Highlights from Blazar Observations by VERITAS



Jon Dumm
for the VERITAS Collaboration

ICRC – Rio de Janeiro
July 4, 2013

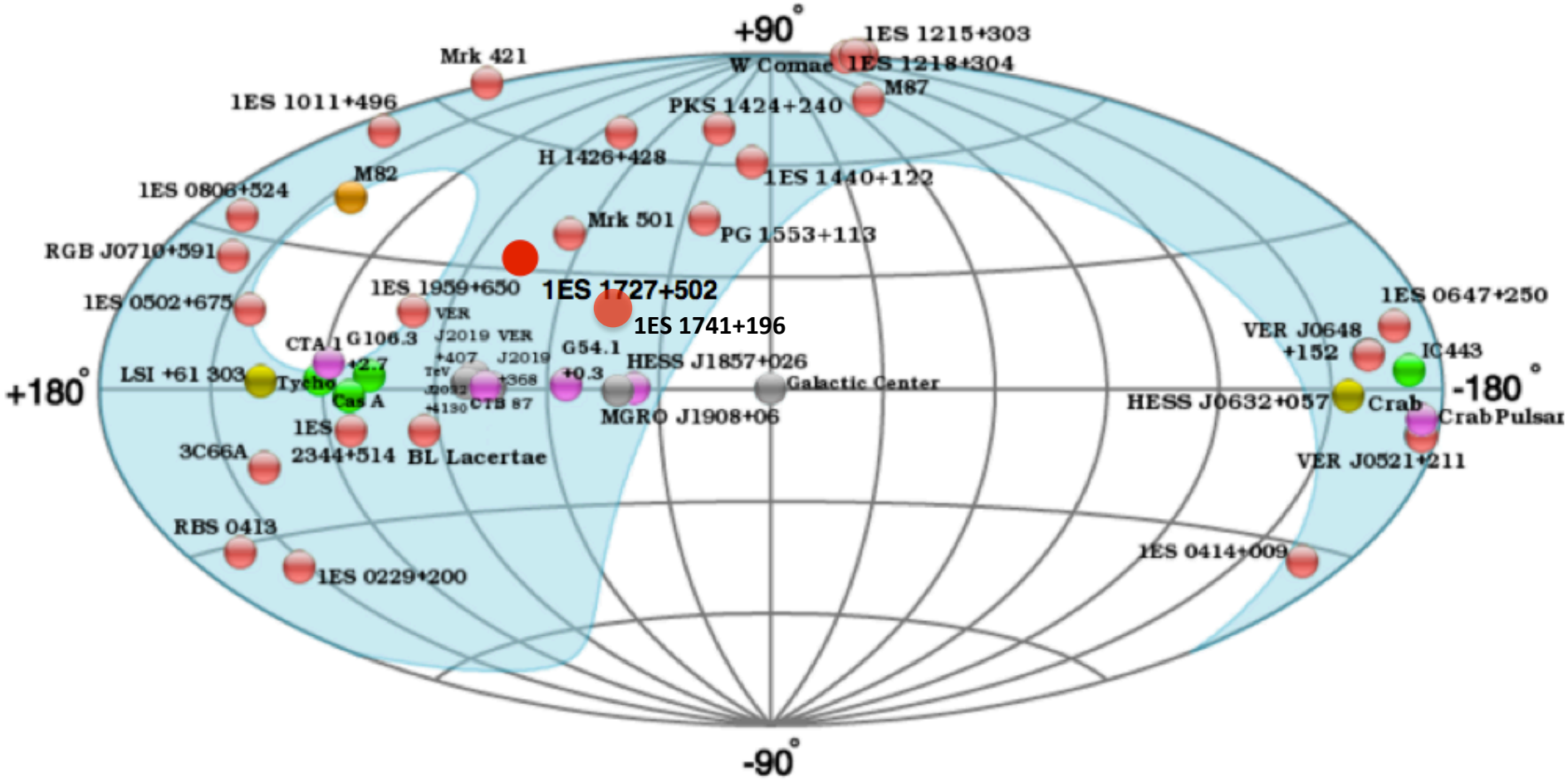
VERITAS



- **85 GeV – 30 TeV**
- **15 – 25% energy resolution**
- **0.1° angular resolution**

- **1% Crab detection in < 30 hrs**
- **Recent Upgrades: Trigger (2011) and Camera (2012)**

The VERITAS Sky



24 blazars dominate the extragalactic VHE sky

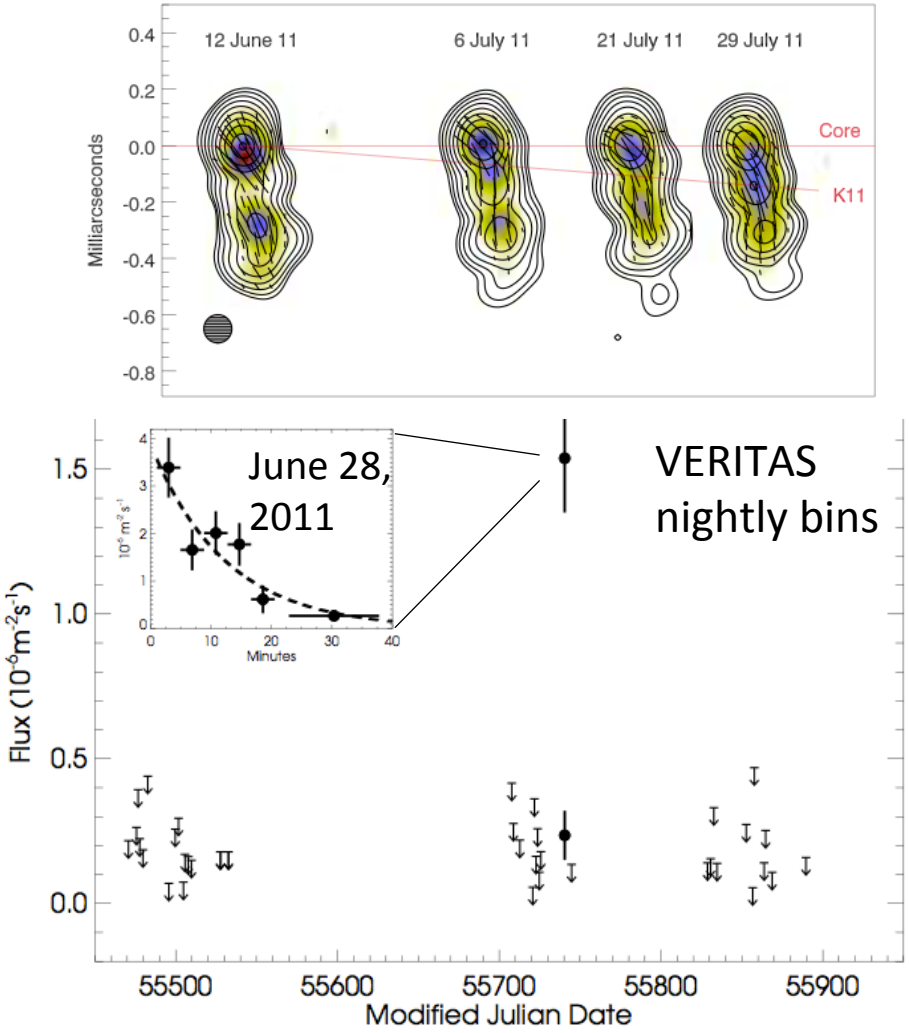
VERITAS Blazars

Key science goals:

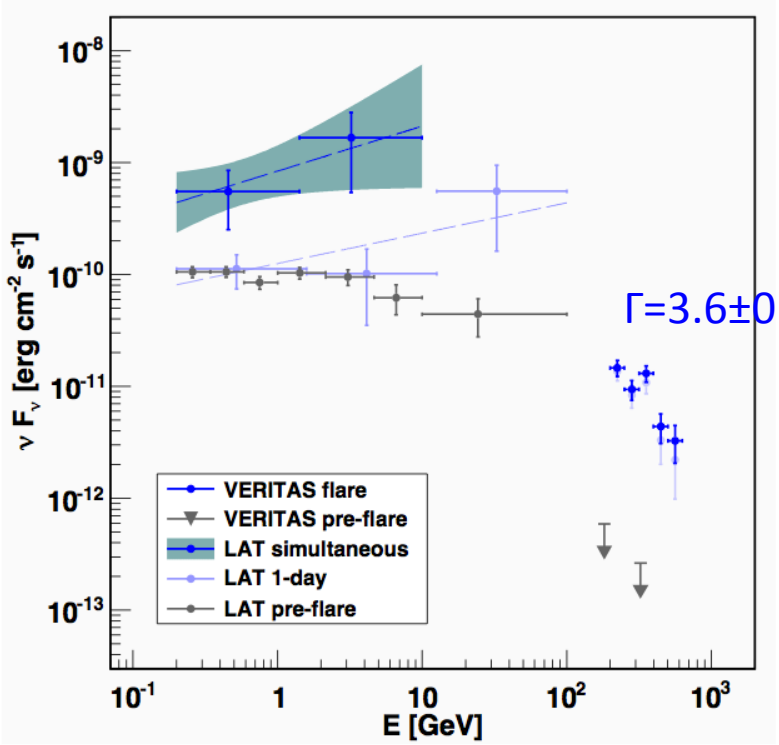
- Supermassive black holes
  - Jet physics
    - Origins of ultra high energy cosmic rays
  - Environment
  - Evolution
- Fundamental physics
  - Search for new particles/processes
    - Axion-like particles
    - Lorentz invariance violation (LIV)
- Cosmology
  - Extragalactic background light
  - Magnitude of intergalactic B field

Source	Type	z
Mkn 421	HBL	0.030
Mkn 501	HBL	0.034
1ES 2344+514	HBL	0.044
1ES 1959+650	HBL	0.047
1ES 1727+502	**HBL**	**0.055**
BL Lac	LBL	0.069
1ES 1741+196	HBL	0.083
W Comae	IBL	0.102
VER J0521+211	IBL/HBL	**0.108**
RGB J0710+591	HBL	0.125
H 1426+428	HBL	0.129
1ES 0806+524	HBL	0.138
1ES 0229+200	HBL	0.139
1ES 1440+122	IBL/HBL	0.162
RX J0648.7+1516	HBL	0.179
1ES 1218+304	HBL	0.182
RBS 0413	HBL	0.190
1ES 1011+496	**HBL**	**0.212**
1ES 0414+009	HBL	0.287
1ES 0502+675	HBL	0.341 ?
3C 66A	IBL	0.3347 < z < 0.41
PG 1553+113	HBL	0.43 < z < 0.62
1ES 0647+250	**HBL**	**~0.45**
PKS 1424+240	IBL	**>0.6035**
B2 1215+30	IBL	?

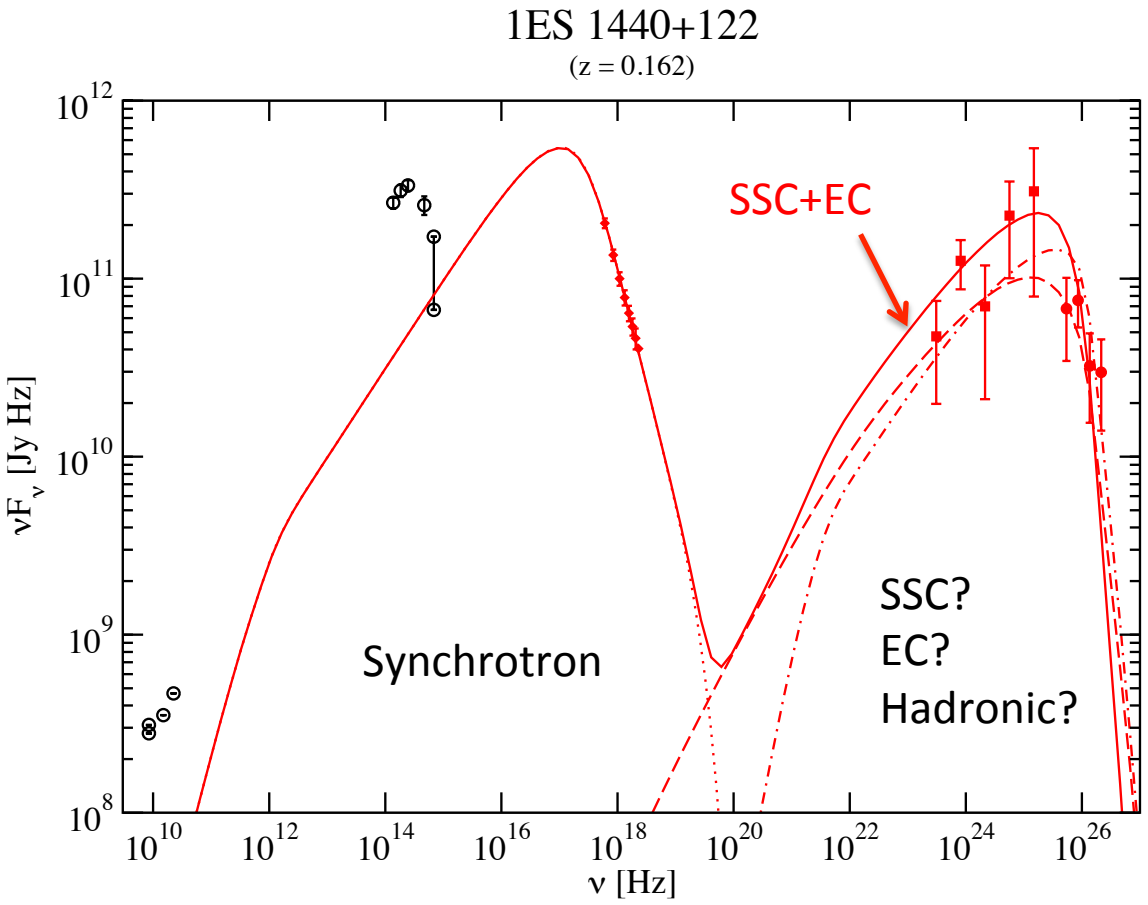
BL Lac: Rapid Variability



- MWL activity → increased VERITAS monitoring
  - 125% Crab units > 200 GeV
  - 13 ± 4 min flare decay time
  - Soft spectrum: Γ=3.6 ± 0.4
- Emergence of radio knot linked to gamma ray flare

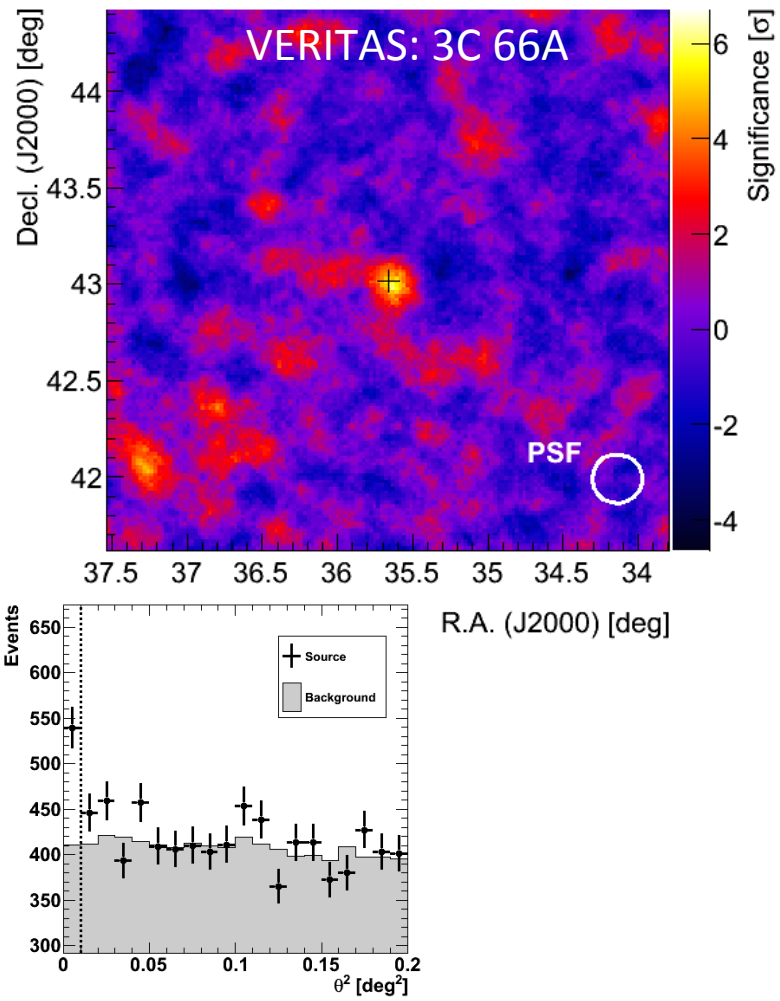


1ES 1440+122 Classification



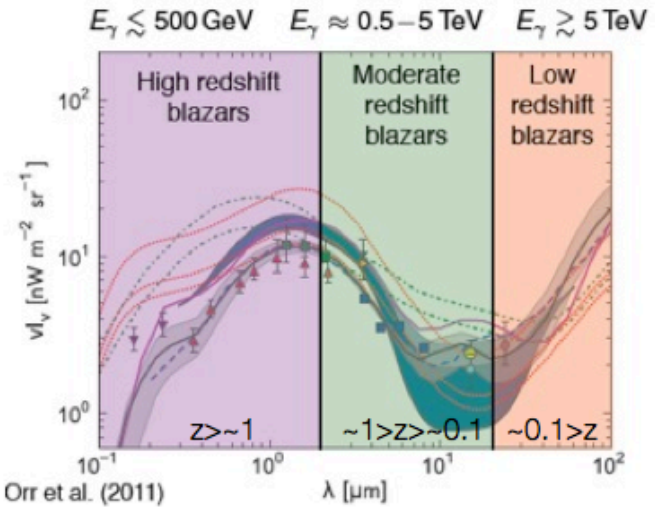
- Using Swift, *Fermi*-LAT, and VERITAS to build SEDs:
  - Synch. self-Compton (SSC)
  - External Compton (EC)
  - Hadronic
- All models fit data well
  - EC closest to equipartition
  - ν_{peak} = ~10^{17} Hz
- ν_{peak} = $10^{16.4}$ Hz from model fit in Nieppola et al. (2006)
- New modeling pushes for HBL classification
- Publication far along

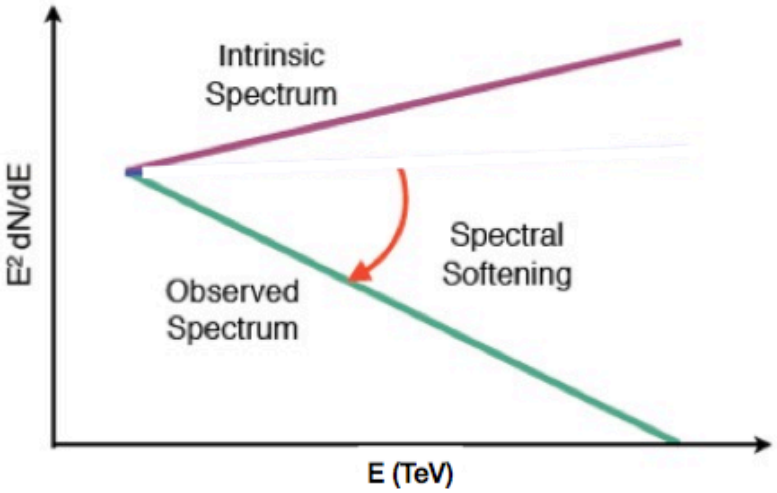
IBLs: Low-state Detections



- VERITAS detections of IBLs and LBLs have been in flaring states
  - Flaring HBLs can have different SED properties
- Little is known about quiescent flux states of lower-frequency peaked BL Lacs
- Deeper observations have lead to quiescent detections of 3C 66A (17 hrs) and W Comae (30 hrs)
- 3C 66A flux ~5x lower than flaring state
- Analysis of optical, UV, X-ray, and GeV gammas rays also underway

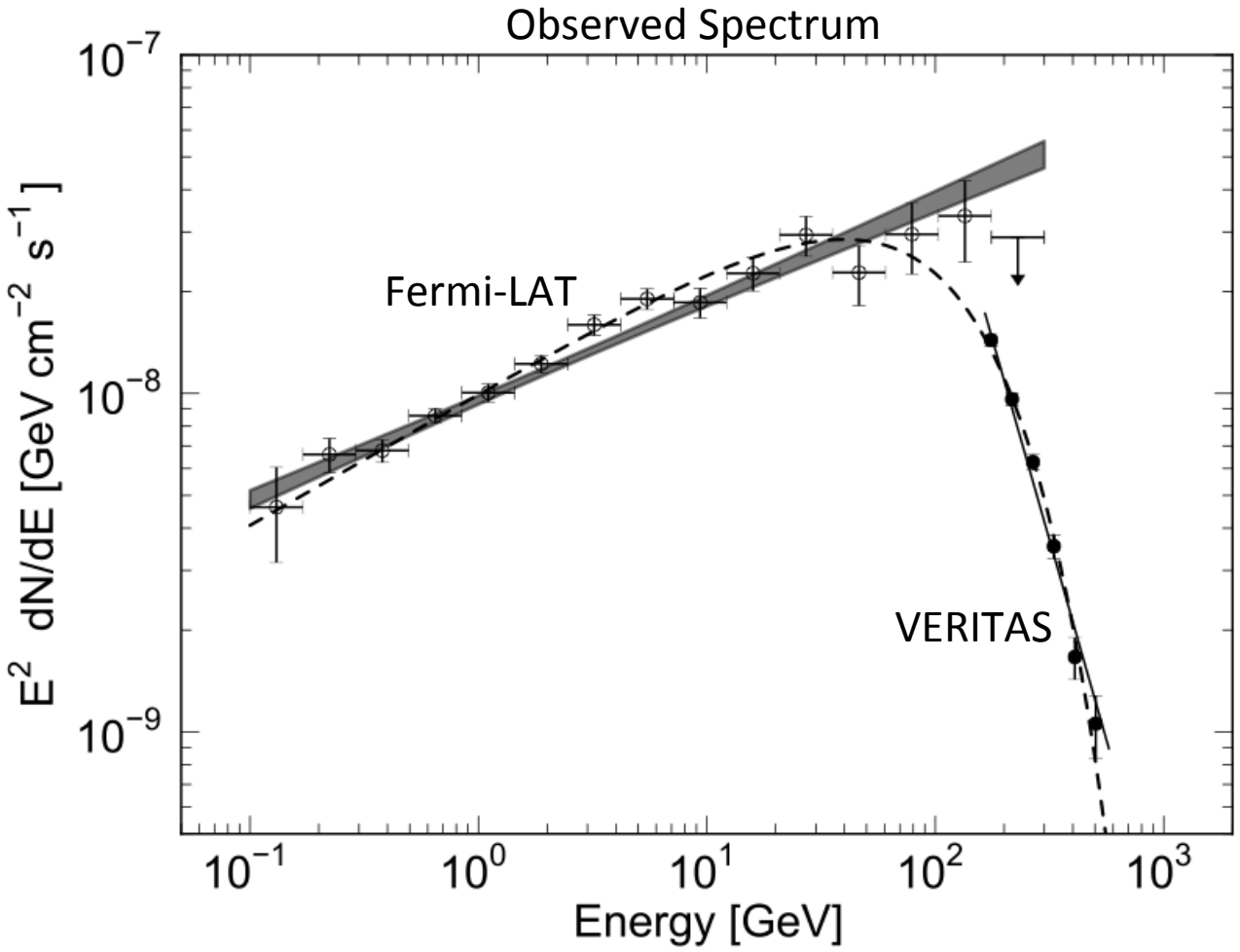
Extragalactic Background Light





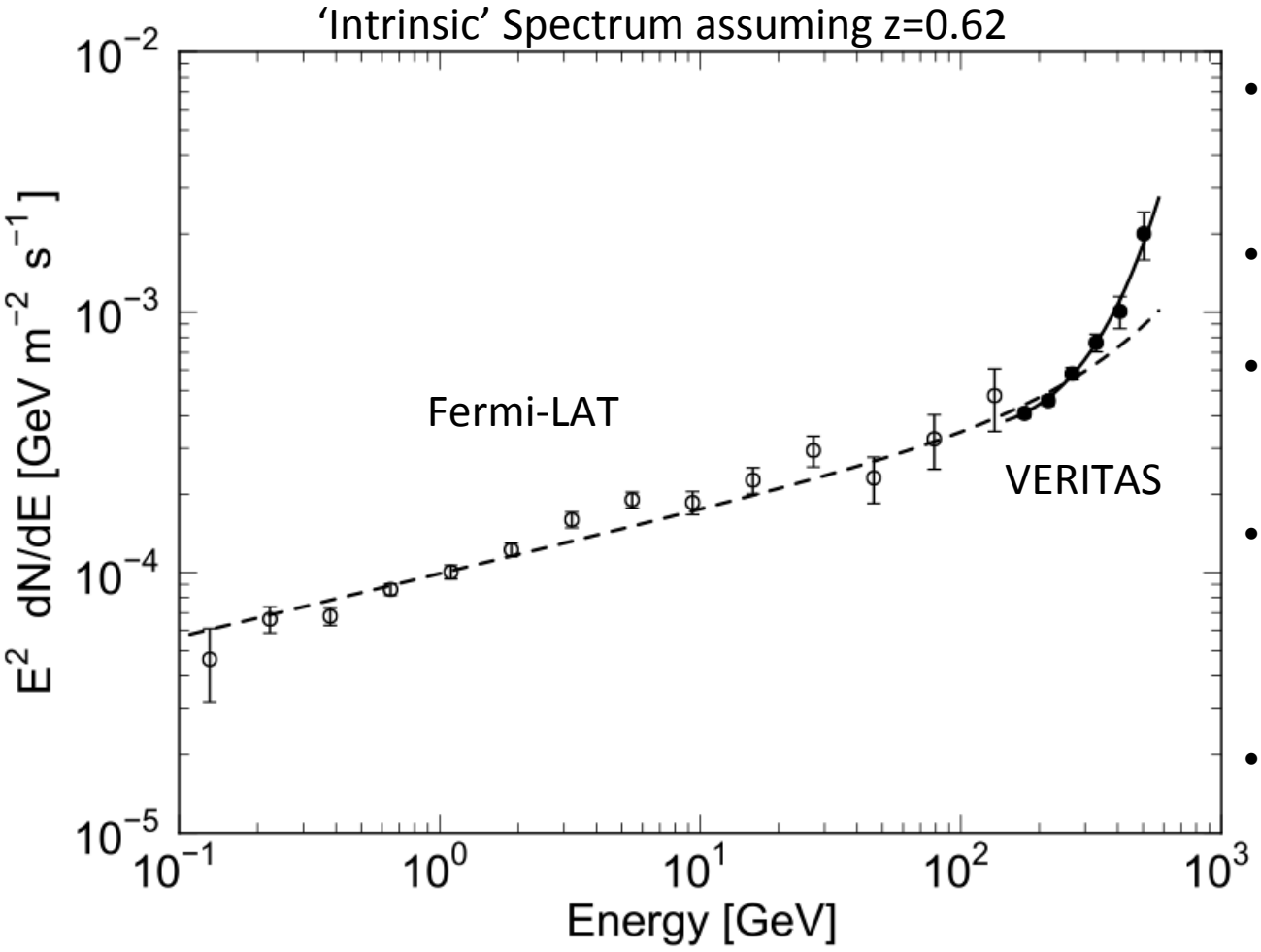
- The Extragalactic Background Light (EBL) originates from radiative energy releases throughout cosmic history
- Spans ultraviolet to infrared
- Encodes information about stellar evolution throughout cosmic history
- Direct measurement difficult
- Pair production attenuates gamma ray flux from distant sources and high energy
  - Modifies spectra in specific ways

PG 1553+113: New Redshift Constraints



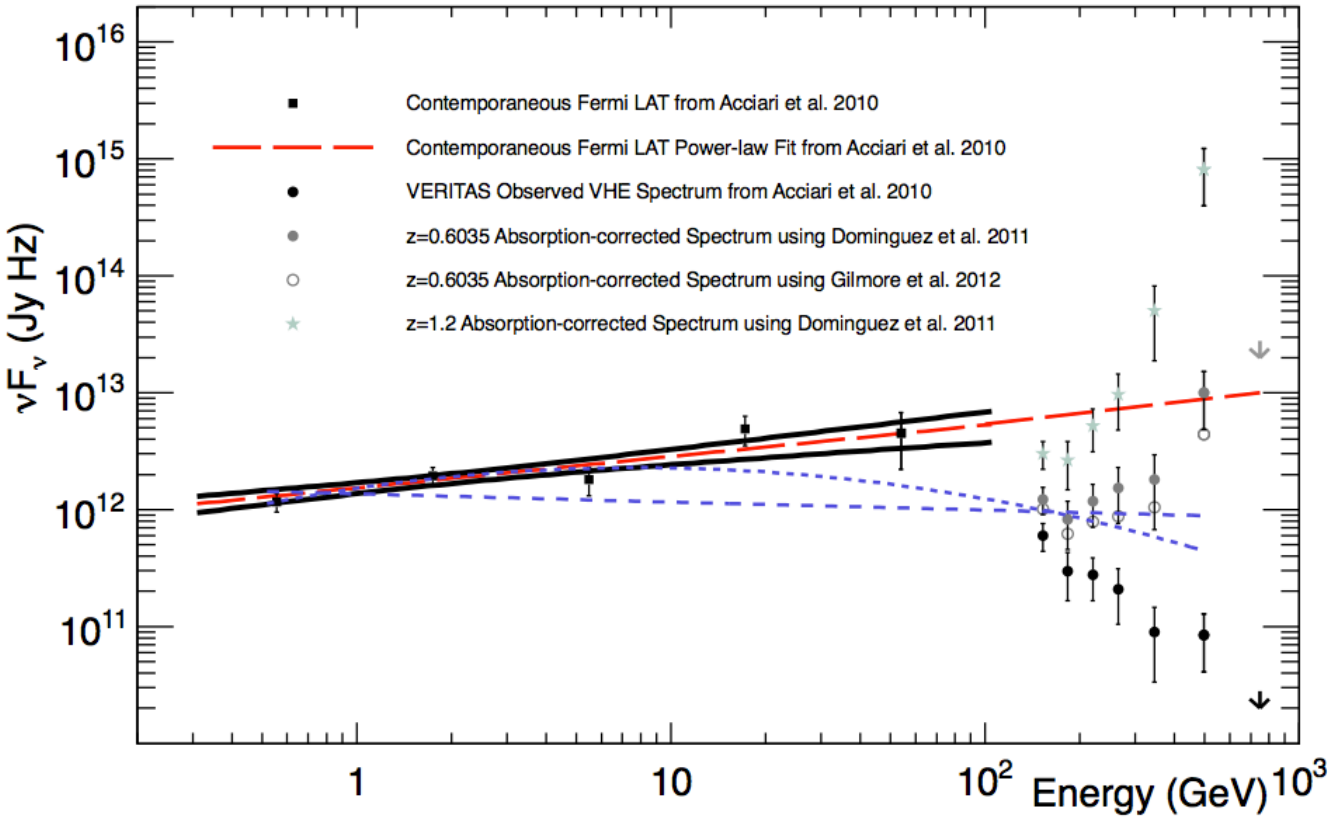
- *Fermi* and VERITAS spectra shown
- Clear cutoff ~100 GeV
- Unknown redshift
  - $z > 0.4$

PG 1553+113: New Redshift Constraints



- *Fermi* and VERITAS spectra shown
- Clear cutoff ~100 GeV
- Unknown redshift
  - z > 0.4
- Assuming minimal EBL, de-absorb to obtain intrinsic spectrum
- At **z>0.62**, the spectrum becomes unphysical for a standard blazar

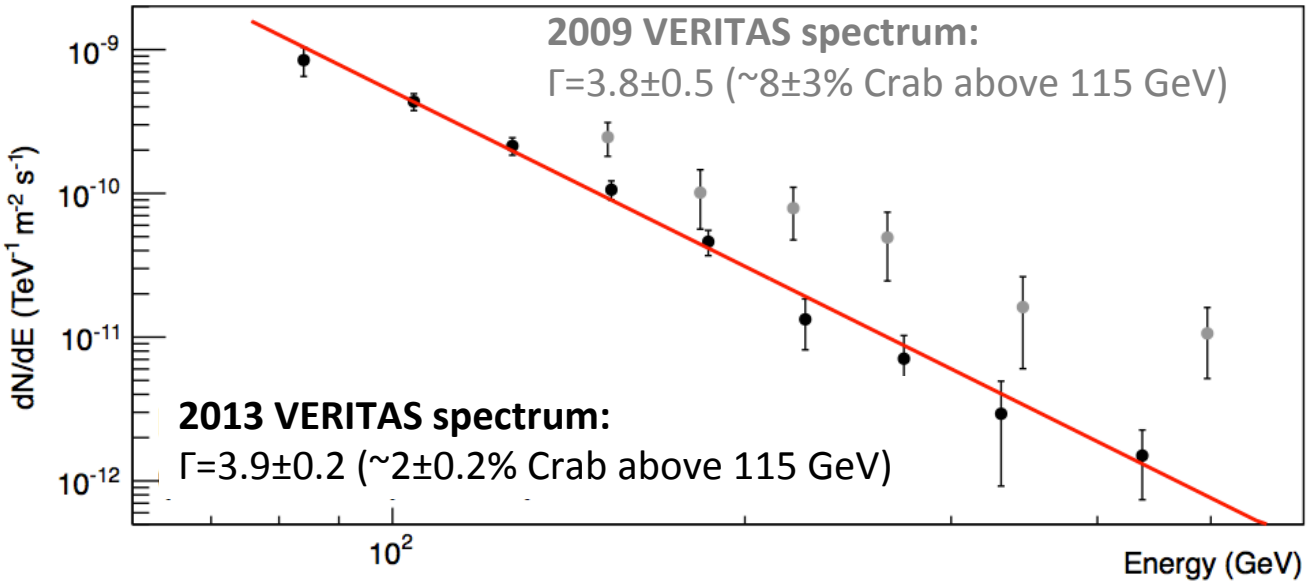
PKS 1424+240: Farthest VHE Detection



- New strict lower limit from absorption features: z > 0.6035
- Correcting for EBL leads to very hard intrinsic spectrum

Furniss et al 2013

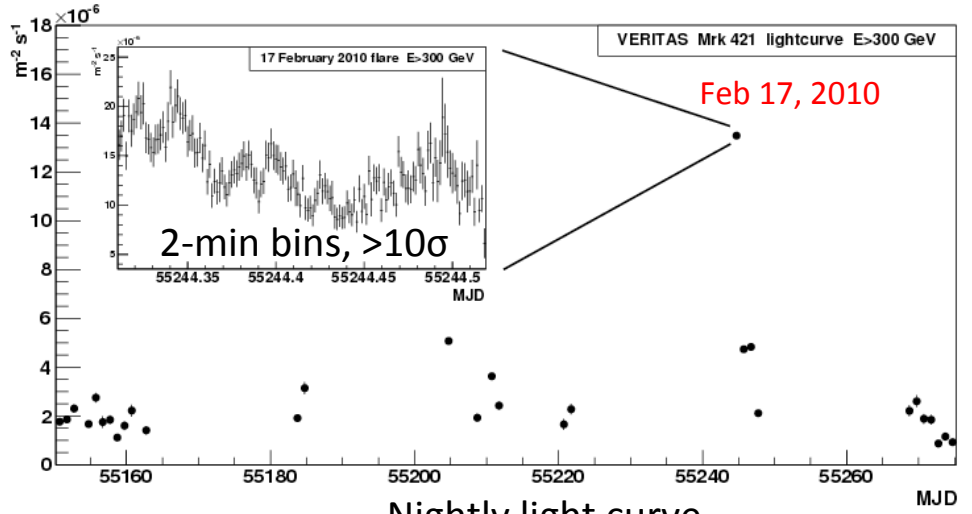
PKS 1424+240: Farthest VHE Detection



- New strict lower limit from absorption features: z > 0.6035
- Correcting for EBL leads to very hard intrinsic spectrum
- **67 hrs of additional data collected so far this season**

Furniss et al 2013

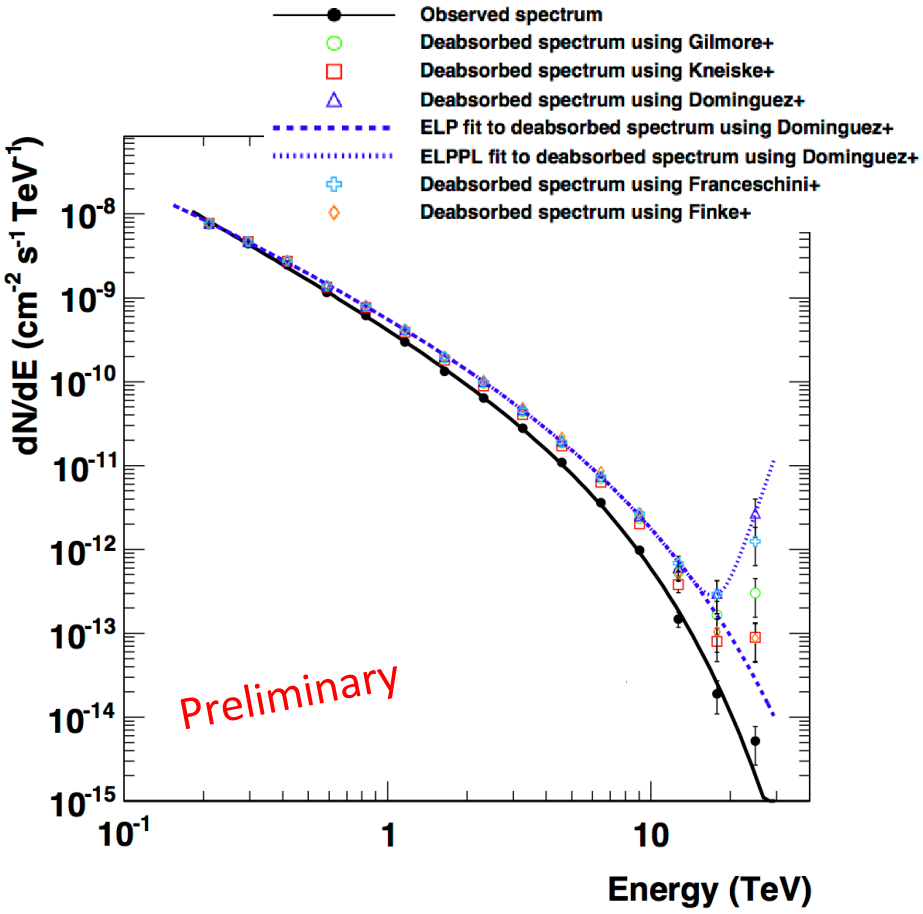
Mrk 421: 2010 Extreme VHE Flare



Nightly light curve

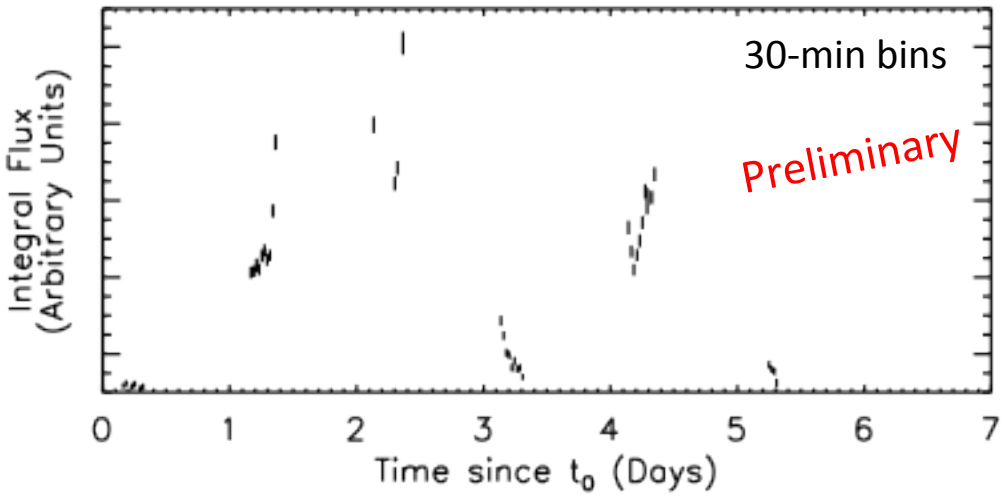
- Multiwavelength campaign, 2009 – 2010
- ~8 Crab flare observed in Feb 2010
- Minute-scale variability detected
- 25 TeV spectral point at high optical depth
- Work underway on SED modeling and LIV – publications underway

Mrk 421: 2010 Extreme VHE Flare



- Multiwavelength campaign, 2009 – 2010
- ~8 Crab flare observed in Feb 2010
- Minute-scale variability detected
- 25 TeV spectral point at high optical depth
- Work underway on SED modeling and LIV – publications underway
- EBL constraints derived from unphysical turn-up in the spectrum
  - Most stringent result: EBL density higher than (1.19 ± 0.4) x Dominguez et al (2011) model ruled out at 95% CL

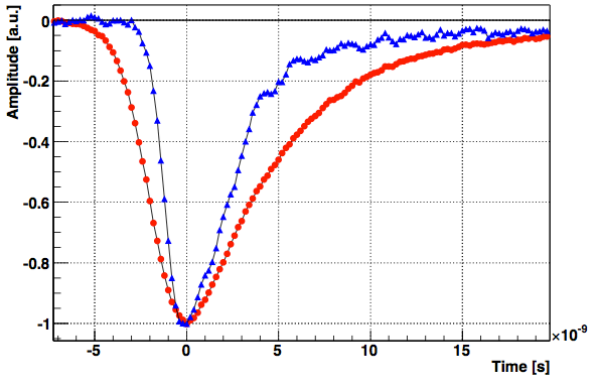
Mrk 421: Recent VHE Flare

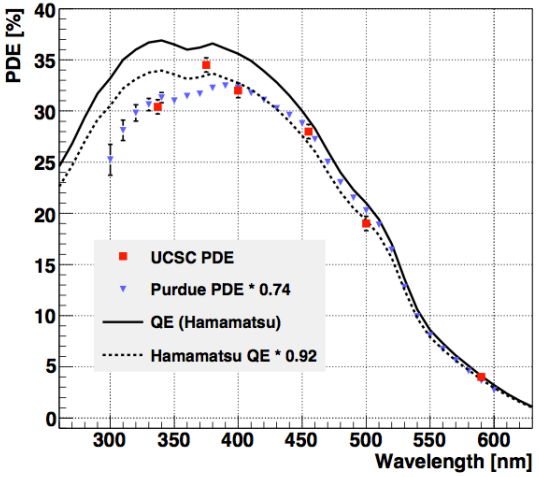


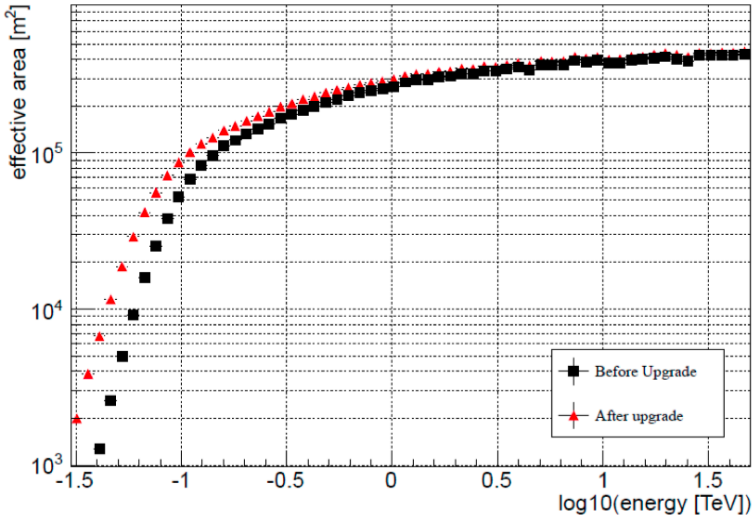
- Monitoring as part of a multiwavelength campaign with **NuSTAR** revealed another extreme flaring event just recently in April
  - Elevated flux observed over ~6 nights
- ~10 Crab units at max
- 11 hrs of truly simultaneous coverage with NuSTAR in April alone
  - Swift and optical coverage as well
  - Fermi pointed observations
- Combining MAGIC and VERITAS data provides excellent VHE coverage
- An extraordinary dataset that we are just beginning to explore in detail!
- Similar campaign with Mrk 501 underway

Camera Upgrade





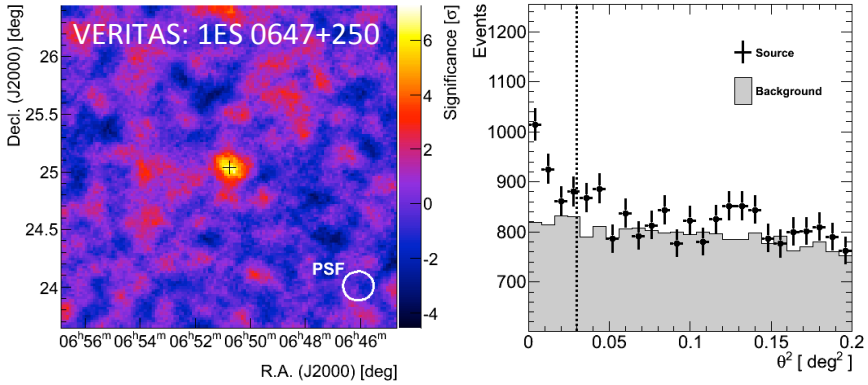


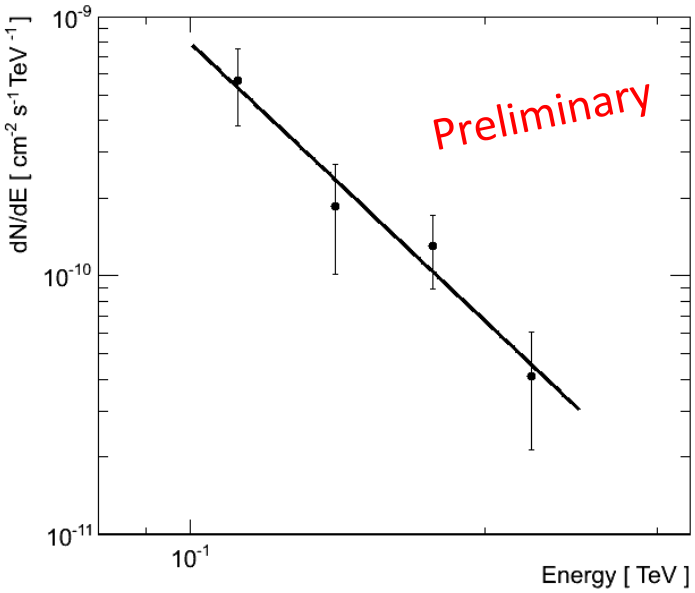


- During Summer 2012, all PMTs replaced
  - Faster pulse shape
  - QE increased >32% (for Cherenkov signal)
- Biggest increase in effective area at low energy
- Currently finalizing calibrations, simulations, and analysis chain

See talk by D. Kieda, Jul 2

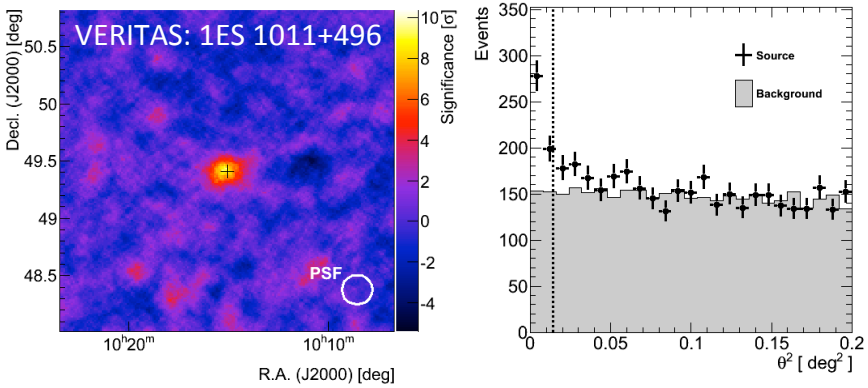
1ES 0647+250: A New VERITAS Detection

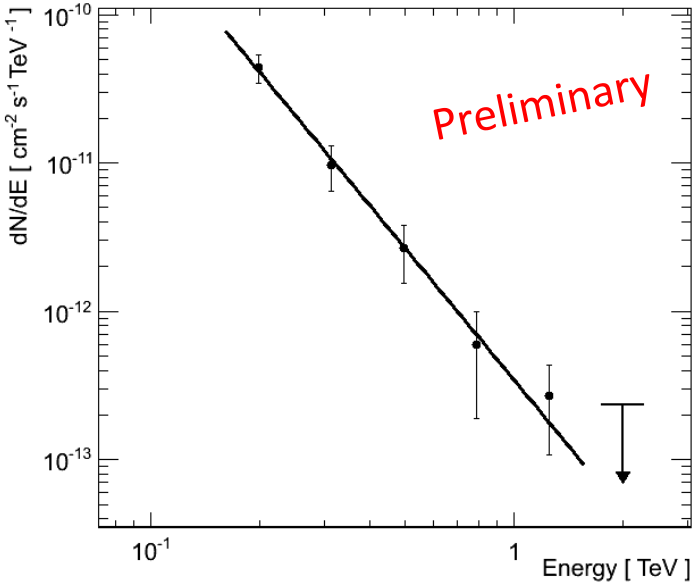




- Redshift uncertain (no spectral features)
  - z = 0.45 ± 0.08 Meisner & Romani 2010
  - z = 0.41 ± 0.06 Kotilainen et al. 2011
  - z > 0.49 Shaw et al. 2013
- VHE discovery by MAGIC in 2011
  - 3% Crab units
- VERITAS monitoring during partial moonlight led to ToO and 10.9 hours of dark time
  - **6.2 σ** detection
  - **2.9% Crab** units > 140 GeV
- Obtained simultaneous X-ray observations
- Spectrum
  - Norm = (9.8 ± 2.26) x 10^{-7} TeV^{-1} cm^{-2} s^{-1} @ 180 GeV
  - Index = 3.6 ± 0.8

1ES 1011+496: A New VERITAS Detection





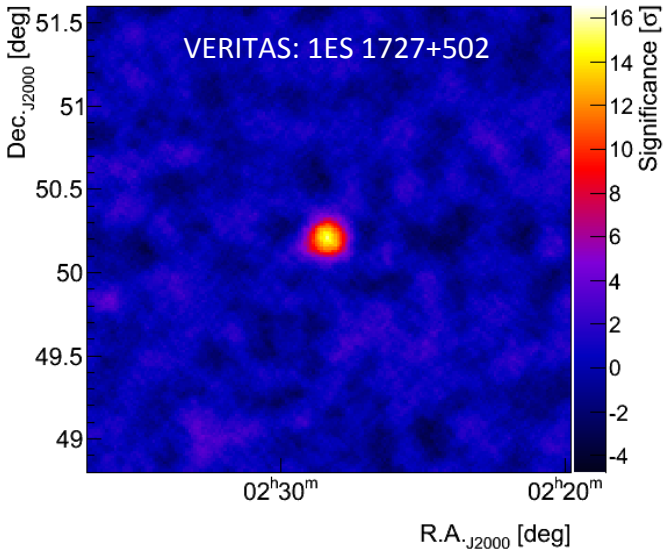
- HBL at z = 0.212
- VHE discovery by MAGIC in 2007
  - 7% Crab units > 200 GeV
  - Γ=4.0 ± 0.5 stat ± 0.2 sys
- Optical and VHE variability reported

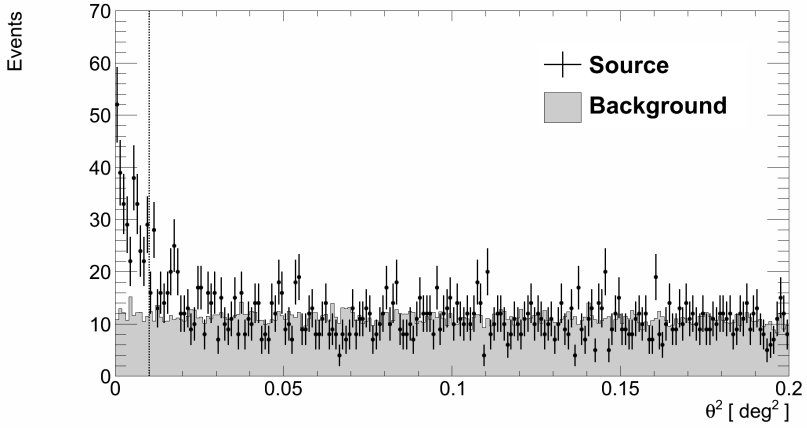
- VERITAS monitored during partial moonlight, triggered ToO and **10.4 hours** of dark time
  - **8.5 σ** detection
  - **6.3% Crab** units > 150 GeV

- Obtained simultaneous X-ray observations

- Spectrum
  - Norm = (4.1 ± 0.9) x 10^{-7} TeV^{-1} cm^{-2} s^{-1} @ 200 GeV
  - Index = 3.0 ± 0.3

1ES 1727+502: A New VERITAS Detection

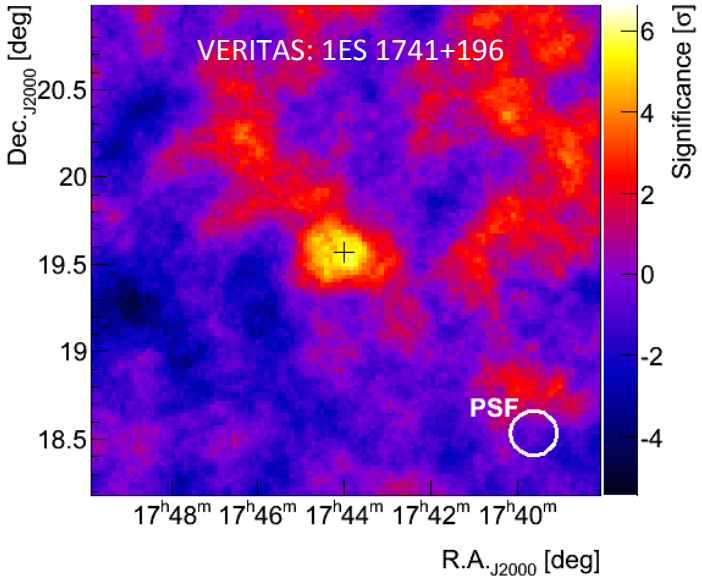




- HBL at z = 0.055
- VHE discovery by MAGIC in 2011
  - 2.1% Crab units > 150 GeV
  - Γ=2.7 ± 0.5 stat

- VERITAS monitored with reduced HV during partial moonlight (35—65%), triggered ToO
- 3 hrs in moonlight + 3 hrs dark
  - -> **14 σ** detection
- ~7 Crab units > 230 GeV

1ES 1741+196: A New VERITAS Detection



- HBL at z = 0.083
- Host galaxy one of the largest and most luminous of BL Lacs
- Potentially a triplet of bound galaxies with tidal tails Heidt, J., et al. A&A (2008) 348, p.113-116
- VHE discovery by MAGIC in 2011
  - 0.8% Crab units
- 26.8-hour exposure (8.5 hours post-upgrade)
  - **5.3 σ** detection
  - **(1.3 ± 0.4)% Crab** units > 130 GeV
  - More details including SED modeling coming

VERITAS Blazars @ ICRC



- *VERITAS results from a three-year observing campaign on the BL Lac object 1ES 0229+200*
  - Evidence for year-scale variability seen in this extreme hard-spectrum HBL
  - See M. Cerruti's talk ID 800, July 3
- *VERITAS long-term observations of several hard spectrum blazars*
  - EBL-corrected TeV spectral index similar to that in GeV range
  - See M. Orr's poster ID 1133
- *Upper limits from non-detected blazar observations*
  - 3.9 σ stacked excess
  - See M. Cerruti's poster ID 799, July 4—6

Conclusions

- Very active blazar science program addressing a range of questions
  - Variability timescales
  - Multiwavelength modeling
  - EBL constraints

- Camera upgraded with new higher QE PMTs
  - Four new VERITAS blazar detections