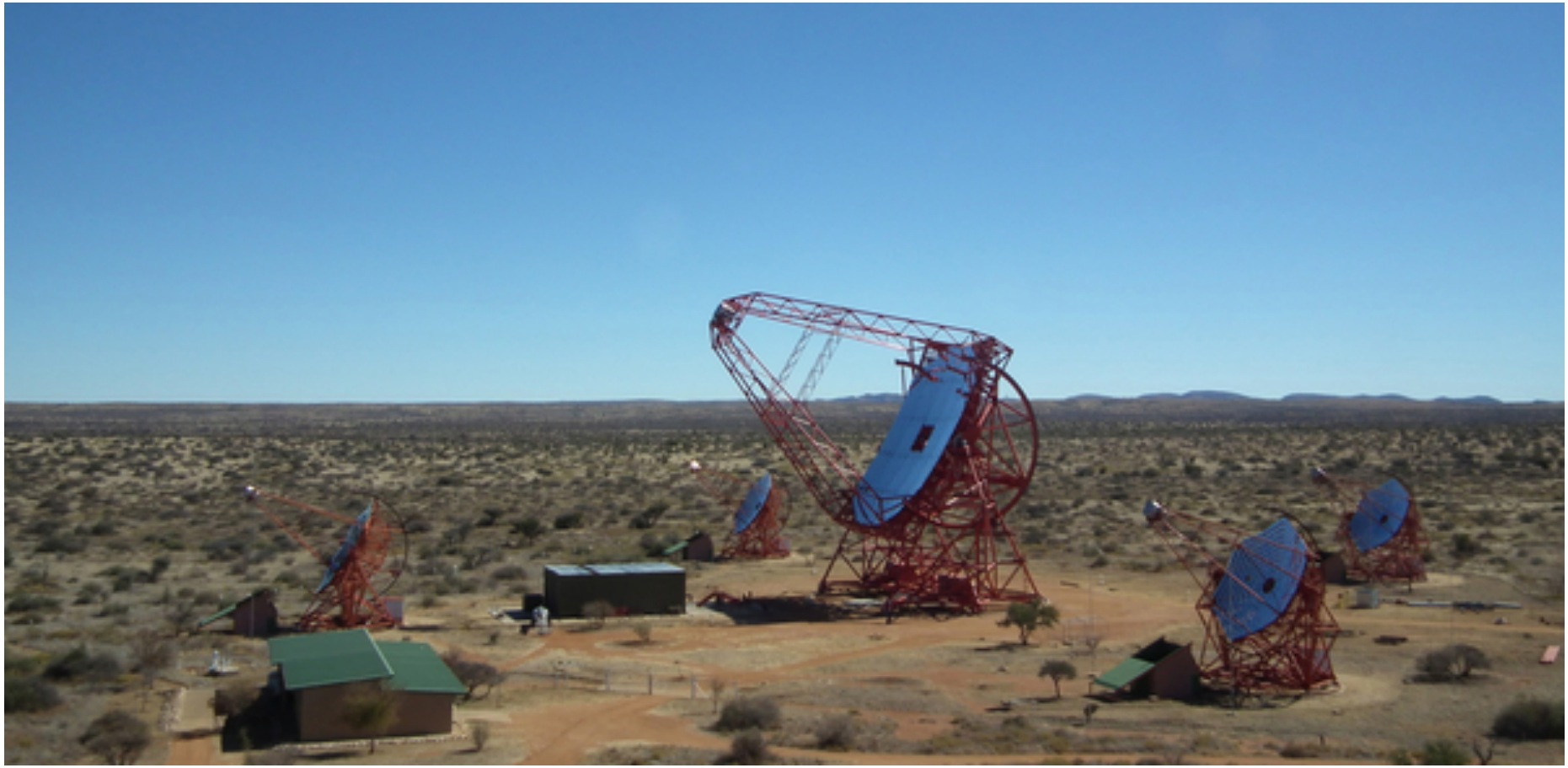
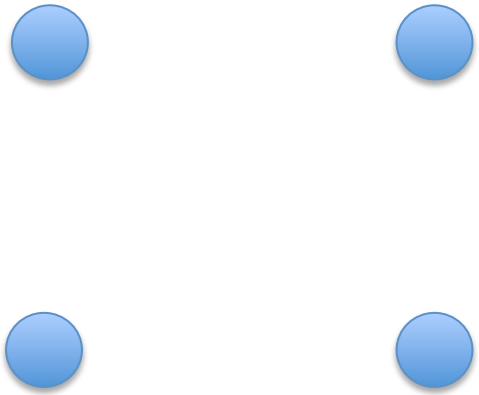
HESSI/II Extragalactic Source Properties



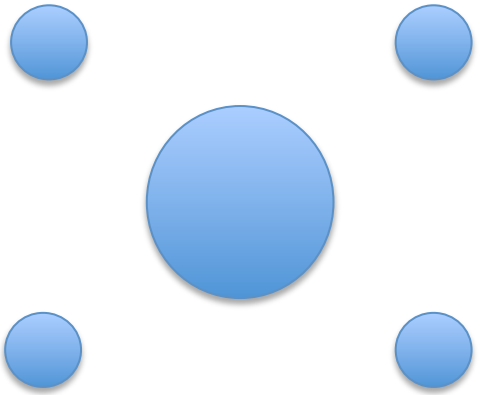
International Collaboration of ~300 scientists from 12 countries
(Germany - France - Austria - Poland - Ireland - United Kingdom - The Netherlands - Australia - Armenia - Sweden - Namibia - South Africa)

HESSI and HESSII Eras

H.E.S.S. Phase I: 2002-2012
- 4 telescopes of 12m
- 100 GeV - 100 TeV



H.E.S.S. Phase II: 2012-++
- Addition of CT5 to the array: 28m
- ~30 GeV - 100 TeV



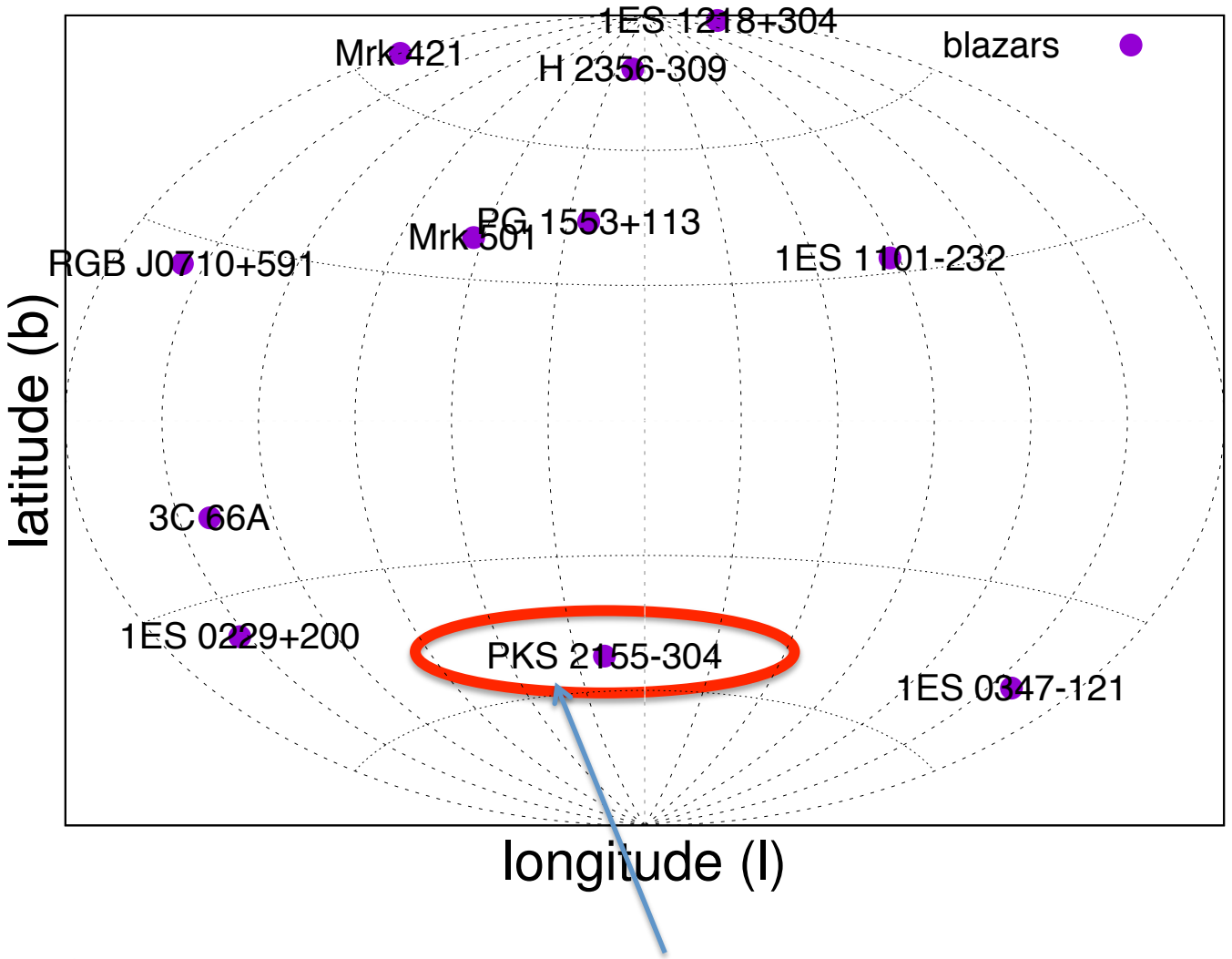
CT5 allows E < 100 GeV measurements
— best for:
- High redshift AGN + GRBs
- EBL studies at large z

Extragalactic Source Classes Detected by HESSI

1. HBL/IBL/LBL (Blazars)
2. FSRQs (Blazars)
3. FR1s
4. Starburst Galaxies

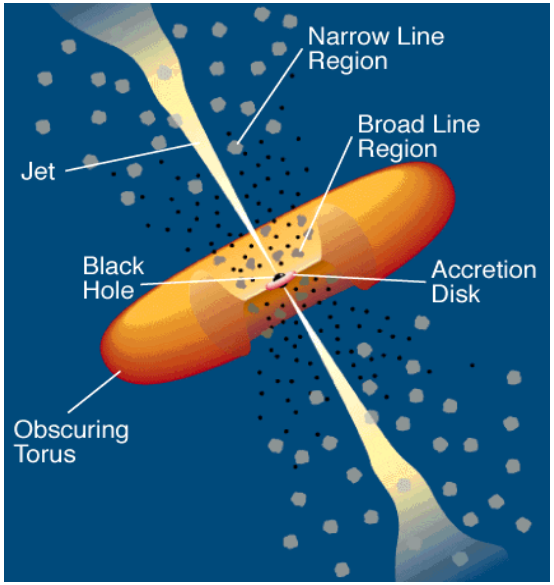
However, a large portion of our results have come from the first of these classes. In the following I shall focus predominantly on one member of the first class(!)
….PKS 2155-304

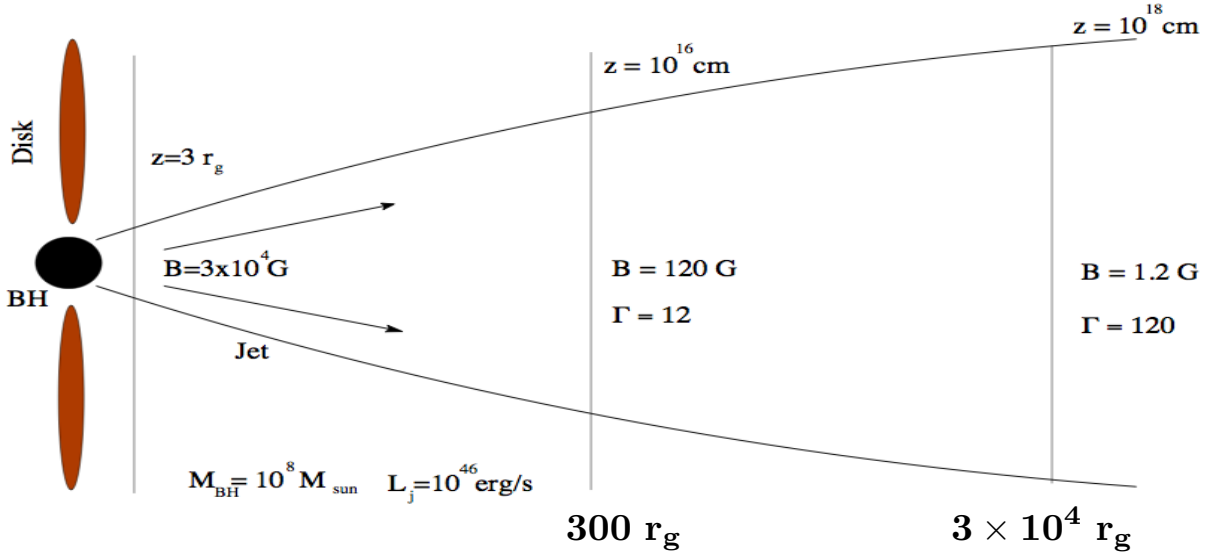
Blazar Focused on in this Talk



Is a bright AGN at low (~100 GeV) energies and known to exhibit variability on many different timescales

Blazars - sub-class of AGN dominated by nonthermal/variable broad band (from R to γ) radiation produced in relativistic jets close to the line of sight, with massive Black Holes as central engines





γ-rays from >100 Mpc sources - detectable because of the Doppler boosting

TeV Blazars

before 2004:

detection of 6 TeV Blazars, extraordinary outbursts of Mkn 501 in 1999, variations on <1h timescales;

=> initiated huge interest in AGN and EBL communities

today:

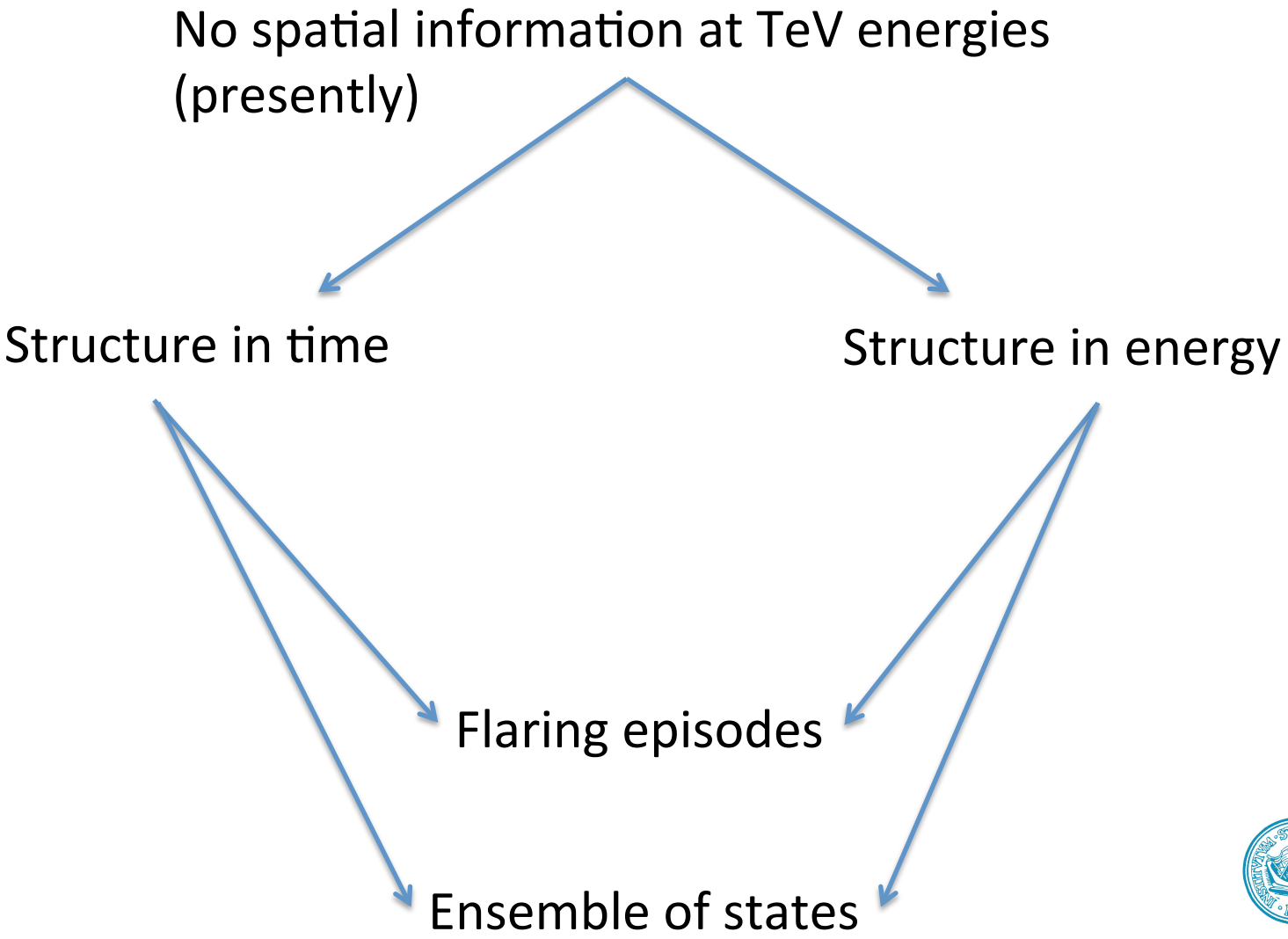
more than three dozen TeV blazars; quite unexpectedly TeV γ-rays from distant blazars;

=> strong impact on both blazar physics and on the diffuse Extragalactic Background Light (EBL) models

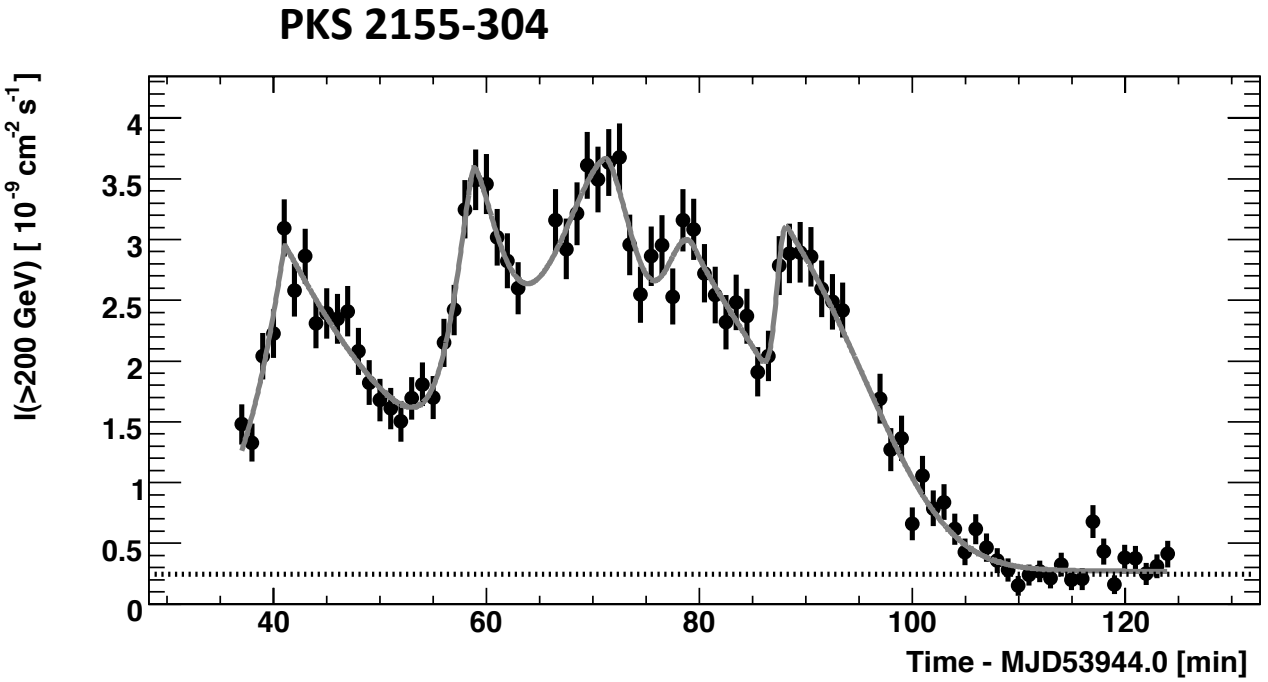
most exciting results - variability on minute timescales
unusually hard gamma-ray spectra

H.E.S.S.

HBL – Archetypal HESS example: PKS 2155-304



Temporal Structure During a Flaring Episode (2006)



$$M_{BH} \approx 10^9\ M_\odot$$

$$R_{Schwarz.} \approx 30\ AU$$

$$\frac{R}{\delta} \leq 0.3\ AU$$

- temporal structure down to minutes (smallest time) found $ct_{var} \ll r_{Schwarz}$
- allows tests of a dispersion relation between different energy photons, proving LIV constraints

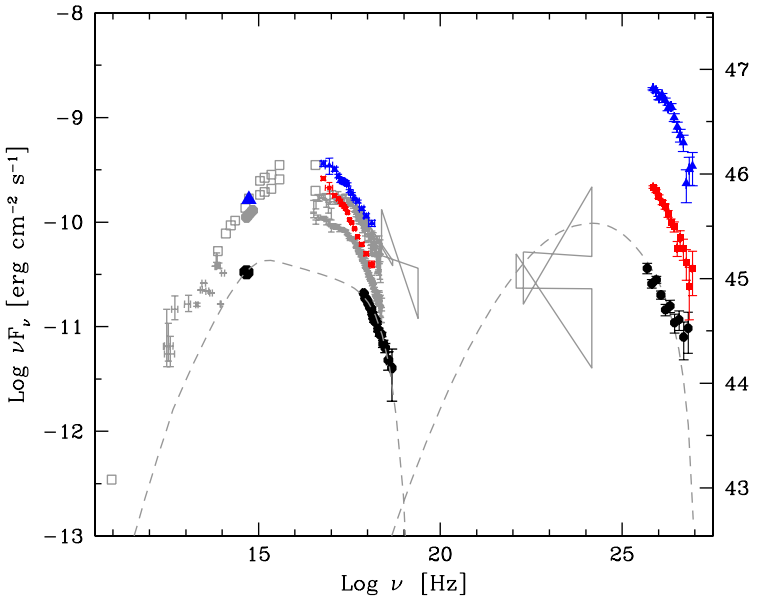
H.E.S.S.

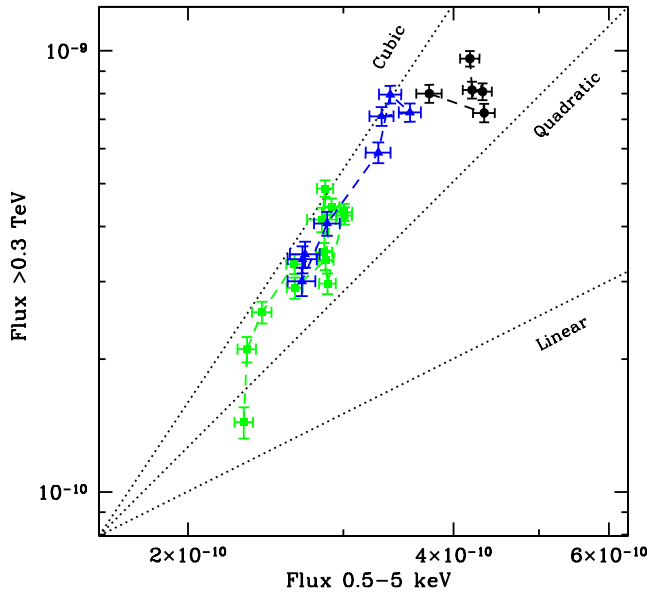
HESS Collaboration: Aharonian et al., Astrophys. Journal, 664 (2007) (astro-ph/**0706.0797**)

Flaring Spectral Energy Distribution and Evolution (2006)

- No time lags observed between X-rays and gamma-rays observed
- Both (EBL corrected) curvature and E_{peak} increased during flaring episode
- X-ray-gamma-ray correlation a key probe to testing the one zone SSC model, which is severely challenged by this flaring event

$$\frac{dN}{dE} = \Phi_0 \left(\frac{E}{E_0}\right)^{-\Gamma - b \log(E/E_0)}$$





A bimodality is emerging for HBL flaring activity: either synchrotron dominated or Compton dominated ("orphan flare") events

HESS Collaboration: A&A 502, 749-770 (2009) (astro-ph/**0906.2002**)

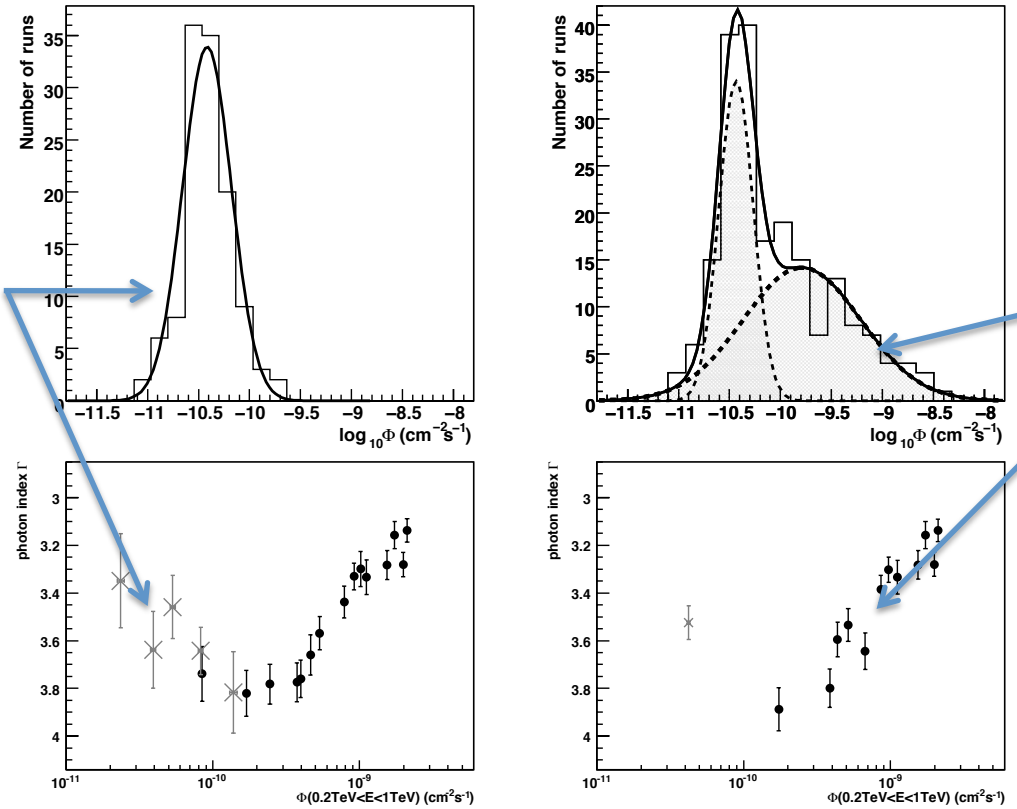
Ensemble of State Brightness Distribution (2005-2007)

Even the "quiescent" state is variable!

Distribution of different integral flux states (>200 GeV) and spectral indices appears bimodal

Quiescent state

Flaring state



HESS Collaboration: Astron. Astrophys. 520 (2010) A83 (astro-ph/**1005.3702**)

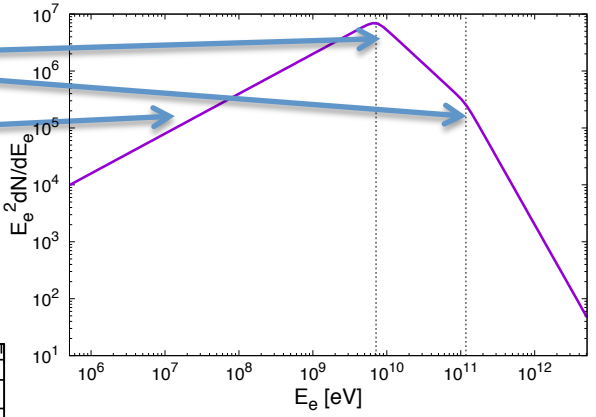
Low State Spectral Energy Distribution (2008)

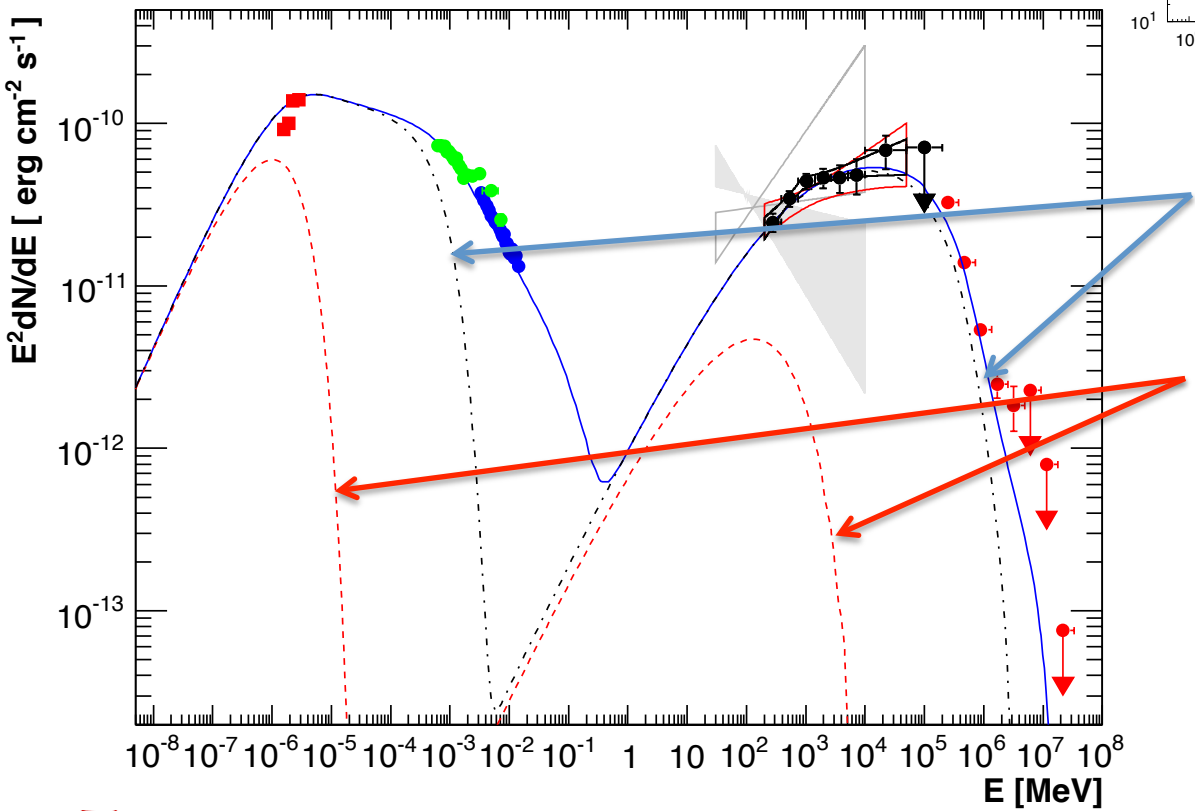
"Straw Man Model"

Cause of breaks?

Physically reasonable?

$$\tau_{\rm cool} \approx \left(\frac{10^{10}\ {\rm eV}}{E_e}\right)\left(\frac{0.02\ {\rm G}}{B}\right) 2\ {\rm yrs}$$





SSC emission from electrons below second break (X-ray-TeV correlation?)

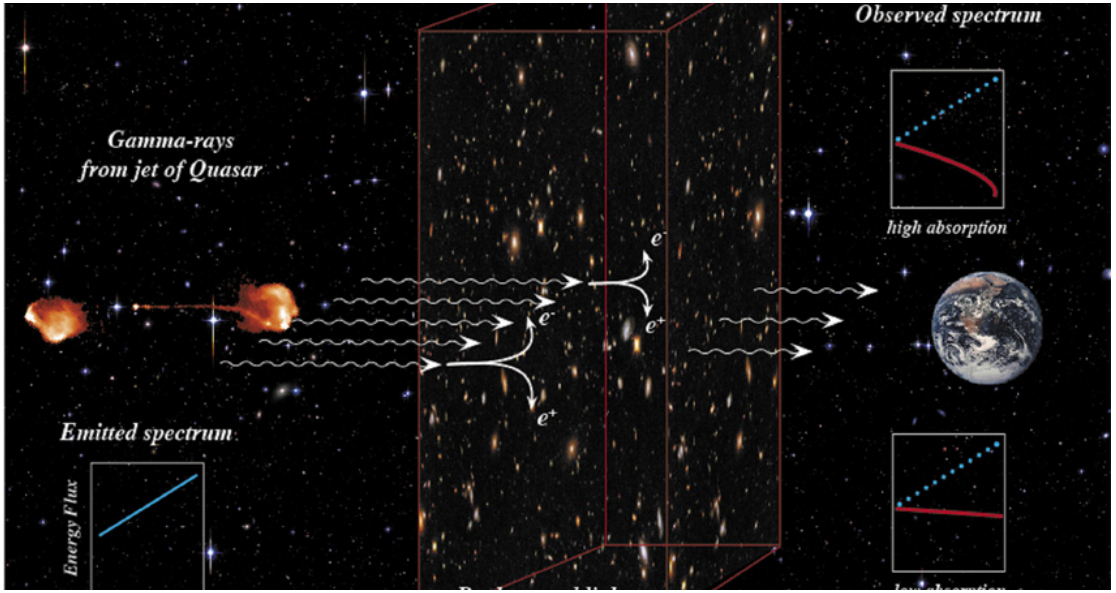
SSC emission from electrons below first break (optical-GeV correlation?)

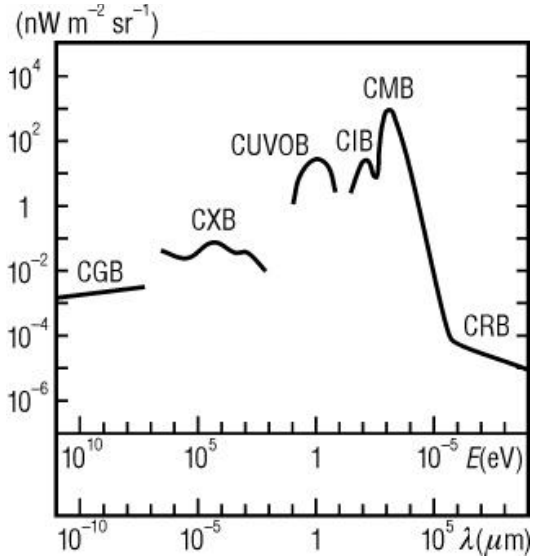
$$\Gamma_{\rm HESS} = 3.34 \pm 0.05_{\rm stat} \pm 0.1_{\rm sys}$$

H.E.S.S.

Astrophys. Journal Lett. 696 (2009) L150-L155 (astro-ph/**0903.2924**)

TeV Blazars and EBL





The “system” to be understood is the full extragalactic space-Earth region

EBL Studies with HESSI Observations

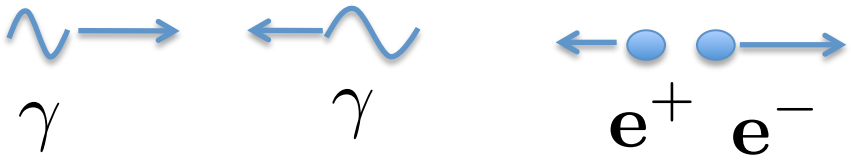
$$J(E_\gamma) = J_0(E_\gamma) \times e^{-\tau(E_\gamma, z)}$$

observe this

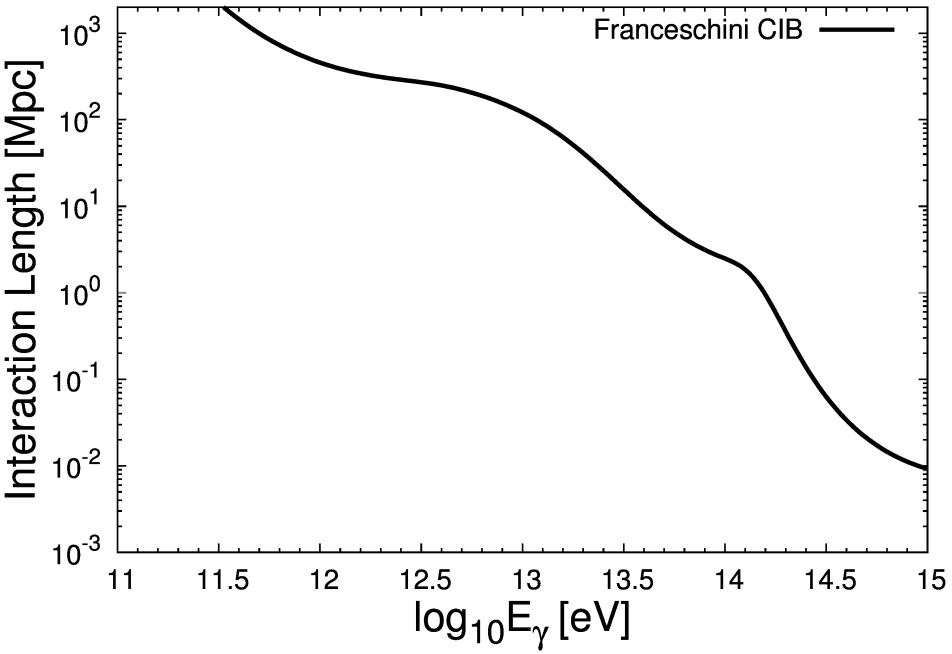
"know" this

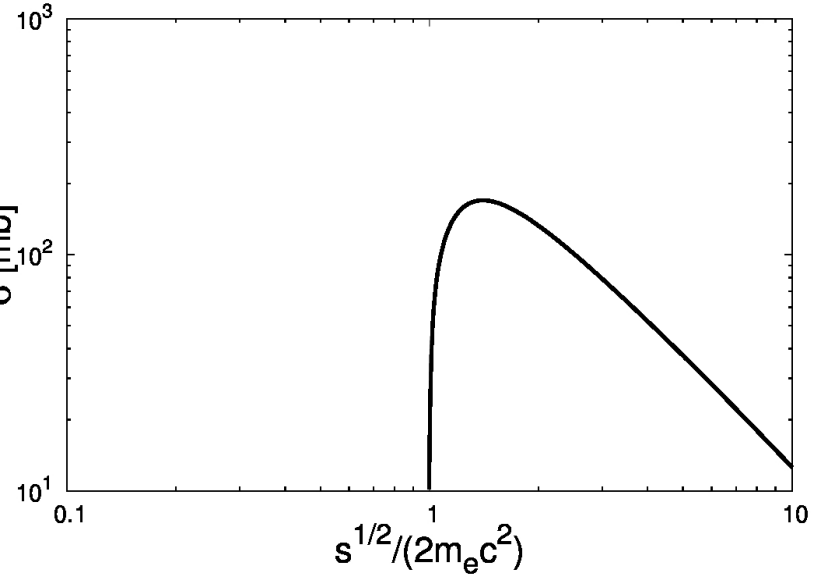
determine this

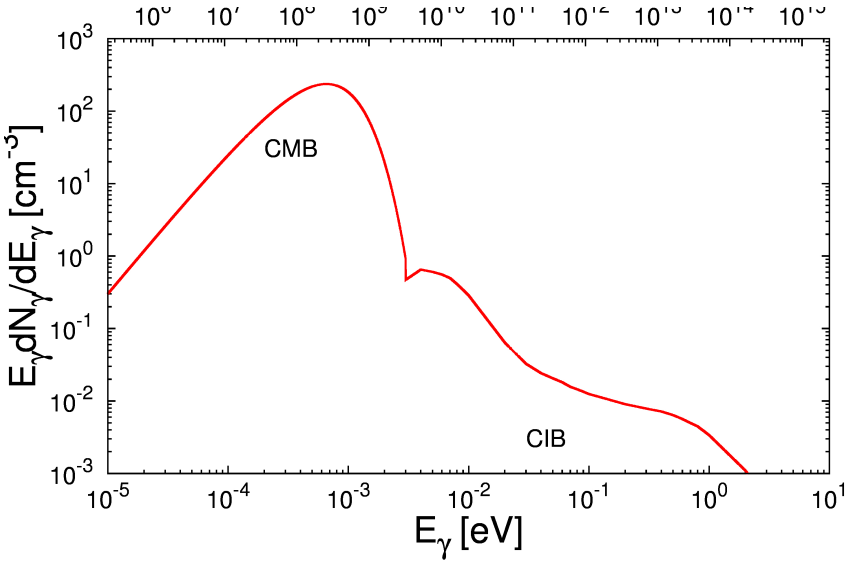
Extragalactic Background Light (EBL) Attenuation of Gamma-Rays



$$\mathbf{R} = \frac{2\mathbf{m_e^2}}{\mathbf{E_\gamma}} \int \frac{1}{\epsilon^2} \frac{\mathbf{dn}}{\mathbf{d}\epsilon} \mathbf{d}\epsilon \int_0^{\mathbf{E_\gamma \epsilon / m_e}} \epsilon' \sigma_{\gamma\gamma}(\mathbf{E_\gamma}, \epsilon') \mathbf{d}\epsilon'$$



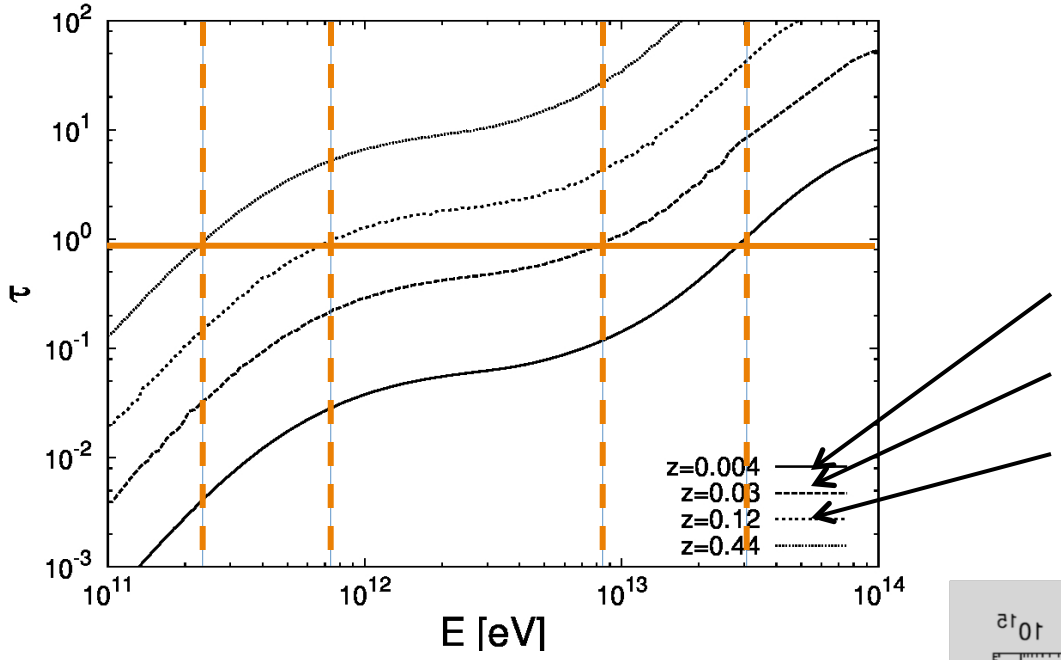




H.E.S.S.

$$E_\gamma^{\mathrm{TeV}} E_\gamma^{\mathrm{eV}} \approx 1$$

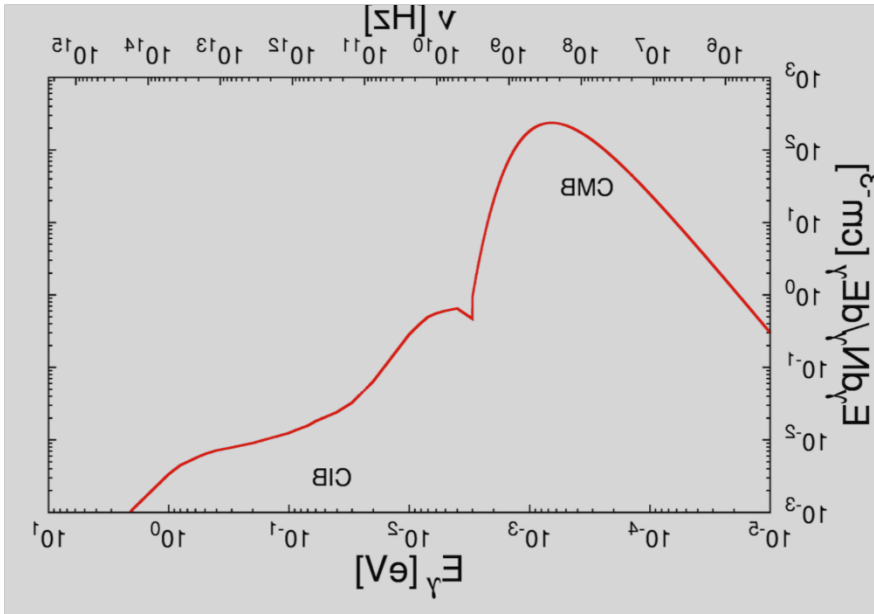
EBL Attenuation



M87

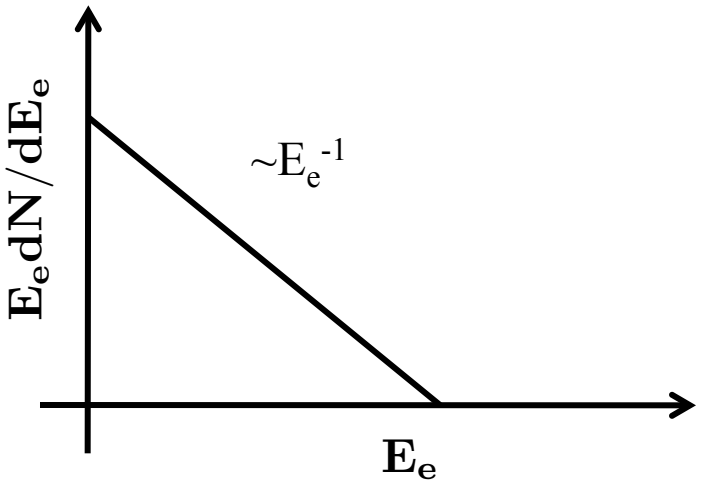
Mkn 501

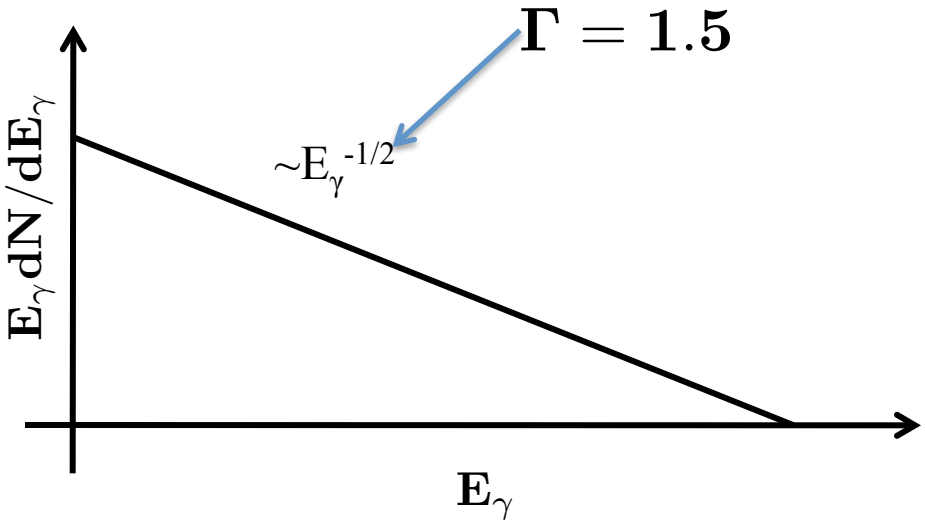
PKS 2155-304



$$E_\gamma^{\mathrm{TeV}} E_\gamma^{\mathrm{eV}} \approx 1$$

HESS Upper Limits on the EBL



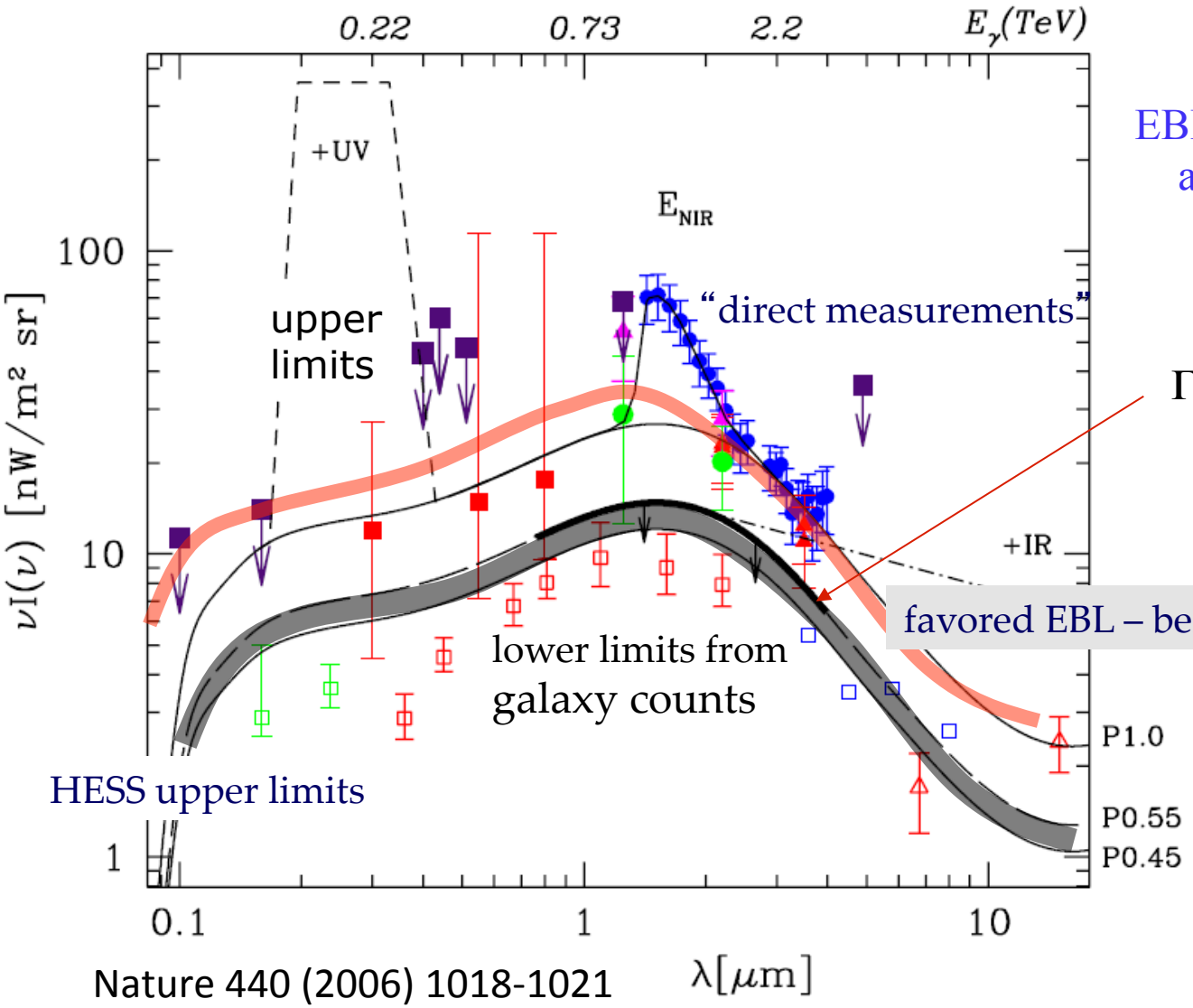


$$\frac{dN}{dE_\gamma} \propto E_\gamma^{-\Gamma}$$

Assume intrinsic gamma-ray spectra have Γ > 1.5

H.E.S.S.

HESS Upper Limits on EBL- Good Agreement with Recent EBL studies



EBL (almost) resolved at NIR ?

Γ=1.5

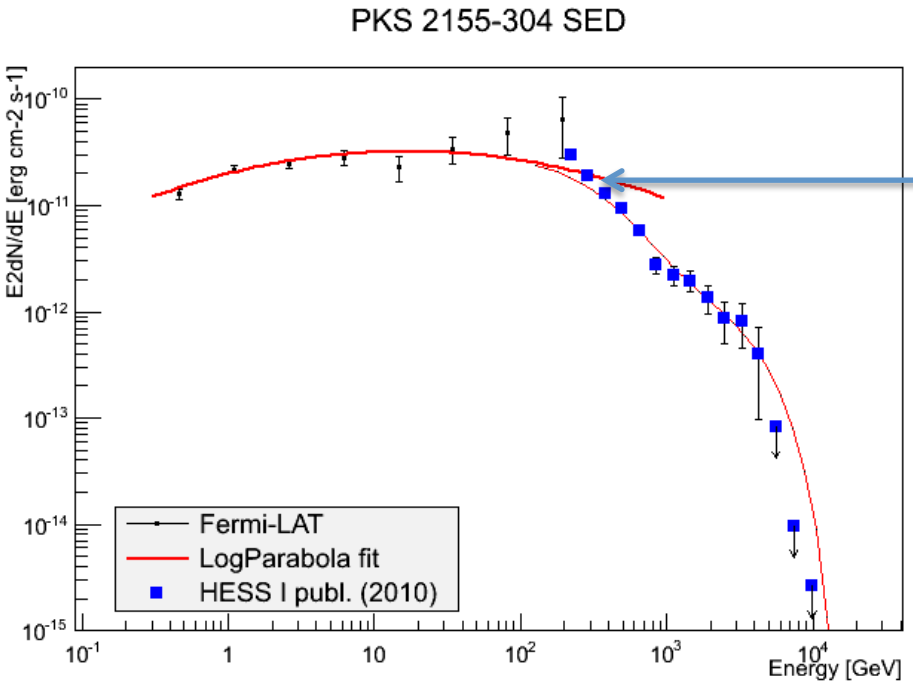
favored EBL – before HESS

Nature 440 (2006) 1018-1021

astro-ph/**0508073**

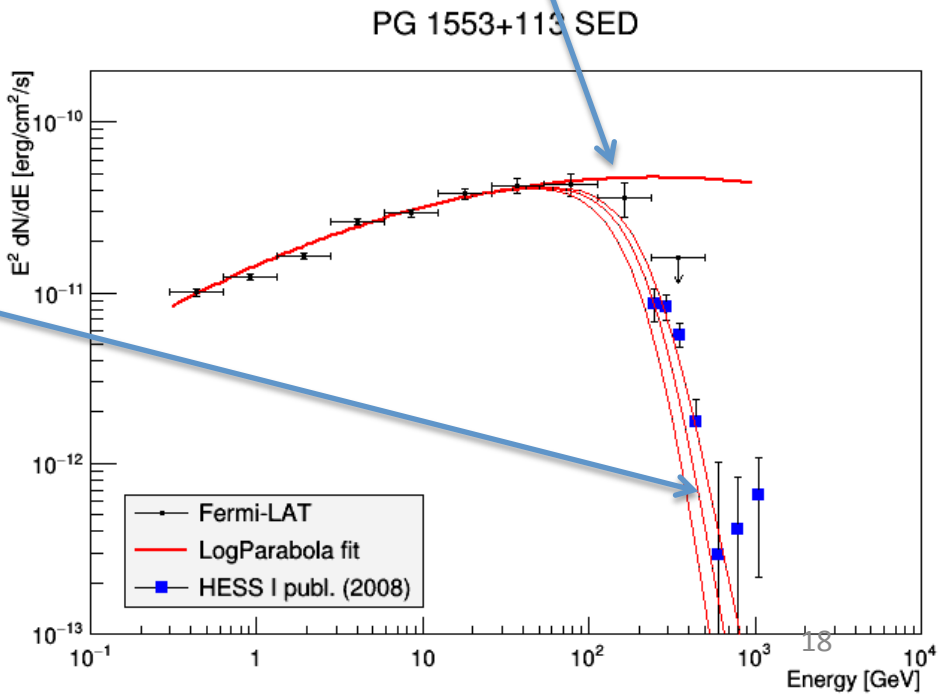
H.E.S.S.

EBL Attenuation



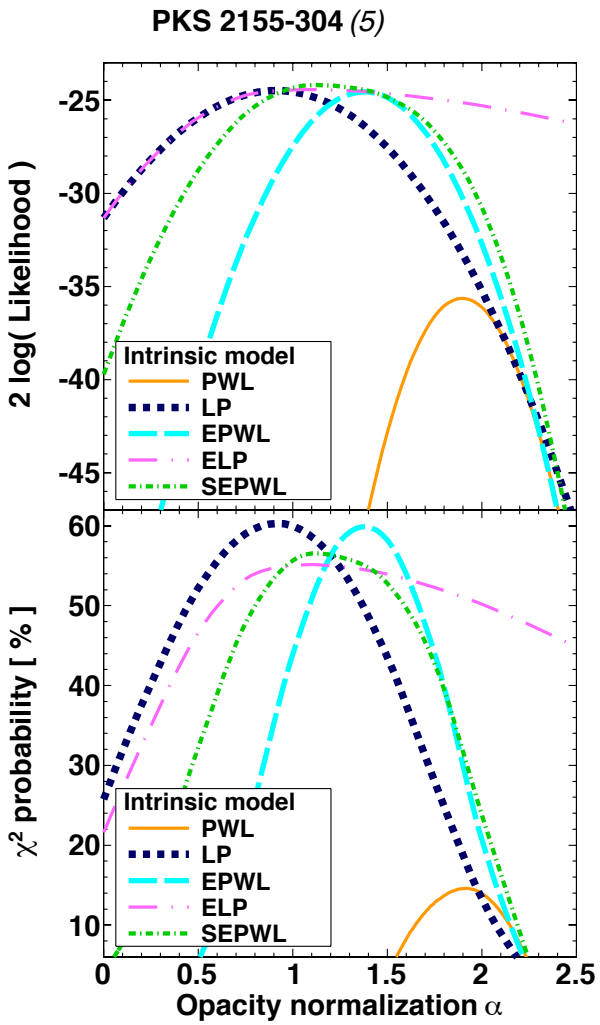
Note EBL induced break features for “high” redshift AGN occur at Fermi/HESS transition energy range

Range of redshifts due to present uncertainty in Source value



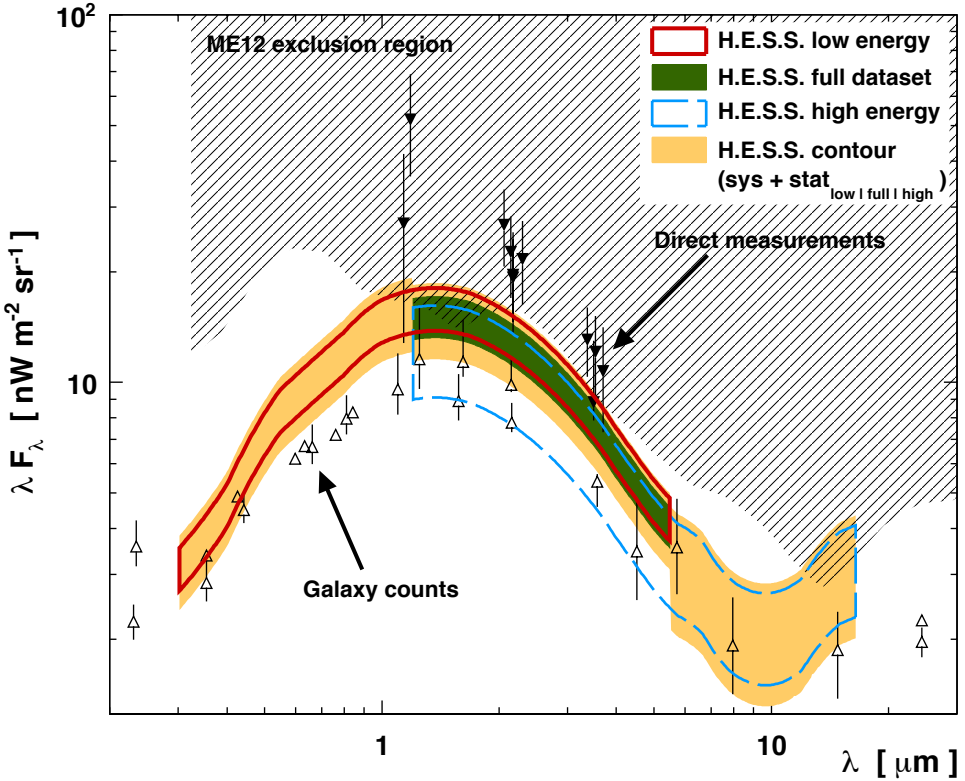
H.E.S.S.

HESS Upper Limits on EBL- Good Agreement with Recent EBL studies



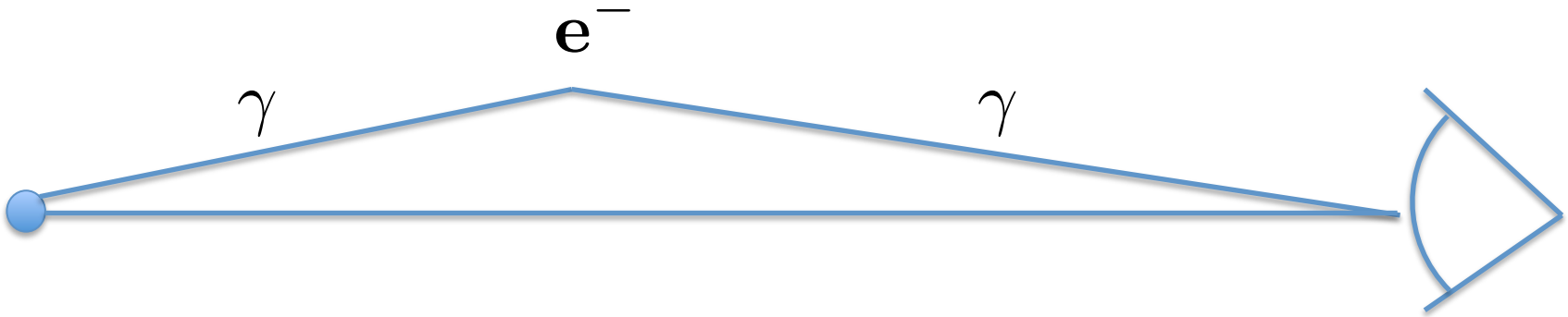
$$\frac{dN_{obs}}{dE} = \frac{dN_{intr.}}{dE} \times \exp(-a * \tau)$$

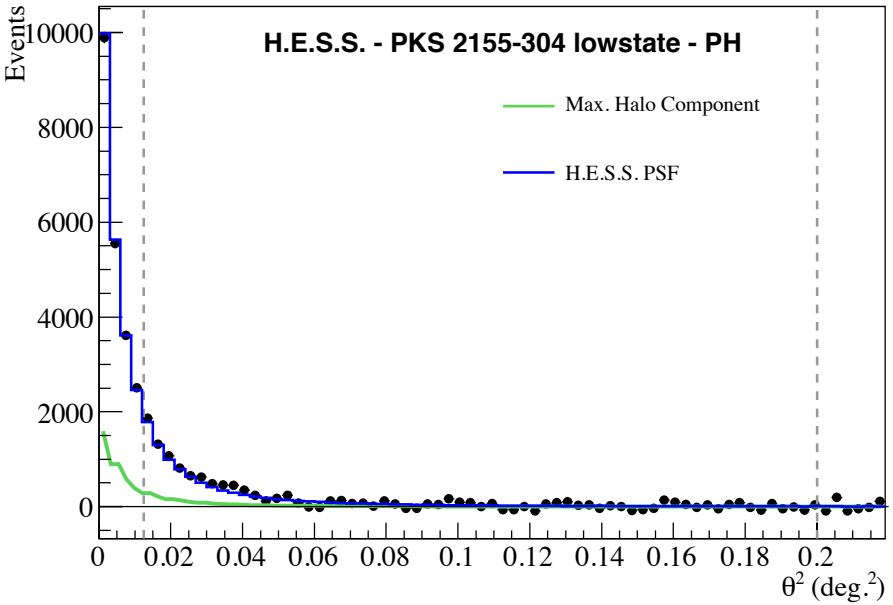
$$a = 1.27^{+0.18}_{-0.15} \pm 0.25_{sys}$$

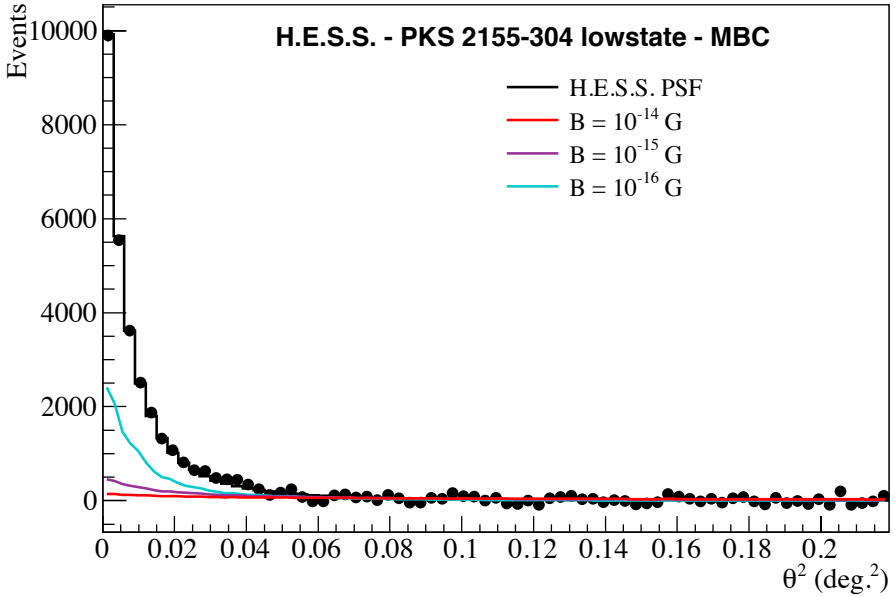


Astron. Astrophys. 550 (2013) A4, (astro-ph/**1212.3409**)

HESS Searches for Angular Extensions Beyond the PSF for Blazars







H.E.S.S.

Astron. Astrophys. 562, A145 (2014), astro-ph/**1401.2915**

Preliminary HESSII AGN Results

H.E.S.S.

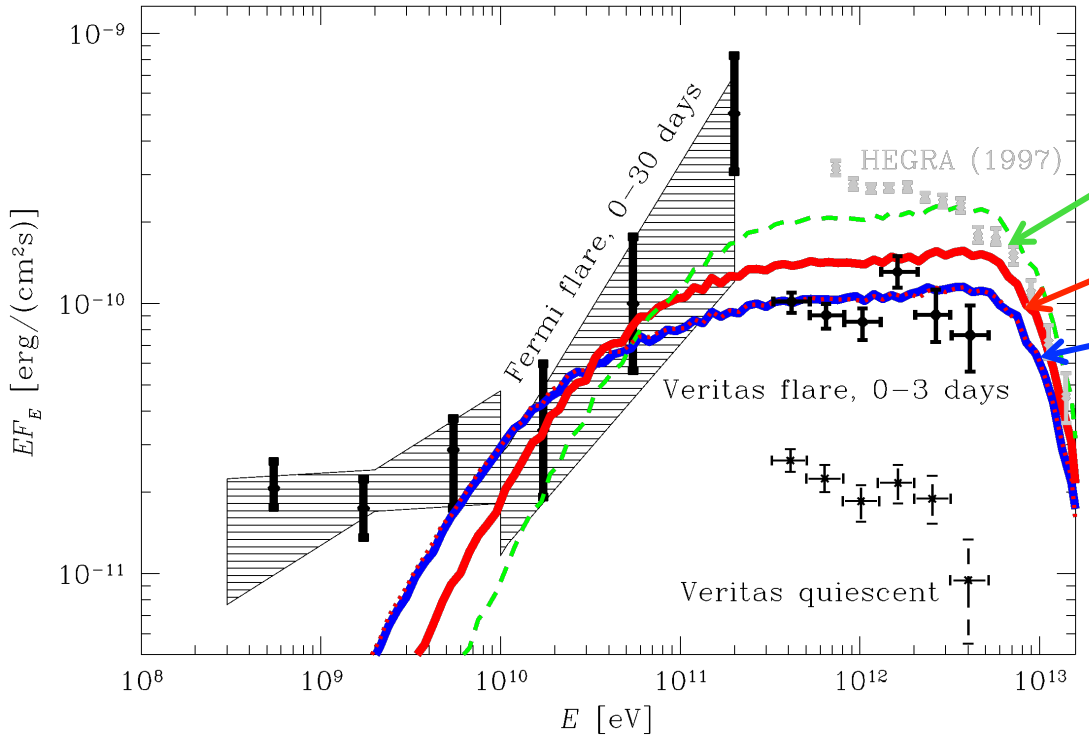
What's Special About <100 GeV?

- Improvement in statistics during flaring events (particularly relevant for AGN + GRB)
- Search for unexpected spectral features at low energies
- EBL studies of AGN at "high" redshift
- Good overlap in energy with Fermi satellite observations needed

H.E.S.S.

Hard Spectra are Hard to Explain!

Mrk 501 (2009) Flare

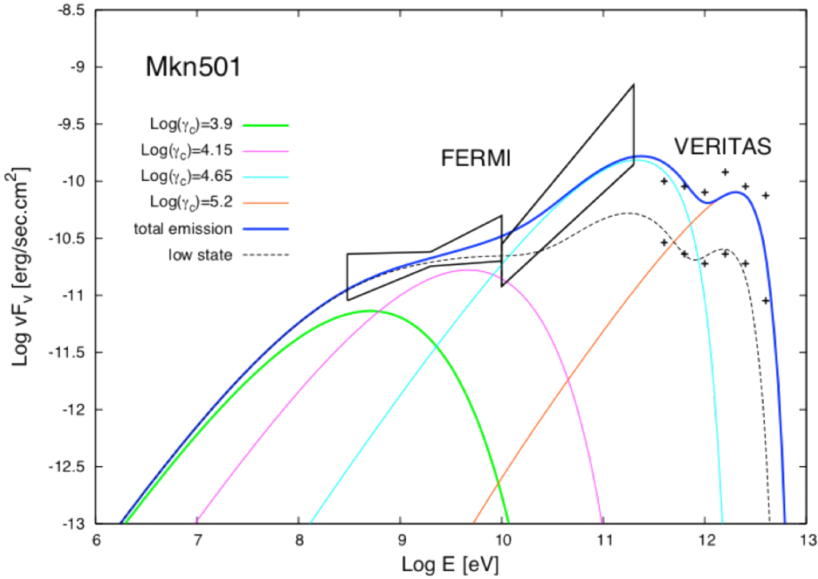


From astro-ph/**1104.2801**

$B = 10^{-16}$ G

$B = 10^{-16.5}$ G

$B = 10^{-17}$ G



From astro-ph/**1108.4568**

H.E.S.S.

HESSII- Mono vs. Stereo

CT5 Mono

- Low energy threshold
- Limited angular resolution
- Limited sensitivity

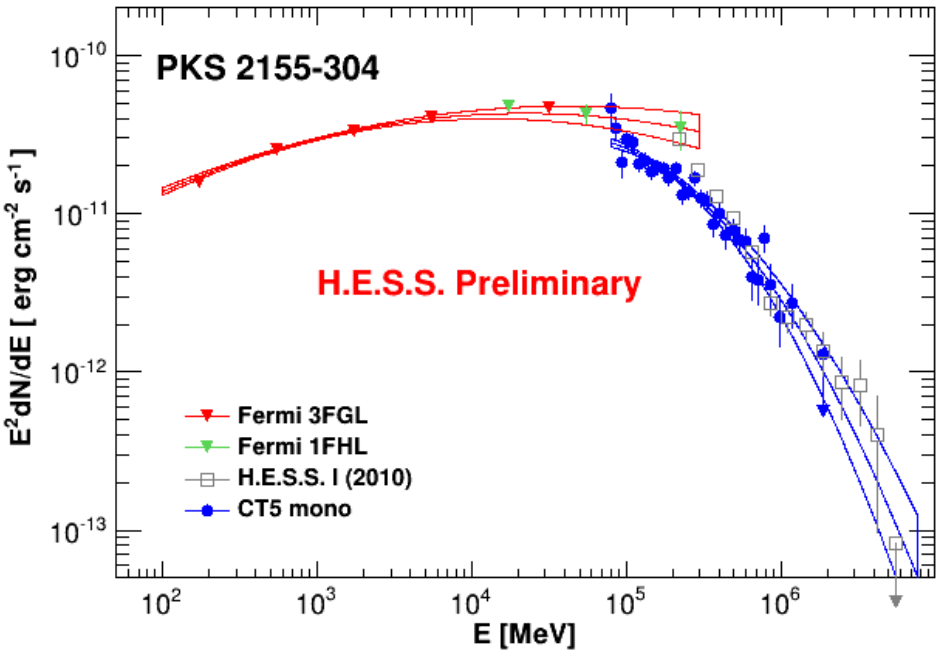
Best for: bright high redshift AGN + GRB

CT1-5 Stereo

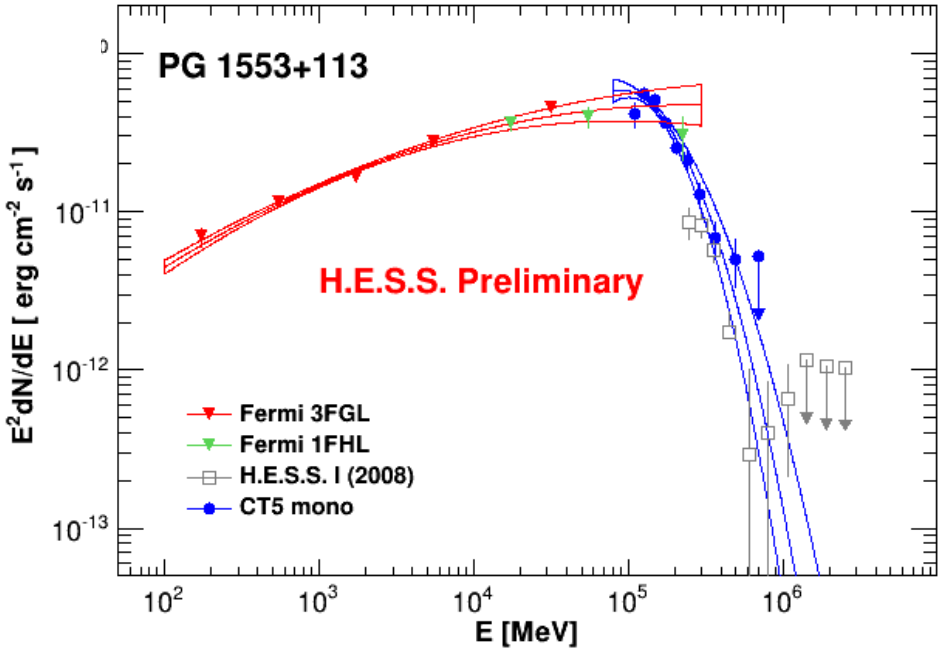
- Higher energy threshold
- Excellent angular resolution
- Excellent sensitivity

Best for: weak AGN And morphology studies

Preliminary HESSII SED Plots



Note- both objects observed in low-states during the HESSII observation campaign



H.E.S.S.

HESSI Conclusions

- PKS 2155-304 was extensively observed by HESSI
- Variability detected down to timescales smaller than the light-crossing time of the event horizon
- Temporal flux studies showed bimodality of the flux level
- The spectral evolution during flares shows interesting X-ray and gamma-ray brightness correlations
- Studies utilising these spectral results (along with other HBL) have provided strong constraints on the level of the extragalactic background light.

HESSII Conclusions

- Good overlap in energy with Fermi satellite measurements is now achieved with HESSII observations
- HESS observations were taken whilst both blazars were in a quiescent state
- Mild variability of PK 2155-304, however, was observed by HESSII, which is consistent with Fermi observations
- Adopting the Franceschini EBL model, the intrinsic curvature of both blazars was measured, though marginal for PG 1553+113.

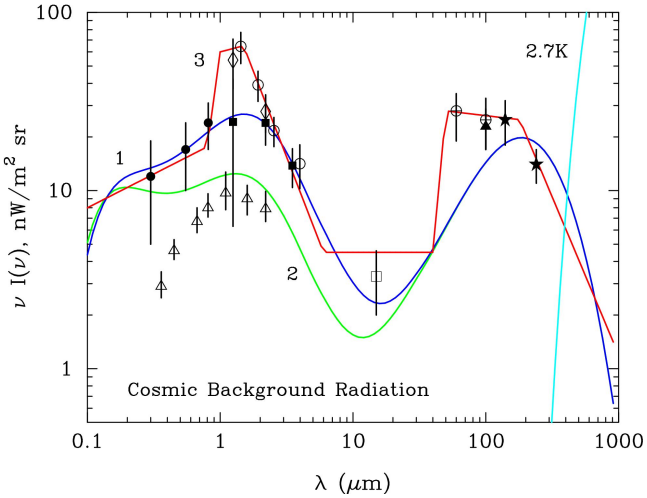
H.E.S.S.

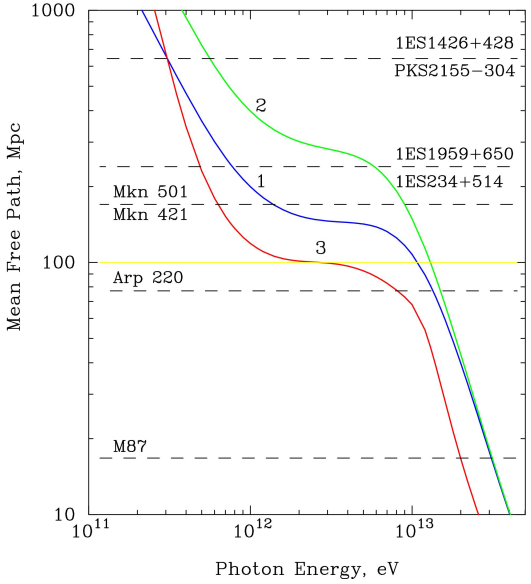
Extra Slides

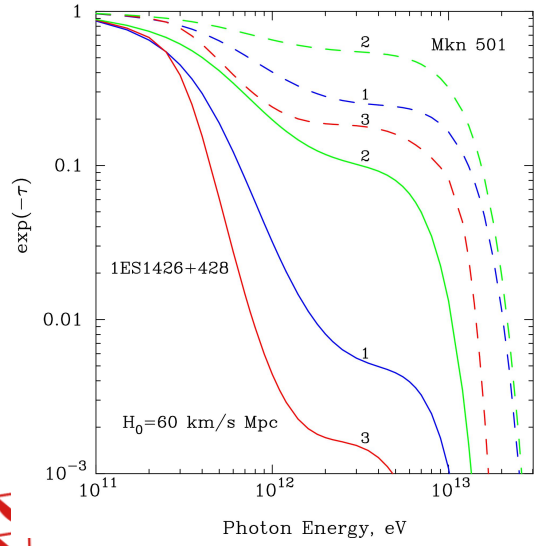
HESS II

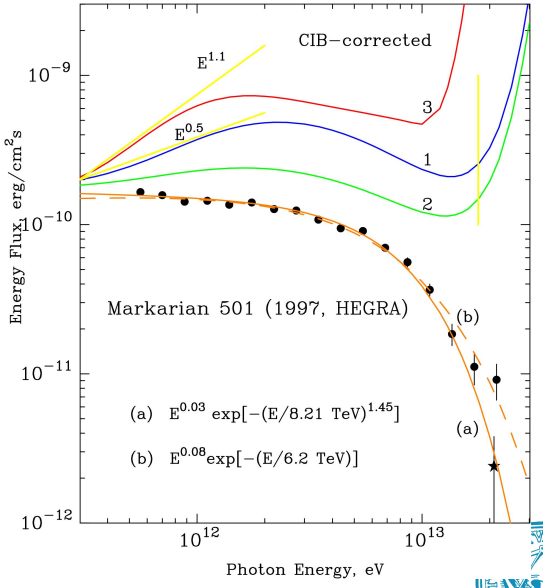
- HESS Phase I (2002-2012) consisted of 4 Cherenkov telescopes of 12m diameter (CT1-4)
- A fifth 28m telescope (CT5) was installed in 2012 -> HESS Phase II
- Mono analysis (CT5 only) is discussed here

Potential Hard Spectra Issues- Mrk 501







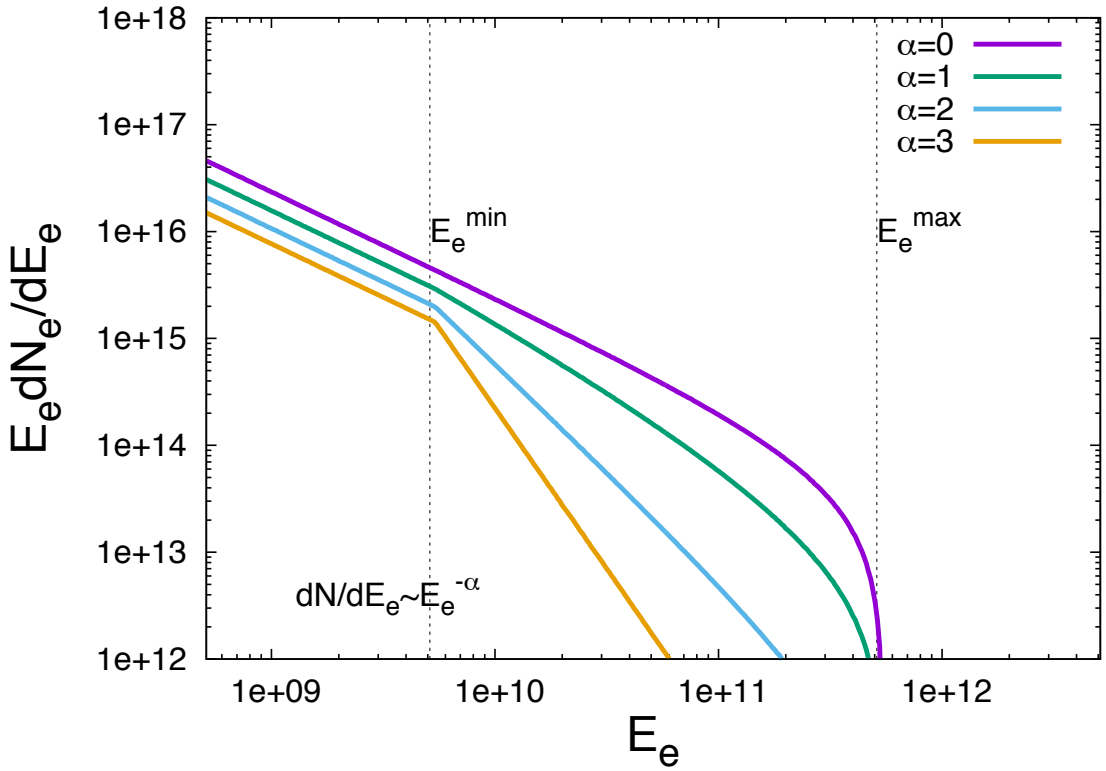


Aharonian 2001

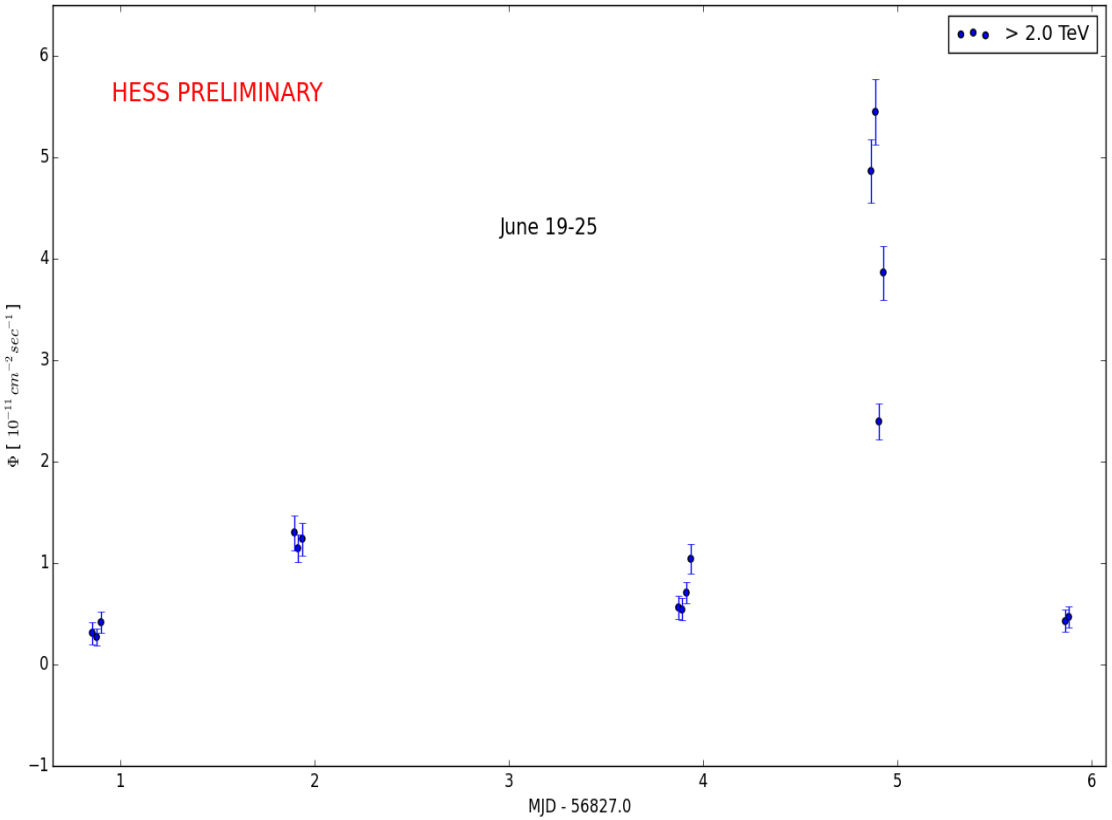
Hard Spectra can be Problematic

$$\frac{\partial \mathbf{f}}{\partial \mathbf{t}} + \dot{\mathbf{E}}\frac{\partial \mathbf{f}}{\partial \mathbf{E}} = \mathbf{Q}(\mathbf{E}) \qquad \mathbf{f} = \int_{\mathbf{E}}^{\infty} \frac{\mathbf{Q}(\mathbf{E})}{\dot{\mathbf{E}}}\mathbf{dE}$$

$$\mathbf{Q}(\mathbf{E}) = \mathbf{E}^{-\alpha}$$



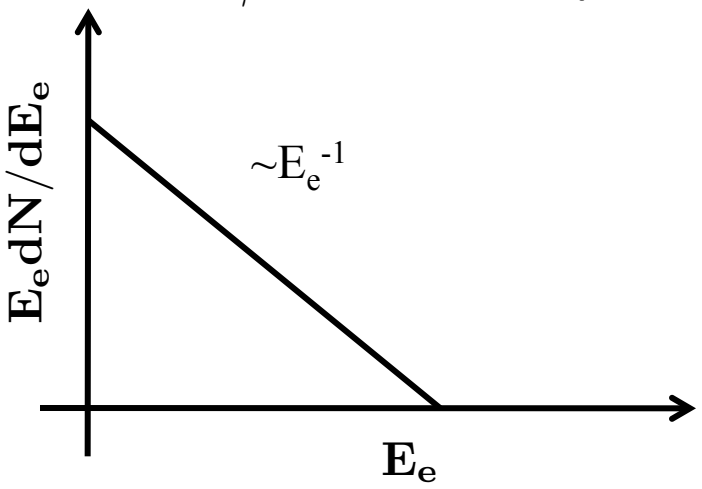
Mrk 501 Massive Flare 2014

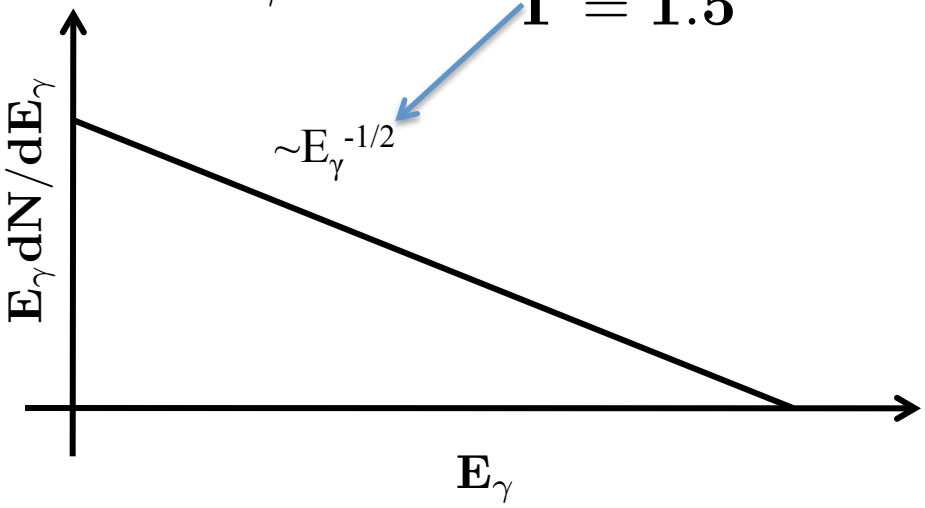


No significant delay between the highest and lowest energy photons is found

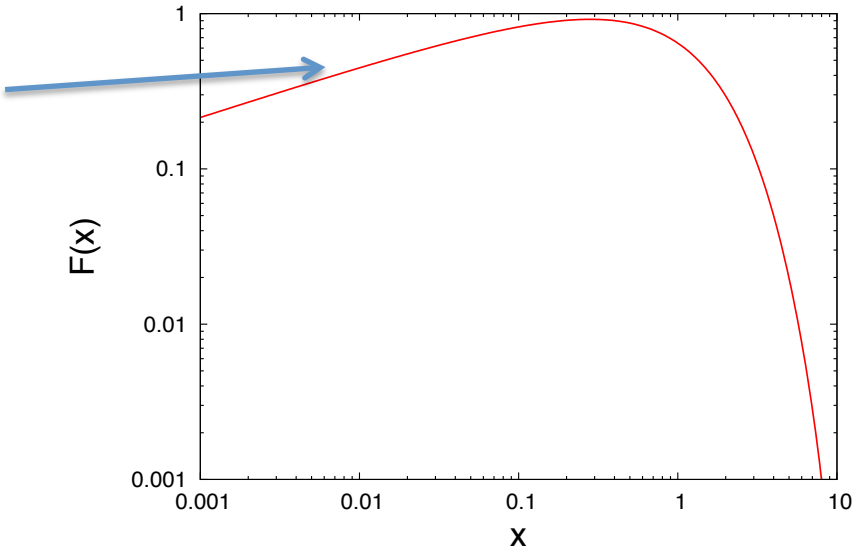
Hard Spectra can be Problematic

$$E_\gamma \frac{dN}{dE_\gamma} \propto E_\gamma^{-(\alpha-1)/2} \int F(x) x^{(\alpha-3)/2} dx\,, \quad \frac{dN}{dE_\gamma} \propto E_\gamma^{-\Gamma}$$



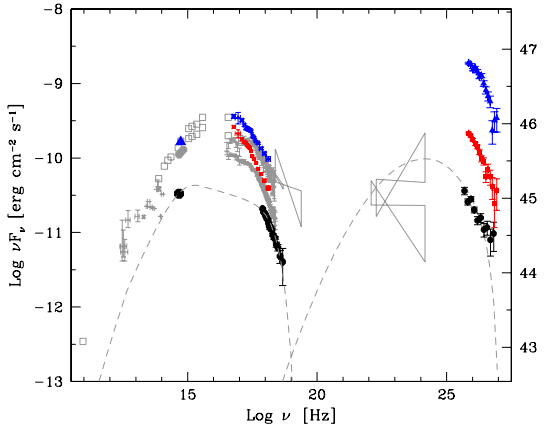


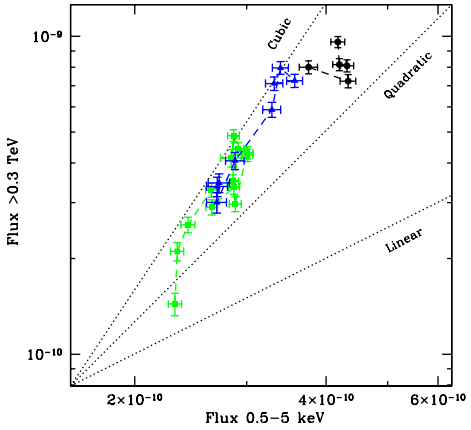
$\Gamma = 0.66$

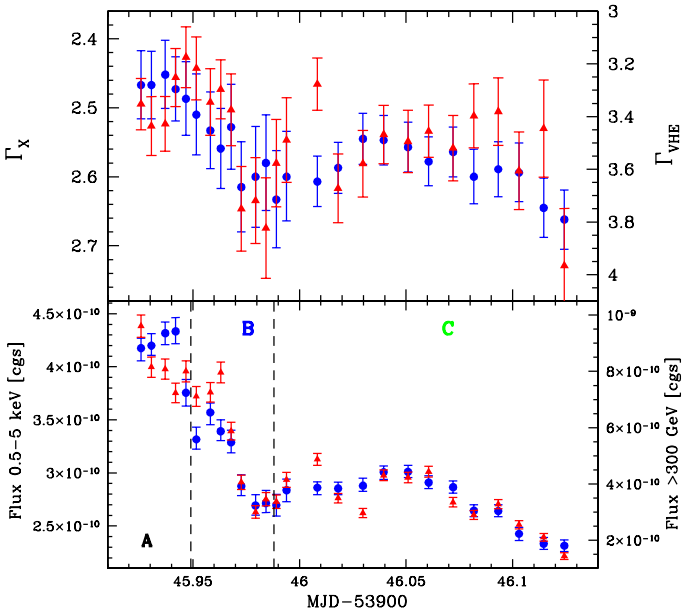


Flaring Spectral Energy Distribution and Evolution (2006)

- No time lags observed between X-rays and gamma-rays observed
- Both (EBL corrected) curvature and E_{peak} increased during flaring episode
- X-ray-gamma-ray correlation a key probe to testing the one zone SSC model, which is severely challenged by this flaring event







A bimodality is emerging for HBL flaring activity: either synchrotron dominated or Compton dominated ("orphan flare") events

H.E.S.S.

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