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Multiwavelength analysis of the PeVatron candidate LHAASO J2180+5157

Astroparticle School, Obertrubach-Bärnfels 2022

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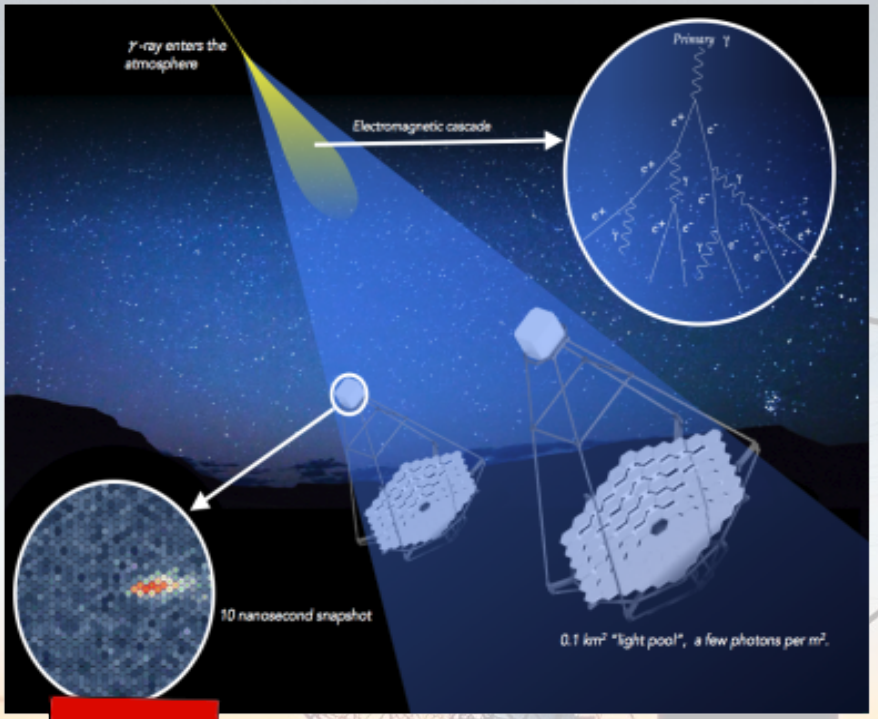
08/10/20222

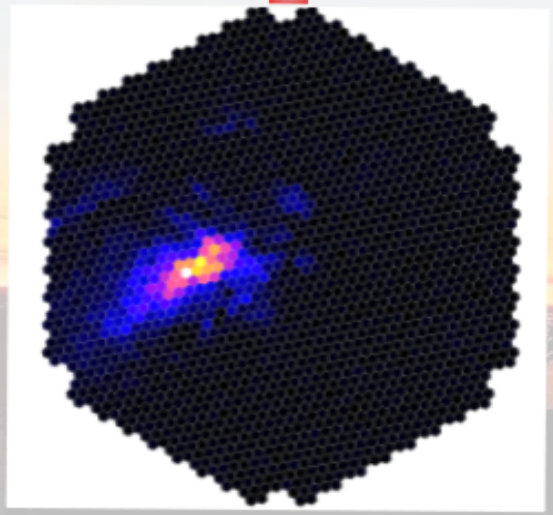
Imaging Air Cherenkov Telescopes



Hillas Parametrization

Physical properties of the primary particle:
- Energy
- Direction
- "Gammaness"

ML → Random Forests (trained with MC data)



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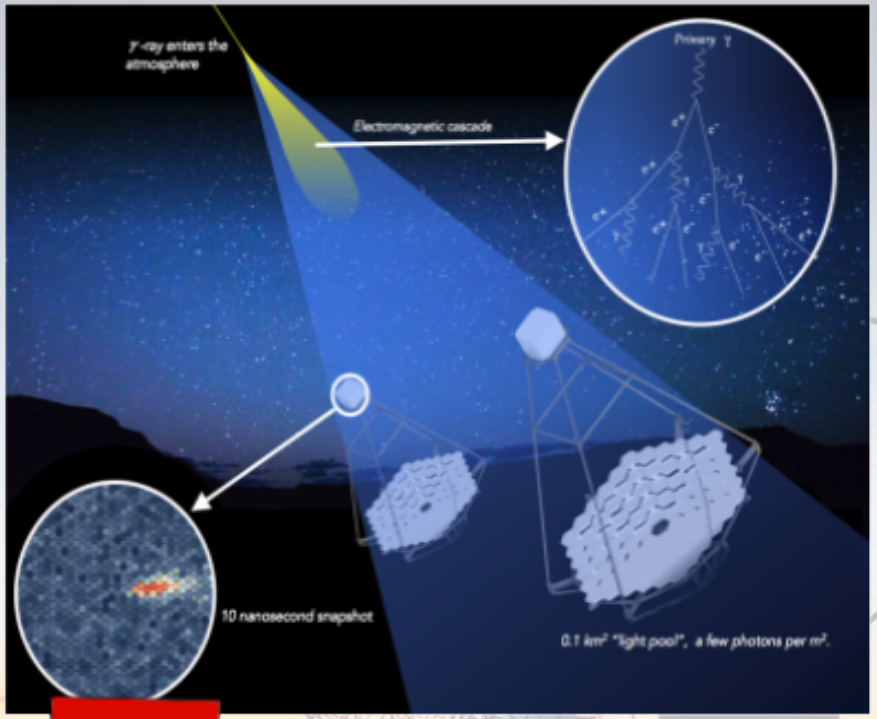

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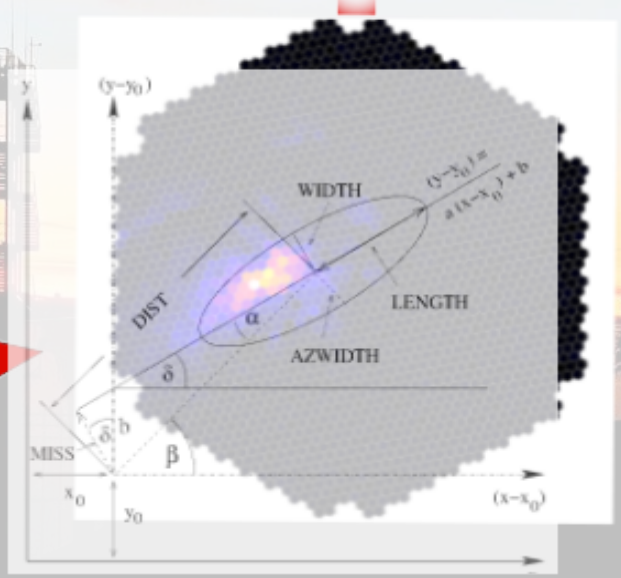

Cherenkov Telescope Array (CTA)

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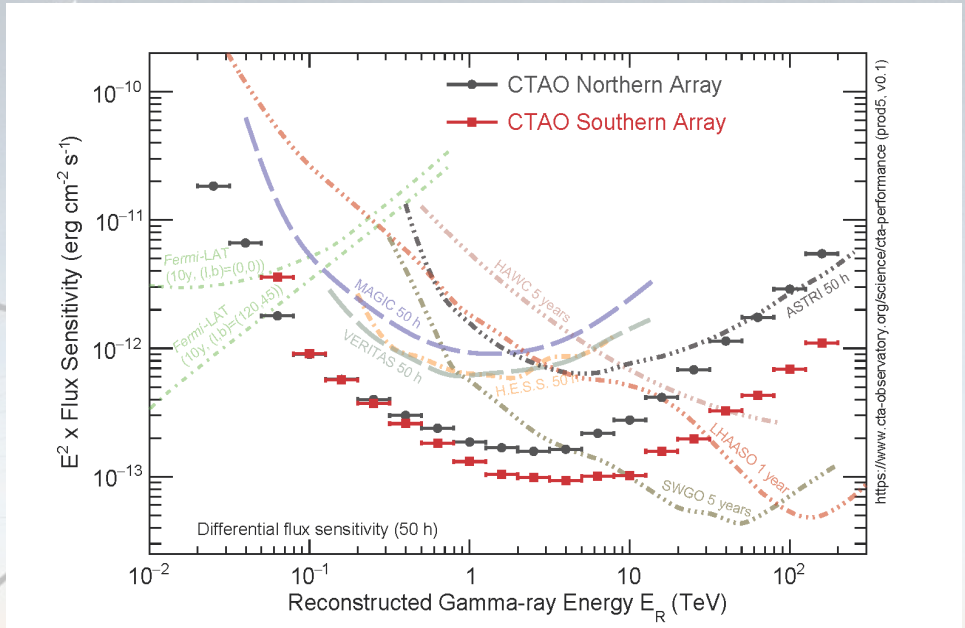
CTA will cover a wide energy range between 20 GeV and 300 TeV

- Sensitivity and performance far superior to current experiments
- 74 telescopes in two array sites:
  - **Northern hemisphere array** (La Palma, Canary Islands)
  - **Southern hemisphere array** (Chile, near Paranal)



The Large Sized Telescope (LST-1)

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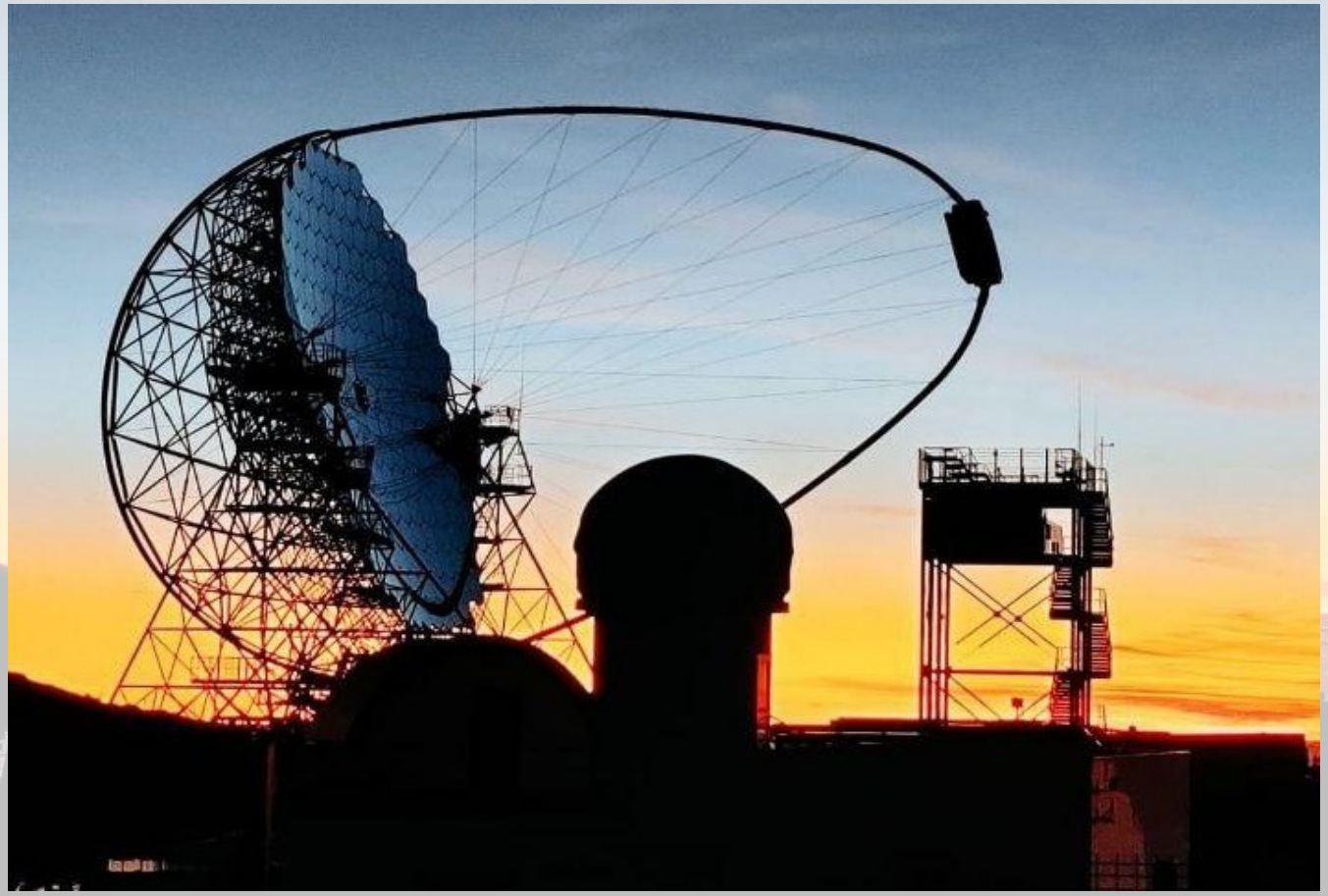
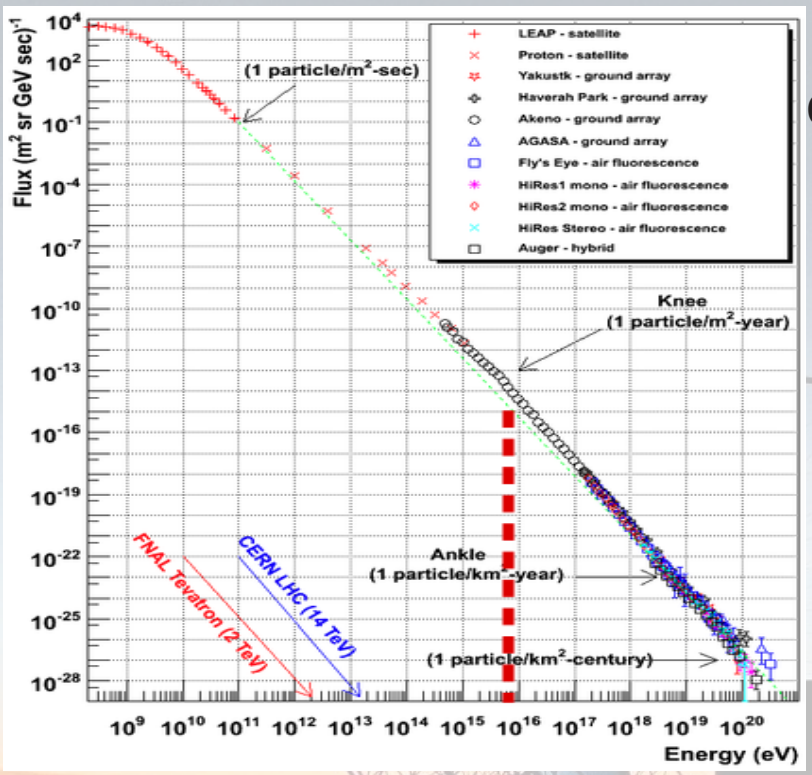
- **Where**: O.R.M. (2200 m a.s.l.), La Palma, Canary Islands (Spain)
- **When**: inaugurated on October 2018 (still in its commissioning phase)
- **Size**: 23 m diameter



The PeVatron hunt



Cosmic Rays (CRs):

- $\sim 92\% \rightarrow$ Protons
- The bulk is thought to be produced in our Galaxy:
  - $B_{GAL} \sim \mu G$; Halo size $\sim$ few kpc
  - protons with $E < 10^{16-17} eV \rightarrow$ confined
- Spectrum: almost "featureless" power-law ($E^{-\gamma}$):
  - change of slope at $\sim 3 PeV$ (*knee*)
  - Galactic CR sources must accelerate particle up to PeV$\rightarrow$ ***PeVatrons***

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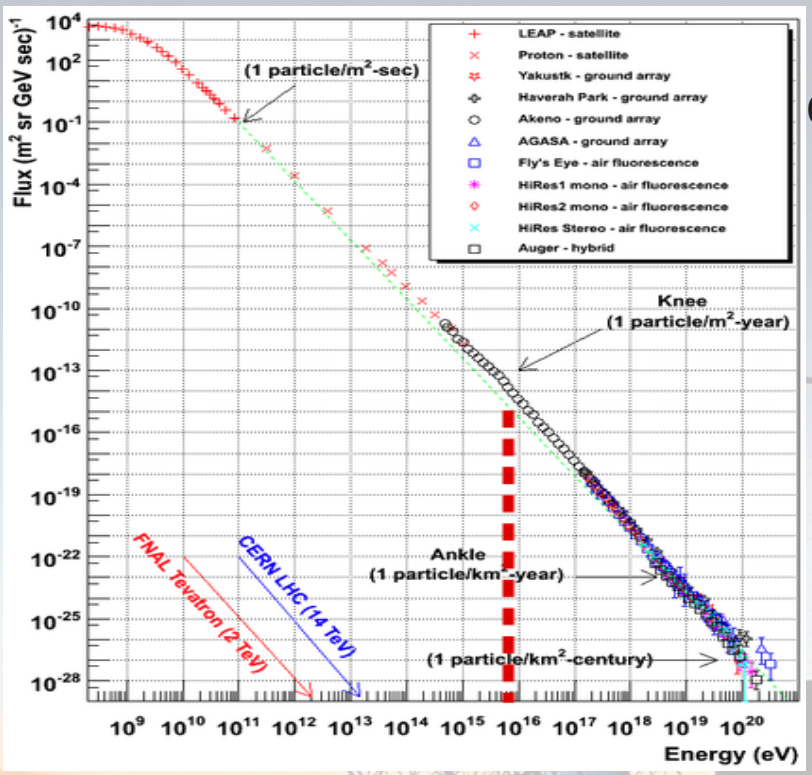

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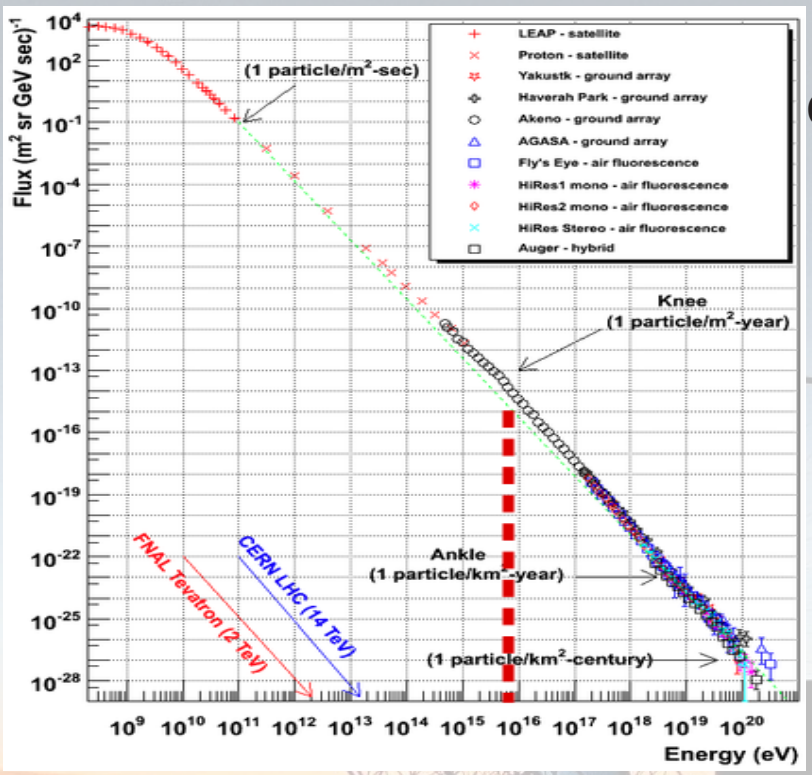
CRs can produce High Energy (E>100 GeV) gamma rays:

- *Inverse Compton* (IC): $e^{\pm} + \gamma_{CMB} \rightarrow \gamma$
- *Bremsstrahlung*
- Hadronic int.:$p + p \rightarrow \pi^0 \rightarrow \gamma\gamma$

The PeVatron hunt



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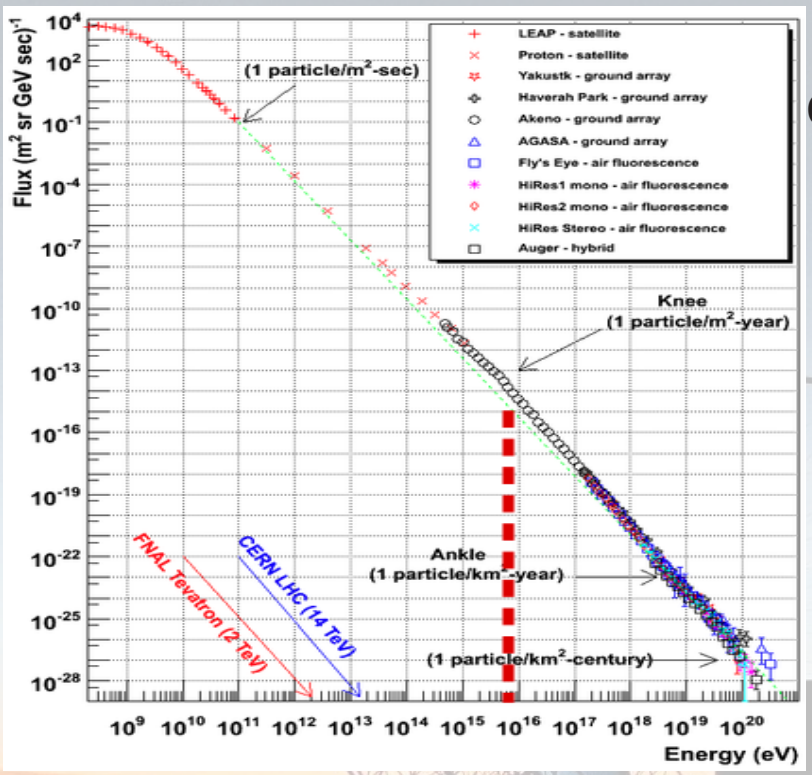
Supernova Remnants (SNRs)

- Can provide the Energy
- Can explain the spectral shape (DSA)
- Detected gamma-rays up to TeV energies

The PeVatron hunt



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Supernova Remnants (SNRs)

- Can provide the energy

PROBLEM: no SNR was identified as a PeVatron so far

energies

LHAASO J2108+5157

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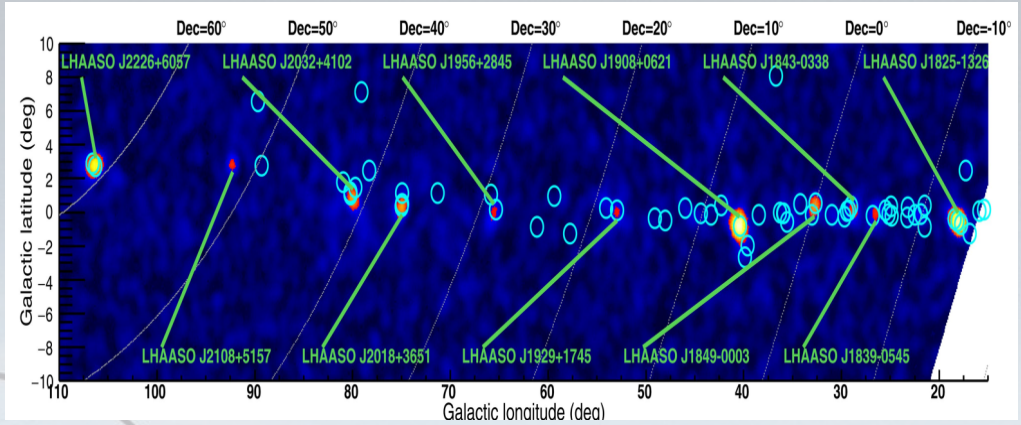
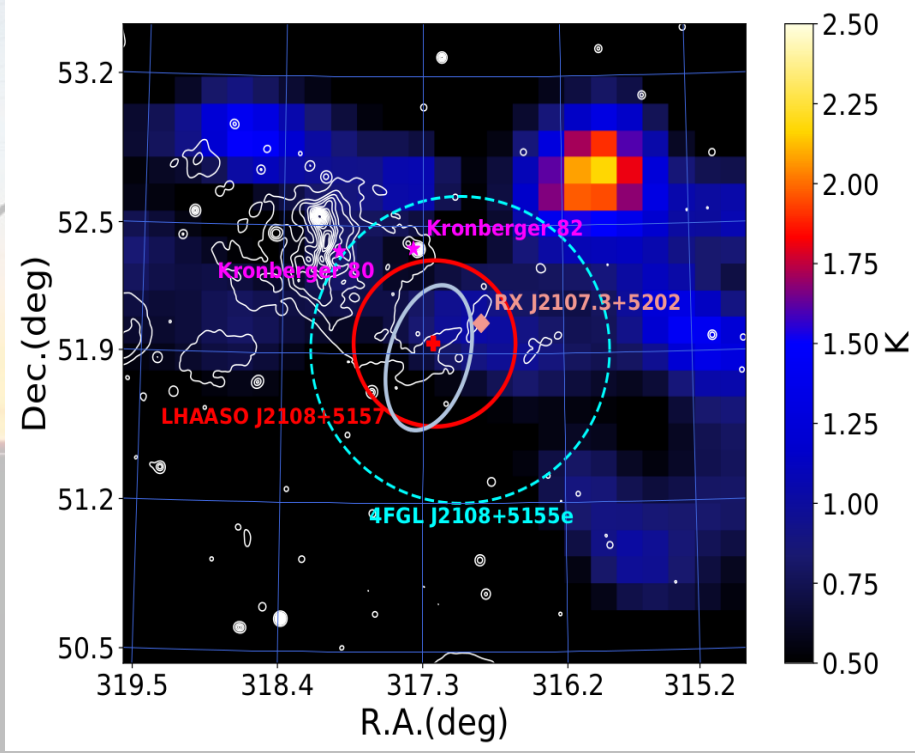
General information:

- Detected photons above E > 100 TeV
- Centroid: RA = 317.22 ± 0.07, Dec. = 51.95 ± 0.05
- UL on extension (95%): 0.26 deg
- Power-law spectrum (20 - 500 TeV): alpha=-2.83

Possible counterparts:

- VHE → no counterpart
- HE → *Fermi*-LAT: 4FGL J2108.0+5155
- X-ray → no counterpart
- 2 young stellar clusters nearby
- 2 molecular clouds nearby (hadronic scenario)

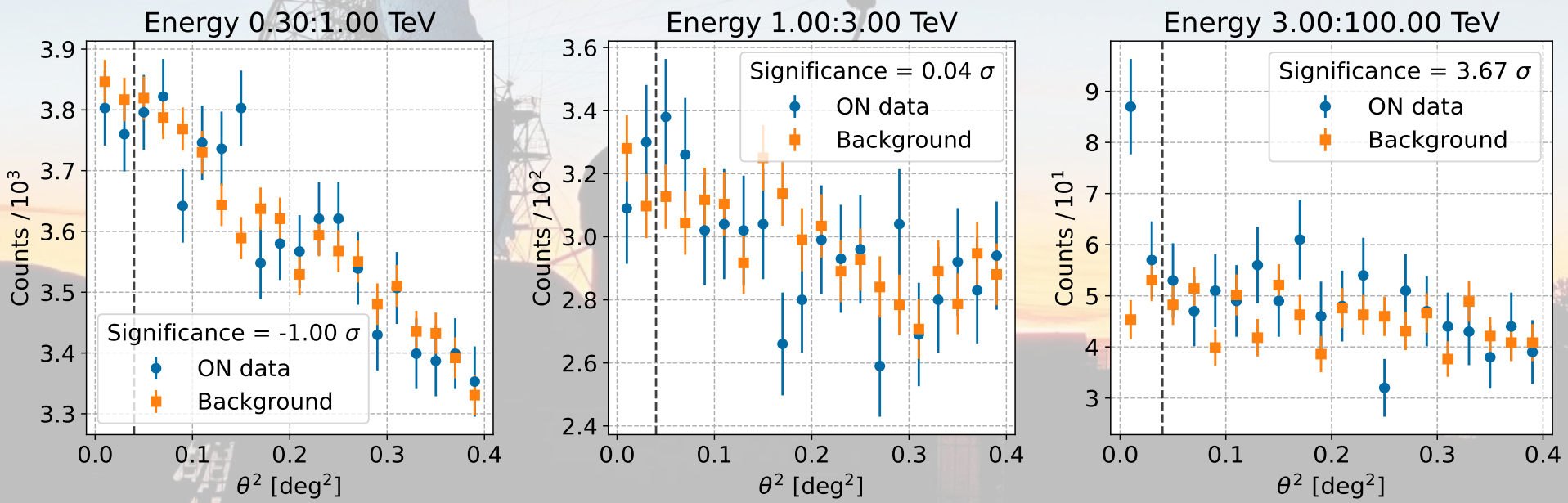




LST-1 observations

- Observed from June to September 2021
- ∼50 hours of effective time after quality cuts
- Blindly chosen energy bins:
  - Hints of VHE emission at E>3 TeV with 3.7σ (LiMa) (S/B 46%)

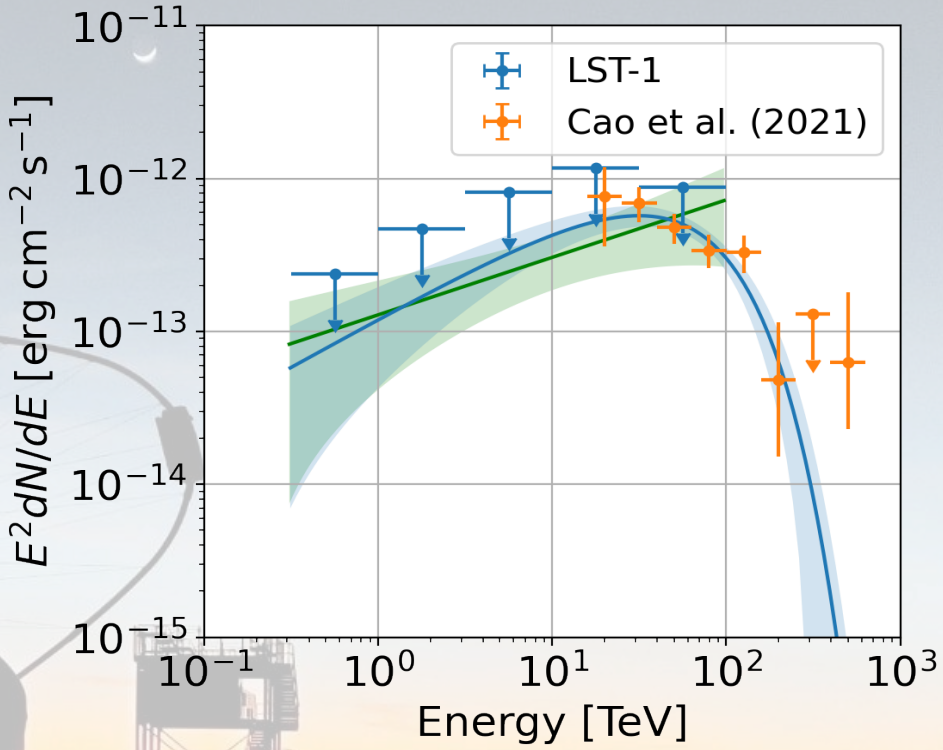
theta^2 (θ^2): the squared angular distance between the reconstructed event directions and the source.



https://arxiv.org/abs/2210.00775

Multiwavelength analysis

- 1D spectral analysis under the point-like source assumption
- Power-law (PL:$f(E) \sim E^{\Gamma}$): spectral model of LST-1 data (100 GeV - 100 TeV)
- Power-law with Exponential Cutoff (ECPL: $f(E) \sim E^{\Gamma} e^{-\frac{E}{E_{cutoff}}}$) fit over LST-1 and LHAASO data
- **Hard spectrum in the TeV range**
- Dedicated analysis of:
  - *Fermi*-LAT data (HE)
  - *XMM*-Newton data (X-ray)
  - Analysis of the molecular clouds



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Data	Spectral model	N_0 [$\times 10^{-14}$cm^{-2}s^{-1}TeV^{-1}]	Γ	E_{cutoff} [TeV]	$-2\log\mathcal{L}$
LST-1	PL	8.02 ± 5.42	-1.62 ± 0.23	-	5.17
LST-1 + LHAASO	ECPL	7.57 ± 4.82	-1.37 ± 0.22	49.98 ± 13.49	7.30

Leptonic scenario: the PWN/TeV halo hypothesis

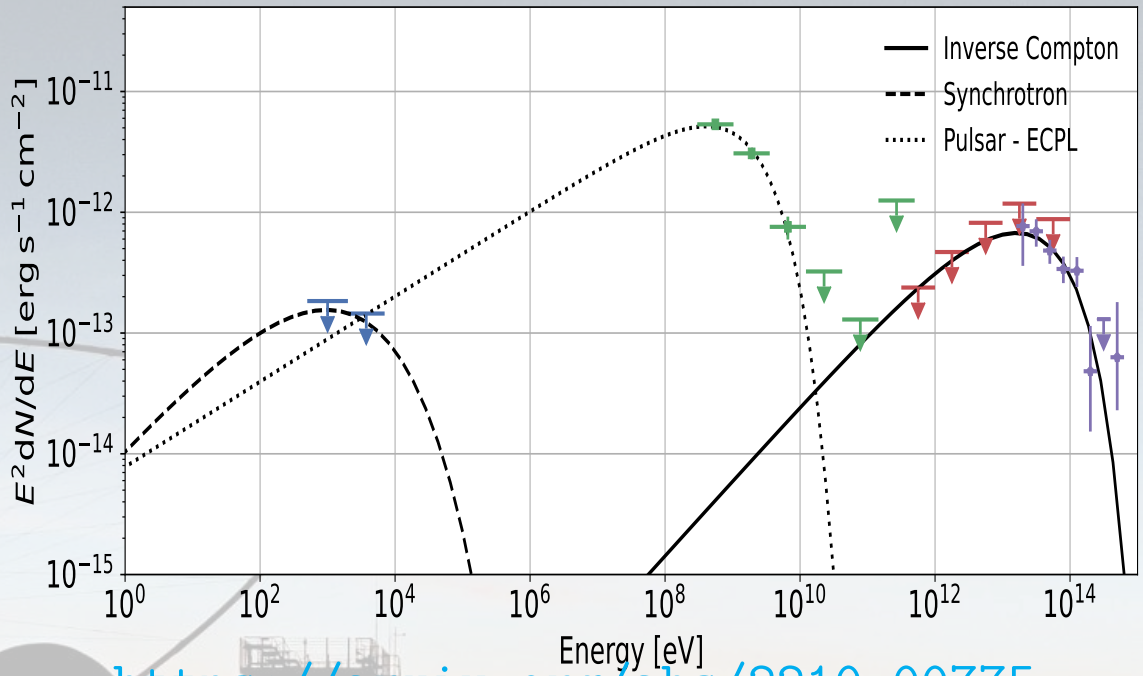
→ **accelerated electrons**

HE (*Fermi*-LAT)

- No radio/X-ray detection → radio quiet pulsars (like Geminga)
- Fit: phenomenological model

VHE-UHE (LST-1+LHAASO)

- Inverse Compton scattering on CMB and FIR photon fields:
  - ECPL→ $E_{cutoff} = 100 TeV$
- Problem: X-ray ULs → B < 1 μG
  - Typical PWN: ∼1 - 100 μG
  - Comparable with B in TeV halo around Geminga



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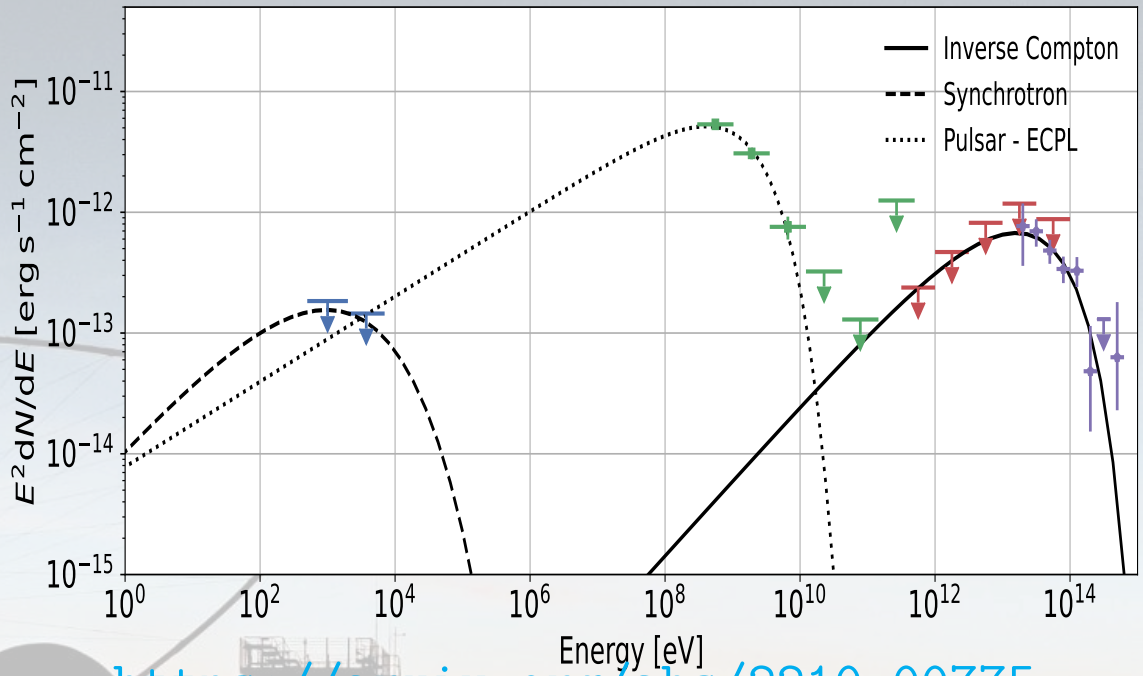

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We compared the TeV emission with population of TeV PWNe/TeV halos:

- From the phenomenological model on HE and X-ray data $\rightarrow \dot{E} = 10^{35-37} erg/s$
- ECPL fit: $E_{cutoff} = 100 TeV \rightarrow t^{IC}{}_{cool} \sim 30 kyr$

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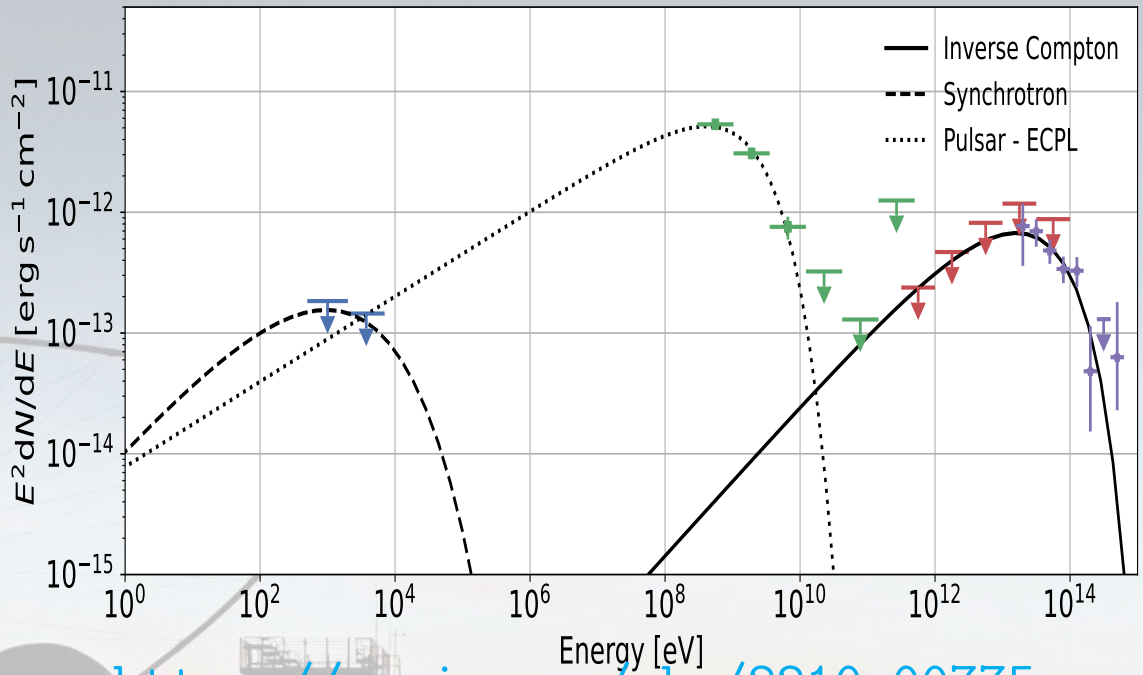

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Total energy released by a pulsar: $E_{psr} = \dot{E} t_{cool}$ (IC cooling time)

E_{tot} (>1GeV)[electrons] = 10^{45} (d/kpc)^{2}erg

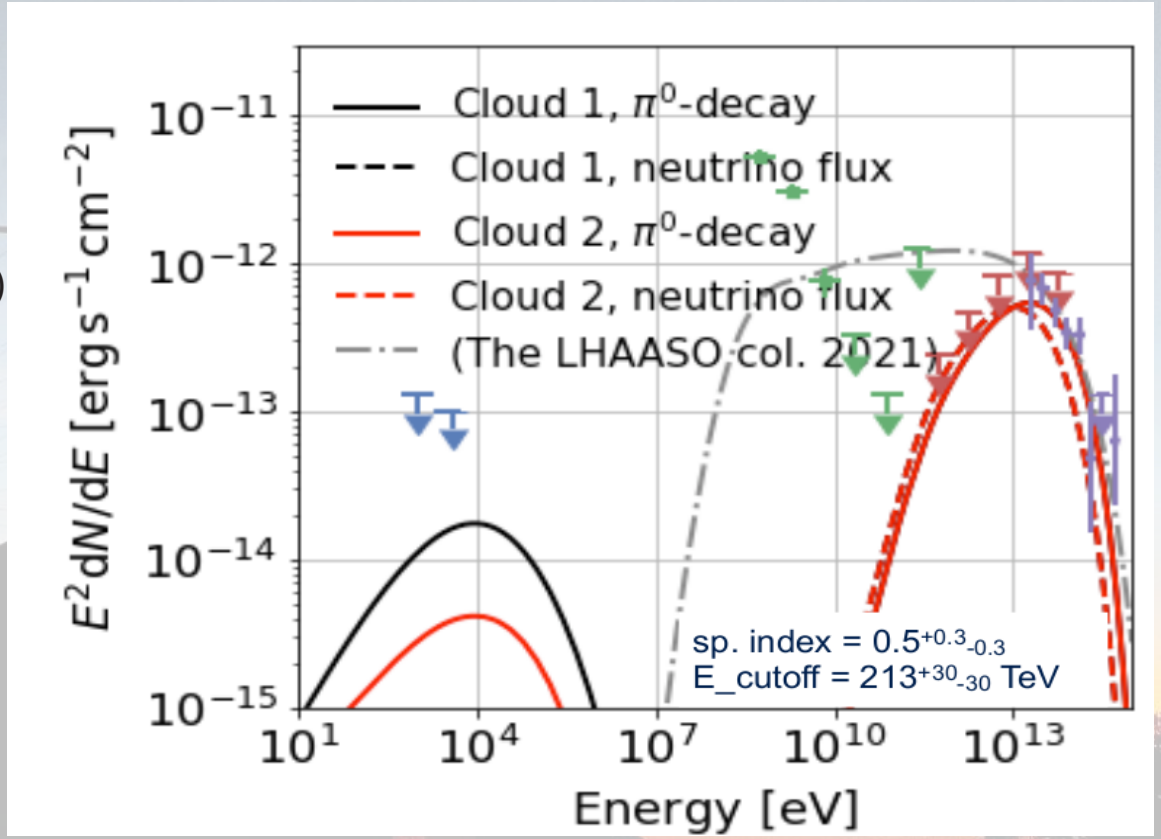
→ **The hypothetical Pulsar detected in the GeV range, can provide electrons energetic enough to justify the observed IC, if closer than ∼10 kpc**

Hadronc scenario

VHE-UHE emission: Interaction of accelerated protons with one of the molecular clouds

$\rightarrow$ ECPL proton distribution model to fit LST+LHAASO flux points

- Two stellar clusters:
  - Kronberger 80 (d = 7.9-13.7 kpc)
  - Kronberger 82 (unknown distance)
- SNR:
  - Total energy in accelerated protons < 10^{47} erg (typical value: $\sim 10^{51}$ erg)
  - Problem: very hard proton spectrum ($\Gamma = 0.5$), inconsistent with diffusive shock acceleration



HE emission:

- Fit of *Fermi-LAT* data with PL: $\Gamma - 3.2 \rightarrow$ too soft compared to old known SNRs
- Interaction of CR sea protons with the clouds (?)

Conclusions

- Although still in its commissioning phase, LST-1 is starting to produce its first physics results! → https://arxiv.org/abs/2210.00775
- Thanks to LST observations, it was possible to provide new information on the still undefined source LHAASO J2108+5157
- Results from LST-1, LHAASO, XMM-Newton and Fermi-LAT were combined to provide a multiwavelength study about LHAASO J2108+5157
- Gamma-ray pulsar + PWN/TeV halo:
  - Low magnetic field required by X-ray ULs: it seems to be consistent with TeV halo hypothesis
- Interaction of relativistic protons with molecular clouds:
  - Acceleration site unknown
  - Hard proton spectral index needed to explain the emission