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Towards Searching for UHE Photons from Galactic PeVatrons:
Estimating Fluxes and Constraining Spectral Parameters

Marcus Niechciol, Chiara Papior*, Markus Risse

Center for Particle Physics, University of Siegen, Walter-Flex-Str. 3, 57072 Siegen

*Contact: papior@hep.physik.uni-siegen.de

PeV Photon Measurements

Introduction

- In the last years, the maximum observed photon energies have increased from the high TeV range to the low PeV range
- Both LHAASO [1] and HAWC [2] published catalogs of PeV photon sources
- Measurements of PeV photons indicate acceleration of leptons and hadrons to even higher energy [3-5], the **acceleration sites** are referred to as **``PeVatrons´´**
- Emission of ultra-high energy (UHE) photons during the acceleration via:
  - Bremsstrahlung, inverse Compton scattering (leptonic)
  - Decay of neutral pions produced in pp- and pγ- interactions (hadronic)
- Source candidates: supernova remnants, pulsars, pulsar wind nebulae, microquasars, etc.

PeVatron Candidates Investigated Here

- Crab nebula (1LHAASO J0534+2200u, Crab) [6,7]
- 1LHAASO J2031+4052u* [6]
- V4541 Sgr North (Northern component of micro-quasar V4641 Sgr, measured by HAWC) [8]
- LHAASO J1819-2541 (V4641 Sgr measured by LHAASO) [9]
- Measurements from sources have been fitted with power-law spectra (PL)
- Spectra: $\Phi(E) = \Phi_0 \times \left(\frac{E}{E_0}\right)^{-\Gamma}$ with flux Φ_0 at pivot energy E_0 and spectral index Γ

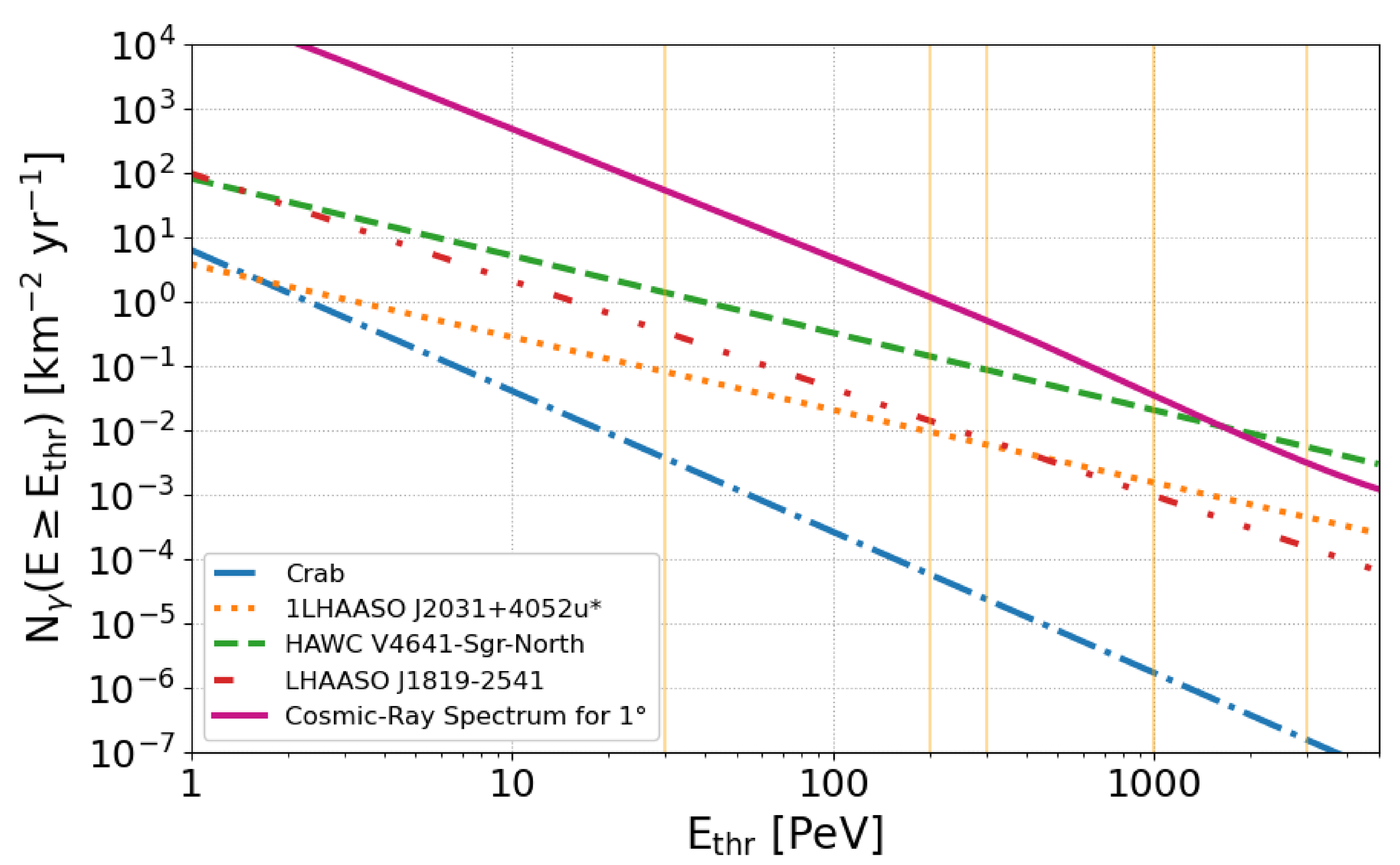
Summary

- Extended analysis as presented in [10]
- Extrapolated photon fluxes for some PeVatron candidates compared to directional upper limits
- Allowed range for **spectral index Γ** can be **constrained** (including central value) for V4641 Sgr North
- First tests of UHE luminosity of PeV γ-sources possible in some cases
  - **Lowering the energy** and **increasing sensitivity** of air shower arrays can reduce the gap between gamma-ray and both present and future air shower observatories, e.g. PEPS[14]

Photon Spectra

Extrapolating Spectra

- PL spectra without indication for high energy cutoffs can be extrapolated to higher energies and integrated as in [10]
- Photon number above threshold energy E_{thr} are shown below



Expected Number of Photons

Exemplary Cosmic Ray Detector

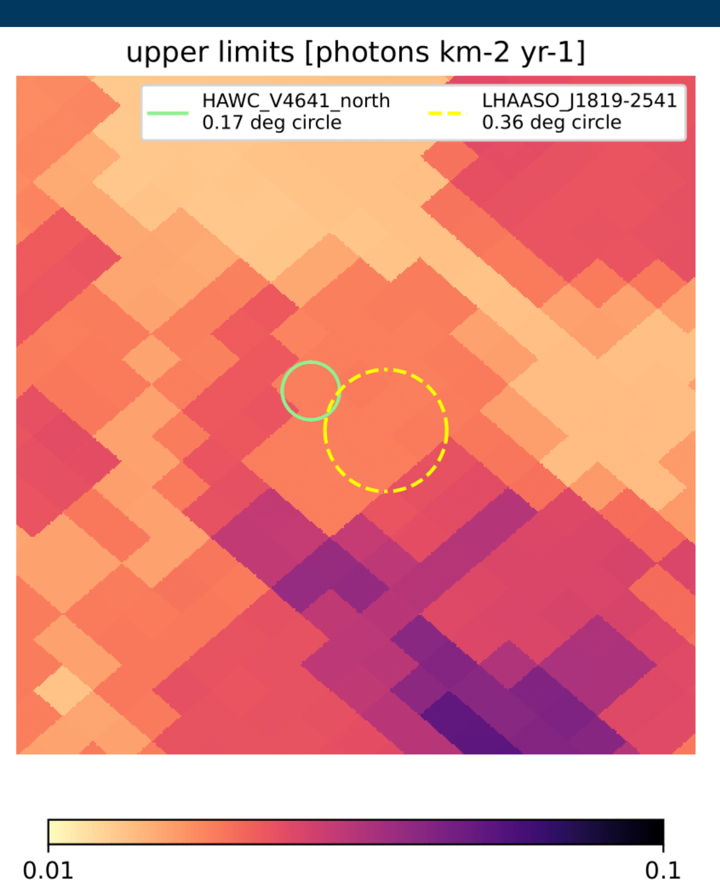
- Surface detector (SD) configurations of the Pierre Auger Observatory with different areas and distances (433 m, 750 m, 1500 m)
- SD areas, lower energy thresholds [11, 12], expected number of photons (N_γ) and cosmic ray (CR) particles from 1° radius during 10 year measurements are given in table

	Detectors	SD-433	SD-750	SD-1500
	Area [km²]	1.95	27.5	3000
Sources	E_{thr} [PeV]	30	300	3000
Crab		0.072	0.0066	0.0046
V4641 Sgr North		27	24	165
LHAASO J1819-2541		6.5	2.0	4.6
CR background		1082	146	96

Number of Photons and Upper Limits

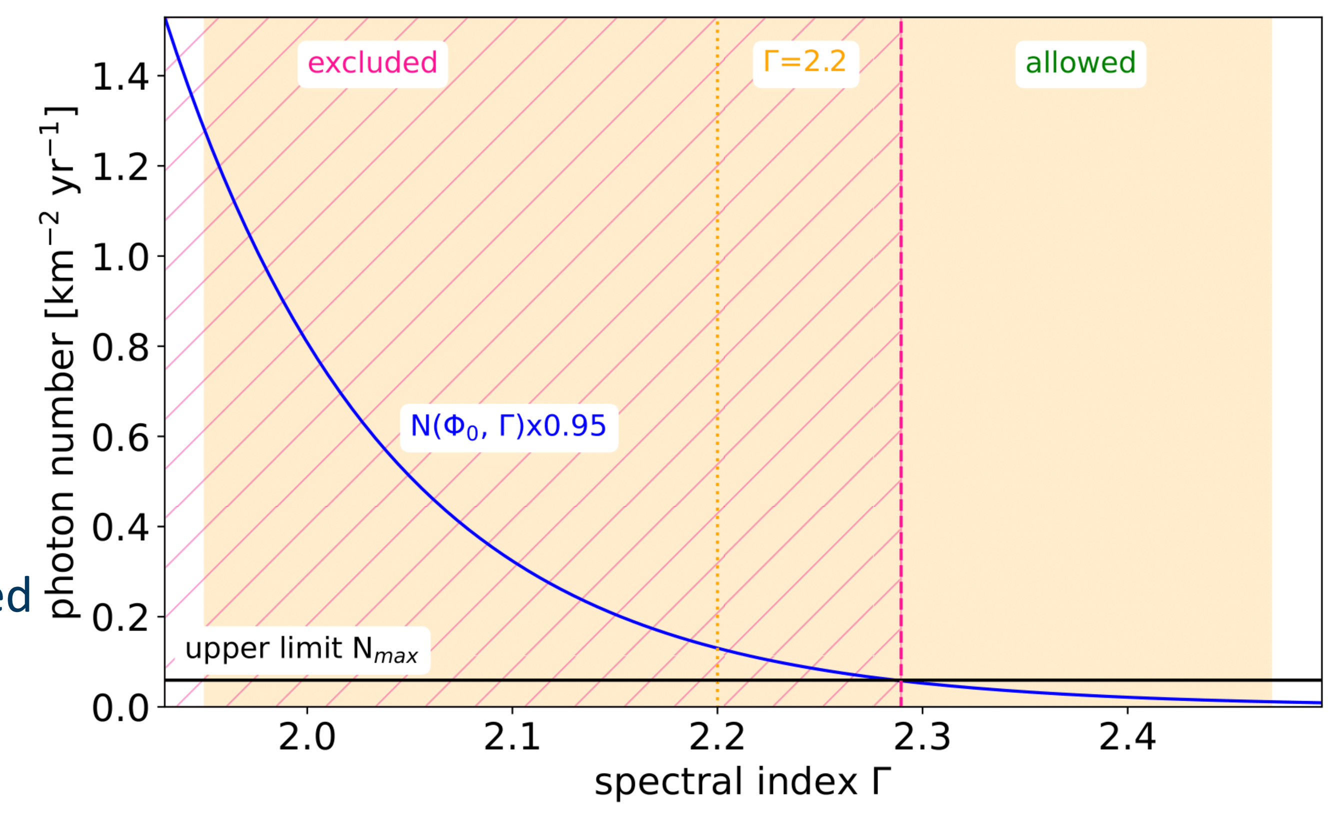
Comparing N_γ to Directional Upper Limits

- V4641 Sgr North (HAWC): 95% upper limit (0.17°)
  - LHAASO J1819-2541: 39% containment radius (0.36°)
    - N_γ in energy range E=200 - 3000 PeV are compared to upper limits on the photon flux[13] in source region
      - LHAASO J1819-2541: upper limits exceed N_γ
      - V4641 Sgr North: N_γ exceeds upper limit
      - Excess in N_γ can be used to constrain spectral parameters



	N_γ	Upper limits
		[1/(km² year)]
V4641 Sgr North	0.13	0.059
LHAASO J1819-2541	0.005	0.27

Constraining Spectral Parameters



- Central value $\Gamma = 2.2$ and error region marked as yellow line and band
- For $\Gamma \geq 2.29$, N_γ decreases below upper limit
- Constrained region is marked in red
- Constraint excludes central value $\Gamma = 2.2$
- Spectral indices can be constrained for exemplary PeVatron sources

References

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Background picture:Tarantula NebulaNASA, ESA.

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