

LHAASO STATUS

- Shaoqiang Xi
- On behalf of LHAASO

概览

1. LHAASO 简介

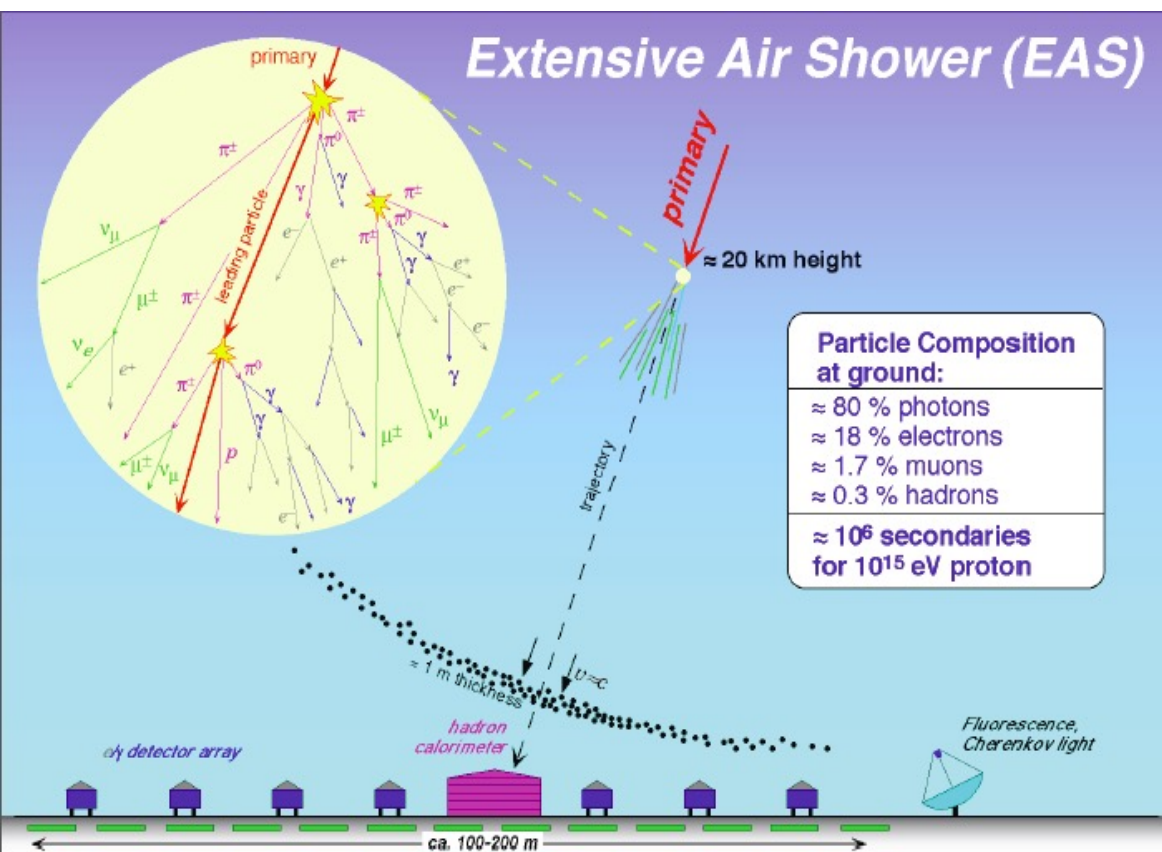
2. LHAASO 科学简介与进展

3. 总结

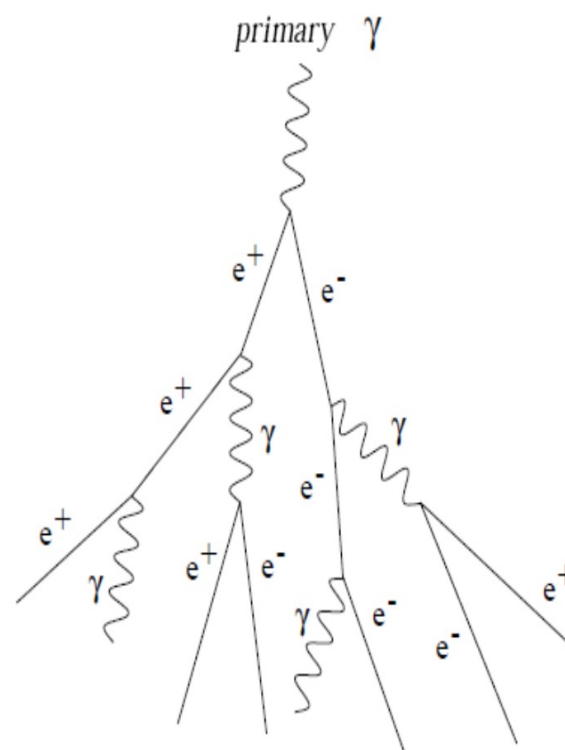
1. LHAASO 简介

伽马射线/宇宙线 探测基础

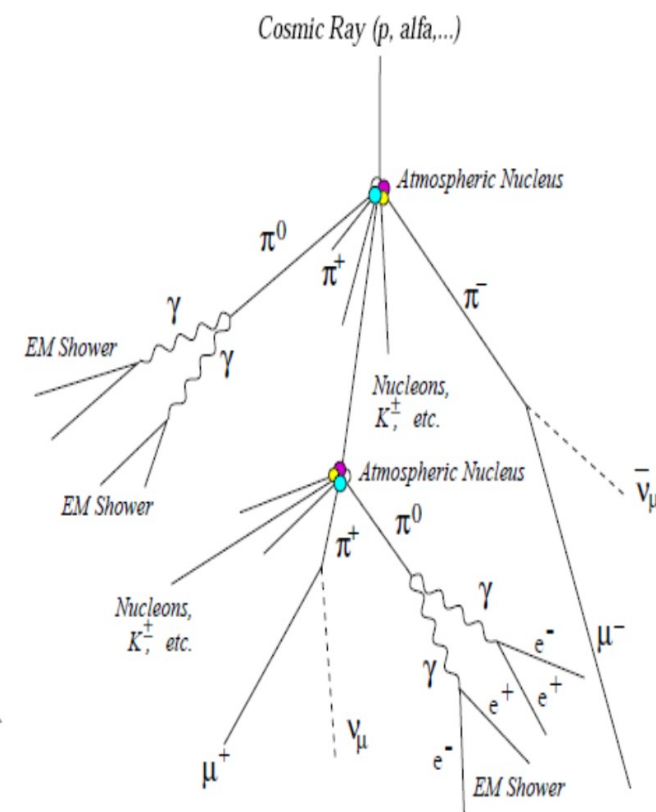
Large High Altitude Air Shower Observatory



伽马光子



宇宙线



LHAASO 位置

- 位置 : $29^{\circ}21'27.6''$ N , $100^{\circ}08'19.6''$ E
- 海拔: 4410 m
- 2021-07 完全竣工



四川稻城



LHAASO, *Nature Astronomy* 5:849 (2021)

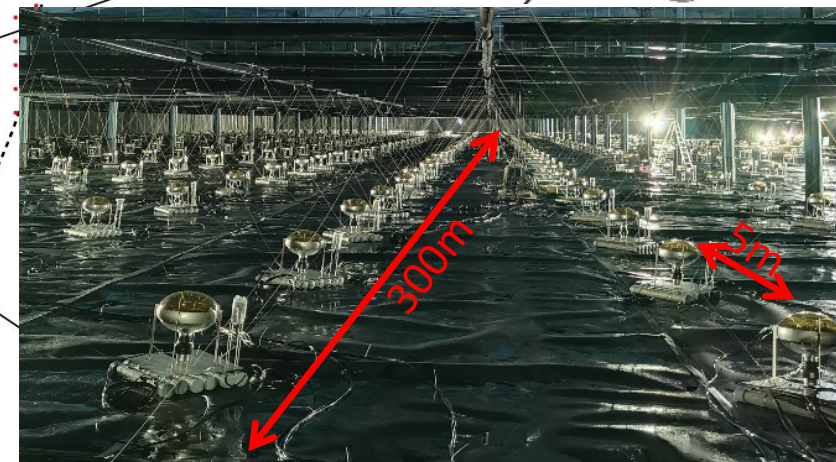
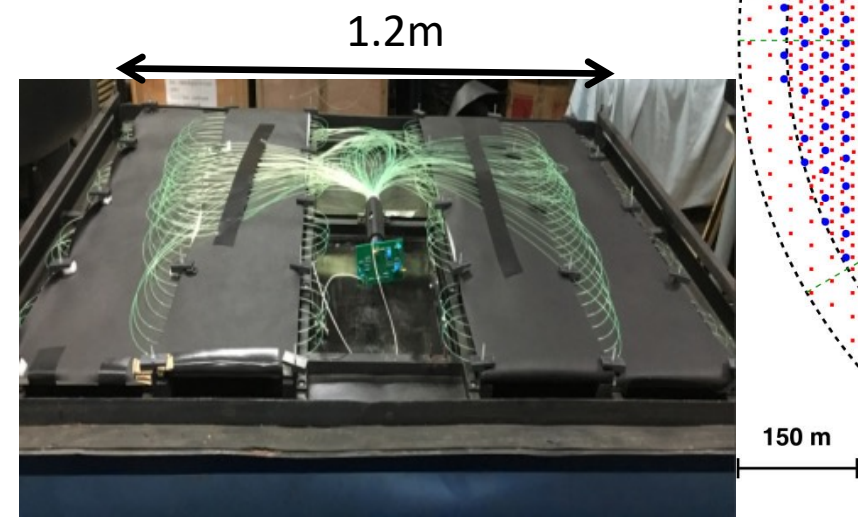
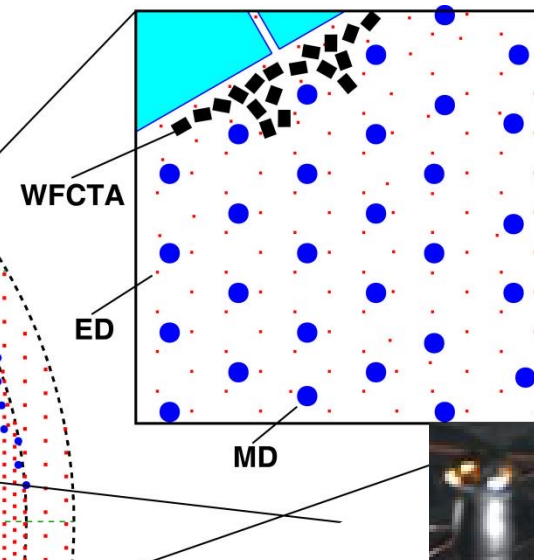
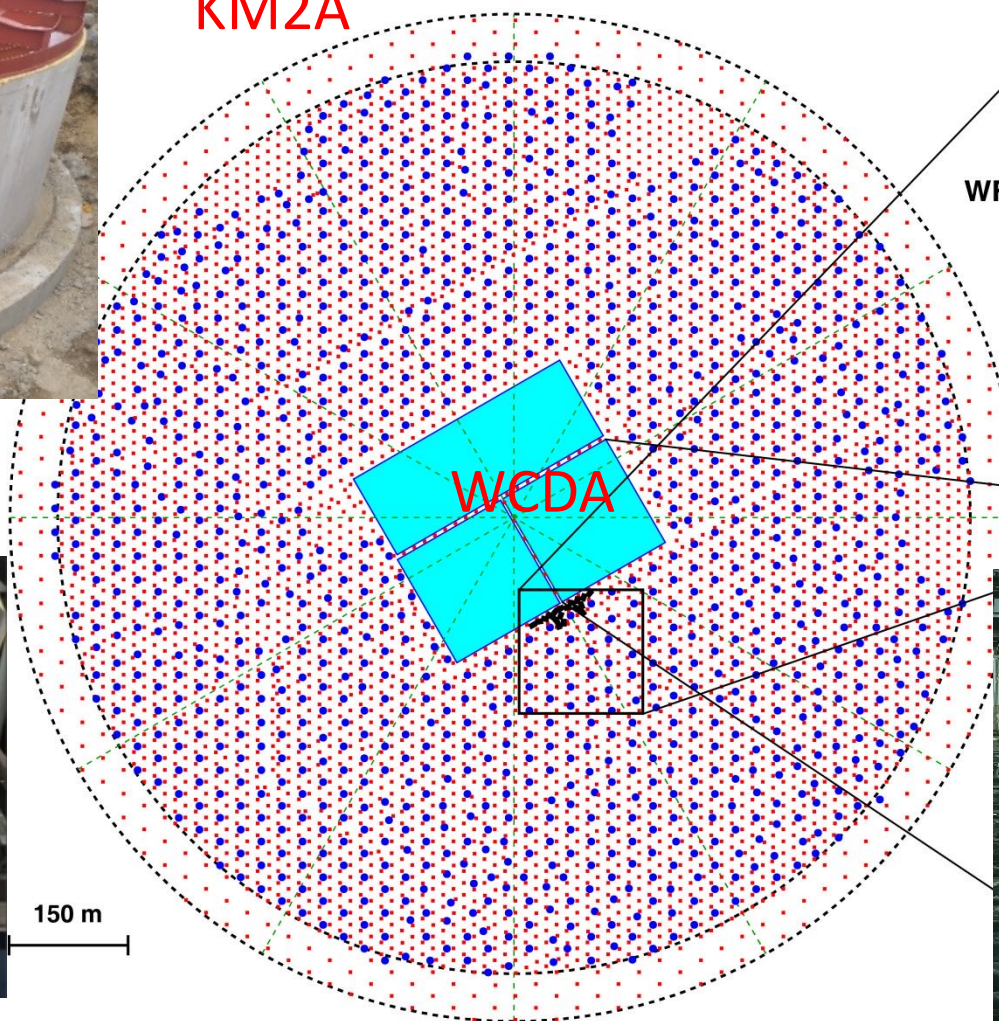
(Aug. 2018, at 4410 m a.s.l.)

LHAASO 探测器布局

WFCTA



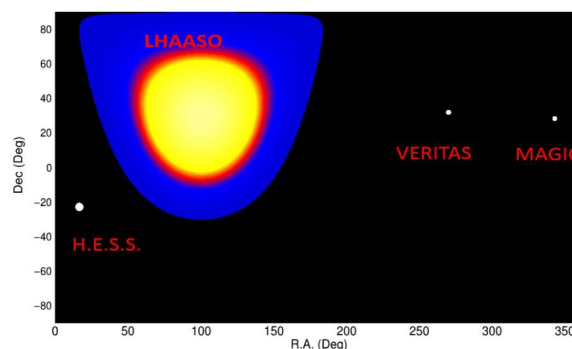
KM2A



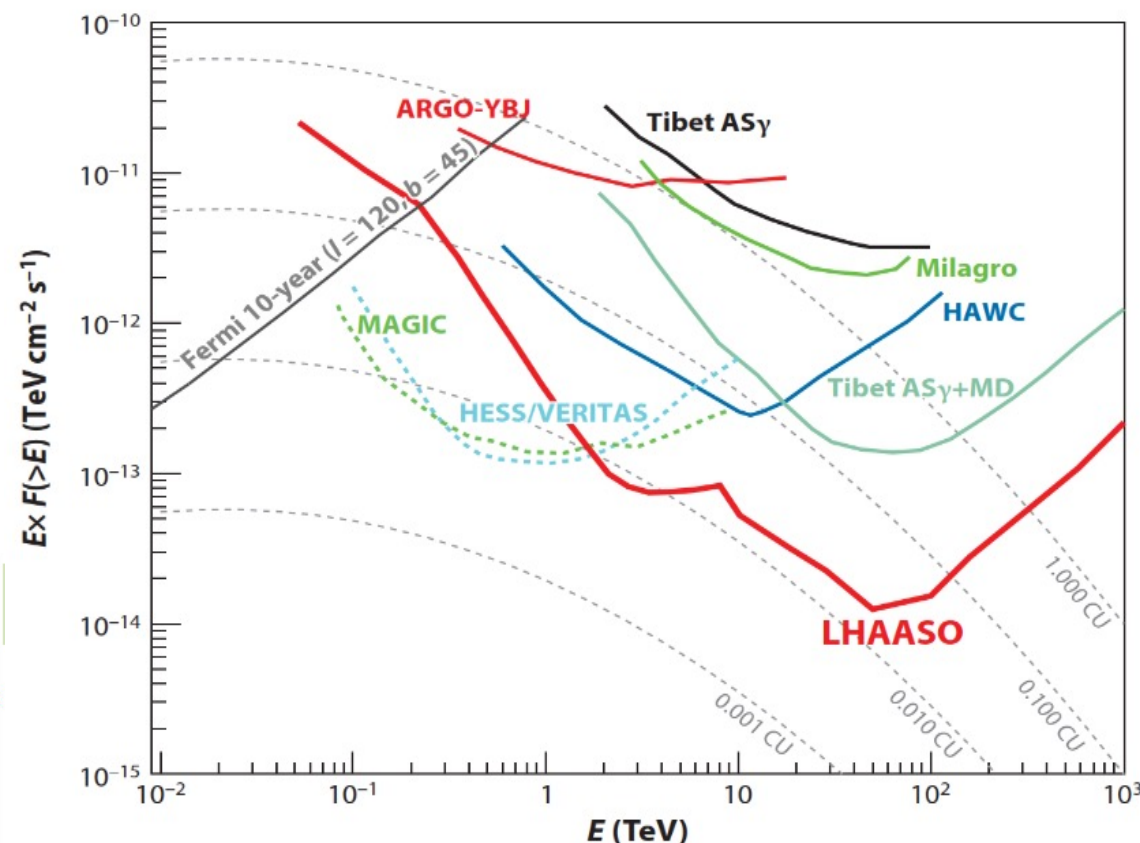
LHAASO 性能

	量程	精度
光子/CR 方向	FoV : 2 Sr Dec.: -20° to 80°	0.2° (100 TeV , 小天顶角)
光子/CR 时间	2019/12 开始 (全天候)	ns
光子/CR 能量	0.5 TeV – 几十 PeV	14% (100 TeV, 小天顶角)

- 最好的100 TeV能区 宇宙线观测站
- 最好的100 TeV 能区 伽马观测站 (独一无二) !
- 最好的TeV能区变源检测站!

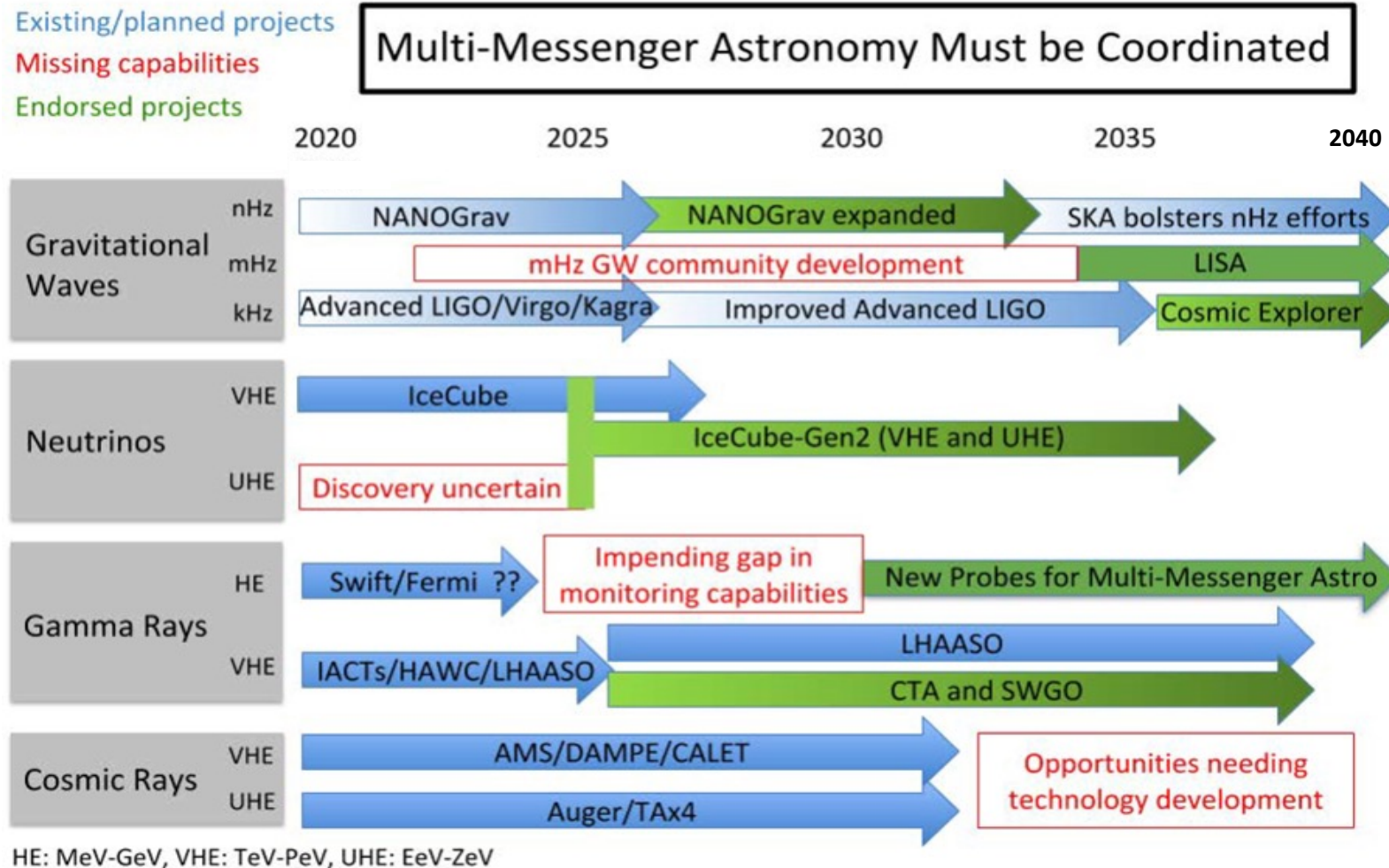


宇宙线排除+有效面积：灵敏度

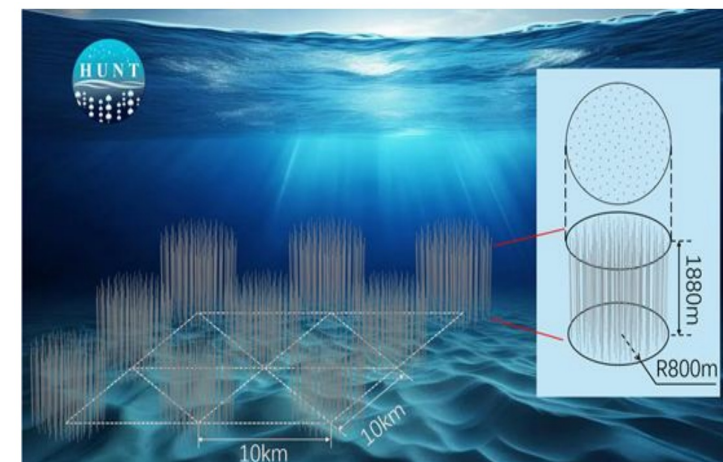


LHAASO 时代： 引领伽马天文/“膝”区宇宙线物理突破

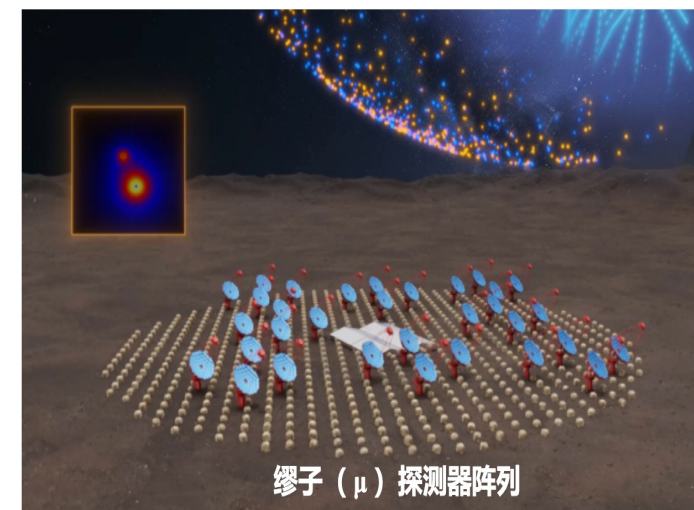
2021 年美国天文天体物理十年规划



HUNT



LACT



2. LHAASO 科学简介与进展

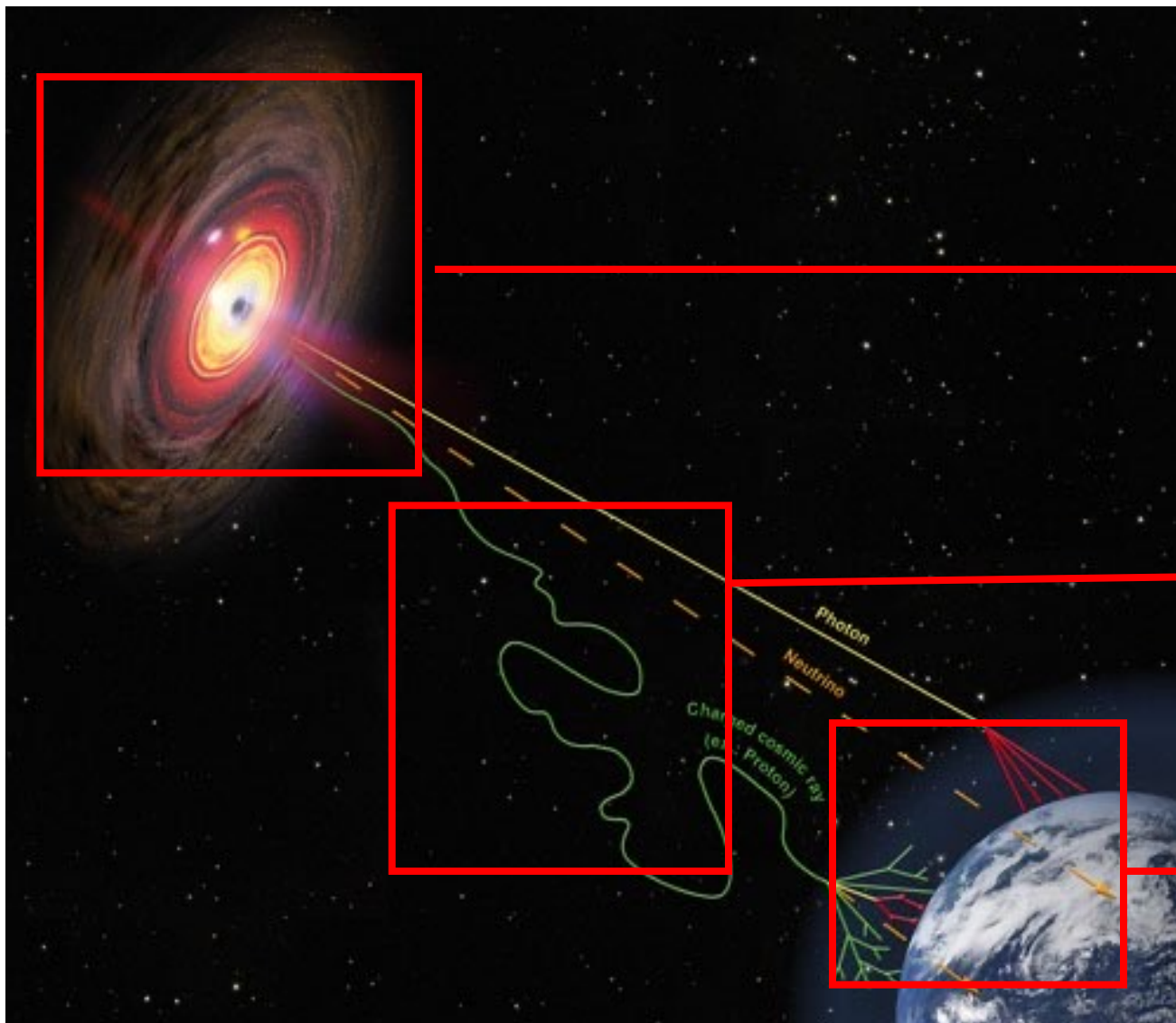
LHAASO最核心的科学 宇宙线起源问题

宇宙线：宇宙中速度接近光速的带电粒子

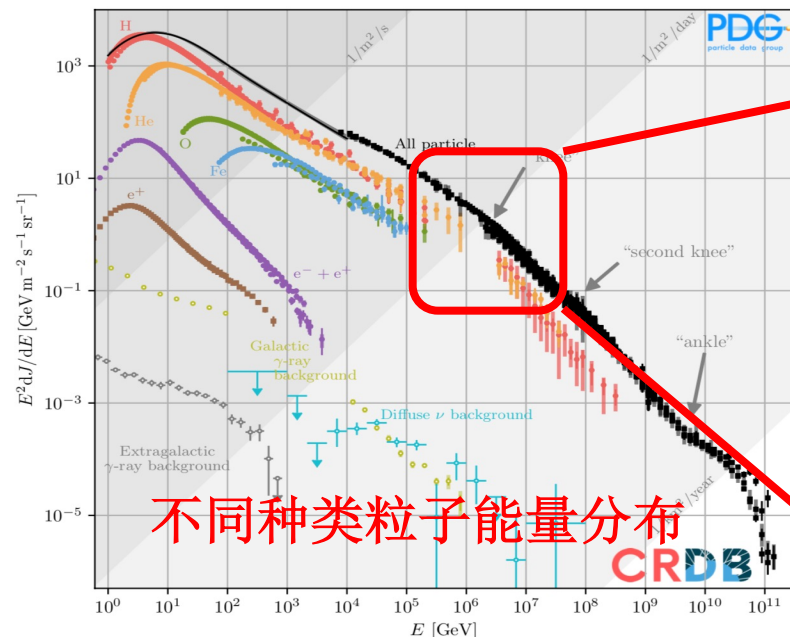
伽马源：示踪靠近加速器区域的宇宙线

弥散伽马射线：示踪整个银河系不同大尺度区域的宇宙线

直接测量到的宇宙线：仅代表地球附近的宇宙线



LHAASO宇宙线相关测量



能量密度:

$\sim 1 \text{ eV cm}^{-3}$

成分:

$\sim 89\%$ 质子
 $\sim 10\%$ 氦核
 $\sim 1\%$ 其它

宇宙线总谱形:

$< 30 \text{ GeV}$: 上升

$< \sim 3 \times 10^{15} \text{ eV}$: -2.7 幂律谱

$< \sim 10^{18} \text{ eV}$: 第一第二膝区(-3.1) (?)

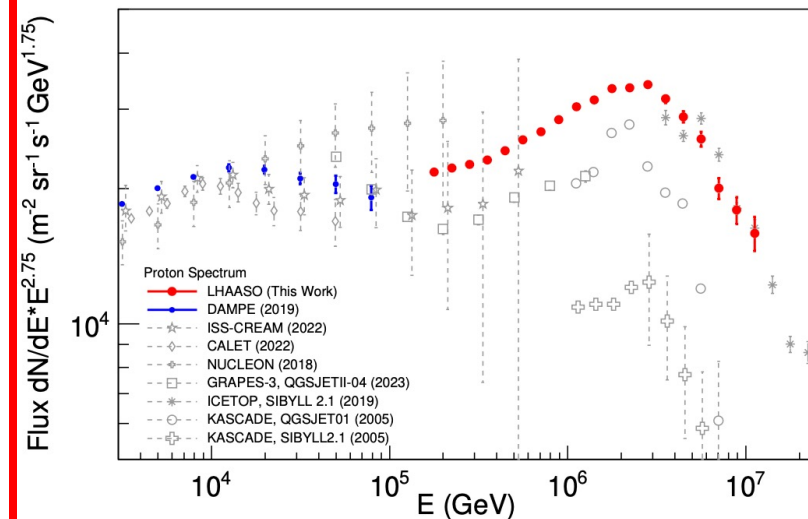
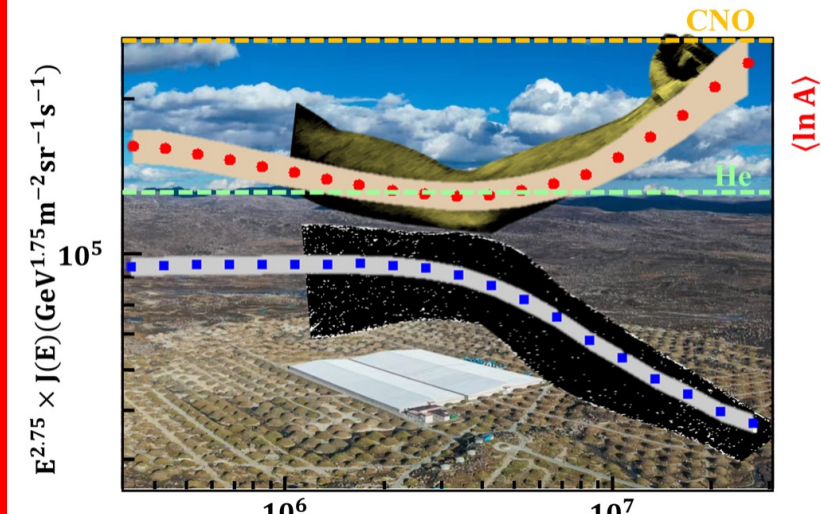
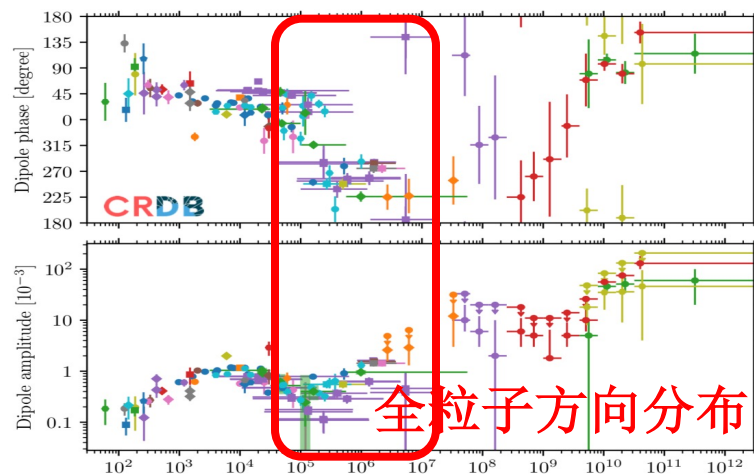
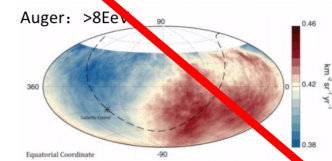
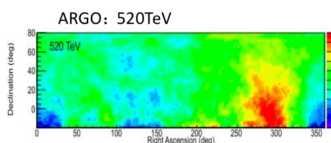
$> \sim 10^{18} \text{ eV}$: 踝区 (?)

幅度:

10^{-3}

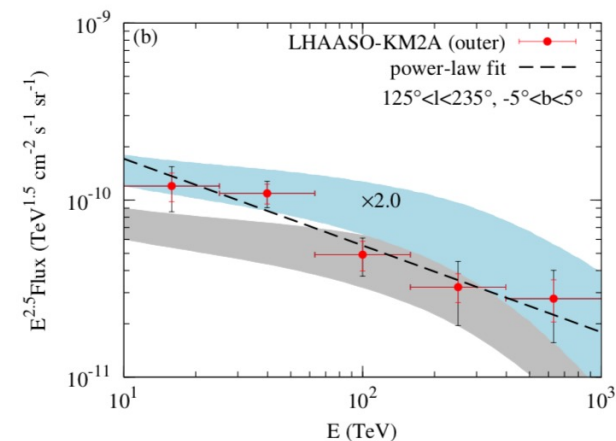
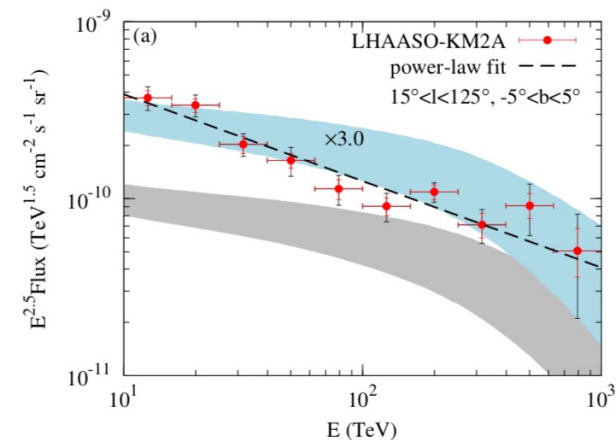
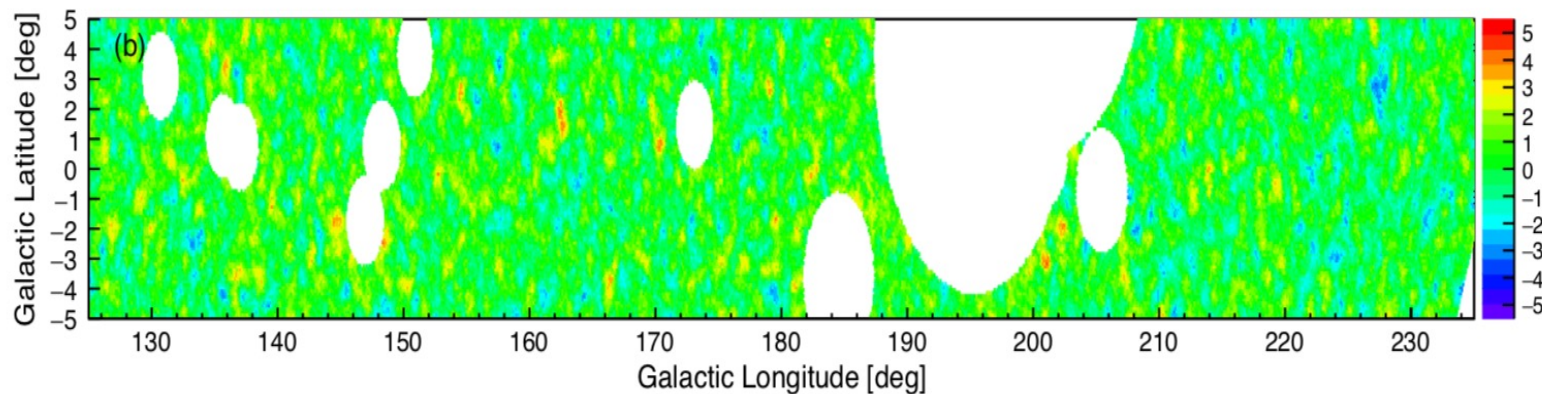
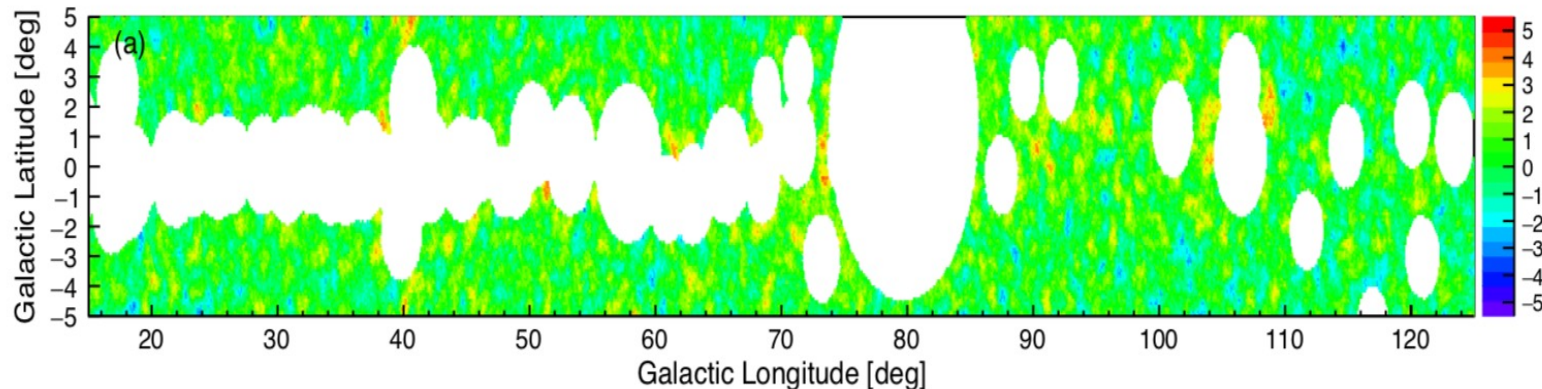
相位:

100 TeV-10 PeV 银心方向



LHAASO: • 精确测量全粒子能谱
• 精确测量到质子谱

LHAASO 伽马射线相关测量之弥散伽马射线辐射

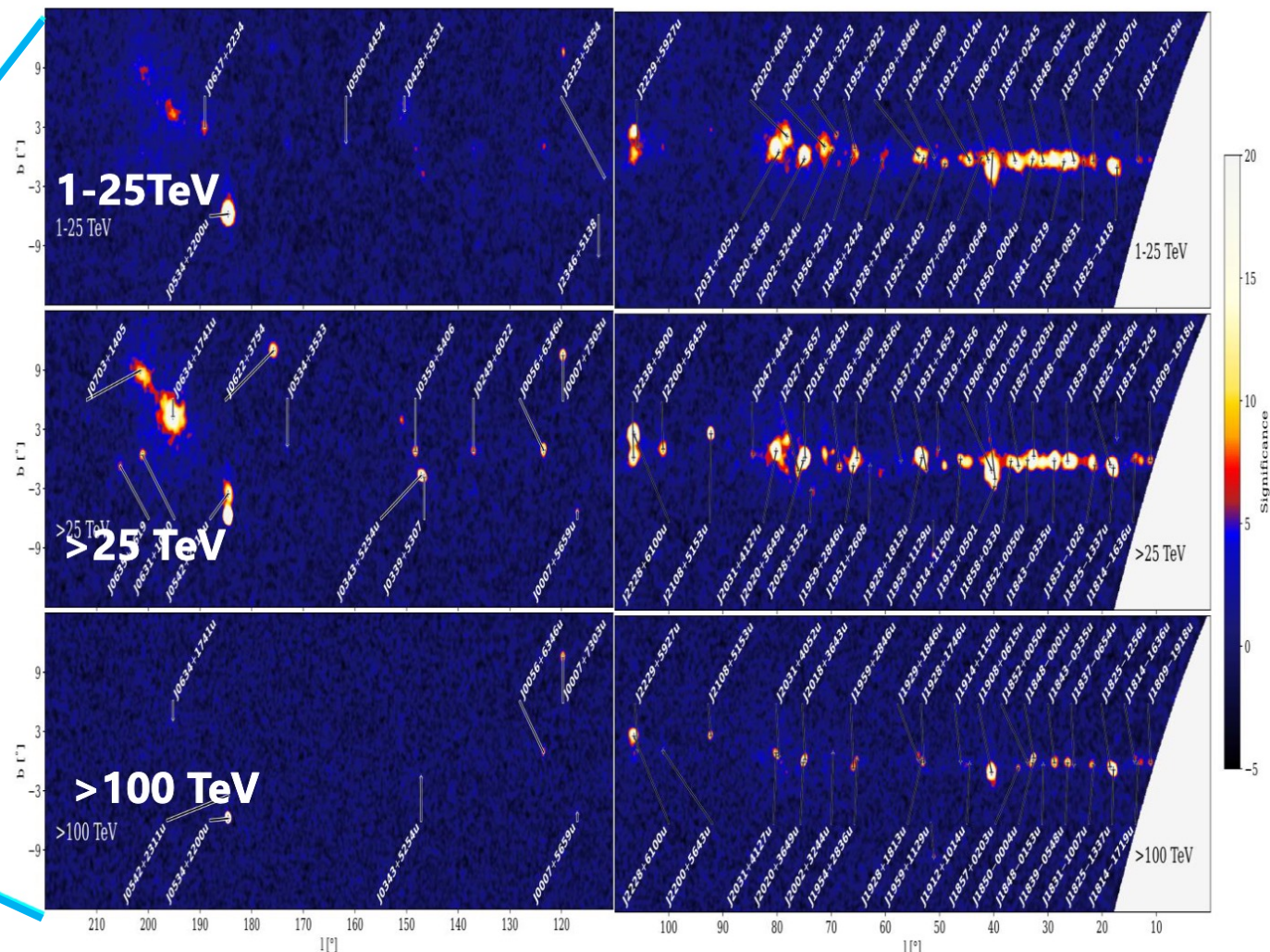
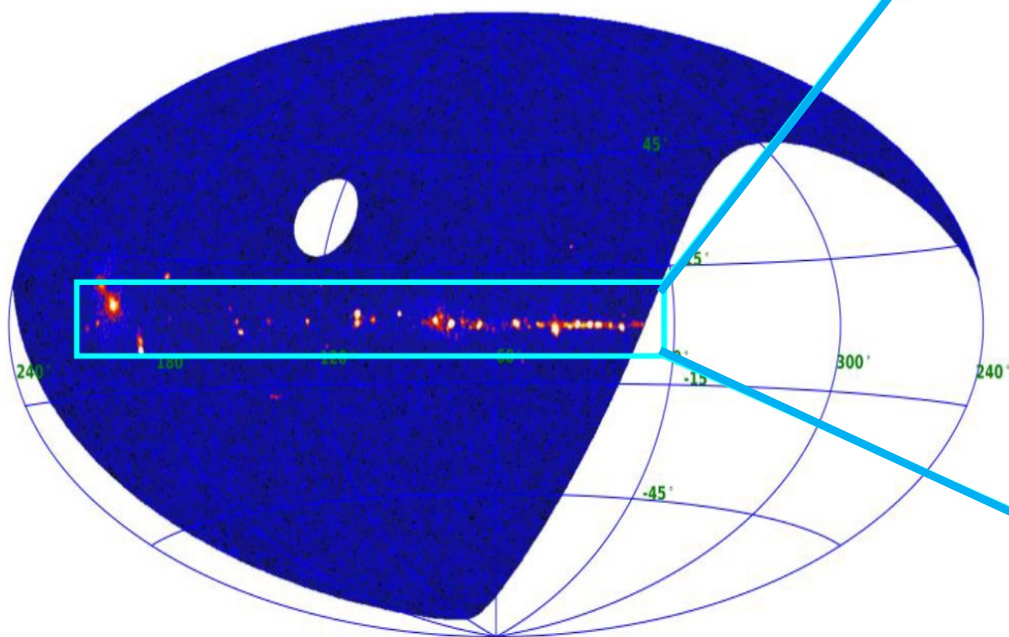


- 白色的区域是挖掉的源的区域
- 有颜色的区域就是测量到的弥散辐射

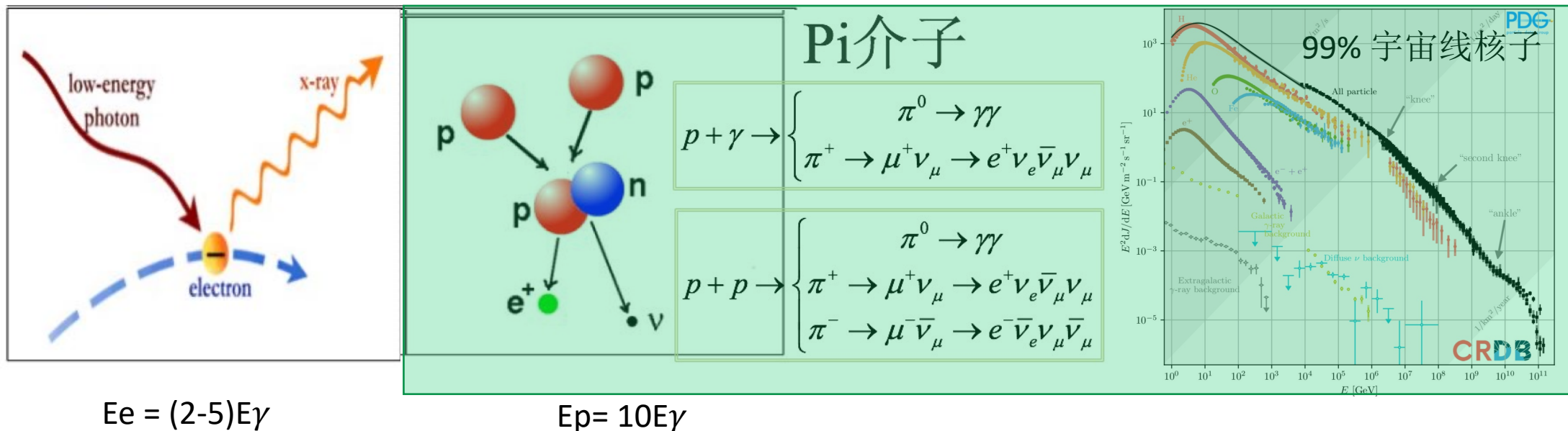
宇宙线密度在银河系不同区域是不同的

LHAASO 伽马射线相关测量之伽马源

- 90 个 TeV 源
- 32 个新发现源
- 40+ 个超高能源



强子伽马信号认证



• 利用源伽马信号认证宇宙线源（强子辐射）

- π^0 鼓包特征强子信号（0.1GeV）
- 物理尺度大
- 高密度
- X射线流强弱，轻子贡献被x射线流强限制

$$\tau_{pp} \approx 6 \times 10^7 \left(\frac{n}{1 \text{ cm}^{-3}} \right)^{-1} \text{ yr} ;$$

$$\tau_{sync} \approx 1.3 \times 10^7 \left(\frac{E}{1 \text{ TeV}} \right)^{-1} \left(\frac{B}{1 \text{ }\mu\text{G}} \right)^{-2} \text{ yr}$$

$$\tau_{lc} \approx 3.1 \times 10^5 f_{KN}^{-1} \left(\frac{E}{1 \text{ TeV}} \right)^{-1} \left(\frac{U_{ph}}{1 \text{ eV cm}^{-3}} \right)^{-2} \text{ yr}$$

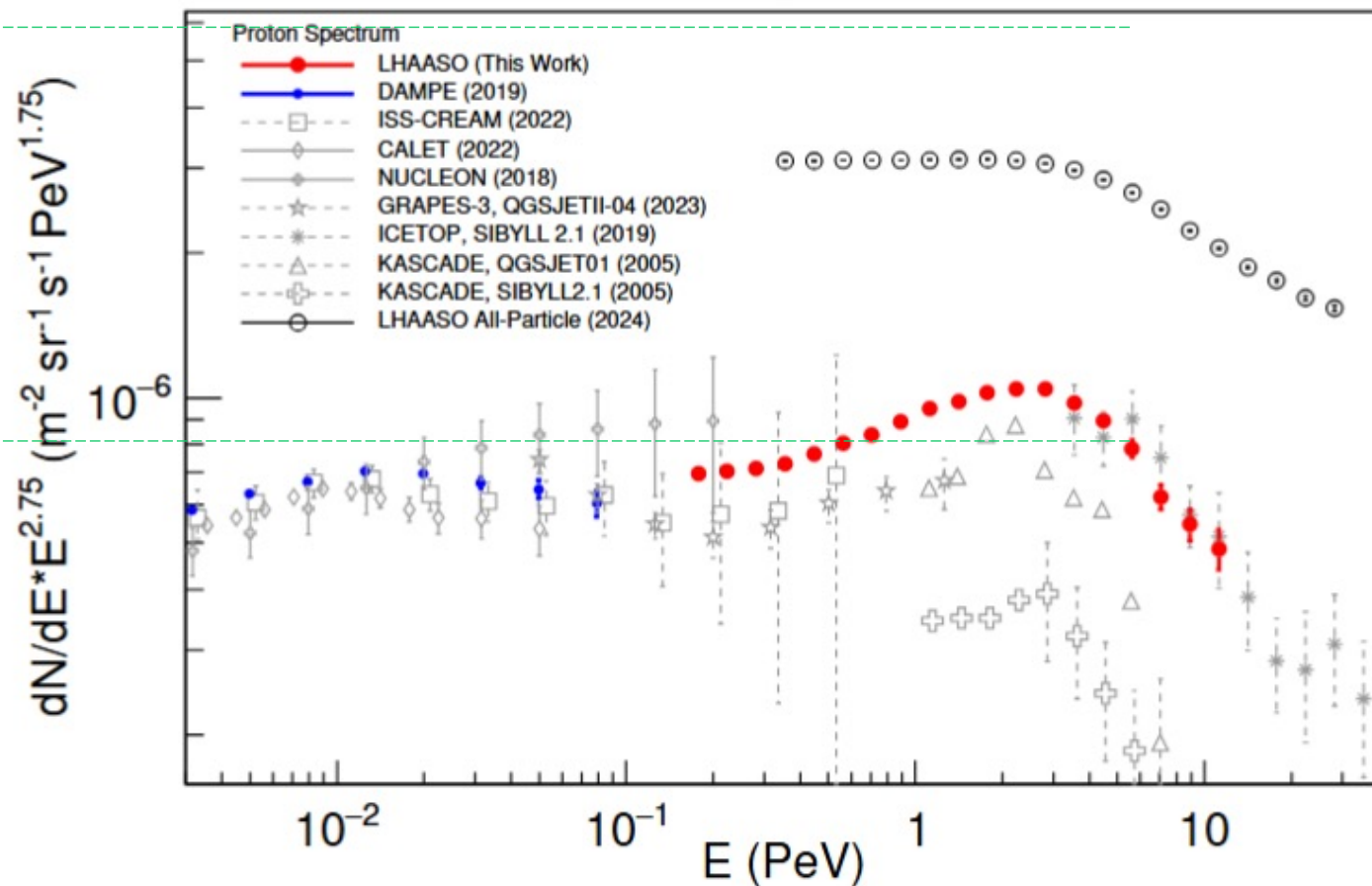
宇宙线源伽马辐射特征要求

- 质子膝约在 3 PeV;
- 能谱变硬的趋势0.1-3 PeV;
- 如何鉴别PeV宇宙线质子源?
强子信号; 加速超过3PeV

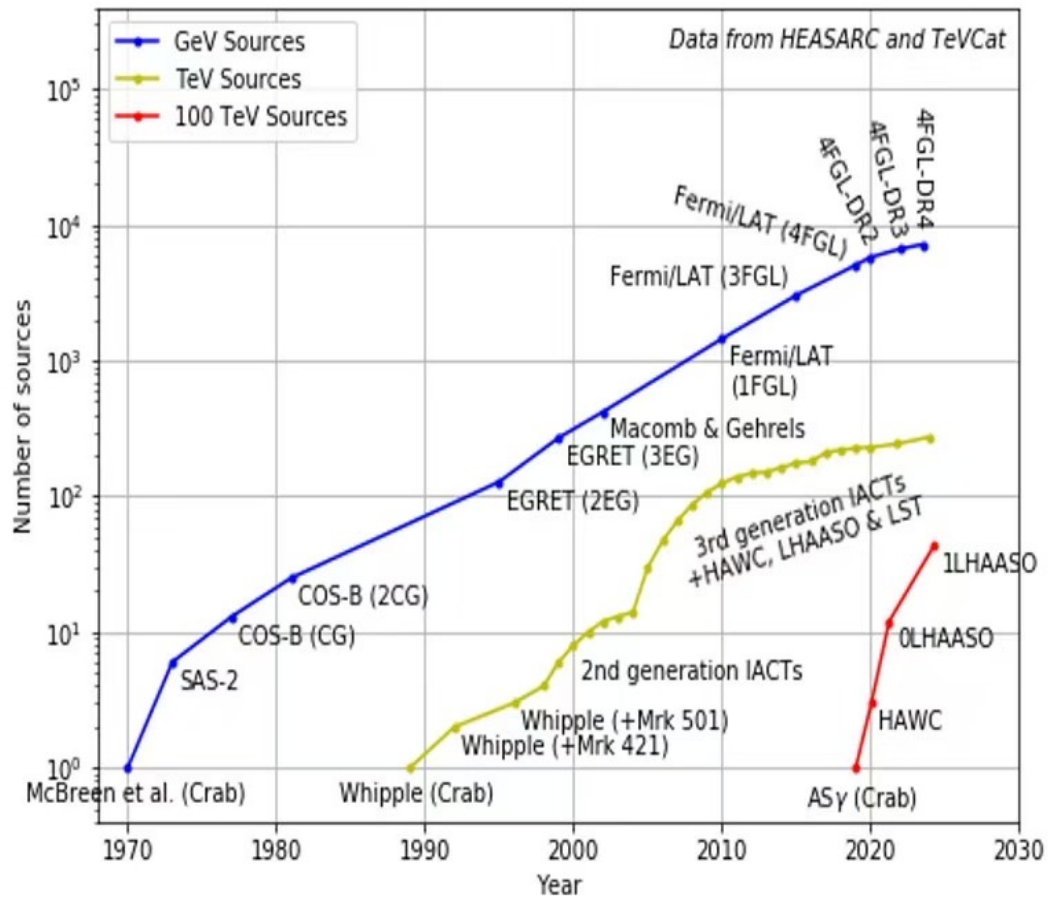
1 PeV 质子 产生的光子谱峰值在 0.1 PeV



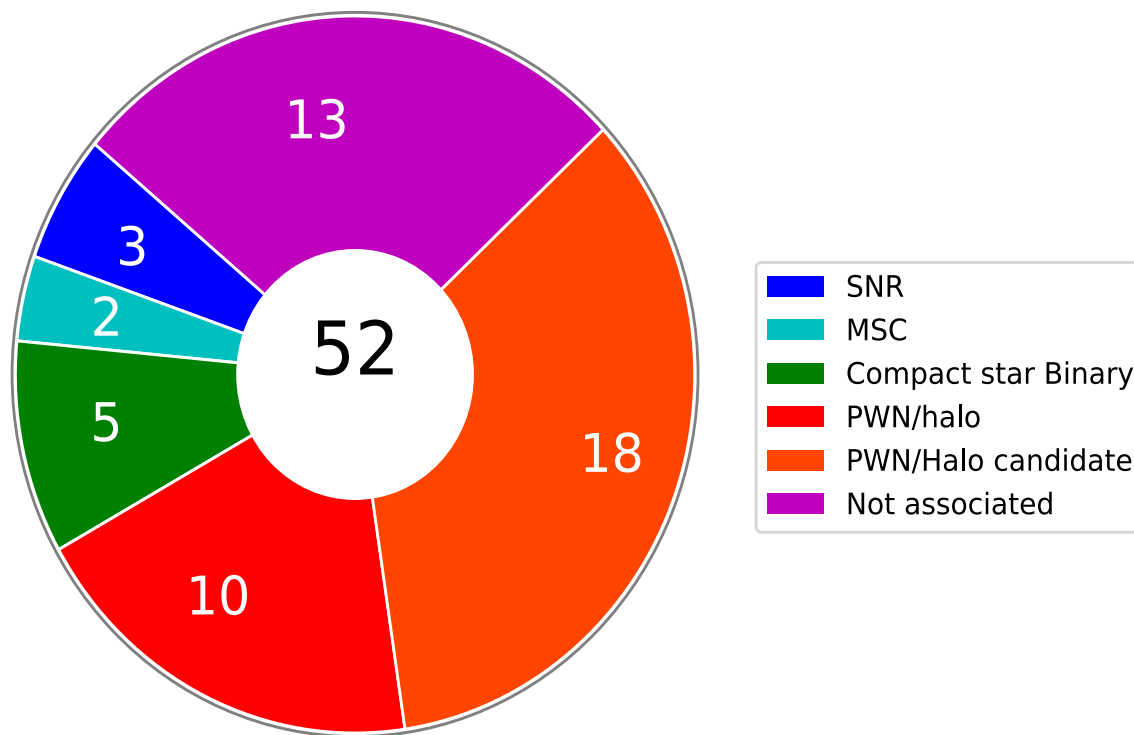
0.1 PeV 光子源就是 UHE伽马射线源



LHAASO 开启超高能伽马天文时代

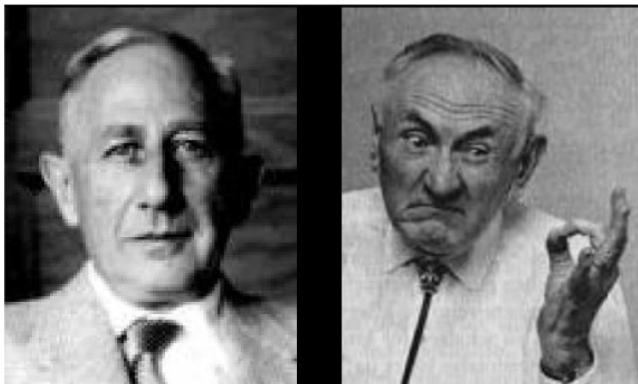


初步分析显示UHE伽马源50+

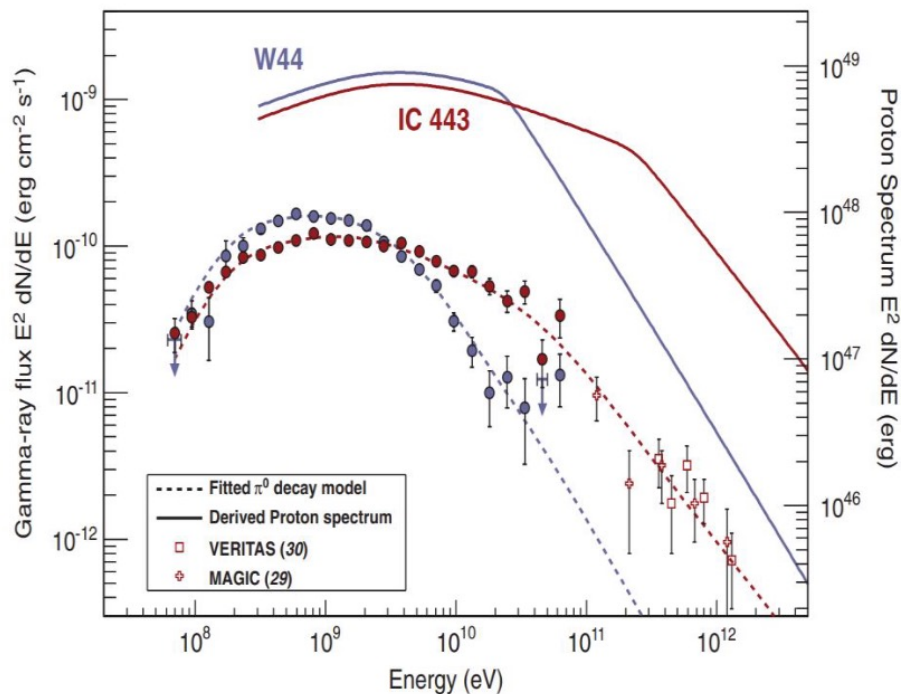


超新星遗迹作为宇宙线源

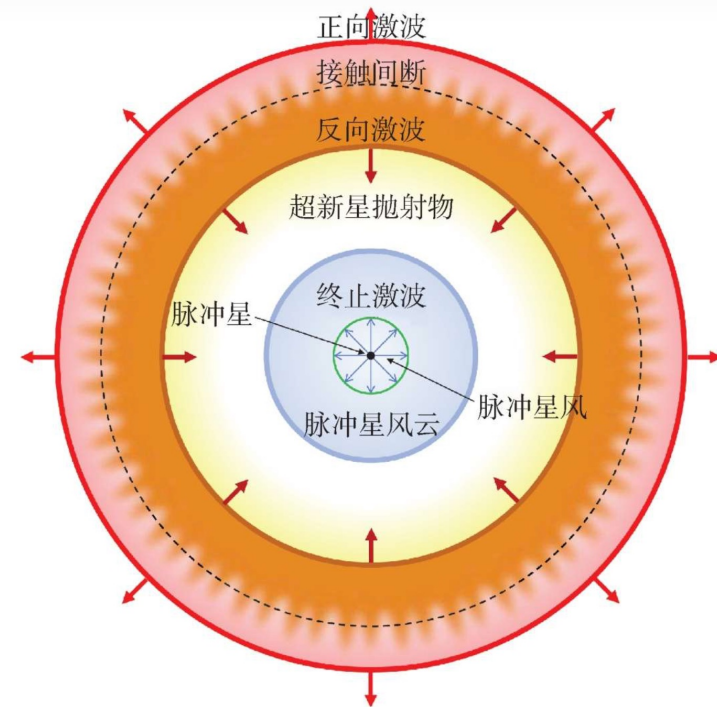
主要的GeV宇宙线源



Baade & Zwicky (1934)

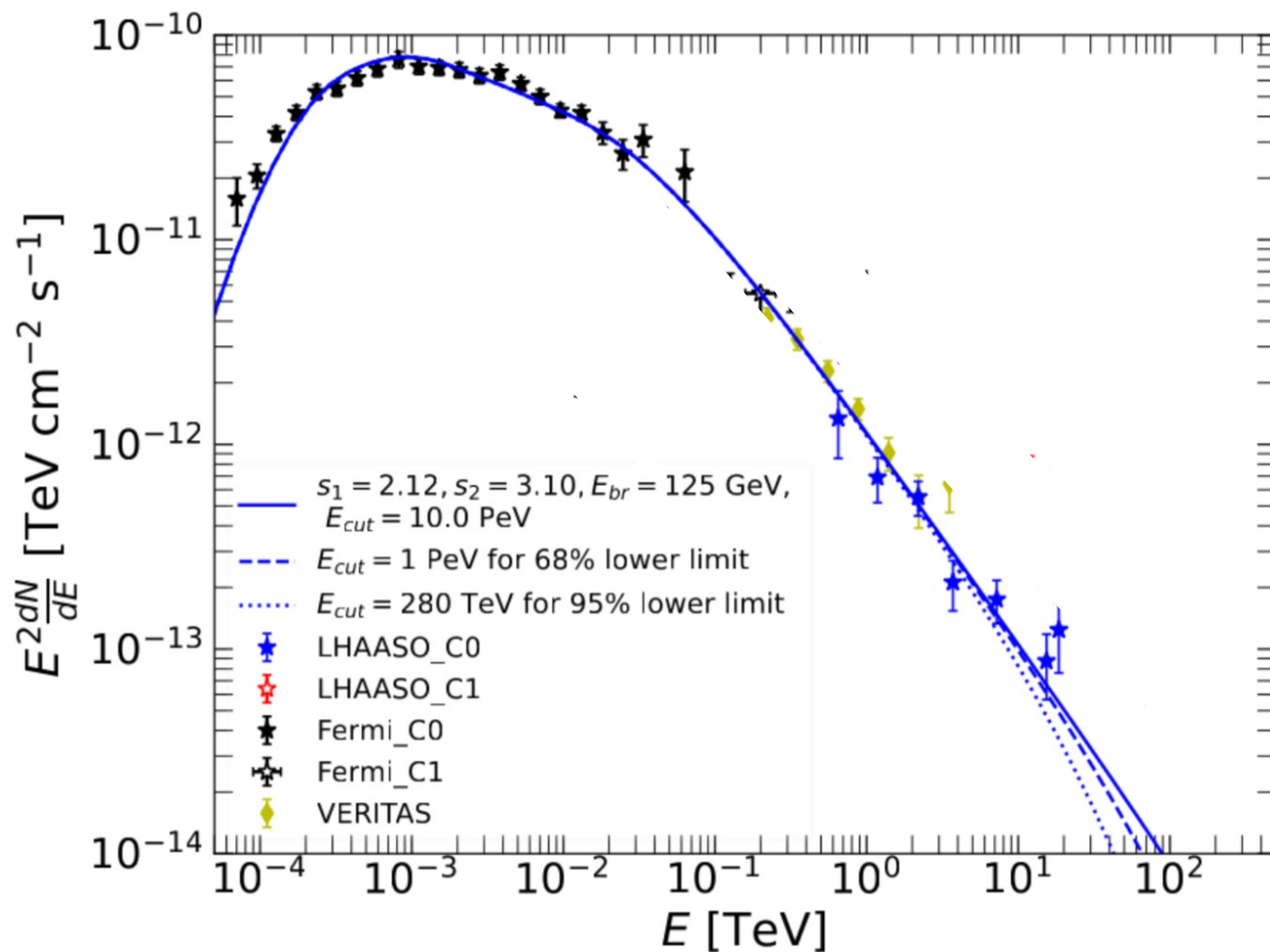


Fermi-LAT Coll. 2013



Pi0 鼓包特征结构被探测； SNR能量预算满足测量的宇宙线能谱要求； ...
能不能加速PeV宇宙？

超新星遗迹 IC 443



C0:

- $N(H)=20/\text{cm}^3$
- Particle distribution inside SNR :

$$Q(P_i) = Q_0 e^{-\frac{P_i}{P_{i,cut}}} P_i^{-s_1} \left[1 + \left(\frac{P_i}{P_{i,br}} \right)^{s_2-s_1} \right]^{-1}$$

$$s_1 = 2.12^{+0.10}_{-0.14}, s_2 = 3.10^{+0.11}_{-0.11}, E_{br} = 125^{+121}_{-72} \text{ GeV}$$

$$E_{cut}^p = 10 \text{ PeV}$$

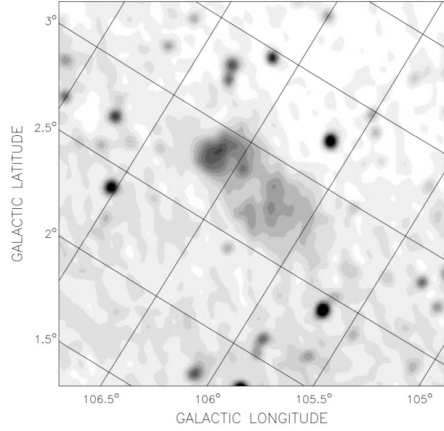
$$E_{cut}^p(68\%) = 1 \text{ PeV}$$

$$E_{cut}^p(95\%) = 0.5 \text{ PeV}$$

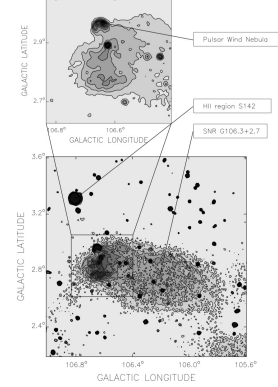
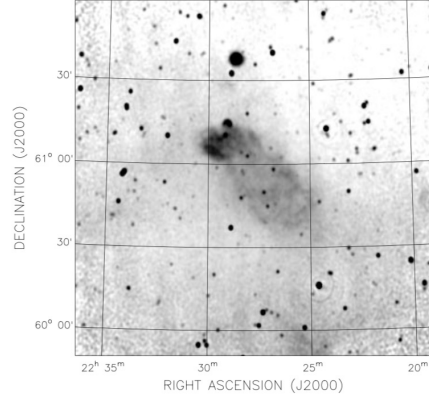
IC 443可能加速粒子能否超过PeV？ 观测上目前还不能给出明确的回答

超新星遗迹 G106.3+2.7

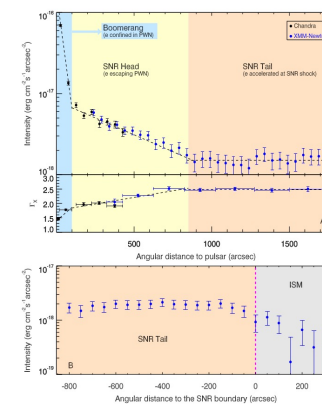
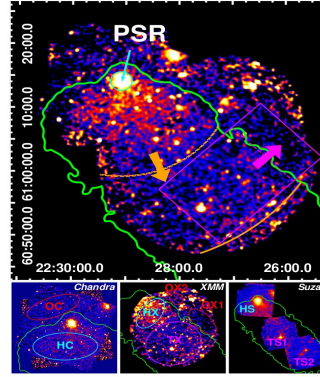
420 MHz Continue



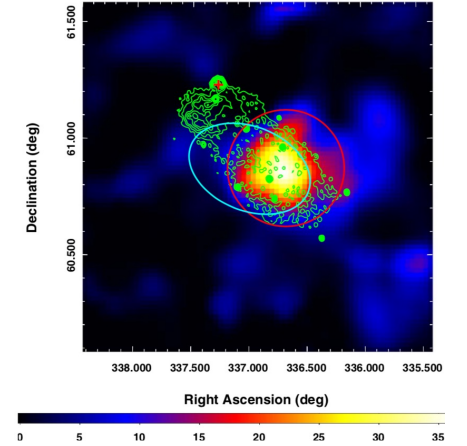
1.4 GHz Continue



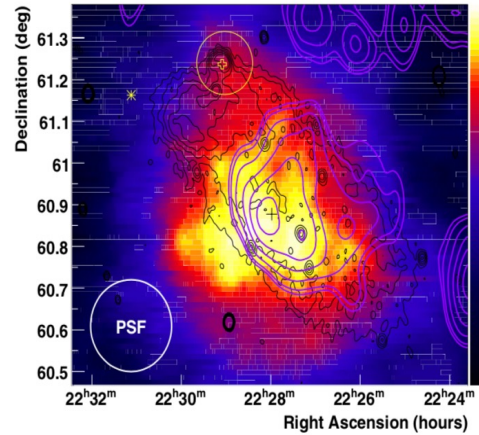
X-ray(Chandra,XXM,Suzaku)



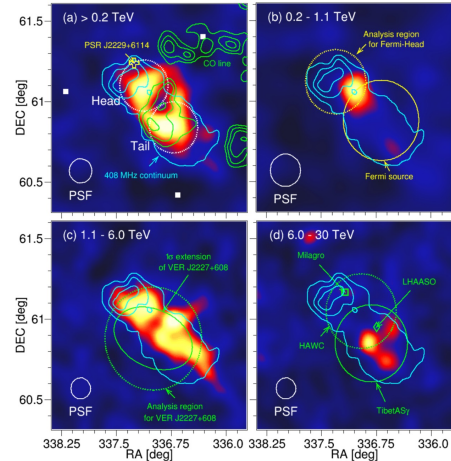
Fermi-LAT 0.2-500 GeV



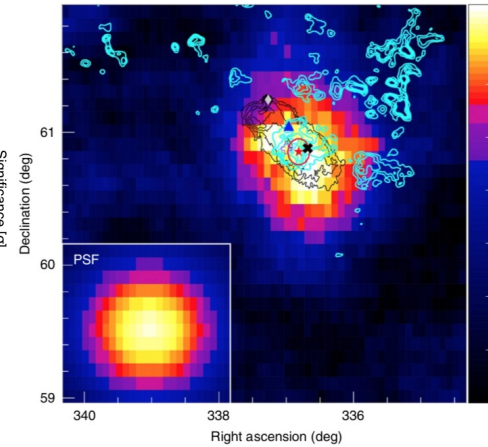
Veritas 1-15 TeV



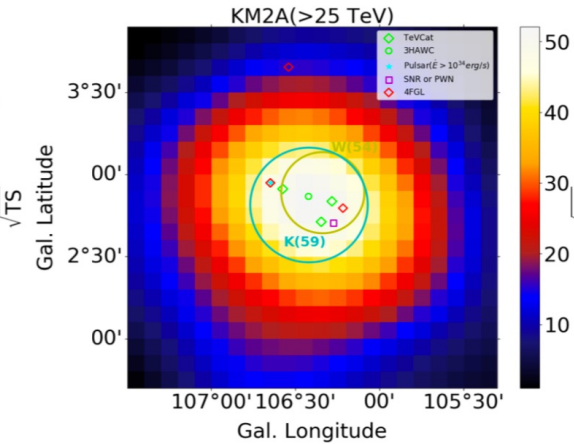
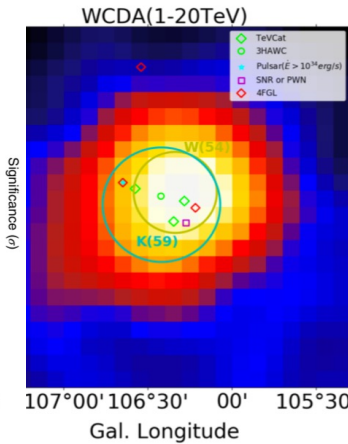
Magic 0.2-30 TeV



Asgamma >10 TeV

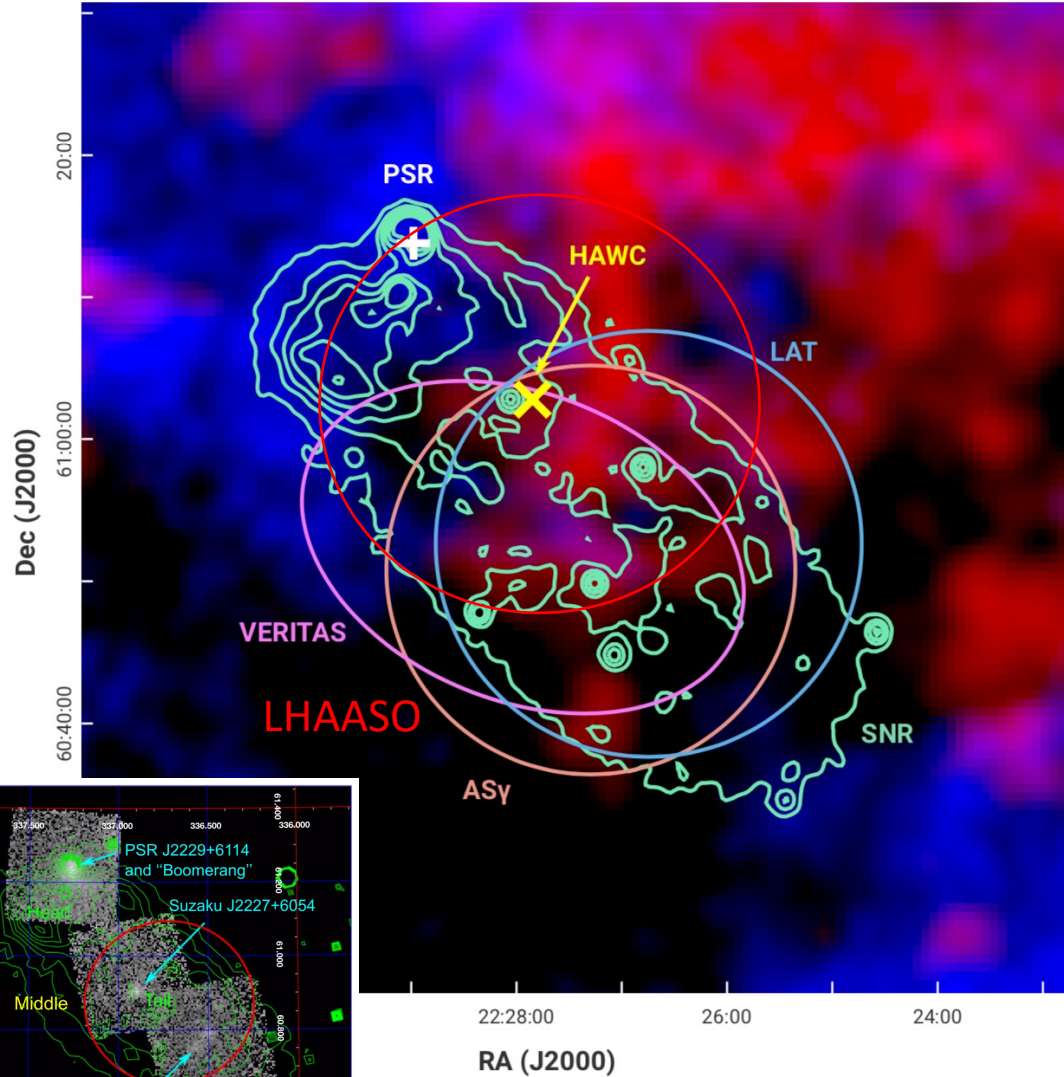


LHAASO >1 TeV

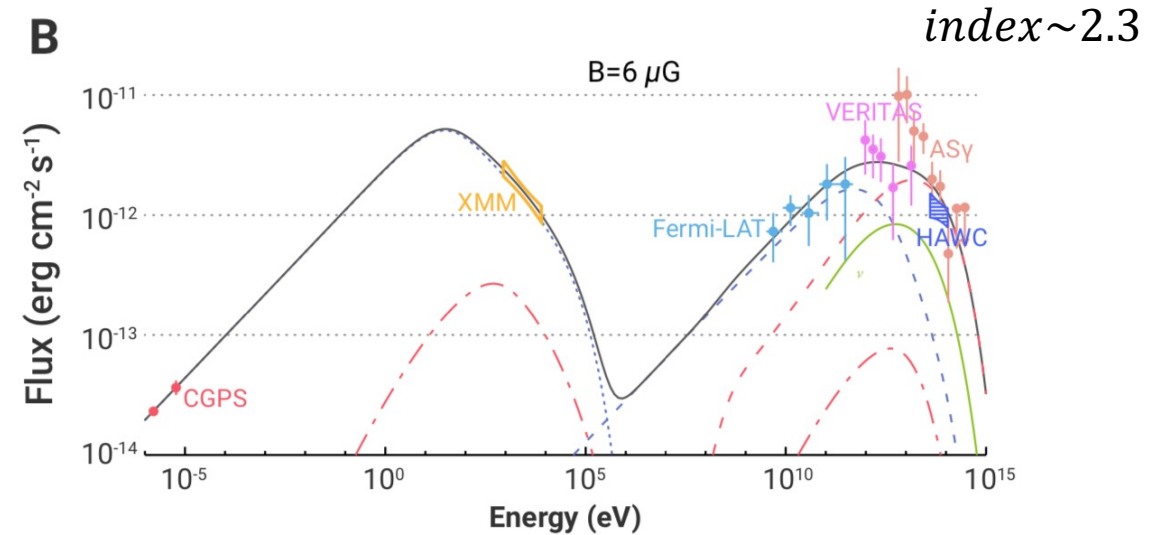
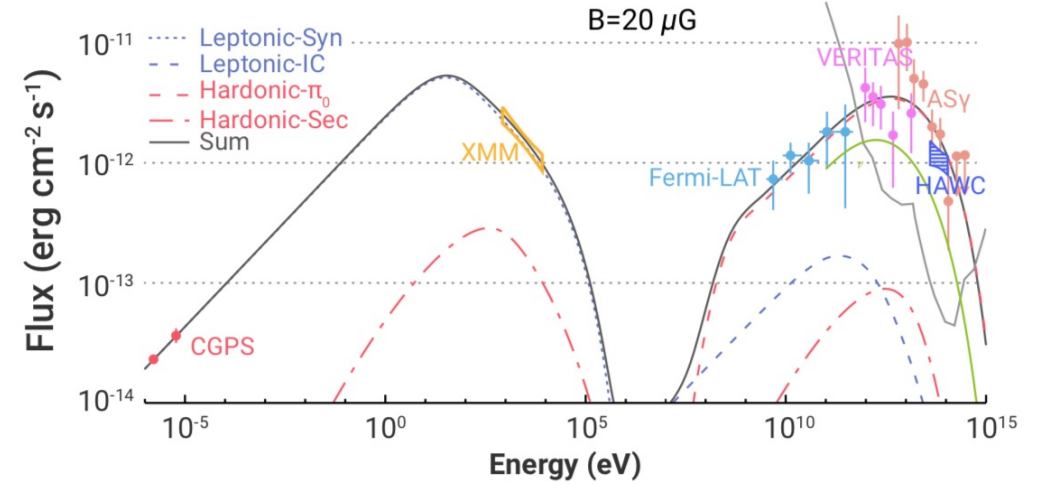


多波段能谱模型

CO (color)+Multiwavelength obs.



The most possible hadronic emission evidence.



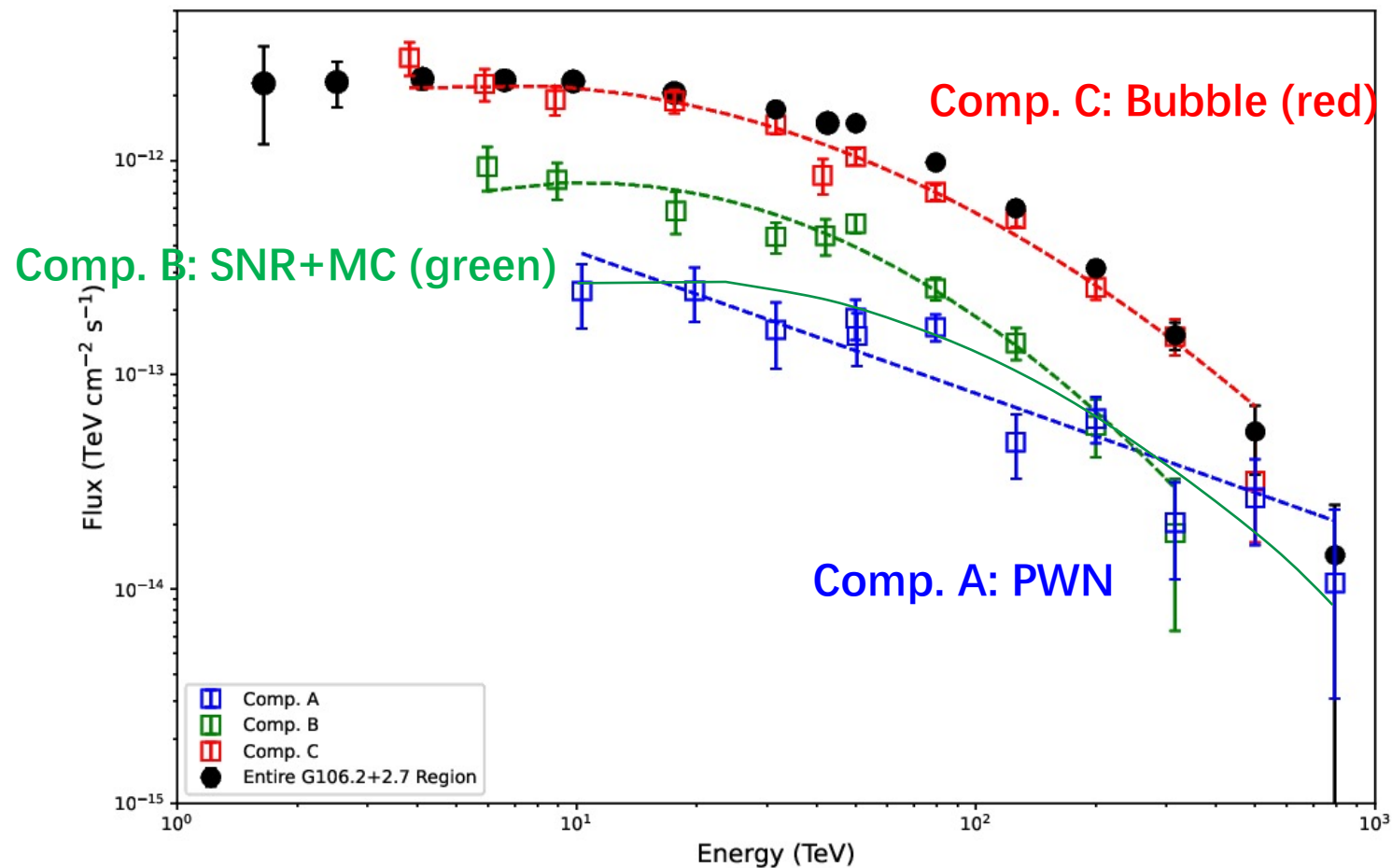
超新星遗迹G106.3 能谱

- 空间得到 SNR+MC成分能谱显示50 TeV 截断

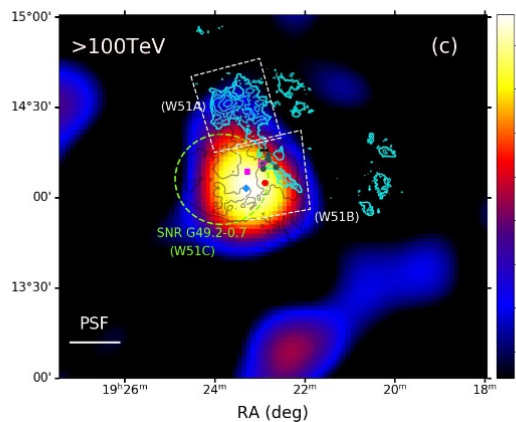
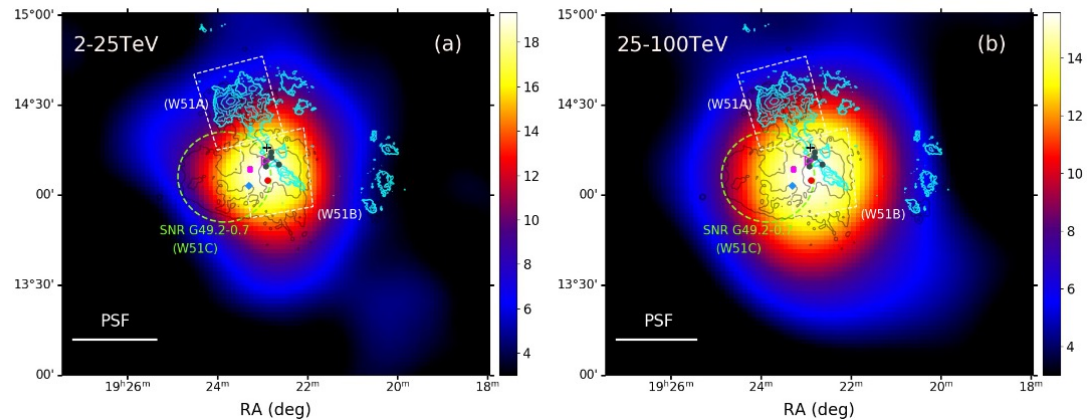
$E_{\gamma, \text{ cutoff}} \sim 50 \text{ TeV}$

$E_{\text{p, cutoff}} \sim 500 \text{ TeV}$

- G106.3 依然不能加速质子超过PeV

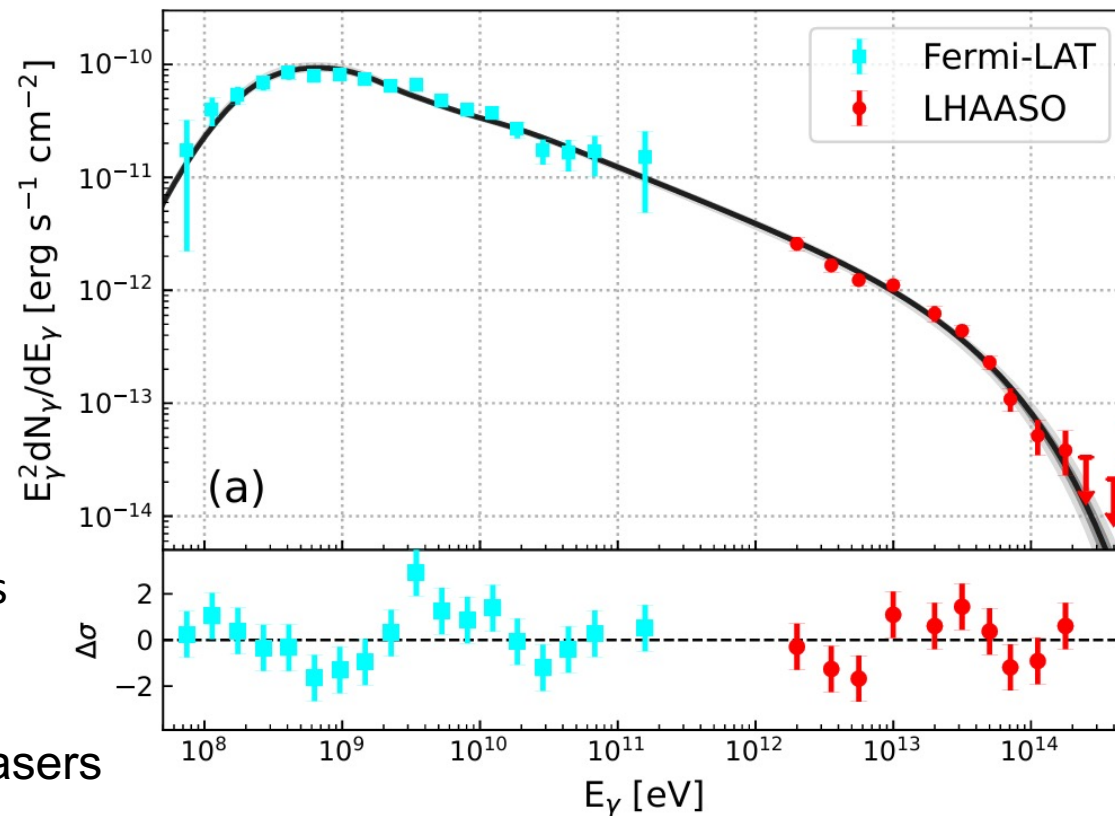


超新星遗迹 W51 C



$D \sim 4.3$ kpc
 $T \sim 18$ kyr
 $M \sim 10^5$ solar mass
 Cyan: gas
 Blue square: PWN
 Black cross: OH masers

Jogler T, 2016: π^0 -decay bump



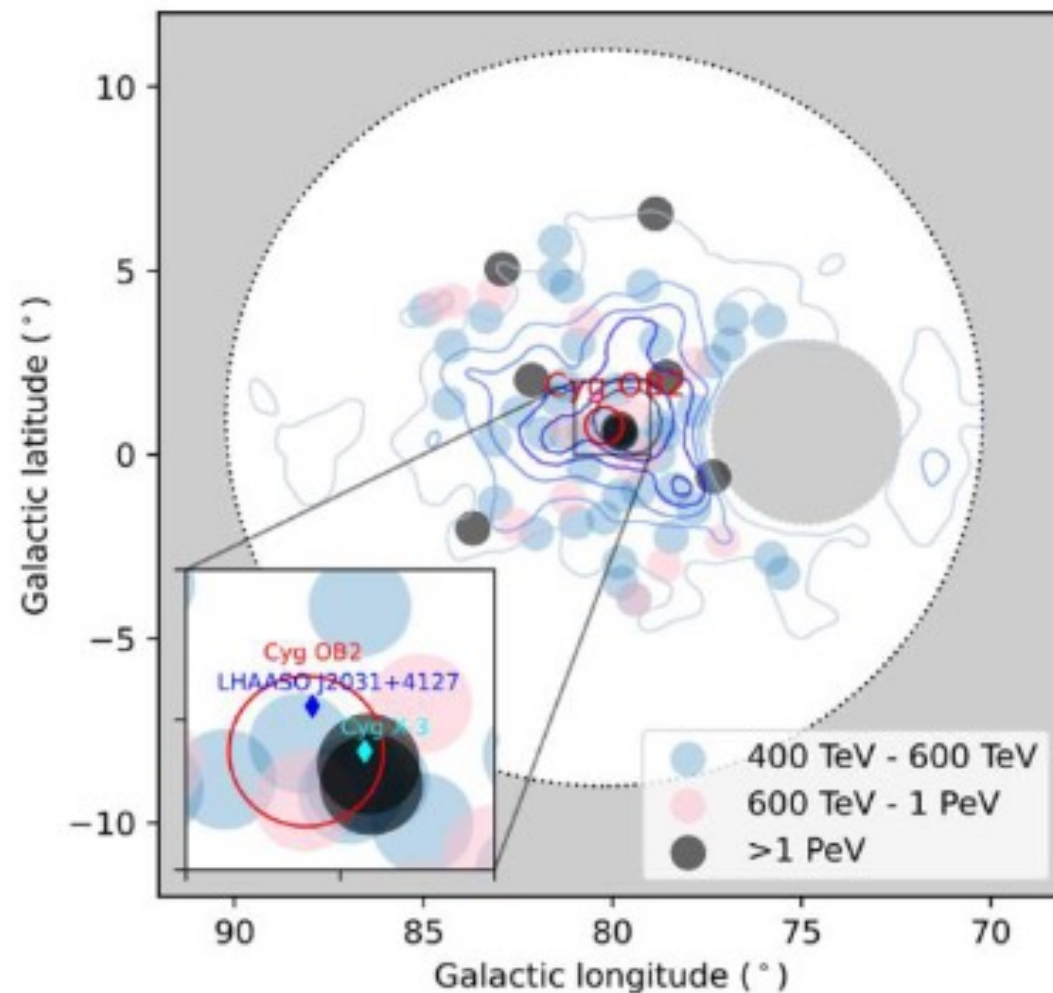
E_γ , cutoff ~ 50 TeV

E_p , cutoff ~ 500 TeV

W51 C-like 超新星遗迹不能作为PeV宇宙线源, 因为明显看到质子能量在 ~ 500 TeV 截断.

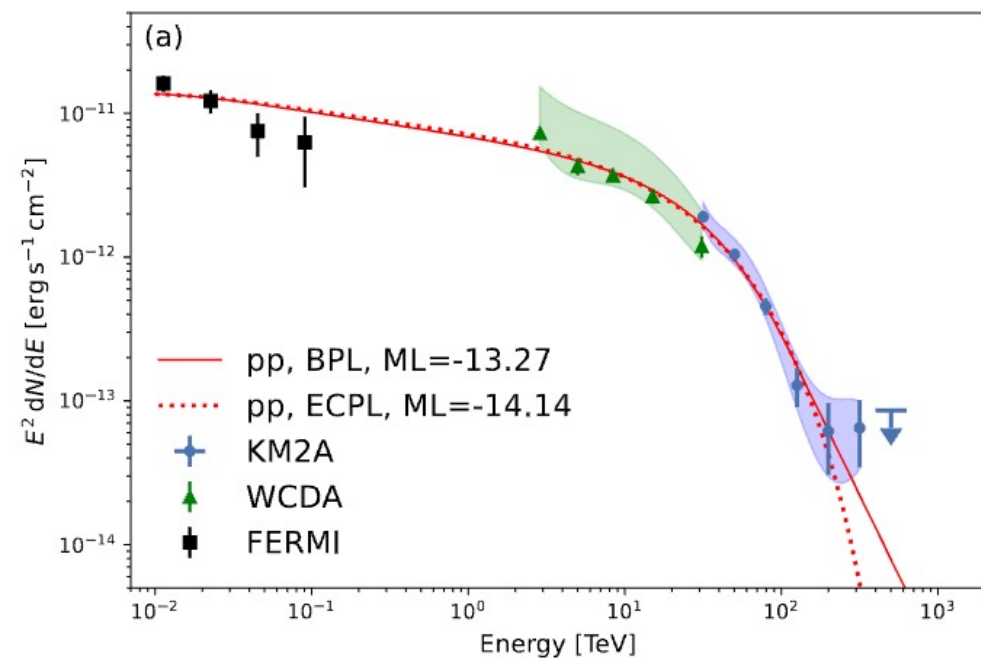
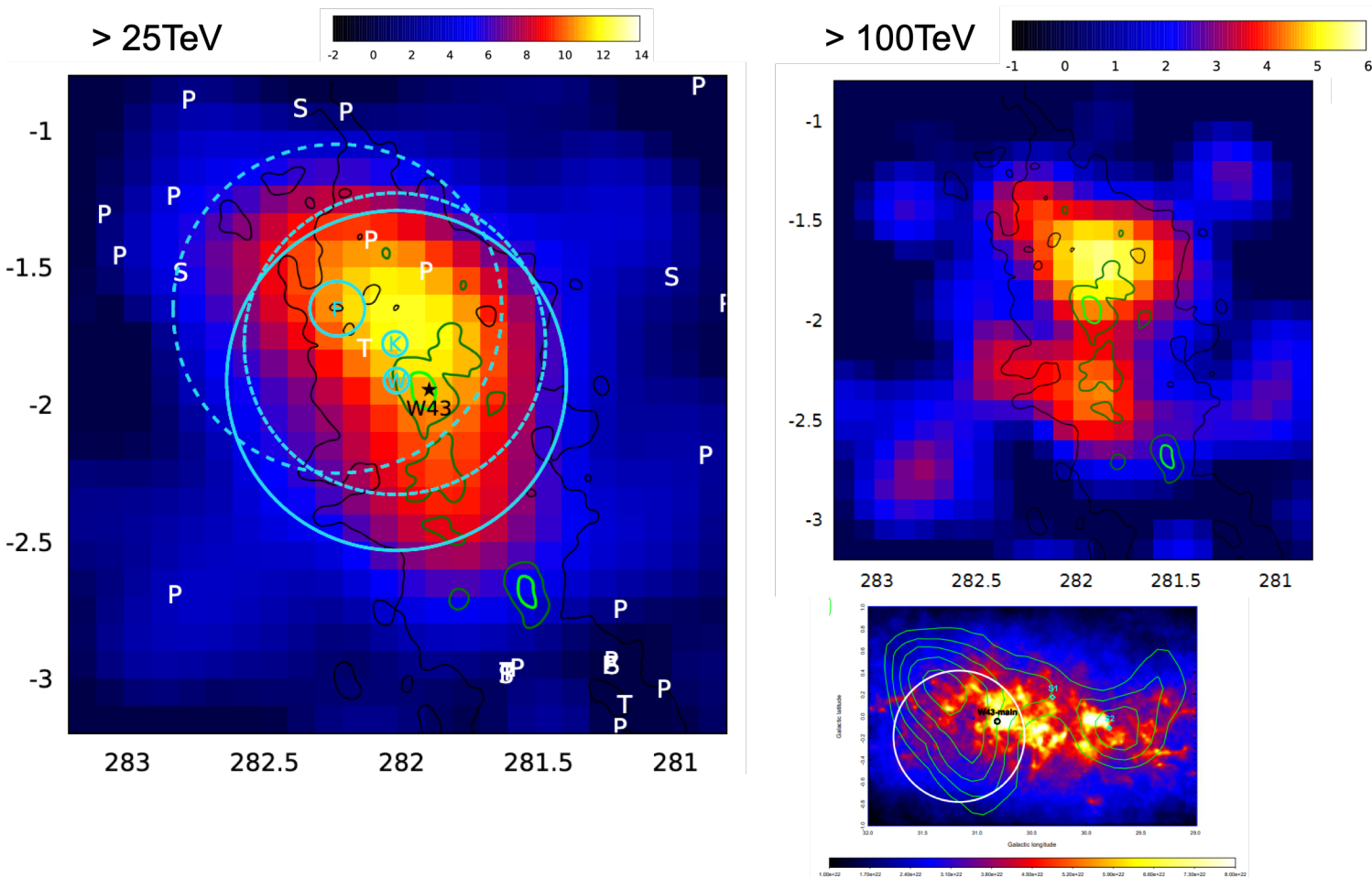
LHAASO首个被认证的宇宙线源区

- 半径大于6度 ($\sim 150\text{pc}$) 的巨型超高能伽马泡
- 与分子云明显成协
- 8个PeV光子(最高2.5PeV)
- 首次探测到10PeV宇宙线加速天体
- 年轻大质量星团Cygnus OB2为最可能加速源



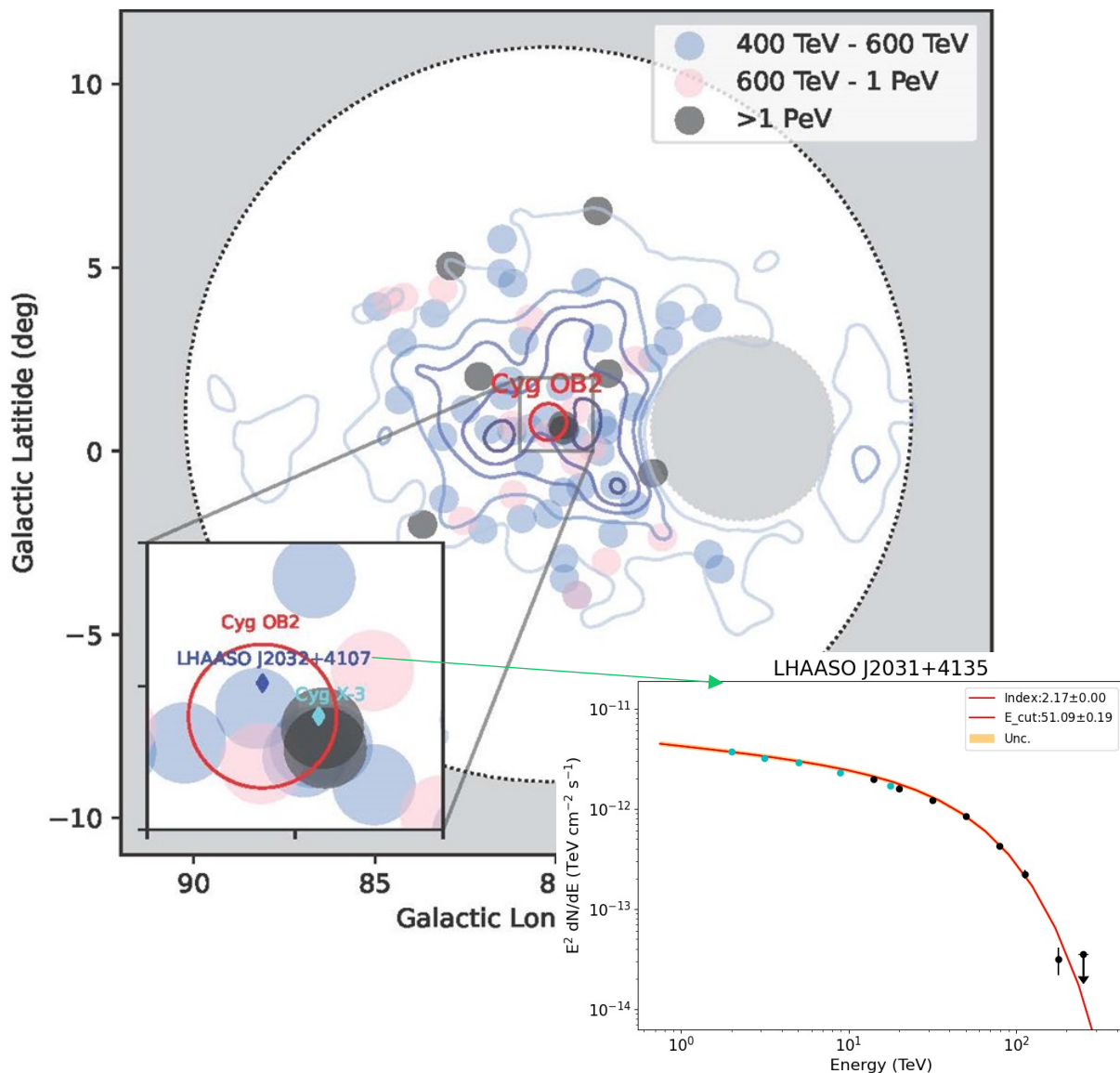
加速器：OB2, binary J2032+4107, MQ X-3不确定

LHAASO 对年轻大质量星团w43的观测



- UHE 伽马射线辐射和稠密分子云很好的位置符合;
- 发现明显的能谱阶段, 大质量星团可能不能作为加速器

Cygnus X-3 (1LHAASO J2031+4052u*)

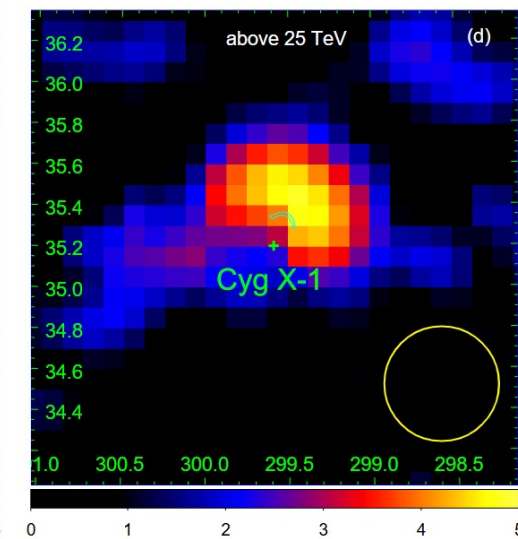
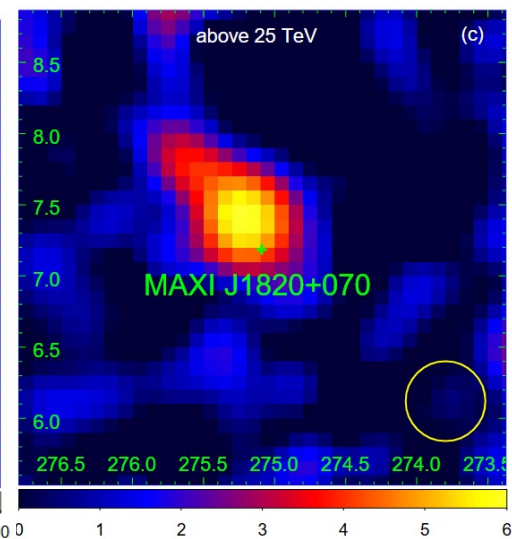
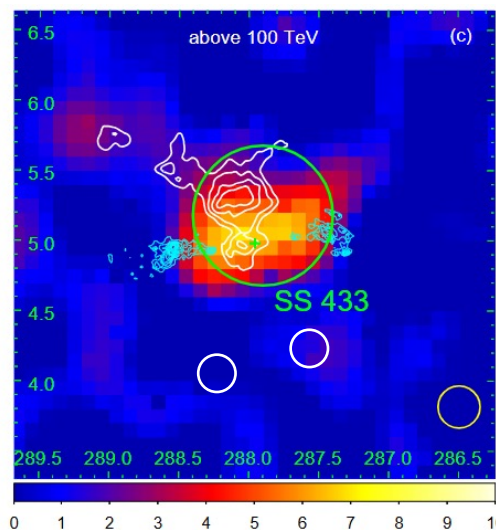
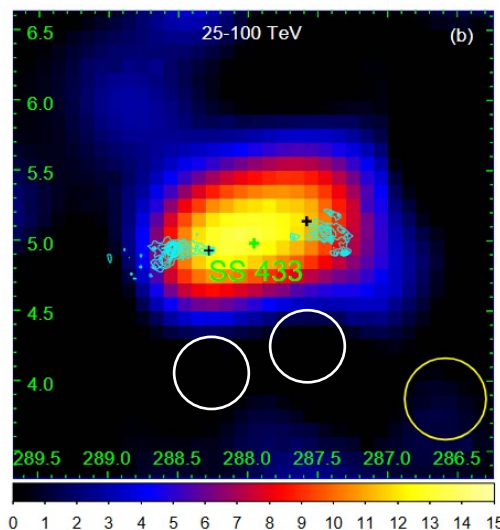
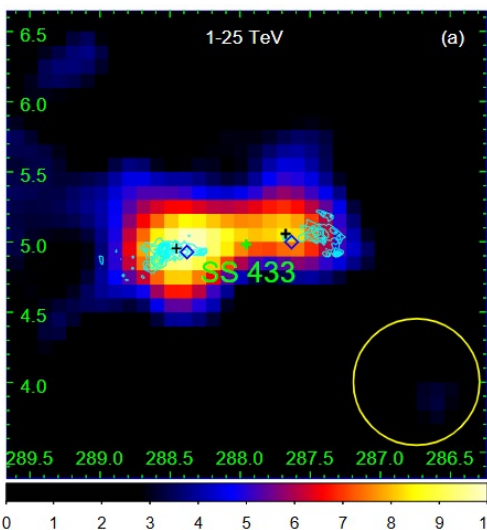
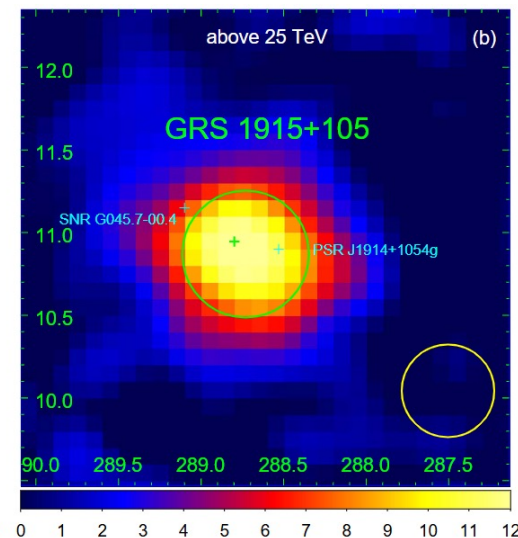
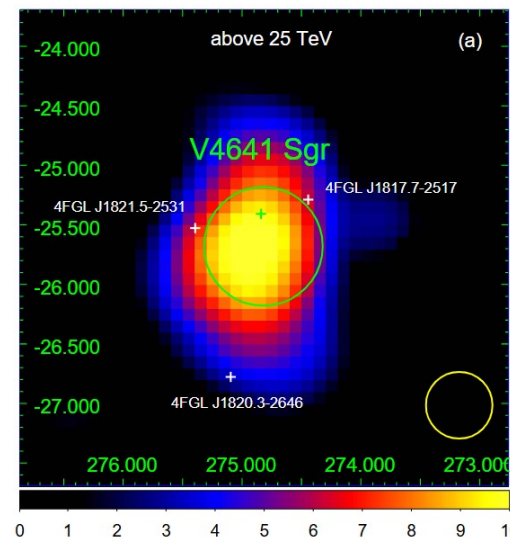


1. 1LHAASO J2031+4052 拥有最硬的能谱指数(index ~ 2.2).
2. 我们的时间相关分析认证了1LHAASO J2031+4052 与Cygnus X-3相关.
3.

超级PeV 加速器.

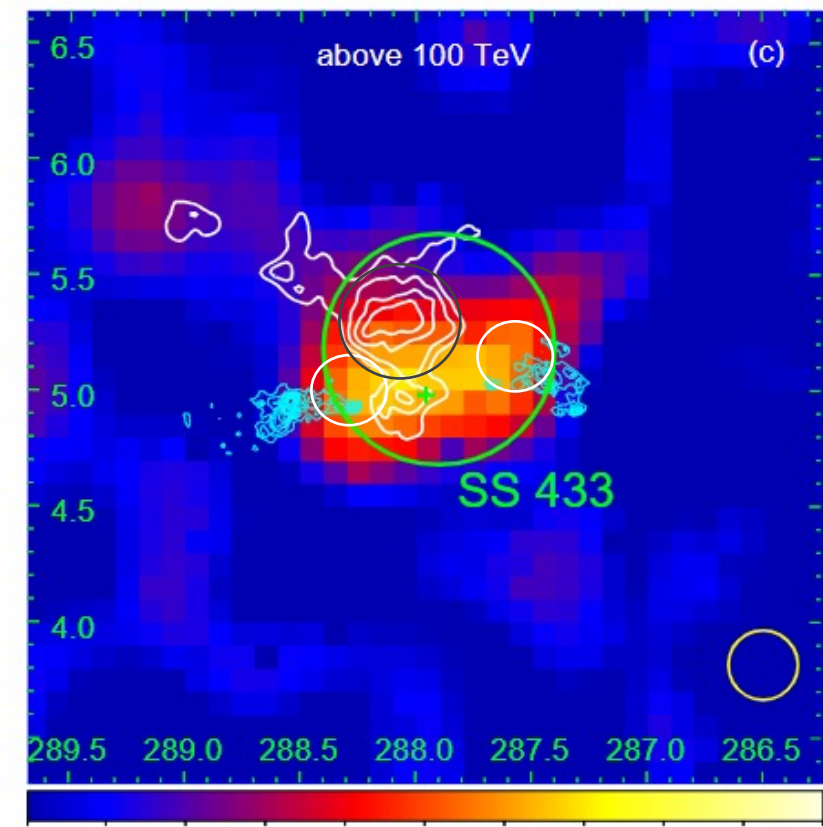
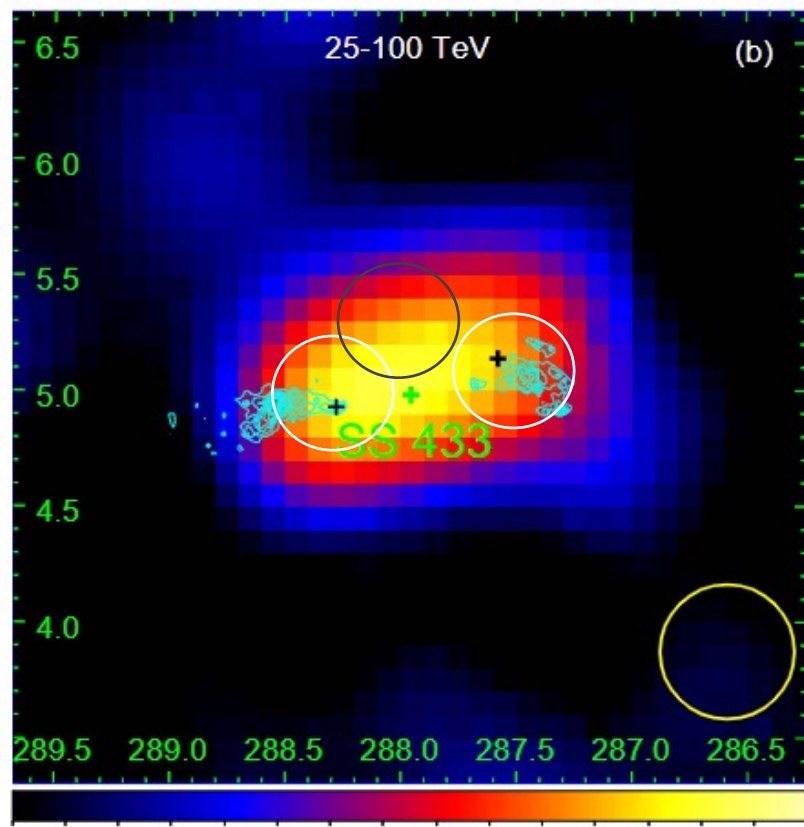
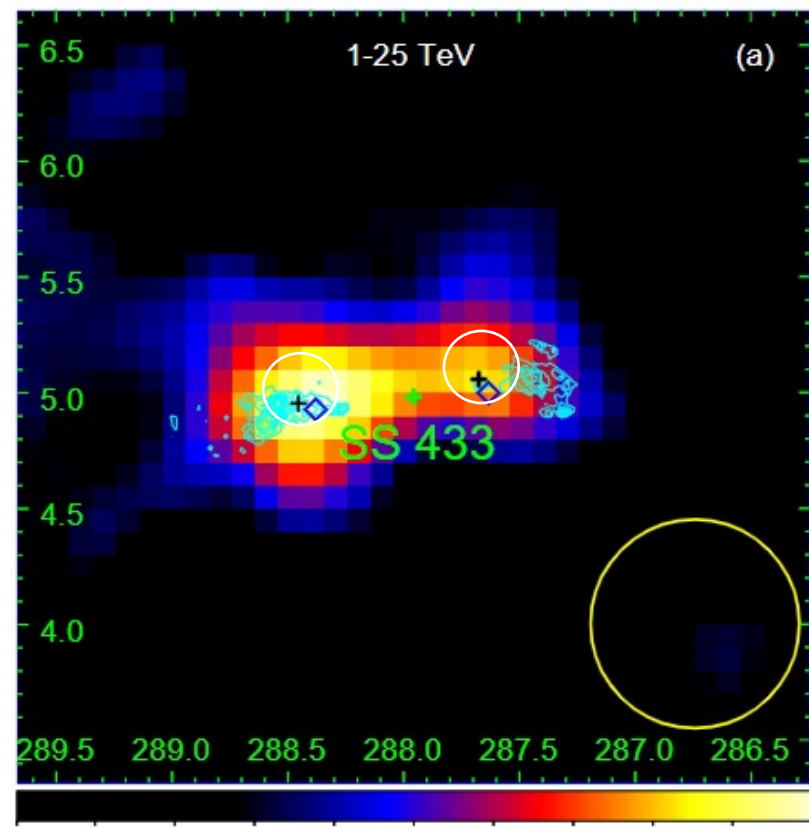
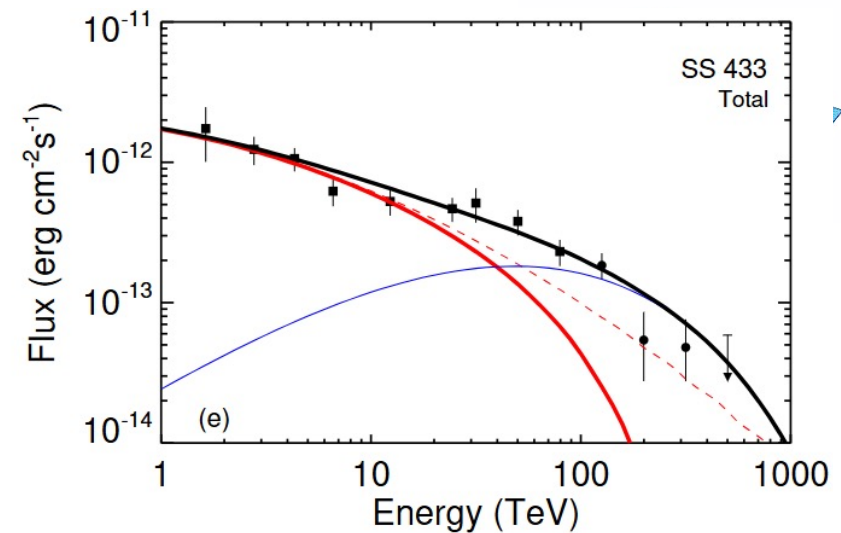
微类星体

- 5 微类星体被报道
- 3 被发现了100 TeV之上的伽马辐射
- 新的一类宇宙线加速器 ($E > 3$ PeV)



SS 433

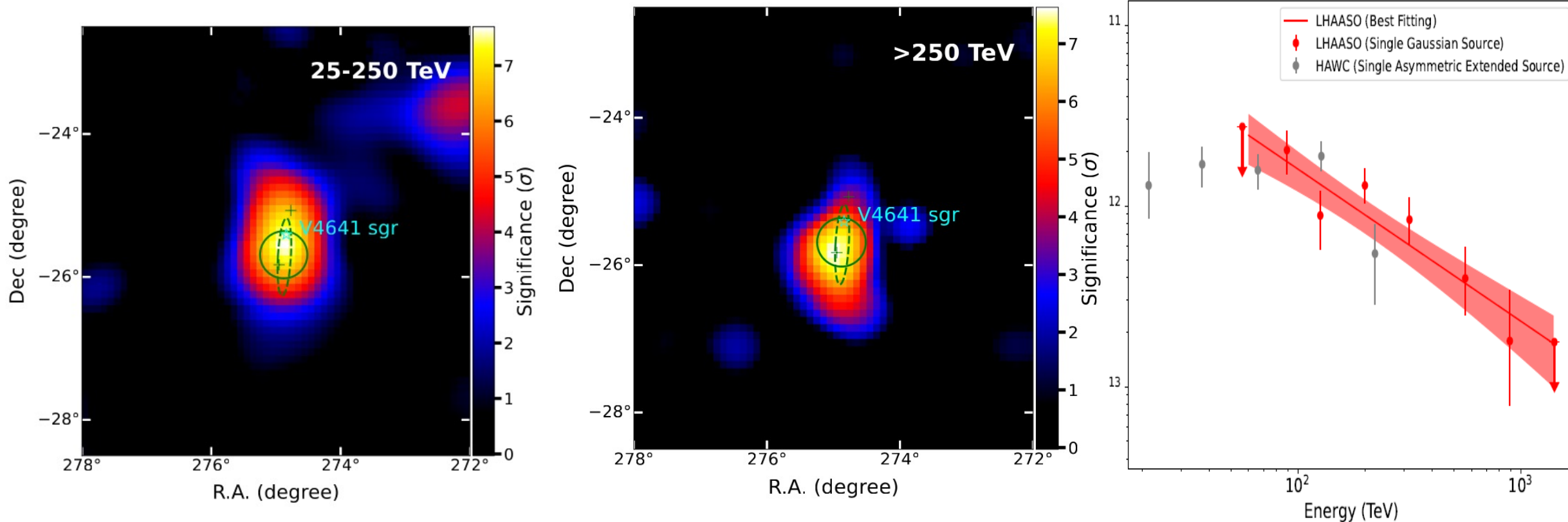
- LHAASO 清晰的策略
- 在<100 TeV, 空间上更符合Jet
- 在>100 TeV, 强子?



V4641 Sgr

- 离地球距离：6.6 kpc
- 物理尺度 ~ 100 pc
- 最高能量光子达到 0.8 PeV.

我们建议强子起源；
尽管轻子起源不能完全排除



蟹状星云

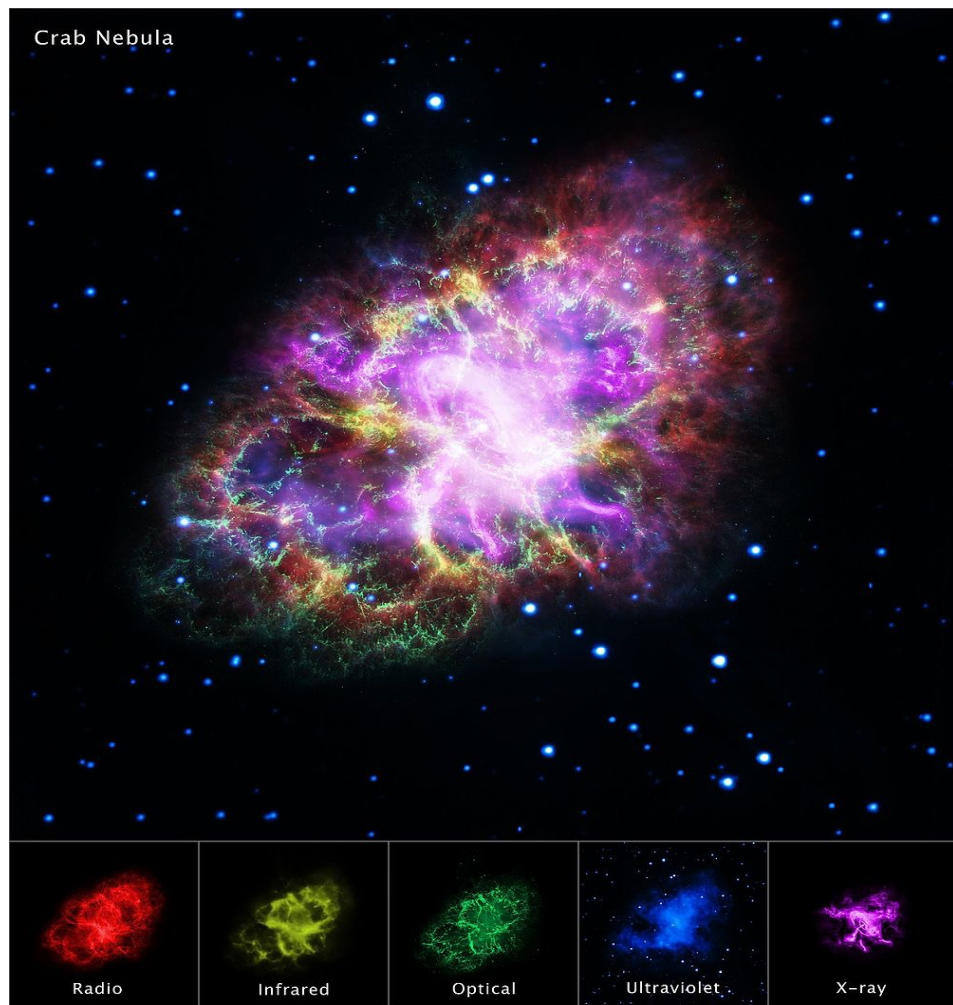
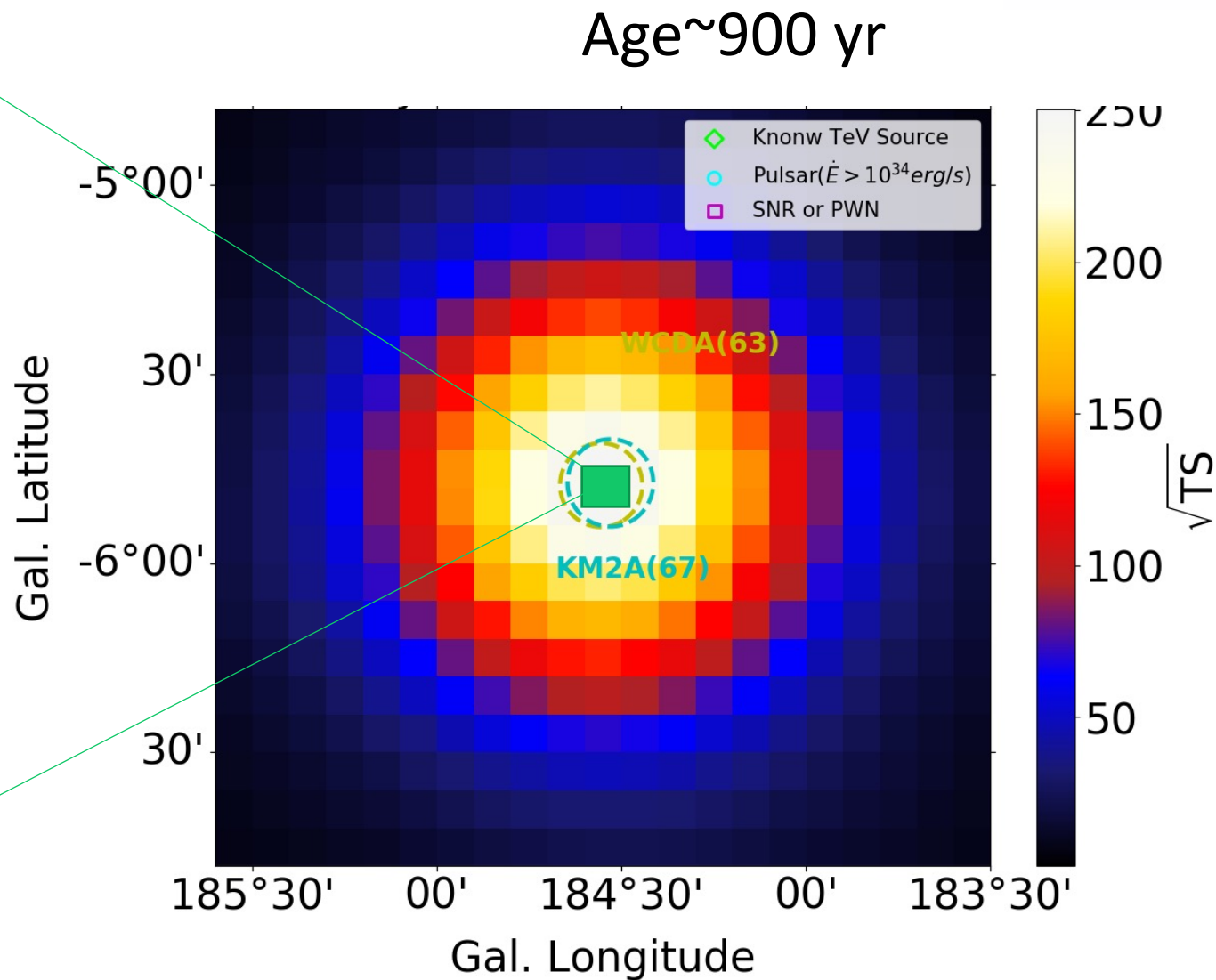


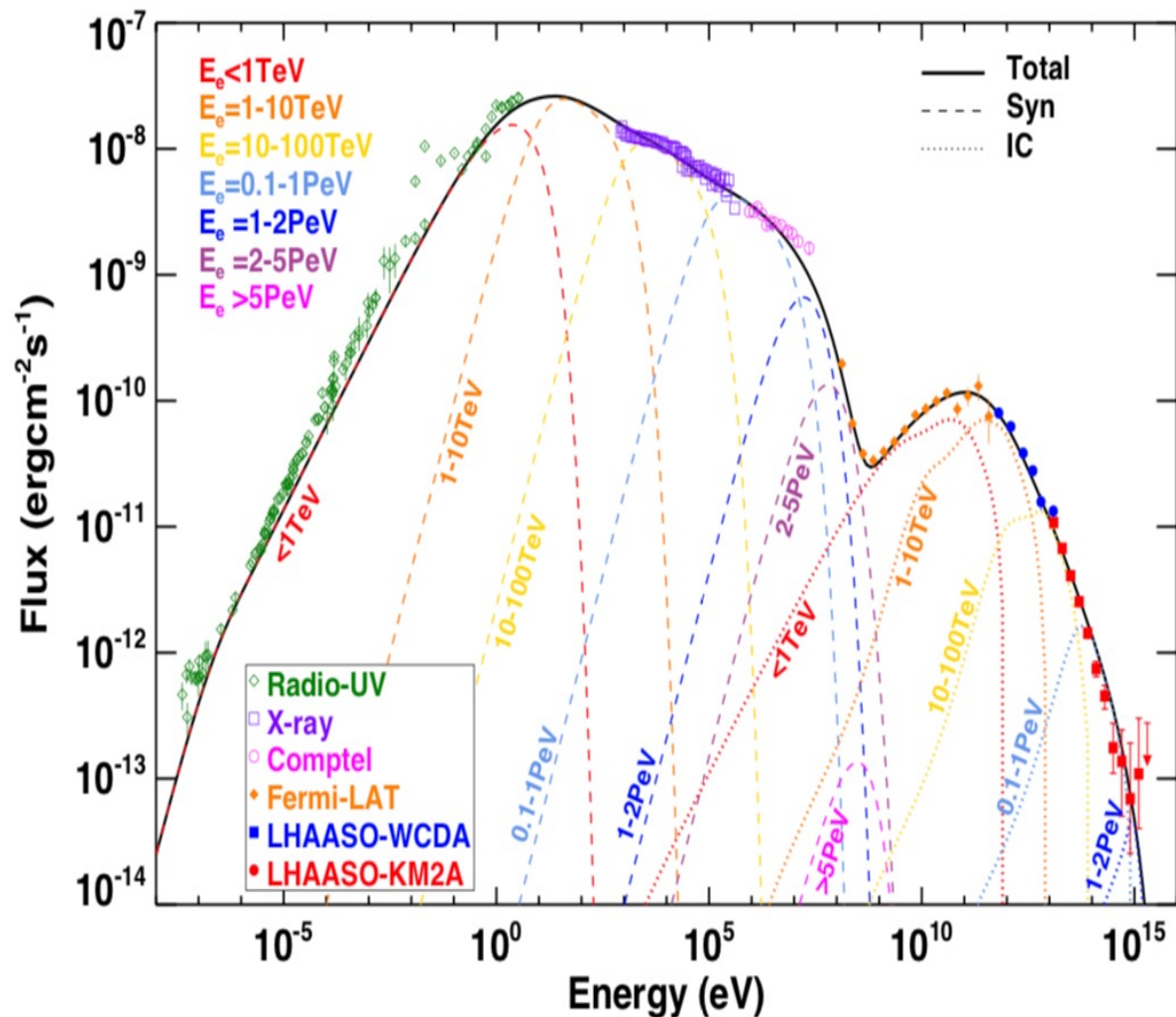
Figure from NASA website.



LHAASO观测下的蟹状星云

Crab PWN 能谱

整个星云多波段辐射能很好的用轻子模型解释！
缺乏强子信号证据！



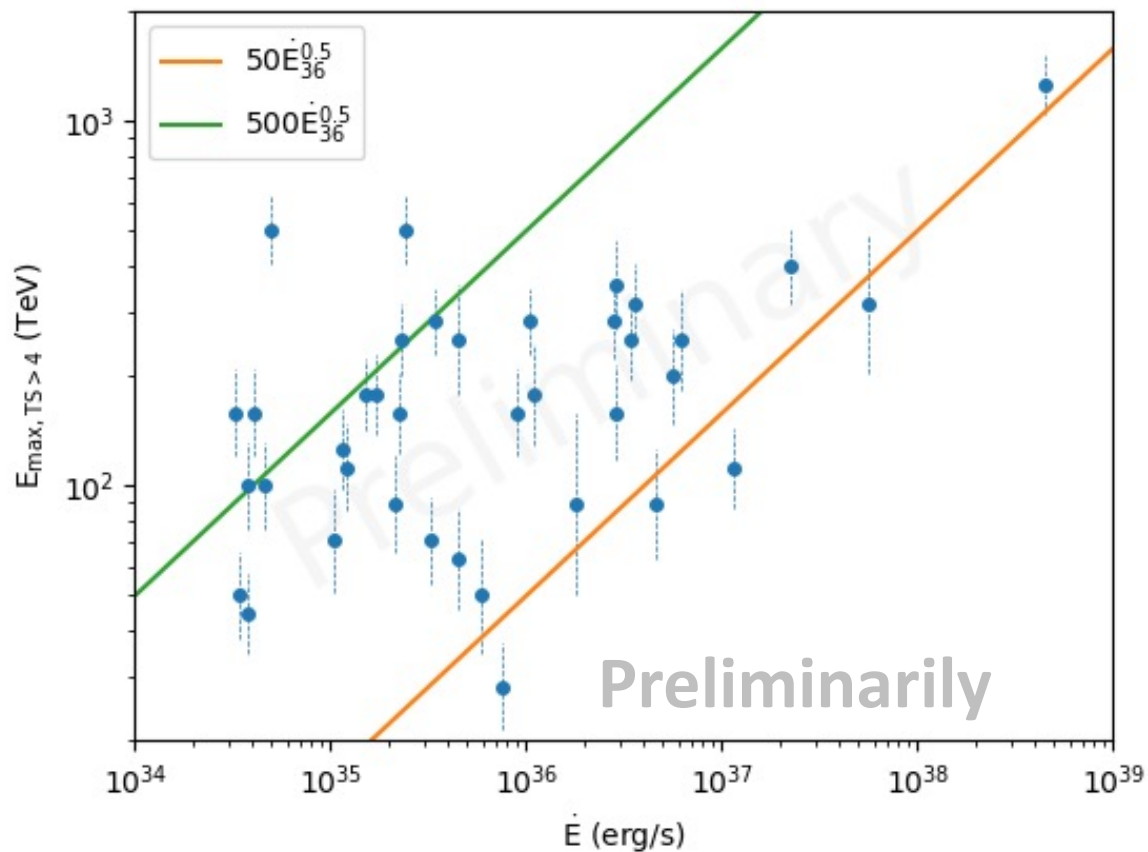
1. One-Zone leptonic model can well describe the whole Crab SED;
2. Good Estimate the currently $B \sim 112 \text{ uG}$;
3. $> 1 \text{ PeV}$ photons detection,

$$E_{\text{max}} \approx 2 \eta_e \eta_B^{1/2} \dot{E}_{36}^{1/2} \text{ PeV}$$

$$\eta = 0.14 \left(\frac{B}{100 \text{ uG}} \right) \left(\frac{E_\gamma}{1 \text{ PeV}} \right)^{1.54}$$

一个极端高效的加速器

PWN 加速效率统计分析



Hillas criterion: $E_{e,\text{max}} \approx 2 \eta_e \eta_B^{1/2} \dot{E}_{36}^{1/2} \text{ PeV}$

$$E_e \approx 2.15 \left(\frac{E_\gamma}{1 \text{ PeV}} \right)^{0.77} \text{ PeV}$$

$$0.1 < \eta_e \eta_B^{1/2} < 3$$

部分PWN拥有非常高的加速效率！

总结

LHAASO 目前运行良好，预计未来将持续领跑世界20 年；

目前观测表明大部分SNR没看到100TeV之上的光子，已经看到100TeV之上辐射的SNR都显示能力在500 TeV附近；

目前观测到的大质量星团加速能力也在500 TeV附近；

微类星体是潜在的PeV宇宙线质子加速器，尤其是Cygnus X-3为代表；部分其它微类星体能加速粒子到PeV，但缺乏确凿的强子证据；

大多数脉冲星风云能加速粒子到PeV，但缺乏强子加速证据；