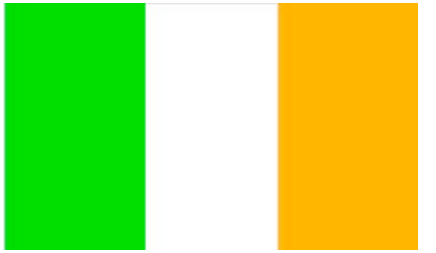
Georgia Tech Physics College of Sciences

VERITAS
a Status Report

Nepomuk Otte on behalf of the VERITAS Collaboration

The VERITAS Collaboration



~100 members, 20 institutions

23 non-affiliated members

+35 associate members

Smithsonian Astrophysical Observatory

Adler Planetarium

Argonne National Lab

Barnard College / Columbia University

Bartol Research Institute / University of Delaware

Georgia Institute of Technology

Iowa State University

Purdue University

University of California, Los Angeles

University of California, Santa Cruz

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University of Iowa

University of Minnesota

University of Utah

Washington University in St. Louis

McGill University, Montreal

University College Dublin

Cork Institute of Technology

Galway-Mayo Institute of Technology

National University of Ireland, Galway

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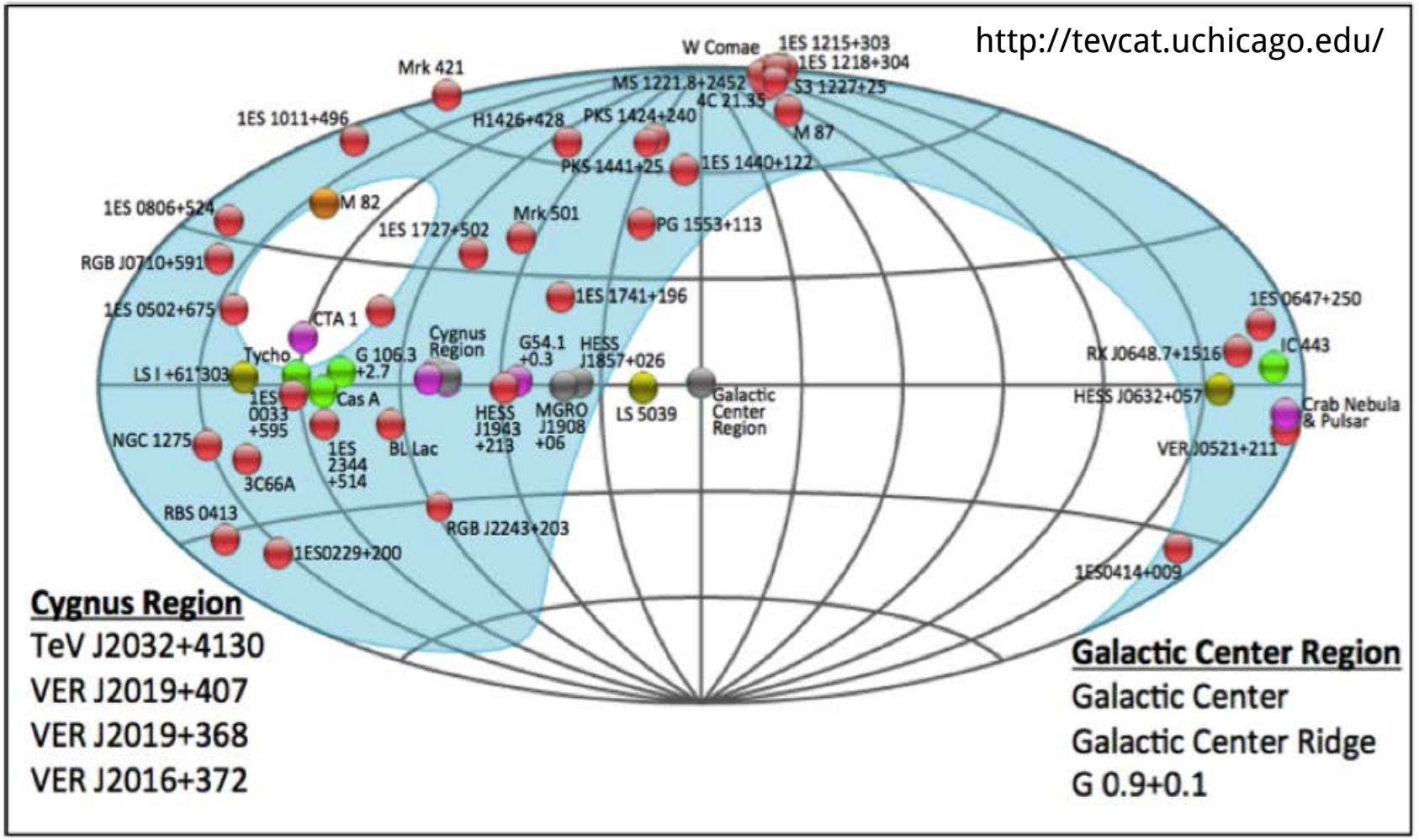
VERITAS Catalog

55 detections, representing at least 8 source classes



35 Extragalactic (64%): 32 blazars, 2 radio galaxies & a starburst galaxy (M82)!
20 Galactic (36%): Crab pulsar, 3 gamma-ray binaries, 7 pulsar wind nebulae, 3 SNRs & 6 unidentified objects

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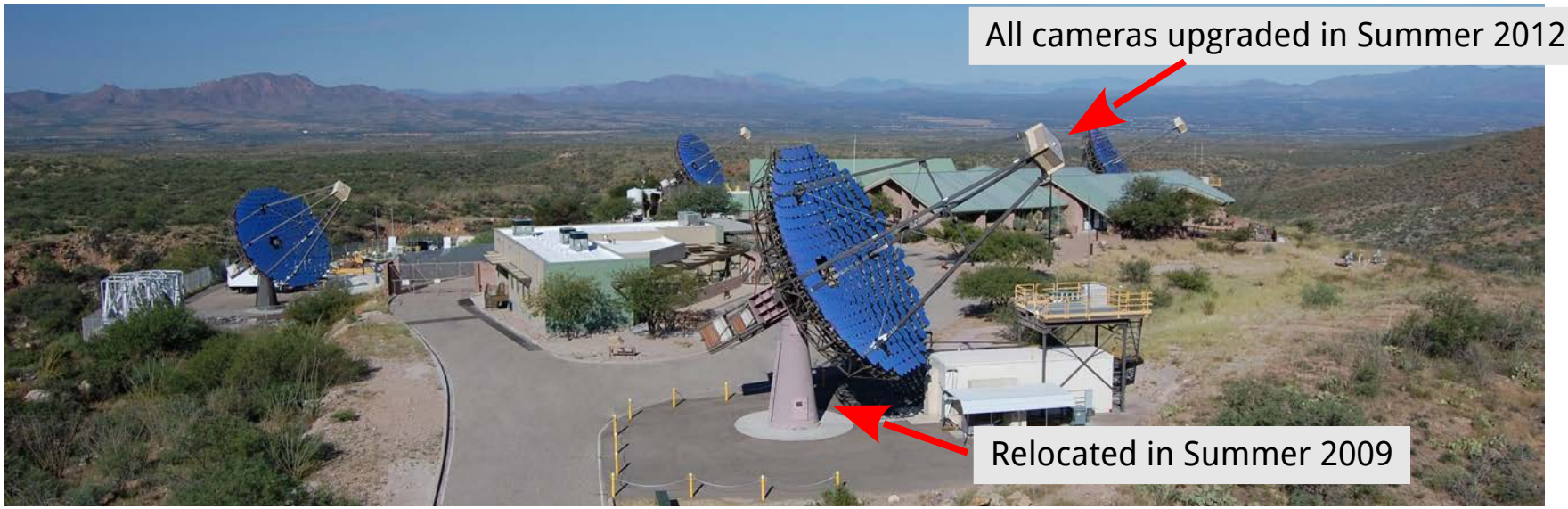
VERITAS in a Nutshell



- VERITAS is an array of four 12 m Cherenkov telescopes in southern Arizona
- 499 high efficiency PMTs per camera
- Energy range from ~85 GeV to >10 TeV
- Sensitivity of 1% Crab in < 24 hours
- ~1400 hours of observations per year (including observation under bright moon light)
- Negligible downtime due to technical problems
- Stable instrument performance over timescales of years

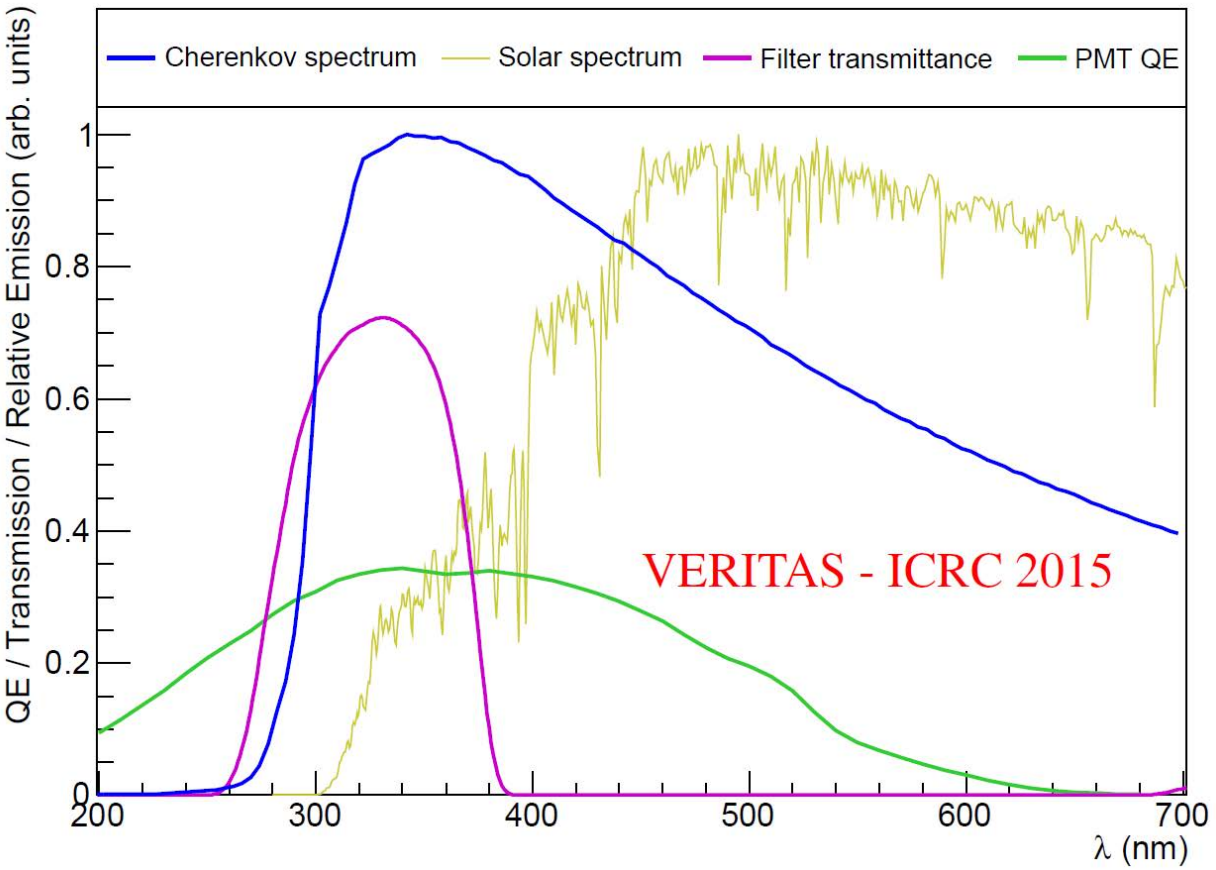
Observations during bright Moon

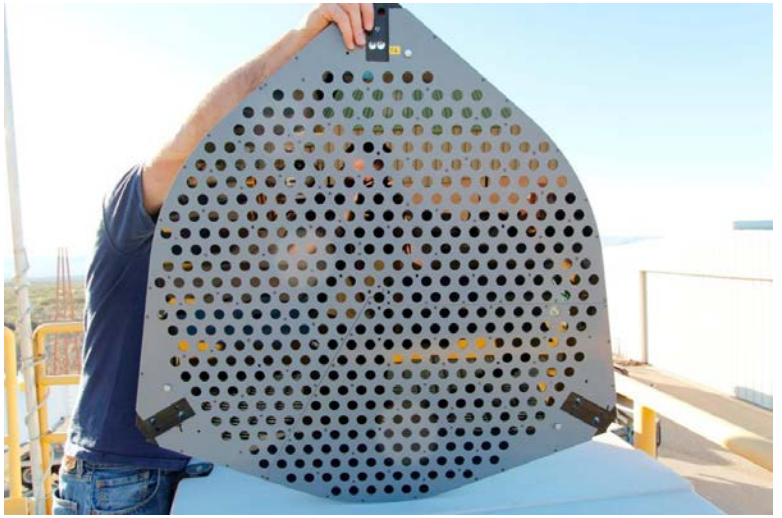
- Increased duty cycle by 40%
- No loss in sensitivity above 1 TeV

Good for:
Catching flaring sources, EBL, hard spectra sources, electron/positron spectra in moon shadow

Full moon observations of the Crab (Sept. 2010)

UV Filters

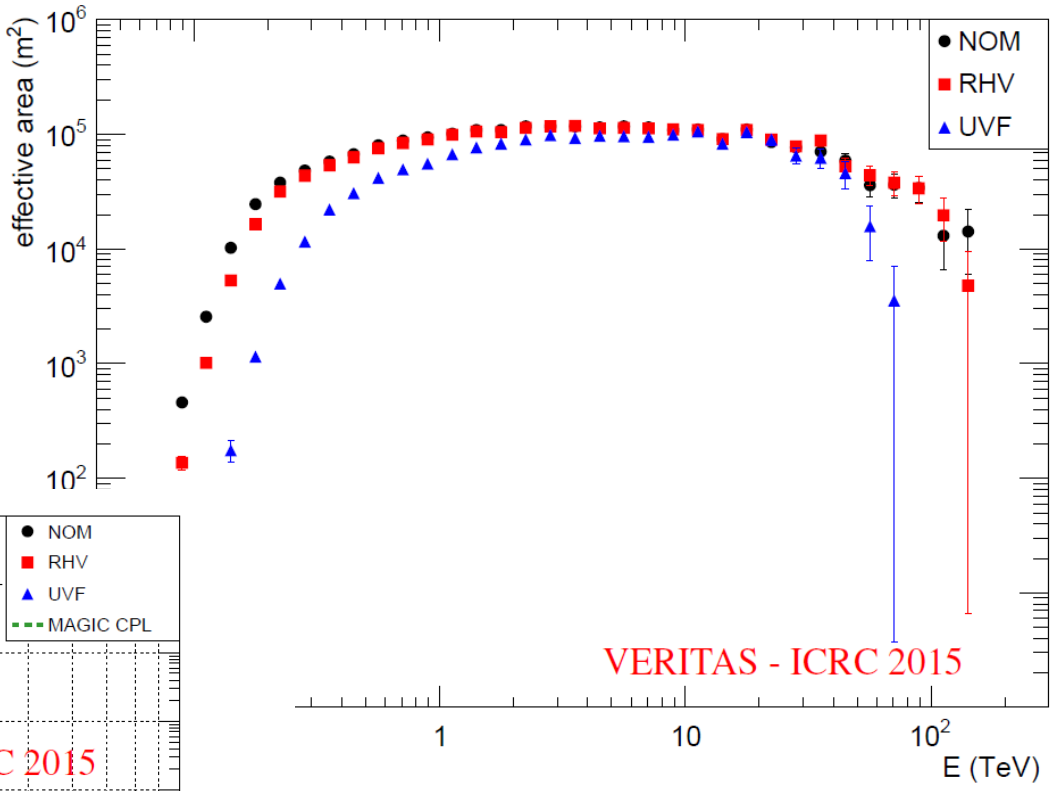


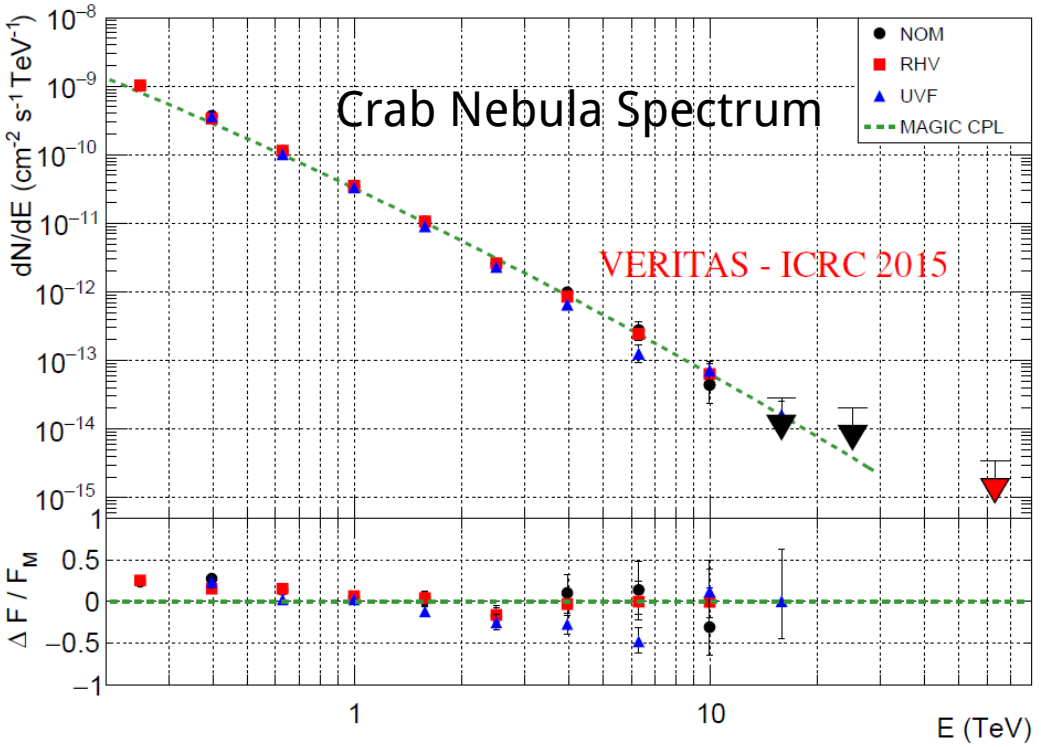


3mm SCHOTT UG-11 filters
Peak transmittance of 72%

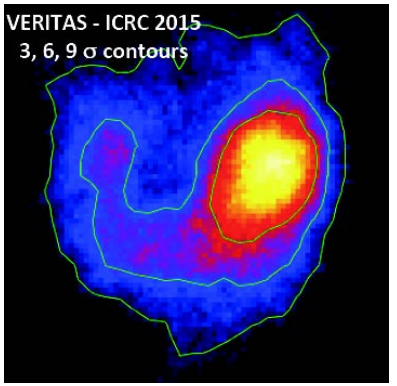
RHV and UV-Filter Performance

- >300 GeV reduced HV and normal operations have same sensitivity
- UV-filters yield 46% nominal sensitivity





Some Recent Highlights



Galactic:

- Resolved morphology of IC 443 SNR
- Improved Cas A and Tycho spectra
- Dramatic flaring (bright + quick) exhibited by LS I +61° 303
- Rich field detected >2 TeV in the Galactic Center Region

Extragalactic:

- Detection of VHE emission from PKS 1441+25 (z=0.939!)
- Two new VERITAS blazar discoveries

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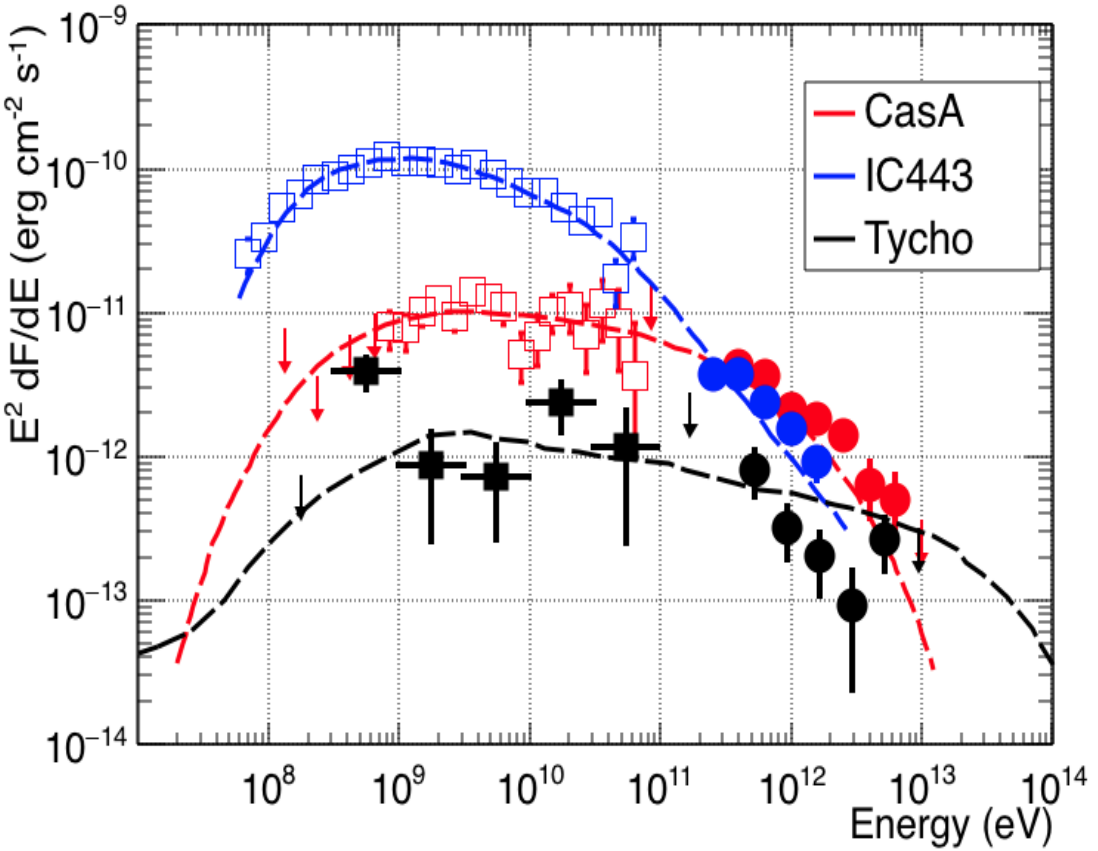
New VERITAS SNR Results:
Deep exposures of three northern SNRs

Objectives:

- Investigate the mechanisms of cosmic-ray acceleration
- Probe the distribution of energetic particles in the acceleration region
- Study the importance of SNR type, age, target material, magnetic fields, progenitor



CasA model (Yuan et al., 2013), Fermi (Yuan et al., 2013), VERITAS (this ICRC)
IC443 model (Ackermann et al., 2013), Fermi (Ackermann et al., 2013), VERITAS (this ICRC)
Tycho model (Slane et al., 2014), Fermi (this ICRC), VERITAS (this ICRC)

> 150 hours of exposure for IC443 and Tycho

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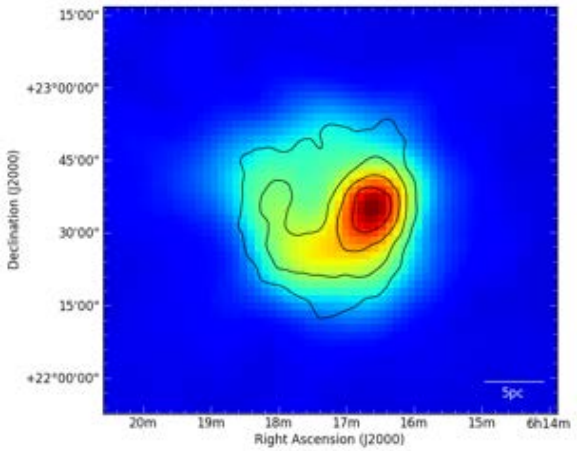
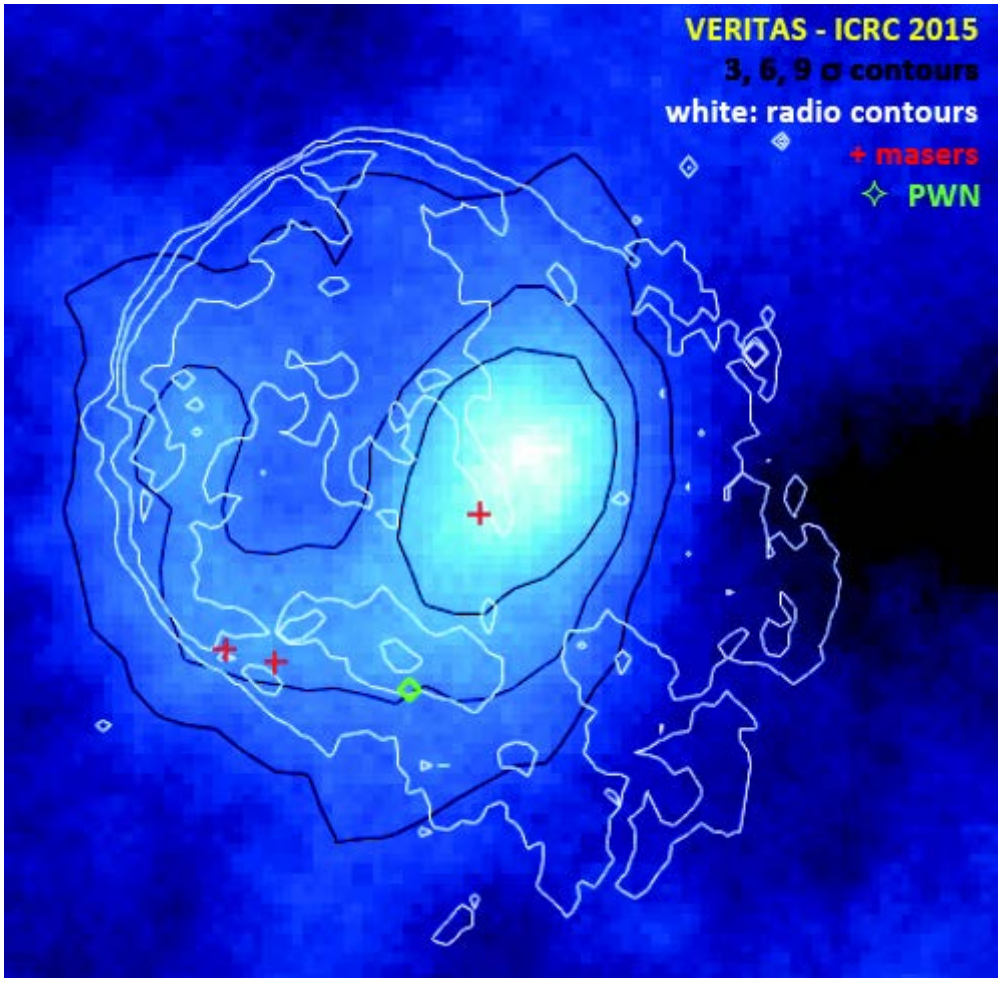
IC 443

- GeV/TeV emission show remarkable spatial correlation
- Anticorrelation with thermal X-rays
- VHE spectral indices do not vary across remnant

Single population of CR interacting with swept up / shocked gas?



courtesy: J. Hewitt for Fermi-LAT Collaboration



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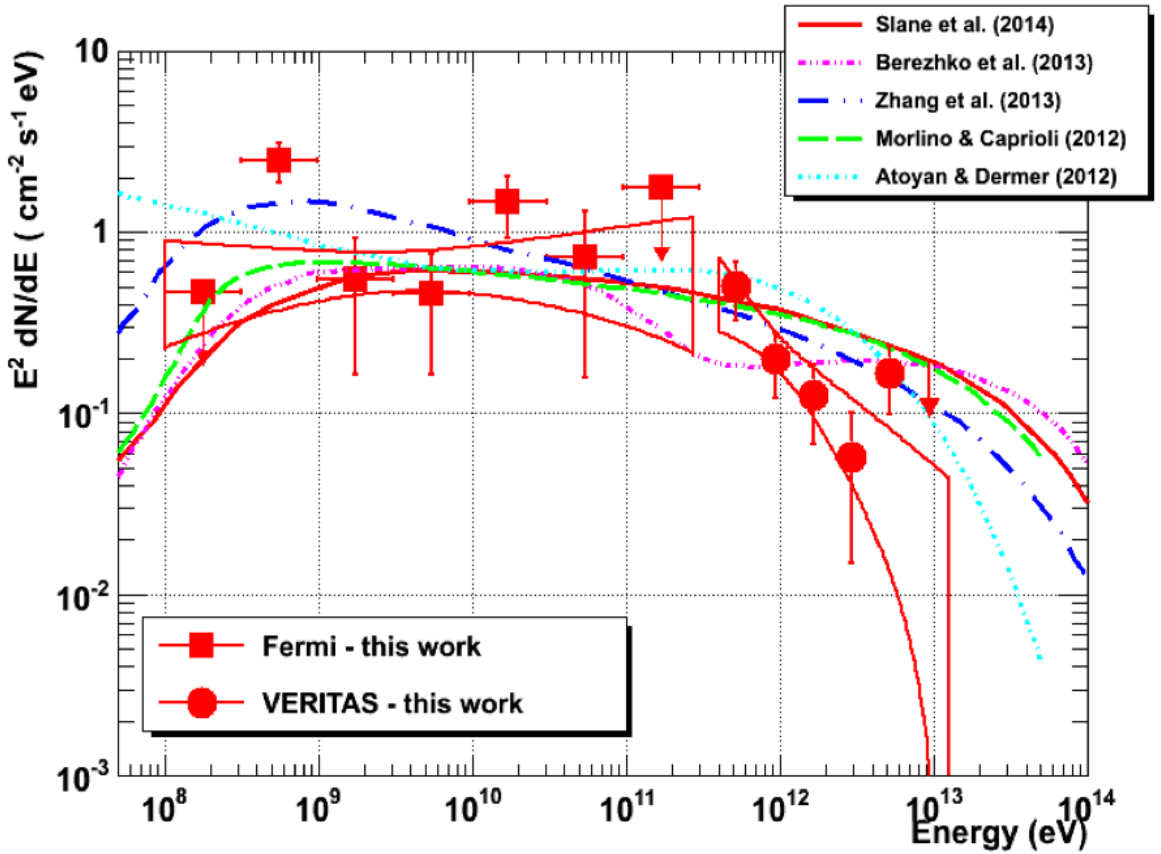
Tycho: Historical 1A SNR



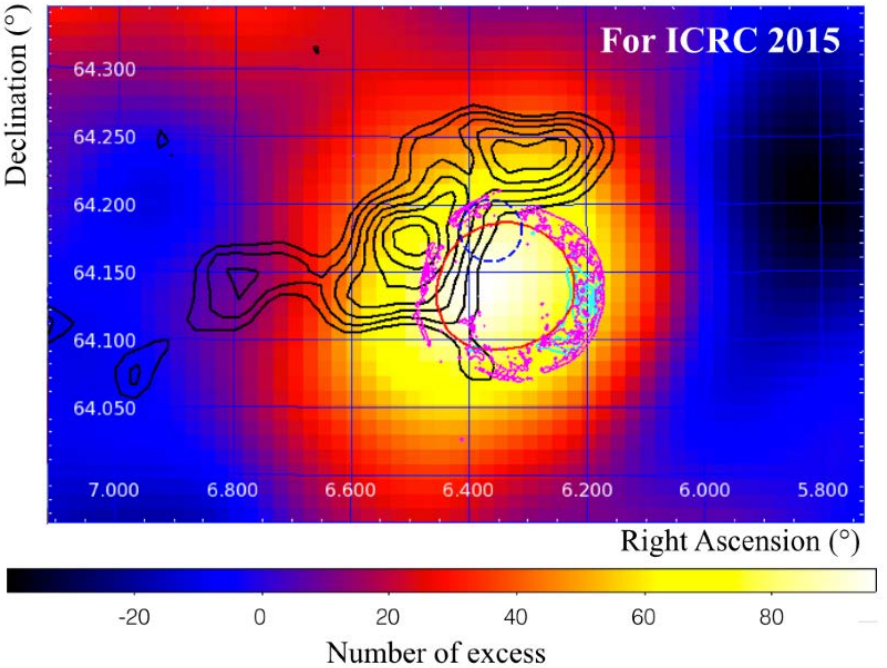
- Updated spectrum extended to lower energies (new PMTs), resulting in a slightly softer best fit index – $2.92 \pm 0.42_{STAT}$ (new) versus $-1.95 \pm 0.51_{STAT} \pm 0.30_{SYST}$ (published)

- Constrains and challenges particle acceleration models

- Good candidate for hadronic emission scenarios
  - exploded in a clean environment
  - young and well-observed at other wavelengths

- Discovered by VERITAS in 2010, we now have ~150 hours

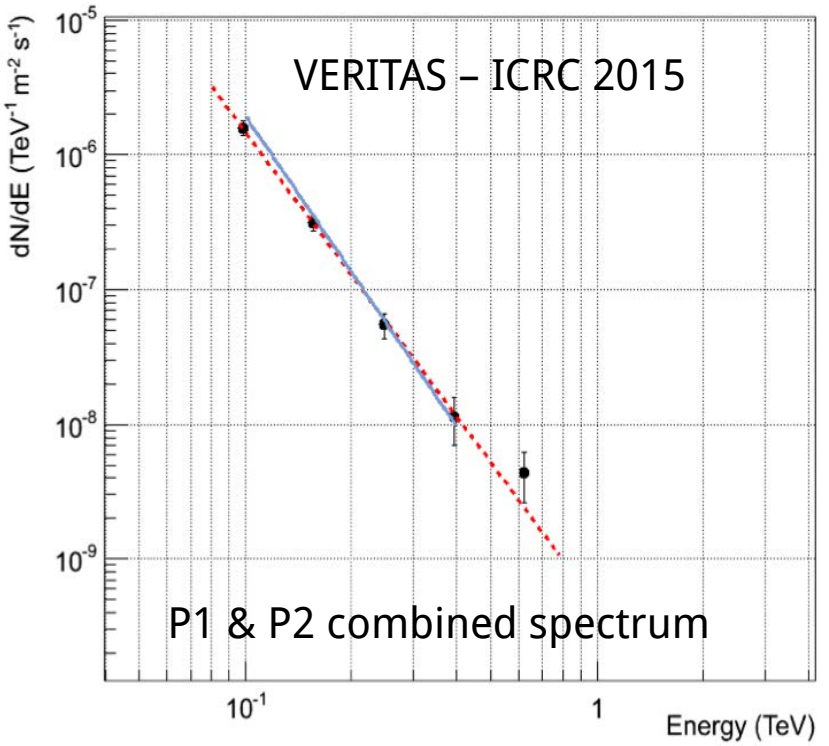
- Models mainly from hadronic particles with some multi-zone leptonic

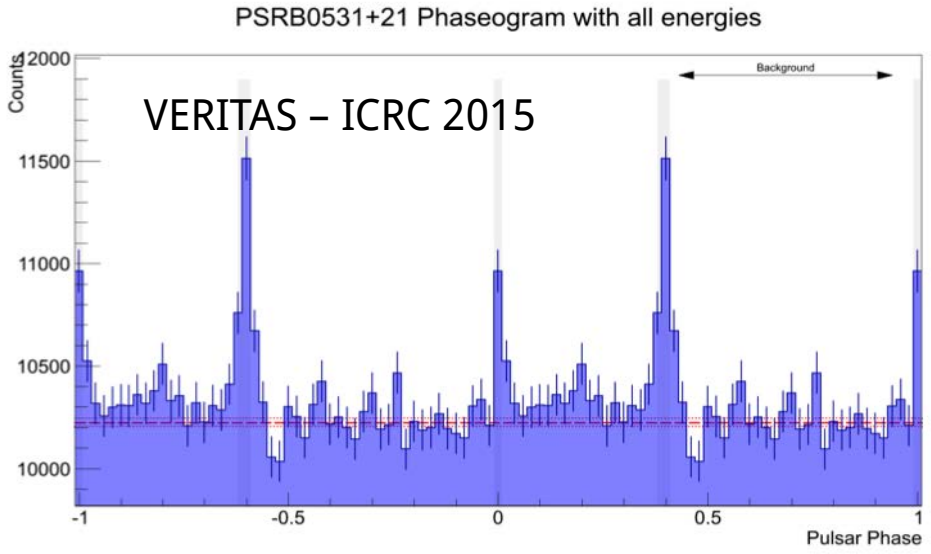


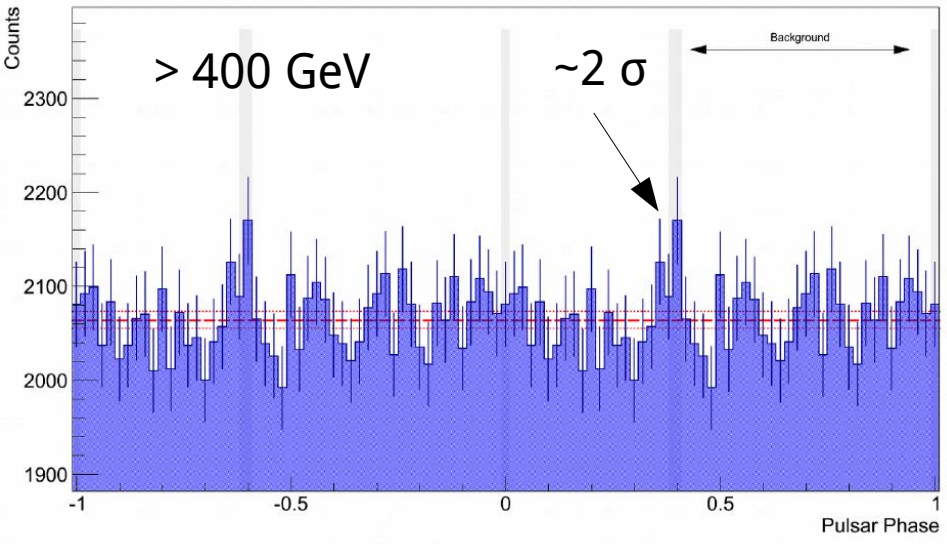
Crab Pulsar

What is the origin of pulsed VHE emission?

- Additional Crab pulsar observations extend VERITAS spectrum to 600 GeV.
- No signal above 600 GeV even after 200 hours of data.
- Analysis and data taking ongoing







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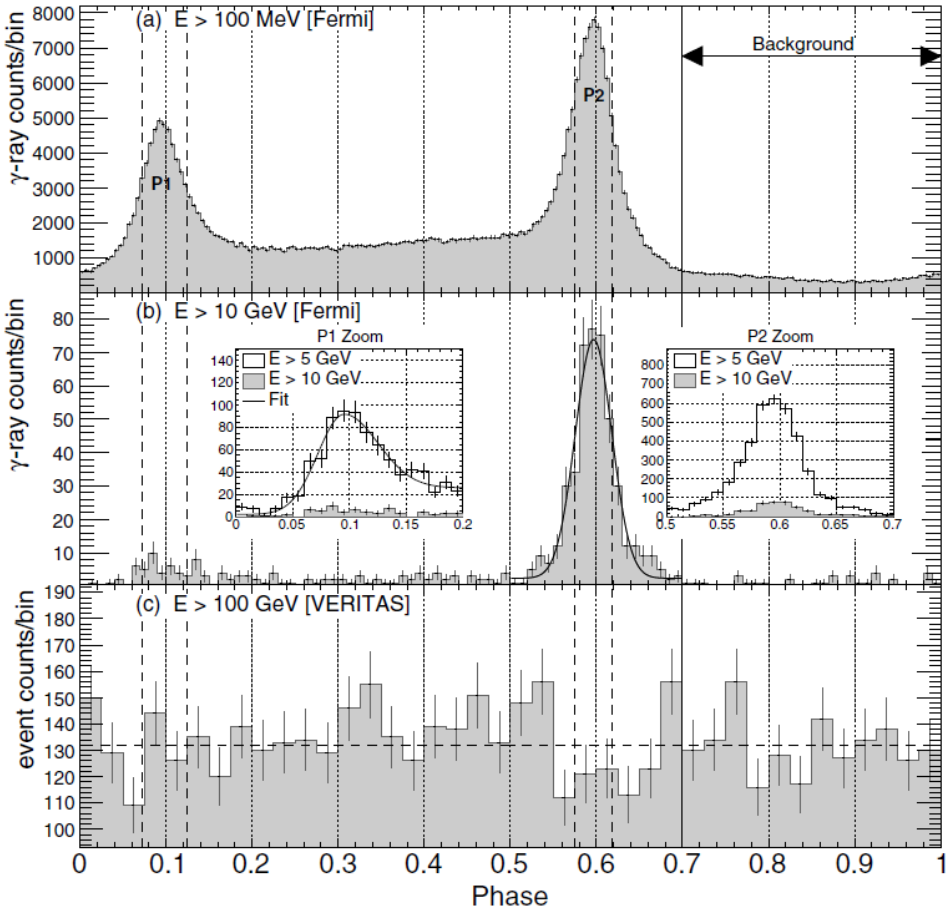
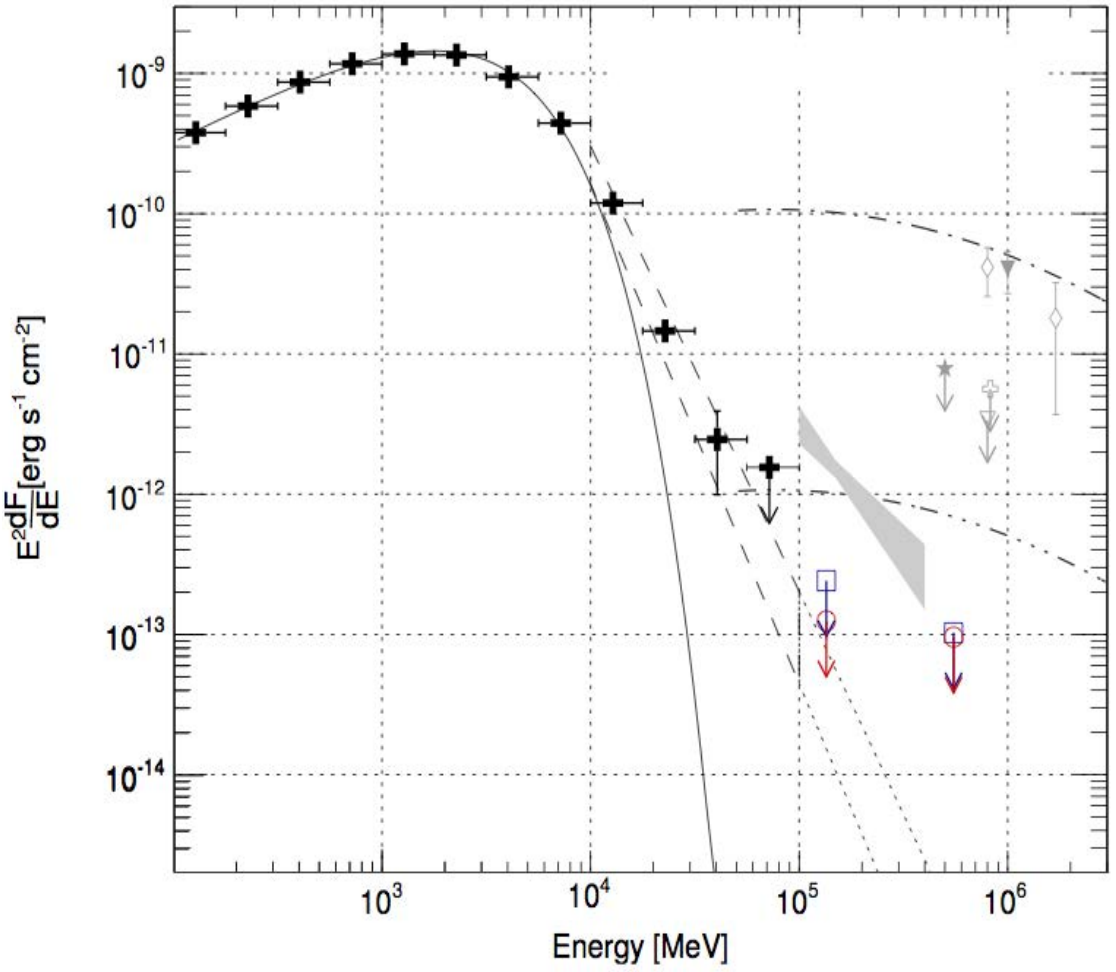
Geminga Pulsar

70 hours of VERITAS observations yield no signal





VERITAS ApJ (2015)

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Ongoing Pulsar Studies

Reanalysis of archival VERITAS data

- Serendipitous observations of 19 pulsars in VERITAS data (see ICRC contribution for list of candidates)
- On/OFF selection based on *Fermi*-LAT recorded pulse profiles
- Analysis and follow-up observations are ongoing

Search for pulsed VHE emission from millisecond pulsars

- Comprehensive study in the VHE band does not yet exist
- *Fermi*-LAT detected MSPs + seed photon fields for IC
- 140 hours allocated for seven targets

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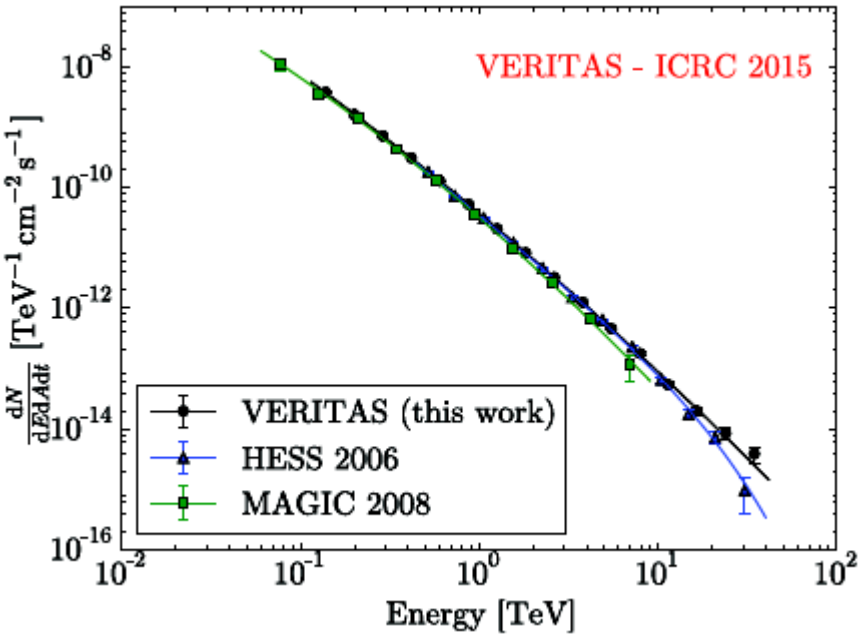
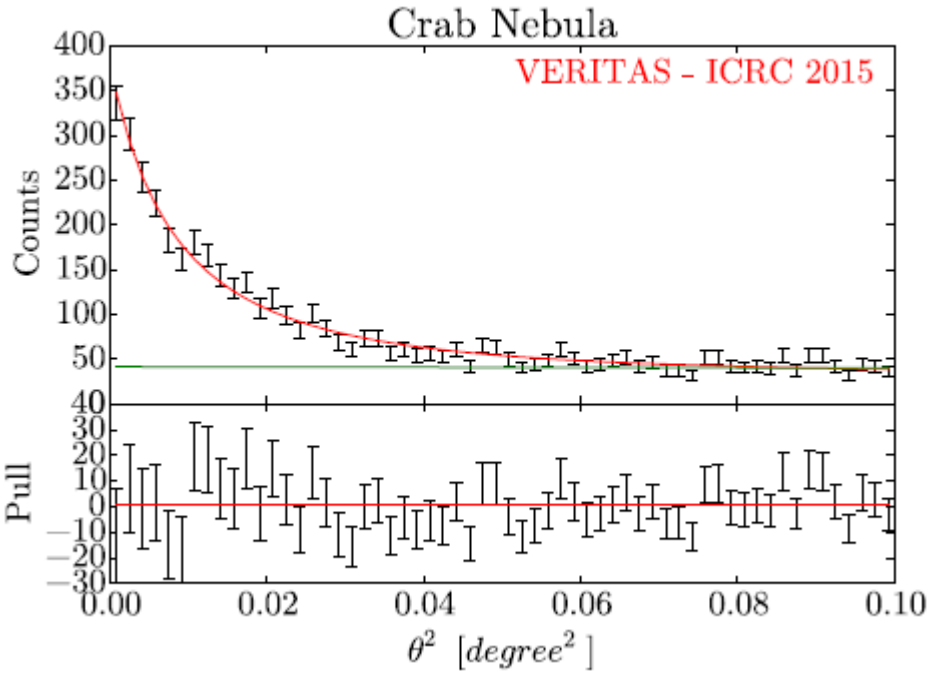
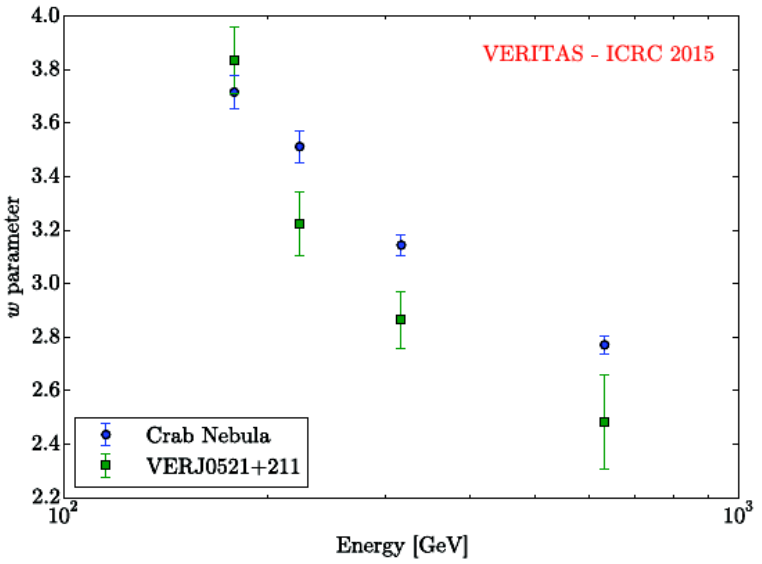
Crab Nebula

- Energy spectrum in agreement with previous published measurements
- No correlated variability with GeV or X-rays
- No evidence for source extension







Blazar Observations

- Scientific objectives:
  - Understand supermassive black holes - the origin of the jet emission, the dynamics and evolution of the black hole environment
  - Cosmology: EBL/IGMF studies
  - Fundamental Physics: Lorenz Invariance

- Newest detections
  - May 2015: S3 1227+25 (see Atel #7516)
  - April 2015: PKS 1441+25 (see Atel #7433)
  - Dec 2014: RGB J2243+203 (see Atel #6849)

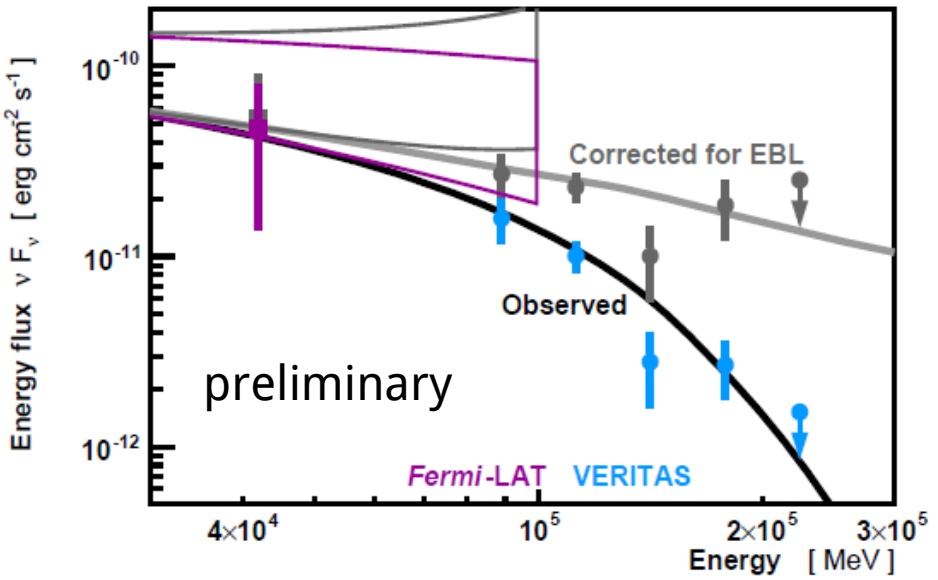
Source	Type	Redshift
Mrk 421	HBL	0.030
Mrk 501	HBL	0.034
1ES 2344+514	HBL	0.044
1ES 1959+650	HBL	0.047
1ES 1727+502	HBL	0.055
BL Lac	IBL	0.069
1ES 1741+196	HBL	0.084
W Comae	IBL	0.102
VER J0521+211	HBL	0.108
RGB J0710+591	HBL	0.125
H 1426+428	HBL	0.129
S3 1227+25	IBL	0.135
1ES 0229+200	HBL	0.139
1ES 0806+524	HBL	0.138
1ES 1440+122	HBL	0.163
RX J0648.7+1516	HBL	0.179
1ES 1218+304	HBL	0.182
RBS 0413	HBL	0.190
1ES 1011+496	HBL	0.212
MS 1221.8+2452	HBL	0.218
1ES 0414+009	HBL	0.287
3C 66A	IBL	$0.33 < z < 0.41$
1ES 0502+675	HBL	0.341 ?
RGB J2243+203	IBL	0.39 ?
PKS 1222+216	FSRQ	0.432
PG 1553+113	HBL	$0.43 < z < 0.58$
PKS 1424+240	IBL	$z \geq 0.604$
PKS 1441+25	FSRQ	0.939
RGB J0521.8+2112	HBL	?
B2 1215+30	IBL	?

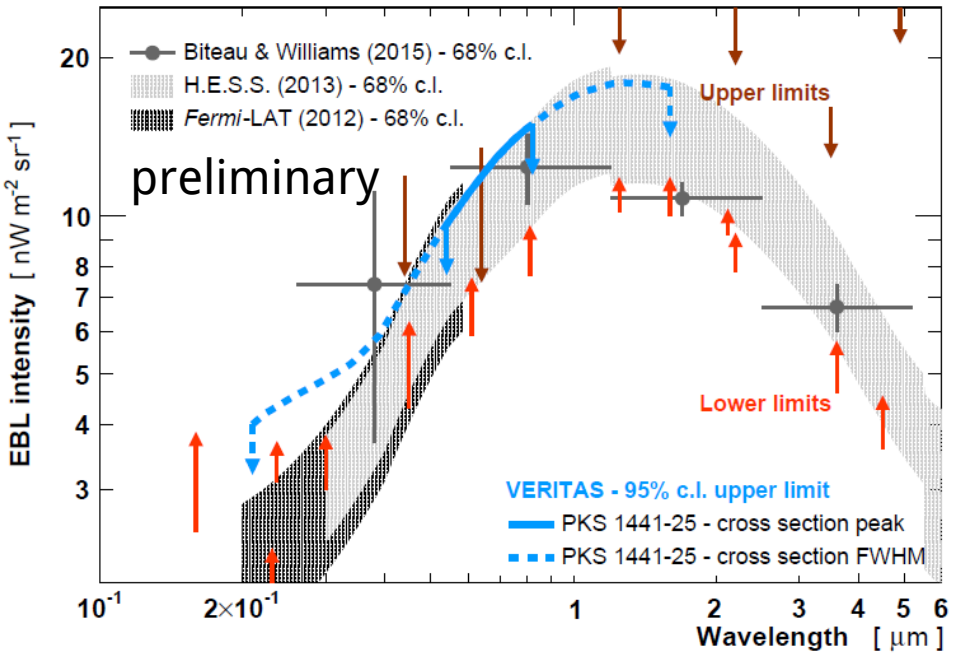
Plus 3 more

PKS 1441+25 (z=0.939)

- Most distant FSRQ detected in VHE
- Triggered by MAGIC / Fermi alerts
- 15 hours of observations with VERITAS
- ~400 gamma rays, 8σ
- 5% Crab above 80 GeV
- Very soft spectral index 5.3±0.5

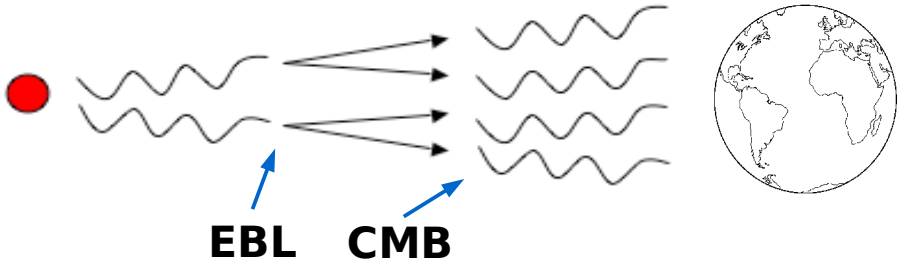
First time that one single source constrains a large fraction of the EBL spectrum

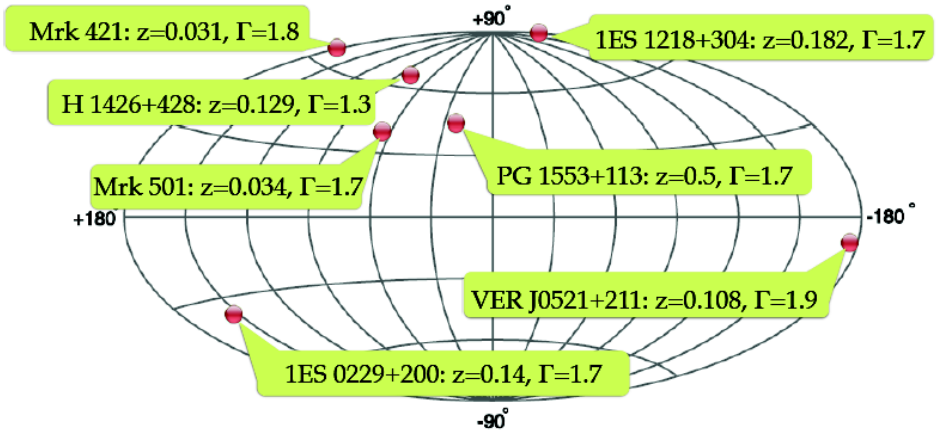


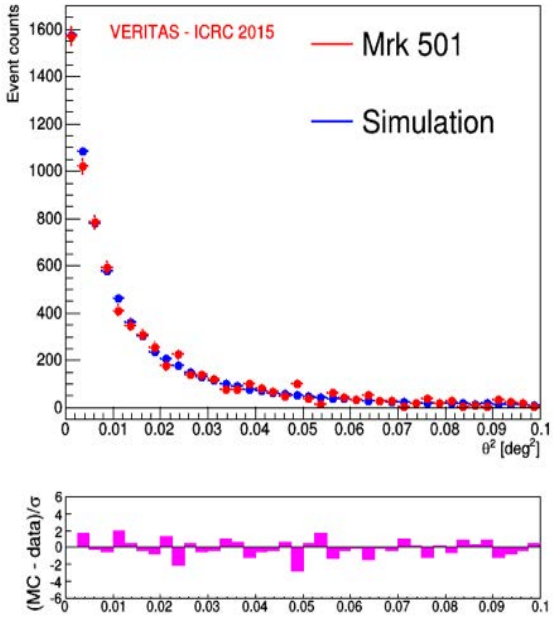


Intergalactic Magnetic Field Constraints

Unambiguous detection of IGMF remains elusive - important to understand large scale structure formation and to understand the propagation of cosmic rays in cosmic voids







- Limits on IGMF magnitude set for model-dependent extended emission by comparing to simulated blazars and using 3D semi-analytical code

  (H. Huan & T. Weisgarber, 2012)

- VERITAS excludes IGMF strengths of (5-10)x10^{-15} G at 95% CL

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Indirect Dark Matter Searches

Search for particle DM annihilation or decay from 100 GeV to the multi-TeV scale

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

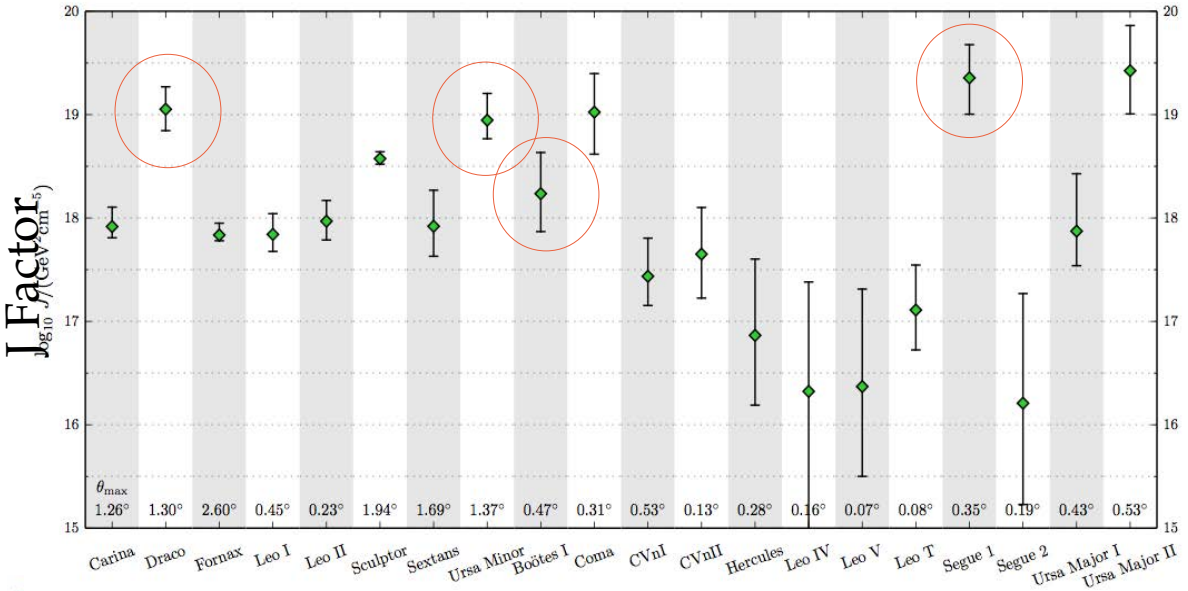
Particle physics model – WIMP, decay channels, etc

Astrophysical factor – DM density, morphology

- Search for signals in DM-dominated regions: ***Dwarf Spheroidal Galaxies (dSphs)***, the Galactic Center, Galaxy Clusters, and ***Fermi Unassociated Sources***

New result on observations of two sub-halo candidates identified from the 2FGL catalog

- Targets identified by lack of variability & MWL counterparts, detectability at VERITAS – 2FGL J0545.6+6018, 2FGL J1115.0-0701

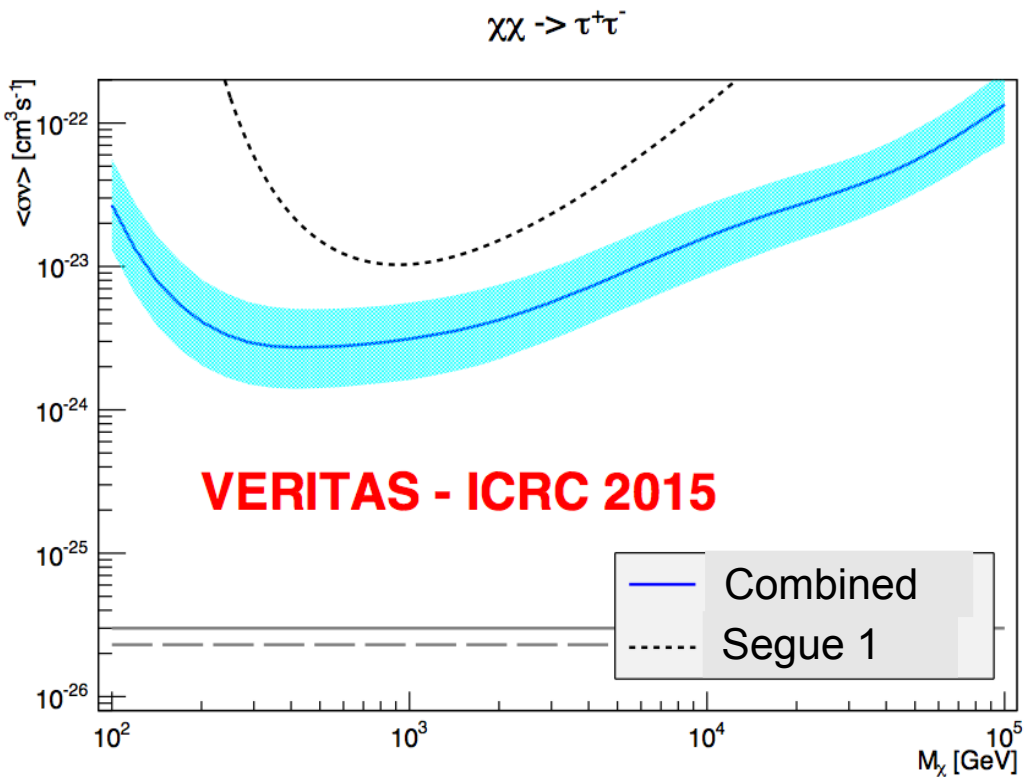


from Geringer-Sameth, et al. PRD 91, 083535 (2015)

150 hours annually
on ~all northern dSphs
and
deep exposures on several high J-factor objects

New combined result with data from 5 dSph galaxies

VERITAS dSph Combined Dark Matter Limits



- Previous single-source results published by VERITAS, the most constraining from 48-hours on Segue 1

  Phys. Rev. D. 85, 062001 (2012)
  (Erratum) Phys. Rev. D. 91, 129903 (2015)

- Dark Matter Search/Limits using 216 hours of Dwarf Spheroidal data

- Methodology (Geringer-Sameth et al., 2015) utilizes individual event energy, dwarf field and direction information

- Limits presented as a band to represent systematic uncertainty in J-Factors

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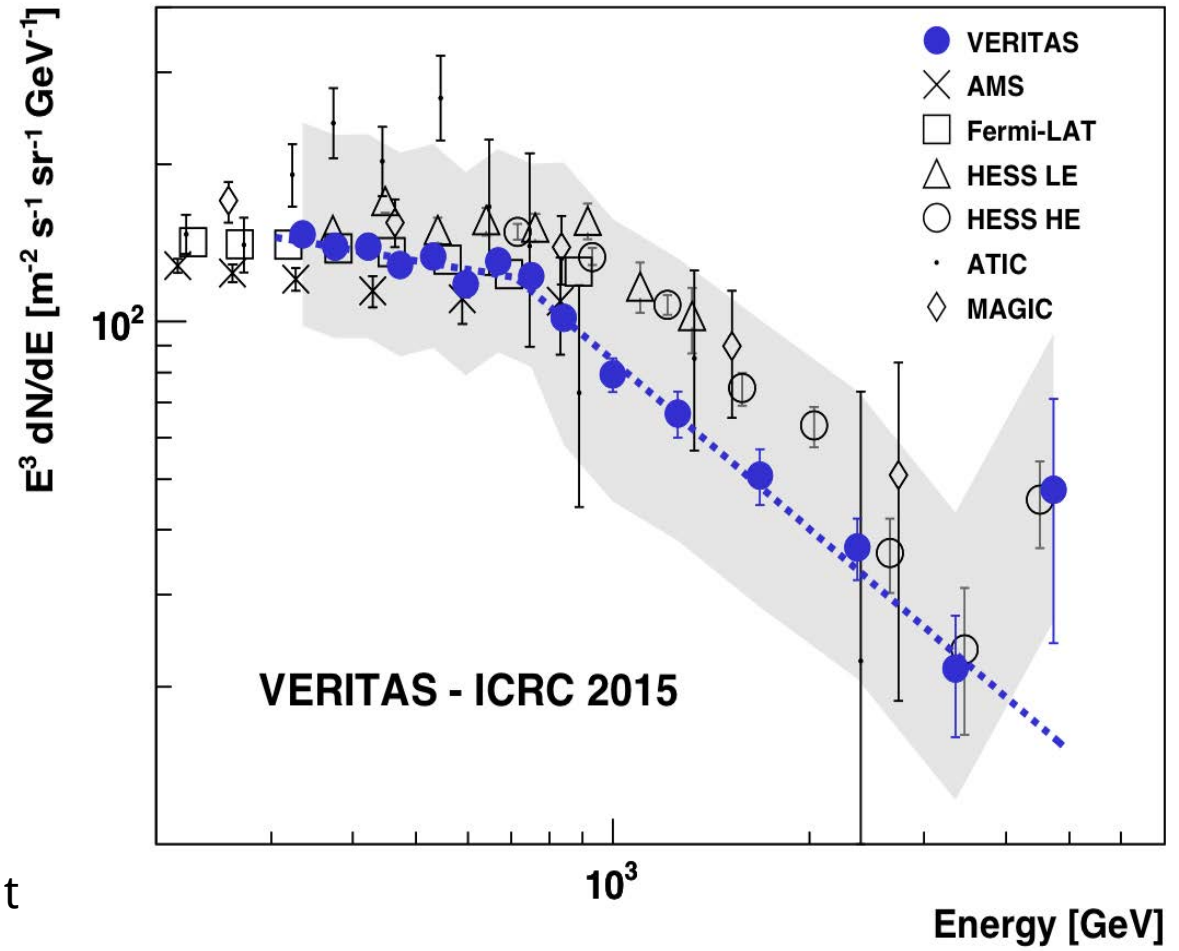
Cosmic-Ray Electrons

Cosmic-ray electrons at TeV energies are a direct probe of nearby (~1kpc) energetics

- 296 hours of data between 2009 and 2012
- Electron-like events selected by Boosted Decision Trees and extended likelihood fitting
- Spectrum agrees qualitatively with other experiments within systematical uncertainty
  - Break at 710 ± 40 GeV
  - Index below (above) break of $-3.2 \pm 0.1_{STAT}$ ($-4.1 \pm 0.1_{STAT}$)
- Confirms evidence of at least one nearby CRE emitter
- Second high-statistics measurement of a break below ~1 TeV



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Summary

- VERITAS is doing extremely well.
- The instruments runs very smooth.
- Moving into an era where data sets with > 100 hours exposure become the norm.
- Systematics become a challenge → analyses need time

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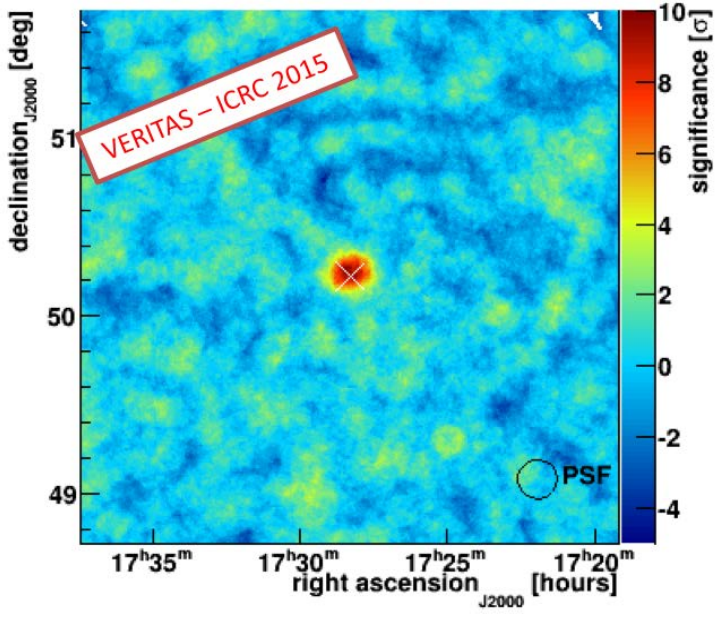
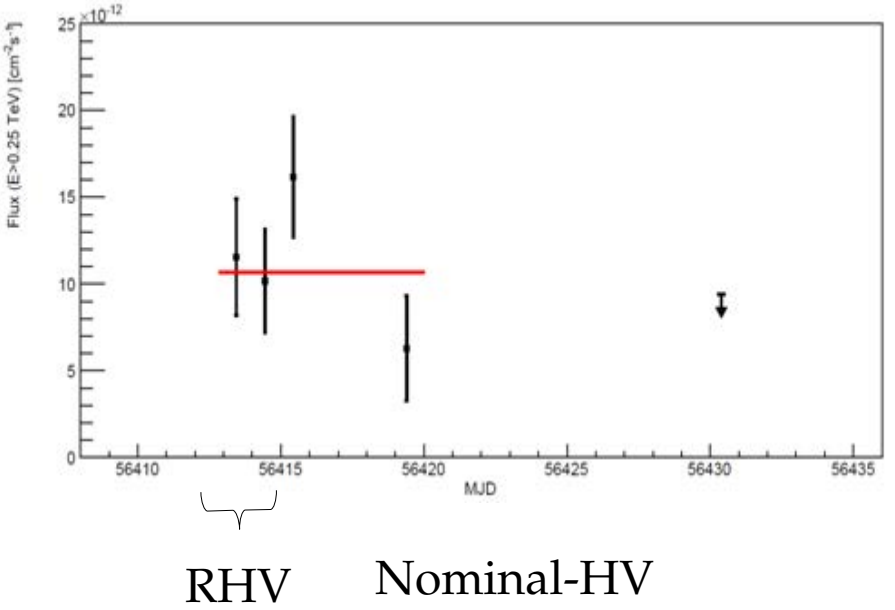
End

Observing with VERITAS

Improving the duty cycle of VERITAS pays off... detection of a flare in 1ES 0727+502





Detected at ~5x archival VHE flux from MAGIC, this detection represents the first evidence of variability in the VHE-band

HESS J0632+057:

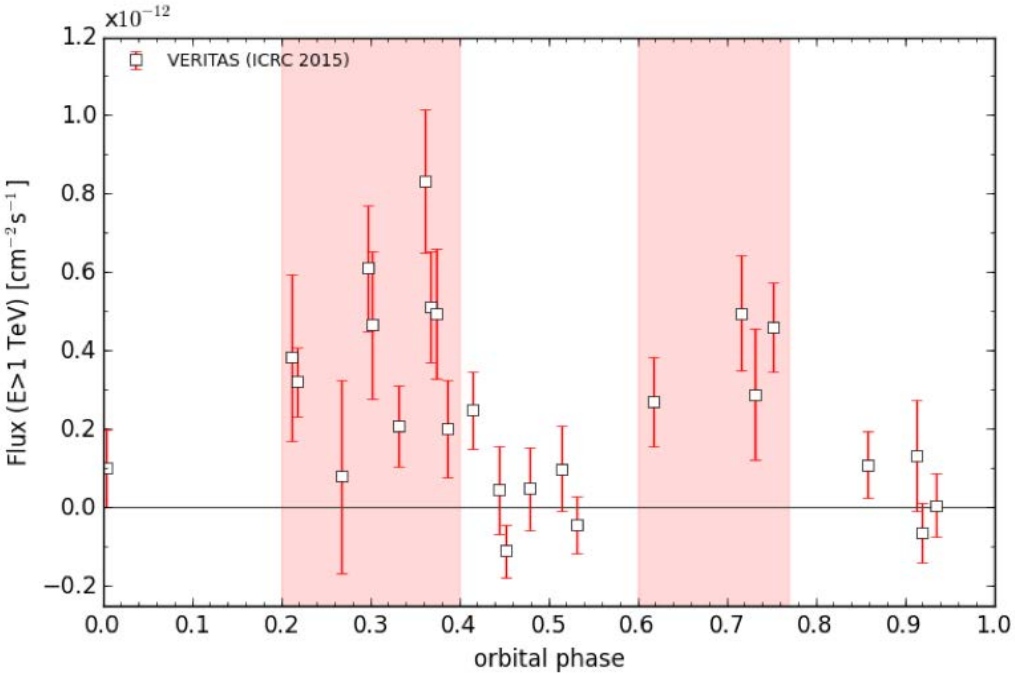
- Binary system consisting of a Be star and a compact object at 1.6 kpc

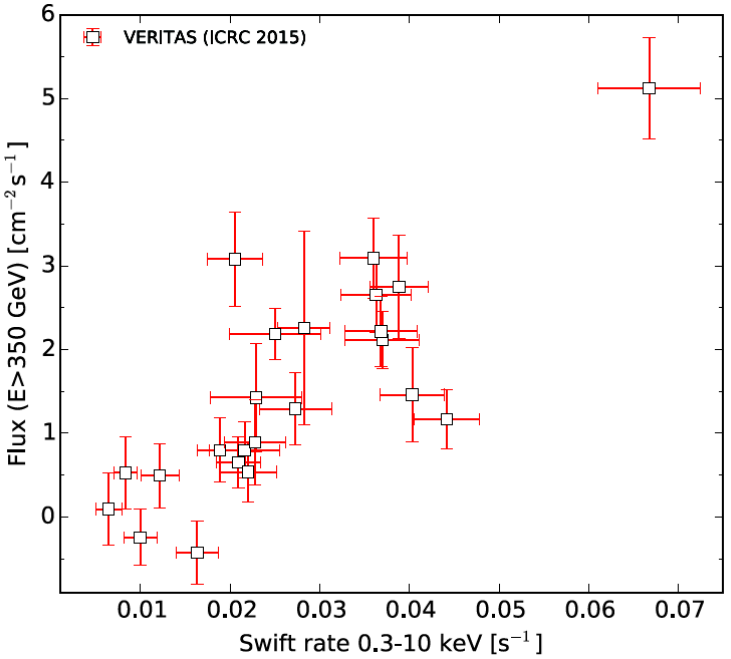
- Period ~315 days (Swift)

- Discovered in gamma-rays
  - Serendipitously discovered by HESS (~3% Crab Nebula flux)
  - Variability detected by VERITAS
  - Observations by HESS, MAGIC, VERITAS (2004-2015)

- Binary nature shown with Swift XRT observations

- VERITAS data covers most of the orbital period and is detected at the phase of ~0.35, and for the first time, the phase of ~0.7
  → matches the overall shape in X-ray





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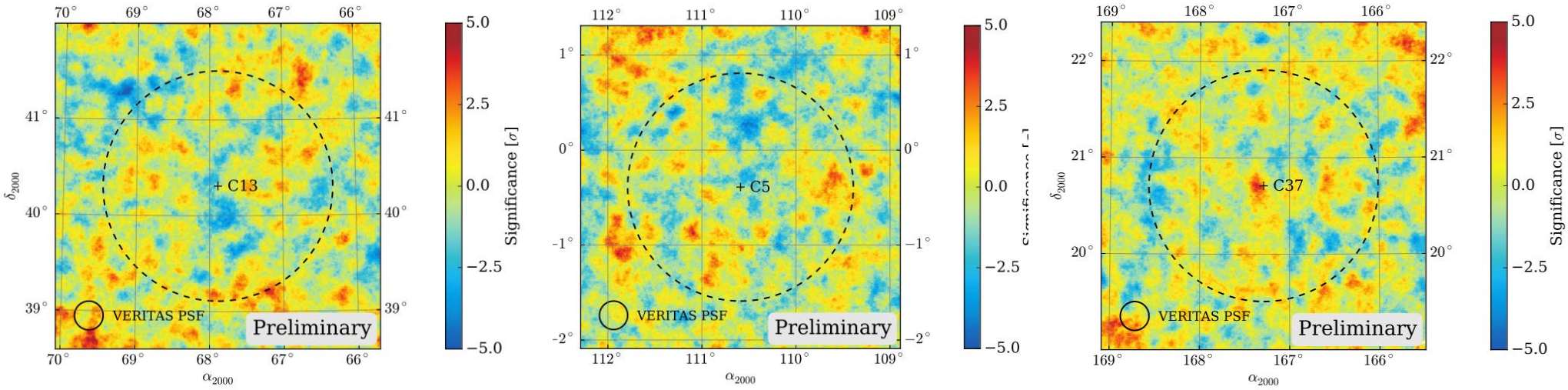
Follow-up of IceCube Events:

IceCube discovery of astrophysical flux of high energy neutrinos provides evidence of sites of cosmic ray generation... however, no significant neutrino point sources seen yet (isotropic)



- Observations of 22 IceCube ν_μ-induced muon-track events for a total of 40 hours
  - muon-track events have good localization, ~1 degree angular uncertainty
  - 3 positions publicly released, 19 shared by a mutual agreement
- No significant signals seen, flux upper limits for each of the positions found in the range of ~2-10% Crab Nebula flux

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