National Key R&D Program
基于高海拔宇宙线观测站LHAASO的科学研究
课题二：LHAASO数据的物理分析
2021年进展报告

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2021年8月24日

课题二承担的工作任务

1. 测量300 GeV-1 PeV能区内伽马点源、弥散源及其能谱
2. **测量30 TeV到3 EeV能区的宇宙线分成份能谱**
3. 测量30 TeV以上能区的宇宙线各向异性
4. **太阳物理，太阳高能宇宙线粒子探测**

利用课题一重建后的数据，分析挖掘物理

KM2A Sky Map with 320 days (E>100TeV ~15 sources>5σ)

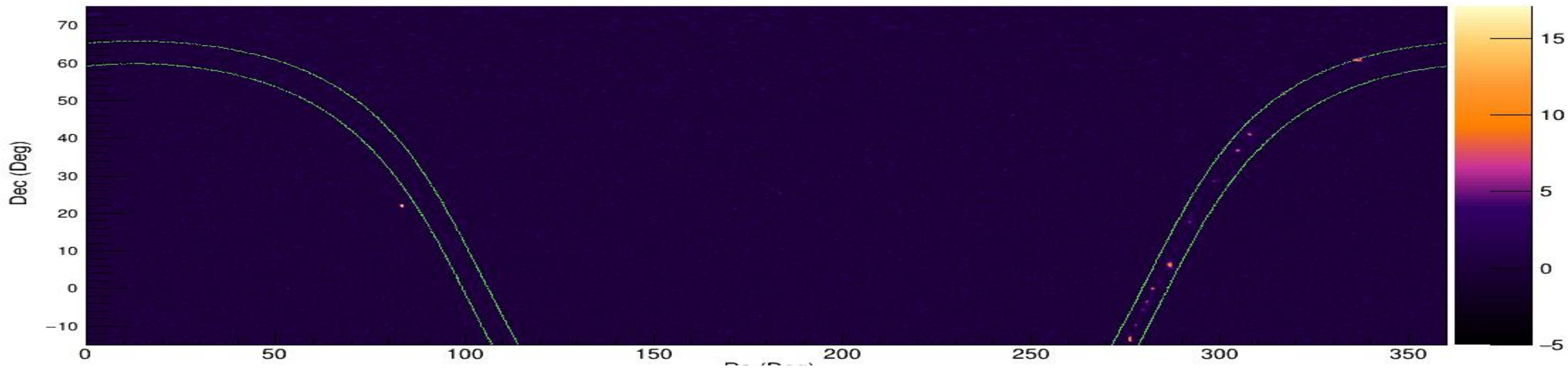
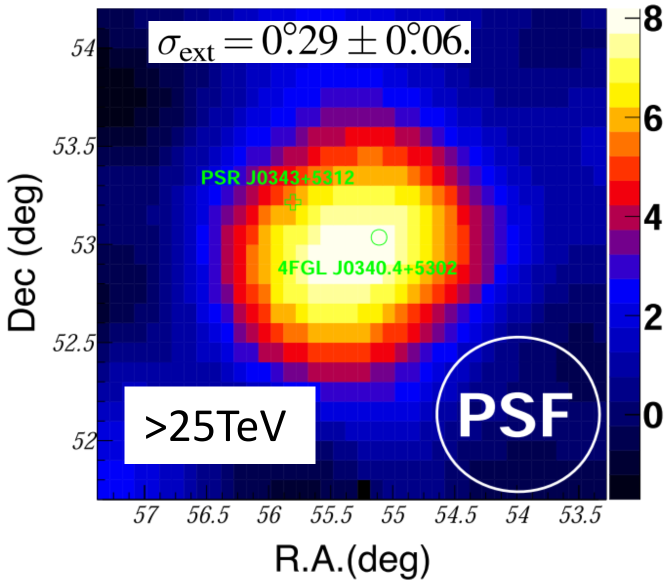


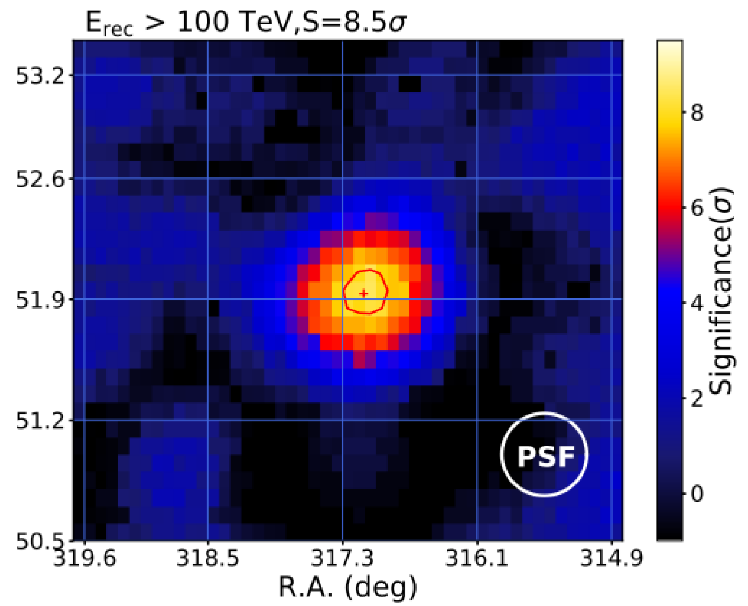
Table 1 | UHE γ-ray sources

Source name	RA (°)	dec. (°)	Significance above 100 TeV (×σ)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	−13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	−5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	−3.65	8.5	$0.26 -0.10^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	−0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71 -0.07^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)

LHAASO collaboration 2021, Nature, 594, 33

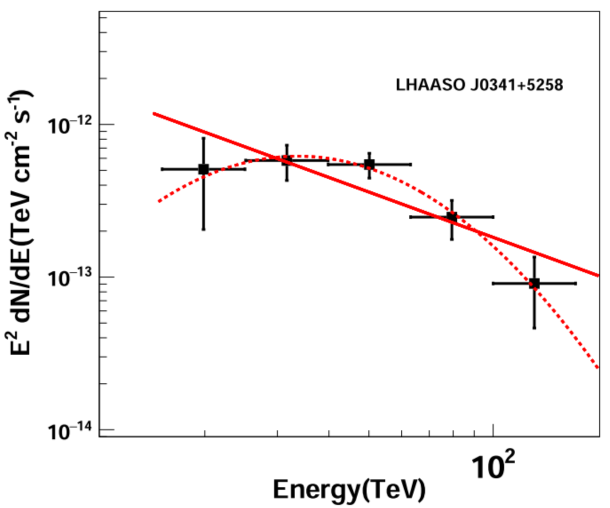
超高能伽马源

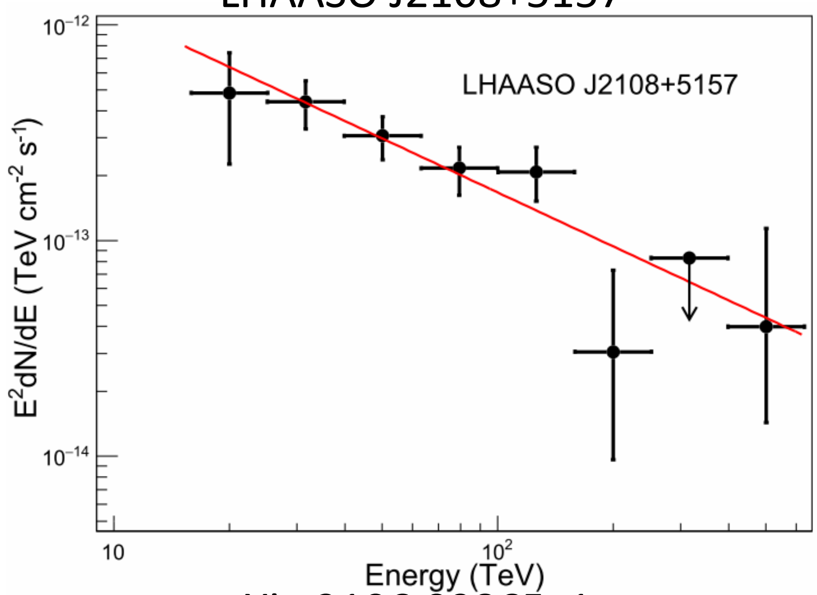




LHAASO J0341 + 5258

LHAASO J2108+5157

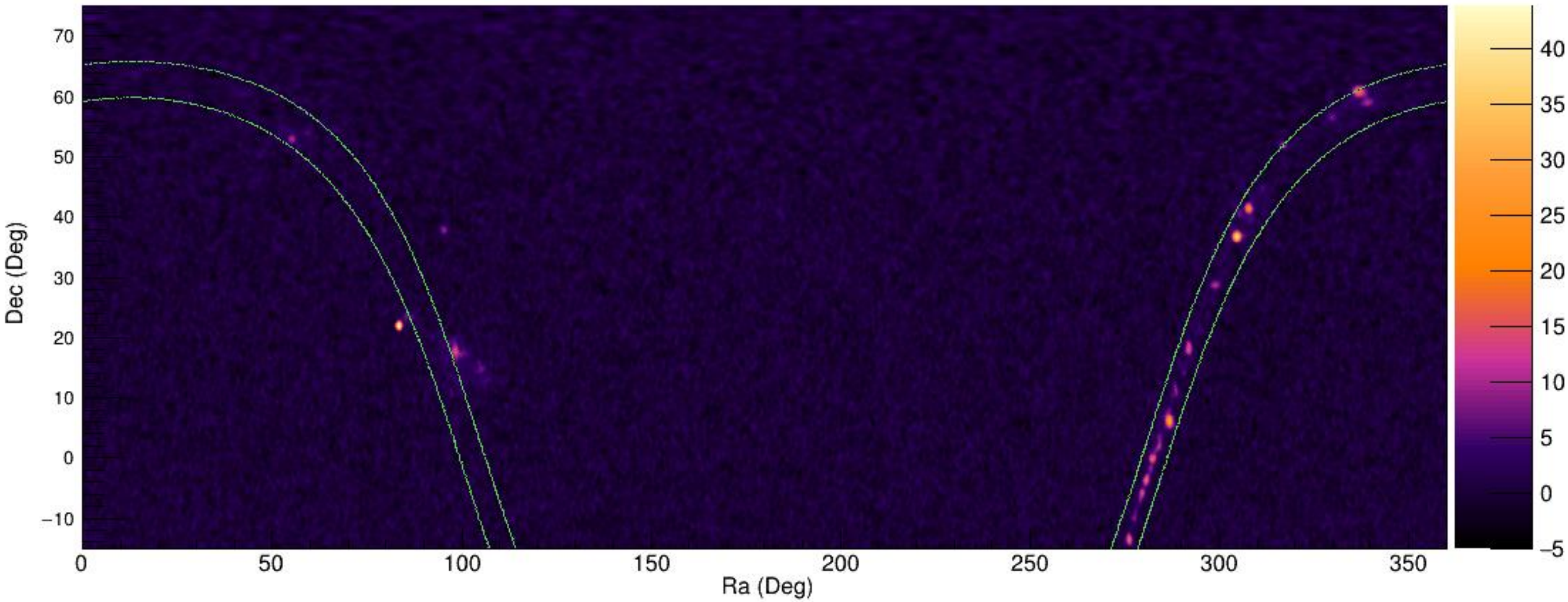




Cao, et al. APJL 917 (2021): L4.

arXiv:2106.09865v1

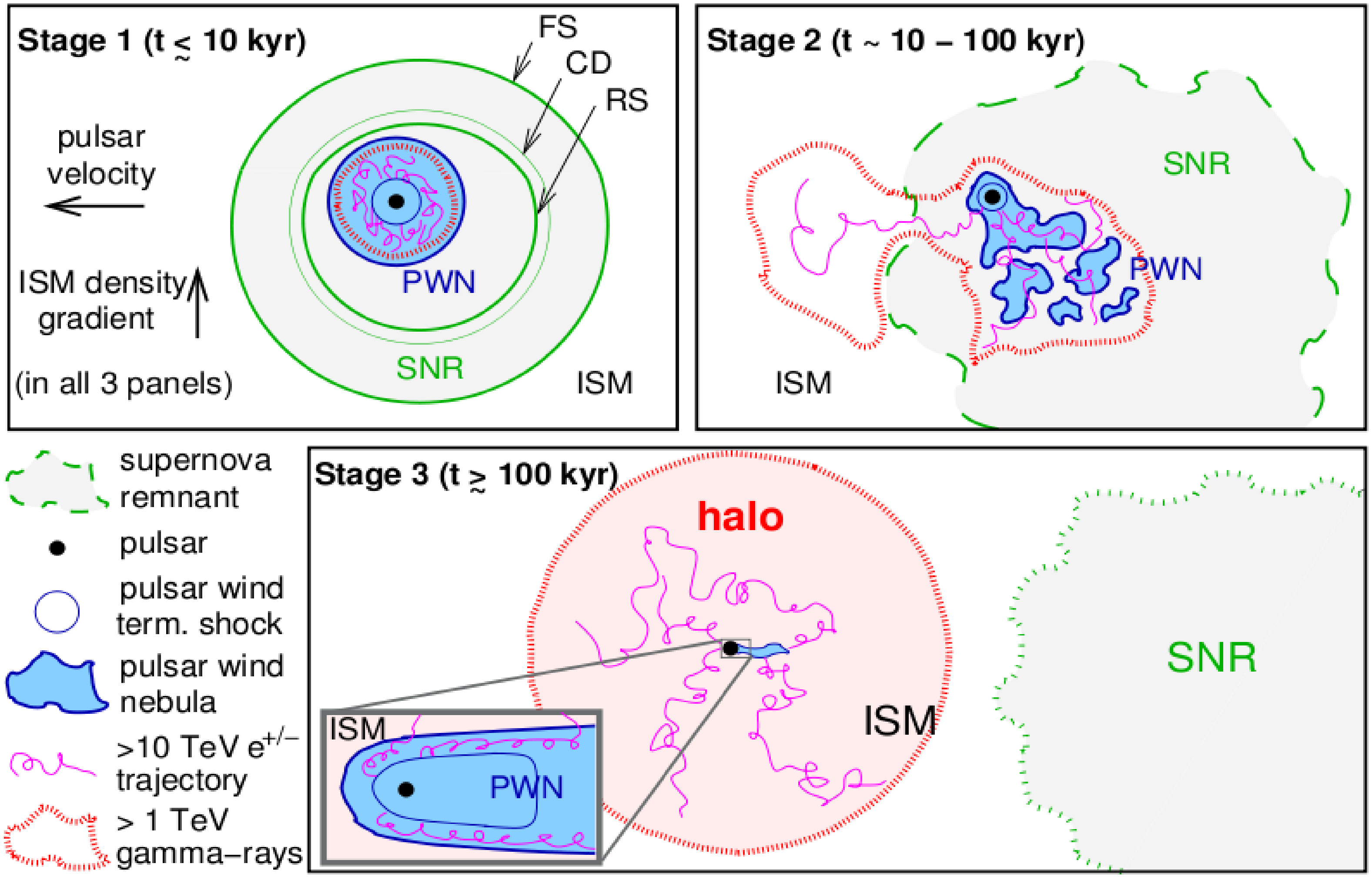
KM2A Sky Map with 320 days (Emedian=40TeV ~32 sources)



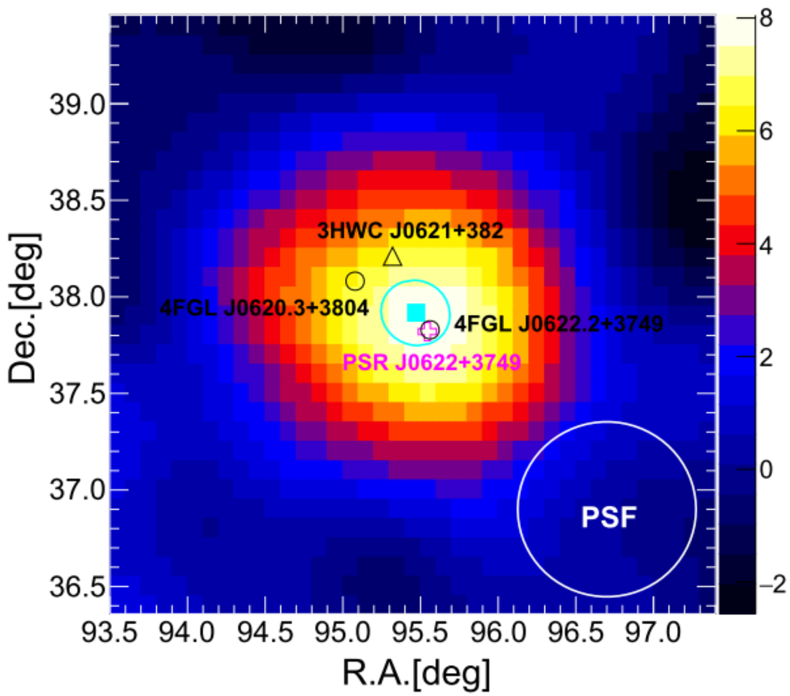
- Map assumes 0.5 degree disk as the spatial morphology.
- Thirty-two sources detected in the catalog, while six of them are new sources.
- Most of these sources are within ~3° of the Galactic plane and are extended in apparent size (larger than PSF) .

BY Youliang Feng

Pulsar halos: extended emission from particles (e+e-) diffuse/escape from pulsar wind nebula



Very-High-Energy Gamma-ray Halo Surrounding PSR J0622 + 3749



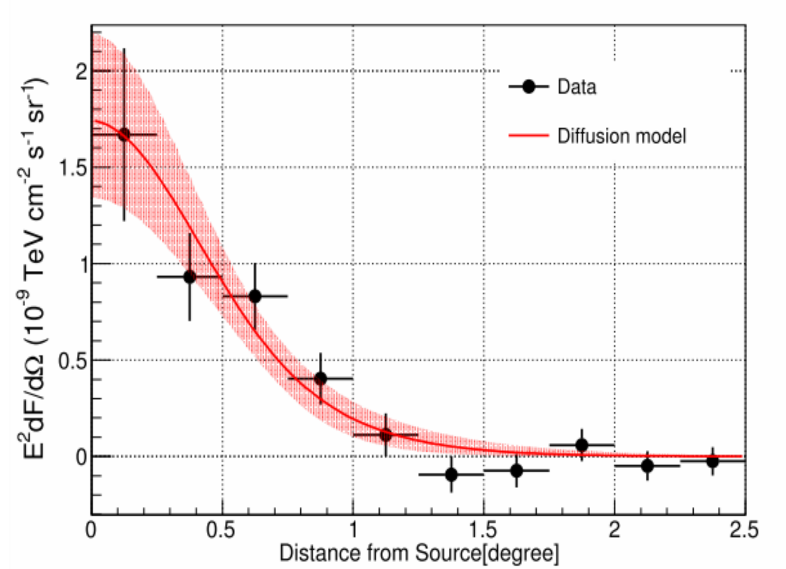
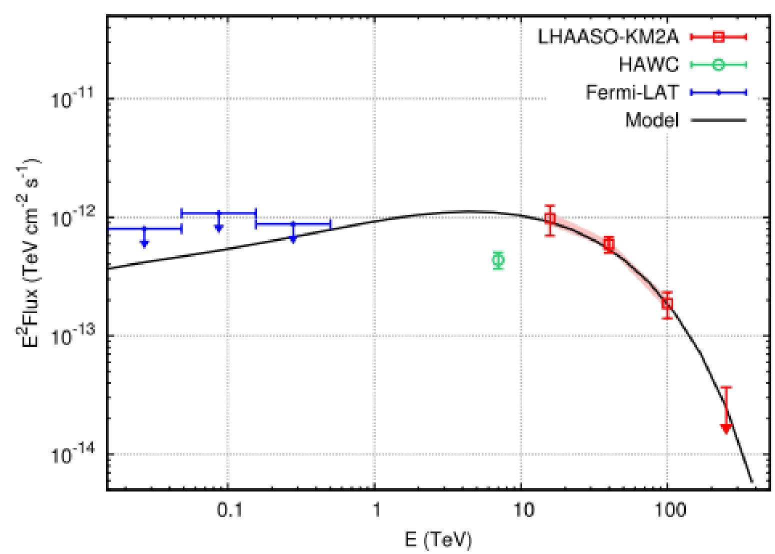


TABLE II. Comparison of the properties of pulsars J0622+3749, Geminga, and Monogem.

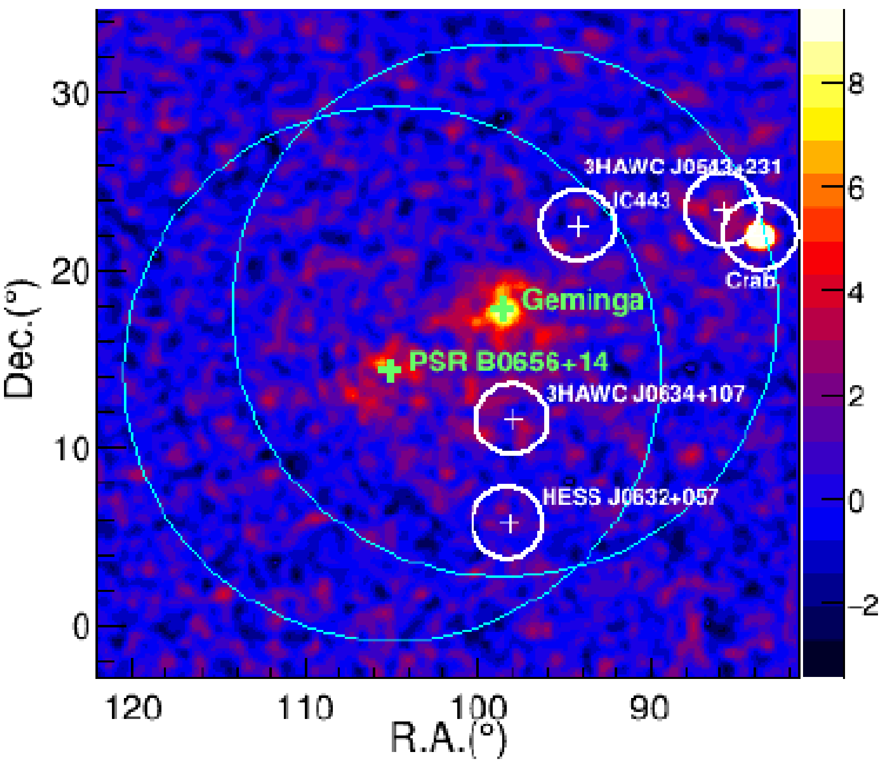
Name	P (s)	$\dot{P}$ (10^{-14} s s^{-1})	L_{sd} (10^{34} erg s^{-1})	τ (kyr)	d (kpc)	Ref.
J0622+3749	0.333	2.542	2.7	207.8	1.60	[25]
Geminga	0.237	1.098	3.3	342.0	0.25	[46]
Monogem	0.385	5.499	3.8	110.0	0.29	[46]

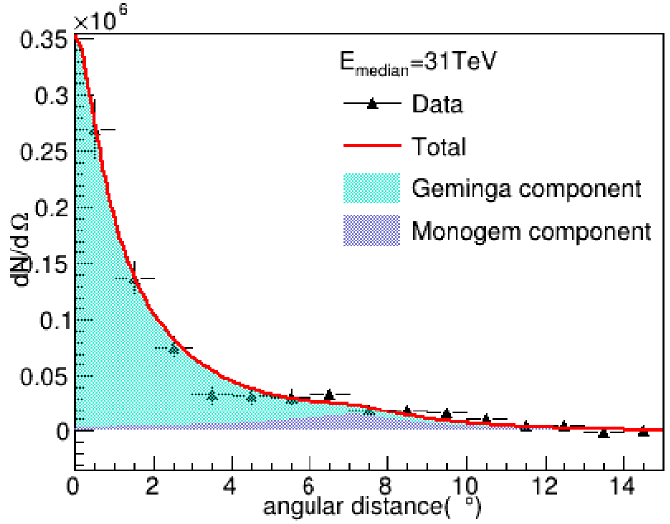


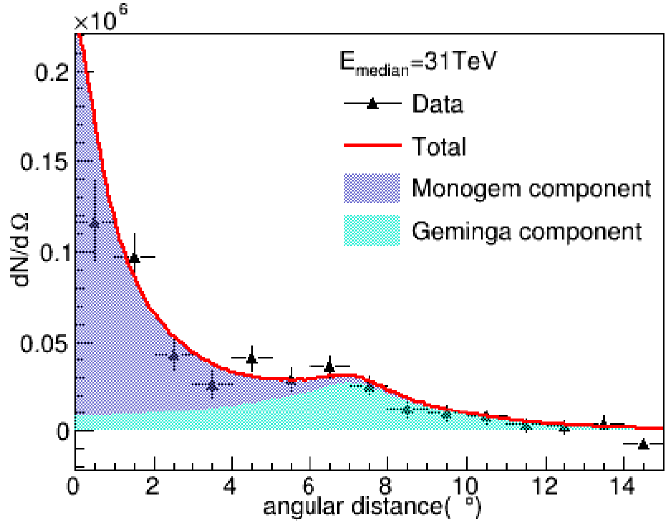
FengYL 报告

Aharonian, et al. PRL, 126, 241103 (2021)

LHAASO observations of Geminga and Monogem



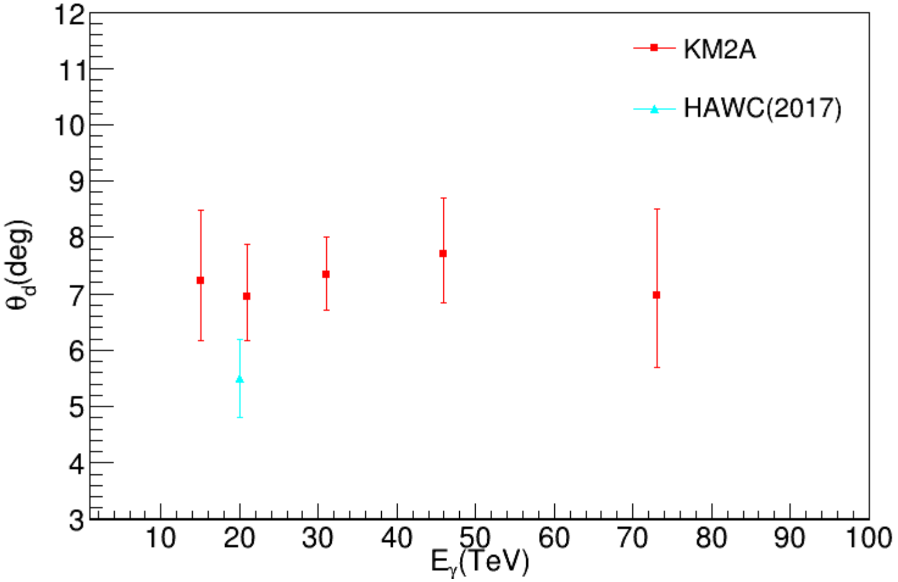




- 两个源在30TeV的显著性
- 扣除有些源

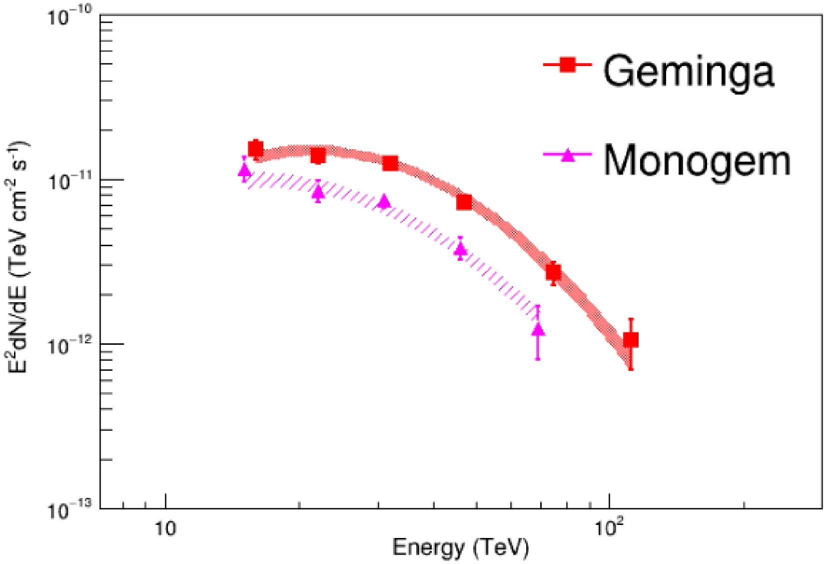
BY YingYing Guo

LHAASO observations of Geminga and Monogem



扩散角度随能量的变化

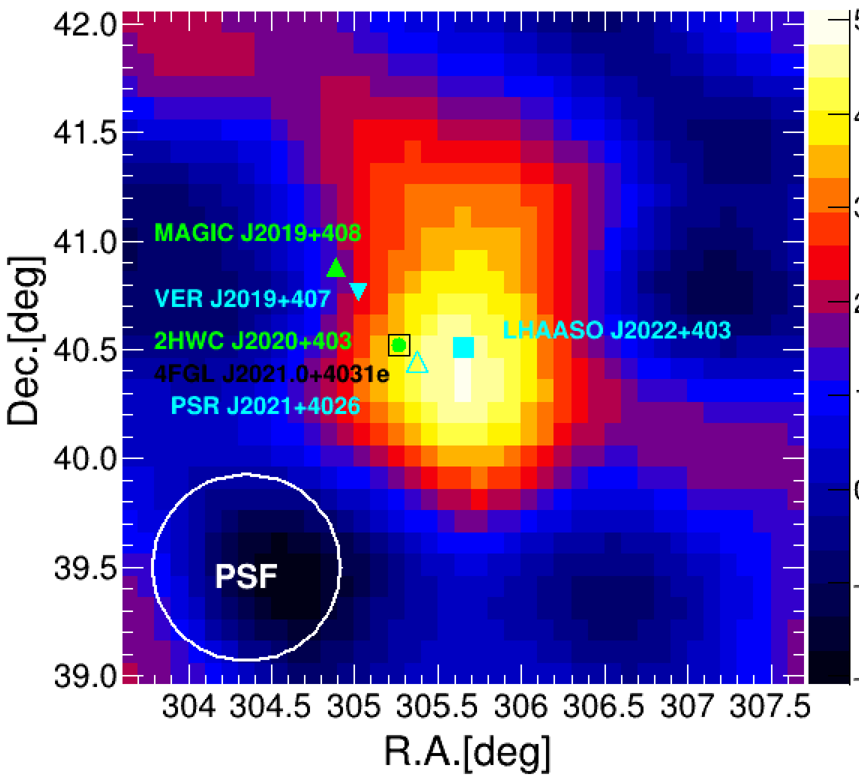
$$f(\theta) = \frac{A}{\theta_d(\theta + 0.085\theta_d)} \exp[-1.54(\theta/\theta_d)^{1.52}]$$



能谱结果

We need detailed measurements of Pulsars!

Gamma cygni (G78.2+2.1)



EXT:0.32+-0.13

B0540+23

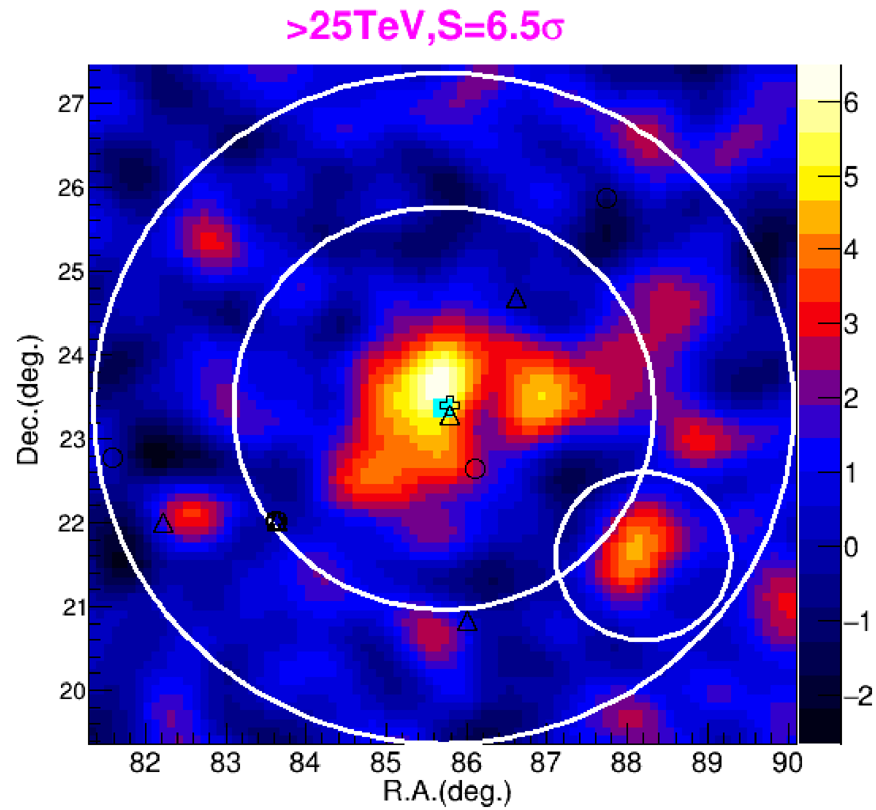


TABLE II. Comparison of the properties of pulsars B0540+23, Geminga, Monogem and J0621+3755.

Name	P (s)	$\dot{P}$ (10^{-14} s s^{-1})	L_{sd} (10^{34} erg s^{-1})	τ (kyr)	d (kpc)	Ref.
B0540+23	0.246	1.542	4.1	253.0	1.56	[47]

FAST观测申请

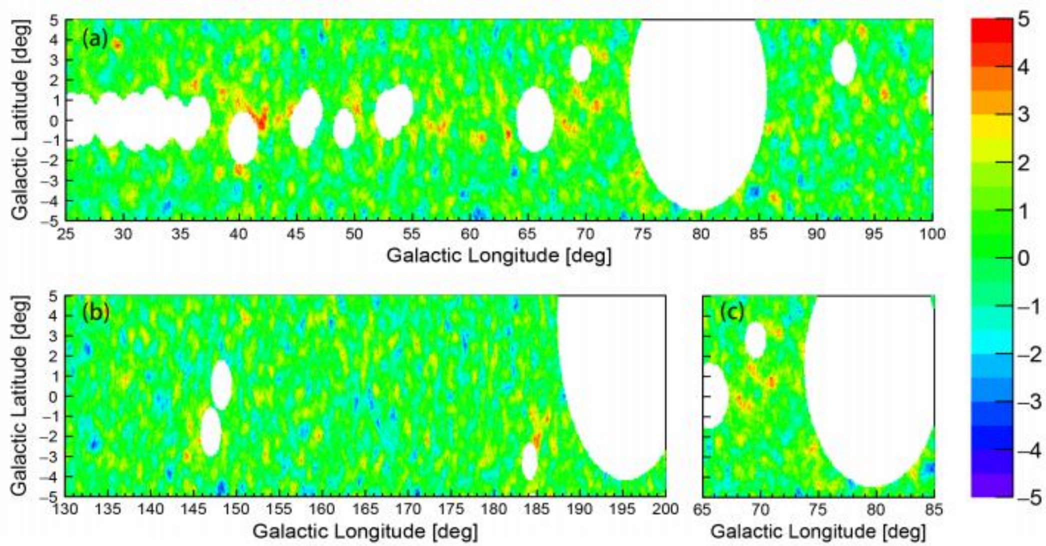
项目号: PT2021_0098

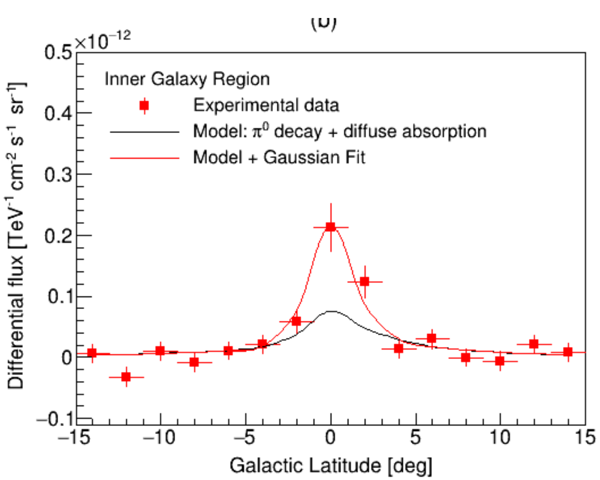
返回 项目信息 暂存 待分配 4 观测计划 历史提交

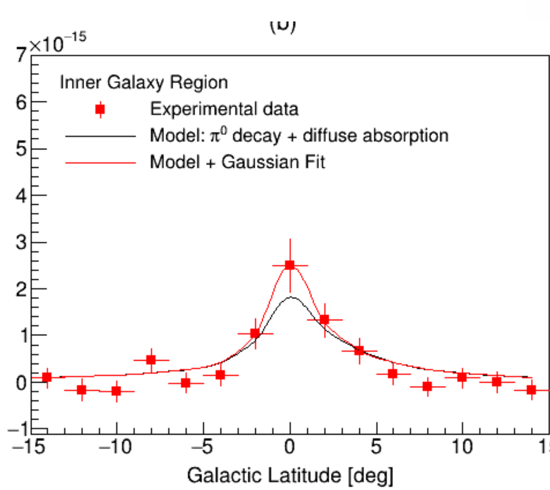
分组序号	名称	观测模式	时长(秒)	状态	基本信息
1	J2236+5913	Tracking	3000	未分配	详细 留言
2	J0341+5258	Tracking	3000	未分配	详细 留言
3	J0358+5359	Tracking	3000	未分配	详细 留言
4	J2108+5155	Tracking	3000	未分配	详细 留言

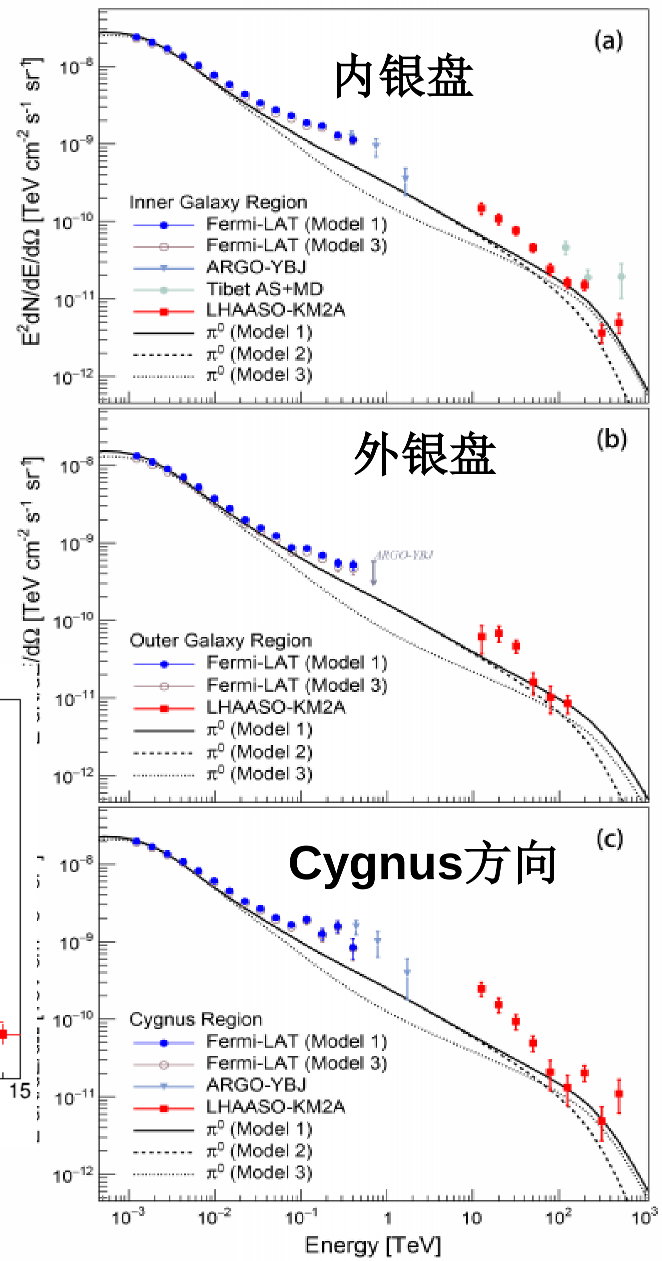
from ZhuHui

Diffuse Gamma-ray Emission from Galactic Plane



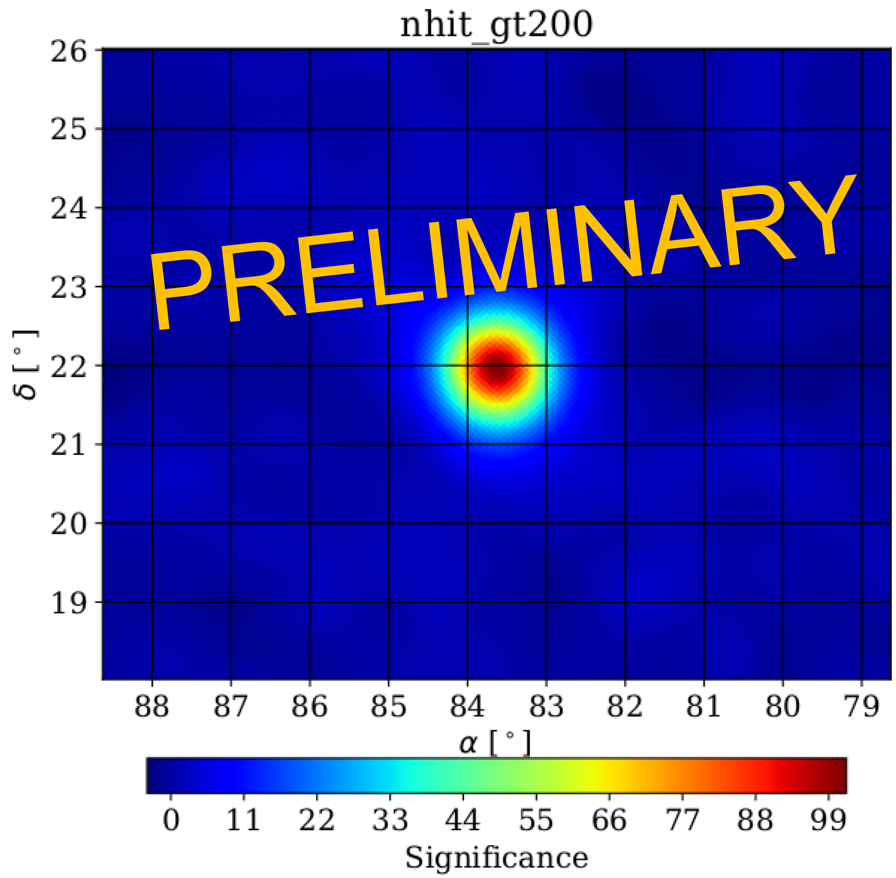


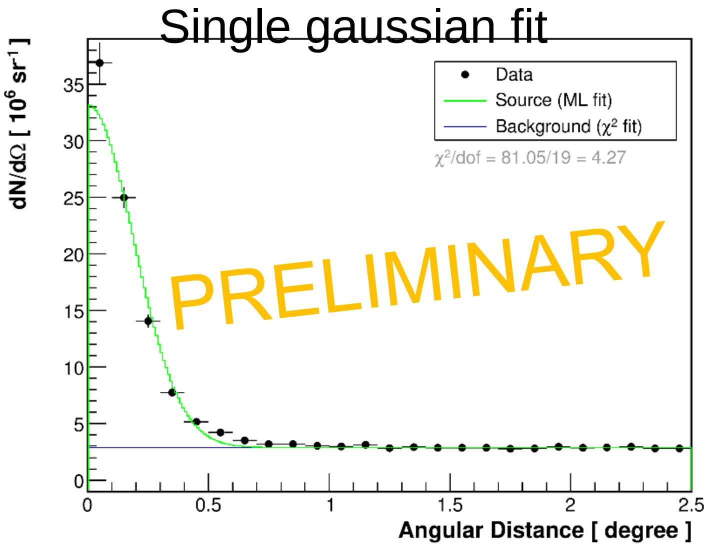


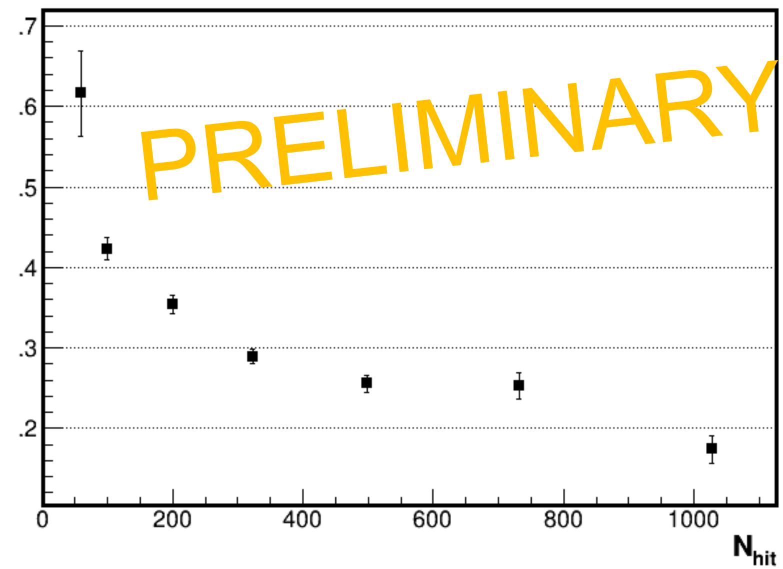


张瑞报告

Observation of Crab nebula with WCDA-full array



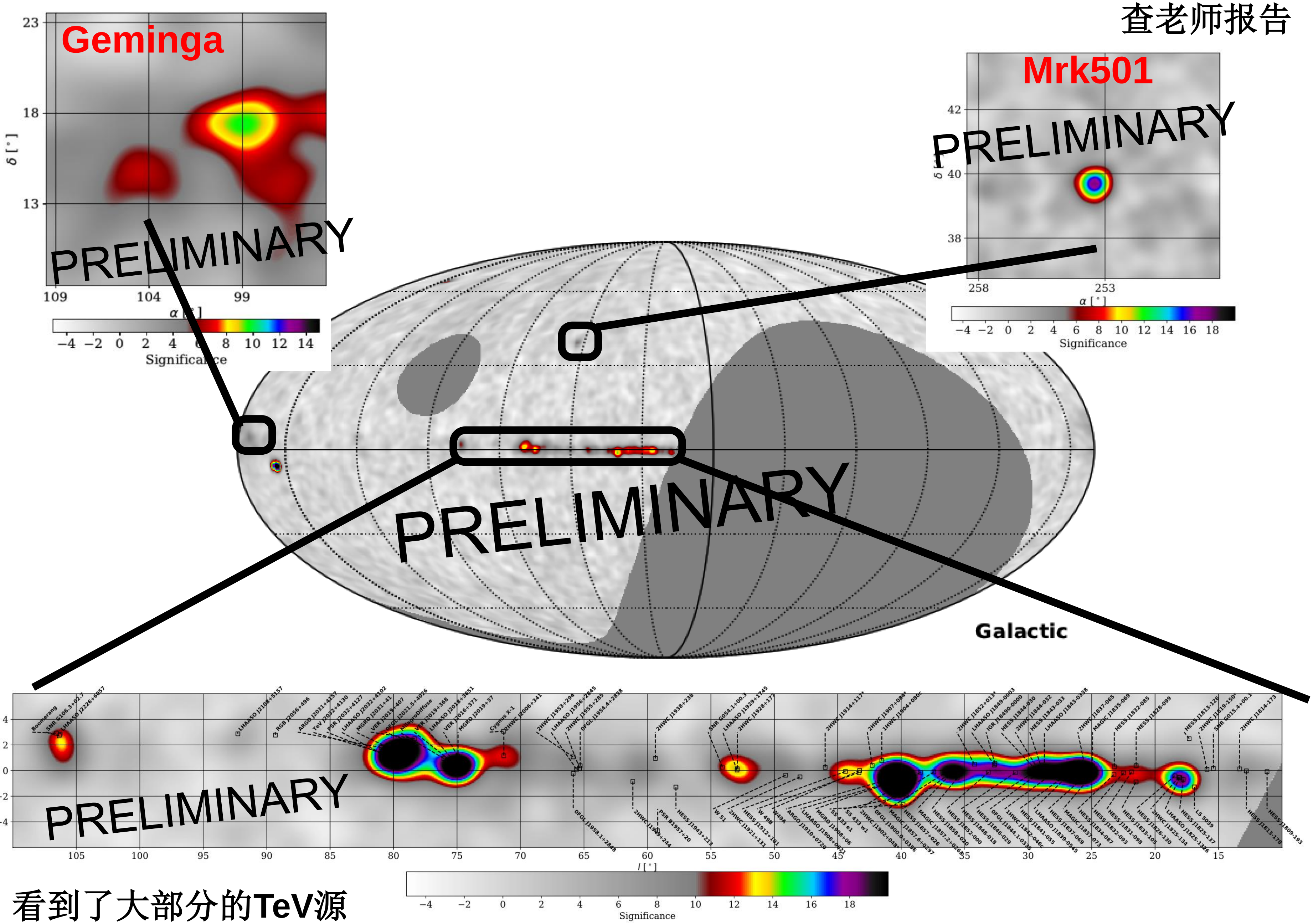




查老师报告

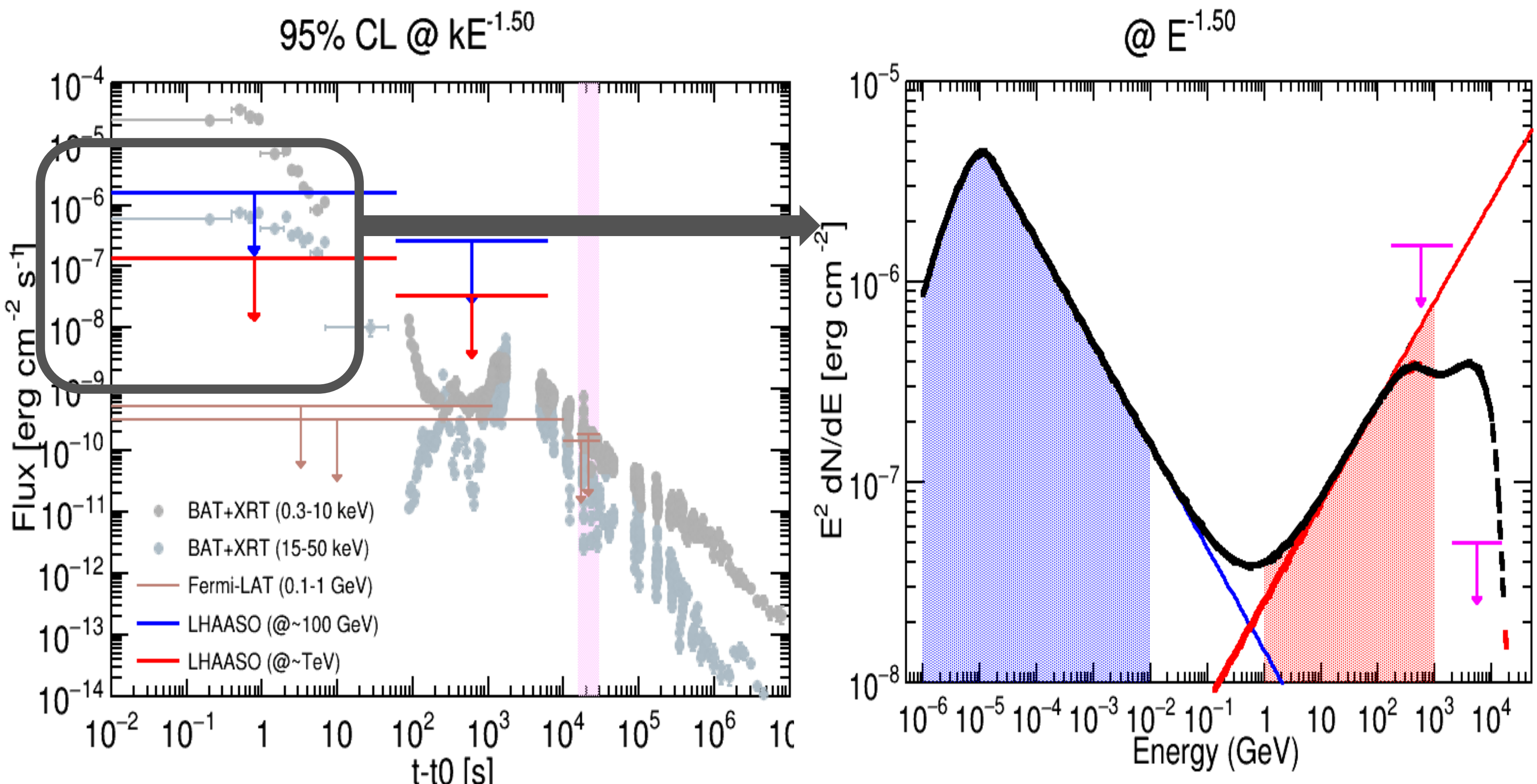
WCDA TeV gamma ray source survey

查老师报告



看到了大部分的TeV源

(1)基于WCDA实验 GRB190829A 分析

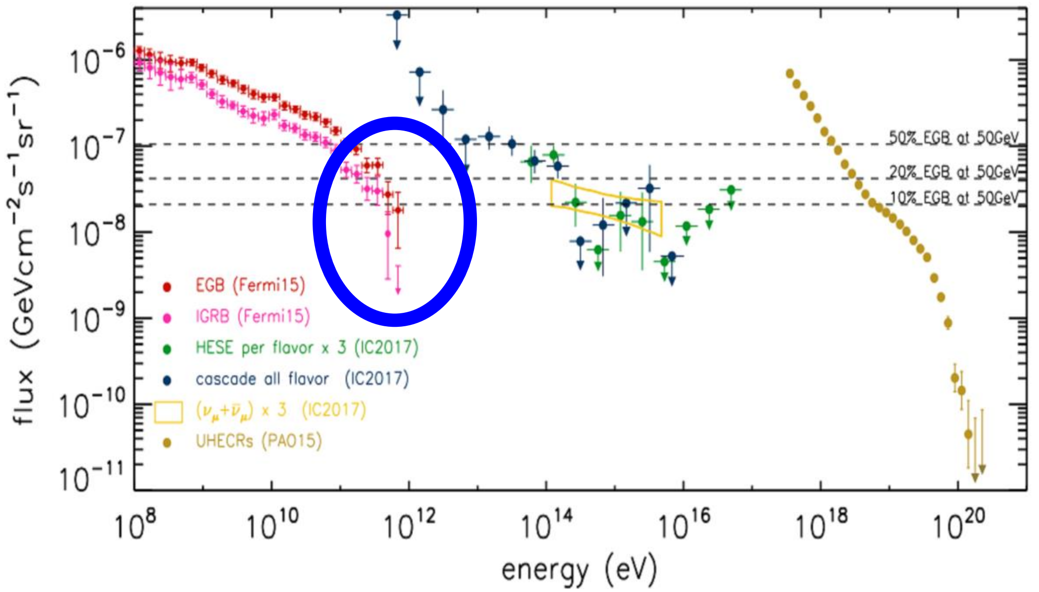


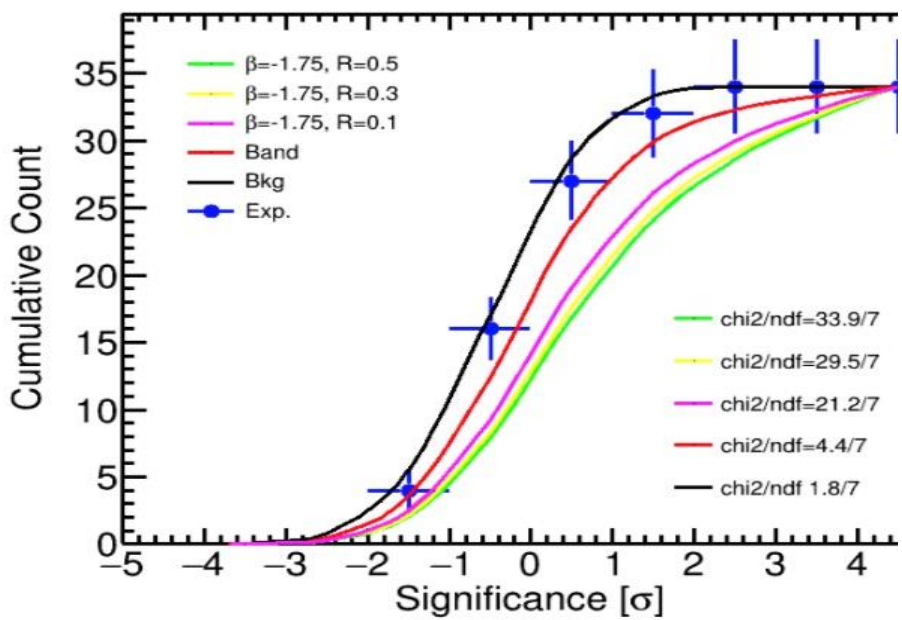
瞬时辐射：辐射机制/LIV研究

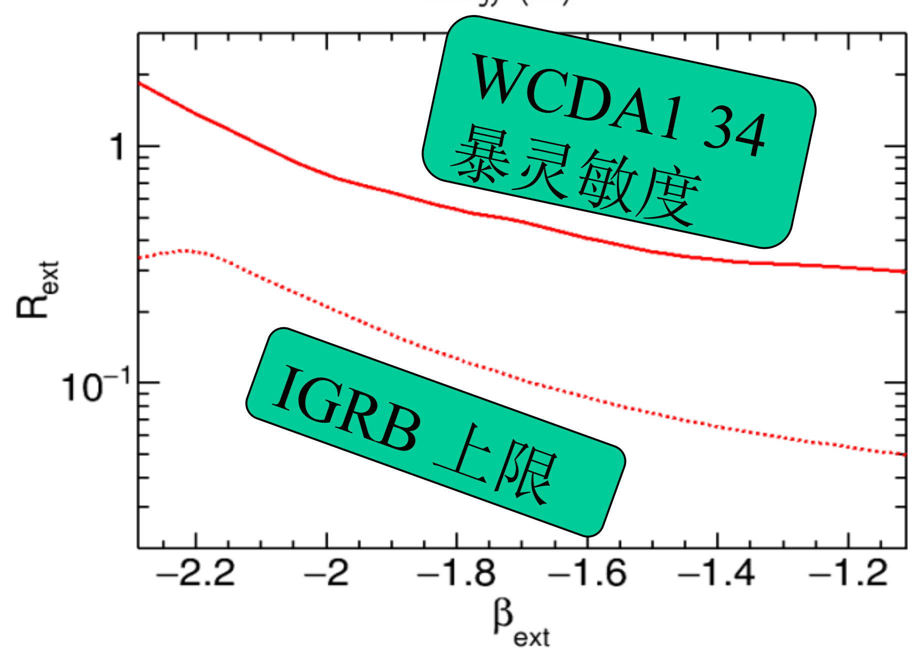
LHAASO 有望有重要结果！

(2)提出基于WCDA开展GRB统计分析

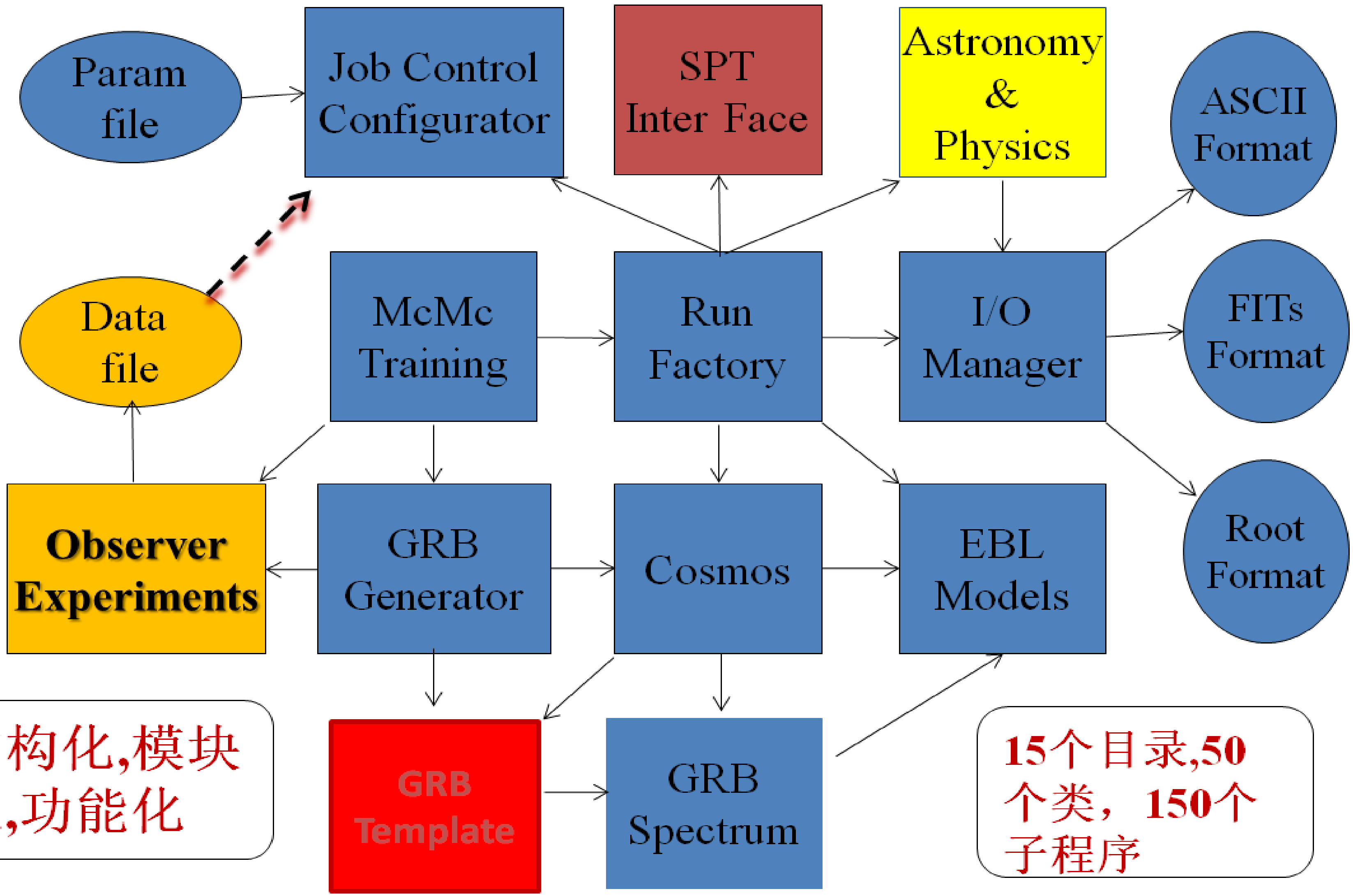
1. 数据分析与GodEyes模拟结合：似然方法
2. 限制GRB对IGRB贡献
3. 限制GRB对中微子及超高能CRs贡献







GodEyes 软件框架



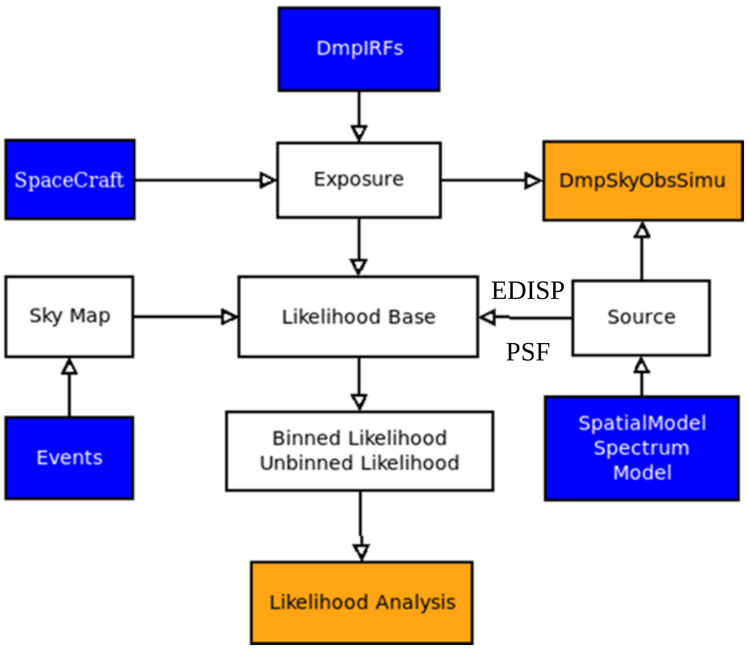
结构化,模块化,功能化

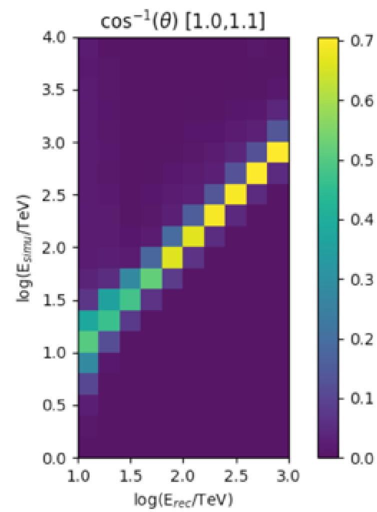
15个目录,50个类，150个子程序

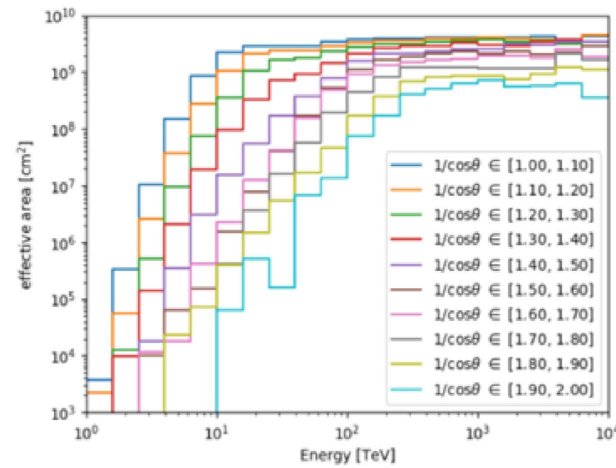
By Guoyq

Science tools for LHAASO-KM2A gamma-ray data analysis

By Huang xy, Duan KK

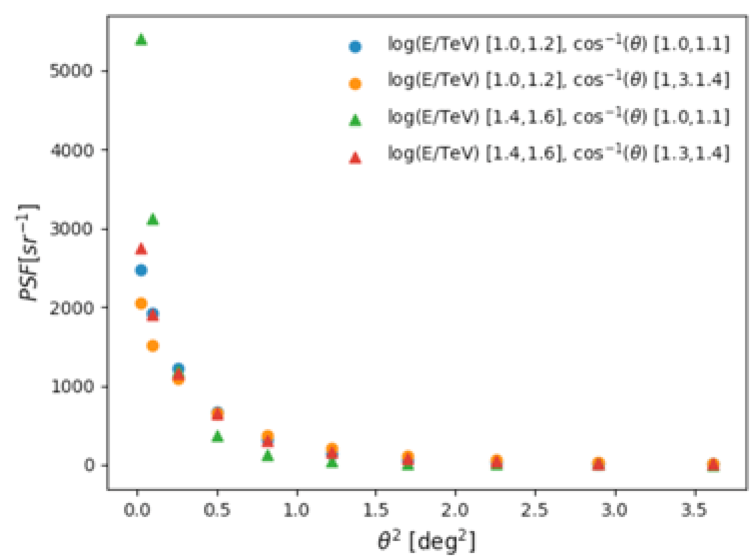






LHTools

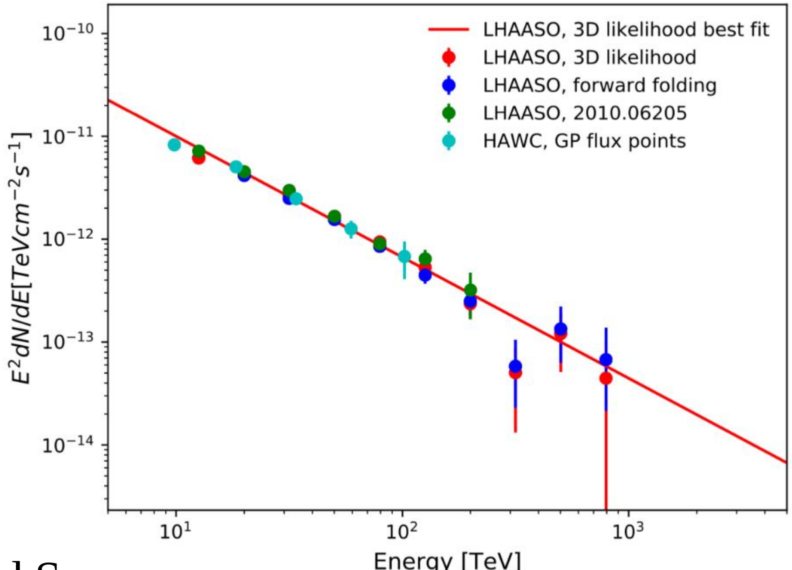
https://gitee.com/duankk/lhtools



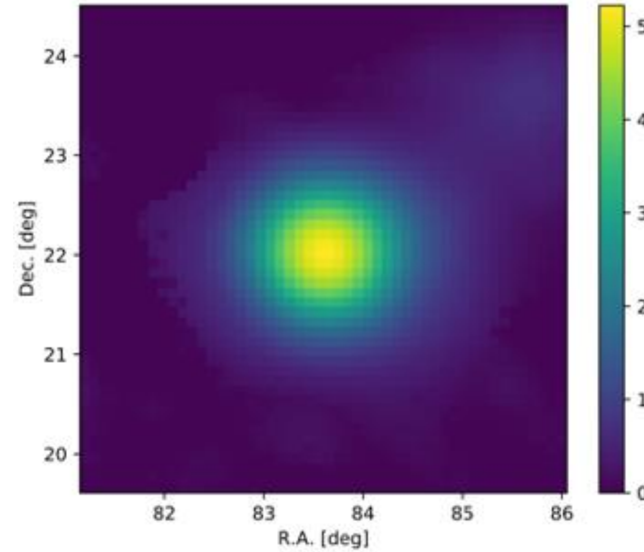
Analysis for Gamma Sources

Point Source

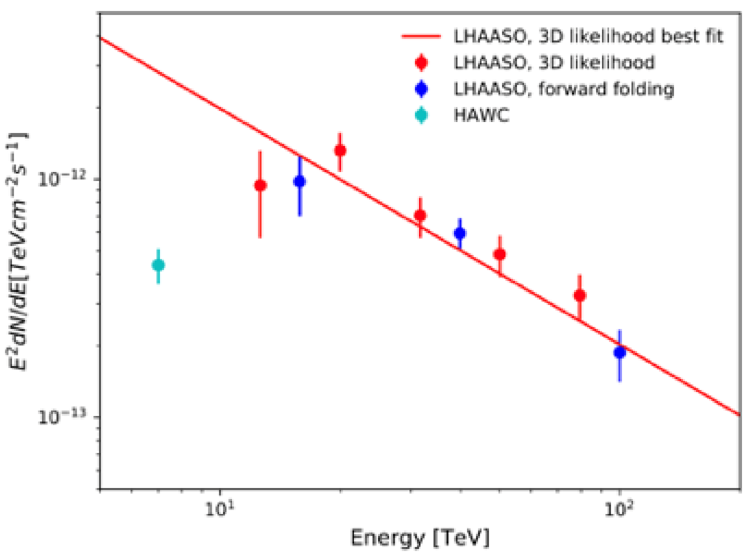
Crab Spectrum

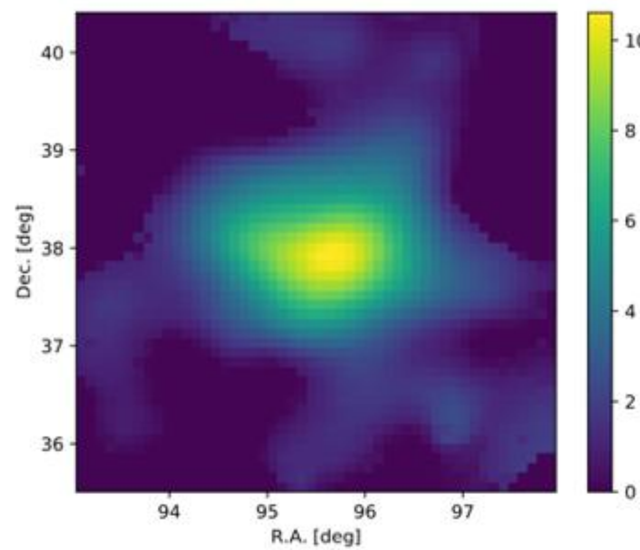


Crab Significance Map



Extended Source

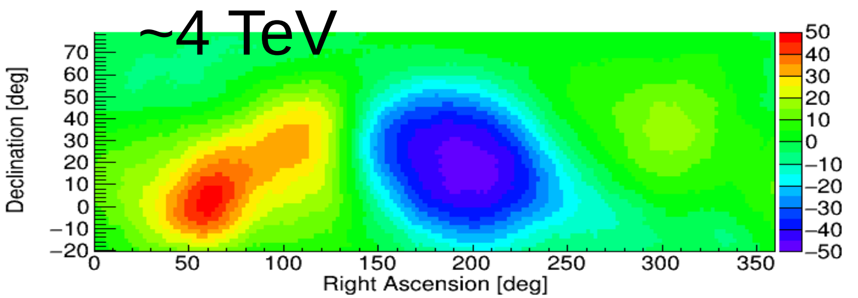


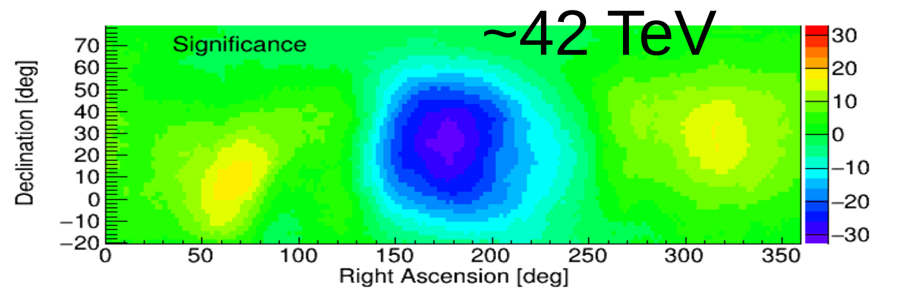


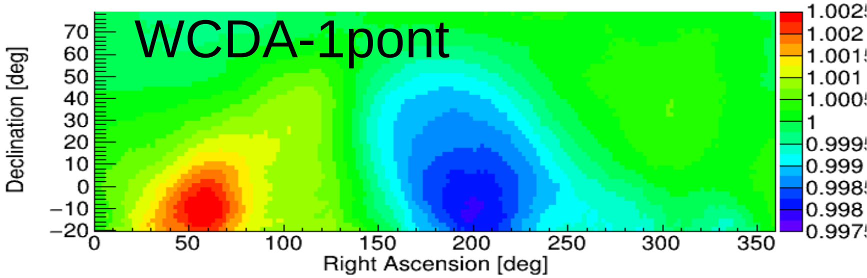
LHAASO J0621+3755 Spectrum

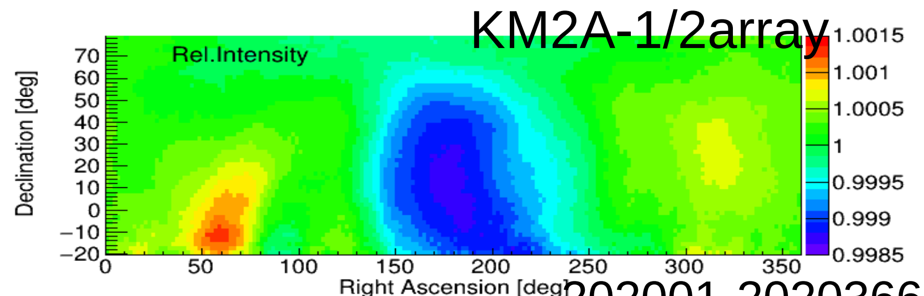
LHAASO J0621+3755 Significance Map

Anisotropy observed by LHAASO

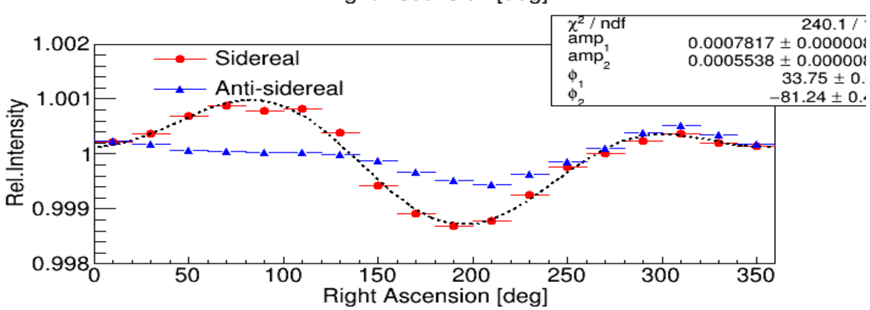


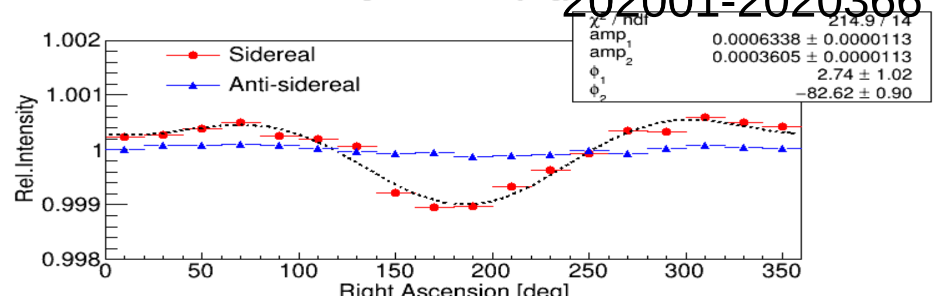




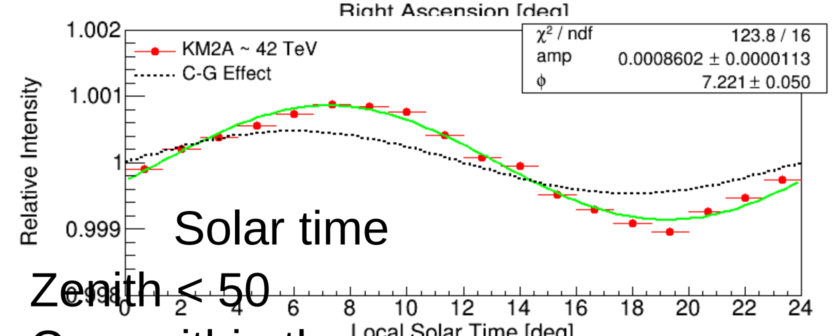


202001-2020366





2019091-366

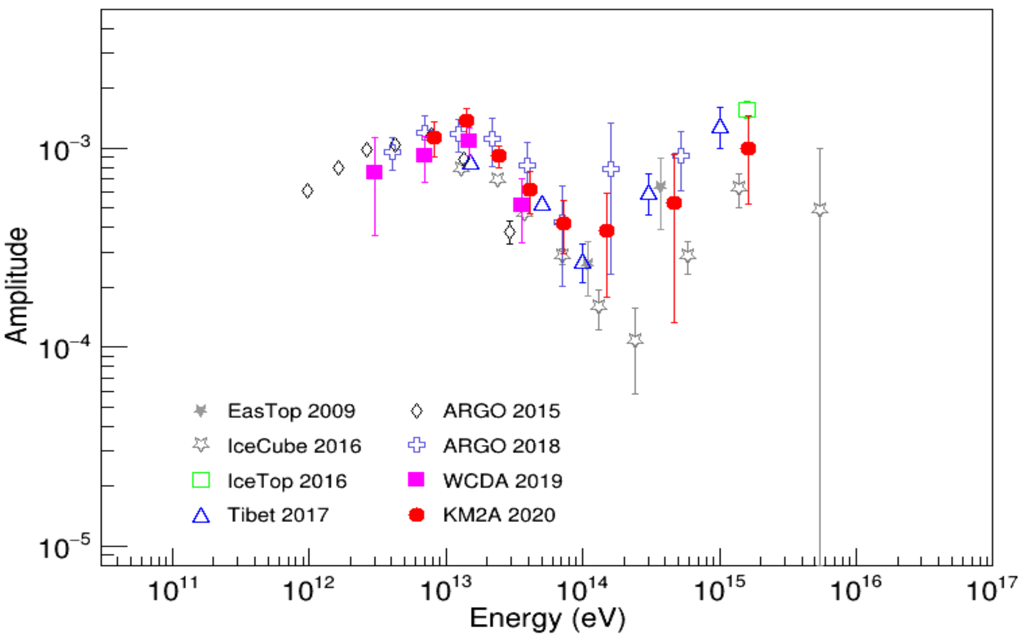


1. Expected Anisotropy
2. Abnormal CG effect
3. nfit>=50, smooth 15degree, ~3.7TeV, 2.85e10 events

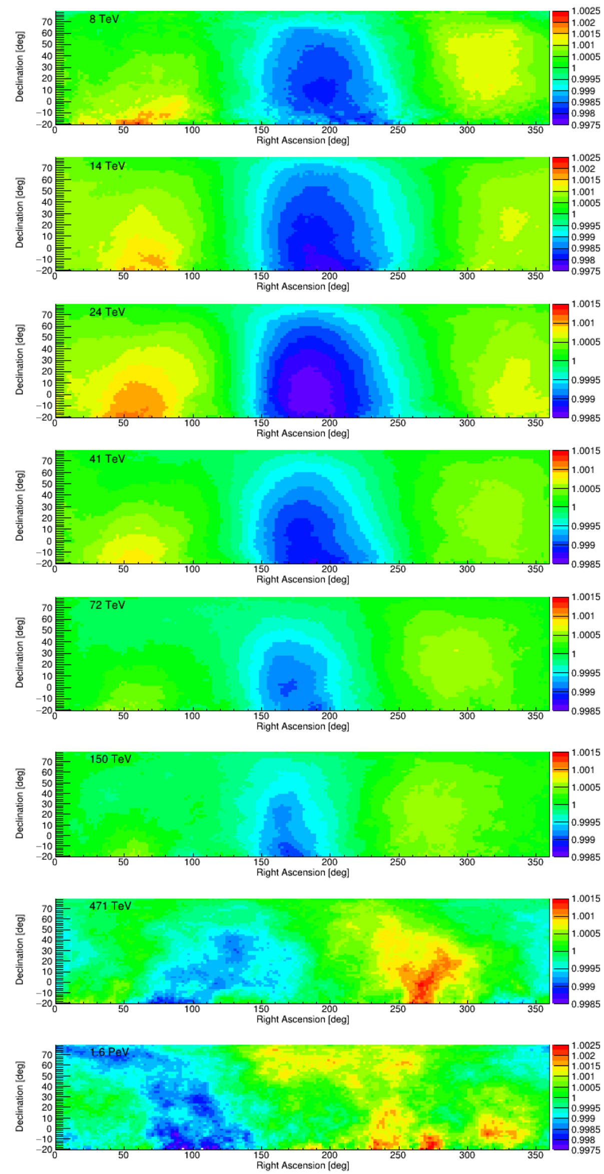
Zenith < 50
Core within the array
About 1.5×10^{10} events are used

Energy dependence of CR anisotropy

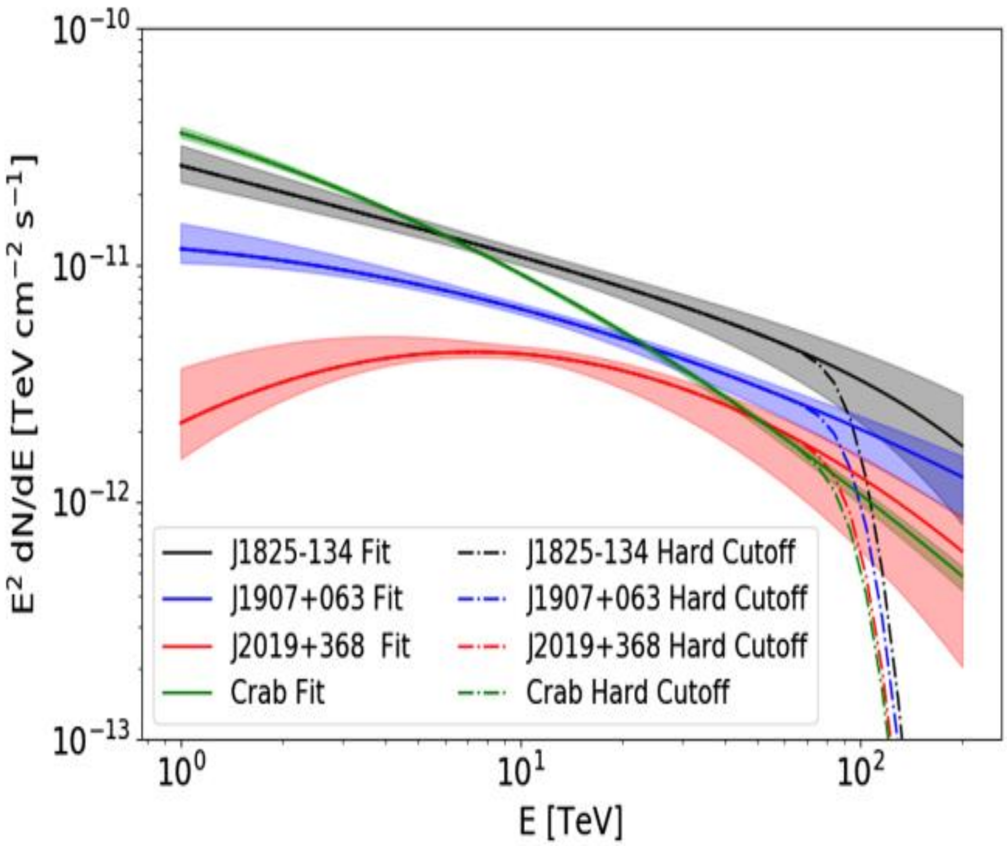
From GaoWei



Compositon dependence?



Lorentz invariance violations (LIV)



Hard cutoff in energy spectrum

Process: γ→ e⁺e⁻

$$E_\gamma^2 - p_\gamma^2 = |\alpha_n| p_\gamma^{n+2} = m_{\gamma,eff}^2,$$

$$E_{LIV}^{(n)} = \alpha_n^{-1/n}, (n > 0)$$

$$m_{\gamma,eff} < 2m_e.$$

$$\alpha_0 \leq \frac{4m_e^2}{E_\gamma^2 - 4m_e^2},$$

$$E_{LIV}^{(1)} \geq 9.57 \times 10^{23} \text{eV} \left(\frac{E_\gamma}{\text{TeV}}\right)^3,$$

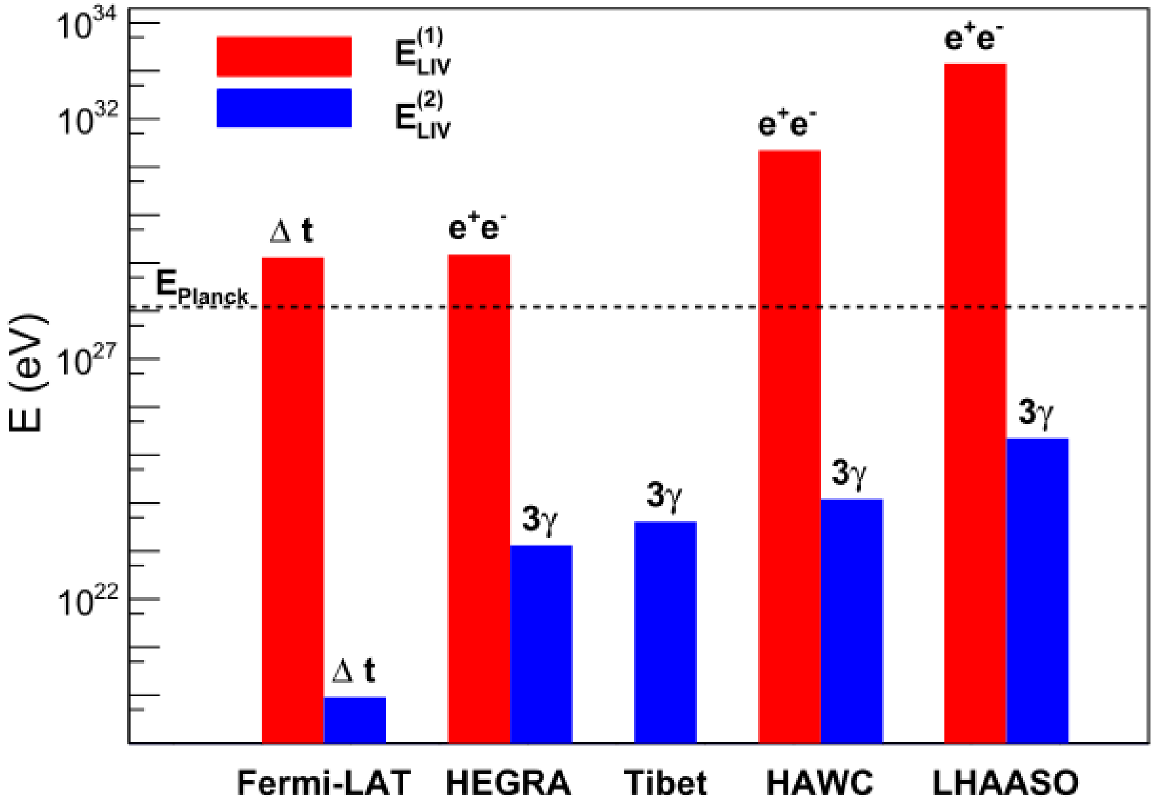
$$E_{LIV}^{(2)} \geq 9.78 \times 10^{17} \text{eV} \left(\frac{E_\gamma}{\text{TeV}}\right)^2.$$

Process: γ→ 3γ

$$\Gamma_{\gamma\to 3\gamma} = 5 \times 10^{-14} \frac{E_\gamma^{19}}{m_e^8 E_{LIV}^{(2)10}},$$

$$E_{LIV}^{(2)} > 3.33 \times 10^{19} \text{eV} \left(\frac{L}{\text{kpc}}\right)^{0.1} \left(\frac{E_\gamma}{\text{TeV}}\right)^{1.9}.$$

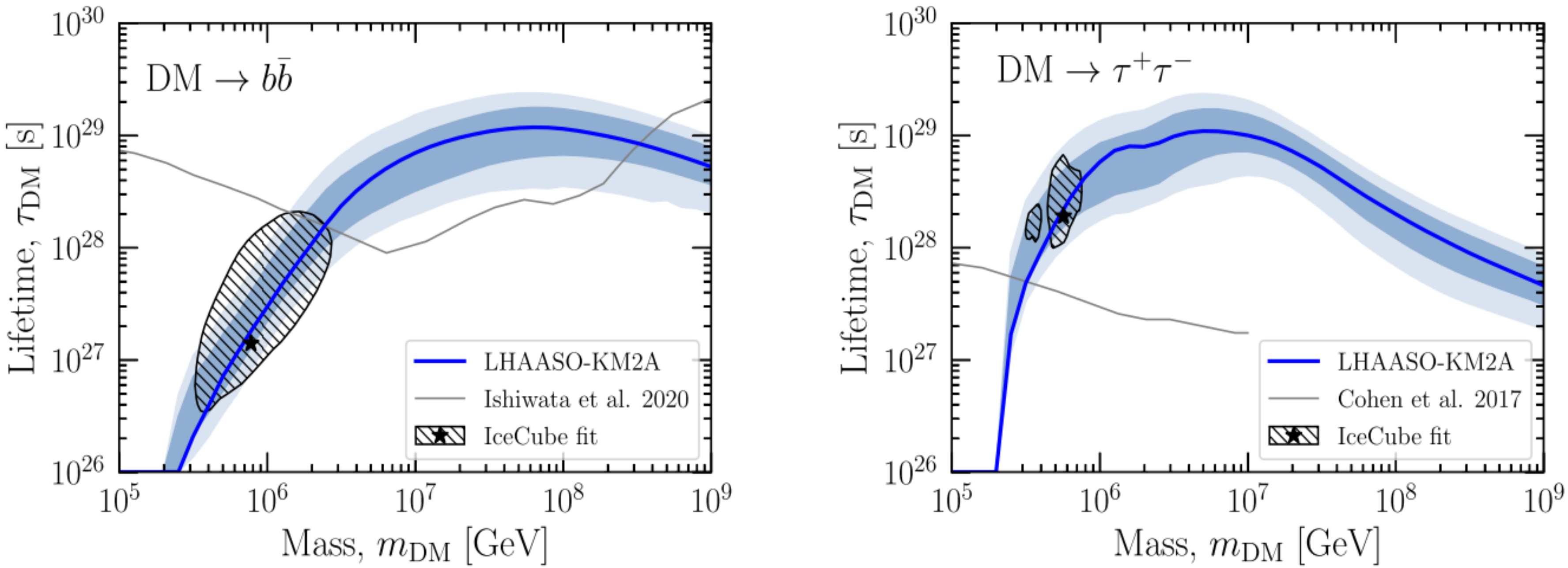
Lorentz invariance violations (LIV)



Source	L (kpc)	$E_{\max}$ (PeV)	$E^{95\%}_{\text{cut}}$ (PeV)	$E^{(1)}_{\text{LIV}}$ (eV) $\times 10^{32}$	$E^{(2)}_{\text{LIV}}$ (eV) $\times 10^{23}$	$E^{(2)}_{\text{LIV}}$ (3γ) (eV) $\times 10^{25}$
J0534+2202	2.0	0.88	$0.75^{+0.043}_{-0.043}$	$4.04^{+0.73}_{-0.65}$	$5.5^{+0.65}_{-0.61}$	$1.04^{+0.12}_{-0.11}$
J2032+4102	1.4	1.42	$1.14^{+0.06}_{-0.06}$	$14.2^{+2.32}_{-2.10}$	$12.7^{+1.36}_{-1.29}$	$2.21^{+0.22}_{-0.21}$

arXiv:2106.12350

Constraints on decaying dark matter with LHAASO



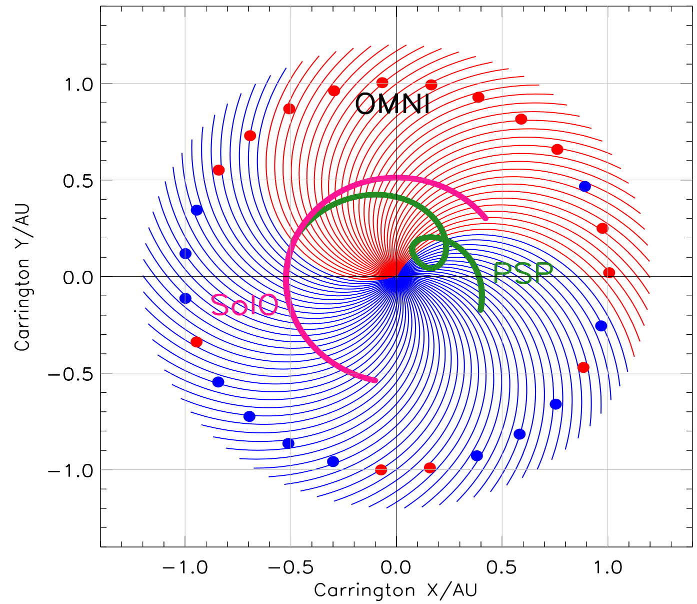
利用高银纬无源区域，计算伽马射线的上限。

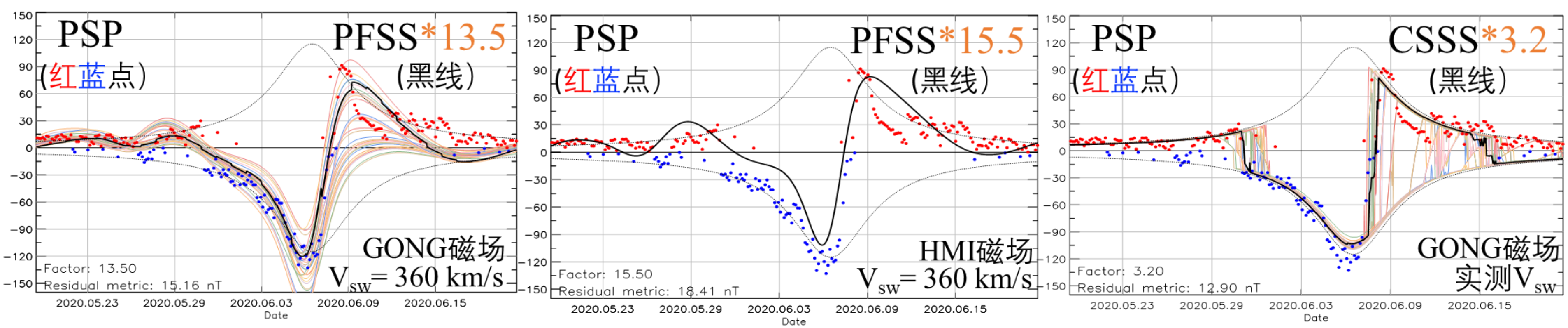
From Li zhe, Kenny

日地空间磁场模型及观测比较

1. **磁场模型:** 日冕磁场: PFSS (势场) 和 CSSS (引入水平电流片)
   行星际磁场: Parker 螺旋线
2. **输入磁图:** 极区磁场填充修正后的单张卡林顿周HMI磁图, 以及 GONG 零点校正的高时间分辨磁图, 进行日地空间磁场模型计算.
3. **观测比较:** 将不同磁场模型外推出的行星际磁场与 PSP (NASA-帕克太阳探针), Solar Orbiter (ESA-太阳轨道器SolO) 和 OMNI (1 AU-L1点) 实地测量磁场比较, 获得磁场模型最优参数.
4. **计划:** 利用 WCDA 日影数据, 结合蒙特卡洛模拟, 进一步对日冕磁场约束优化。

日地空间磁场及卫星轨道





LHAASO
高海拔宇宙线观测站

总 结

1. 研发任务基本按实施方案实施。
2. KM2A有一批新发现和WCDA新天图。
3. 各向异性工作，系统误差，成分分析。
4. 初步天文分析软件的建立。
5. 新物理工作开展。
5. 能谱工作（见马玲玲报告）。

谢谢各位！