Γ-RAY ASTRONOMY FROM GROUND & SPACE

Zhen Cao, IHEP

Coll. w/ R.Yang, J.Li, X.Wang, Q.Yuan

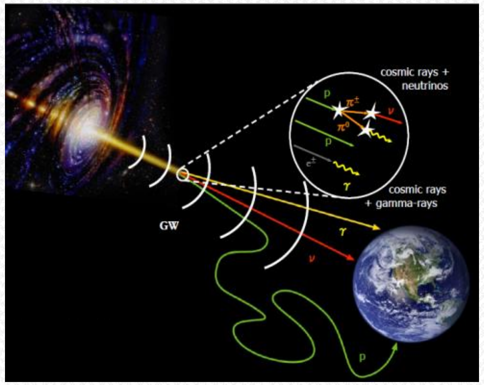
TAUP2023, Vienna, Aug., 2023

Outline

- Science Subjects
- Observational Instruments
- Diffuse γ-rays
- Discrete sources
  - *Galactic Sources*
    - Steady Radiation
    - Variable Sources
  - *Extra galactic emitters*
    - AGNs
    - GRBs
- Exploring in Physics Frontier
- Summary and Outlook

Science: Non-thermal radiation of the universe, particle acceleration, origin of CRs

- Multi-messenger Astronomy era

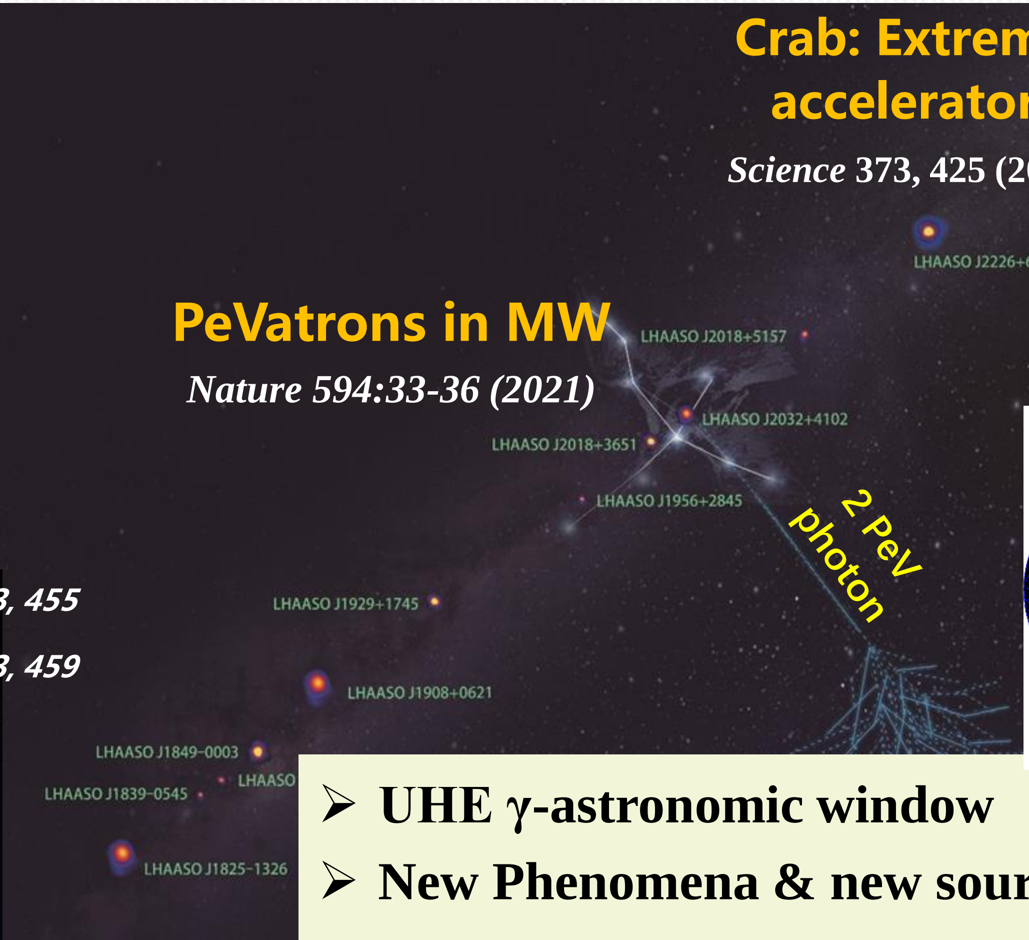


Nature 575 (2019) 7783, 455

Nature 575 (2019) 7783, 459

GRB *Science 372 (2021) 6546, 1081*

BOAT *Science 380, 1390 (2023)*

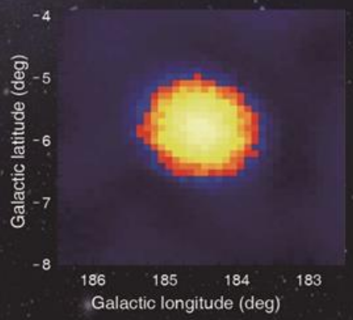


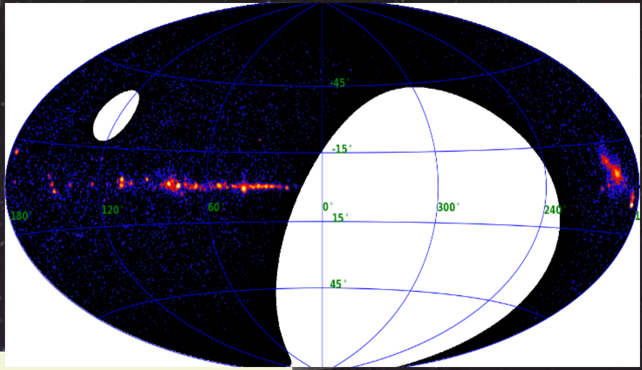
PeVatrons in MW

Nature 594:33-36 (2021)

Crab: Extreme accelerator

Science 373, 425 (2021)

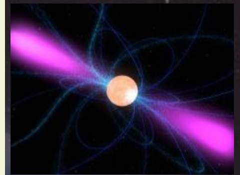


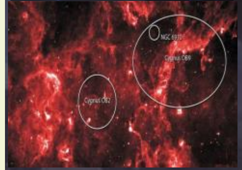


- ➢ **UHE γ-astronomic window**
- ➢ **New Phenomena & new sources (>30)**

  —— All kinds of HE objects：

  SNR, Pulsar, PWN, YMC, binary, SBG, AGN, GRB …





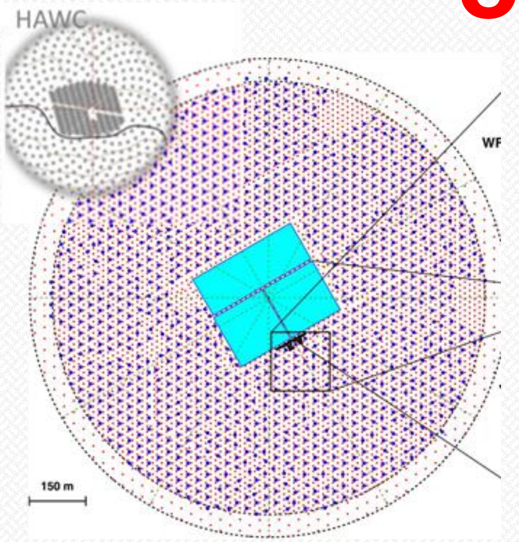
Observational Instruments

	Instrument	energy range	Effective area (m^2)	sensitivity (milli-CU†)	energy resolution (%)	PSF (°)	FoV (sr)	duty cycle (%)
	Fermi-LAT[a)]	20 MeV - 300 GeV	~ 0.95	10 - 30	8 - 18	0.15 - 3.5	~ 2.4	~ 60
Pointing	H.E.S.S.[b)]	10 GeV - 50 TeV	$\sim 10^5$	~ 5	15	< 0.1	~ 0.03	$\sim$10
	MAGIC[c)]	$\geq$ 50 GeV	$\sim 10^5$	~ 7	16	≤ 0.07	0.02	$\sim$18
	VERITAS[d)]	50 GeV - 50 TeV	$\sim 10^5$	~ 5	10 - 15	0.08 - 0.13	0.02	10-14
	CTA-LST1[e)]	20 GeV - 300 GeV	$\sim 10^4$	~ 10	10 - 30	0.05 - 0.1	0.02	$\sim$10
Surveying	ASγ[f)]	10 TeV - 1 PeV	$\sim 7 \times 10^4$	~ 200	20 - 40	~ 0.8	~ 2.0	90
	ARGO-YBJ[g)]	50 GeV - 10 TeV	$\sim 0.8 \times 10^4$	~ 300	>13	~ 0.5	~ 2.0	86
	HAWC[h)]	100 GeV - 100 TeV	$\sim 3 \times 10^4$	~ 50	20 - 50	~ 0.69	> 1.5	95
	LHAASO-WCDA[i)]	100 GeV - 20 TeV	$\sim 0.8 \times 10^5$	~ 12	$\sim$33	0.2 - 0.84	~ 2.0	95
	LHAASO-KM2A[i)]	10 TeV - 4 PeV	$\sim 10^6$	~ 12	15 - 40	0.2 - 0.6	~ 2.0	95

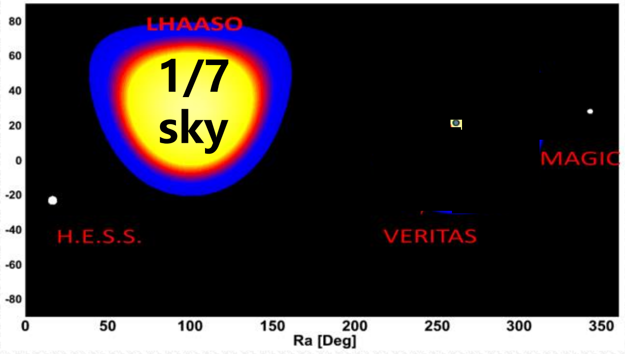
- H.E.S.S. is the only one in southern hemisphere and finished all-sky survey along the Galactic plane using the pointing observational instrument


H.E.S.S.
MAGIC
VERITAS
Pointing Devices
Angular Resolution 3’
FoV<10°
300 m Ø “light pool”, 10⁵ m²

Wide FoV Surveying Facilities on the ground



3 Generations of EAS arrays



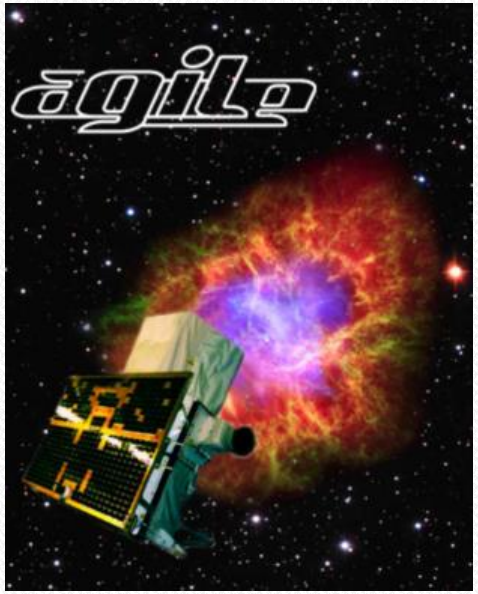
ARGO-YBJ 4300 m a.s.l

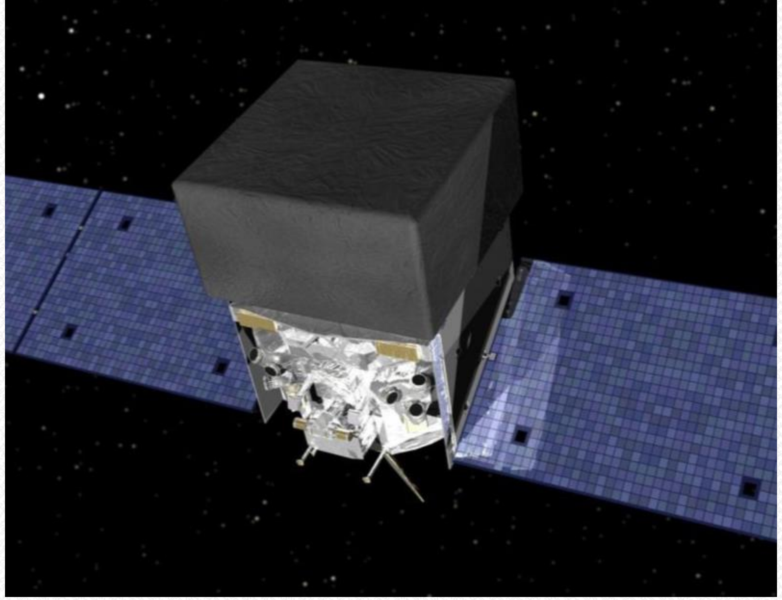
ASγ 4300 m a.s.l.

HAWC 4100 m a.s.l.

LHAASO 4410 m a.s.l.

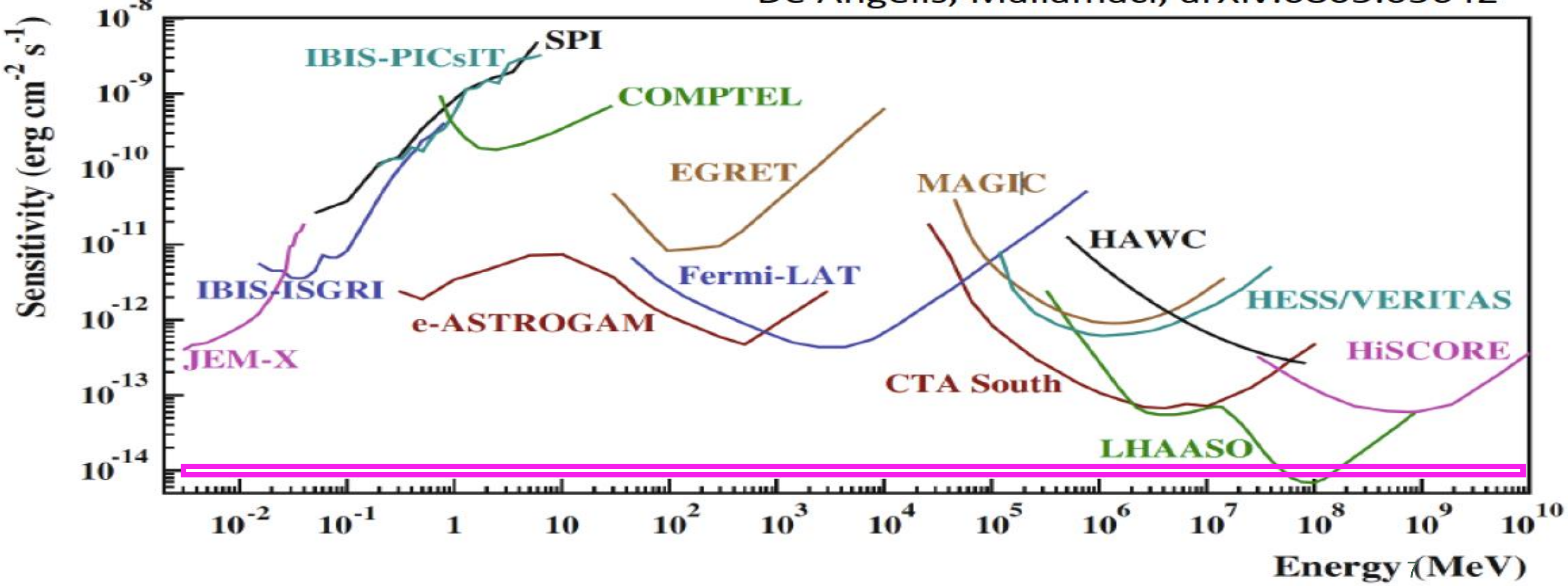
FERMI-LAT & AGILE in space w/ wide FoV



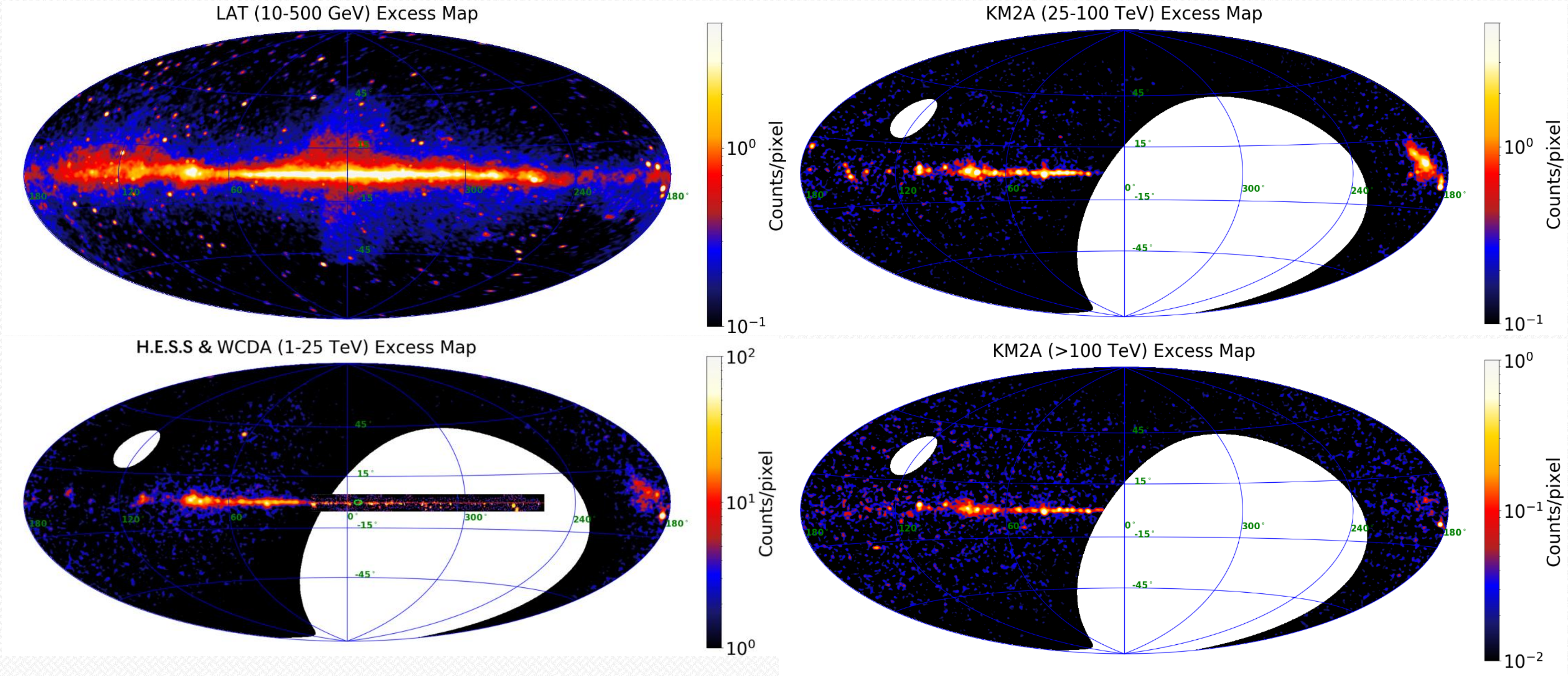


Sensitivity: 10^{-14} erg/cm^2/s

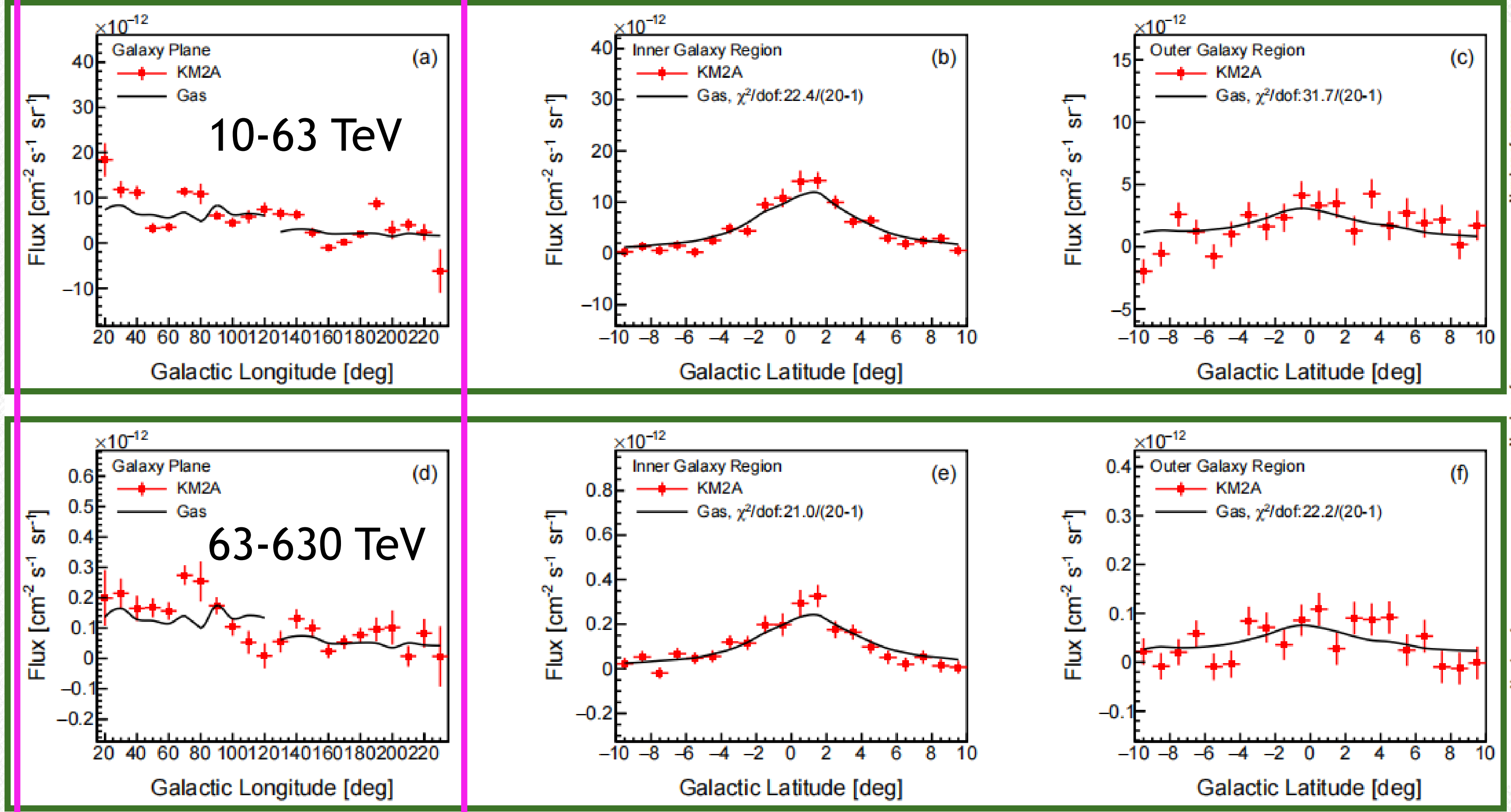
De Angelis, Mallamaci, arXiv:0805.05642

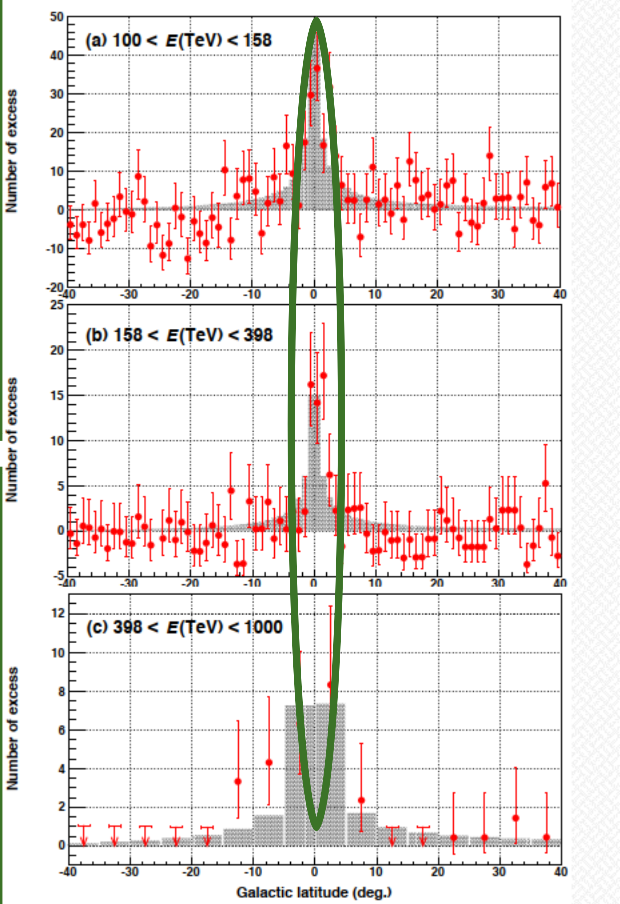


Diffuse galactic γ-rays above 10 GeV



Spatial Distribution on Longitudes and latitudes





LHAASO(2023)

ASγ Coll., Phys. Rev. Lett. 126, 141101 (2021)

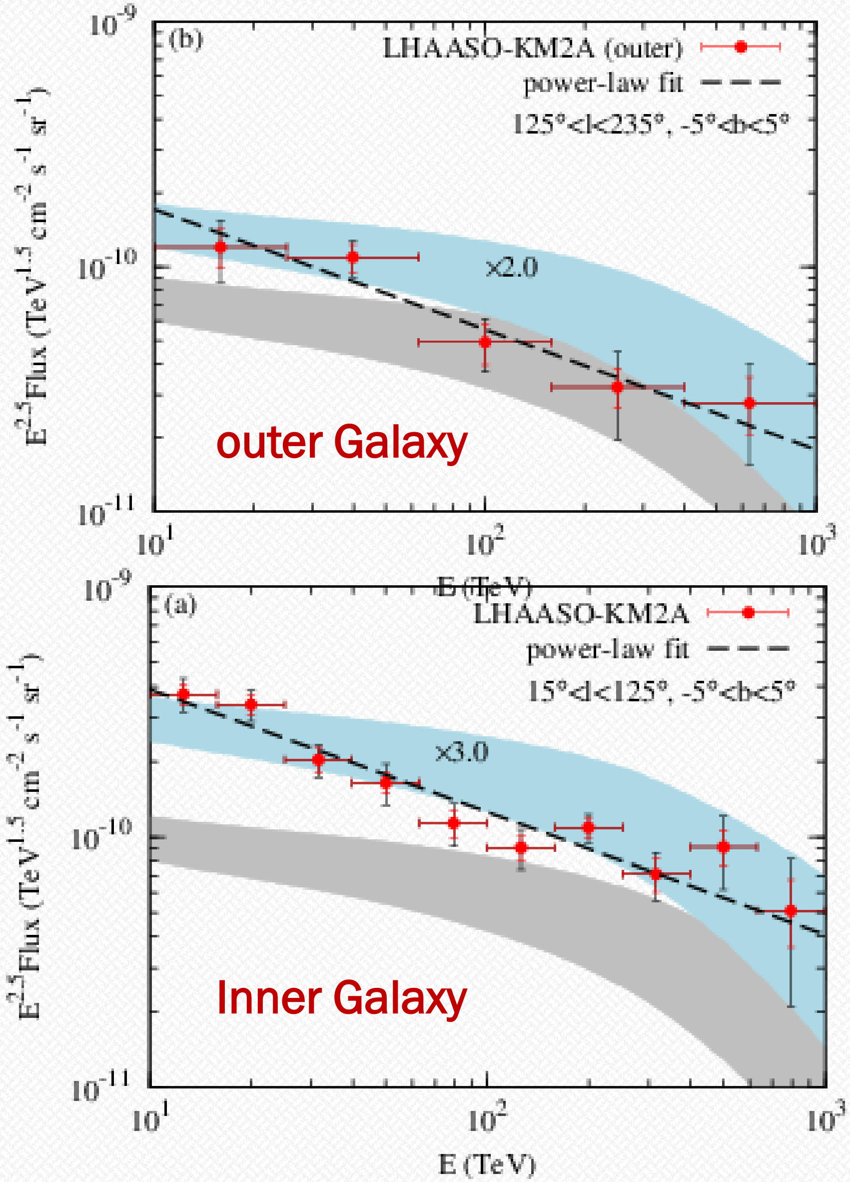
Roughly consistent with gas distributions for b,

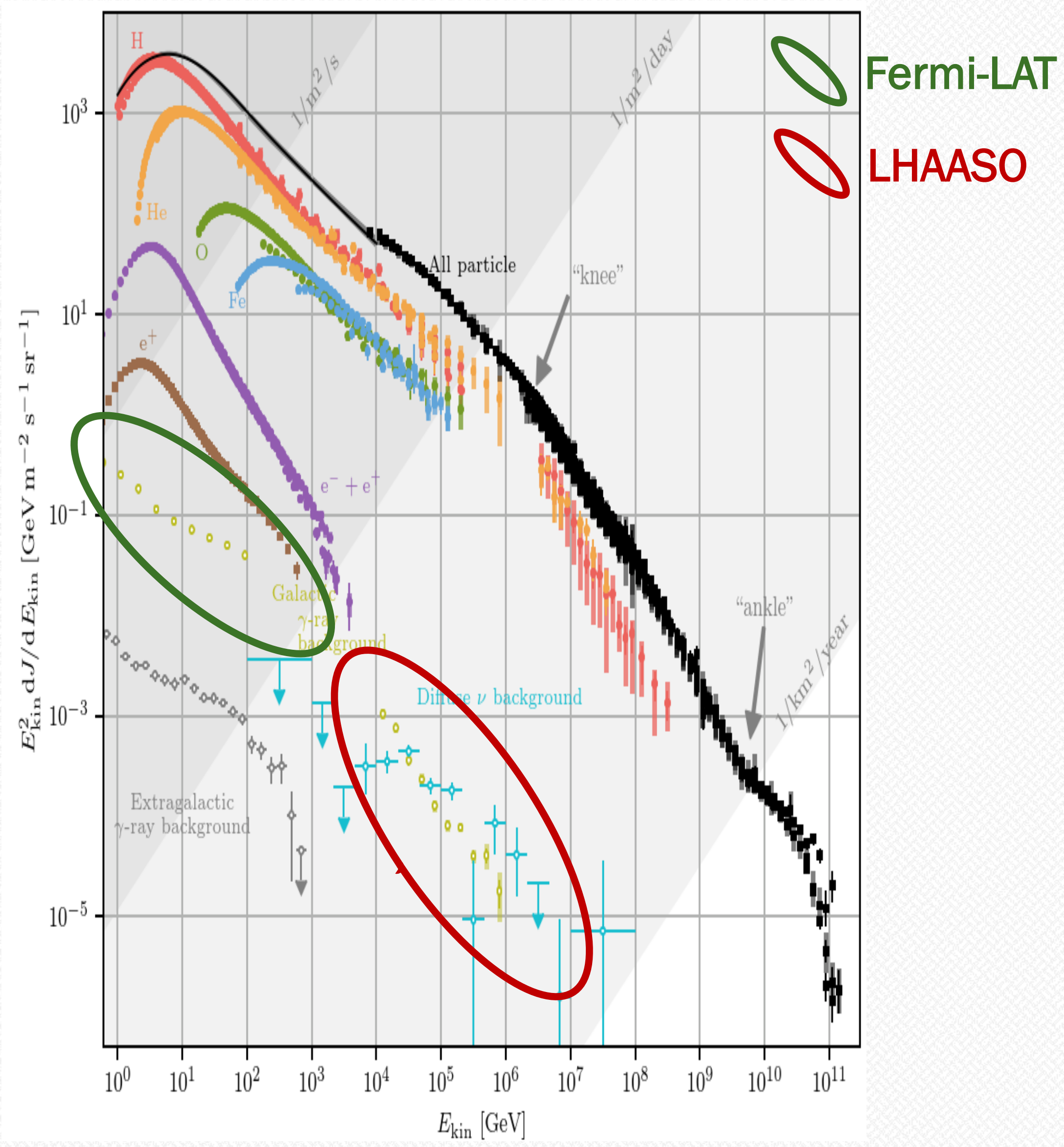
but show deviation for l distribution

Contamination from the discrete sources due to sensitivity to resolve them

Energy Distribution of GDE

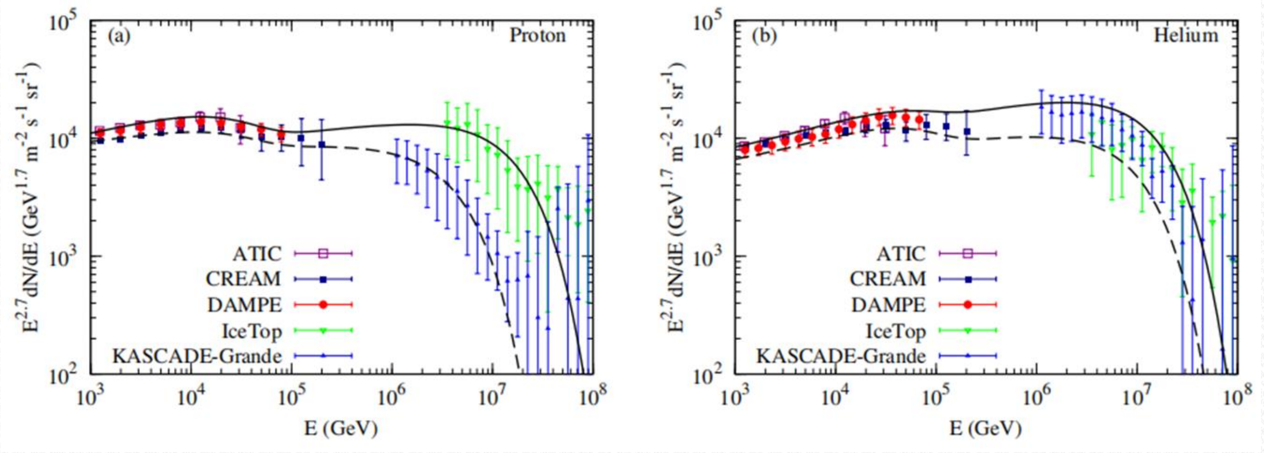
Predictions using local CR intensity and column density of gas are lower than measured that may indicate existence of contamination of extended discrete sources found in more sensitive observations (see below)

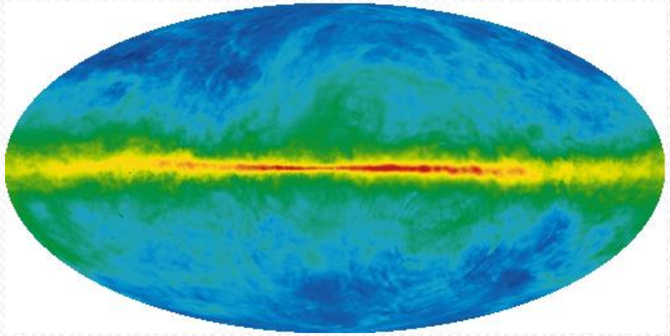




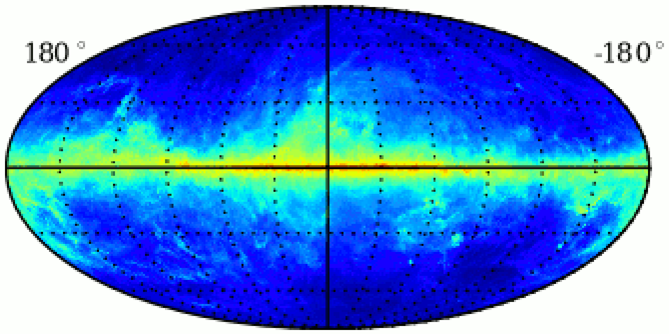
Origins of Galactic diffuse γ rays

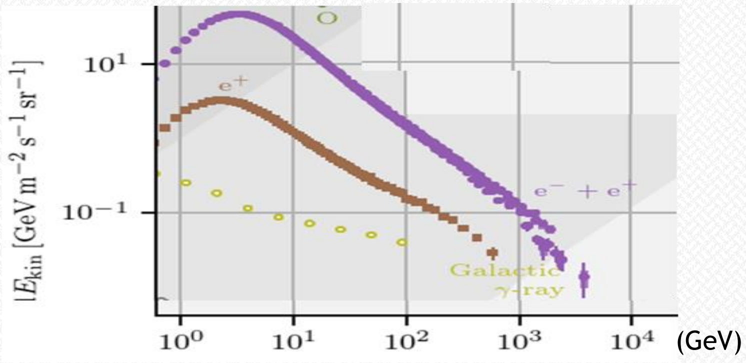
$p, \alpha + ISM \rightarrow \pi^0 \rightarrow 2\gamma$



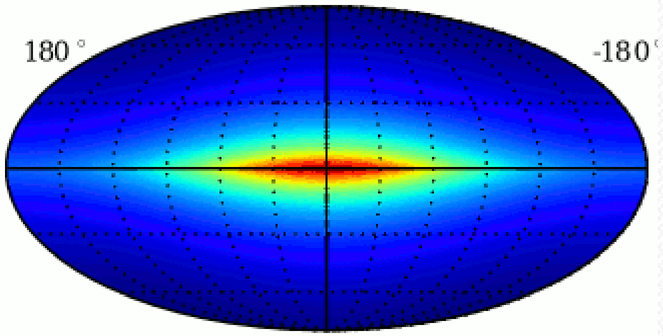


$e + ISM \rightarrow \gamma$ (bremsstrahlung)



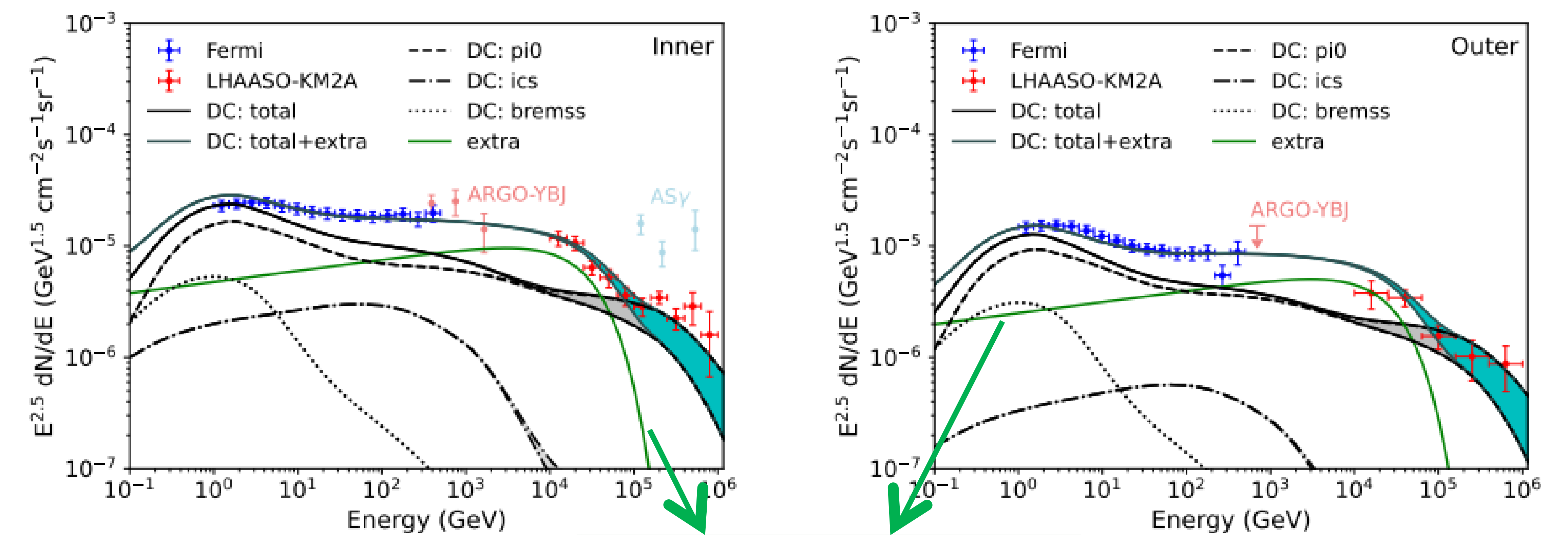


$e + ISRF \rightarrow \gamma$ (inverse Compton)



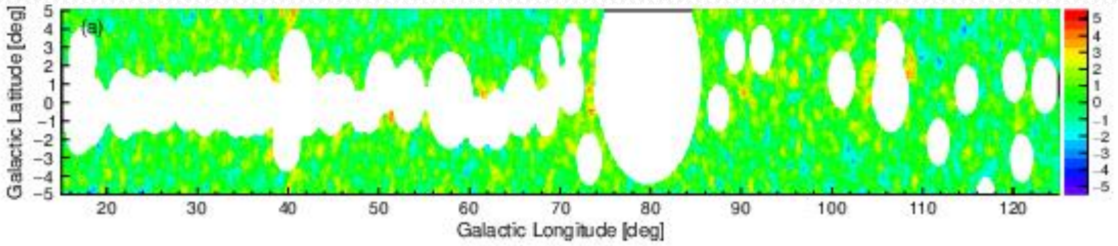
11

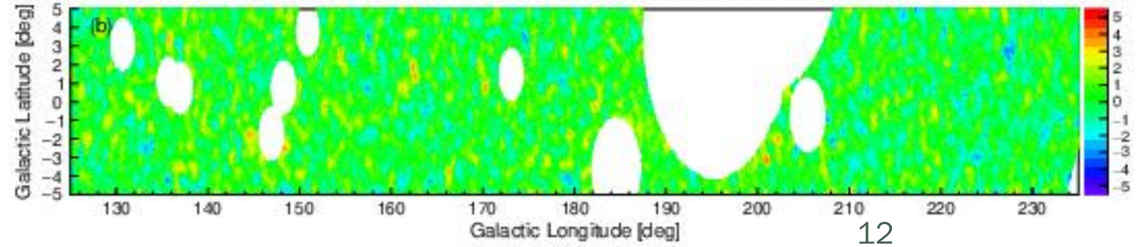
Unresolved source population?



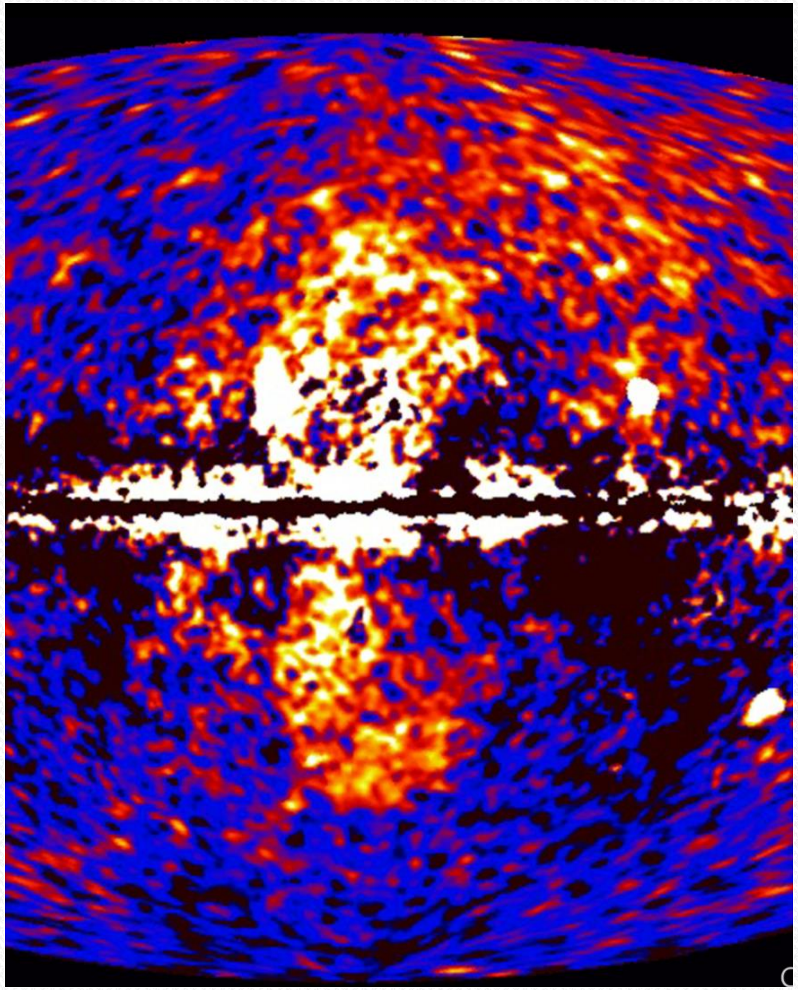
$$\propto E^{-2.40} \exp\left(-E/30\ \mathrm{TeV}\right)$$

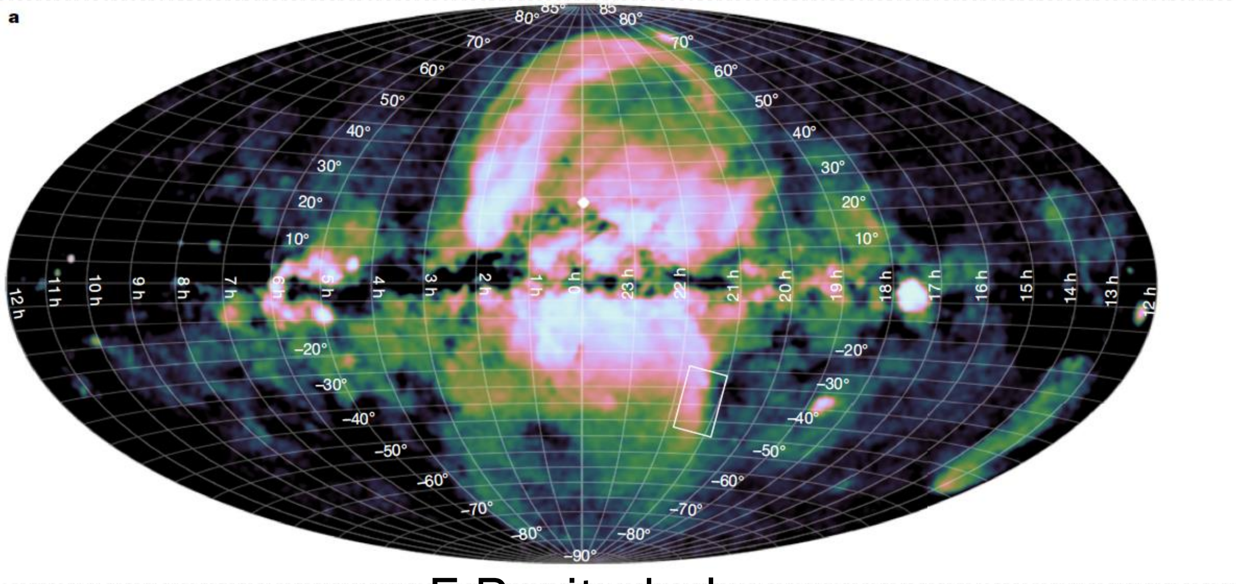
- SEDs of GDE in two regions
- Higher than prediction, contamination of sources?



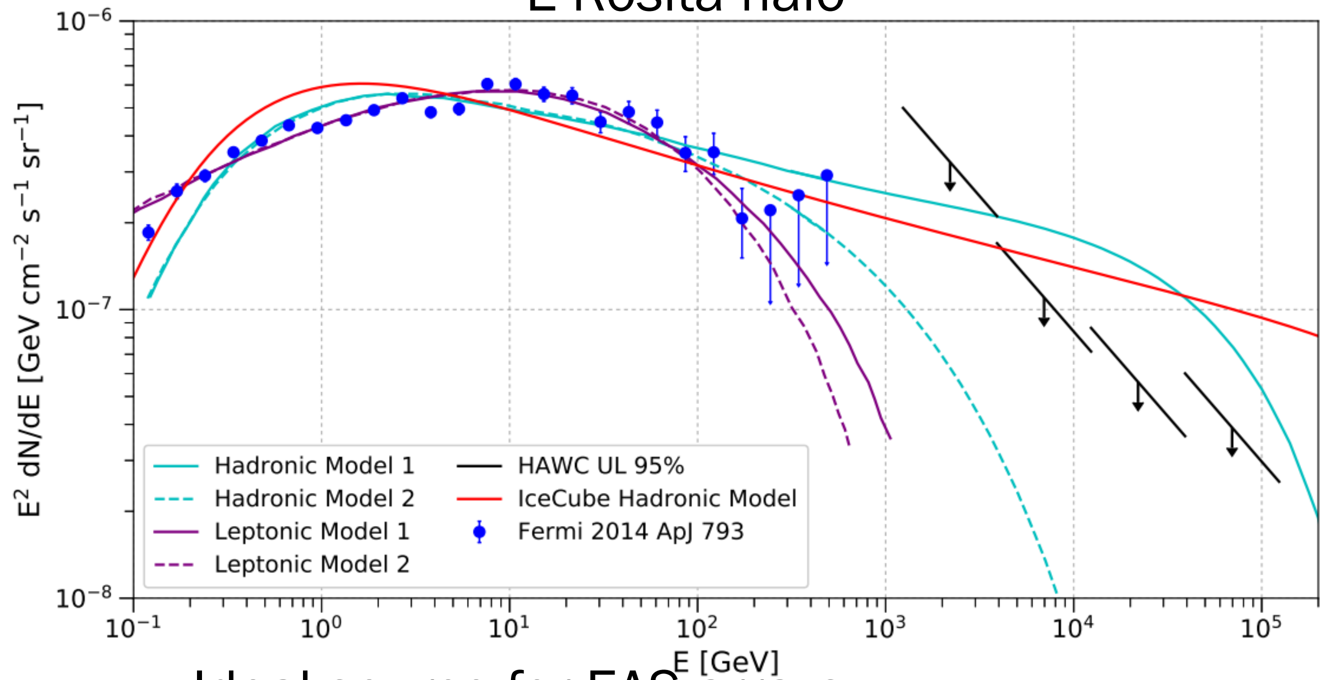


Fermi bubble





E-Rosita halo

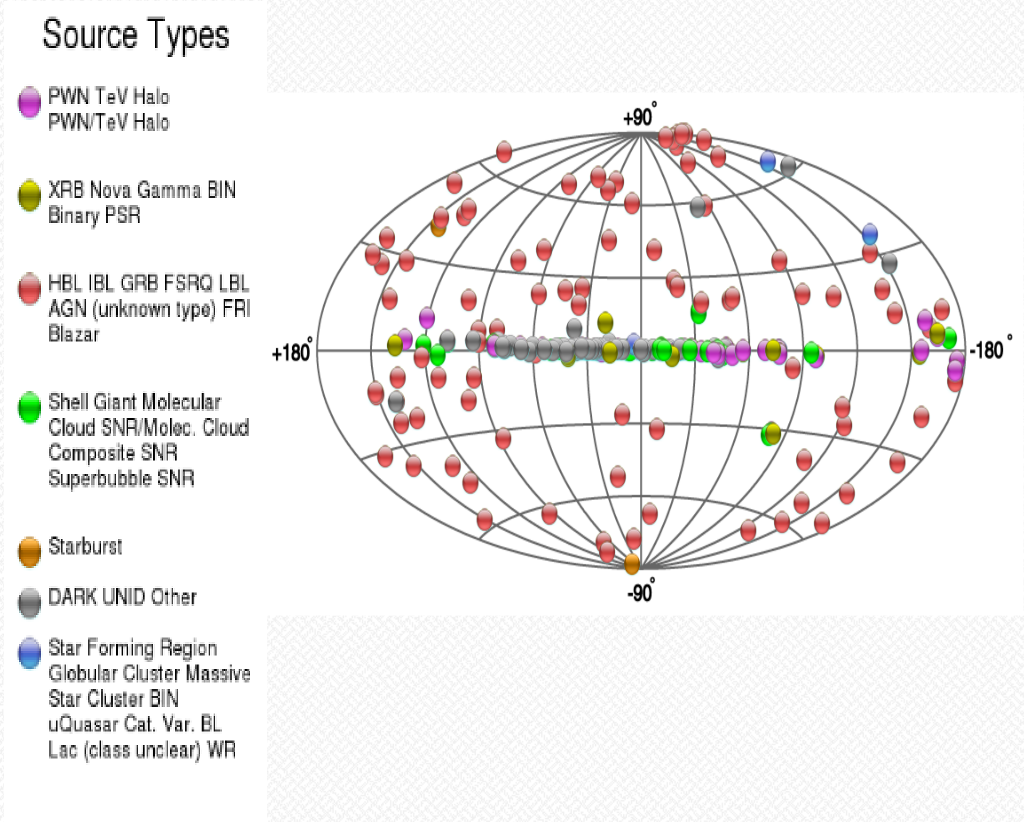


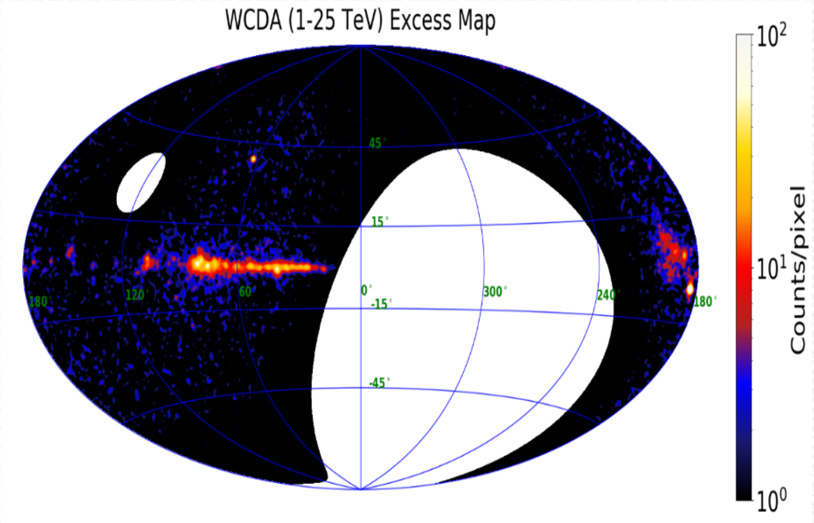
Ideal source for EAS arrays

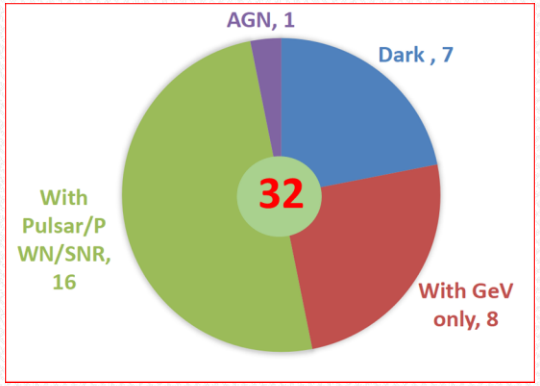
HAWC set strong upper limits

Discrete VHE/UHE γ-ray sources

- 7100+ Sources listed in Fermi-LAT catalogs (4FGL...)
- TeVCat increases from 270 sources to ~300 sources after LHAASO published 32 new sources in its 1st catalog
- Amongst them ~200 are in the galactic plane (|b| < 5°)
- ~50% of them are associated with known celestial objects, and others are unidentified. 8 unidentified can be associated with GeV sources



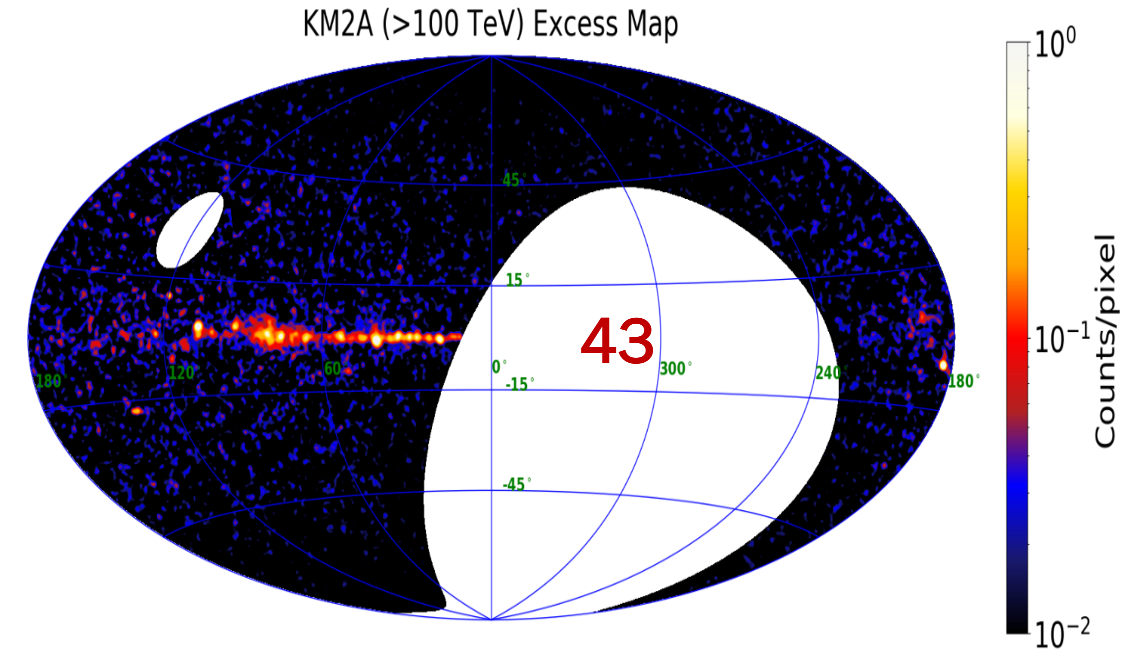


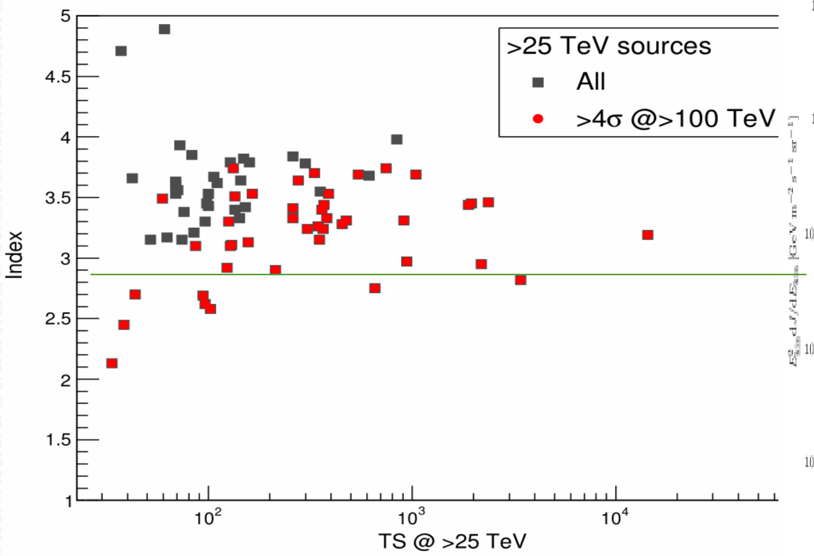


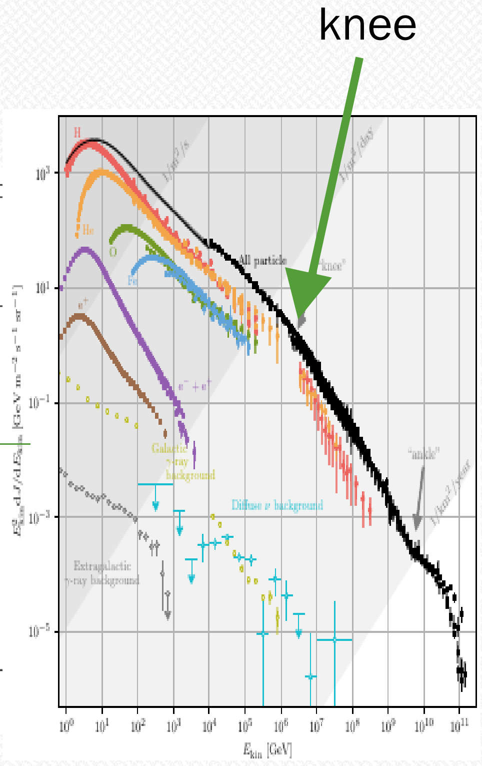
43 PeVatrons are discovered

- Photons having E_γ>100 TeV are detected in the 43 sources significantly (>**4σ**)
- The spectra of the PeVatrons are typically soft, w/ spectral index > 3.
- 8 of them have hard spectra so that there is no emission detected in 1-10 TeV band

Implication: **Our Galaxy is full of PeVatrons, the candidates of the origin of cosmic rays around/above the knee**

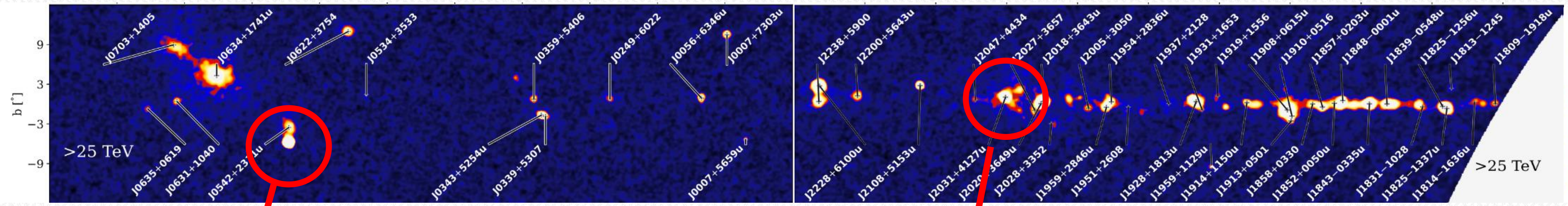


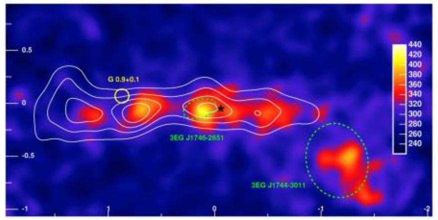




The stars

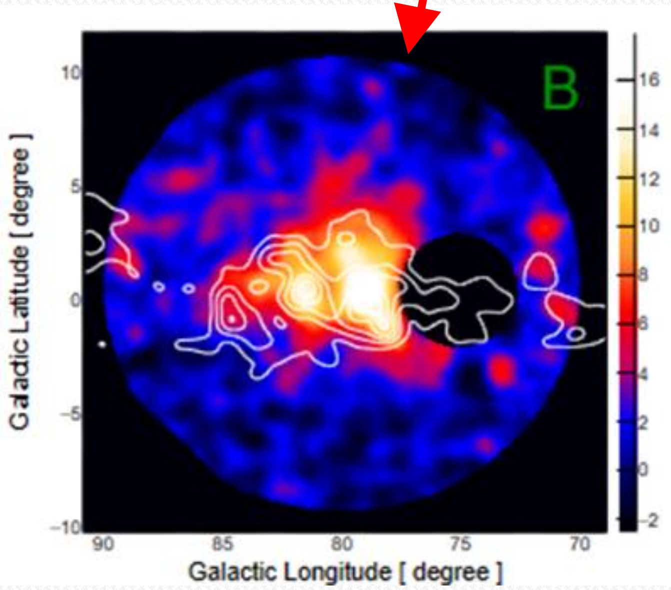
The most fascinating objects: the Crab, Cygnus X, Galactic Center and RX J1713-3946





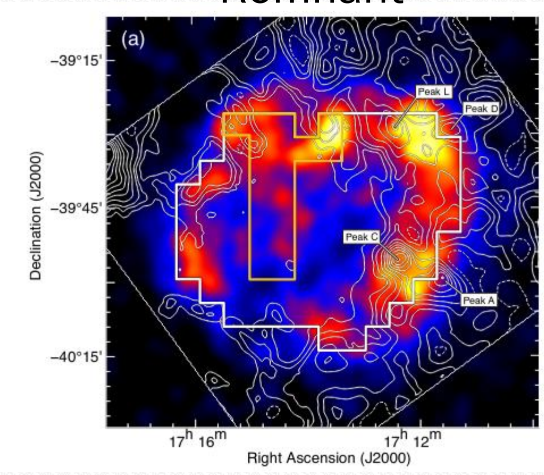
G.C.

Pulsar
&
Pulsar
Wind
Nebula



Young Massive
star cluster

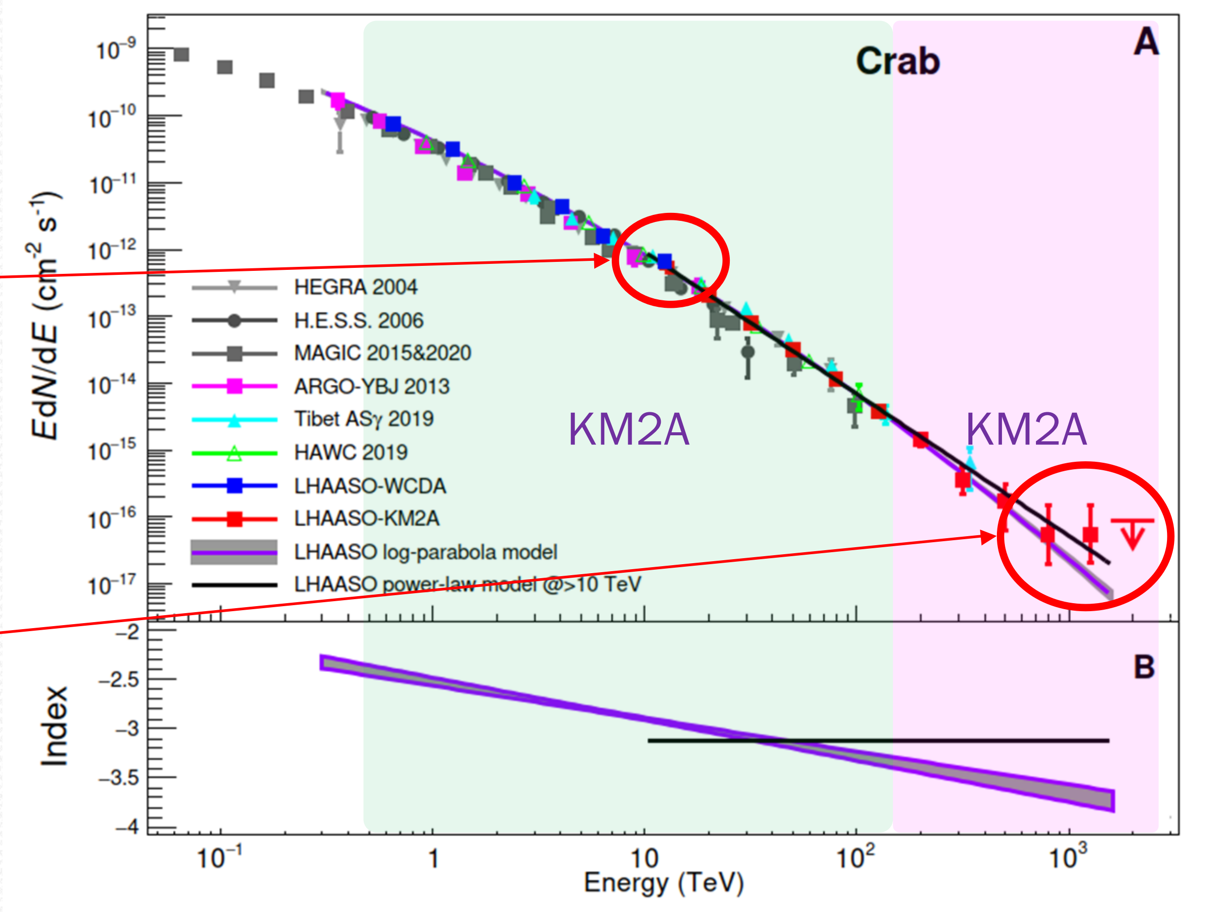
Supernova
Remnant



SED of the Crab: "standard Candle" & PeVatron

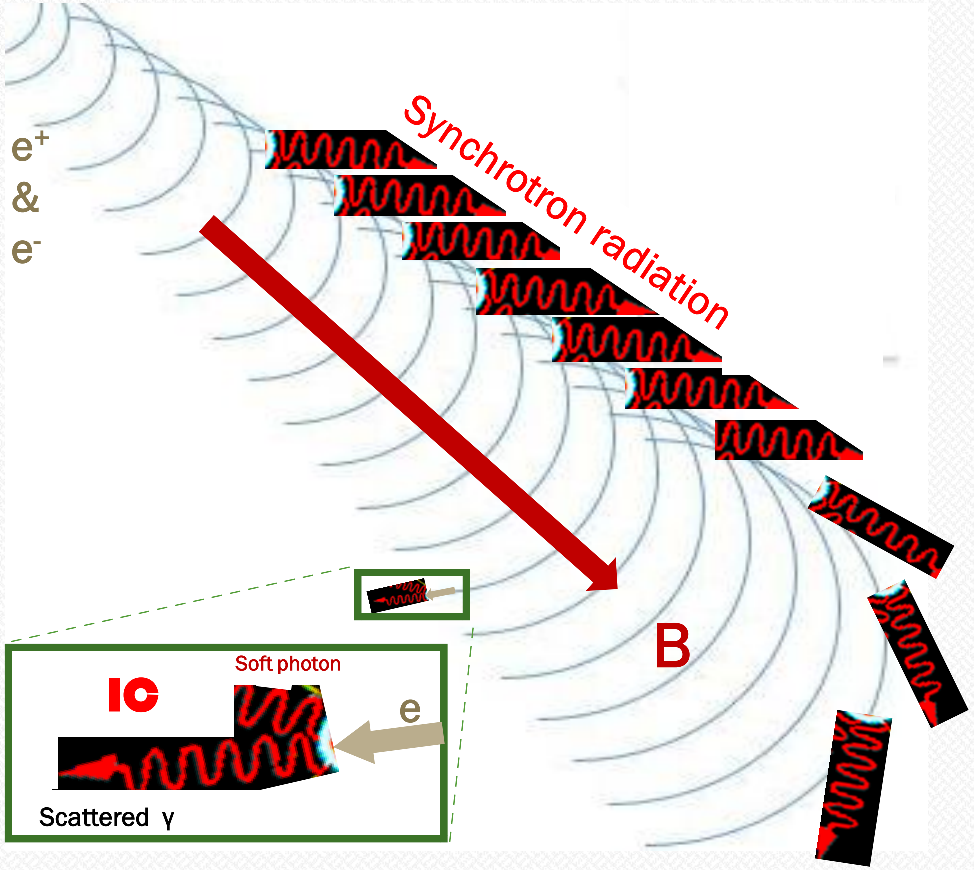
Zhen Cao， *et al.*, LHAASO, *Science*, p425-430, 2021

- LHAASO: (comparison)
  - Covering 3.5 decades of energy
  - Agreeing with other experiments below 100 TeV
  - Self cross-checking between WCDA & KM2A
- LHAASO: (discovery)
  - Unique UHE SED
  - A PeVatron without ambiguity
  - Clear origin: a well-known PWN
- Challenge basic theory of electron acceleration

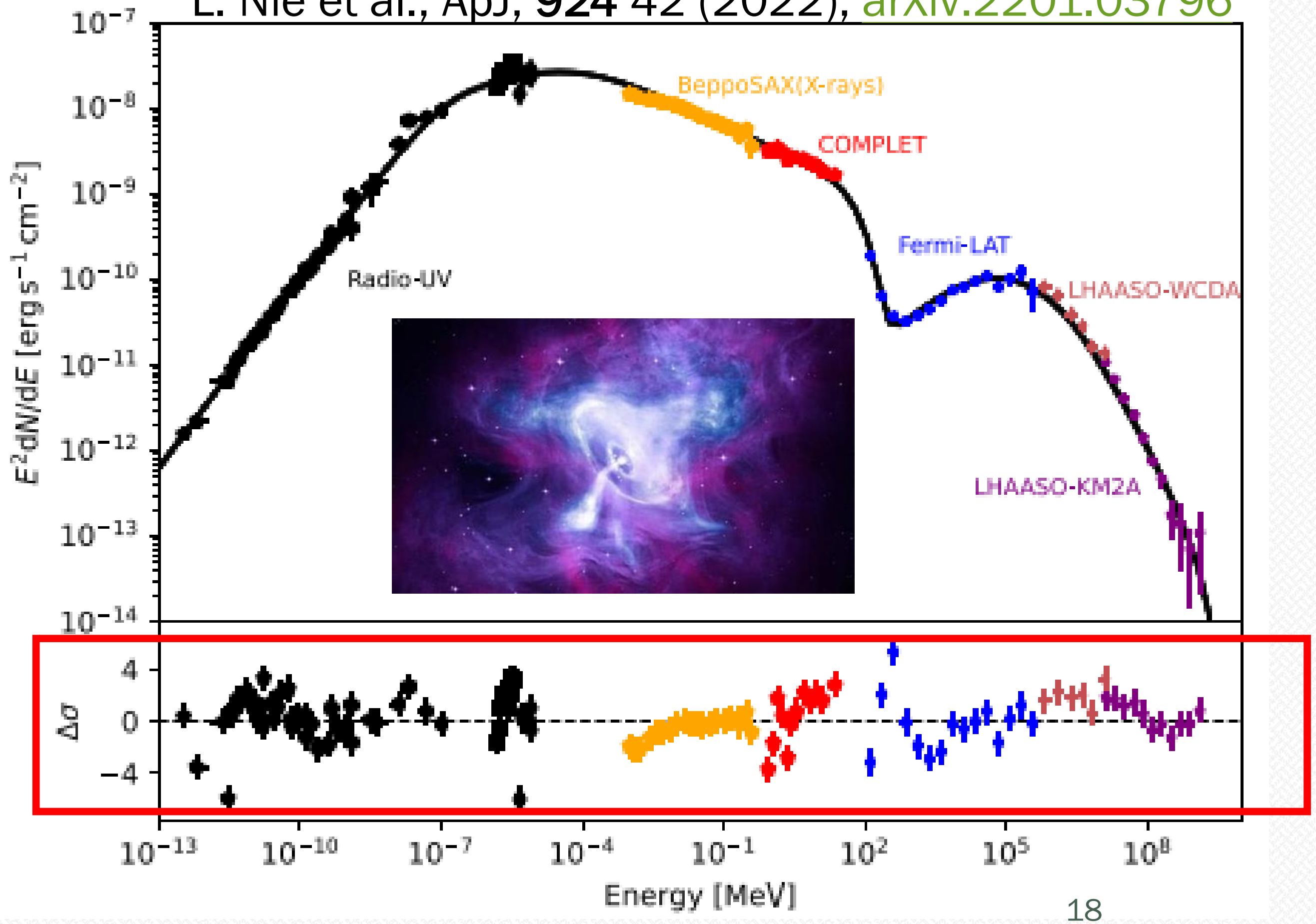


"Extreme Electron PeVatron"

- One-zone Leptonic Model： non-negligible fact, however…
- It is hardly to be recognized as a "reasonably good fitting"
- Challenge: 1.4 PeV photon must be emitted by **2.8 PeV electron implying $\bar{\varepsilon}$/B~26% !**

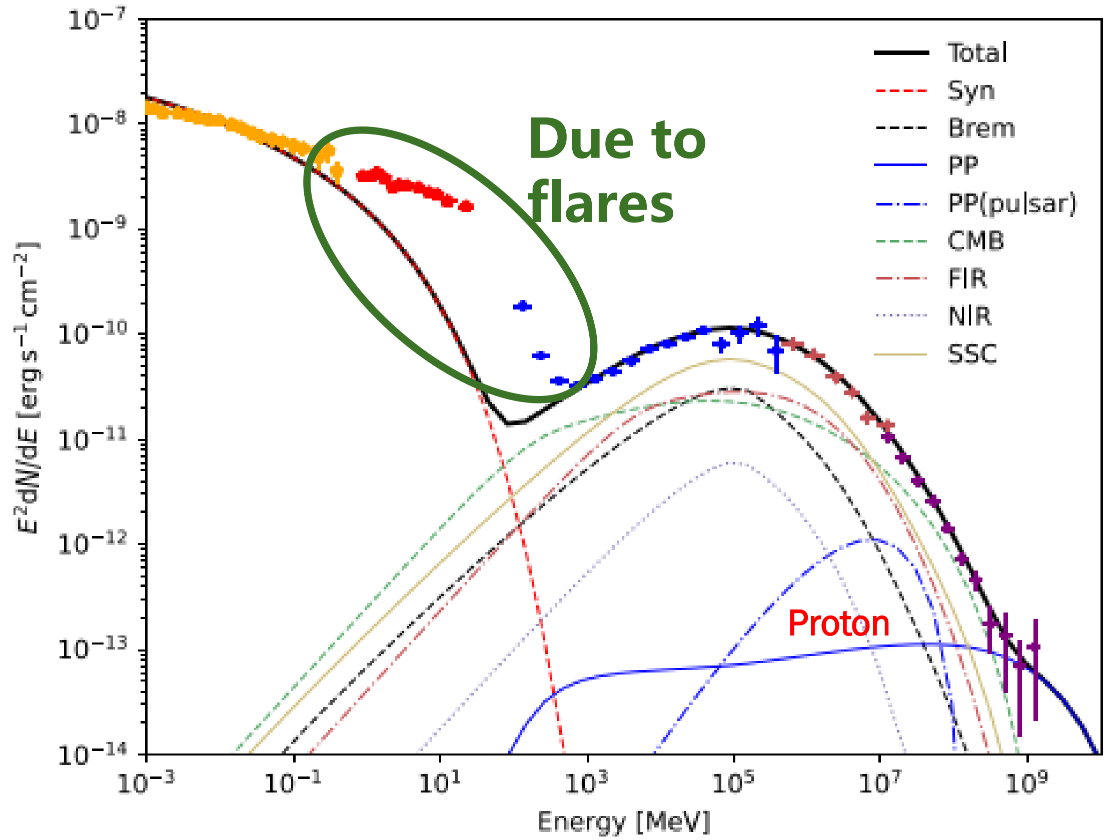


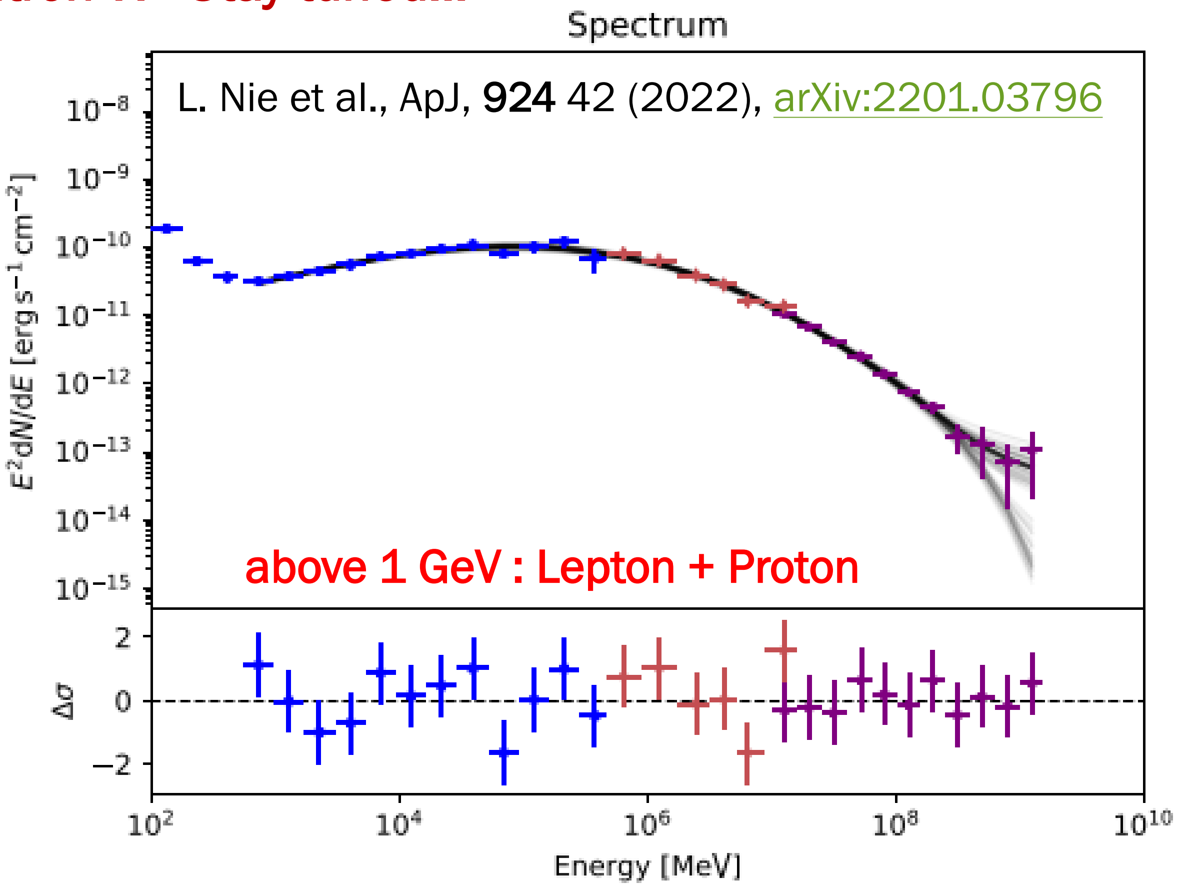
L. Nie et al., ApJ, **924** 42 (2022), arXiv:2201.03796



Seems to be a plausible interpretation

- Relaxing the tension of 2.8 PeV electron's acceleration
- **Origin of CRs above the knee: a Super-PeVatron ?! Stay tuned…**

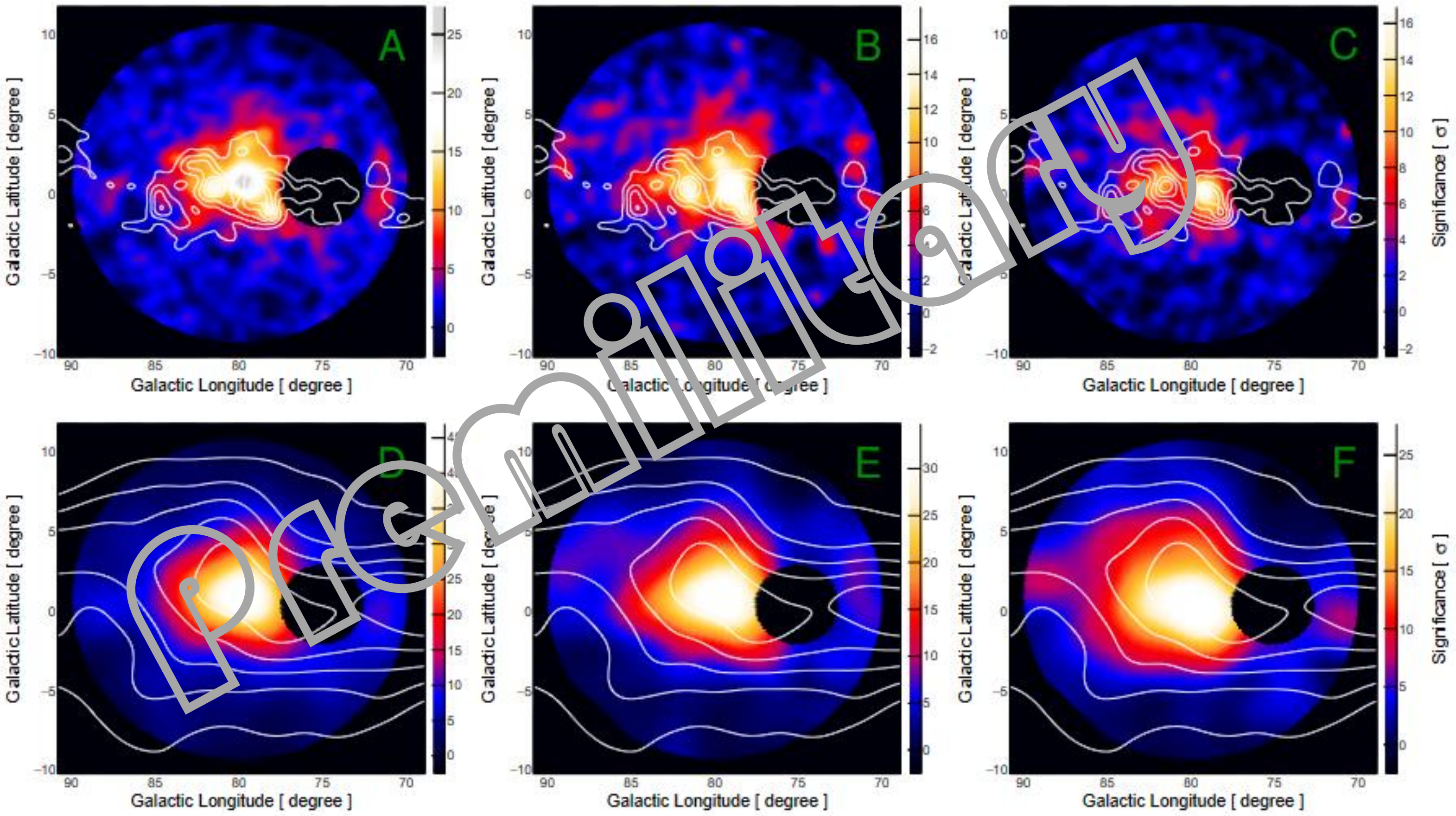


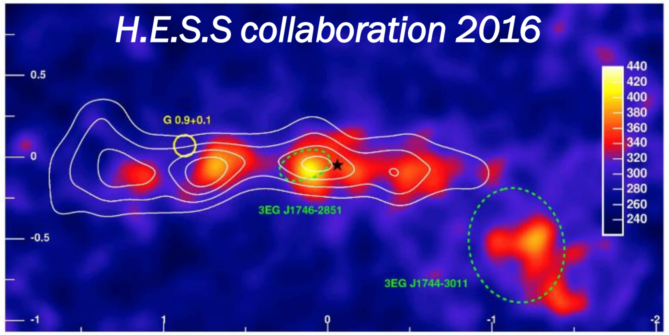


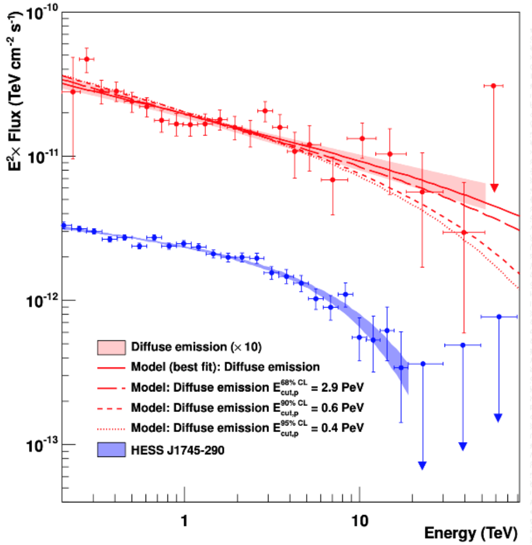
- Majority of sources in catalog 1-LHAASO are found associated with PWNe
- **The contribution to the origin of CRs above the knee is certainly not negligible !!**

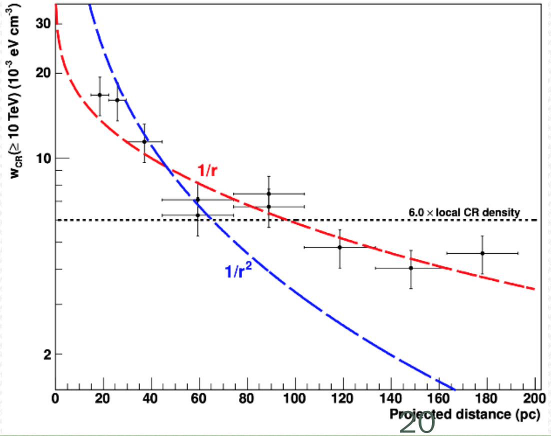
G.C. and Cygnus X

- G.C. is the first indication of PeVatron using 40 TeV photons
- Cygnus is emitting photons up to 2 PeV is a bubble associated with the local gas distribution in at lease 6°
- Strong core emitting a couple photons with E_{max}~1.4 PeV
- **Super-PeVatron: origins of 10 PeV CRs ?!**



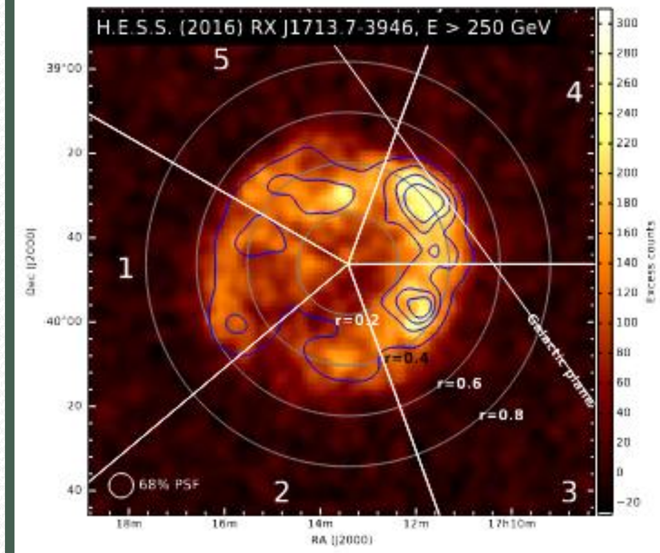




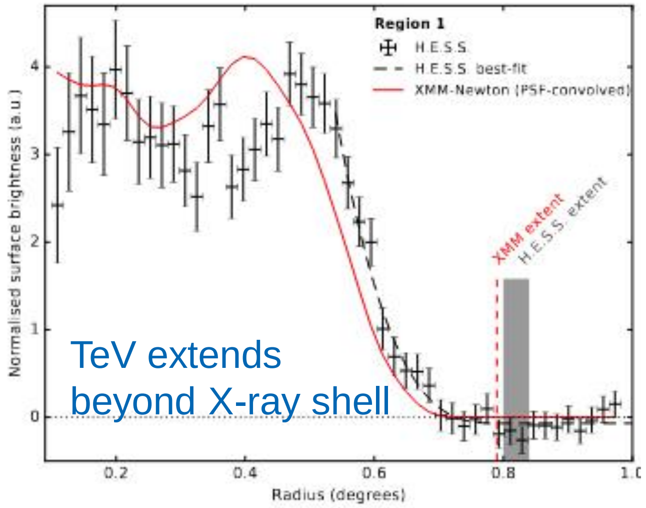


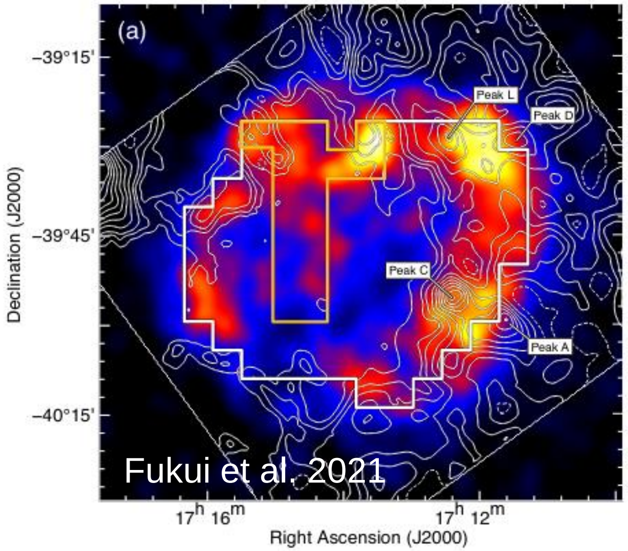
Cong's talk in this conference

Young SNRs



HESS Collaboraiton 2018

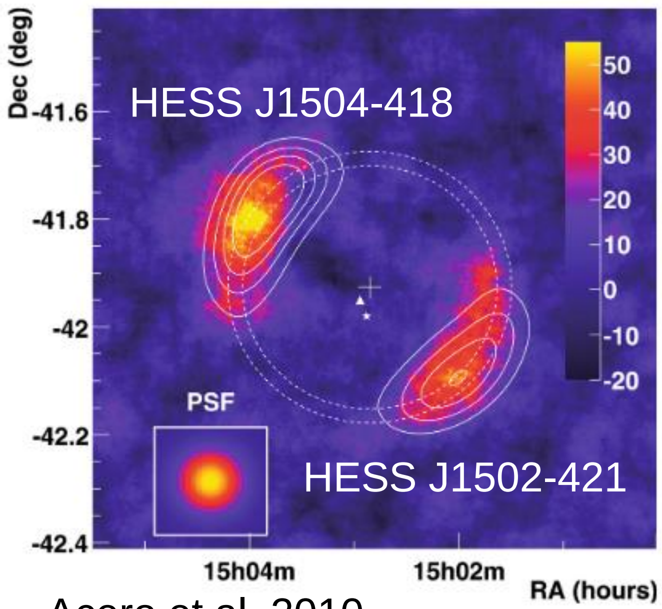




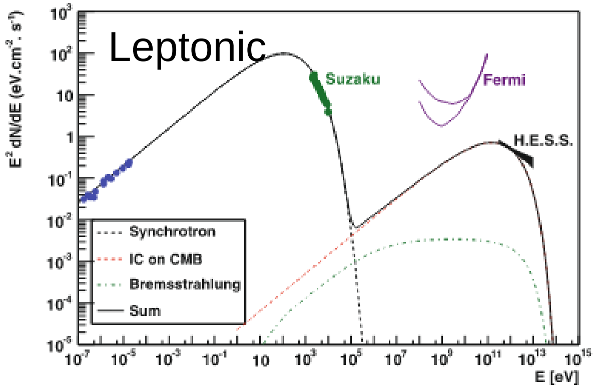
SNR J1713.7-3946
1.1-1.7kyr (SN 1629?)
d=1.1kpc

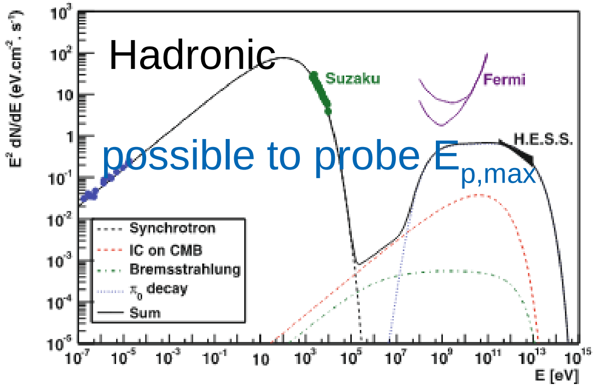
Interacting with clouds:
Promising hadronic
gamma-ray emitter

SN 1006
d=1.6-2.2kpc
in low gas density environment

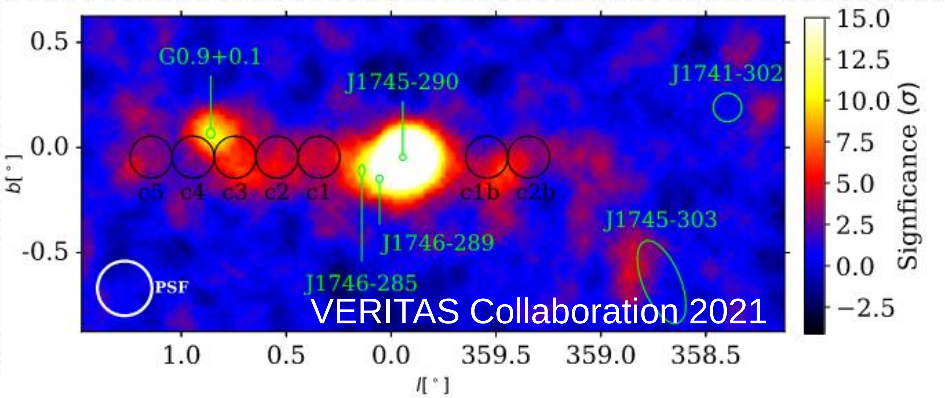


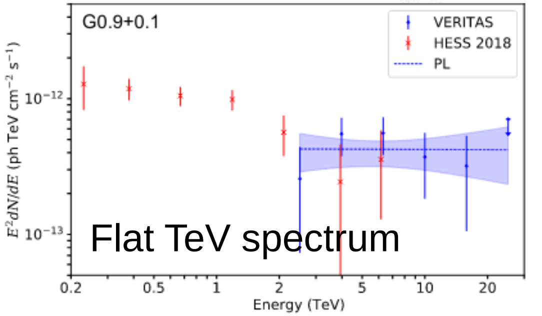
Acero et al. 2010





SNR G0.9+0.1 in GC direction, d=8.5-10kpc





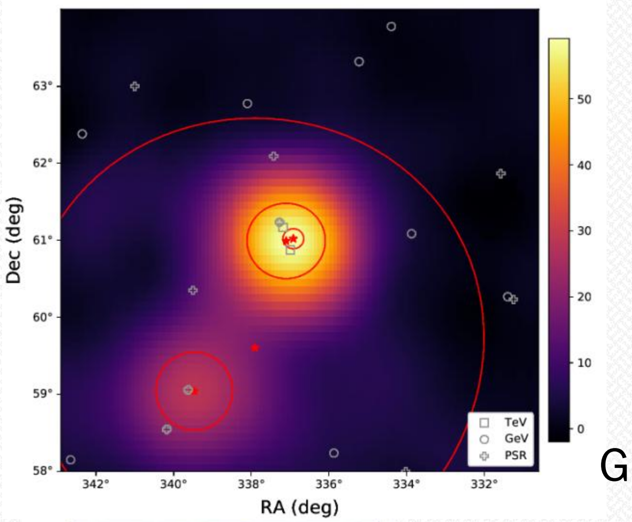
Composite SNR

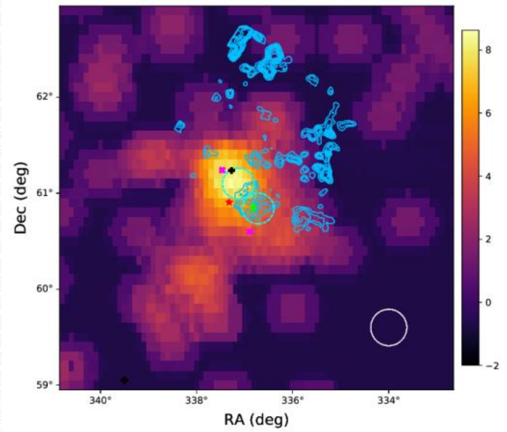
PSR J1747-2809
Characteristic age
5.3kyr
Spindown Luminosity
4.3e+37

SNRs are good candidates of origins of CR below the knee

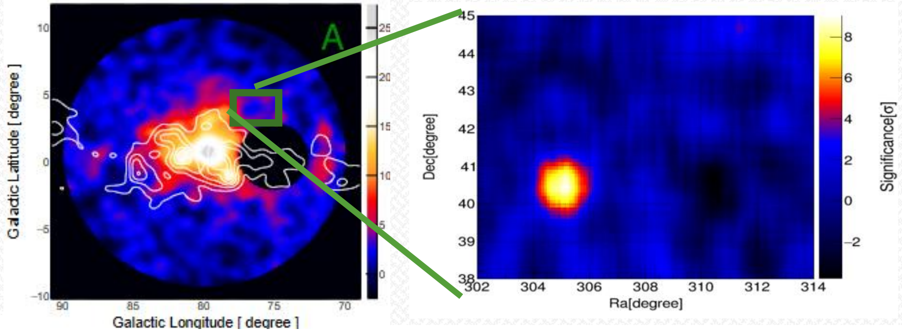
Very young SNRs G1.9+0.3

- Shock speed ~ 14,000 km/s
- X-ray observations reveal NOT efficient accelerator
- H.E.S.S. reveals L(>1 TeV) < 1e32 erg/s can be used to set limit on proton energy budget

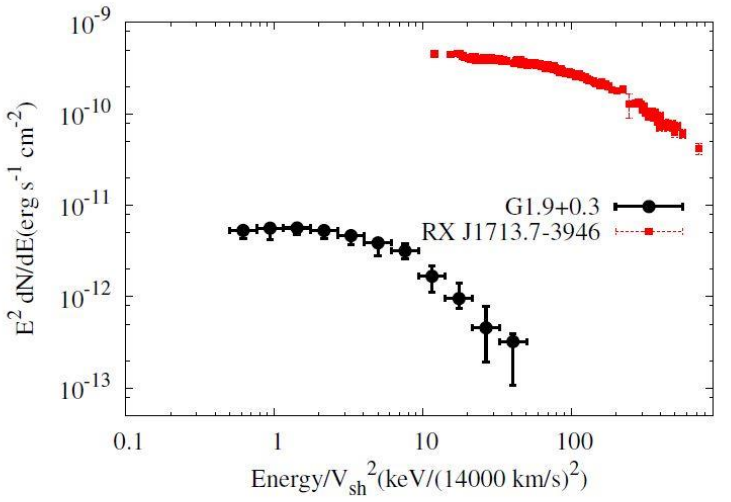


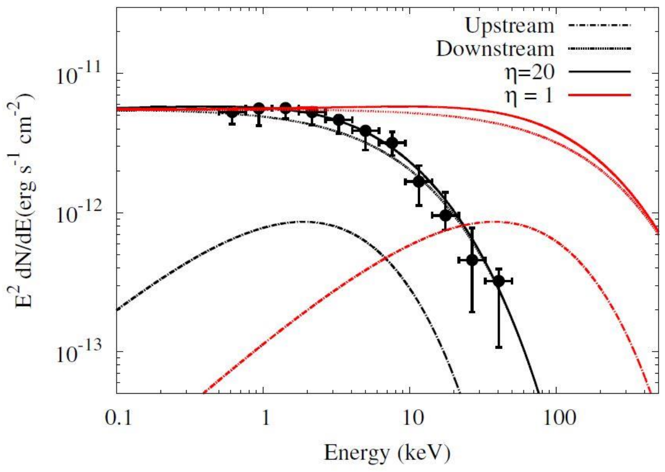


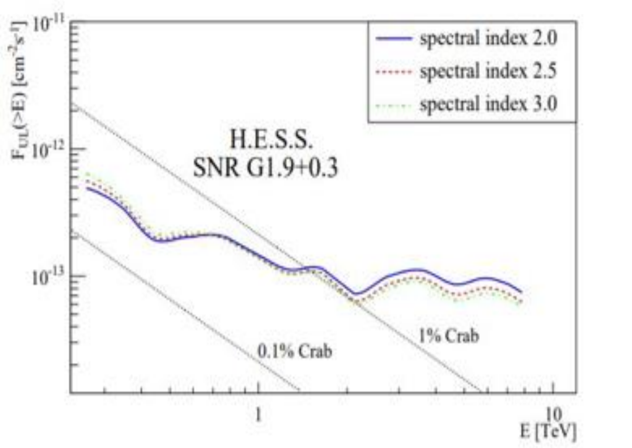
G106.3+2.7-Boomerang



γ-Cygni



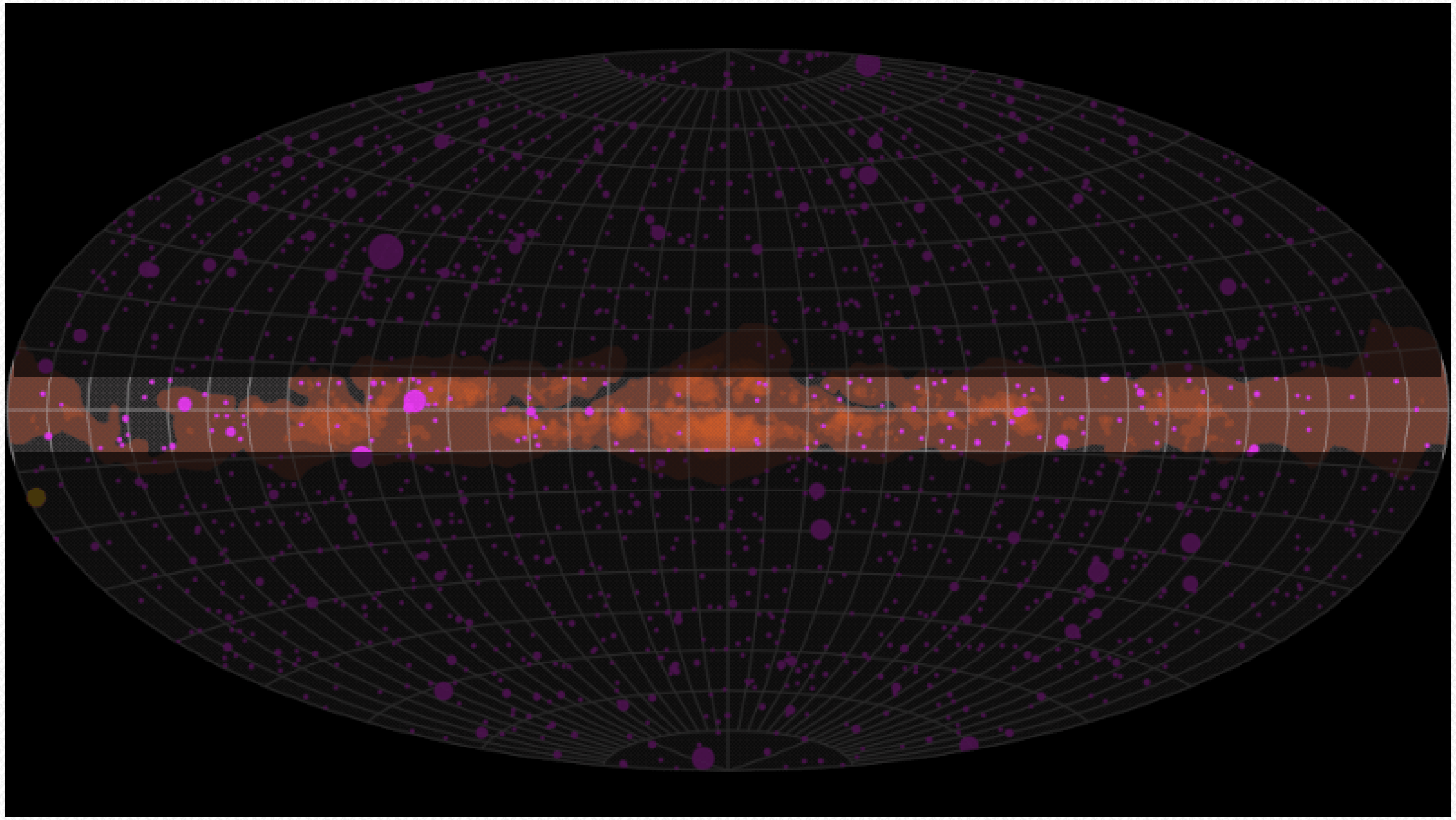




X-ray observations on G1.9+0.3 (Aharonian et.al 2016)

Variable Sources

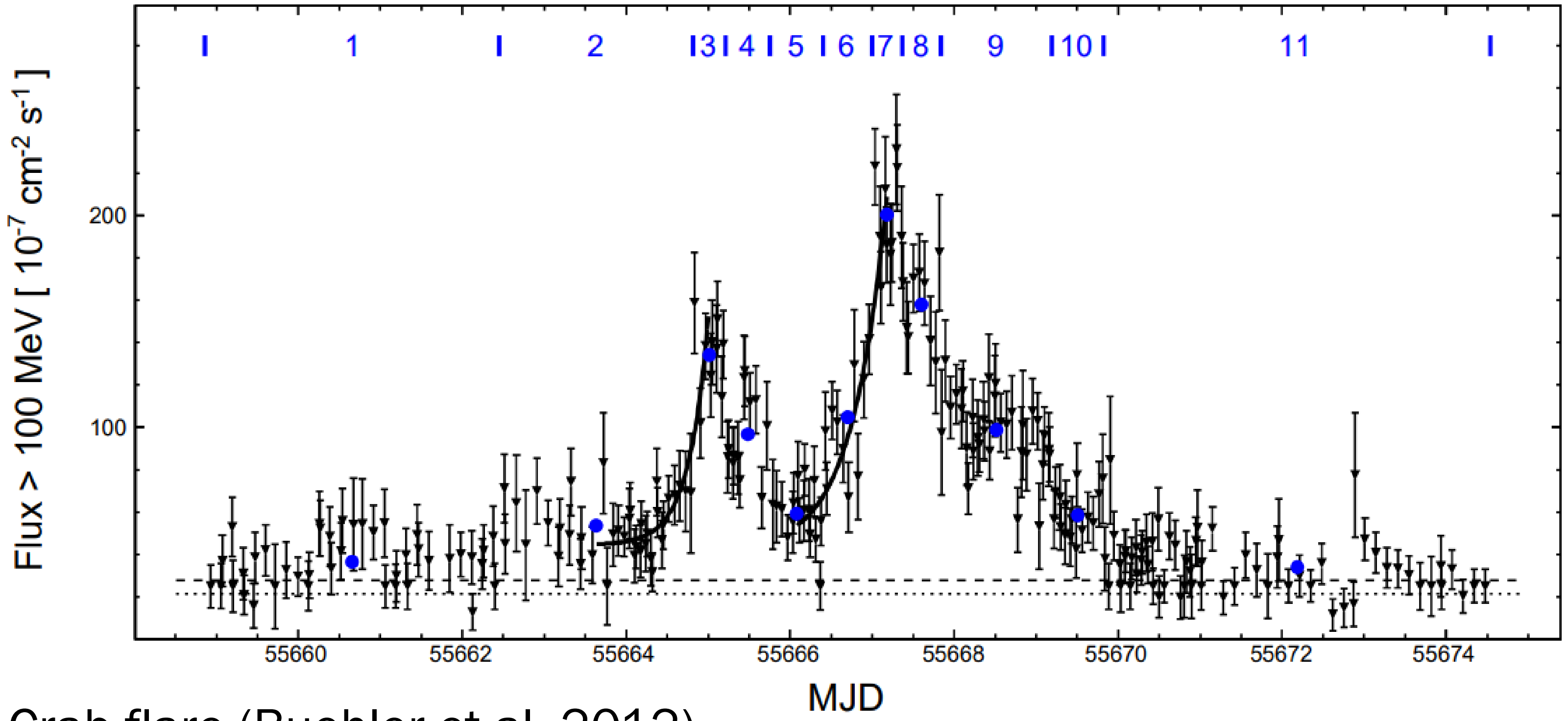
- Cosmic gamma-ray fireworks observed by Fermi/LAT
- Gamma-ray sky is dynamic and variable
- Brightness (circle size) of objects varies all the time
- Over 90% of these sources are blazars
- Inside our Galaxy, there are many variable sources



Credit: NASA's Marshall Space Flight Center/Daniel Kocevski

Crab Flares

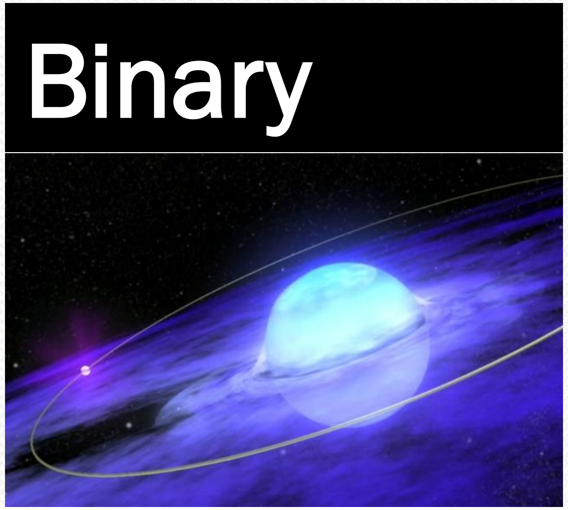
- The Crab nebula shows flare activity
- Time scale: hours to days (Abdo et al. 2011; Buehler et al. 2012)
- Only seen in GeV band !!
- The mechanisms under debate

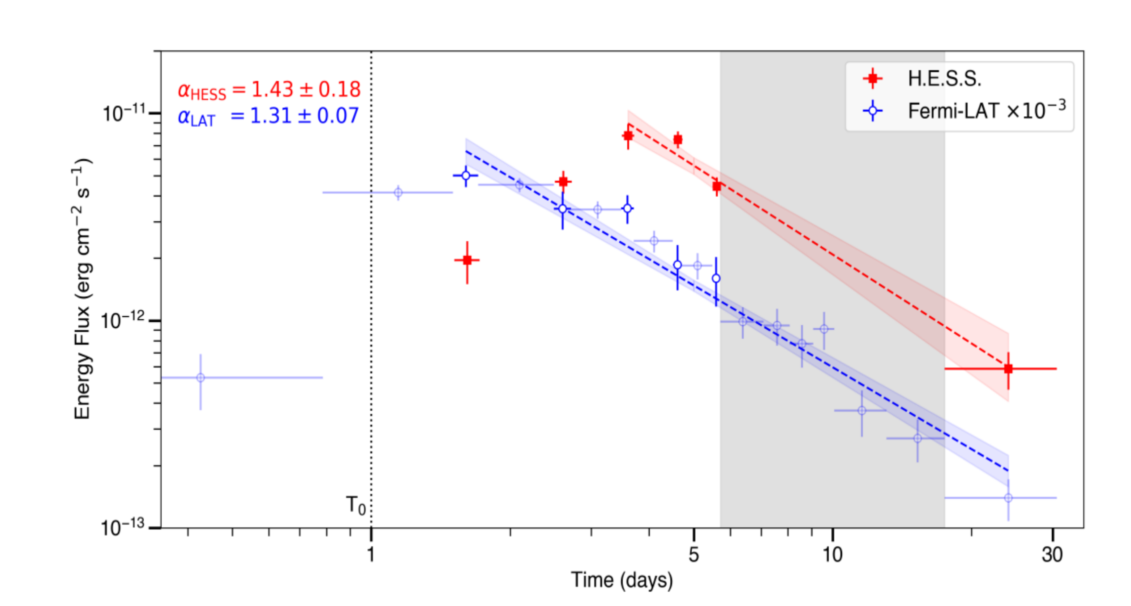


2011 April Crab flare (Buehler et al. 2012)

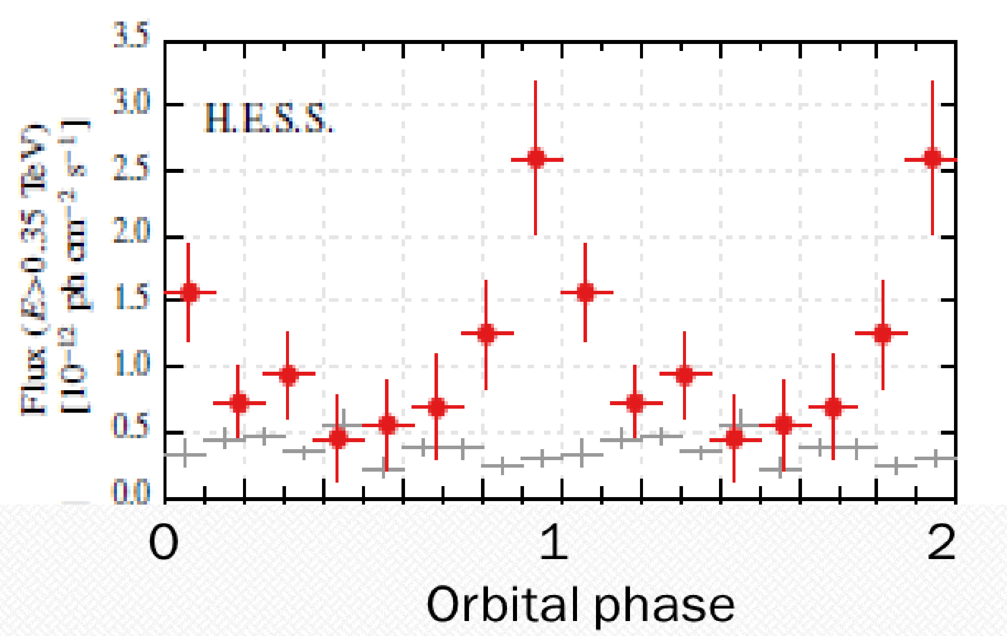
Variability

- orbital modulated
- jet activity in micro quasar
- flare activity like Nova





Gamma-ray light curves of RS Oph (Nova) during outburst. Aharonian et al. 2022



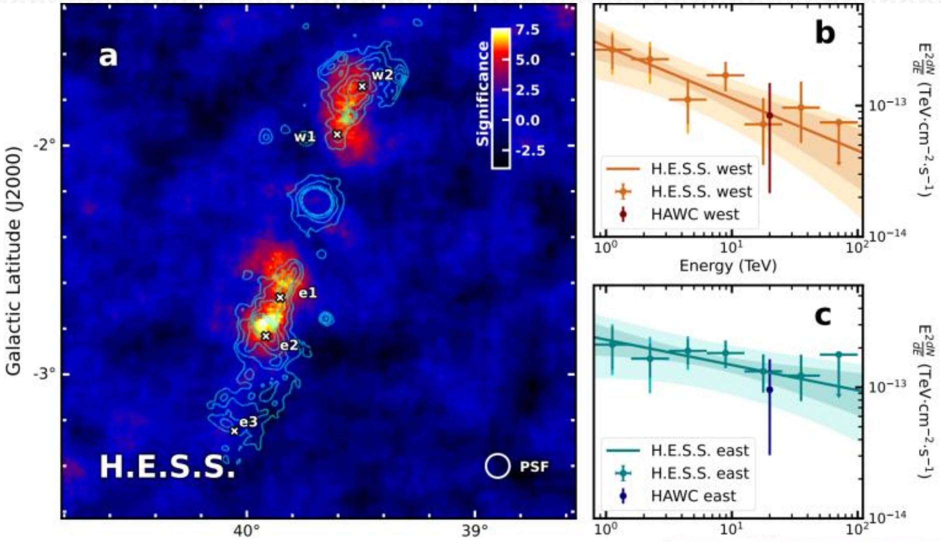
1FGL J1018.6-5856 (gamma-ray binary), HESS collaboration et al. 2015

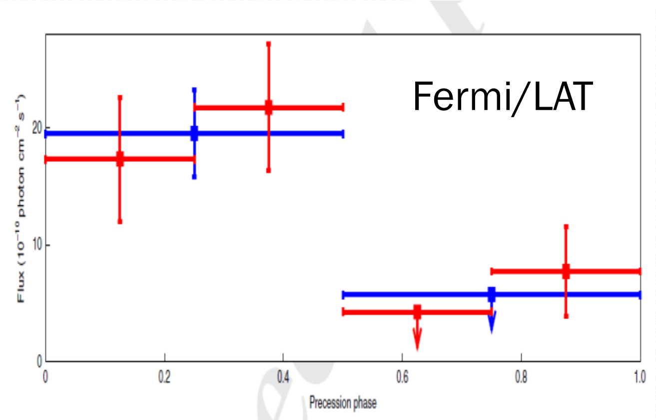
SS433 is a micro-quasar

Laura Olivera-Nieto representing H.E.S.S. and HAWC (2023)

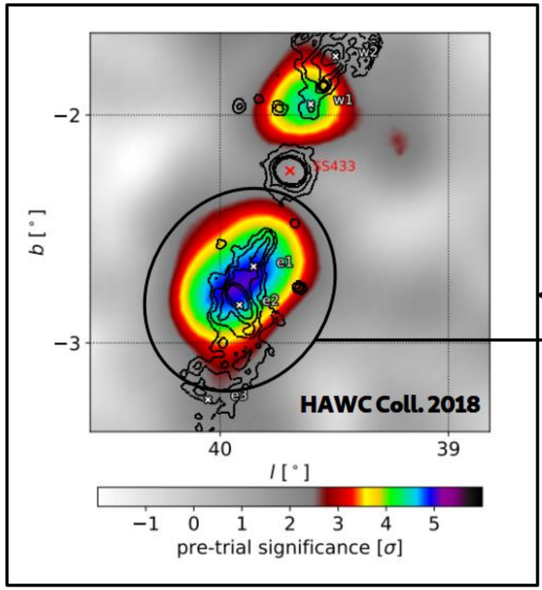
- limited exposure
- ~200 h of observations
- better resolution

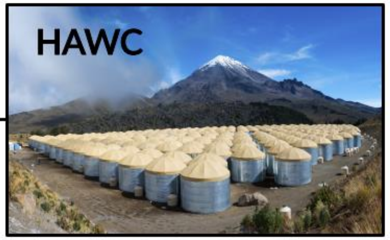
used the central telescope for improved background rejection at high energies (Olivera-Nieto et al 2022)



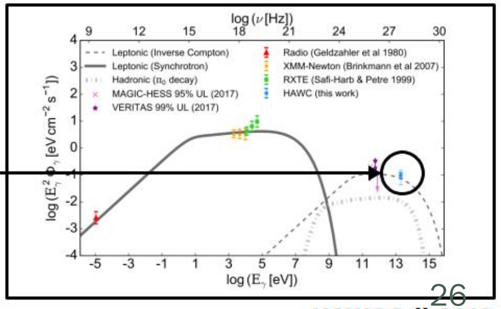


SS 433 (microquasar), Li et al, 2020





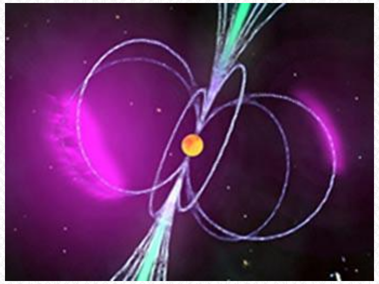
- wide field o
- continuous observation
- (relatively) p resolution
- 1-100 TeV



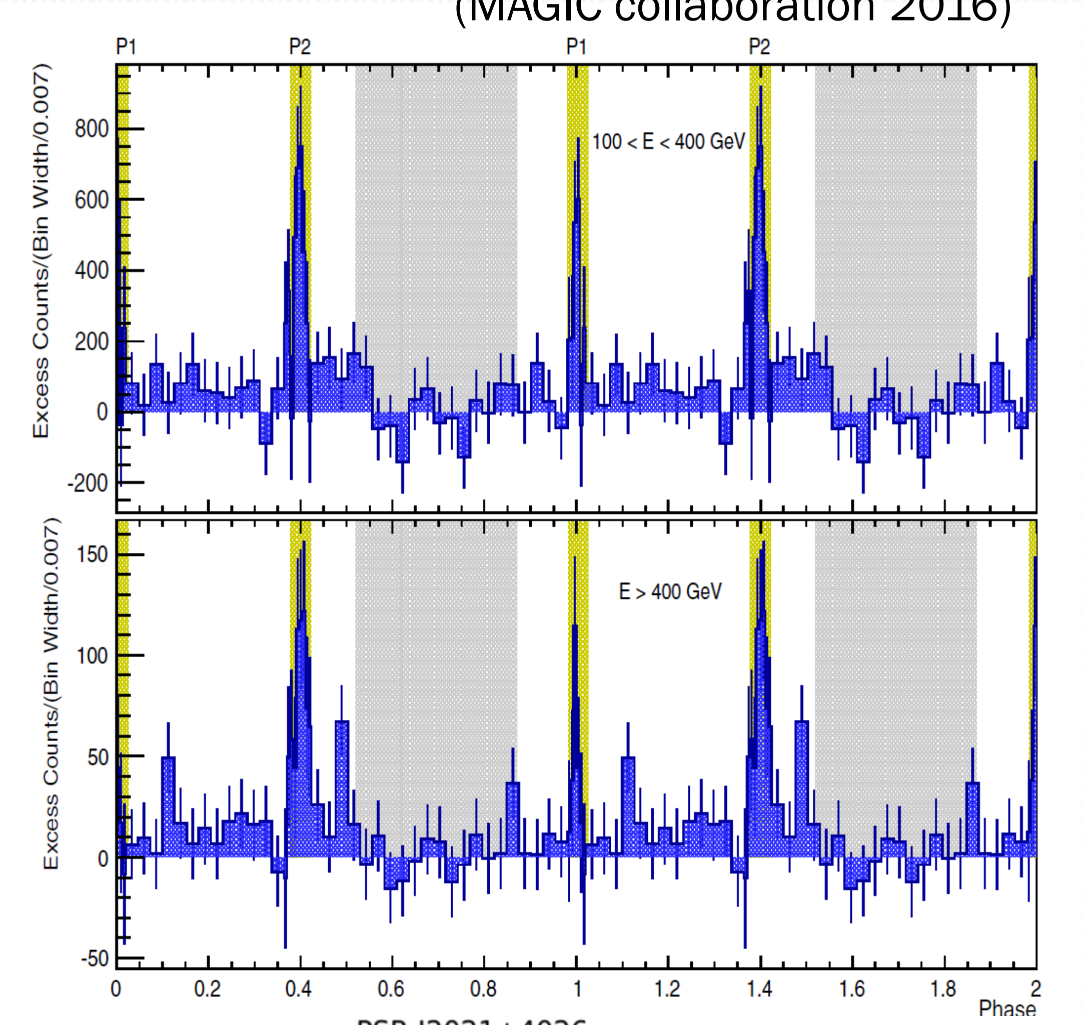
HAWC Coll. 2018

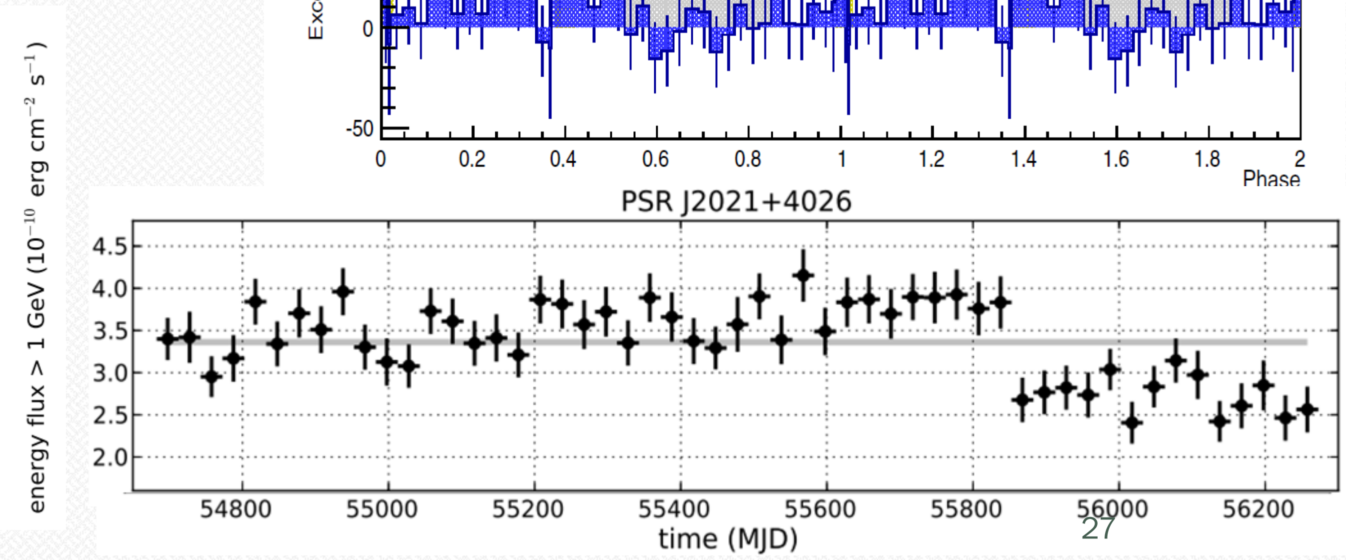
Pulsation signal at VHE

- Gamma-ray pulsars show steady pulsation on their spin periods ranging from several milliseconds to seconds, mainly seen in GeV.
- Only the Crab and Vela pulsar are pulsating both in GeV and TeV
- PSR J2021+4026 is observed for the gamma-ray flux variability on time scales of several years (Allafort et al. 2013), making it the only variable gamma-ray pulsar



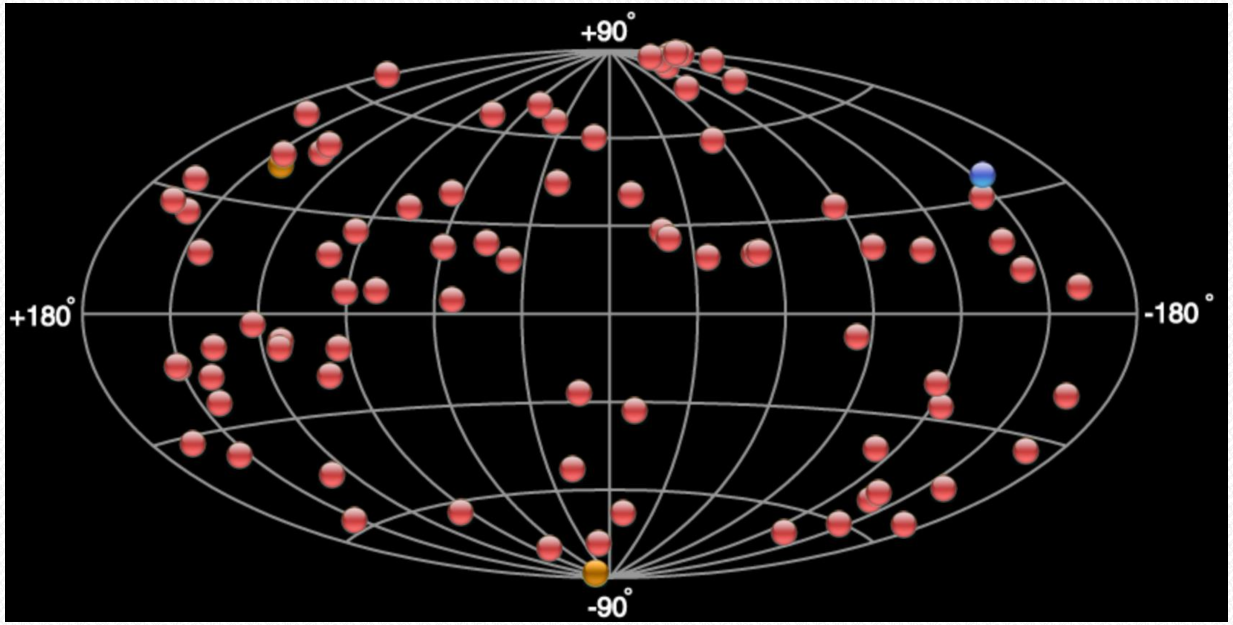
(MAGIC collaboration 2016)

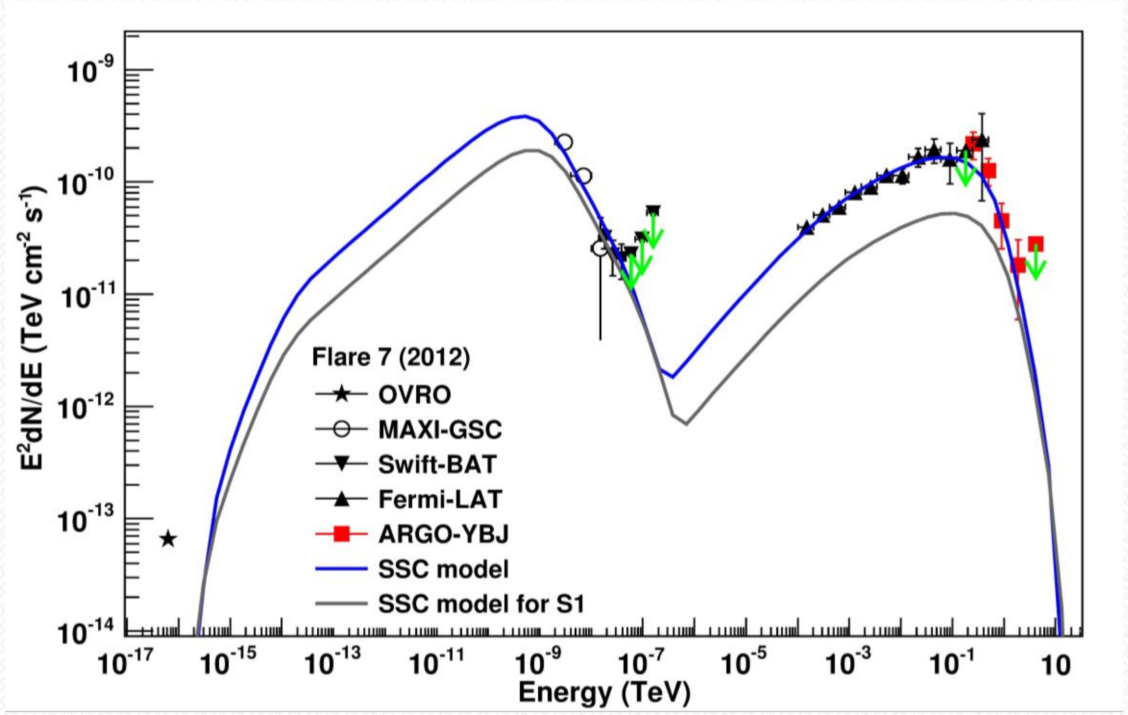




Extra Galactic Sources

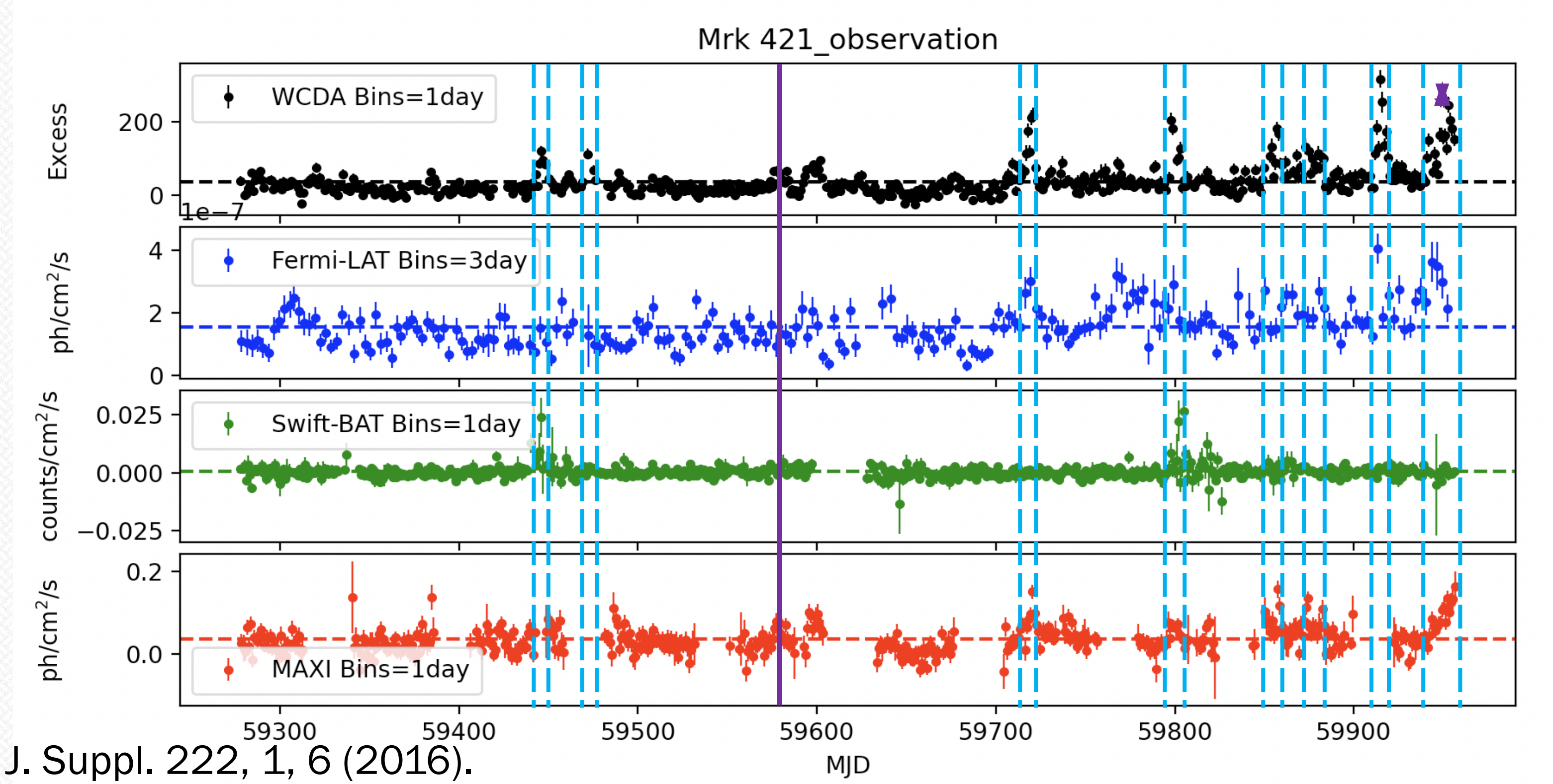
- ~77 identified sources listed in TeV-Catalog with distance > 2 Mpc
- Most of them are BL lacs, few FRSQs and 3 star-burst galaxies
- The best studied are two Markarian AGNi: Mrk 421 and Mrk 501
- Established radiation mechanism: leptonic SSC model



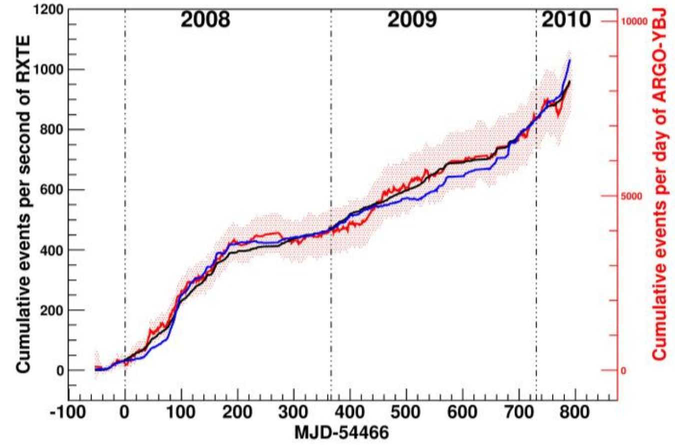


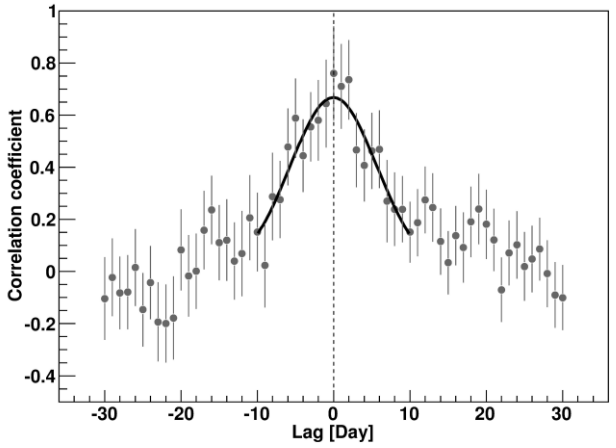
Multi-wavelength observation of Mrk 421

- **Mrk 421**
  - WCDA (nhit > 100)
  - Fermi_LAT (0.1-100 GeV)
  - Swift_BAT (15-50 KeV)
  - MAXI (2-20 KeV)
- **Mrk421 Flares (~days)**
- **Nice correlation between X-ray and VHE γ-rays**



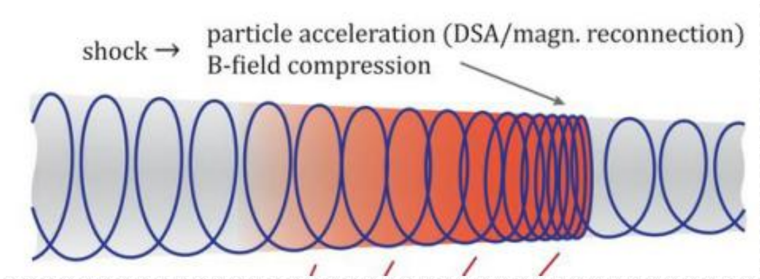
B. Bartoli et al. (ARGO-YBJ), Astrophys. J. Suppl. 222, 1, 6 (2016).





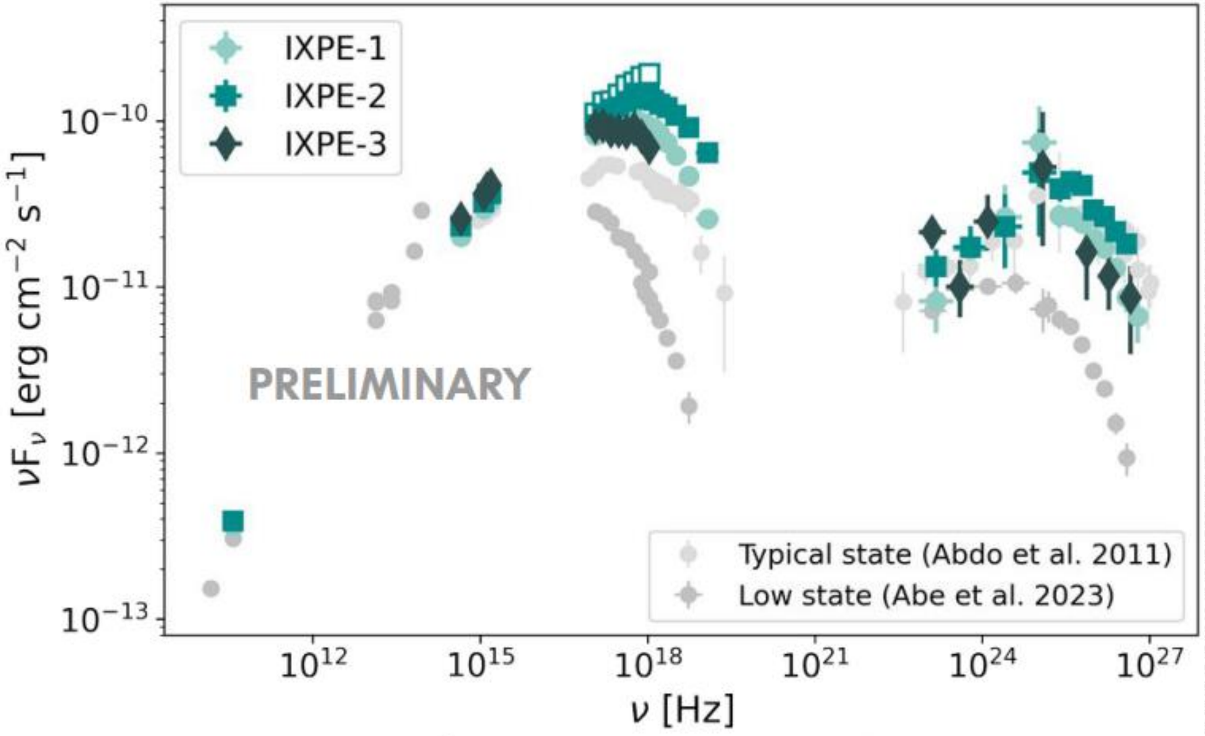
- **No time lag** between X-rays and γ-rays in flares in the scale of one day
- Good support evidence for the SSC model

Lea Heckmann representing MAGIC in this conference



Mrk 501

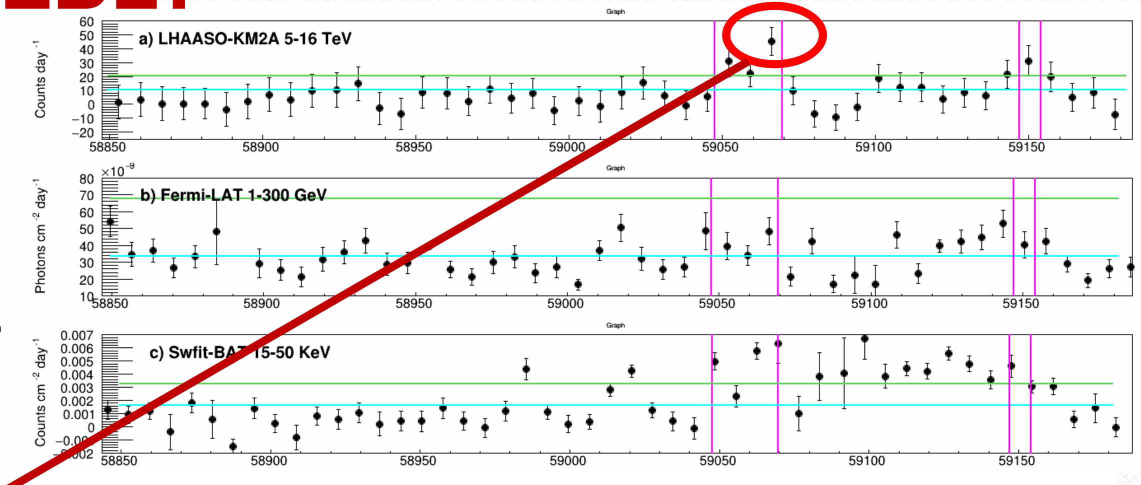
- However, spectra show more unusual features:
  - Extreme states for IXPE-1 & 2 $\nu_{synch} > 2.4 \times 10^{17}$ Hz (~1keV)
  - Shift to lower energies for IXPE-3
  - Low Compton Dominance (CD)
- Theoretical description – two zones
  - Compact region:
    - Dominating in the X-ray/VHE
  - Extended region:
    - Dominating at lower energies
    - Stretches further along the jet

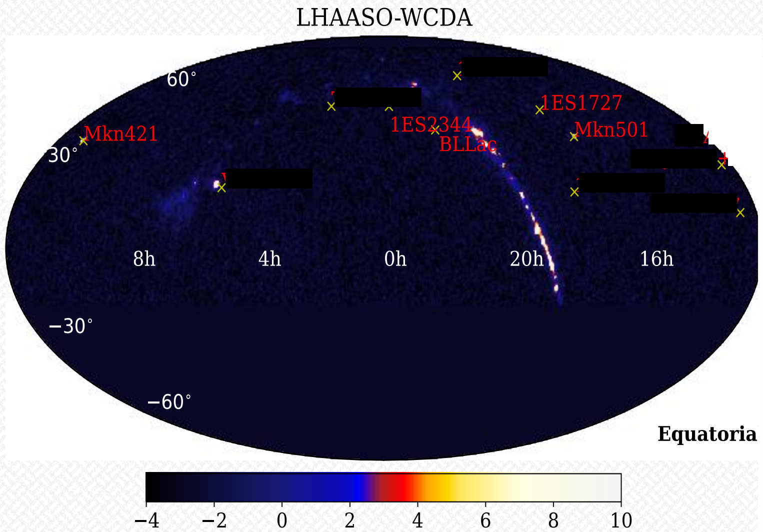


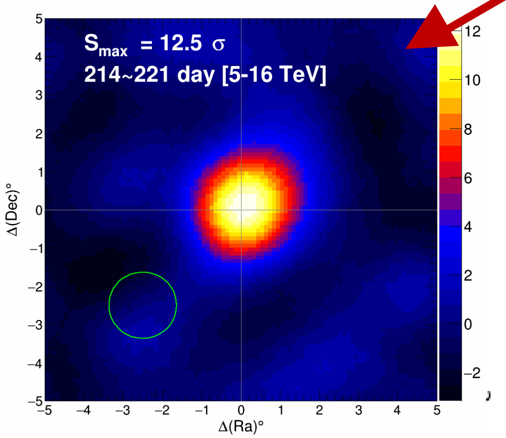
States	ν_s [Hz]	ν_{IC} [Hz]	CD
$IXPE\text{-}1_{pheno}$	$5.4 \pm 0.2 \times 10^{17}$	$2.1 \pm 0.4 \times 10^{25}$	0.30
$IXPE\text{-}2_{pheno}$	$7.9 \pm 0.6 \times 10^{17}$	$2.5 \pm 1.1 \times 10^{25}$	0.30
$IXPE\text{-}3_{pheno}$	$9.0 \pm 7.8 \times 10^{16}$	$2.4 \pm 10.3 \times 10^{24}$	0.18
Typical_{pheno}	$2.9 \pm 0.2 \times 10^{17}$	$4.8 \pm 1.3 \times 10^{25}$	0.49
Low_{pheno}	$1.1 \pm 0.4 \times 10^{16}$	$1.5 \pm 1.0 \times 10^{24}$	0.24

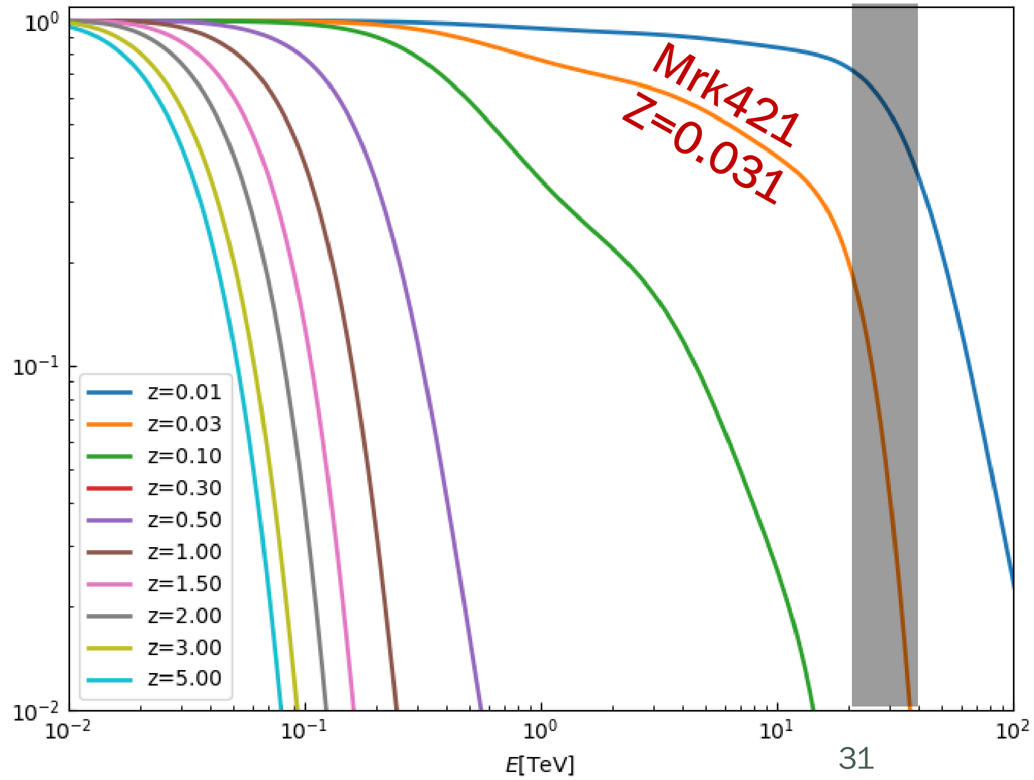
30 TeV photons from Mrk's ? EBL?

- HAWC detected extra-galactic sources
- LHAASO has 10+ sources above 4σ
- Even KM2A receives signals from Mrk421



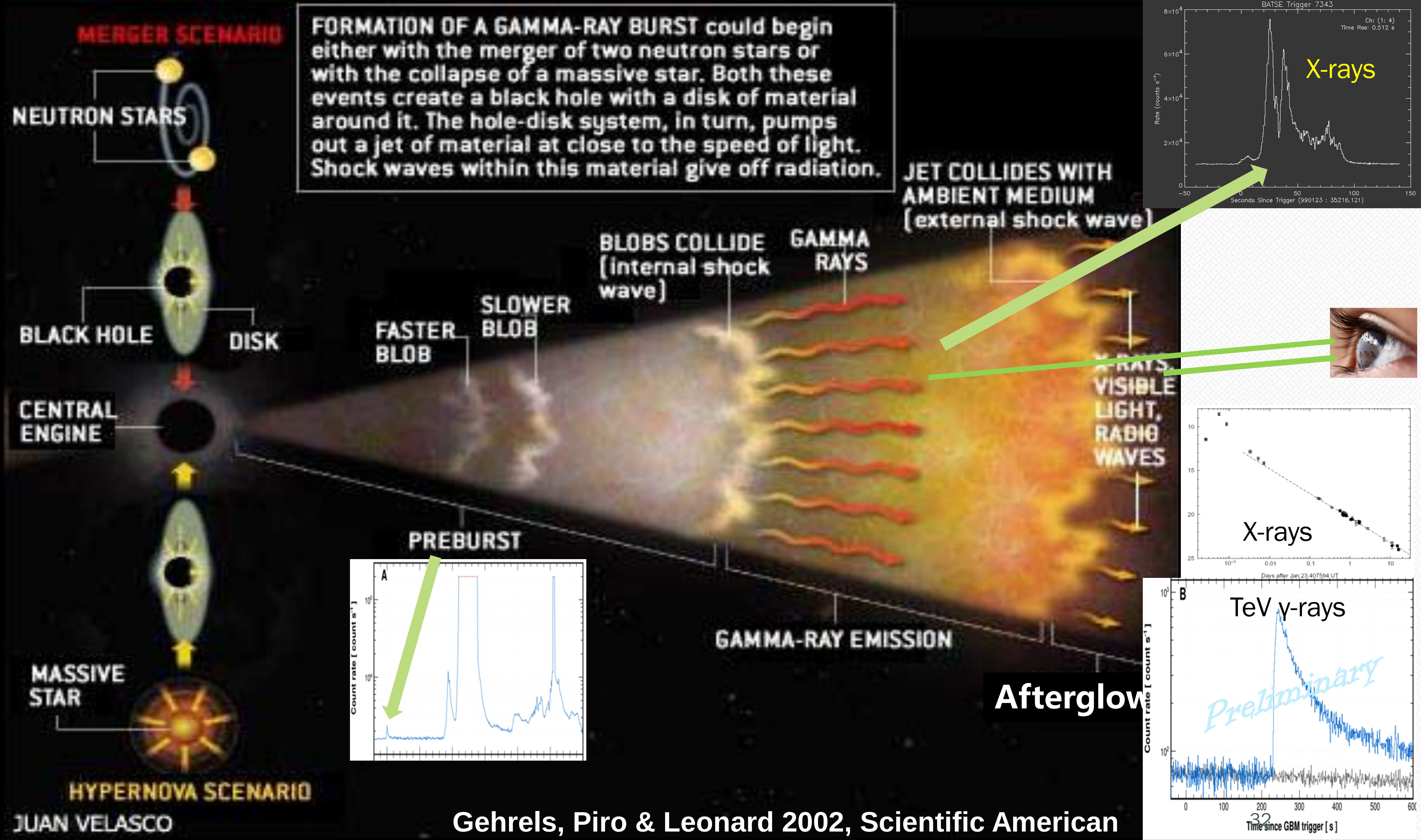






Source	Redshift	"Pass 4" TS	"Pass 5" TS
M87	0.004	13.2	29.6
1ES1215+303	0.130	12.8	43.8
VER J0521+211	0.108	10.3	18.2

GRB model

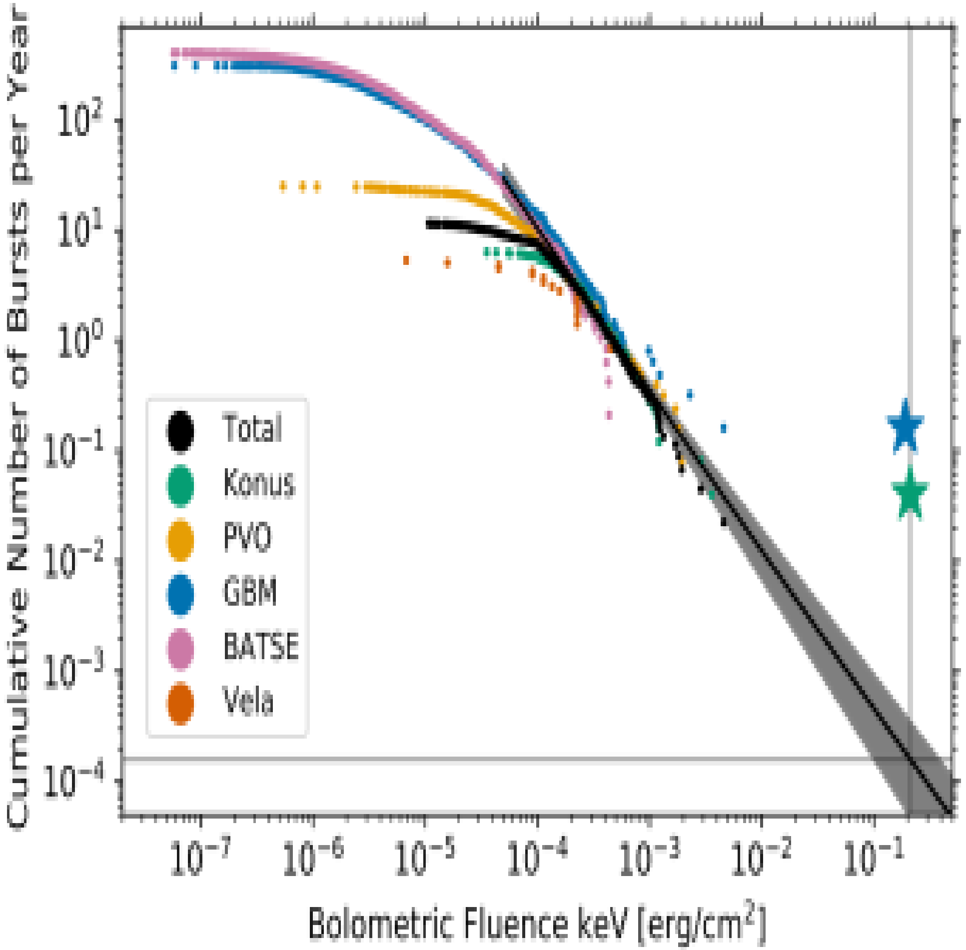


MERGER SCENARIO
NEUTRON STARS
BLACK HOLE
DISK
CENTRAL ENGINE
MASSIVE STAR
HYPERNOVA SCENARIO
JUAN VELASCO
FORMATION OF A GAMMA-RAY BURST could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.
FASTER BLOB
SLOWER BLOB
BLOBS COLLIDE (internal shock wave)
GAMMA RAYS
JET COLLIDES WITH AMBIENT MEDIUM (external shock wave)
X-RAYS, VISIBLE LIGHT, RADIO WAVES
PREBURST
GAMMA-RAY EMISSION
Afterglow
BATSE Trigger 7343
X-rays
Seconds Since Trigger (990123 : 35216.121)
X-rays
Days after Jan 23.407594 UT
A
Count rate [count s⁻¹]
B
TeV γ-rays
Preliminary
Time since GBM trigger [s]
Gehrels, Piro & Leonard 2002, Scientific American

GRB 221009A:
The brightest of all time

- Highest fluence / peak flux (An et al. 2023)
- Nearby： Z=0.152
- Highest energy / peak luminosity (An et al. 2023)
- Once a 1,000/10,000 yr event (Burns et al. 2023)

By Bing Zhang



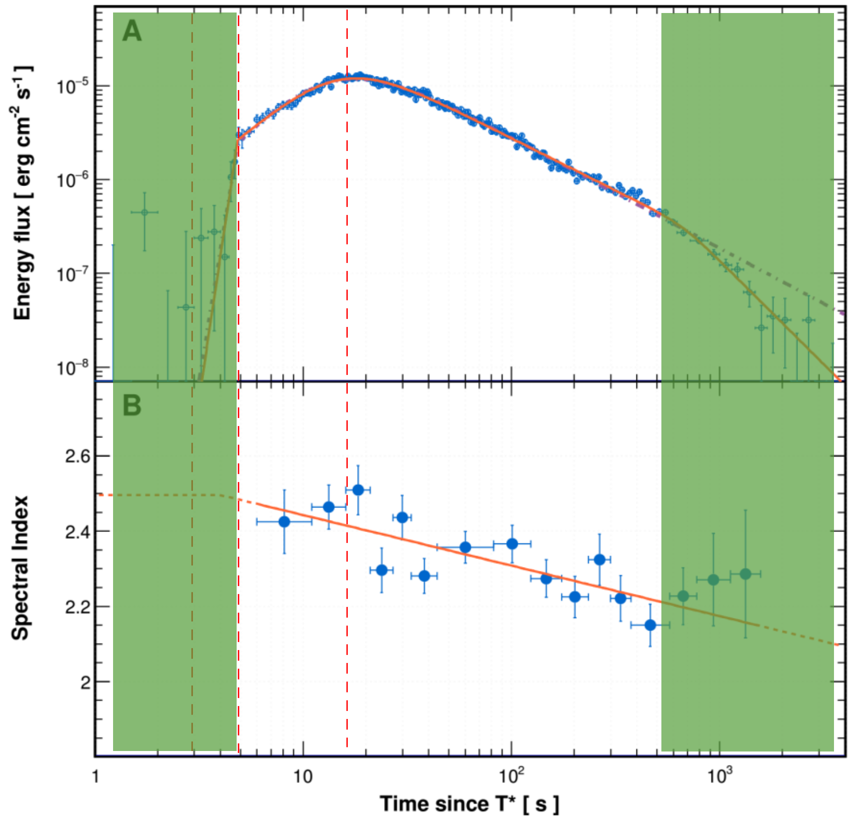
Rising phase measurement for the first time using 64,000 photons!

- **Synchrotron Self-Compton mechanism** is implied by the broken power-law
- Light curve ~t^2 favors k=0 (ISM), and disfavors k=2 (stellar wind)

$$n \propto R^{-k}$$

$$F_\nu = \begin{cases} F_m^{IC}\left(\frac{\nu}{\nu_m^{IC}}\right)^{-\frac{p-1}{2}} \propto t^{\frac{16-(9+p)k}{4}}\nu^{-\frac{p-1}{2}}, & \nu_m^{IC} < \nu < \nu_c^{IC} \\ F_m^{IC}\left(\frac{\nu}{\nu_c^{IC}}\right)^{-\frac{1}{2}} \propto t^{\frac{8-3k}{4}}\nu^{-1/2}, & \nu_c^{IC} < \nu < \nu_m^{IC} \\ F_m^{IC}(\nu_m^{IC})^{\frac{p-1}{2}}(\nu_c^{IC})^{\frac{1}{2}}\nu^{-\frac{p}{2}} \propto t^{\frac{8-(2+p)k}{4}}\nu^{-\frac{p}{2}}. & \nu > \max(\nu_m^{IC}, \nu_c^{IC}) \end{cases} \quad (12)$$

$$\alpha_1 = 1.82^{+0.21}_{-0.18}$$



- **The fast rising**: implying a free expansion with an increase of number of electrons accelerated at the external shocks

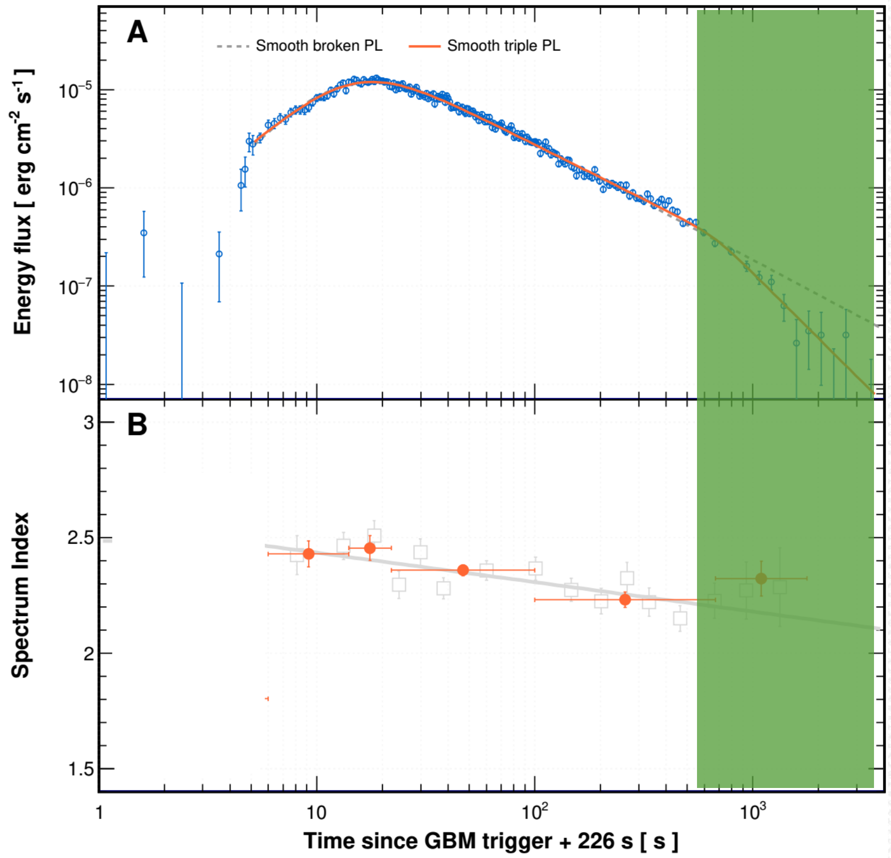
Decay phase: SSC

$$\alpha_2 = -1.115^{+0.012}_{-0.012}$$

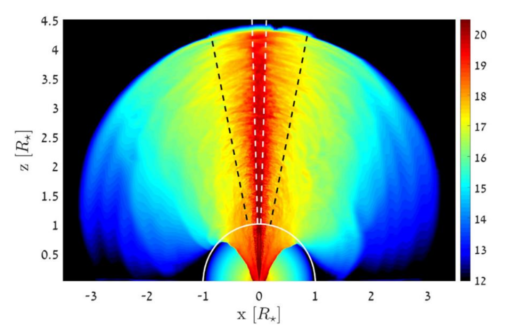
- Standard decaying behavior

$$F_\nu = \begin{cases} F_m^{IC}\left(\frac{\nu}{\nu_m^{IC}}\right)^{-\frac{p-1}{2}} \propto t^{\frac{11-9p}{8}}, & \nu_m^{IC} < \nu < \nu_c^{IC} \\ F_m^{IC}\left(\frac{\nu}{\nu_c^{IC}}\right)^{-\frac{1}{2}} \propto t^{\frac{1}{8}}, & \nu_c^{IC} < \nu < \nu_m^{IC} \\ F_m^{IC}(\nu_m^{IC})^{\frac{p-1}{2}}(\nu_c^{IC})^{\frac{1}{2}}\nu^{-\frac{p}{2}} \propto t^{\frac{10-9p}{8}}, & \nu > \max(\nu_m^{IC}, \nu_c^{IC}) \end{cases} \quad (13)$$

$$dN_e/dE \propto E_e^{-p} \qquad p \sim 2.1$$

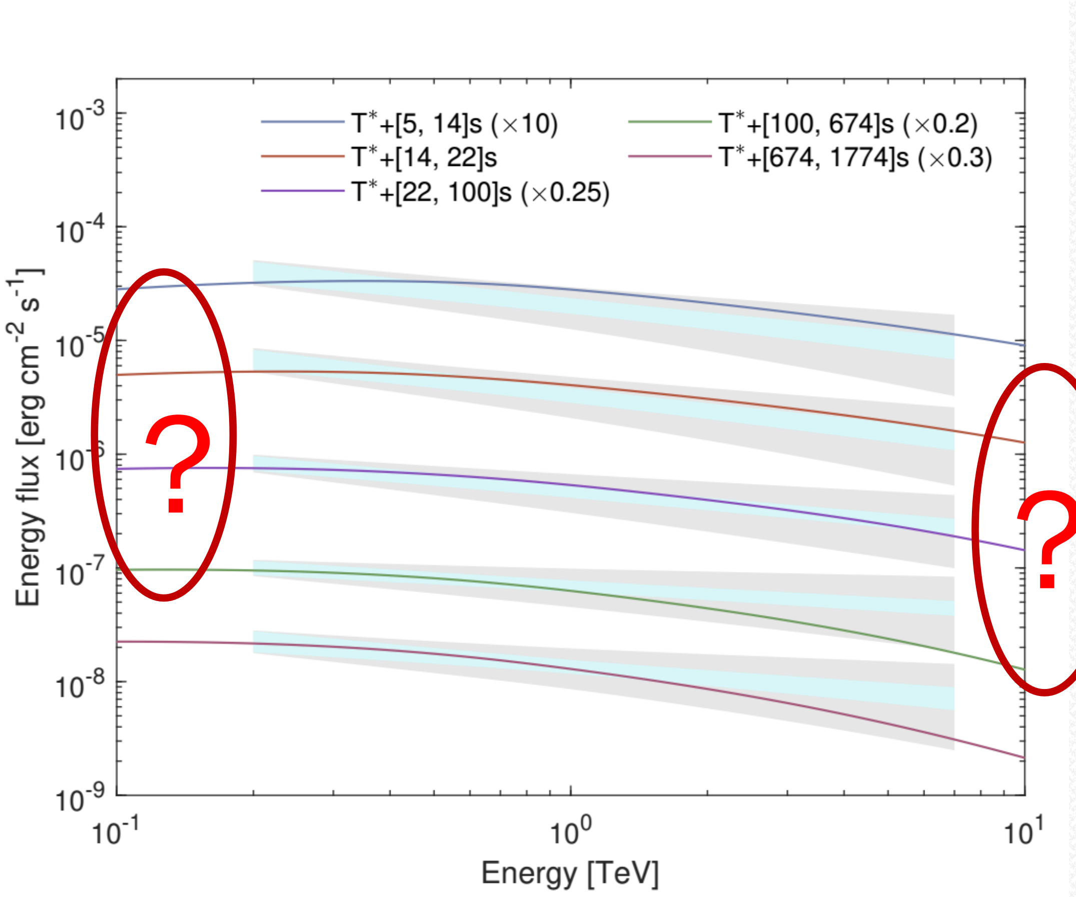


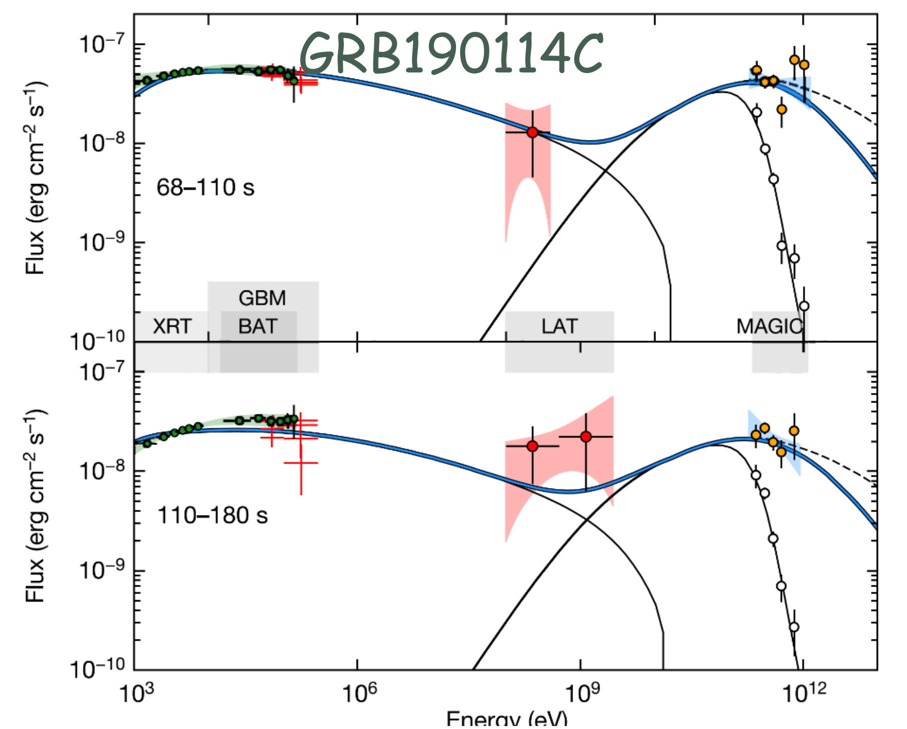
A fast component indicates the break of the structured jet with a core of 0.6°

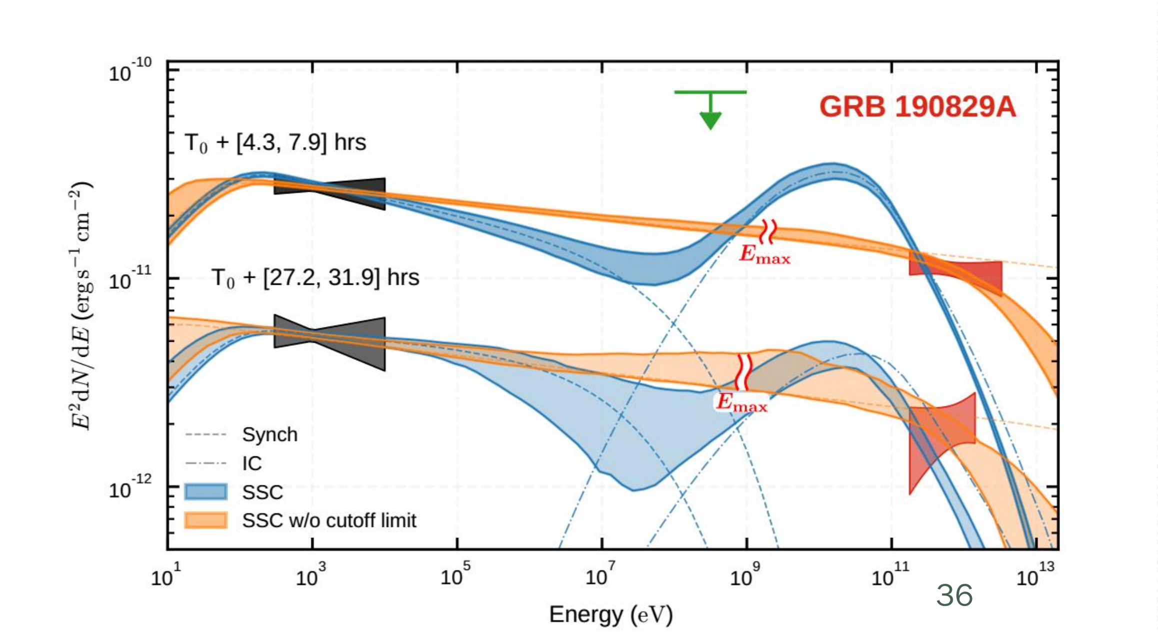


Gottlieb et al. 2021

Time-sliding analysis for SEDs of the afterglow







Is there a SSC bump below 200 GeV ?
At higher energy than 7 TeV, are
Very exciting events !?

Exploring for New Physics

- Lorentz Invariance Violation Testing

In the superluminal LIV

$$\gamma \rightarrow e^- e^+$$

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

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

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

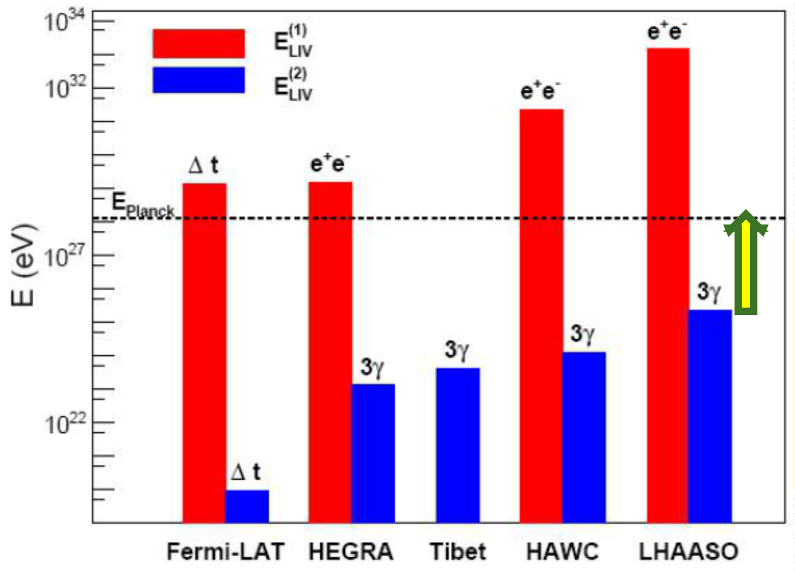
$$\gamma \rightarrow 3\gamma$$

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

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

New CLs method

Source	L (kpc)	E_{max} (PeV)	$E_{cut}^{95\%}$ (PeV)
J0534+2202	2.0	0.88	$0.75^{+0.043}_{-0.043}$
J2032+4102	1.4	1.42	$1.14^{+0.06}_{-0.06}$

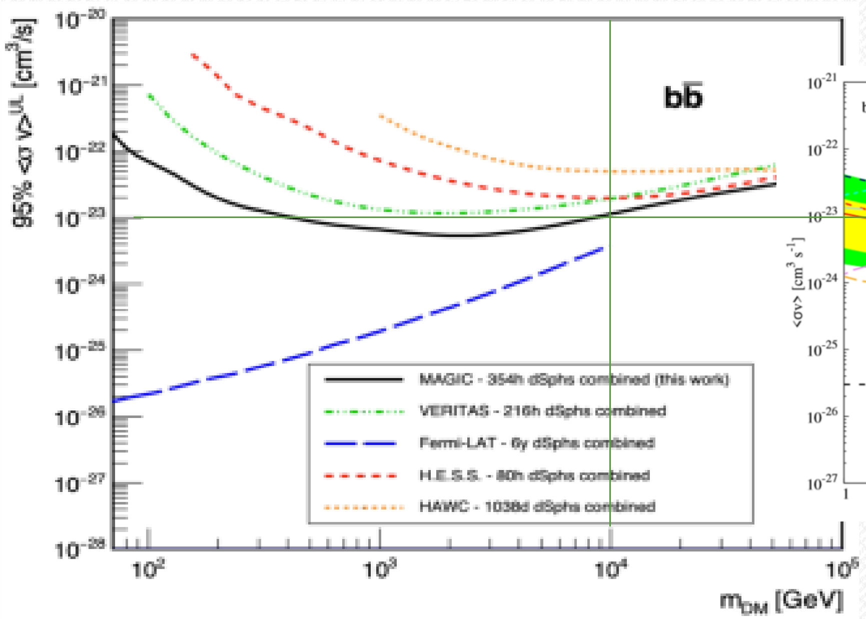


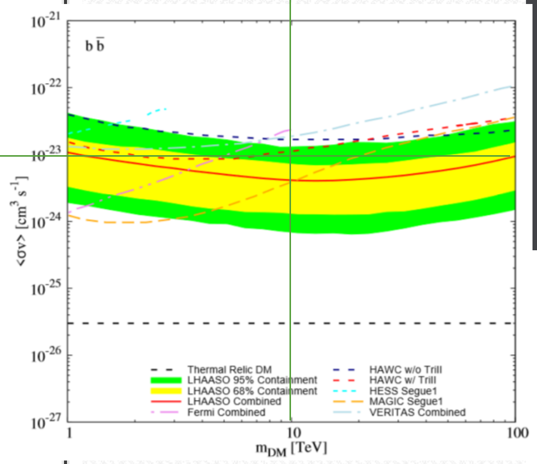
3 orders of magnitudes below the Planck-scale

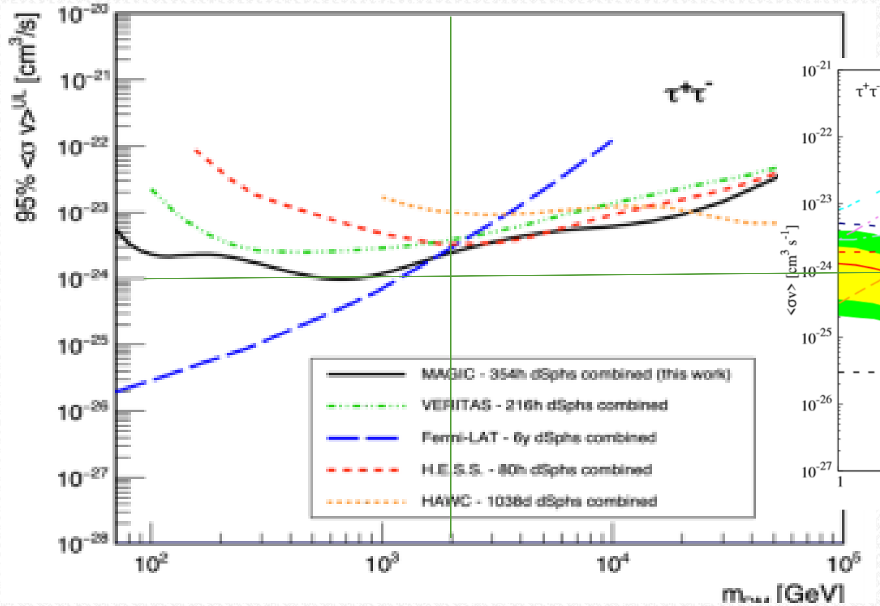
LHAASO Coll. PRL, 128.051102 (2022)

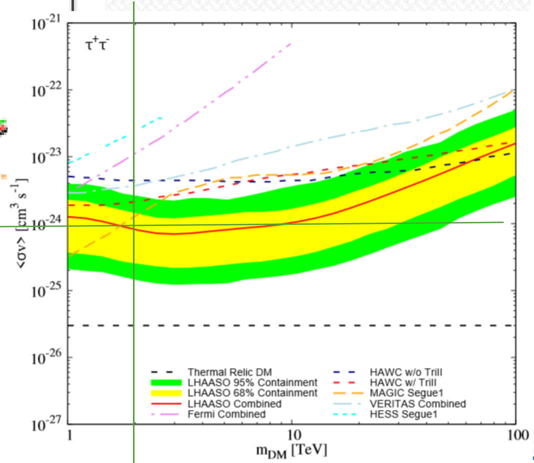
Heavy Dark Mater Search

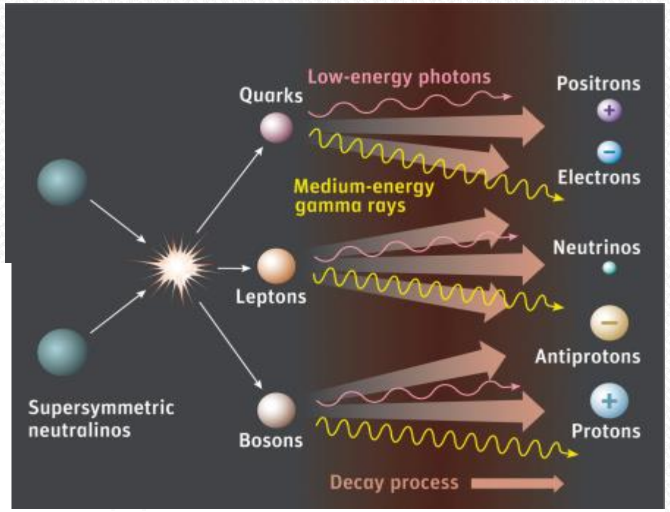
- Signals of annihilation or decay of DM particles
- ~ 20 dwarf galaxies in the FoV of LHAASO
- LHAASO has a good sensitivity to DM in Dwarf Galaxies for m_{DM} > 20 TeV









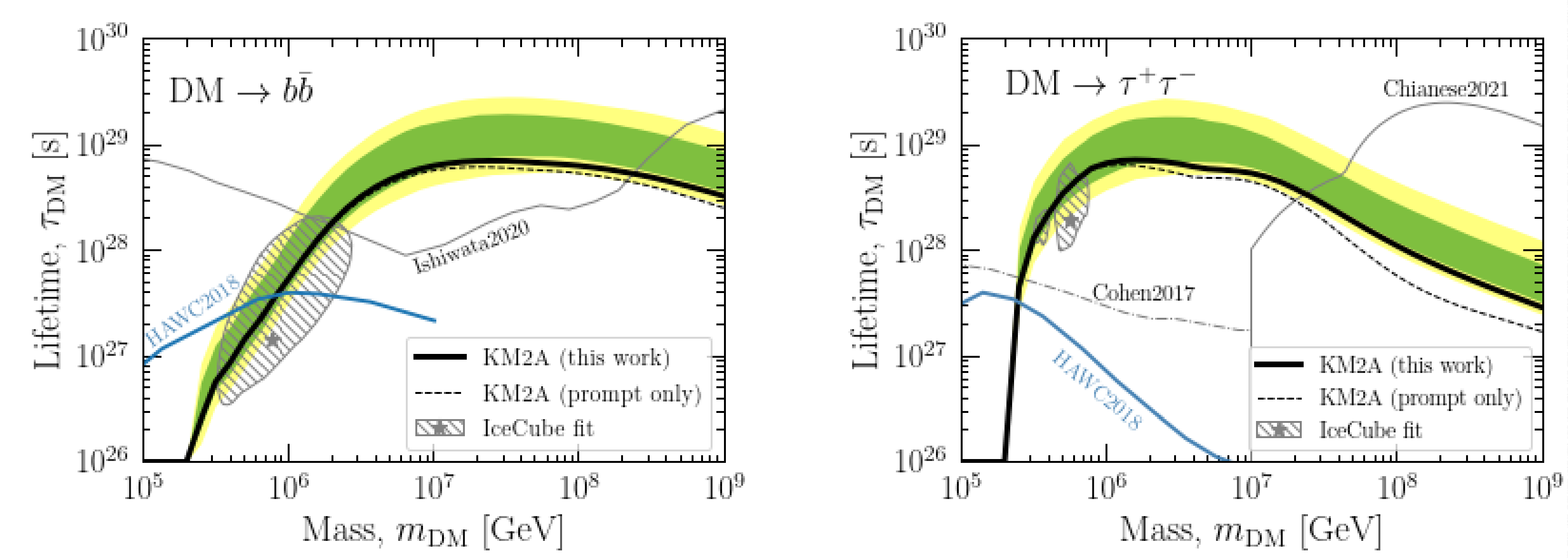


Source	RA. (deg)	DEC. (deg)	θ_{max} (deg)	$\log_{10} J_{obs}$ (GeV^{2}cm^{-5})
Boötes I	210.02	14.50	0.47	18.2 ± 0.4
Canes Venatici I	202.02	33.56	0.53	17.4 ± 0.3
Canes Venatici II	194.29	34.32	0.13	17.6 ± 0.4
Coma Berenices	186.74	23.90	0.31	19.0 ± 0.4
Draco	260.05	57.92	1.30	18.8 ± 0.1
Draco II*	238.20	64.56	–	18.1 ± 2.8
Hercules	247.76	12.79	0.28	16.9 ± 0.7
Leo I	152.12	12.30	0.45	17.8 ± 0.2
Leo II	168.37	22.15	0.23	18.0 ± 0.2
Leo IV	173.23	−0.54	0.16	16.3 ± 1.4
Leo V	172.79	2.22	0.07	16.4 ± 0.9
Pisces II*	344.63	5.95	–	16.9 ± 1.6
Segue 1	151.77	16.08	0.35	19.4 ± 0.3
Sextans	153.26	−1.61	1.70	17.5 ± 0.2
Triangulum II*	33.32	36.18	–	20.9 ± 1.3
Ursa Major I	158.71	51.92	0.43	17.9 ± 0.5
Ursa Major II	132.87	63.13	0.53	19.4 ± 0.4
Ursa Minor	227.28	67.23	1.37	18.9 ± 0.2
Willman 1*	162.34	51.05	–	19.5 ± 0.9

Dwarf Galaxies in the FoV of LHAASO

Heavy Dark Mater Search

- Signals of annihilation or decay of DM particles
- And good for MD in the galactic halo for m_{DM} > 200 TeV



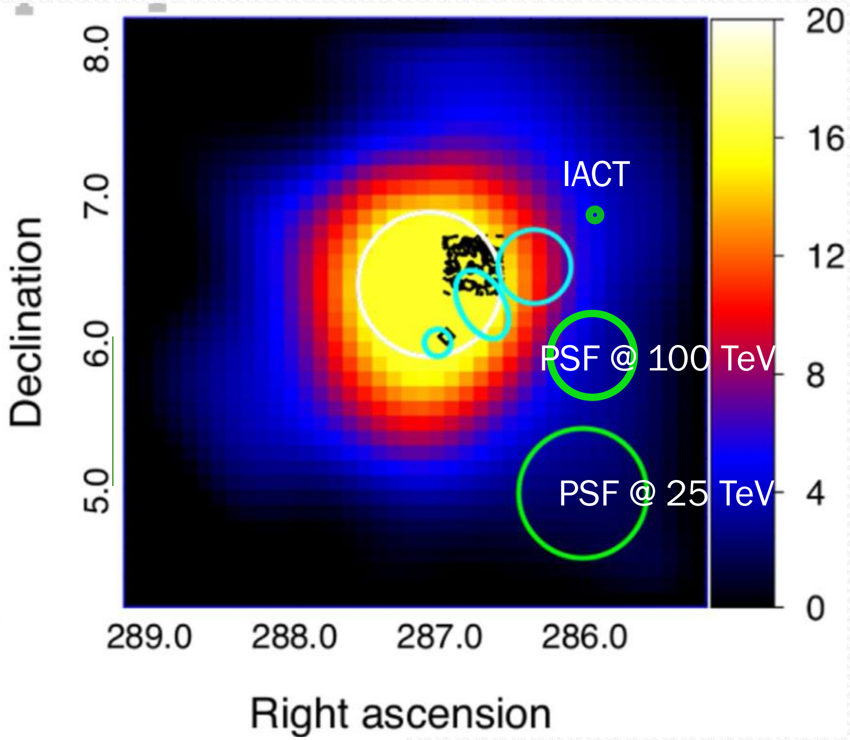
Accepted by PRL, https://arxiv.org/abs/2210.15989

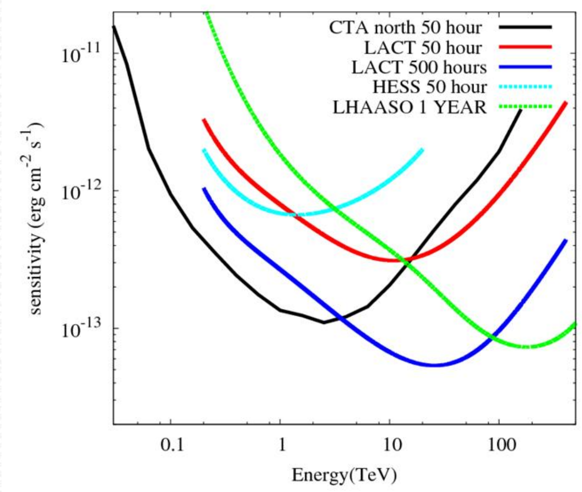
Summary

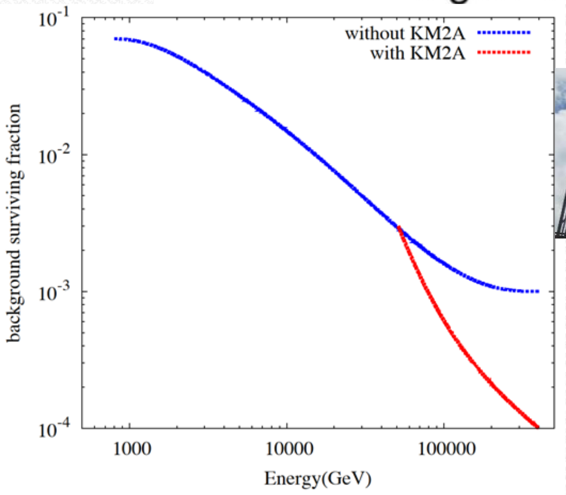
- GeV/TeV γ-ray are very fruitful, now step in PeV era
- Diffuse photon flux is measured, interpretation is still open issue
- 7100+ sources in GeV, 300 in TeV and 43 above 100 TeV are detected and published in catalogs w/~40% of them unidentified
- Lots of new phenomena in new territory
- Radiation mechanisms and particle acceleration processes are still far to be understood even for few well identified sources
- Fundamental issues, LIV and DM, are tested w/ limits renewed constantly
- Upgrading in instrumentation is certainly demanded

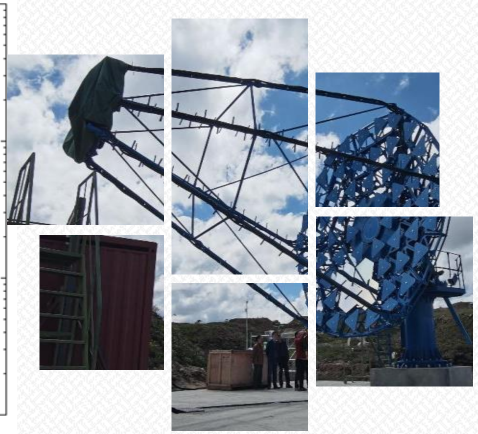
Spatial Resolution in UHE band

- In UHE band, EAS array resolution: 0.26°, difficult to resolve the fine structure in source region
- In Northern sky, we need the IACT resolution above 100 TeV
- CTA North and ASTRI? Seem to be not sufficient
- LACT is an idea of
  - *using IACT technique*
  - *taking the advantage of μ-content measured by LHAASO*
  - *operating 500 hrs on each PeVatron candidate*
  - *To reach the required sensitivity at 100 TeV*



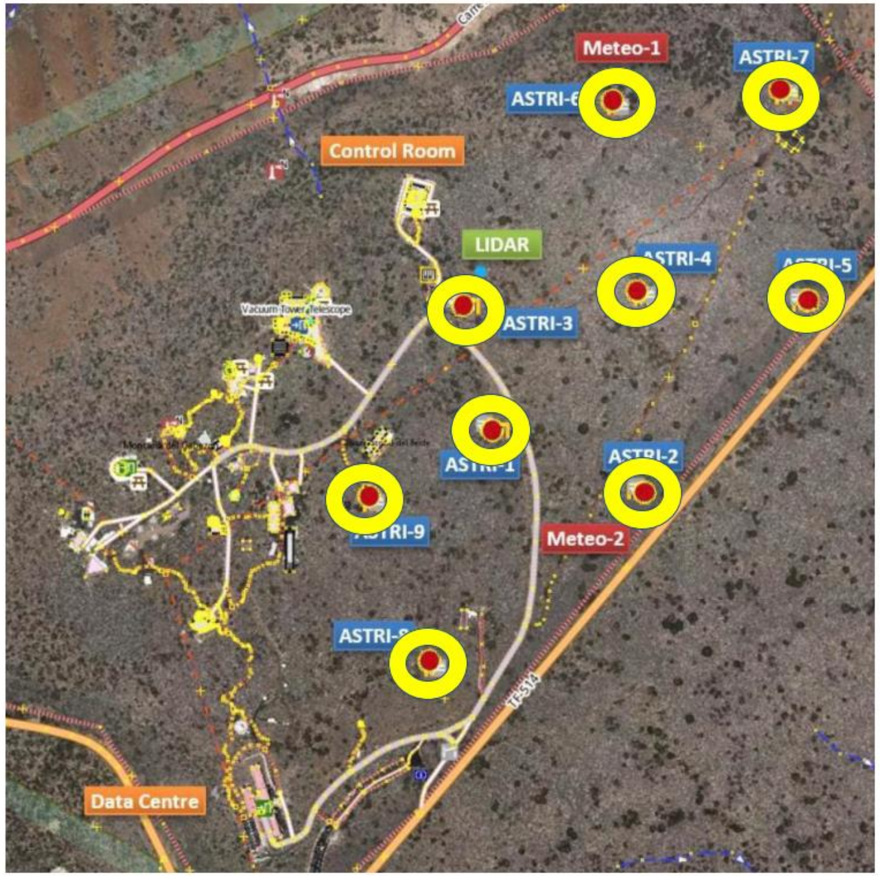


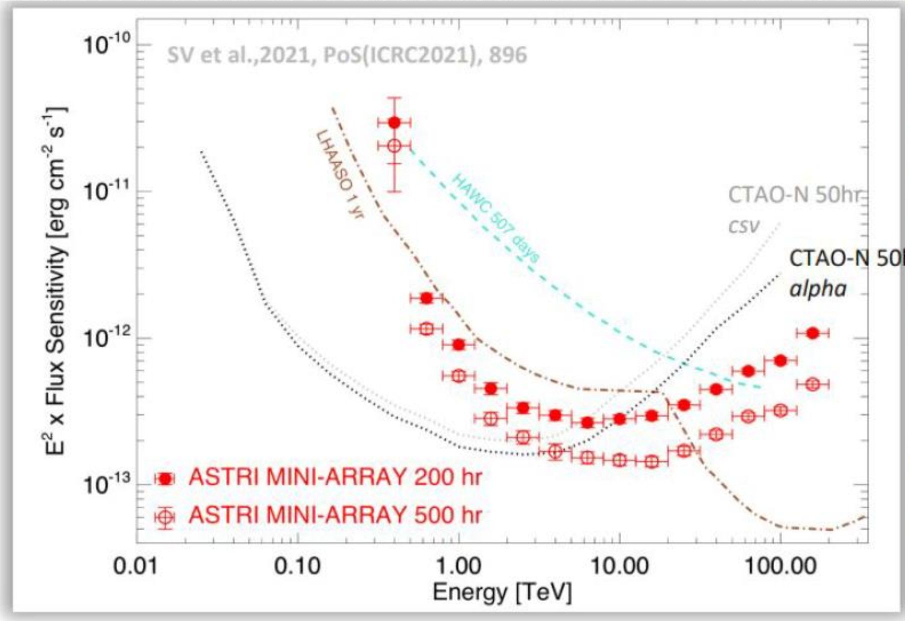




ASTRI

- 9 SSTs forms an array
- Covering 0.5 km^2 ?
- Sensitive around 10 TeV
- Built by 2025
- Strategy: **500 hrs** on one source





June 2022

Phase 0
- 1 Telescope Structure
- m-ICT

Spring 2023

Phase 1
- 3 Telescope Structures

Late 2023

Phase 2
- 3 Telescope Structures + Cameras

Late 2024

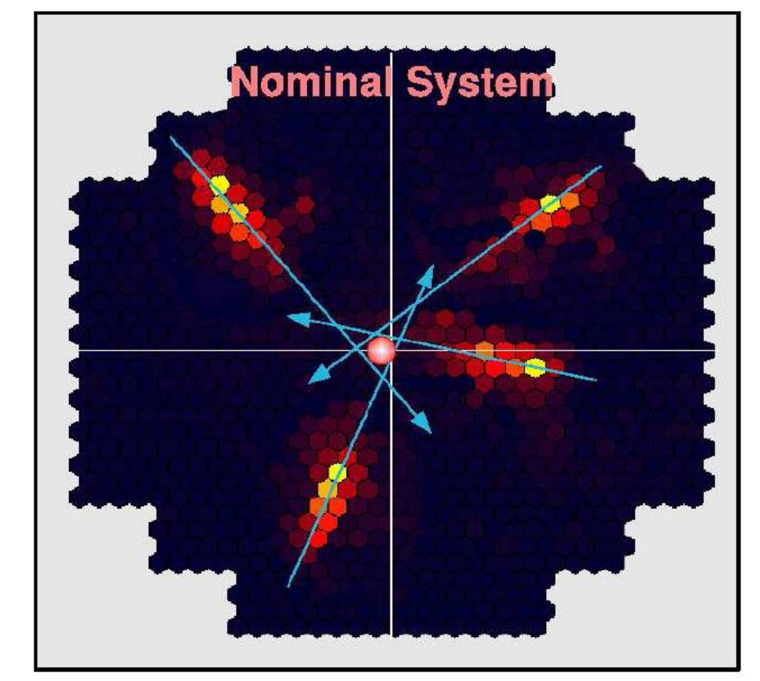
Phase 3
- Full Array

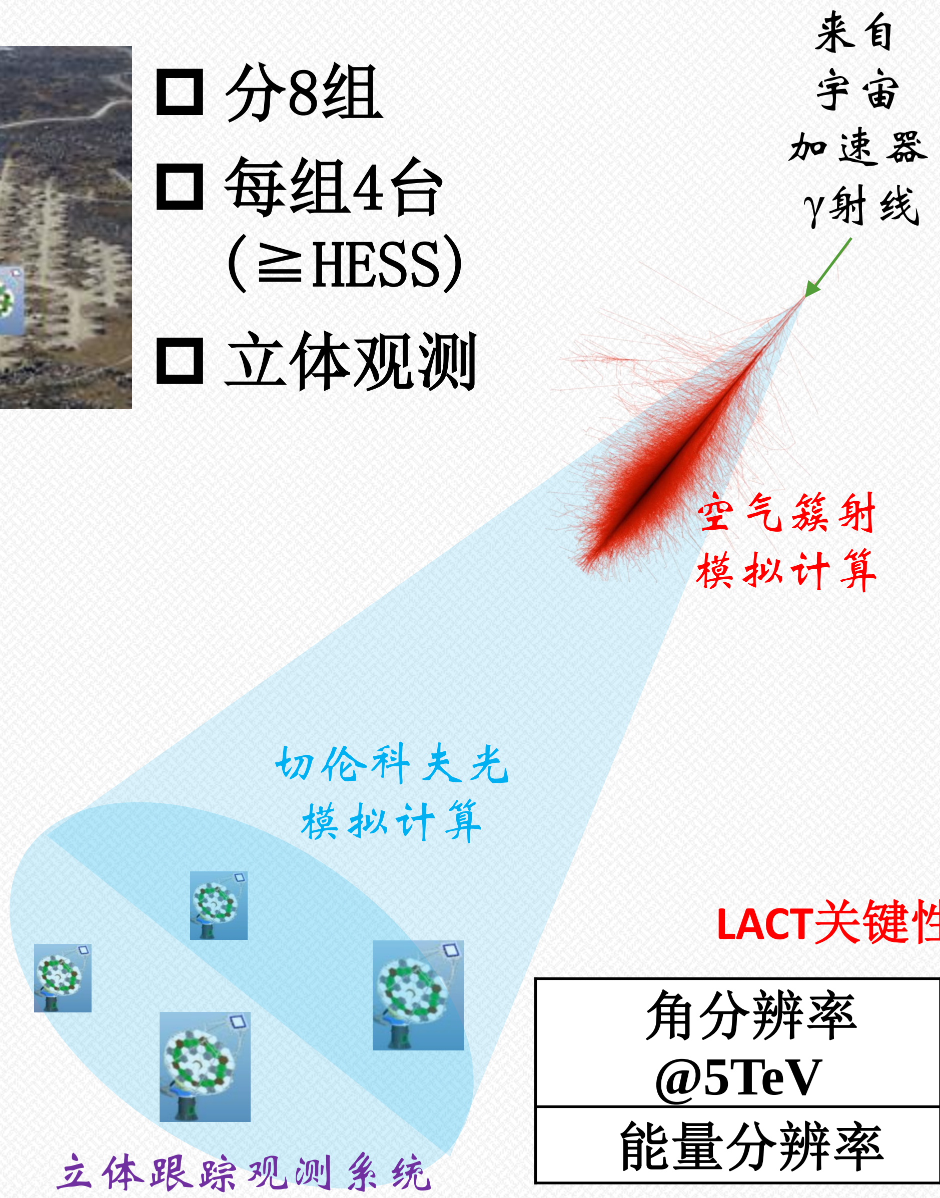
Mid 2025

Thanks for attention!

大型超高能伽马源立体跟踪观测设备（LACT）

- 分8组
- 每组4台
  （≧HESS）
- 立体观测

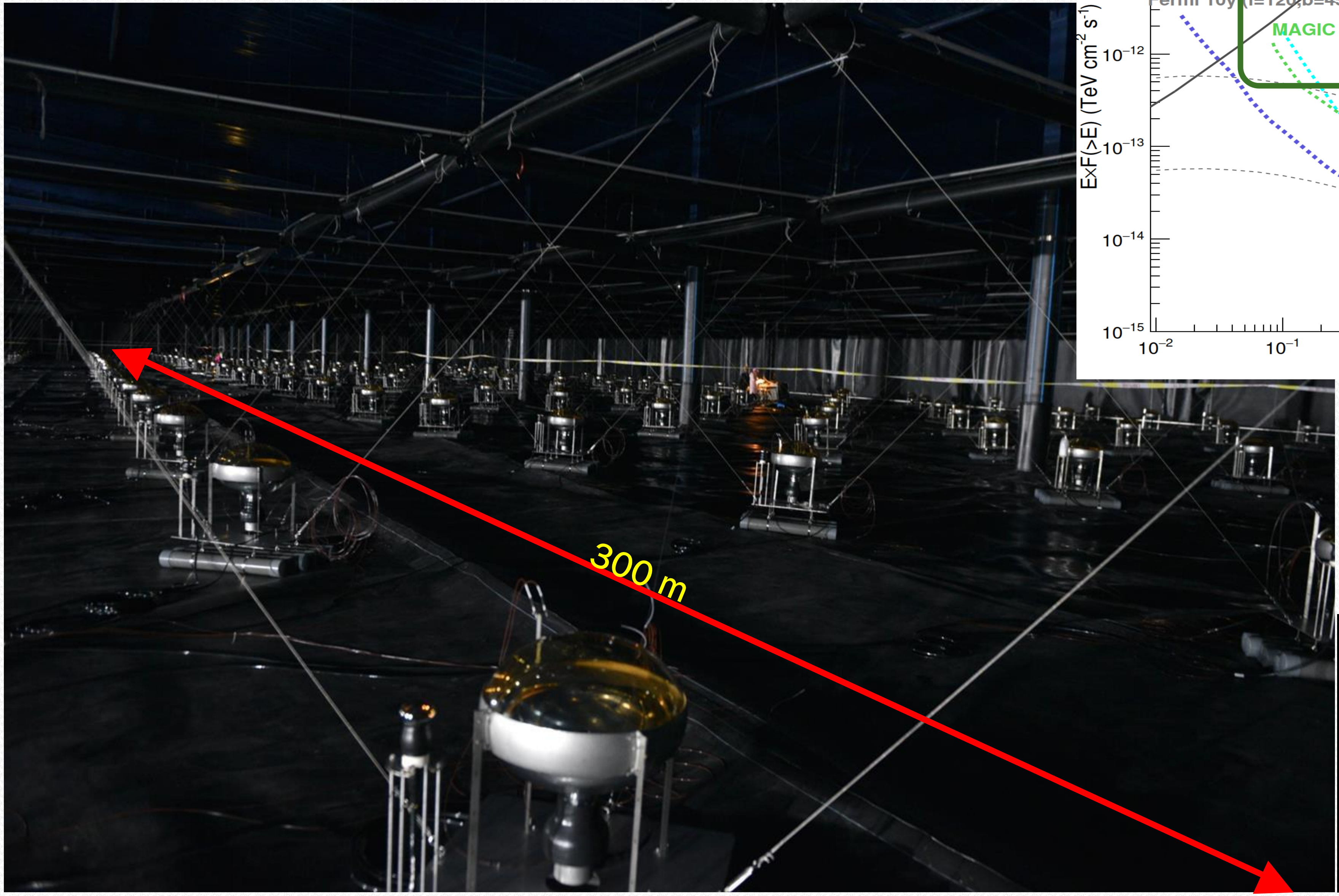


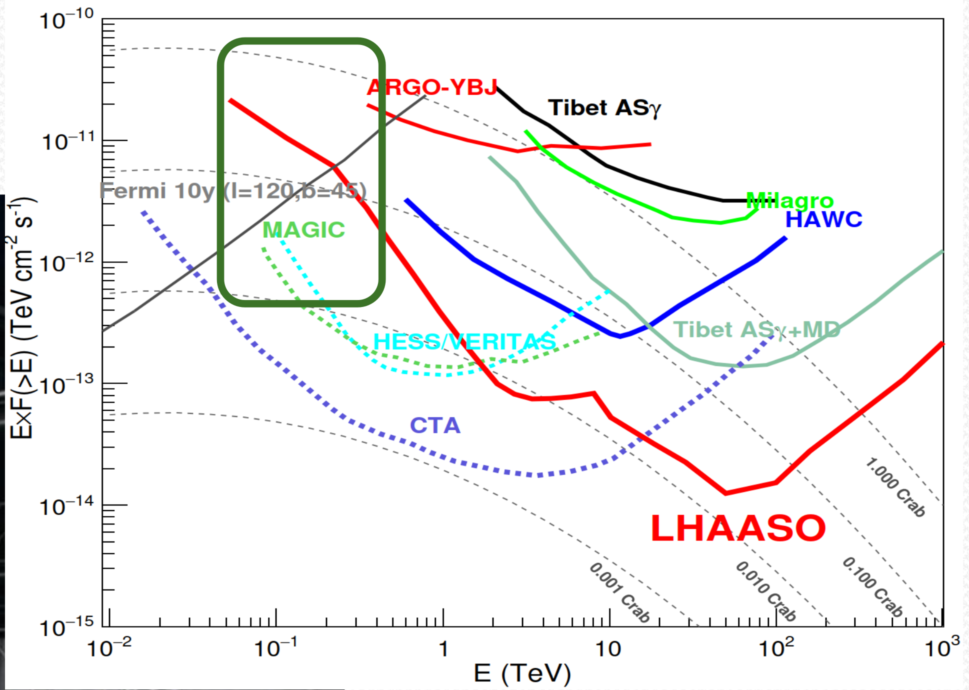


LACT关键性能指标

角分辨率 @5TeV	<0.06°
能量分辨率	<15%

Water Cherenkov Detector Array (WCDA) with 20” PMTs

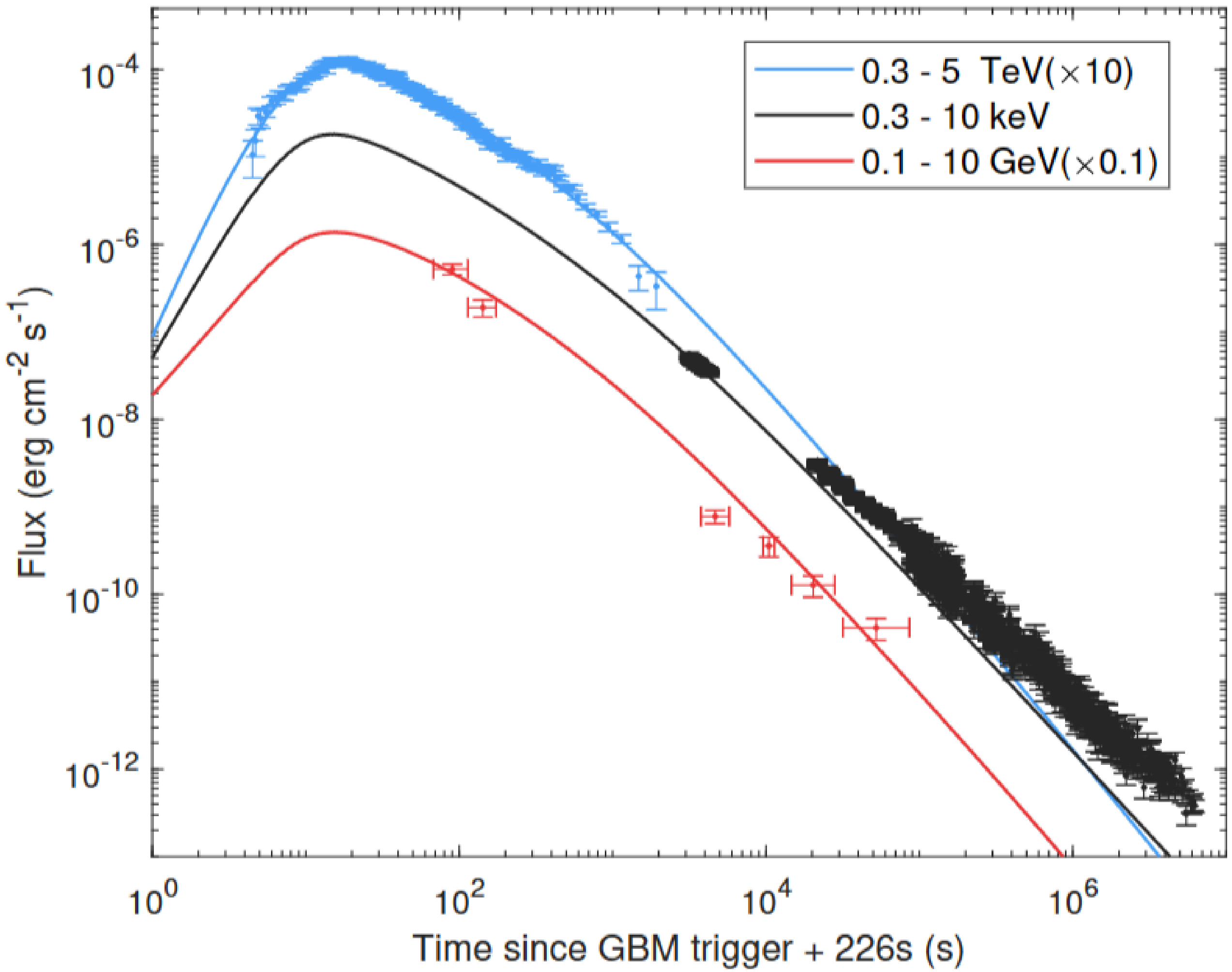




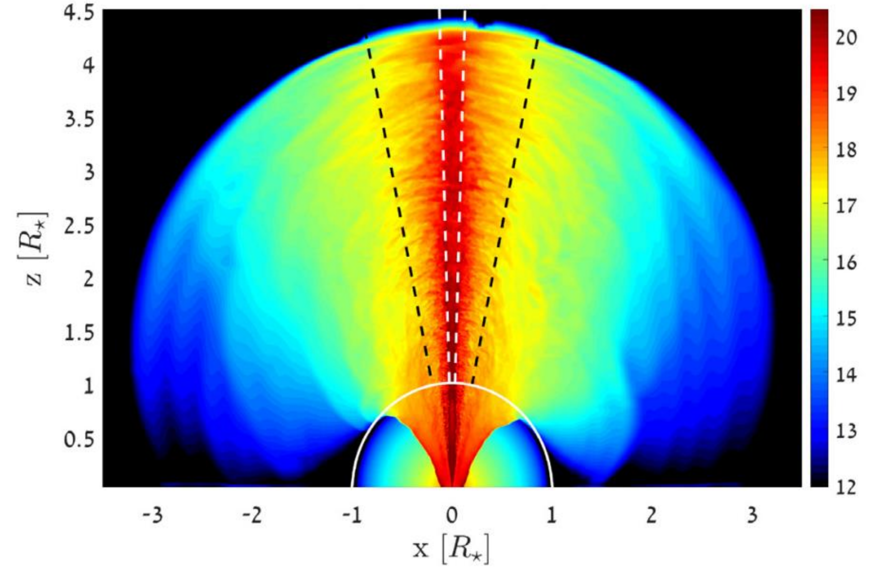
20” PMTs

Deployed in 70% WCDA

Inner core is not sufficient… ?



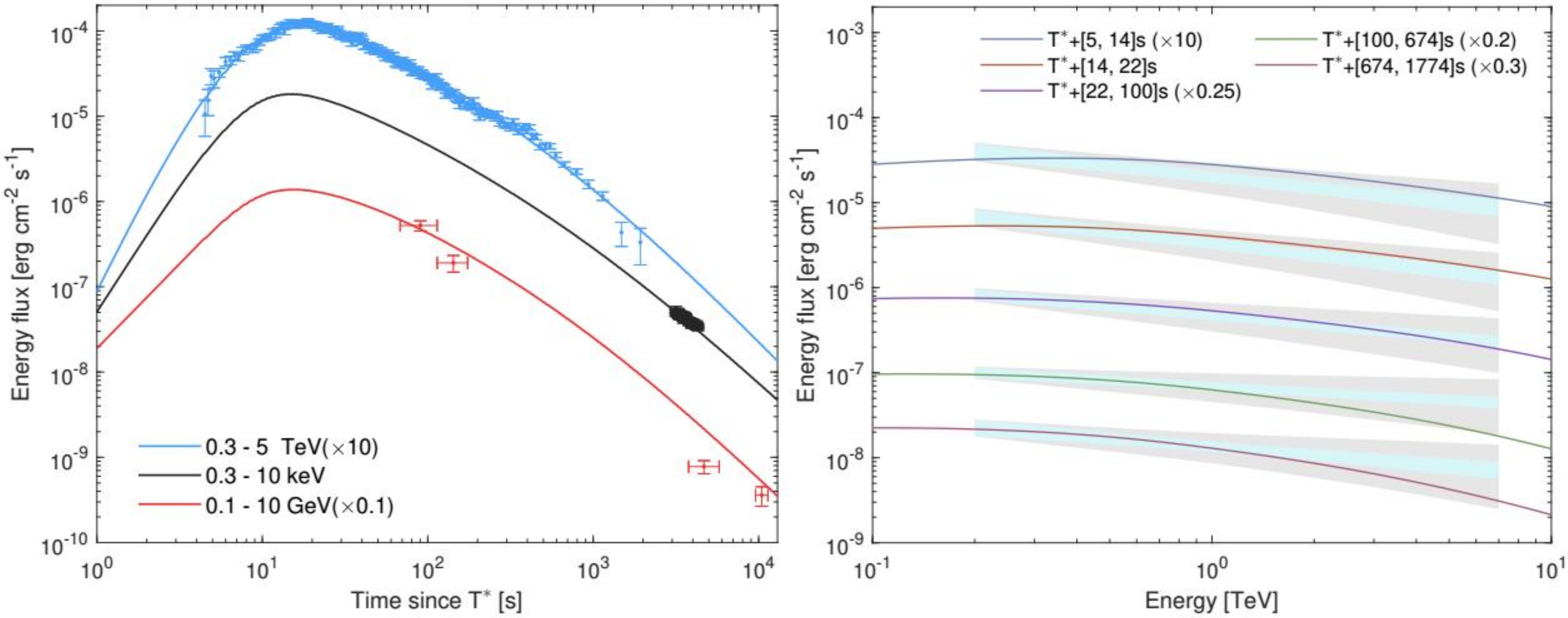
- Some wider components are outside the core?
- Implying an "structured jet"



Gottlieb et al. 2021

Multi-wavelength modelling of afterglow synchrotron + SSC:

simultaneously fit light-curves in ΔE and time-sliding SEDs



$$E_k = 1.5 \times 10^{55}\,\text{erg},\ \Gamma_0 = 560,\ \epsilon_e = 0.025,\ \epsilon_B = 6 \times 10^{-4},\ p = 2.2,\ n = 0.4\,\text{cm}^{-3} \text{ and } \theta_0 = 0.8^\circ\ .$$

Instruments in 3-generations developments in last 30 years

Key technical issues

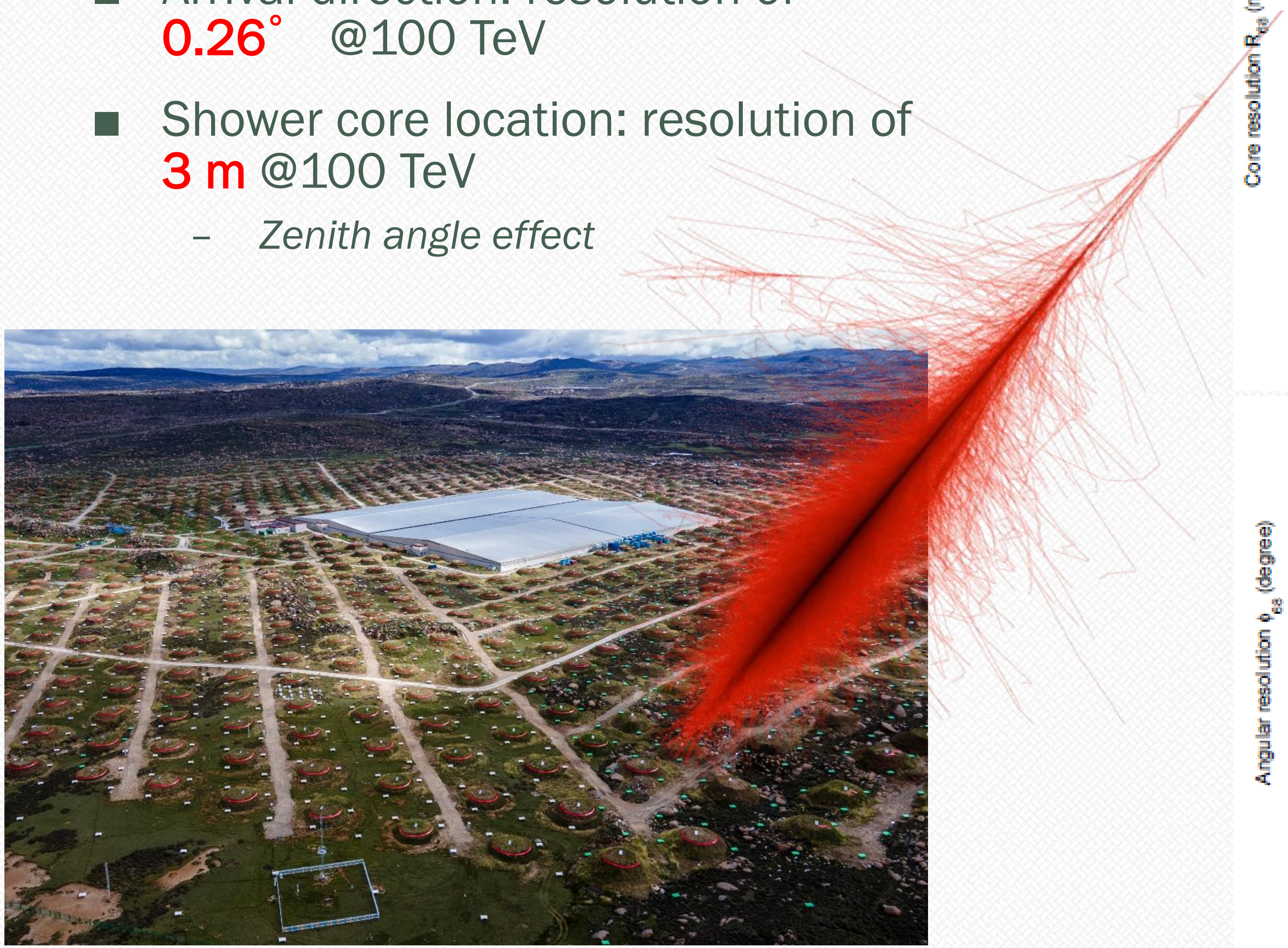
- Altitudes of Arrays
- Filling factor
- γ/CR separation
- Size of Arrays

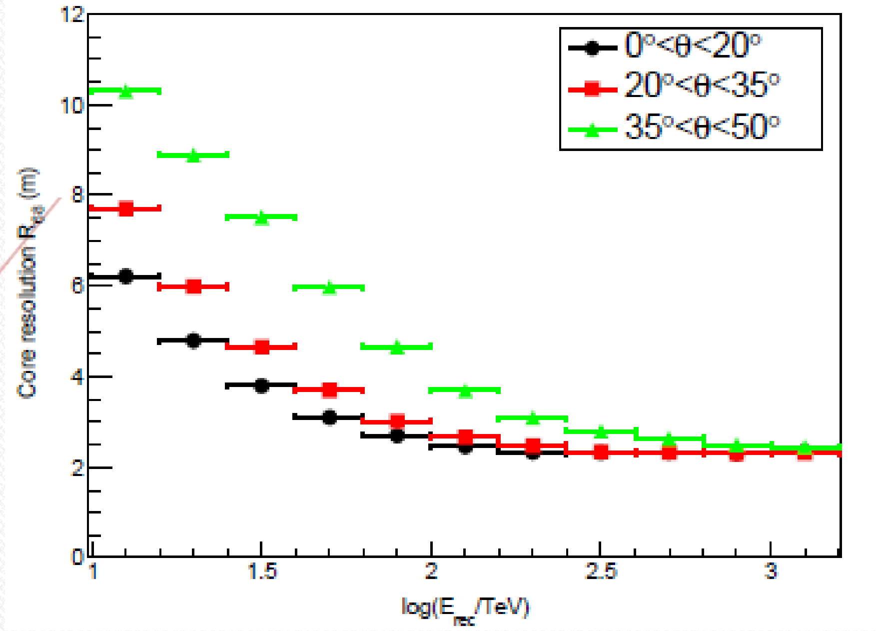
Cutting edge Techniques

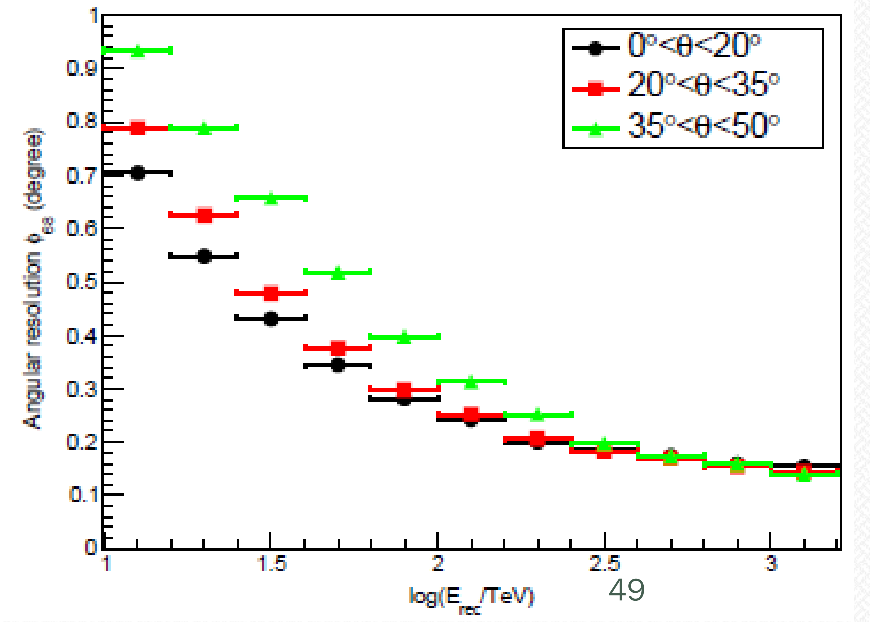
- 0.2 ns clock synchronization
- 20” PMTs
- Inexpensive solution of μ-content detection
- Trigger-less DAQ

Performances

- Arrival direction: resolution of **0.26°** @100 TeV
- Shower core location: resolution of **3 m** @100 TeV
  - *Zenith angle effect*

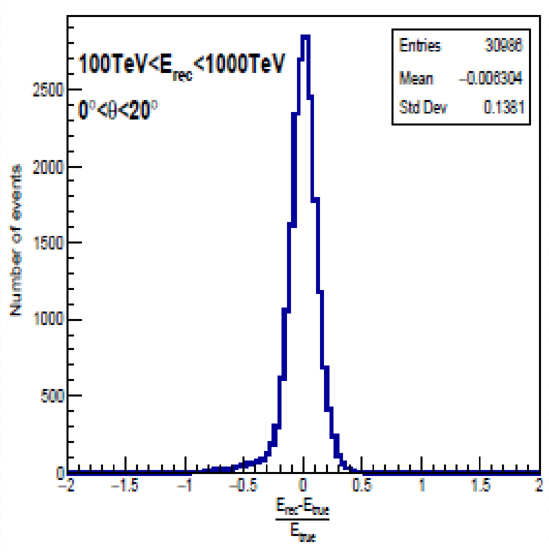


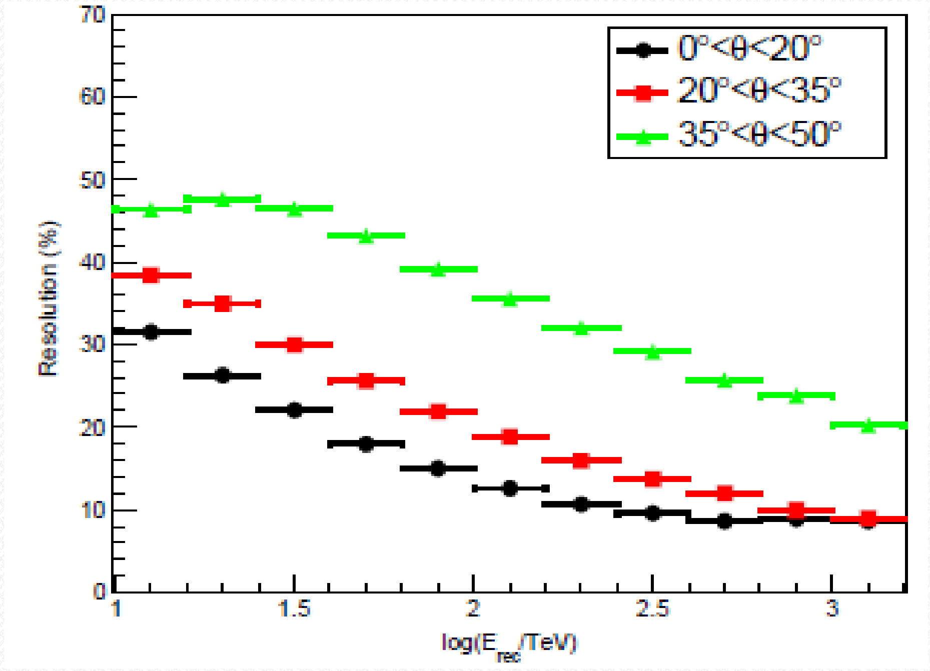


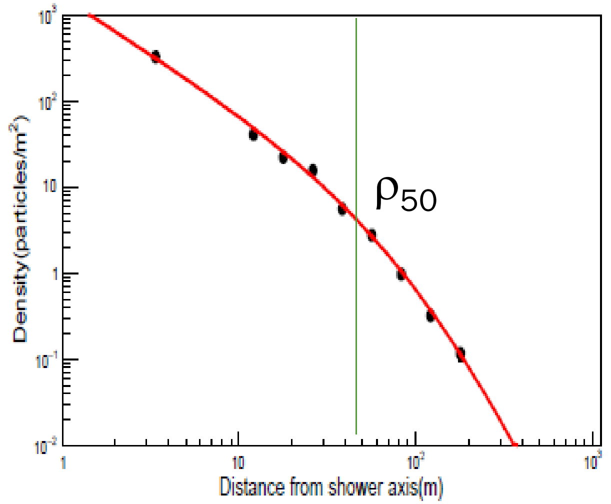


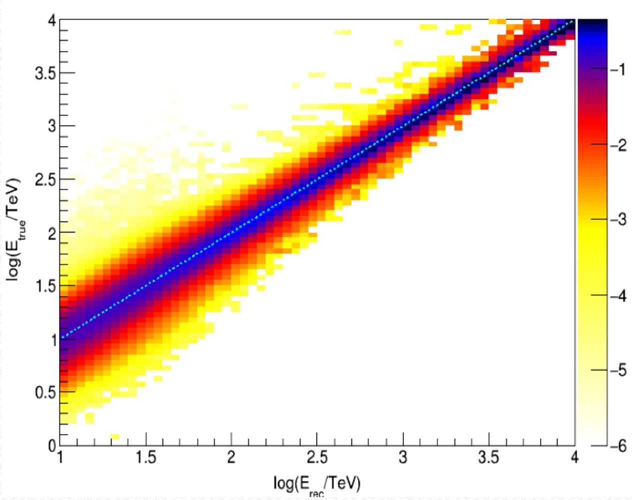
γ-ray Energy Resolution

- **δE/E~14%**
  (E>100 TeV)
- Linear response
  - Lateral distribution
  - ρ_{50} E-estimator



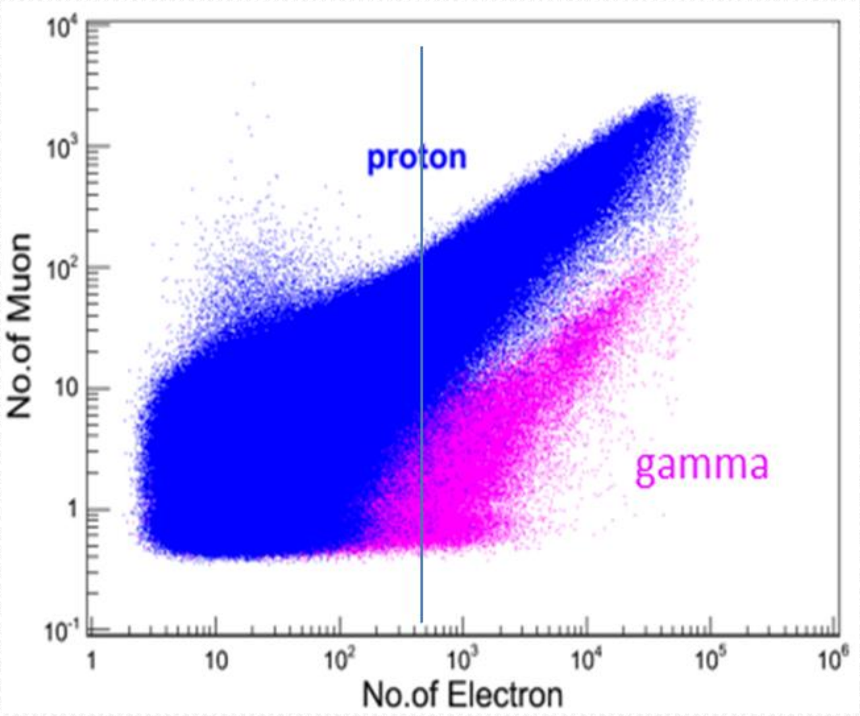


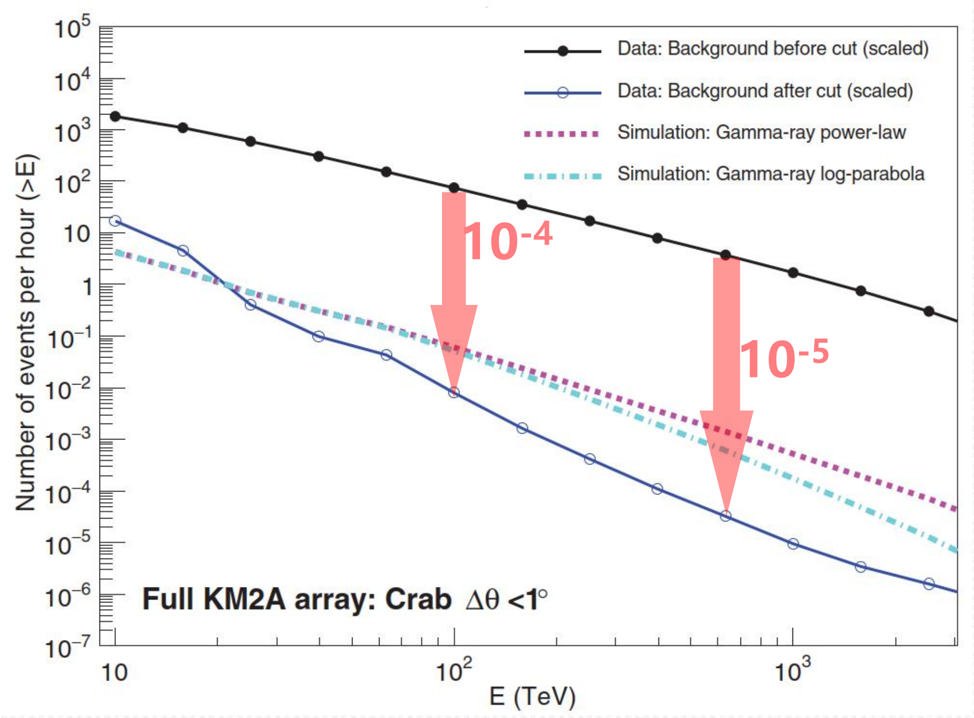




CR background Rejection Power

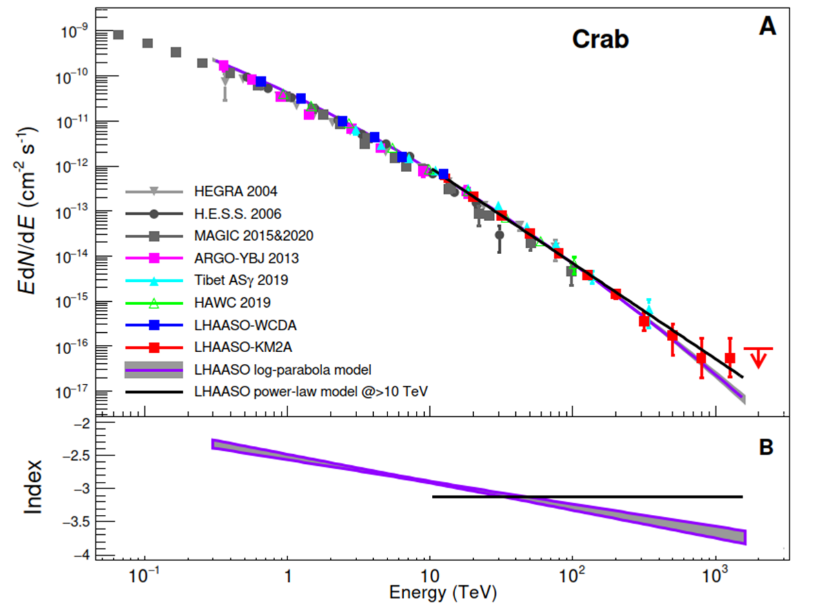
- Counting number of measured muons in a shower
- Cutting on ratio $N_{\mu}/N_{e}<1/230$
- BG-free ($N_{\gamma}>10N_{CR}$) Photon Counting for showers E>100 TeV from the Crab

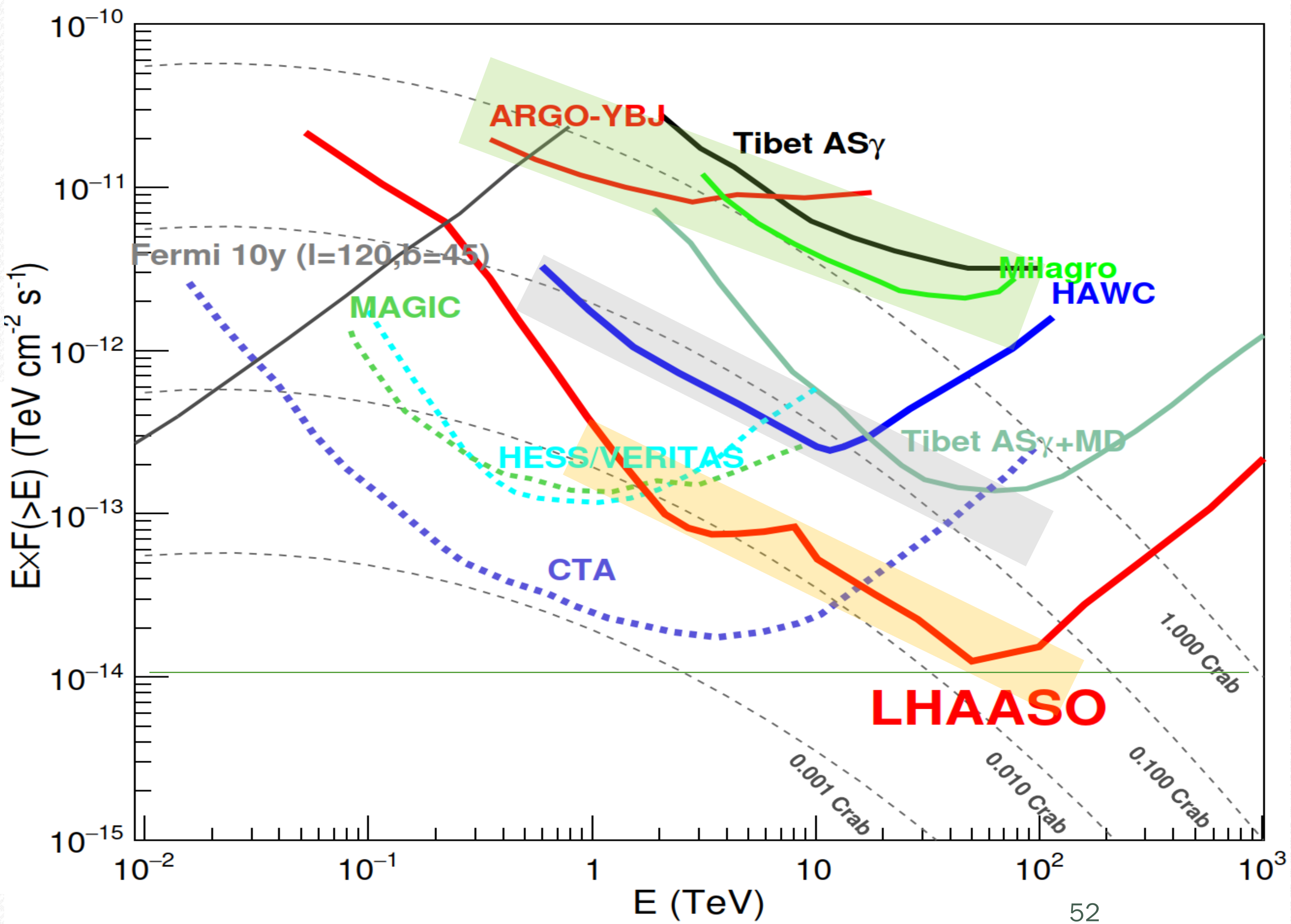




Survey Sensitivity

- 3^{rd} Generation of the survey device reaches the sensitivity of 10^{-14} $TeV/cm^2/s$, i.e. 12 mCU
- Precise measurements for SEDs

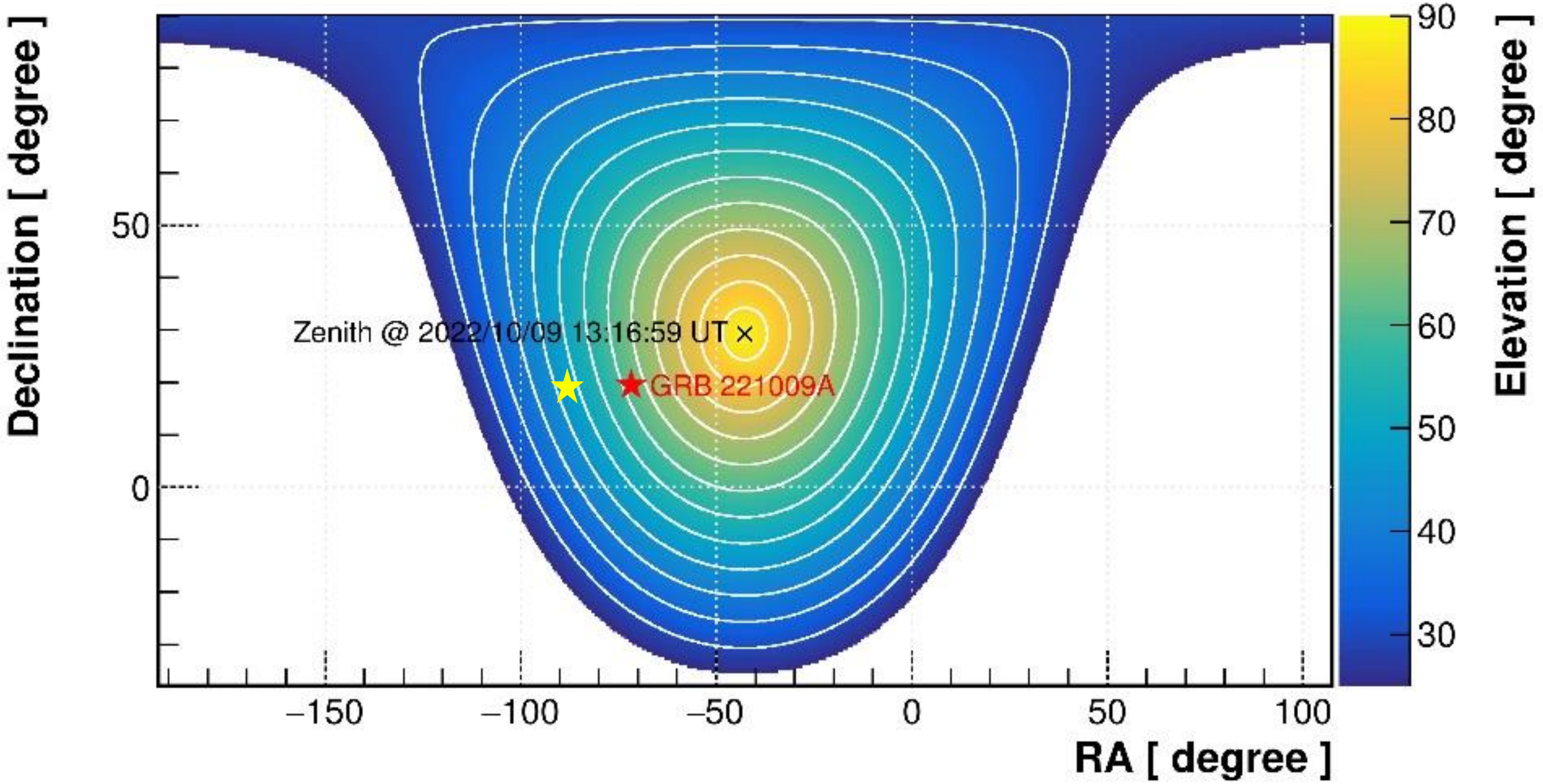




Very wide FoV, Continuously monitoring

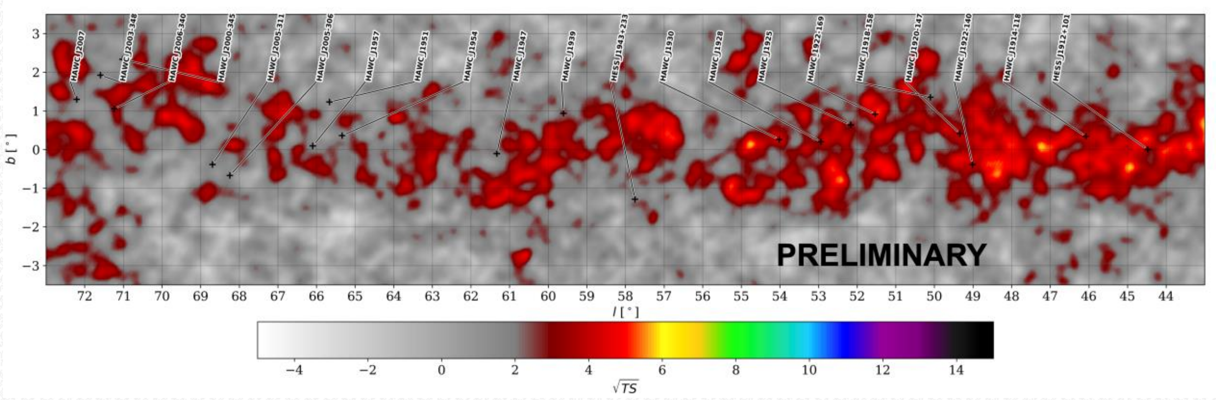
- FoV: ~1/6 of entire sky at any moment, good for very extended structures
- 24 hrs monitoring all sources for variability, long term variability
- Transient phenomena

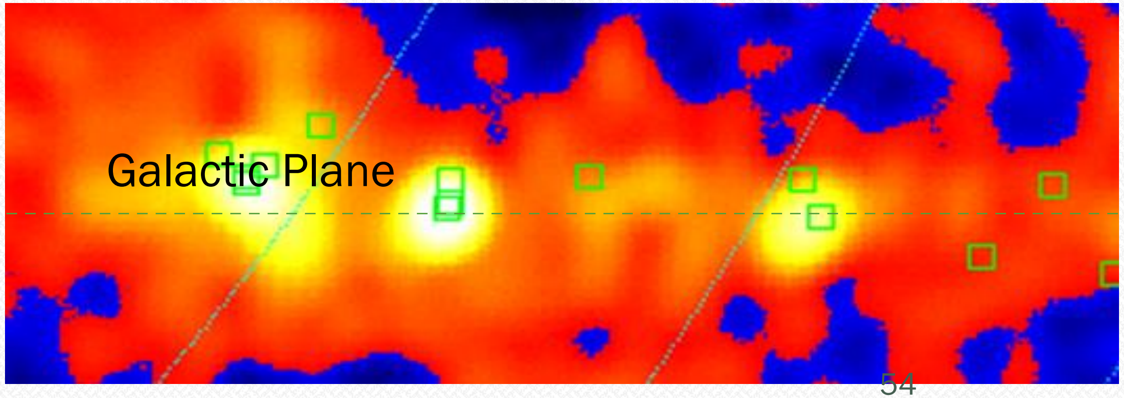
e.g. GRB221009A



Galactic Diffuse γ-ray Measurement

- Currently, HAWC result is preliminary
- LHAASO's result is under preparation
- ASγ has published GDE distributions with 0.9 PeV photon detected

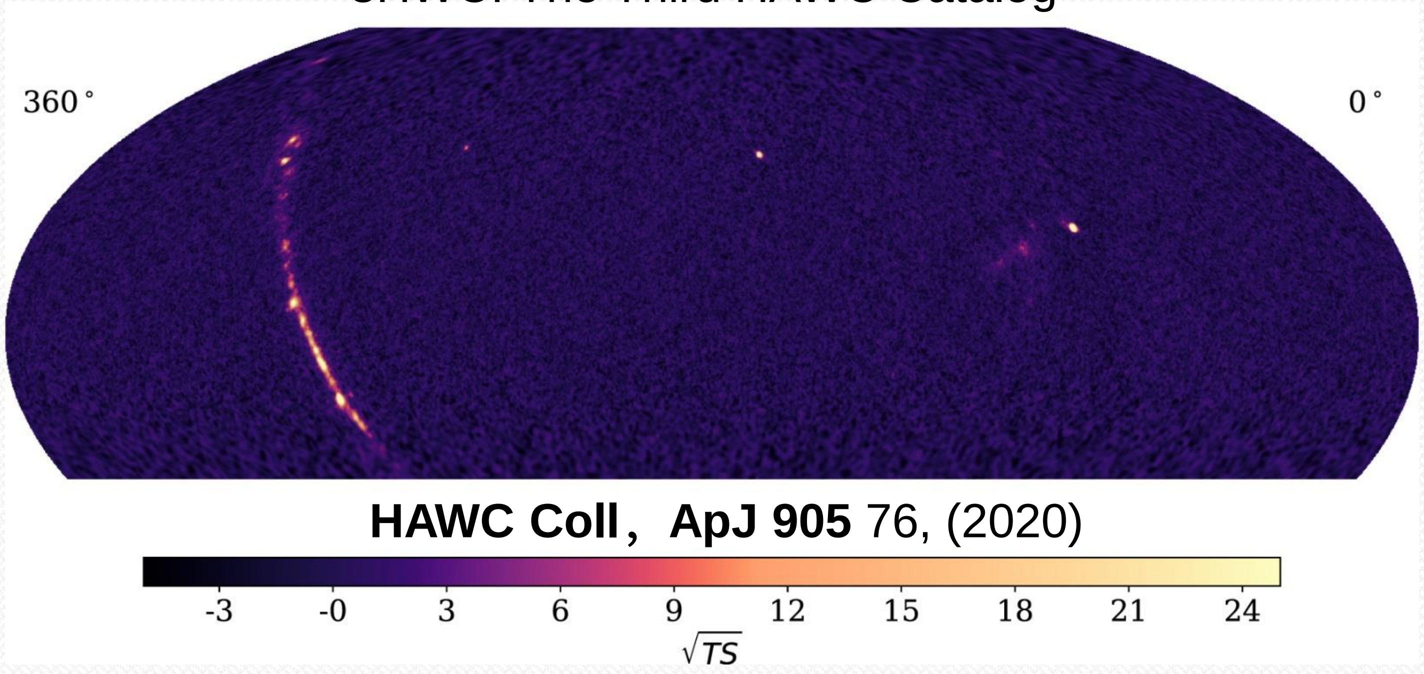




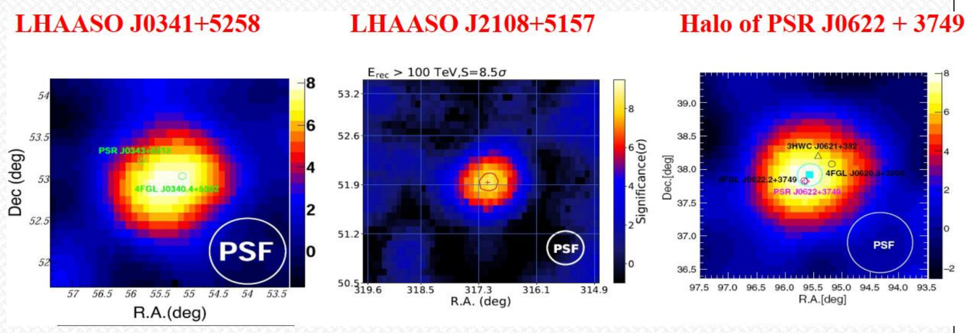
TeV/UHE Source Catalogs:

- HAWC: Ver-3 Catalog of γ-ray sources
- LHAASO: PeVatron Catalog (Ver-0)
- LHAASO will publish the Ver-1 Catalog of VHE/UHE Catalog of γ-ray sources

3HWC: The Third HAWC Catalog



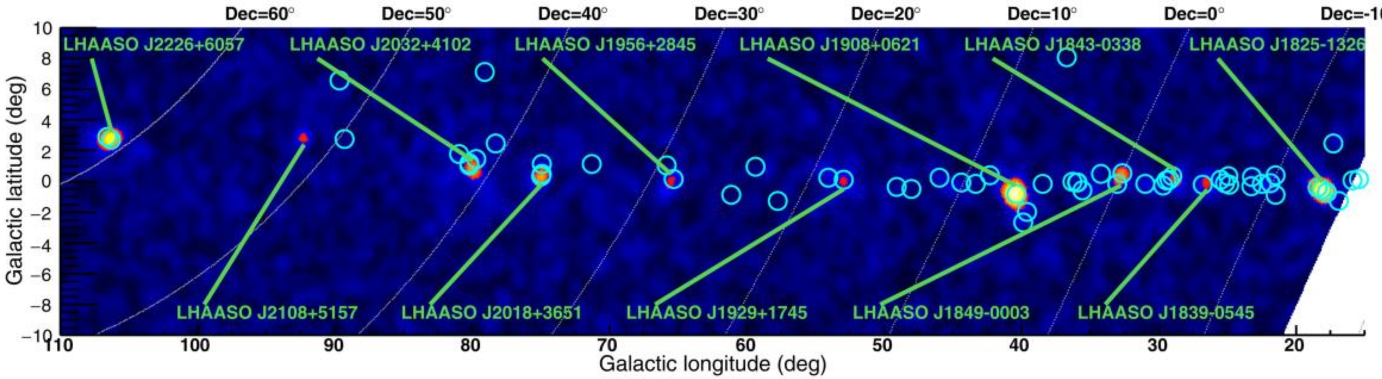
HAWC Coll, **ApJ 905** 76, (2020)



ApJL 917:L4 (2021)

ApJL 919:L22 (2021)

PRL 126:241103 (2021)

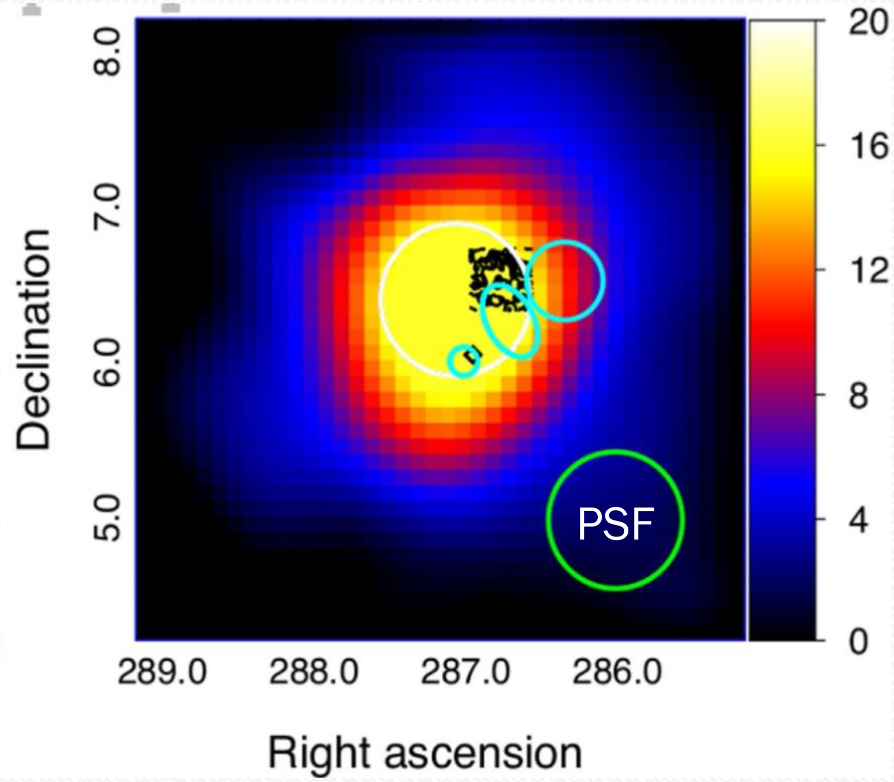


LHAASO Coll., *Nature*, 594, 33-36, 2021

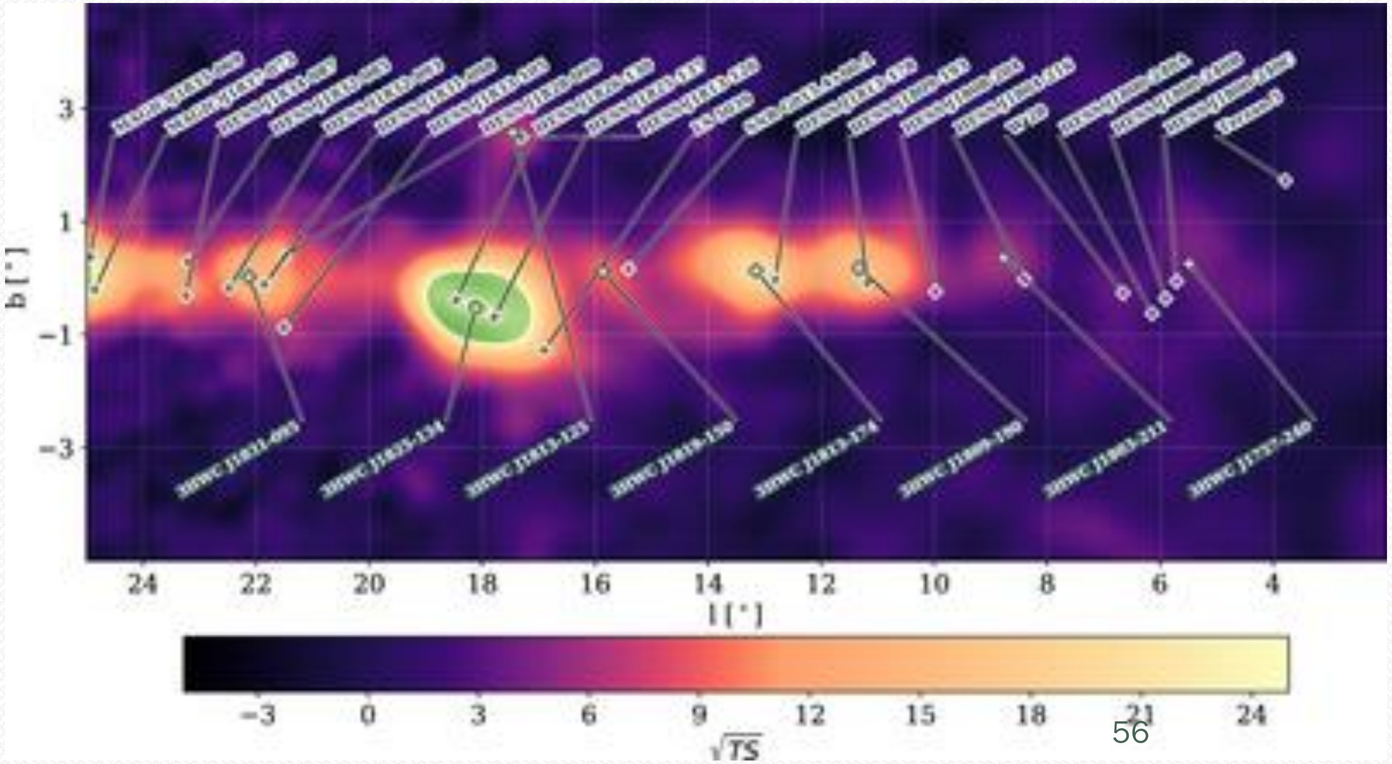
Morphology Measurements

- PSF ~ 0.3°
- Good for extended sources
- **A big issue of the resolution!**

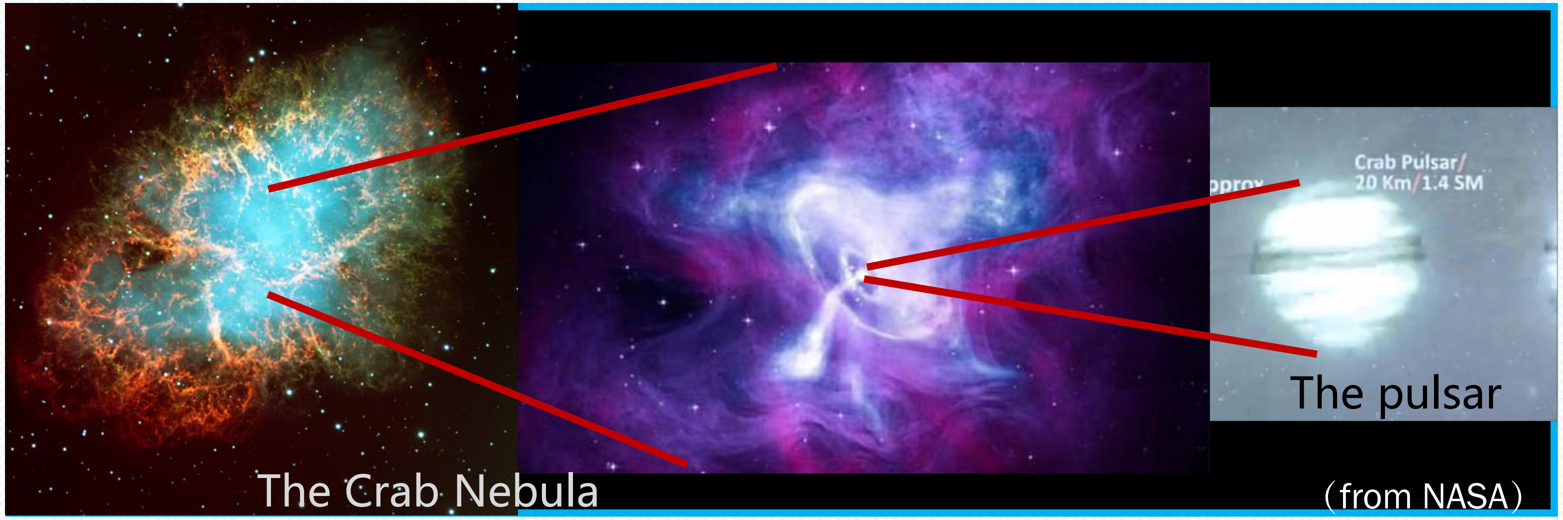
LHAASO Coll., *Nature*, 594, 33-36, 2021



HAWC Coll., ApJ 905 76 (2020)



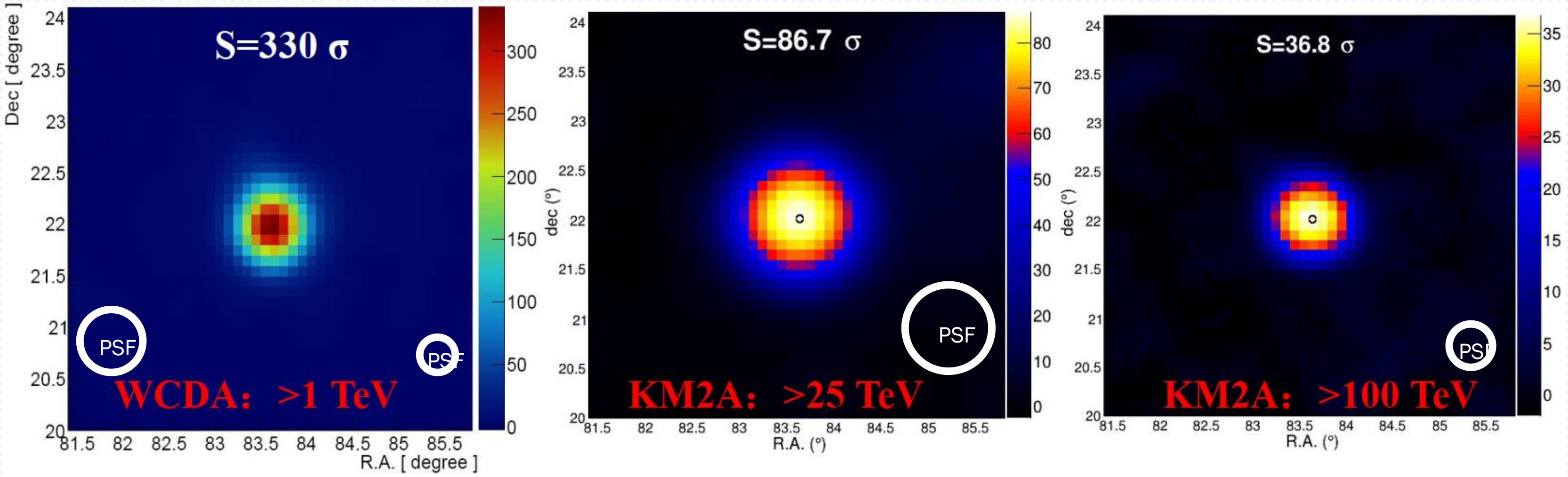
Standard candle for γ-ray Observation

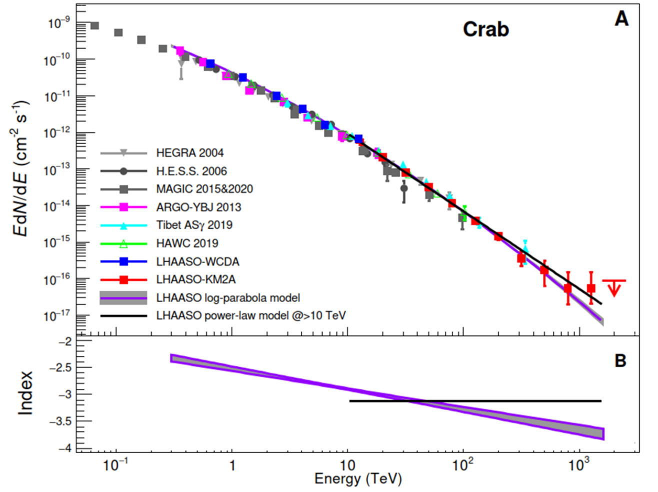


The coverage of 3.5 orders of magnitudes of energy

1 - 12 TeV	25-100 TeV	0.1-1.2 PeV
PSF: 0.22°	0.30°	0.15°

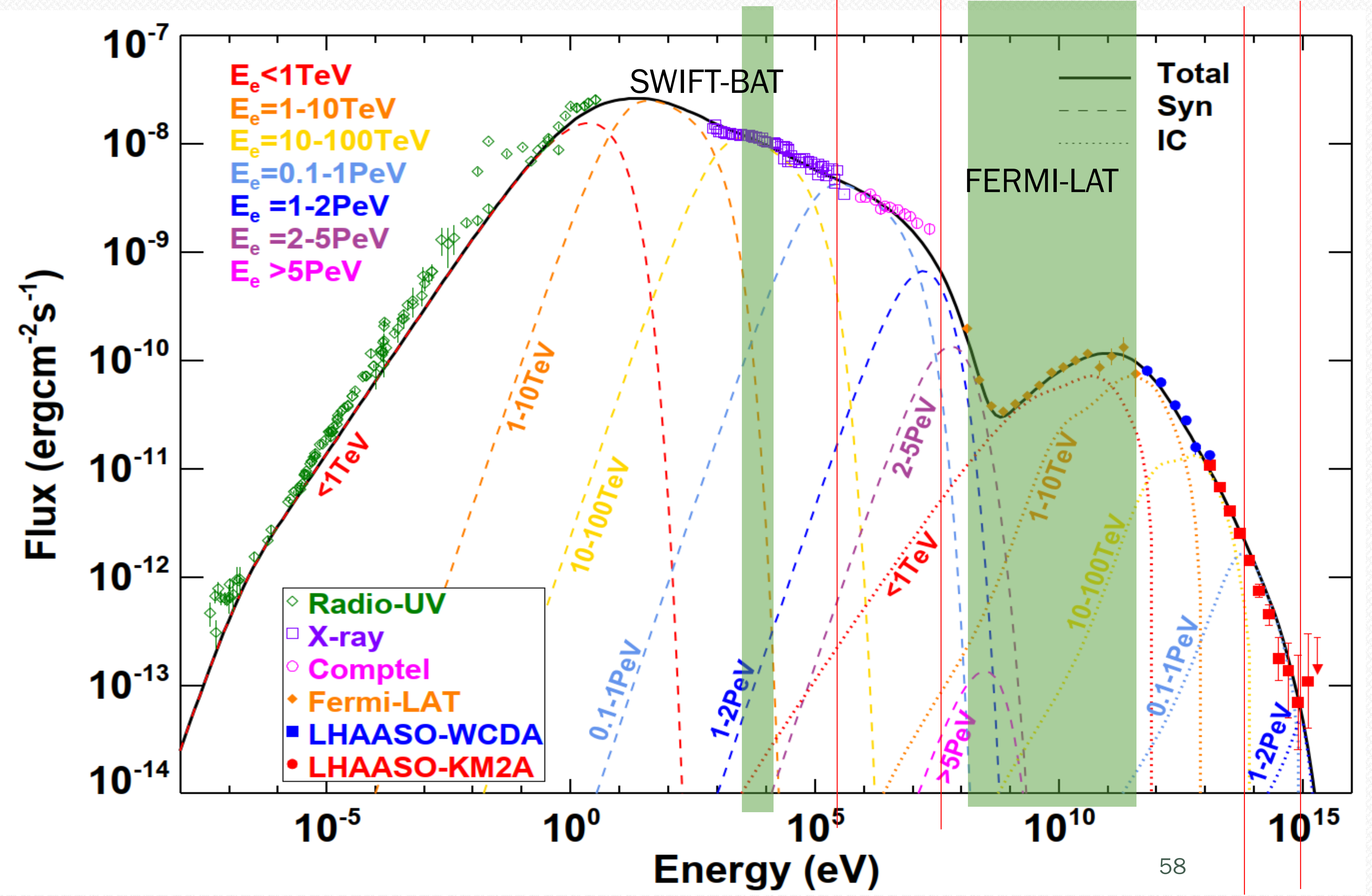
Pointing accuracy: 0.01°





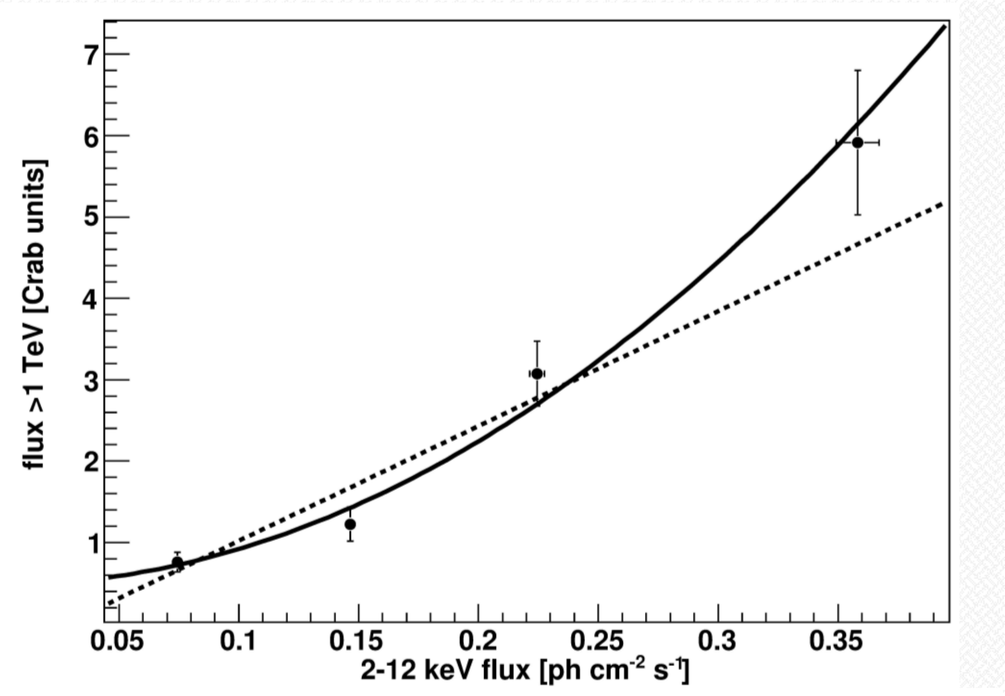
Electronic Origin of the Crab Radiation

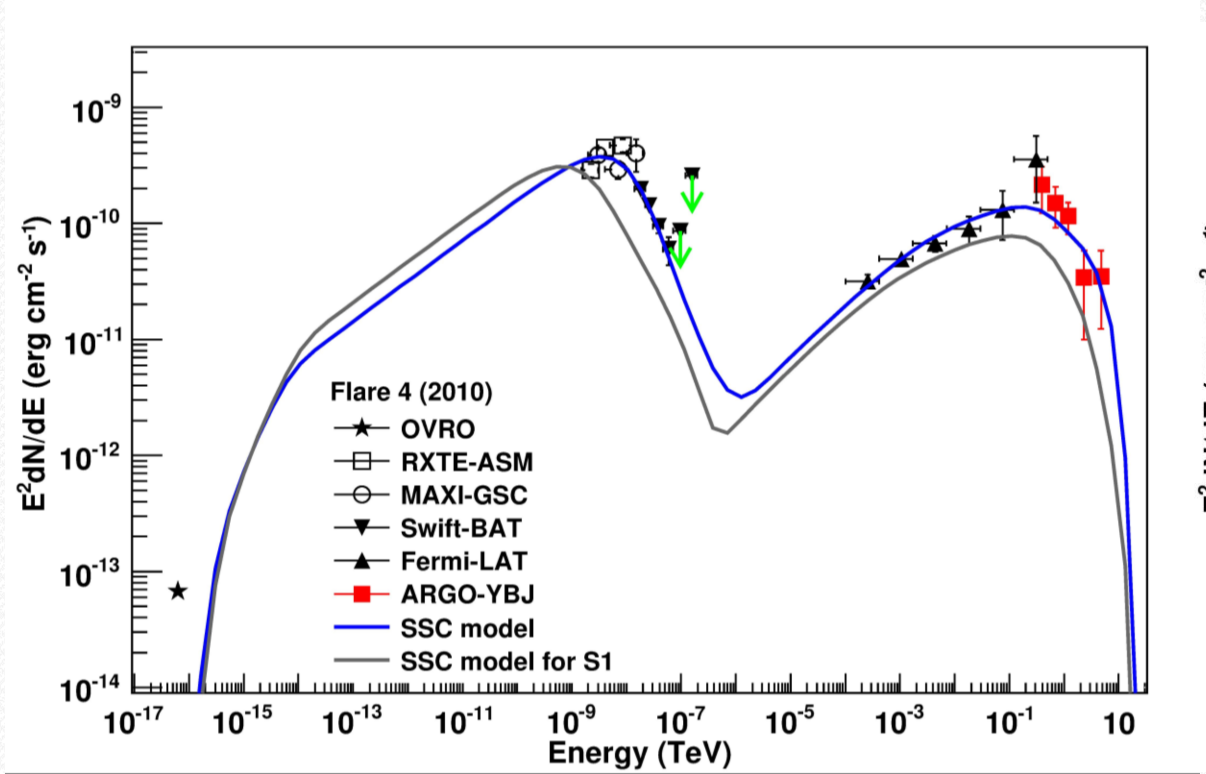
- 22 decades
- One bulk of e^+s & e^-s
- Synchrotron radiation
- Inverse Compton scattering

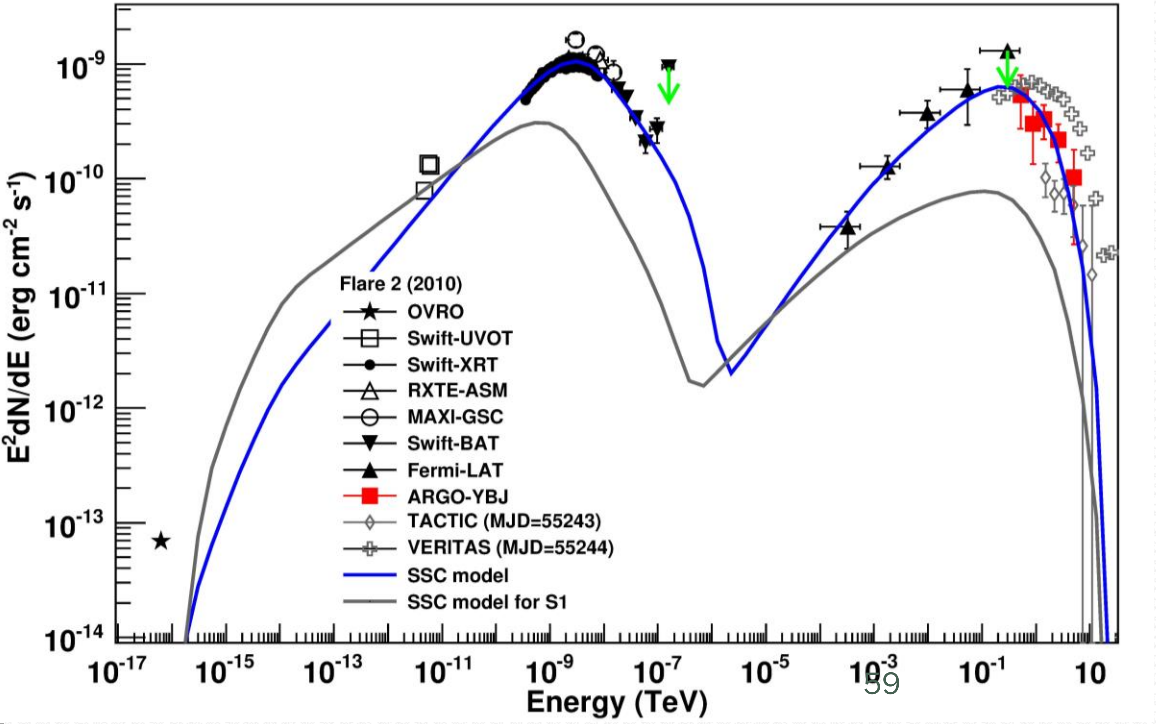


Multi-wavelength observation of Mrk 421

- Spectral Energy Distributions
  - Good correlation between X-ray and γ-ray fluxes
  - Reads a supportive evidence of SSC as well
  - VERITAS seems found harder spectrum in VHE band

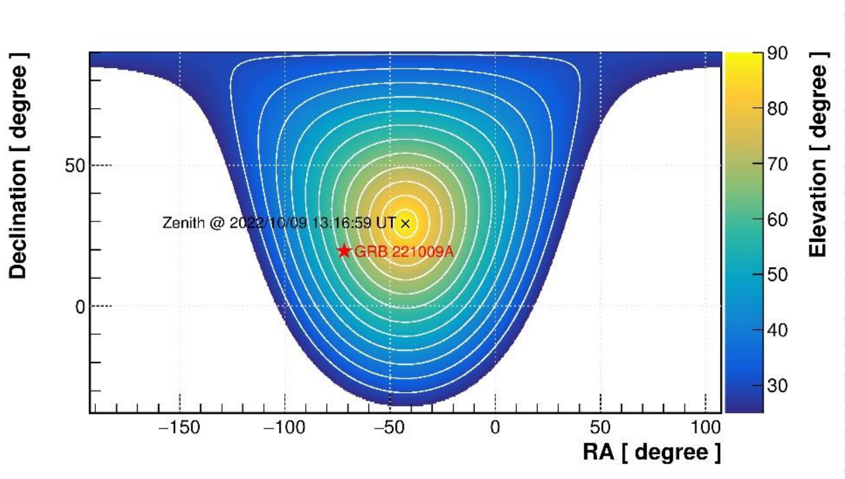




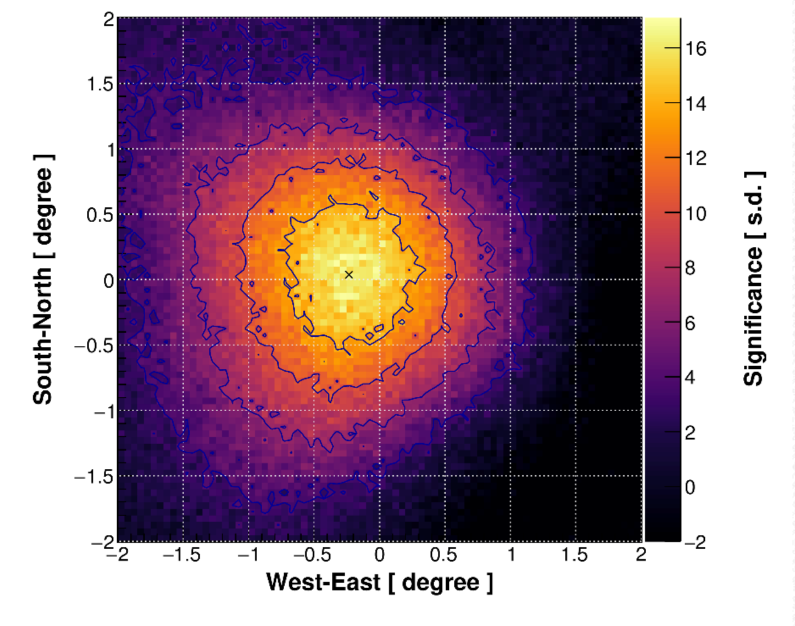


GRBs in the VHE/UHE band

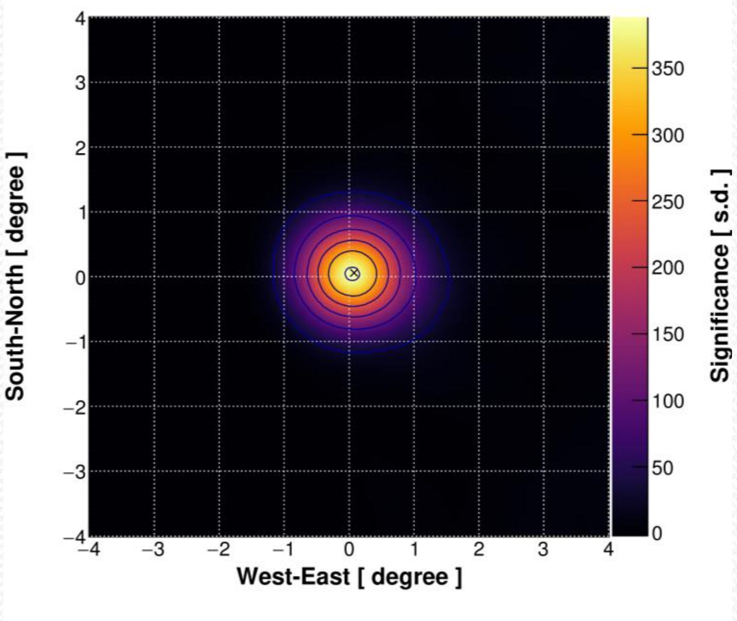
- GRB: 221009A the brightest one in last 60 years
  - *>50,000 photons recorded above 300 GeV*
  - *Significance > 350σ*
  - *Photon energy: E_{max} > 12 TeV*
- AGNs: long term monitoring for variabilities, flares



Photon energy E: 0.5 TeV



3 TeV



8 TeV