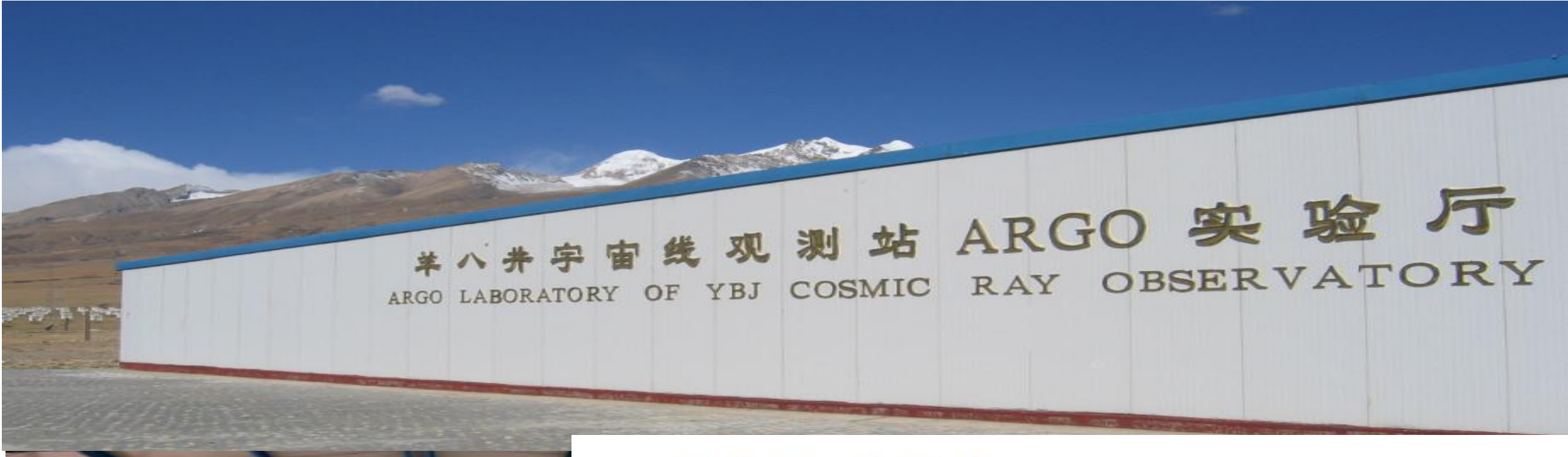
- 在(百GeV~ 几十TeV)能区，各家实验观测到一个大体相同的各向异性结构，
- 扣除掉大尺度结构后，一些中尺度或者略小尺度结构值得注意
- 各向异性结构随时间的变化大家的观点还不太一致。
- 几百TeV~PeV能区ICECUBE观测到不同的大尺度各向异性结构

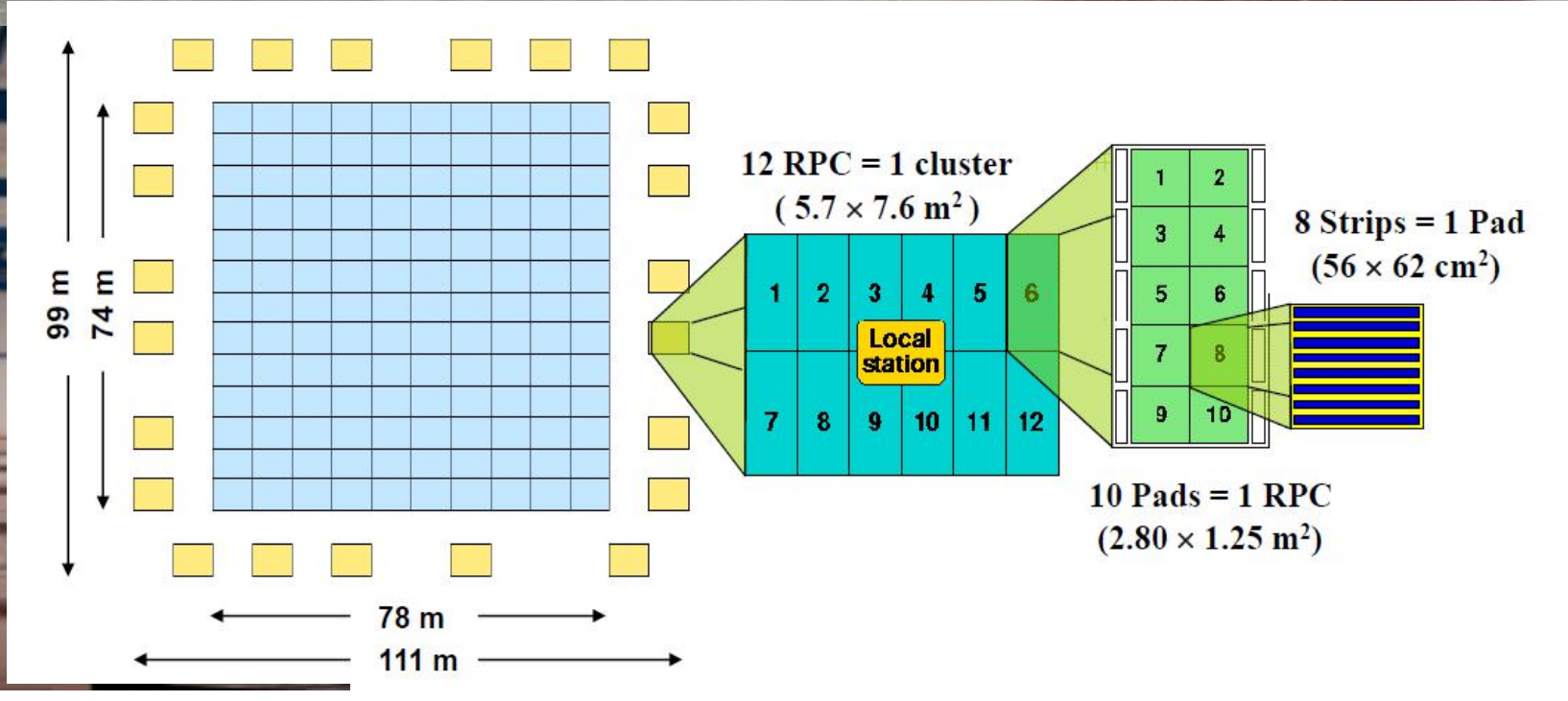
羊八井ARGO-YBJ实验

羊八井国际宇宙线观测站（北纬30° 06’ 38 ”， 东经90° 31’ 50”， 海拔4300米）

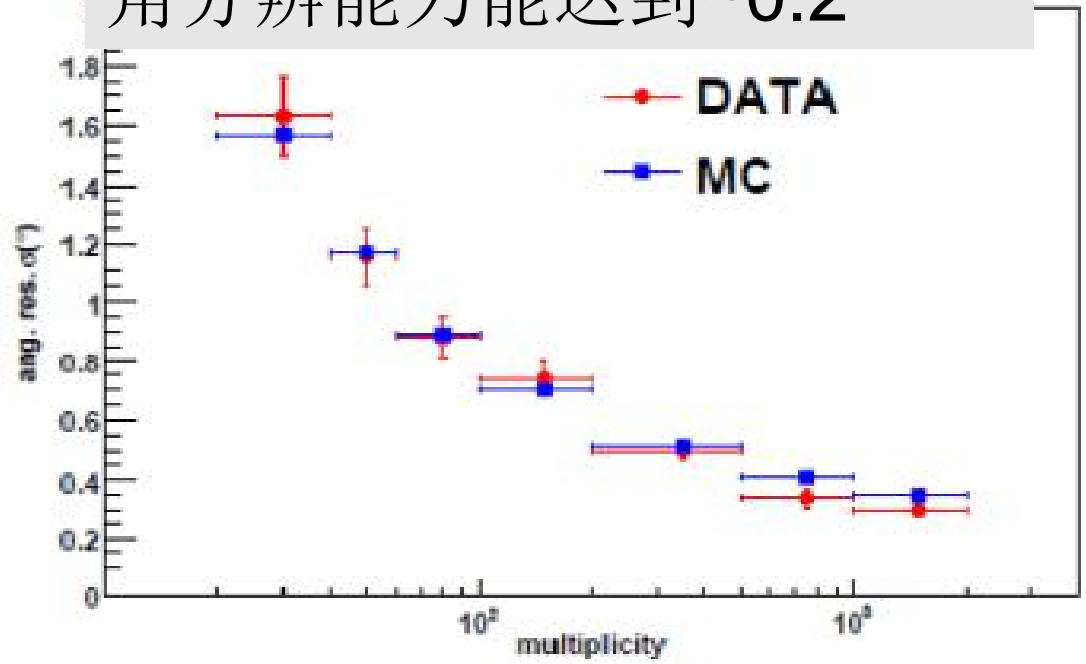
优势： 高海拔、全覆盖、全天候、大视场

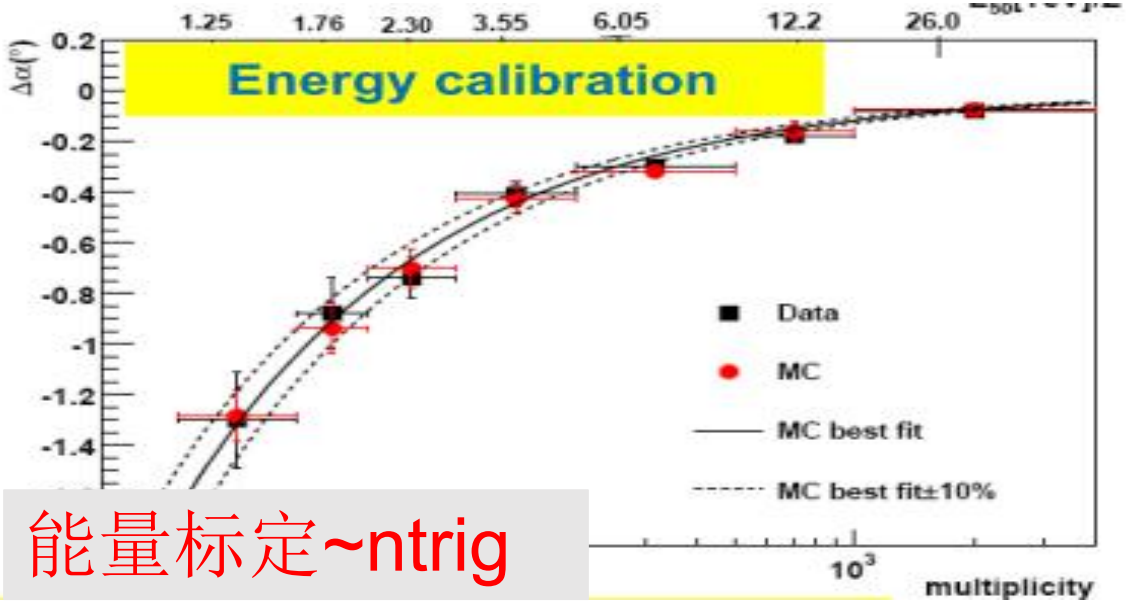



羊八井宇宙线观测站 ARGO 实验厅
ARGO LABORATORY OF YBJ COSMIC RAY OBSERVATORY


99 m
74 m
78 m
111 m
12 RPC = 1 cluster
(5.7 × 7.6 m²)
Local station
8 Strips = 1 Pad
(56 × 62 cm²)
10 Pads = 1 RPC
(2.80 × 1.25 m²)

角分辨能力能达到~0.2°





能量标定~ntrig

- 数据选择:
  - Phase: 2008.01~2012.12 （5 years）
  - Nhits>=40
  - Zenith angle < 45 degree
- 分析方法:
  - 等天顶角方法+χ2 拟合
  - 东西方法检验

事例数：2008: ~ 5.76×10^10

2009: ~ 5.83×10^10

2010: ~ 5.07×10^10

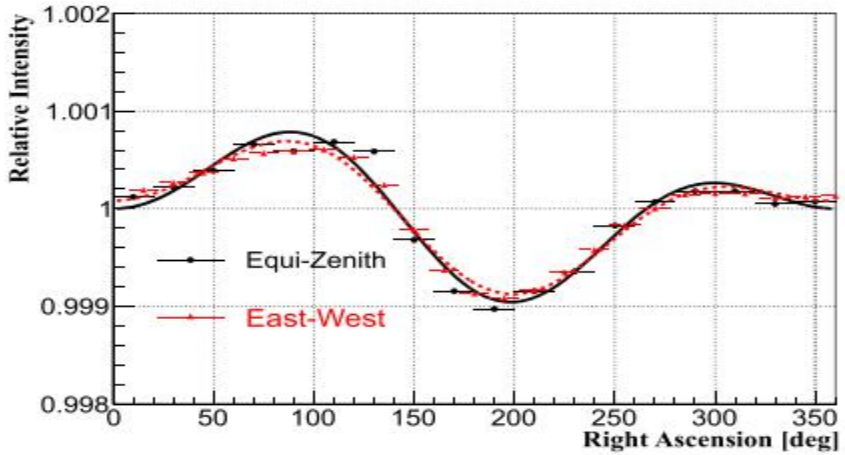
2011: ~ 5.97×10^10

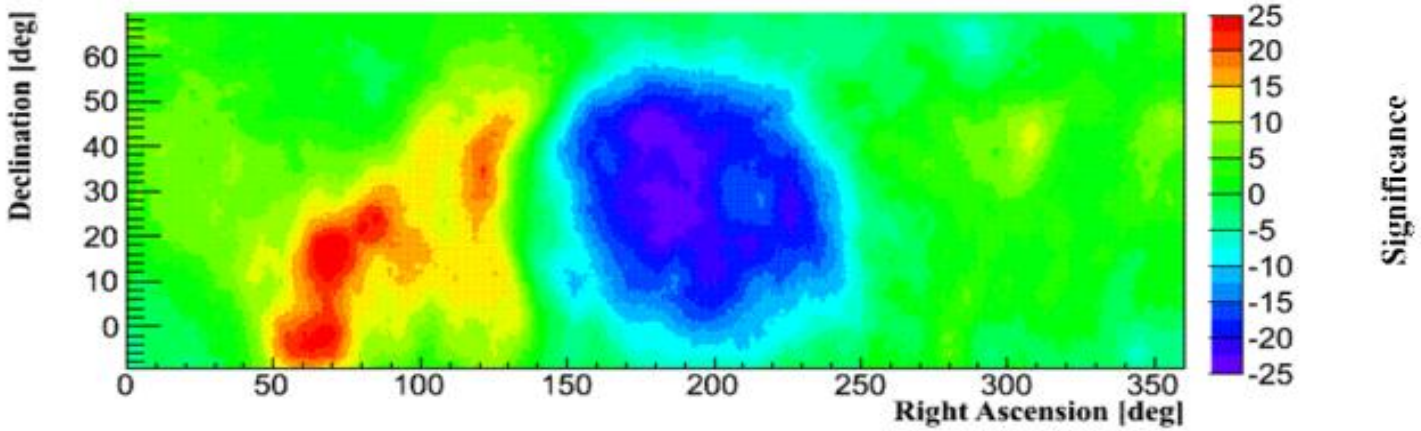
2012: ~ 6.19×10^10

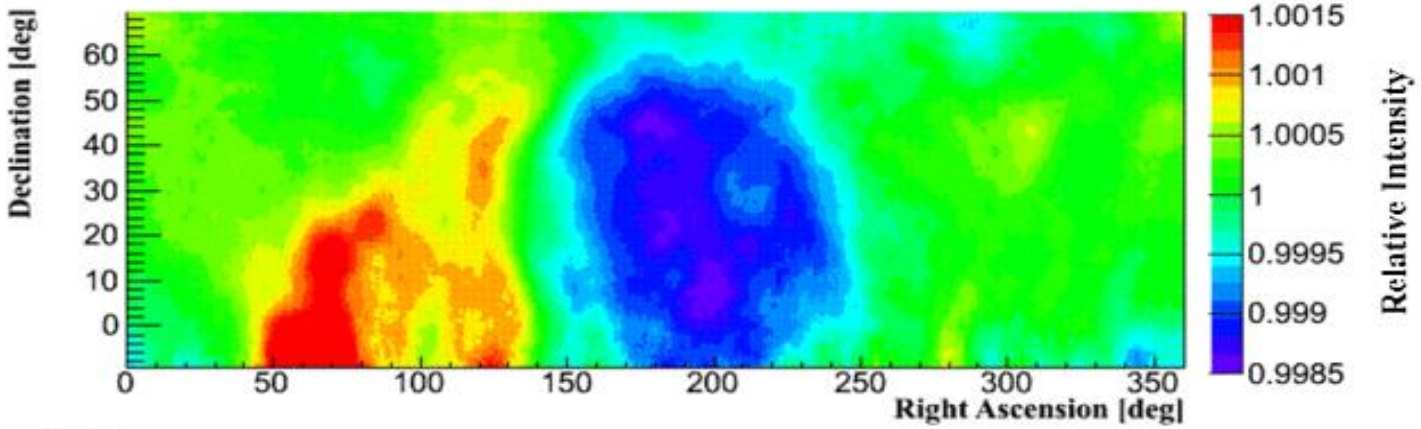
ARGO-YBJ实验结果

- 大尺度各向异性 2008-2009太阳23-24周期平静期的结果
- 2008-2012年的结果。
- 中小尺度的观测结果

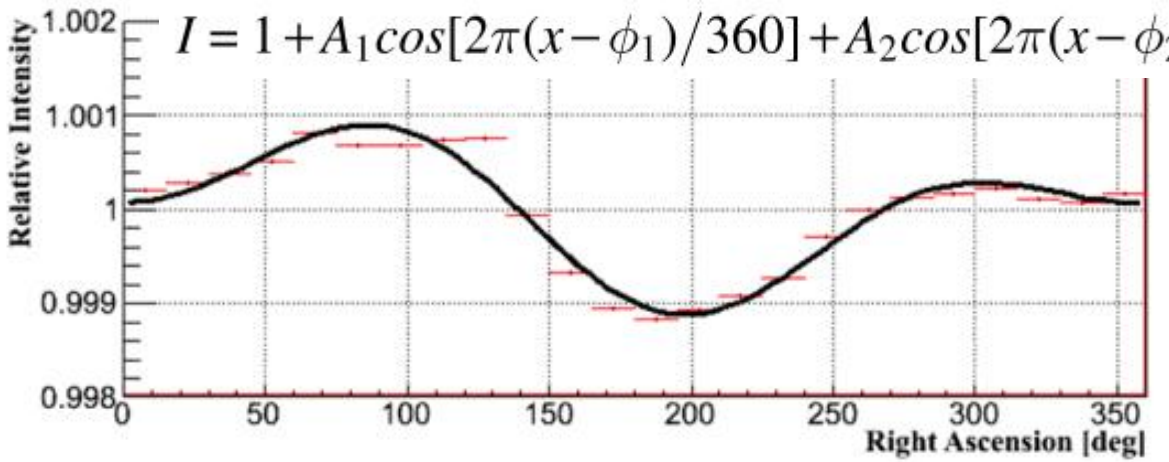
- 2008.01-2009.12



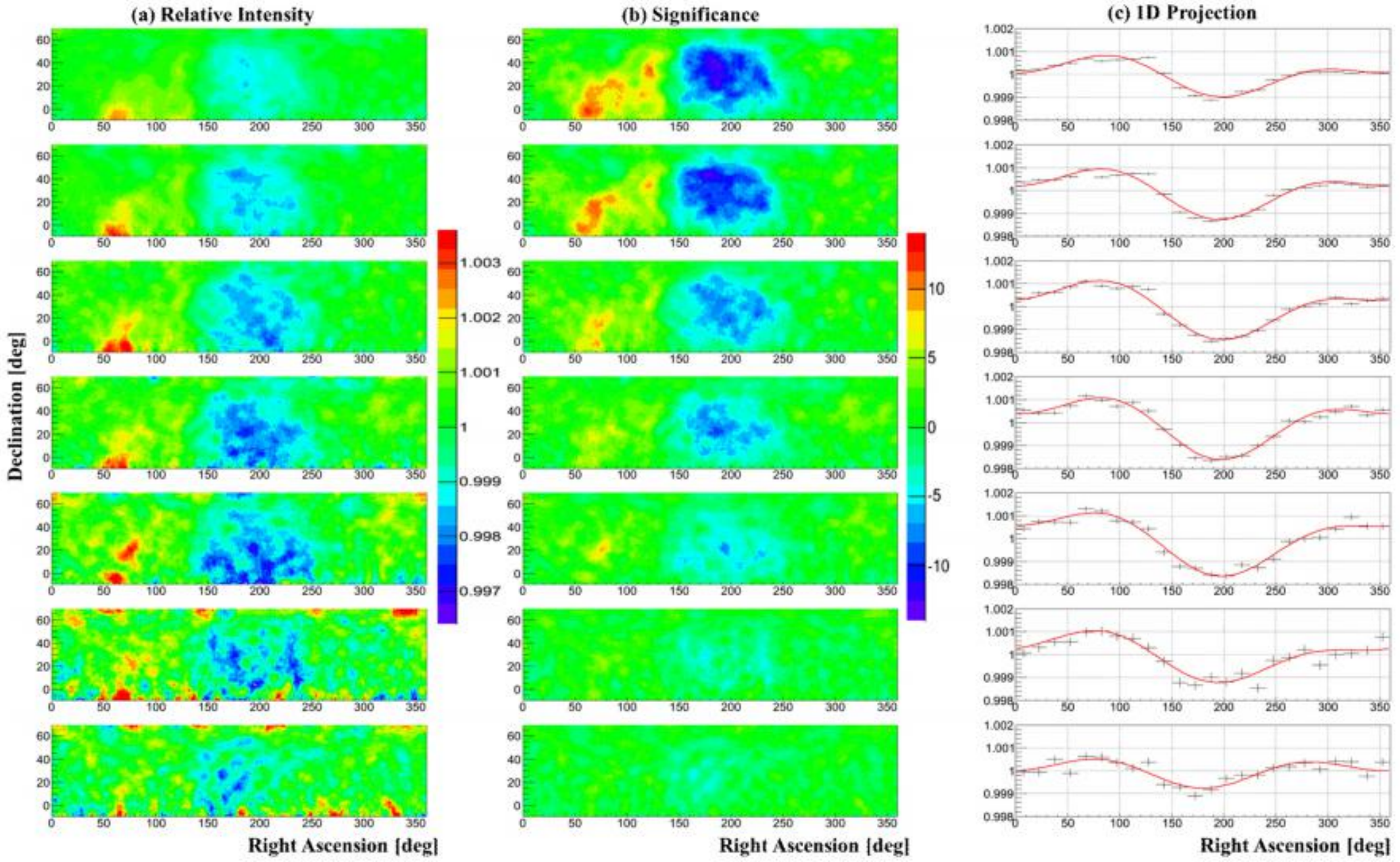


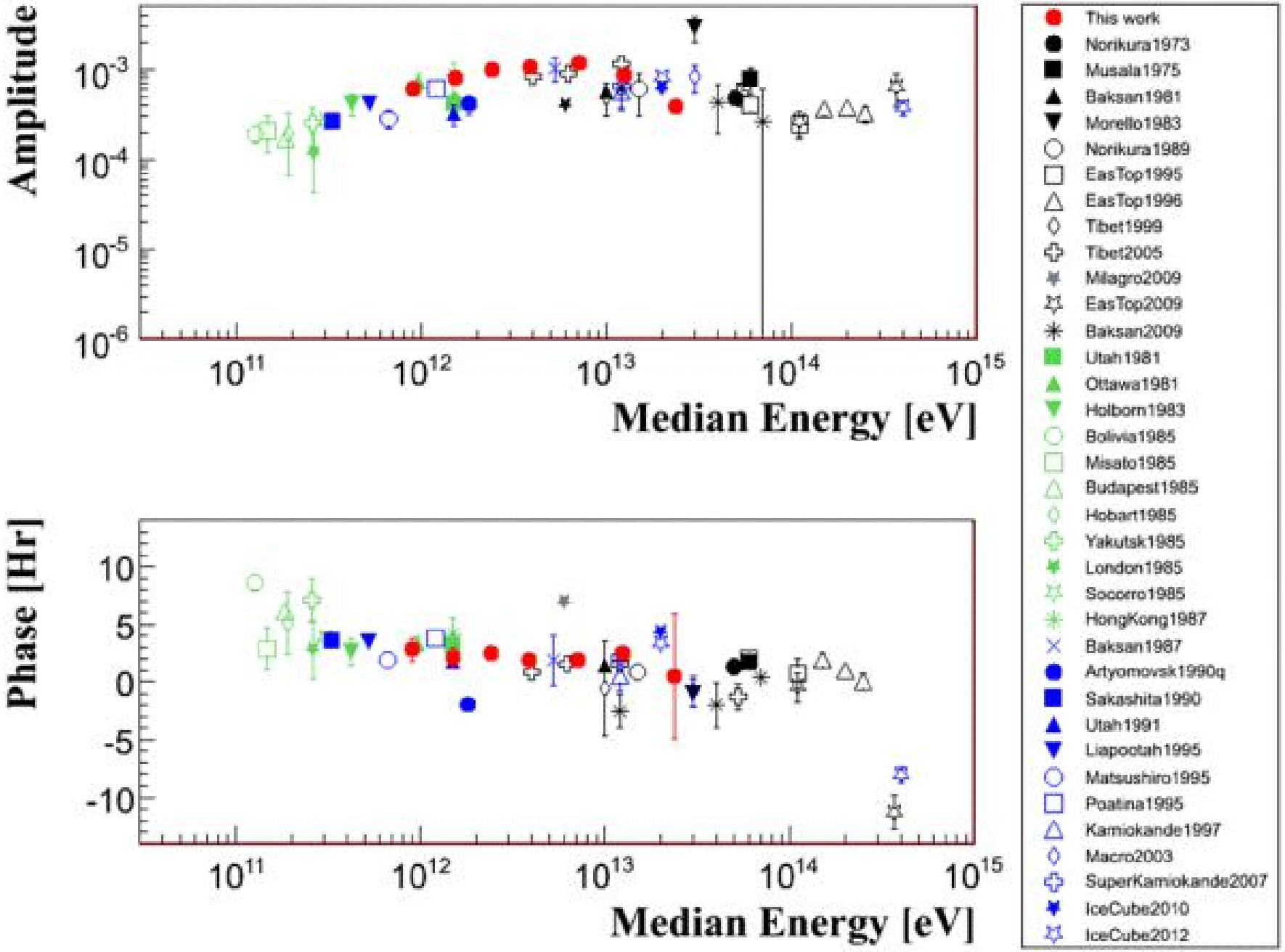


$$I = 1 + A_1 cos[2\pi(x-\phi_1)/360] + A_2 cos[2\pi(x-\phi_2)/180]$$

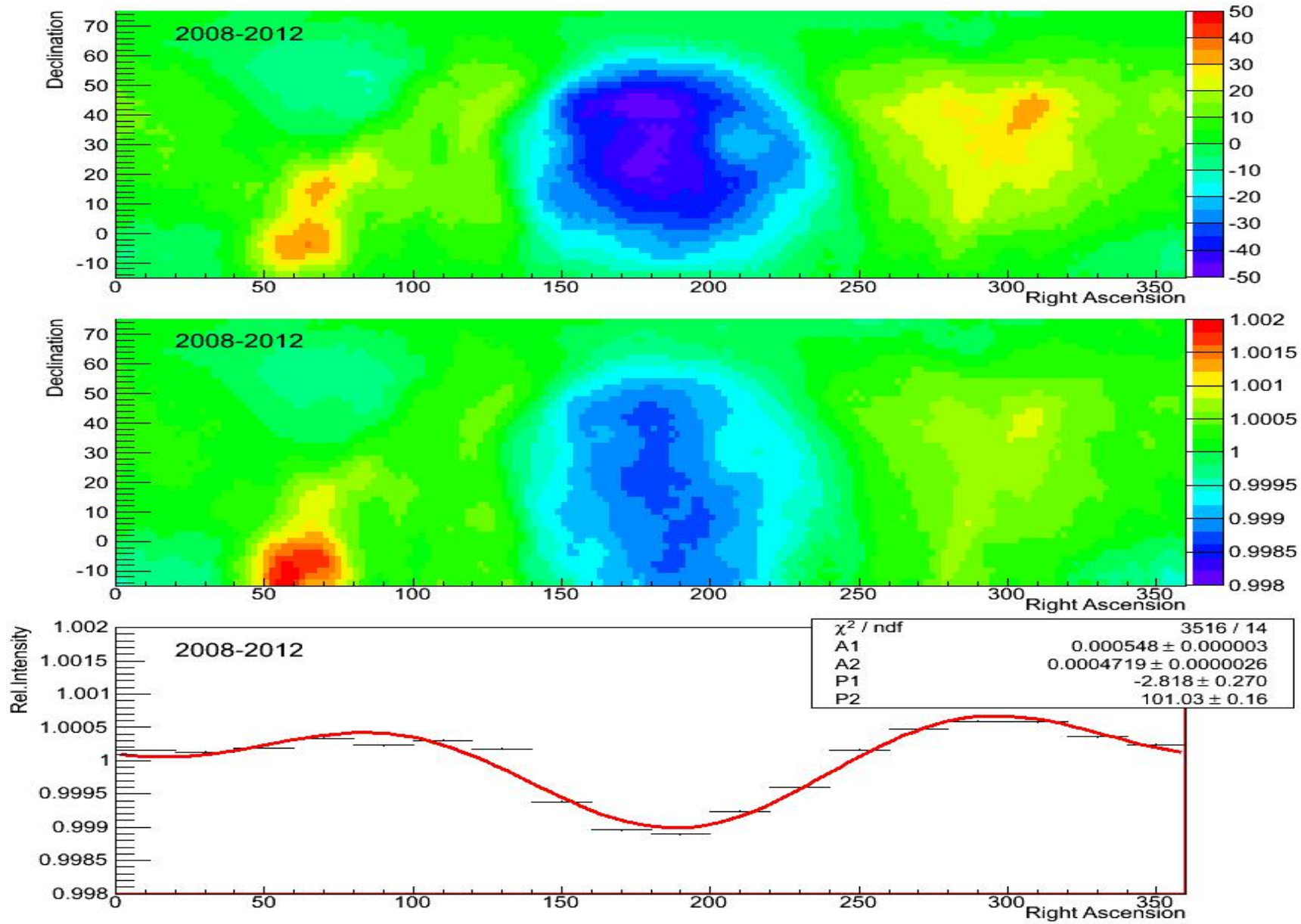


能量依赖

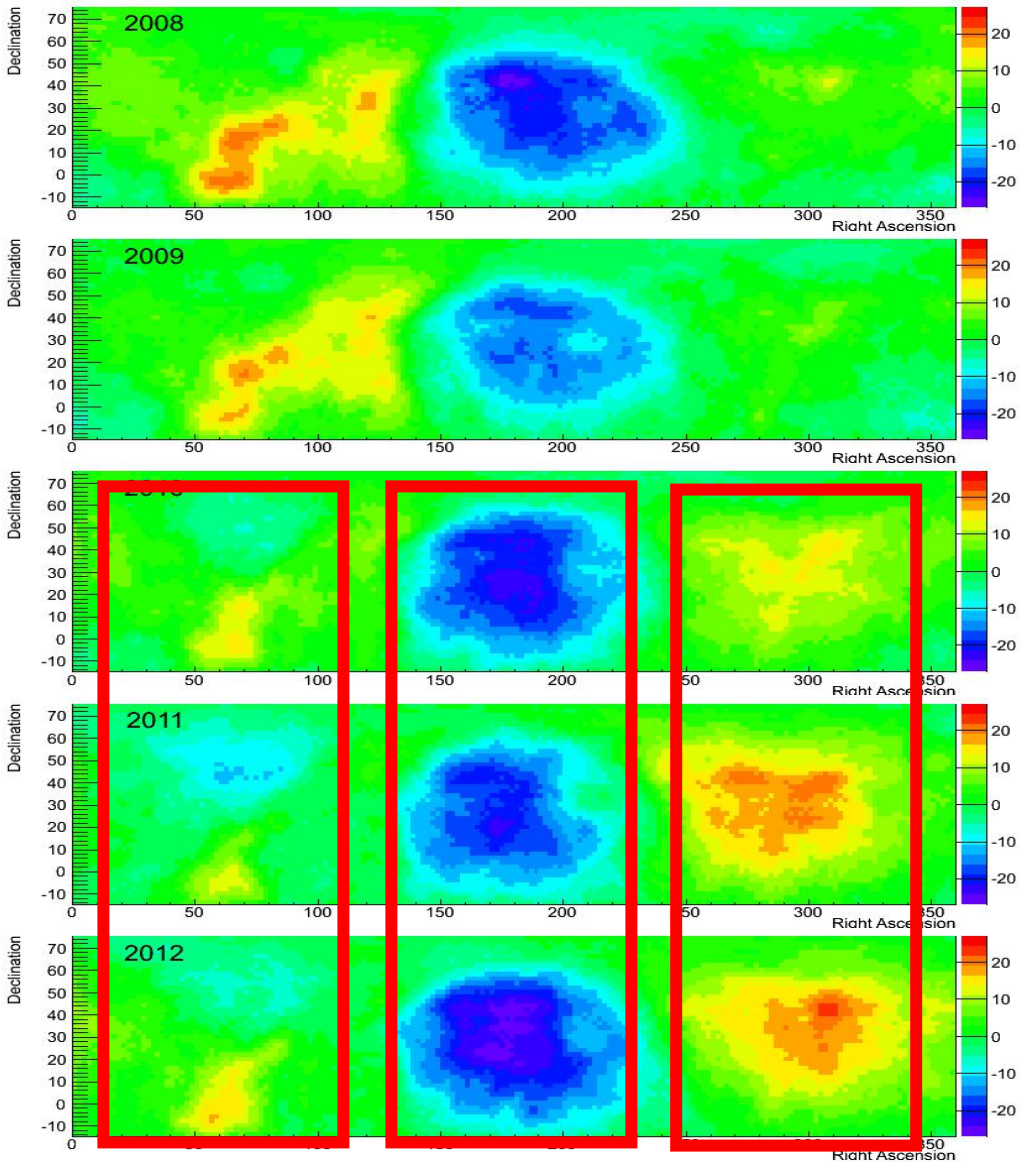

(a) Relative Intensity
(b) Significance
(c) 1D Projection
Declination [deg]
Right Ascension [deg]
Right Ascension [deg]
Right Ascension [deg]
1.003
1.002
1.001
1
0.999
0.998
0.997
10
5
0
-5
-10

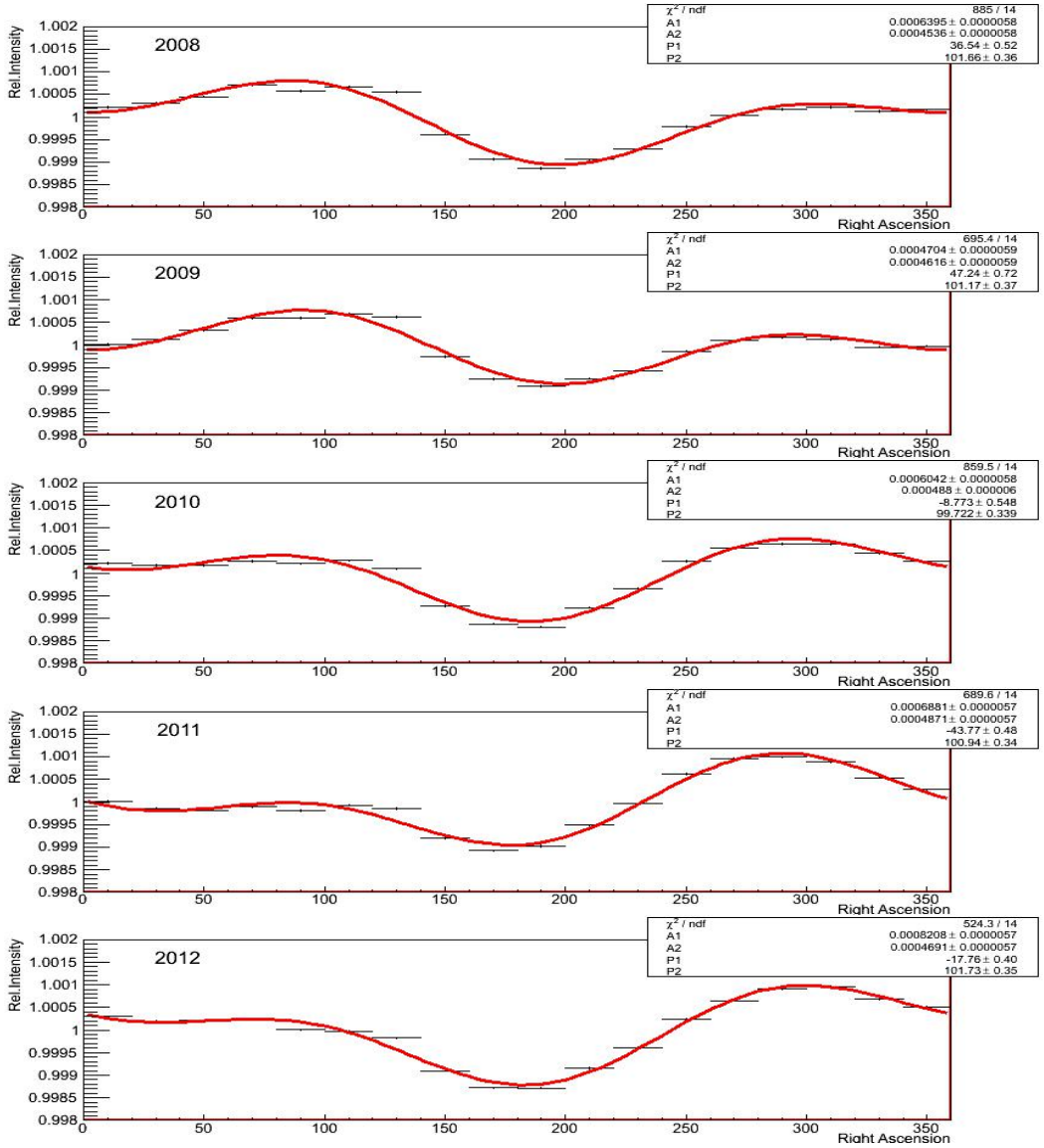

Amplitude
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
Median Energy [eV]
Phase [Hr]
10
5
0
-5
-10
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
Median Energy [eV]
This work
Norikura1973
Musala1975
Baksan1981
Morello1983
Norikura1989
EasTop1995
EasTop1996
Tibet1999
Tibet2005
Milagro2009
EasTop2009
Baksan2009
Utah1981
Ottawa1981
Holborn1983
Bolivia1985
Misato1985
Budapest1985
Hobart1985
Yakutsk1985
London1985
Socorro1985
HongKong1987
Baksan1987
Artyomovsk1990q
Sakashita1990
Utah1991
Liapootah1995
Matsushiro1995
Poatina1995
Kamiokande1997
Macro2003
SuperKamiokande2007
IceCube2010
IceCube2012

The Sidereal Anisotropy (5 years)



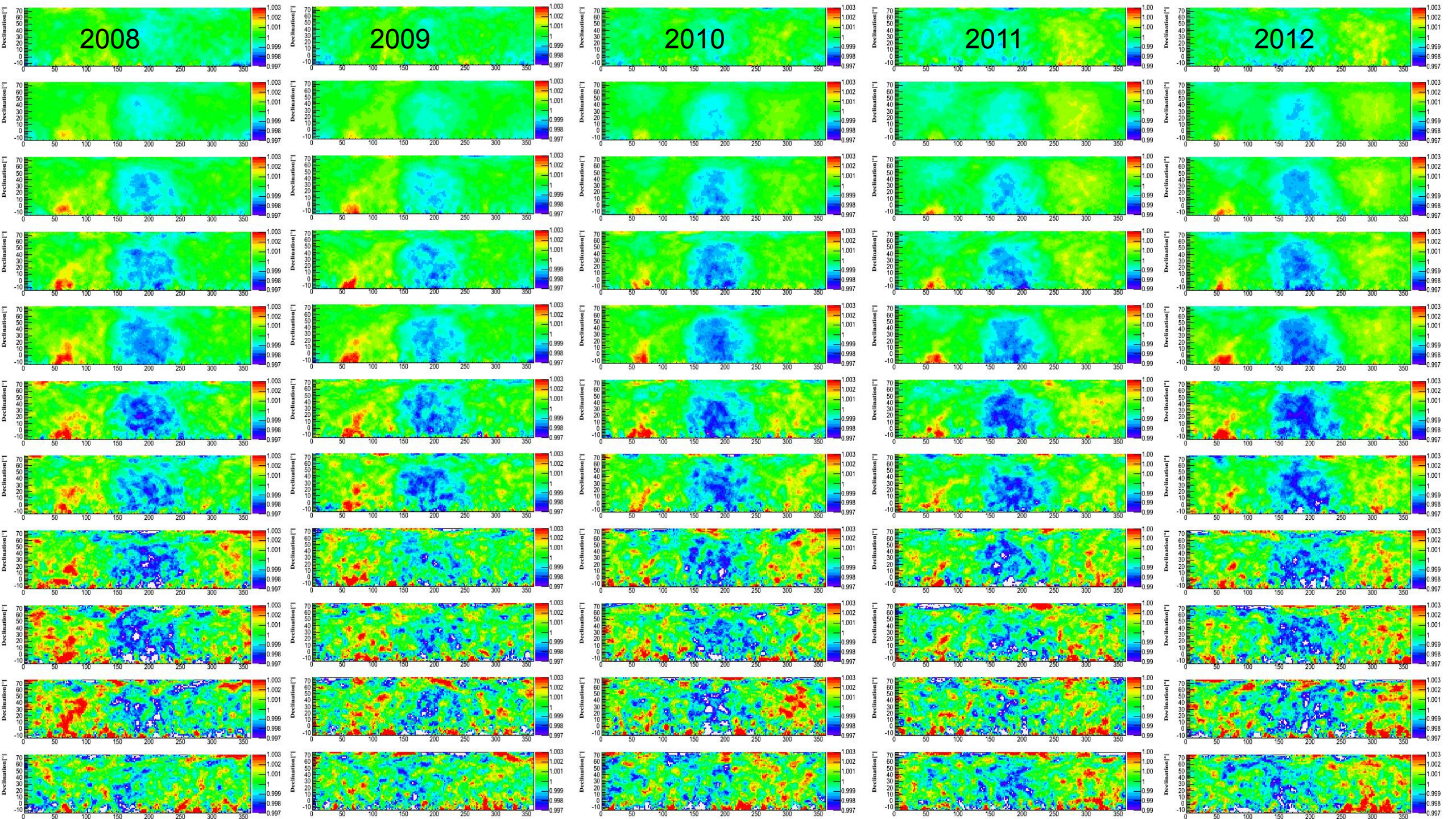
Annual variation of the Sidereal Anisotropy



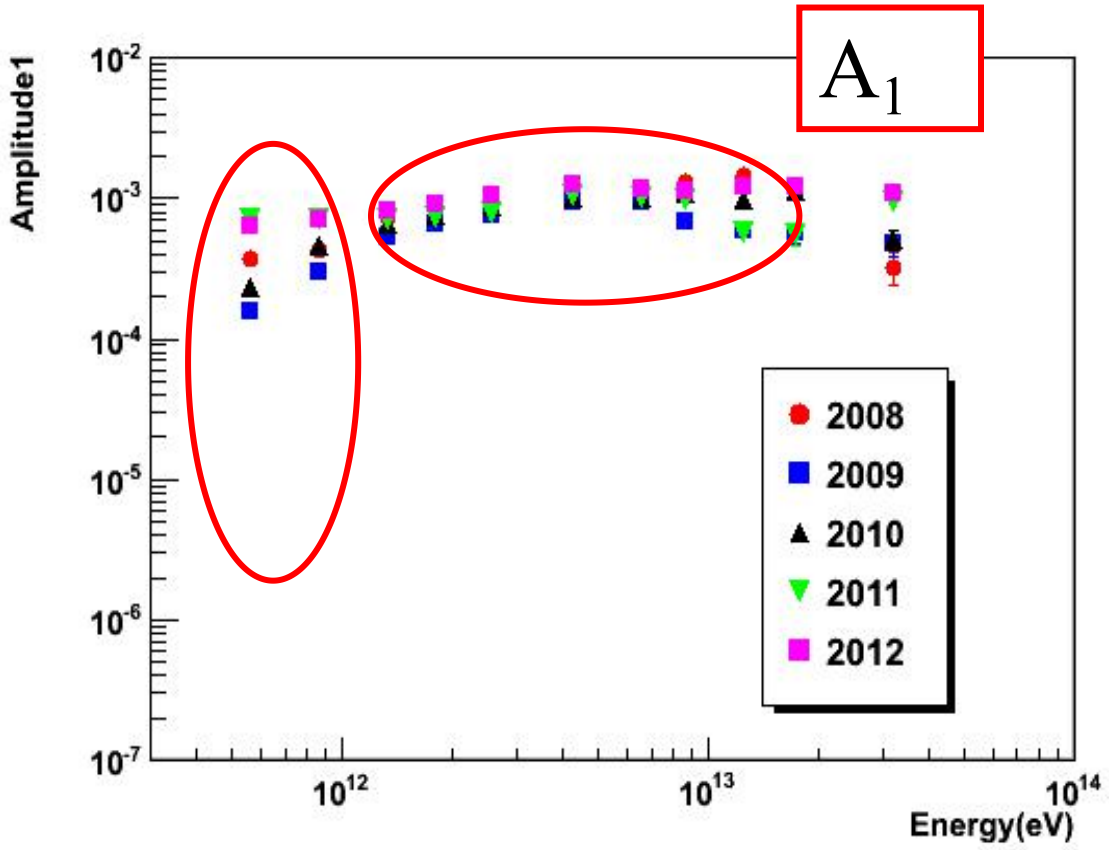


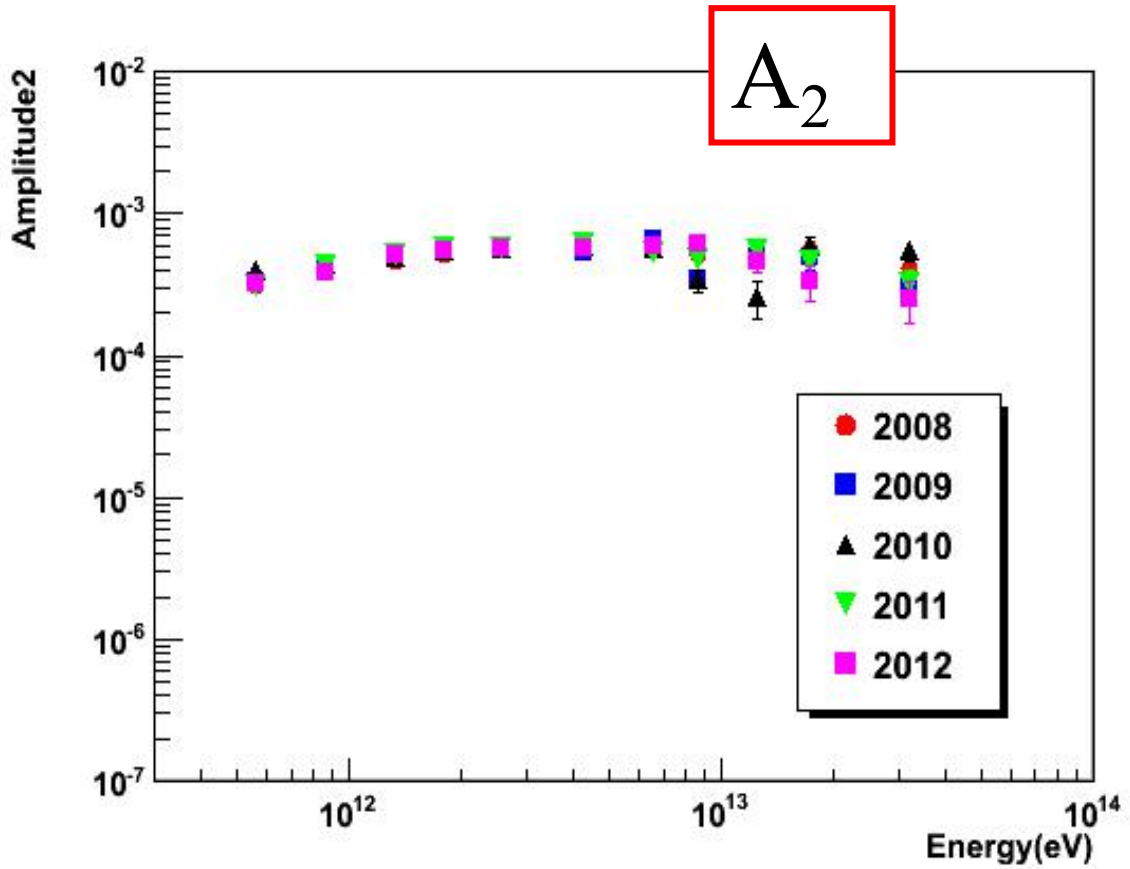
五年11个能段谐波函数分析

year	2008	2009	2010	2011	2012
Nhits 20-40					
Nhits 40-60					
Nhits 60-80					
Nhits 80-100					
Nhits 100-200					
Nhits 200-300					
Nhits 300-500					
Nhits 500-700					
700~1000 Nhits					
Nhits 1000~1500					
Nhits >1500					

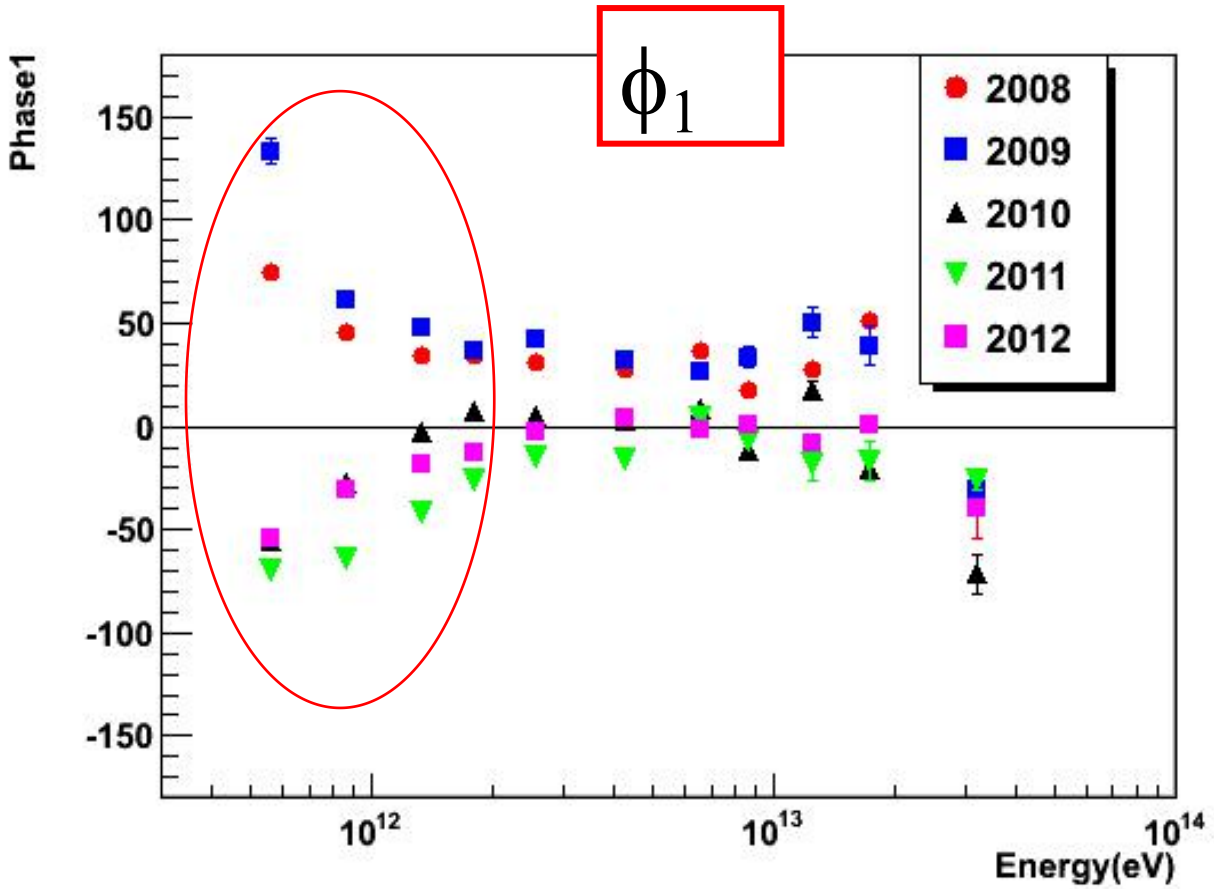

2008
2009
2010
2011
2012
Declination[°]

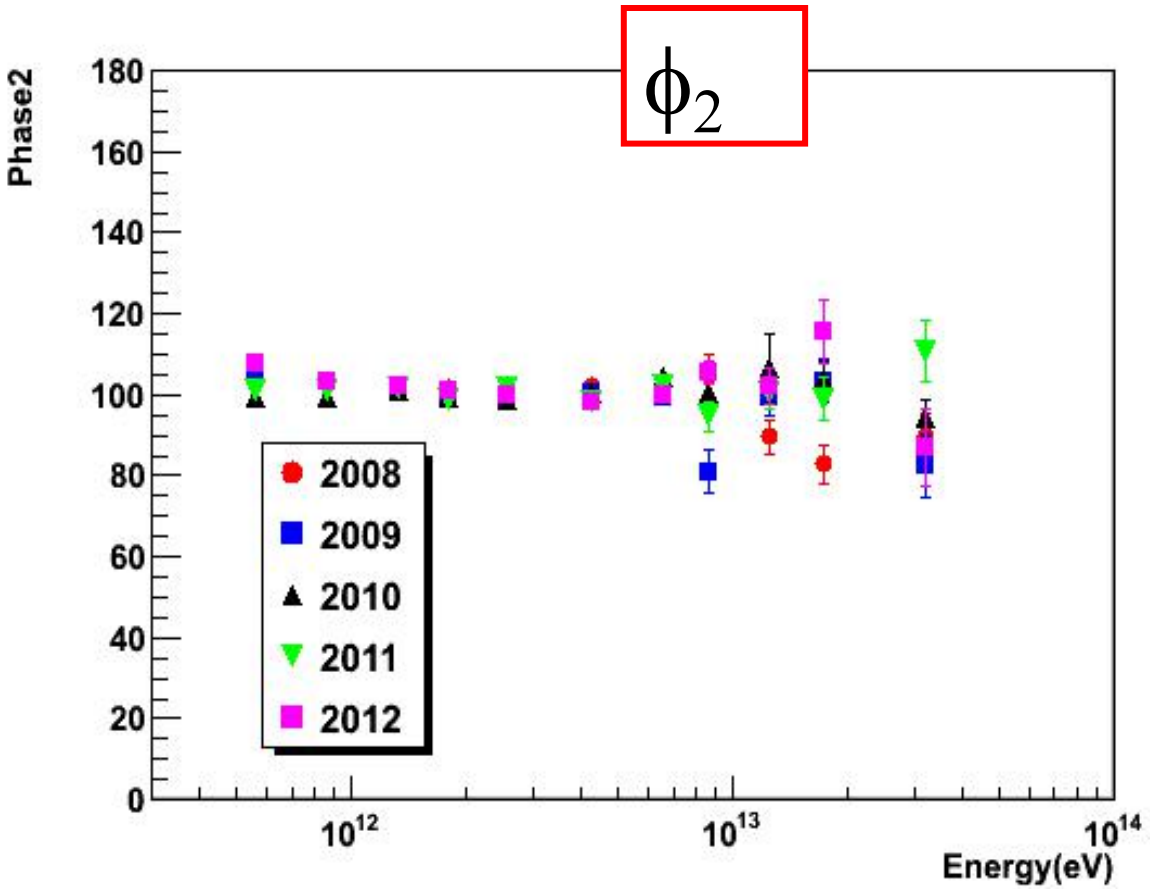
$$I = 1 + A_1 cos[2\pi(x-\phi_1)/360] + A_2 cos[2\pi(x-\phi_2)/180]$$





$$I = 1 + A_1 cos[2\pi(x-\phi_1)/360] + A_2 cos[2\pi(x-\phi_2)/180]$$





Phys.Rev.Lett.101:221101,2008

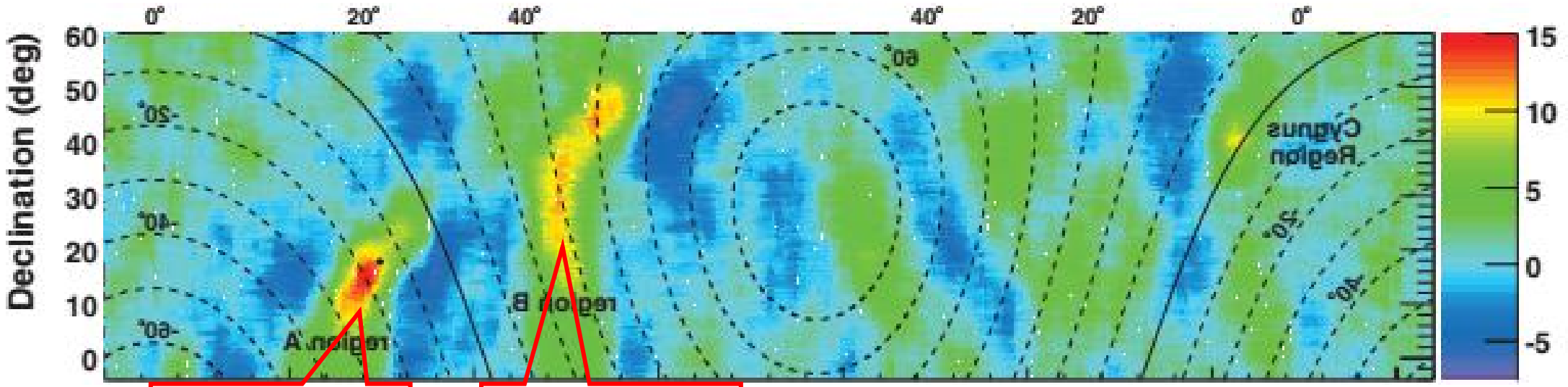
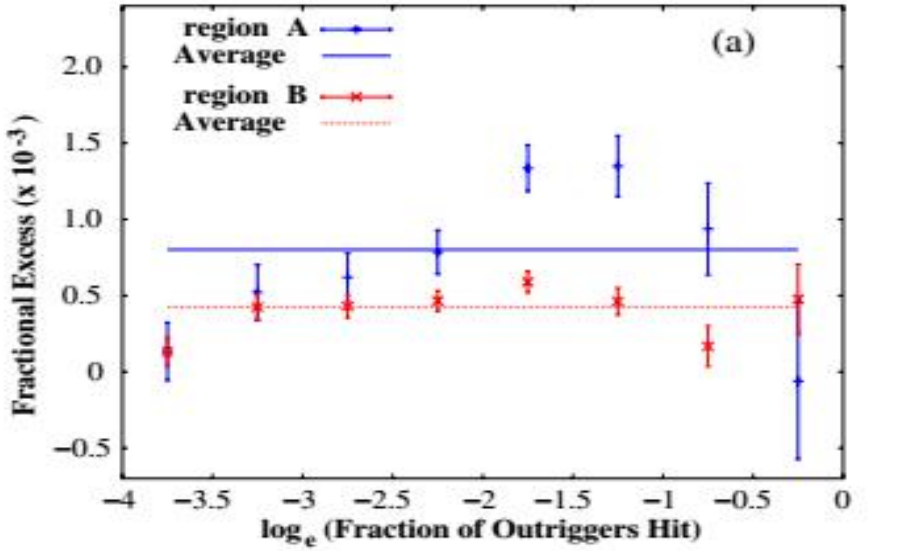
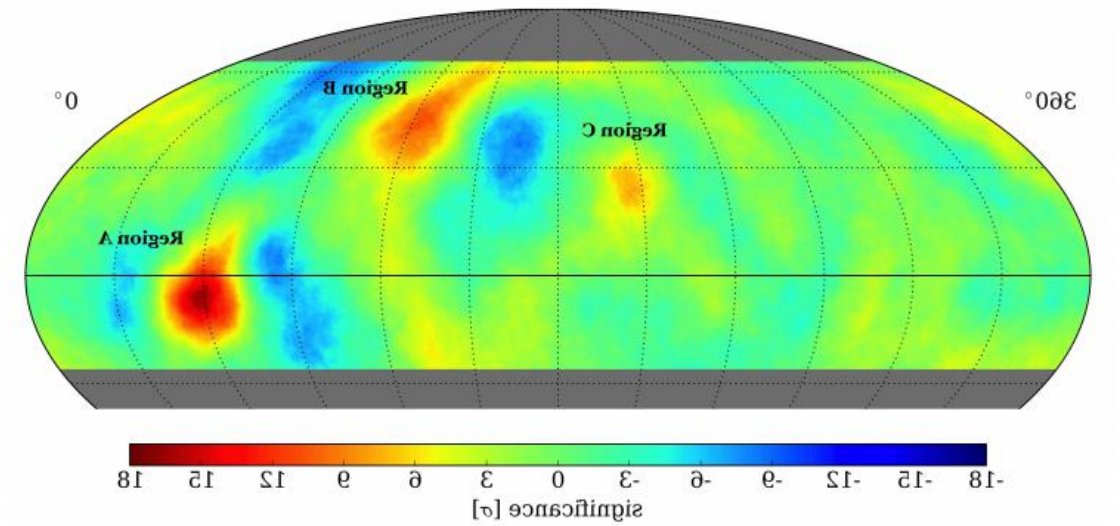


FIG. 1 (color). Map of significances for the Milagro data set without any cuts t
bin w the significance. The
Galac dot marks the directi
motio llar matter. The fracti
B it is $\sim 4 \times 10^{-4}$. The deep deficits bordering the regions of excess appear beca
excess.

Smoothing radius 10°



HAWC结果



Observation of Cosmic-Ray Anisotropy with HAWC
Astrophys. J. 796 (2014), 108.

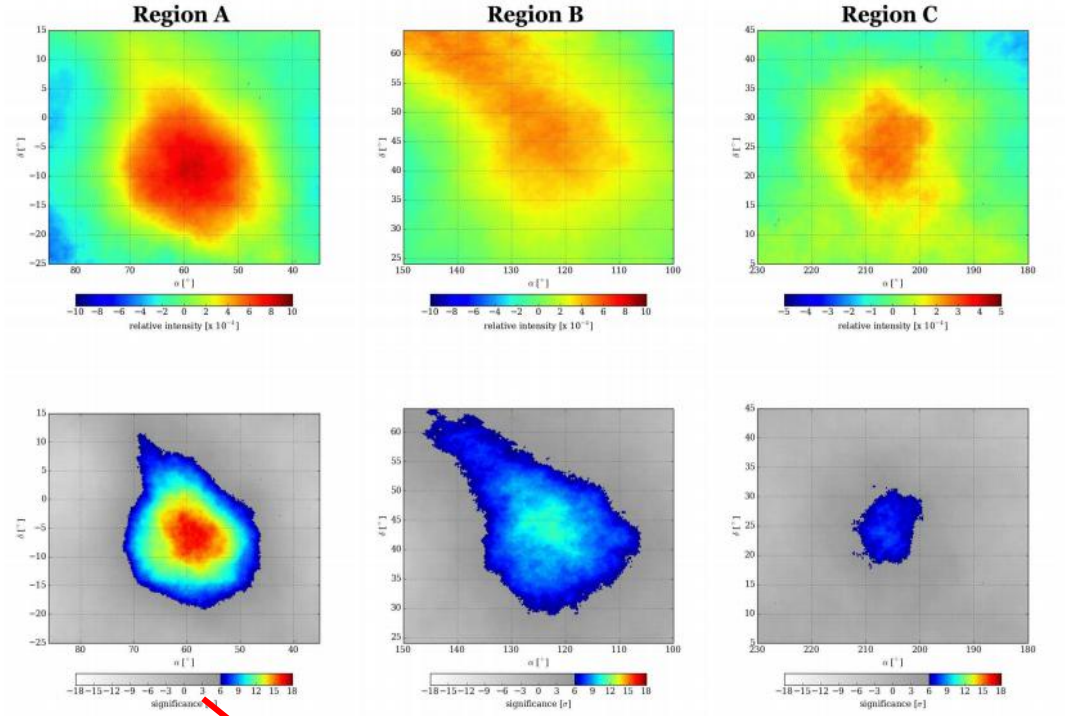
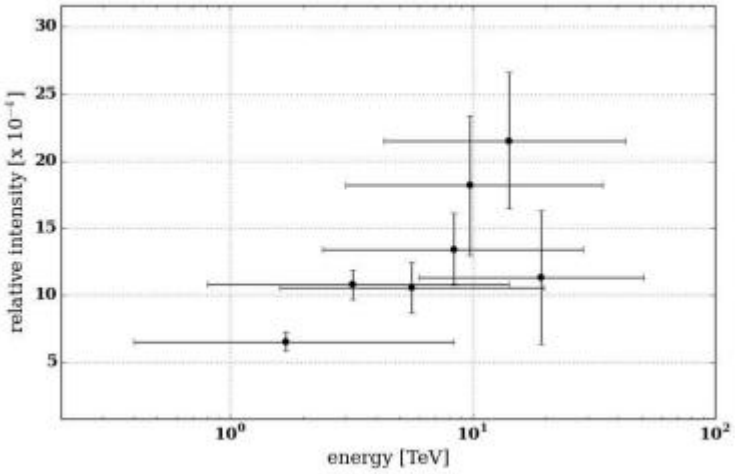
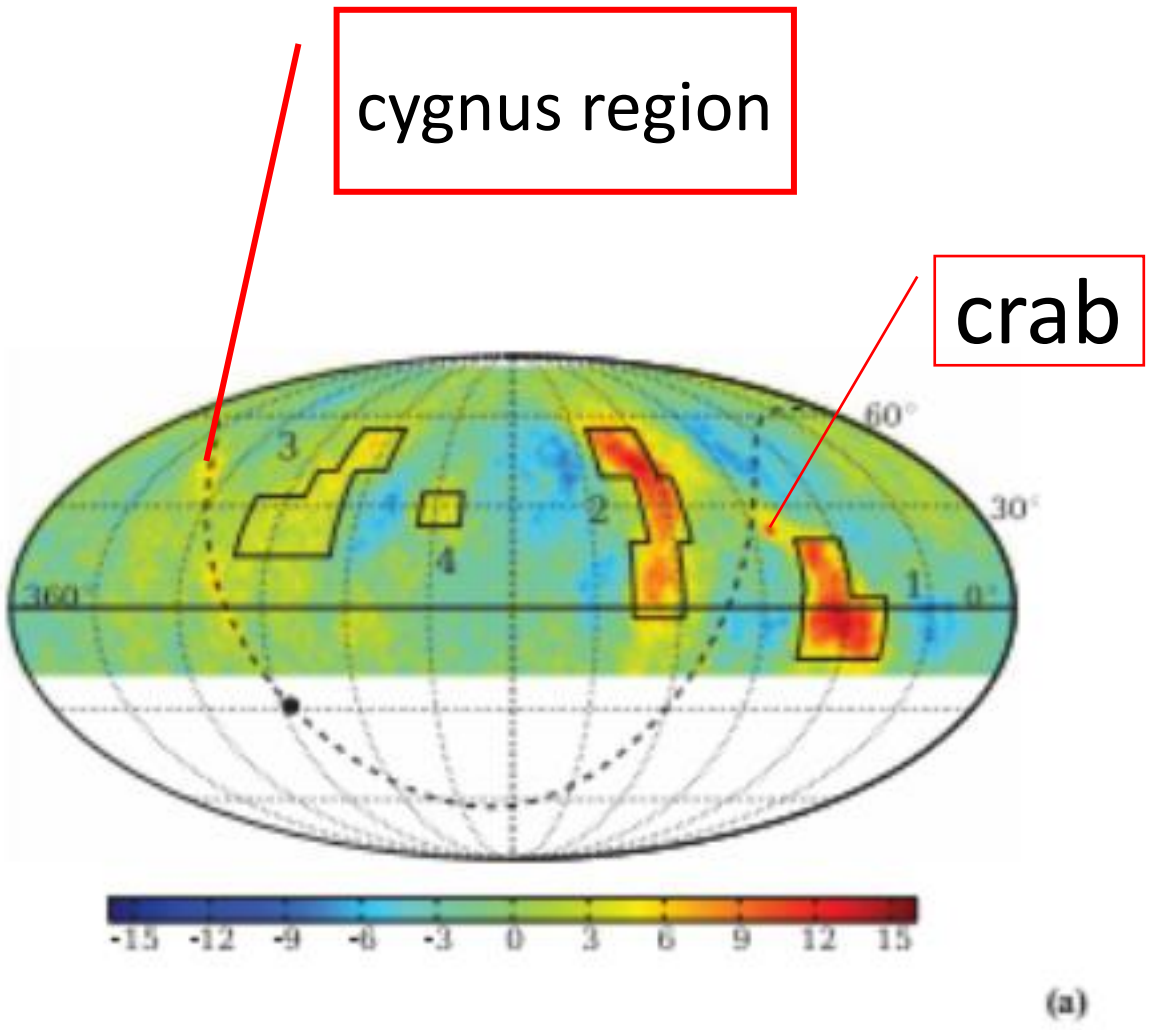
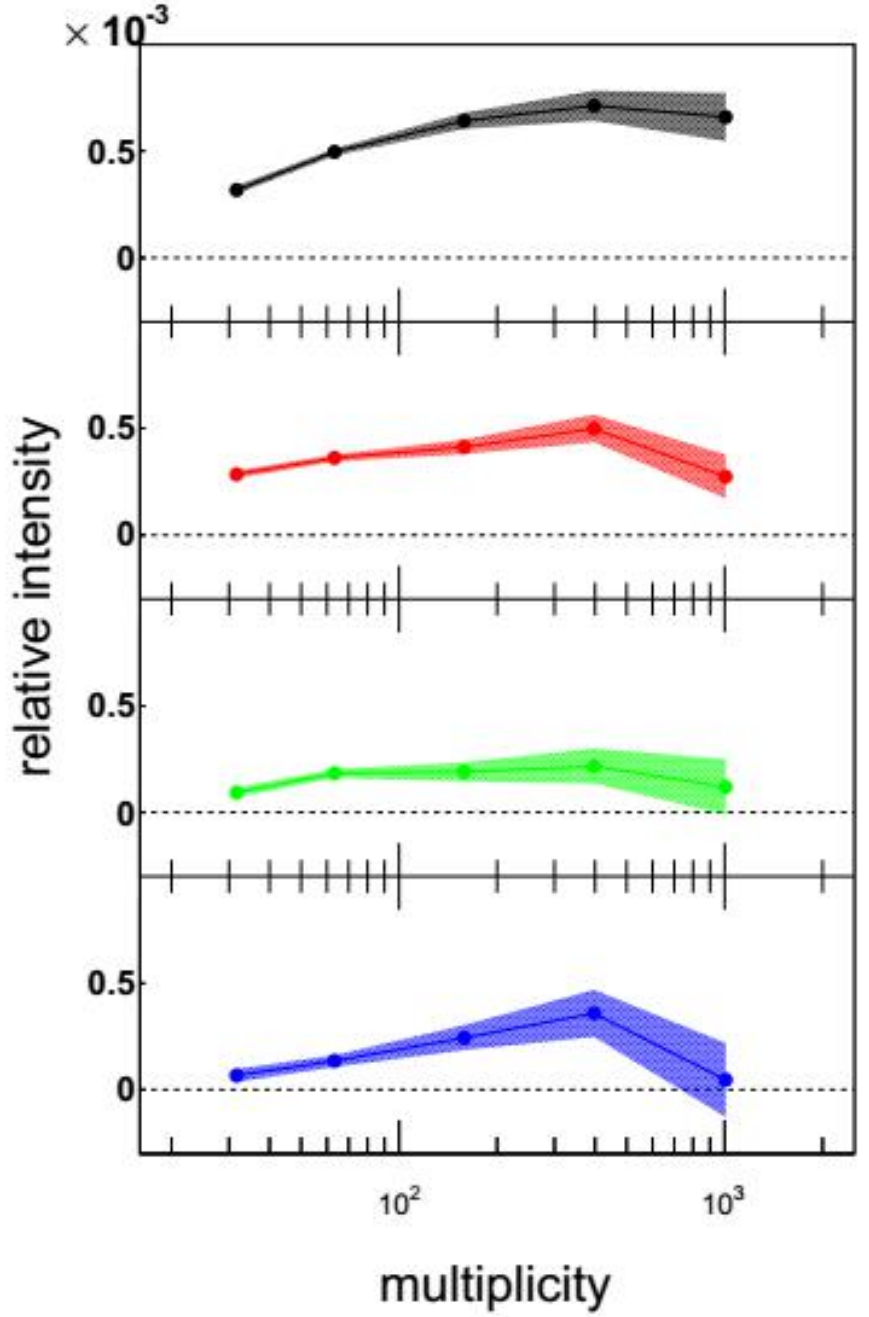


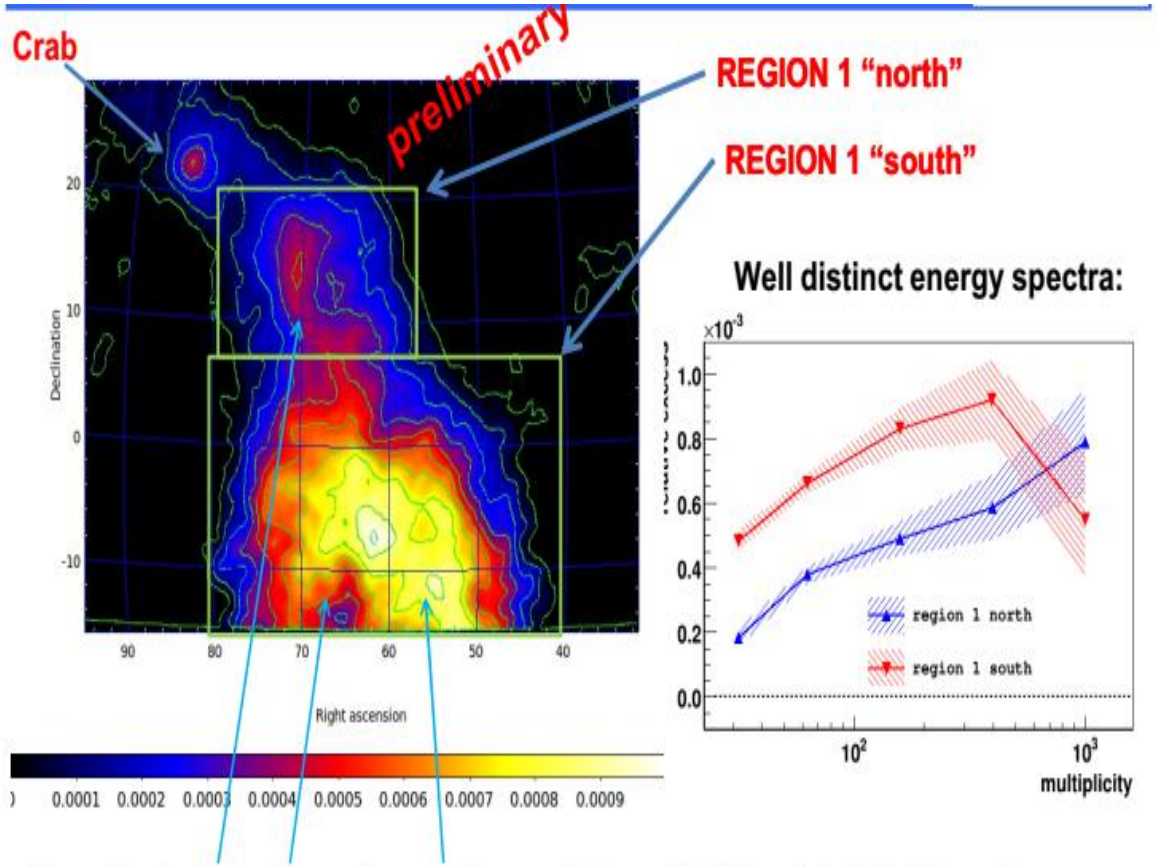
Figure 7. Relative intensity *(top row)* and pre-trial significance *(bottom row)* of the cosmic-ray flux in the vicinity of Region A *(left)*, Region B *(center)*, and Region C *(right)*, from the map shown in Fig. 5.







ARGO-YBJ中等尺度观测结果

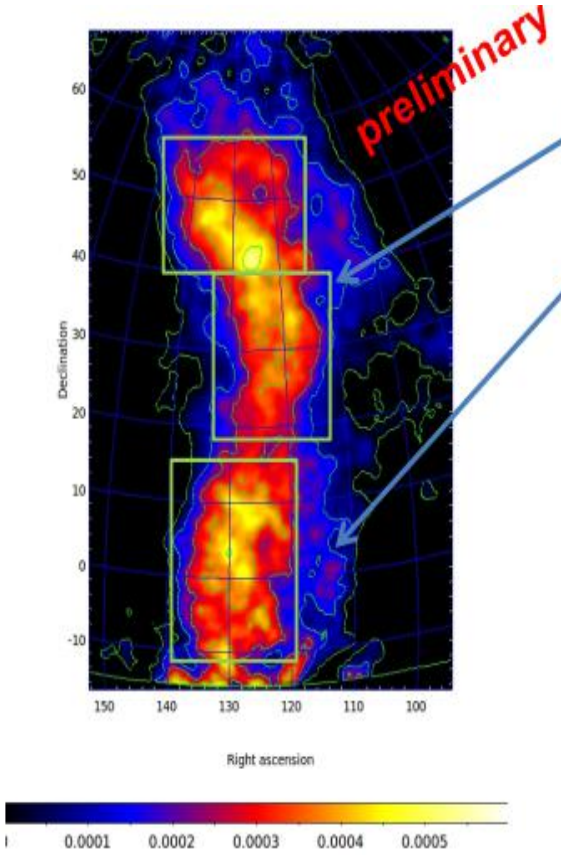


Well distinct energy spectra:

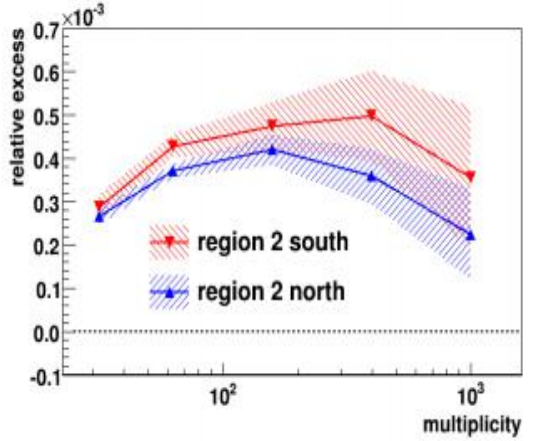
The region is going to show quite a complex morphology with high statistical significance (more than 12 s.d.). That suggests that even more detailed studies wll be possible in the next future.

1区放大

2区放大



The energy spectra of the two sub-regions are close to each other, suggesting that the nature of the diffuse emission might be the same all over 60 degrees in declination.



各向异性分析小结：

- 小尺度——伽马射线源
- 大尺度——宇宙线带电粒子天区分布
- 中尺度是什么？不知道
- 伽马射线？有，贡献多少？缺乏粒子分辨能力。

- LHAASO阵列能量跨越范围广（100GeV-PeV）视张角大，具有γ/质子分辨，成分分辨能力。为我们进一步理解宇宙线的各种性质，解决各向异性中的难题提供了可能。