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LHAASO Observations on SNR Cassiopeia A

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LHAASO collaborations

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SNRs as CR source/Pevatrons

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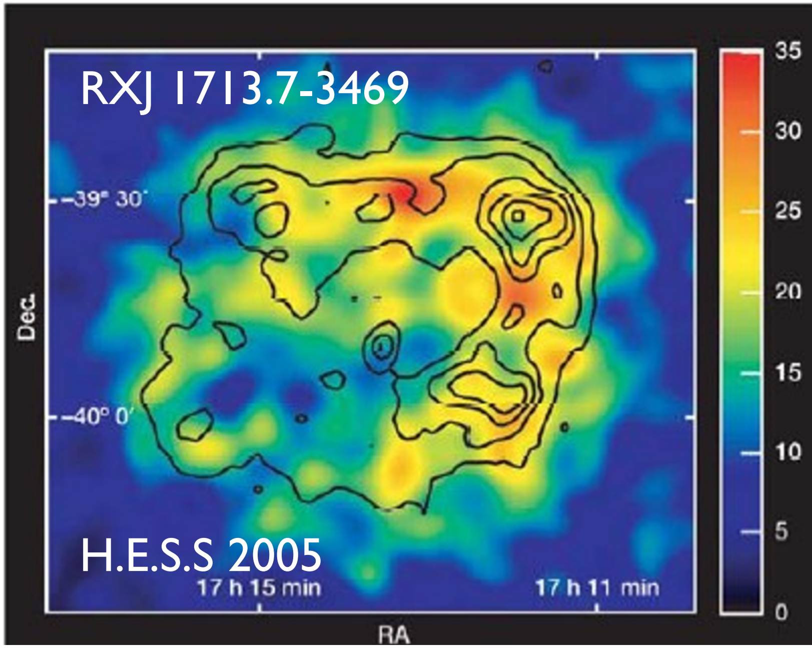
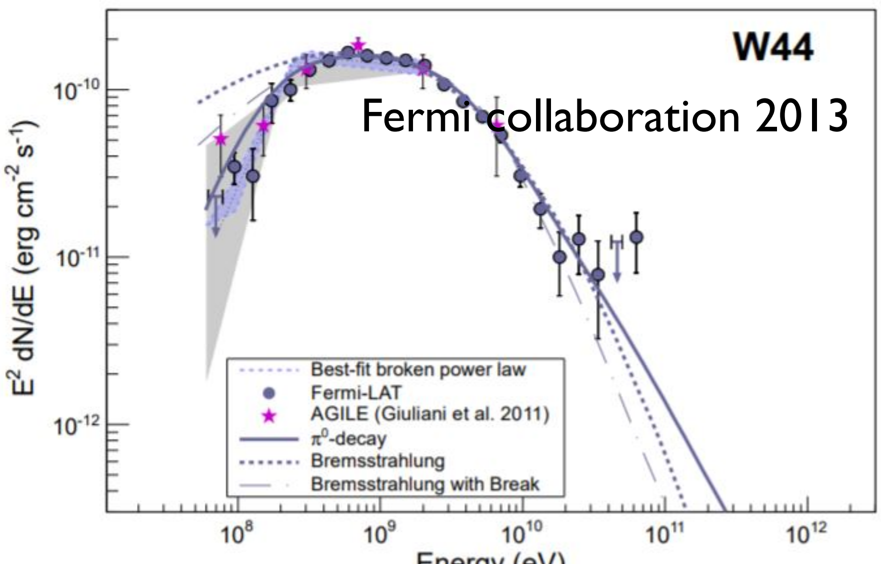
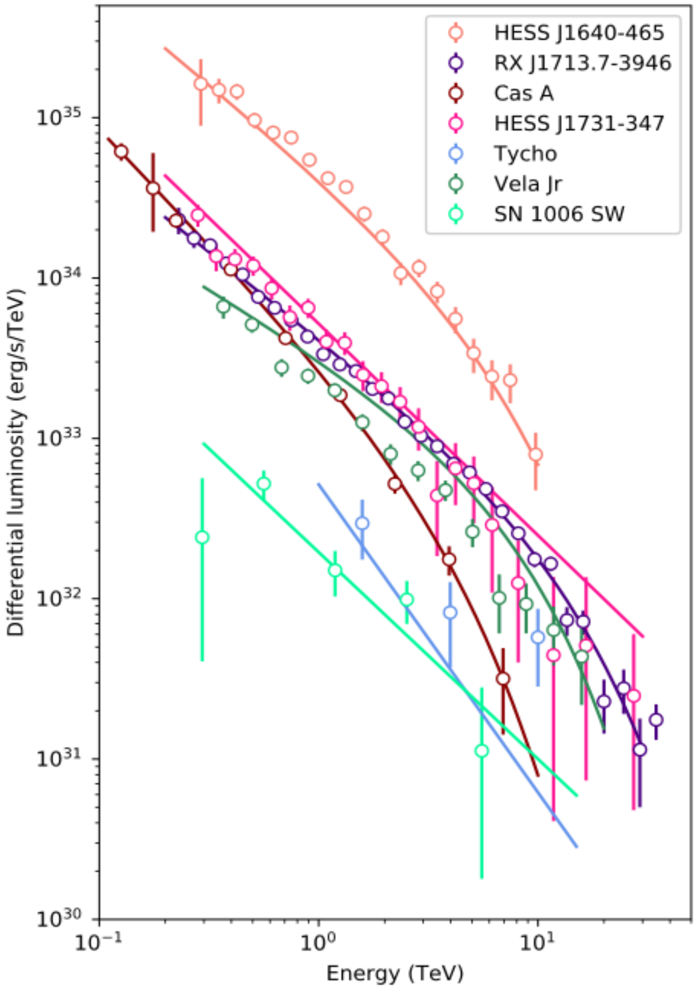
- Powerful enough to account for all Galactic CRs
- DSA efficient enough to extract 10% of Kinetic power (Caprioli's talk)
- Magnetic amplification observed (x-ray filaments)
- Gamma-ray observations reveal strong proof/ hints
- Clear Pion-decay feature in mid-age SNRs
- Break at ~ 10 GeV, Cannot account for all CRs up to PeV

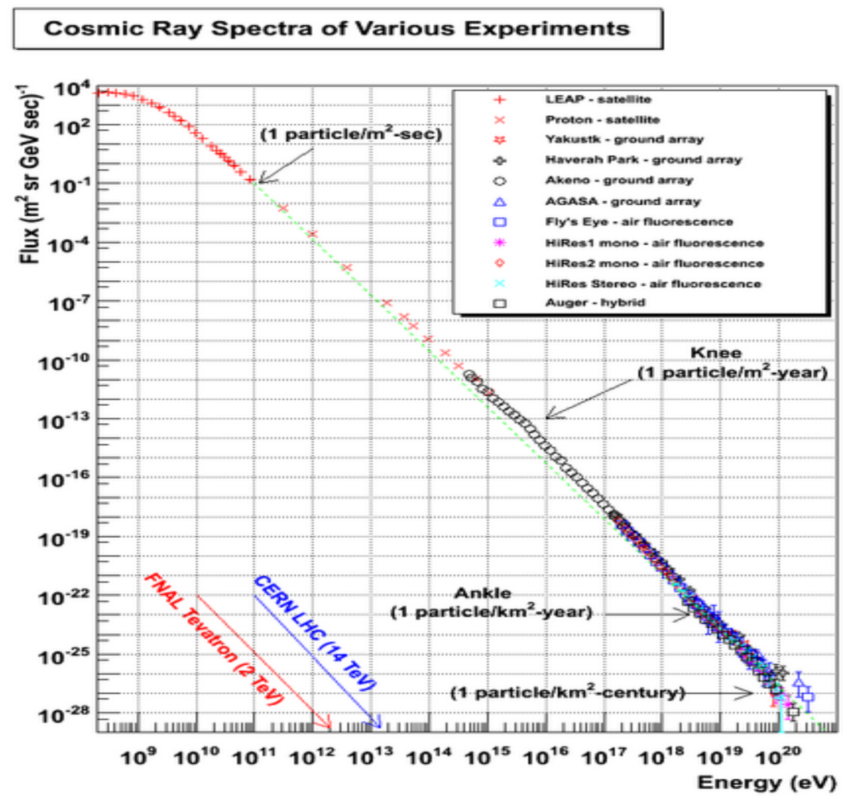




Gamma-ray observation of Young SNRs



- All young SNRs show soft spectrum or early cutoff at ~ 10 TeV
- corresponding to CR energy of 100 TeV
- Hard to address a single power law spectrum of CRs up to PeV



Very young SNRs?

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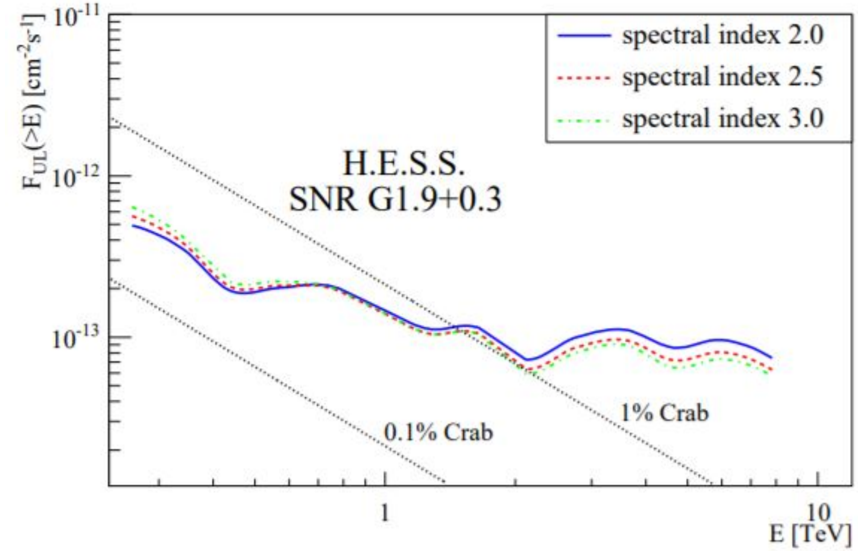
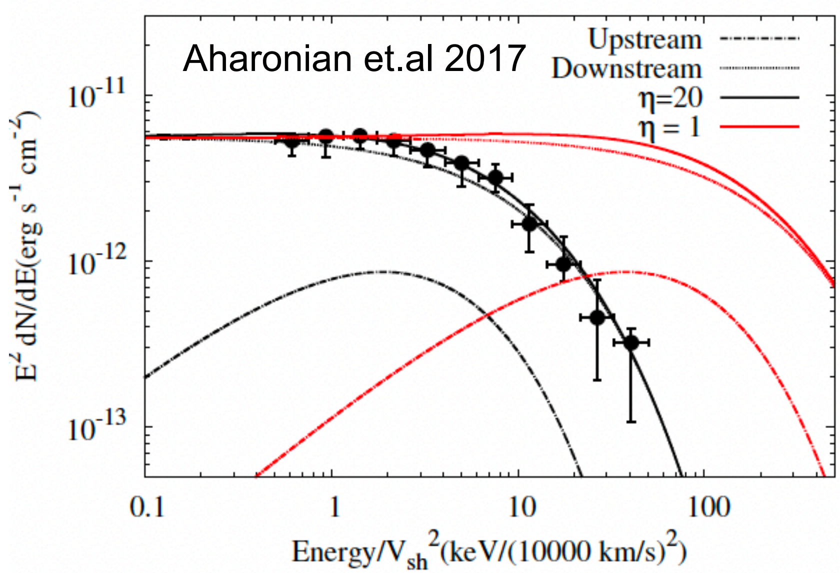
- The youngest SNR in the Galaxy:
  G1.9+0.3, t ~ 100 yr
- VHE protons cannot propagate more than 30 pc.
- HESS reveals L(>1 TeV) < 1e32 erg/s can be used to set limit on proton energy budget.
- Considering a high density in the vicinity (near GC), the total energy on VHE protons are below 1e45 erg. Not enough to account for the CR flux up to the knee.
- X-ray observations also reveal a low acceleration efficiency





Very young SNRs?

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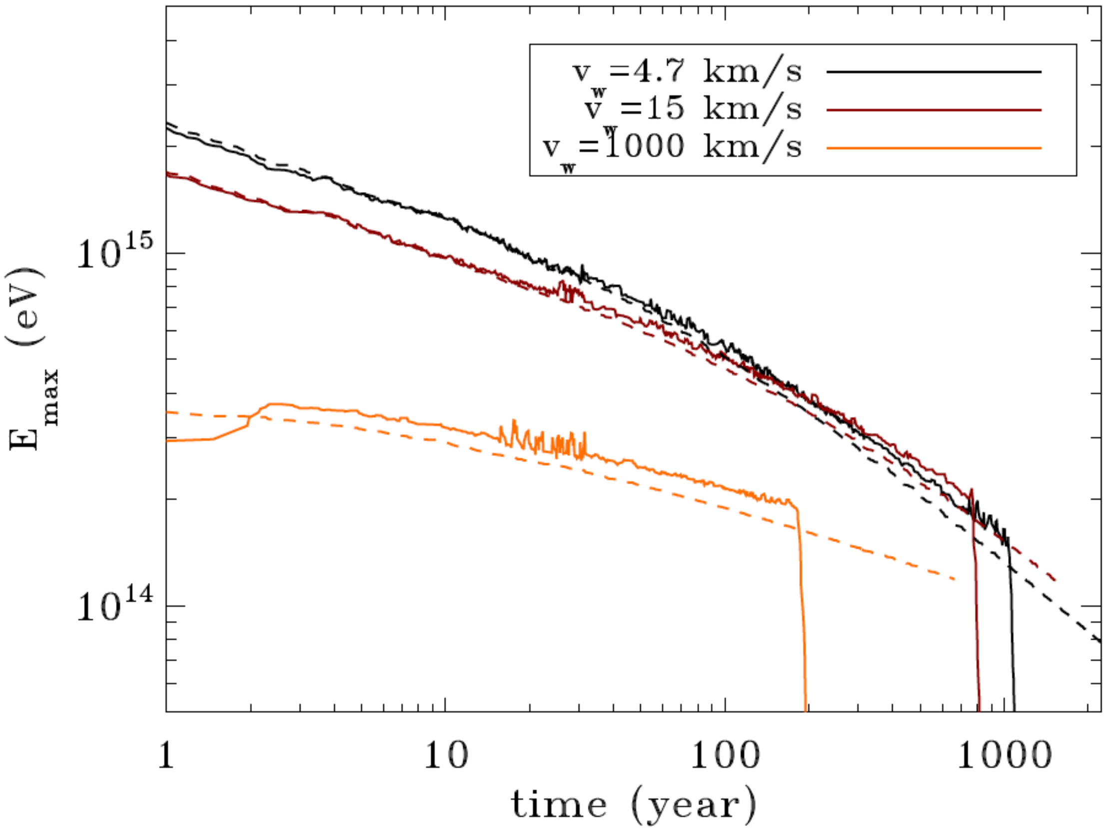
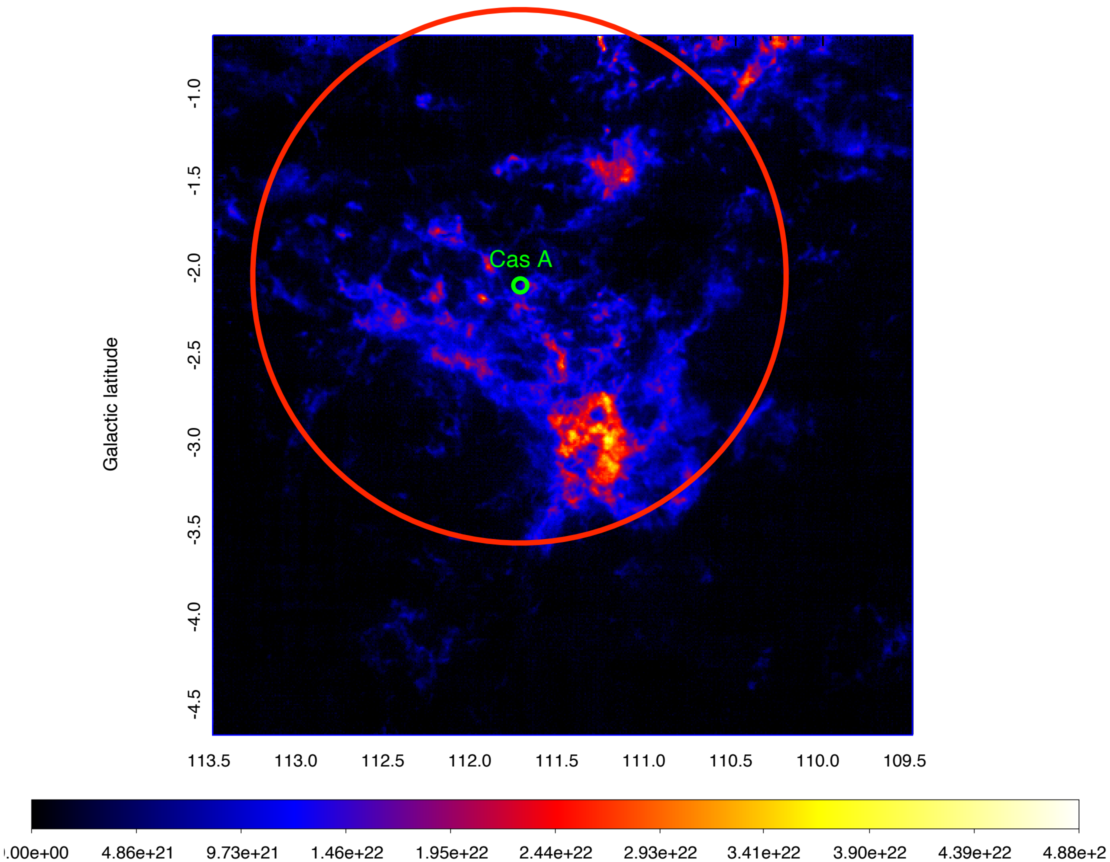
- Dense environment (dense wind in red giant)
- Lager escaping current and more efficient magnetic field amplification
- Higher cosmic energy (Schure & Bell 15, Bell et.al 13)



Can be Pevatron at first decade

PeV CRs already escape from the remnant?

Cas A is special



Giant Molecular clouds in the vicinity (Ma et.al 2019 MWISP survey)

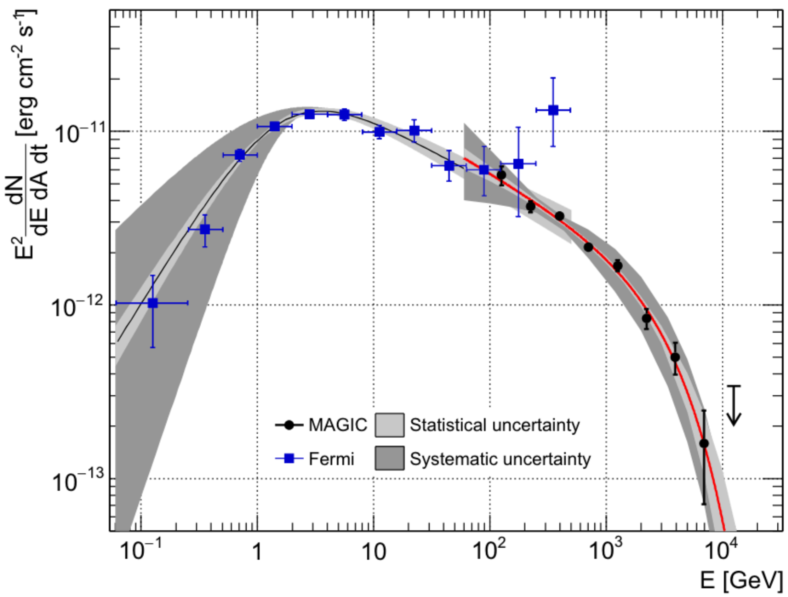
average cubic density > 10 cm^{-3}

total mass ~10^6 solar mass

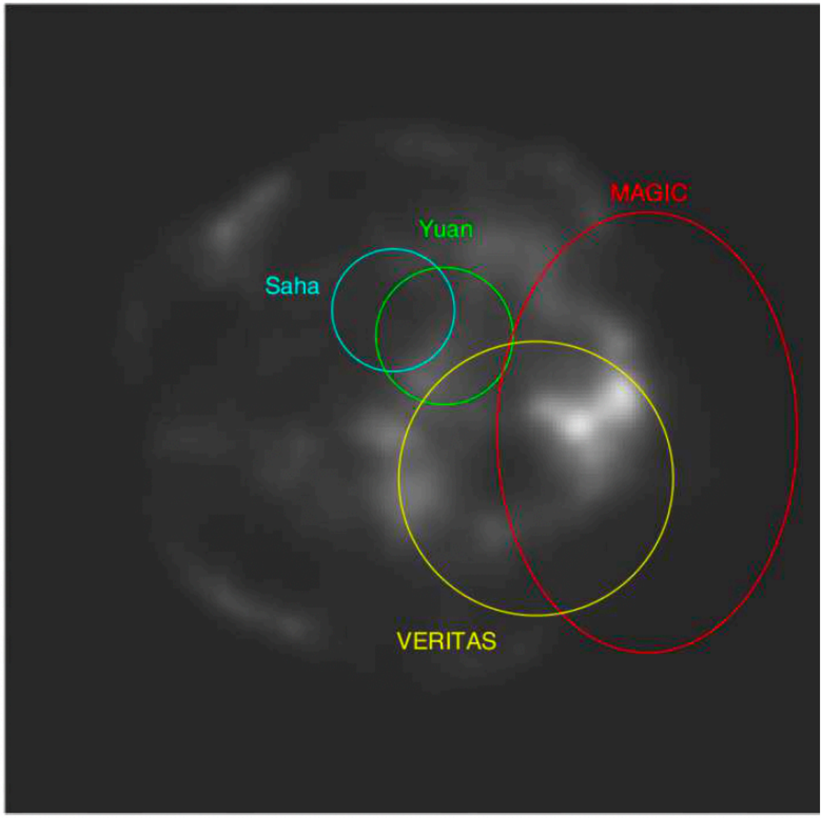
young age (~340 yrs), CR still within 100 pc(red circle)

best site to constrain the escaped CRs

Cas A is special



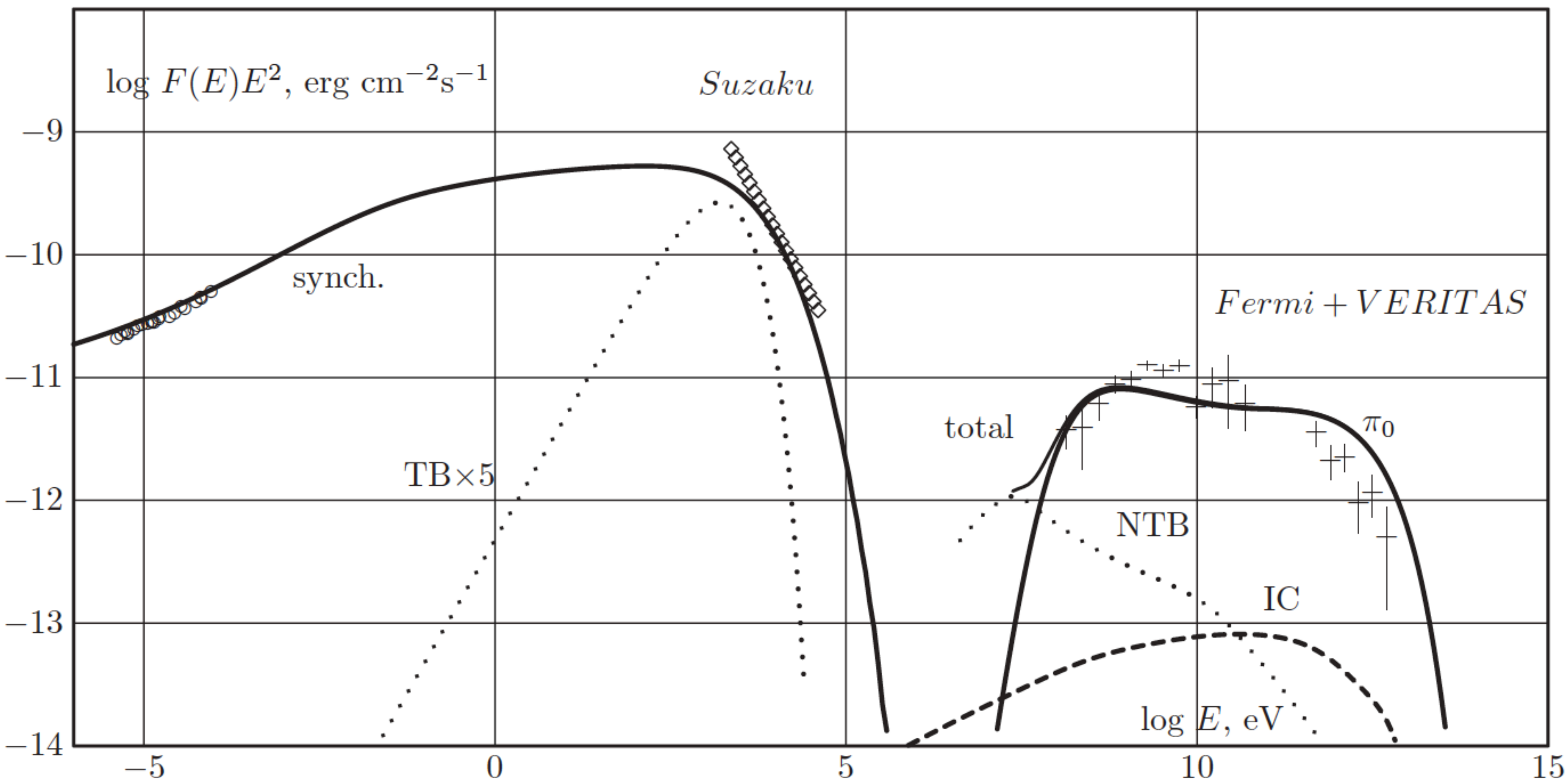
Magic collaboration 2017 reveal hint for cutoff



Grefenstette et.al 2015

Nustar observatiosn Show clear On-going acceleration (see Woo's poster S4.13)

Cas A is special



Multi-wavelength fitting, required a acceleration efficiency of more than 20%
(Zirakashvili et.al 2014)

Intro of LHAASO

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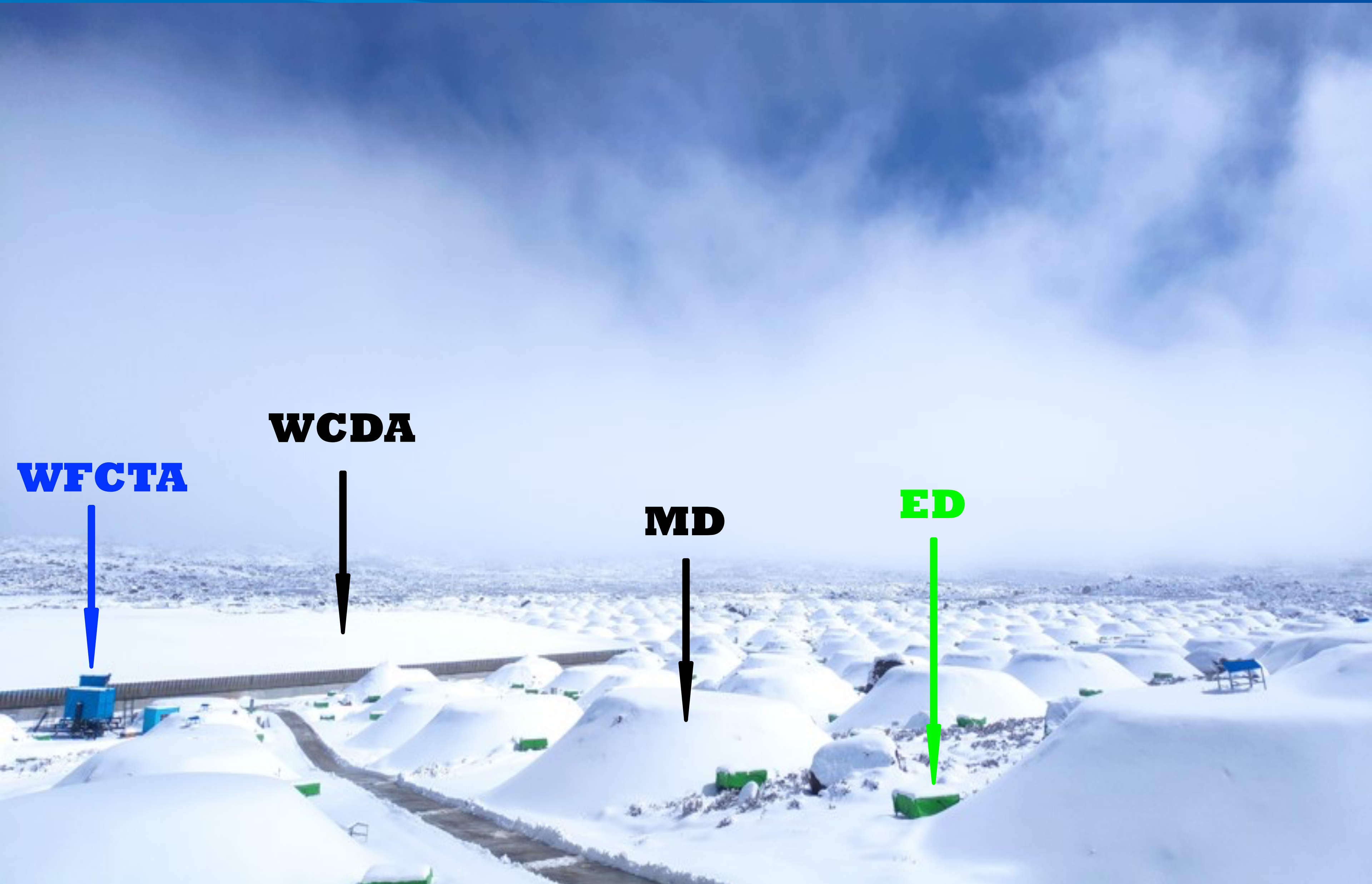

LHAASO site

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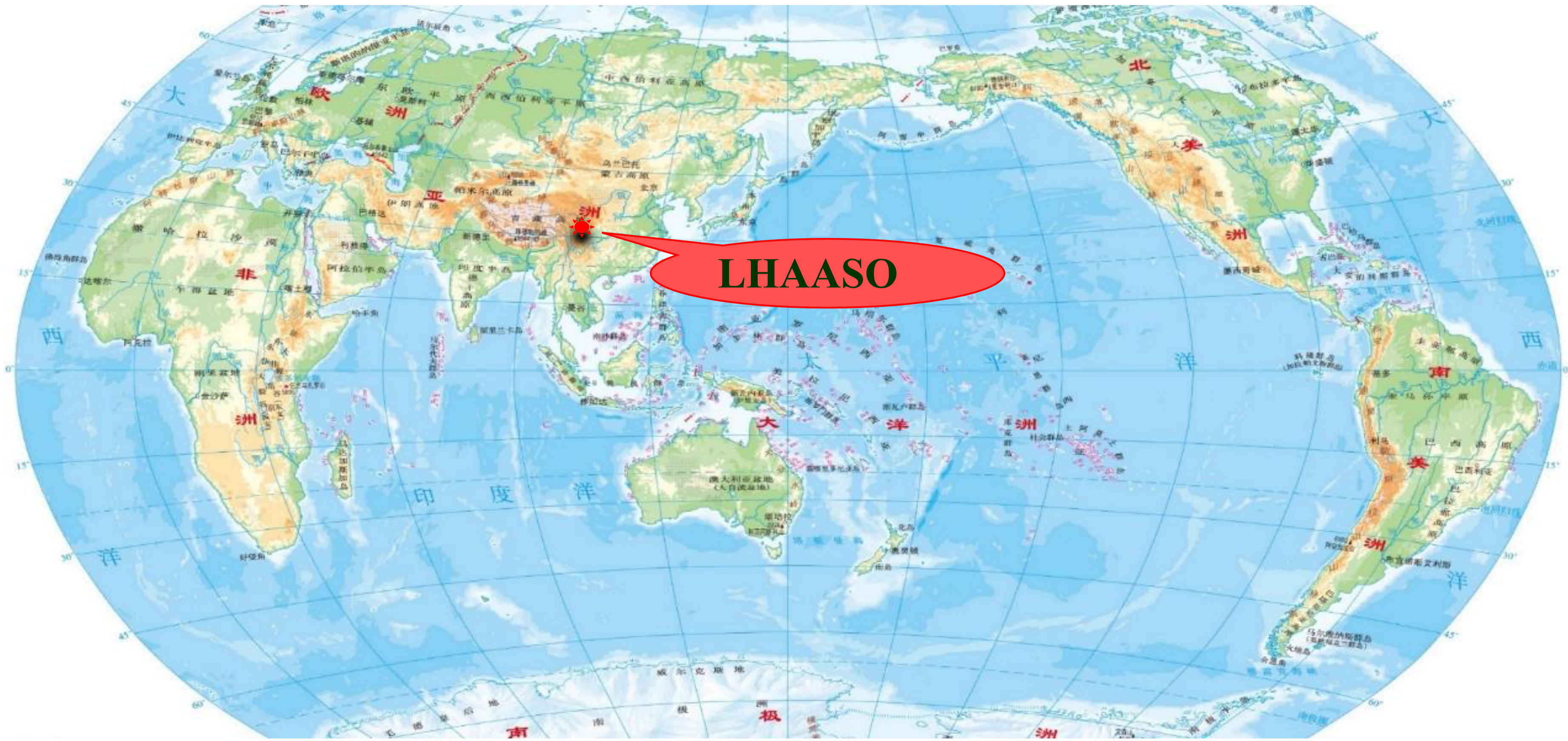
- Haizi Mountain, Sichuan province, China
- Location： 29◦21’ 27.6” N, 100◦08’19.6” E
- Altitude： 4410 m a.s.l.
- 10 km from Yading Airport



LHAASO collaborations

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- **280 Scientists**

- **32 institutions**
- **from 5 countries**

Zhen Cao[1,2,3], F. Aharonian[4,5], Q. An[6,7], Axikegu[8], L. X. Bai[9], Y. X. Bai[1,3], Y. W. Bao[10], D. Bastieri[11], X. J. Bi[1,2,3], Y. J. Bi[1,3], H. Cai[12], J. T. Cai[11], Zhe Cao[6,7], J. Chang[13], J. F. Chang[1,3,6], B. M. Chen[14], E. S. Chen[1,2,3], J. Chen[9], Liang Chen[1,2,3], Liang Chen[15], Long Chen[8], M. J. Chen[1,3], M. L. Chen[1,3,6], Q. H. Chen[8], S. H. Chen[1,2,3], S. Z. Chen[1,3], T. L. Chen[16], X. L. Chen[1,2,3], Y. Chen[10], N. Cheng[1,3], Y. D. Cheng[1,3], S. W. Cui[14], X. H. Cui[17], Y. D. Cui[18], B. D'Ettorre Piazzoli[19], B. Z. Dai[20], H. L. Dai[1,3,6], Z. G. Dai[7], Danzengluobu[16], D. della Volpe[21], X. J. Dong[1,3], K. K. Duan[13], J. H. Fan[11], Y. Z. Fan[13], Z. X. Fan[1,3], J. Fang[20], K. Fang[1,3], C. F. Feng[22], L. Feng[13], S. H. Feng[1,3], Y. L. Feng[13], B. Gao[1,3], C. D. Gao[22], L. Q. Gao[1,2,3], Q. Gao[16], W. Gao[22], M. M. Ge[20], L. S. Geng[1,3], G. H. Gong[23], Q. B. Gou[1,3], M. H. Gu[1,3,6], F. L. Guo[15], J. G. Guo[1,2,3], X. L. Guo[8], Y. Q. Guo[1,3], Y. Y. Guo[1,2,3,13], Y. A. Han[24], H. H. He[1,2,3], H. N. He[13], J. C. He[1,2,3], S. L. He[11], X. B. He[18], Y. He[8], M. Heller[21], Y. K. Hor[18], C. Hou[1,3], H. B. Hu[1,2,3], S. Hu[9], S. C. Hu[1,2,3], X. J. Hu[23], D. H. Huang[8], Q. L. Huang[1,3], W. H. Huang[22], X. T. Huang[22], X. Y. Huang[13], Z. C. Huang[8], F. Ji[1,3], X. L. Ji[1,3,6], H. Y. Jia[8], K. Jiang[6,7], Z. J. Jiang[20], C. Jin[1,2,3], T. Ke[1,3], D. Kuleshov[25], K. Levochkin[25], B. B. Li[14], Cheng Li[6,7], Cong Li[1,3], F. Li[1,3,6], H. B. Li[1,3], H. C. Li[1,3], H. Y. Li[7,13], J. Li[1,3,6], K. Li[1,3], W. L. Li[22], X. R. Li[1,3], Xin Li[6,7], Xin Li[8], Y. Li[9], Y. Z. Li[1,2,3], Zhe Li[1,3], Zhuo Li[26], E. W. Liang[27], Y. F. Liang[27], S. J. Lin[18], B. Liu[7], C. Liu[1,3], D. Liu[22], H. Liu[8], H. D. Liu[24], J. Liu[1,3], J. L. Liu[28], J. S. Liu[18], J. Y. Liu[1,3], M. Y. Liu[16], R. Y. Liu[10], S. M. Liu[8], W. Liu[1,3], Y. Liu[11], Y. N. Liu[23], Z. X. Liu[9], W. J. Long[8], R. Lu[20], H. K. Lv[1,3], B. Q. Ma[26], L. L. Ma[1,3], X. H. Ma[1,3], J. R. Mao[29], A. Masood[8], Z. Min[1,3], W. Mitthumsiri[30], T. Montaruli[21], Y. C. Nan[22], B. Y. Pang[8], P. Pattarakijwanich[30], Z. Y. Pei[11], M. Y. Qi[1,3], Y. Q. Qi[14], B. Q. Qiao[1,3], J. J. Qin[7], D. Ruffolo[30], V. Rulev[25], A. Sáiz[30], L. Shao[14], O. Shchegolev[25,31], X. D. Sheng[1,3], J. Y. Shi[1,3], H. C. Song[26], Yu. V. Stenkin[25,31], V. Stepanov[25], Y. Su[32], Q. N. Sun[8], X. N. Sun[27], Z. B. Sun[33], P. H. T. Tam[18], Z. B. Tang[6,7], W. W. Tian[2,17], B. D. Wang[1,3], C. Wang[33], H. Wang[8], H. G. Wang[11], J. C. Wang[29], J. S. Wang[28], L. P. Wang[22], L. Y. Wang[1,3], R. N. Wang[8], W. Wang[18], W. Wang[12], X. G. Wang[27], X. J. Wang[1,3], X. Y. Wang[10], Y. Wang[8], Y. D. Wang[1,3], Y. J. Wang[1,3], Y. P. Wang[1,2,3], Z. H. Wang[9], Z. X. Wang[20], Zhen Wang[28], Zheng Wang[1,3,6], D. M. Wei[13], J. J. Wei[13], Y. J. Wei[1,2,3], T. Wen[20], C. Y. Wu[1,3], H. R. Wu[1,3], S. Wu[1,3], W. X. Wu[8], X. F. Wu[13], S. Q. Xi[1,3], J. Xia[7,13], J. J. Xia[8], G. M. Xiang[2,15], D. X. Xiao[16], G. Xiao[1,3], H. B. Xiao[11], G. G. Xin[12], Y. L. Xin[8], Y. Xing[15], D. L. Xu[28], R. X. Xu[26], L. Xue[22], D. H. Yan[29], J. Z. Yan[13], C. W. Yang[9], F. F. Yang[1,3,6], J. Y. Yang[18], L. L. Yang[18], M. J. Yang[1,3], R. Z. Yang[7], S. B. Yang[20], Y. H. Yao[9], Z. G. Yao[1,3], Y. M. Ye[23], L. Q. Yin[1,3], N. Yin[22], X. H. You[1,3], Z. Y. You[1,2,3], Y. H. Yu[22], Q. Yuan[13], H. D. Zeng[13], T. X. Zeng[1,3,6], W. Zeng[20], Z. K. Zeng[1,2,3], M. Zha[1,3], X. X. Zhai[1,3], B. B. Zhang[10], H. M. Zhang[10], H. Y. Zhang[22], J. L. Zhang[17], J. W. Zhang[9], L. X. Zhang[11], Li Zhang[20], Lu Zhang[14], P. F. Zhang[20], P. P. Zhang[14], R. Zhang[7,13], S. R. Zhang[14], S. S. Zhang[1,3], X. Zhang[10], X. P. Zhang[1,3], Y. F. Zhang[8], Y. L. Zhang[1,3], Yi Zhang[1,13], Yong Zhang[1,3], B. Zhao[8], J. Zhao[1,3], L. Zhao[6,7], L. Z. Zhao[14], S. P. Zhao[13,22], F. Zheng[33], Y. Zheng[8], B. Zhou[1,3], H. Zhou[28], J. N. Zhou[15], P. Zhou[10], R. Zhou[9], X. X. Zhou[8], C. G. Zhu[22], F. R. Zhu[8], H. Zhu[17], K. J. Zhu[1,2,3,6], and X. Zuo[1,3]

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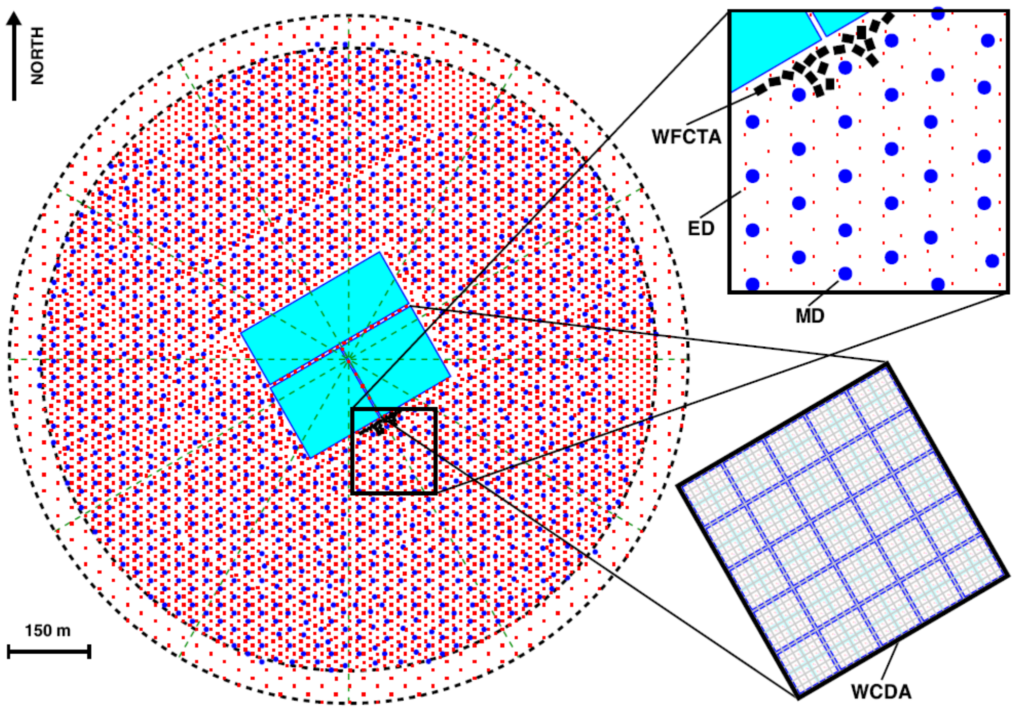
LHAASO layout

All detectors are in DAQ since 2021-7-19



1.3 km^2

- **5195 EDs**
  - 1 m^2 each
  - 15 m spacing
- **1188 MDs**
  - 36 m^2 each
  - 30 m spacing

KM2A

- **3120 WCDs**
  - 25 m^2 each

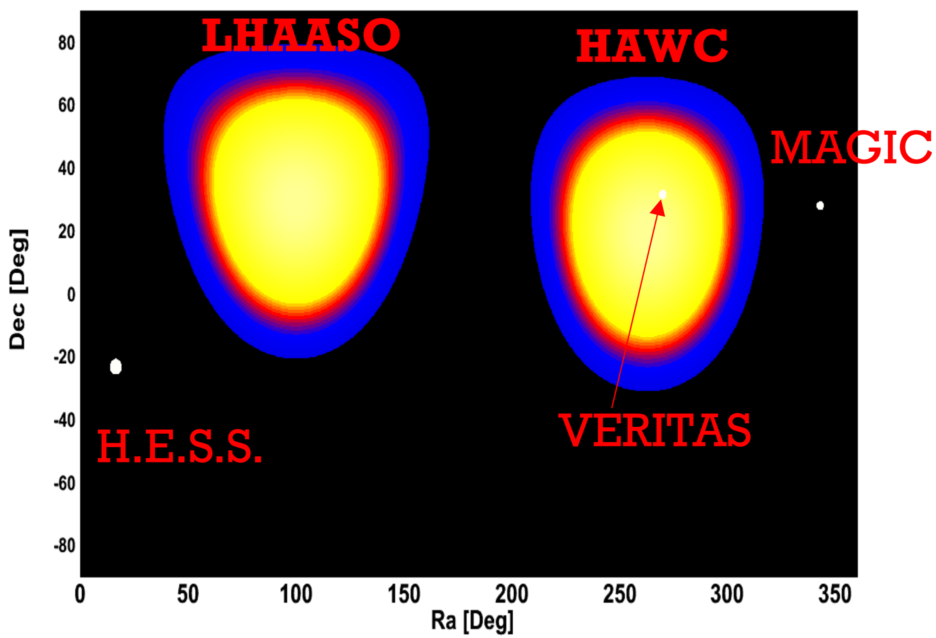
WCDA

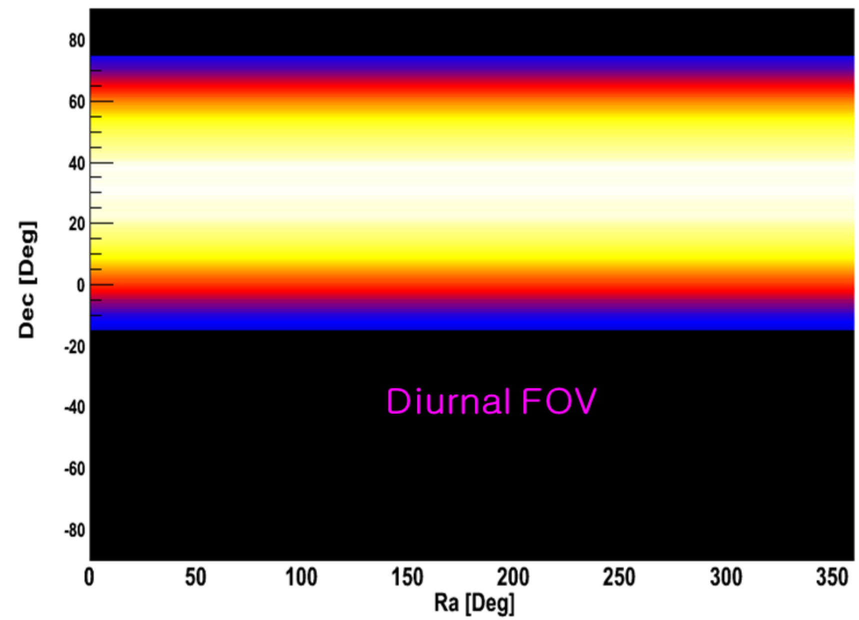
- **18 WFCTs**

WFCTA

LHAASO FOV

- **High duty cycle: ~100% running time**
- **Large FOV:**
  - **1/7 of the sky at any time**
  - **60% of the sky in a diurnal observation**





γ-ray/cosmic ray discrimination

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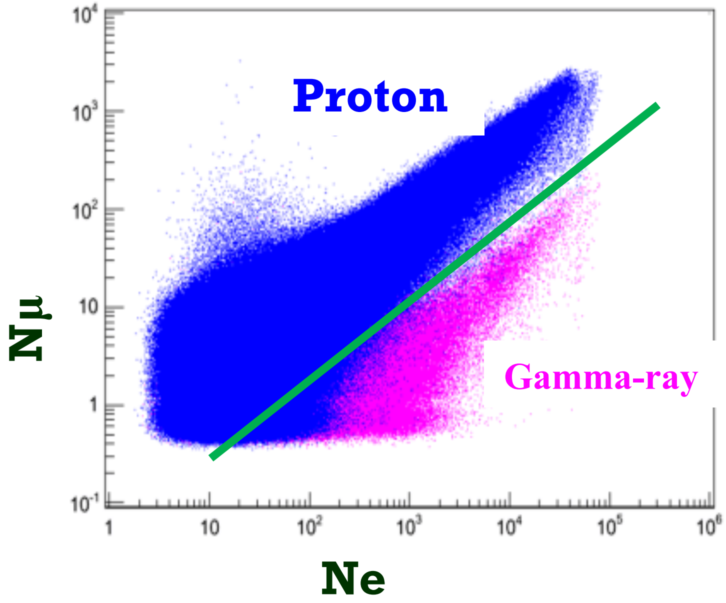

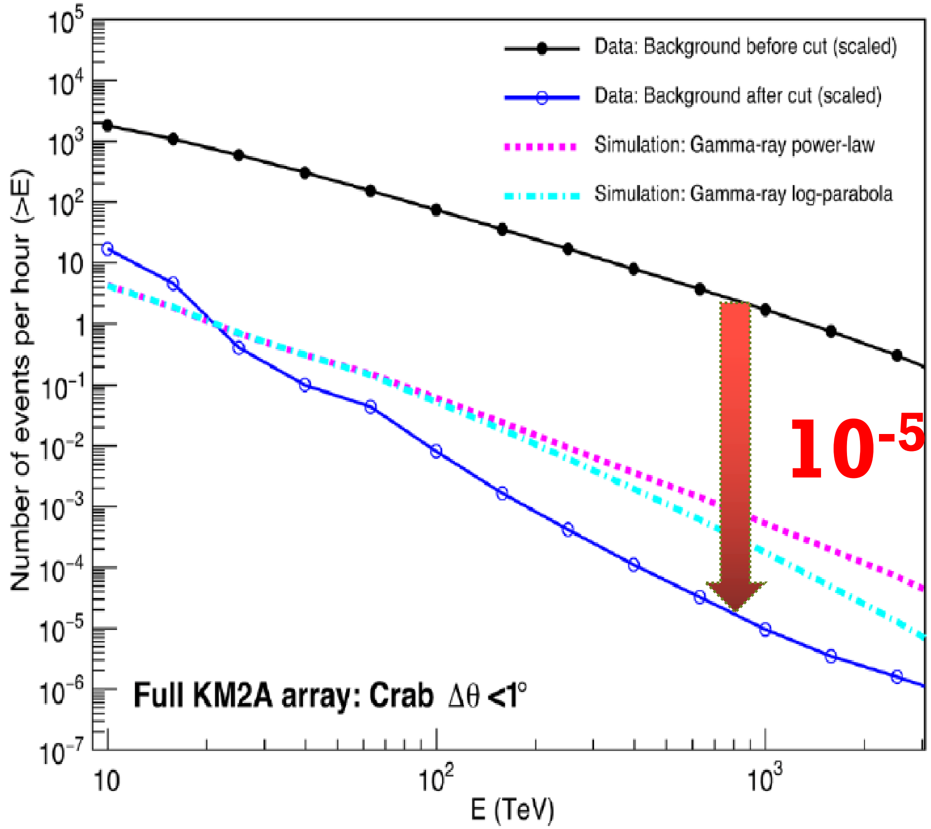

Cosmic ray rate before cut

Gamma-ray rate

Cosmic ray rate after cut

LHAASO Sensitivities

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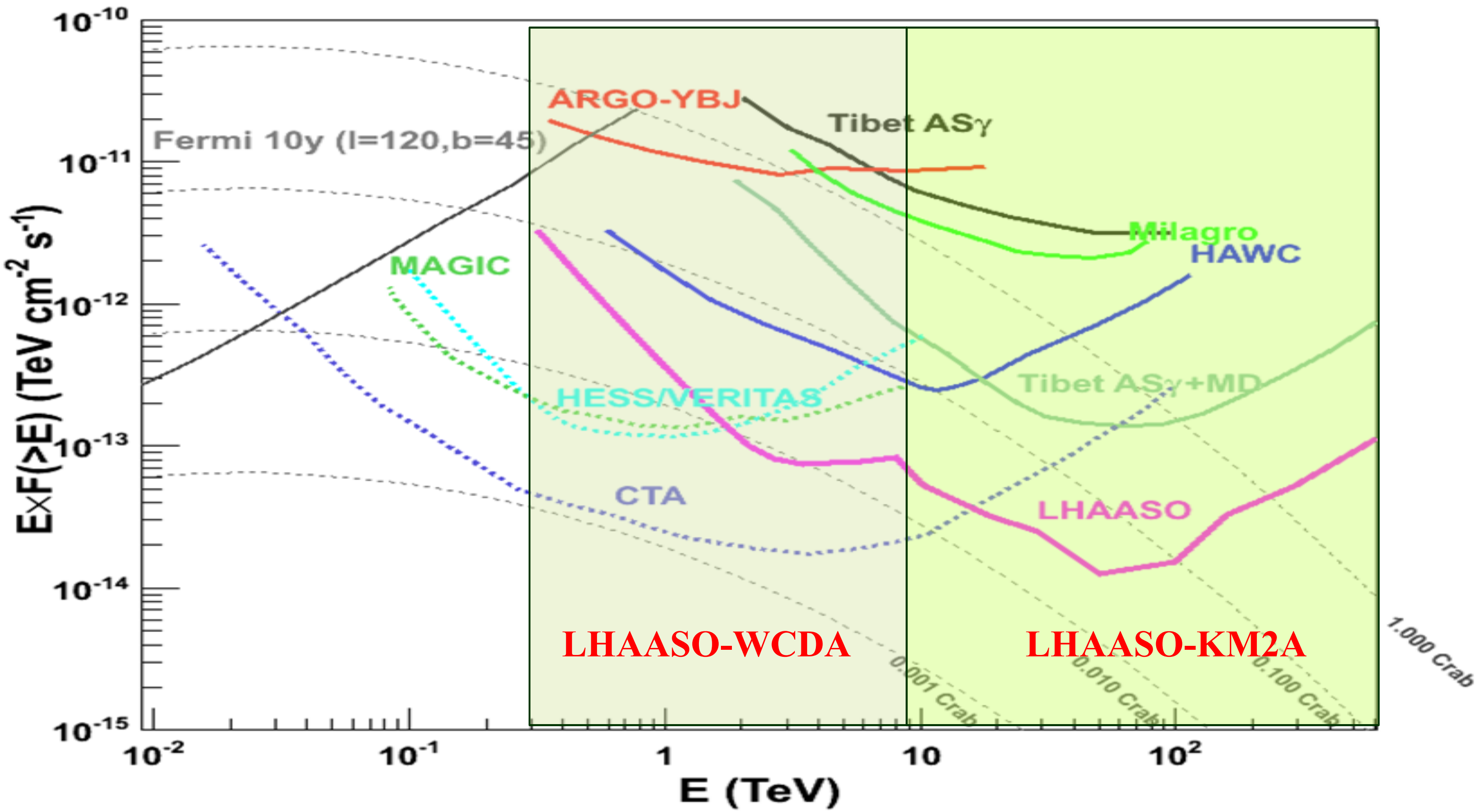

Unprecedented sensitivities above 20 TeV

LHAASO-KM2A observations

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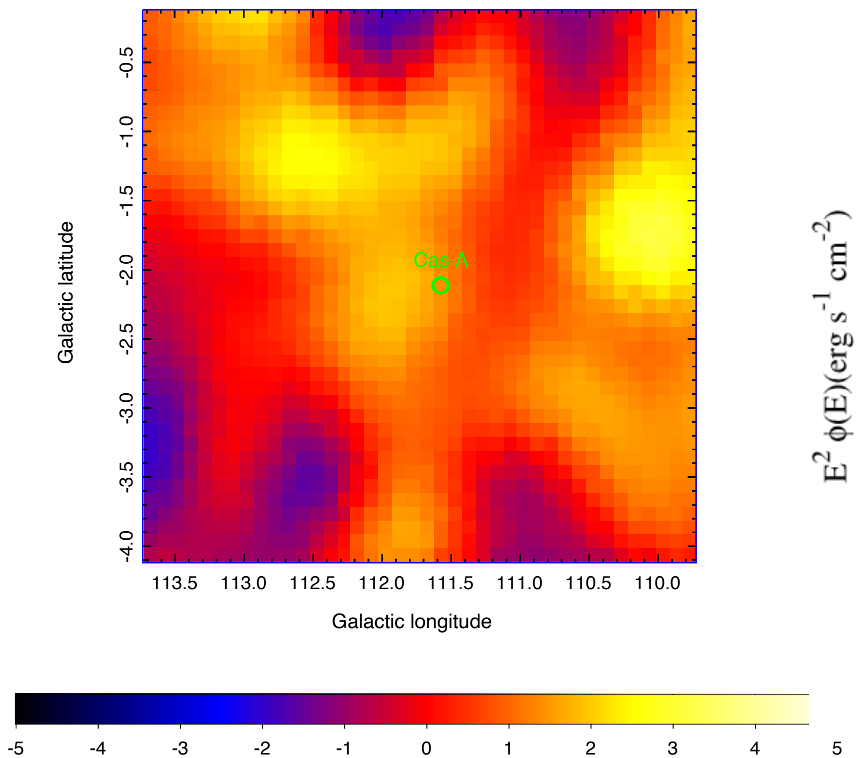
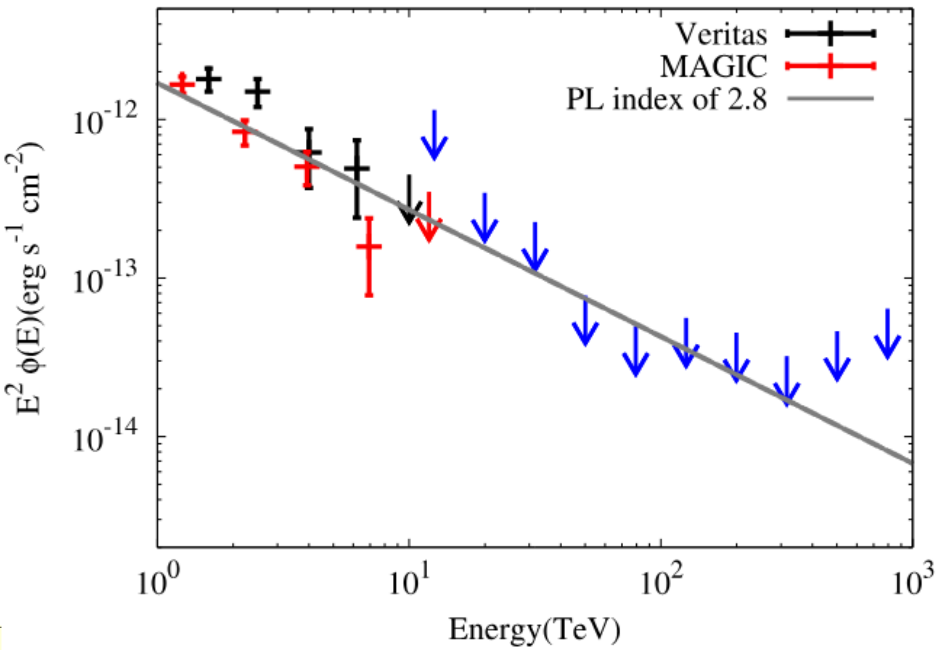




KM2A significance map above 25 TeV

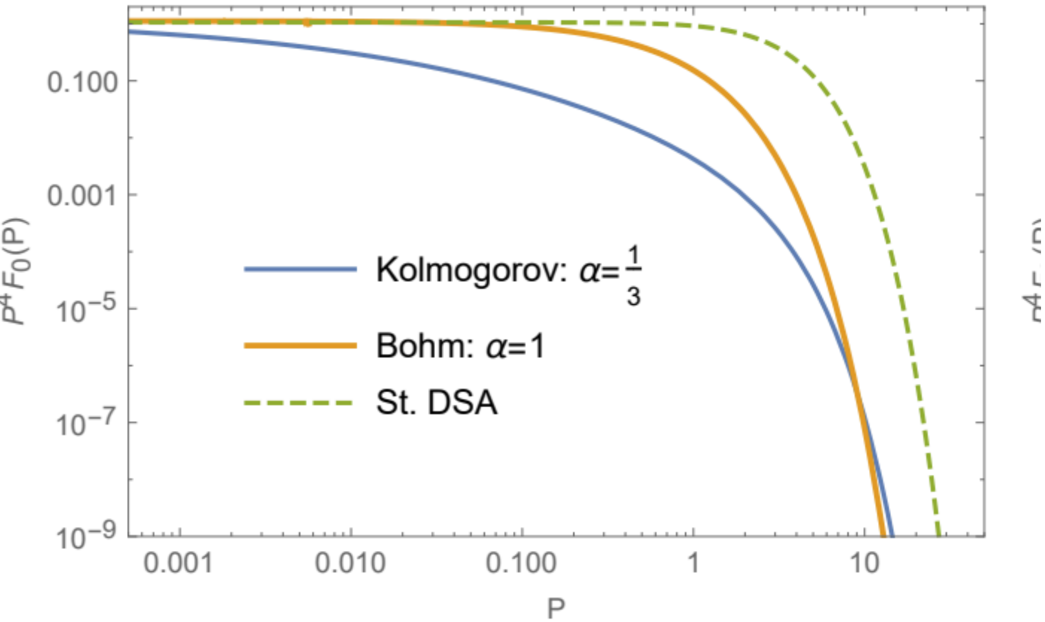
Two scenarios

1. Cas A is active PeVatrons (and gamma-ray emitter) with a softer CR spectrum (2.4-2.7). KM2A upper limits for **Point source** at about 100 TeV can give constraints.

2. Cas A was a PeVatron and PeV protons have escaped, the **diffuse emission** around can set upper limit.

Case 1: softer PeVatron

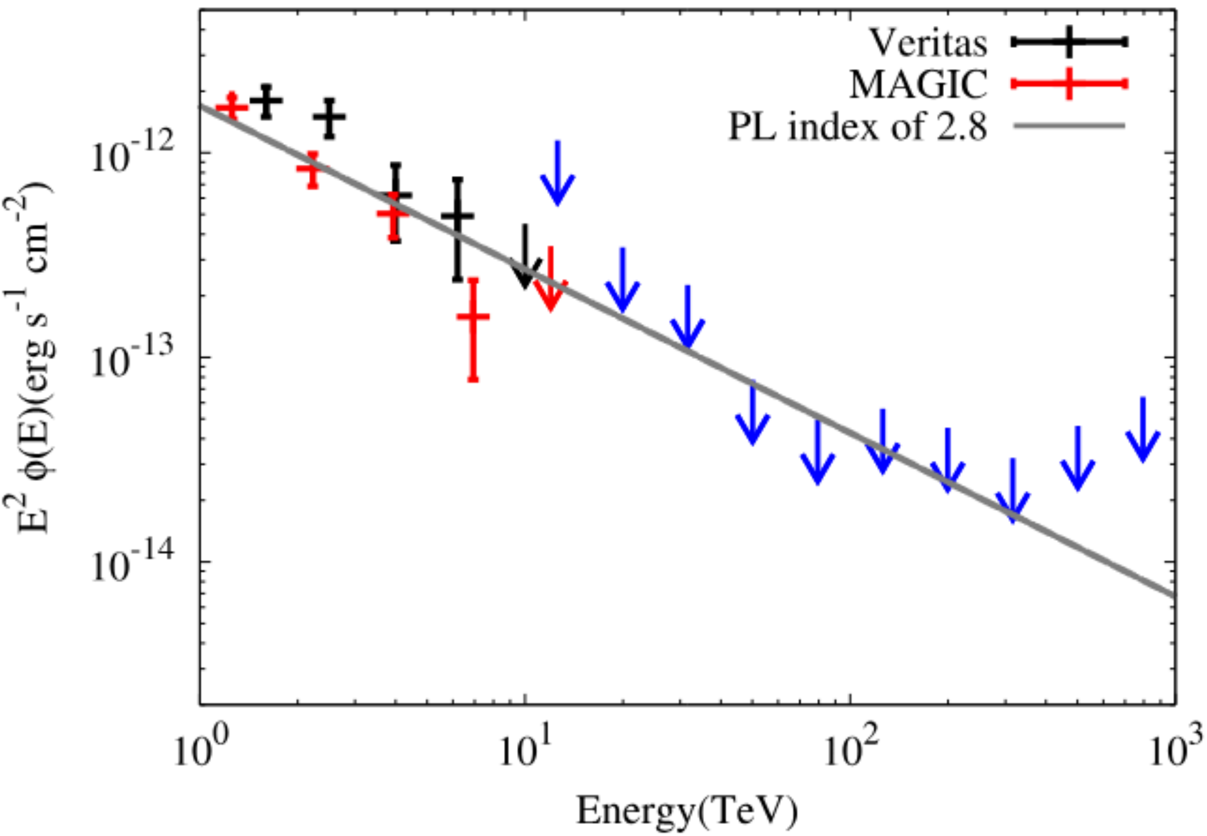
1. Cas A is active PeVatrons (and gamma-ray emitter) with a softer CR spectrum (2.4-2.7). KM2A upper limits for **Point source** at about 100 TeV can give constraints.



Also Caprioli's talk

- Cas A can still be PeVatron, but with a softer injection spectra (2.4-2.7)
- VHE gamma-ray on point source can set stringent upper limit.

Case 1: softer PeVatron



- The power-law index must be larger than 2.8 (proton index of 2.9)

Case II： PeV CR escaped

2. Cas A was a PeVatron and PeV protons have escaped, the diffuse emission around can set upper limit:

in any case the diffusion length should be smaller the c*t ~110 pc~1.8 degree. The flux upper limit from **1.8 degree disk** region should be the most conservative case.

- How many > 100TeV CRs required?
- Total CR luminosity 1-3 e41 erg/s above 1 GeV (e.g., Drury 12, from Galprop)
- 1.5 - 5 e40erg/s for index of 2.0, 1.0-3.0e39 erg/s for index of 2.4
- Cas A type once per century :
  ~5e49 erg for index of 2.0
  ~3e48 ergs for index of 2.4

Case II： PeV CR escaped

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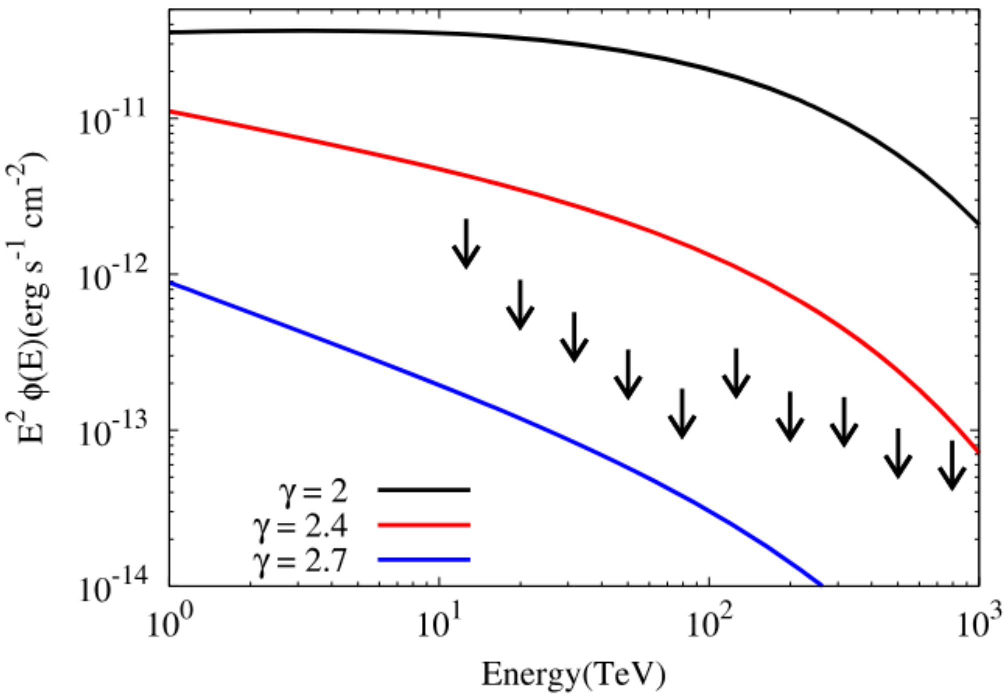

- total CR power above 100 TeV < 3e47 erg (n~10 /cm^3)
- The required CR power depends on index.
- can only consistent with theoretical requirement with index >2.6 (assuming Cas A type as the only PeVatron)
- Even for a lower energy density (n~1 /cm^3), injection index >2.4

Conclusion

- In most cases there are strong tension with hypothesis that Cas A - type SNRs as major PeVatrons.

- Softer injection spectrum seem feasible, but also require major modification to the current CR propagation model (very soft injection spectrum and different energy dependence in confinement time)

- Our method is very conservative and robust:

  Much larger integration area in the the diffusion regime

  No GDE are subtracted （GDE impact is also small）