甚高能伽马射线观测研究进展

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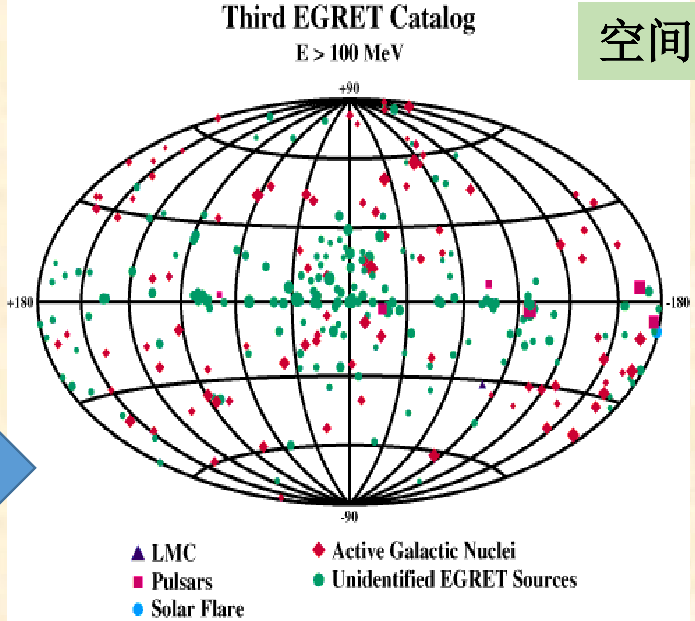
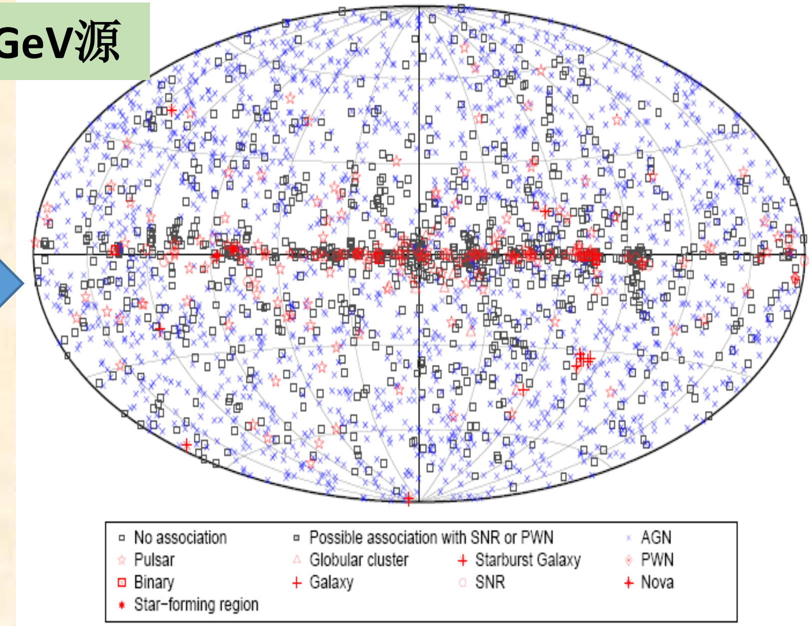
中国物理学会高能物理分会第十届全国会员代表大会暨学术年会

1971年
首个伽马源



空间实验GeV源



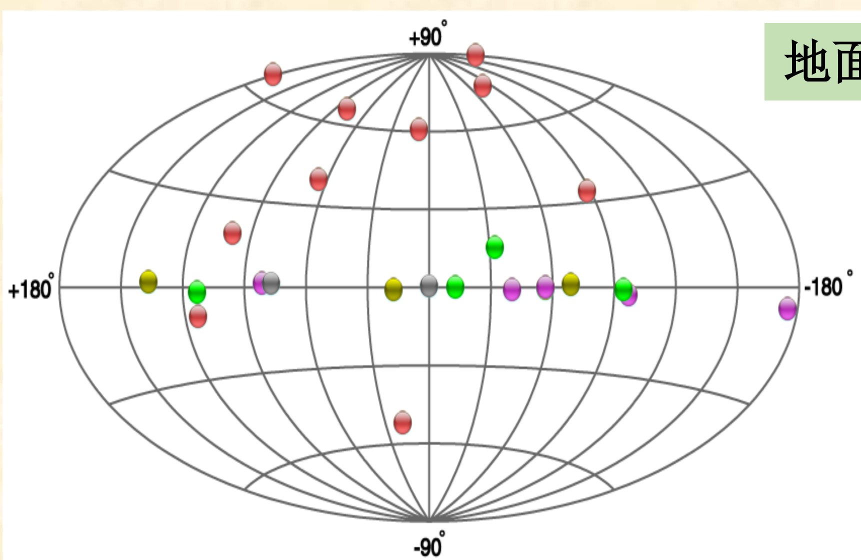
EGRET:1991-2000, 271个

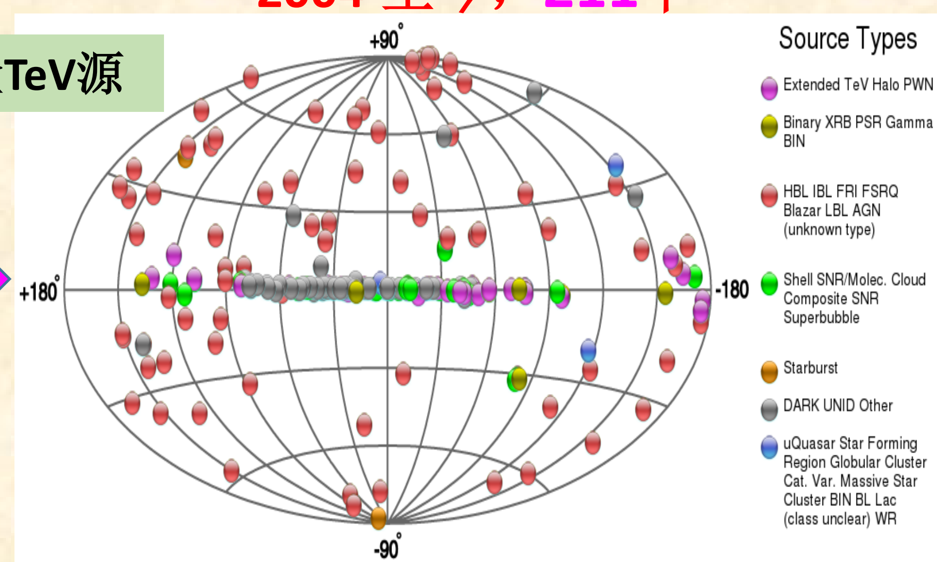
Fermi-LAT:2008-至今, 4年3033个, 8年5524个

1989-2004, 15个

2004-至今， 211个

地面实验TeV源





一、甚高能伽马射线的产生及传播

甚高能伽马射线产生机制

- 逆康普顿过程 $e + \gamma_{\text{low energy}} \longrightarrow e_{\text{low energy}} + \gamma_{\text{VHE}}$
- 强作用过程 $\text{p} + \text{nucleus} \rightarrow \text{p}' \ldots + \pi^{\pm} + \pi^{0} + \ldots$

  $\pi^0 \rightarrow 2\gamma$
- 暗物质湮灭 $\chi\chi \rightarrow \gamma\gamma$　　$\chi\chi \rightarrow \gamma Z$

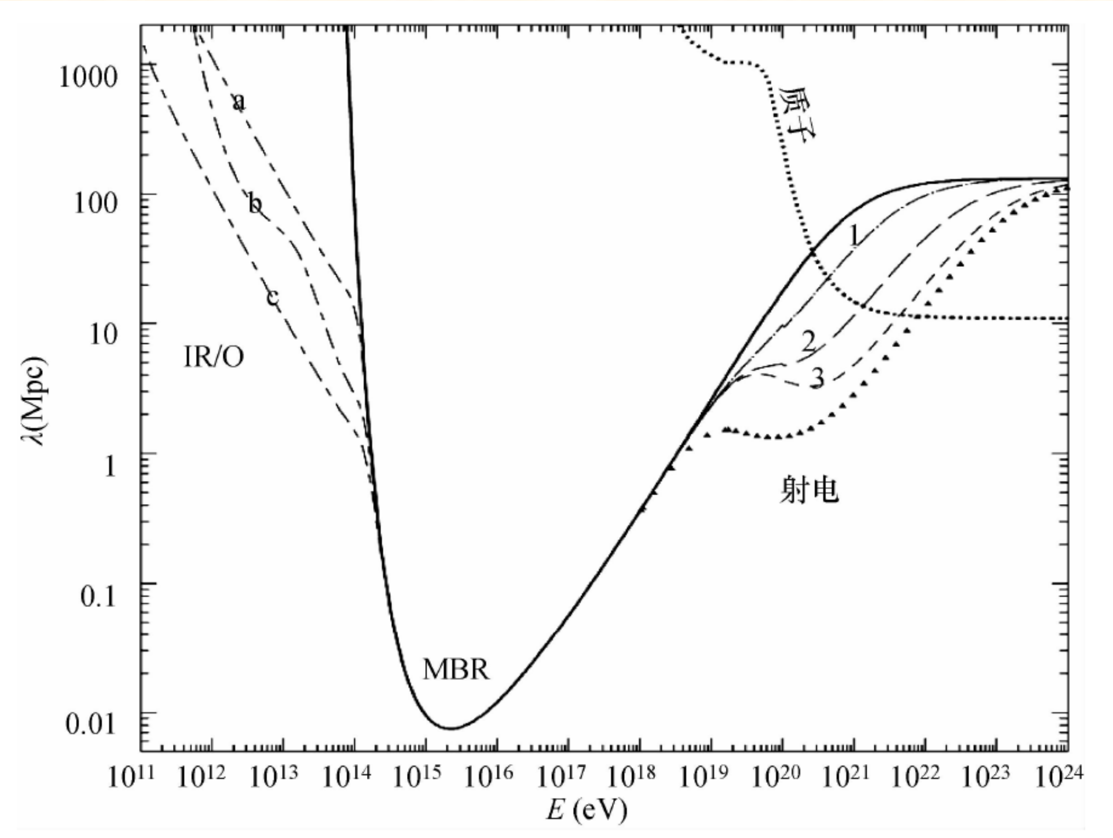
  $qq \rightarrow jets \rightarrow n\,\gamma\text{'s}$

伽马射线天文学研究是探索高能粒子起源和加速的重要手段!

寻找宇宙源的核心就是研究伽马射线的产生机制！

甚高能伽马射线传播

- $\gamma + \gamma_{低能} \rightarrow e^+ + e^-$
- 影响河外源100GeV以上辐射能谱；
- 只能观测河内源产生的100TeV伽马射线。



二、地面探测器及进展

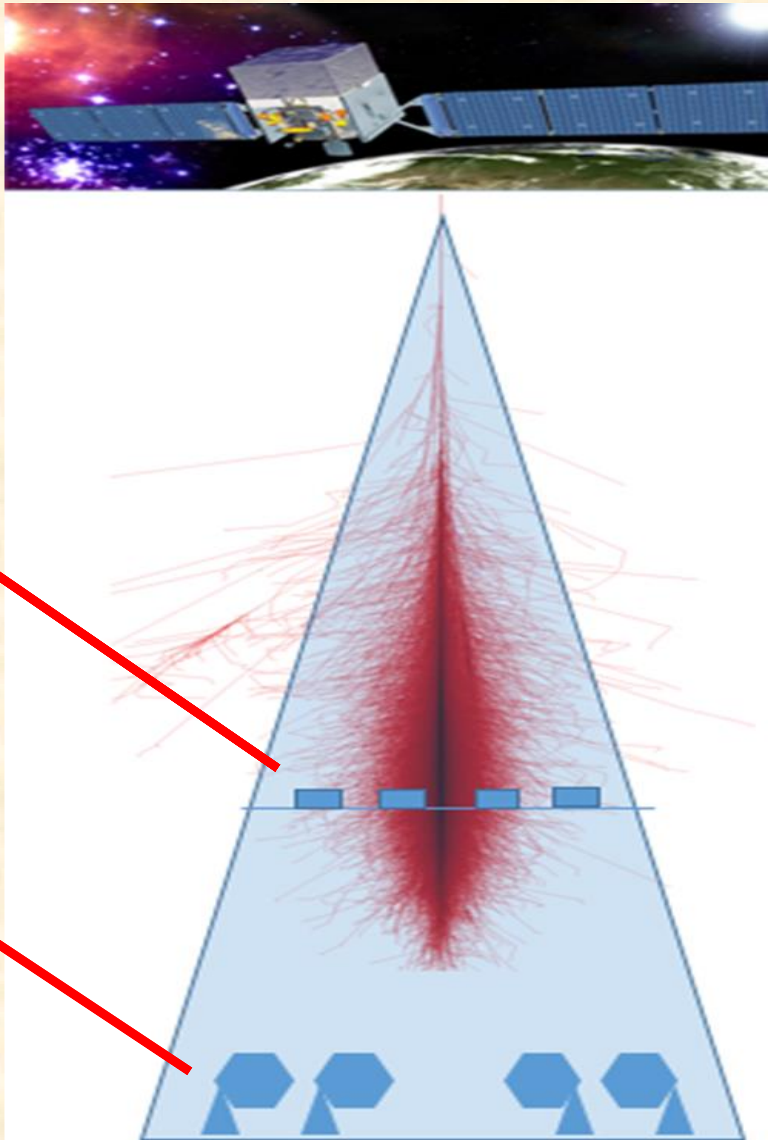
地面甚高能伽马射线探测器

- **EAS阵列**

ASγ (4300m): 1990-2008
Milagro(2630m): 1999-2008
ARGO-YBJ(4300m): 2006-2013
ASγ +MD(4300m)： 2013-至今
HAWC(4100m)： 2015-至今
LHAASO(4410m): 2019?-2021-

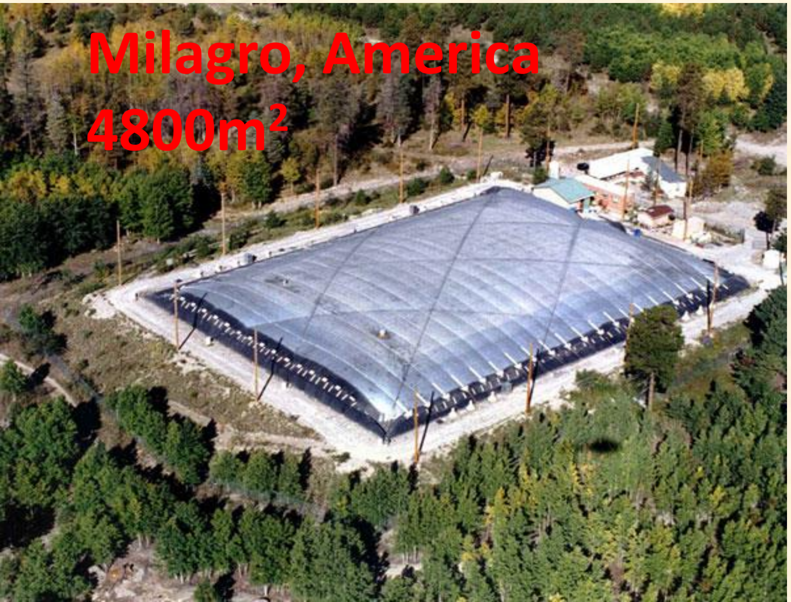
- **IACT**

HESS(1800m): 2003-2012-至今
CANGAROO III(160m): 2004-2008
MAGIC(2225m)： 2004-2009-至今
VERITAS(1268m): 2007-至今
CTA south(?): 2021?-
CTA north(2225m): ?



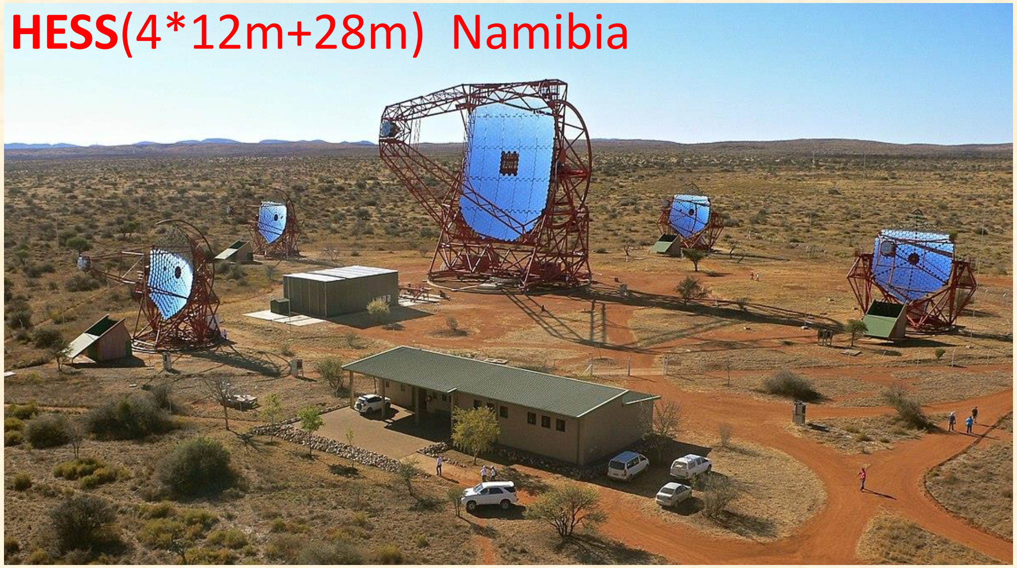
EAS阵列


Tibet ASγ
36900m2
ARGO
5800m2

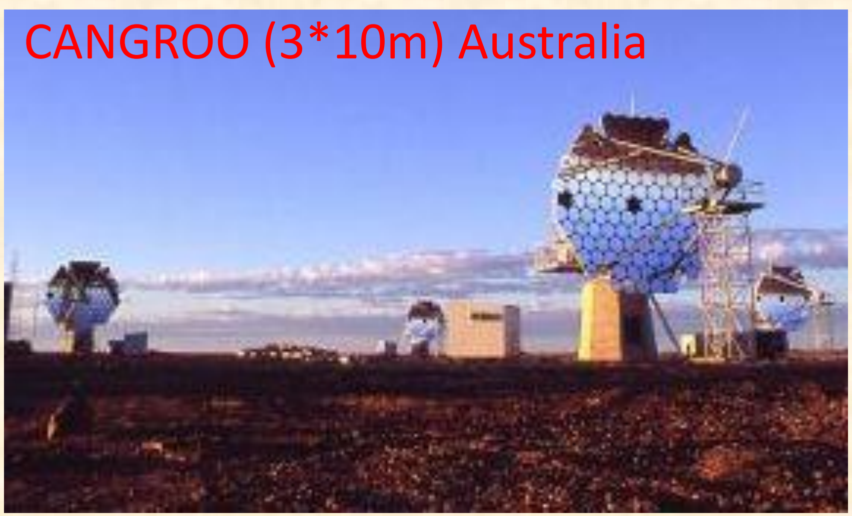

Milagro, America
4800m2


HAWC, Mexico
22000m2

IACT


HESS(4*12m+28m) Namibia

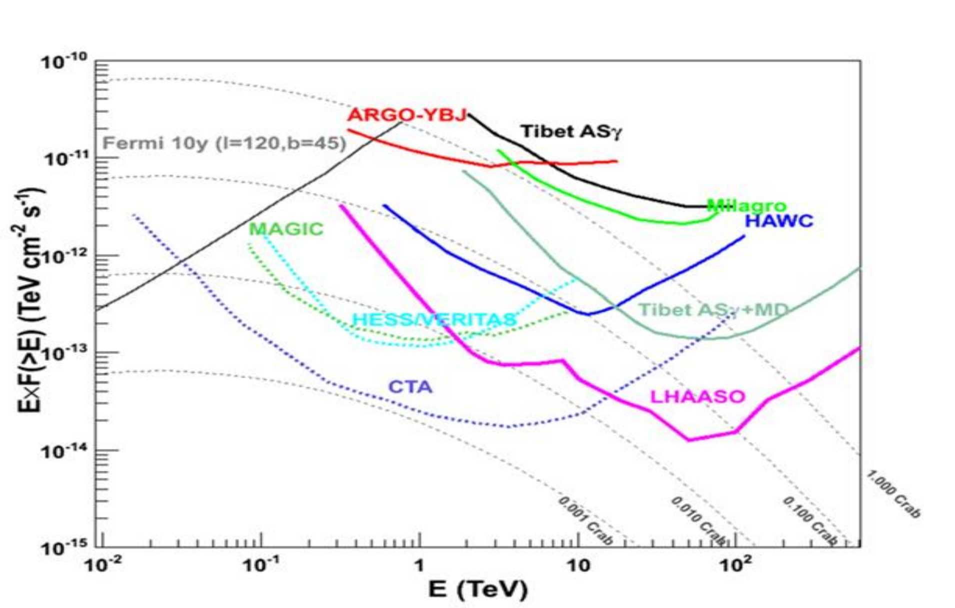

MAGIC(2*17m) Spain
Daniel López / IAC

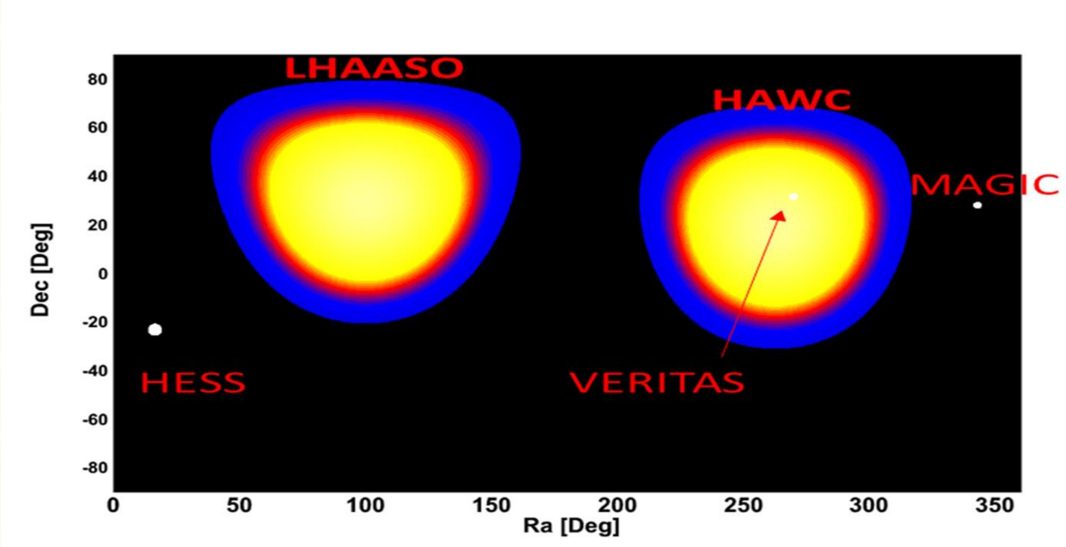

CANGROO (3*10m) Australia


VERITAS(4*12m) America

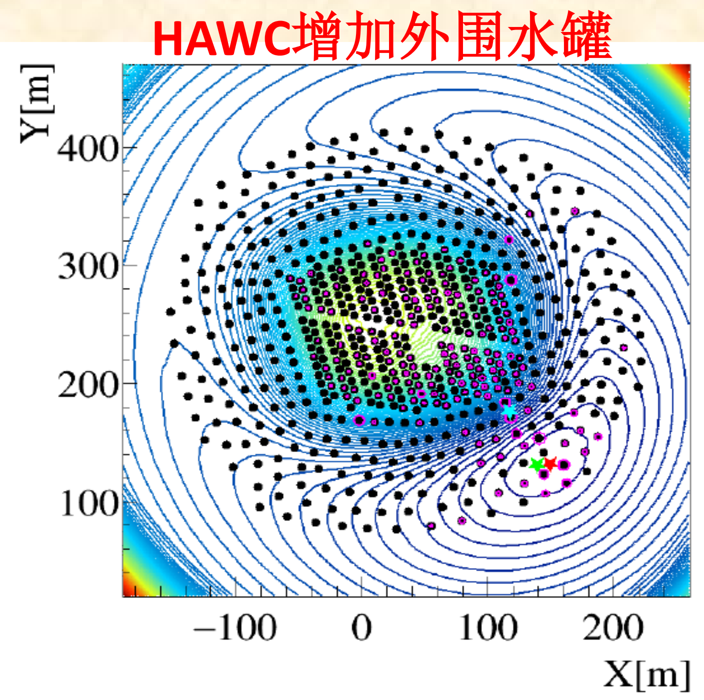
两种技术比较

- EAS阵列
  - 角分辩率：~0.5度
  - 灵敏度:　　1~0.1 Icrab
  - 视场：　　2sr
  - 运行时间：>90%
  - AGN,扩展源,大天区扫描
- IACT
  - 角分辩率:　~ 0.06 度.
  - 灵敏度:　　~0.7% Icrab
  - 视场:　　　3~5 度
    (CTA) >7度
  - 运行时间：~15%
  - 点源,小扩展源,AGN,部分天区扫描

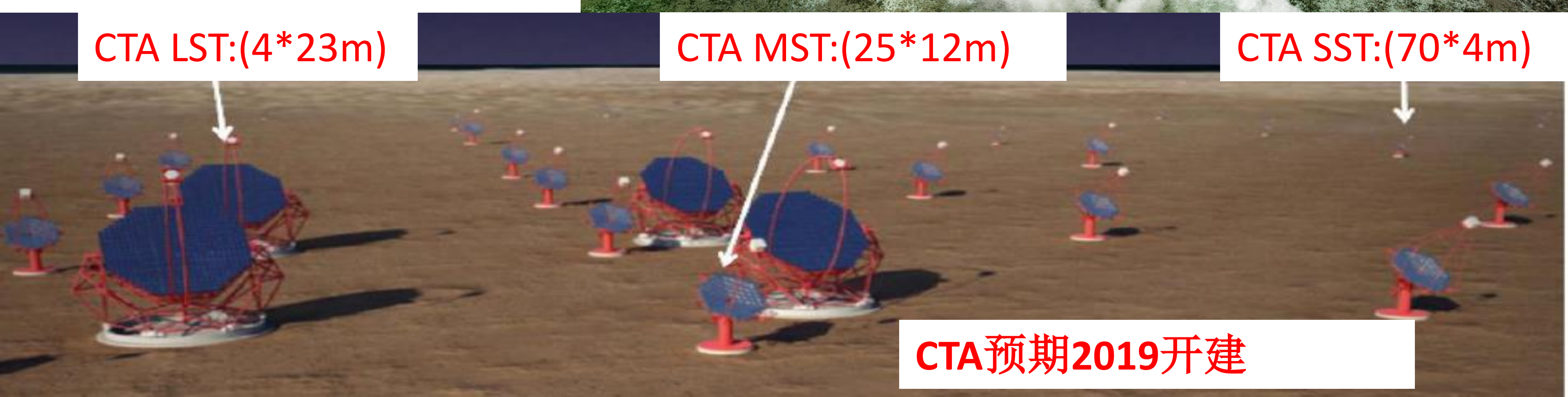




最新进展


HAWC增加外围水罐
Y[m]
400
300
200
100
−100
0
100
200
X[m]

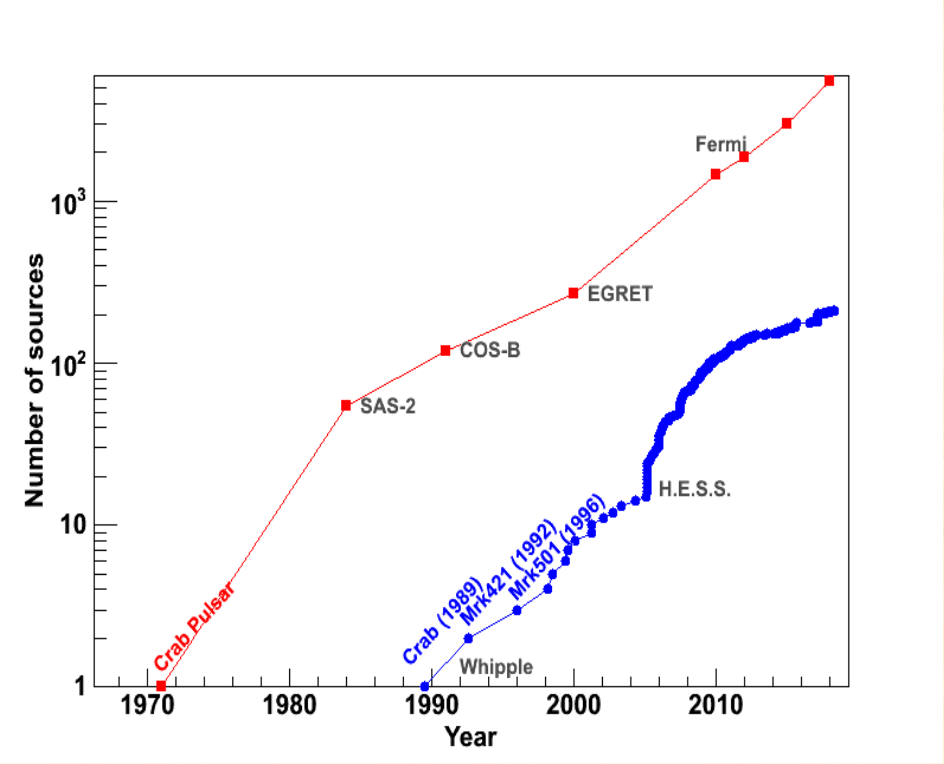

LHAASO于2017正式开建

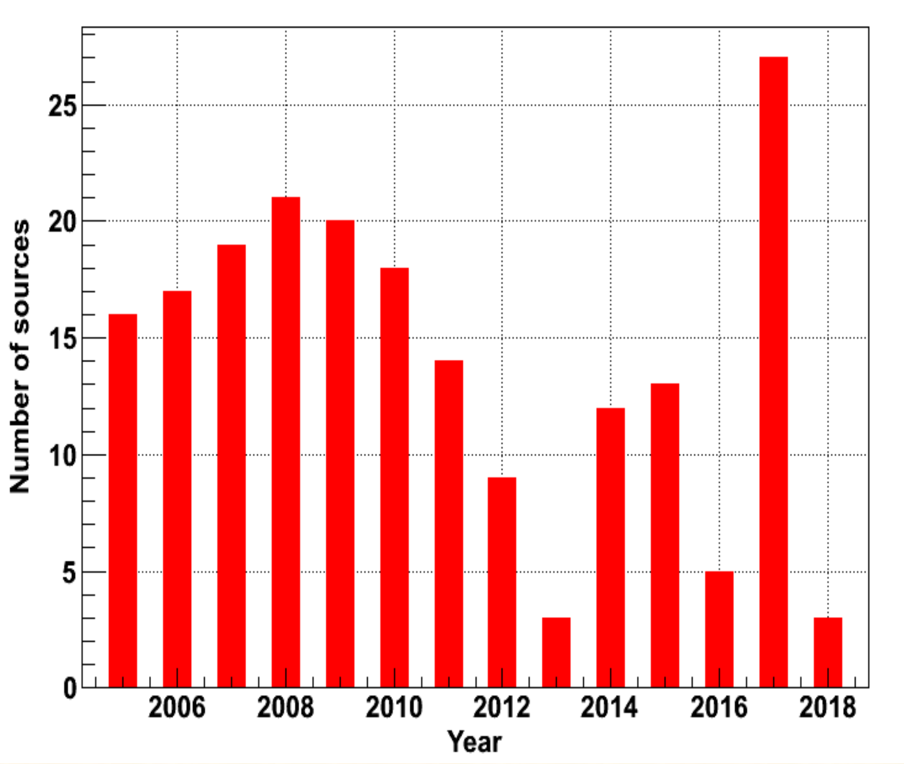

CTA LST:(4*23m)
CTA MST:(25*12m)
CTA SST:(70*4m)
CTA预期2019开建

三、甚高能伽马射线重要进展

TeV源的增长

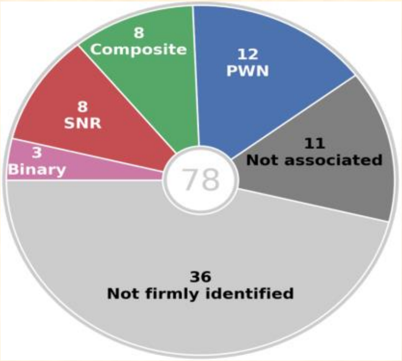
- 借助于Fermi卫星在几十GeV观测信息，IACT发现的TeV源数仍在增长,但已经明显变缓.



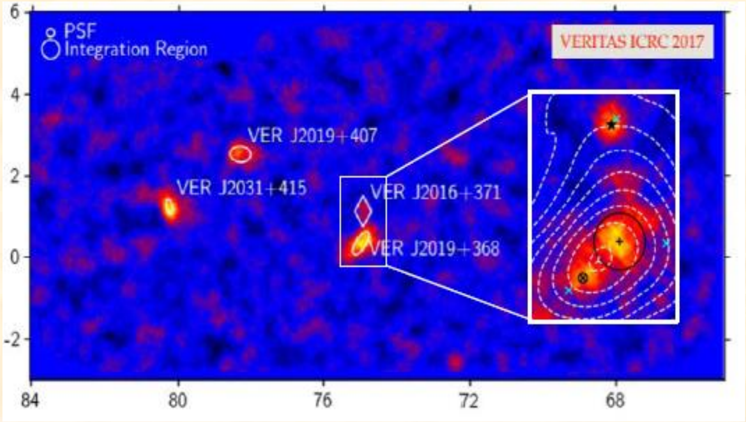


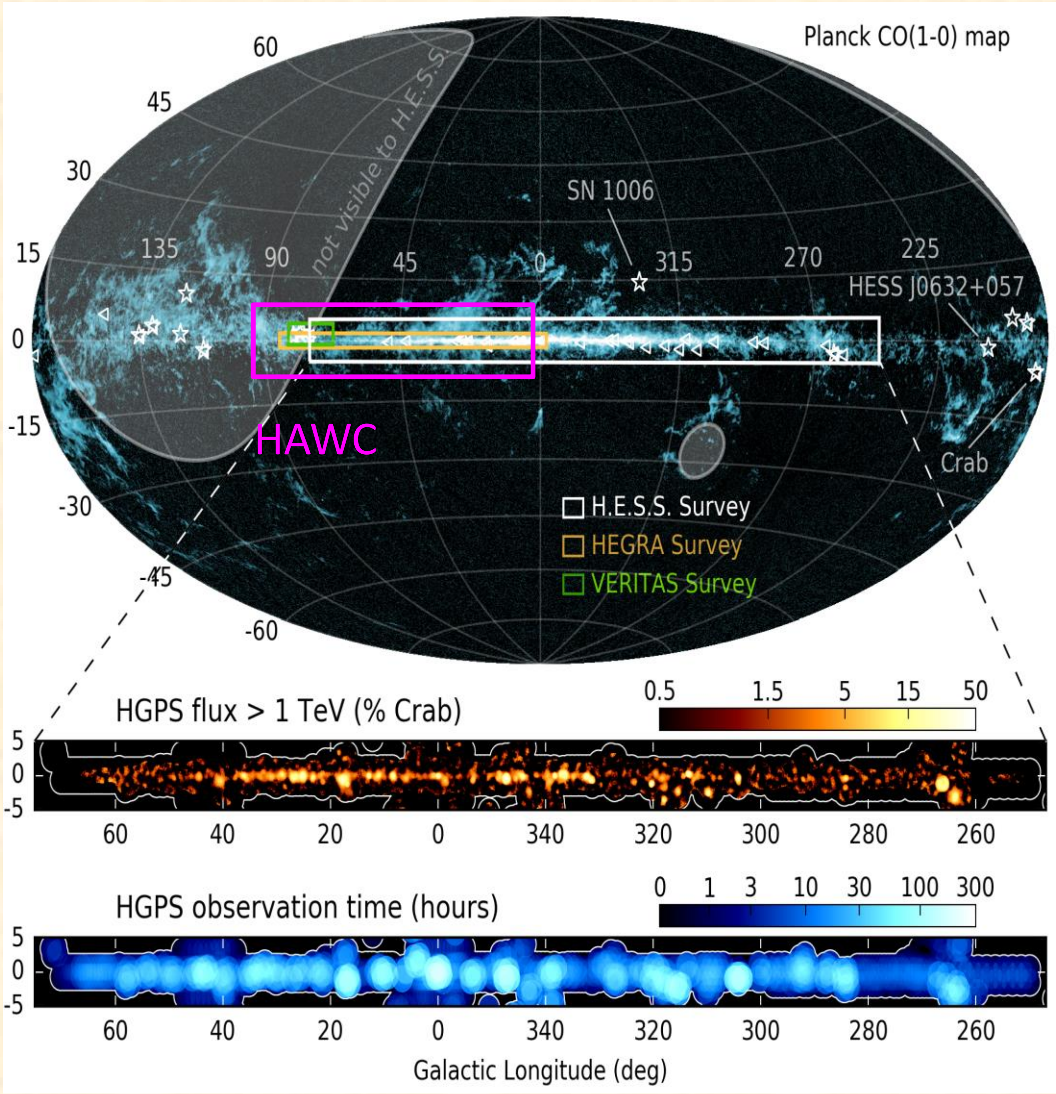
IACT对银盘的扫描

- HESS Galactic Plane survey 3000h,~1% Icrab,78个源



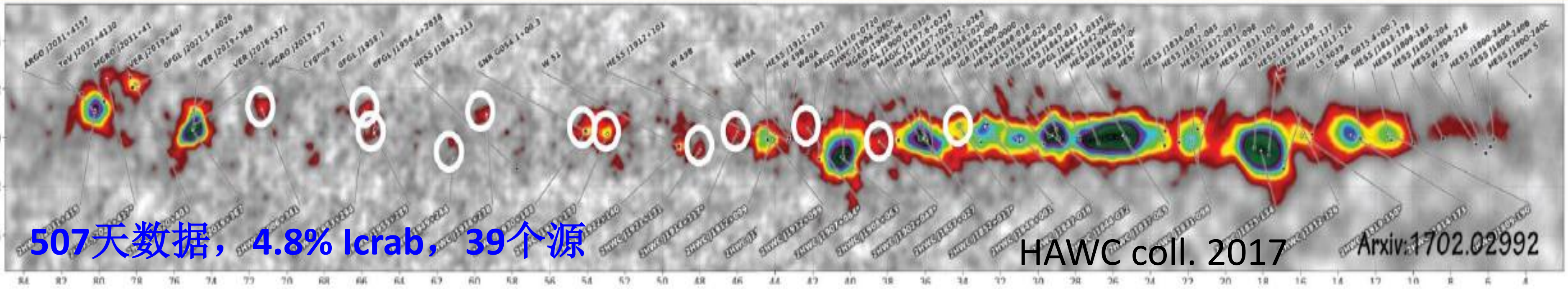
- VERITAS Cygnus survey, 135h+175h,~1% Icrab, 5个源





HESS coll. 2018

HAWC Second Catalog



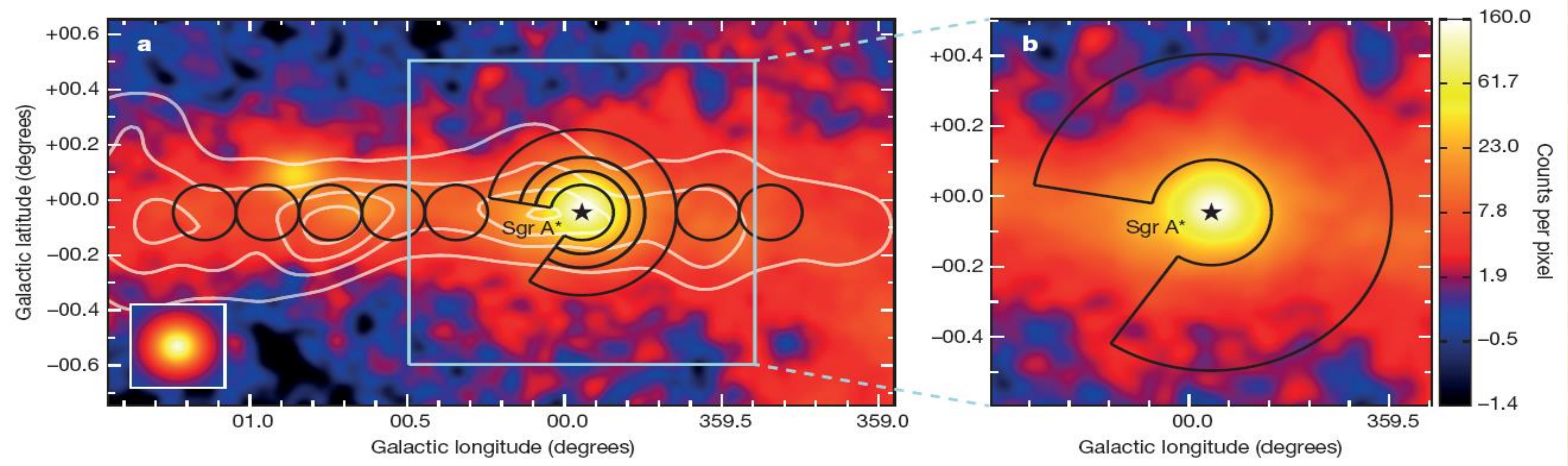
- 16 sources are 1 degree away from known TeV gamma-ray sources
- Follow-up studies by using VERITAS & Fermi-LAT data
  - VERITAS has 187 hours of exposure on 13 out of 16 sources
    - Non-detection on 12 sources
    - 1 detection – 2HWC J1953+294
  - Fermi accumulated 8.5 years of exposure over all sky, improved sensitivity with Pass 8 (E>10GeV)
    - Non-detection for 13 sources
    - Detection on a known TeV source, SNR G54.1+0.3

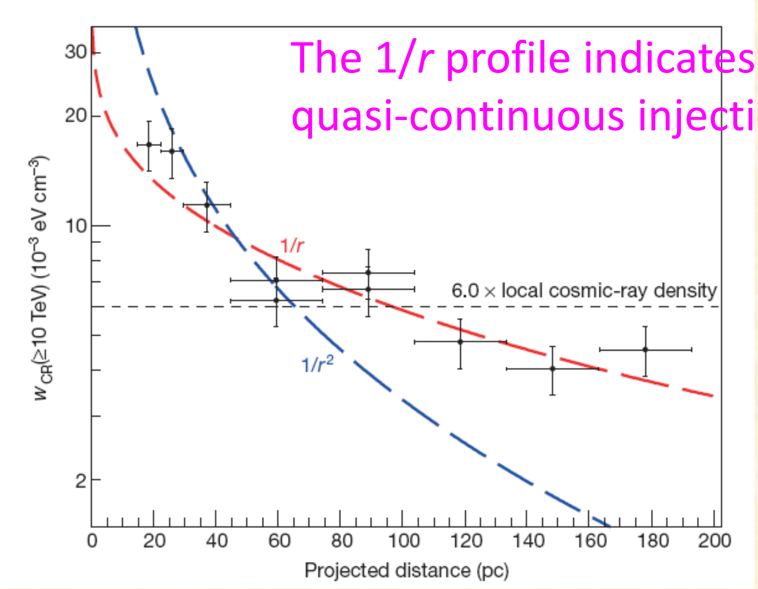
arXiv:1708.05744

- HESS follow-up on 1 source : Non-detection

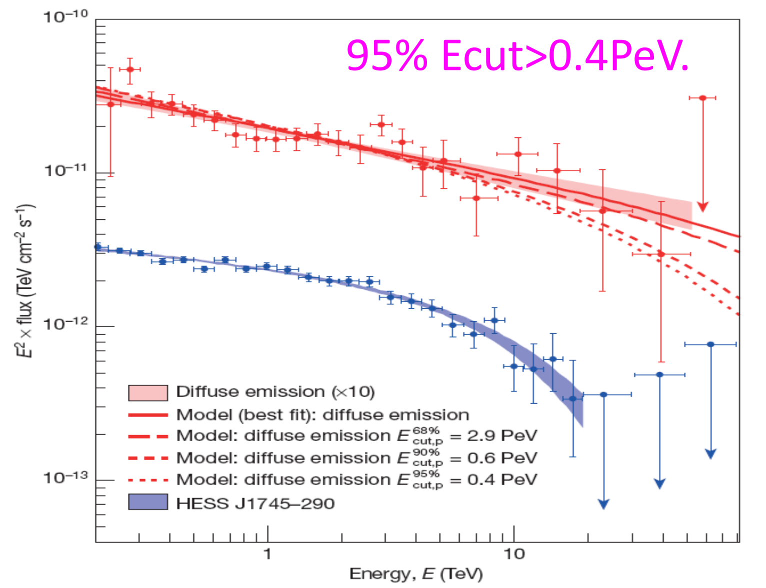
较硬的能谱？大的扩展度(>0.23度)？

Acceleration of PeV protons in the Galactic Centre！？





The 1/*r* profile indicates a quasi-continuous injection.

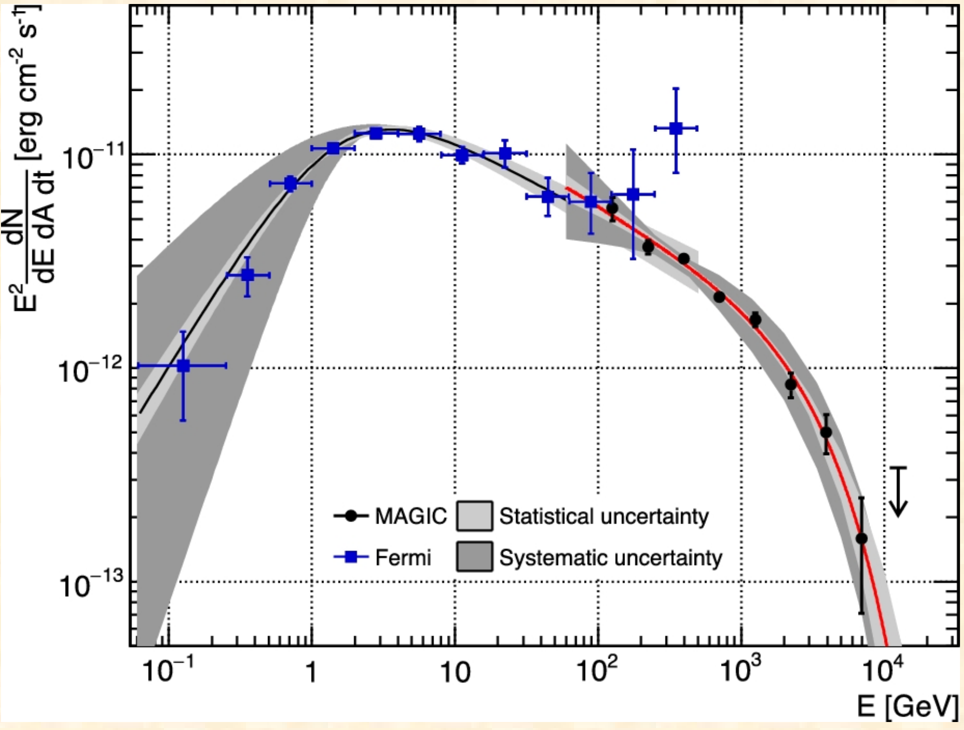


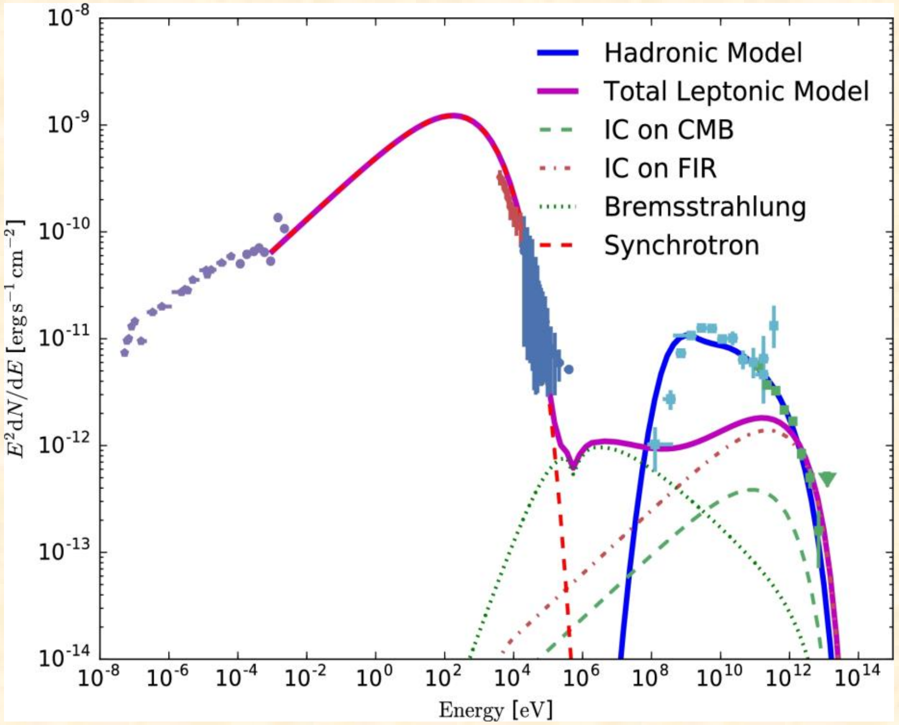
95% Ecut>0.4PeV.

HESS coll. 2016, Nature

SNR

- 虽然有几个SNR被认为是强子起源，但是并没有找到能加速PeV宇宙线证据。
- Cassiopeia A (330 yr)： MAGIC: 160 h, Eγcut=3.5TeV， 强子起源Epcut~10TeV， 未到达PeV能区。

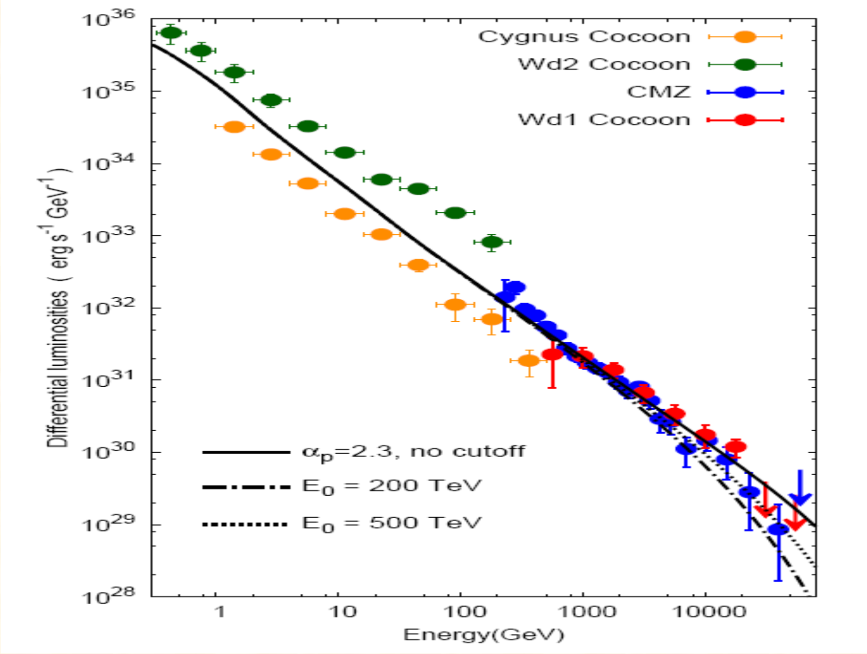


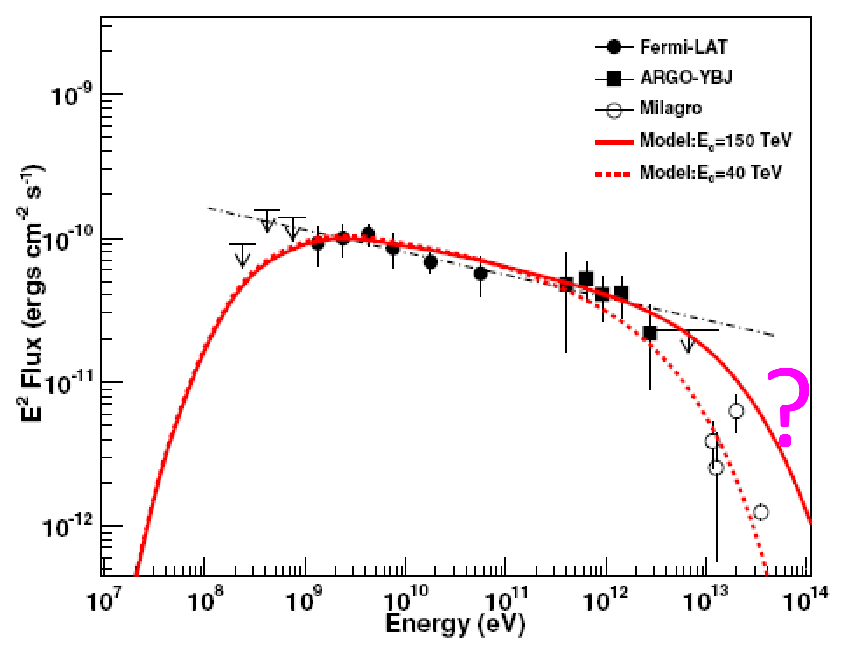


MAGIC coll. 2017

Massive Stars as Major Factories of Galactic Cosmic Rays?

- The analysis of gamma-ray data show that the hard energy spectra of parent protons continue up to ~ 1 PeV.
- The population of young massive stars can provide production of CRs at a rate of up to 10^{41} erg/s, **which is sufficient to support the flux of Galactic CRs without invoking other source populations**.



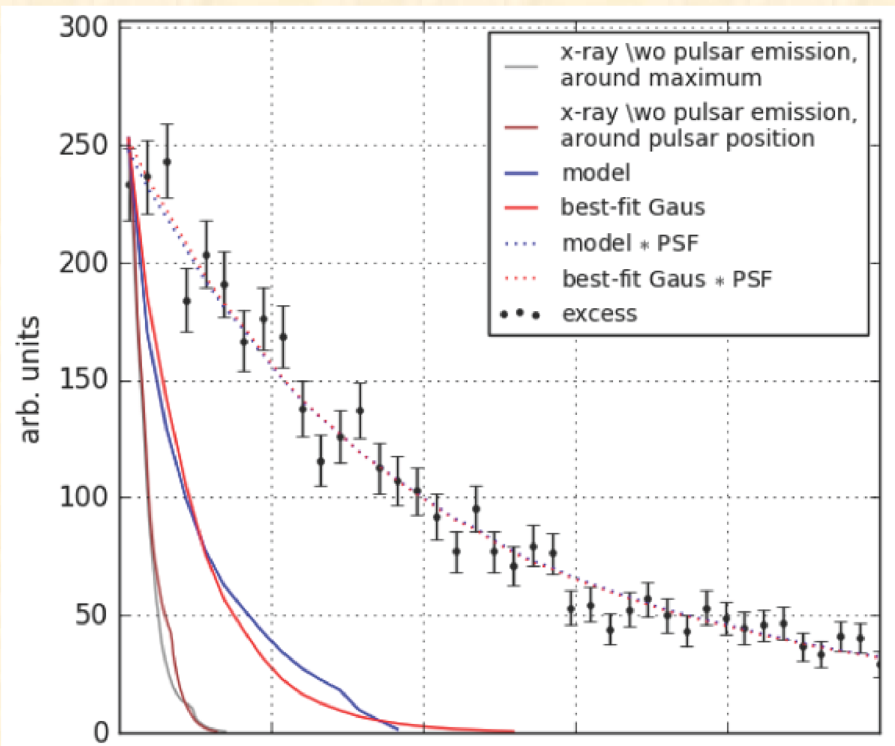


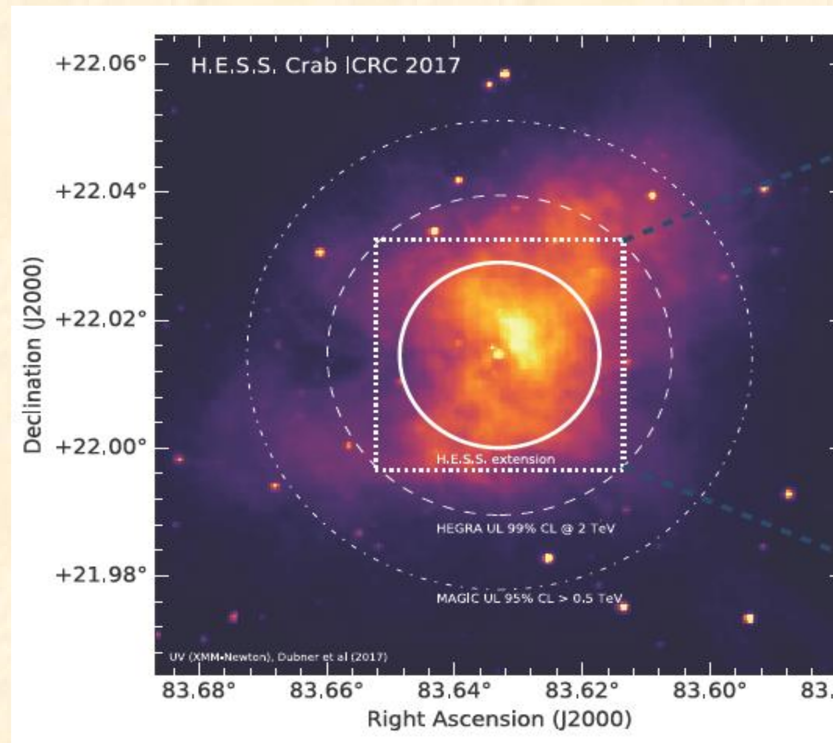
Aharonian et al. 2018

ARGO-YBJ coll. 2014

PWN： Crab

- **IACT首次测定Crab Nebula在TeV的扩展度！** $(52.2 \pm 2.9_{stat} \pm 7.8_{sys})''$
- **IC扩展度比X射线段大，与模型吻合!**

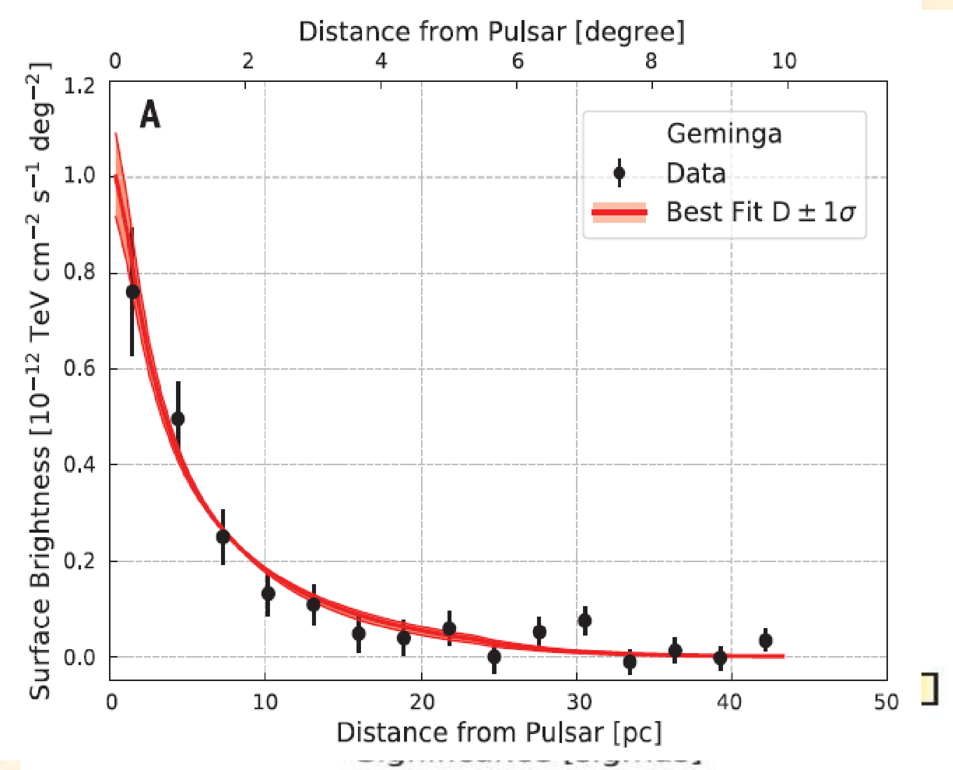


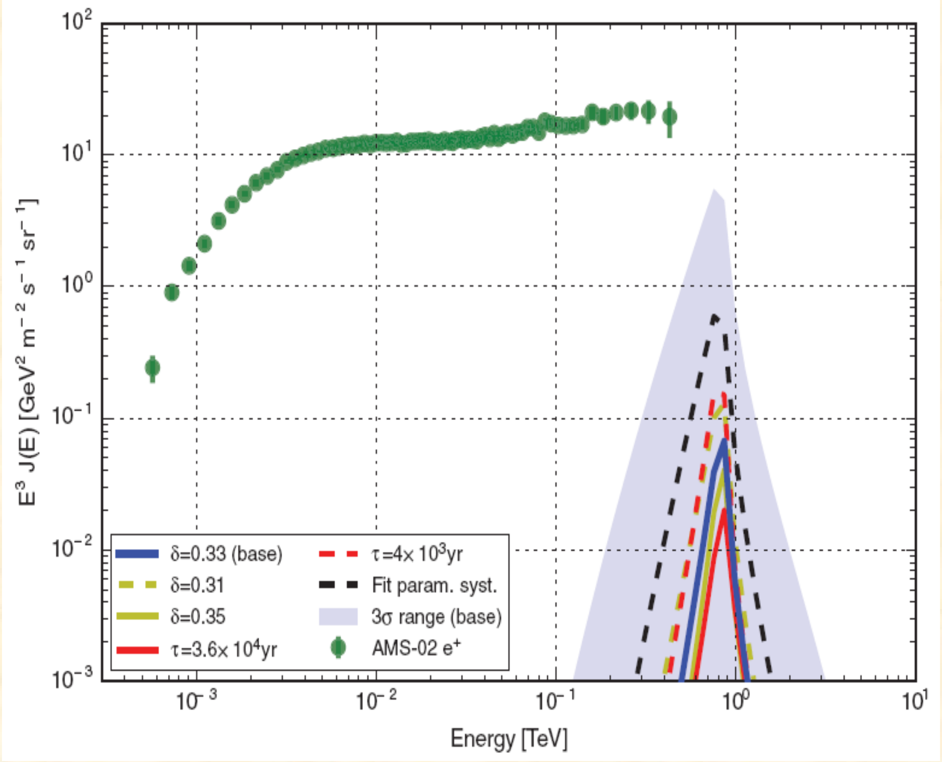


HESS coll. 2017

PWN：Geminga

- **HAWC通过扩展度拟合的扩散系数比常用系数小100倍**
- **地球附近的正电子不太可能起源与Geminga！**

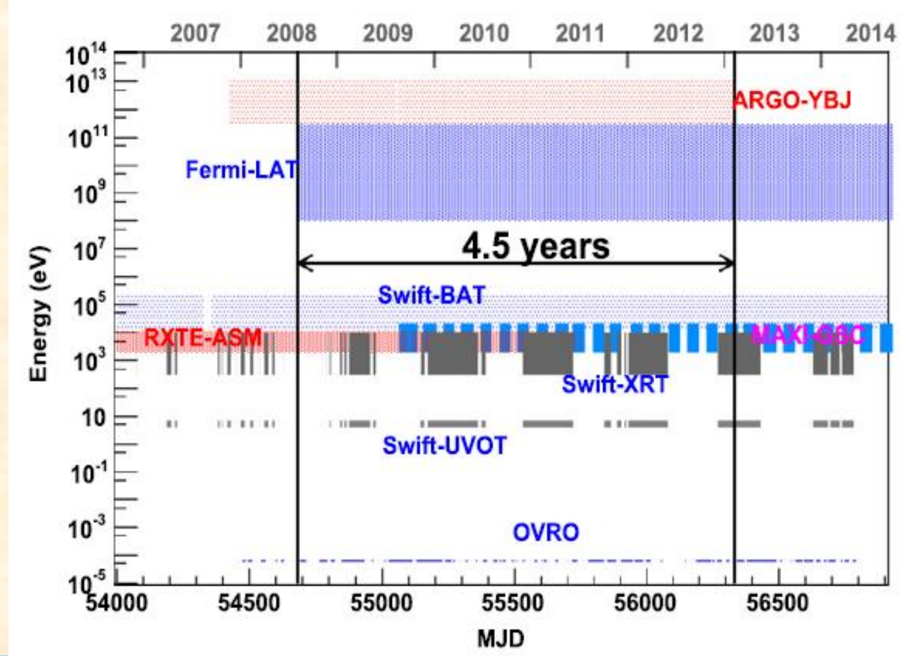




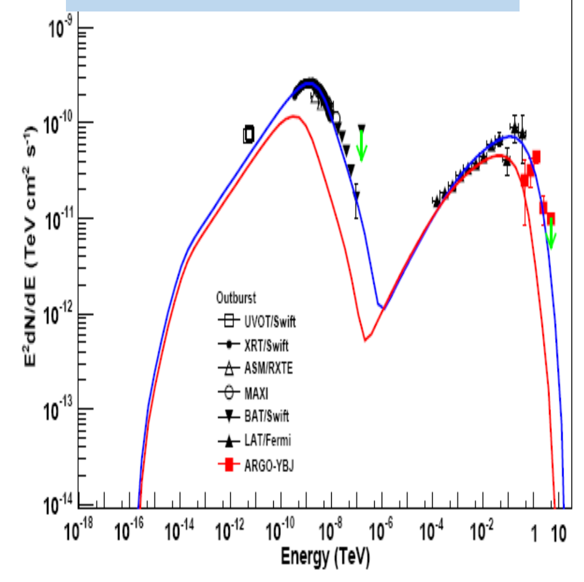
HAWC coll. 2017, Science

AGN：Mrk421

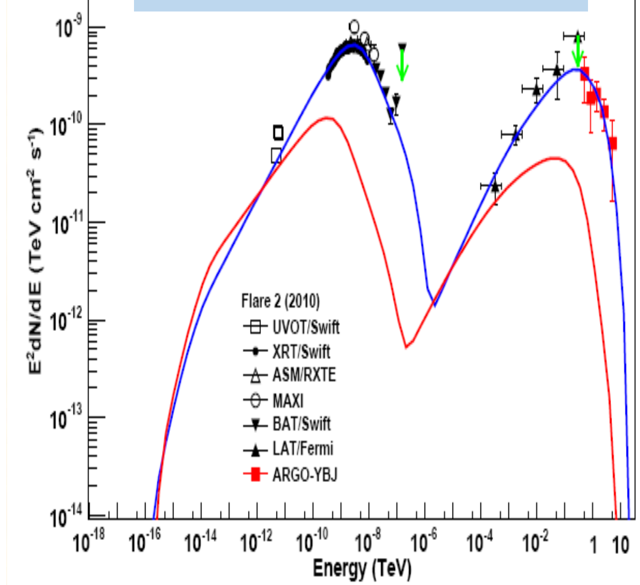
ARGO-YBJ对Mrk421进行了4.5年多波段研究，观测到7个大的flare（其中IACT只观测了1.5个）系统研究了多个爆发期能谱演化特征并分为三类，具有不同的起源。



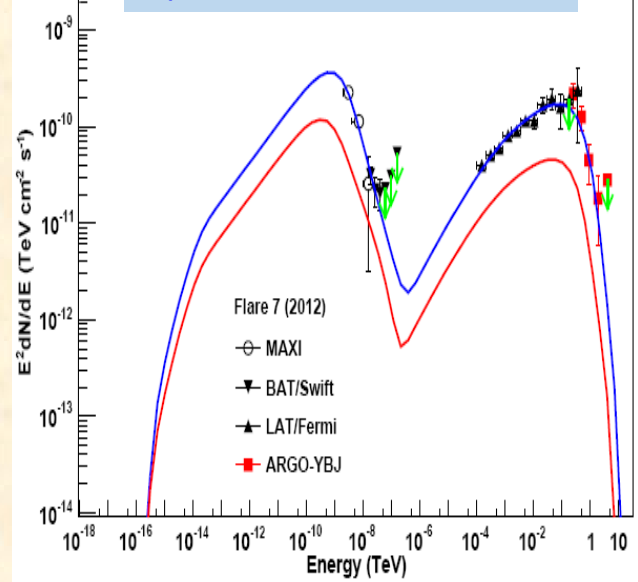
Type 1: 5 states



Type 2: 3 states



Type 3: 1 state



ARGO-YBJ coll., 2016

小结

- **IACT**的高灵敏度、低阈能和**EAS**阵列的全天候、大视场在**TeV**伽马天文观测中都具有重要的作用，两者互相补充。
- 甚高能伽马天文领域取得了重要的进展，但相对应于空间高能伽马天文仍有巨大 提升空间。
- 现有测量主要在**10TeV**以下，对一些关键问题急需要更高能的信息。
- 未来**CTA**的更高灵敏度和**LHAASO**更高能量的观测必会进一推动甚高能伽马天文取得重要进展。

谢谢！