VERITAS and Very High Energy (VHE) Gamma-ray Astronomy

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Basic outline

- VERITAS overall design & working principles
- Observational highlights

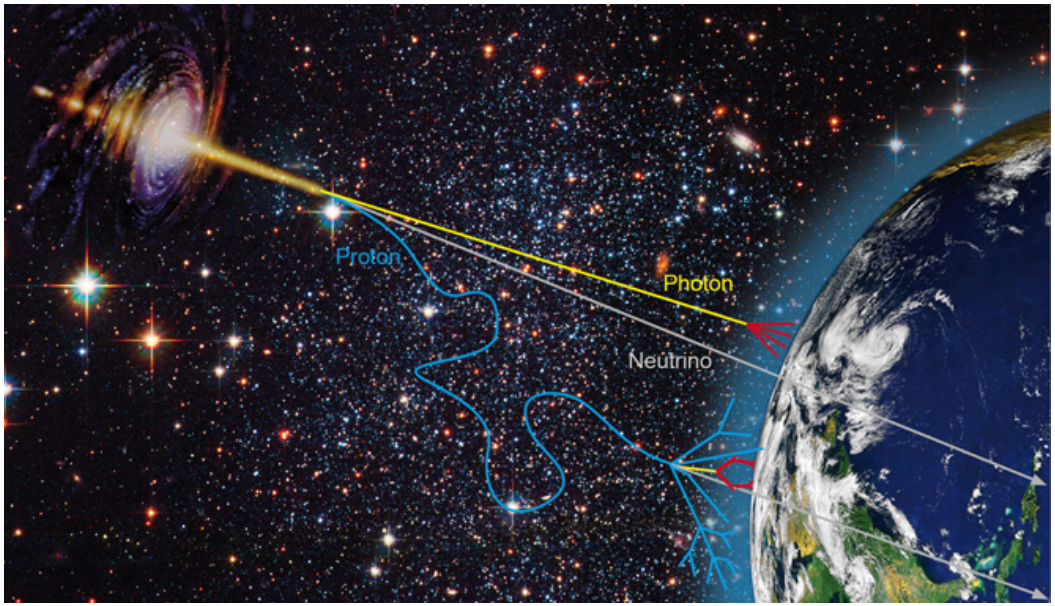
What is VERITAS?

- Acronym for "Very Energetic Radiation Imaging Telescope Array System"
- An array of four 12-meter optical telescopes
- Uses the atmospheric Cherenkov imaging technique to detect very high energy gamma ray (100GeV – 10TeV)
- Fred Lawrence Whipple Observatory in Mount Hopkins, Arizona, US
- Commissioned in 2007, major upgrades in 2009 and 2012

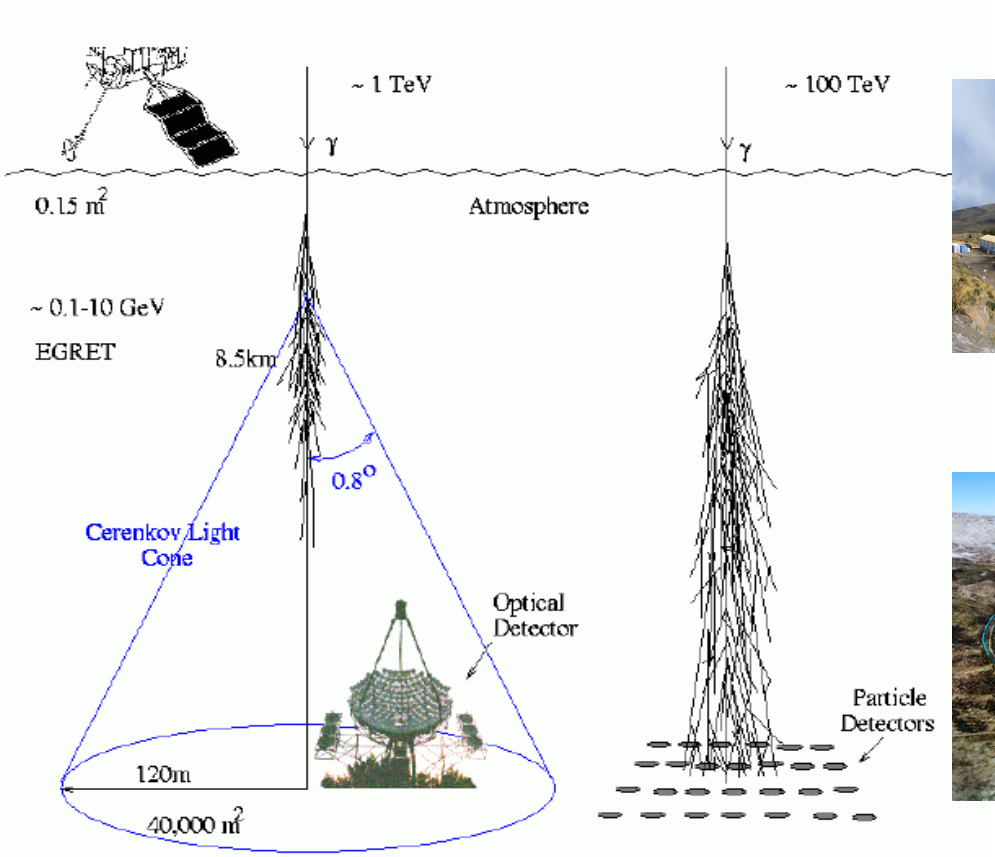
Bradbury et. al. arXiv:astro-ph/9907248v1

Why VHE gamma-ray?

Victor Hess,1912



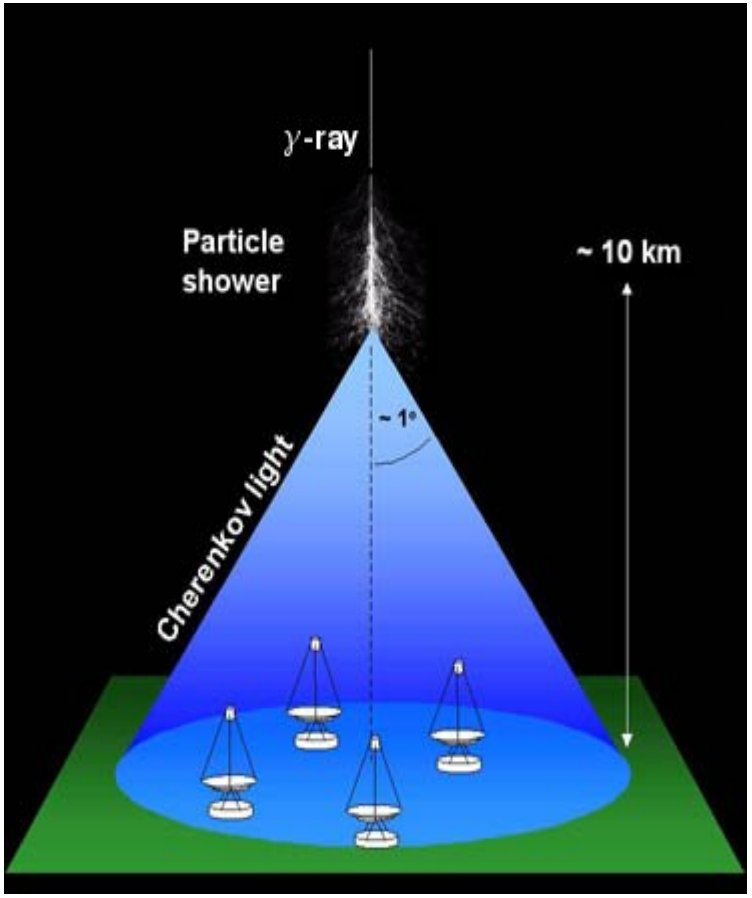
Why ground based?

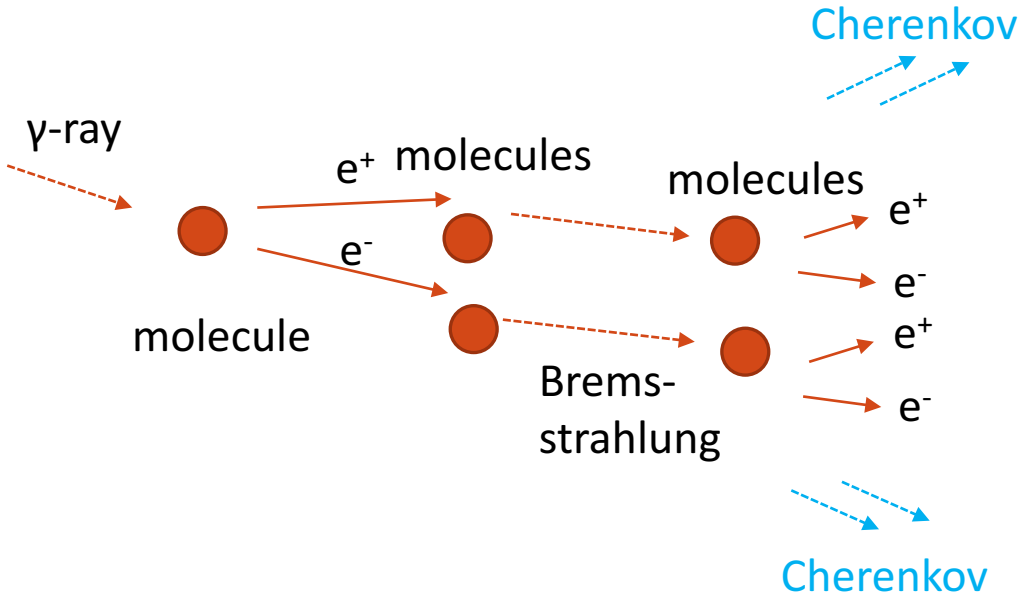


Cherenkov telescopes vs. Air shower arrays

	Cherenkov Telescope	Air Shower Array
Energy Threshold	Low (<200 GeV)	High (>10 TeV)
Background Rejection	Excellent (>99.7%)	Moderate (>50%)
Field of View	Small (<2°)	Large (>45°)
Duty Cycle (uptime)	Low (5%-10%)	High (>90%)

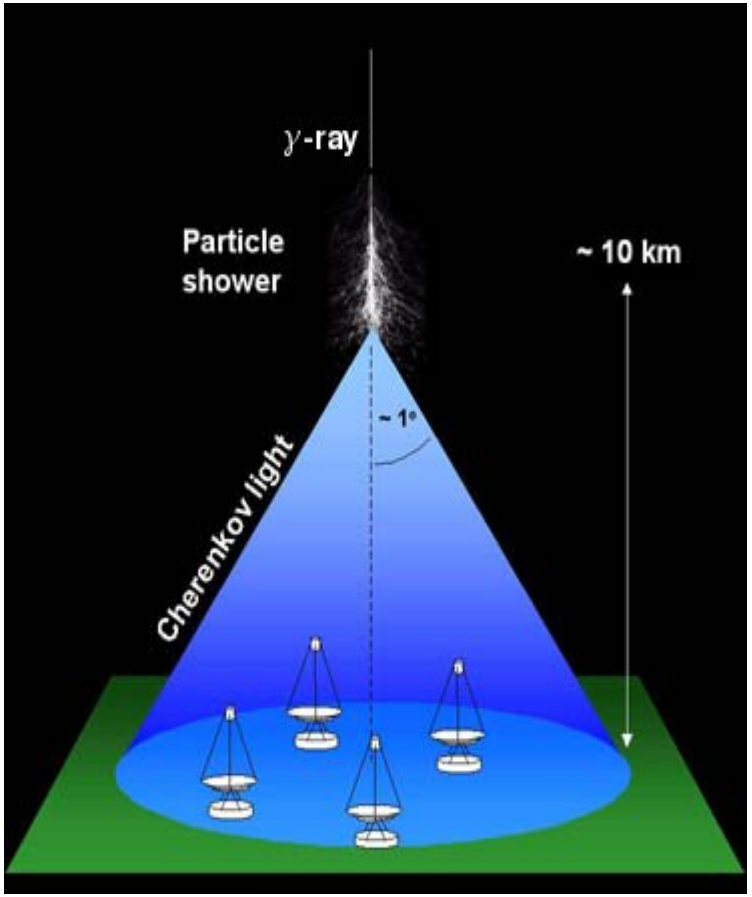
Quick intro to VHE γ-ray astronomy





- The result is a shower of charged particles (mainly e^+ e^-)
- $V_{charged} > V_{light} = 0.9997c$ ➡ Cherenkov

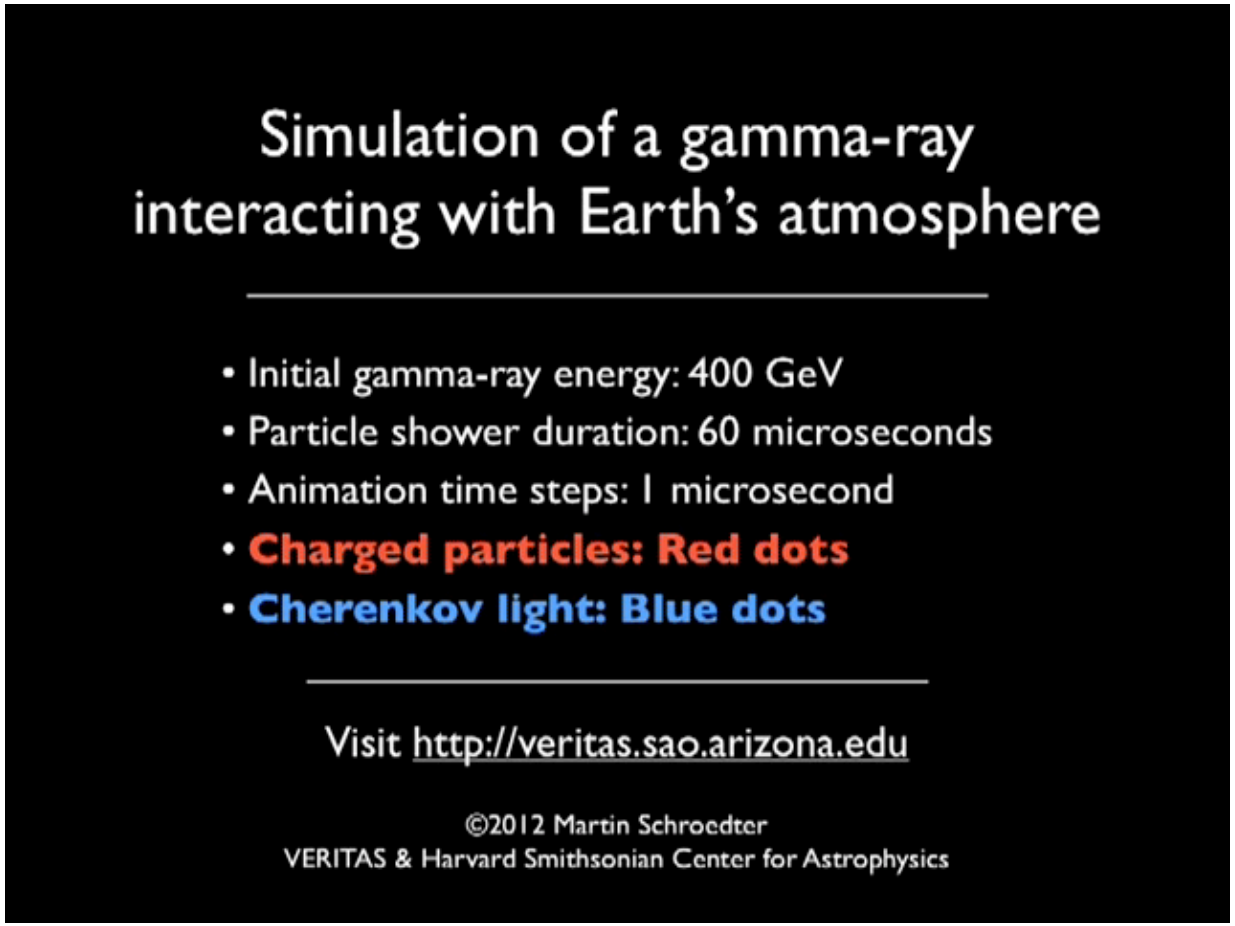
Quick intro to VHE γ-ray astronomy



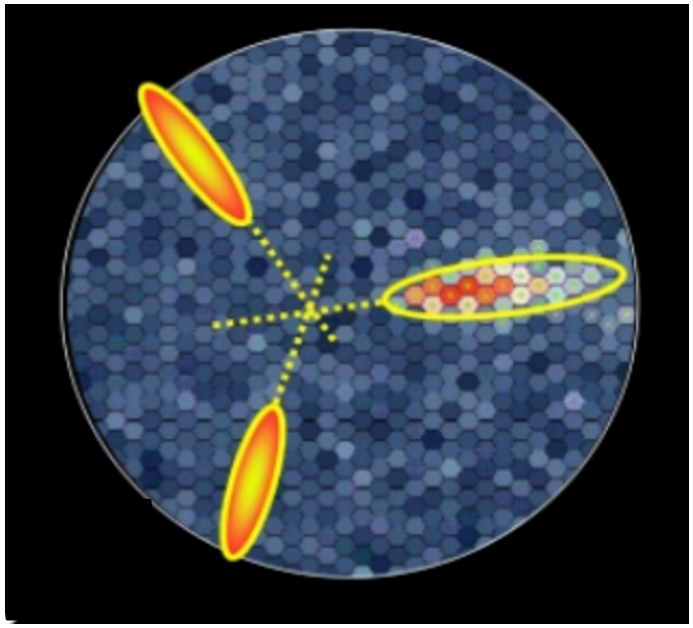
This Cherenkov light…

- Is confined in a cone of ~1 deg
- Falls upon ~10^4 m^2 of land area
- Is mainly Blue light / UV
- Has nanosecond duration
  (requires fast imaging techniques)

Let's watch a simulation



Seeing and extracting the signal



Weekes 2003: *Very high energy gamma-ray astronomy*

- Each telescope sees a "rod" in the sky (or rather, an elongated elliptical signal)
- Extrapolating the "rod" backwards leads to the source's position
- Brightness at shower maximum indicates incident γ-ray energy (Energy resolution ~17%)
- The elongated signal shape is used to reject charged cosmic ray background (can be 10^4 stronger) [Explanation]
- Coincidence operation removes single muon background

VERITAS site (1268m above sea level)

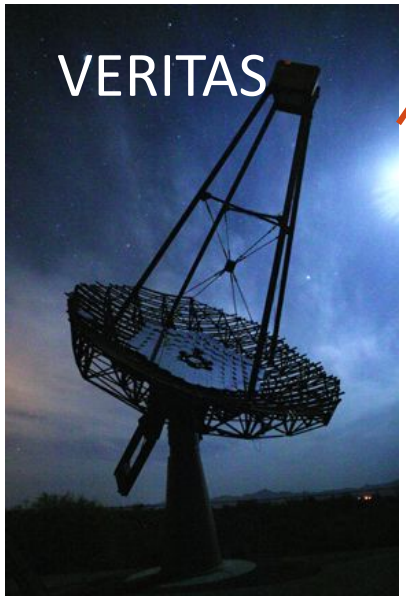
Reflector of VERITAS

- D=12m, f/1.0
- 315 Aluminized Pyrex glass facets

VERITAS's camera

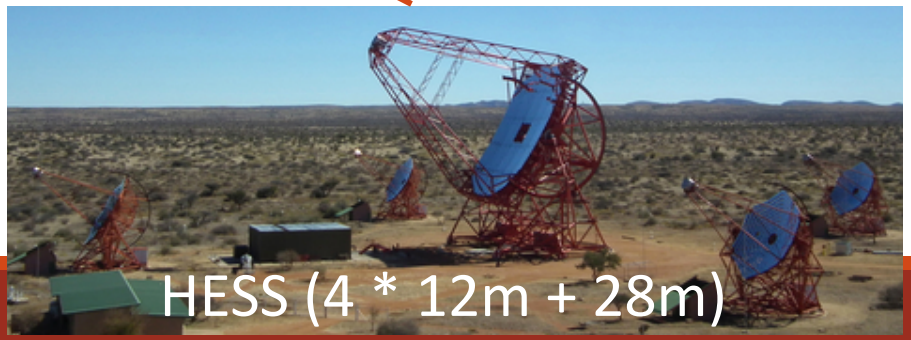
- 1.8m wide, 3.5 deg FOV
- 499 fast response photomultiplier tubes (PMTs)
- Each PMT views 0.15 deg of the sky
- "Exposure time" of each individual "picture" ~ 2ns

Similar projects



cta
cherenkov telescope array

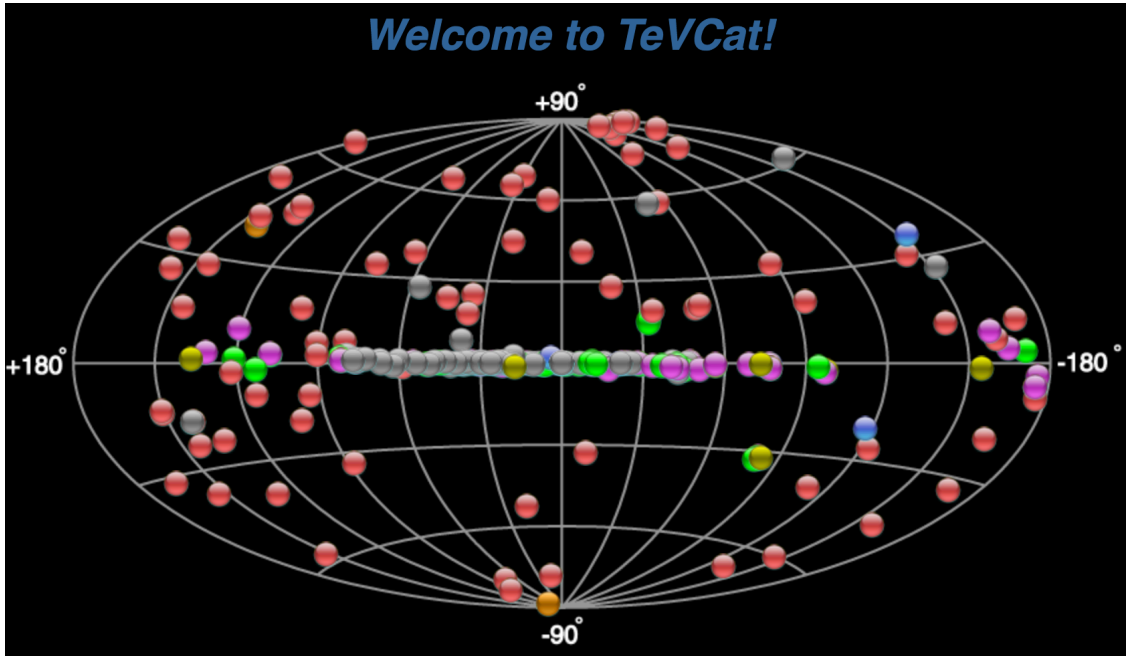
30+, planned



Section 2:

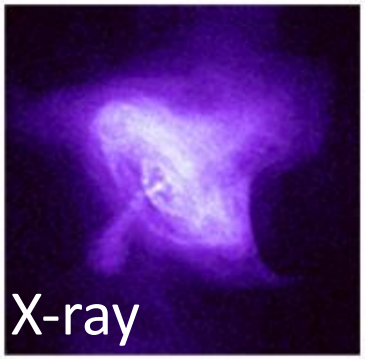
Observational Highlights of VERITAS

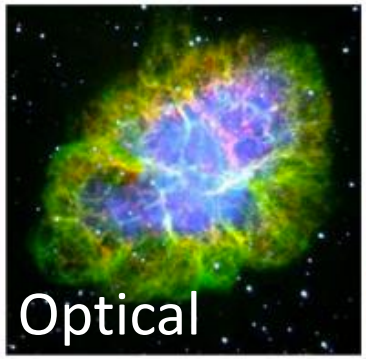
VHE γ-ray sources

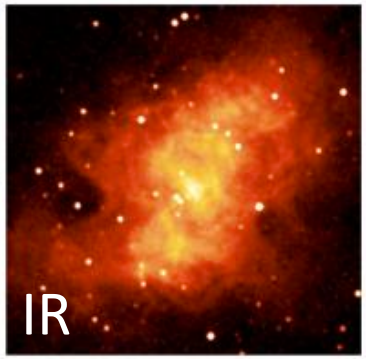


- 210 sources in total, 7 categories
- Galactic sources: PWN, SNR, binary
- Extragalactic sources: blazars, BL Lacs, starburst galaxies

Crab

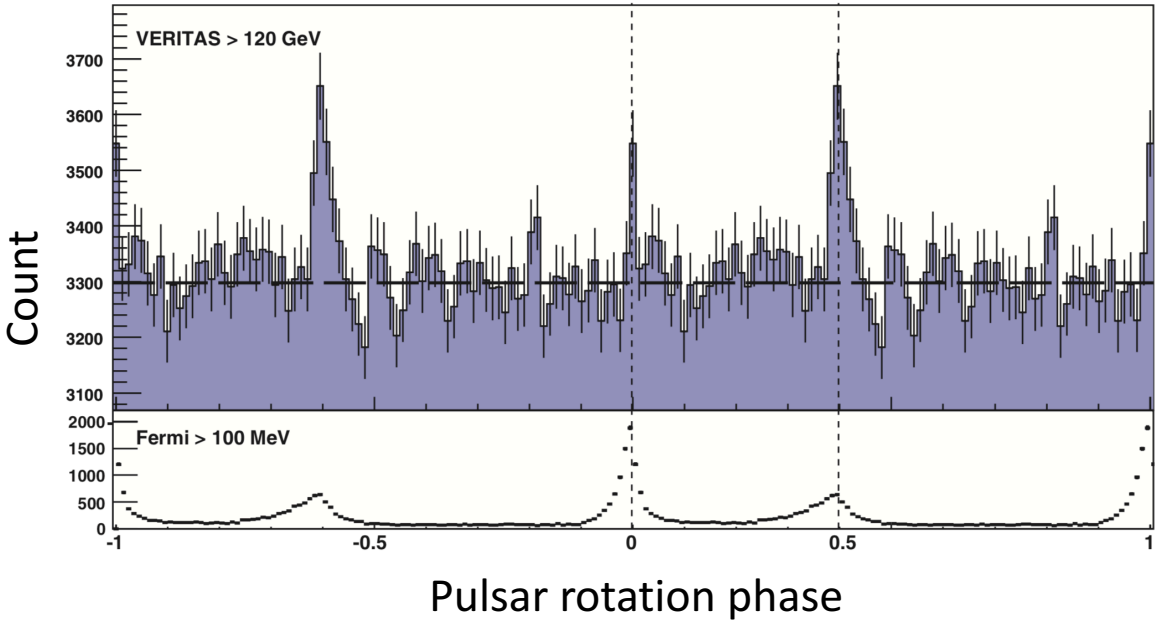






- Brightest steady TeV γ-ray source
- Often used as a standard reference (crab unit)

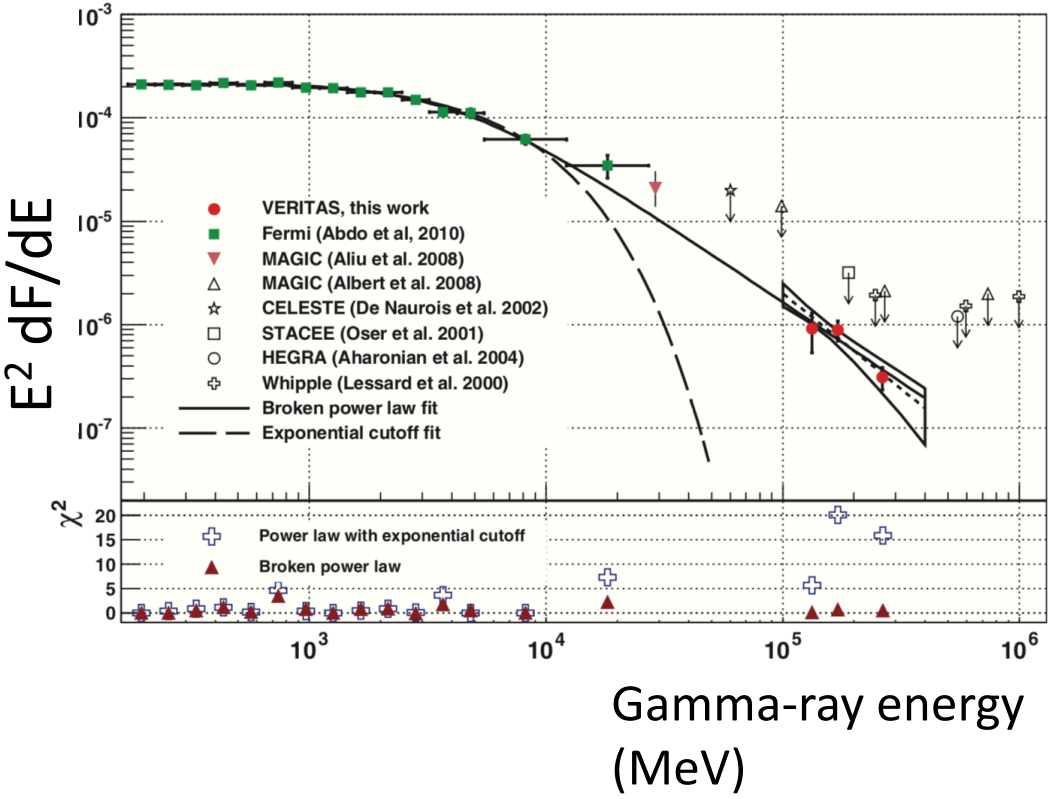
Phase folded event distribution (aka. pulse profile)

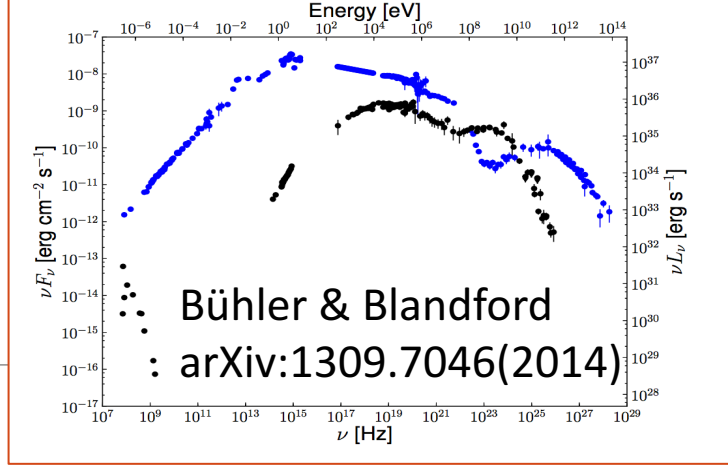


- 170 hrs of combined exposure
- 2 main pulses coincident with radio ones

Science **334**, 69 (2011)

Crab

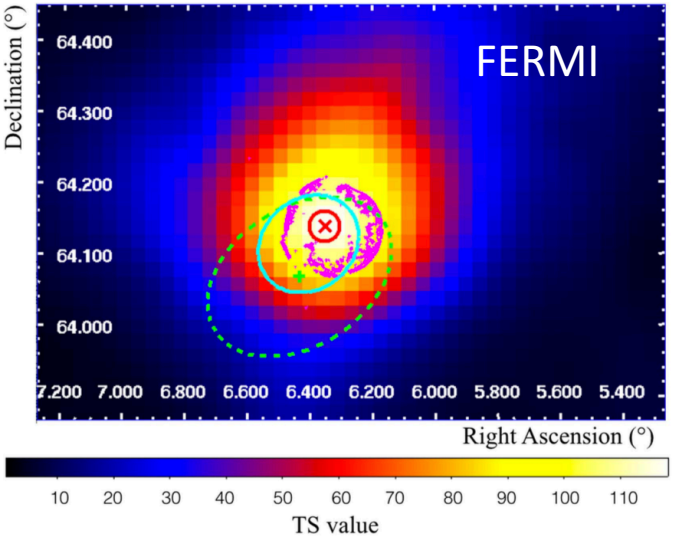


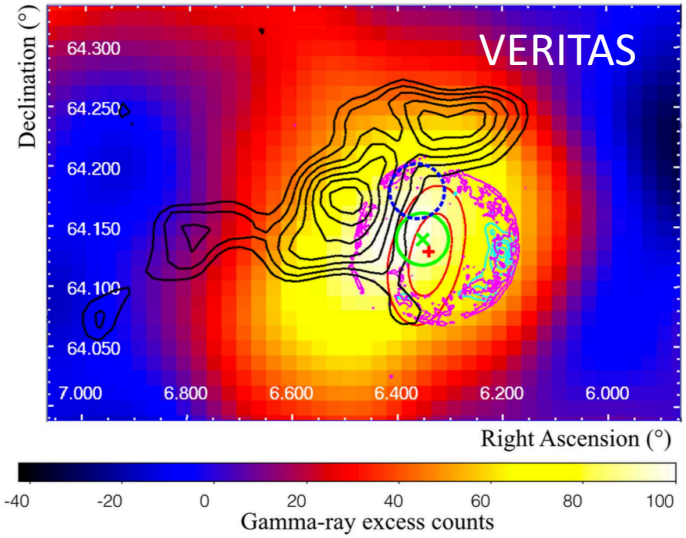


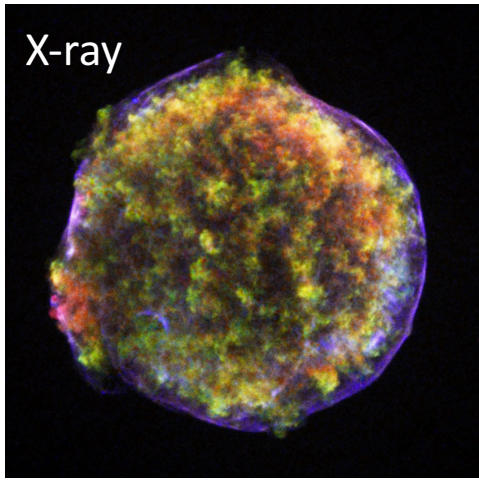
- SED above 100 GeV still follows a power law
- Most models predict a power law with exp. cutoff

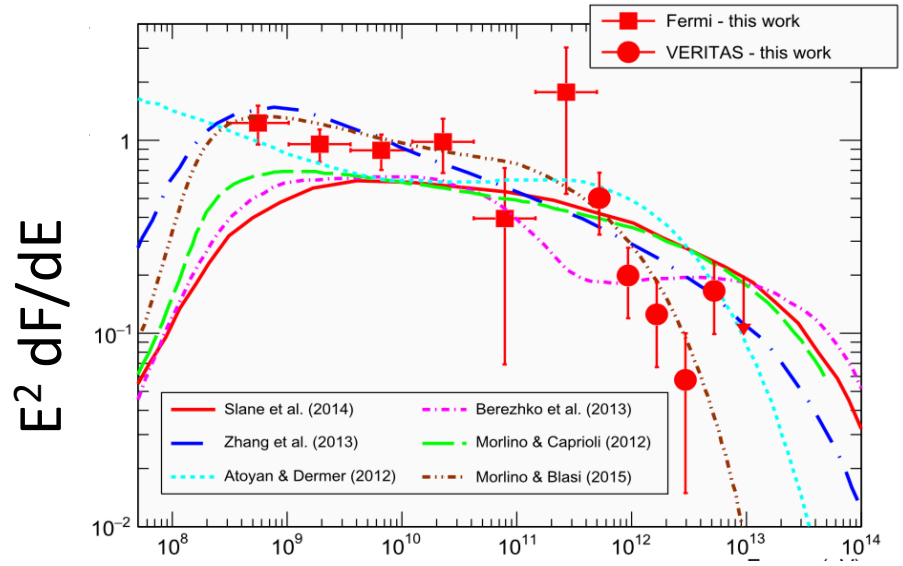
Science **334**, 69 (2011)

Tycho's SNR









- 0.9% C.U., 147 hrs of data

ApJ **836**, 23 (2017)

Origin of cosmic rays?

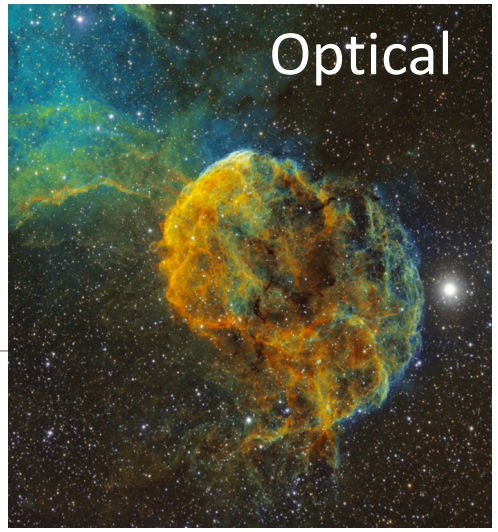
- Both leptons and hadrons of TeV energy can present in SNRs due to interaction of ejecta with molecular cloud (diffuse shock wave acceleration)
- Leptonic production (aka. Inverse Compton scattering)

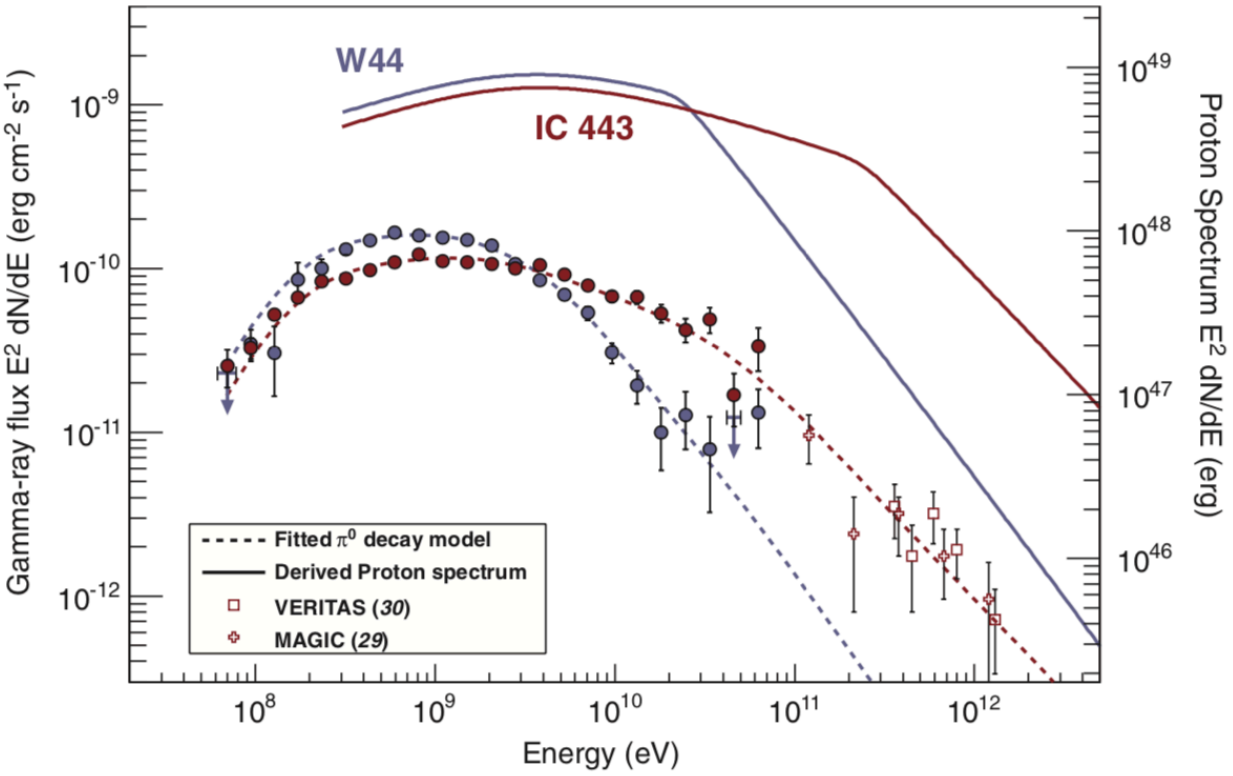
  e^- (high energy) + γ (CMB or IR) → e^- (low energy) + γ (VHE)
- Hadronic production

  p (high energy) + nucleus → p' + π^0 + π^+ + π^-

  π^0 → 2 γ
- If Hadronic mechanism is dominant, we will thereby have an explanation for the origin of cosmic rays (at least part of it)

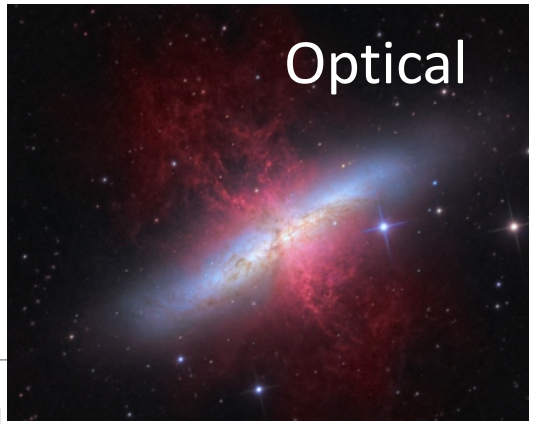
IC443

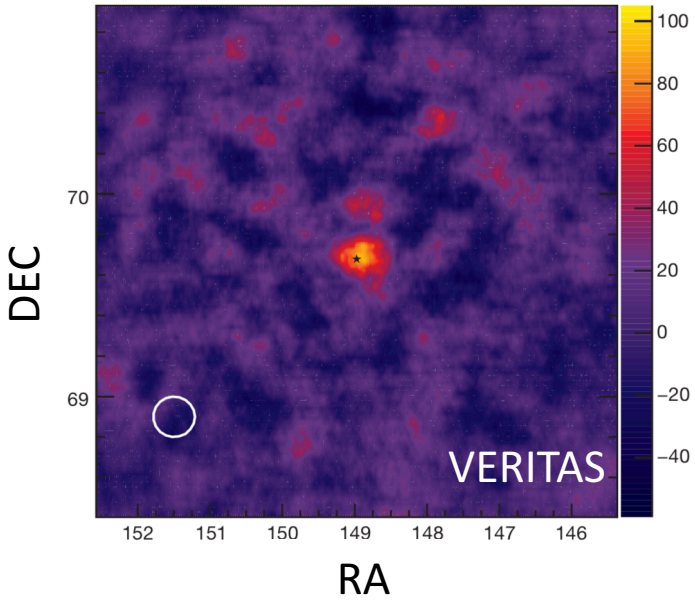


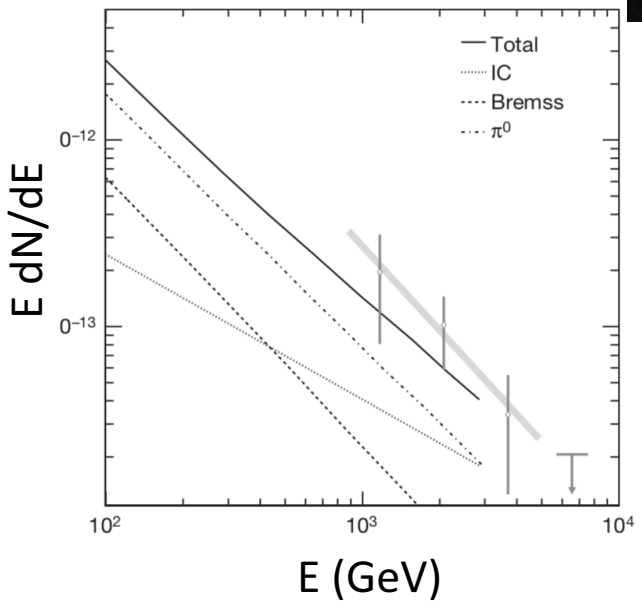


Science **339**, 807 (2013)

M82







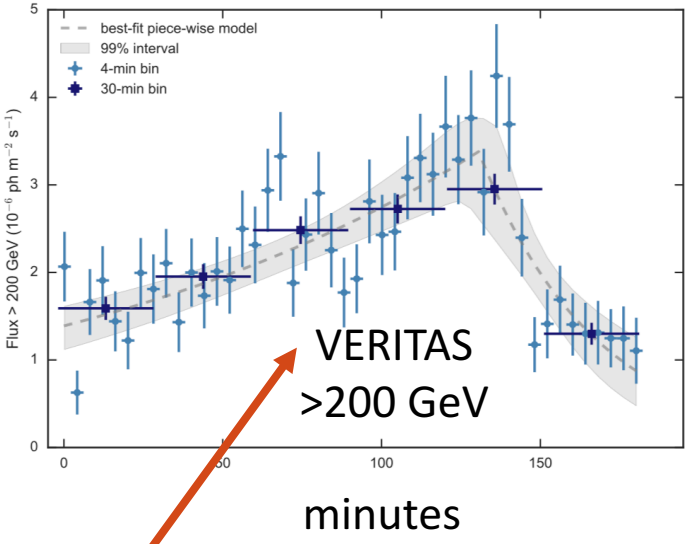
- No prominent AGN activity
- Interaction w/ M81 creates a central starburst region

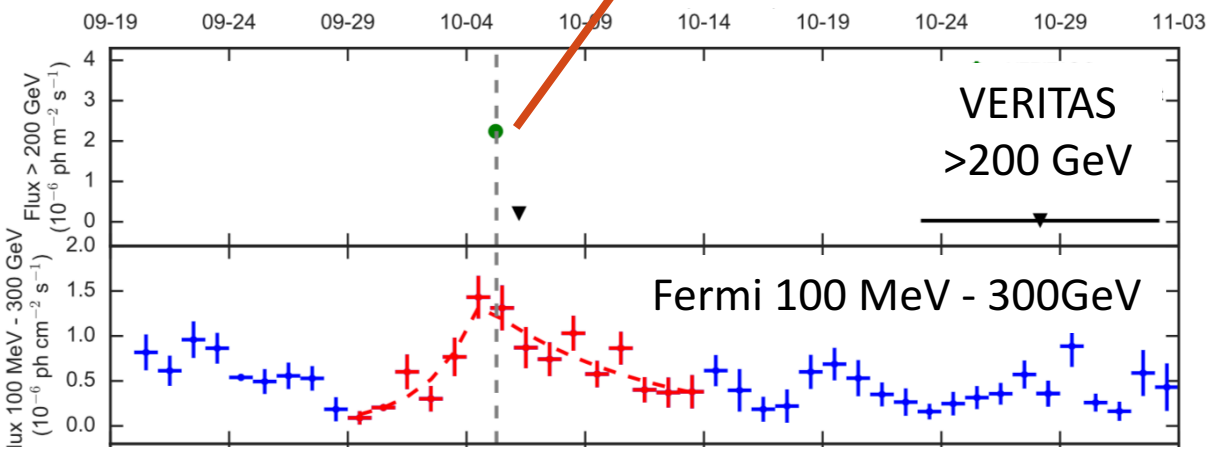
- 175 hrs of observation in 2008-2009, collected 91 γ-ray events
- Data + model analysis ➡ CR density in starburst region 500x Milky Way value
- Consistent of a 30x higher SN rate

Nature **460**, 117 (2009)

BL Lacertae flare

- VERITAS observed a VHE flare from BL Lac on Feb 28, 2011, and a second flare on Oct 5, 2016
- The second flare almost reached 1 C.U.
- Coincides with the peak of a GeV flare observed by Fermi
- Rise & decay time ~ tens of minutes, indicating an emitting region ~ 10 R_s (M_{BH} ~ 10^8 M_{sun})

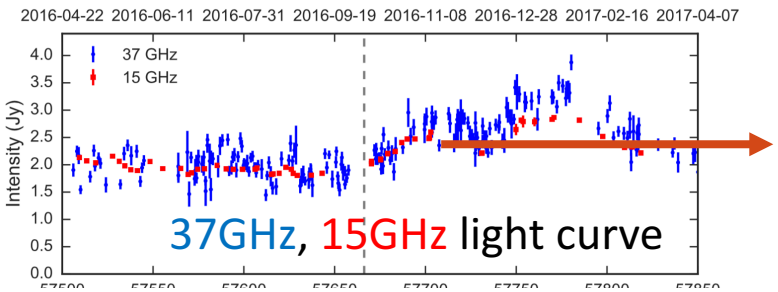




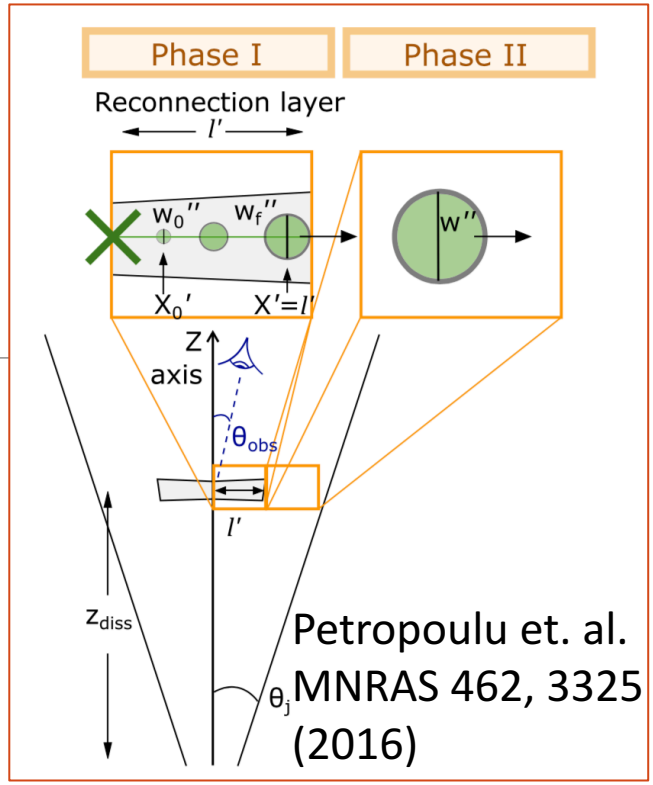
date

arXiv:1802.10113v1 (2018)

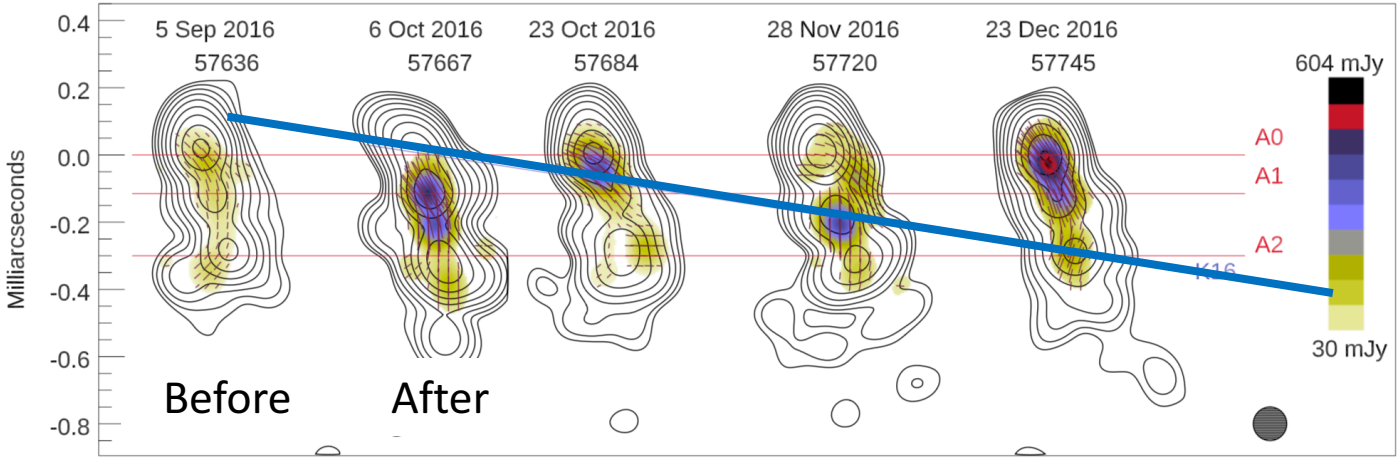
BL Lacertae flare



Delayed radio flare?



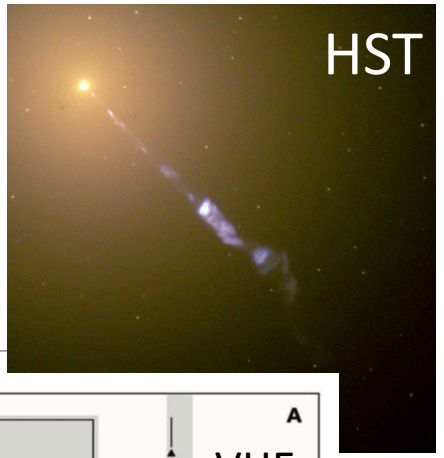
VLBI imaging @ 43GHz

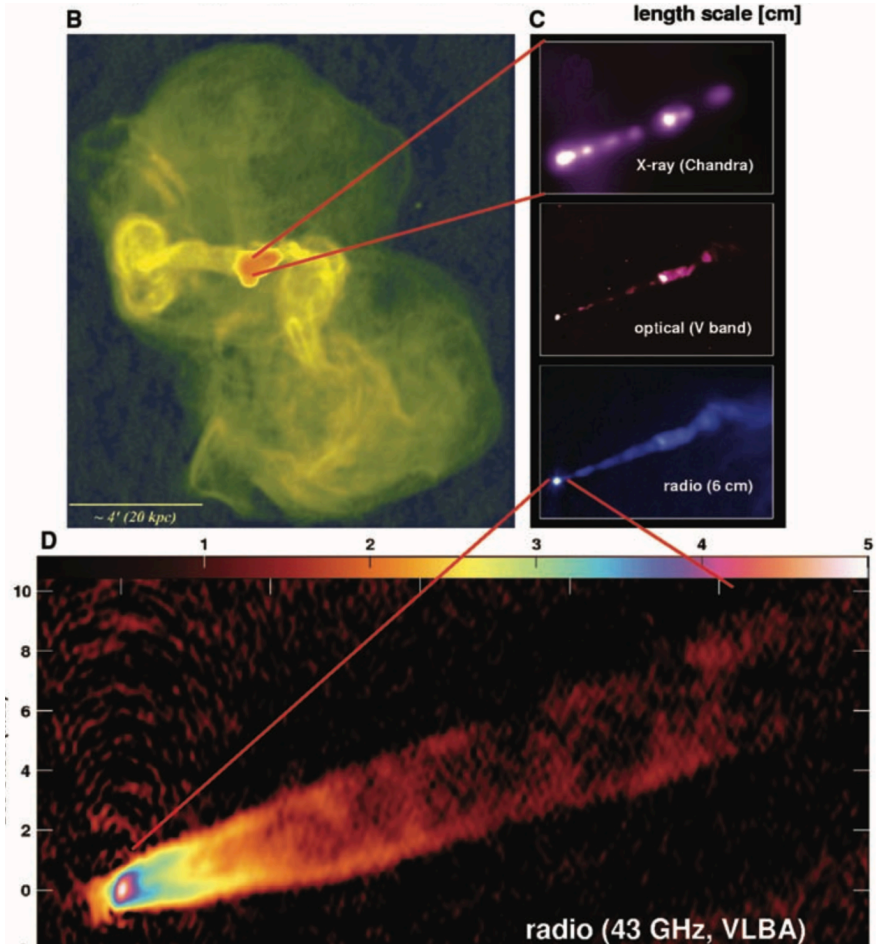


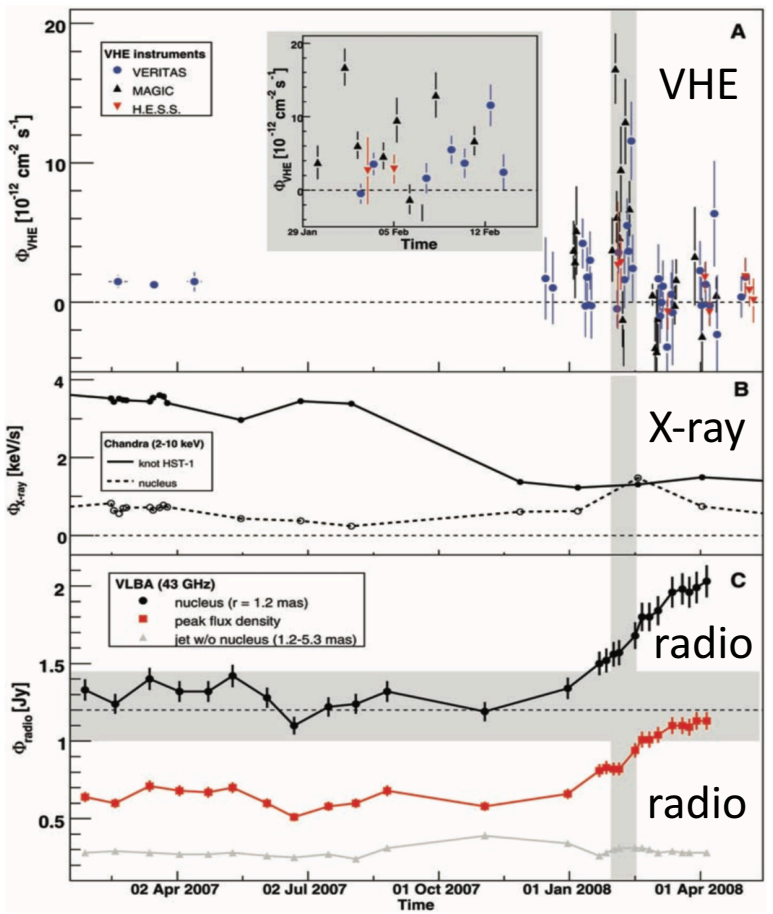
A moving "knot" K16

arXiv:1802.10113v1

VHE flare from the M87 jet



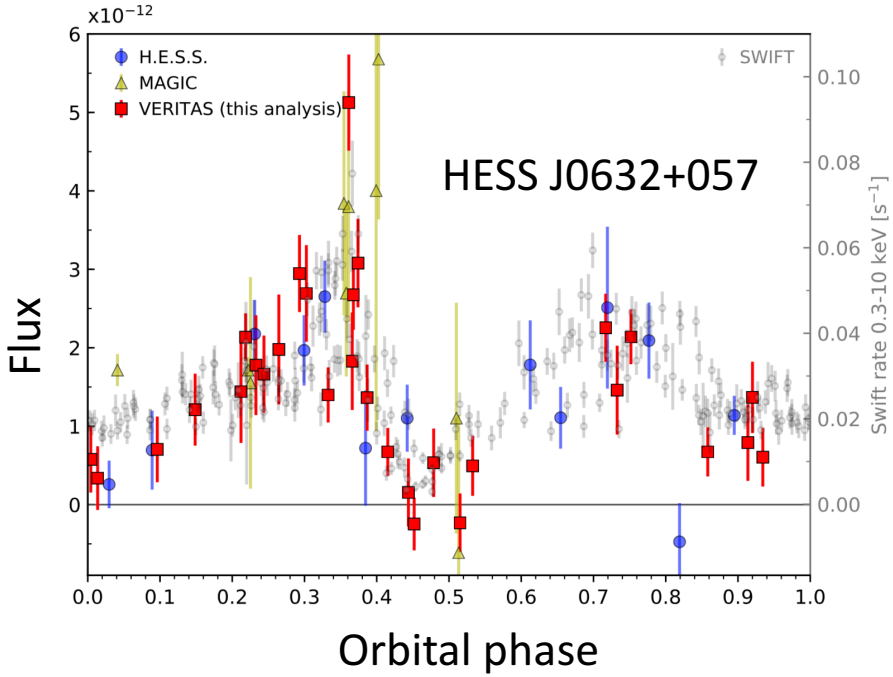




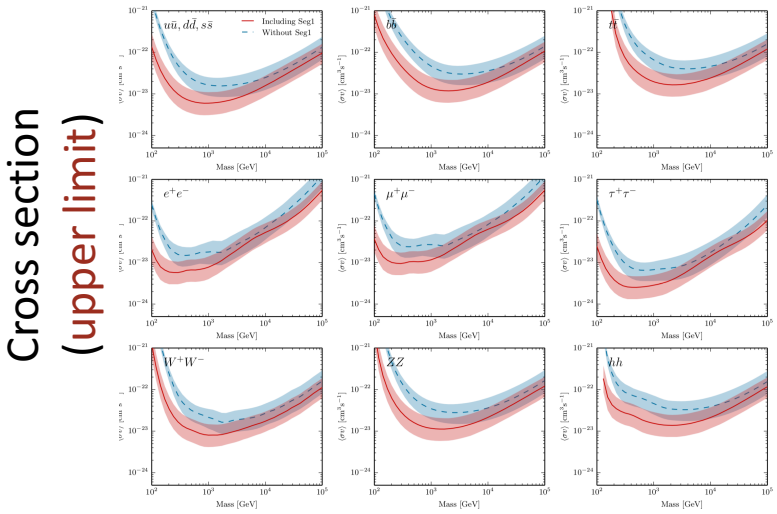
Science **325**, 444 (2009)

And more!

- An unexpected VHE binary (B-type star + BH or NS?)



- Upper limit on WIMP annihilation cross section from dwarf galaxies

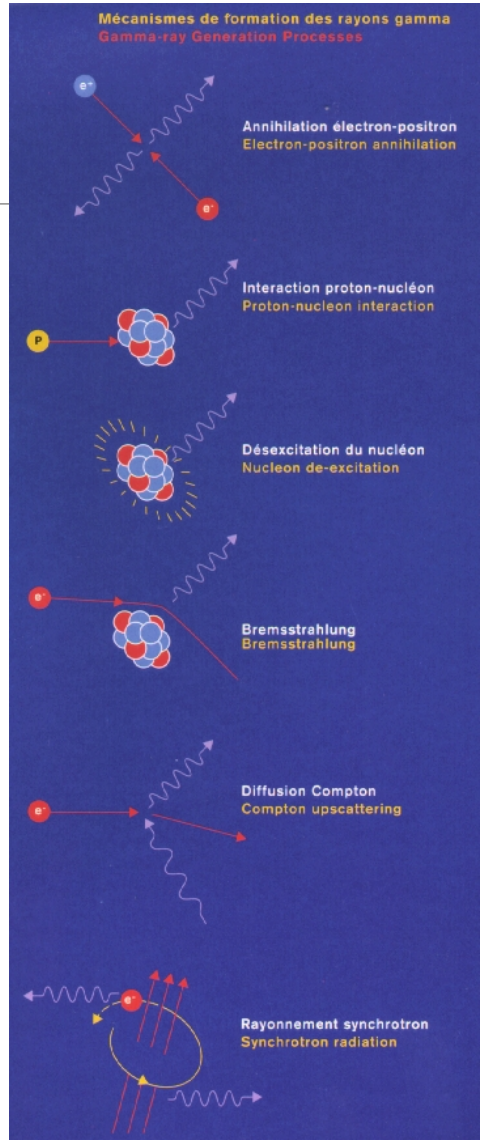


arXiv:1708.04045

PhysRevD, 95, 082001 (2017)

Into the future

- Basic questions of high energy astrophysics
  - Where are the "cosmic accelerators" that produce high energy cosmic ray particles? (SNR? AGN? Others?)
  - What are the acceleration mechanisms at work in these accelerators? (Shock wave? Reconnection? Blandford-Znajek?)
  - What are the particle species that are accelerated? (protons? electrons? positrons?)
  - How are these high energy γ-ray produced?



Learn more:

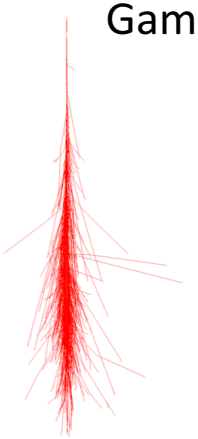
- VERITAS: https://veritas.sao.arizona.edu/
- HESS: https://www.mpi-hd.mpg.de/hfm/HESS/pages/about/telescopes/
- MAGIC: https://magic.mpp.mpg.de/
- TeVCat: http://tevcat.uchicago.edu/
- Science with CTA: https://arxiv.org/pdf/1709.07997.pdf
- ***References on individual slides.***

The End

Thank You!

γ-ray vs. Cosmic ray

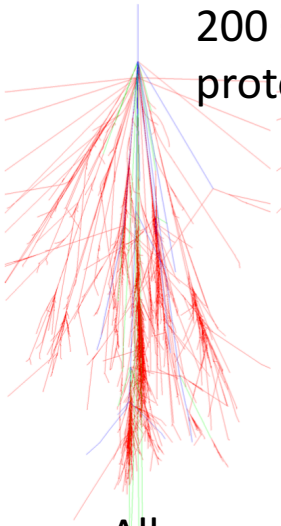
50 Gev Gamma



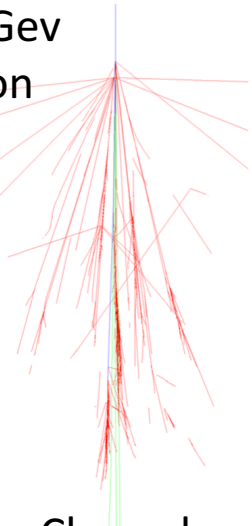
All

Cherenkov

200 Gev proton

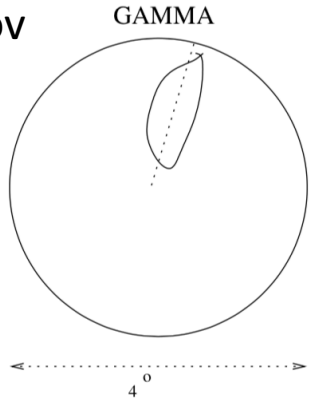


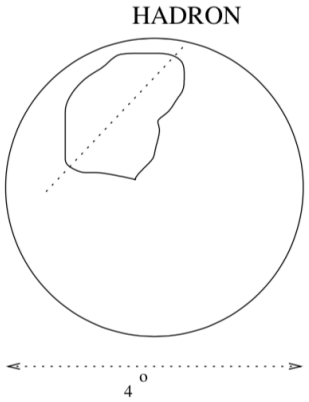
All



Cherenkov

Lorenz & Wagner 2012, arXiv:1207.6003v1





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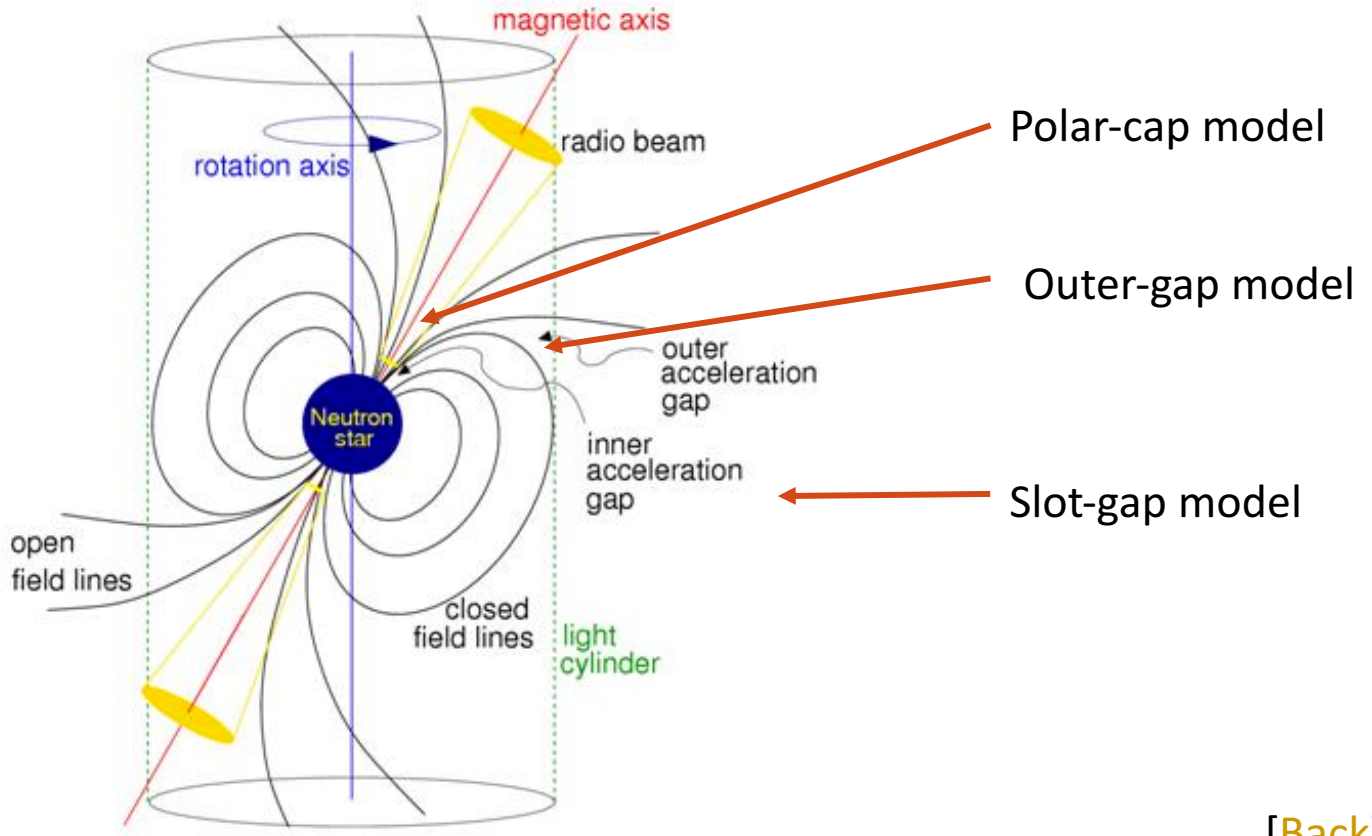
NS radiation mechanism & proposed sites for HE radiation



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