Universität Siegen

Naturwissenschaftlich-Technische Fakultät

Searching for photons beyond PeV energies from galactic sources

•Chiara Papior, Marcus Niechciol, Markus Risse

Experimentelle Astroteilchenphysik

Center for Particle Physics Siegen

Universität Siegen

CPPS Retreat 15.02.2024

Funded by

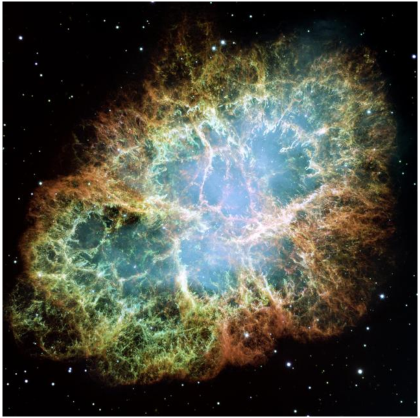
DFG Deutsche Forschungsgemeinschaft

German Research Foundation

PeVatrons as Sources

Crab Pulsar: one of the first identified PeVatrons

- PeVatrons: galactic sites of lepton/hadron acceleration up to PeV energies
- Potentially responsible for cosmic rays up to the knee ($\approx 3 - 4\,\mathrm{PeV}$)
- potential PeVatron objects: pulsars and pulsar wind nebulae, supernova remnants, etc.

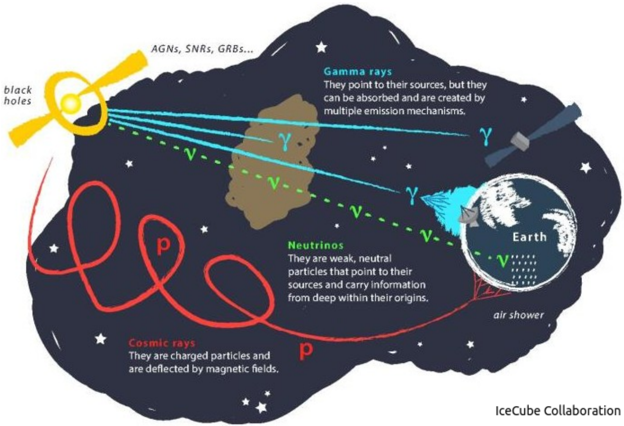


Hubble image of Crab Nebula, NASA/ESA/JPL/Arizona State Univ.

Acceleration mechanisms

- Acceleration mechanisms not fully understood yet but there are theories: (e.g. A.M. Hillas (1984))
- shock front (Fermi) acceleration or statistical acceleration
  - particles gain energy in small increments through numerous encounters with changing magnetic fields
  - slow mechanism
  - at high energies, inverse-Compton scattering and synchrotron radiation counteract the acceleration of leptons
- direct acceleration through extended electric fields
  - electromagnetic fields are responsible for instant energy gain, e.g. in neutron stars or other rapidly spinning magnetized conductors

Probing PeVatrons

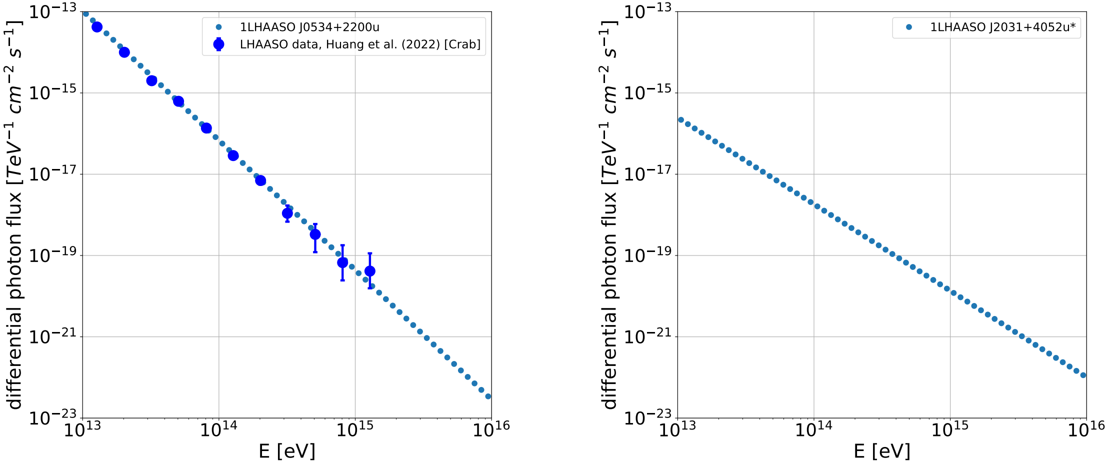


- Charged particles are affected by magnetic fields during their propagation $\rightarrow$ challenging to trace them back to source
- During their acceleration and propagation, they interact and produce secondary photons $\rightarrow$ second messenger from PeVatrons

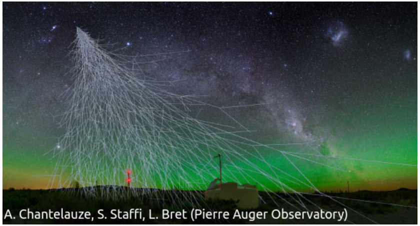
Photon emission from PeVatrons

- Hadronic mechanism:
- creation of neutral pions through interactions of hadrons with background photons → pion decay: $\pi^0 \rightarrow 2\gamma$
- Electron-Pair-Production
- Elastic Scattering
- Photo-Disintegration
- Leptonic mechanisms:
  - Bremsstrahlung produced due to acceleration of electrons
  - Inverse Compton scattering
  - Triplet-Pair-Production
- Photon energies are roughly one order of magnitude lower than hadron energies, close to lepton energies (e.g. P. Cristofari (2021), T. Sudoh, T. Linden, D. Hooper (2021))
- Photons interact further via Pair- and Double-Pair-Production

Example PeVatron: Crab Nebula and 1LHAASO J2031+4052u*

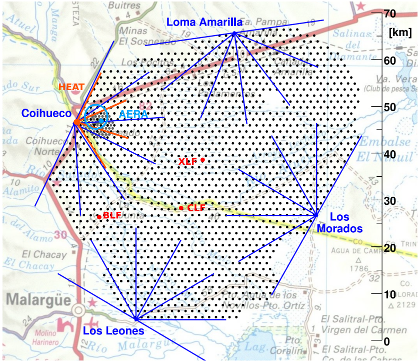


Can we measure PeVatron photons at even higher energies with giant air-shower arrays?



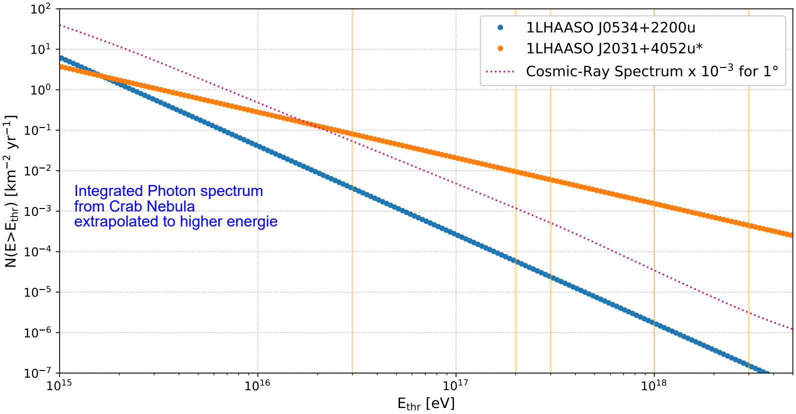
- measurement of secondary particles in air-showers
- challenges: differentiating between hadron- and photon-induced air-showers

The Pierre Auger Observatory as an example of giant-air shower arrays: present minimum energy: $3 \times 10^{16}\,\mathrm{eV}$

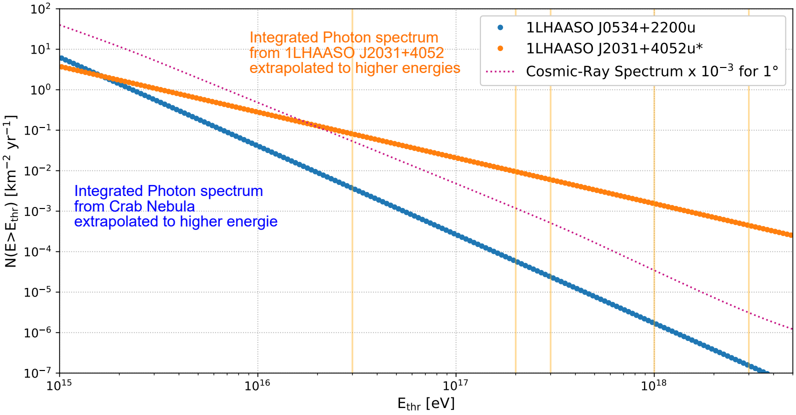


Pierre Auger Coll. Universe 4, 128 (2018)

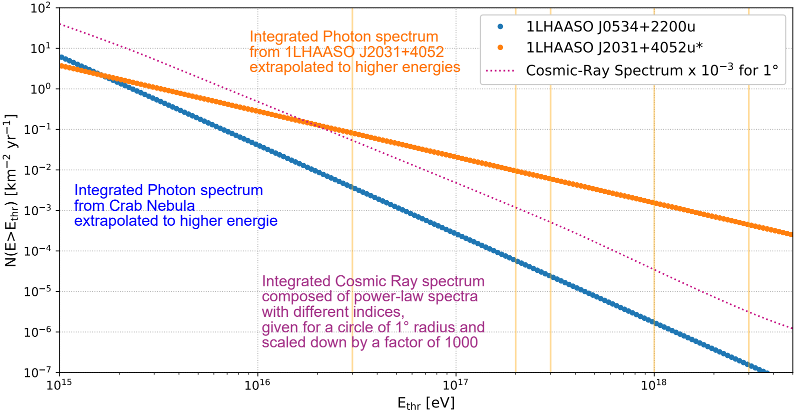
Comparing photon spectra and cosmic ray background



Comparing photon spectra and cosmic ray background



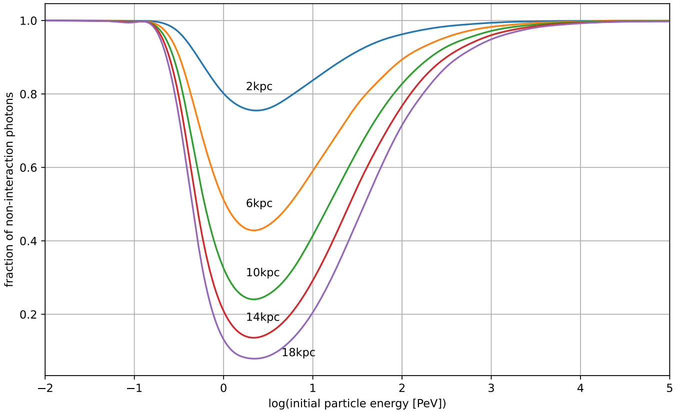
Comparing photon spectra and cosmic ray background



Likelihood of detection

Detector parameters		$N_\gamma(E > E_{thr}) \times A \times 10\,\mathrm{yr}$ for a source like		$N_{CR}(E > E_{thr}) \times A \times 10\,\mathrm{yr}$
Area A $[\mathrm{km}^2]$	Energy threshold E_{thr} $[\mathrm{eV}]$	Crab Nebula	LHAASO J2031+4052u*	per point source
1.95 (cf. Auger SD-433)	3×10^{16}	0.072	1.6	1080
27.5 (cf. Auger SD-750)	3×10^{17}	0.007	1.7	150
3000 (cf. Auger SD-1500)	3×10^{18}	0.005	13.4	100
27.5 (cf. Auger Hybrid, HeCo + SD-750)	2×10^{17}	0.002	0.4	50
3000 (cf. Auger Hybrid, FD + SD-1500)	1×10^{18}	0.008	6.9	150

Work in Progress: Propagational effects



- How do propagational effects influence the measured spectra?
- What kind of effect can we expect for extrapolated spectra?

Conclusion and Outlook

- Background suppression of about $10^{-3} - 10^{-1}$ are necessary to make discrimination between photons and cosmic-ray particles feasible
- Current level of background suppression at around 10^{-3} and above
- Observation of photons are still challenging but slight improvements in energy thresholds would increase photon number noticeably
- Current work in progress: Estimating the influence of propagation effects on measured photon spectra and the effects on extrapolated spectra