Highlights from Extragalactic Observations by VERITAS

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and the VERITAS Collaboration

Rencontres de Moriond

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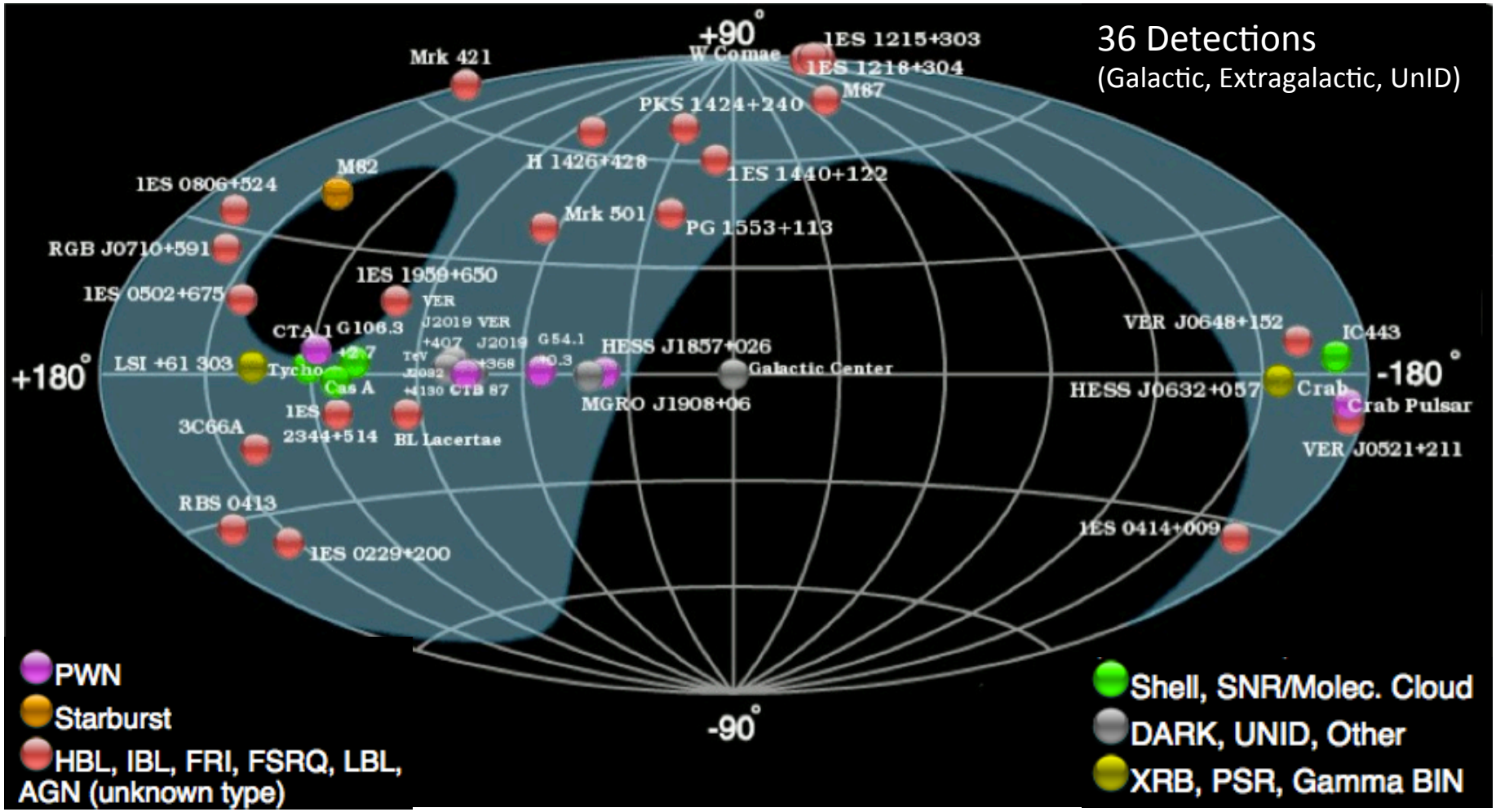


VERITAS



- **100 GeV – ~30 TeV**
- **15 – 20% energy resolution**
- **0.1° angular resolution**
- **1% Crab detection in < 30 hrs (pre-upgrade)**
- **Recent Upgrades: Trigger (2011) and Camera (2012)**

The VERITAS Sky



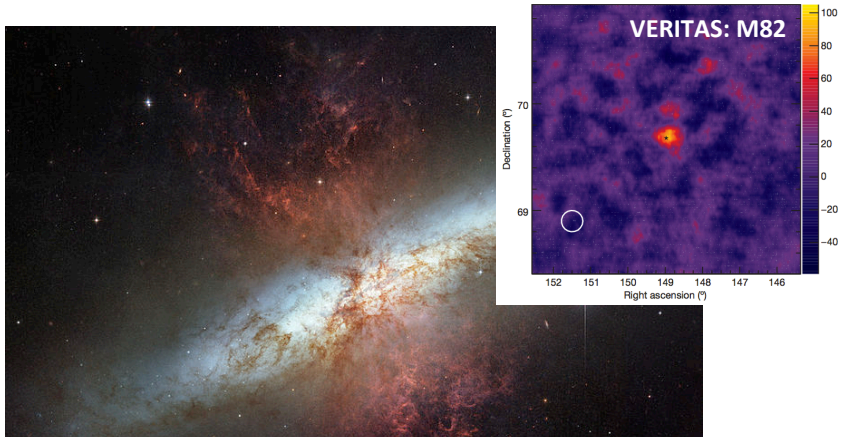
Extragalactic Sources

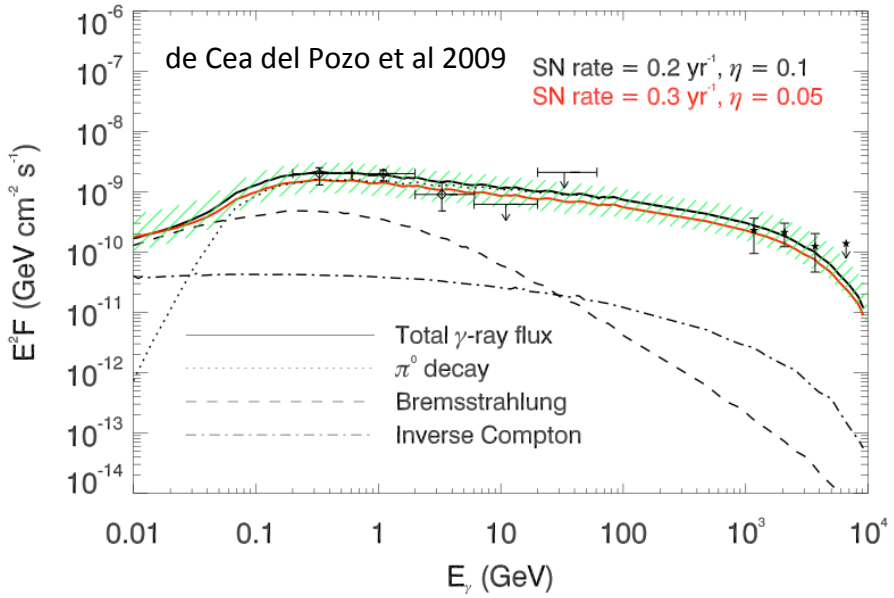
Key extragalactic science goals:

- Supermassive Black holes
  - Jet physics
    - origins of ultra high energy cosmic rays
  - Environment
  - Evolution
- Fundamental physics
  - Search for new particles/processes
  - Lorentz invariance violation
  - Dark matter
- Cosmology
  - Extragalactic background light
  - Magnitude of intergalactic B field

Source	Type	z
M 82	Starburst	-
M 87	FR I	0.004
Mkn 421	HBL	0.030
Mkn 501	HBL	0.034
1ES 2344+514	HBL	0.044
1ES 1959+650	HBL	0.047
BL Lac	LBL	0.069
1ES 1741+196	HBL	0.083
W Comae	IBL	0.102
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	Blazar	0.179
1ES 1218+304	HBL	0.182
RBS 0413	HBL	0.190
1ES 0414+009	HBL	0.287
PG 1553+113	HBL	0.43 < z < 0.47
1ES 0502+675	HBL	0.341 ?
3C 66A	IBL	0.444 ?
PKS 1424+240	IBL/HBL	?
VER J0521+211	Blazar	?
B2 1215+30	IBL/HBL	?

M82: Nearby Starburst Galaxy





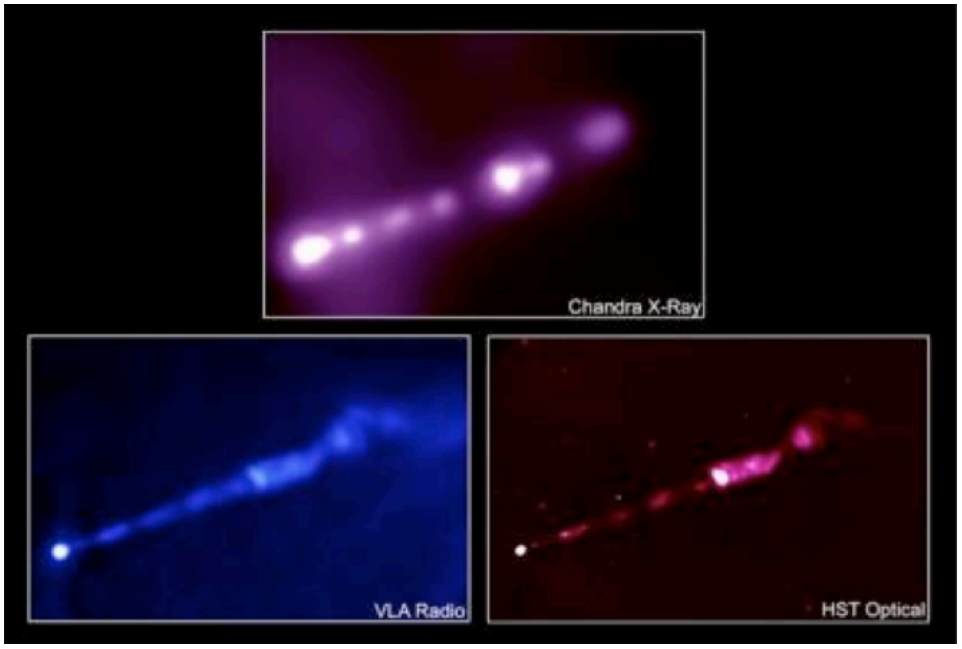
- M82 is a prototypical starburst galaxy
  - Close: distance ~ 3.9 Mpc
  - Diameter ~ 1'
  - Central SMBH: < 3 x 10^7 M_{sun}
    - No evidence for AGN
- Tidal forces with nearby M81 => active starburst region
  - Star formation rate: ~10x Milky Way
  - High supernova rate: 0.1 – 0.3 / year
- VERITAS 2007 – 2009: 137 hours of data
  - higher than normal 700 GeV threshold at elevation ~ 39°

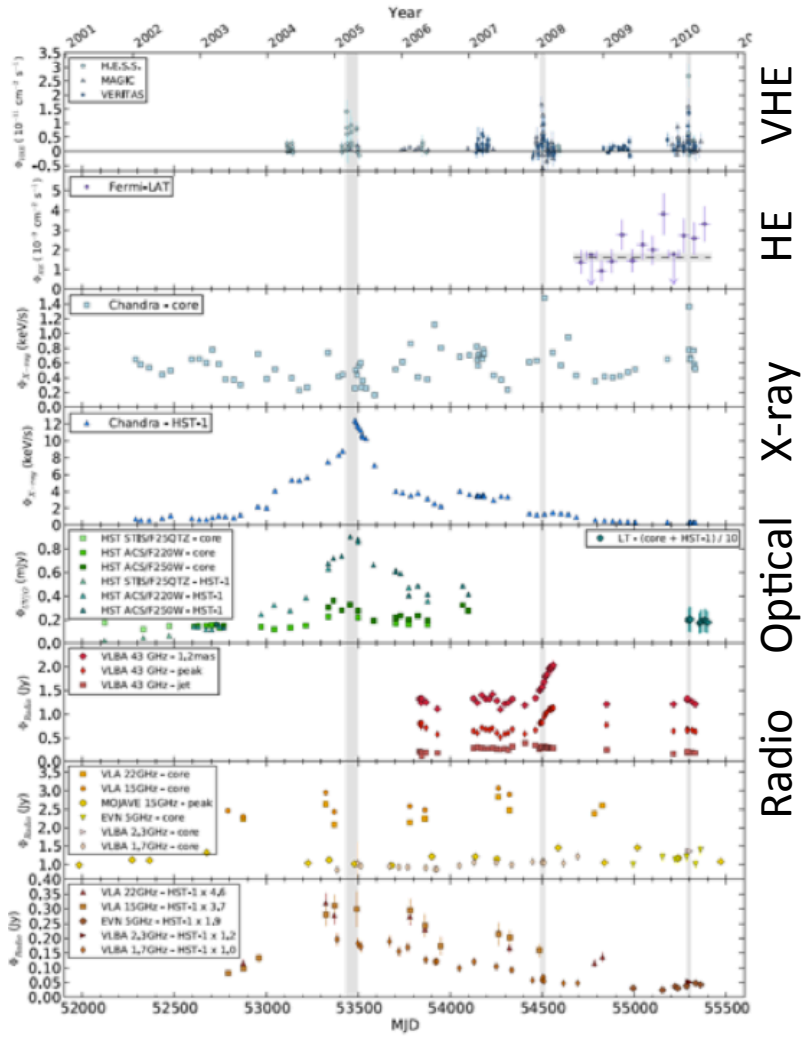
CR hadrons + gas → pions → **γ-rays**
CR e^- + ambient photons → **γ-rays**

Nice model agreement with **$E^{-2.5}$** power-law connecting Fermi-LAT and VERITAS detection

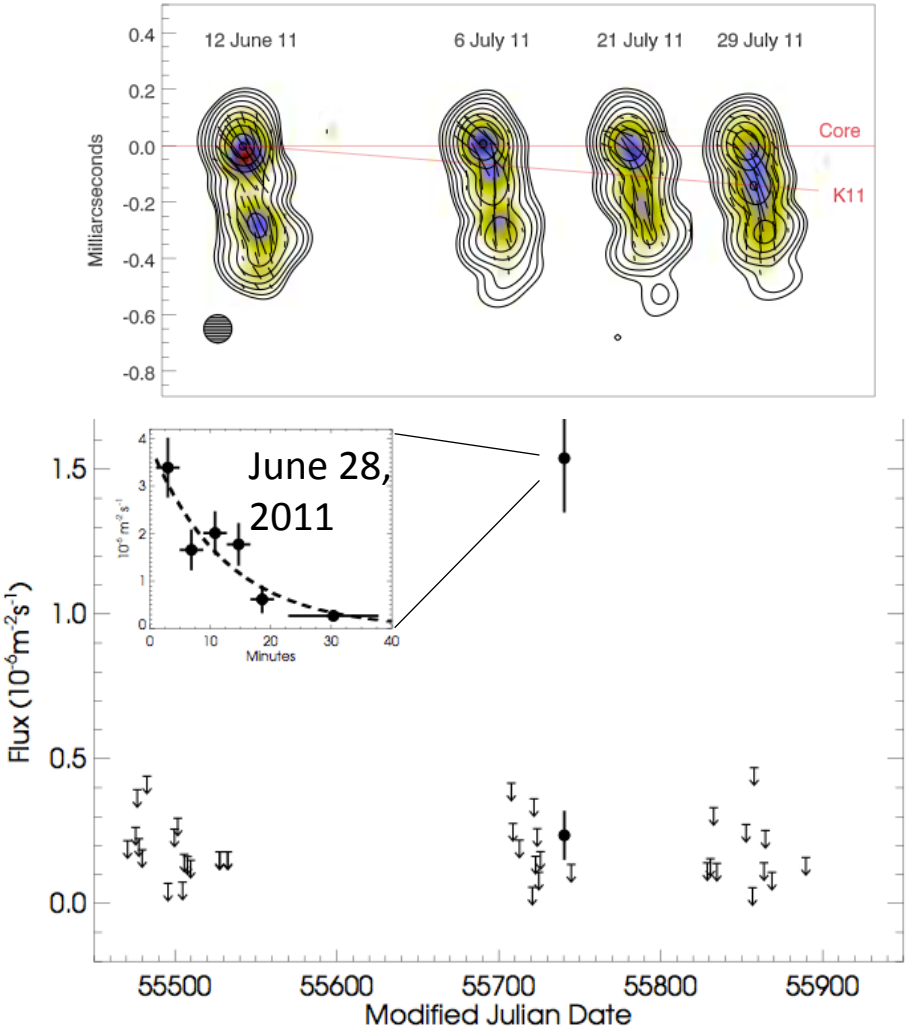
M87: Nearby Radio Galaxy

- Jet substructure evident in MWL imaging
- Coordinated MWL γ-ray, X-ray and Radio campaign
  - VERITAS/MAGIC/HESS/VLBA/Chandra, 2008 – 2011
- Multiple flares detected in 2005, 2008, 2010
  - 1% – 20% Crab units > 250 GeV

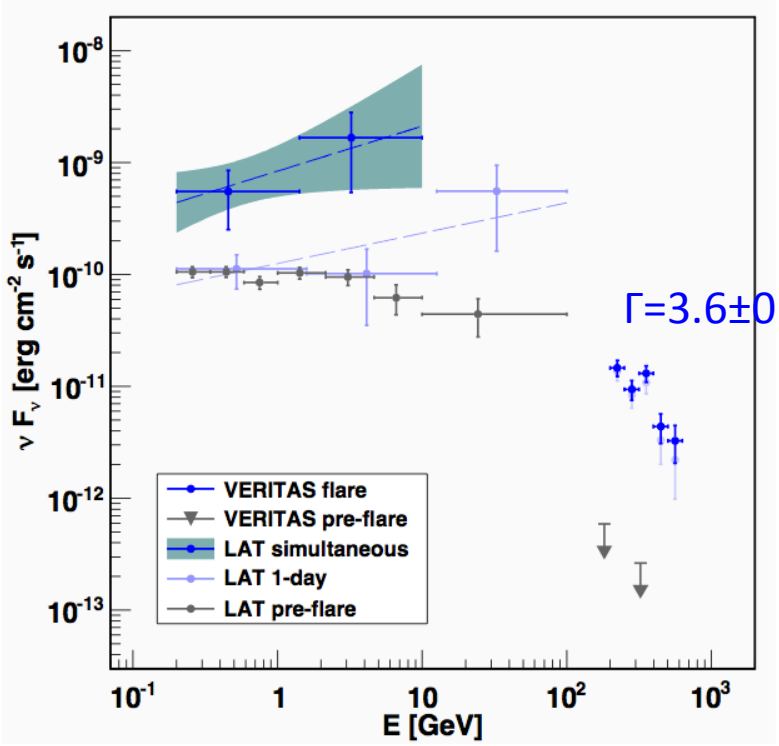




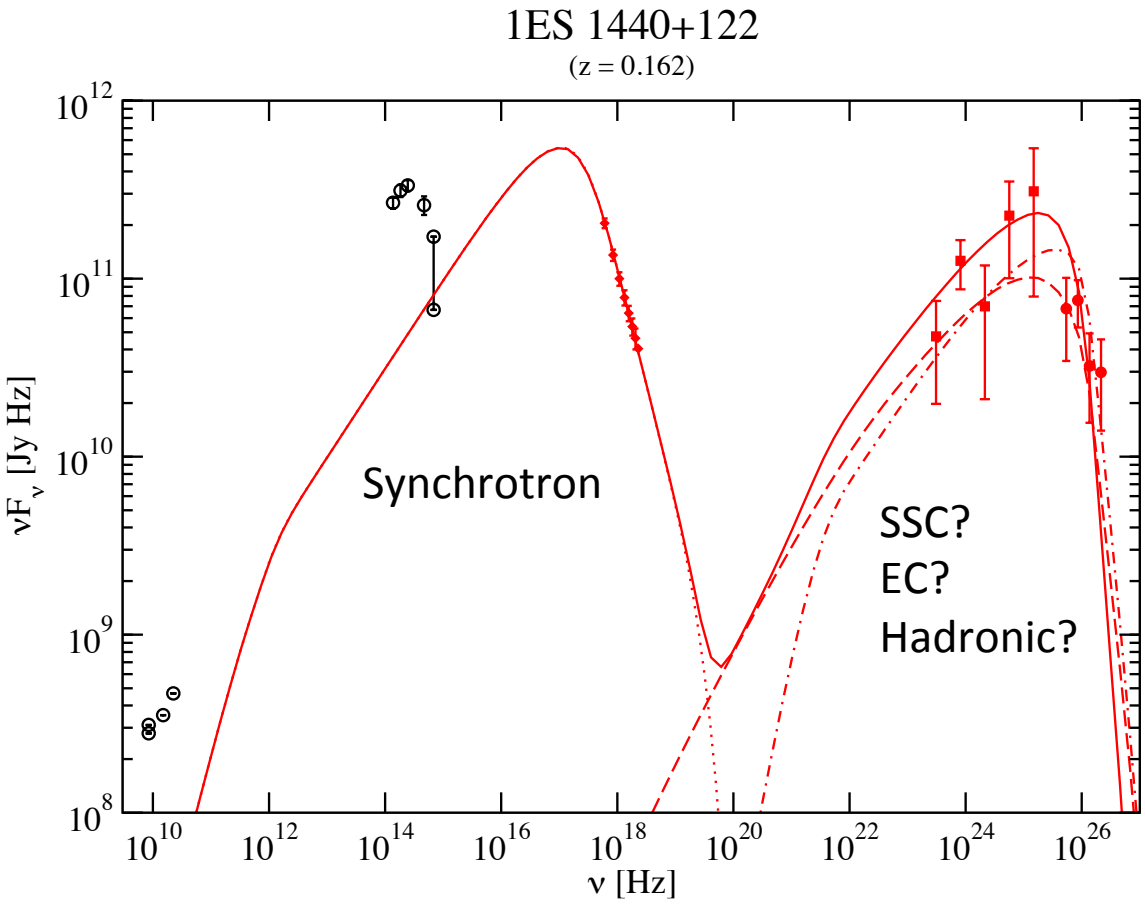
BL Lac: Rapid Variability



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



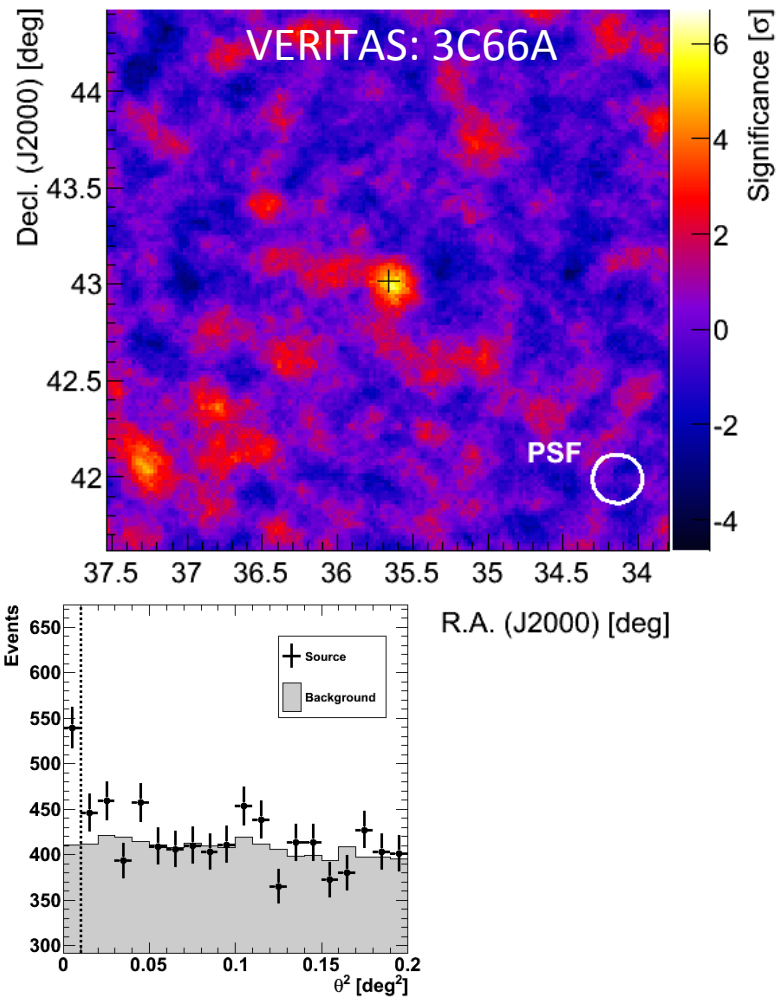
1ES 1440+122 Classification



- 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
  - $\nu_{peak} = \sim 10^{17}$ Hz
- $\nu_{peak} = 10^{16.4}$ Hz from model fit in Nieppola et al. (2006)
  → borderline case between IBL and HBL

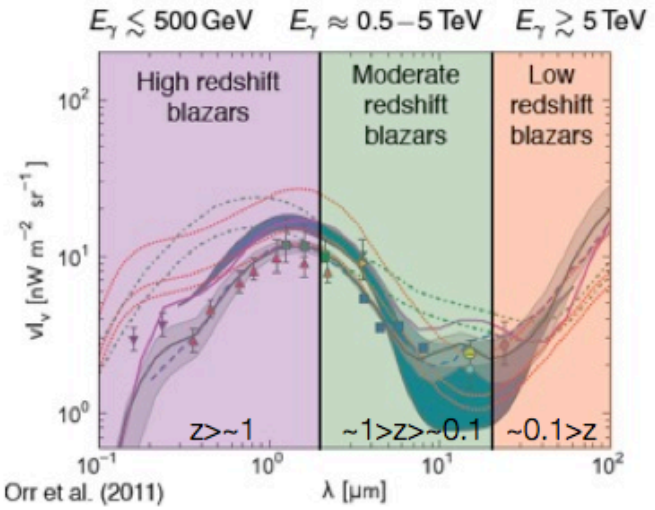
External Compton model shown, fitting jet parameters to SED

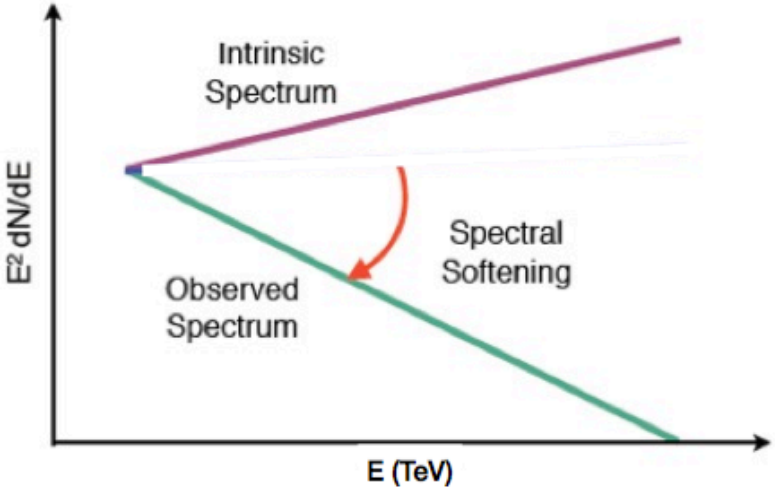
3C66A: Low-state Detection



- 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 3C66A (17 hrs) and W Comae (30 hrs)
- 3C66A flux ~5x lower than flaring state
- Analysis of optical, UV, x-ray, and GeV gammas rays also underway

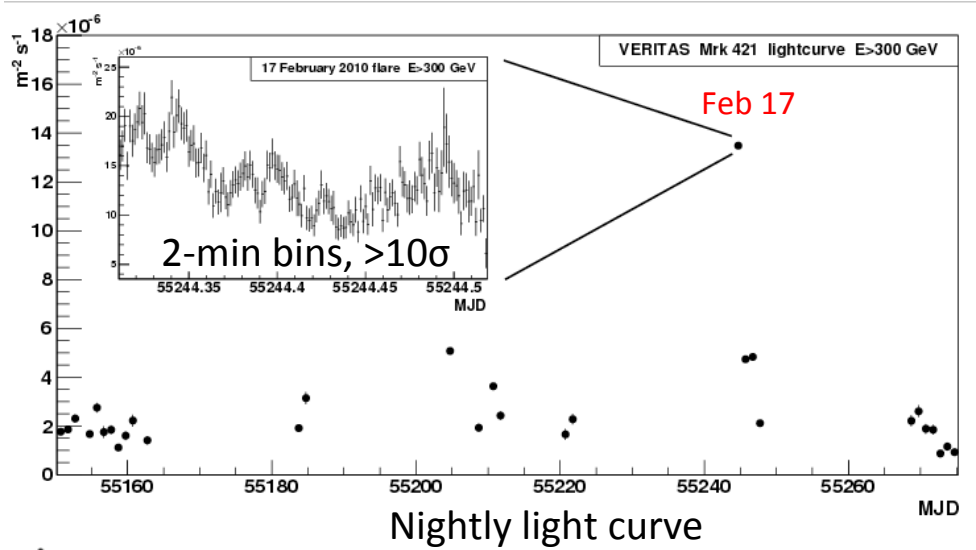
Extragalactic Background Light



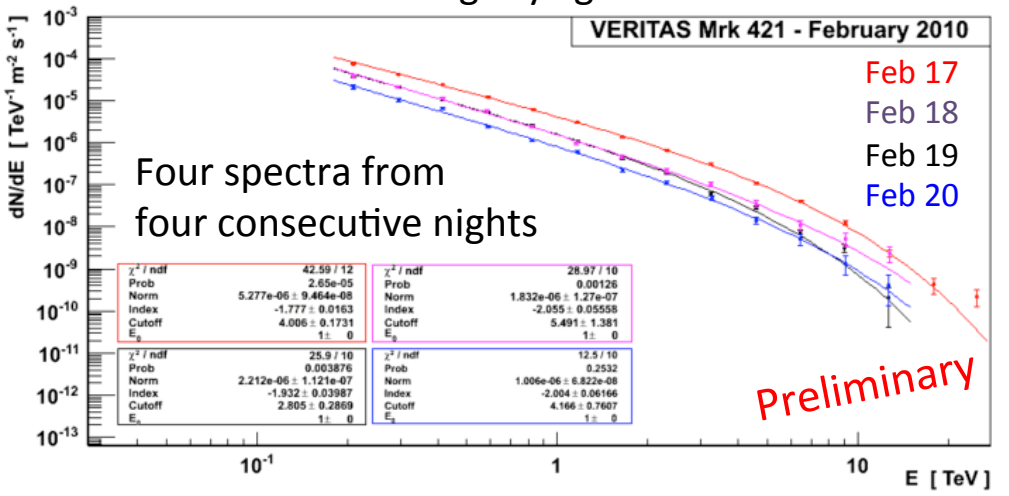


- The Extragalactic Background Light (EBL) originates from all radiative energy releases since reionization
- Spans ultraviolet to infrared
- Encodes information about stellar evolution throughout cosmic history
- Direct measurement difficult
- Pair production attenuates gamma ray flux from distant sources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

Mrk 421: Extreme VHE Flare

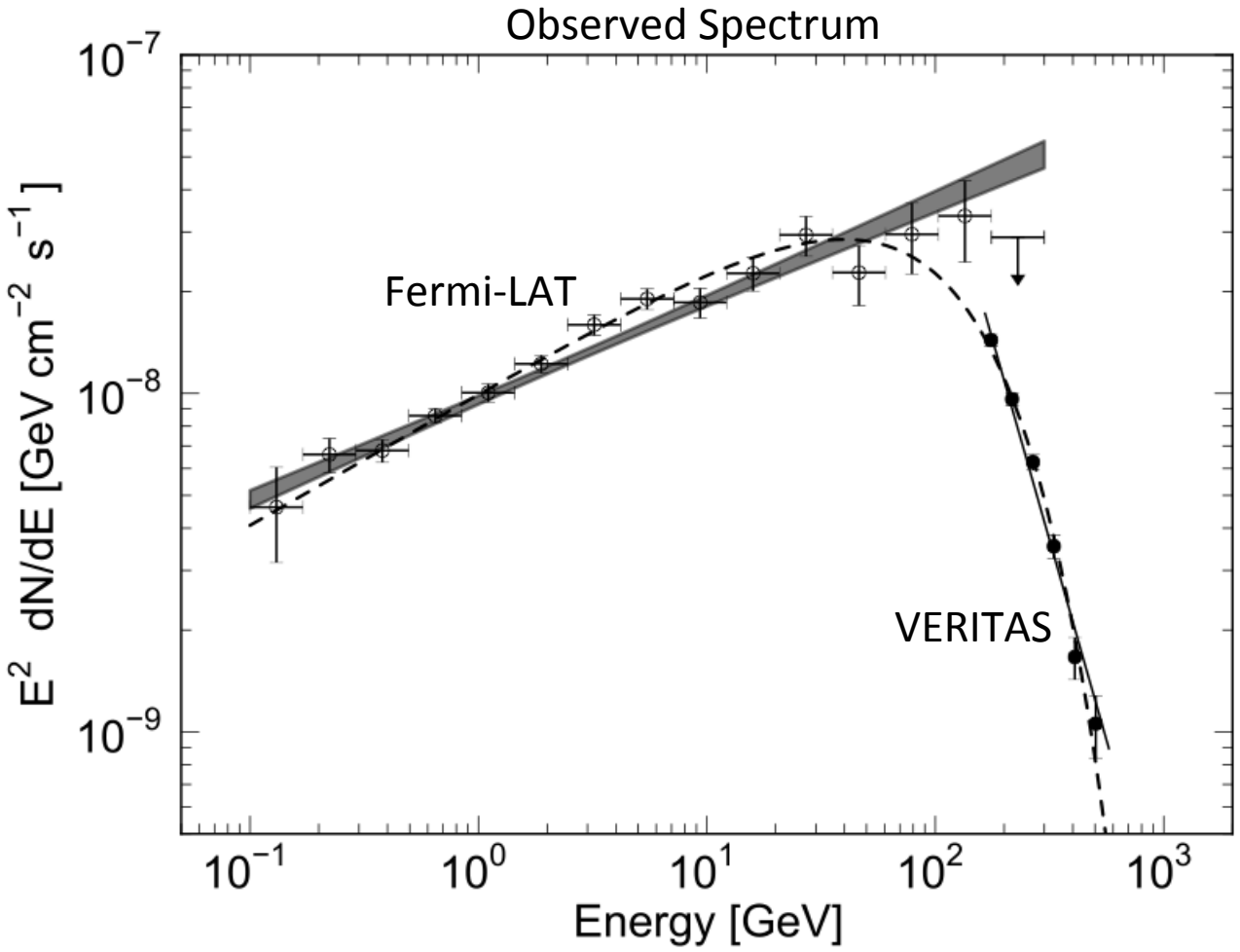


Nightly light curve



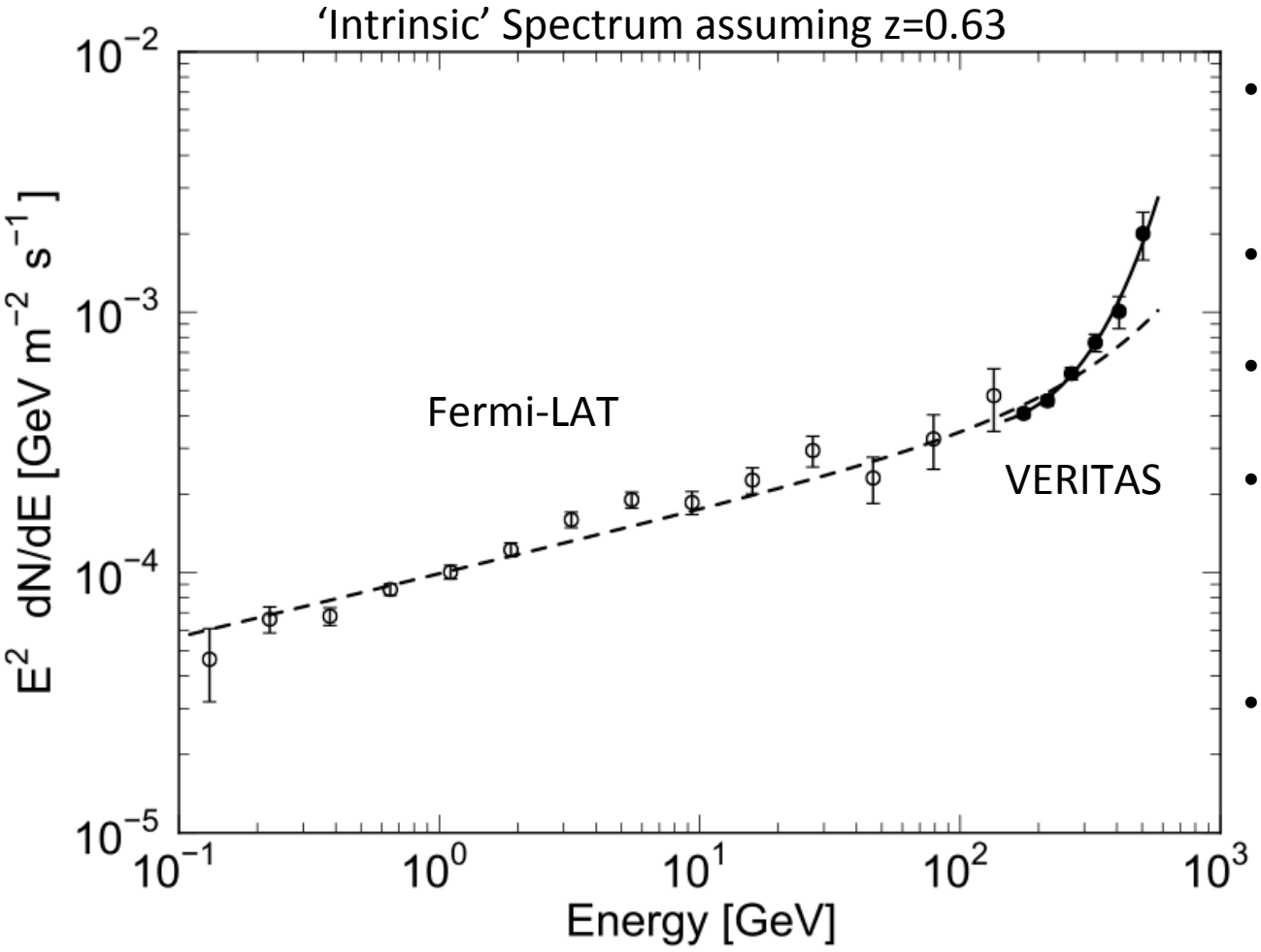
- Multiwavelength campaign, 2009 – 2010
- ~8 Crab flare observed in Feb 2010
- Minute-scale variability detected
- > 20 TeV spectral point at high optical depth
- Work underway on SED modeling, EBL, and LIV – publications underway

PG 1553+113: New Redshift Constraints



- Fermi and VERITAS spectra shown
- Clear cutoff ~100 GeV
- Unknown redshift

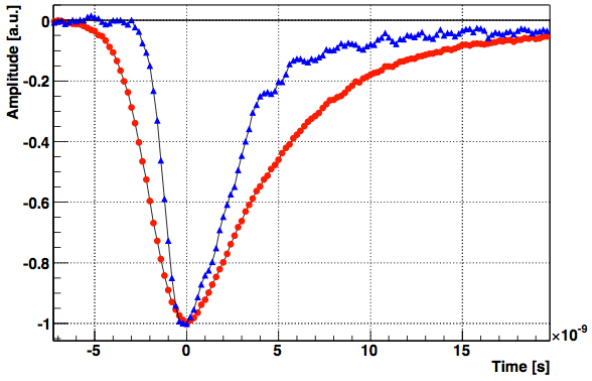
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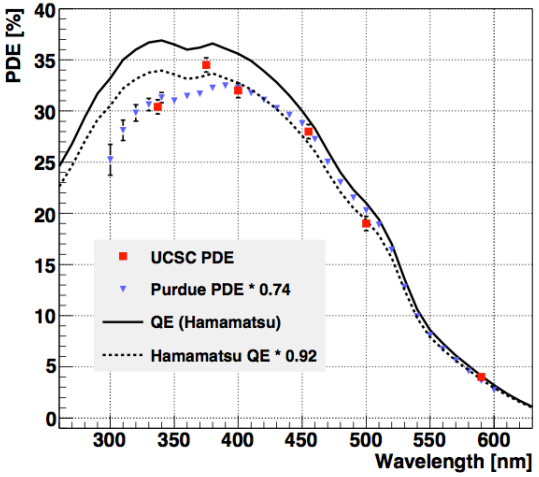


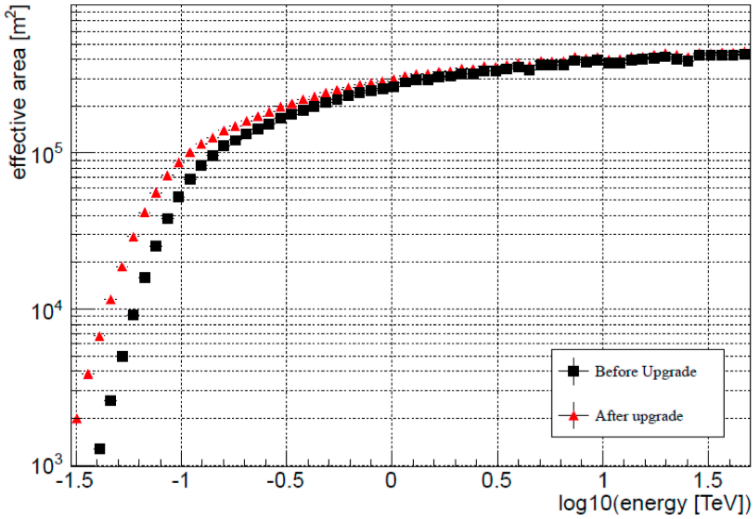
- Fermi and VERITAS spectra shown
- Clear cutoff ~100 GeV
- Unknown redshift
- Assuming minimal EBL, de-absorb to obtain intrinsic spectrum
- At **z>0.63**, the spectrum becomes unphysical for a standard blazar

Camera Upgrade



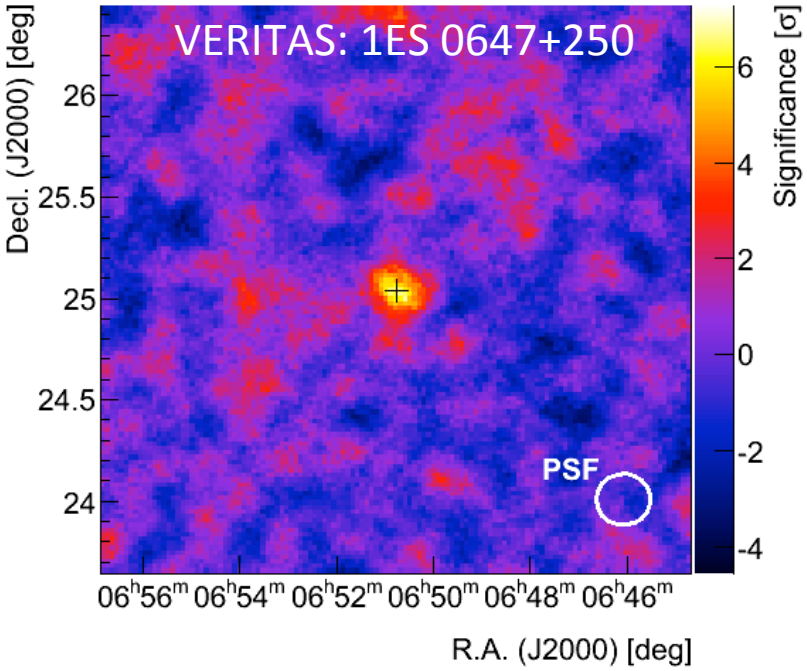




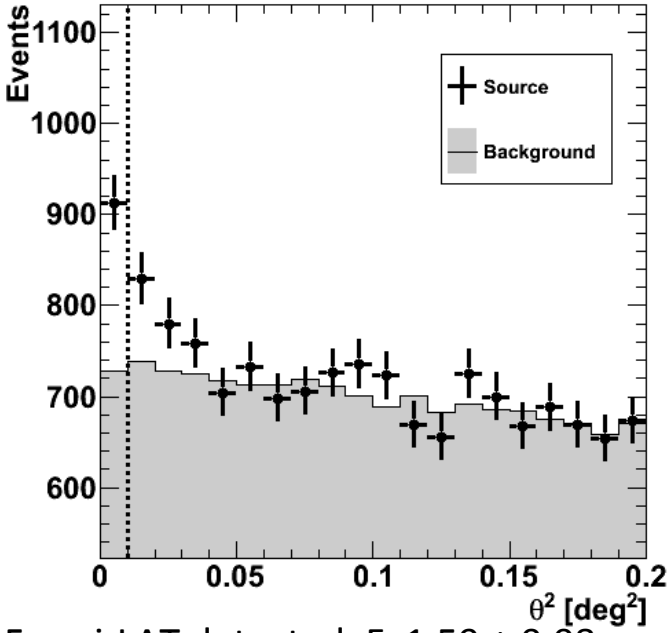


- During Summer 2012, all PMTs replaced
  - Faster pulse shape
  - QE increased 35% (for Cherenkov signal)
- Biggest increase in effective area at low energy
- Currently finalizing calibrations, simulations, and analysis chain

1ES 0647+250: A New VERITAS Detection

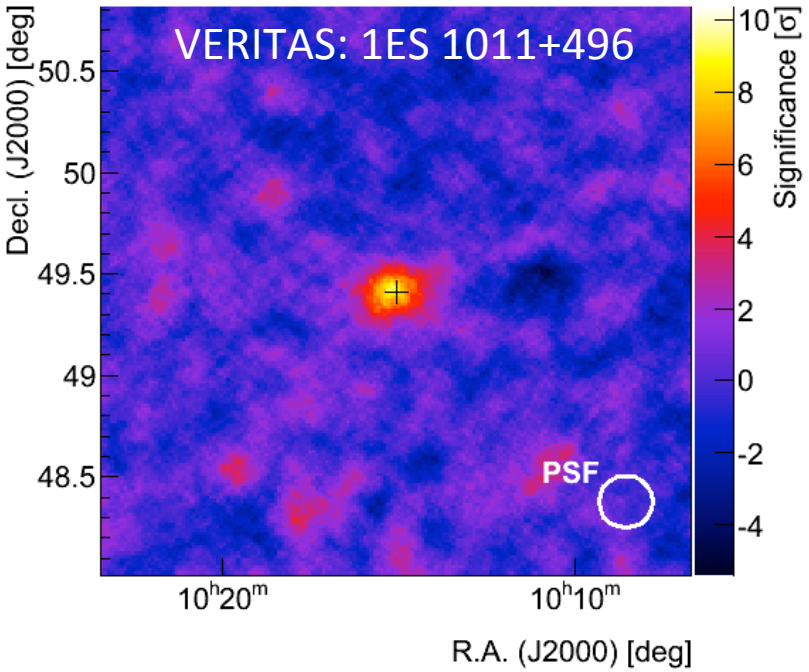


- Redshift uncertain (no spectral features)
  - z = 0.45 ± 0.08 Meisner & Romani 2010
  - z = 0.41 ± 0.06 Kotilainen et al. 2011
  - z > 0.49 Shaw et al. 2013

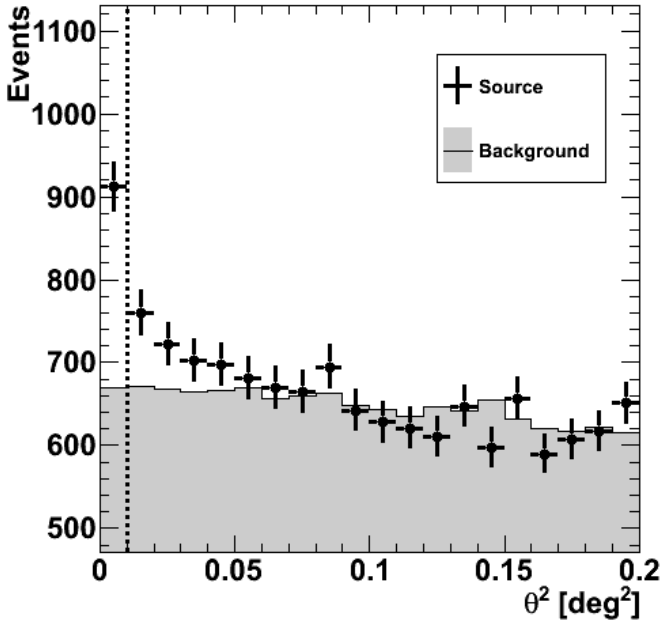


- Fermi-LAT detected, Γ=1.59 ± 0.08
- VHE discovery by MAGIC in 2011, 3% Crab units
- VERITAS monitoring during partial moonlight lead to ToO and 10.9 hours of observing
  - **6.2σ** detection
  - **2.9% Crab** units > 138 GeV
  - more details coming

1ES 1011+496: A New VERITAS Detection



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



- VERITAS monitored during partial moonlight, triggered ToO
- Detected at **8.5σ** in 10.4 hours
- ~**6.3% Crab** units > 151 GeV
- Obtained simultaneous x-ray observations
- Again, more details underway

Conclusions



- Very active extragalactic science program addressing a range of questions
  - Supermassive black holes
  - Fundamental physics
  - Cosmology

- Camera upgraded with new higher QE PMTs
  - Two new VERITAS soft-spectrum blazar detections

Backup Slides