



PKS 1441+25: Insights from a New Gamma-ray Quasar



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For The VERITAS Collaboration
& Multiwavelength Partners
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UNIVERSITY OF CALIFORNIA
SANTA CRUZ

SPOL, ASAS-SN, OVRO,
NuSTAR, CRTS

Outline:

- Introduction to PKS 1441+25
- VERITAS detection
- Long, mid and short term light curves
- Spectral Energy Distribution
- Constraint on the emission region location
- Constraint on the extragalactic background light
- PKS 1441+25 in context



PKS 1441+25

- **5th FSRQ detected at VHE!** by MAGIC & VERITAS in April, 2015
- VERITAS observations triggered by *Fermi* & MAGIC
- **$z=0.939$ – 2nd most distant VHE emitter to date!**
 - Potential to probe the extragalactic background light (EBL)
- Coordinated multiwavelength observations
 - Potential to study the location of the emission zone

Discovery of Very High Energy Gamma-Ray Emission from the distant FSRQ PKS 1441+25 with the MAGIC telescopes

ATel #7416; **R. Mirzoyan (Max-Planck-Institute for Astrophysics)**
on 20 Apr 2015; 02:09 UT

Credential Certification: Masahiro Teshima (mteshima@mpa-garching.mpg.de)

Subjects: Gamma Ray, TeV, VHE, AGN, Blazar

Referred to by ATel #: [7417](#), [7433](#), [7459](#)

Tweet 9 Recommend 22

The MAGIC collaboration reports the discovery of Very High Energy (VHE; $E > 100$ GeV) gamma-ray emission from the FSRQ PKS 1441+25 (RA=22h 59m 59s DEC=+25d01m44s), located at redshift $z=0.939$ (Shaw et al. 2012, ApJ, 756, 122). The object was observed with the MAGIC telescopes for ~2 hours during the night of 17/18, and for ~4 hours during 18/19. A preliminary analysis of the data yields a detection with a statistical significance of more than 11 standard deviations for the night of April 17/18, and more than 11 standard deviations for 18/19. This is the first time a significant signal at VHE gamma rays has been seen from PKS 1441+25. T

**MAGIC Detection:
Announced
20 April 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@astro.columbia.edu)

Subjects: Gamma Ray, TeV, VHE, AGN, Blazar

Tweet 3 Recommend 2

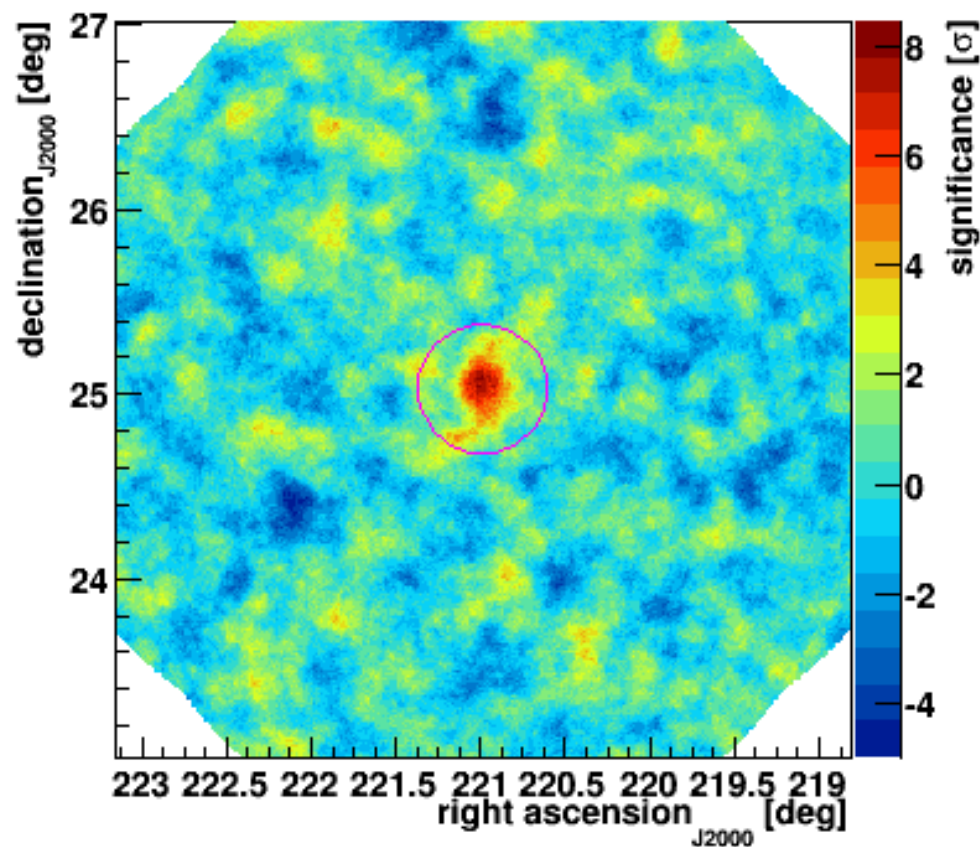
The VERITAS collaboration reports the discovery of Very High Energy (VHE) gamma-ray emission from the flat spectrum radio quasar PKS 1441+25 (RA=22h 59m 59s DEC=+25d01m44s) on the night of April 21, 2015 (UT). Observations were triggered by the detection of a significant signal from PKS 1441+25 with the MAGIC telescope (see ATel #7416). The VERITAS collaboration has also been recently detected (see ATel #7416). VERITAS observed the quasar for about 4 hours, detecting it at a significant level. Preliminary analysis indicates that the source flux was 8.0 ± 1.5 (stat) $\times 10^{-11}$ $\text{ph cm}^{-2} \text{s}^{-1}$ above 80 GeV. VERITAS will continue to monitor the source for the next few days (weather permitting). Multi-wavelength observations are highly encouraged. The VERITAS contact person is Reshmi Mukherjee (muk@astro.columbia.edu). VERITAS (Very Energetic Radiation Imaging Telescope Array

**VERITAS Detection:
Announced
23 April 2015**



VERITAS Detection of PKS 1441+25

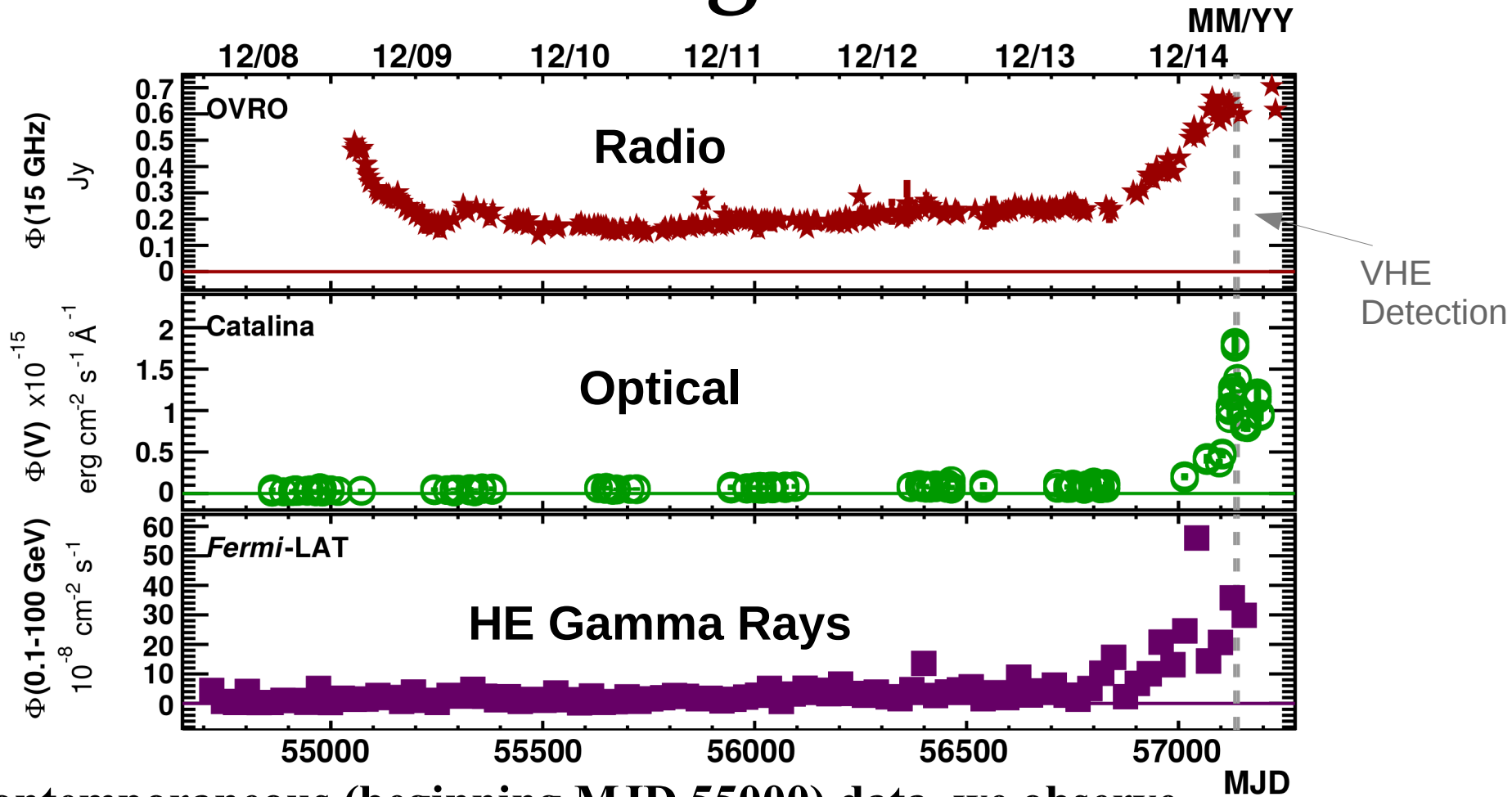
- VERITAS: An array of 4 Imaging Atmospheric Cherenkov Telescopes
- Southern Arizona
- Detection:
 - 21-28 April, 2015
 - 7.7σ in 15.0 hours
 - $\Phi (>80 \text{ GeV}) =$
 $(5.0 \pm 0.7) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$
- May 2015 observations show no detection



VERITAS Sky map of
PKS 1441+25 during April, 2015



2008-2015 Light Curve



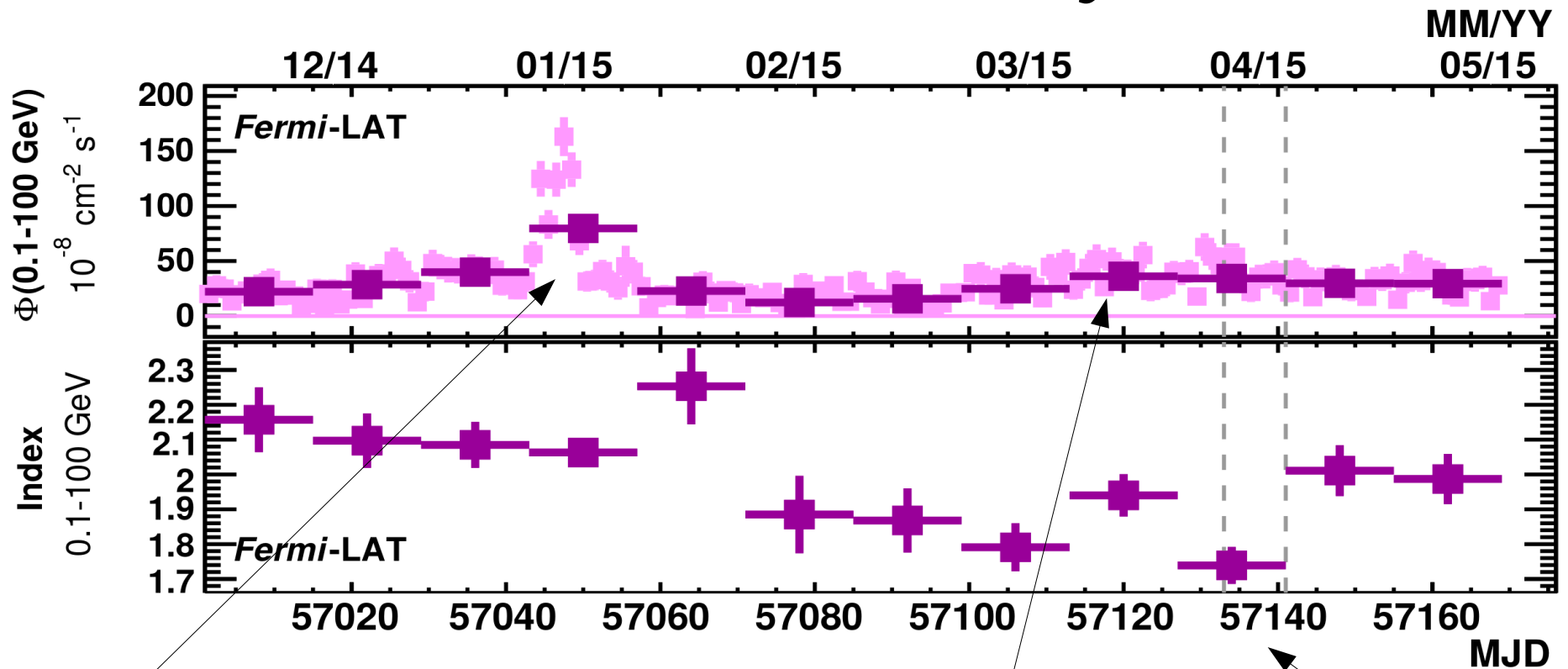
Using contemporaneous (beginning MJD 55000) data, we observe correlated brightening of the source beginning MJD ~ 56900 (Sept. 2014)
 Suggests large-scale emission, located where synchrotron self-absorption is small.

Radio – Gamma rays Pearson correlation coefficient: 0.75 ± 0.02 (5.4 sigma)

Optical – Gamma rays Pearson correlation coefficient: 0.89 ± 0.02 (4.8 sigma)



Fermi-LAT: December 2014-May 2015



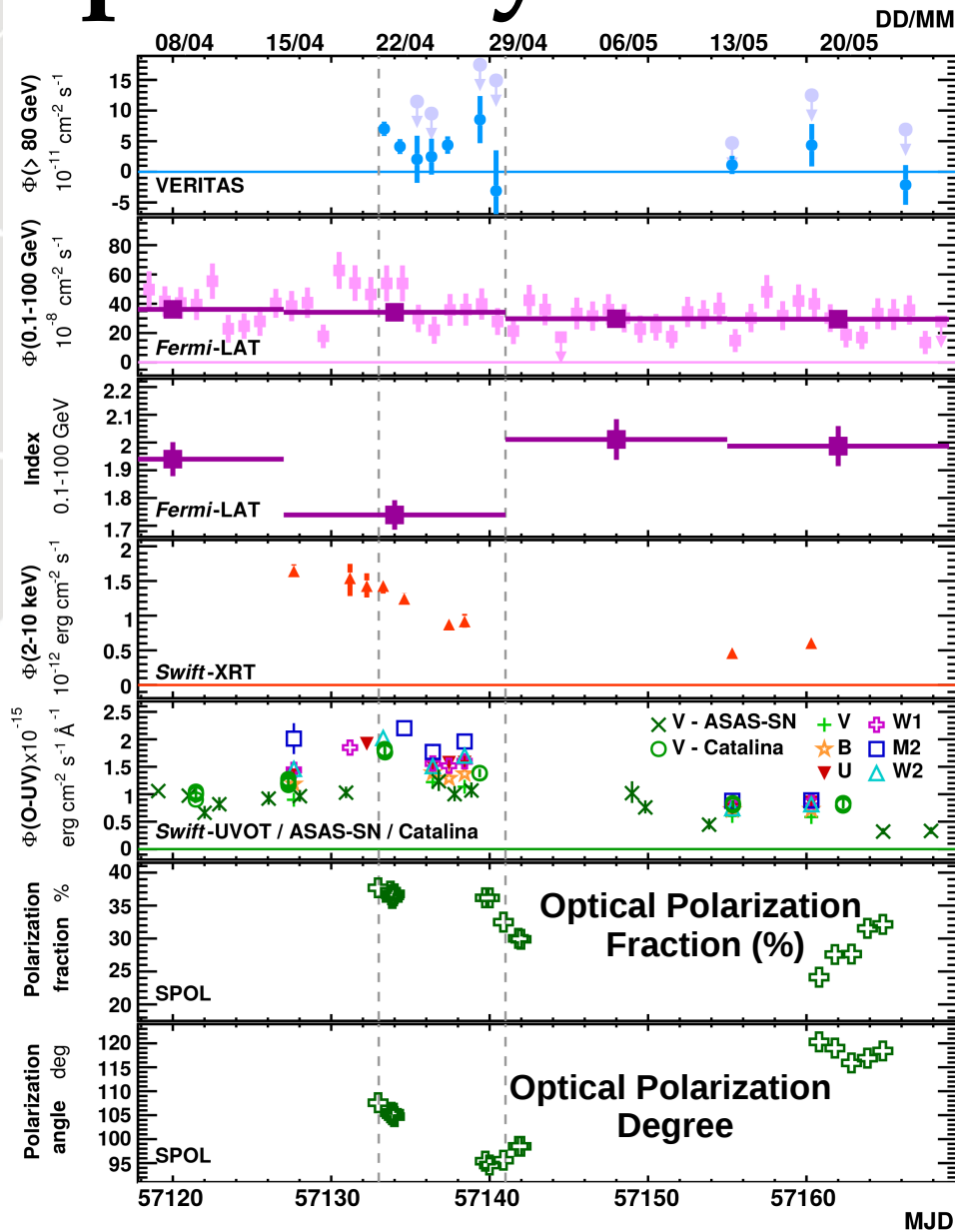
Interestingly, this FSRQ underwent a more significant flare during January 2015.
(See Atel #6878 from LAT Collab.)

Brightening during April, 2015.

Harder during VERITAS detection
Potentially a good way to trigger VHE observations!



April-May 2015 MWL Light Curve



Elevated optical, X-ray, and Fermi-LAT flux during the VERITAS detection.

Harder LAT spectrum during VERITAS detection

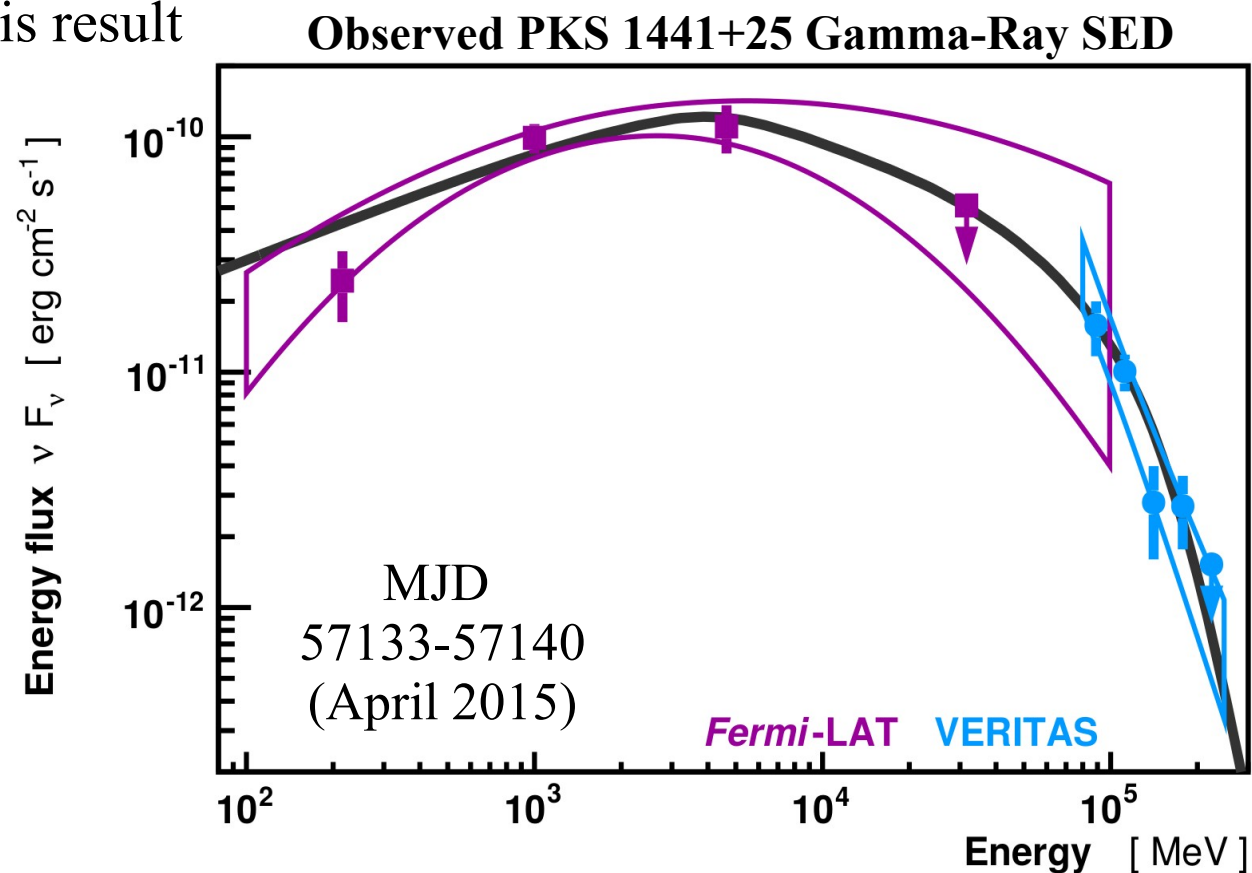
Very high flux polarization fraction (in optical) + high radio polarization, among the highest in the MOJAVE blazar sample

MJD 57133-57140 (grey lines): active phase for SED & EBL reconstruction

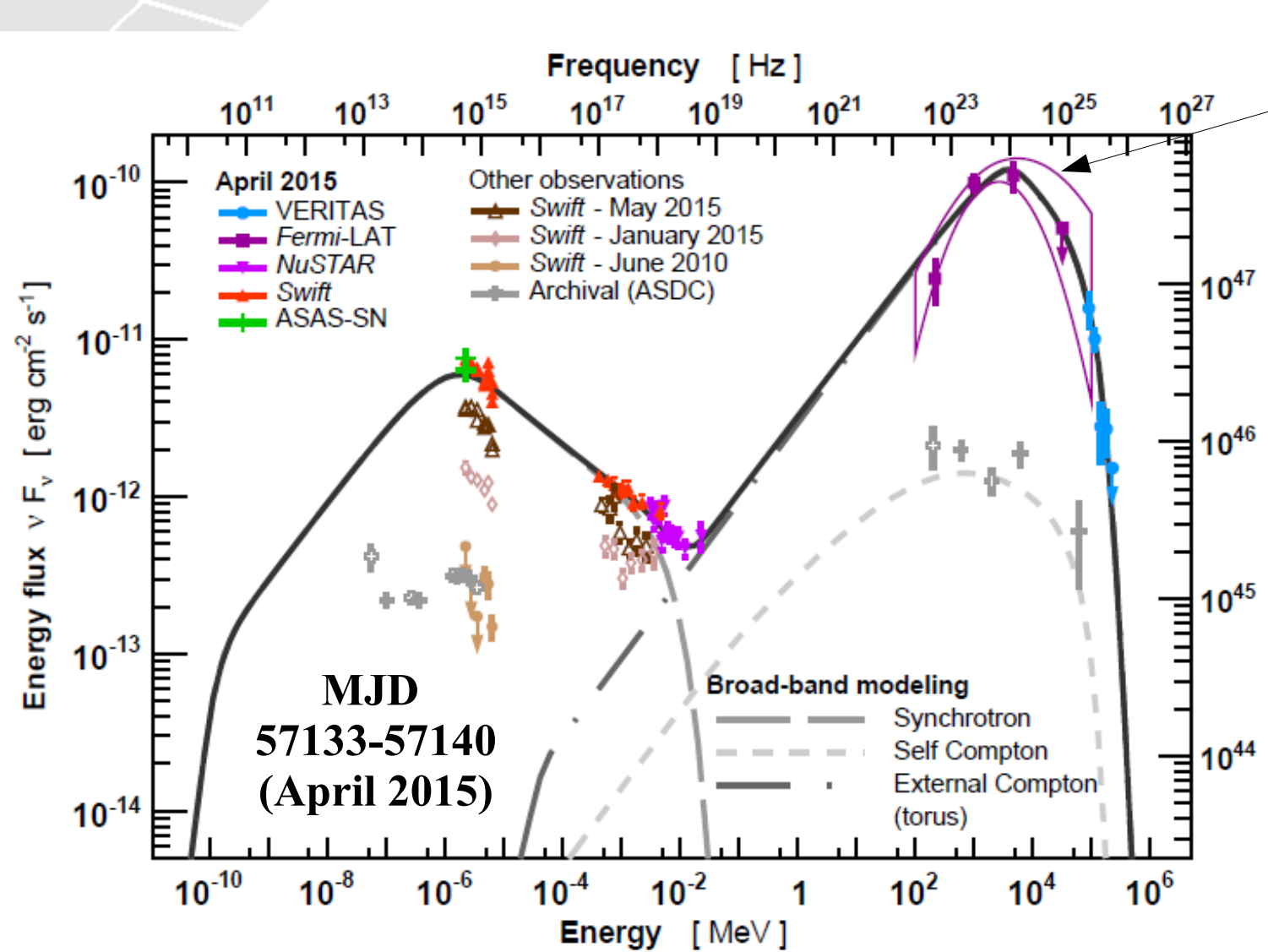


Gamma-ray Observations

- Excellent gamma-ray coverage from the ground & from space:
 - *Fermi*-LAT, VERITAS and MAGIC
- Preference for curvature (3.2σ) seen in *Fermi*-LAT spectrum
 - Pass 8 data strengthens this result
 - 2.7σ pref. using Pass 7
 - MJD 57113 – 57140
- VERITAS data:
 - $\Gamma_{\text{VHE,measured}} = 5.3 \pm 0.5$
- Good continuity and energy coverage by combing the instruments' data



Broadband SED



~100x flux increase compared to archival data

Model parameters are similar to those of other FSRQs

High break in e-spectrum to explain optical to X-ray data

Jet Lorentz factor ~ 12
Jet opening angle $\sim 4.8^\circ$

Min. variability time scale in observer frame: comparable to flux halving in X-rays of ~ 2 weeks



Constraining the Location of the Emitting Region

Strict Lower Limit on Distance to BH: Estimate on more precise distance to BH:
> 5,000 Schwarzschild Radii ~200,000 Schwarzschild Radii

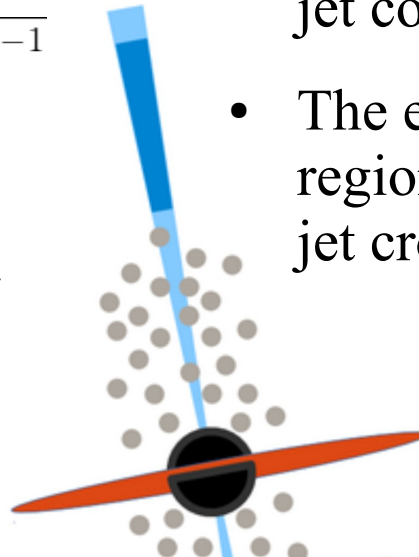
- Detection of >100 GeV photons (>200 GeV in galaxy's rest frame)
 - Must originate outside the BLR to avoid pair production

- Radius of the BLR:

$$r_{BLR} \simeq 10^{17} \text{ cm} \sqrt{L_{disk}/10^{45} \text{ erg s}^{-1}}$$

- $r_{BLR} \sim 0.03 \text{ pc} \sim 5,000 R_{Schw}$
- Based on $M_{BH} = 10^{7.83 \pm 0.13} M_{solar}$ (Shaw+12)

- Use the simplest single zone emission model
 - Consistent with the SED & MWL variability
- Assume the whole cross-section of the jet contributes; and we know $R \sim 0.1 \text{ pc}$
- The emission could be further if the region only takes up a fraction of the jet cross-section.



Constraining the EBL

- Combination & continuity of *Fermi*-LAT & VERITAS data allows us to constrain the EBL from ~ 0.2 - $2.0 \mu\text{m}$:

Simultaneously fit the VHE spectrum and the EBL normalization:

$$\chi^2 = \sum_{i=1..n} \frac{(\phi_i - \phi_0 \times e^{-\Gamma \log(E_i/E_0) - \alpha \tau(E_i)})^2}{\sigma_{\phi_i}^2} + \Theta(\Gamma_{\text{LAT}} - \Gamma) \times \frac{(\Gamma_{\text{LAT}} - \Gamma)^2}{\sigma_{\Gamma}^2},$$

with free: α , Γ , and Φ_0

$$\Gamma_{\text{LAT}} = 2.76 \pm 0.43$$

Φ_i = VERITAS flux at E_i

$$E_0 = 120 \text{ GeV}$$

Account for uncertainty on index: $\sigma_{\Gamma} = 0.5$

This formula allows for a VHE spectrum softer, but not harder, than the HE one.

We constrain $\alpha < 1.5$ at 95% c.l.

Using 3 EBL models:

Gilmore et al. 2012

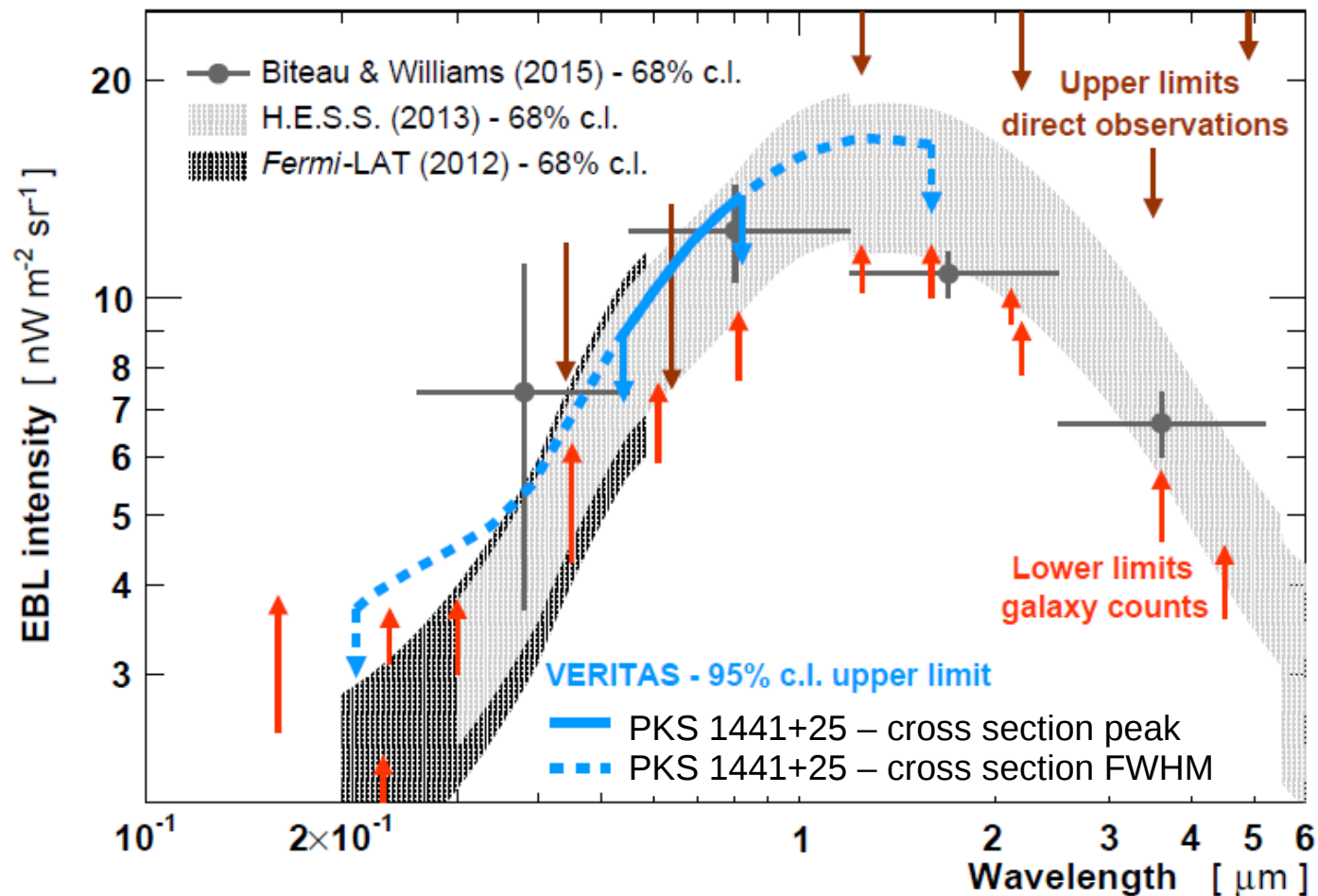
Franceschini et al. 2008

Dominguez et al. 2011



Constraining the EBL

- Combination & continuity of *Fermi*-LAT & VERITAS data allows us to constrain the EBL from ~ 0.2 - $2.0 \mu\text{m}$:



PKS 1441+25 in Context

- 5th VHE FSRQ detected; 2nd most distant VHE emitter
- Expanding the size of the observed VHE universe
- Dimmest HE source in the 3FGL also detected at VHE
 - Important step in understanding the class
- Correlation between optical, radio & high energy – first solid evidence in an FSRQ
- Highlights the importance of MWL triggering of VHE observations
 - Hardening at HE is a good VHE trigger
- Emitting region >0.03 pc ($\sim 5,000 R_{\text{Schwarzschild}}$) from the black hole
- First stringent upper limit on the EBL placed by a single source



Thank you! Questions?



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