Results from VERITAS

Astrophysics and Cosmology with High-Energy Photons

Gernot Maier
for the VERITAS Collaboration

DESY

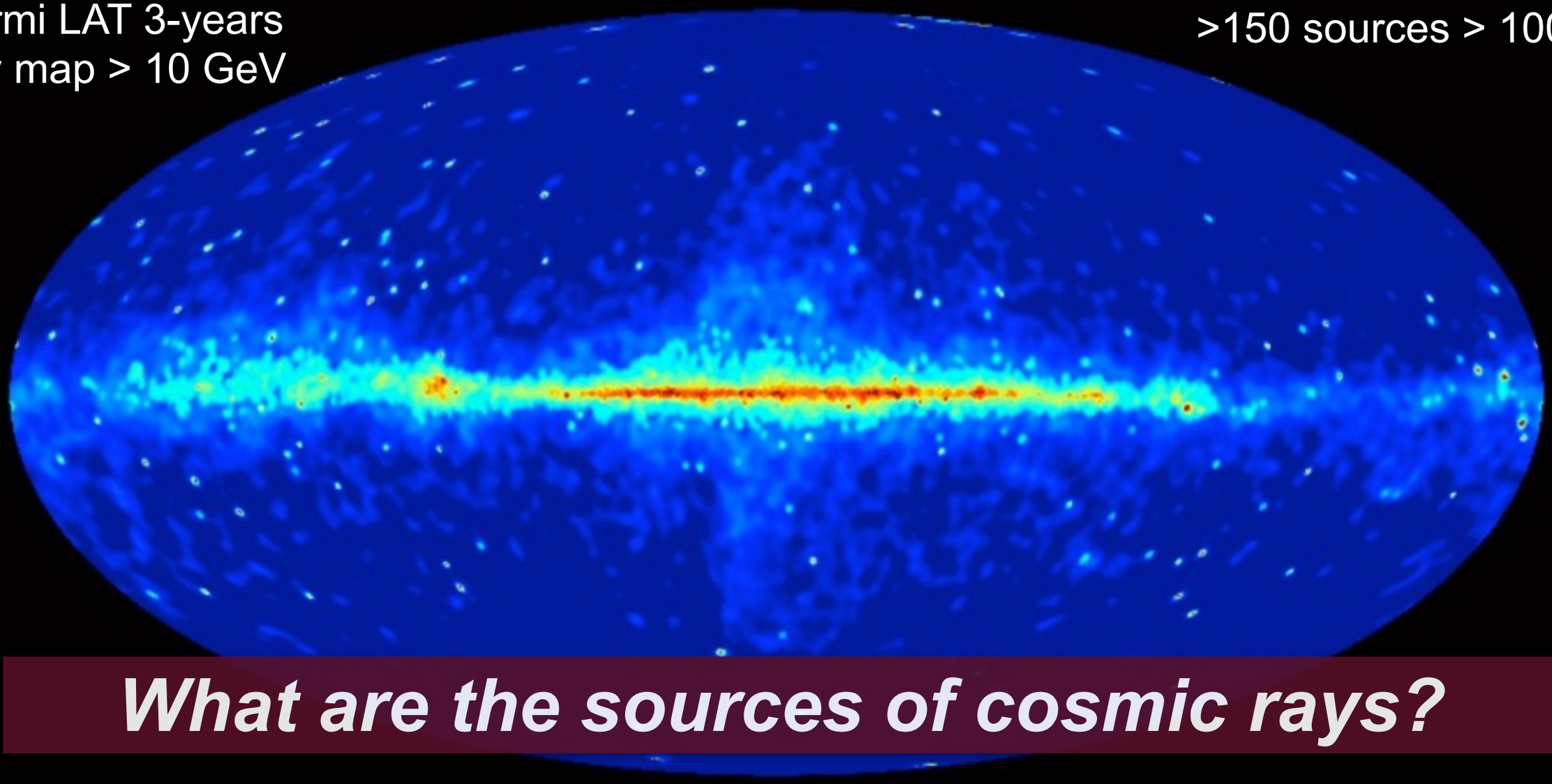
HELMHOLTZ ASSOCIATION

Alliance for Astroparticle Physics

The high-energy gamma-ray sky

>2500 sources @ MeV-GeV
>500 sources > 10 GeV
>150 sources > 100 GeV

Fermi LAT 3-years
sky map > 10 GeV

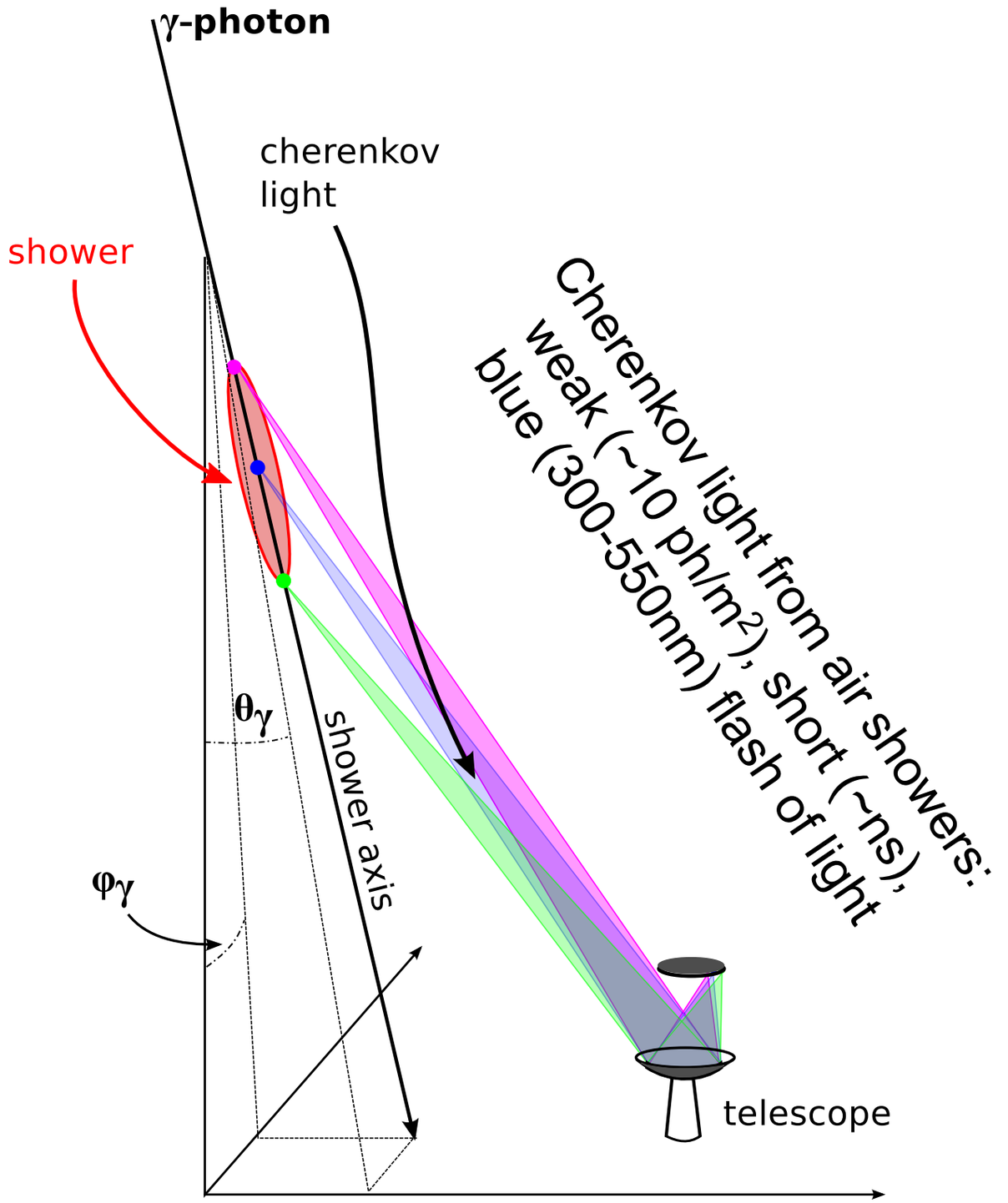


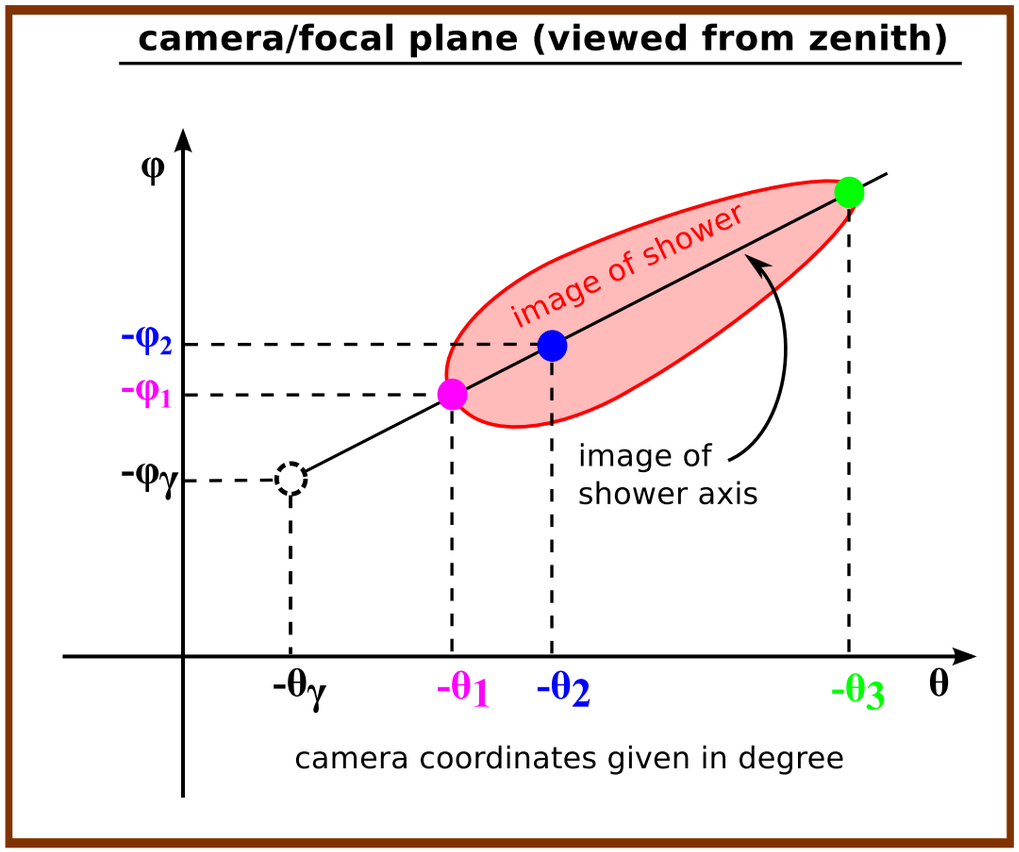
What are the sources of cosmic rays?

What are the conditions for particle acceleration in astrophysical objects?

Cosmology? Dark Matter?

Detection technique for very-high energy photons

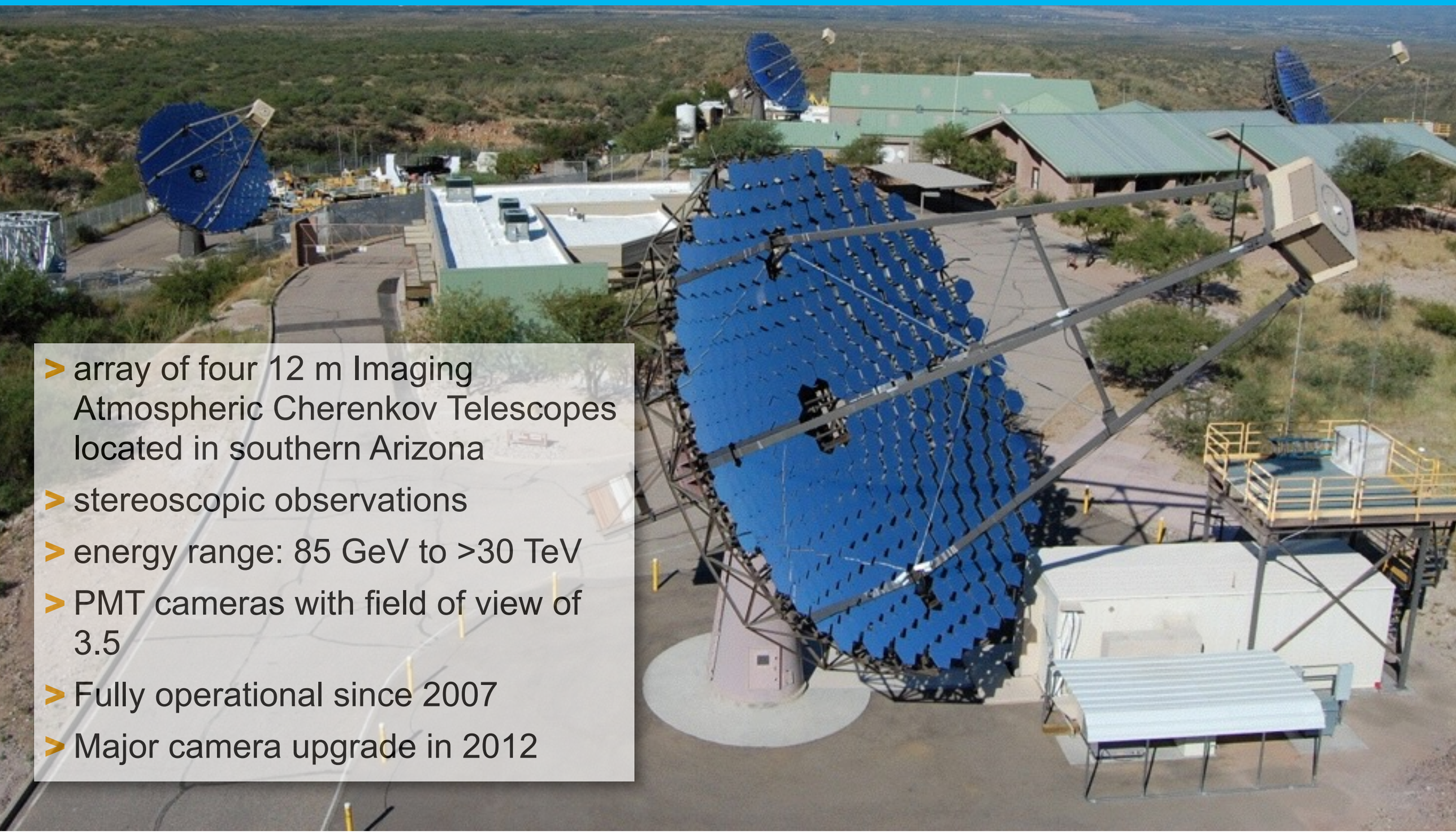




Imaging atmospheric Cherenkov Astronomy: sensitive energy range 30 GeV to 300 TeV

Sketch by Christian Skole

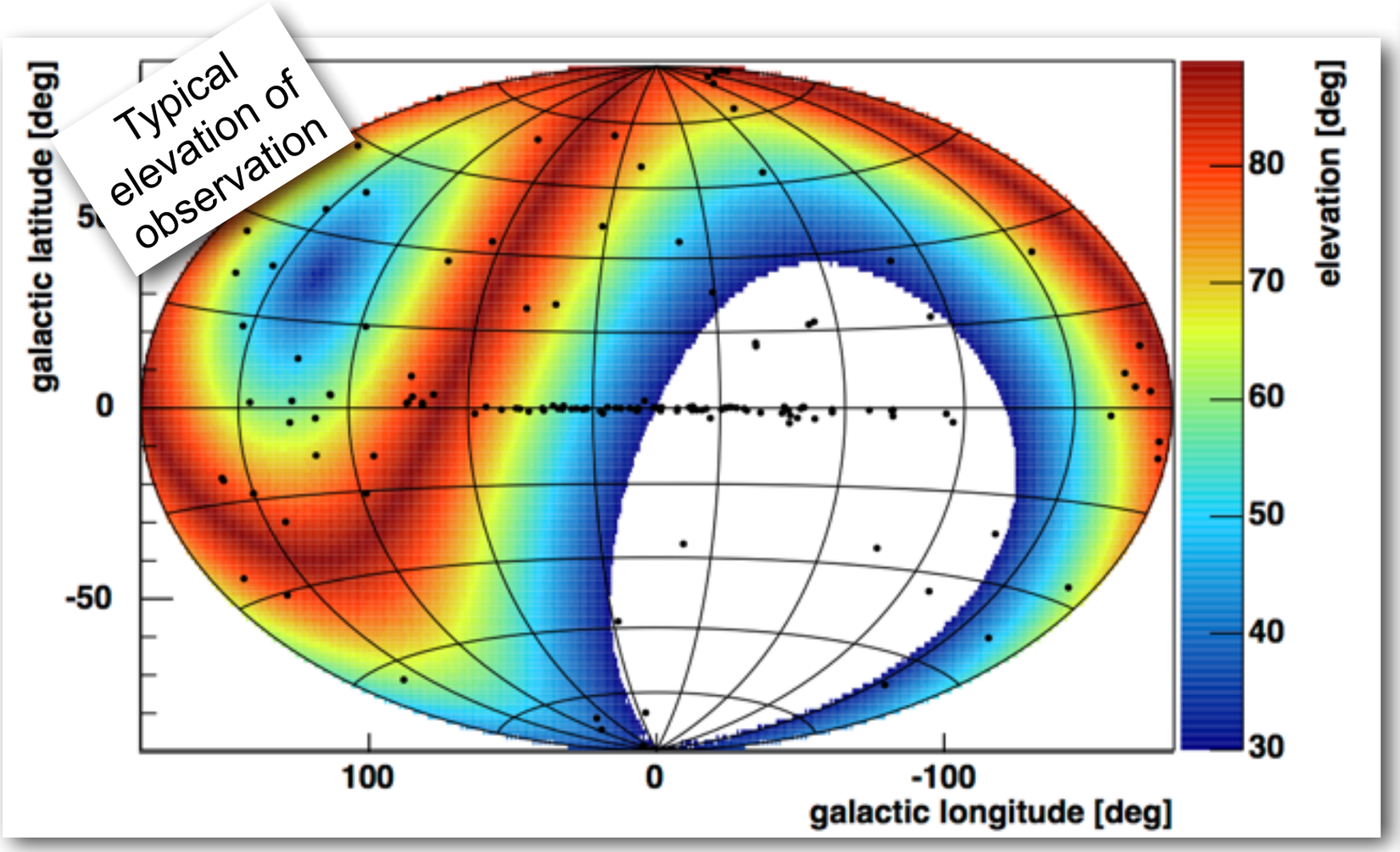
Very Energetic Radiation Imaging Telescope Array System

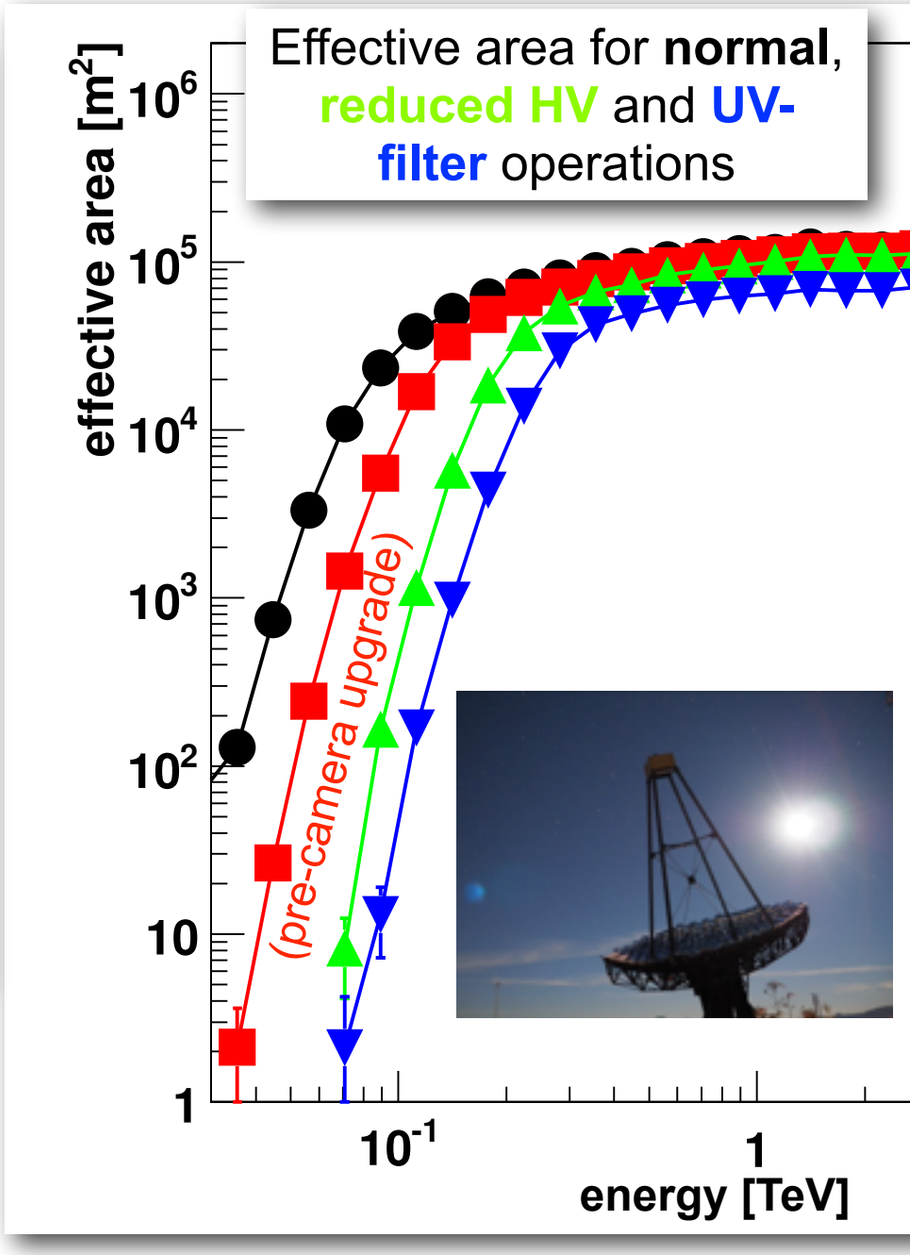


- array of four 12 m Imaging Atmospheric Cherenkov Telescopes located in southern Arizona
- stereoscopic observations
- energy range: 85 GeV to >30 TeV
- PMT cameras with field of view of 3.5
- Fully operational since 2007
- Major camera upgrade in 2012

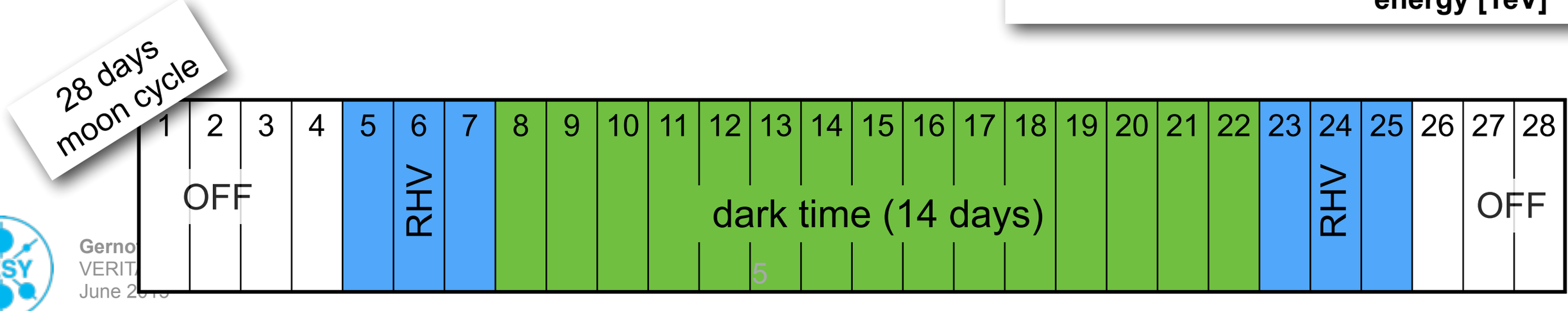
http://veritas.sao.arizona.edu

Observing with VERITAS





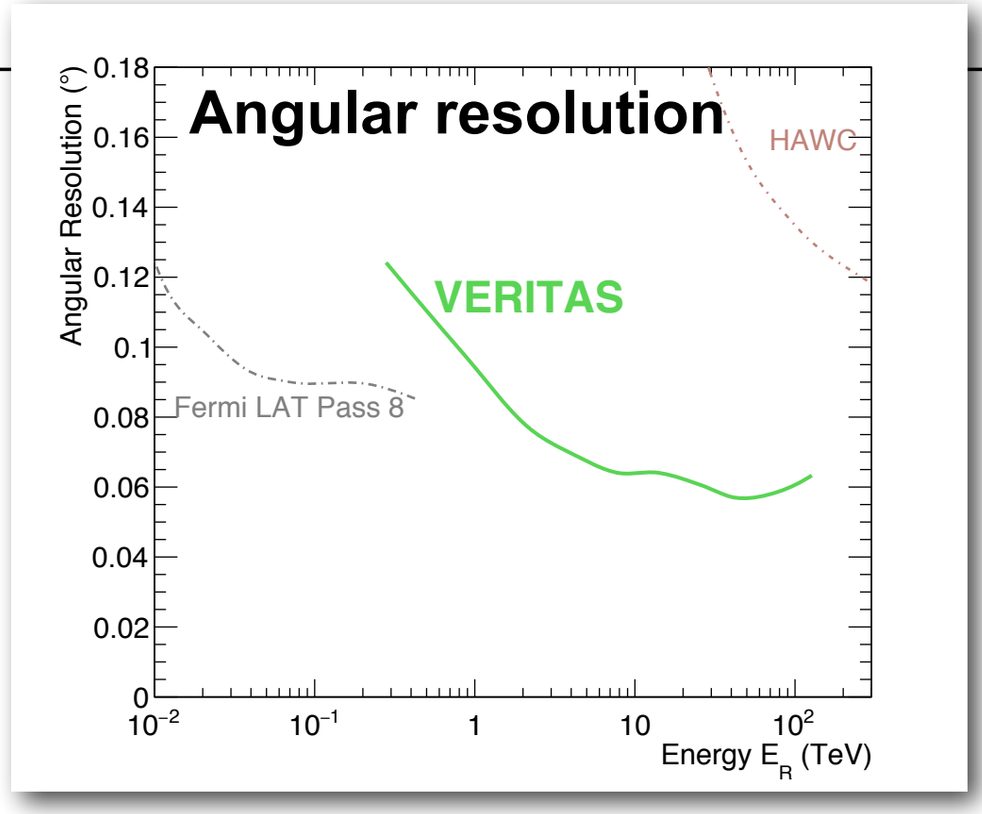
VERITAS operates from mid-September through early-July
about 1000 hours of observations / year



VERITAS Performance & Sensitivity

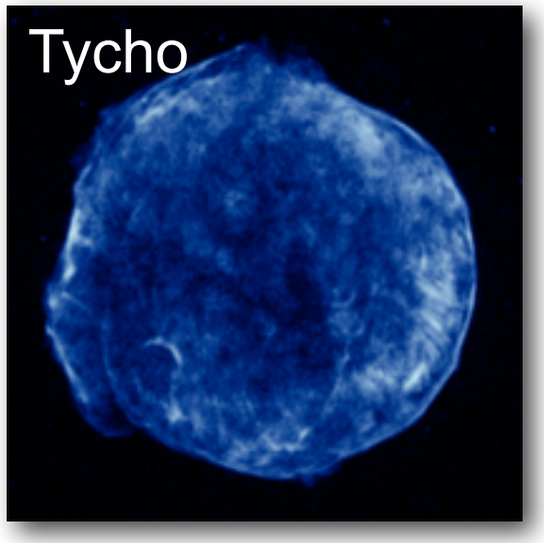
Time to detect a Crab Nebula-like source:

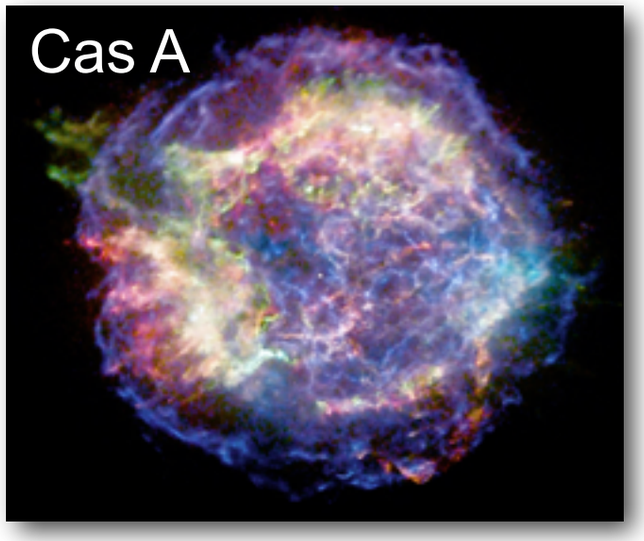
1% Crab Flux in 25 h
10% Crab flux in 25 min

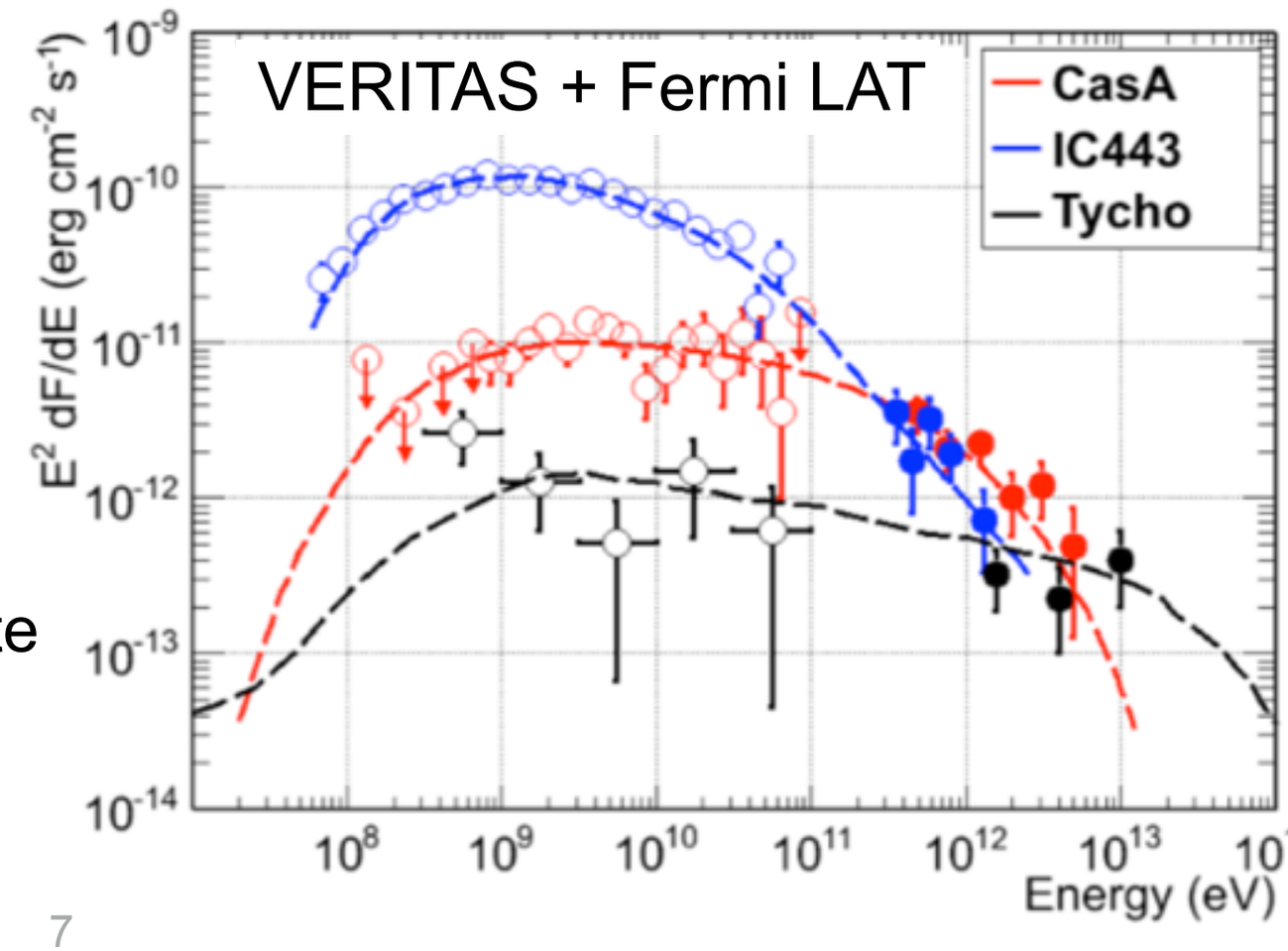


Particle Acceleration in Supernova Remnants

- efficient cosmic-ray acceleration observed in many supernova remnants
- gamma-ray observations can:
  - probe the distributions of high-energy particles in the acceleration region
  - study the evolution of SNRs as cosmic-ray accelerators
  - study the importance of progenitor, SNR type, age, target material, magnetic fields, …
  - study the propagation of cosmic rays away from the acceleration site

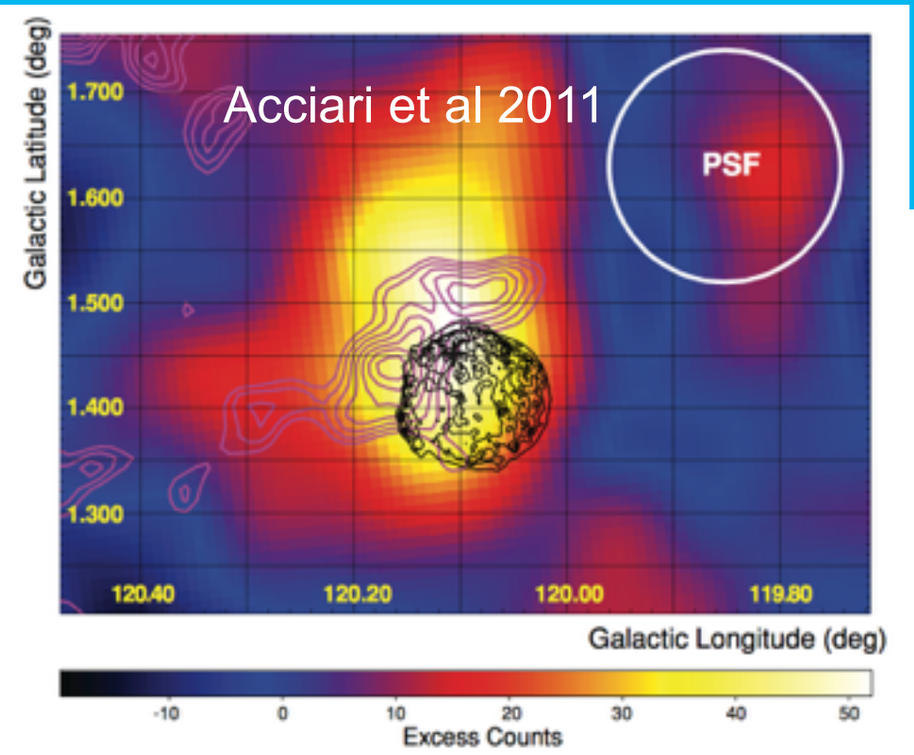






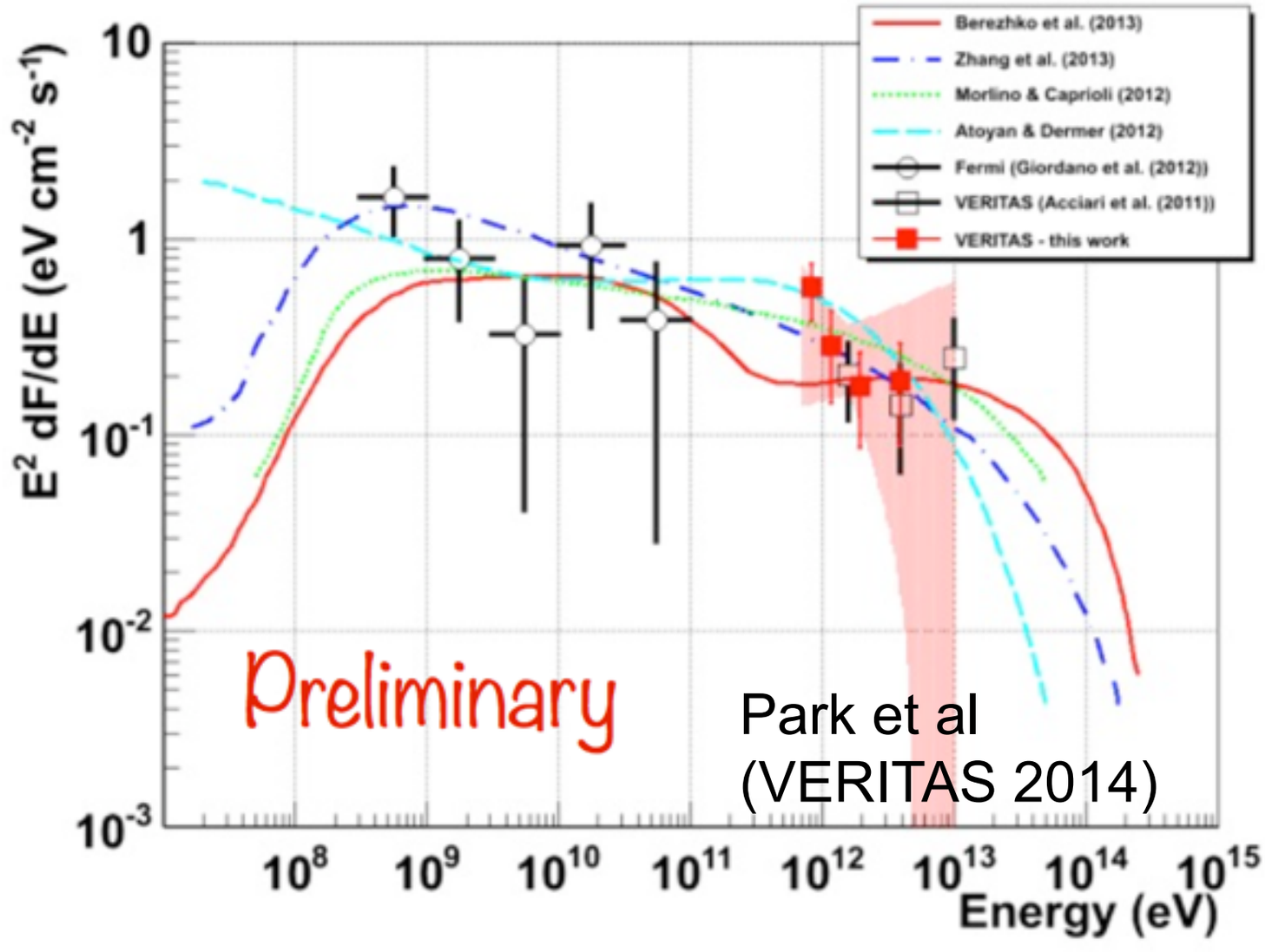
Tycho - a historical type Ia SNR

- exploded in a relatively clean environment
- GeV-TeV emission provides solid case for hadronic emission
- >100 h of VERITAS observations
  - part of the long-term observation plan: exposure x2



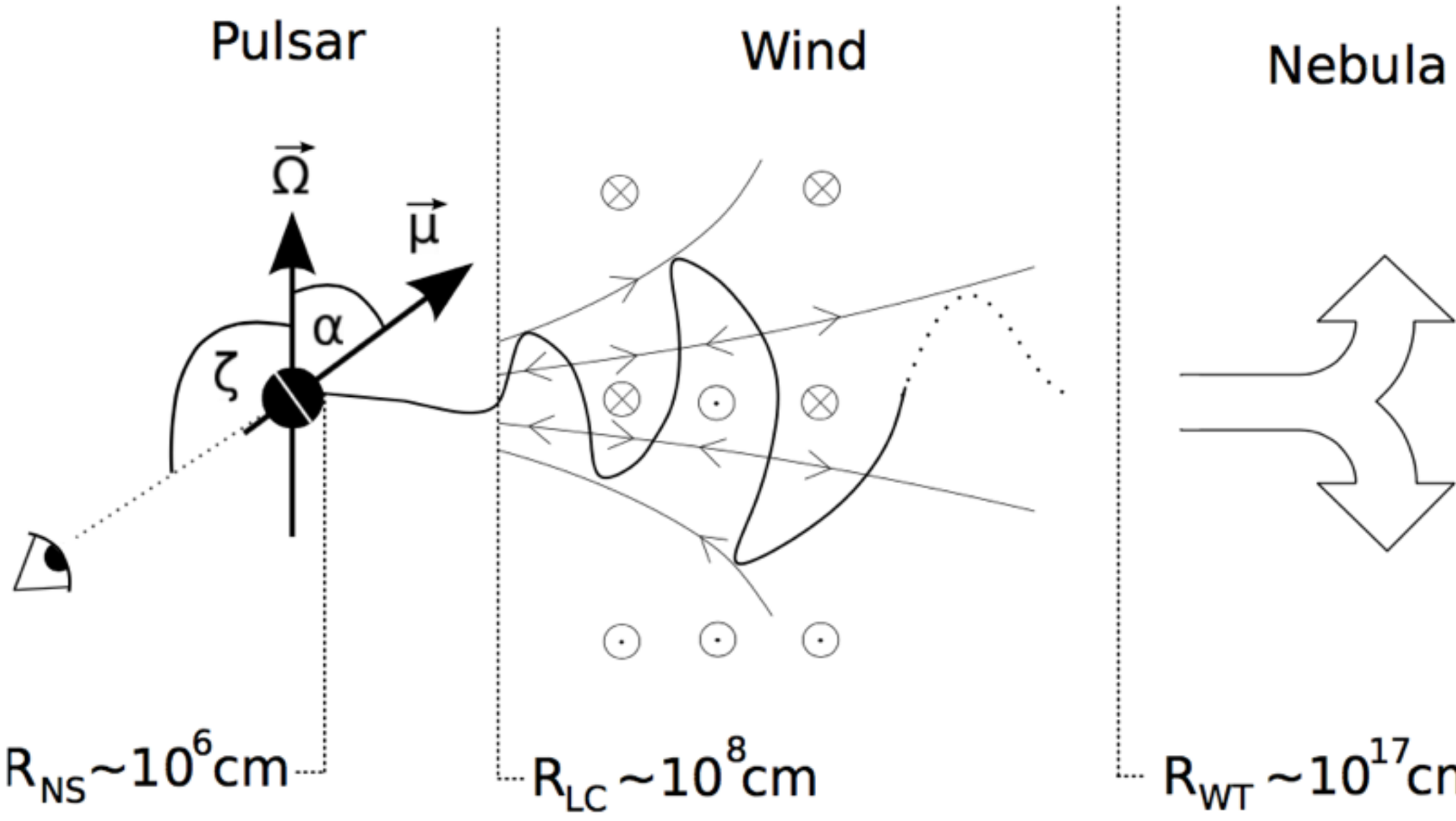
Models:

- Emission mainly from hadronic particles:
  - interaction with interstellar medium (smooth+clumped ISM)
  - interaction with nearby molecular cloud
- multi-zone leptonic model



Pulsars and Pulsar Wind Nebulae

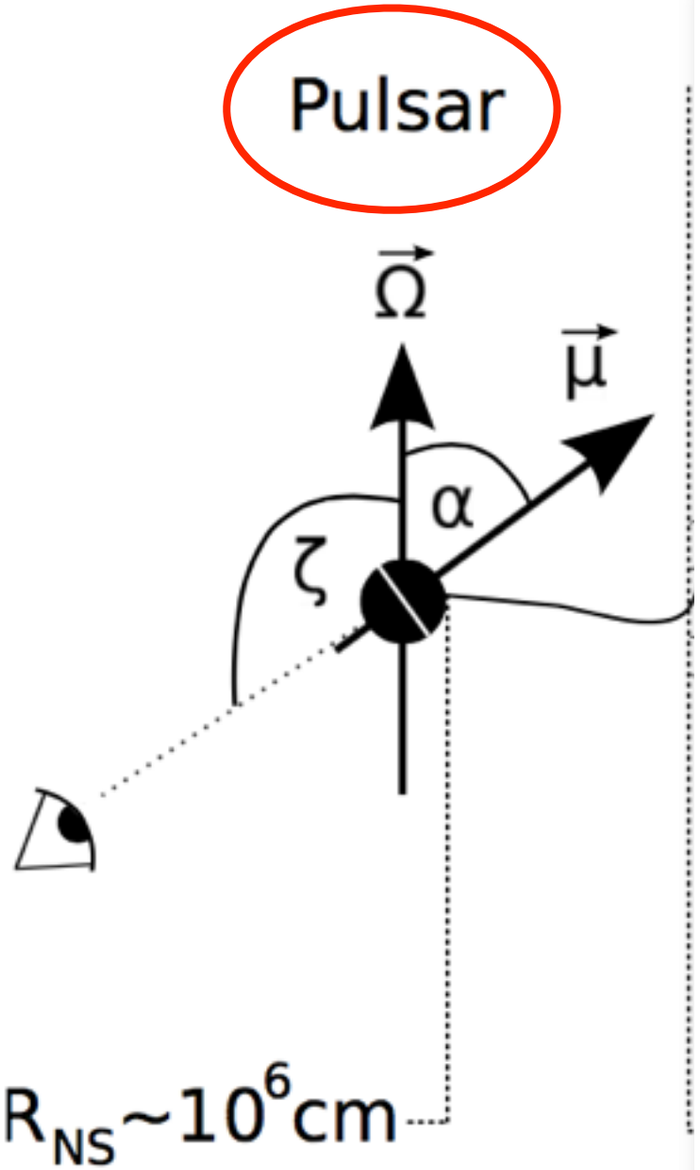
Bühler & Blandford 2013



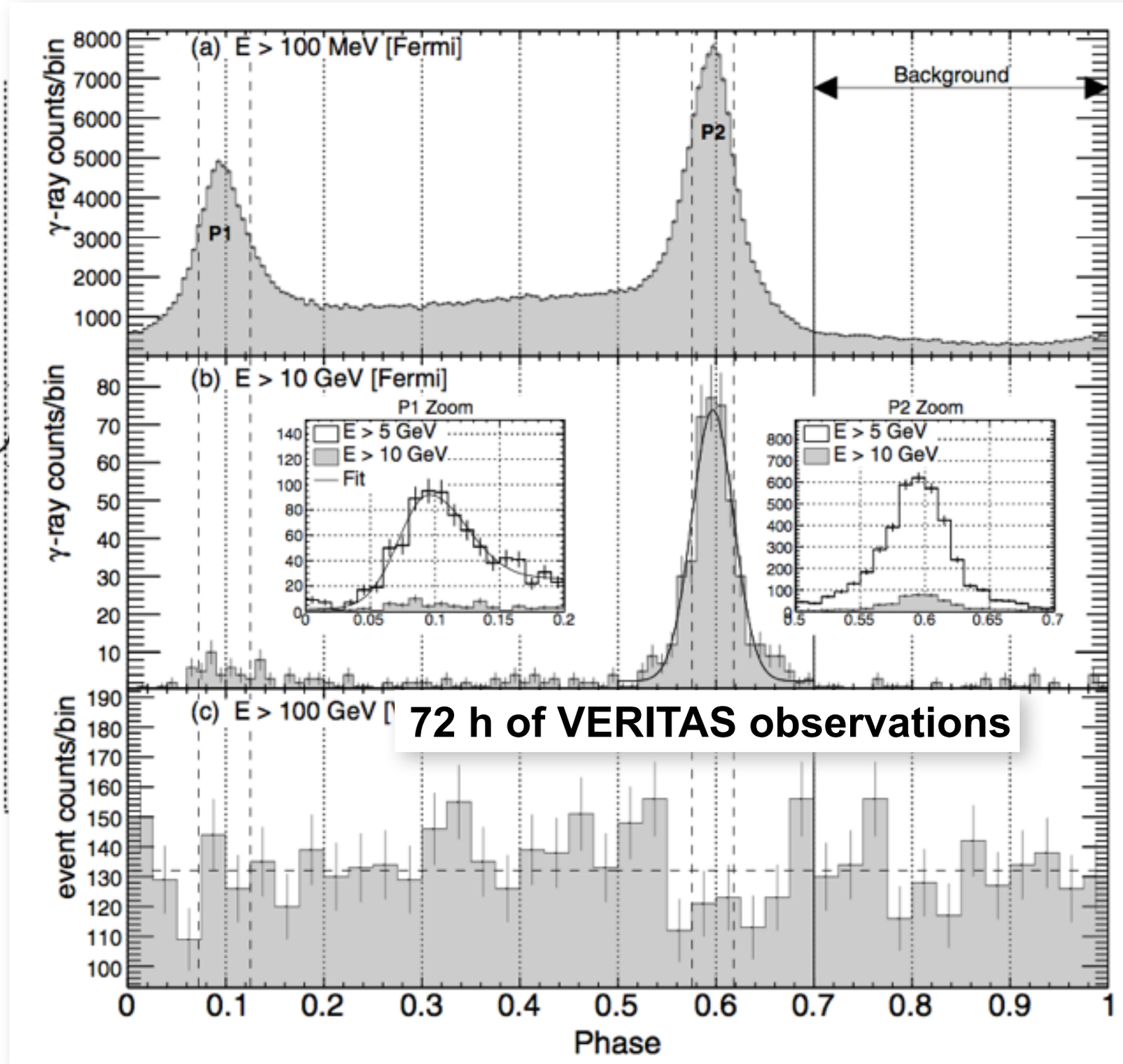
Crab Pulsar detected at hundreds of GeV

>40 TeV pulsar wind nebulae known

Pulsars and Pulsar Wind Nebulae - Geminga

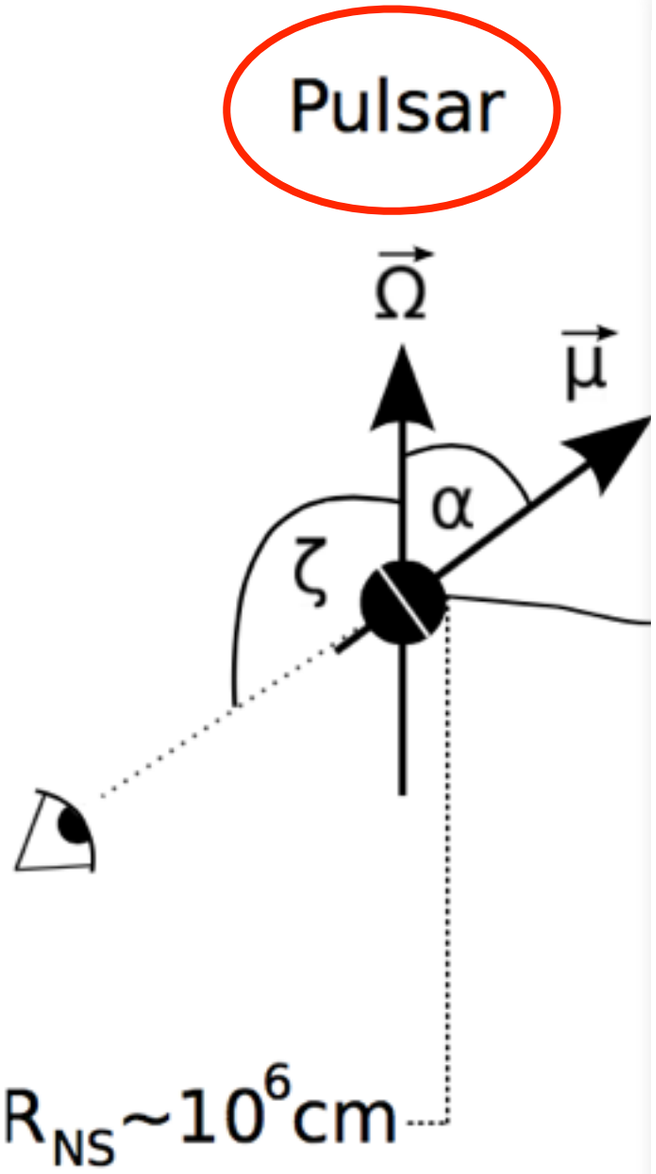


Crab Pulsar detected at hundreds of GeV

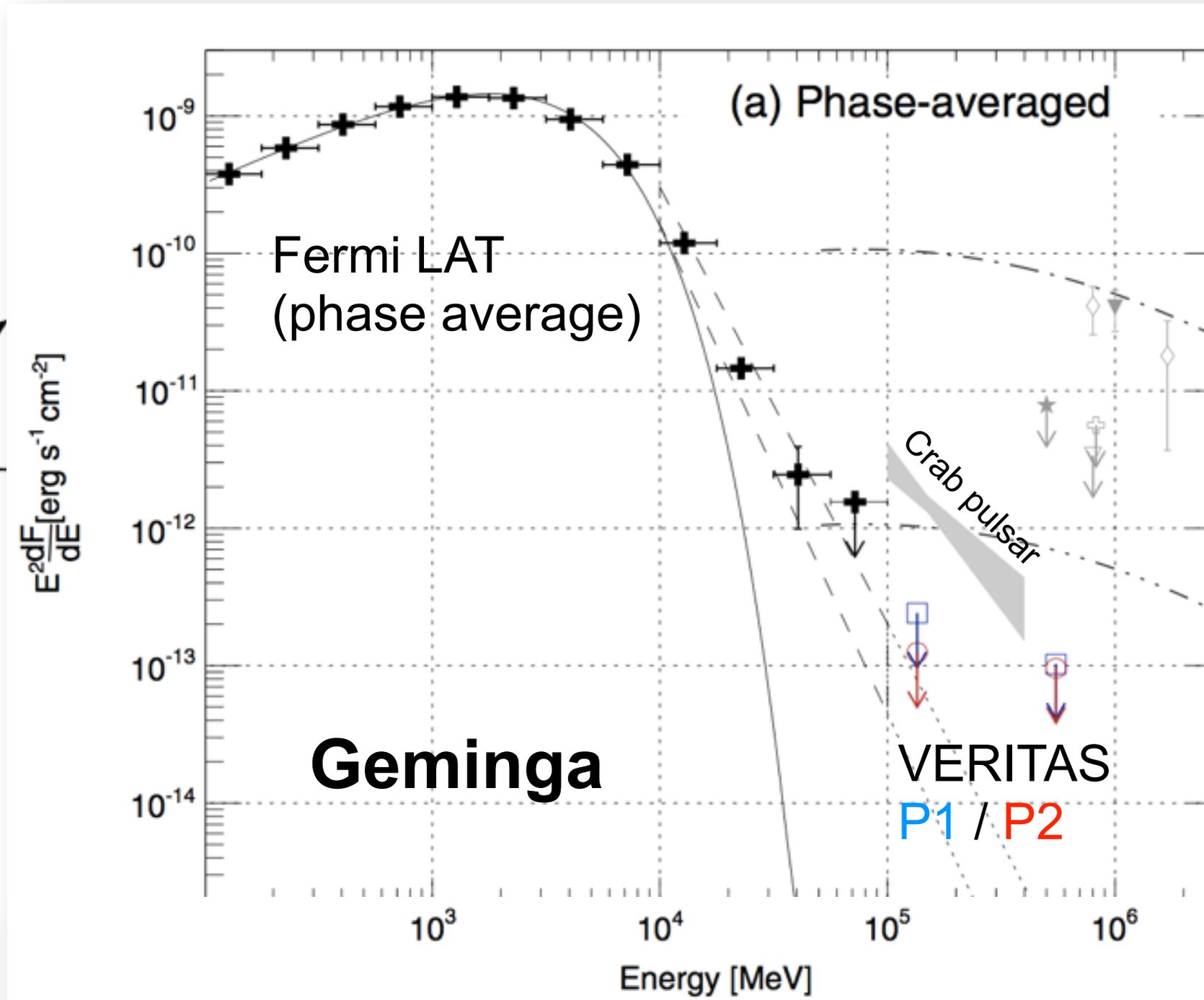


Aliu et al (VERITAS, ApJ 2015)

Pulsars and Pulsar Wind Nebulae - Geminga



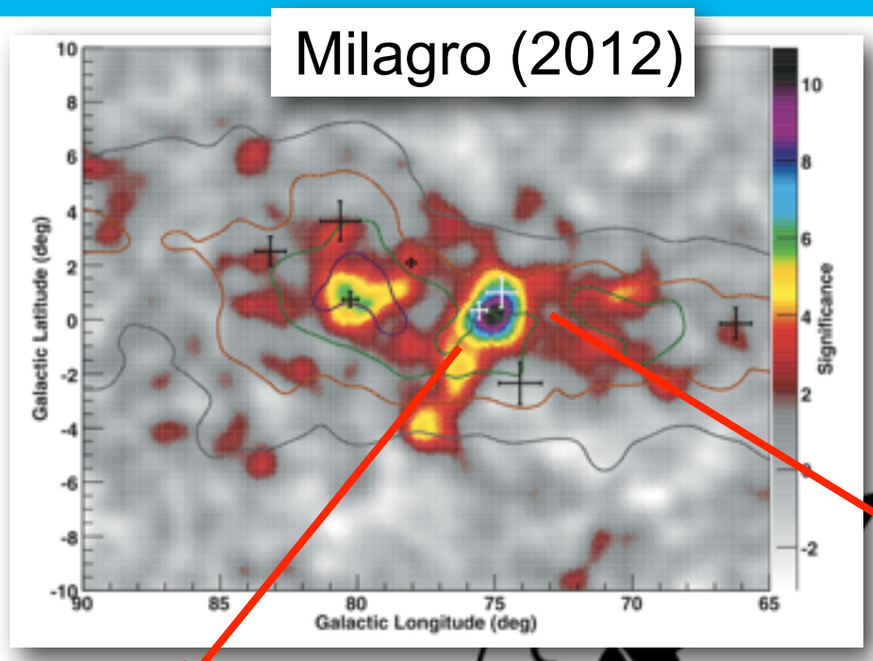
Crab Pulsar detected at hundreds of GeV

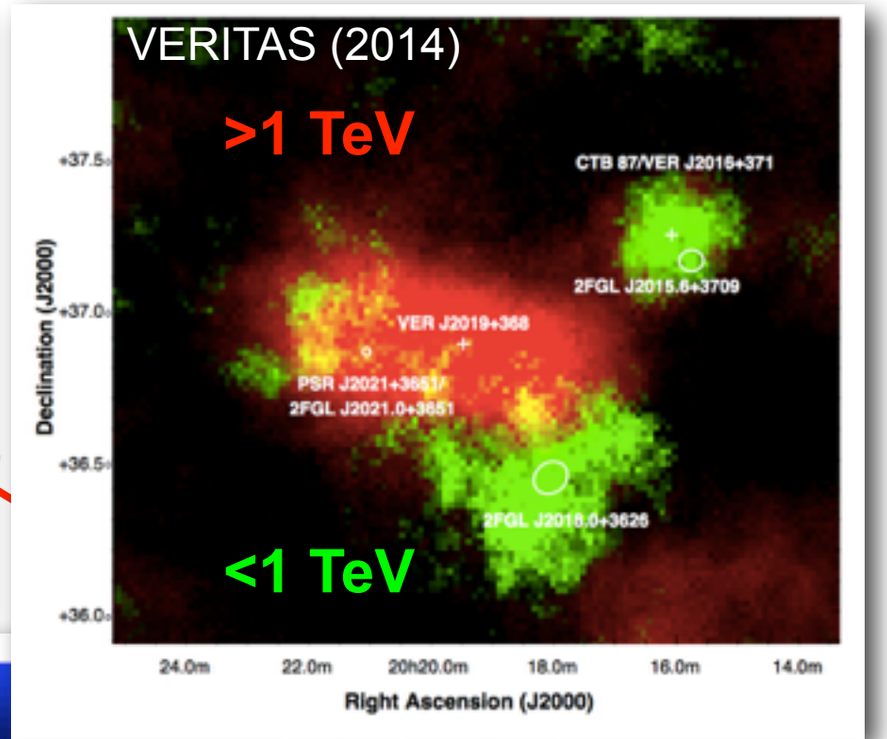


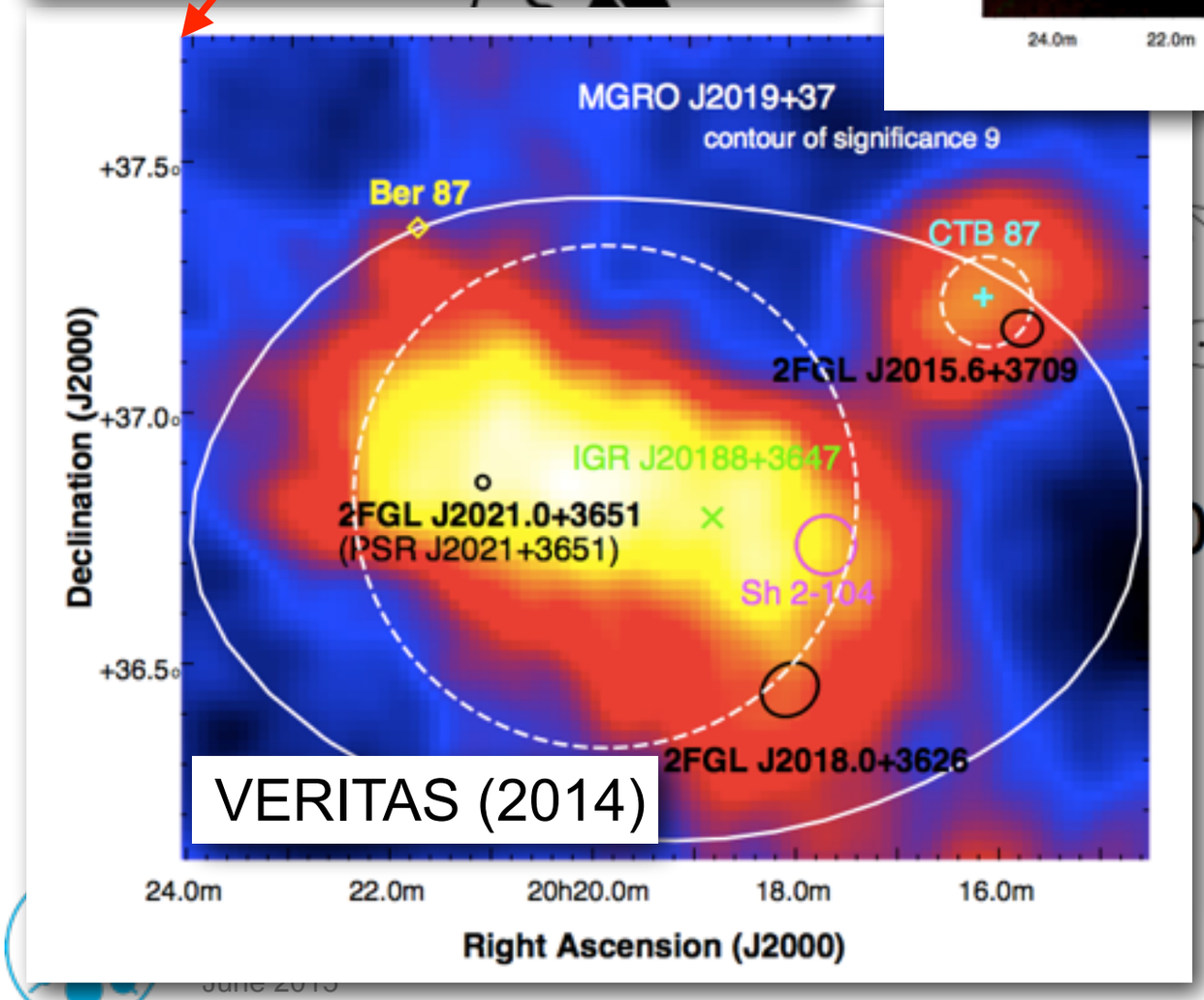
VERITAS limits at 0.3% Crab Nebula level (>135 GeV)

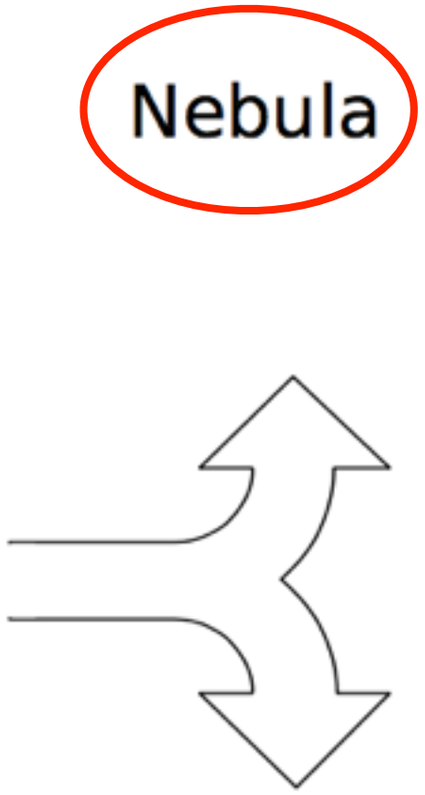
Aliu et al (VERITAS, ApJ 2015)

Pulsars and Pulsar Wind Nebulae - MGRO J2019+37



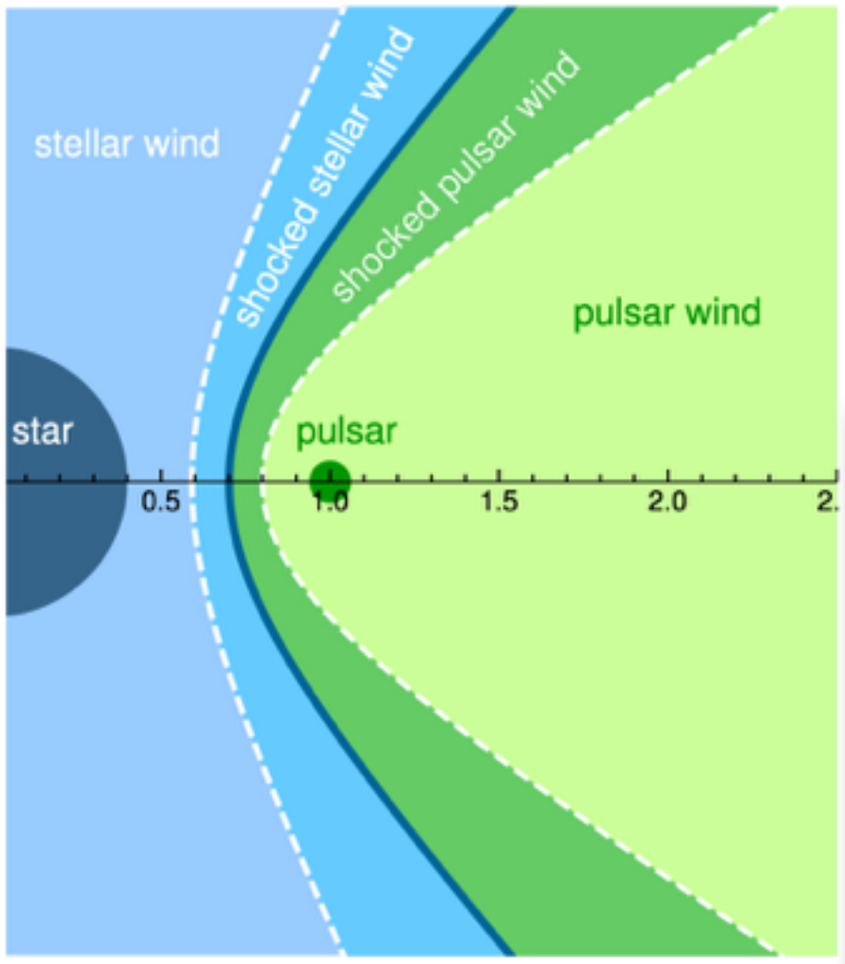






- MGRO J2019+37 detected by MILAGRO
- VERITAS resolves two sources:
  - CTB 87 (PWN)
  - 2nd source unclear (coincident with pulsar PSR J2021+3651)

Gamma-ray binaries: laboratories for pulsar wind nebulae?

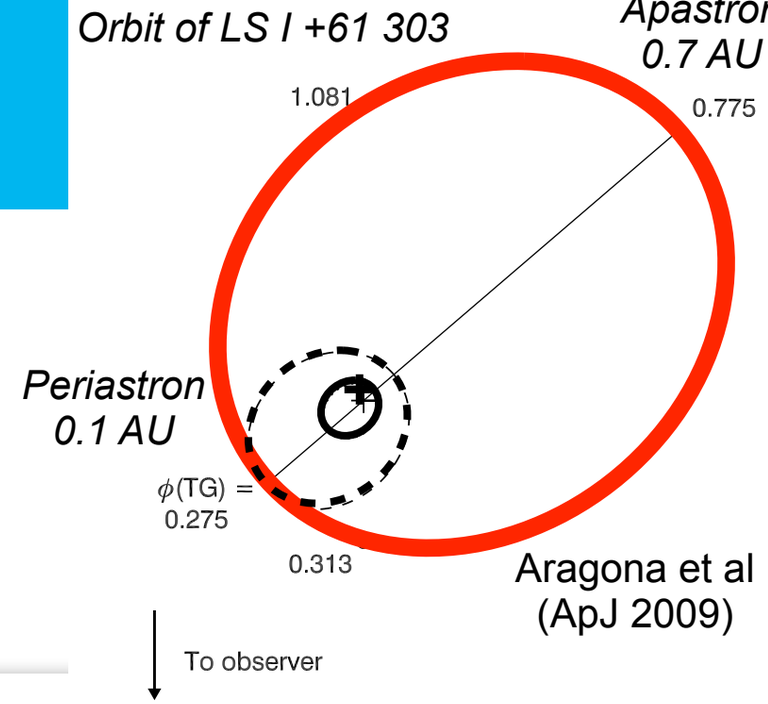


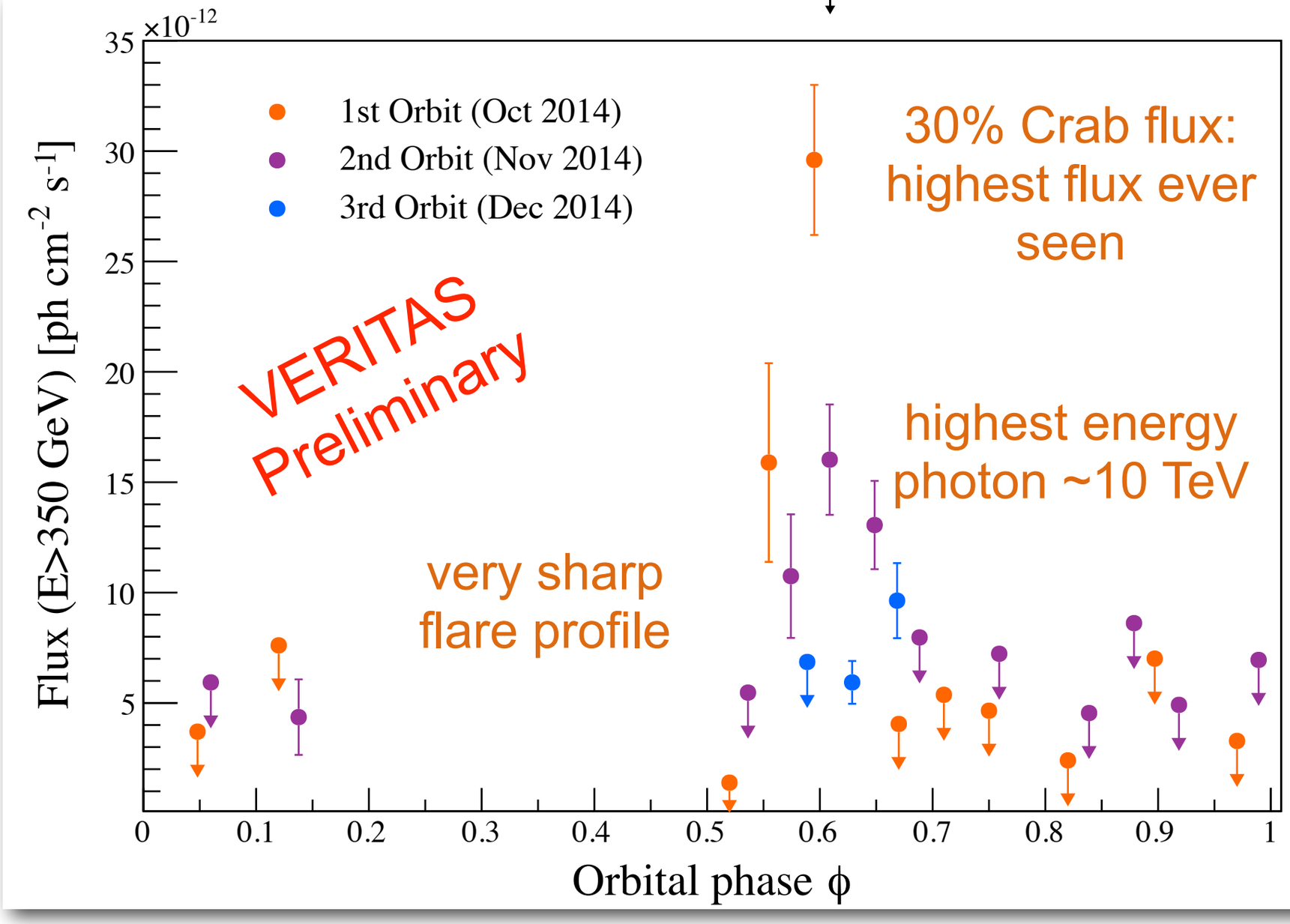
Sketch from Szostek & Dubus (2011)

LS I +61 303

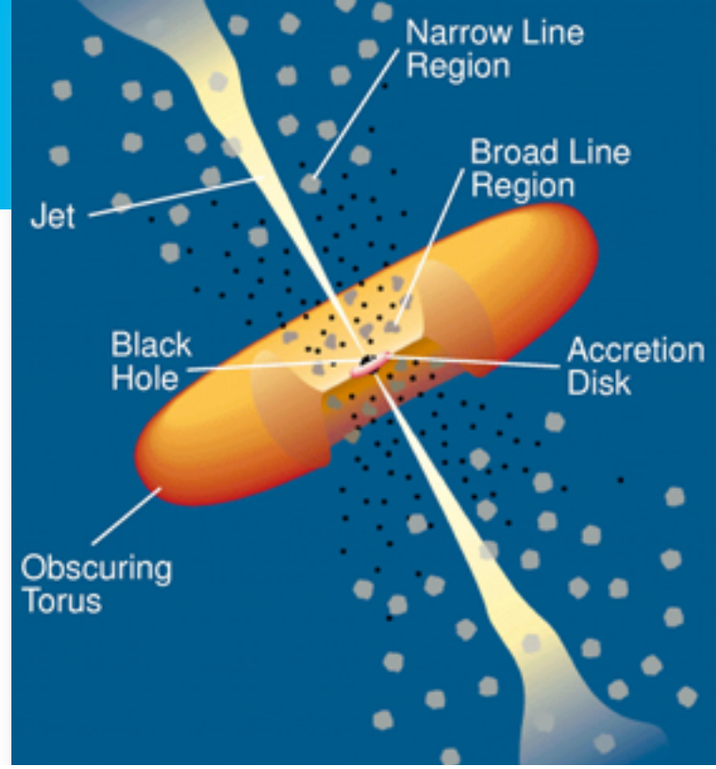
Observations Oct - Dec 2014

Astronomer's Telegram #6785

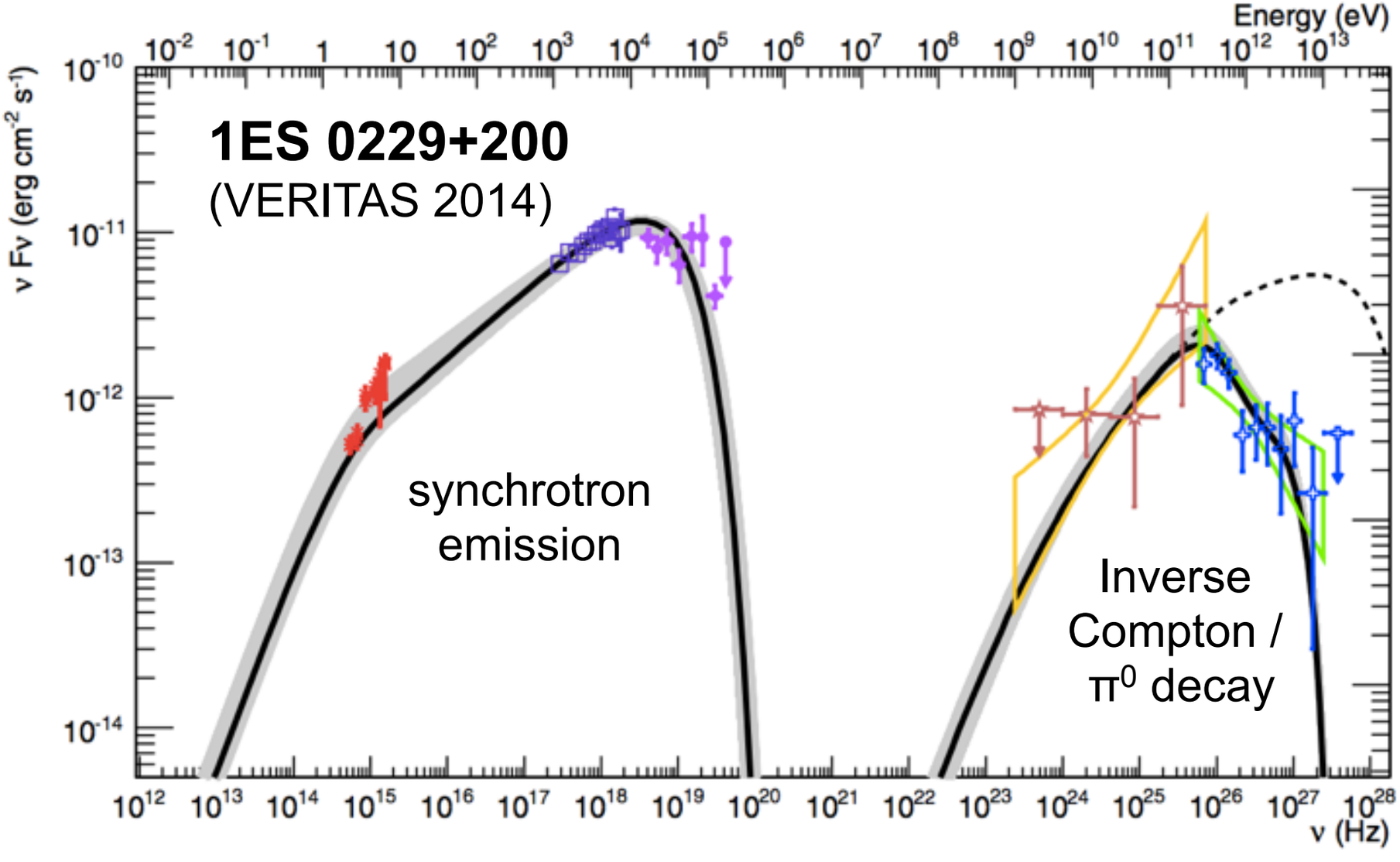




Observations of Active Galactic Nuclei



- AGN are among the most energetic phenomena in the Universe (possibly the sources of ultra-high energy cosmic rays with energies > 10^{19} eV)
- VERITAS detected more than 35 AGN
- newest detections:
  - May 2015: S3 1227+25 (see ATel #7516)
  - April 2015: PKS1441+25 (see ATel #7433)
  - Dec 2014: RGB J2243+20 (see ATel #6849)



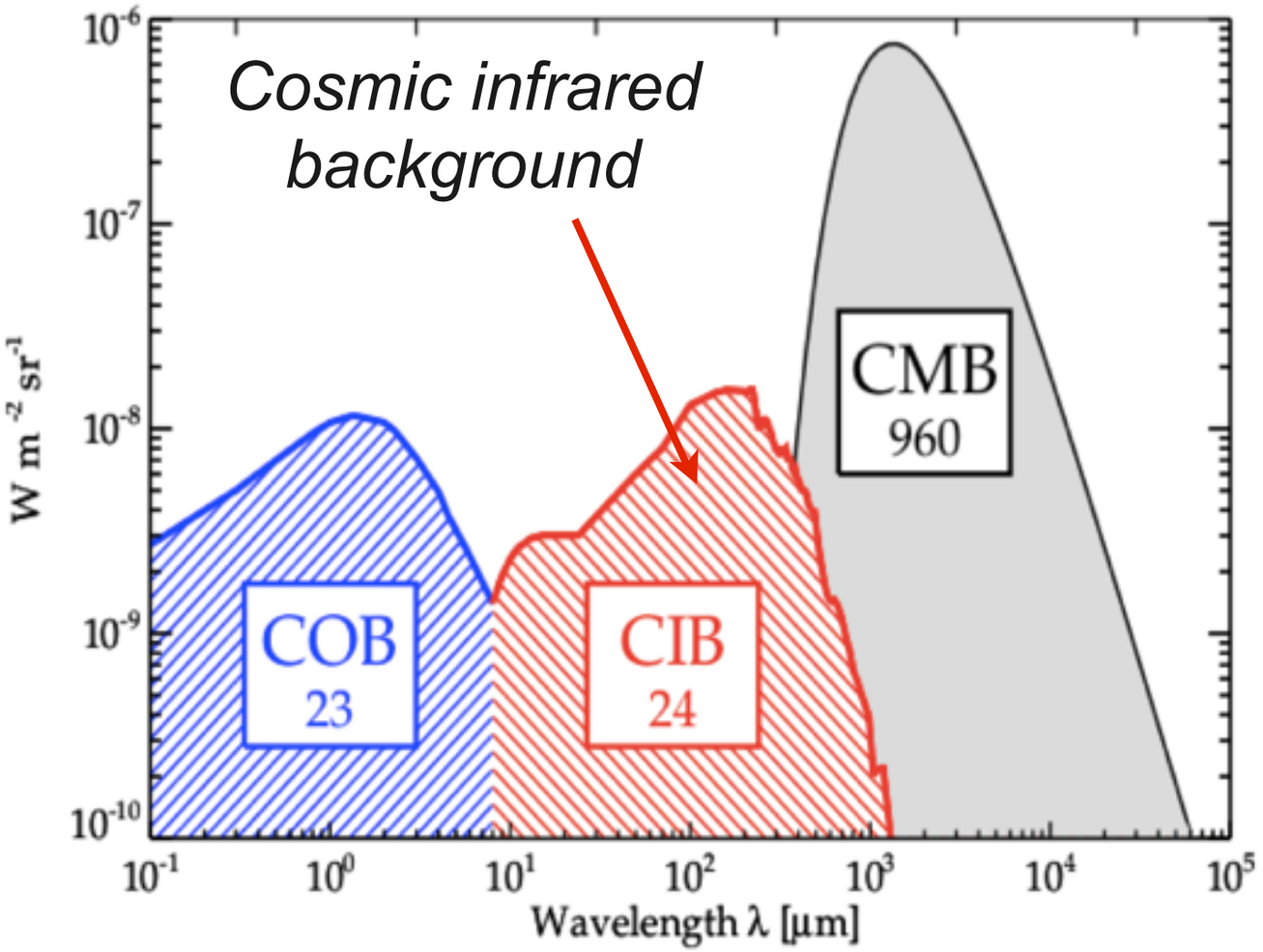
Probing the Extragalactic Background Light (EBL)

EBL optical depth to gamma rays

$\gamma_{HE}\gamma_{EBL} \rightarrow e^+e^-$

$$\tau(E,z) = \int_0^z \mathrm{d}z' \frac{\mathrm{d}l}{\mathrm{d}z}(z') \int_0^{+\infty} \mathrm{d}\epsilon\, n(\epsilon, z') \int_{-1}^{1} \mathrm{d}\mu \frac{1-\mu}{2} \sigma_{ee}(\epsilon, E \times (1+z'), \mu)$$

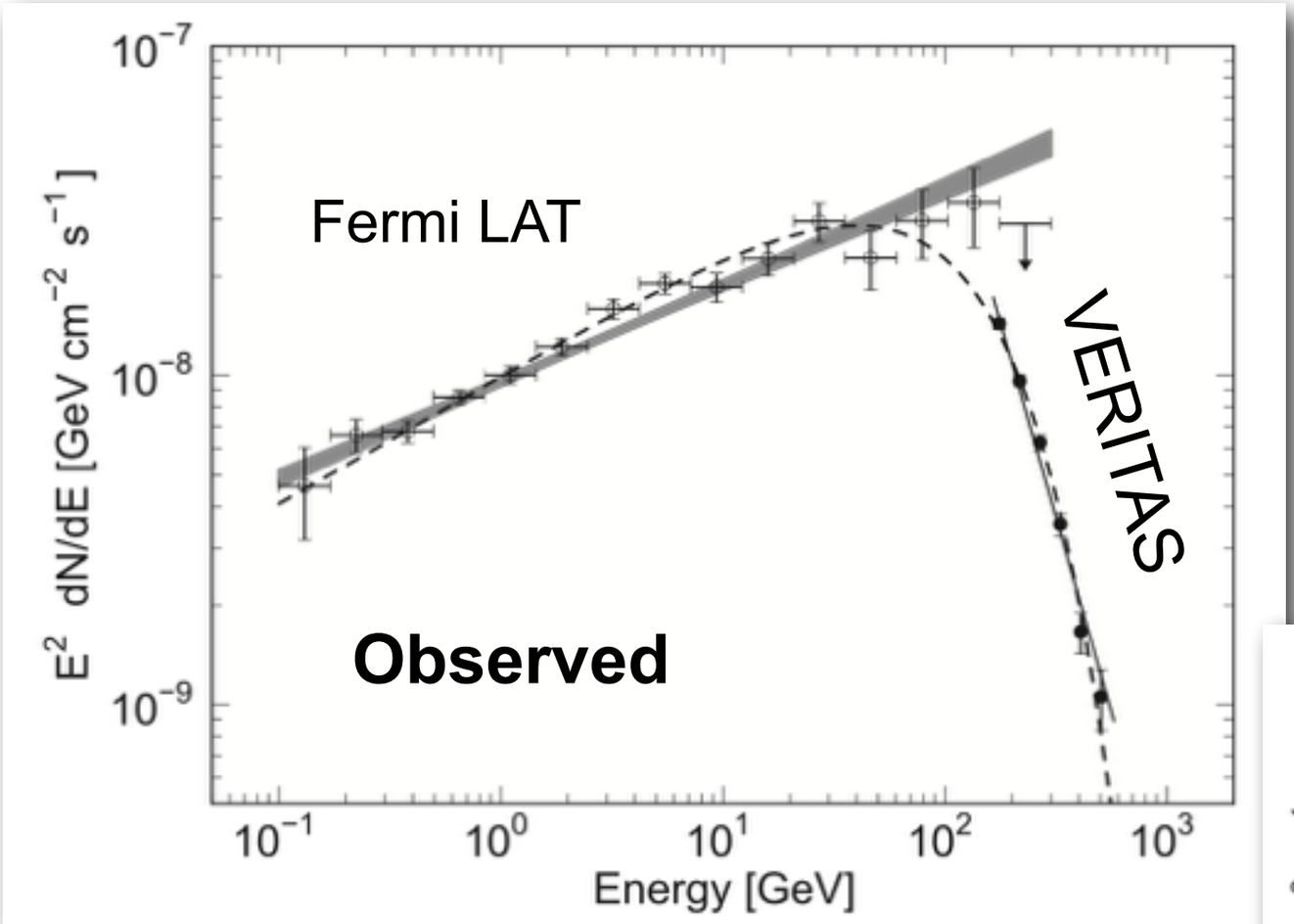
cosmo **astro/cosmo** **particle physics**



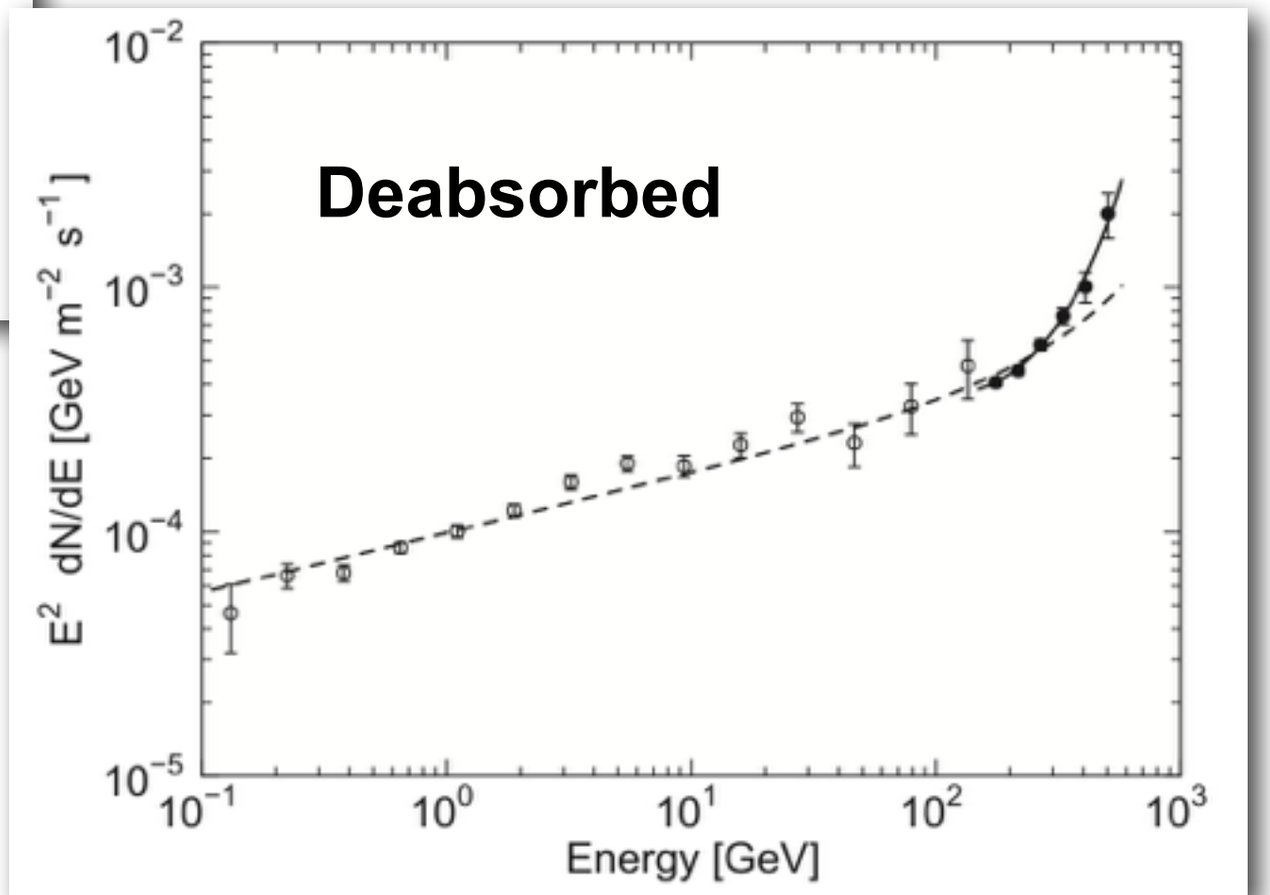
expect a unique redshift-dependent imprint on γ-ray spectra

- Most blazars at z < 0.25
- a handful are very distant:
  - 3C 279: z = 0.536
  - PKS 1424+240: z > 0.60
  - S3 0218+357: z = 0.944
  - PKS 1441+25: z = 0.939

PG 1553+113



High-frequency-peaked BL Lac (HBL) at z > 0.395
VERITAS data from May 2010 to June 2012



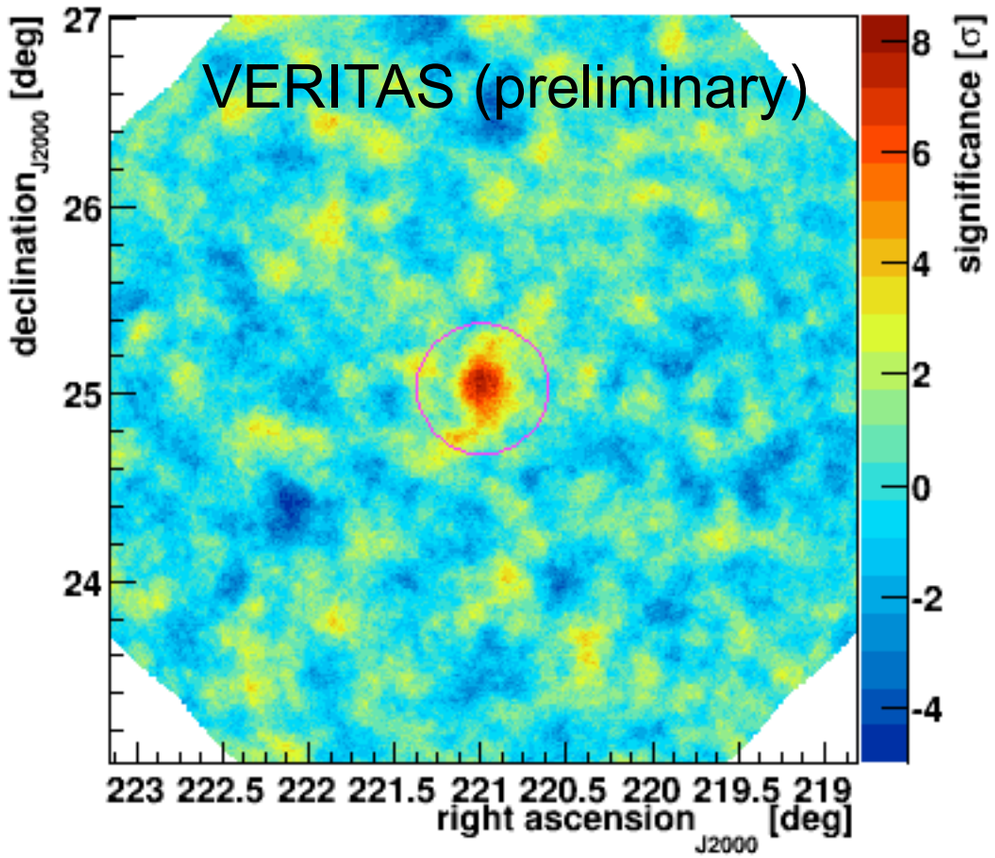
Place limits on EBL / redshift assuming intrinsic (i.e. deabsorbed) spectrum cannot have an exponential rise
z < 0.62

Aliu et al (VERITAS, ApJ 2015)

Very-high-energy gamma-ray emission from PKS 1441+25 detected with VERITAS

ATel #7433; ***Reshmi Mukherjee (Barnard College, Columbia University)***
*on **23 Apr 2015; 03:37 UT***
Credential Certification: Jamie Holder (jholder@physics.udel.edu)

- flat spectrum radium quasar
  - only 5th FSRQ detected by ground-based gamma-ray observatories
- second most distant TeV blazar: z = 0.939 (light travel time 7.5 Gyr)
- ~8 σ detection with VERITAS in 80-200 GeV range in April 2015
  - no significant excess detected in May 2015
- coverage from radio to TeV gamma rays
  - ASSAS-SN, SPOL, Swift, NuSTAR, Fermi-LAT, and VERITAS
- allow us to put constraints on the EBL in the optical domain obtained from one set of observations



Indirect Dark Matter Search

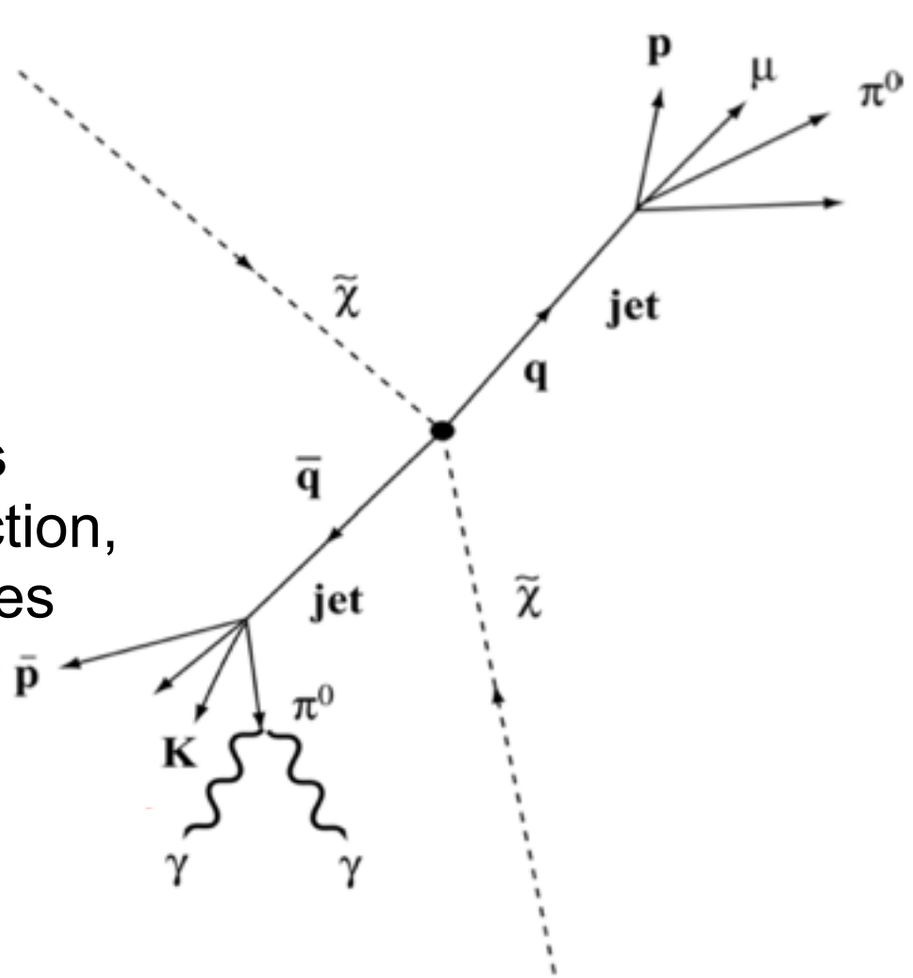
gamma-ray flux from DM annihilation

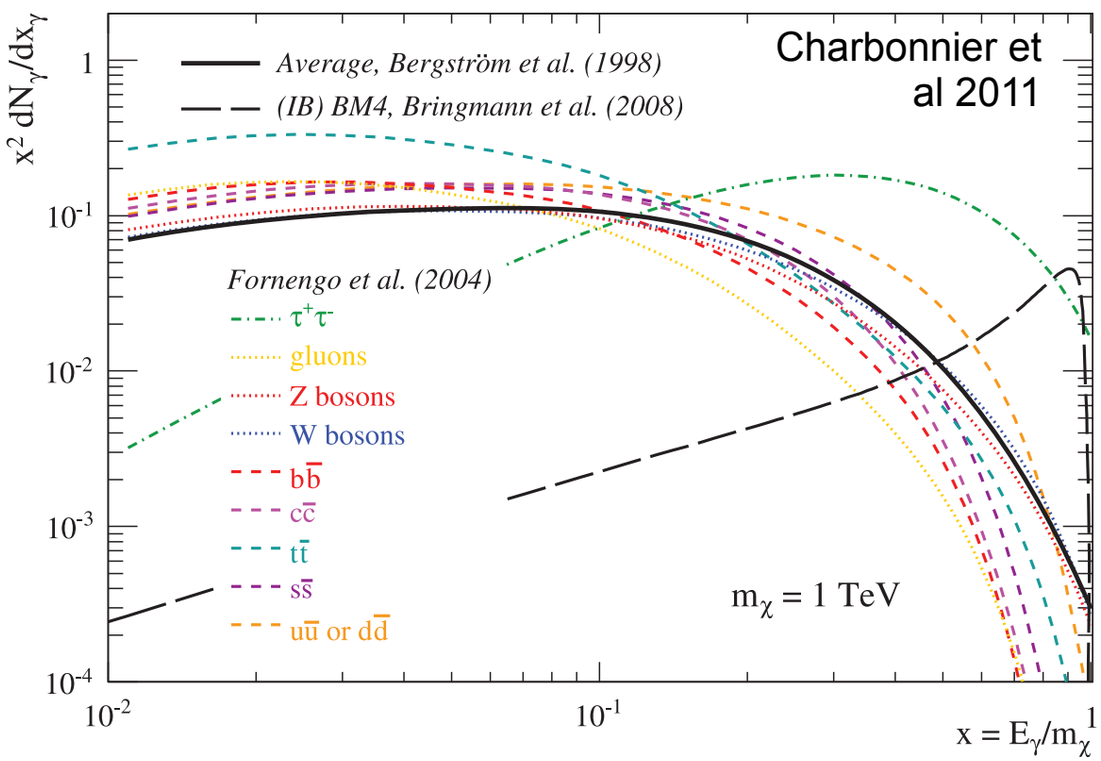
$$\frac{d\Phi}{dE} = J(\psi) \cdot \frac{d\Phi^{PP}}{dE}$$

particle physics
(mass, cross section, annihilation modes branching ratios)

astrophysical factor
(DM morphology at emission region)

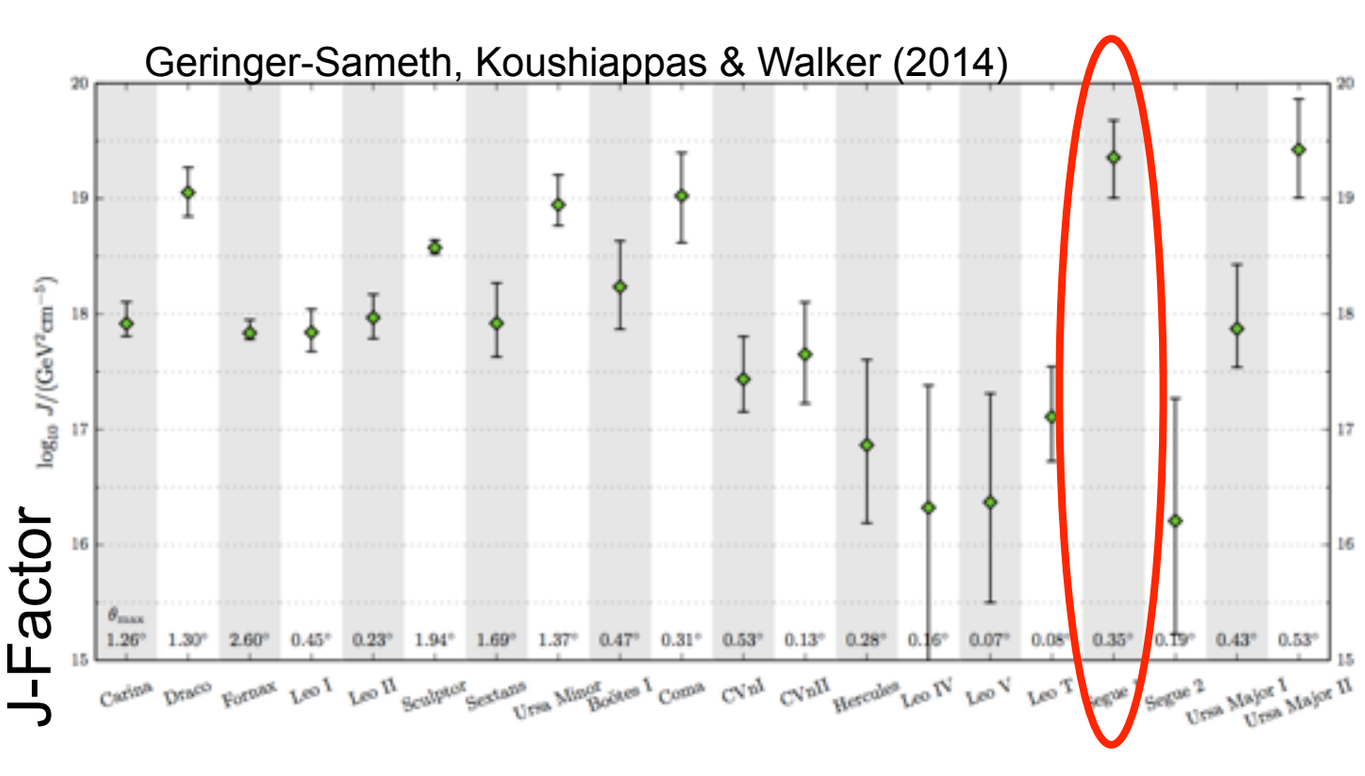
$$J(\psi) = \frac{1}{4\pi} \int d\Omega \int d\lambda \left[\rho^2(r(\lambda,\psi)) \cdot B_{\vartheta_r}(\theta)\right]$$





Search for gamma-ray emission in dark-matter dominated region with little astrophysical background:
dwarf spheroidal galaxies

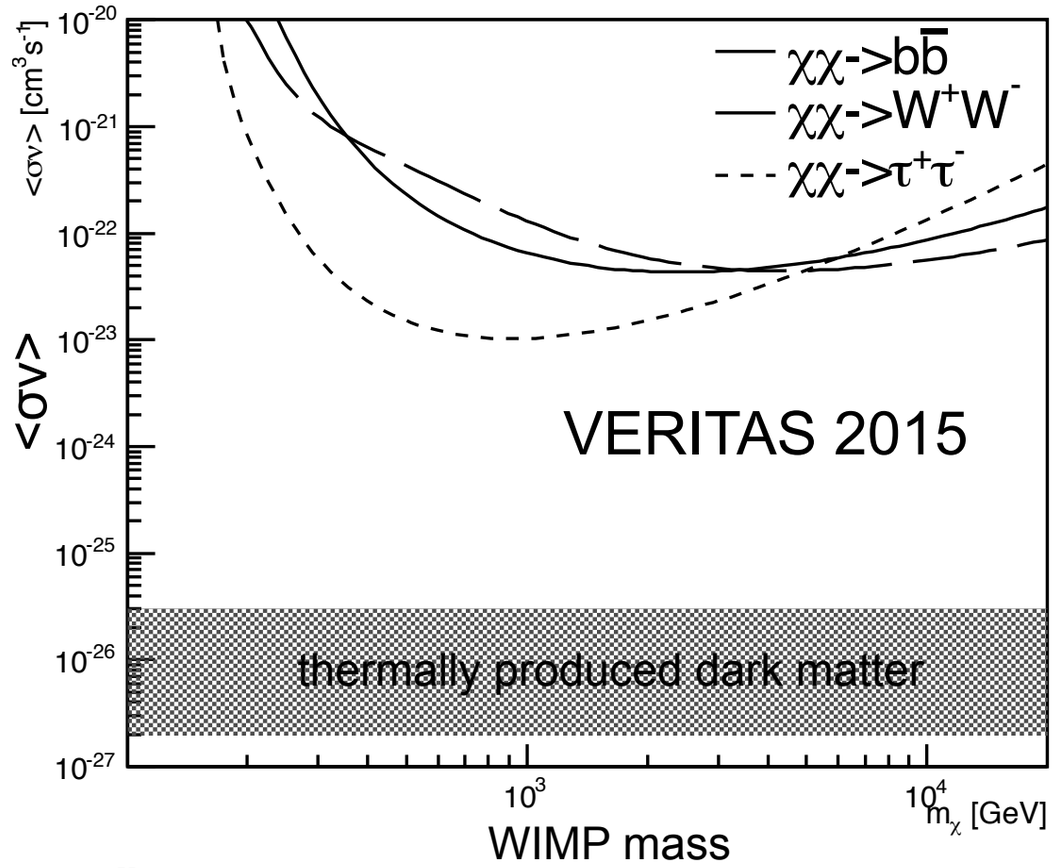
Dwarf Spheroidal Galaxies - Segue I

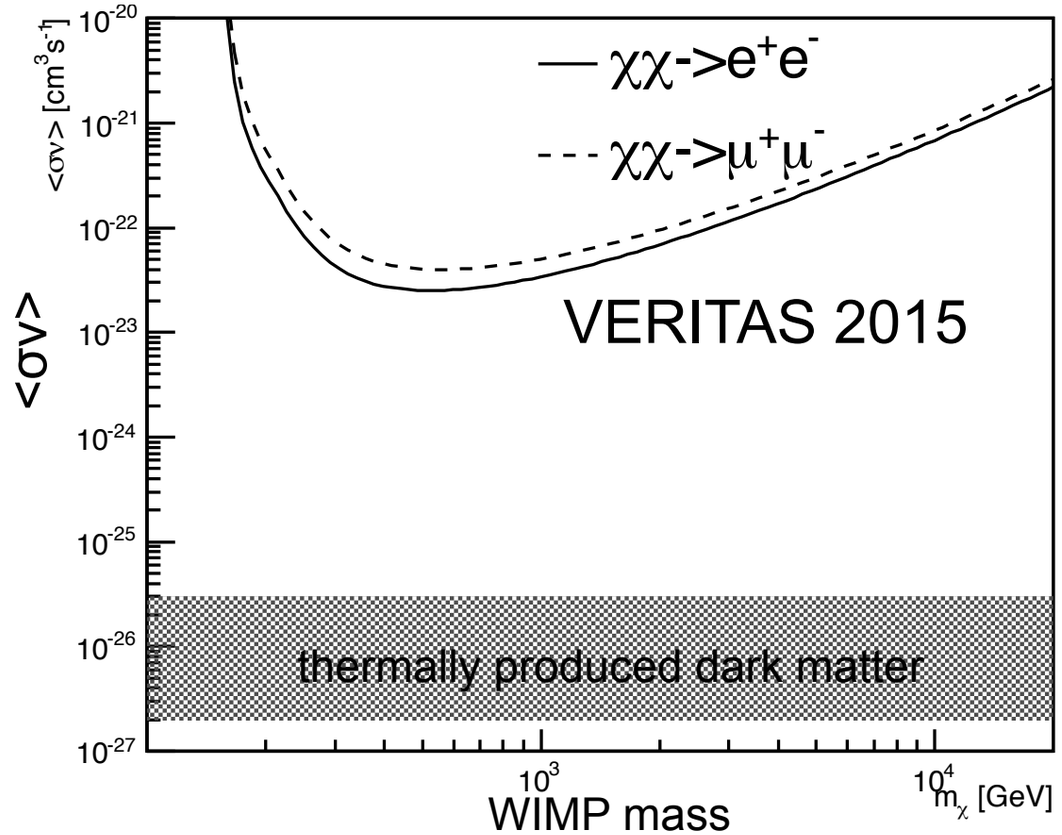


- 48 h of VERITAS observations of Segue I
- $\langle\sigma v\rangle \sim O(10^{-23})\ cm^{-3}s^{-1}$

Phys. Rev. D. 85, 062001 (2012)
Erratum June 2015 (to be published)

ICRC 2015 combined analysis from all dwarf fields using energy and spatial information of events





Conclusions

- **VERITAS** is a stable instrument, running smoothly after several major upgrades - more sensitive than ever
- deep studies & sophisticated modelling: long-term observing plan
- large synergies with Fermi LAT, HAWC and other observatories
- lots of new results will be presented in August at the ICRC in The Hague