AVENGe

May 29-31, 2023

Gamma-ray astronomy and the search of the lost Pevatrons

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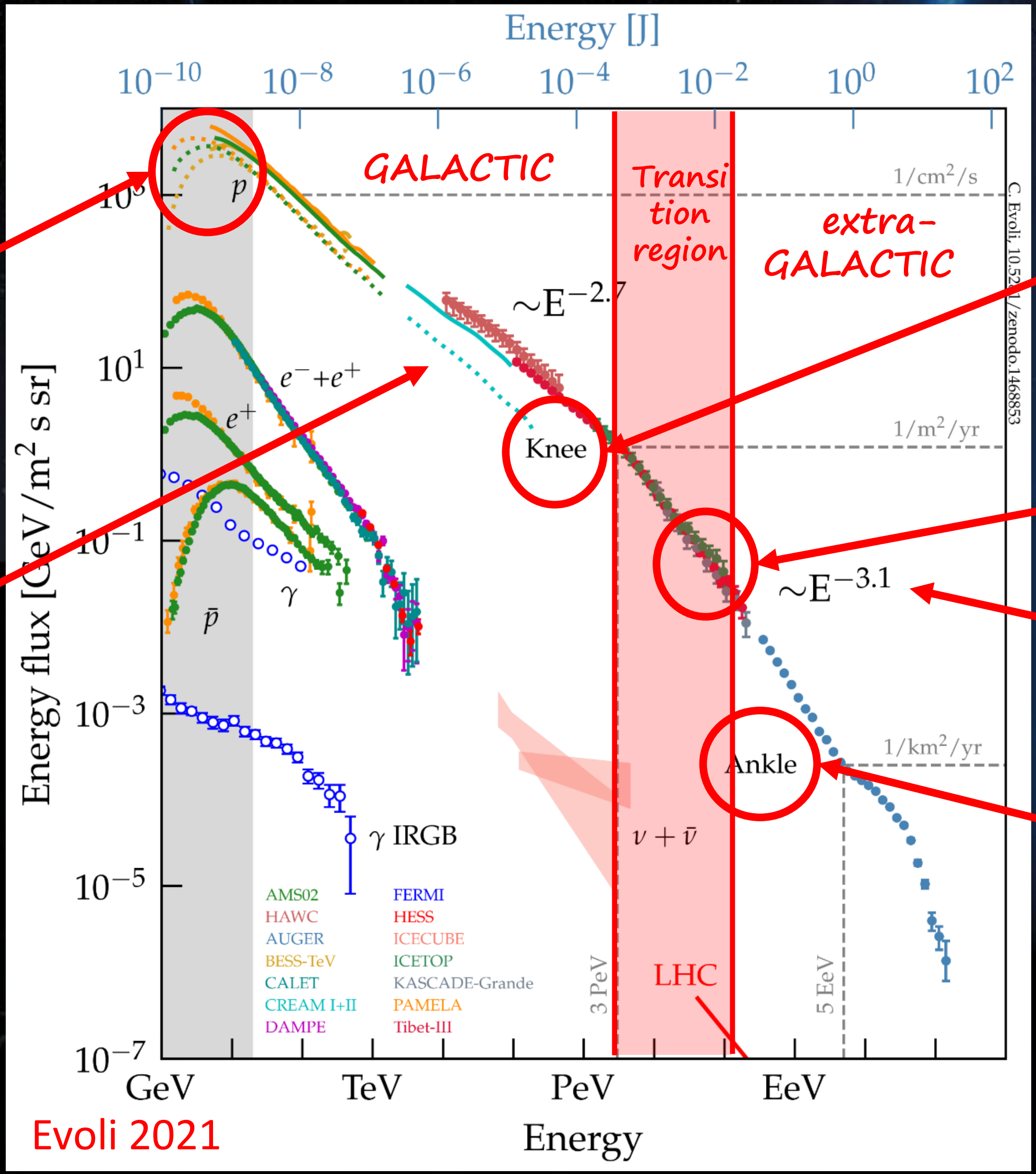
Cosmic Ray Overview: screenshot slide

Protons (85 %)
Nuclei (13%)
Electrons/Positrons (2%)

Solar modulation

power law $E^{-2,7}$

$W_{CR} \sim 1$ eV/cm^3



CR "Knee"

CR "Second Knee"

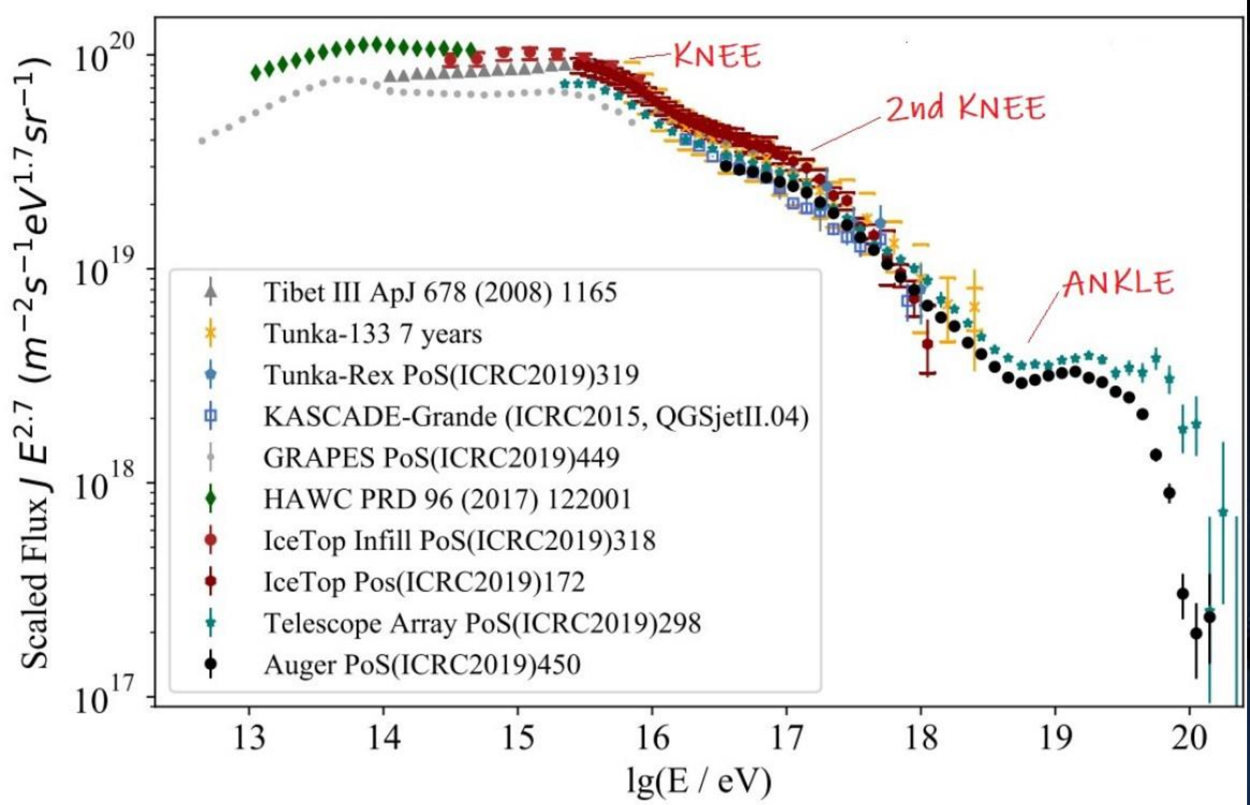
power law $E^{-3,1}$

CR "Ankle"

Galactic component

Cosmic Ray Overview

Schroder+19



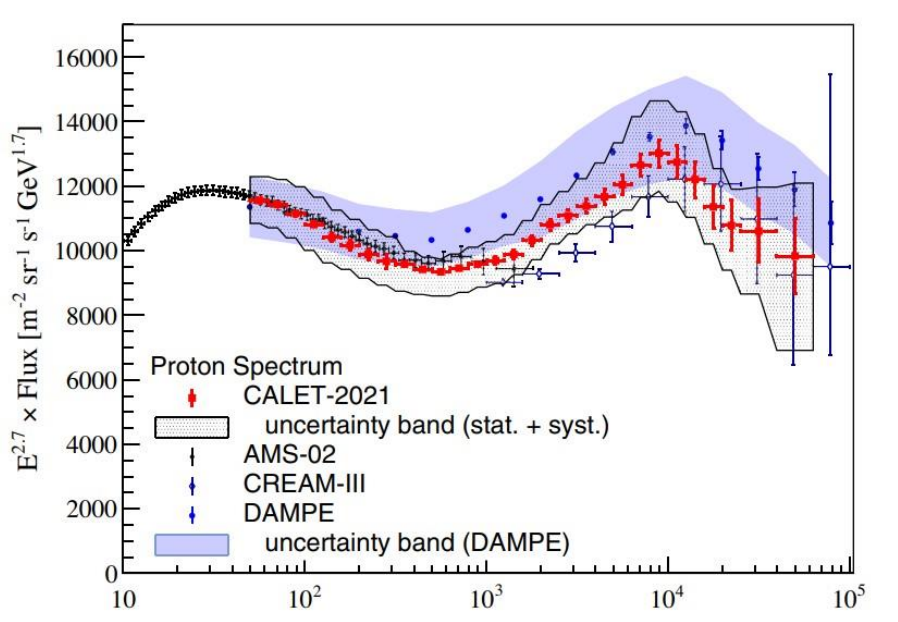
Between the knee and the second knee (~10^{17} eV) should be the transition from Galactic to extragalactic component.

Extra-Galactic component

- Limited information
- Extra-Galactic magnetic field
- Origin connected to transition region

But also the Galactic Component is not so bright and clear

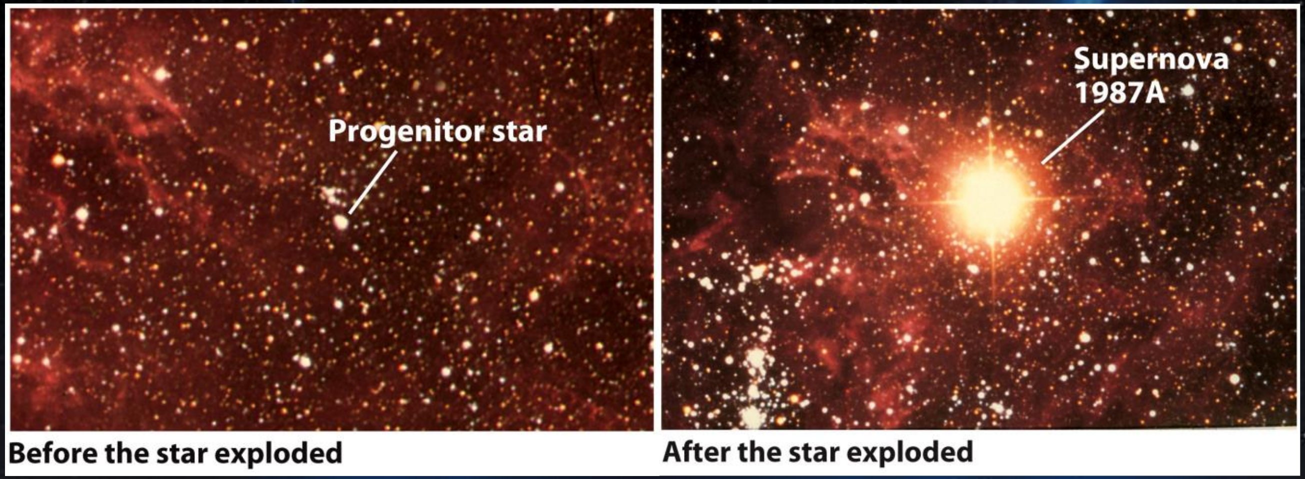
Recent results by CALET/DAMPE show that the region below 1 PeV may not be as featureless as we thought, showing hardening and steepening between 100 GeV and 100 TeV



Adriani+22

The main candidates: Supernova Remnants

1934 Zwicky & Baade
(SNR hypothesis)



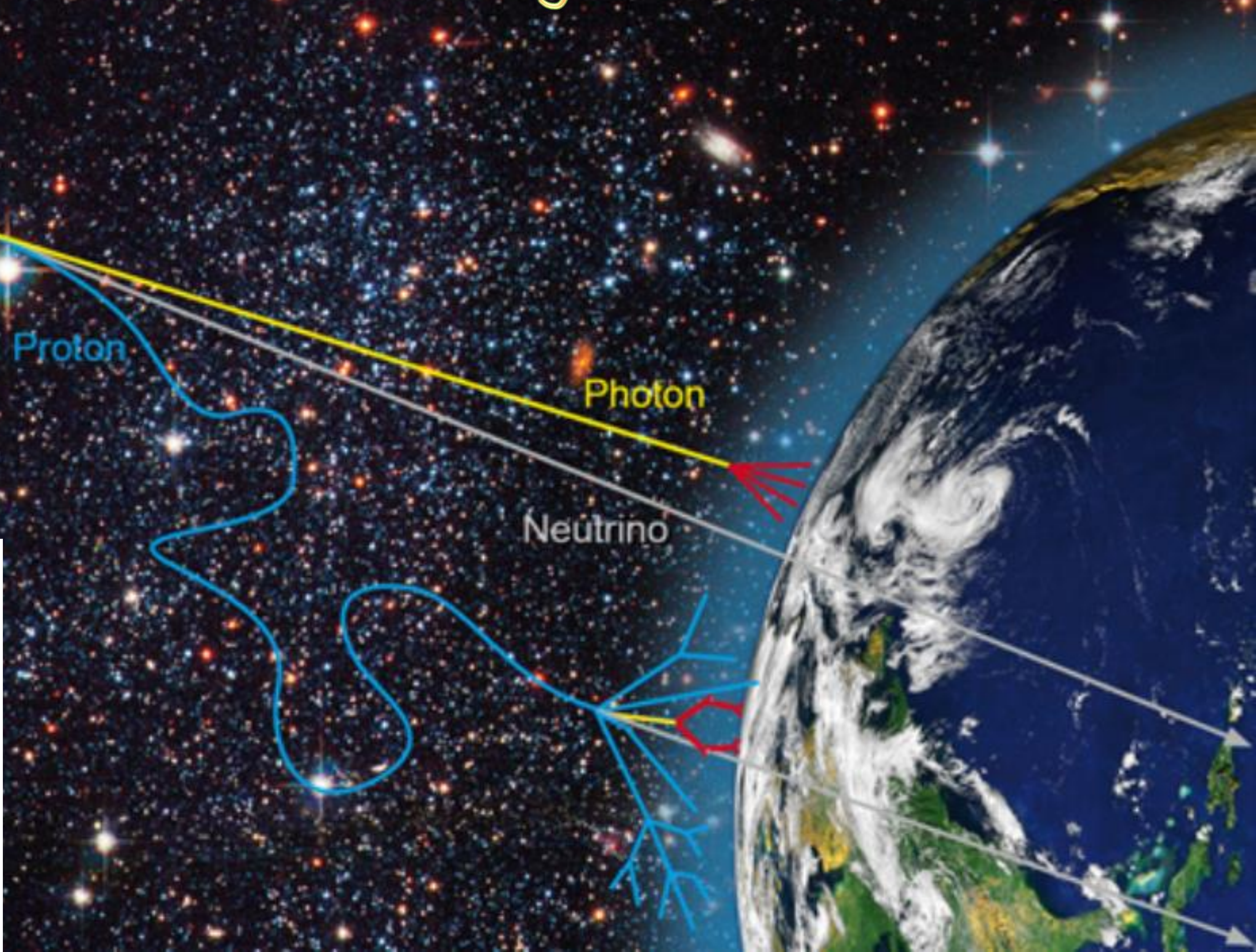
1959. V.Ginzburg
(quantitative)

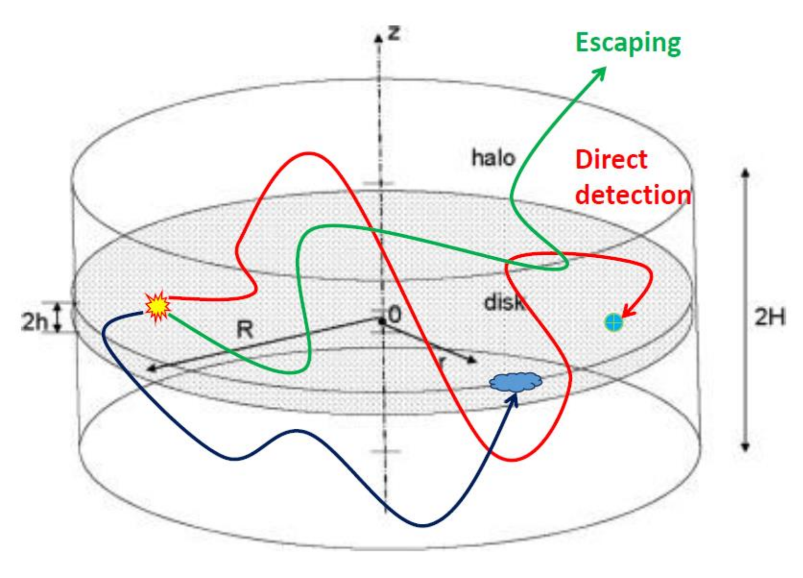
$$\begin{cases} L_{SN} = R_{SN} E_{kin} \approx 3 \times 10^{41} \text{erg/s} \\ L_{CR,gal} \sim 3 \times 10^{40} \text{erg/s} \end{cases}$$

Efficiency of order 10% per SN is sufficient to accomodate CR energetics.

- *COLLISIONLESS SHOCKS*:
  energy dissipated via wave–particle interaction instead of particle–particle collisions.
- *STRONG SHOCKS AND DSA*: $\mathcal{R} = \frac{u_u}{u_D} = \frac{4M_s^2}{3 + M_s^2}$ $\quad M_s \to \infty \;, \; \mathcal{R} \to 4$
- *MAGNETIC FIELD AMPLIFICATION*

How can we study CRs?





Messengers and Instruments

Direct Detection (E<100 GeV) | **Space Based**

Particles

- Proportional tubes and scintillators (e.g. CREAM, TRACER)
- Magnetic Spectrometers and silicon tracker (e.g. PAMELA, AMS-02)

Gamma-rays

- Silicon Tracker and calorimeter (AGILE, Fermi-LAT)

NEUTRINOS

Indirect Detection (E>100 GeV) | **Ground Based**

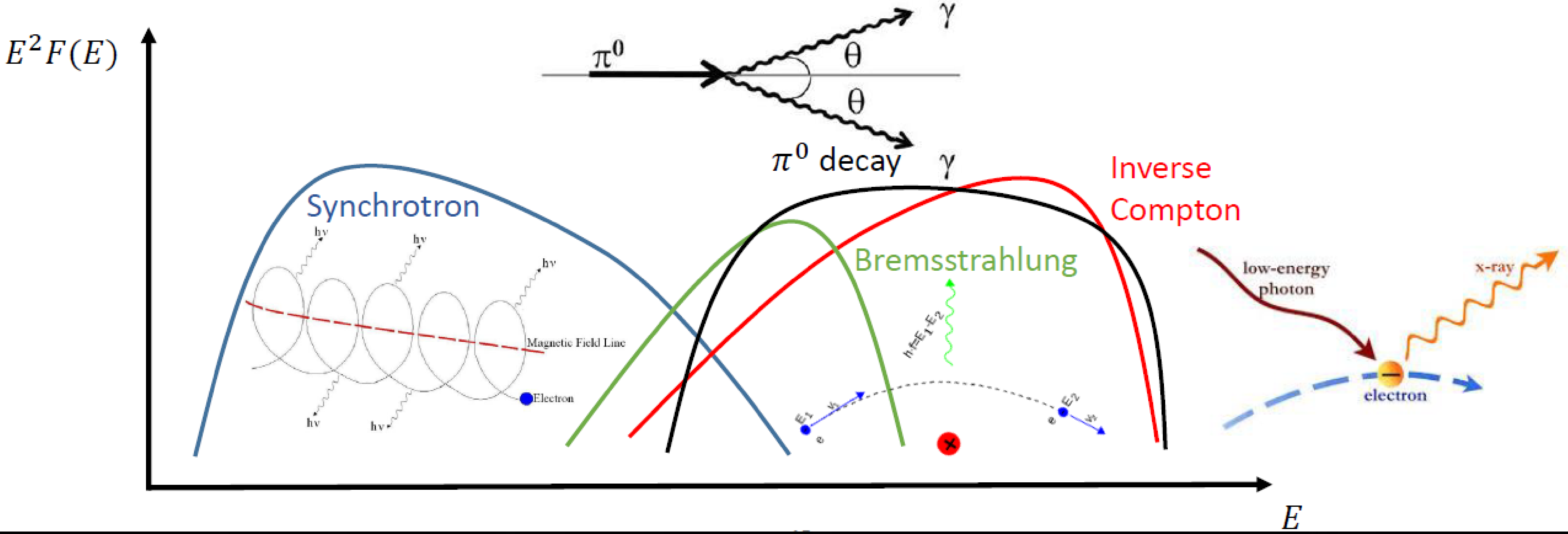
Particles&Gamma

- Scintillators and Multiple Resistive plate chambers (e.g. KASCADE-Grande, Tibet_AS gamma, Argo)
- Water Cherenkov (e.g. Milagro, HAWC)
- Hybrid: water Cherenkov and fluorescence (e.g. Auger) or scintillators (e.g. LHAASO)

Gamma-rays

- Imaging Atmospheric Cherenkov Telescope (e.g. HESS, VERITAS, MAGIC → ASTRI-MA, CTA)

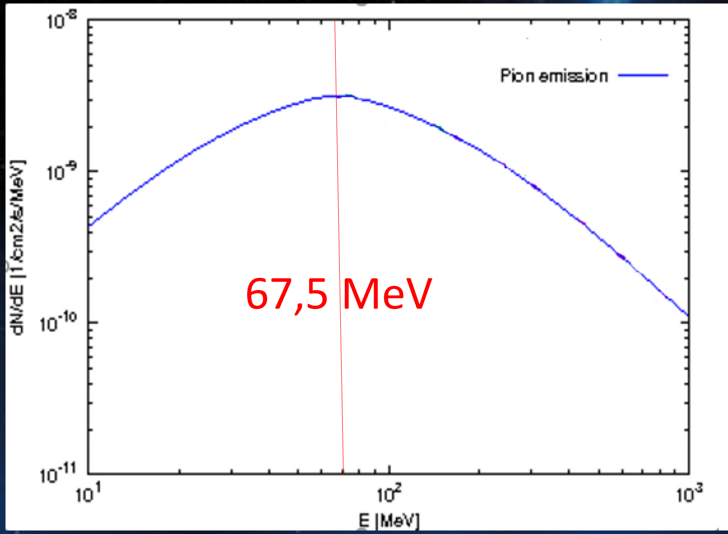
Radiative procesess: very quick look

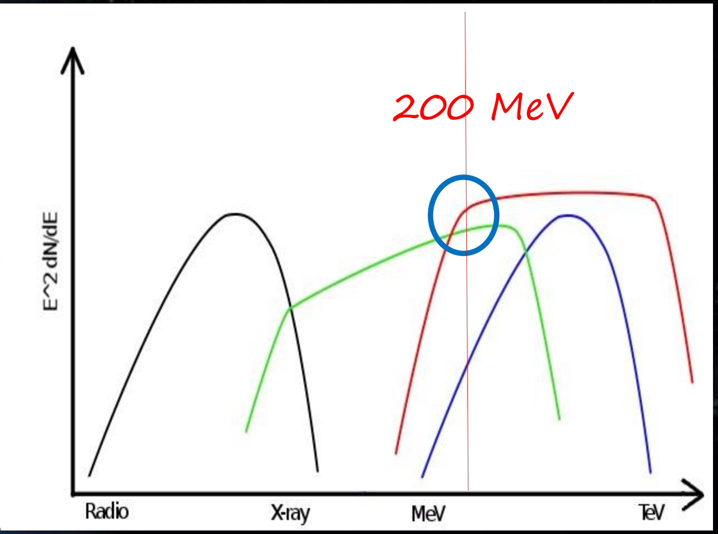


CR Acceleration: direct evidences

Low-Energies

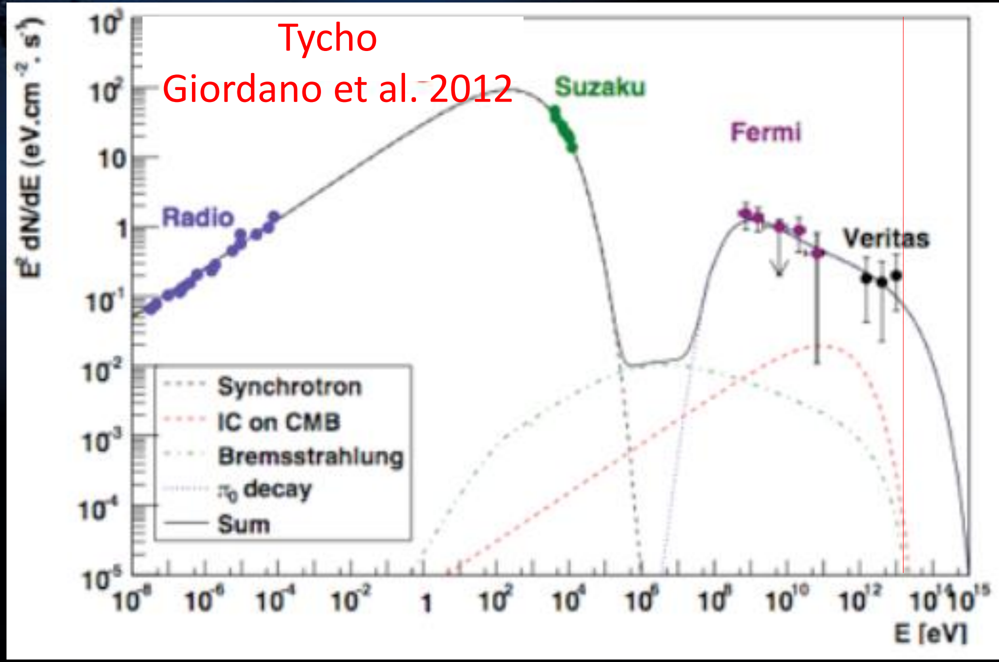
→ Pion bump detection: distinction leptonic from hadronic component only at E<200 MeV



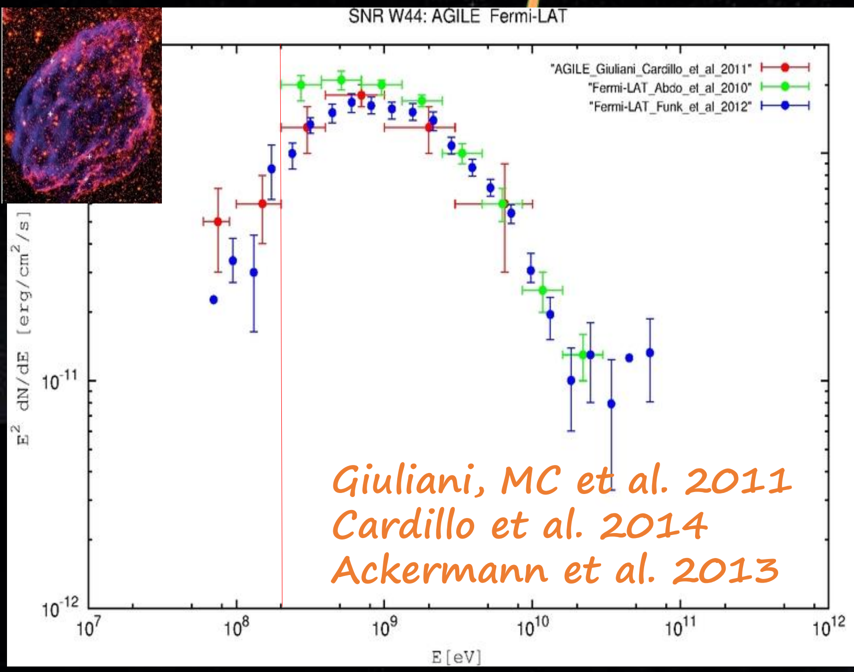


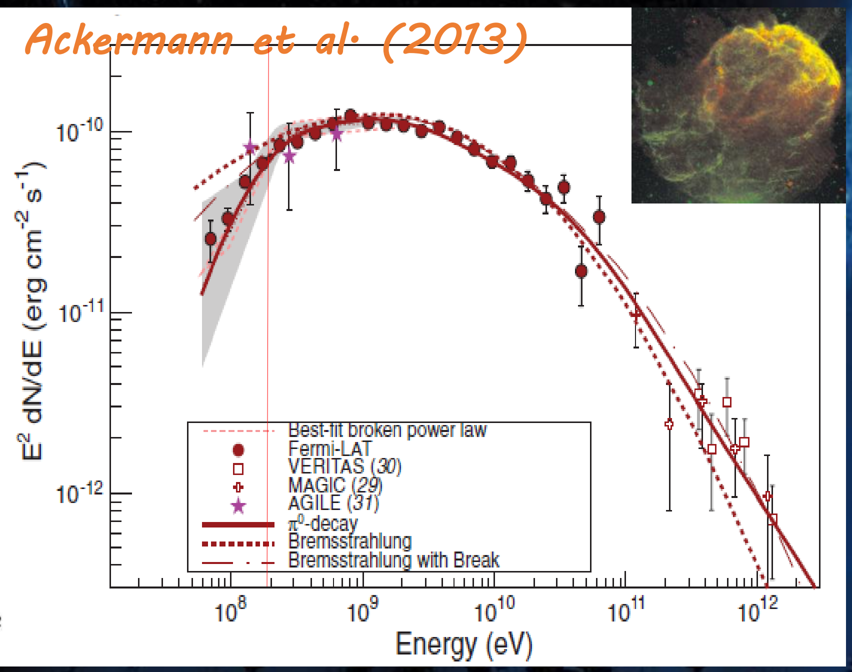
High-Energies

Pevatrons → gamma-ray at E>100 TeV can be only of hadronic origin (<u>should be...</u>)



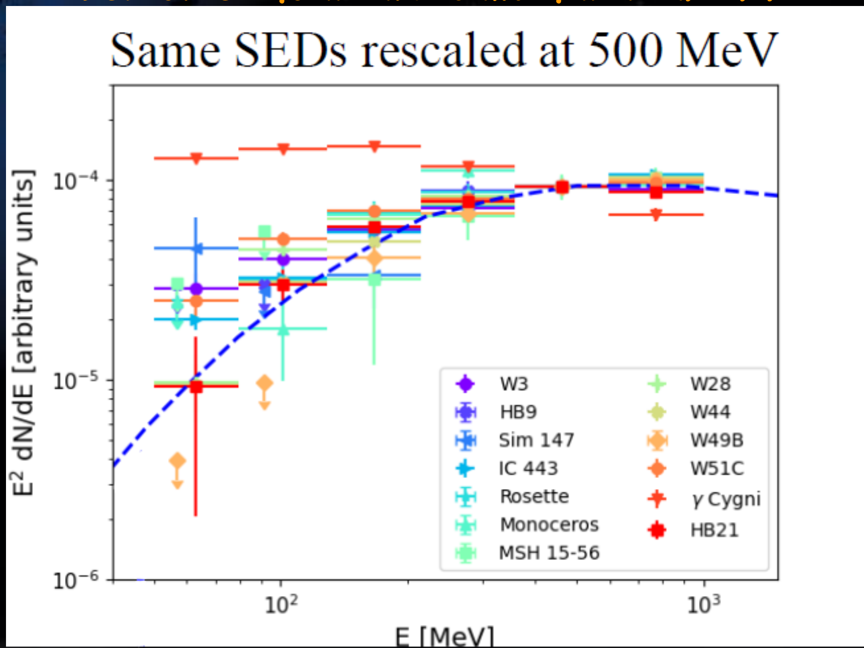
Supernova Remnants: Low-Energies





Gamma-ray emission below 200 MeV detected by AGILE from the SNR W44, then confirmed by Fermi-LAT also in IC443

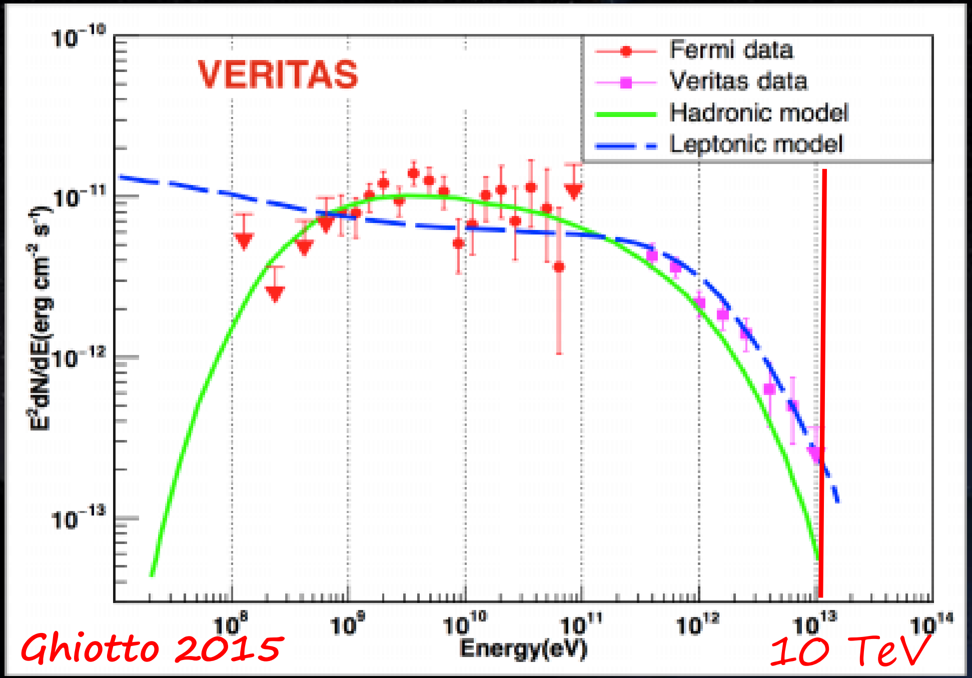
Lemoine-Goumard talk Gamma2022

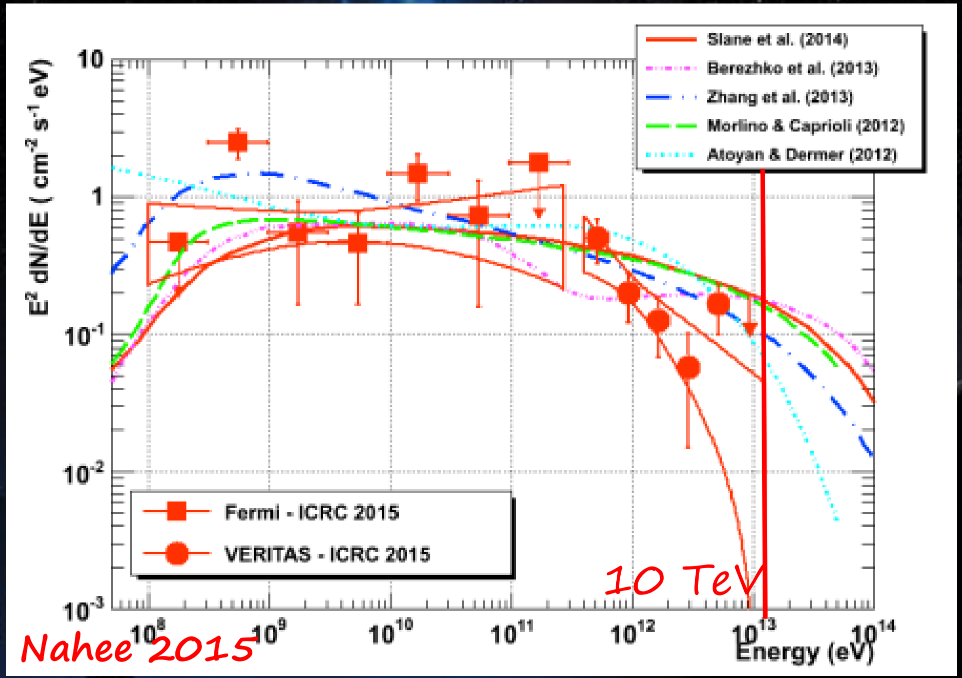


- Presence of a broken PL and of a very steep HE spectral index → not expected from diffusive shock acceleration theory;
- The shock of middle-aged remnants are slow (vs < 100 km/s)→ acceleration efficiency ξ_{CR} has to be too high in order to explain the emission: $P_{CR} = \xi_{CR} \rho v_{sh}^2$

Presence of CRs confirmed but not confirmation of freshly accelerated CRs (likely RE-accelerated or D suppression) [Cardillo et al. 2016, Celli et al. 2019]

High-energy gamma-rays





Despite the great amount of SNRs detected in the gamma-ray band, no young SNRs show gamma-ray emission up to $E \geq 100\,TeV$

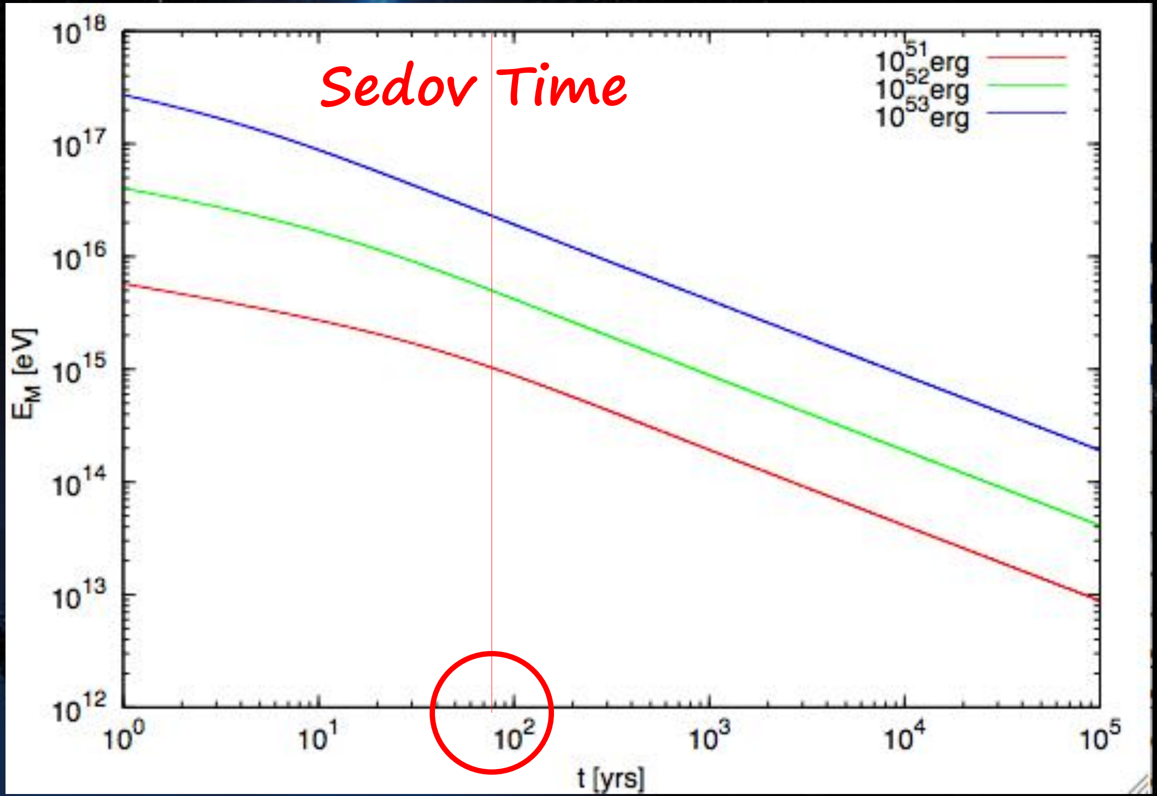
⇩

What is the probability to detect SNR emitting Pevatron gamma-rays?

Maximum energy estimation

Cardillo, Amato, Blasi 2015

- Current driven regime (NR Bell instability)
- Simulation results about growth rate (Bell, Schure 2013)
- Ejecta and Medium density profile



Type I (ISM)

$$E_M(R) = \frac{2Ze}{10}\sqrt{4\pi\rho R^2}\frac{\xi_{CR}}{c\Lambda}V_{sh}^2 = 130\left(\frac{\xi_{CR}}{0.1}\right)\left(\frac{M_{ej}}{M_\odot}\right)^{-2/3}\left(\frac{n_{ISM}}{cm^{-3}}\right)^{1/6}\left(\frac{E_{SN}}{10^{51}erg}\right) TeV$$

Type II (wind)

$$E_M(R) = \frac{2Ze}{5}\sqrt{4\pi\rho R^2}\frac{\xi_{CR}}{c\Lambda}V_{sh}^2 = 1\left(\frac{\xi_{CR}}{0.1}\right)\left(\frac{M_{ej}}{M_\odot}\right)^{-1}\left(\frac{\dot{M}}{10^{-5}M_\odot/yr}\right)^{1/2}\left(\frac{V_w}{10km/s}\right)^{-1/2}\left(\frac{E_{SN}}{10^{51}erg}\right) PeV$$

Main Conclusions

- We have the proof of CR energization from some middle-aged SNRs but no proof of freshly accelerated CRs

- Main hypothesis:
  - middle-aged SNRs re-accelerate CRs (Cardillo et al. 2016)
  - Middle aged SNRs could accelerate CRs but in regions with suppressed diffusion coefficient (Celli et al. 2019)

- Type II SNRs can accelerate particles up to the knee through the NRH instability

but...

- Type II SNRs can accelerate particles up to the knee at very early time → detection problem

- Distant MCs could be "the only hope" of a Pevatron detection (Gabici 2009)

And what if SNR do not were galactic CR sources?

Where do most CRs come from?

Theory

- Energetics
  $P_{CR} \sim 10^{40} - 10^{41}$ erg/s
- Power-law injected spectrum
  - Required from acceleration theory
- Maximum energy
  - They must explain the PeV proton energies
- Anisotropy
  - Source distribution has to be correlated with CR anisotropy (at PeV, $\sim 10^{-3}$)
- Composition
  - They must explain CR composition and its energy dependence

Receipt to be a CR source

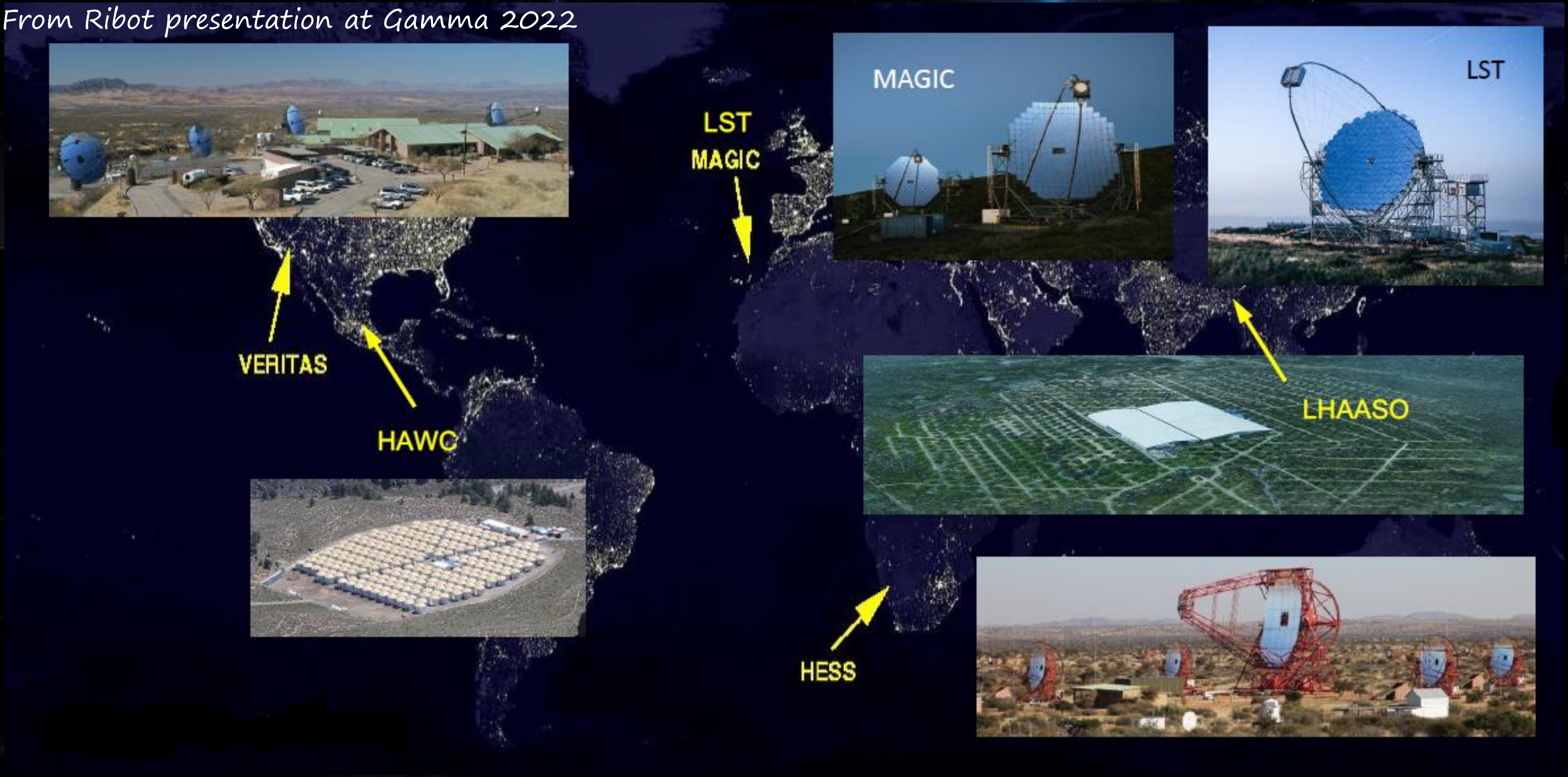
MC&Giuliani 2023

Observations

- Detected VHE-UHE Emission
- Spectral curvature
  - Signature of Emax, KN, spectral breaks
- Spatially-resolved emission
- Correlation with target material
  - Not perfect: i.e. emission is convolution of CR distribution with gas
- Energy-dependent morphology
  - Expected in general due to energy dependence of transport and/or cooling
- A multi-wavelength counterpart!

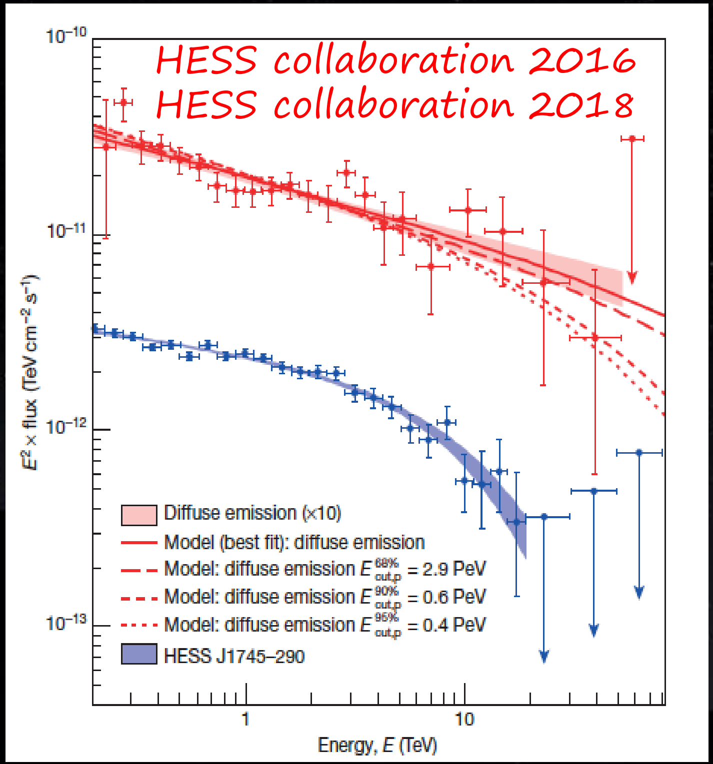
Current Cherenkov Facilities

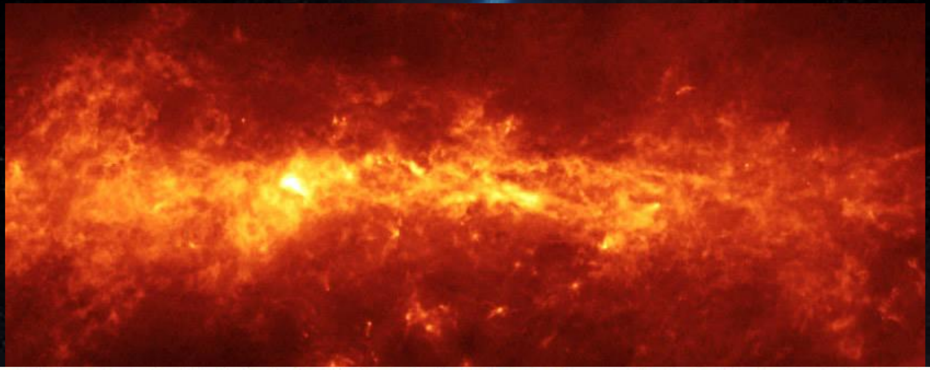
From Ribot presentation at Gamma 2022



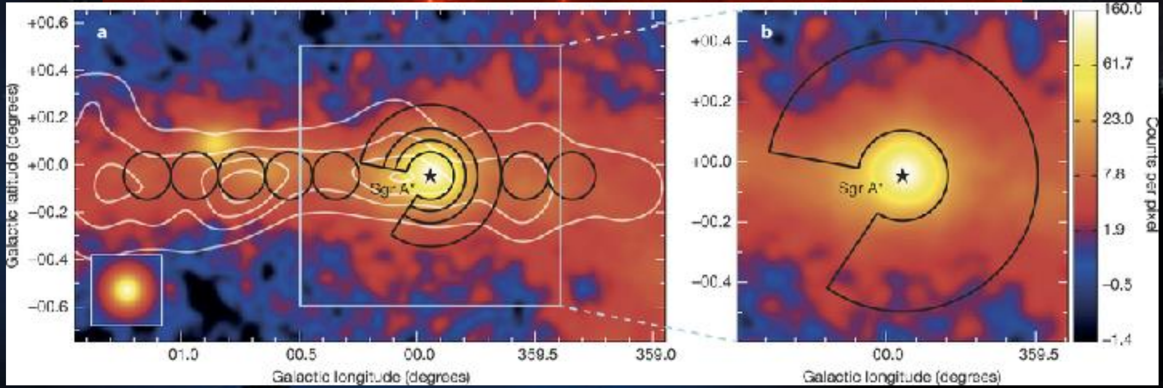
Other sources
(Before LHAASO)

Other Sources? – Galactic Center Region

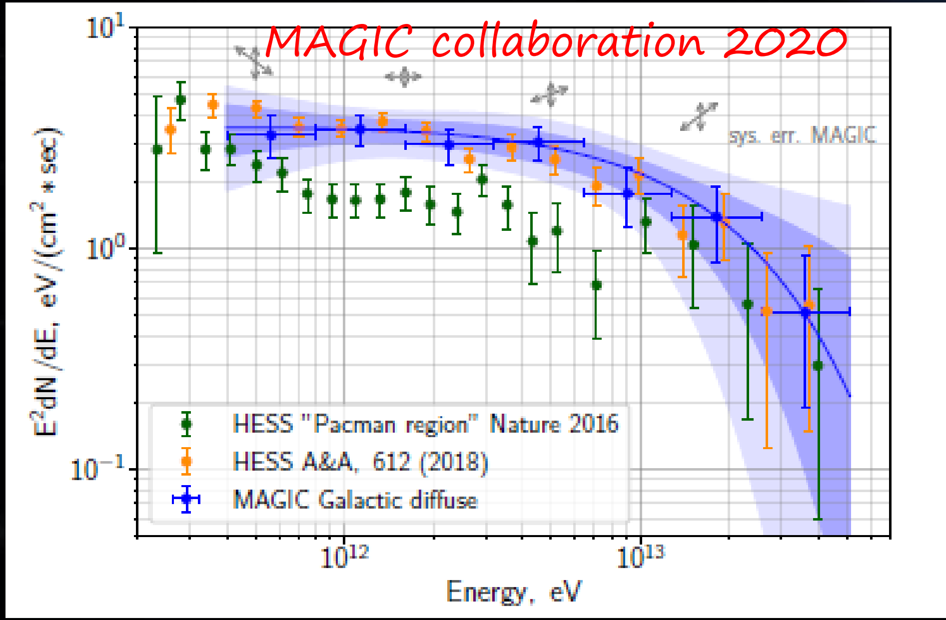




APEX+Planck: Dust (ATLASGAL-Konsortium/Csengeri+ 2016)



HESS collaboration 2016



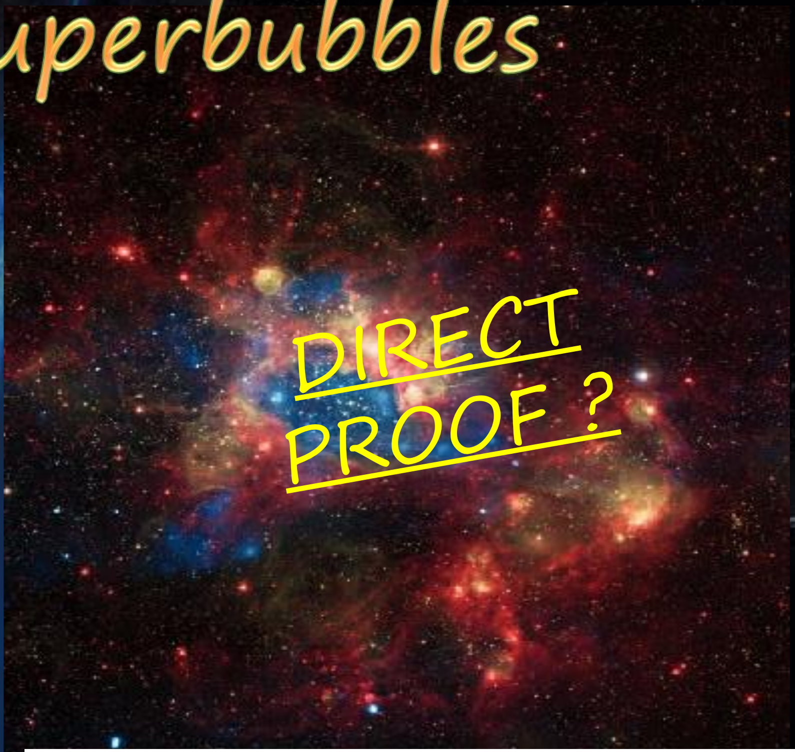
- Perfect correlation between molecular gas distribution and gamma-ray emission seen by HESS
- CR energy density 10 times greater than CR sea
- CR spectrum with and index γ_E =2.3-2.4 up to 100 TeV (but with large error bars)
- Spatial distribution with 1/r (continuous injection)
- Maybe from Sgr A* (Rodríguez-Ramírez et al., 2019)
- First spectro-morphological analysis on-going (Devin talk Gamma 2022)

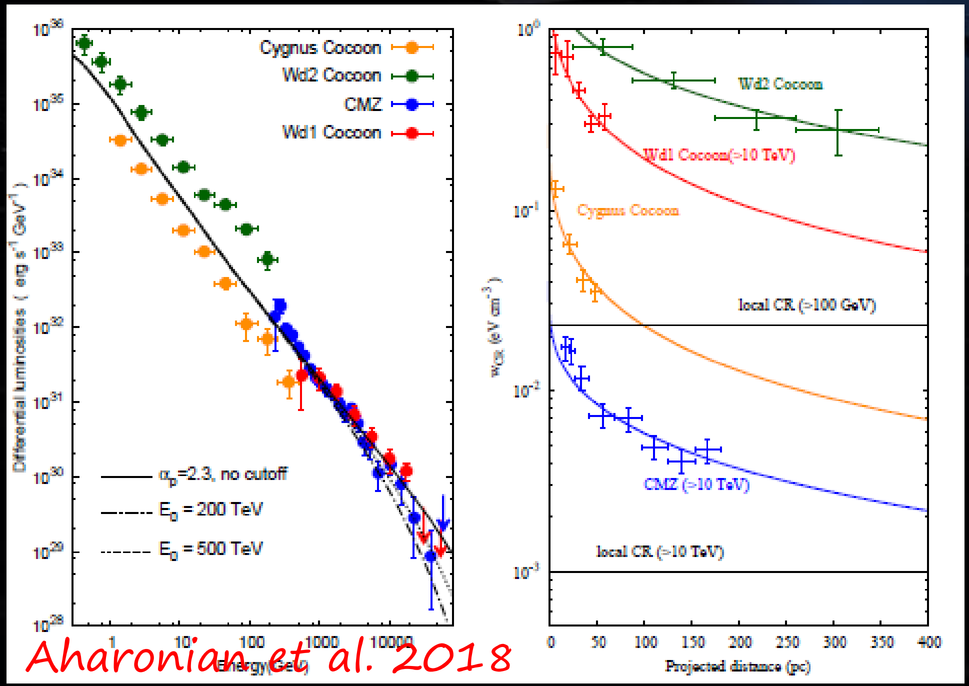
Other sources? – From GCR to Superbubbles

Hot and rarefied extended cavities formed by OB stars winds containing also a lot of SNRs [Bykov 1992]:

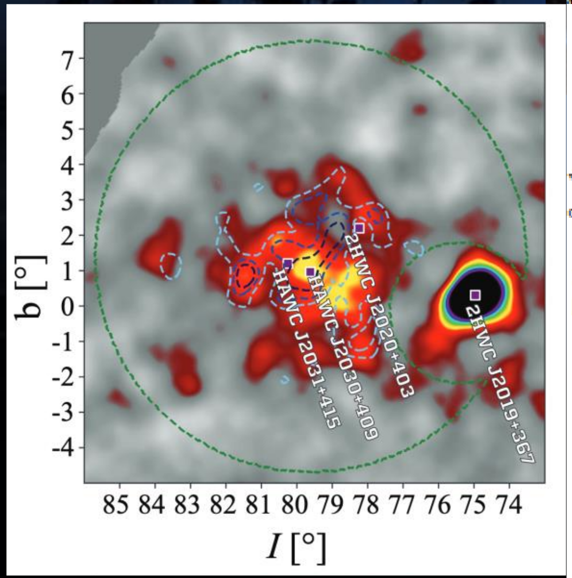
- Multiple shocks and winds
  - → enhanced turbulence and acceleration
- No radiative phase
  - → larger acceleration efficiency
- Low-energy spectrum slope similar to the one measured by Voyager
- Explanation of some CR composition anomalies
  - → ^{22}Ne, Be abundances [Higdon+ 2003, Tatischeff 2018]
- Spatial and spectral behavior similar to the GC one [Aharonian 2018]

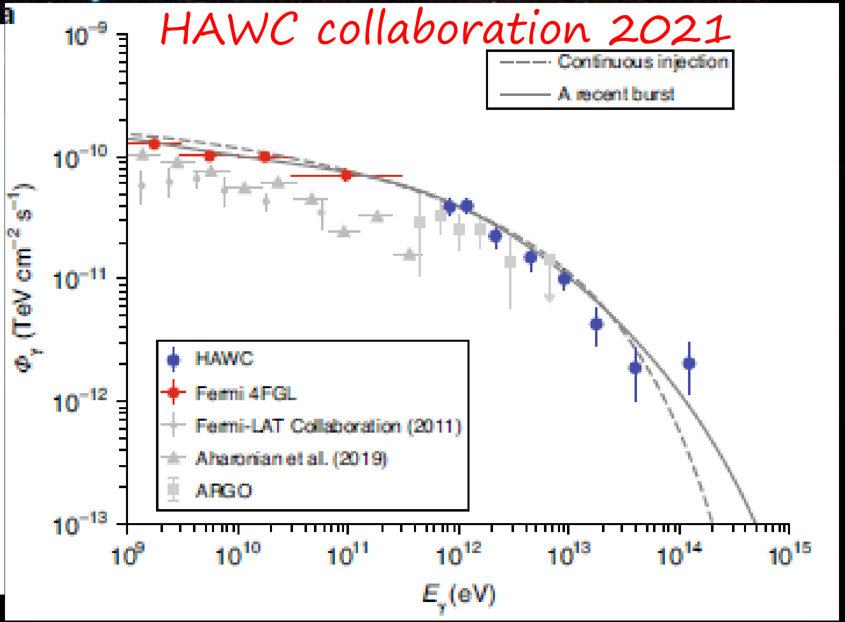
Vieu thesis 2023





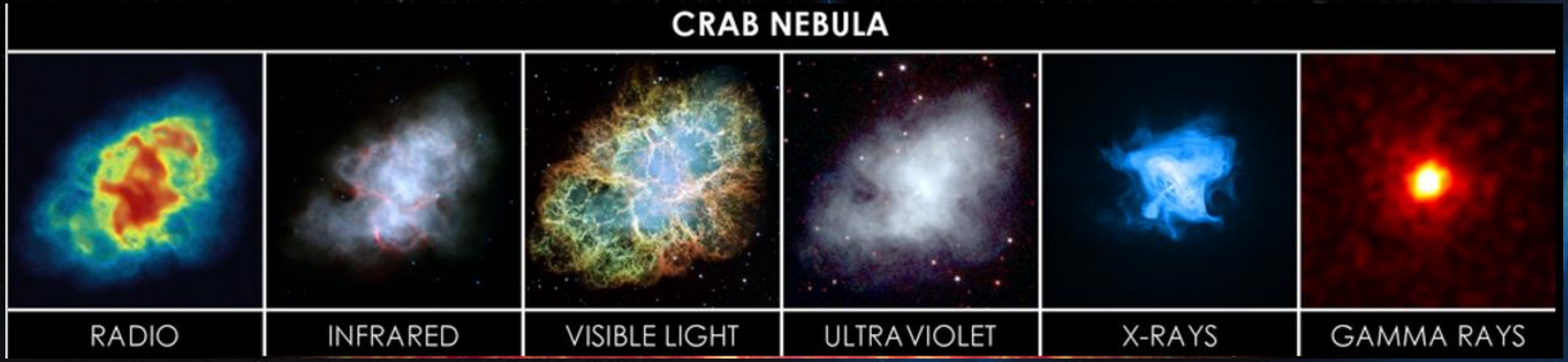
Aharonian et al. 2018



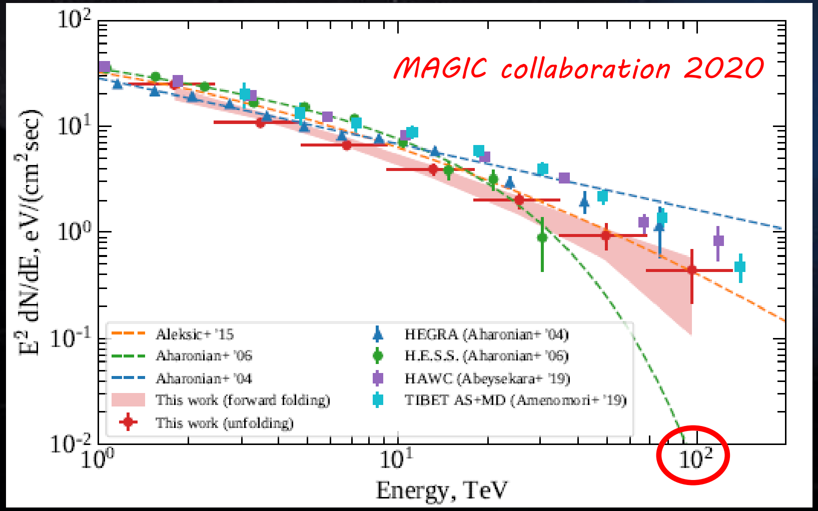


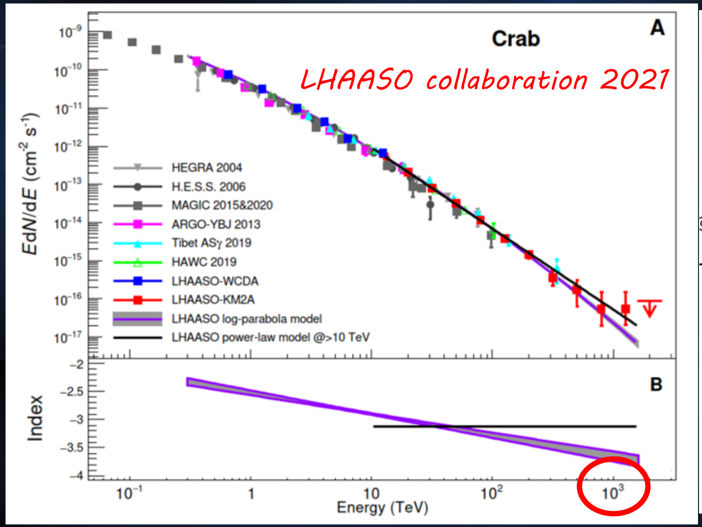
HAWC collaboration 2021

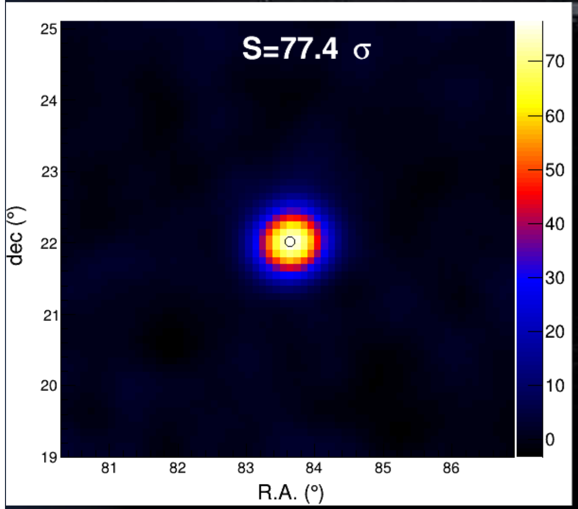
Other Sources? - CRAB NEBULA



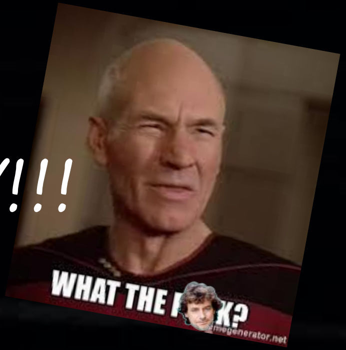
Standard Candle for Gamma-ray astronomy (when it is not flaring)







Detection above 1 PeV!!!



but...

Crab is a PWN (leptonic source)

So...

Leptonic origin of gamma-rays possible!!

There is a hadronic component?

Other sources? - Gamma-ray binaries &: Microquasars

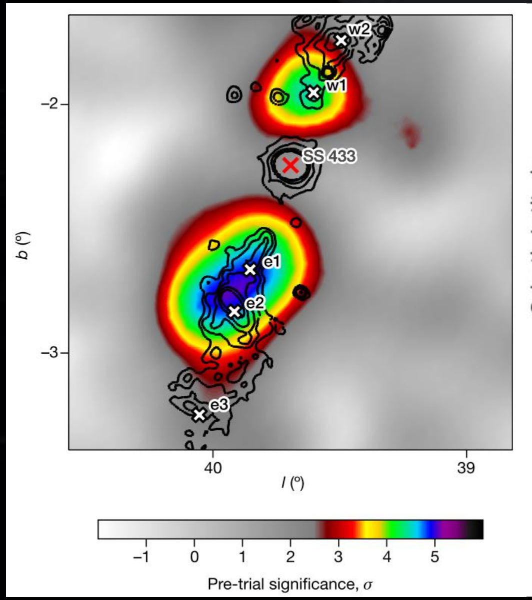
Binary stellar systems (BS/BH+Companion)

Cyg X-1, Cyg X-3 and **SS 433** (emitting X-rays) show HE emission up to GeV.

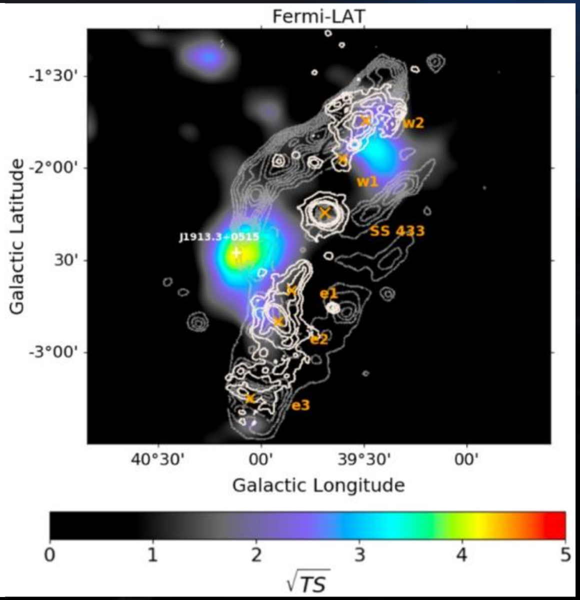
The Manaetee Nebula (Safi-Arb Gamma2022)

SS 433

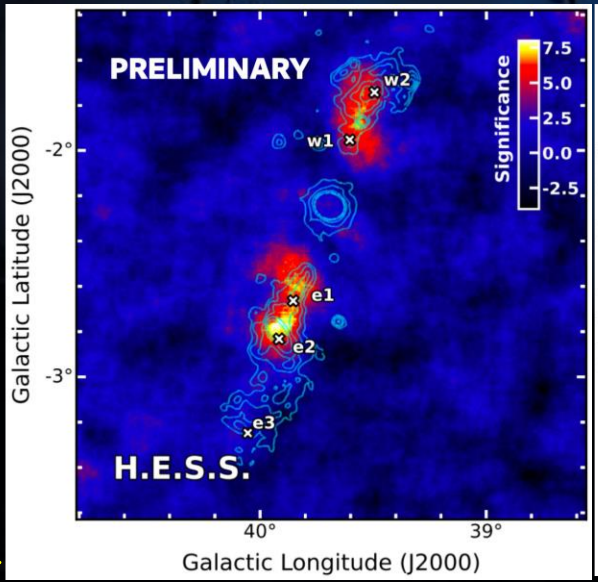
HAWC (HAWC2018)

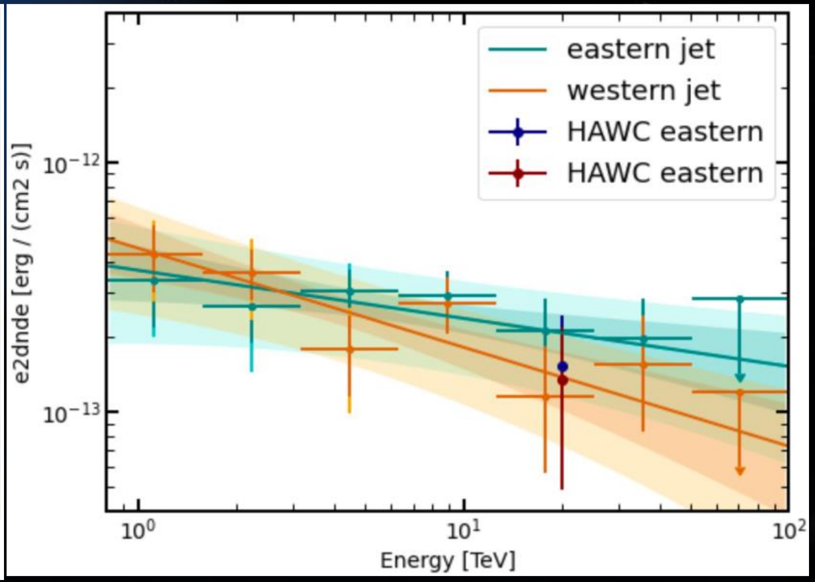


Fermi-LAT (Fang+2020)



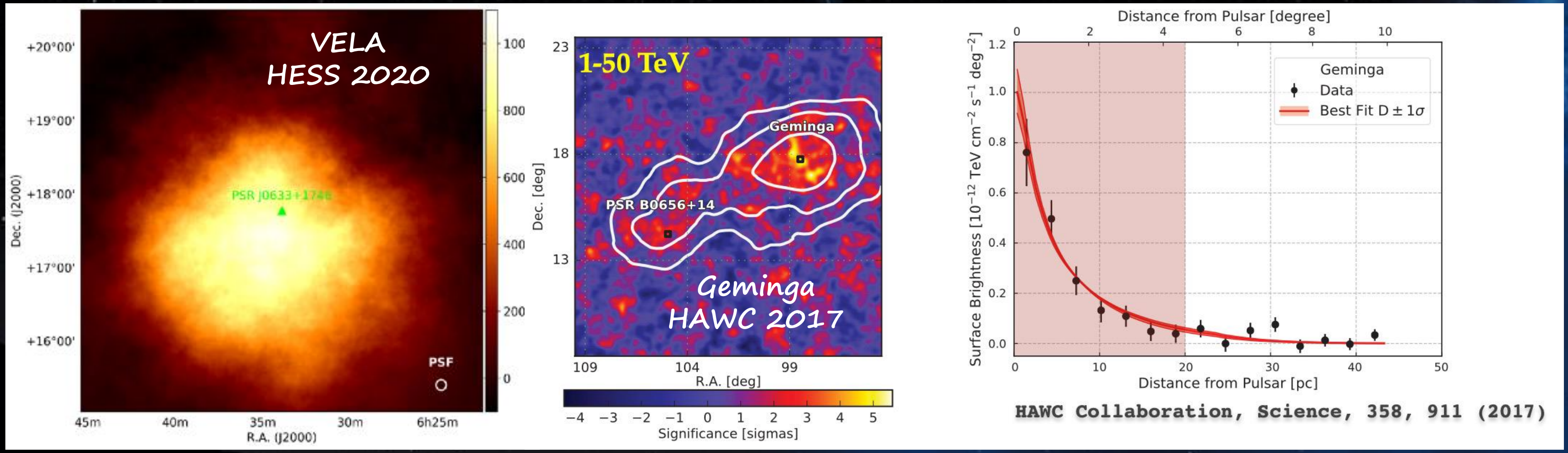
HESS



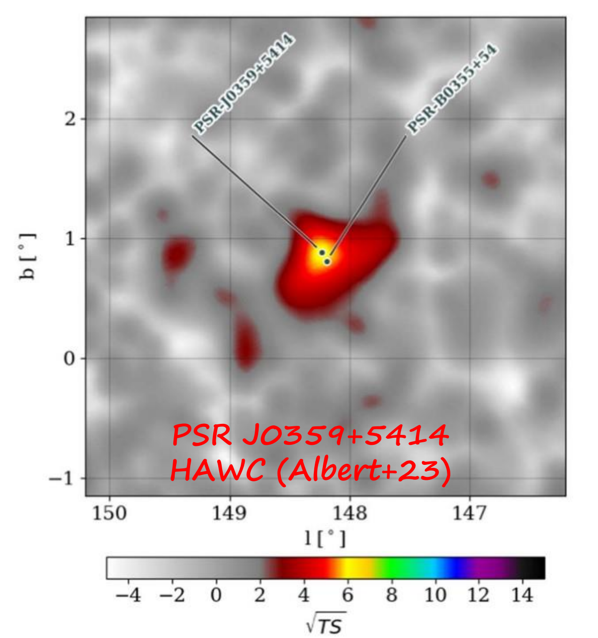


Olivera-Nieto Gamma2022

And for the propagation: TeV HALOS



- Both pulsar and extended emission evaded detection for a long time
- Escaping electrons and positrons (due to RS that disrupts PWN) form an extended halo of GeV and TeV gamma-rays



- TeV halo candidate near the Galactic plane in a non-crowded region.
- This TeV halo candidate shares similar characteristics to others, suggesting that TeV halos could be a general feature of middle-age pulsars.

TeV Halos as new source class

↓

Propagation study

Pevatrons

HIGH-ENERGY ASTROPHYSICS

PEVATRON = an object capable of accelerating PARTICLES (hadrons or leptons) up to the PeV (=10[15] eV) range

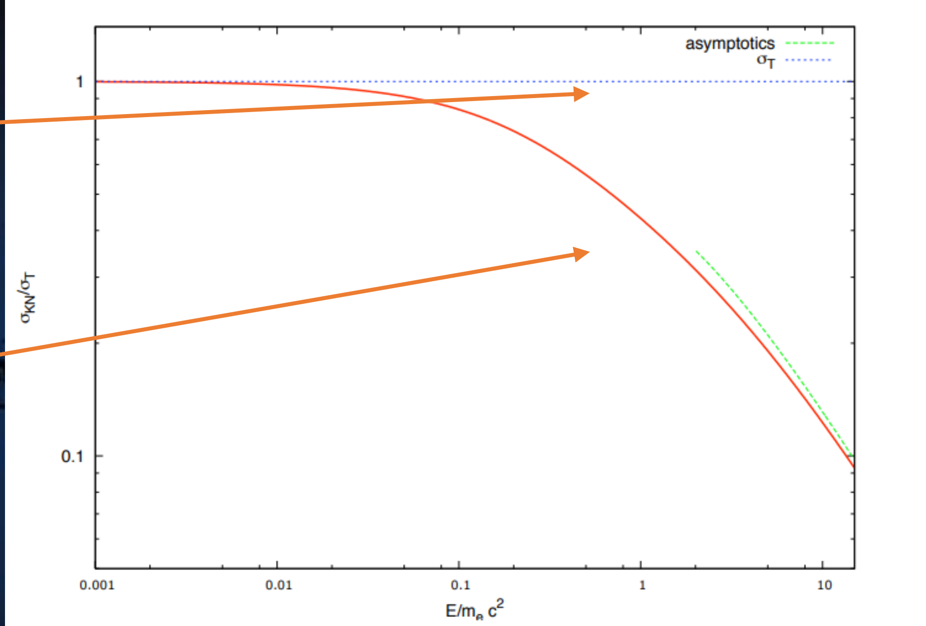
INVERSE COMPTON (leptonic)

Thomson scattering ($h\nu_i \ll m_e c^2$)

- transfer small,
- scattering almost elastic,
- Thomson cross-section applied

Klein-Nishina scattering ($h\nu_i \gg m_e c^2$)

- transfer large,
- scattering deeply inelastic,
- need to use cross-section derived from QED.



COSMIC RAY CONTEXT

PEVATRON= an object capable of accelerating HADRONS up to the PeV (=10[15] eV) range

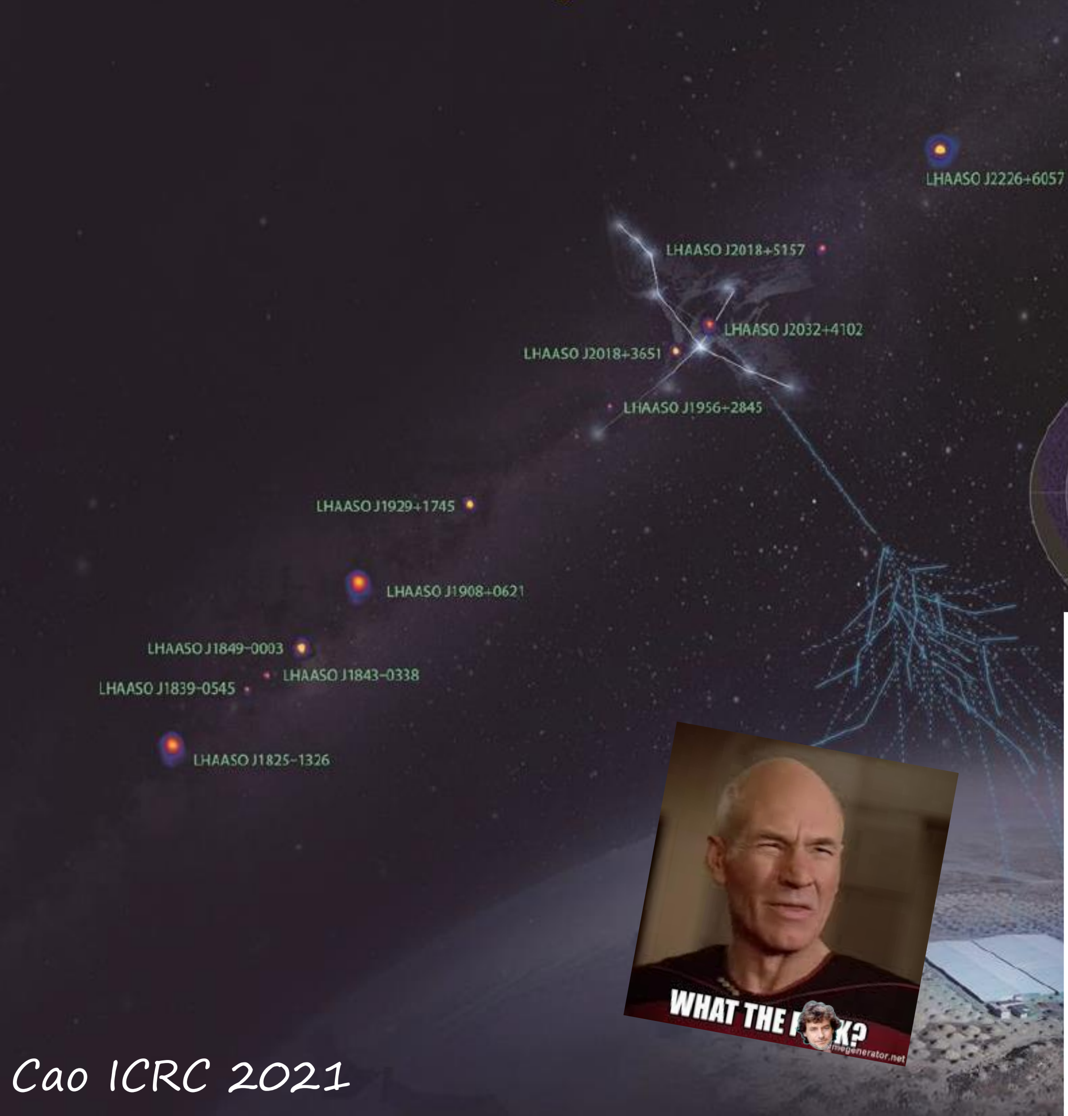
Ok…
We have some hints of emission around 100 TeV…
… but just one PeVatron (the Crab)…
And it could be a leptonic one…

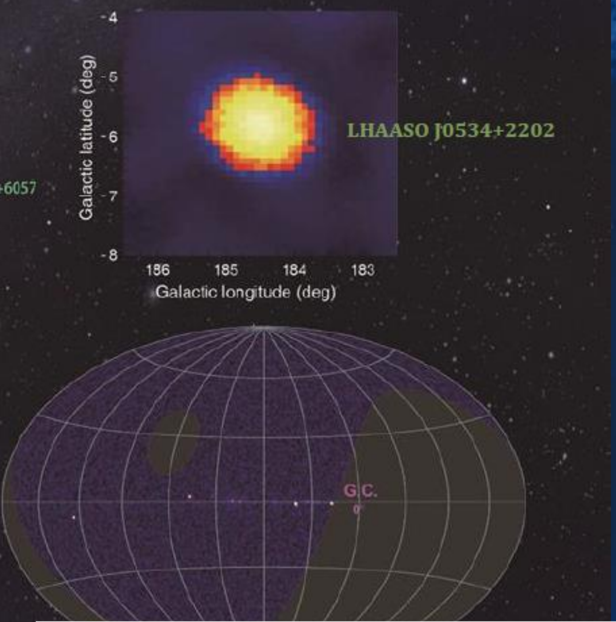
…when suddenly…

"PeVatrons" storm from LHAASO

OUR GALAXY IS FULL OF "PEVATRONS"!!!!!!

LHAASO, Nature, 594, p.33-36, 2021





12 "PeVatrons" discovered with high significance ($>7\sigma$)!!

LEPTONIC
Or
HADRONIC?

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)

Cao ICRC 2021

Extended Data Table 2 | List of energetic astrophysical objects possibly associated with each LHAASO source

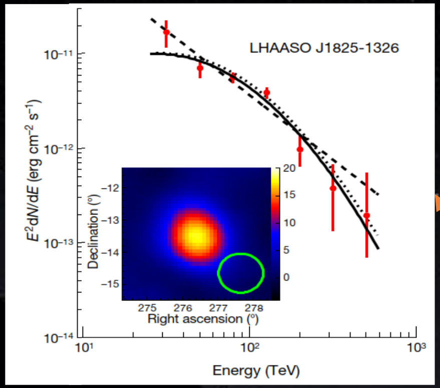
LHAASO Source	Possible Origin	Type	Distance (kpc)	Age (kyr)[a]	L_s (erg/s)[b]	Potential TeV Counterpart[c]
LHAASO J0534+2202	PSR J0534+2200	PSR	2.0	1.26	4.5×10^{38}	Crab, Crab Nebula
LHAASO J1825-1326	PSR J1826-1334	PSR	3.1 ± 0.2^d	21.4	2.8×10^{36}	HESS J1825-137, HESS J1826-130,
	PSR J1826-1256	PSR	1.6	14.4	3.6×10^{36}	2HWC J1825-134
LHAASO J1839-0545	PSR J1837-0604	PSR	4.8	33.8	2.0×10^{36}	2HWC J1837-065, HESS J1837-069,
	PSR J1838-0537	PSR	1.3^e	4.9	6.0×10^{36}	HESS J1841-055
LHAASO J1843-0338	SNR G28.6-0.1	SNR	9.6 ± 0.3^f	$< 2^f$	—	HESS J1843-033, HESS J1844-030,
						2HWC J1844-032
LHAASO J1849-0003	PSR J1849-0001	PSR	7^g	43.1	9.8×10^{36}	HESS J1849-000, 2HWC J1849+001
	W43	YMC	5.5^h	—	—	
LHAASO J1908+0621	SNR G40.5-0.5	SNR	3.4^i	$\sim 10 - 20^j$	—	MGRO J1908+06, HESS J1908+063,
	PSR 1907+0602	PSR	2.4	19.5	2.8×10^{36}	ARGO J1907+0627, VER J1907+062,
	PSR 1907+0631	PSR	3.4	11.3	5.3×10^{35}	2HWC 1908+063
LHAASO J1929+1745	PSR J1928+1746	PSR	4.6	82.6	1.6×10^{36}	2HWC J1928+177, 2HWC J1930+188,
	PSR J1930+1852	PSR	6.2	2.9	1.2×10^{37}	HESS J1930+188, VER J1930+188
	SNR G54.1+0.3	SNR	$6.3^{+0.8\ d}_{-0.7}$	$1.8 - 3.3^k$	—	
LHAASO J1956+2845	PSR J1958+2846	PSR	2.0	21.7	3.4×10^{35}	2HWC J1955+285
	SNR G66.0-0.0	SNR	2.3 ± 0.2^d	—	—	
LHAASO J2018+3651	PSR J2021+3651	PSR	$1.8^{+1.7\ l}_{-1.4}$	17.2	3.4×10^{36}	MGRO J2019+37, VER J2019+368,
	Sh 2-104	H II/YMC	$3.3 \pm 0.3^m/4.0 \pm 0.5^n$	—	—	VER J2016+371
LHAASO J2032+4102	Cygnus OB2	YMC	1.40 ± 0.08^o	—	—	TeV J2032+4130, ARGO J2031+4157,
	PSR 2032+4127	PSR	1.40 ± 0.08^o	201	1.5×10^{35}	MGRO J2031+41, 2HWC J2031+415,
	SNR G79.8+1.2	SNR candidate	—	—	—	VER J2032+414
LHAASO J2108+5157	—	—	—	—	—	—
LHAASO J2226+6057	SNR G106.3+2.7	SNR	0.8^p	$\sim 10^p$	—	VER J2227+608, Boomerang Nebula
	PSR J2229+6114	PSR	0.8^p	$\sim 10^p$	2.2×10^{37}	

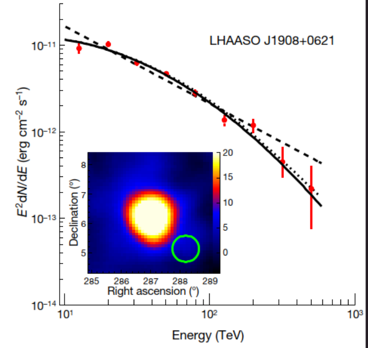
Other sources
(After Lhaaso)

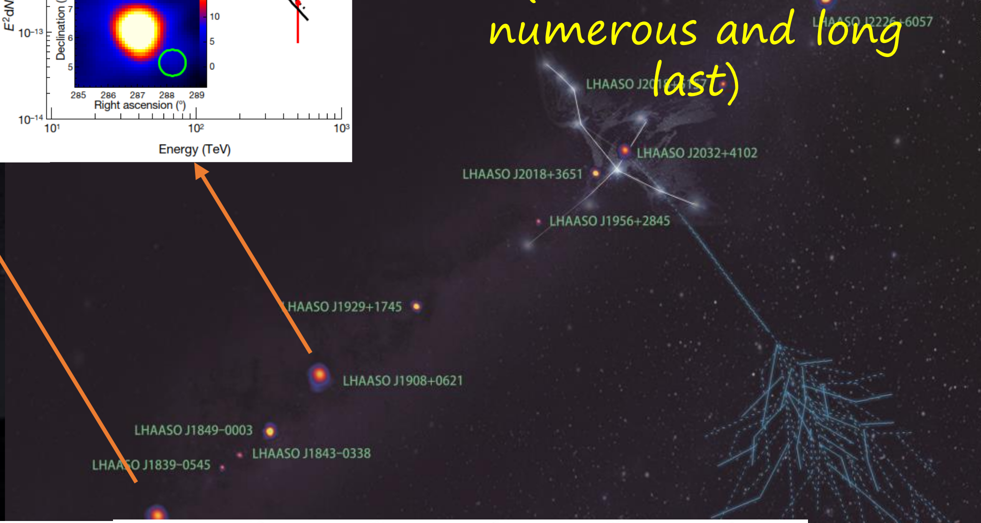
Pulsar Wind Nebulae

HAWC

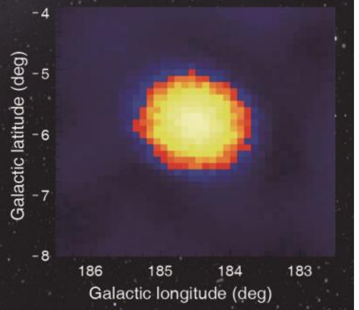
Cao et al. 2021

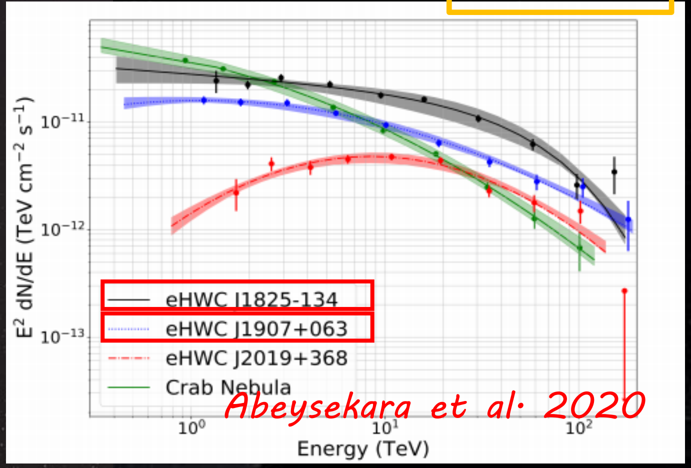






The majority could be PWN!!! (statistics: more numerous and long last)

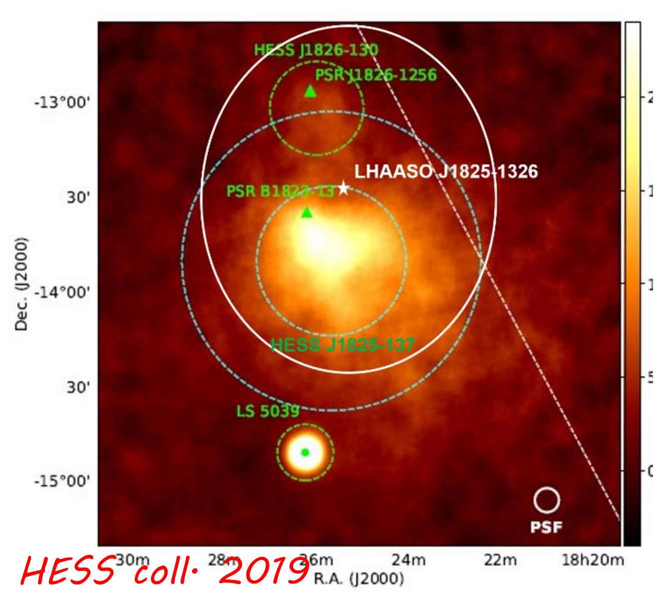




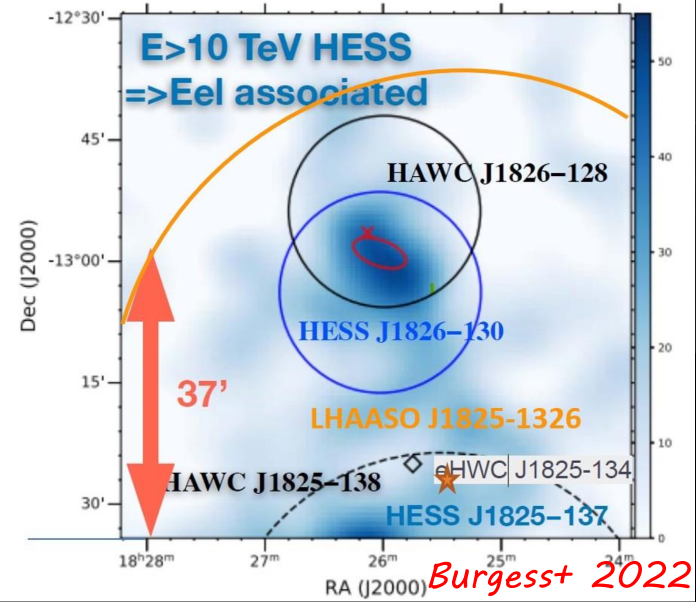
Abeysekara et al. 2020

LHAASO J1825-1326
PWN? SNR?
[MC&Giuliani 2023]

LHAASO J1908+621
PWN?SNR?
[MC&Giuliani 2023]

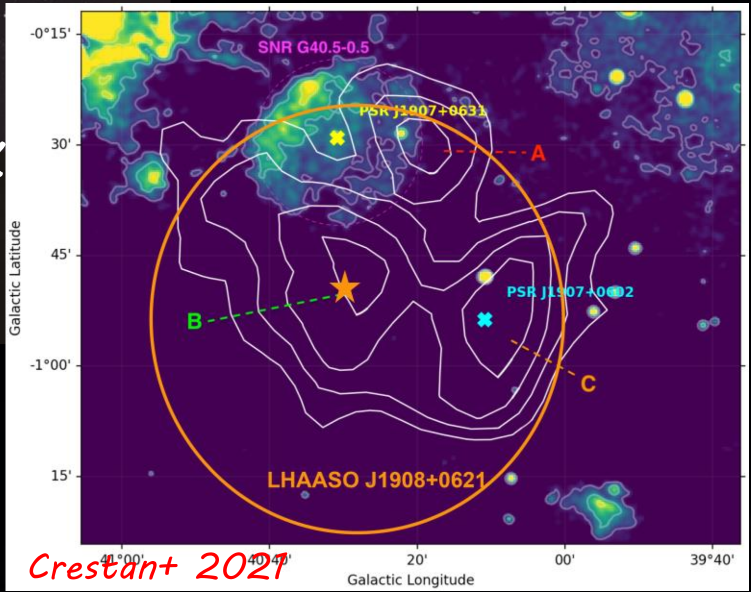


HESS coll. 2019



Burgess+ 2022

Very Complex Environment and low angular resolution



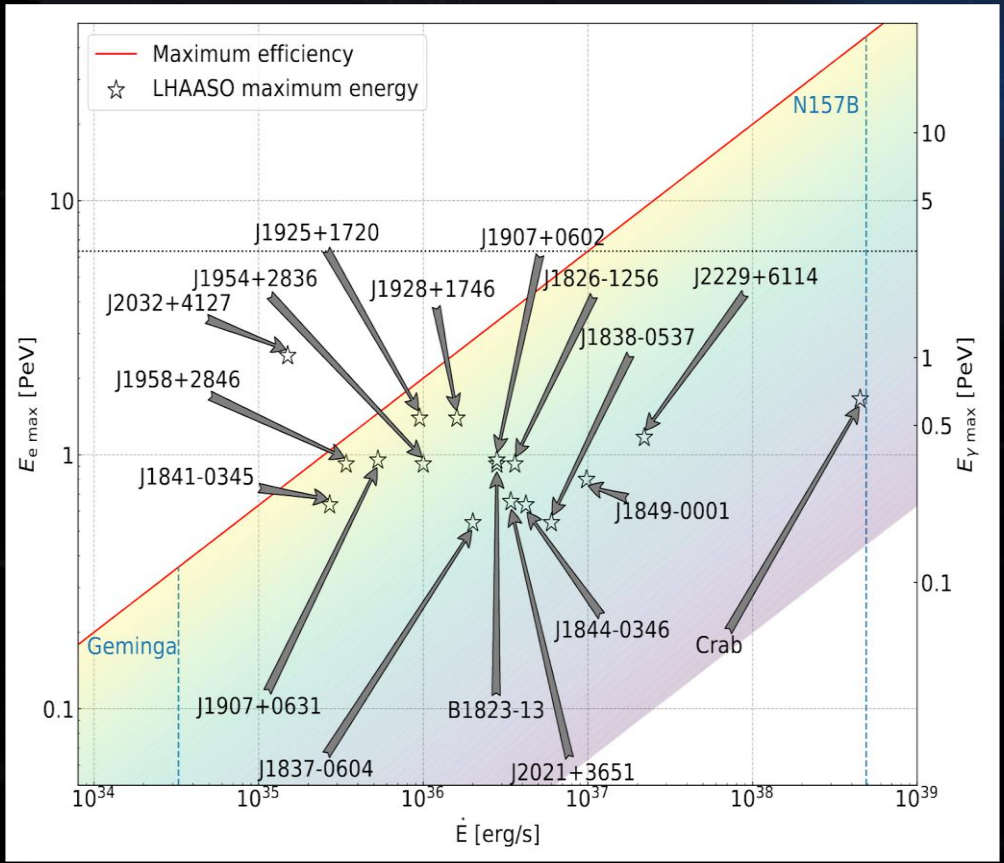
Crestan+ 2021

Pulsar Wind Nebulae

Leptonic origin of gamma-rays > 100 TeV is possible

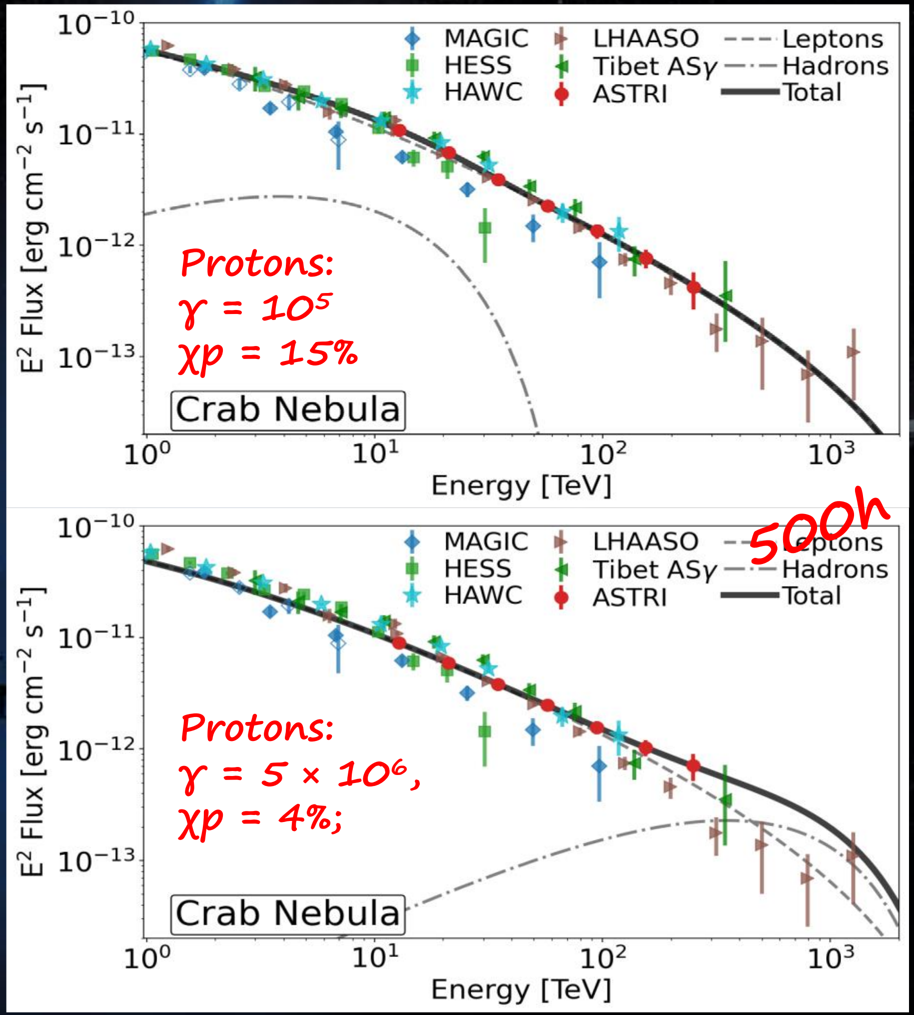
→ IC on BKG photon field (no KN effect due to an increase of the cooling time in radiation dominated environments [low B]) [Breuhaus+ 2022]

Acceleration is limited by the maximum potential drop (not in the Crab)



DeOnaWilhelmi+ 2022

Vercellone+ 2022



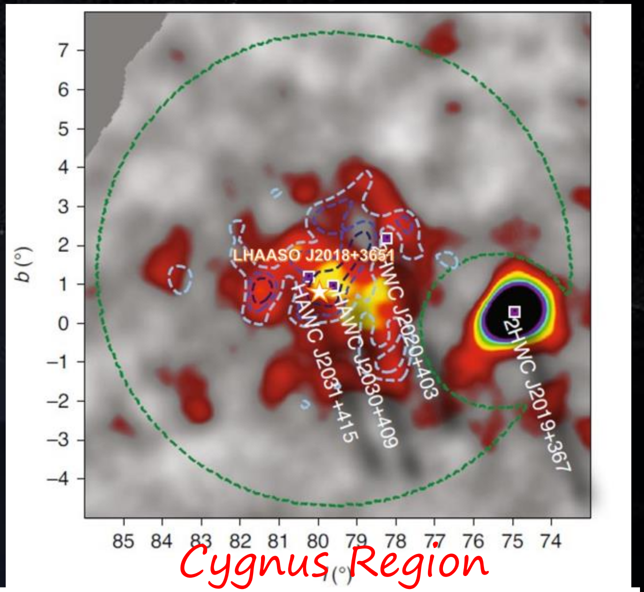
If there are protons (hadrons):

- ~few % of the total energy (Guepin+ (2020))
- pp emission may show up in the high energy tale of IC emission

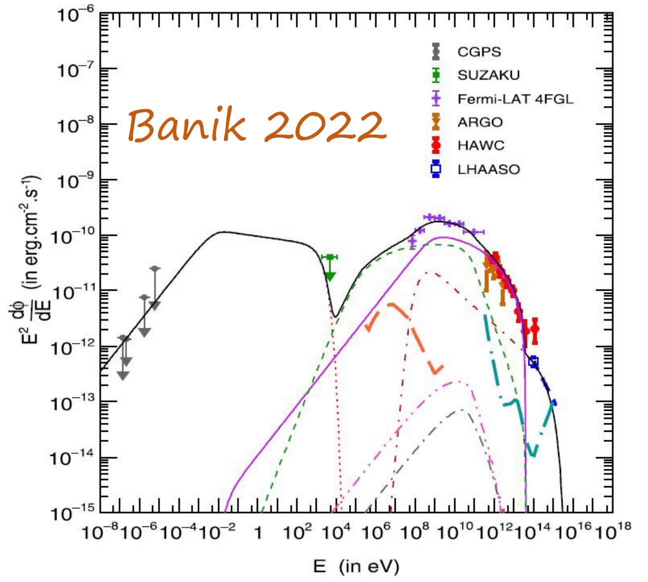
Young Massive Star Clusters (inside superbubbles)

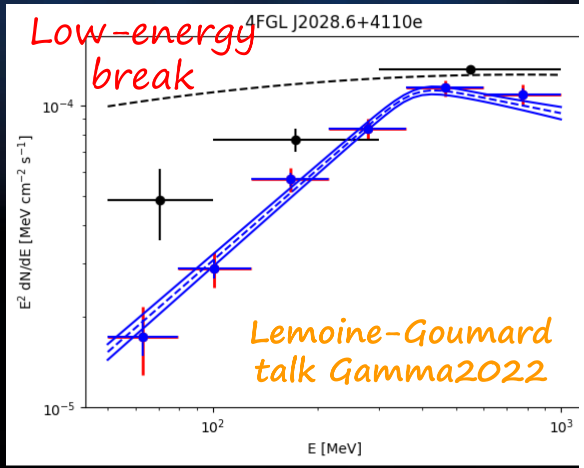
- Clusters with age < few Myrs that can reach M up to 6×10^4 Solar masses
- Acceleration at 1 PeV possible at Wind Termination Shocks [Morlino 2021, Vieu et al. 2022]
- Collective effects in the most compact clusters (size of a few pc) can generate a collective ourflows (right amount of power [Vink 2022])
- Several physical ingredients to a deep analysis (cluster population, stellar population inside, stellar wind, cluster wind, PA model, gas distribution) [Morlino CTAO general meeting]

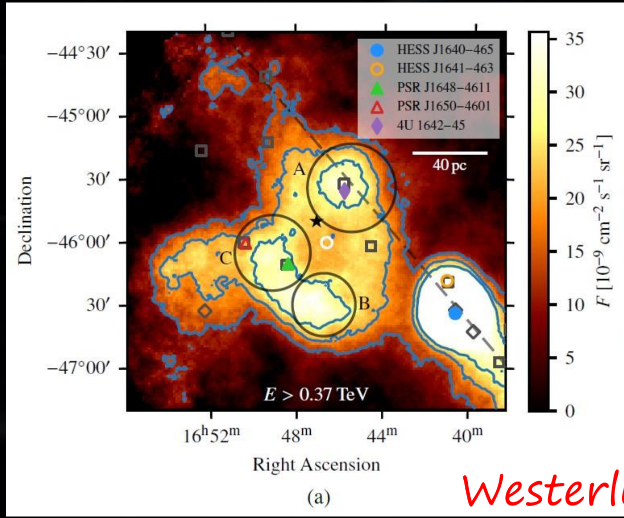
Abeysekara+ 2021 (HAWC coll)

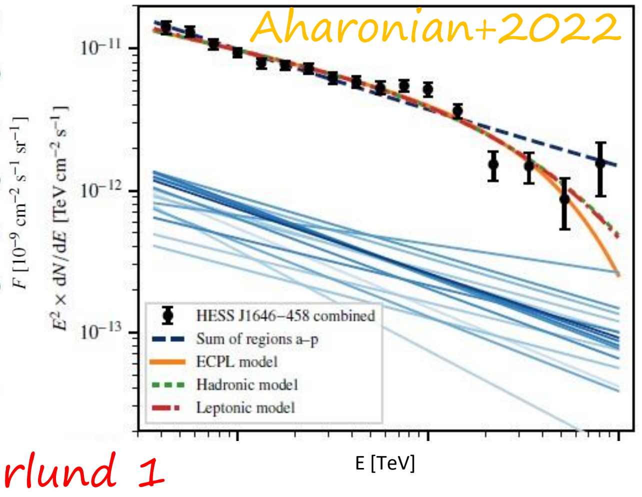


Cygnus Region





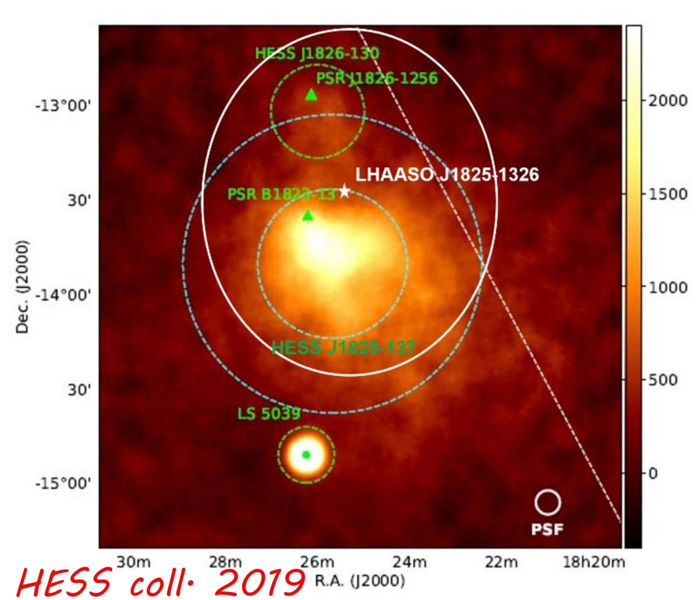




Westerlund 1

TeV HALOS

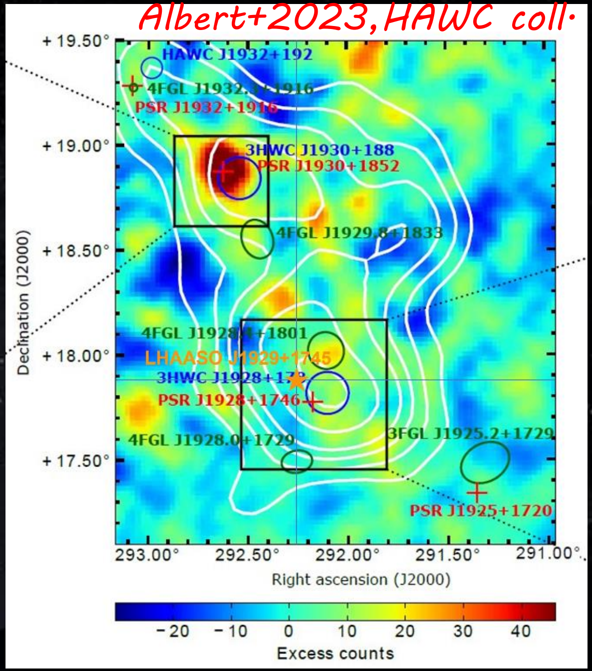
LHAASO J1825-1326



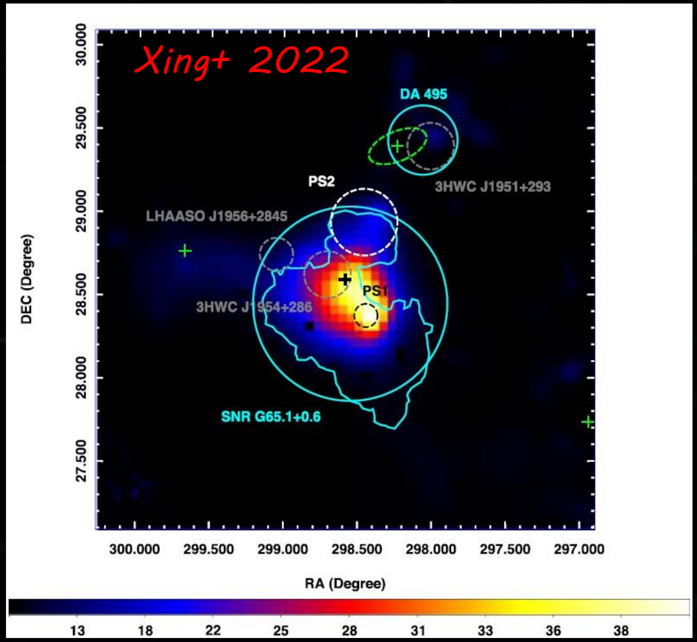
Several LHAASO sources could be TeV halos!

[MC&Giuliani 2023]

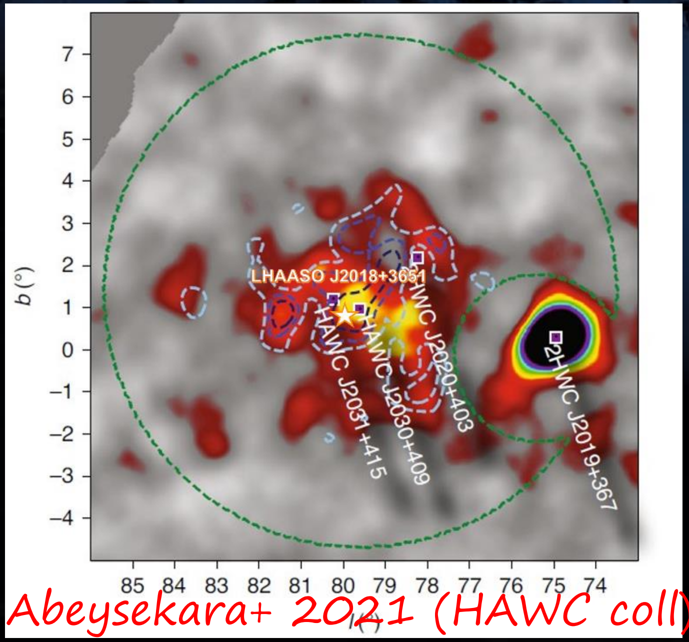
LHAASO J1929+1745



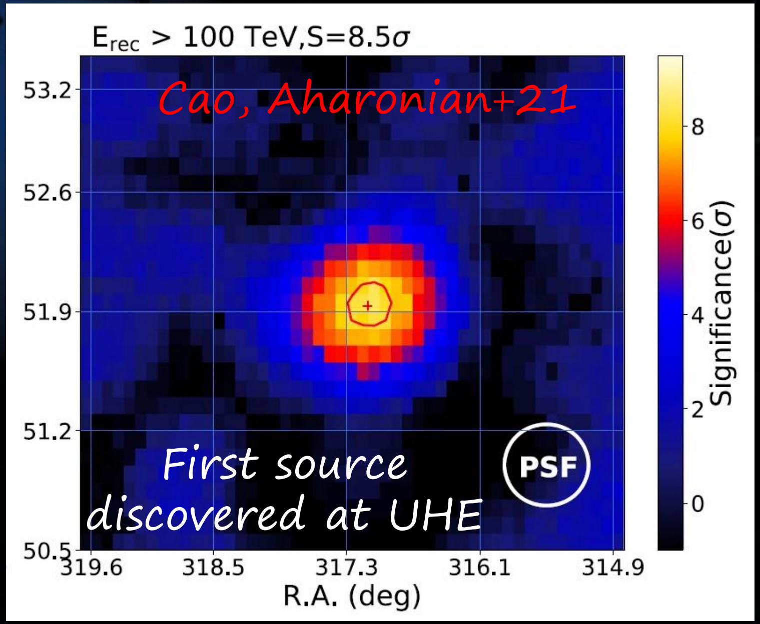
LHAASO J1956+2845



LHAASO J2032+4102

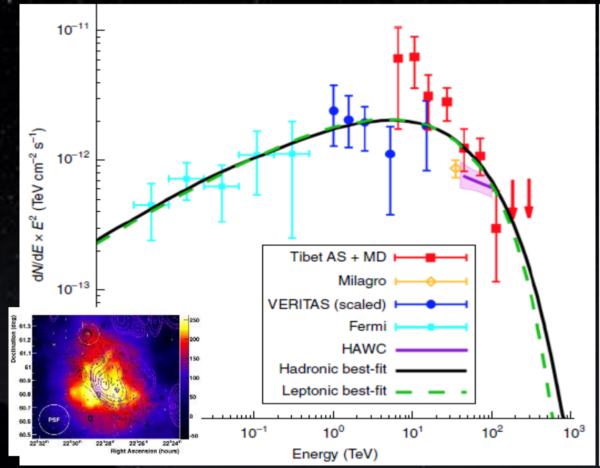


LHAASO J2108+3651

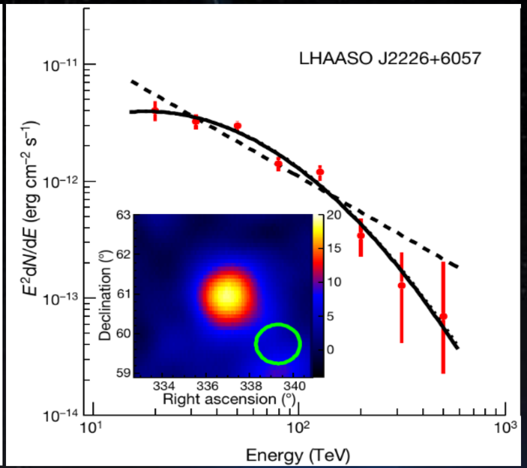


And finally... The Supernova Remnants

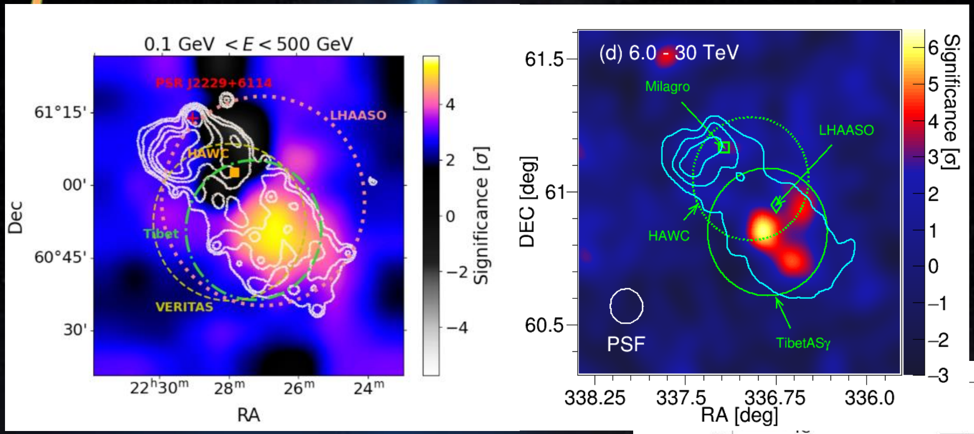
LHAASO J2226+6057



Tibet AS collaboration 2021

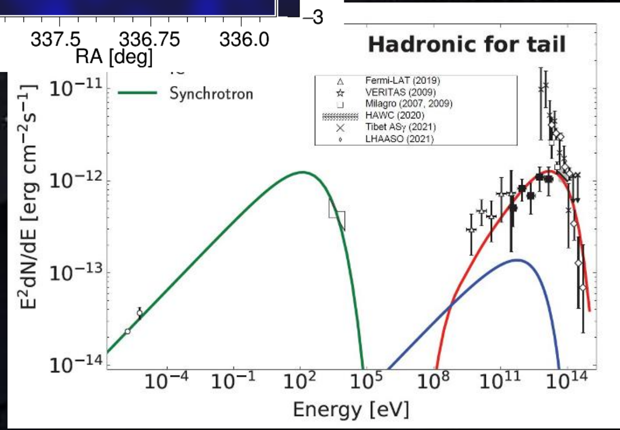


Cao+ (LHAASO coll) 2021



Fang+ 2022

MAGIC coll. 2023

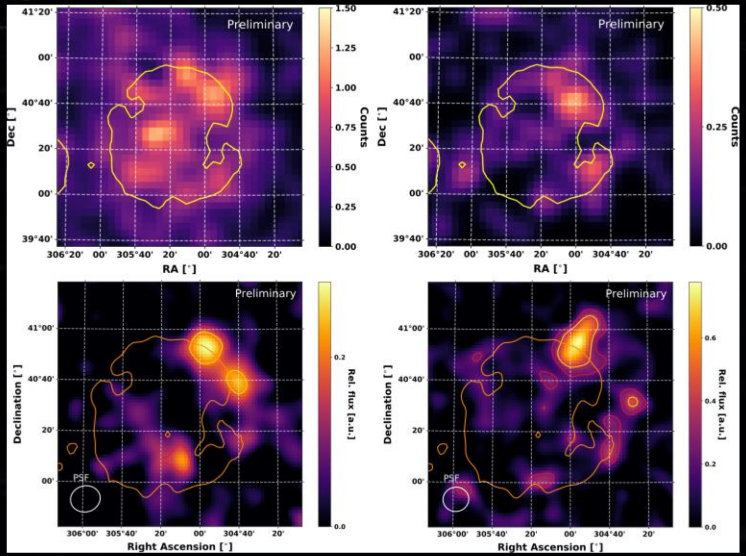


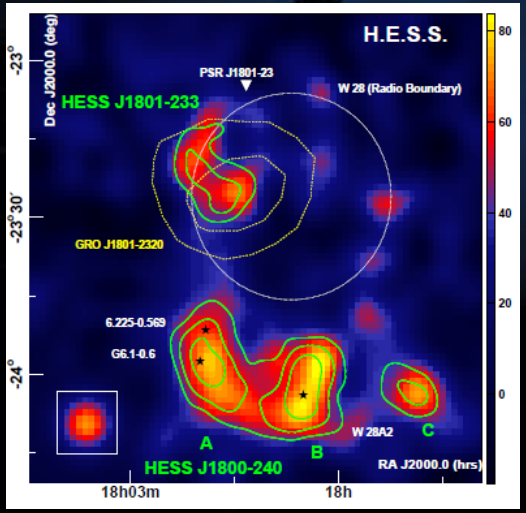
Fermi-LAT and MAGIC detection favoured hadrons from SNR/MC interaction

Celli Talk Gamma2022

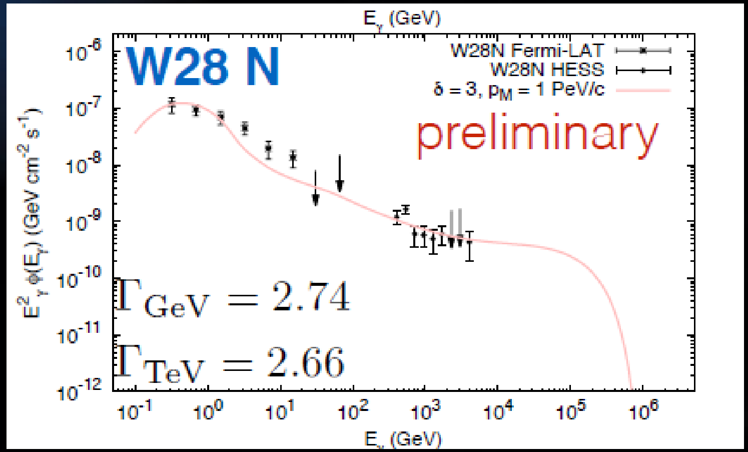
Propagation study

Gamma Cygni (MAGIC collaboration 2019)

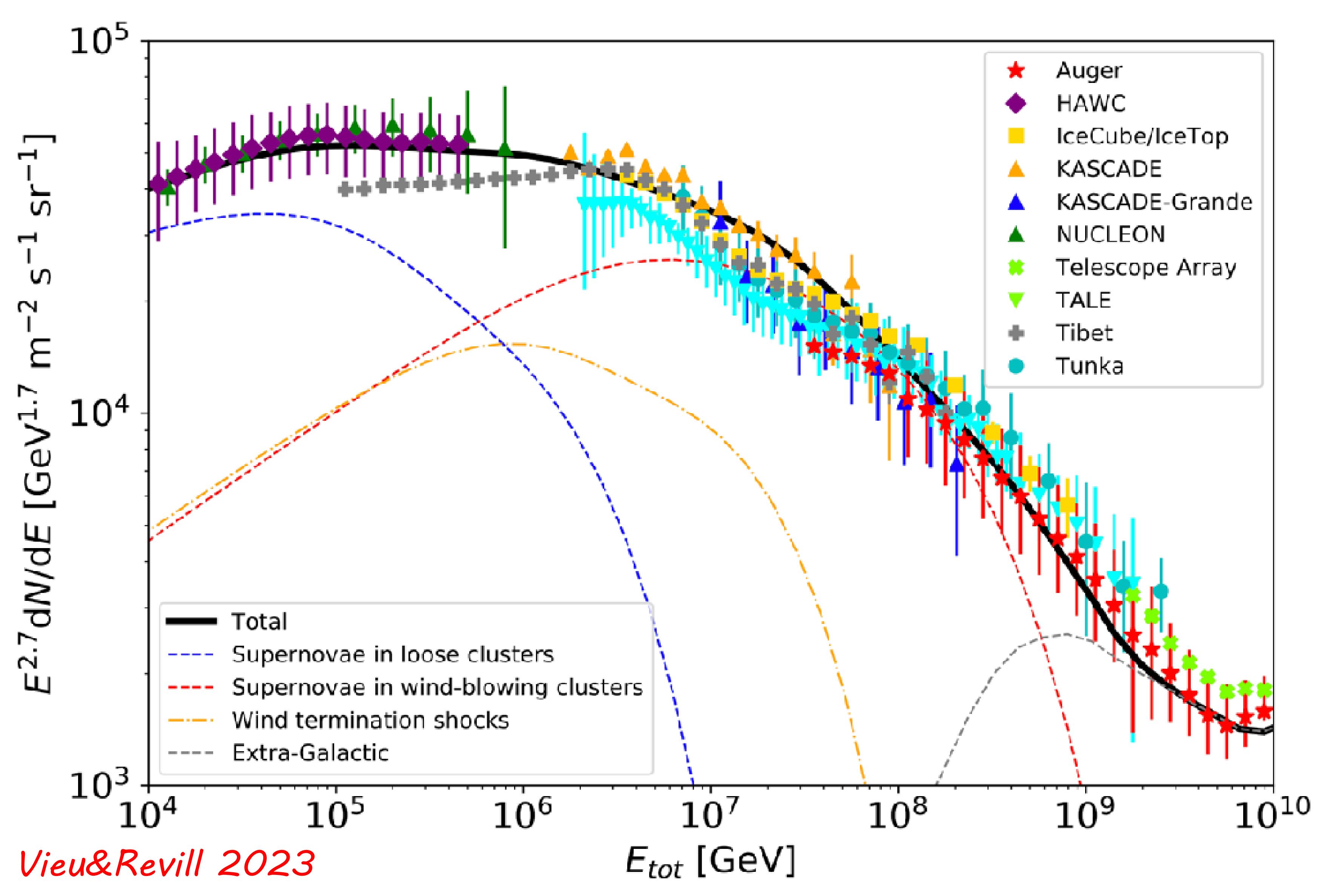




W28 (Aharonian et al. 2008)



More kinds of source is "mel che one"



Sources	Ra (°)	Dec (°)	σ >100 TeV	Emax (PeV)	Origin	Neutrino constraints	Favoured model
LHAASO J0341+5258	55.34	52.97	6 at 25 TeV	not defined	not identified	no	few information
LHAASO J0534+2202	83.55	22.05	**17.8**	0.88 ± 0.11	**Crab PWN**	yes (Huang+22a,b, Abbasi+23)	Lepto-Hadronic (Nie+22, Vercellone+22)
LHAASO J00621+3755	95.47	37.92	3.1	not defined	TeV halo, PWN	no	challenging
LHAASO J1825-1326	276.45	-13.45	**16.4**	0.42 ± 0.16	**TeV halo,** PWN, SNR	yes (Huang+22a)	Leptonic (Burgess+22)
LHAASO J1839-0545	279.95	- 5.75	7.7	0.21 ± 0.05	**PWN,** MSC	no	Hadronic (Banik+21)
LHAASO J1843-0338	280.75	- 3.65	8.5	$0.26^{+0.16}_{-0.10}$	PWN, SNR	no	challenging
LHAASO J1849-0003	282.35	- 0.05	10.4	0.35 ± 0.07	**PWN,** MSC	no	challenging
LHAASO J1908+621	287.05	6.35	**17.2**	0.44 ± 0.05	**PWN,** SNR	yes (Huang+22a)	Lepto-Hadronic (DeSarkar+22)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71^{+0.16}_{-0.07}$	**PWN ,** TeV halo, SNR	no	challenging
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	**PWN ,** TeV halo, SNR	no	challenging
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	**PWN,** YMC	no	Leptonic (Yang+23)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	**YMSC,** PWN, TeV halo	yes (Banik+22)	Hadronic (Banik+22)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	**TeV halo**	yes (Kar+22)	Hadronic (Kar+22)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	**SNR,** PWN	no	Hadronic (Fang+22, MAGIC23)

HIGHEST ENERGY SENSITIVITY

WIDE BAND SENSITIVITY

GOOD ANGUKAR RESOLUTION

NEUTRINOS

MC&Giuliani 2023

What we need in the next future?

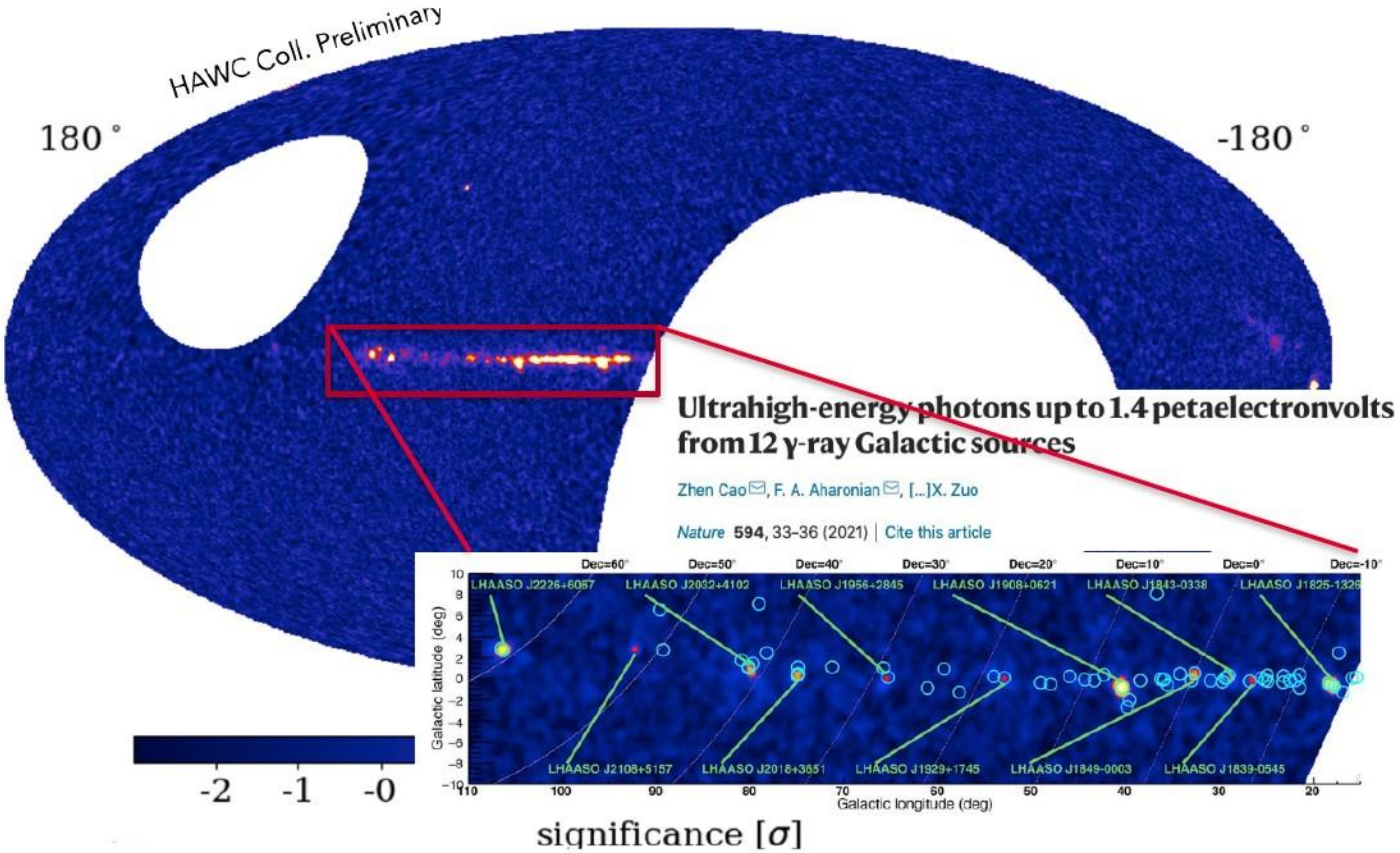
- Wide FoV with almost homogeneous off-axis acceptance
  - ✓ Multi-target fields, surveys, and extended sources (GC, SNRs, TeV halos)
  - ✓ Enhanced chance for serendipitous discoveries

- Sensitivity: better than current IACTs (E > 10 TeV):
  - ✓ Extended spectra for PeVatron confirmation and lepto/hadro origin discerning (SNRs, Micro-quasars, PWN)
  - ✓ Diffusion coefficient constraints (Gamma-Cygni, SNRs, TeV halos)

- Energy/Angular resolution: $\leq 10\%$ / $\leq 0.1°$ (E $\leq$ 10 TeV)
  - ✓ Characterize extended sources morphology
    - ✓ Energy dependence
    - ✓ Identification acceleration regions
  - ✓ MW association
  - ✓ Spectral Shape (hadrons vs leptons)

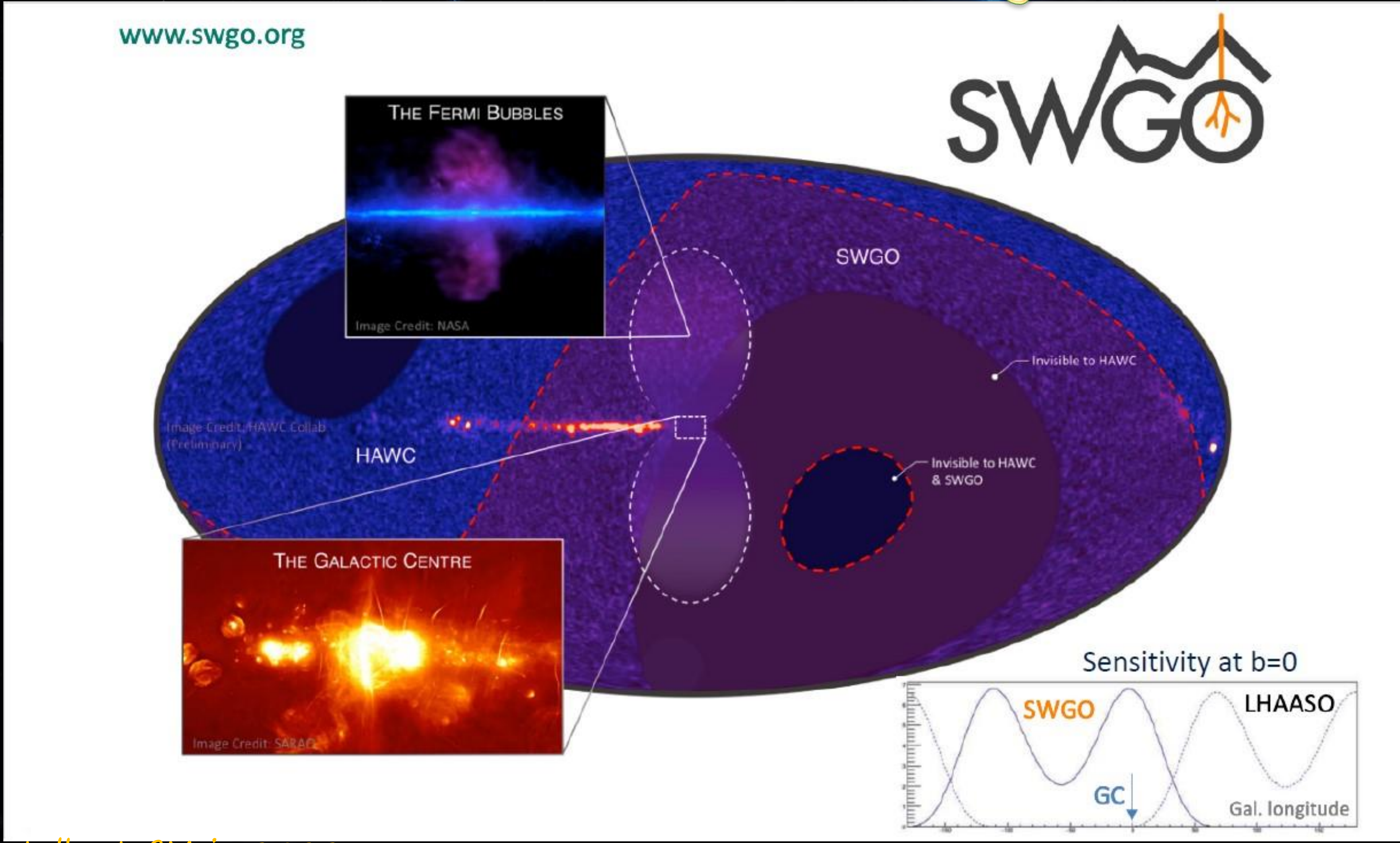
And we would like also
a neutrino detection, thanks!

The current VHE sky



Morlino's talk at CTA CM in 2022

The future VHE sky



Morlino's talk at CM in 2022

ASTRI Mini-Array

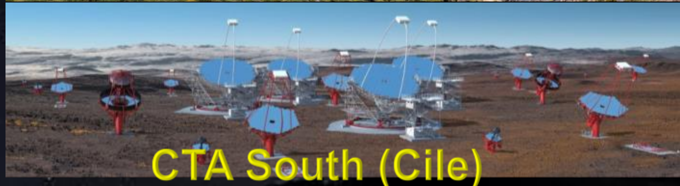
cta cherenkov telescope array — the observatory for ground-based gamma-ray astronomy

Serra La Nave (Sicily)

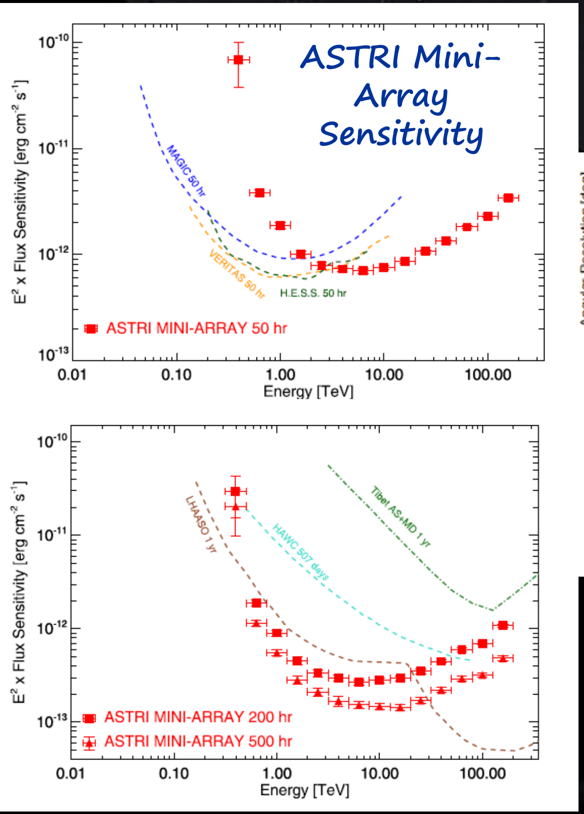
Teide Observatory (Tenerife)

Hoffman&Zanin 2023

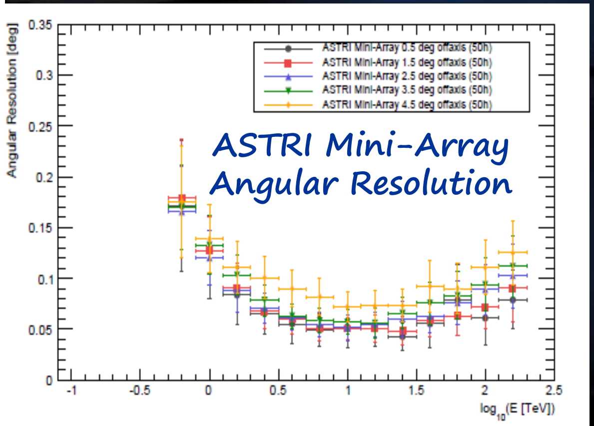
CTA North (La Palma)

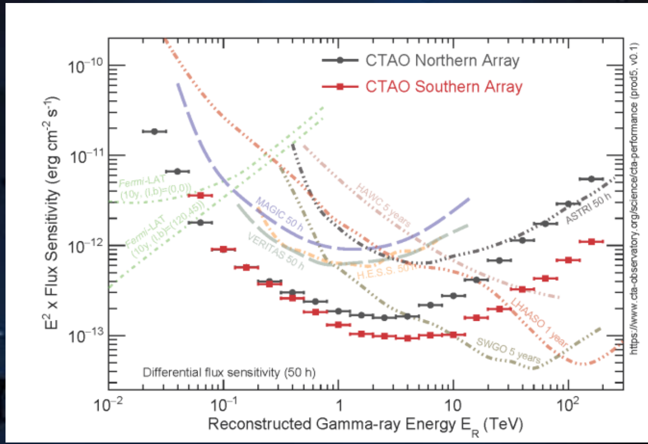


CTA South (Cile)

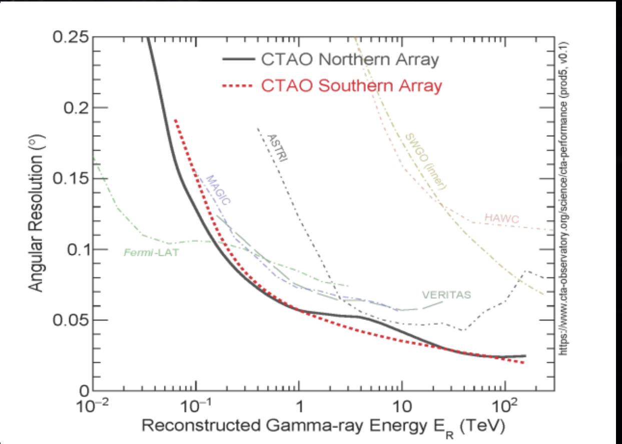


Scuderi et al. 2022, JHEAP, 35, 52
Vercellone et al., 2022, JHEAP, 35, 1
D'Aì et al., 2022, JHEAP, 35, 139





CTA Sensitivity



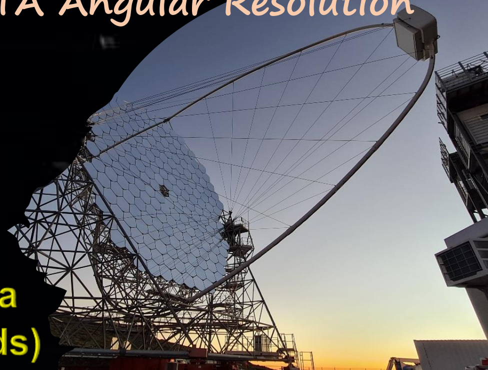
CTA Angular Resolution

CTA website (https://www.cta-observatory.org/science/ctao-performance/#1472563157648-91558872-faf1)

1 telescope operative → in the next one-two months!

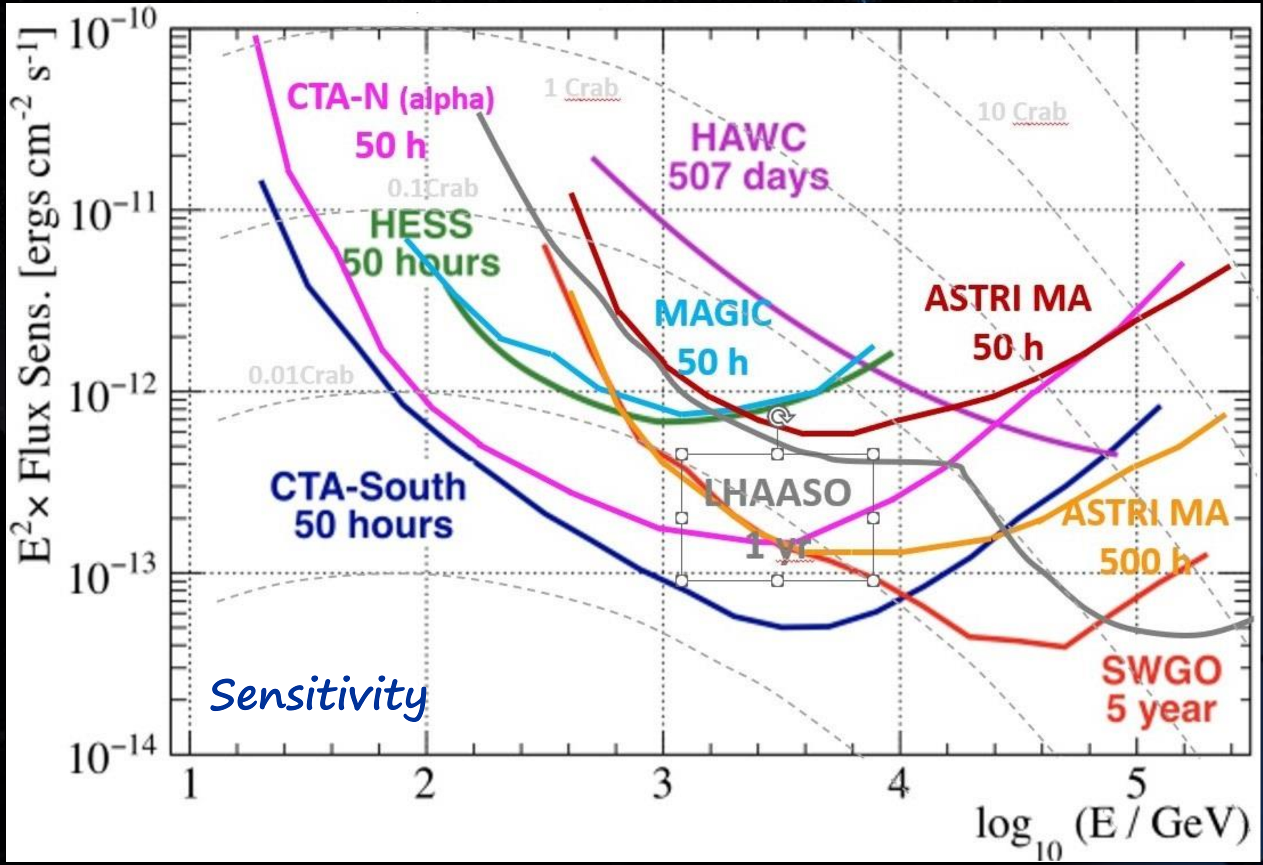
3 telescopes operative → early 2024

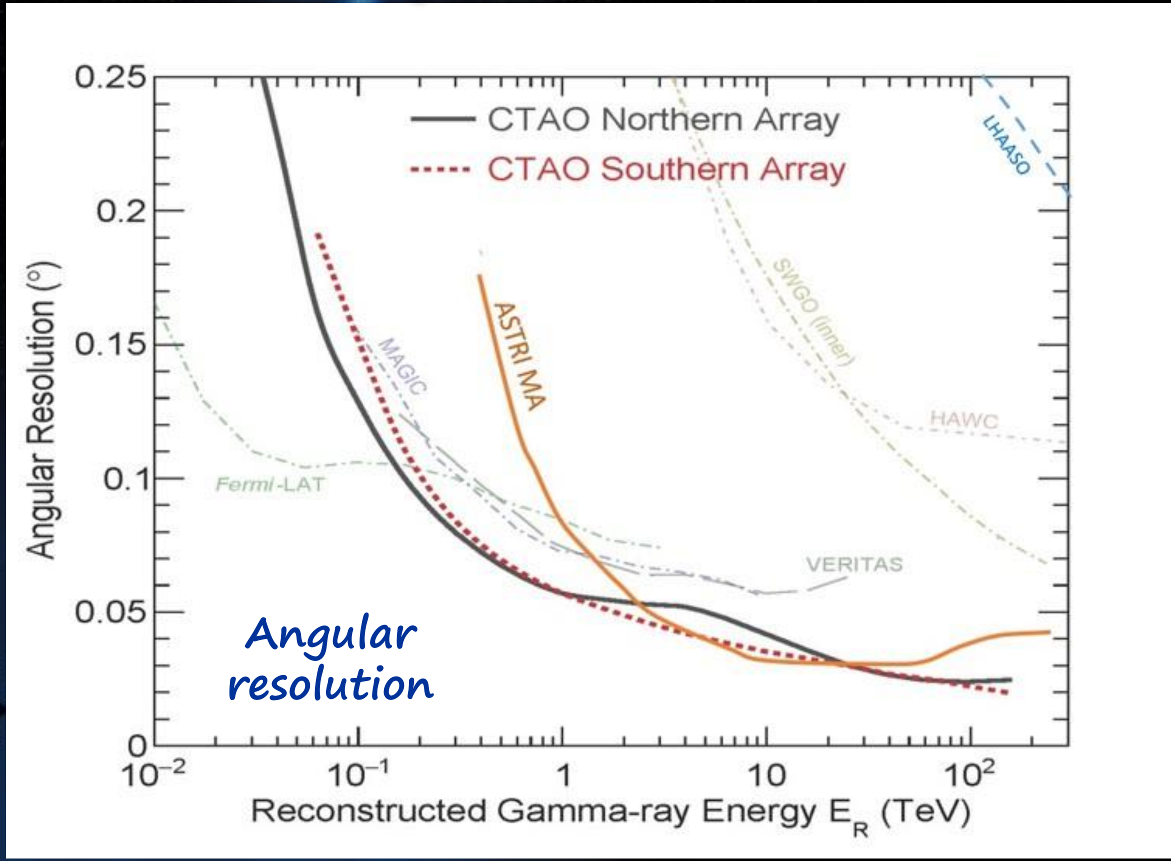
Complete Array→ by the end of 2024



LST1, La Palma (Canarian Islands)

CTA&ASTRI Mini-Array





- Sensitivity: better than current IACTs (E > 10 TeV):
  - ✓ Extended spectra and cut-offs contsraints
- Energy/Angular resolution: ≤ 10% / ≤ 0.1° (E ≤ 10 TeV)
  - ✓ Characterize extended sources morphology

Vercellone+ 2022,
Scuderi+ 2022,
CTA website,
MC&Giuliani 2023

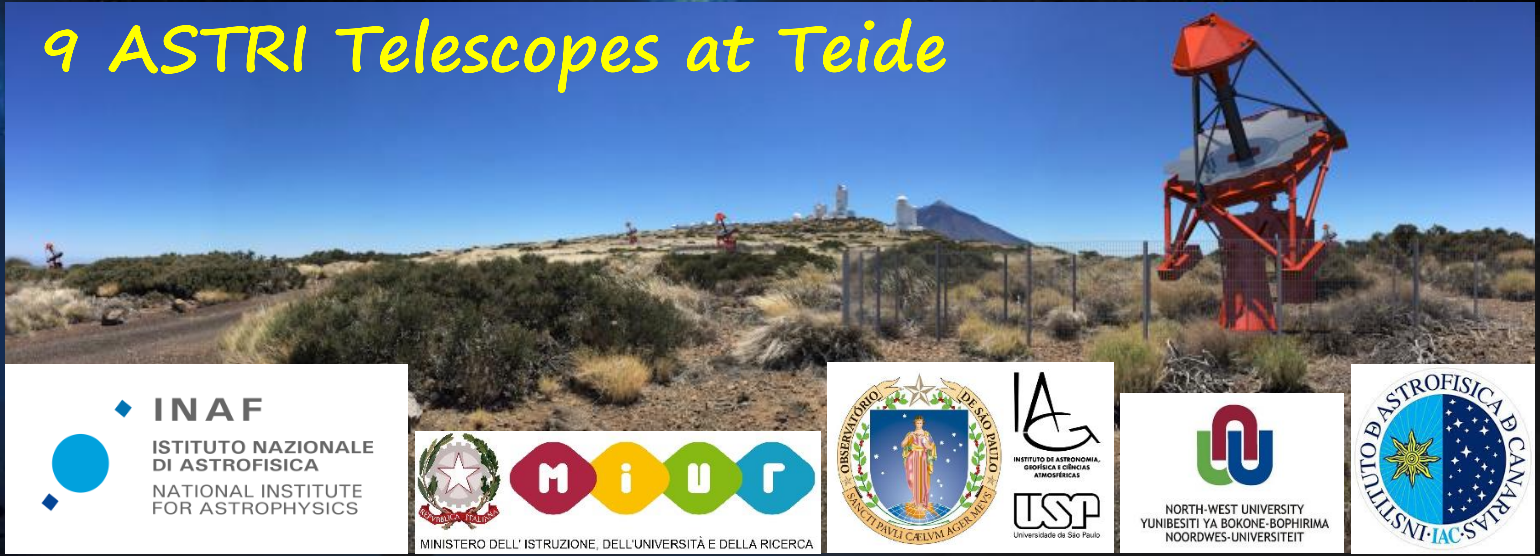
PI: Giovanni Pareschi
PM: Salvo Scuderi
PS: Andrea Giuliani

The ASTRI Project
(Astrofisica con Specchi a Tecnologia Replicante Italiana)

ASTRI-Horn Prototype

- **INAF** "Flag Project" funded by MIUR → ***end-to-end prototype for CTAO at Serra la Nave (Mount Etna, Sicily)***
- First Crab detection above 5 sigma (Lombardi et al. 20)
- ***Structure and mirrors selected for CTA SSTs***

ASTRI Mini-Array



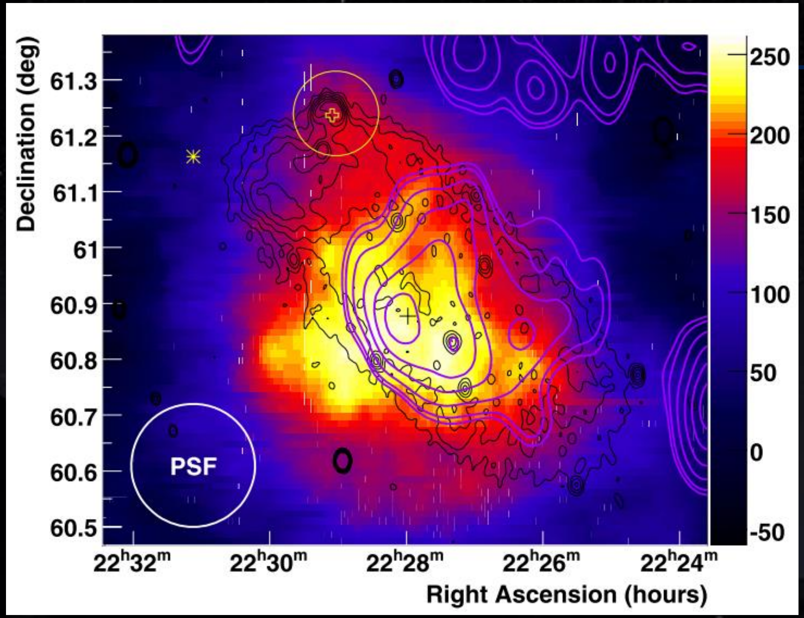
- **INAF** commitment with the Italian government and international partners (University of Sao Paulo/FPESP – Brazil, North-West University – South Africa, IAC – Spain) [more than ***150 researchers***]
- ***Dedicated Funding***
- Being deployed at the ***Teide Observatory (Tenerife, Canarian Islands)*** in collaboration with IAC

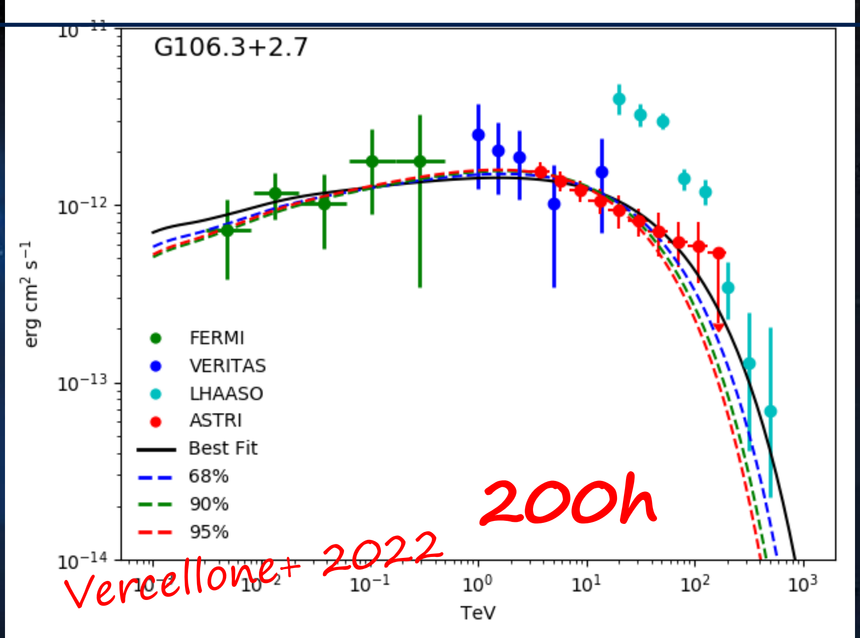
ASTRI Mini-Array Core Science at the Observatorio del Teide

Vercellone et al. 2022

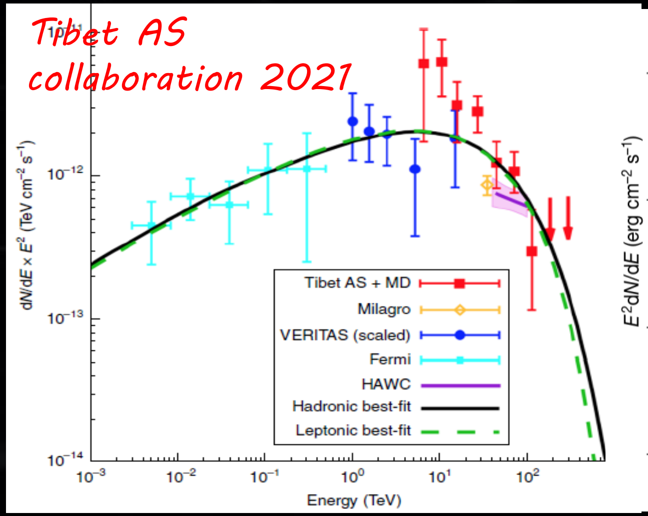
1. ASTRI Mini-Array expected Performances
2. ASTRI Mini-Array Core Science and Simulation Setup
3. Pillar-1: Origin of Cosmic Rays
4. Pillar-2: Cosmology and Fundamental Physics
5. Gamma-Ray Burst and Multi-Messangers Astrophysics
6. Non Gamma-ray Astrophysics
7. Multi-wavelength opportunities
8. Conclusions

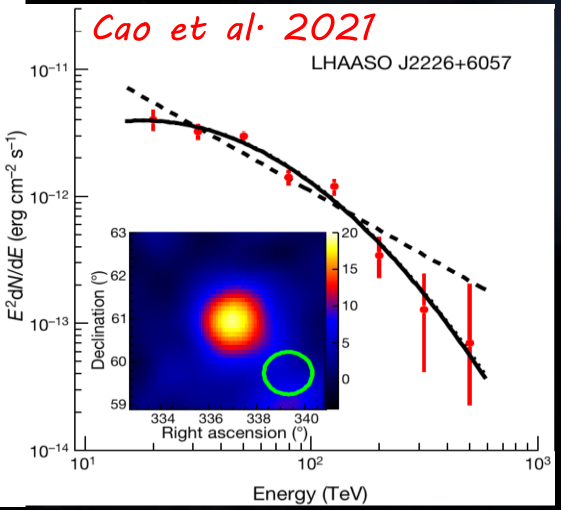
ASTRI Mini Array & Pevatron hunting: SN 106.3+2.7





- Morphology and spectrum from VERITAS [LHAASO points added in a second moment]
- Detection @100TeV w ASTRI MA (200h exp) with high significance

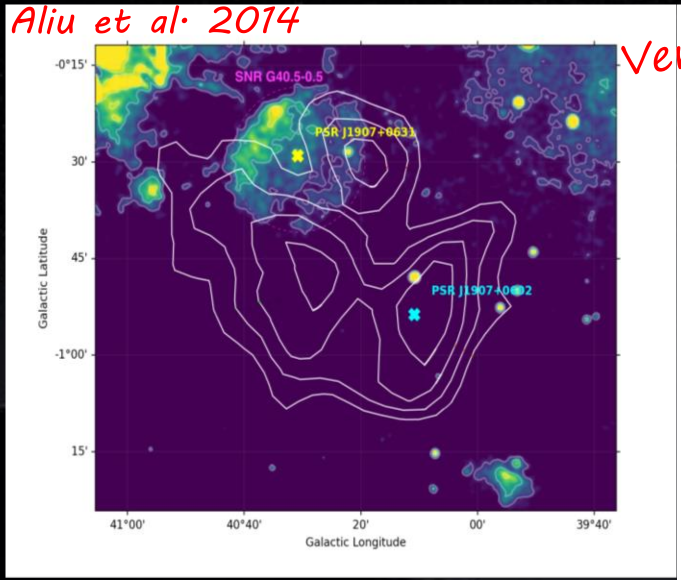


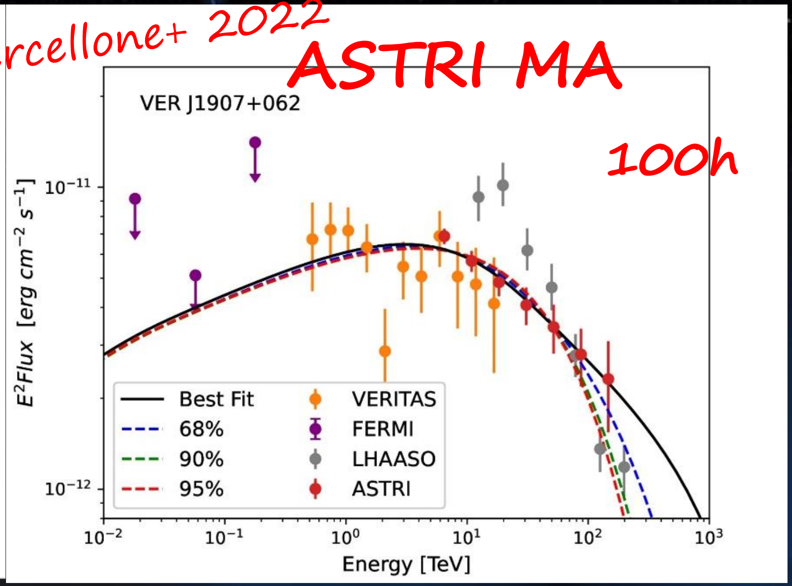


With the ASTRI-MA angular resolution:

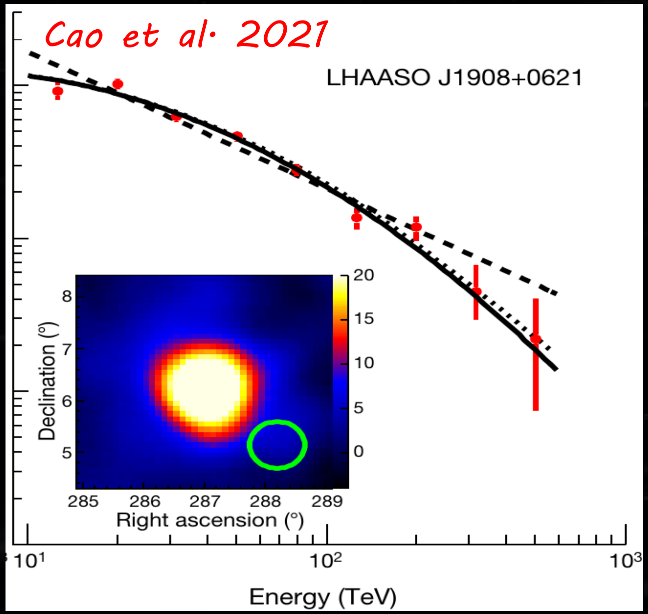
- *association of the SNR with the Molecular cloud, separating it from the pulsar*
- *different morphologies at different energies*

ASTRI Mini Array & Pevatron hunting – eHWC 1907+063

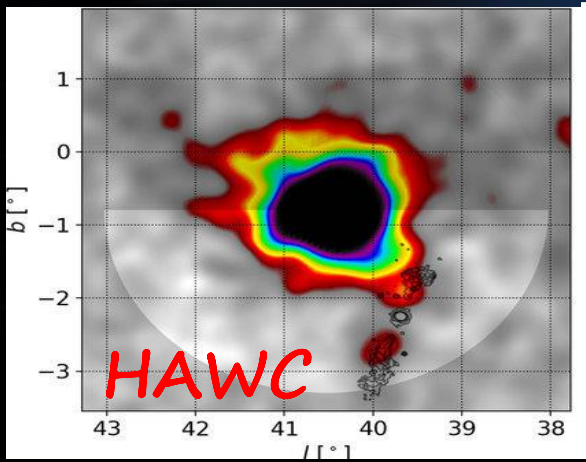




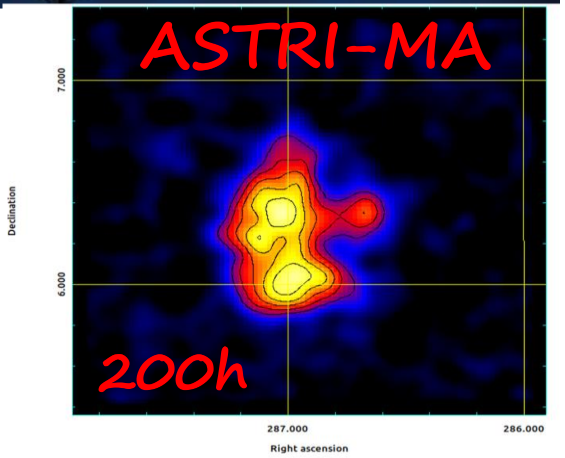
- Morphology from VERITAS (Aliu et al. 2014)
- PL spectrum from HAWC (Abeysekara et al. 2017) [LHAASO points added in a second moment]
- Detection @100TeV w ASTRI MA (100h exp) with high significance
- **ASTRI MA, in the near future, will be the only instrument able to resolve TeV extended sources**



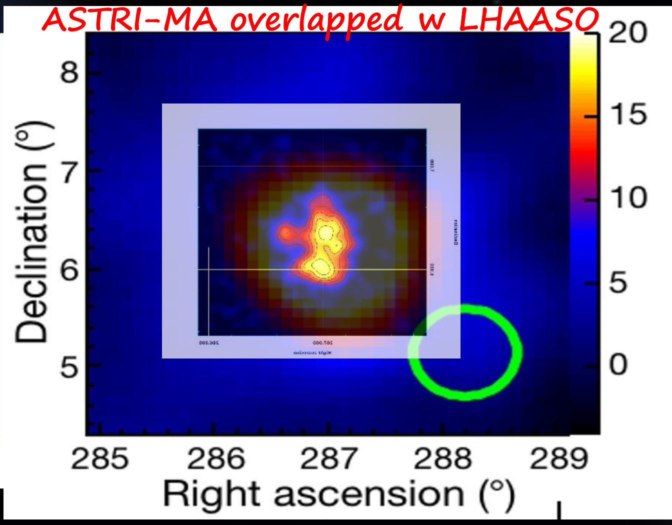
[Different scale]



Abeysekara+ 2017

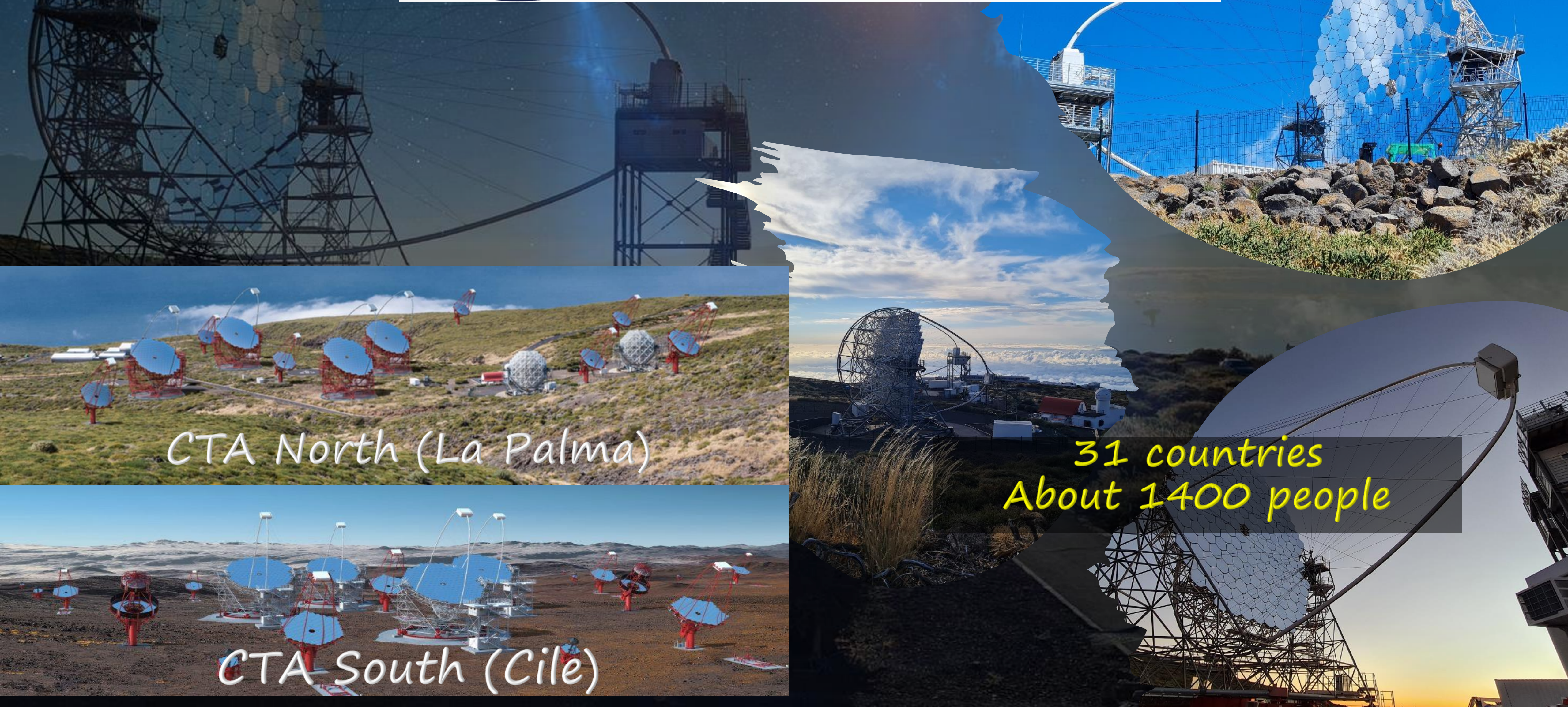


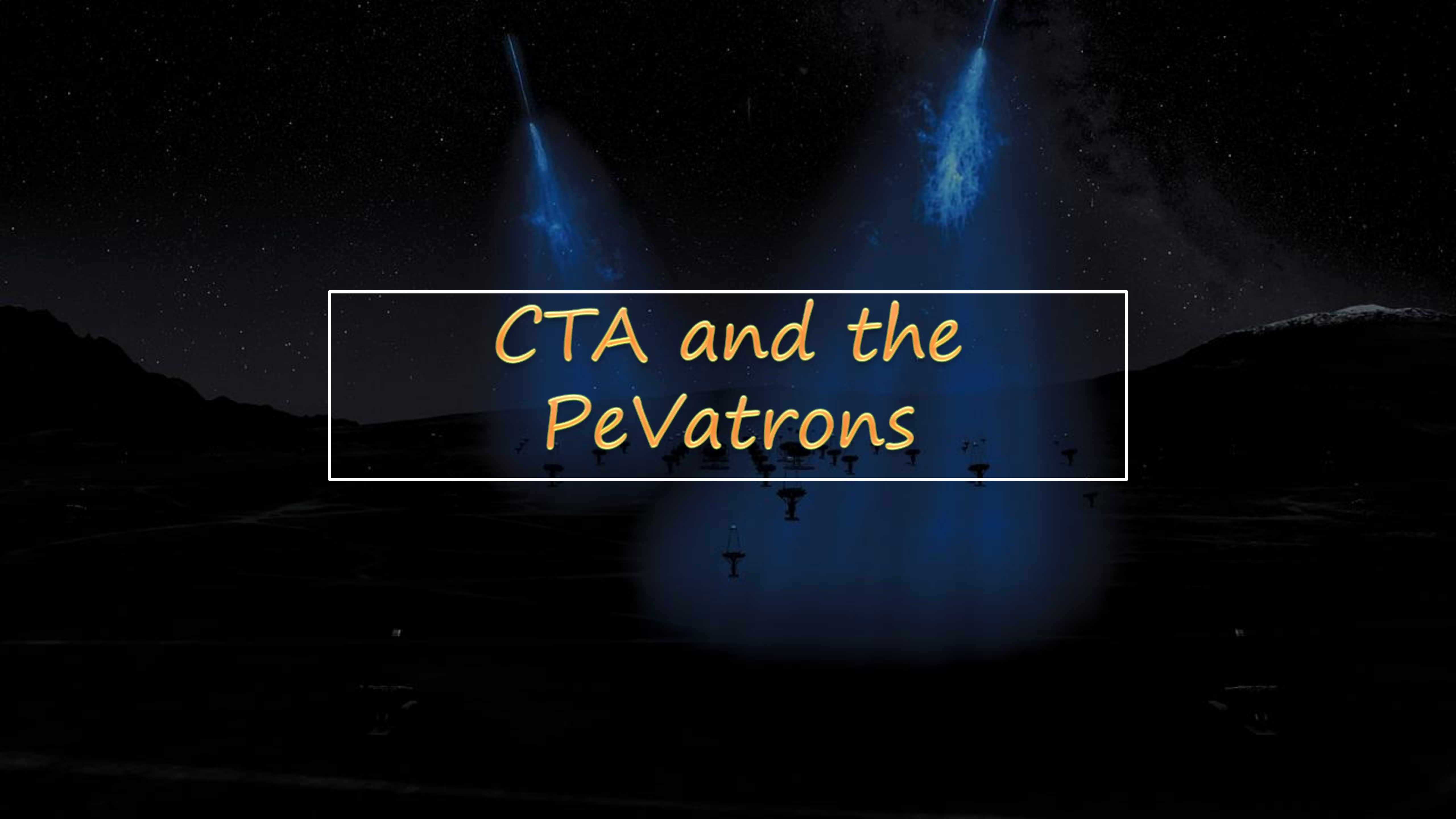
Crestani+ 2021



cherenkov telescope array

the observatory for ground-based gamma-ray astronomy




CTA and the
PeVatrons

CTA key Science Projects

B.L.

50h deep observation of RX J1713.7-3946 (morphology studies)

50h follow up of the 5 best PeVatron candidates

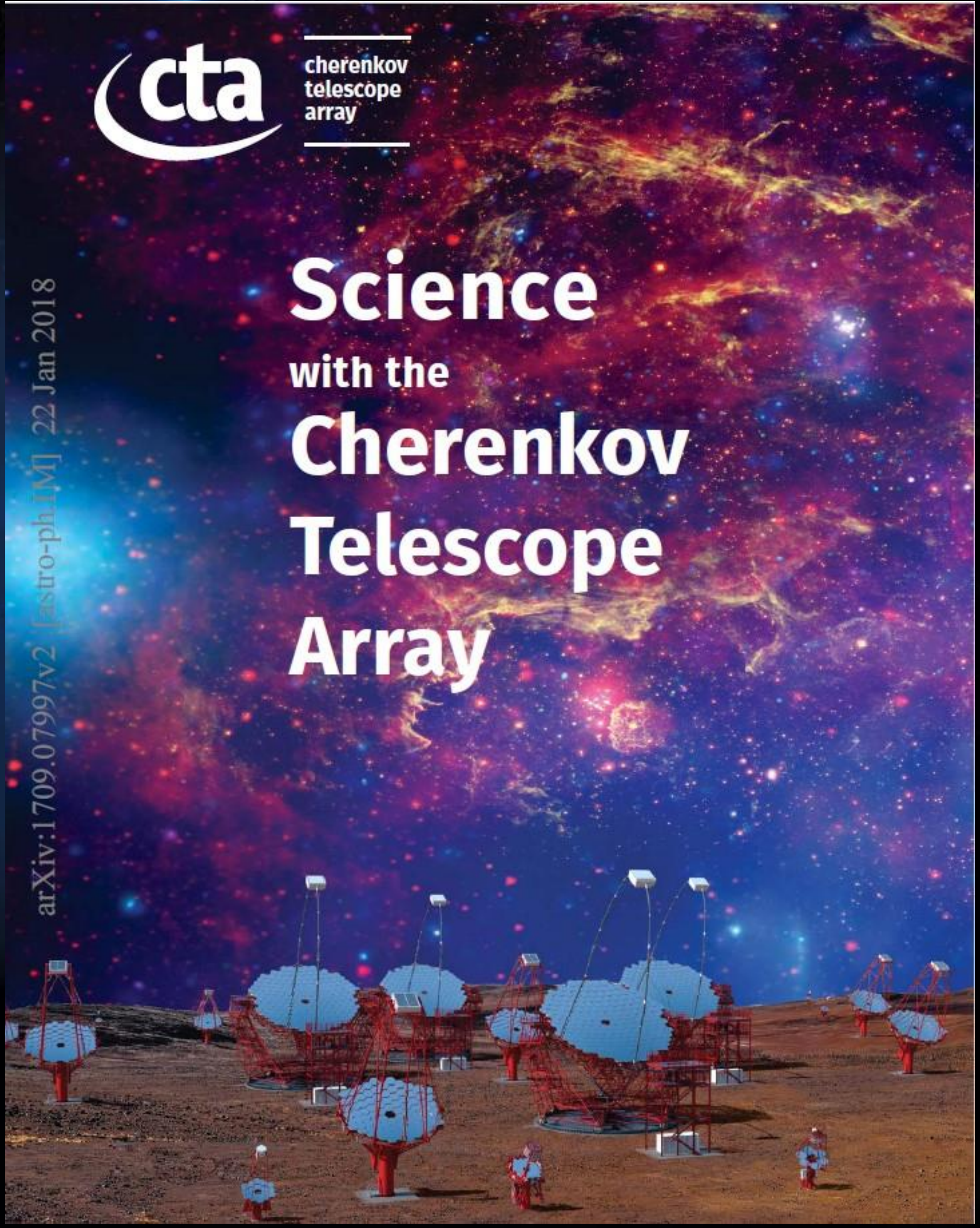
PeVatron

Galactic Center (see Pintore's talk)

Star Forming Regions

>500h on Galactic Centre Region

1. 40h on Westerlund 1
2. 130h on Cygnus
3. Other sources no linked to PeVatrons



Works in progress

Sensitivity of the Cherenkov Telescope Array to spectral signatures of hadronic PeVatrons with application to Galactic Supernova Remnants

CTA Consortium paper, 2023

Astroparticle Physics 150 (2023) 102850

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

Sensitivity of the Cherenkov Telescope Array to spectral signatures of hadronic PeVatrons with application to Galactic Supernova Remnants

A B S T R A C T

The local Cosmic Ray (CR) energy spectrum exhibits a spectral softening at energies around 3 PeV. Sources which are capable of accelerating hadrons to such energies are called hadronic PeVatrons. However, hadronic PeVatrons have not yet been firmly identified within the Galaxy. Several source classes, including Galactic Supernova Remnants (SNRs), have been proposed as PeVatron candidates. The potential to search for hadronic PeVatrons with the Cherenkov Telescope Array (CTA) is assessed. The focus is on the usage of very high energy γ-ray spectral signatures for the identification of PeVatrons. Assuming that SNRs can accelerate CRs up to knee energies, the number of Galactic SNRs which can be identified as PeVatrons with CTA is estimated within a model for the evolution of SNRs. Additionally, the potential of a follow-up observation strategy under moonlight conditions for PeVatron searches is investigated. Statistical methods for the identification of PeVatrons are introduced, and realistic Monte-Carlo simulations of the response of the CTA observatory to the emission spectra from hadronic PeVatrons are performed. Based on simulations of a simplified model for the evolution for SNRs, the detection of a γ-ray signal from in average 9 Galactic PeVatron SNRs is expected to result from the scan of the Galactic plane with CTA after 10 h of exposure. CTA is also shown to have excellent potential to confirm these sources as PeVatrons in deep observations with $\mathcal{O}(100)$ hours of exposure per source.

- Spectral cutoff detection maps for 10h
- Spectral CO detection vs source extension
- PeVatron Test Statistic (PTS) method
- PeVatron Detection maps (point-like sources)
- Follow-up observations with high Night Sky Background conditions → PeVatrons studies are possible and do not subtract observation time to other KSP

Star Forming Regions: YMSCs et al.

Massive star clusters (PeVatrons):

- Model ready (Morlino et al 2021),
- analysis for Cygnus X region [S-w-CTA], Westerlund 1 [S-w-CTA] almost done, Westerlund 2 under progress
- Drafting not started yet

Isolated Massive Stars (Stellar wind contribution to GCRs):

- Analysis and models for HH80-81 (YMS) and BD 43 (massive runaway) underway, model ready.
- Model for YMSCs under progress.
- Drafting not started yet.
- Inclusion of Eta Carina and Gamma2 Velorum under discussion

Starburst galaxies (proving gamma-ray/dense gas correlation → increasing SF and SN activities):

- analysis + model for starburst galaxies (NGC 253, M82, Arp220 [S-w-CTA]),
- drafting of this section done partly, needs to be revised

• Gamma-ray - star formation rate correlation:

- Model ready (by P. Kornecki)
- Drafting started

From 2023 Consortium meeting

TeV halos

From 2022 Consortium meeting

Preliminary population studies show that CTA could detect a significant fraction of such TeV halo sources, and resolve the shape of their profile for a number of such objects depending on the realization of intrinsic properties.

However, in this work all PWNe are assumed to develop a pulsar halo, if not then results need to be rescaled according to the proper fraction!

LHAASO J2108+5157

- Discover in the UHE domain w no PSR in 1 deg!
- Inside the Cygnus Region
- Association with a MC confirmed

A&A 673, A75 (2023)
https://doi.org/10.1051/0004-6361/202245086

Astronomy & Astrophysics

Multiwavelength study of the galactic PeVatron candidate LHAASO J2108+5157

49.3h with LST (June-September 2021) and 1D spectral analysis (point-like assummption) [3.7sigma at E>3 TeV]

→ ULs (2.2 sigma) 300GeV-100 GeV but important constraints through combination with LHAASO, Fermi-LAT and XMM-Newton (ULs)

➡ TeV halo and MC interaction possible but with challenging requirements → complete modeling (combined haronid/leptonic component)

IMPORTANT MESSAGES

- A very brilliant future with ASTRI Mini-Array and CTA and synergy with current VHE instruments
- PeVatrons could be studied also in HNSB conditions → no time taken to other KSPs
- Deep observations are fundamental to obtain key results on some candidate PeVatrons (due to the fact that they are extended)
- A lot of work to do → we need more specific and "focused" information (taking into account the Observatory role of CTA→ 40% of time for KSPs):
  - choice of a few LHAASO "hadronic PeVatrons" candidates → possibly of different kinds (e.g. SNR, YMSC)
  - estimation of exposure time necessary for these sources
  - simulation of observation from the two sites and combination of the results → focus on the morphology reconstruction


Grazie
a tutti voi!