Recent Observations of Active Galactic Nuclei with H.E.S.S.

Robert Wagner
for the H.E.S.S. Collaboration

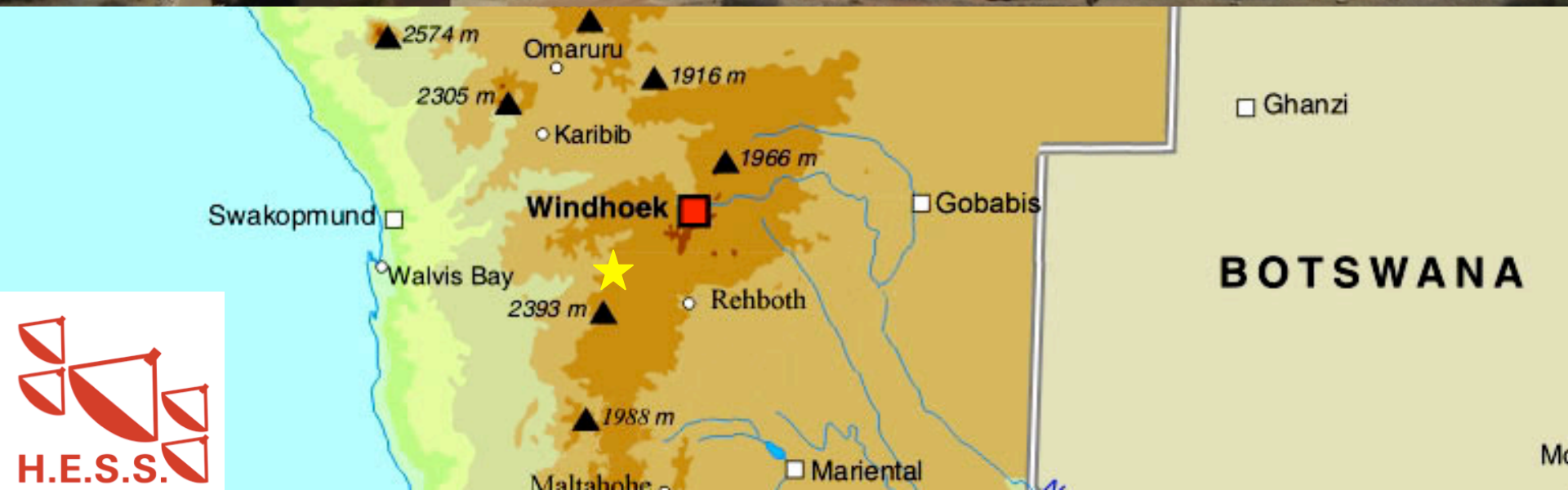
H.E.S.S.

Stockholms universitet

H.E.S.S.

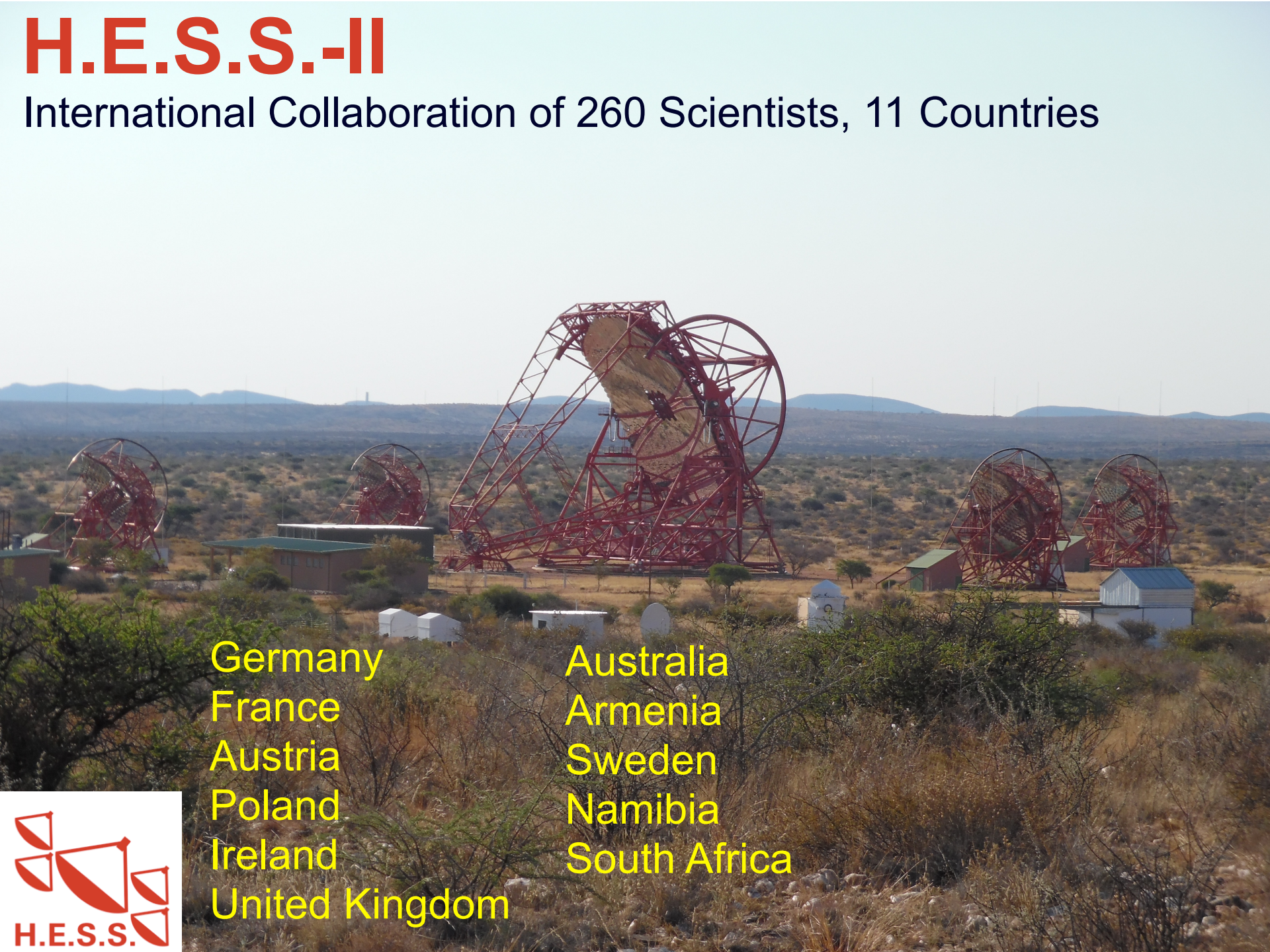
High Energy Stereoscopic System

Khomas Highlands, near Windhoek, Namibia



H.E.S.S.-II

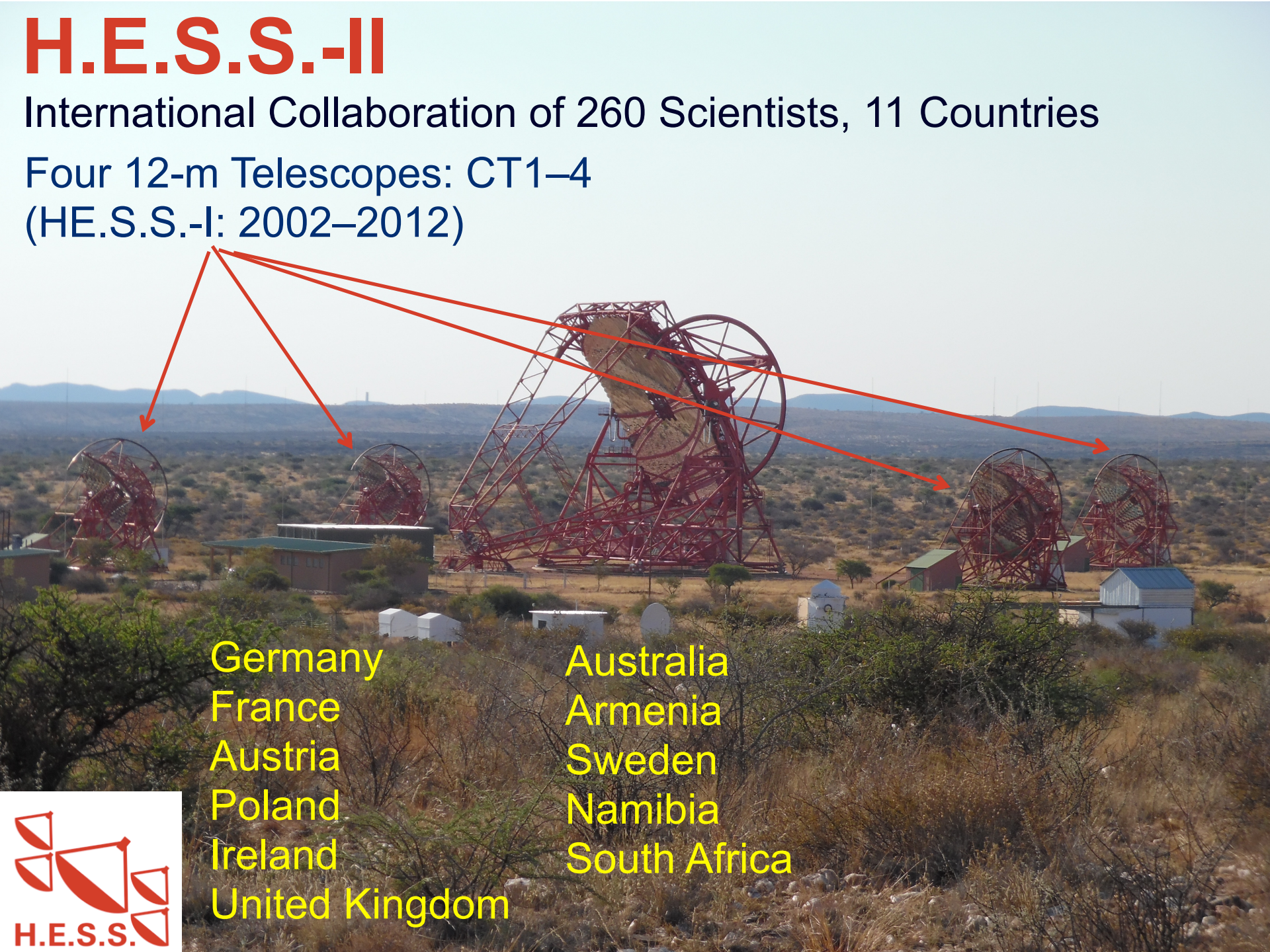
International Collaboration of 260 Scientists, 11 Countries



H.E.S.S.-II

International Collaboration of 260 Scientists, 11 Countries

Four 12-m Telescopes: CT1–4
(HE.S.S.-I: 2002–2012)



Germany
France
Austria
Poland
Ireland
United Kingdom

Australia
Armenia
Sweden
Namibia
South Africa

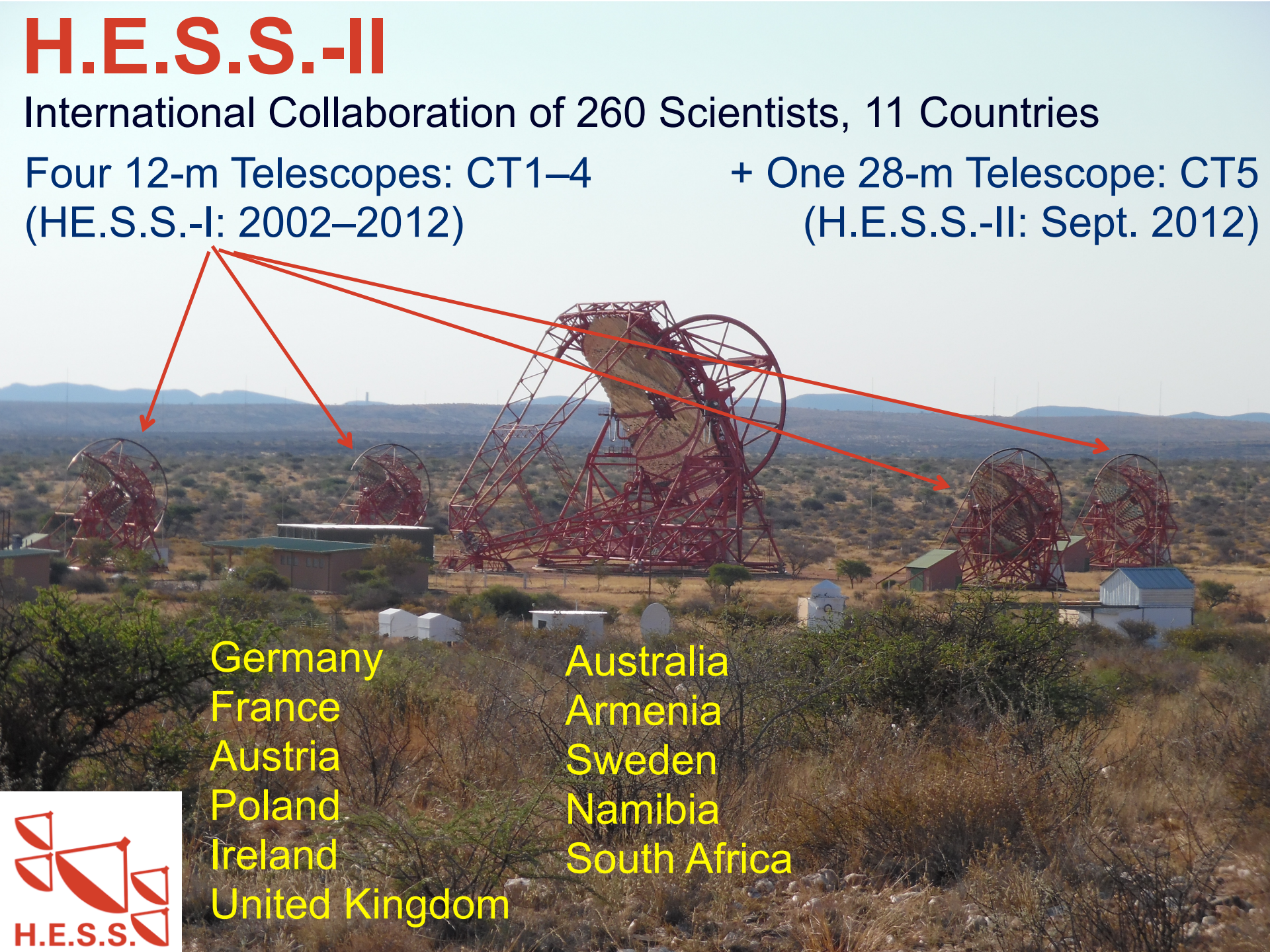
H.E.S.S.

H.E.S.S.-II

International Collaboration of 260 Scientists, 11 Countries

Four 12-m Telescopes: CT1–4
(HE.S.S.-I: 2002–2012)

+ One 28-m Telescope: CT5
(H.E.S.S.-II: Sept. 2012)



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Poland
Ireland
United Kingdom

Australia
Armenia
Sweden
Namibia
South Africa

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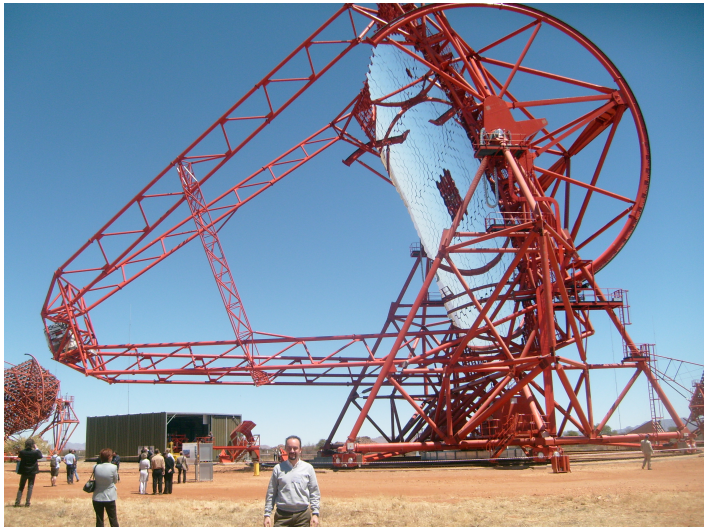
H.E.S.S.-II Observations/Analyses

- CT5 Mono: Only CT5 data
  → Lowest energy threshold
  (< 100 GeV)



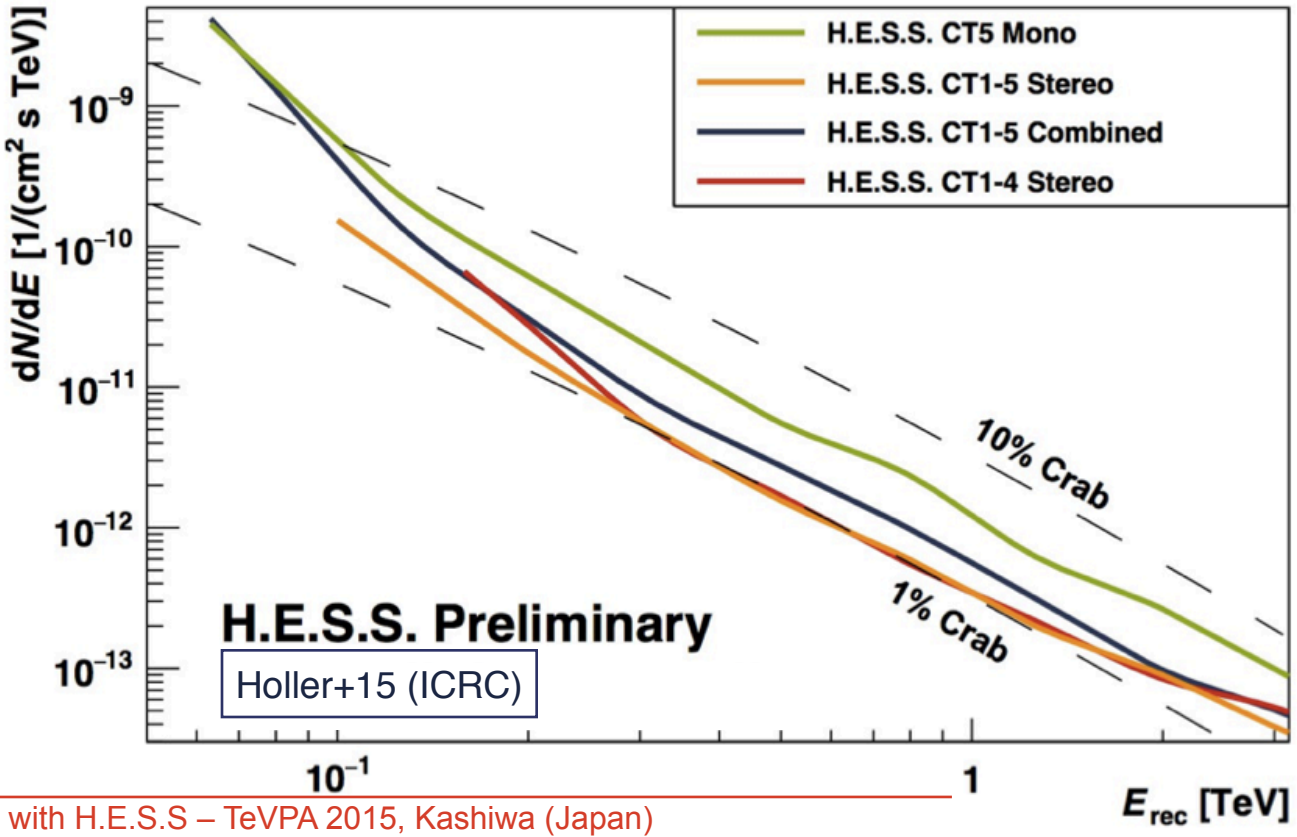
- HESS-II Hybrid:
  Complete array (CT1 – 5):
  → Best background rejection,
  → slightly higher energy threshold than CT5 mono

H.E.S.S.-II Observations/Analyses

Two types of triggers supported: mono (CT5) and stereo (any two or more telescopes in coincidence)

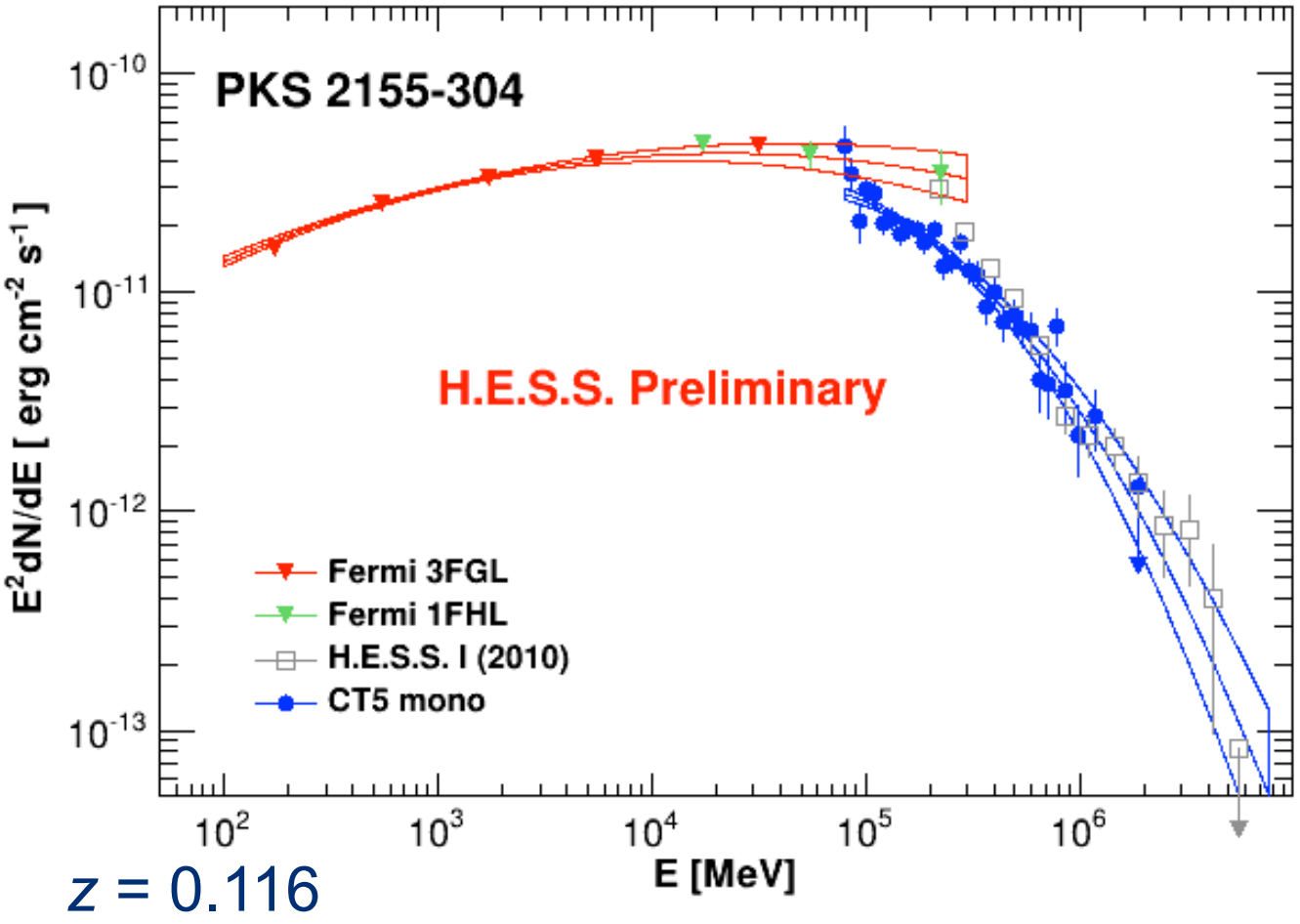
- Stereo data analysis similar to H.E.S.S. I (some adaptations to deal with two telescope types)
- Mono data analysis relies on the finely-pixelated CT5 camera images
- For more technical aspects see

Zaborov+15 (ICRC)



CT 5 Mono Observations of Blazars

- Significant overlap with Fermi-LAT
- Excellent agreement with H.E.S.S.-I (CT1-4)



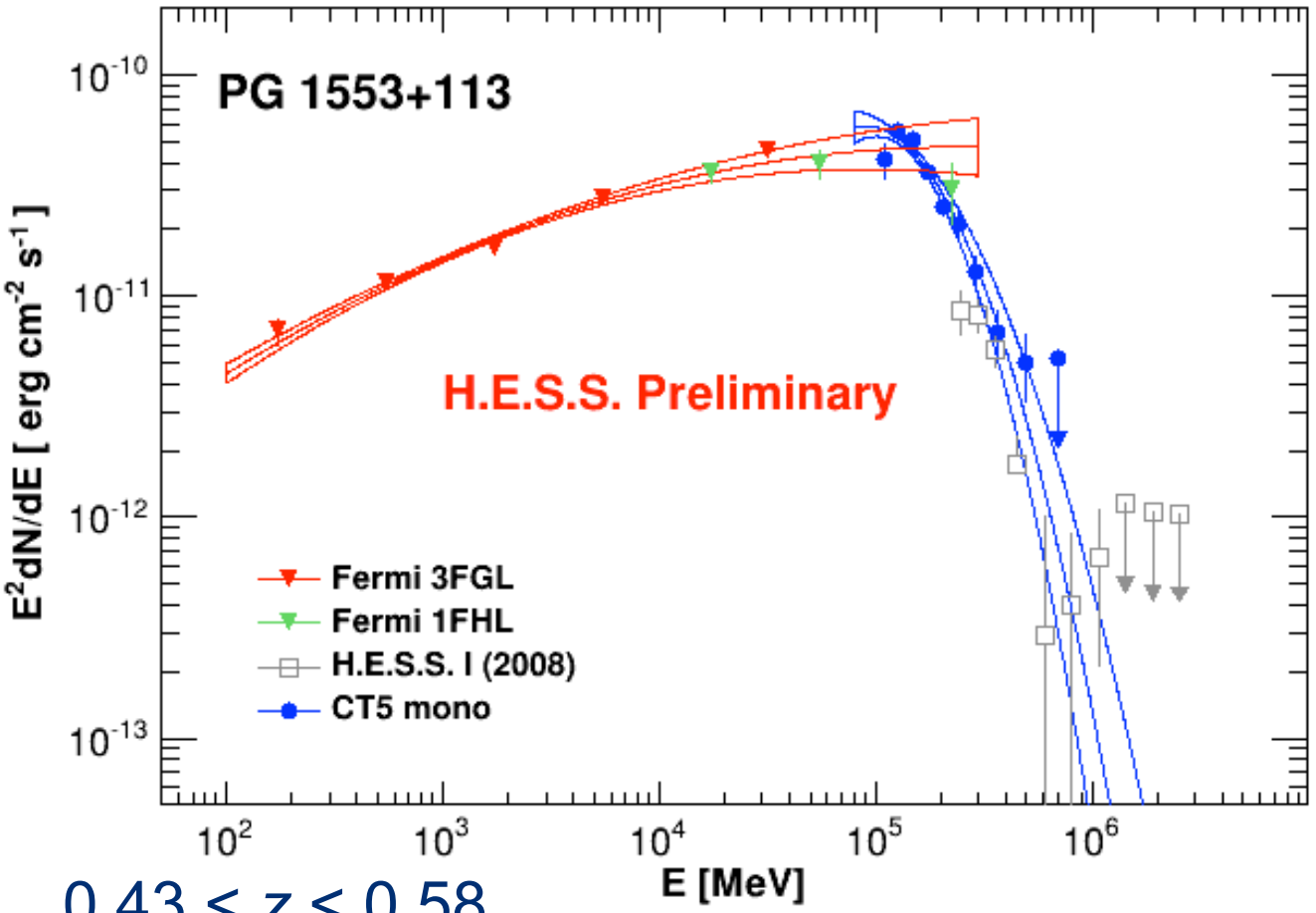
$z = 0.116$

- detected at ≈ 40 σ (CT5 mono standard cuts)
- energy threshold ≈ 80 GeV
- significance distribution does not show any unexpected features
- source is detected at 10 σ, using only gamma-like air shower events with reconstructed energy < 100 GeV
- width of significance distribution indicates presence of a (small) systematic effect in background subtraction

(D. Zaborov)

CT 5 Mono Observations of Blazars

- Significant overlap with Fermi-LAT
- Excellent agreement with H.E.S.S.-I (CT1-4)



$0.43 < z < 0.58$

- detected at > 25 σ (CT5 mono loose cuts)
- energy threshold ≈ 100 GeV
- significance distribution does not show any unexpected features
- analysis in 3 energy bins equally spaced in log of reconstructed energy between 100 and 250 GeV
- detected at 10 σ in first energy bin, at > 15 σ in second and third bins, resp.

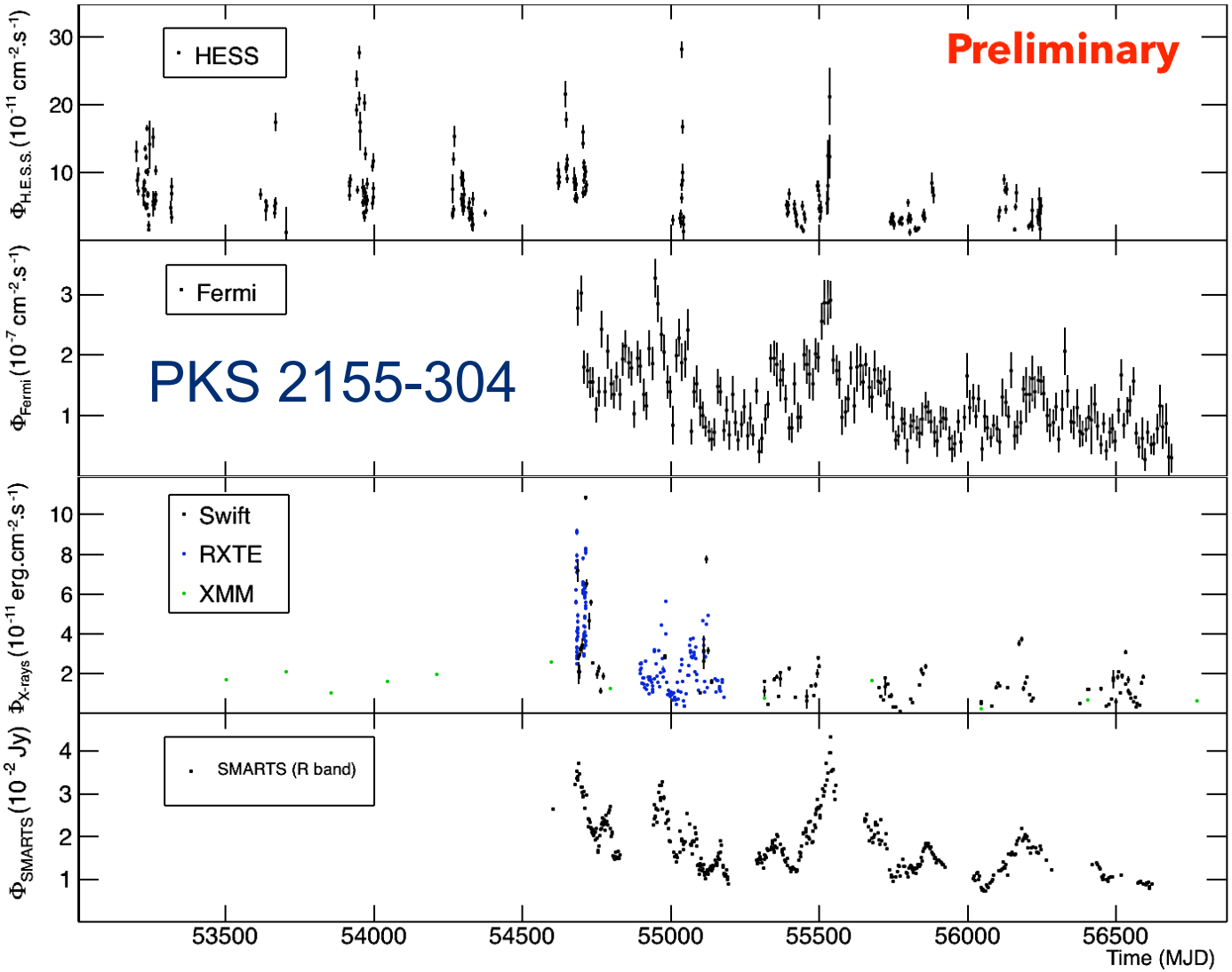
(D. Zaborov)

H.E.S.S.-II Extragalactic Observing Program

- **ToO observations** & long-term monitoring of known VHE AGN
  - Particle acceleration / particle content / site of γ-ray emission region(s)
  - Physics beyond the standard model (LIV)
- Discovery of new potential VHE sources (including radio galaxies, radio-quiet AGN and non-active galaxies)
  - Population studies
  - EBL studies (see Schüssler/H.E.S.S. coll., this meeting)
  - Origin of cosmic rays
- Gravitationally lensed blazars
- **GRB follow-up (prompt and early afterglow)**
- IceCube neutrino counterparts
- Search for dark matter annihilation signatures

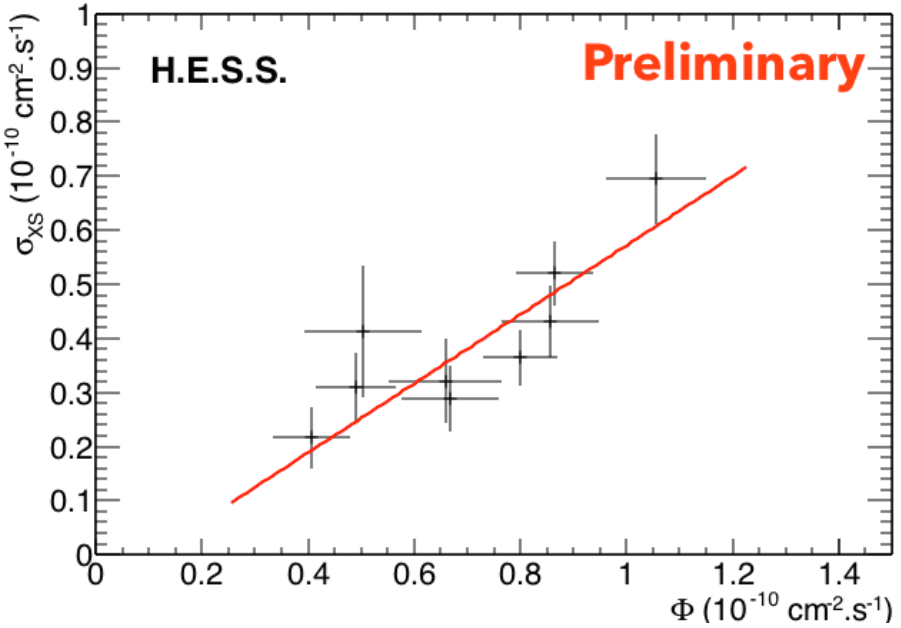
Long-term monitoring of known TeV blazars

≈13 year time line since H.E.S.S.-I first light



(J. Chevalier)

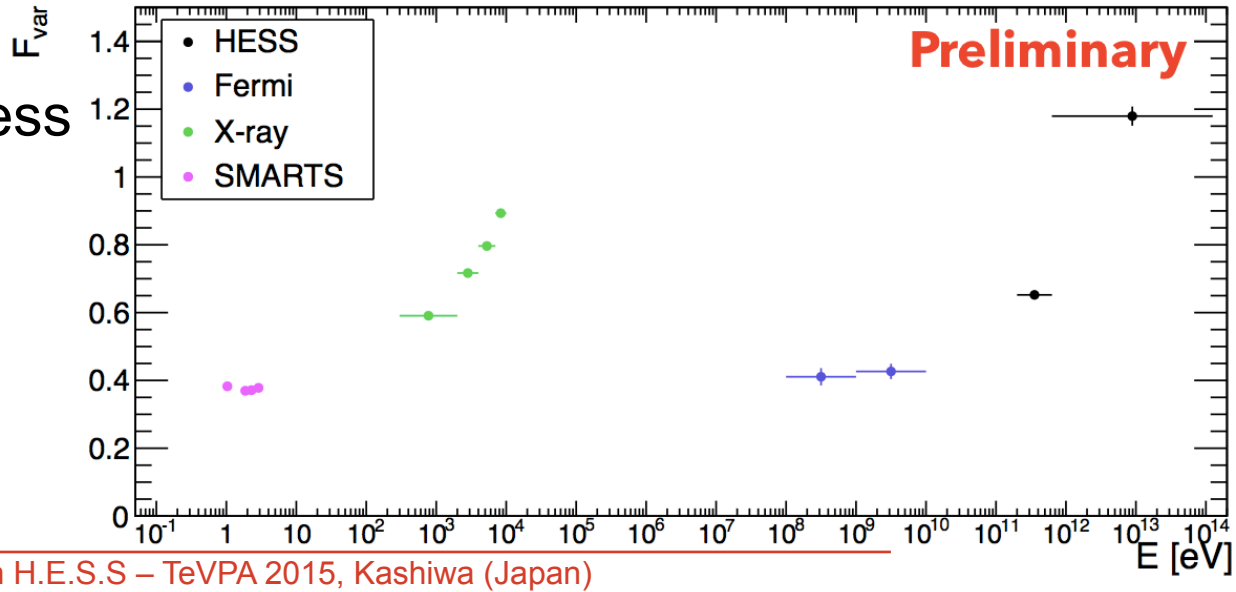
Long-term monitoring of known TeV blazars



PKS 2155-304

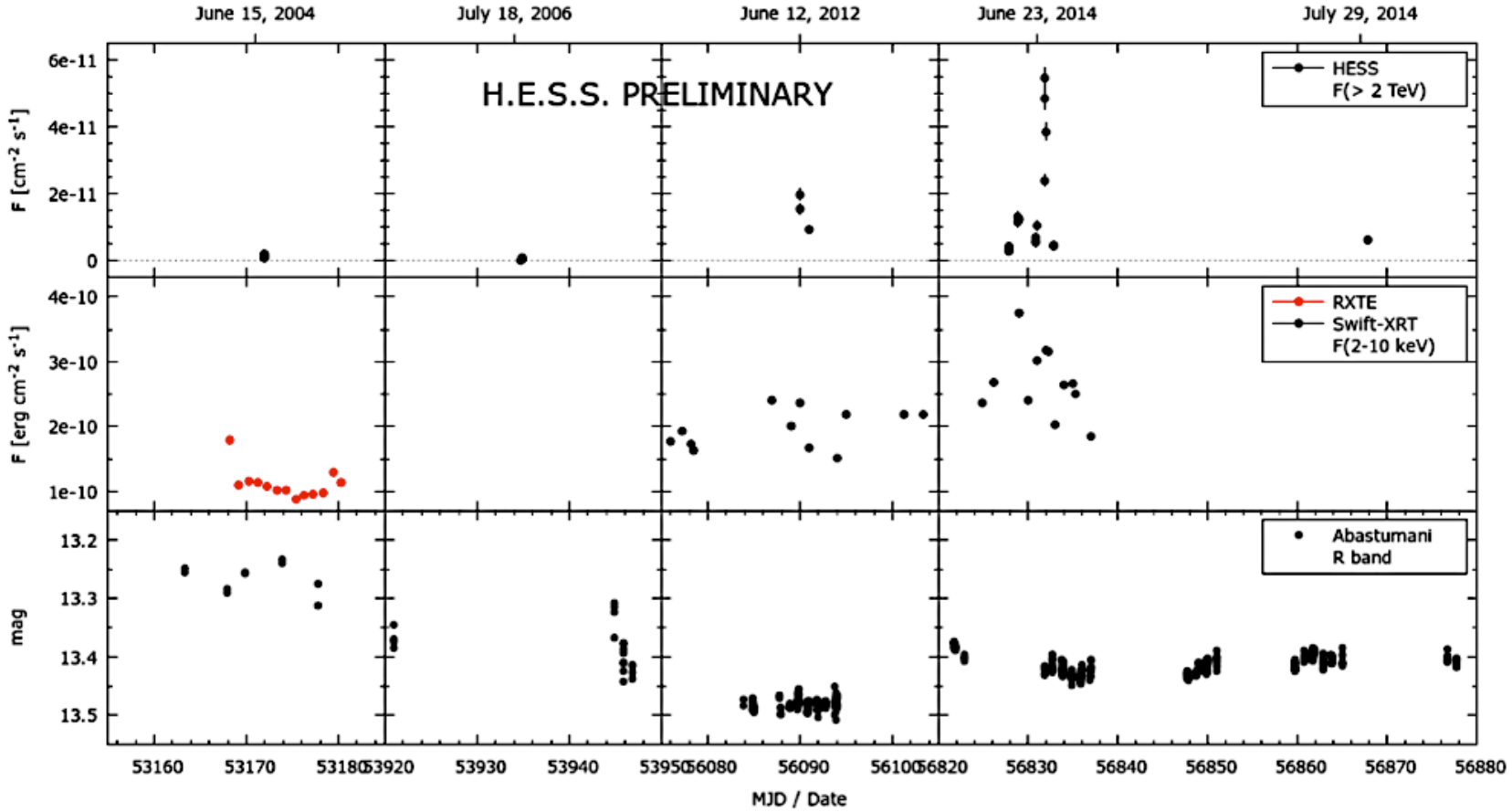
Fractional variability amplitude F_{var} increasing throughout SED components

Excess rms variability
σ_{xs} ~ flux Φ
→ Multiplicative process



(J. Chevalier)

Mkn 501 at multi-TeV energies 2004-2014



No obvious correlation of the variability in different bands
No correlation of optical and X-rays

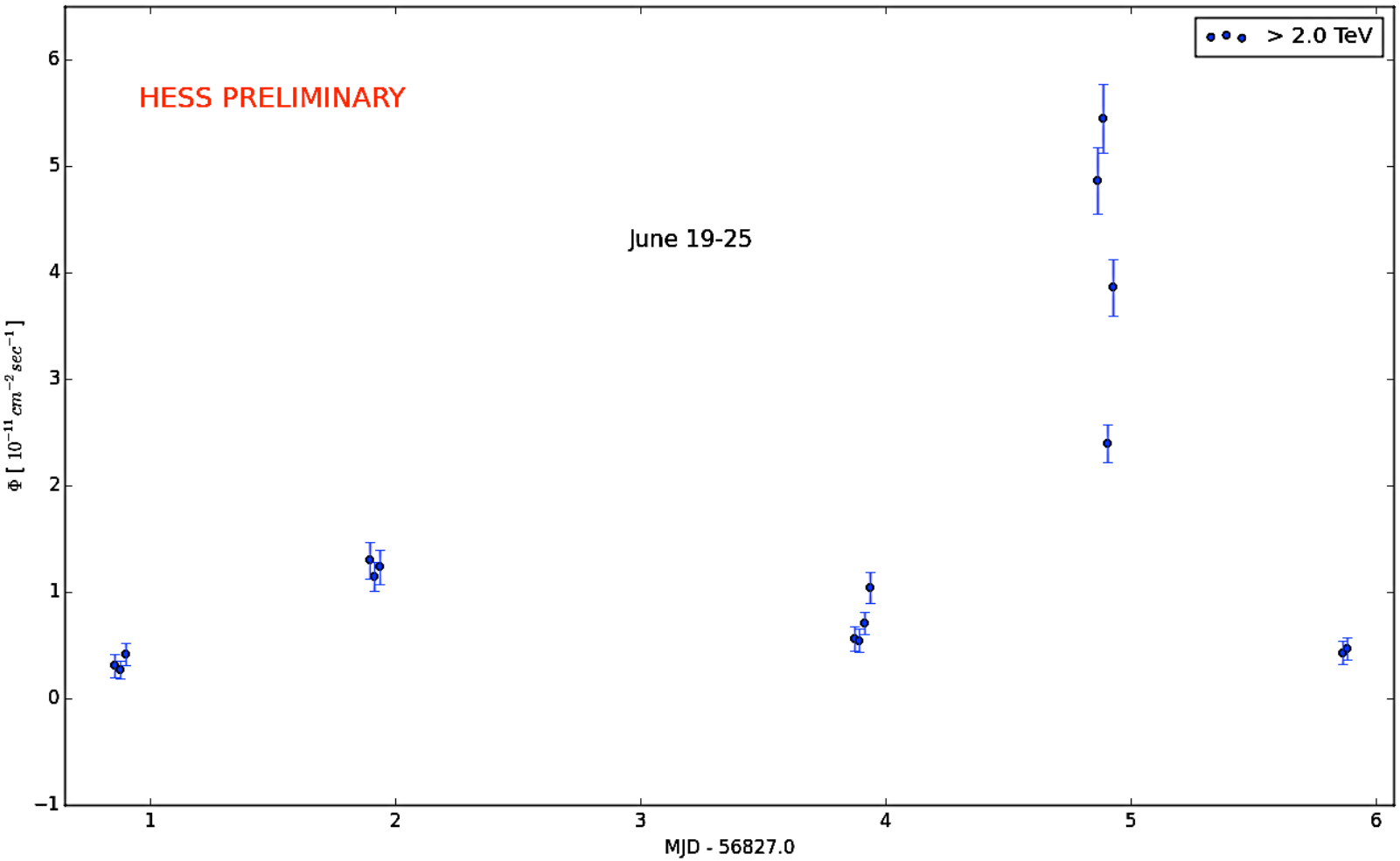
→ two or more zones/mechanisms needed

(G. Cologna)

Rapid variability at multi-TeV energies

Major flaring state in June 2014

Run-by-run light curve

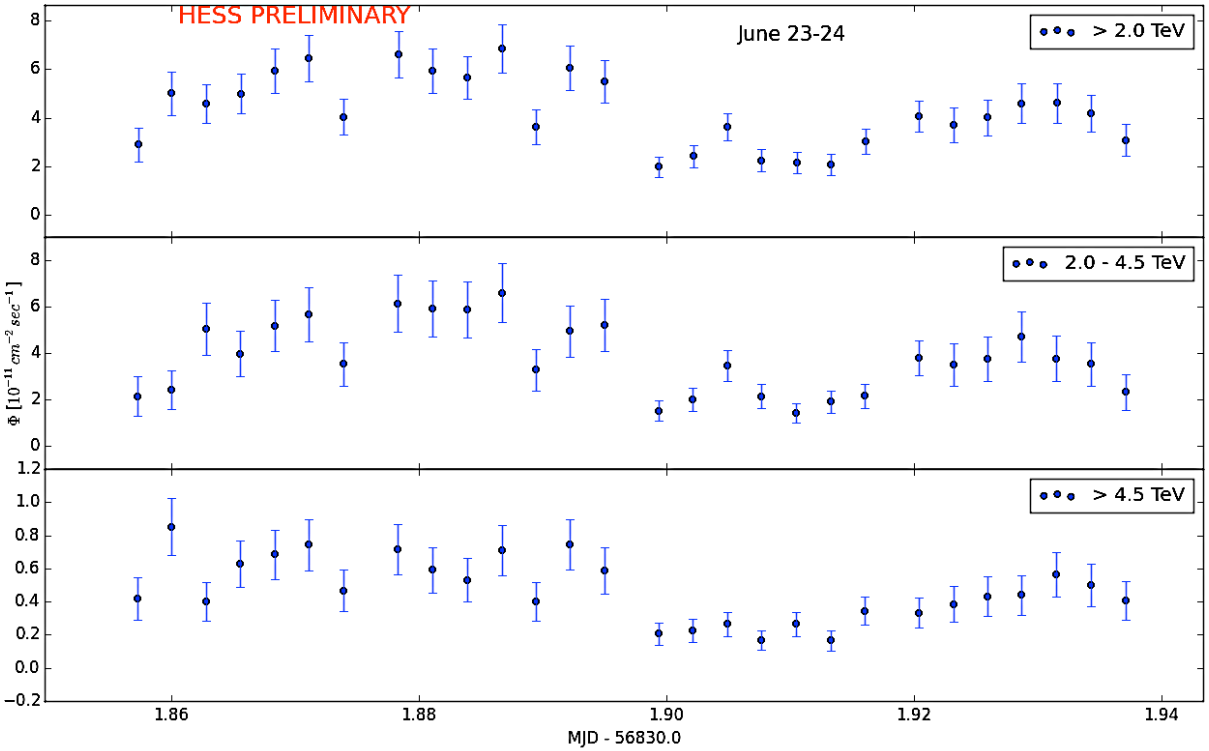


(G. Cologna, N. Chakraborty)

Rapid Variability at multi-TeV energies

Major flaring state in June 2014

4-minute binned light curve



τ_{min} (> 2 TeV) < 10 min!

- Flux doubling time scale < 10 minutes
- X-rays observations follow VHE ones by ~ 90 min
- 4 x TeV flux in 90 min
- (Assuming SSC model, quadratic correlation expected)

(G. Cologna, N. Chakraborty)

Statistical Analysis of Time-Domain Behavior

Probability Distribution Function: Lognormality

Flux probability distribution function: PDF of $F(E>2\ \text{TeV})$ lognormal distribution

→ multiplicative processes (vs. additive processes/normal distribution)

→ similar to PKS 2155-304 flaring in 2006
with very similar linear excess flux – RMS correlation

Abramowski+10
Chevalier+15

may be a natural outcome of a "cascade-like"
hadronic scenario or an intrinsic jet-disk connection

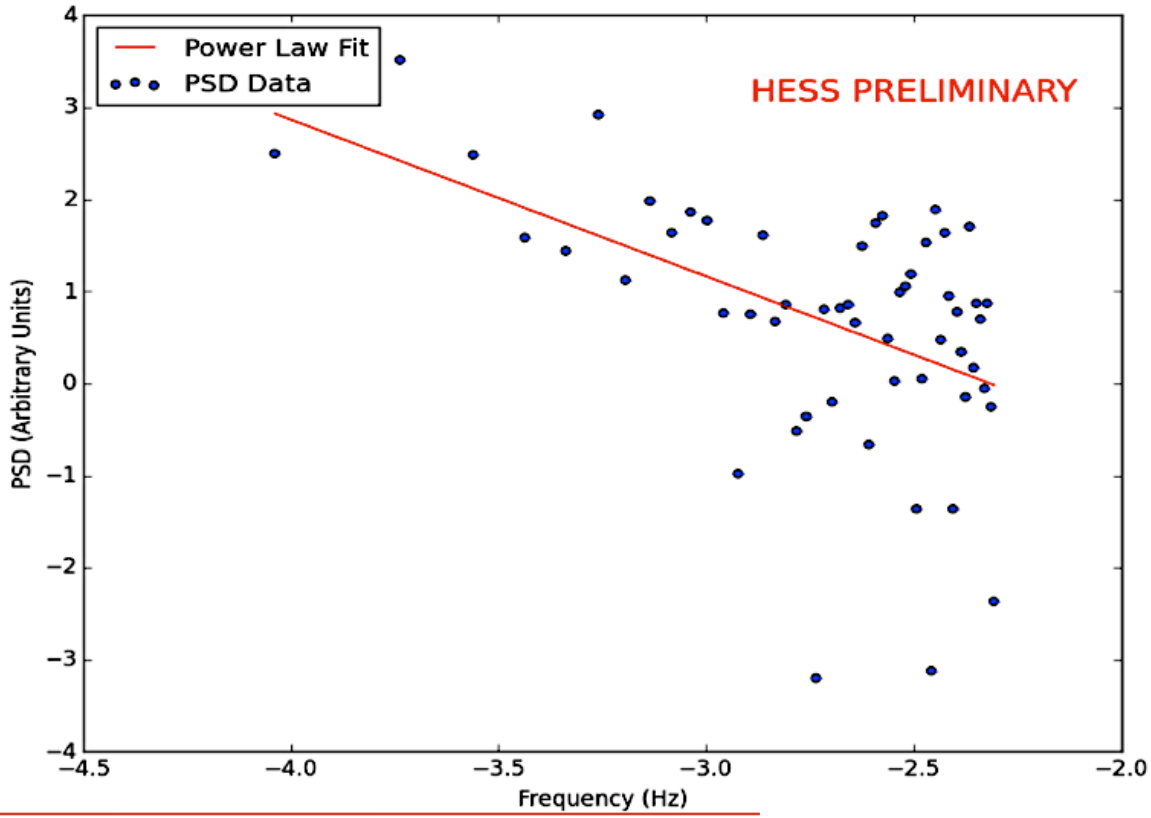
Power Spectral Density (PSD):

single power law of index 1.7

→ similar to the flaring state of PKS 2155-304 that had an red-noise index of ≈ 2.0

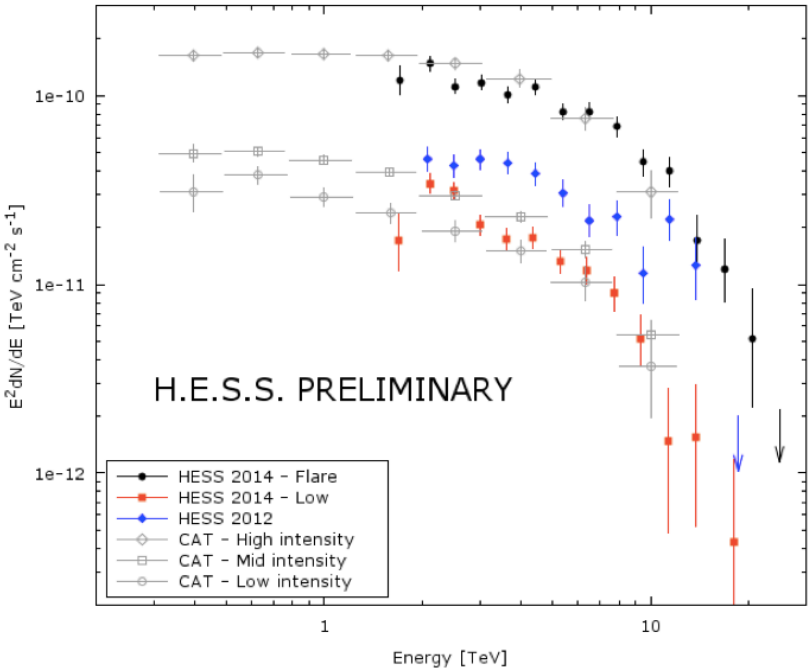
bin size of 4 minutes:
fluctuations at frequencies

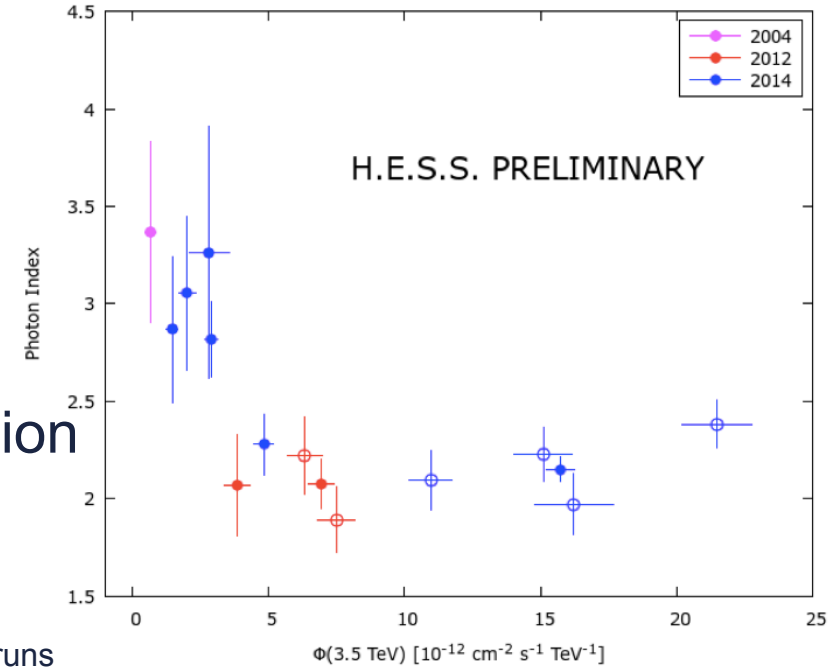
higher than $\approx 2 \times 10^{-3}$ are suppressed.



Mkn 501: Spectra

- Spectra clearly curved
- EBL absorption, $\tau \geq 1$ expected above ≈ 8 TeV (Franceschini et al 2008)
- PL+EBL fit:
  - 2014 flare: $\Gamma = 2.15 \pm 0.06_{stat} \pm 0.2_{sys}$
  - 2012: $\Gamma = 2.2 \pm 0.1_{stat} \pm 0.2_{sys}$
  - 2014 low: $\Gamma = 2.7 \pm 0.1_{stat} \pm 0.2_{sys}$
- CPL/CPL+EBL do not improve fit
  → No signs of Klein-Nishina suppression

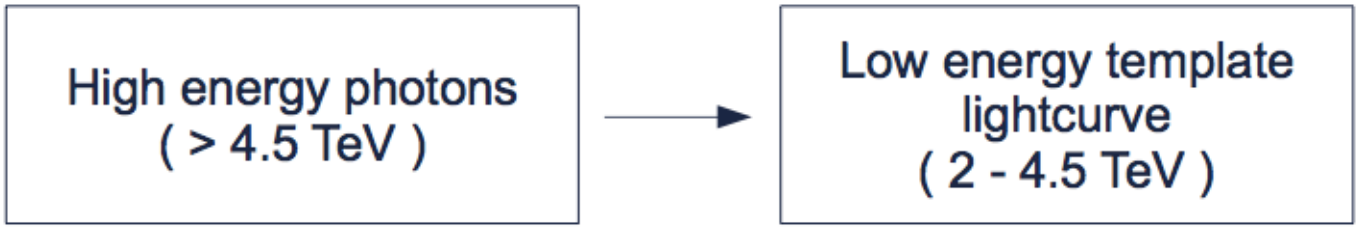




Full circles: nights Open circles: runs

Mkn 501: LIV Studies

- Hard energy spectrum: Promising for LIV Studies
- Methodology: Template Lightcurve as in H.E.S.S. Coll. 2011

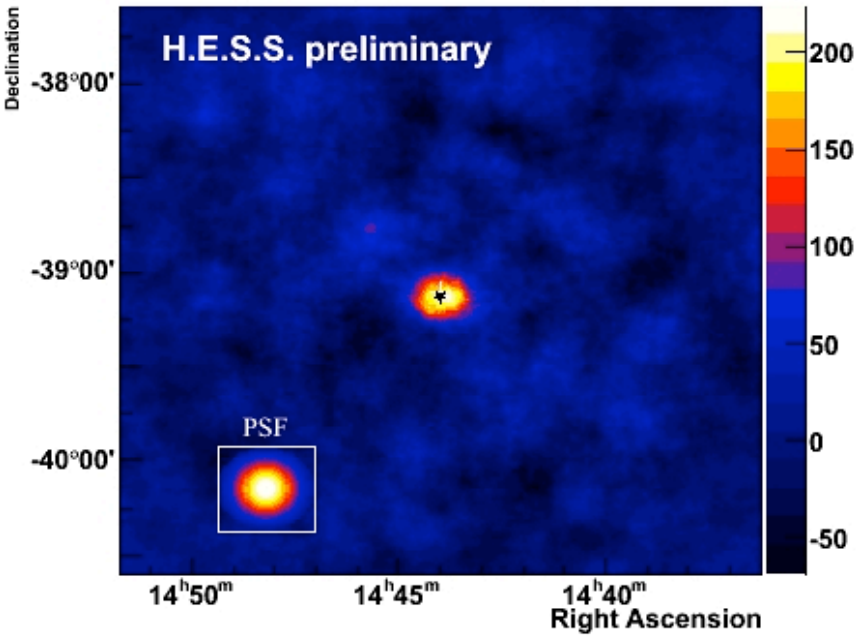


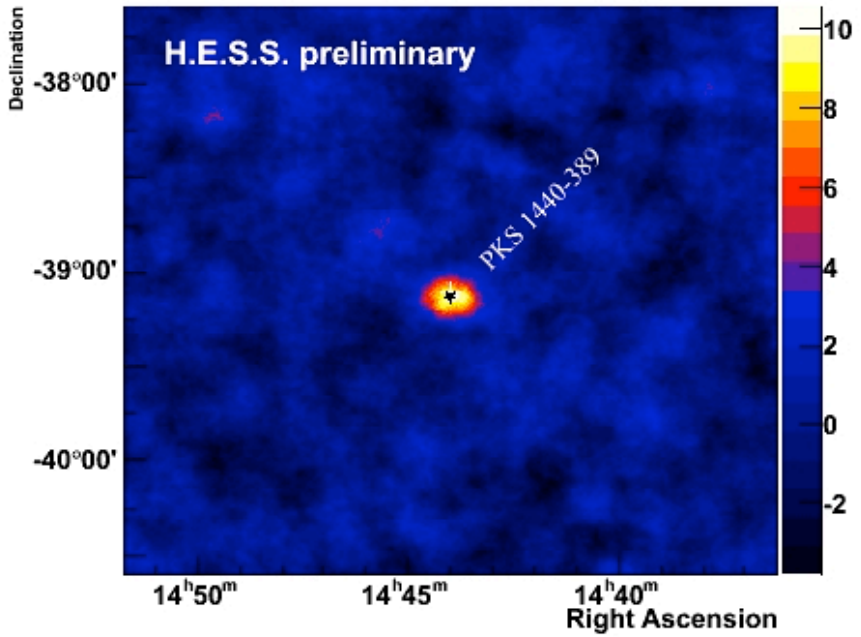
95% CL Quantum Gravity limits		
	Linear term	Quadratic term
Sub-luminal	8.5×10^{17} GeV	1.15×10^{11} GeV
Supra-luminal	6.4×10^{17} GeV	1.0×10^{11} GeV
PKS 2155-304 (sub.)	2.1×10^{18} GeV	6.4×10^{10} GeV
GRB 090510 (sub. / sup.)	(1.8×10^{19} / 3.2×10^{19}) GeV	(4.0×10^{10} / 3.0×10^{10}) GeV
Mrk 501 (MAGIC 2005)	2.1×10^{17} GeV	2.6×10^{10} GeV

Best limits on the quadratic term yet!

New Discoveries: PKS 1440-389

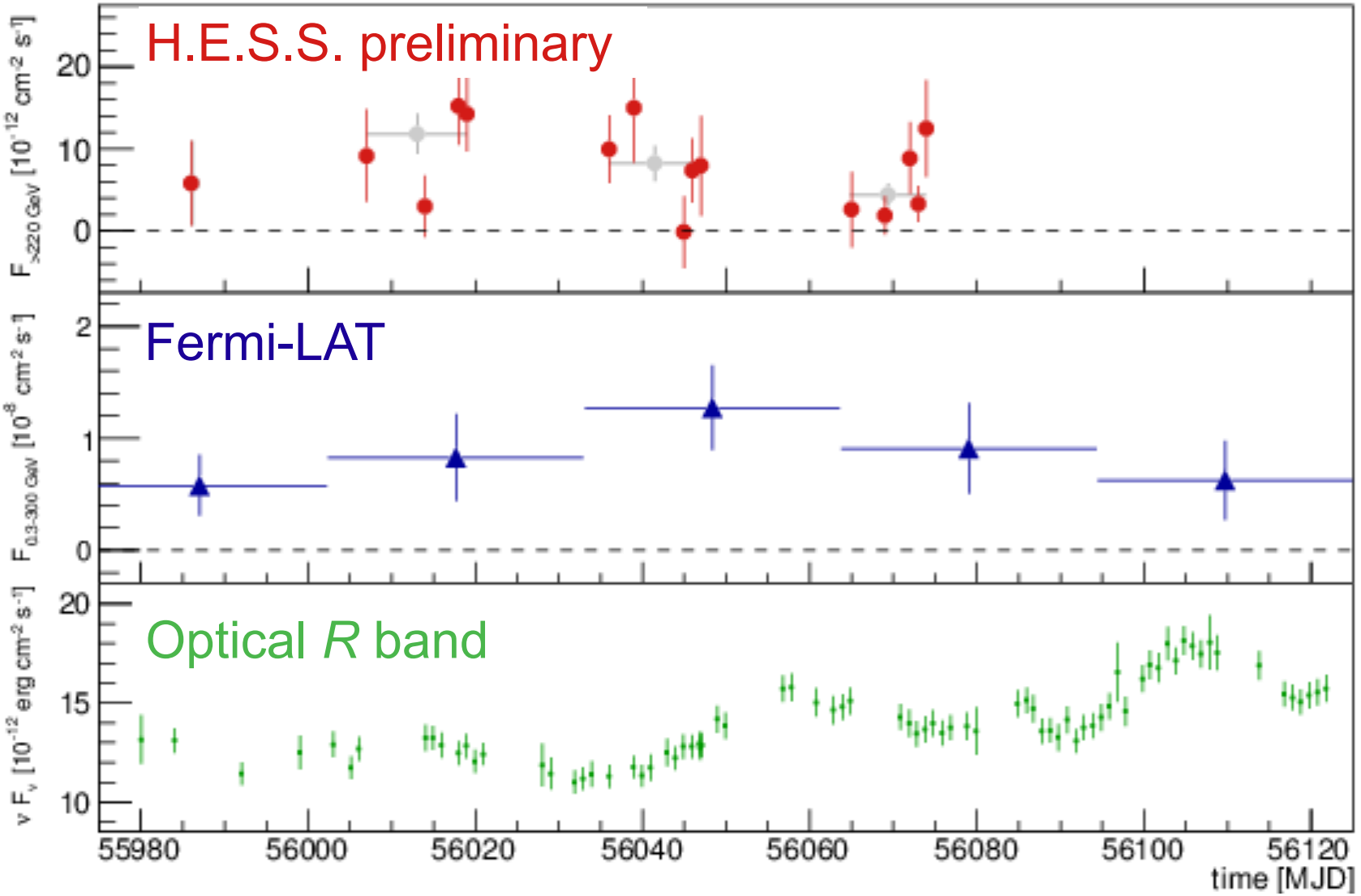
- HBL at uncertain redshift:
  - $z = 0.065$ (preliminary 6dF Galaxy Survey);
  - $0.14 < z < 2.2$ (Shaw et al. 2013)
- H.E.S.S. observations motivated by hard Fermi-LAT spectrum: $\Gamma_{2FGL} = 1.77 \pm 0.06$
- Total live time of ≈12 h during Feb. 29–May 27, 2012
- 183 excess events → 9.1 σ





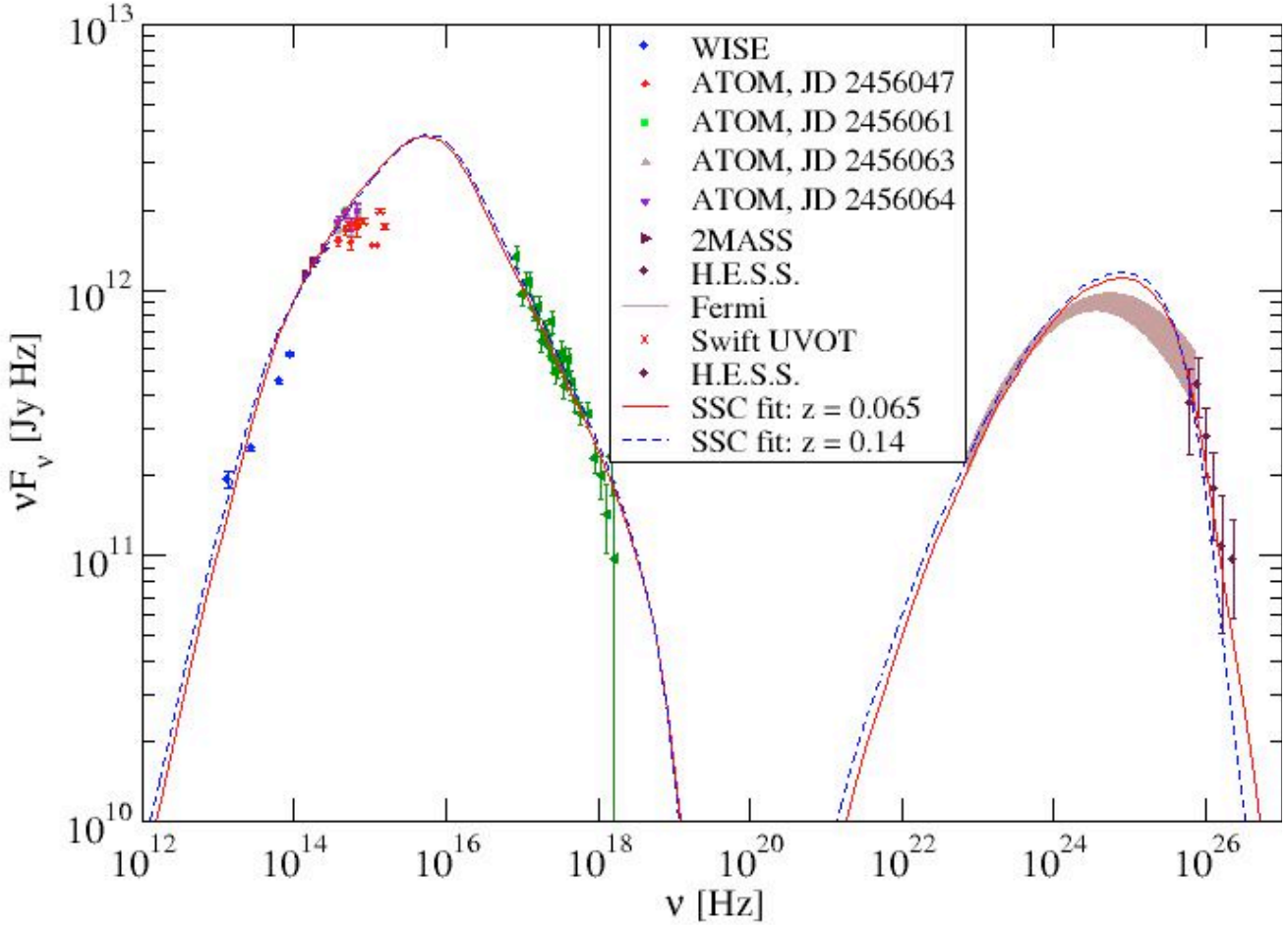
(H. Prokoph, Y. Becherini)

New Discoveries: PKS 1440-389



(H. Prokoph)

New Discoveries: PKS 1440-389



Steep H.E.S.S. spectrum ($\Gamma = 3.61 \pm 0.34$)

Single-zone SSC model provides good SED fit

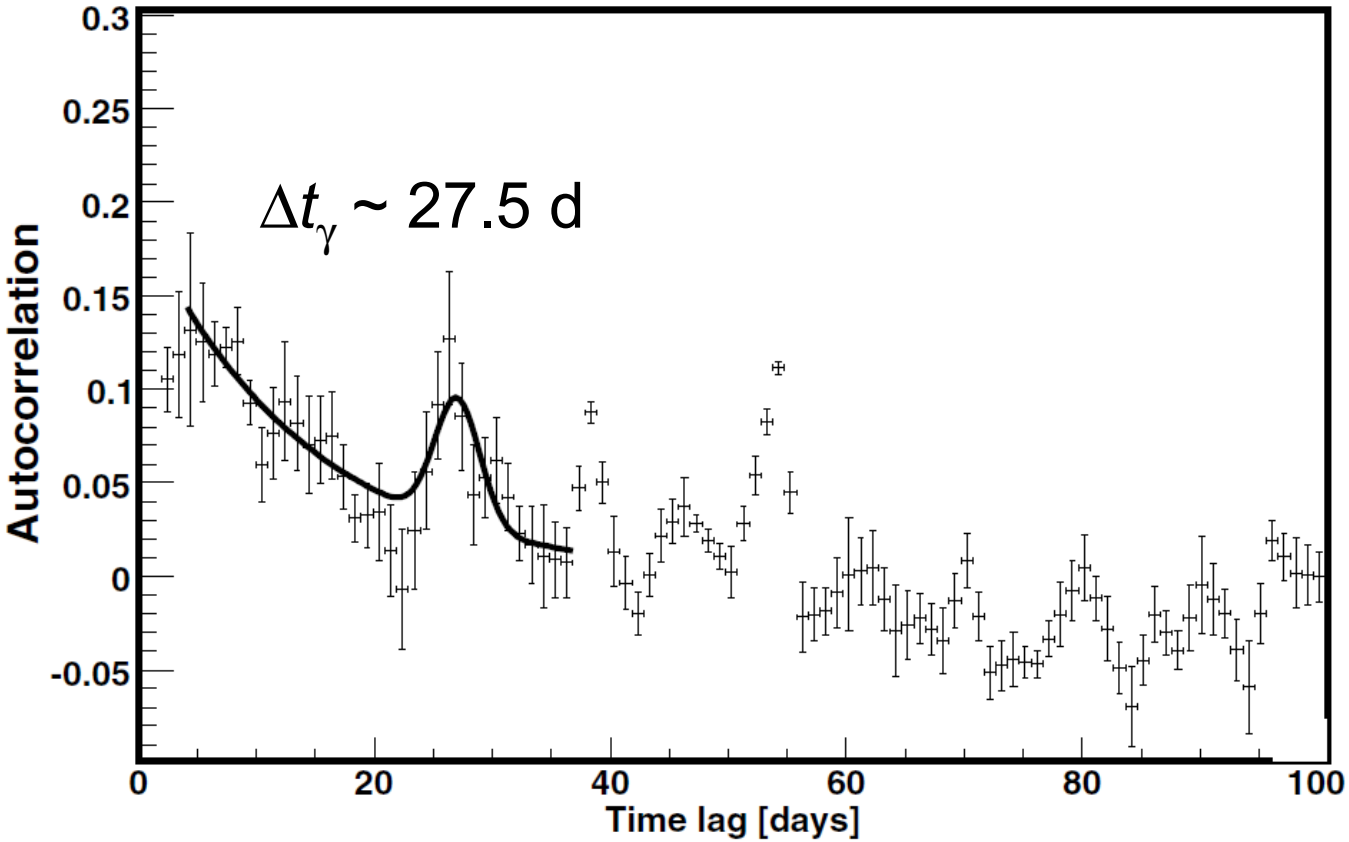
slightly sub-equipartition B field ($L_B/L_e \approx 0.1$)

H.E.S.S. spectrum difficult to reconcile with $z > 0.14$ due to EBL absorption

(H. Prokoph)

Gravitationally Lensed Gamma-Ray Blazars

PKS 1830-211 (z = 2.5)



Lensing galaxy at z = 0.89

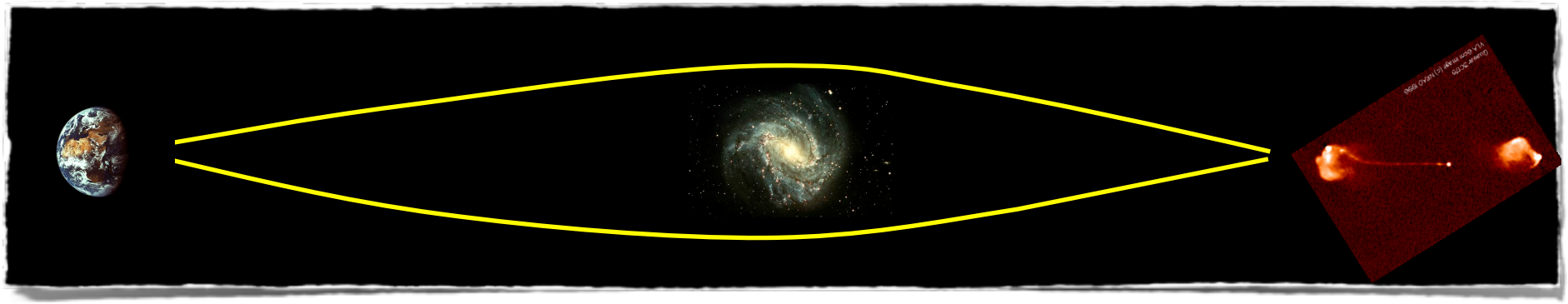
Δt_{radio} ~ 26 d

Magnification ratio = 1.52

Fermi-LAT γ-ray flare July 27, 2014
→ H.E.S.S. observations timed to detect the delayed image flare (August 12 – 26)

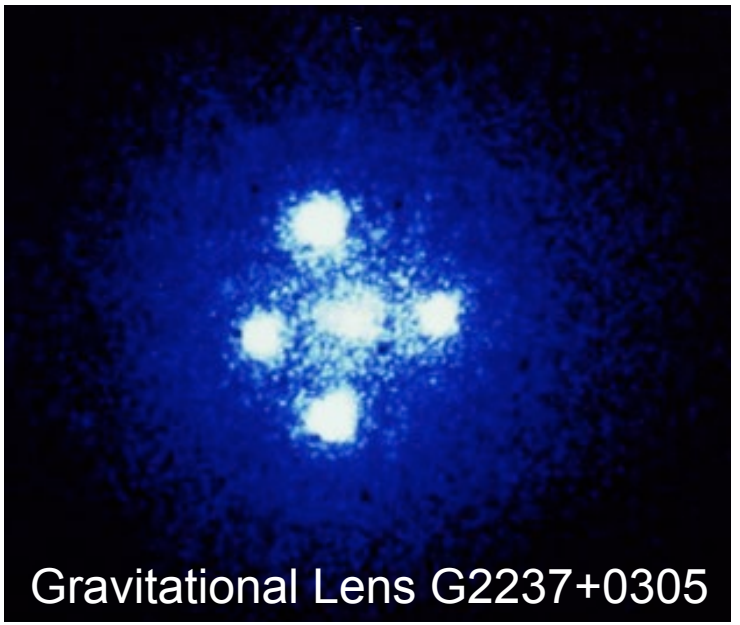
Barnacka+11

Gravitationally Lensed Gamma-Ray Blazars

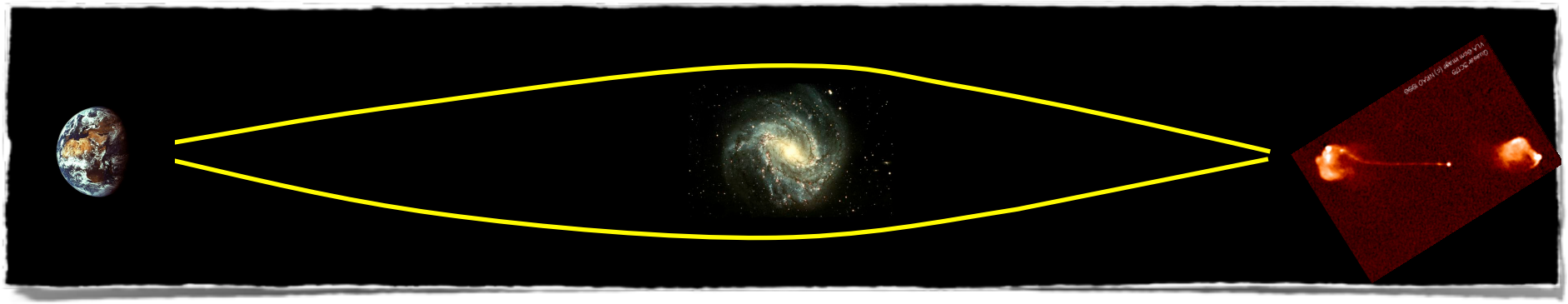


→ Magnification of one of the images

→ Time delay between two images



Gravitationally Lensed Gamma-Ray Blazars



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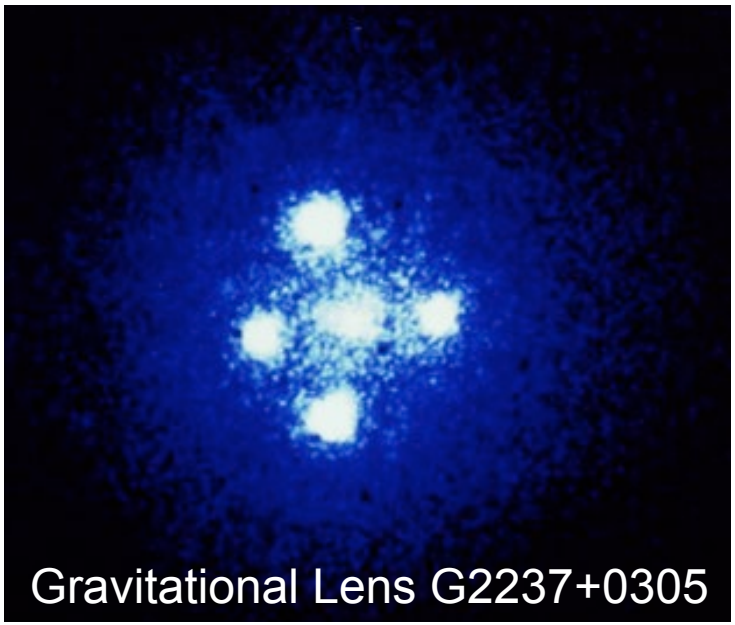
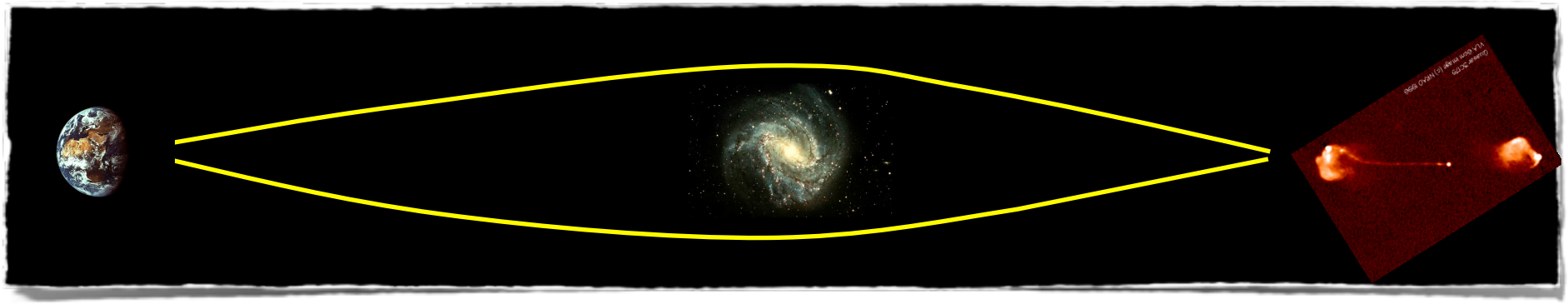
Possible way of "imaging" gamma-ray emission regions in blazars!



Gravitationally Lensed Gamma-Ray Blazars



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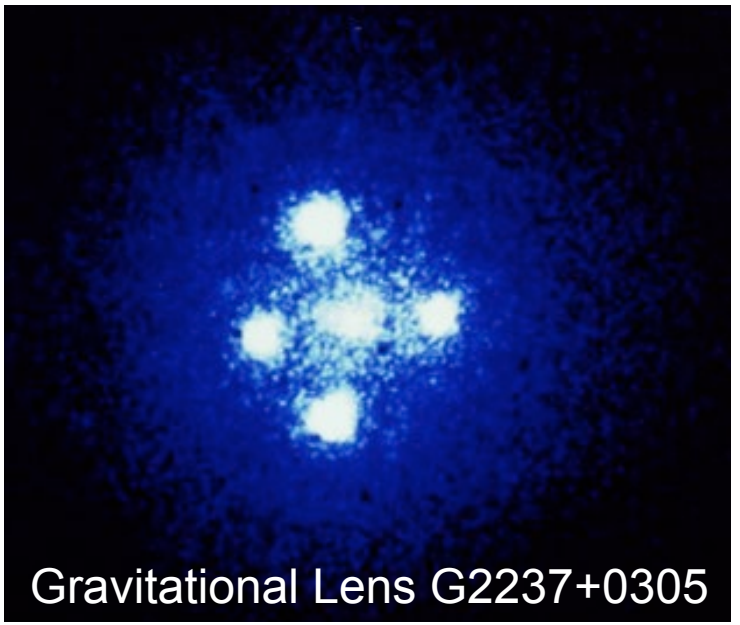
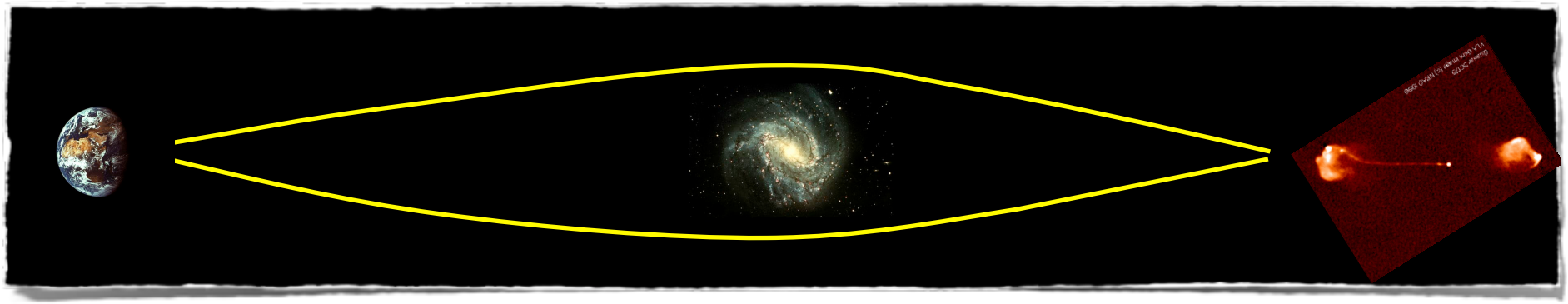
Possible way of "imaging" gamma-ray emission regions in blazars!

Gravitational lensing echoes observed in two blazars at GeV energies (Fermi)


Gravitational Lens G2237+0305

Gravitationally Lensed Gamma-Ray Blazars



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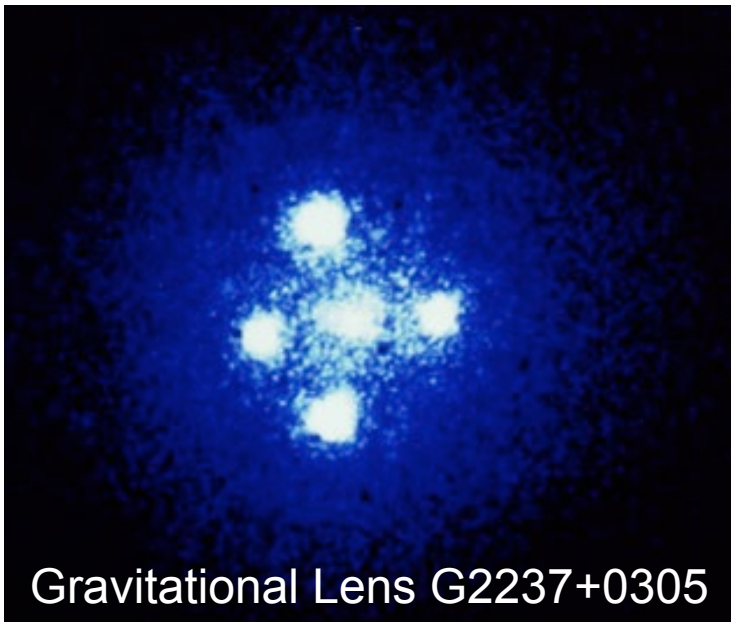
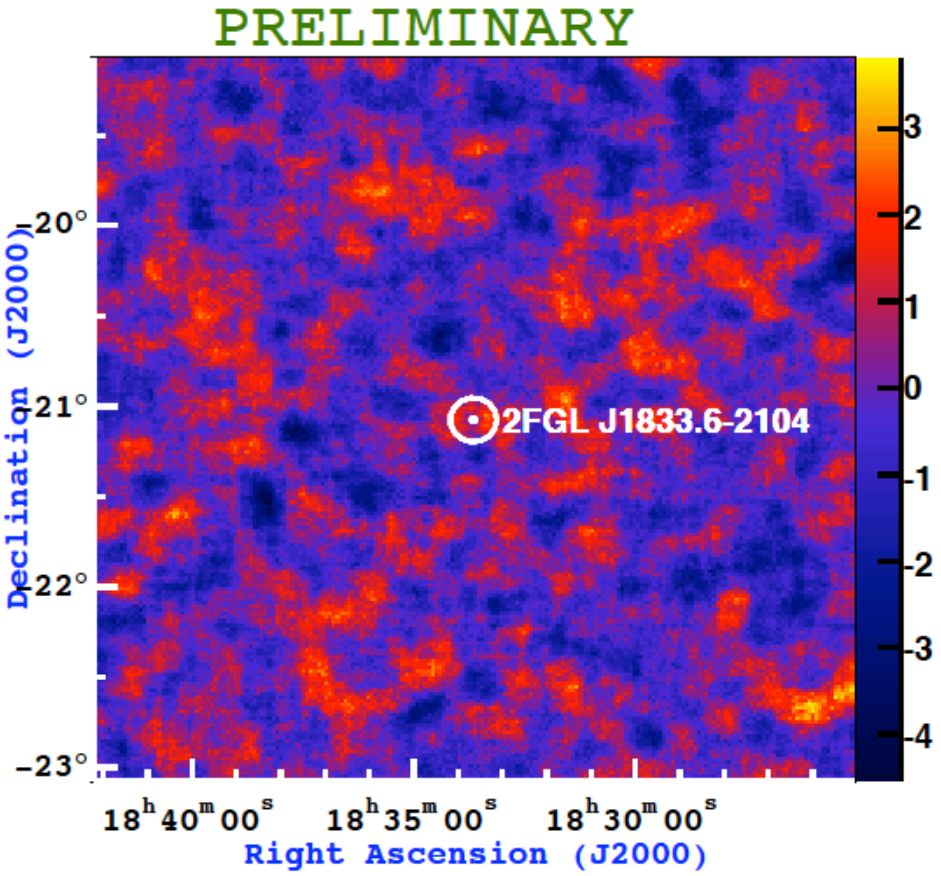
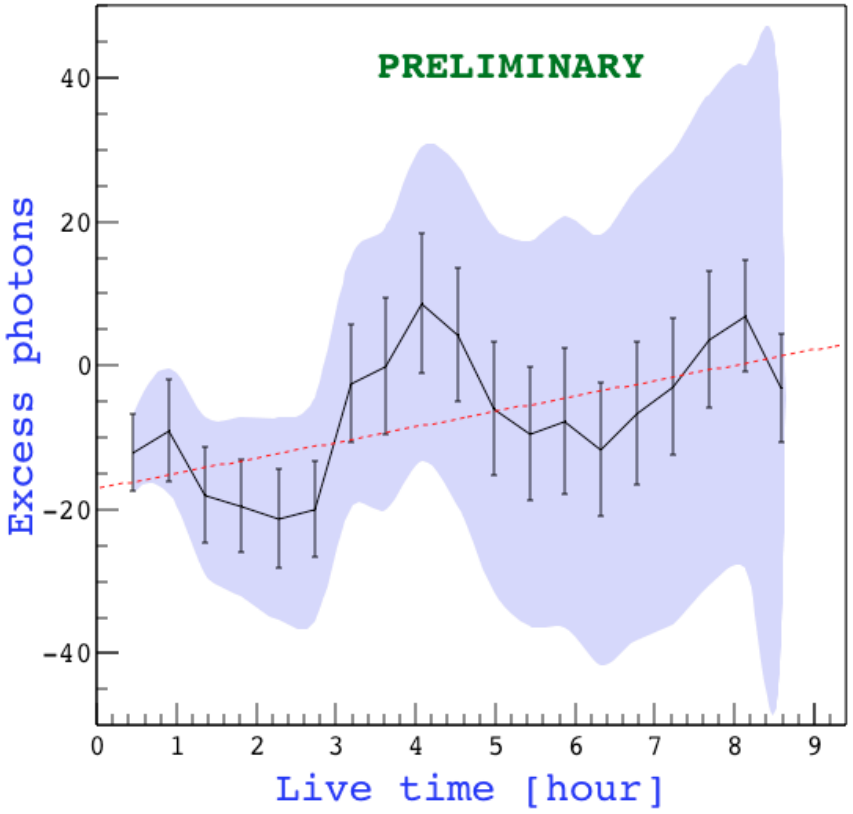

Gravitational Lens G2237+0305

MAGIC detection of B0218+357, z = 0.94
(see Sitarek/MAGIC coll., this meeting)

Gravitationally Lensed Gamma-Ray Blazars

PKS 1830-211 (z = 2.5)

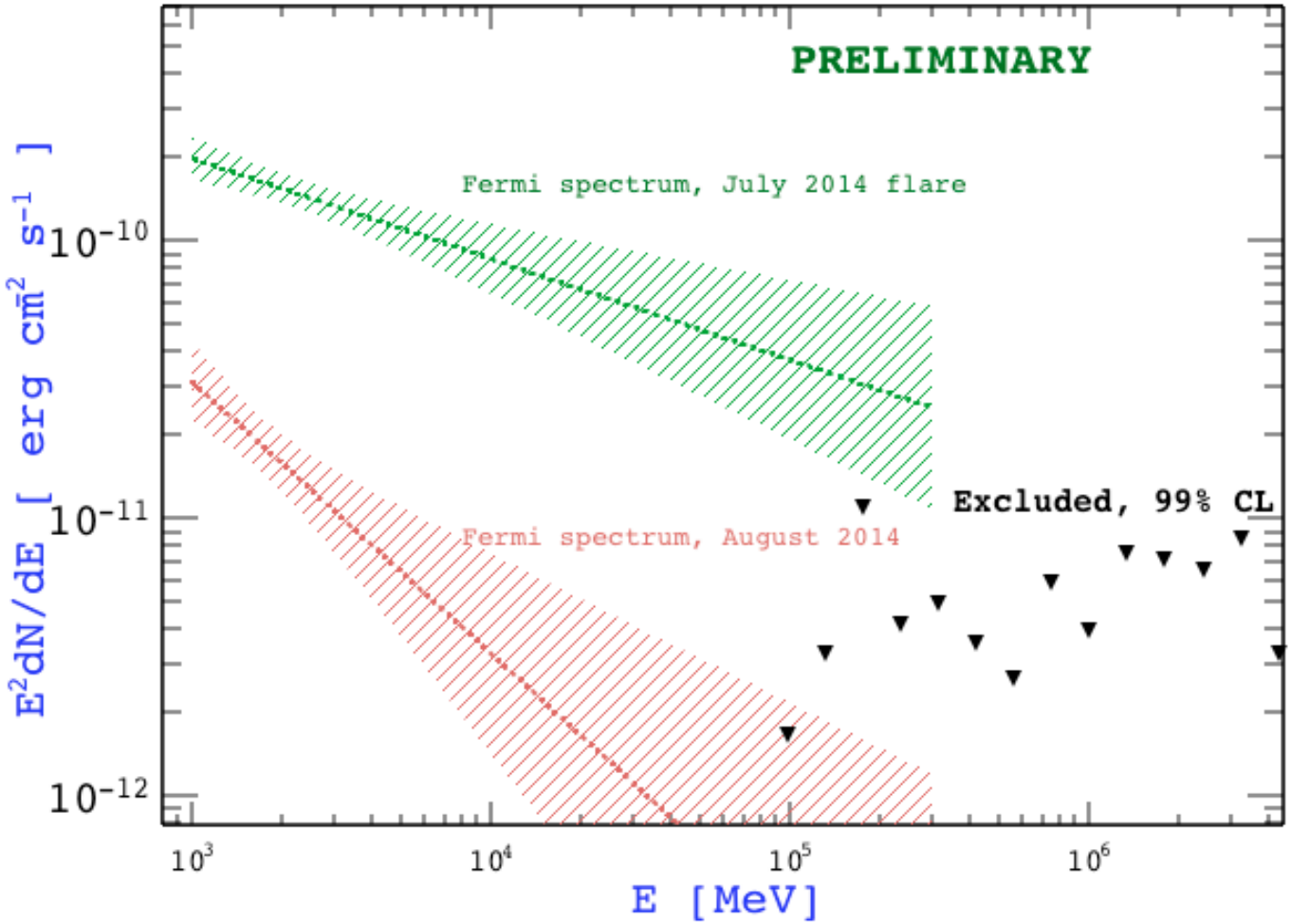




No evidence for excess
(neither in total exposure nor temporary increase)

Gravitationally Lensed Gamma-Ray Blazars

PKS 1830-211 (z = 2.5)



H.E.S.S. ULs far below extrapolation of Fermi flare spectrum

→ EBL absorption effect?

or different locations of HE vs. VHE γ-ray production region?

Summary

- H.E.S.S. II analyses using both CT5 Mono and the full H.E.S.S.-II array
- Analysis of two bright AGN using H.E.S.S. CT5 data
  → both detected with high significance, with an energy threshold of ≈ 80 GeV and ≈ 100 GeV for PKS 2155-304 and PG 1553+113, respectively
  → spectra compatible with earlier H.E.S.S. quiescent/Fermi-LAT results
- Long-term Monitoring of PKS 2155-304 reveals lognormal (multiplicative) variability
- Rapid (<10 min) variability of Mrk 501 at > 2 TeV:
  Lognormal variability and statistical behavior as observed in PKS 2155-304
  Also used for an improved limit on quadratic LIV term
- Continued discovery of new extragalactic VHE sources, including PKS 1440-389
- Non-detection of lensing-delayed VHE flare in PKS 1830-211
  → different HE vs. VHE γ-ray emission regions?