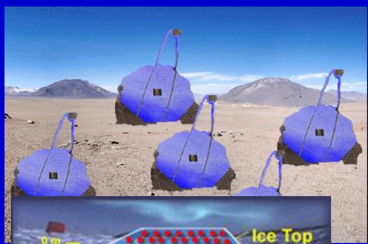
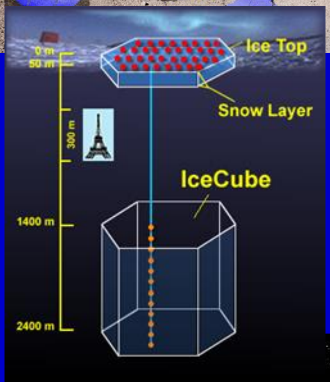
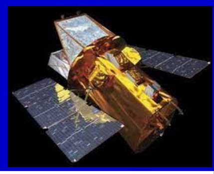
Looking for physics in the weather: gamma-ray blazars

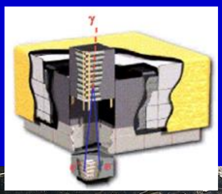
P. Coppi, Yale

[~30 years after the launch of CGRO, have we learned anything?]









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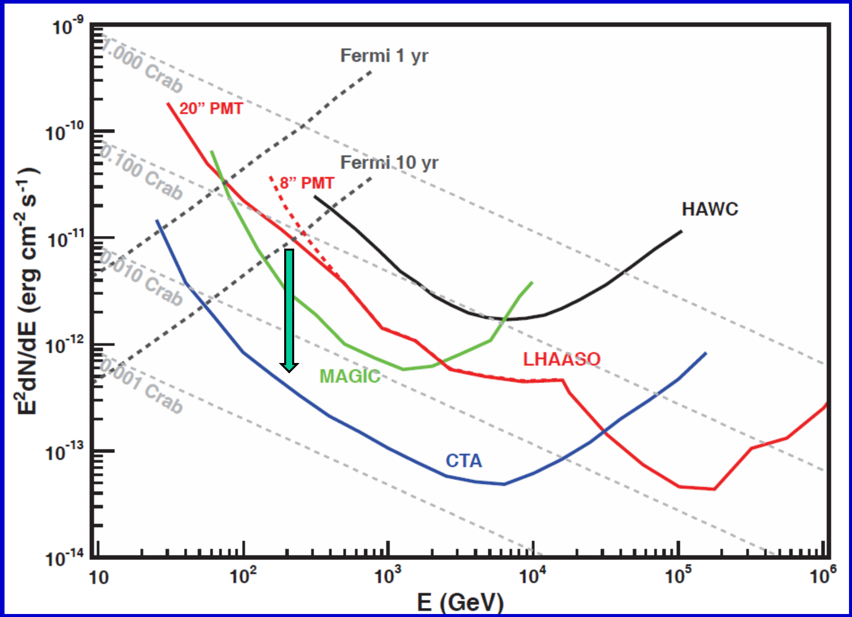
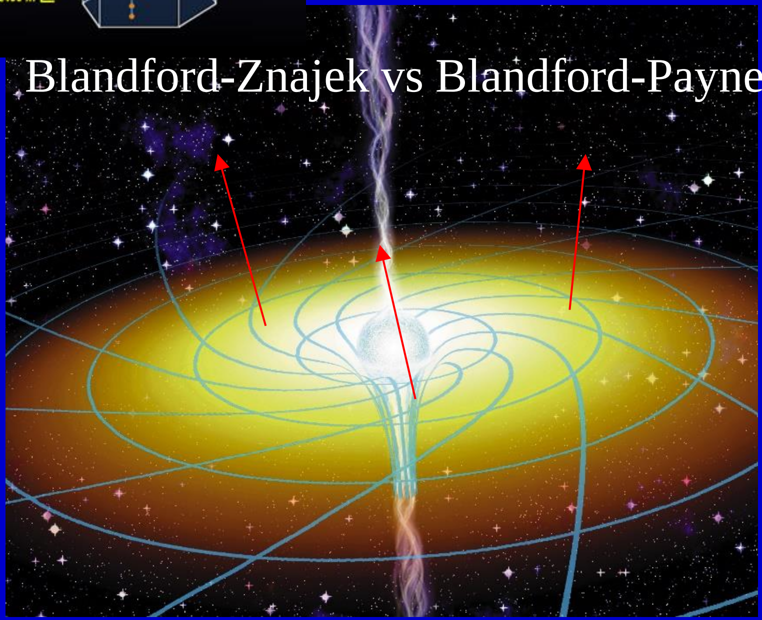




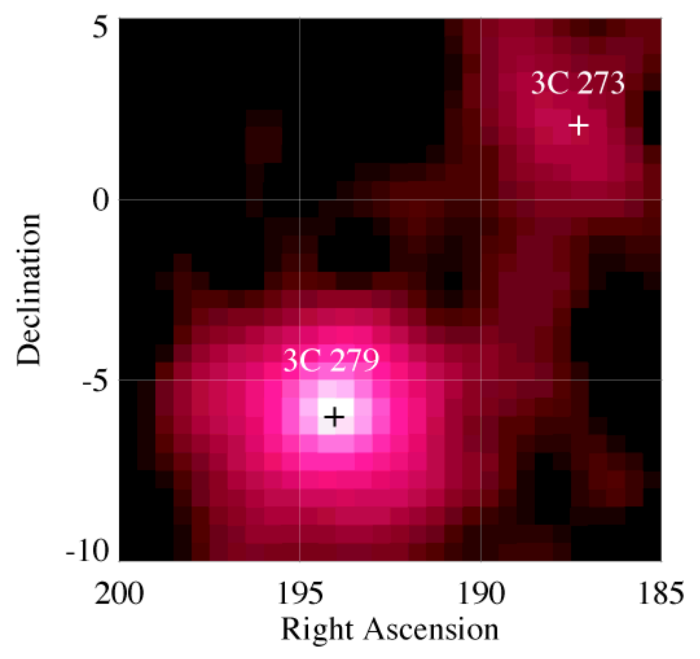
1. ~~The standard model right after CGRO~~

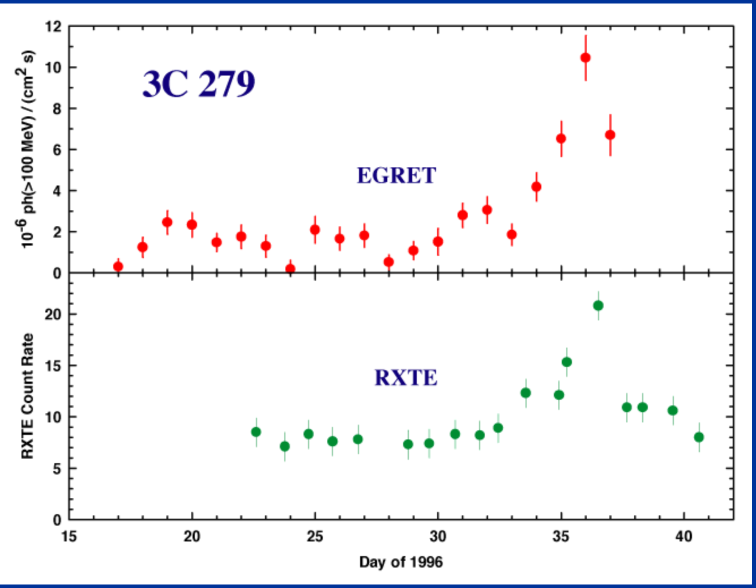
2. Some progress = confusion at a higher level

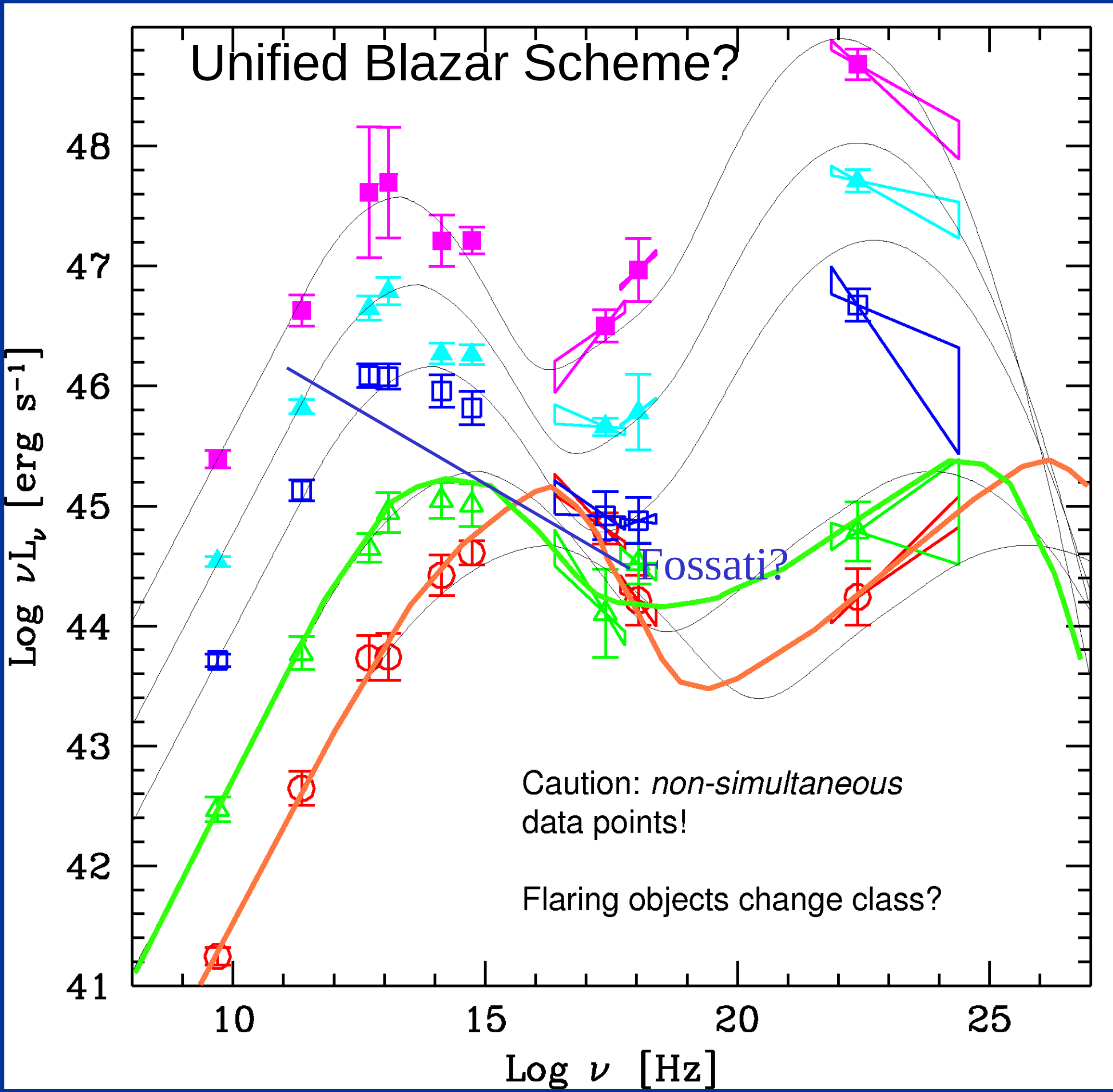
3. Things we need to work on and future prospects

CGRO/EGRET and the "GeV" Blazars- a Compton catastrophe?

[Ghisellini: Biggest mistake since cosmological constant]







Donato et al. 2002,
Fossati et al. 1998

Key Considerations from ~CGRO era

1. Apparent gamma-ray luminosity *large*, $\sim 10^{49+}$ erg/sec (>> likely L_{Edd}) => anisotropic emission

2. Two "bump" emission, optical-X and gamma-ray, vary in correlated manner? Same emission region =>
   potential problem because gamma-rays can pair produce off co-spatial photons in lower energy bump.

3. Rapid variability (hours-day) imply compact emission region => high pair production optical depth => no gamma-rays!? (Compactness problem, same for GRB) => *Doppler boosting*! + anisotropy = relativistic jet!

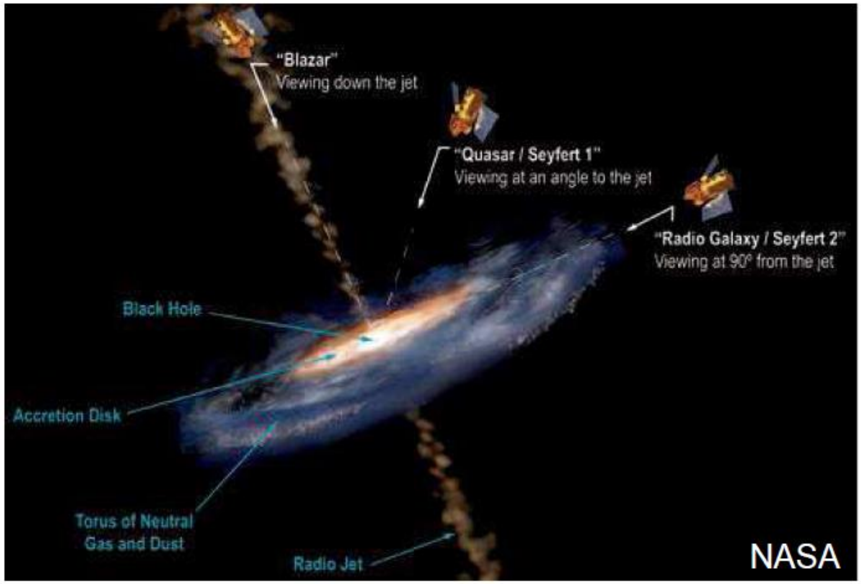
4. Even if emission is boosted by δ^4 and $\delta \sim 10$, $L_{true} \sim 10^{45+}$ erg/sec = non-trivial fraction of jet kinetic power (10^{46} erg/sec) inferred from, e.g., radio lobes. Can't ignore but also can't kill jet => zone of avoidance.

5. Emission is done by energetic particles – need lots of them, jet can't be empty/pure Poynting flux by time gamma-ray emission starts and probably by time get to lobes, jet likely baryon loaded/dominated – although by *number* jet particle content could dominated by pairs (e.g., Sikora et al. 2006)
   [Clue: Fabian – particle content of cluster bubbles? k/f ~1]

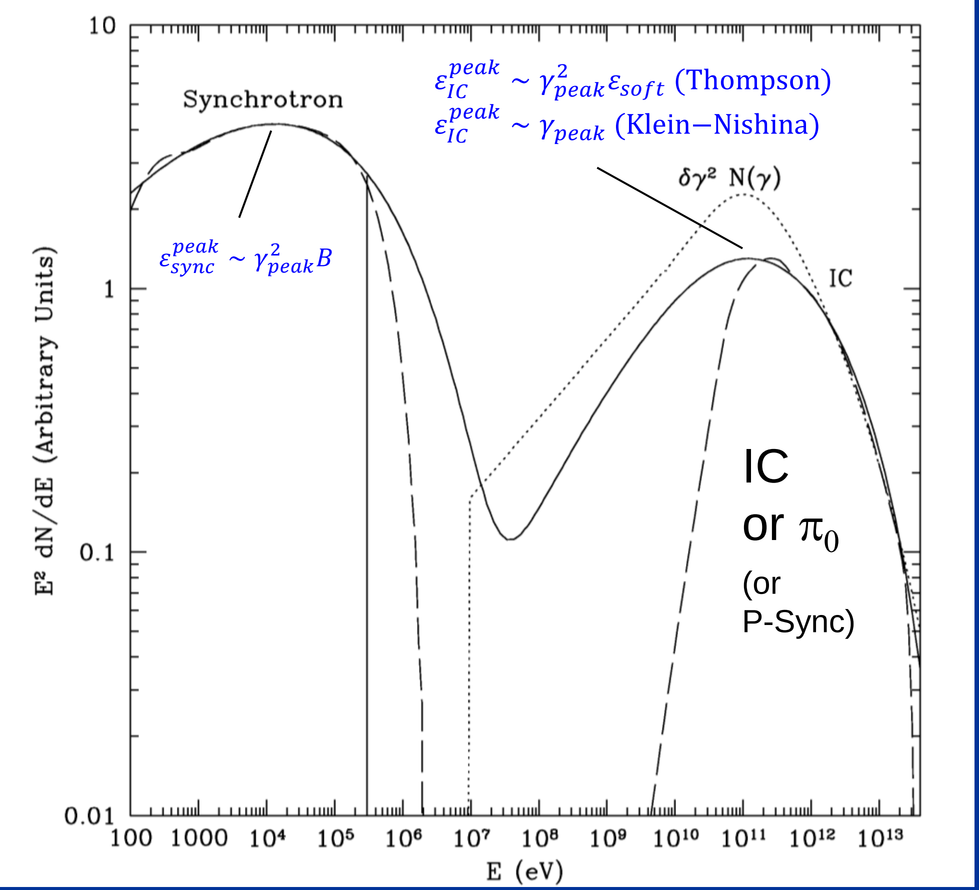
What's up after 10+ years of Fermi/IACT blazar observations??

Key questions on blazars

- Emission mechanisms (for HE component)
  - Leptonic (IC of synchrotron or external photons) vs hadronic ($\pi^0 \rightarrow \gamma\gamma$, proton synchrotron)
- Emission location
  - Single zone for all wavebands (completely constraining for simplest leptonic models)
  - Opacity effects and energy-dependent photospheres
- Particle acceleration mechanisms
  - Shocks, magnetic reconnection, turbulence acceleration
- Jet composition
  - Poynting flux, leptonic, ions
- FSRQ/BLLac dichotomy
- Jet confinement
  - External pressure, magnetic stresses
- Accretion disk—black hole—jet connection
- Effect of blazar emission on host galaxies and galaxy clusters
- Blazars as probes of the extragalactic background light (EBL)



VHE Astrophysics I.
A Generic Source ....



Multiwavelength observations very powerful/critical!

E.g., if have synchrotron/IC model $L_{IC}/L_{syn}=U_B/U_{rad}$, constrain B if know U_{rad}.
Also, *correlated* IC/synch. spectra!

Process(es) directly responsible for observed X-ray/γ-ray emission?

- Compton scattering $(e\gamma \rightarrow e\gamma)$
- synchrotron radiation $(eB \rightarrow eB\gamma)$

lowest order, most "efficient"

- Bremsstrahlung $(ee \rightarrow ee\gamma, pe \rightarrow pe\gamma)$
- π^0 decay $(\pi^0 \rightarrow \gamma\gamma)$ — almost always accompanied by $\pi^{\pm} \rightarrow ...e^{\pm}$
- proton synchrotron $(pB \rightarrow pB\gamma)$

VHE Astrophysics II

O.K. Where do we get required GeV/TeV electrons/pairs/pions?

- Acceleration (bottom-up)

  Direct acceleration by $\vec{E}$ (e.g., pulsar)

  Stochastic shock/wave acceleration (e.g. $1^{st}/2^{nd}$ order Fermi process)

  "leptonic" models

- Creation at desired energies (top-down)

if $p\gamma \to x$ dominates, generically get E.M. cascade (P.I.C.).

$$\left\{ \begin{array}{l} p\gamma \to pe^+e^- \\ (p/n)\gamma \to (n/p)\pi^\pm \\ \gamma\gamma \to e^+e^- \\ \gamma e \to ee^+e^- \end{array} \right. \quad ..e^\pm, \nu$$

or $pp \to pp\pi$

don't need to be ultrarelativistic, e.g., SNR

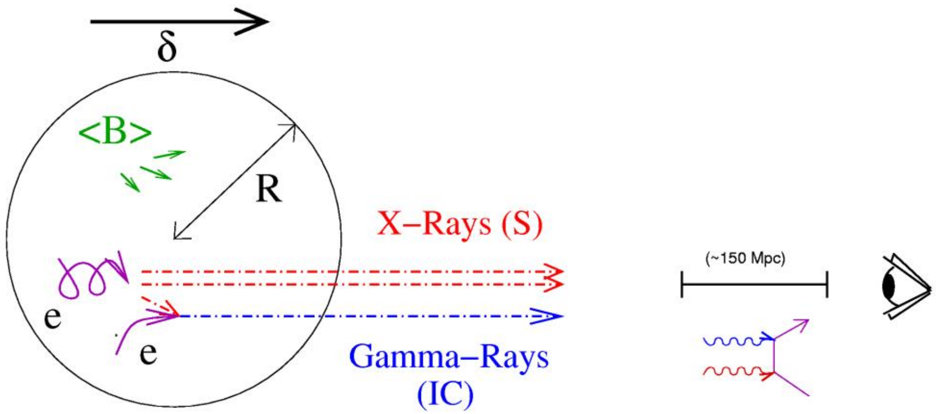
but need large target matter densities

"hadronic" models

Neutrinos: "smoking gun" for hadronic models

Big advantage of hadronic models: protons easier to accelerate to very high energies
Big disadvantage … : protons harder to extract energy from *(INEFFICIENT!)*

Mkn 501 – Synchrotron Self–Compton Models



Model parameters:
- δ Doppler Factor
- R Size
- <B> Magnetic field
- e Electron Distribution:
  - – Intensity
  - – Acceleration Spectrum

Model Constraints:

$\Delta t < 1$ day
=> Small Radius ($\delta 10^{15}$ cm)

Cooling Times: B>0.025

SSC Photons =>
Accounts already for
TeV Flux ($\delta = 25$)

Optically Thin: Doppler Factor >15

Approaches:

– Reconstruct e–Spectrum from X–Ray Spectrum

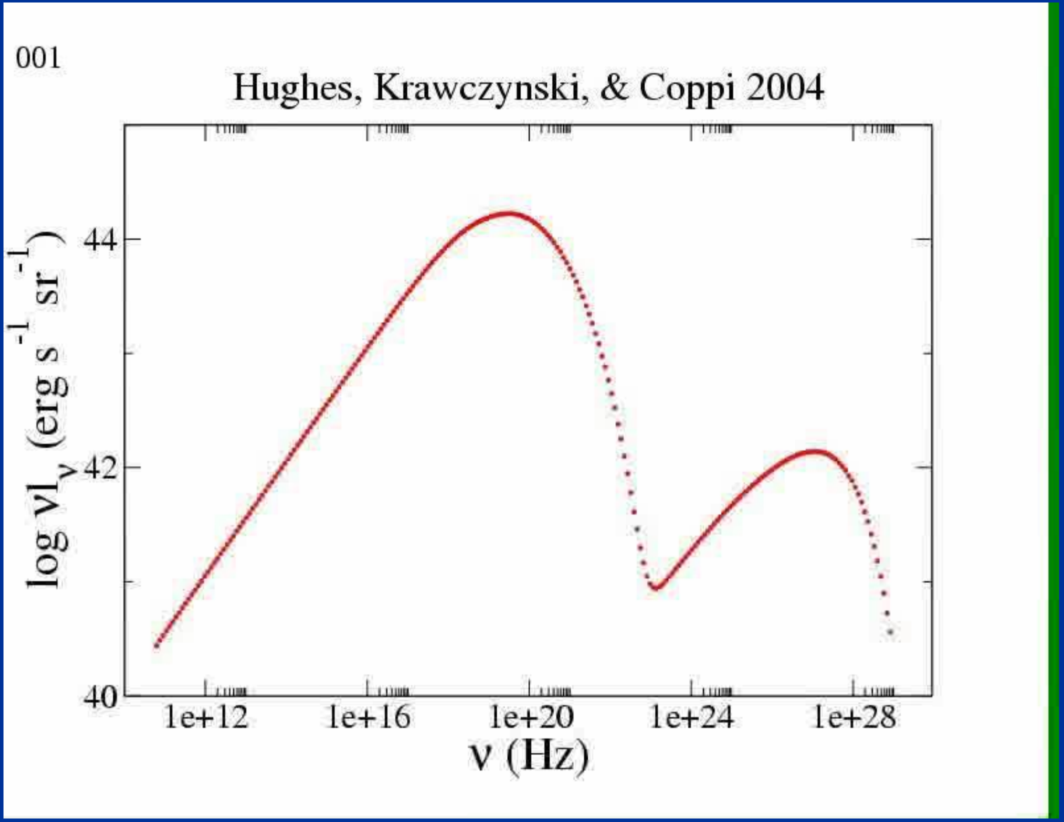
– Time Dependent Model of X–Ray and TeV Gamma–Ray Emission

Bjet_MCMC

Krawczynski, Coppi, & Aharonian 2002

Variability "in principle" very constraining:

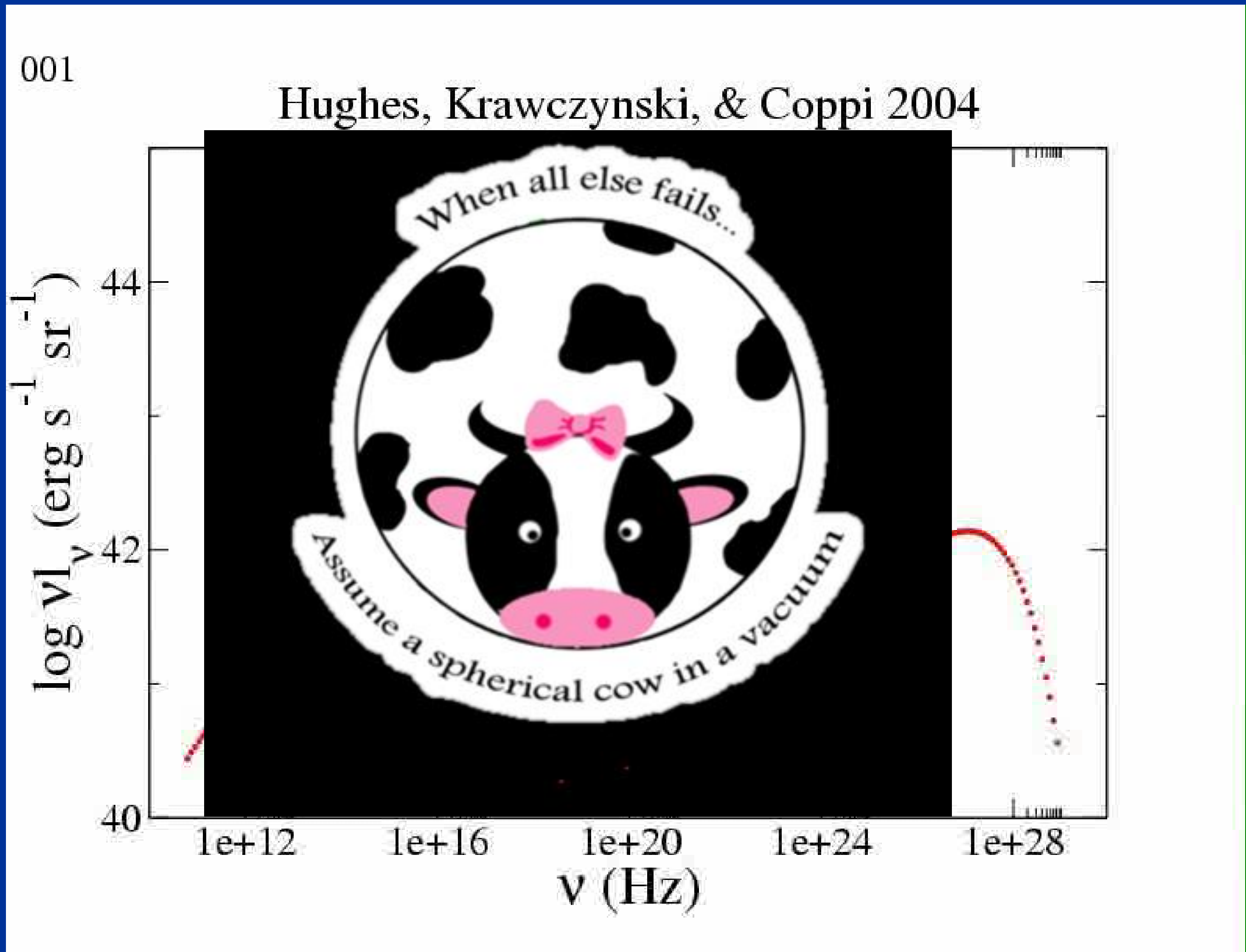
simple (?) TeV blazar [one zone SSC, no "external" radiation]



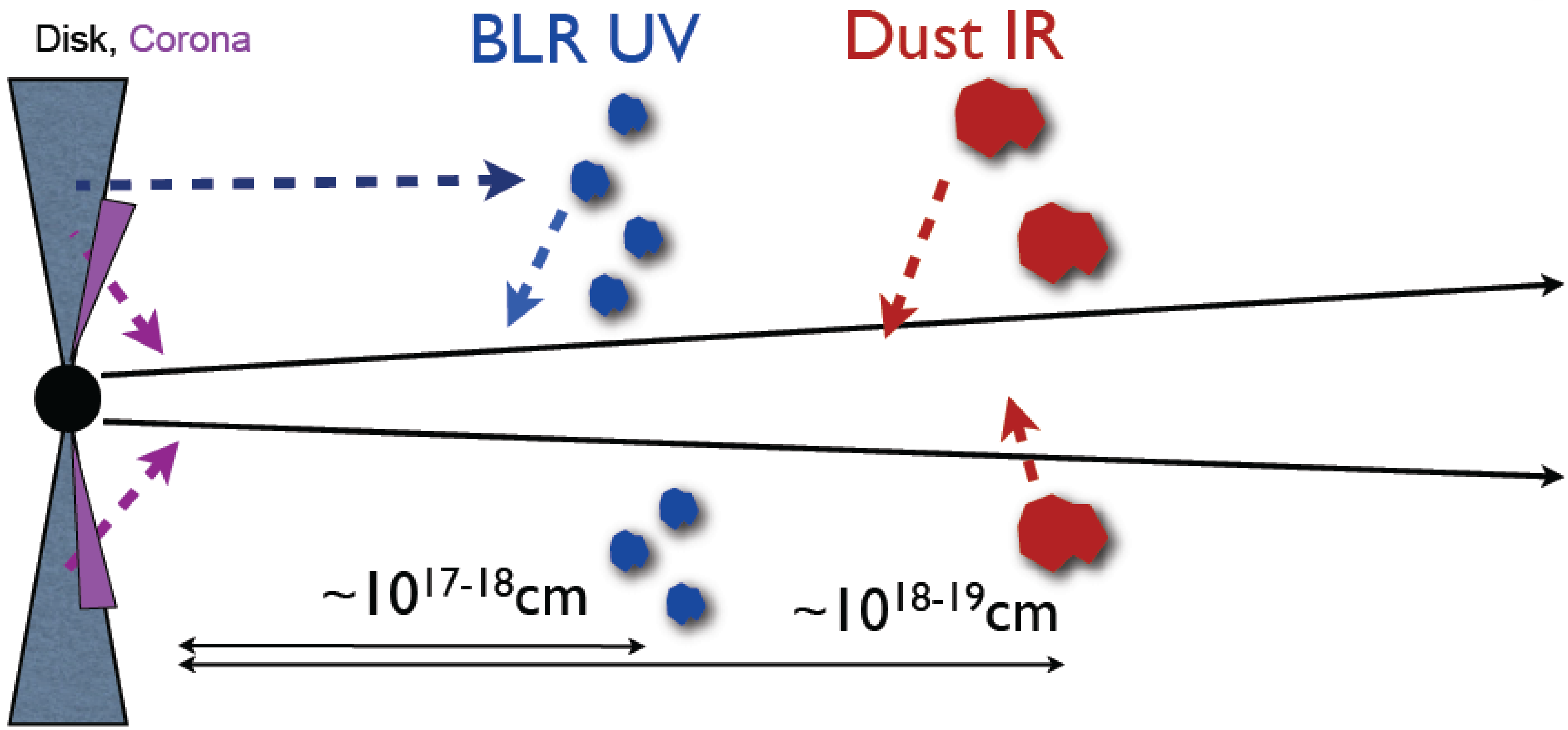
Shows hard-soft vs intensity hysteresis, cooling lags, and L_Compton ∝ L_Sync^2

… monitoring both peaks allows one to unambiguously determine model parameters

Unfortunately, this matches observations only some of the time …
(or *never* in some objects!)

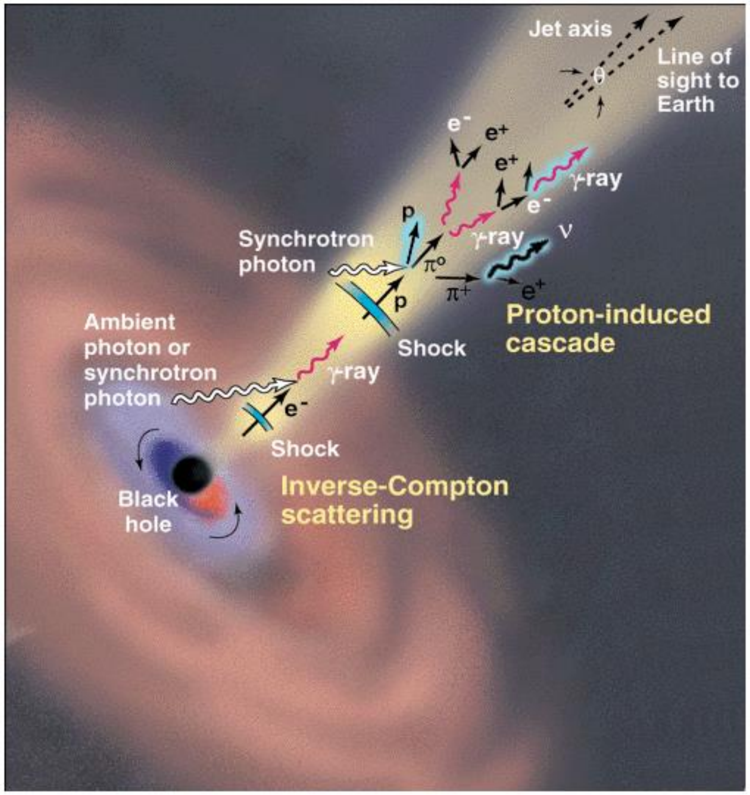


Where the gamma-rays come from ?

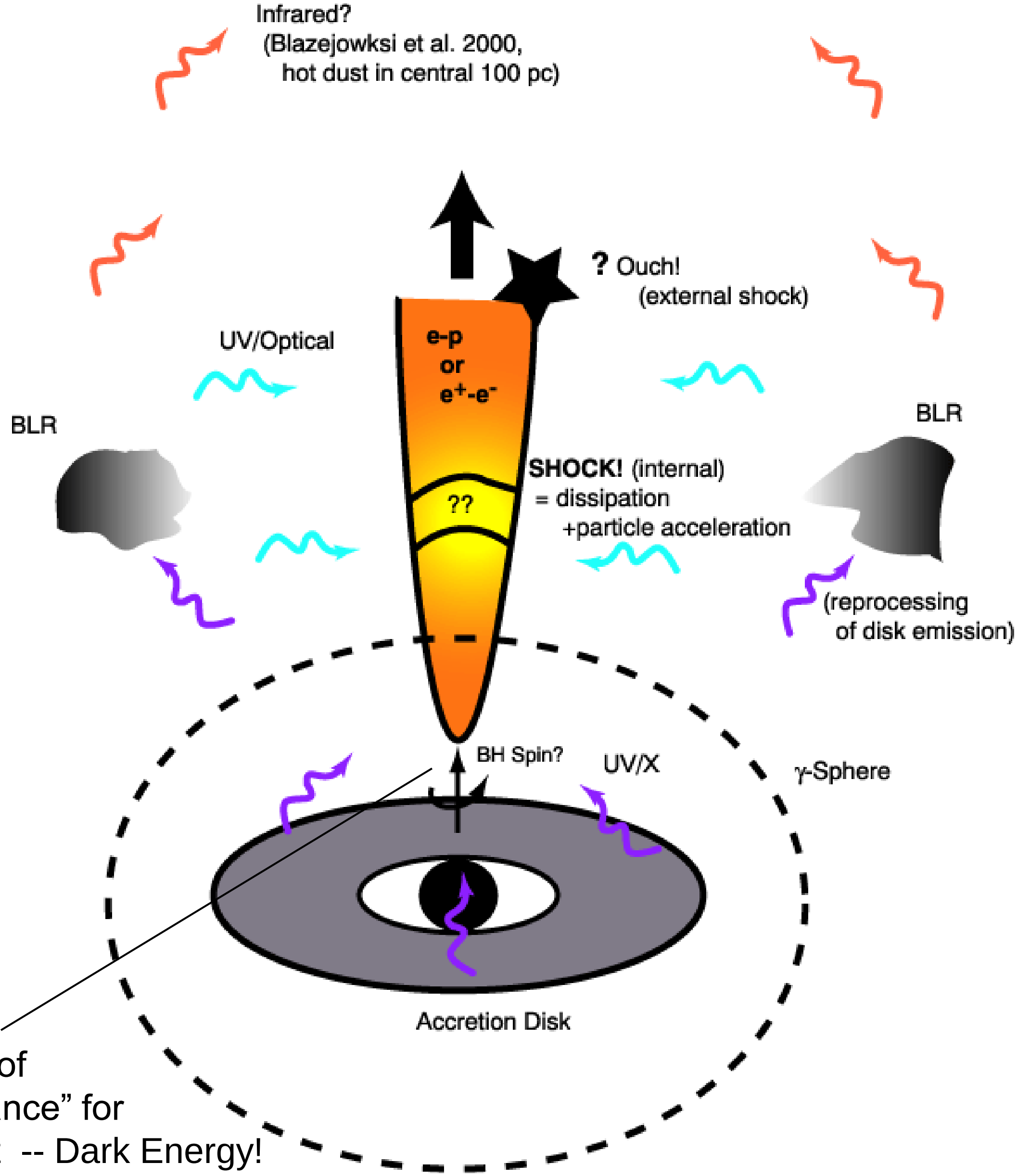


NB: Following Arguments valid for FSRQ-like blazars only
(objects with radiatively efficient disk, BLR emission, no or very weak TeV emission);
NOT FOR HBLs / TeV BLLacs !!

Blazar Emission Mechanisms: Idealized vs. Real Life



(Buckley, Science, 1998)



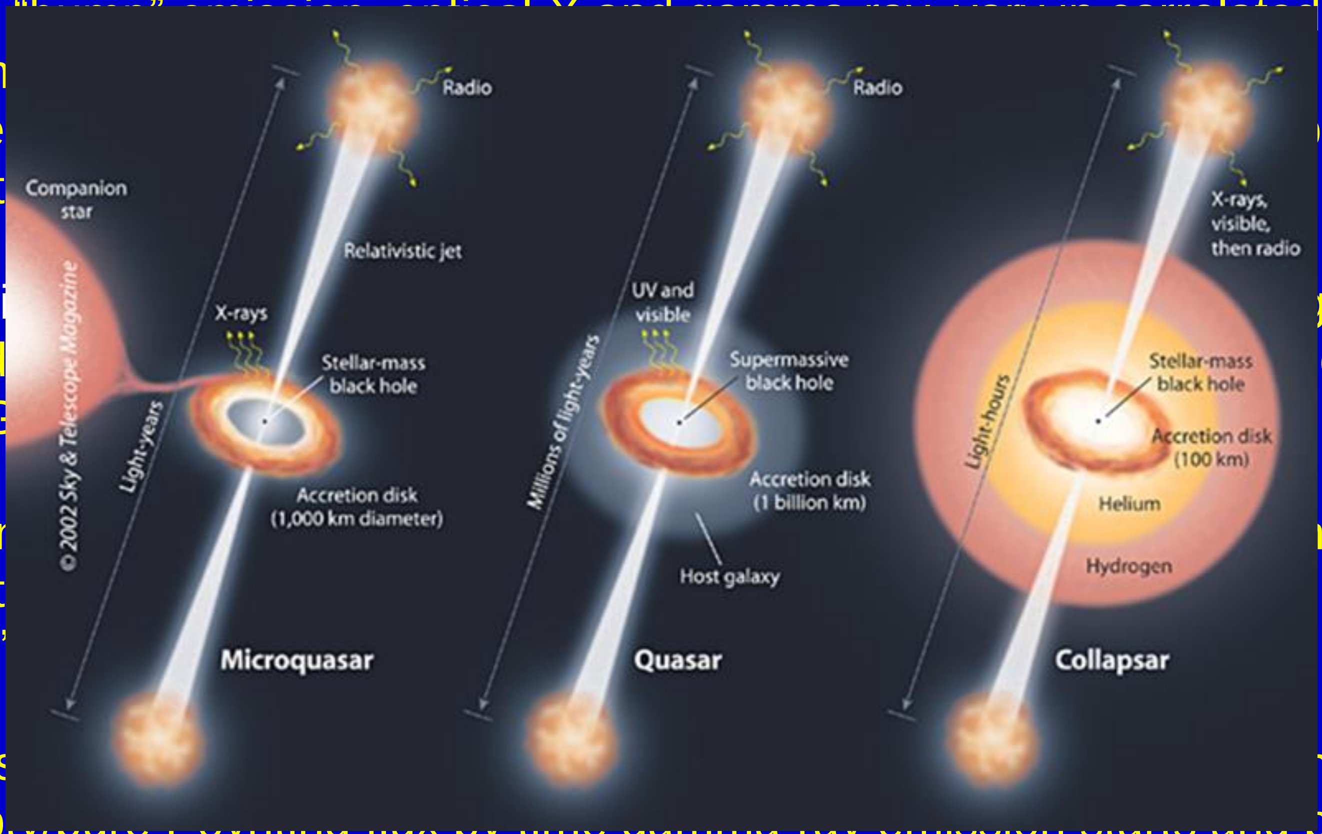
"Zone of
Avoidance" for
pair jet -- Dark Energy!

The central engine of a generic gamma-ray blazar is a MESSY place!

Key Considerations from ~CGRO era

1. Apparent gamma-ray luminosity *large*, ~10^{49+} erg/sec (>> likely L_{Edd}) => anisotropic emission

2. Two … manner?
   Sam …
   pote … atial
   phot …



3. Rapi … gh pair
   prod … em, same
   for G …

4. Ever … non-trivial
   fract … lobes.
   Can' …

5. Emis … n't be
   empty/pure Poynting flux by time gamma-ray emission starts and probably by time get to lobes, jet likely baryon loaded/dominated – although by *number* jet particle content could dominated by pairs (e.g., Sikora et al. 2006)
   [Clue: Fabian – particle content of cluster bubbles? k/f ~1]

Theoretical Considerations [Complications] III.

Is the observed high energy cutoff in some objects intrinsic or simply due to photon-photon pair production (inside source or intergalactic)?

Depends on ambient radiation field, but for 3C279

γ-sphere: $r_{\rm emission} \lesssim 100\, R_g$ ($\sim 10^{15}$ cm), $\tau_{\gamma\gamma} > 1$ for E $\gtrsim$ 10 MeV

$r_{\rm emission} \lesssim 10^{17}$ cm (BLR), $\tau_{\gamma\gamma} > 1$ for E $\gtrsim$ 50 GeV

$r_{\rm emission} \lesssim$ parsecs (dust torus), $\tau_{\gamma\gamma} > 1$ for E $\gtrsim$ 1 TeV

So 3C279 should not be VHE source, but it is!!

[N.B. Estimates don't apply to Mrk 421/501 -- BL Lacs appear to have weak central radiation fields. Accretion disk underluminous for black hole mass]

Costamante, Meyer et al. No Fermi breaks at > 10 GeV/BLR absorption features!

What is the origin of the spectral breaks seen in X-rays/gamma-rays?

- Superposition of different emission components?
- Transition from efficient to "inefficient" cooling (particles escape before cooling)?
- Acceleration process: E_max or **E_min** ("quasi-thermal" pool)? => α_x~0.5?
- *Klein-Nishina effects? Cascading [also => E_{min}]?*

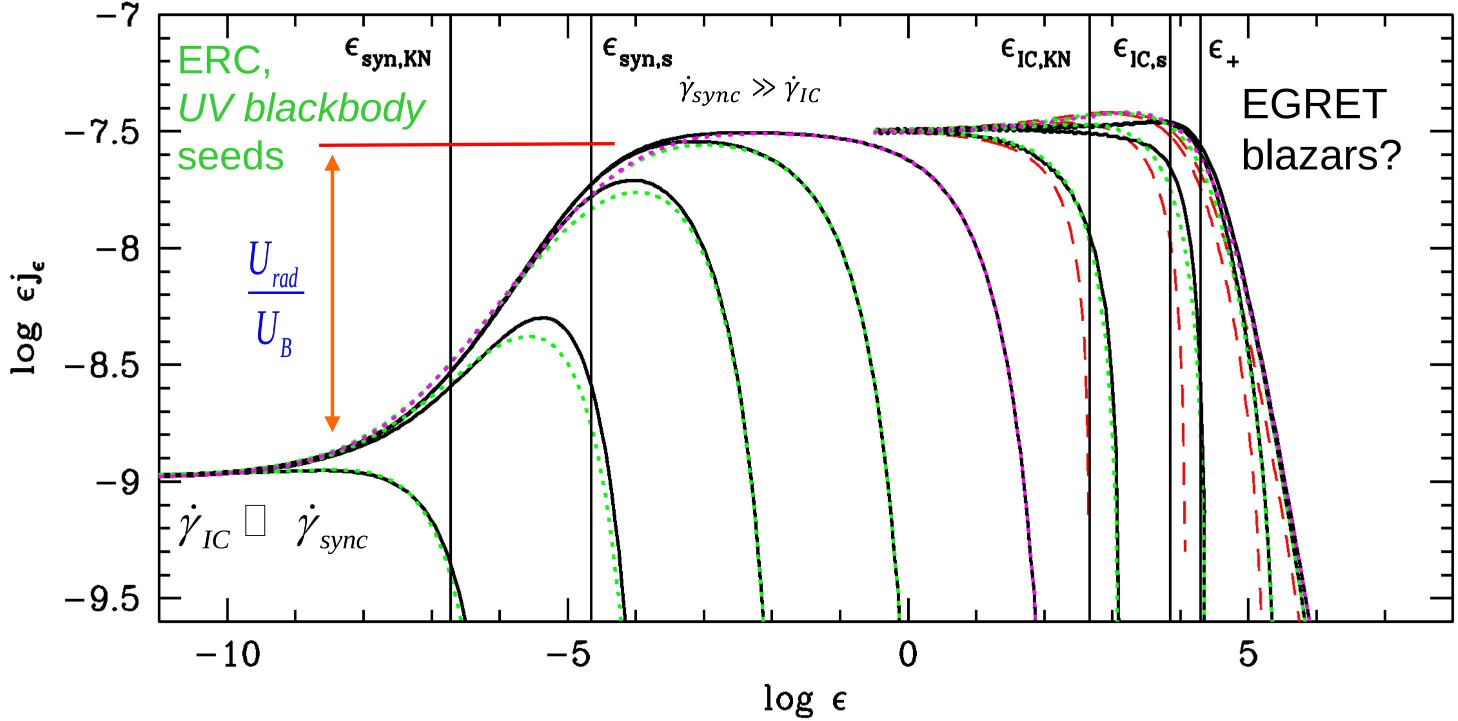
Example complication…

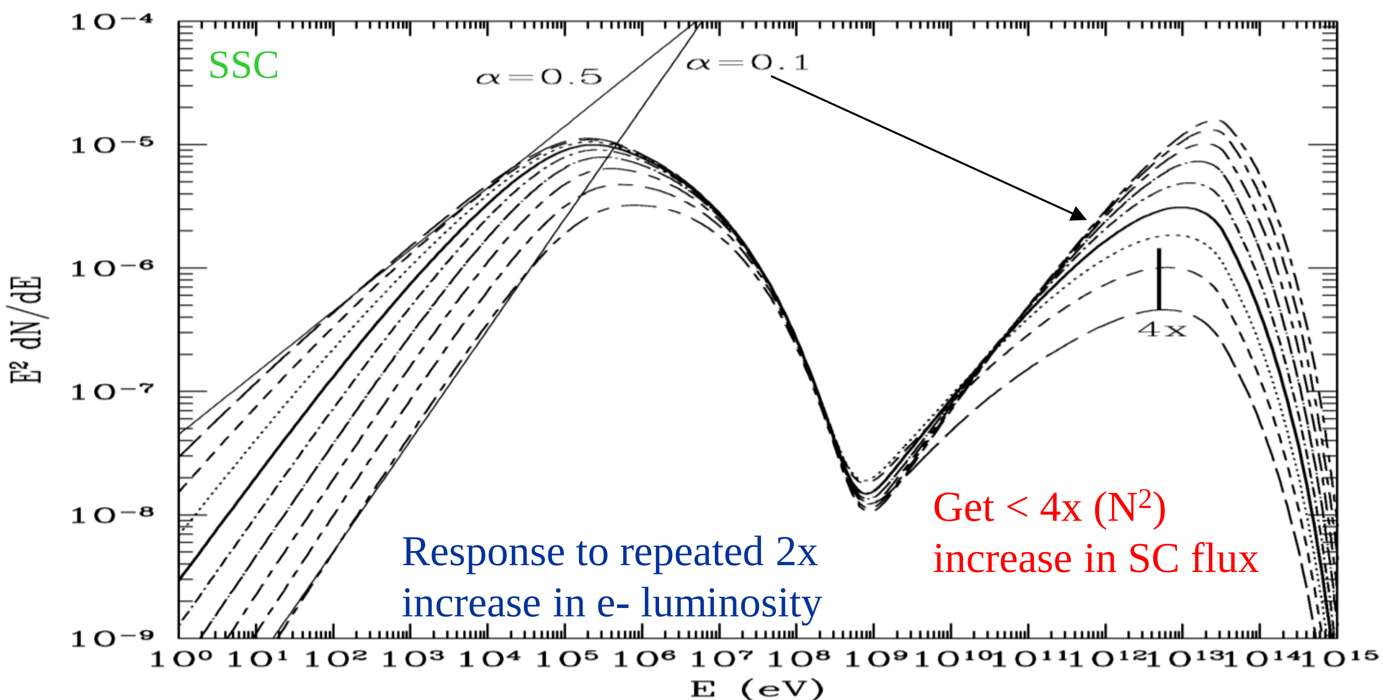
What happens if significant fraction of soft target photons interact with scattering electrons in *Klein-Nishina* limit?

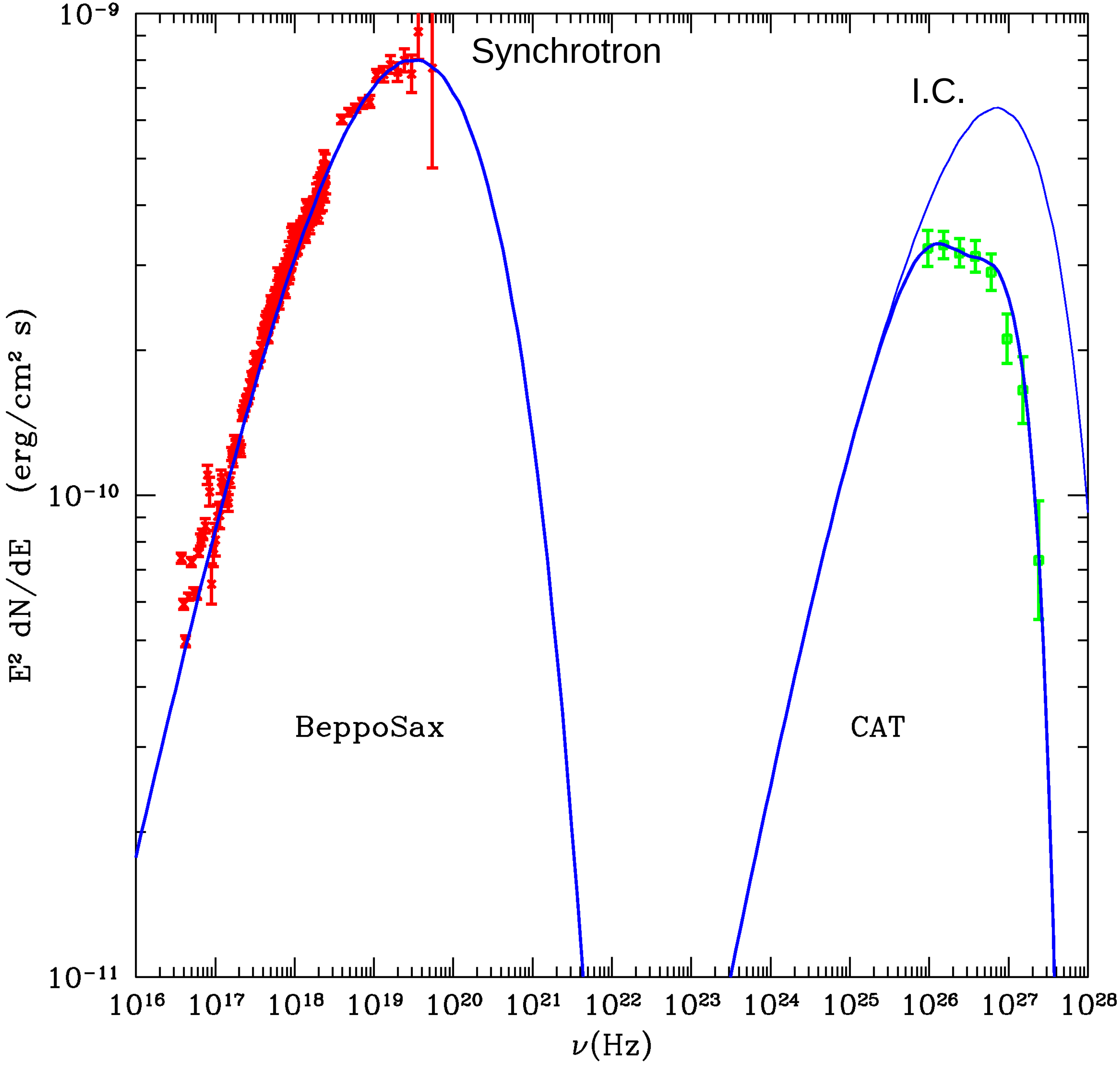
Be careful in interpreting origin of spectral features such as “bumps” and break energies!

Can get spectral Index *harder* than 0.5!

LEARN ABOUT TARGET PHOTON FIELD.







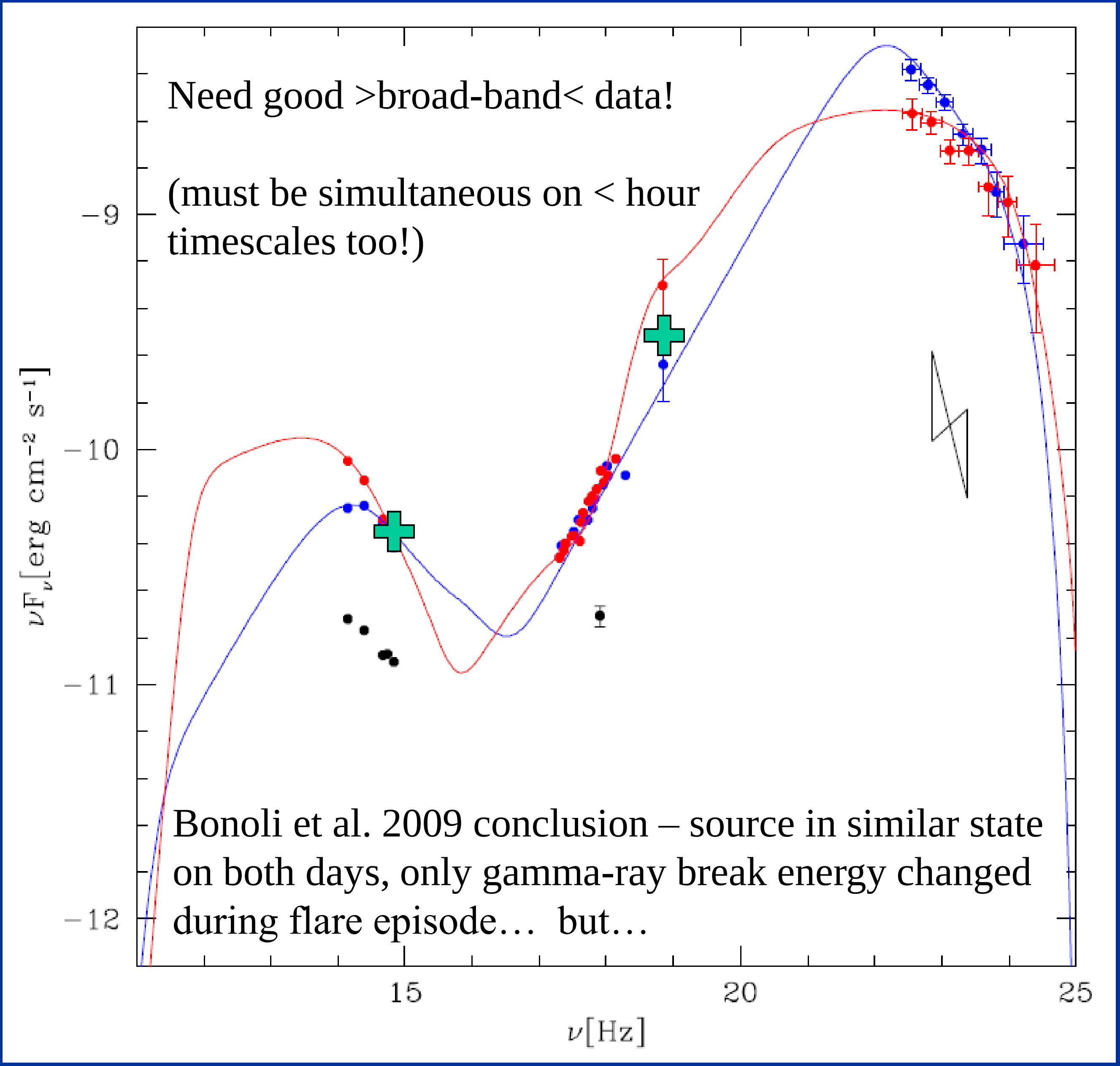
Simultaneous SSC fit to BeppoSax and CAT for Mrk 501 flare of April 16, 1997 using fully self-consistent model

-- *including* Klein-Nishina effects

X-ray spectrum, harder than 0.5!

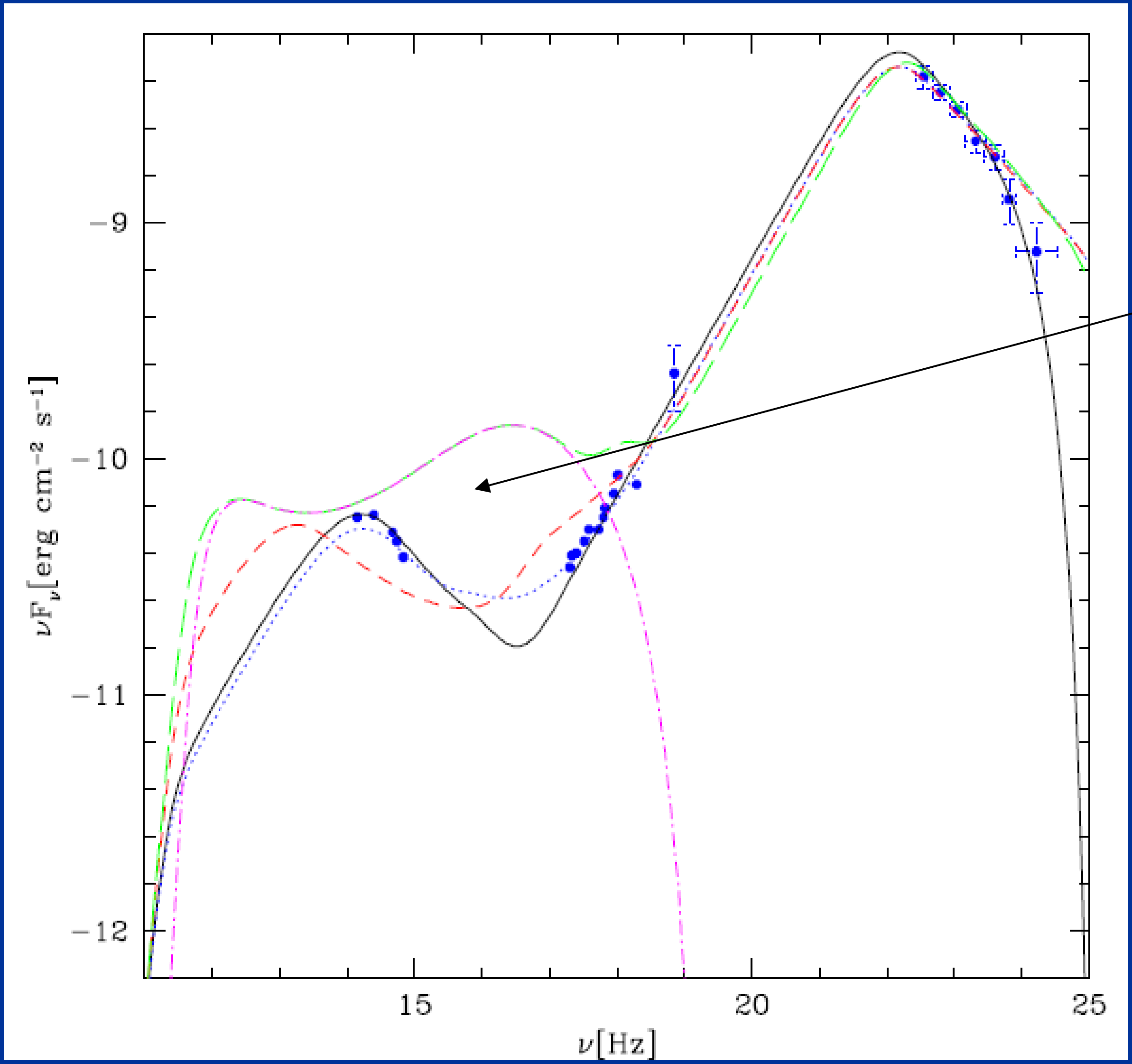
[Minor detail – SSC fit parameters stable ~ 2 months! A single blob would be far away by that time]

One zone fit to 3C 454.3 Dec 2-3 2009, Follow Bonoli et al. 2009…. Except Include SMARTS NIR/opt



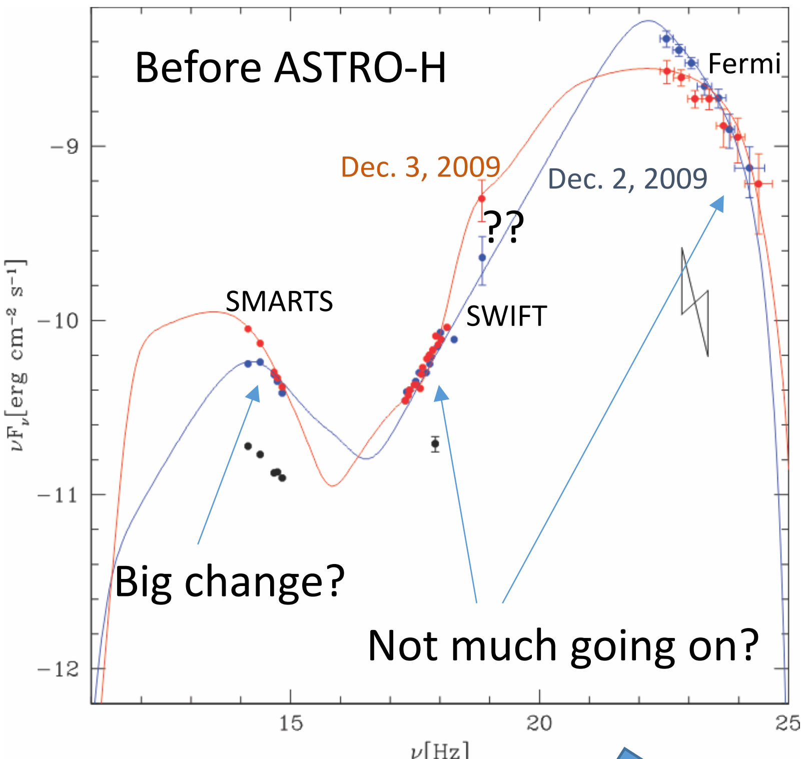
Keep Basic Model Same –

Fiddle With Bulk Lorentz Factor and High-Energy Electron Cutoff

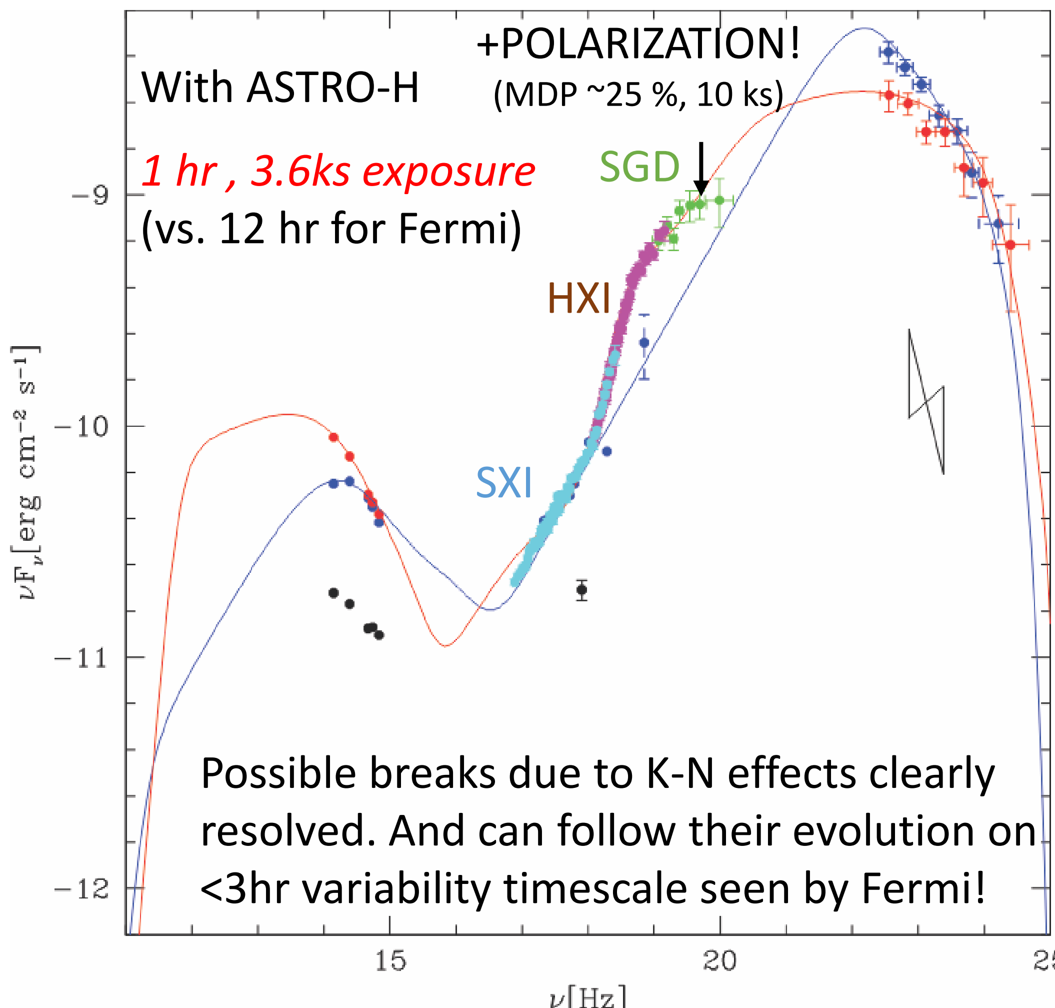


Is this kind of behavior ruled out?

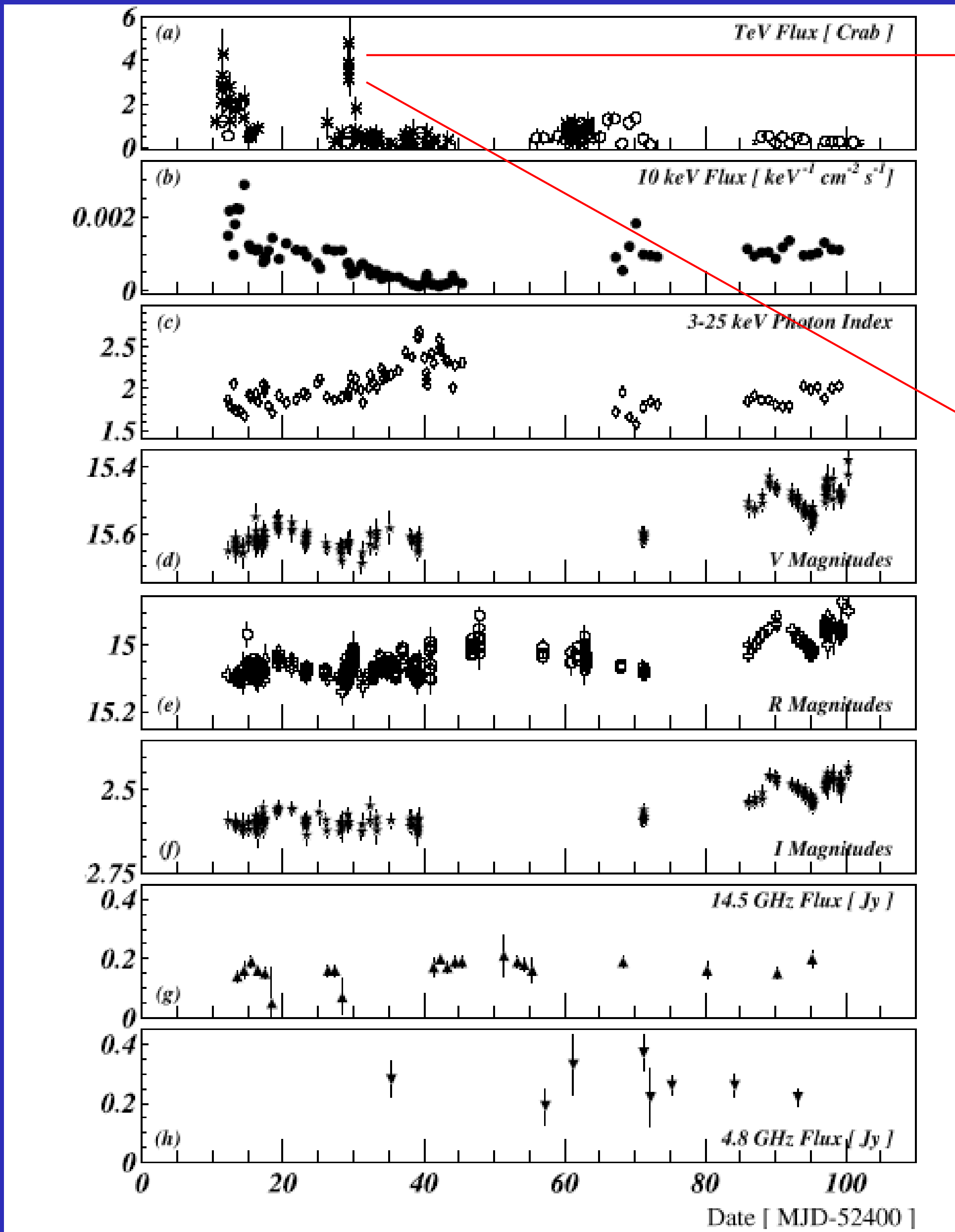
If ASTRO-H had been available during big Fermi blazar flares, we would have significantly better understanding of source like 3C454.

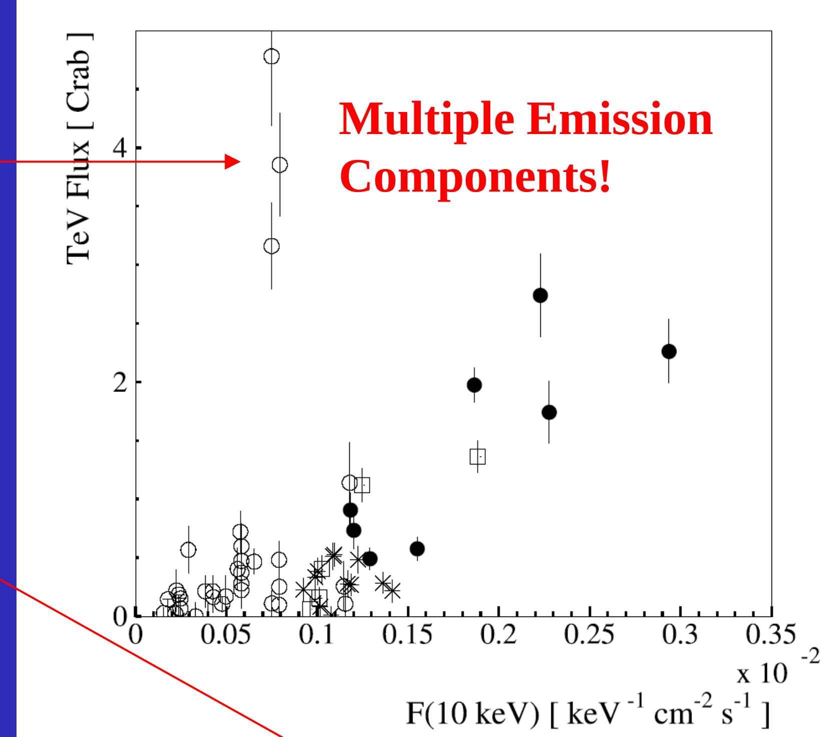


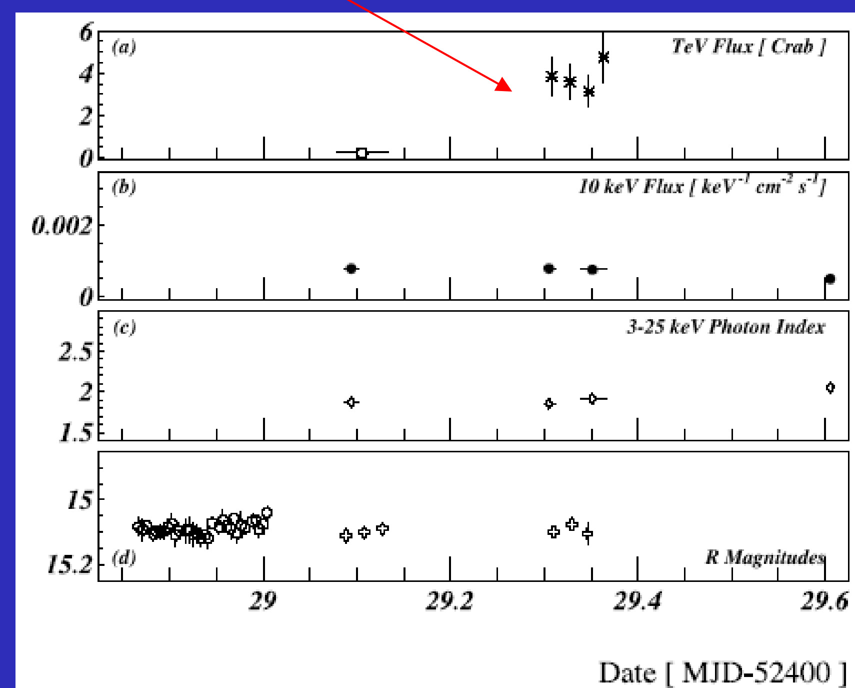
3C454 on two nights in December 2009…



Oops!! -- 1ES1959 May-Aug 2002

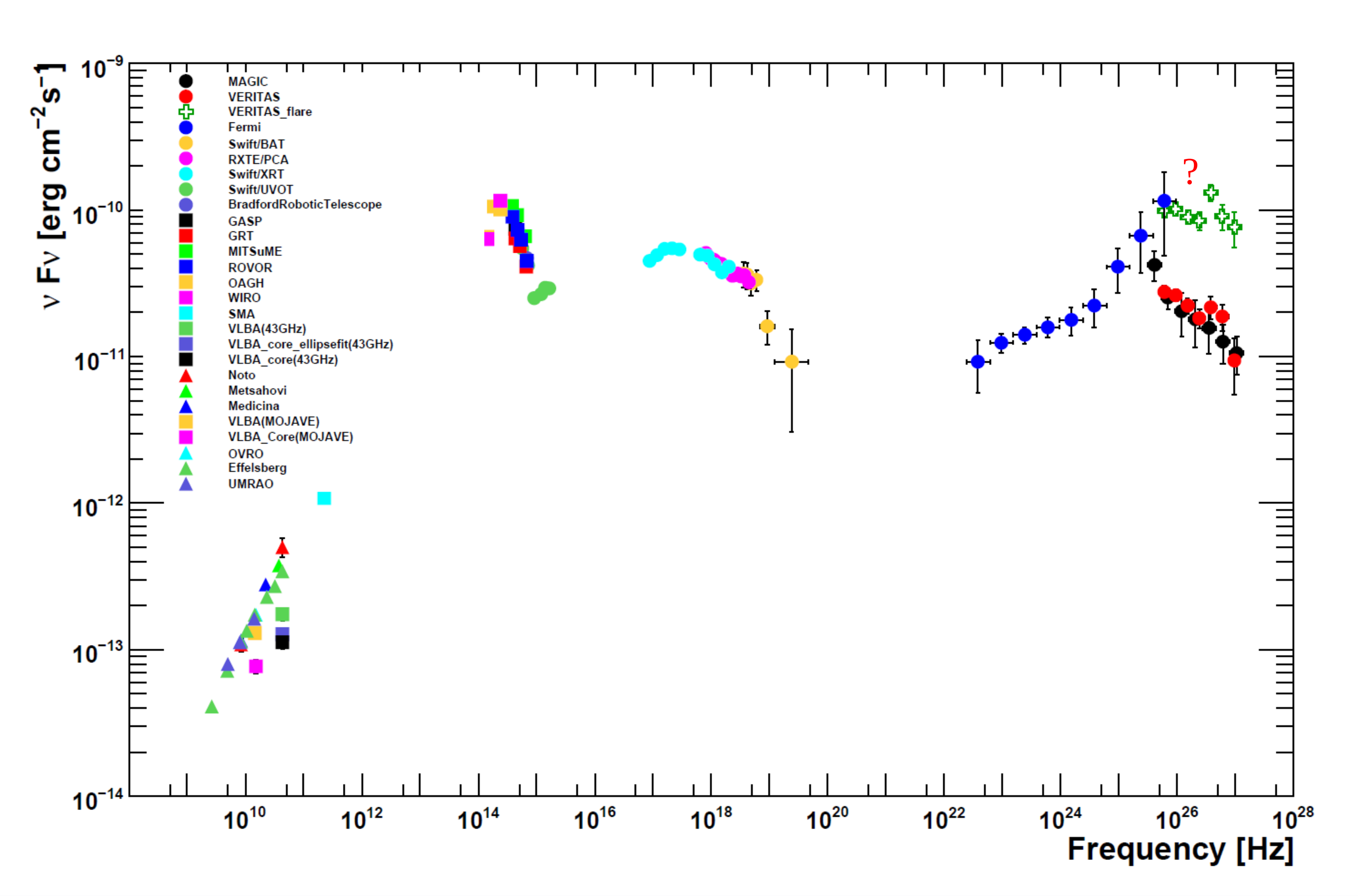




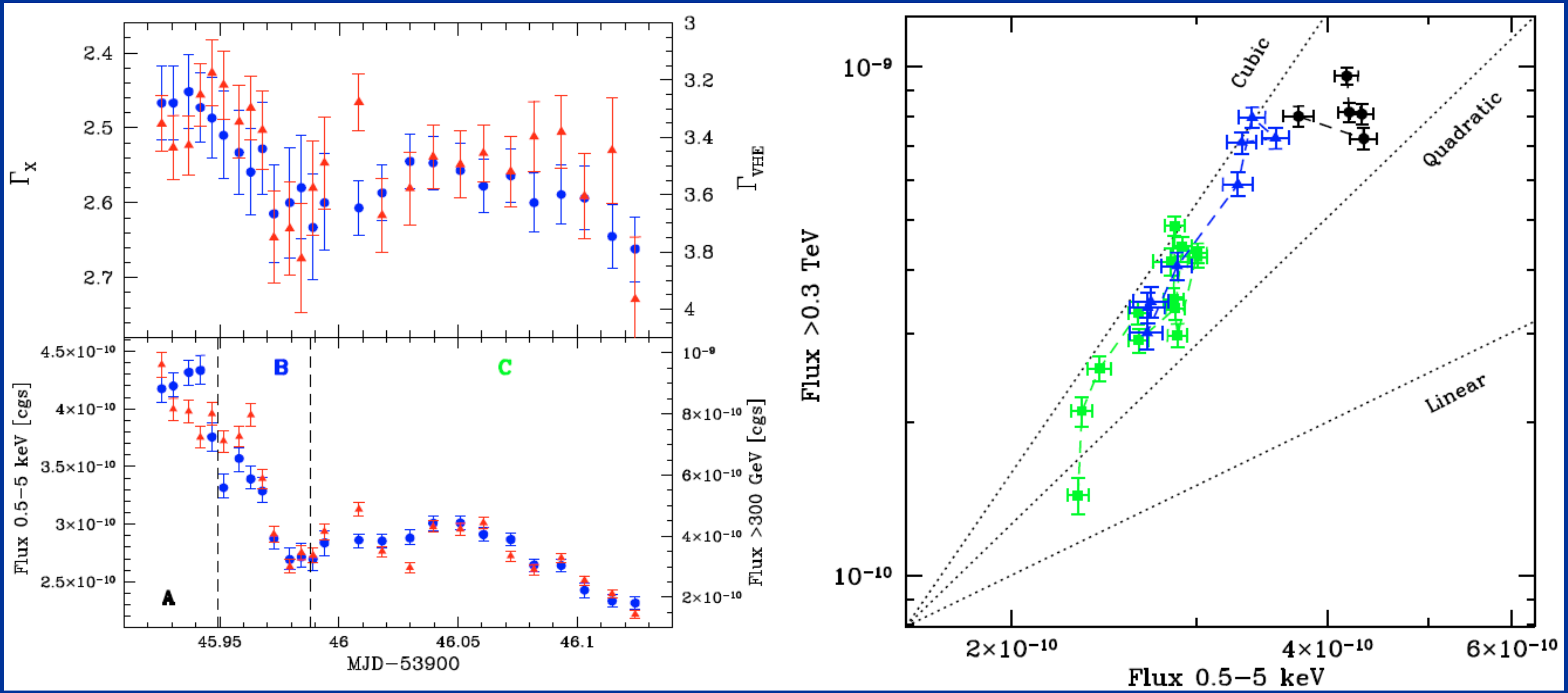


Krawczynski et al. 2004

Mrk 501 – extra VHE component? Barely seen by Fermi (Mrk 501 is "boring" Fermi source)

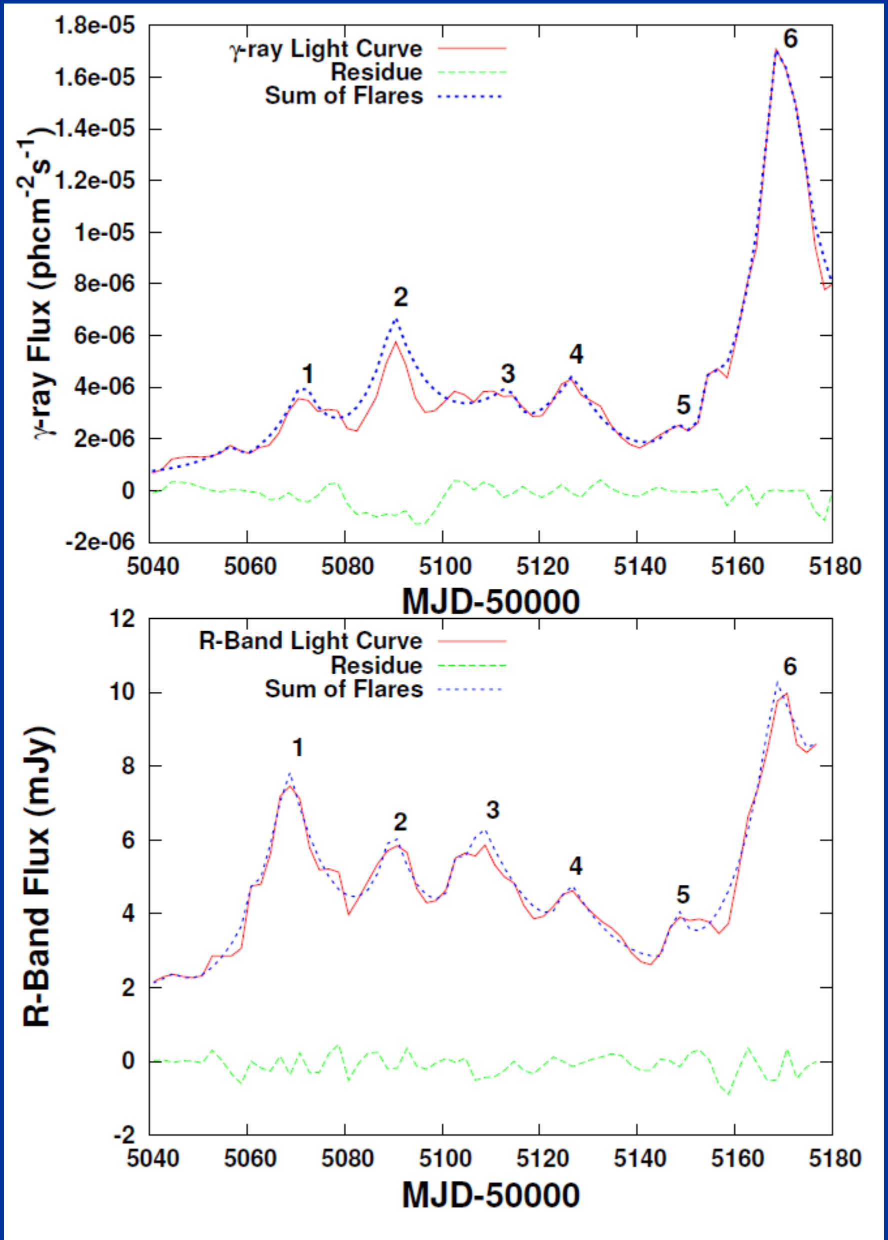


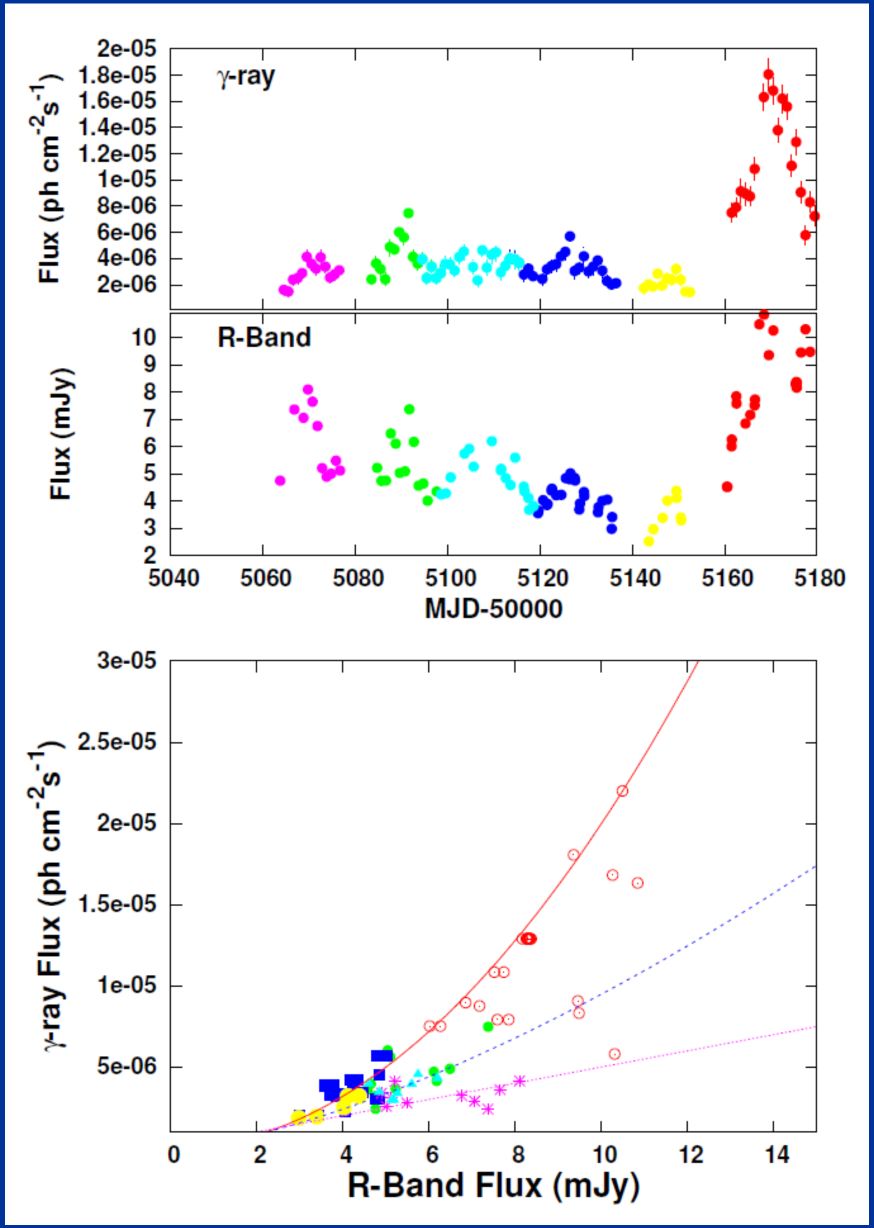
Famous PKS 2155 (HESS) Flare of an "IBL"
Multiple Emission Components – Dilution!?



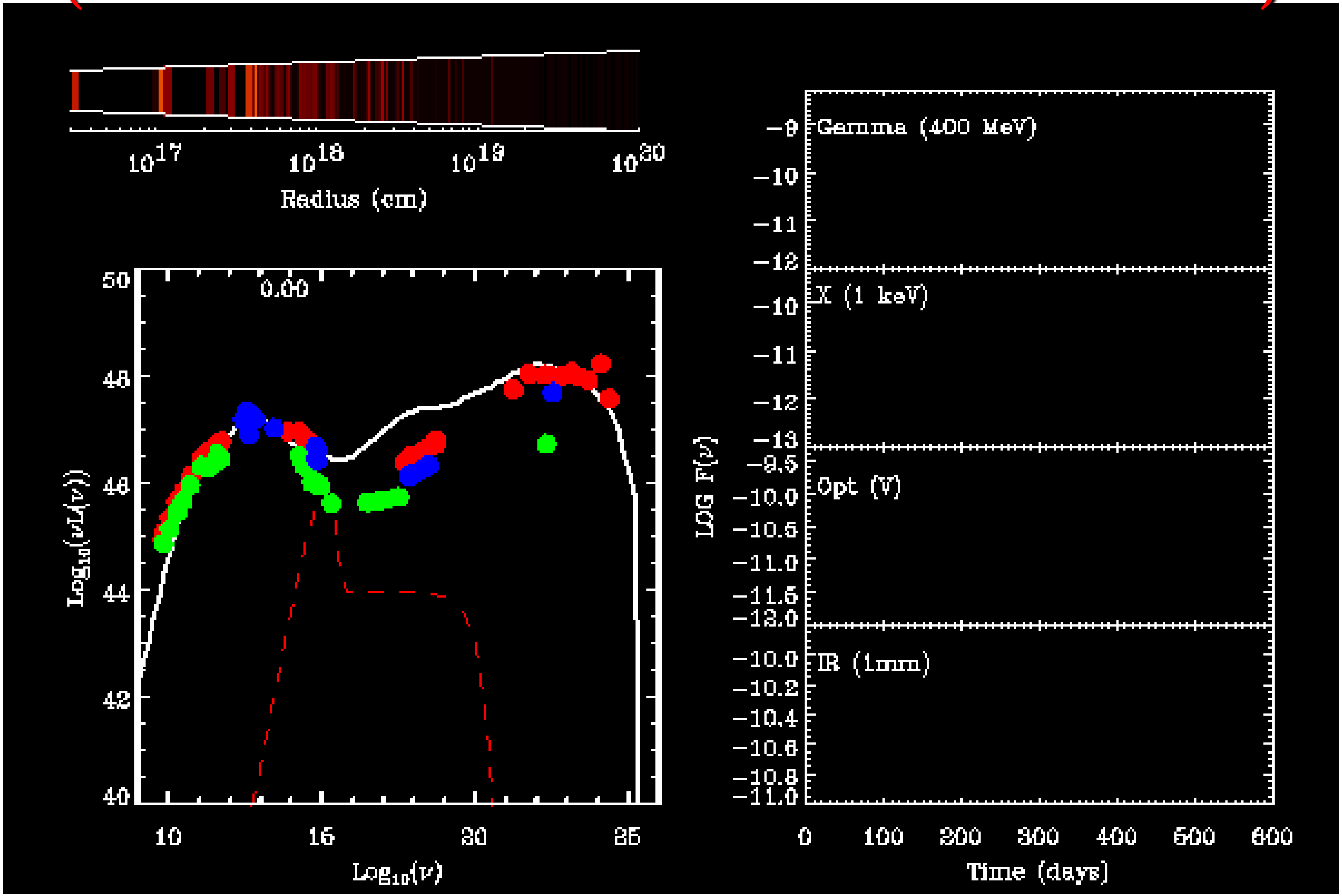
Very fast (~5min) variability! [N.B. Now also seen in 3C279, FSRQ!]

3C 454.3 2009 Flare – SMARTS + Fermi (Chatterjee et al.) - "states"?





Numerical simulations for 3C 279. Spada et al. 2001 (Internal shock – "Christmas tree"-like model)



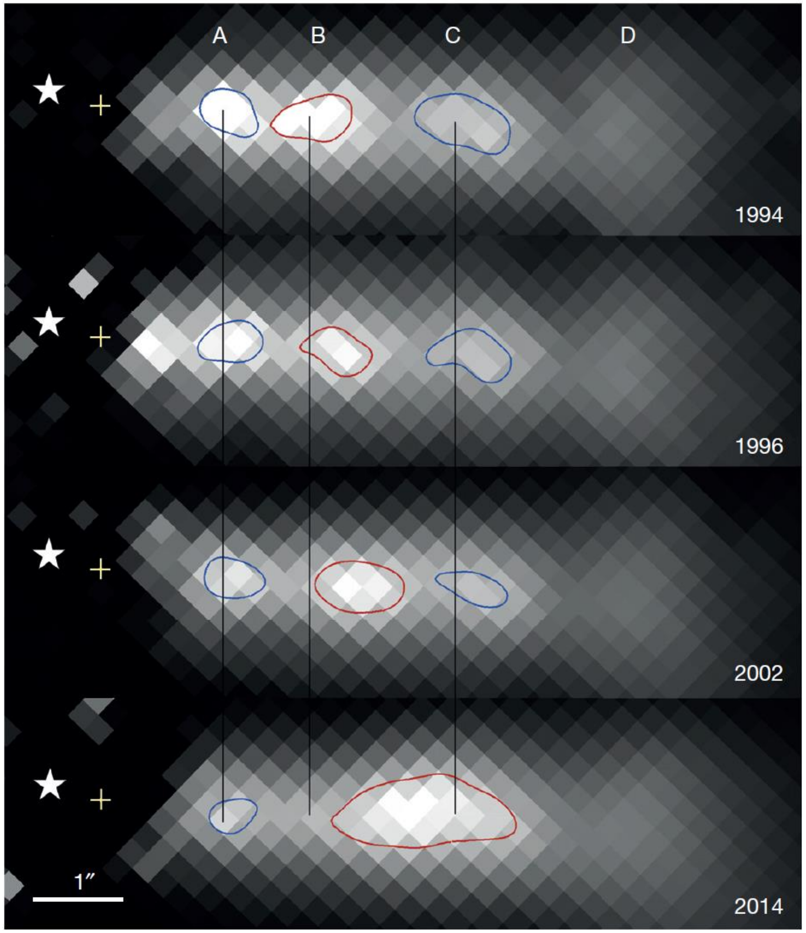
LETTER

Where does jet gamma-ray emission occur? If have enough sensitivity, probably everywhere … (though not at the same time)

doi:10.1038/nature14481

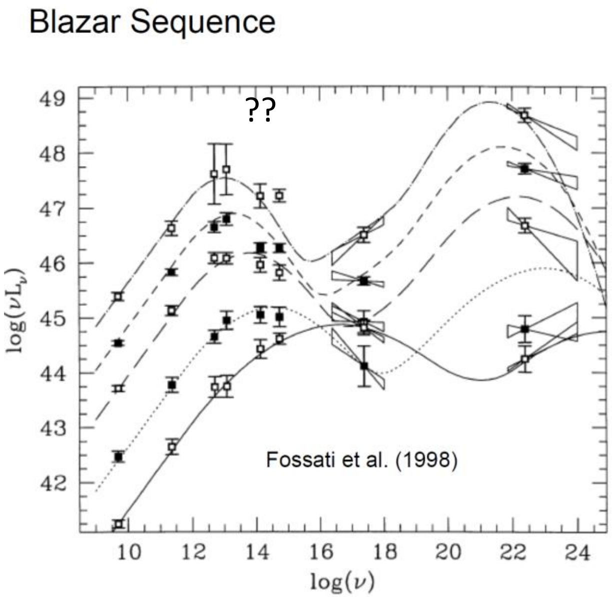
A kiloparsec-scale internal shock collision in the jet of a nearby radio galaxy

Eileen T. Meyer[1,2], Markos Georganopoulos[2,3], William B. Sparks[1], Eric Perlman[4], Roeland P. van der Marel[1], Jay Anderson[1], Sangmo Tony Sohn[5], John Biretta[1], Colin Norman[1,5] & Marco Chiaberge[1,5,6]

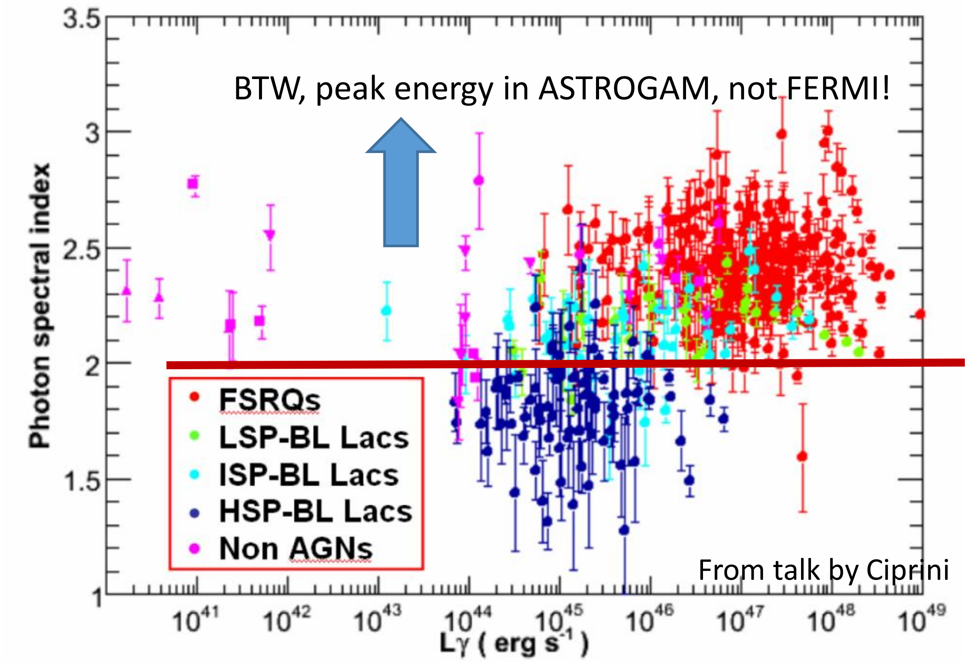


Jets of highly energized plasma with relativistic velocities are associated with black holes ranging in mass from a few times that of the Sun to the billion-solar-mass black holes at the centres of galaxies[1]. A popular but unconfirmed hypothesis to explain how the plasma is energized is the 'internal shock model', in which the relativistic flow is unsteady[2]. Faster components in the jet catch up to and collide with slower ones, leading to internal shocks that accelerate particles and generate magnetic fields[3]. This mechanism can explain the variable, high-energy emission from a diverse set of objects[4–7], with the best indirect evidence being the unseen fast relativistic flow inferred to energize slower components in X-ray binary jets[8,9]. Mapping of the kinematic profiles in resolved jets has revealed precessing and helical patterns in X-ray binaries[10,11], apparent superluminal motions[12,13], and the ejection of knots (bright components) from standing shocks in the jets of active galaxies[14,15]. Observations revealing the structure and evolution of an internal shock in action have, however, remained elusive, hindering measurement of the physical parameters and ultimate efficiency of the mechanism. Here we report observations of a collision between two knots in the jet of nearby radio galaxy 3C 264. A bright knot with an apparent speed of (7.0 ± 0.8)*c*, where *c* is the speed of light in a vacuum, is in the incipient stages of a collision with a slower-moving knot of speed (1.8 ± 0.5)*c* just downstream, resulting in brightening of both knots—as seen in the most recent epoch of imaging.

The Fossati (yes) vs.
Giommi-Padovani (no!) controversy



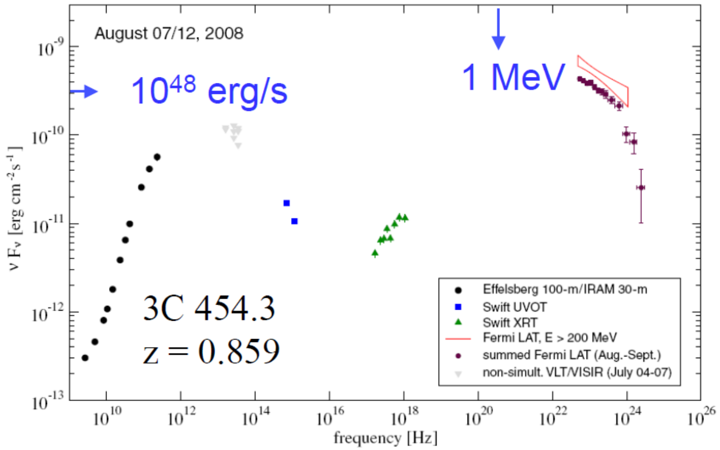
Best guess answer – sort of, but huge scatter and overlap of classes?

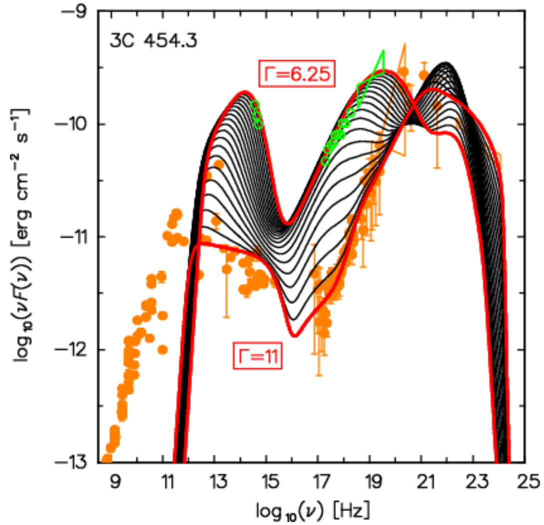


In real life, individual objects change peak energy/class! (E.g., 3C454.3, next slide)

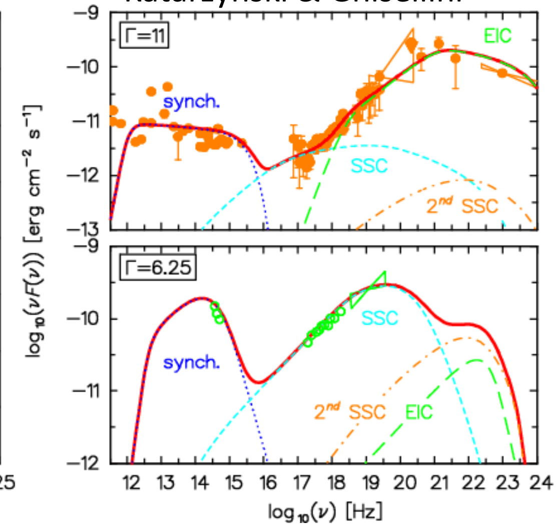
Another example of messy blazar behavior:

Here is well-known (?) MeV blazar, 3C 454 (at least in low state)

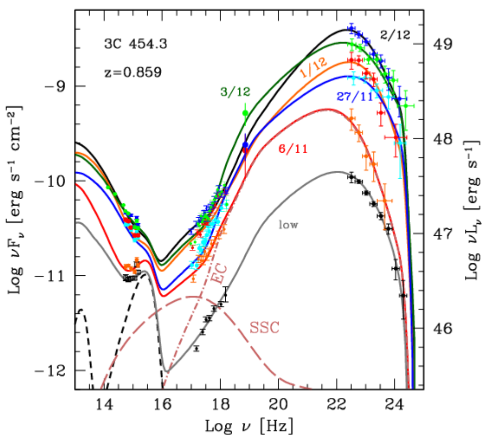


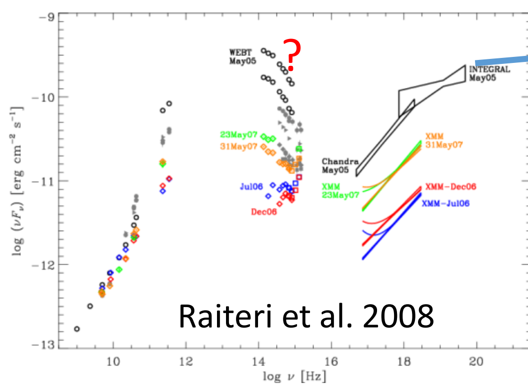


Katarzynski & Ghisellini



Tavecchio & Ghisellini





Raiteri et al. 2008

??, If spectrum really rolls over as INTEGRAL suggests,what about Compton dominance?
(May 05 is huge flare
for synch component…)

Where does
TXS 0506 sit
in the ~Fossati relation?

It doesn't! Compton
dominance too low
and synchrotron peak
energy too high for
luminosity… Weirdo

[Aside, emission lines
detected and host
galaxy seen
$\Rightarrow L_{Edd} \sim 10^{46}$ erg/sec,
not so different from
NGC 1068, and line ratio
also consistent
with Sey 2… BUT
x-rays are definitely
beamed here!!]

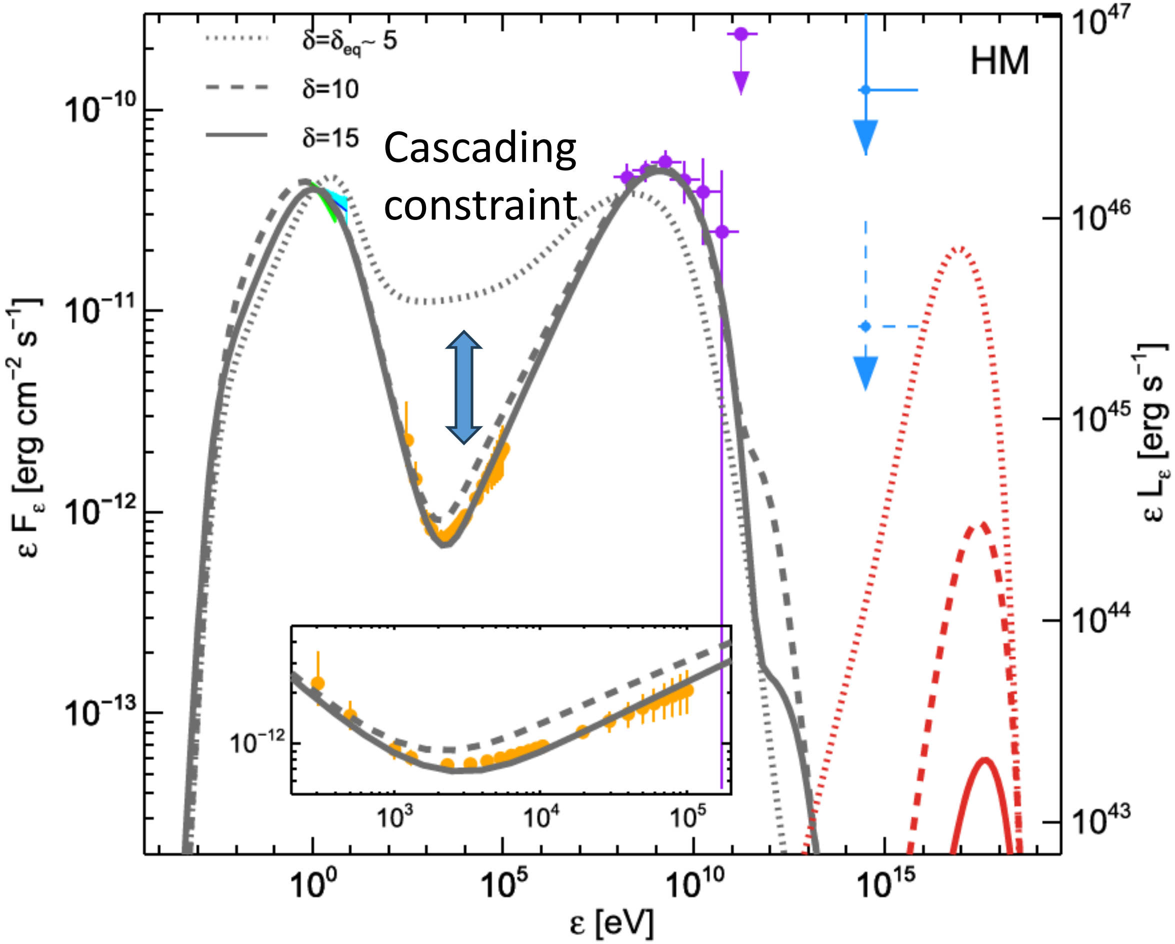


Figure 6. Hadronic model (HM3) for the SED of TXS 0506+056 flare (Ep. 1), as computed for different values of the Doppler factor (gray curves), together with resulting all-flavor neutrino fluxes (red curves) and electromagnetic observations (colored points, showing allowed ranges at 90% confidence). Photon attenuation at $\varepsilon_\gamma \gtrsim 3 \times 10^{11}$ eV due to interactions with the extragalactic background light is not included here. All-flavor neutrino-flux upper limits of producing an event similar to the IceCube-170922A are shown in blue (from Figure 4 of Aartsen et al. 2018a) for 0.5 (solid blue line) and 7.5 years (dashed blue line).

Reminder:

The trouble with AGN jets and ICECUBE neutrino(s)…

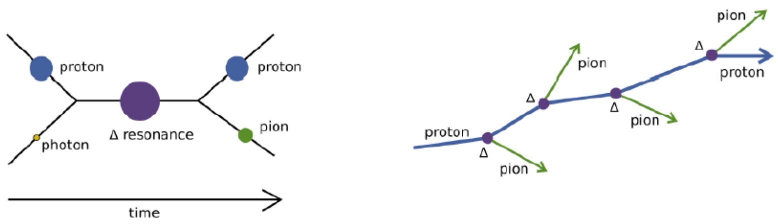


Figure 3: Left: Photo-pion production via excitation of a Δ-resonance in collision of an ultra-high energy cosmic ray proton with a CMB photon. Right: Trajectory of a super-GZK proton through the CMB, suffering attenuation due to repetitive photo-pion production [Credits: W. Bietenholz, arXiv:1305.1346].

- If one particle is a photon ($e_2 = p_2$ and $m_2 = 0$), then threshold energy

$$e_2 \left(\gamma_1 - \sqrt{\gamma_1^2 - 1}\ \cos\theta \right) = \delta m\ c\ \left(1 + \frac{\delta m}{2 m_1} \right)$$

Example: Consider reaction $p + \gamma \to p + \pi^0$ on CMB photons (mean energy $E_2 =< h\nu > \simeq 3kT \simeq 7 \times 10^{-4}$ eV [SI], $e_2 = E_2/c$). Threshold energy for most favourable collision angle ($\cos\theta = -1$ head-on) for high γ_1:

$$\Rightarrow 2\gamma_1 \simeq \frac{m_{\pi^0} c}{e_2} \left(1 + \frac{m_{\pi^0}}{2 m_p} \right) \quad \text{or} \quad \gamma_1 \simeq 10^{11}$$

Rieger lecture notes

In delta-function approximation, pion has ~0.1-.2 energy of proton, and neutrino has ~.3 of energy of pion. ICECUBE sees neutrinos from ~1 TeV – 1 PeV. To make TeV neutrino, need proton of energy ~20 TeV, or $\gamma \sim 2 \times 10^4$. => need target photon E~3.5 keV [X-rays], and lots of them (for efficient production)… where do you get these?

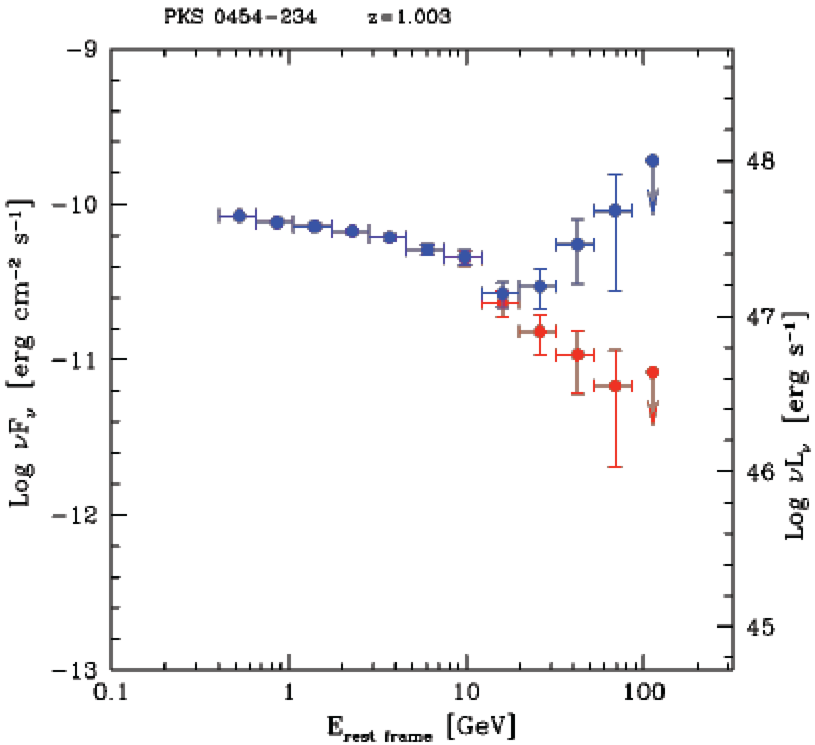
Compactness (pair production) problem…

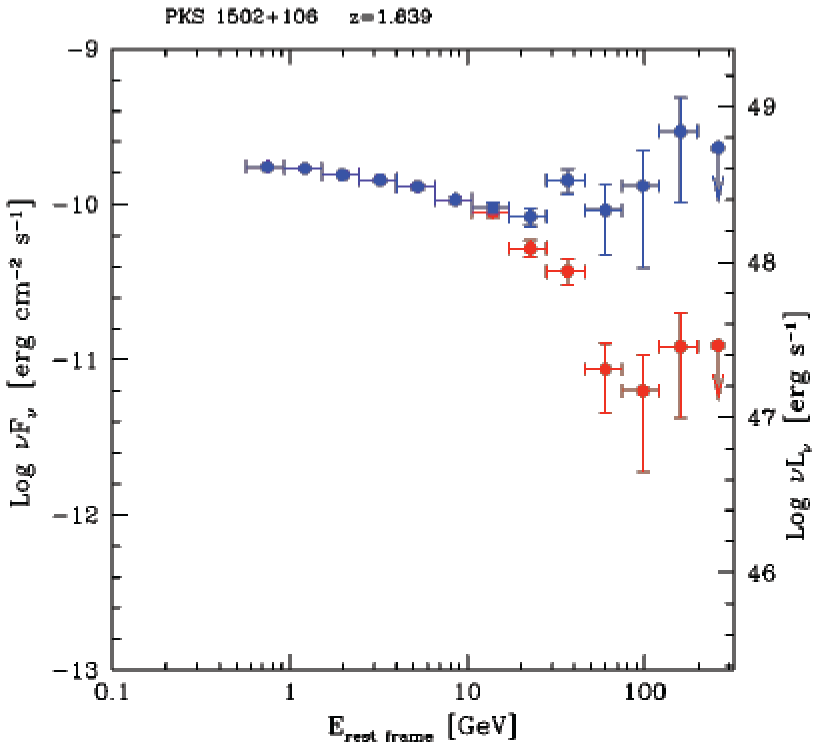
Beaming doesn't help you with this!

No evidence of strong BLR cut-offs !

With tau =3 (path a few 10^{16} cm), absorption would already be too strong:

LAT spectra: original, observed ; BLR de-absorbed



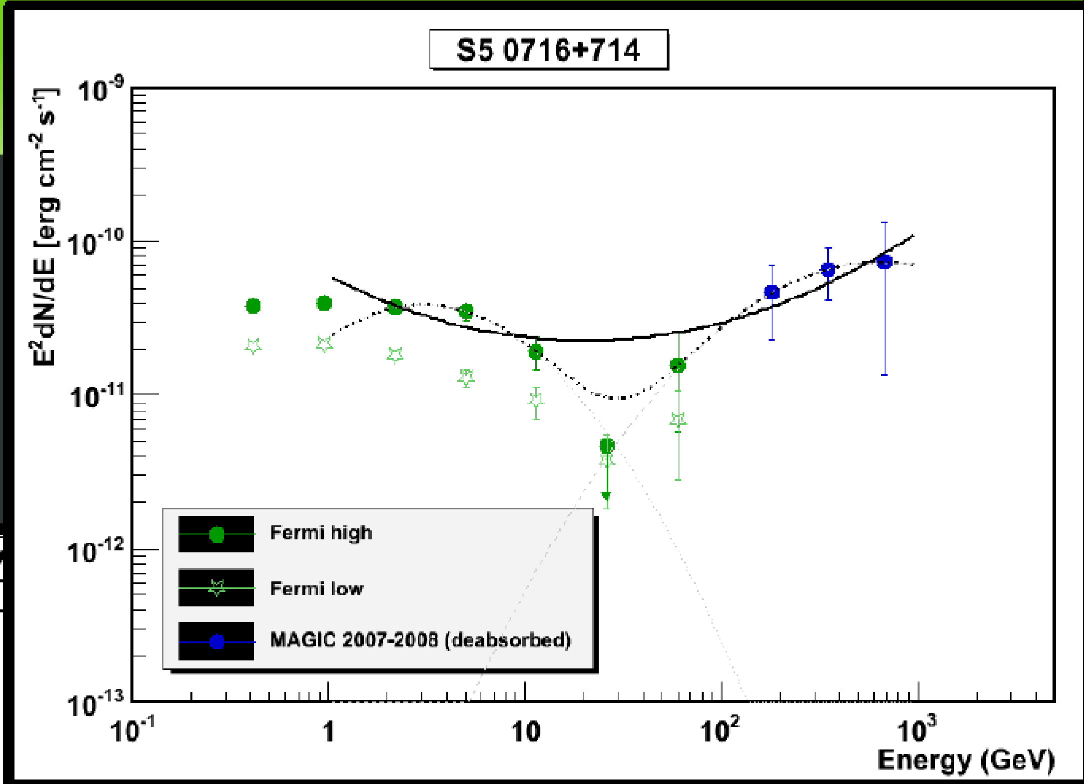


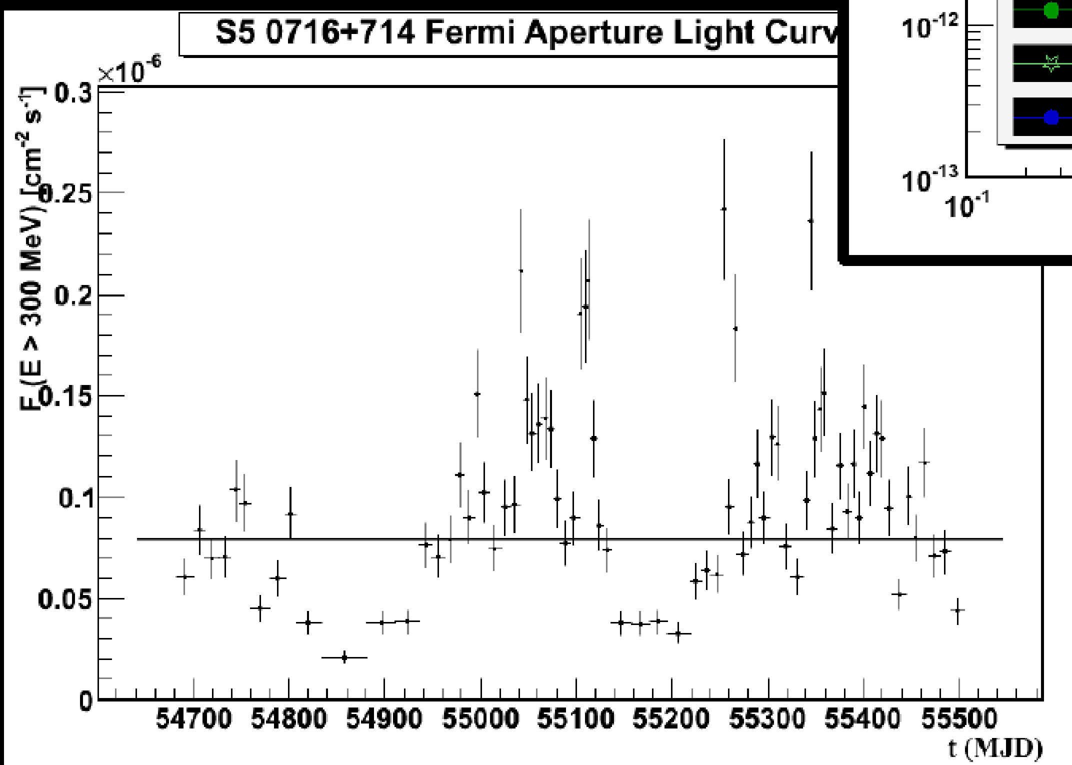
R_{blr} ~4×10^{17} L_{disk} ~2×10^{46}

R_{blr} ~0.8×10^{18} L_{disk} ~6×10^{46}

S5 0716+714

G. Senturk et al. 2011





Aside #2: Is there enough target material in the nucleus of AGN (merging galaxy)?

ALMA Resolves the Nuclear Disks of Arp 220

Nick Scoville[1], Lena Murchikova[1], Fabian Walter[2], Catherine Vlahakis[3], Jin Koda[4], Paul Vanden Bout[3], Joshua Barnes[5,6], Lars Hernquist[7], Kartik Sheth[8], Min Yun[5] Show full author list

Published 2017 February 8 •

The Astrophysical Journal, Volume 836, Number 1

We present 90 mas (37 pc) resolution ALMA imaging of Arp 220 in the CO (1-0) line and continuum at $\lambda = 2.6\,\mathrm{mm}$. The internal gas distribution and kinematics of both galactic nuclei are well resolved for the first time. In the west nucleus, the major gas and dust emission extends out to 0."2 radius (74 pc); the central resolution element shows a strong peak in the dust emission but a factor of 3 dip in the CO line emission. In this nucleus, the dust is apparently optically thick ($\tau_{2.6\mathrm{mm}} \sim 1$) at $\lambda = 2.6\,\mathrm{mm}$ with a dust brightness temperature of ~147 K. The column of interstellar matter at this nucleus is $N_{\mathrm{H2}} \geqslant 2 \times 10^{26}$ cm^{-2}, corresponding to ~900 gr cm^{-2}. The east nucleus is more elongated with radial extent 0."3 or ~111 pc. The derived kinematics of the nuclear disks provide a good fit to the line profiles, yielding the emissivity distributions, the rotation curves, and velocity dispersions. In the west nucleus, there is evidence of a central Keplerian component requiring a central mass of 8 × 10^8 $M_\odot$. The intrinsic widths of the emission lines are $\Delta v(\mathrm{FWHM}) = 250$ (west) and 120 (east) km s^{-1}. Given the very short dissipation timescales for turbulence ($\lesssim$10^5 years), we suggest that the line widths may be due to semicoherent motions within the nuclear disks. The symmetry of the nuclear disk structures is impressive, implying the merger timescale is significantly longer than the rotation period of the disks

(Very) Extreme BL Lacs Exist!

Correct for EBL absorption? Ouch

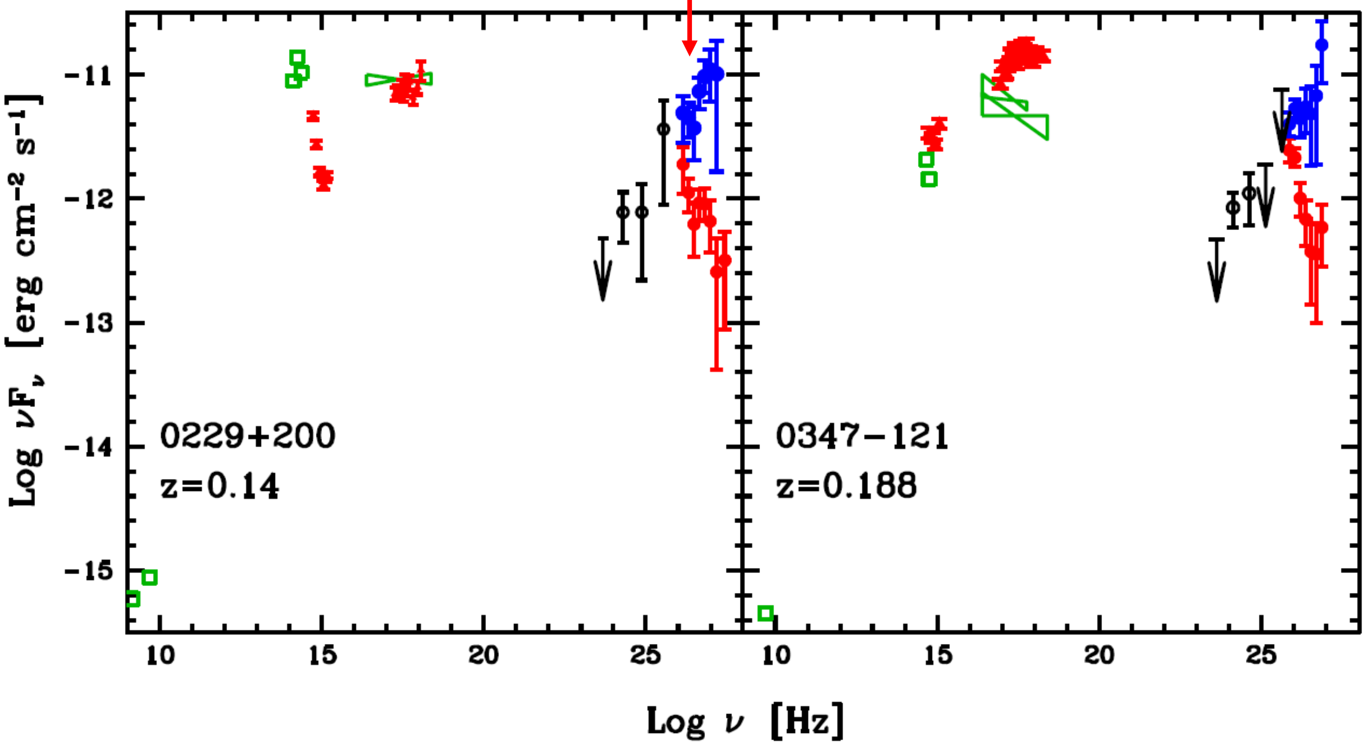
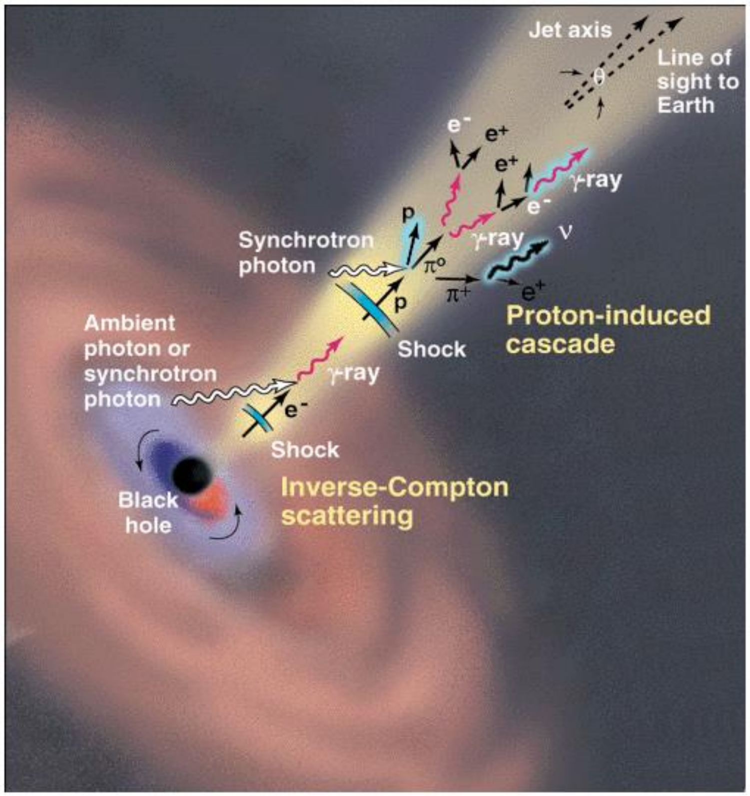
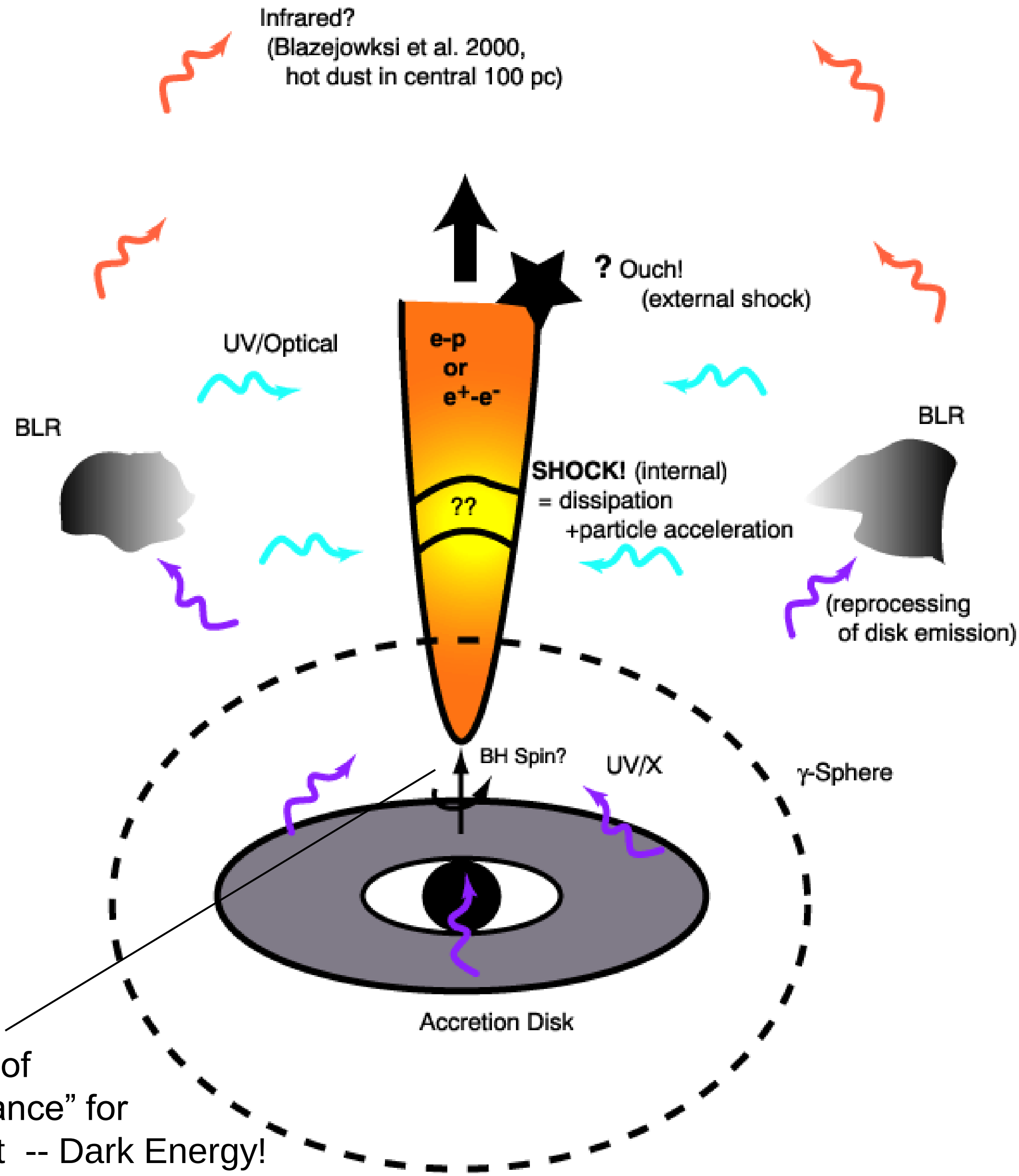


Figure 1. SED of 1ES 0229+200 (left) and 1ES 0347−121 (right), two of the most representative EHBL detected at TeV energies (see Tavecchio et al. 2011 for references). Blue symbols show the TeV spectrum corrected for the absorption by EBL using the model of Domínguez et al. (2011). The black points for 1ES 0229+200 report the *Fermi*/LAT spectrum obtained by Vovk et al. (2012), while those for 1ES 0347−121 come from Tanaka et al. (2014).

Blazar Emission Mechanisms: Idealized vs. Real Life



(Buckley, Science, 1998)



"Zone of Avoidance" for pair jet -- Dark Energy!

The central engine of a generic gamma-ray blazar is a MESSY place!

“Orphan” γ-Ray Flares and Stationary Sheaths of Blazar Jets

Nicholas R. MacDonald[1,2], Svetlana G. Jorstad[1,3], and Alan P. Marscher[1]
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[2] Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany
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Abstract

Blazars exhibit flares across the entire electromagnetic spectrum. Many γ-ray flares are highly correlated with flares detected at longer wavelengths; however, a small subset appears to occur in isolation, with little or no correlated variability at longer wavelengths. These “orphan” γ-ray flares challenge current models of blazar variability, most of which are unable to reproduce this type of behavior. MacDonald et al. have developed the *Ring of Fire* model to explain the origin of orphan γ-ray flares from within blazar jets. In this model, electrons contained within a blob of plasma moving relativistically along the spine of the jet inverse-Compton scatter synchrotron photons emanating off of a ring of shocked sheath plasma that enshrouds the jet spine. As the blob propagates through the ring, the scattering of the ring photons by the blob electrons creates an orphan γ-ray flare. This model was successfully applied to modeling a prominent orphan γ-ray flare observed in the blazar PKS 1510−089. To further support the plausibility of this model, MacDonald et al. presented a stacked radio map of PKS 1510−089 containing the polarimetric signature of a sheath of plasma surrounding the spine of the jet. In this paper, we extend our modeling and stacking techniques to a larger sample of blazars: 3C 273, 4C 71.01, 3C 279, 1055+018, CTA 102, and 3C 345, the majority of which have exhibited orphan γ-ray flares. We find that the model can successfully reproduce these flares, while our stacked maps reveal the existence of jet sheaths within these blazars.

What could happen in a messy environment? “Compton Mirror” and “external/internal” (moderately beamed?) photons from a jet sheath?

[often see limb brightening in FRI radio images?]

Acceleration in sheath (boundary, shear layer)?

``Stratified” jet w/structure, e.g., Γ(Θ)?

Pair sheath?

The Astrophysical Journal, 850:87 (14pp), 2017 November 20 MacDonald, Jorstad, & Marscher

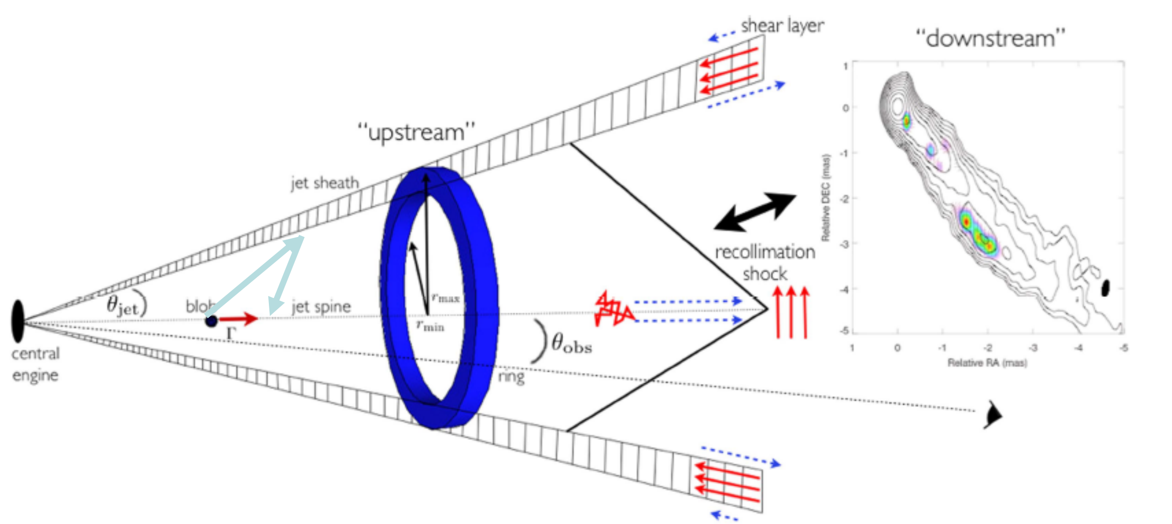
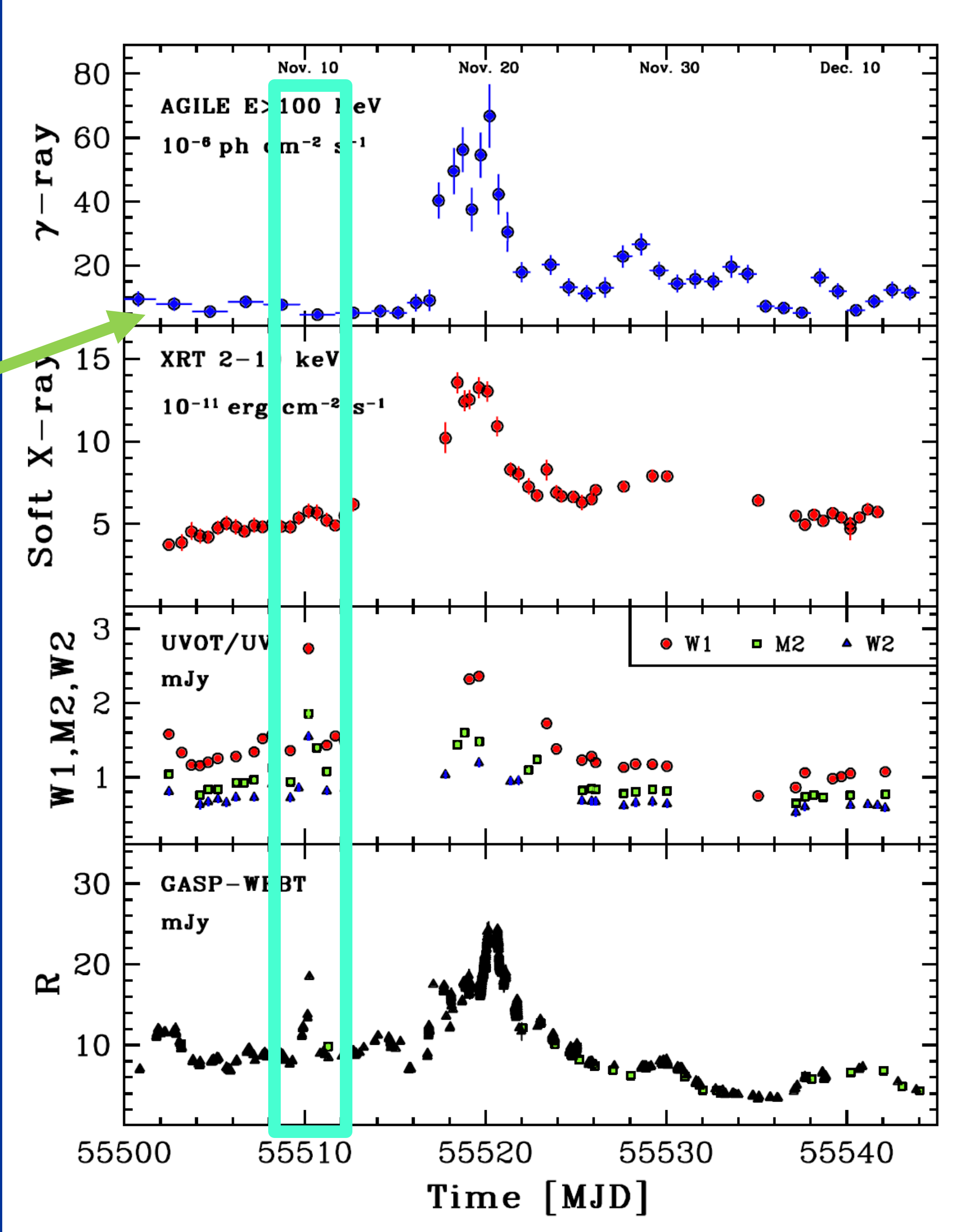


Figure 1. Schematic of the relative locations along the jet of both the ring of shocked sheath plasma in our model and the location of the radio core/sheath detected farther “downstream” in the stacked radio images of 3C 273 (see Figures 2 and 3). This sketch is projected onto the plane of the sky. We posit that the ring is located ~4 pc from the central engine, while the radio cores in our stacked maps are located farther downstream from the central engine (at a scale of $\gtrsim$10 pc). We propose that the radio core in 3C 273 is associated with a recollimation shock that compresses initially tangled magnetic field along the spine of the jet and orders that field perpendicular to the jet axis (the red vectors just to the right of the recollimation shock). The jet has an opening angle $\lesssim 2°$ and the recollimation shock subtends an angle to the jet axis $\lesssim 10°$. In contrast to the spine, velocity shear between the sheath and the ambient medium (blue vectors denote relative speed) aligns the magnetic field lines on the outer edges of the jet to be roughly parallel to the jet axis, resulting in the spine-sheath polarization signature we detect in our stacked map of 3C 273 (shown in the “downstream” portion of this figure and in Figure 3).

Vercellone et al. 2011

Gamma-Ray
“Plateau” State

-- NO short-term
variability



“The Flare”
- 3C 454.3
(Nov. 2010)

Disk-Jet Connection?

Isler et al. 2013 [see also Leon-Tavares 2013]

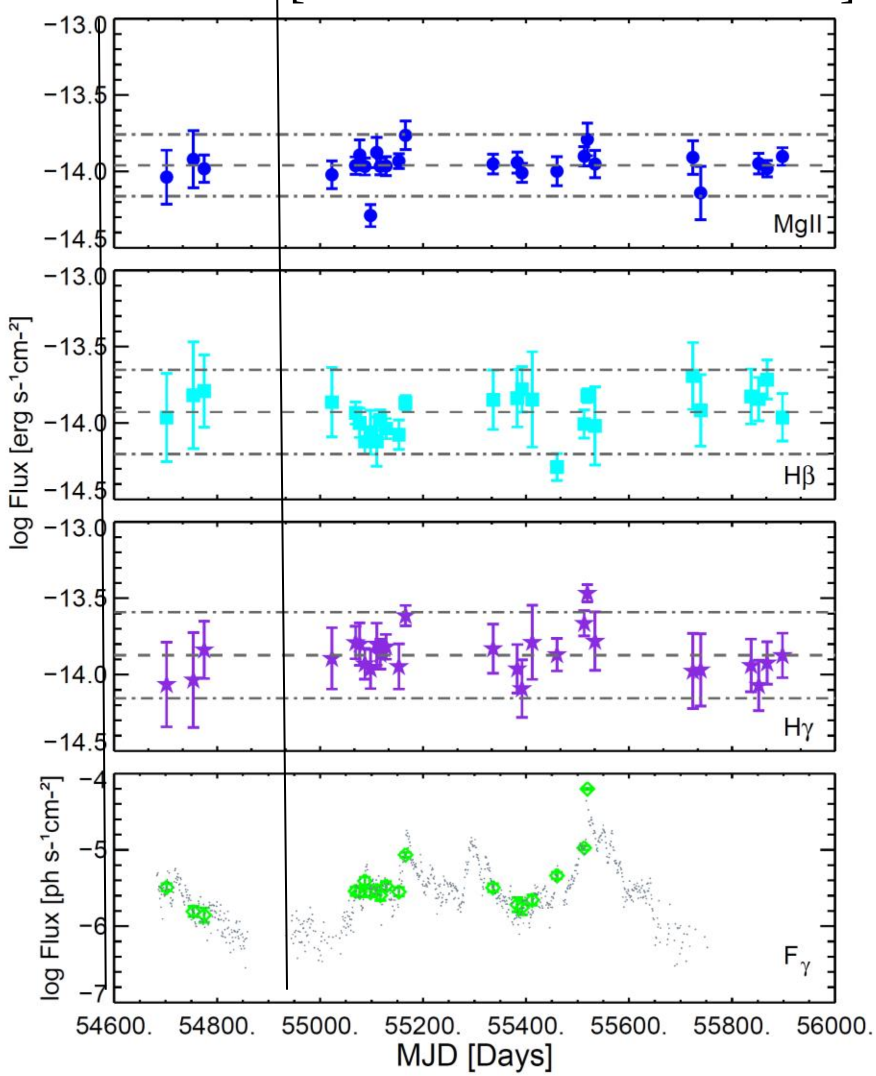


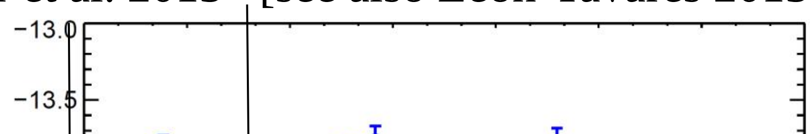
FIG. 4.— Broad emission line flux light curves for Mg II (blue circles), Hβ (cyan squares) and Hγ (purple stars). The bottom panel shows the *Fermi* γ-ray light curve (TS >25) for the same MJD (filled diamonds) and over the total observed interval (grey points). The average flux of each emission line is represented by the dashed lines and 2σ deviations are marked by dot-dashed lines. Over the 3.3 years of observation, the line fluxes deviate by more than 2σ above the mean only on MJD 55165 and 55518 in Mg II and Hγ. This lack of strong detectable variability in the line emission is in stark contrast to the factor of nearly 100 variations in gamma-ray flux over the same time period, as seen in the bottom panel. However, the highest γ-ray flare phases (MJD 55167 and 55520) correspond to the greatest deviation in the Hγ and Mg II line fluxes. The rise and fall of the Hγ line flux, in particular, appears to trace the rise and fall of the γ-ray flux. Both epochs during which the Hγ and Mg II emission lines deviate from the mean are also coincident with 7mm core ejections (Jorstad et al. 2012).

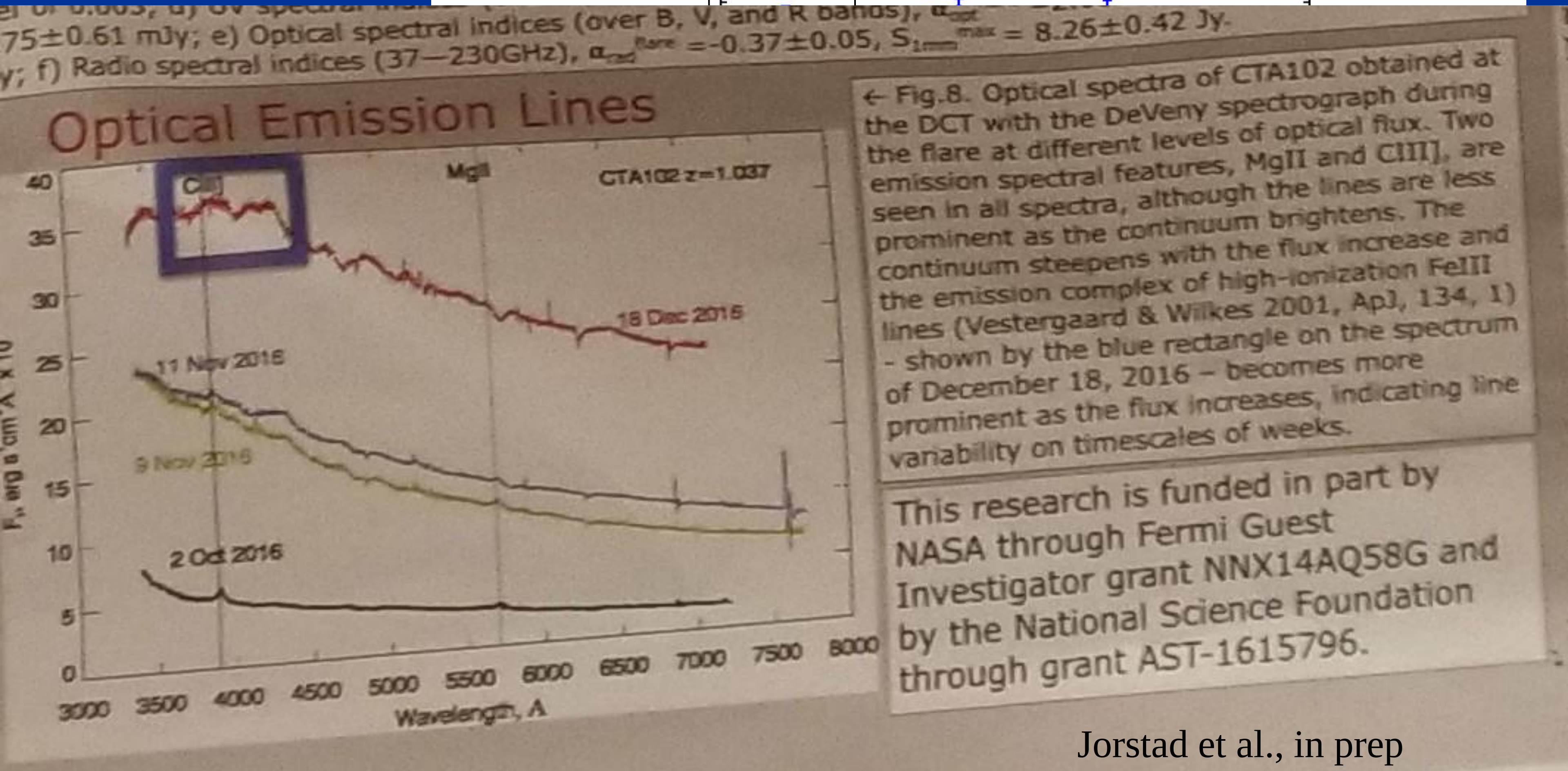
Central Engine vs. Jet?

Disk-Jet Connection?

Time Resolved BLR Behavior of 3C 454.3 7

Isler et al. 2013 [see also Leon-Tavares 2013]





Jorstad et al., in prep

Central Engine vs. Jet?

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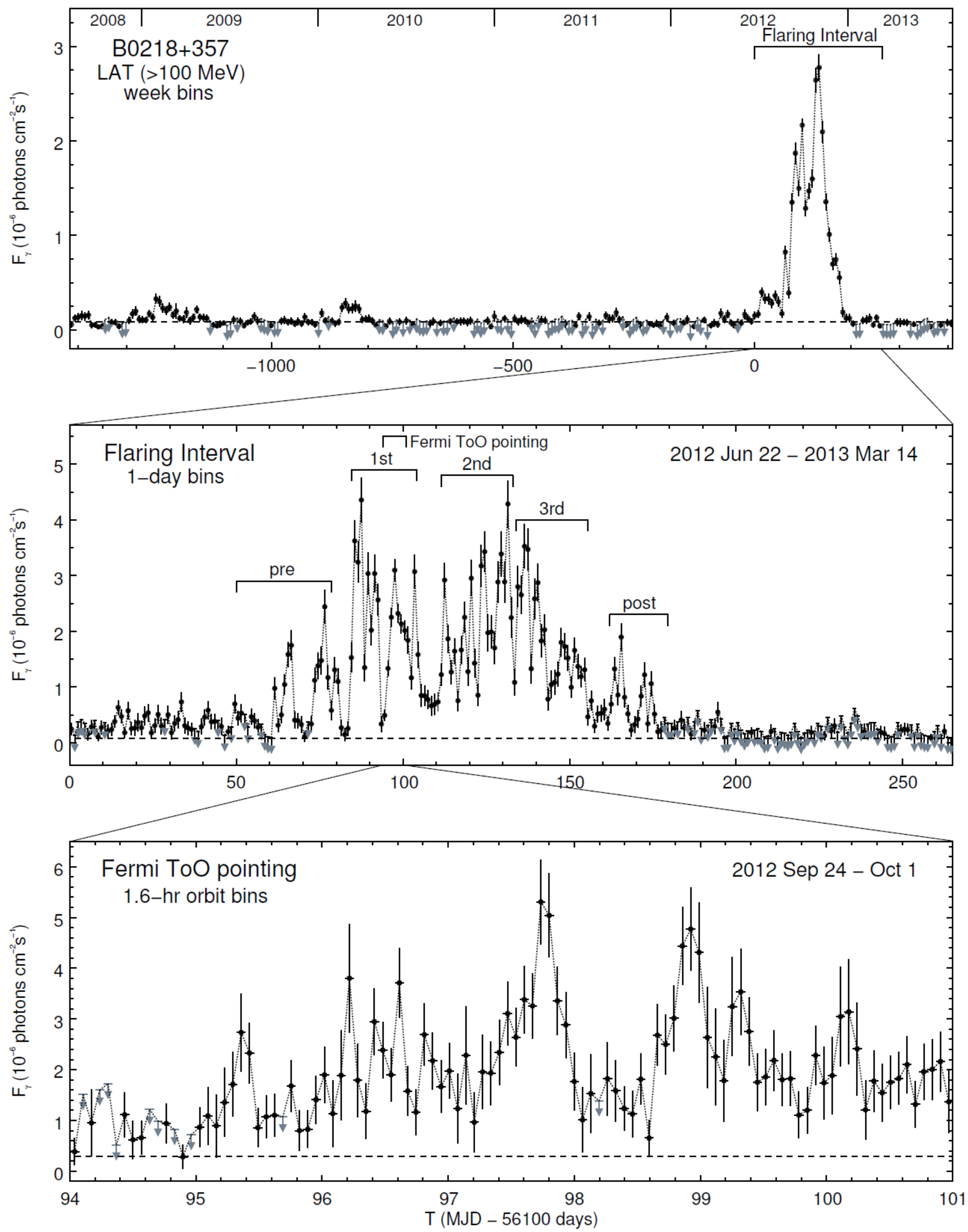
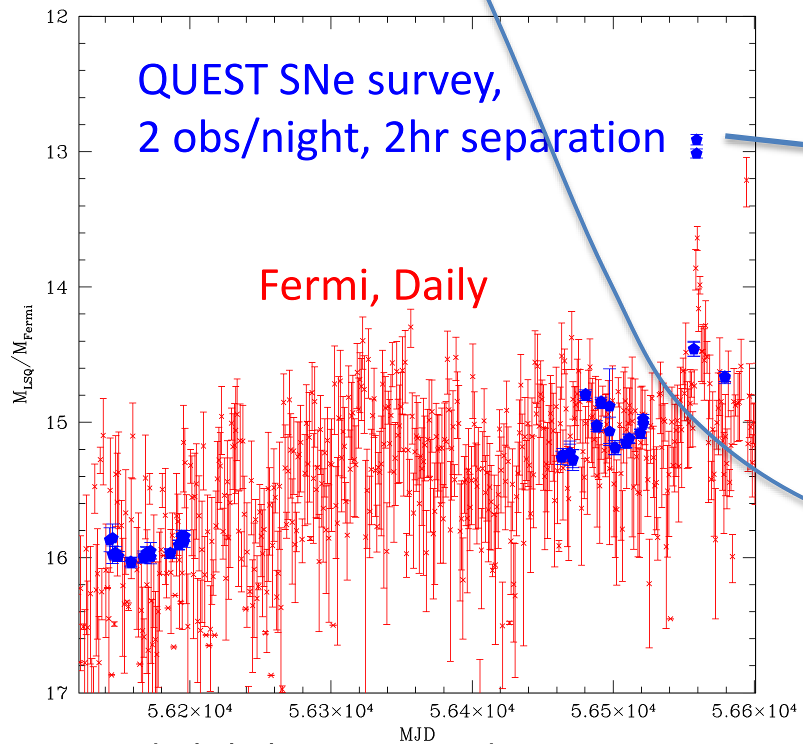
Fractal Variability?

Gravitational Lens Delayed Gamma-ray Flares in B0218+357

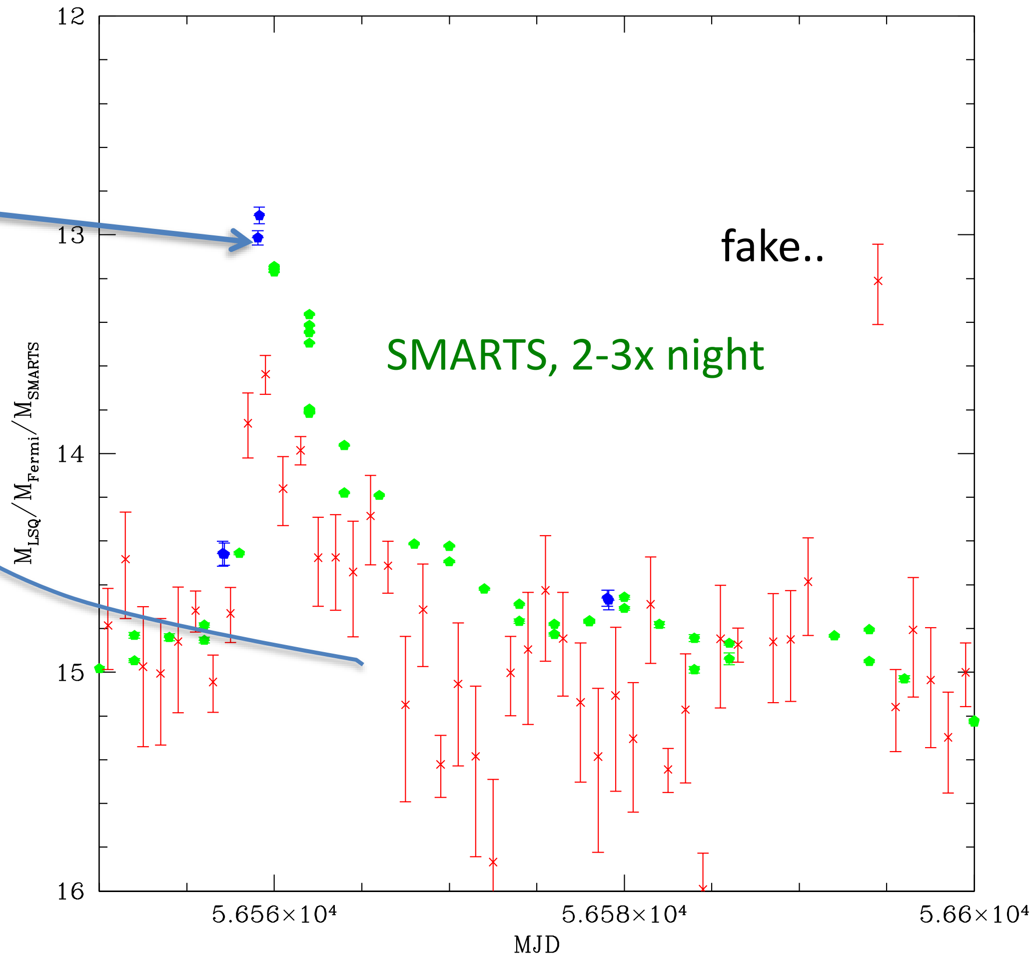
Cheung et al. 2014



Optical vs. Gamma-Ray Variability: 2013 flare in 3C 454.3

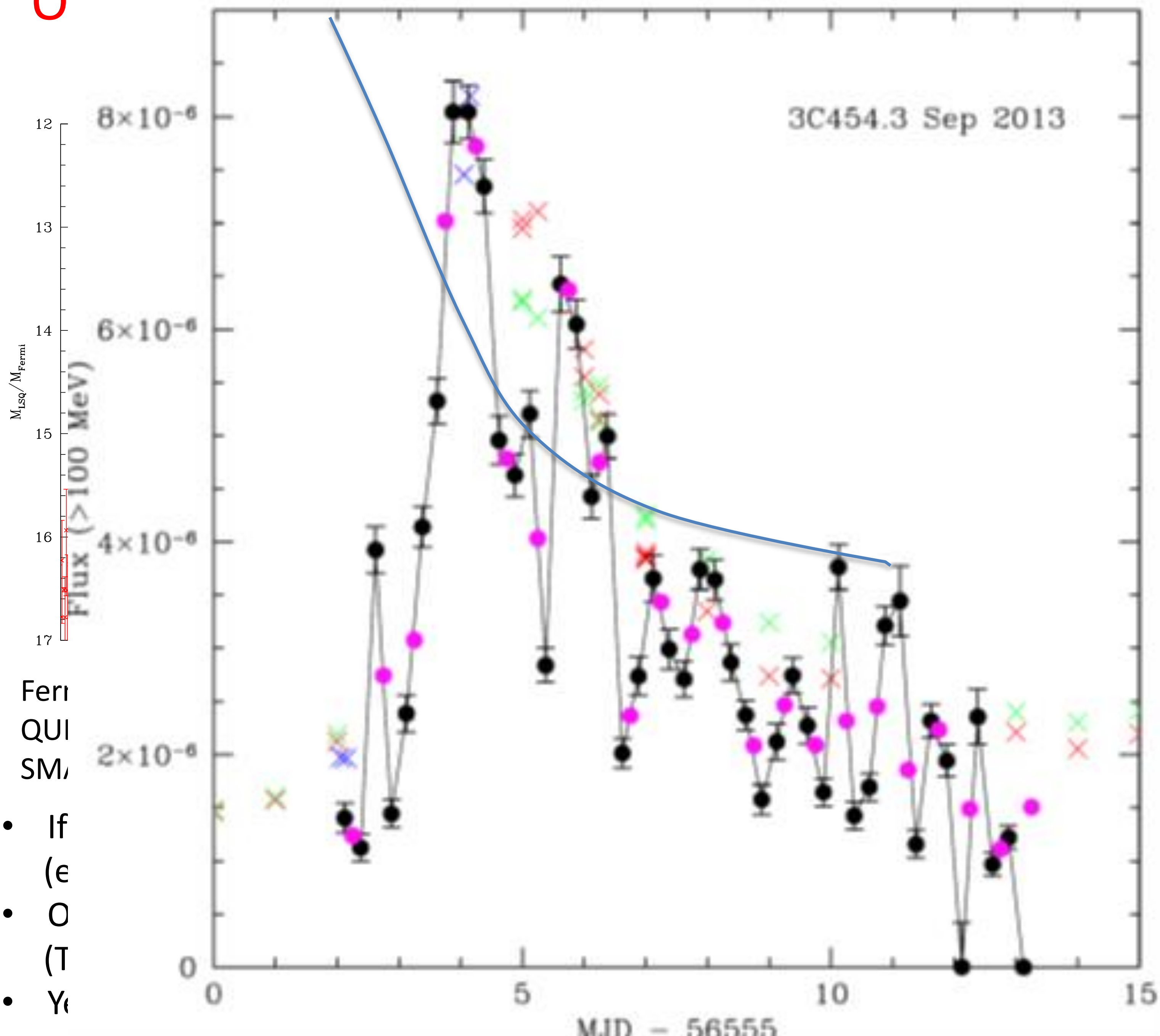


Fermi *daily* lightcurve – red
QUEST lightcurve, V – blue
SMARTs lightcurve, B - green



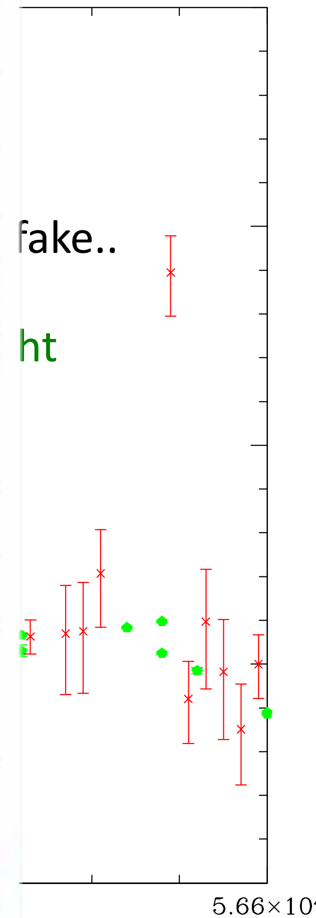
- If you only had SMARTS and Fermi daily coverage, good luck measuring leads/lags (e.g., SMARTS missed peak).
- On 2hr timescales, QUEST typically sees <10% variability (~15% at flare peak). But if as before (TBD), gamma-rays will have ~2x(+) variability on that timescale!?
- Yet on ~daily timescales, optical and gamma-ray fluxes track well??

O C 454.3



fake..

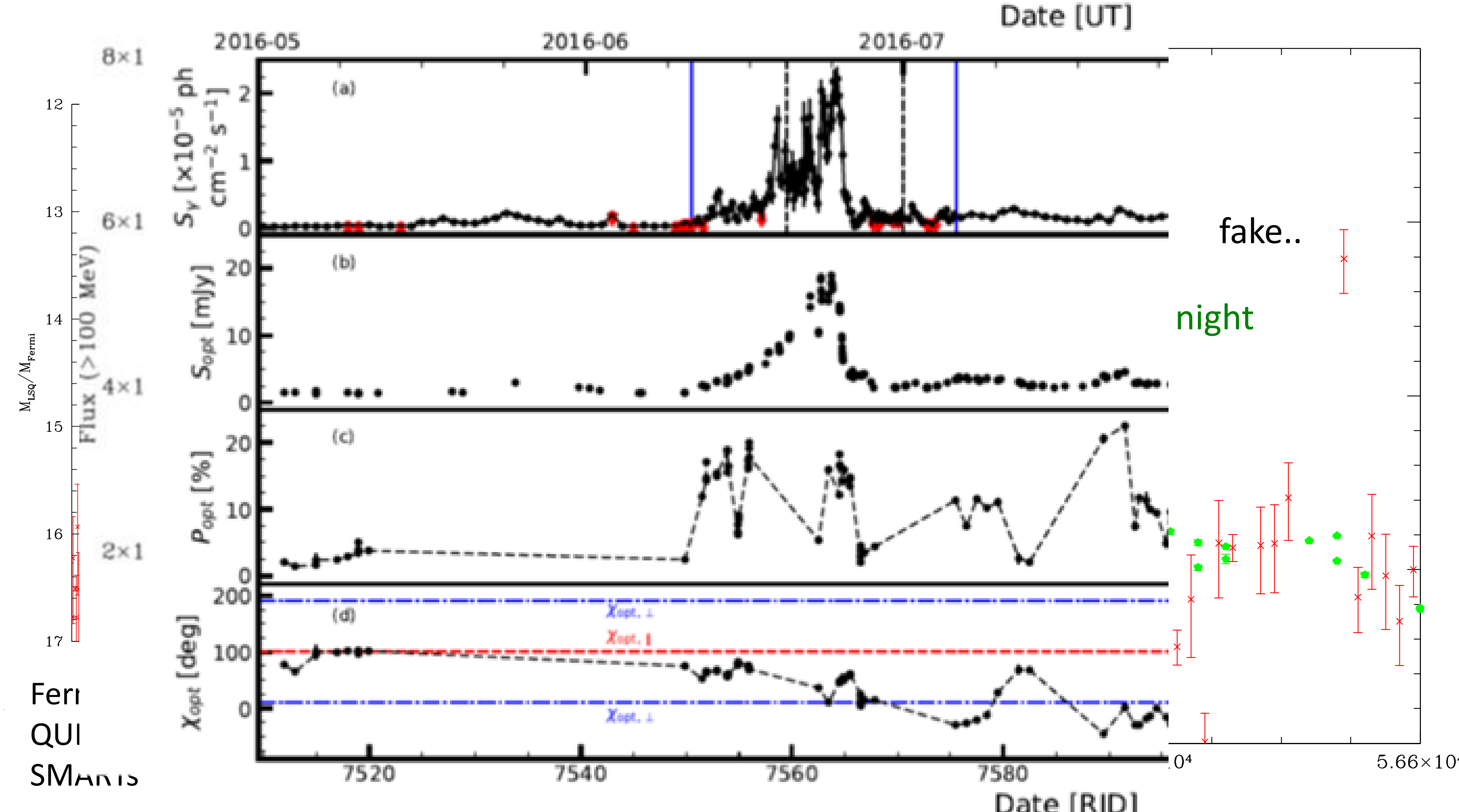
ht



Ferr
QUI
SMA

- If ls/lags
  (e
- O). But if as before
  (T
- Y

O 13 flare in 3C 454.3



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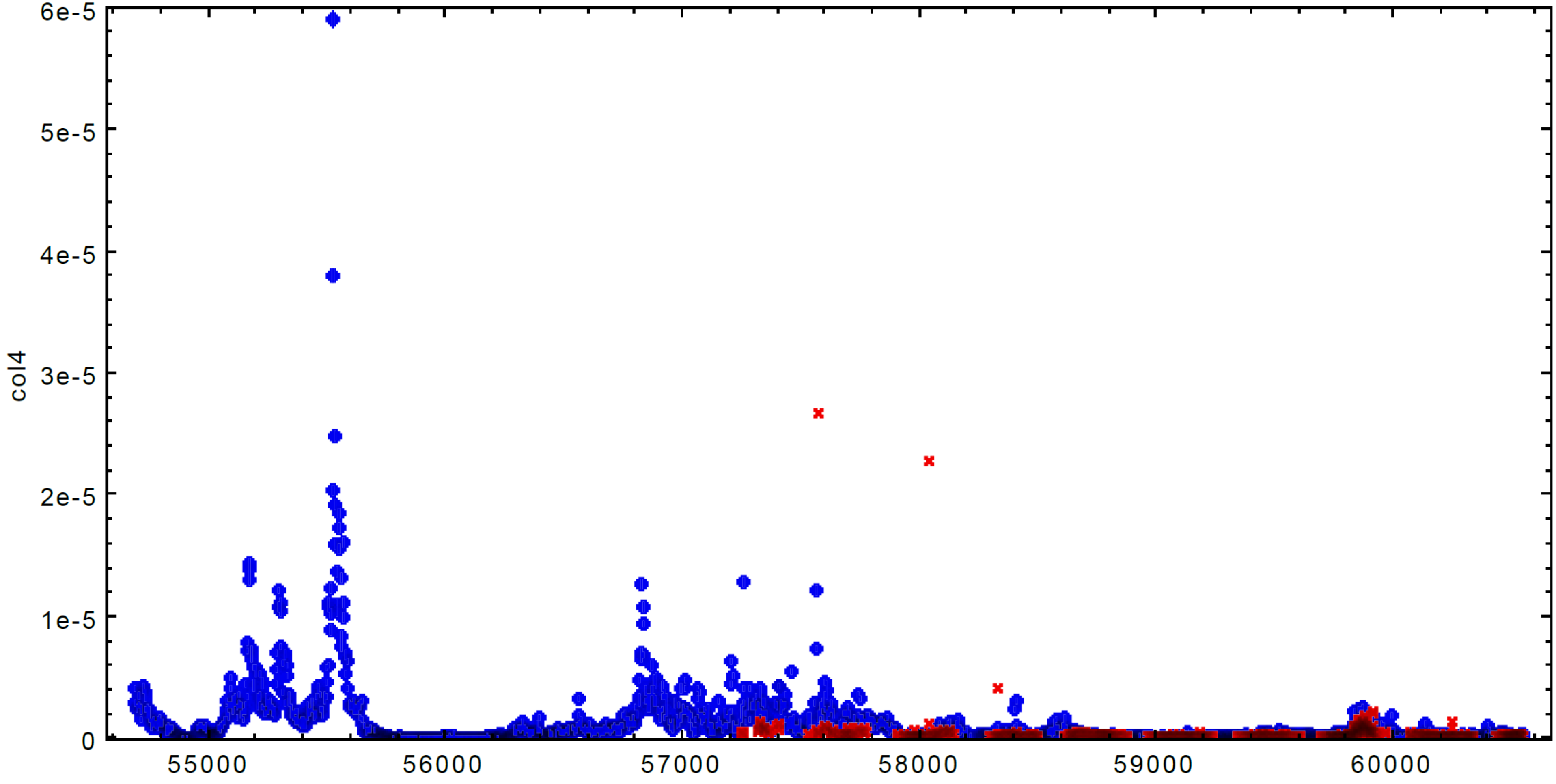
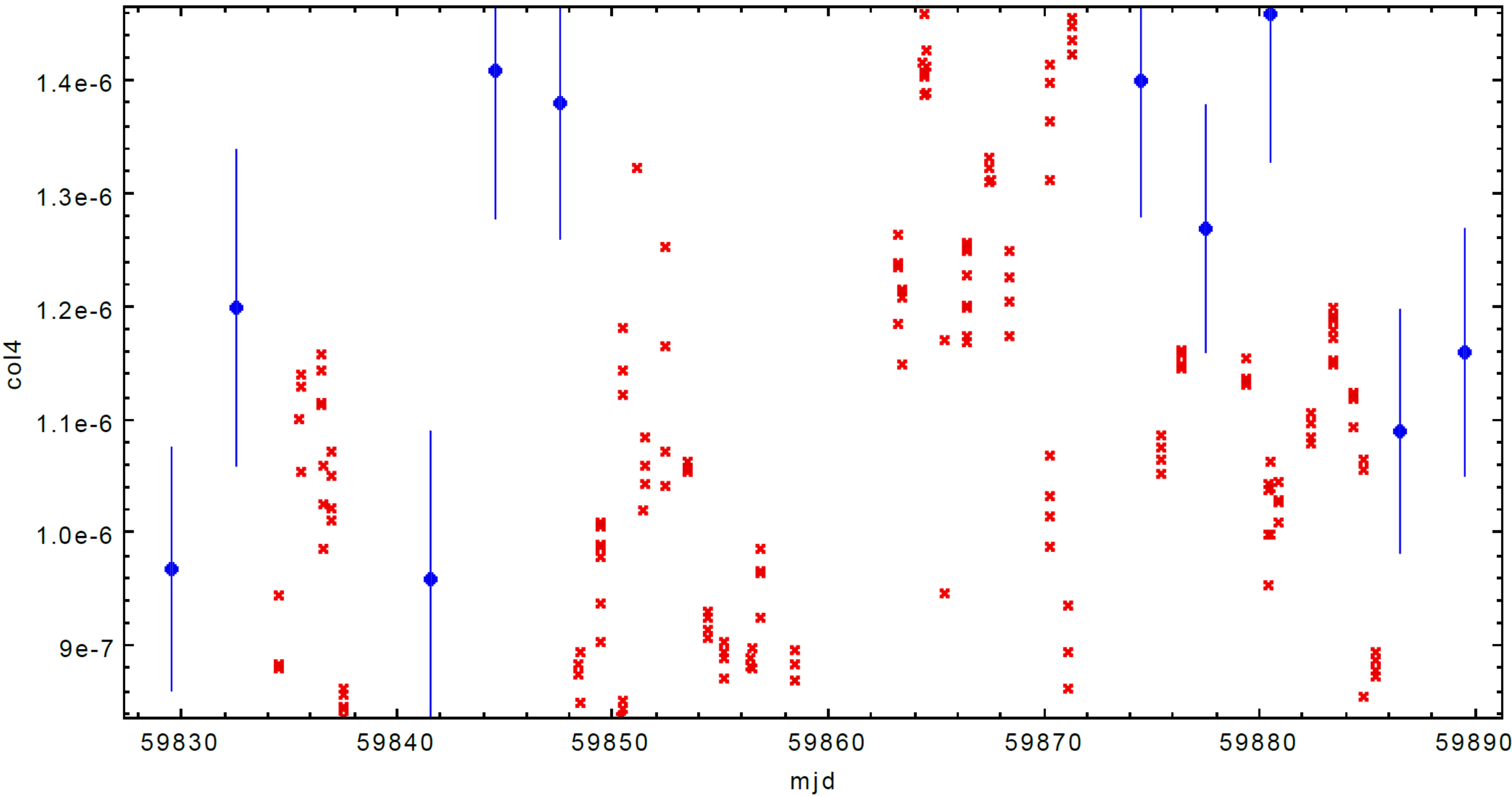
- Yet on ~daily timescales, optical and gamma-ray fluxes track well??

More 3C454.3 – the big picture, low duty cycle, blue = Fermi (3 day), red = optical (ATLAS)



Varying Compton dominance (L_{gamma}/L_{opt})

More 3C454.3 – big zoom, blue = Fermi (3 day), red = optical (ATLAS)



There is intranight variability in optical, but usually ~10-20% NOT factors of 2 that can be see in gamma-rays.

Spectral Evolution on Short Timescales?

[work by S. Saitoh]

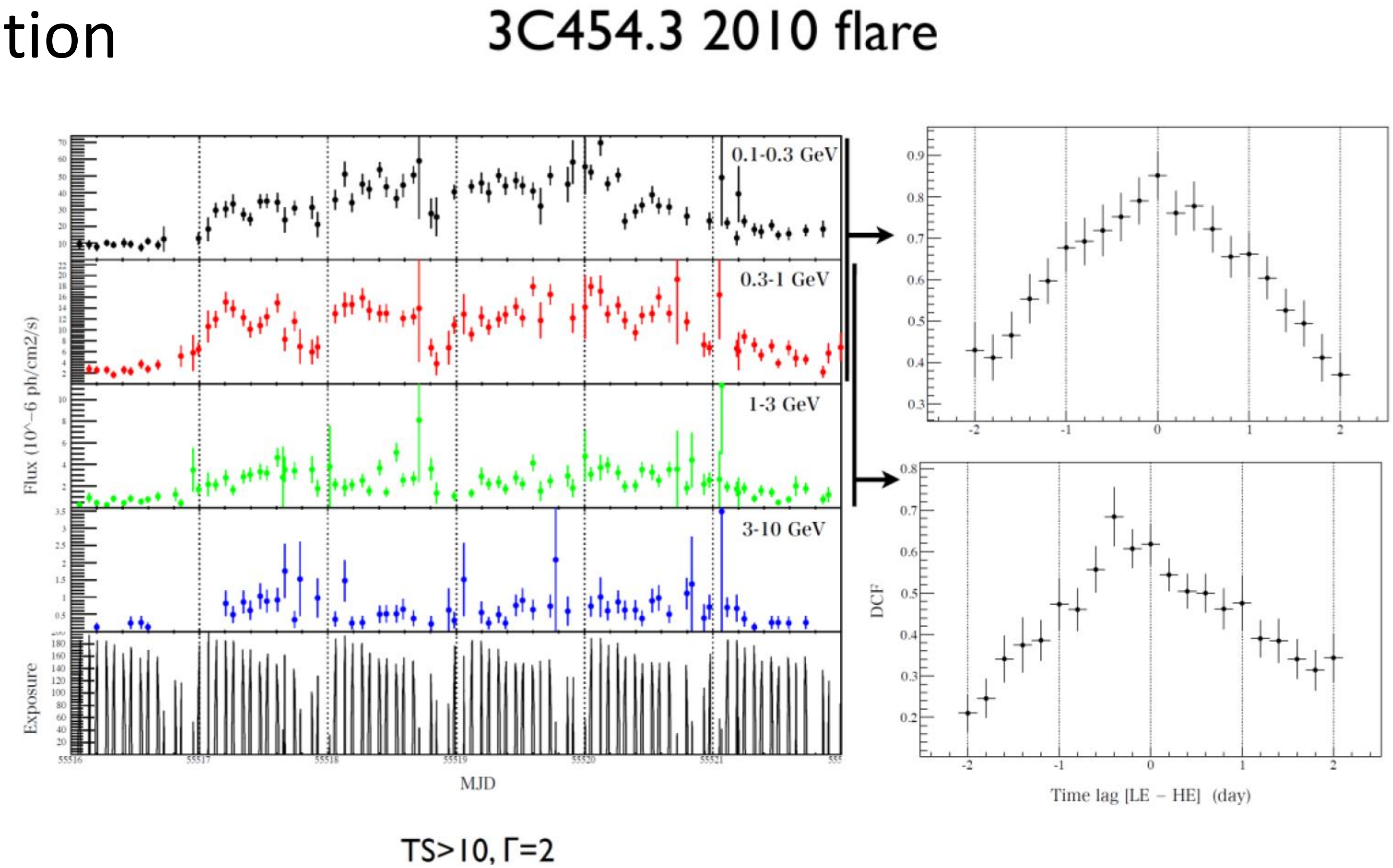


Fig. 2: ***(left panel)*** Sample light curves from the giant flare of the blazar 3C454.3 in 2010 shown for four different energy bands. The light curve points are obtained by integrating flux over the ~30 minute exposure windows shown in the bottom graph, properly taking into account the variation in exposure during the window. Note that there is clear evidence for fast and repeated variability (greater than factor 2 on ~0.5-1 hour timescales.) ***(right panels)*** Discrete correlation function computed between the 0.1-0.3 and the 0.3-1 GeV energy bands *(top)* and the 1-3 GeV *(bottom)* energy bands as a function of time lag/lead between the bands. Fluxes in the various bands do not behave identically, i.e., there is spectral evolution during the flare, and there is a moderate (~2 sigma) detection of a high-to-low energy lag above ~1 GeV.

3C454.3 2009 flare

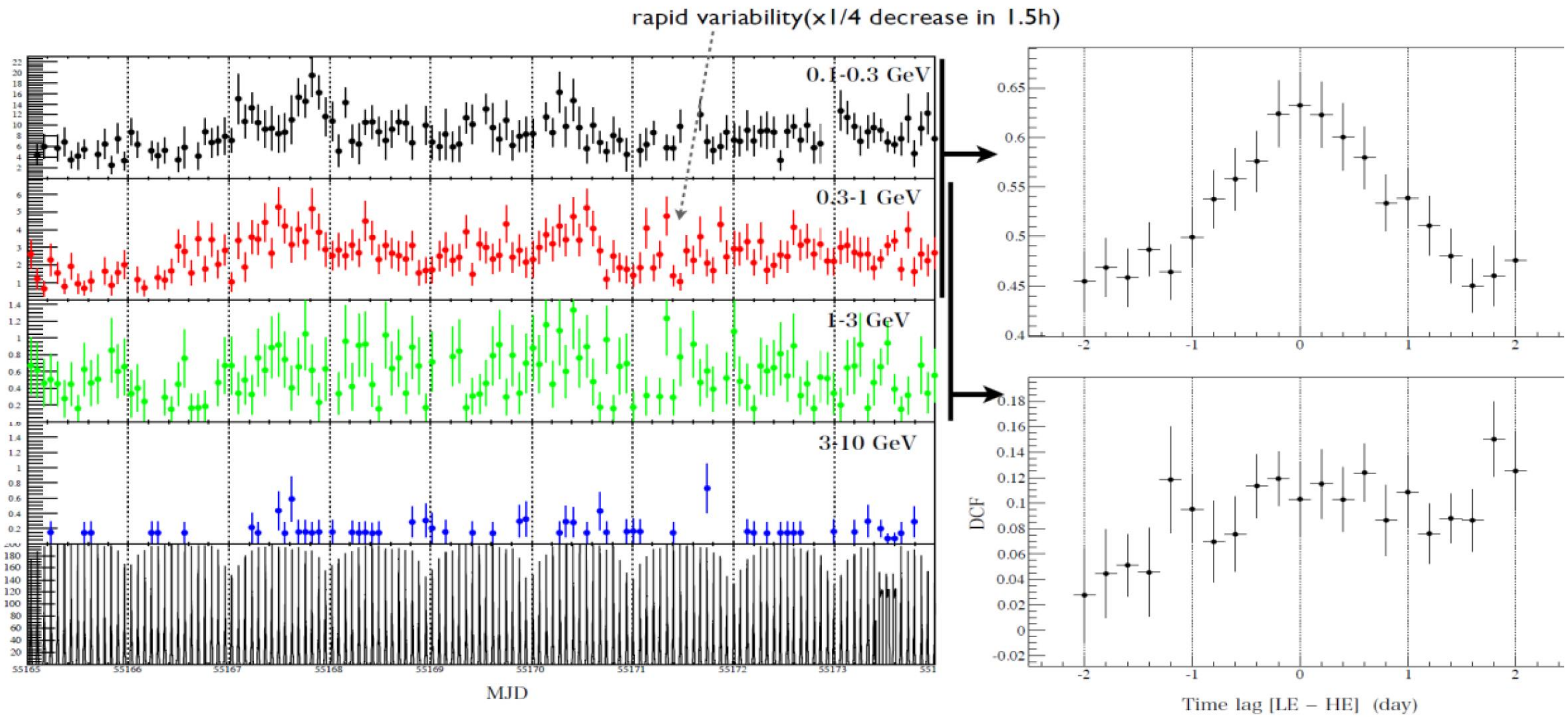
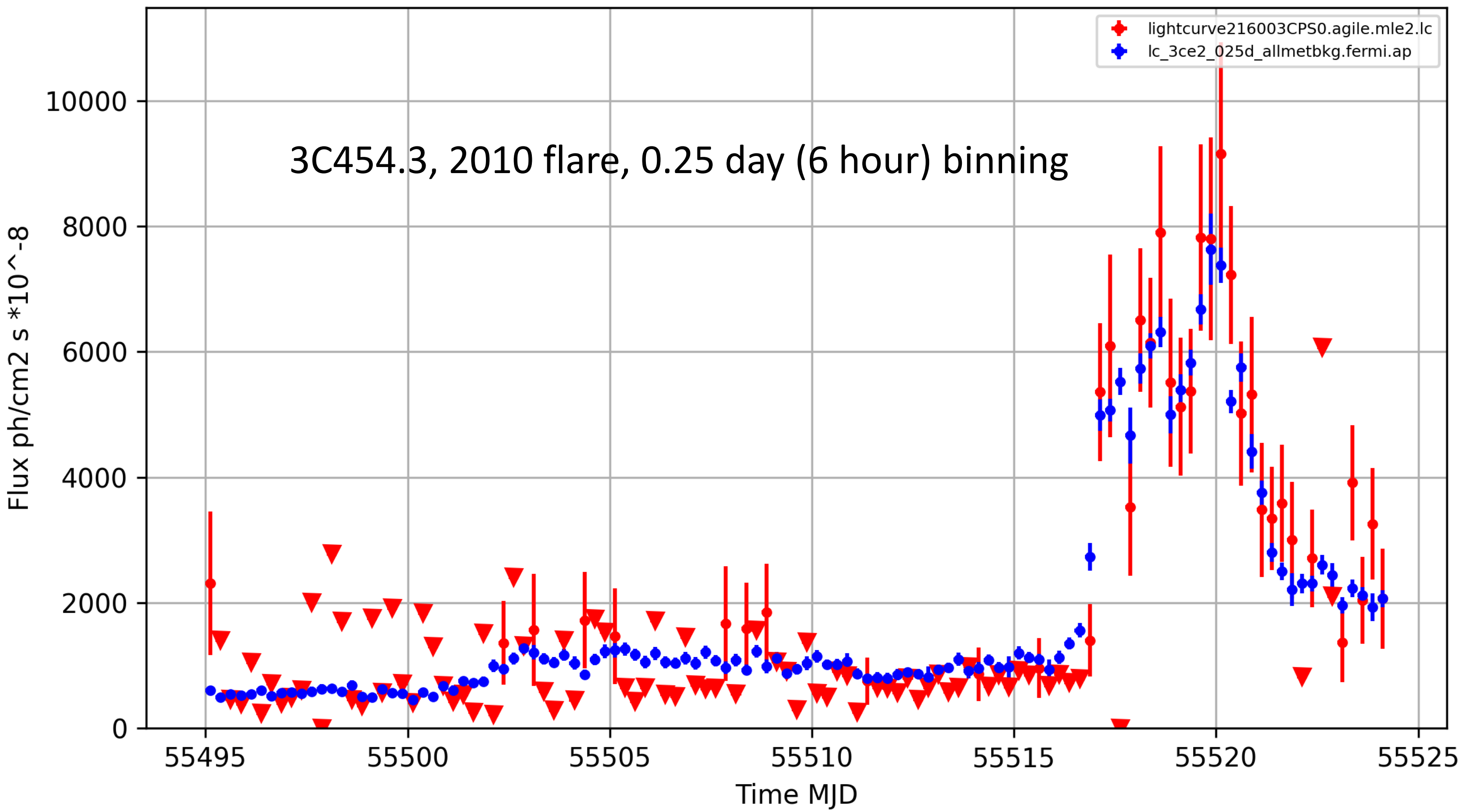


Fig. 3: Similar to Fig. 2, except the data is for the large 3C454.3 in 2009. Interestingly, the short timescale behavior below ~1 GeV is qualitatively similar, but *not* above 1 GeV – compare the 0.3-1 vs 1-3 GeV correlation functions in the lower of the two right panels.

We’re trying to help short timescale lightcurve issue – fast aperture photometry pipeline (A. Bulgarelli et al.) for BOTH AGILE and Fermi that can work on intraorbit timescales



AGILE = red, Fermi = blue, complementary time coverage, if seen by both, flaring is real!

Variability Take-Away Points

- In the brightest flares, there is strong evidence for variability on < 3hr timescales, the shortest binning time typically used in Fermi light-curve analysis.
- Gamma-ray variability appears *fractal*. Amplitude increases with decreasing binning timescale. Day+ flares actually made of many (>2x) subflares…
- <30 minutes variability possible, but not so common
- Spectral variability *is* present on these short timescales too.
- => DON'T USE DAILY bins for detailed SED analysis! Can get "unphysical" time-average SED (if peak moves), or washes out cutoff (e.g., if R_{blob}/R_{BLR})
- Variability characteristics useful for identifying "states"
- *Pointed mode* Fermi observations + ~*continuous* multi-wavelength coverage (not one or two snapshots per night) are essential for unraveling what's going on. *THERE is action on < Fermi scanning timescale, e.g., initially missed Crab flares…*
- Rapid variability is a problem for GeV blazars too…!!
- Connection between optical/NIR and GeV not entirely obvious... **BAD optical-gamma correlation on short (< day) timescales for FSRQ.**
- **Out of ~3000 Fermi blazars, can only see ~hr variability in ~10s = tip of iceberg!**

Some other issues:

Shortest variability timescales decreased over years, inferred Doppler factors increased, recent papers quote δ~50 with batting an eye. As VLBI frequency (resolution) increased, also have reports of similar Doppler factors (~30). How do we reconcile this with Grand Unified Blazar/Radio Galaxy FRI-FRII theory/statistics? [Look at time-averaged Emission?]

Related: What is gamma-ray emission as f(viewing angle)? Data is there to do better job but not so clear yet.

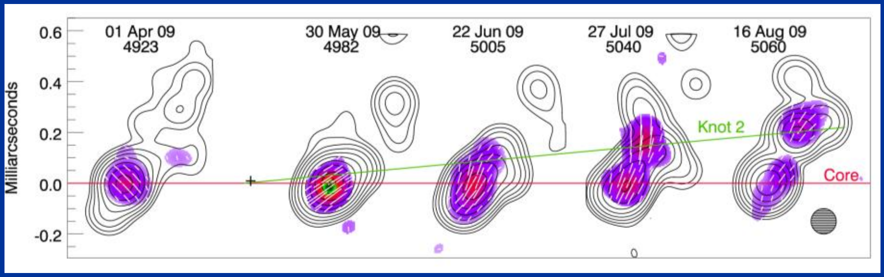
High Doppler factors often imply very inefficient emission regions (=> huge bulk jet power if you're not careful)?

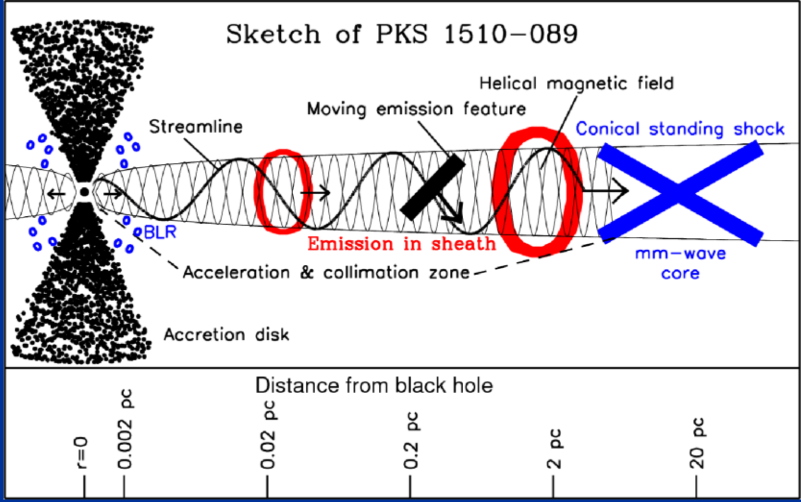
If rapid variability implies small emission region, have opposite efficiency problem? How do you get so much power out of such a small region? Is that really possible via reconnection, jets-in-jets, etc.?

Minute variability for 10^9 solar mass black hole more extreme than 10 msec variability for few solar mass black hole (GRB)?

Connection to central engine? Will have much better understanding of central engine variability with LSST. Compare to gamma variability? Follow-up TDEs!

What to do?[A. Marscher]





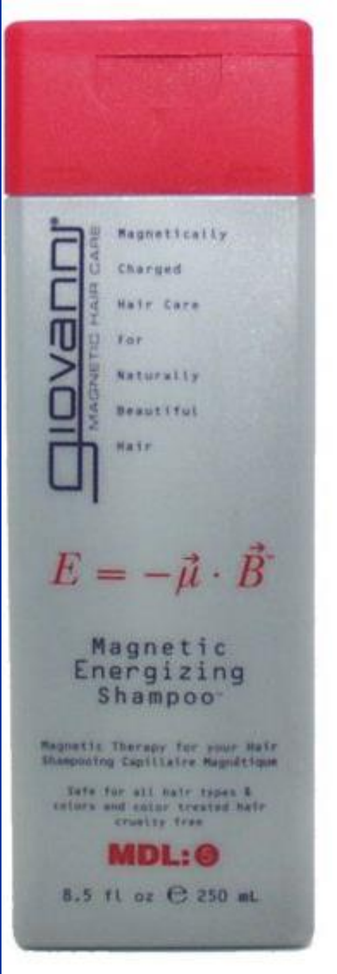
1. Many γ-ray flares occur as "blob" passes through or continues downstream of core, a "steady" feature, e.g., standing (recollimation?) shock.

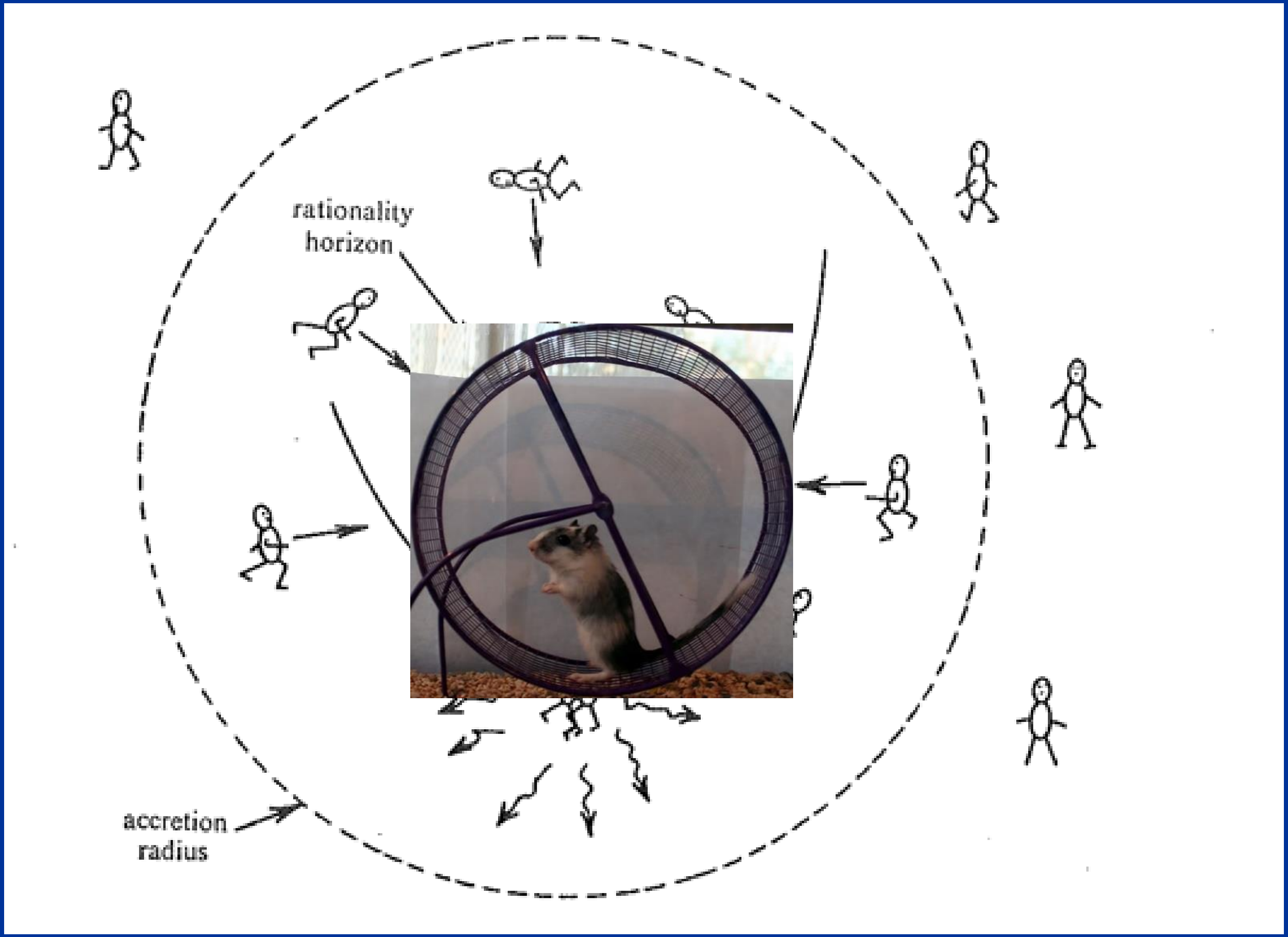
2. Some flares - include multiple wavebands, others are "orphans" → energy range of power-law distribution of electrons is sometimes broad, sometimes narrow; not all events accelerate electrons to high enough energies or involve enough seed photons to make γ-rays.

3. It is clear that the multi-waveband emission of blazars is complex, *with multiple components possibly active at any given time* and some having low duty cycles.

4. This means: (1) less complete observational programs can give misleading results, [need large sample + good broad-band variability sampling] , (2) we need to maintain a long-term comprehensive program to sample the range of behavior in order to develop realistic models.

Recent Progress in Understanding Particle Acceleration in Astrophysical Sources?

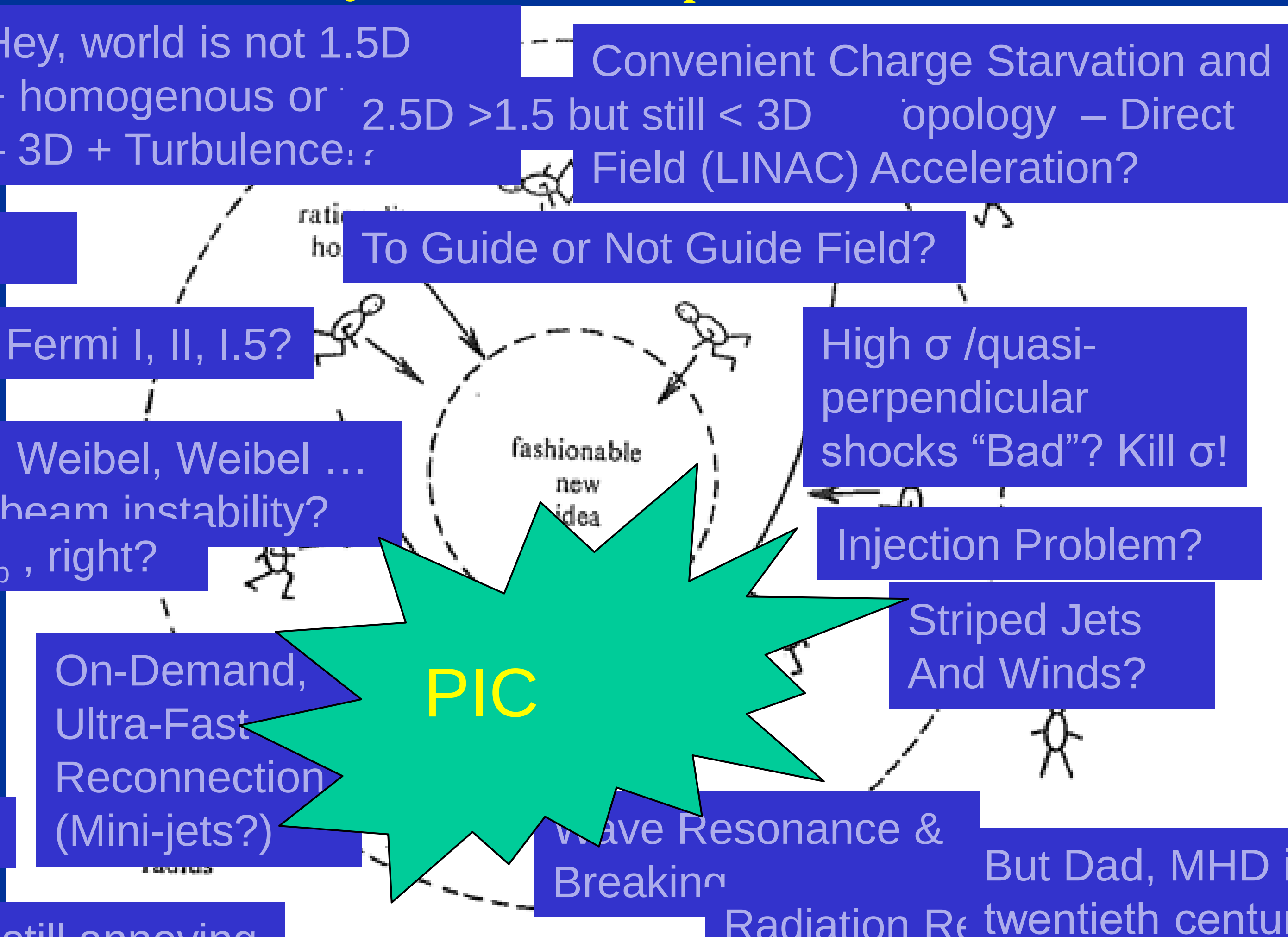




With apologies to D. McCray + K. Nalewajko

Recent Progress in Understanding Particle Acceleration in Astrophysical Sources:

Better Observations + Bigger Computers = Neither Sources nor Acceleration Theories Quite What Expected ....



Hey, world is not 1.5D
+ homogenous or
– 3D + Turbulence

2.5D >1.5 but still < 3D

Convenient Charge Starvation and
opology – Direct
Field (LINAC) Acceleration?

Drift, Kink Mode?

To Guide or Not Guide Field?

Fermi I, II, I.5?

High σ /quasi-perpendicular shocks "Bad"? Kill σ!

Weibel, Weibel, Weibel …
Two beam instability?

$L_{AGN/GRB} \sim 40\ c/\omega_p$, right?

Injection Problem?

PIC

Tearing Modes

On-Demand, Ultra-Fast Reconnection (Mini-jets?)

Striped Jets And Winds?

Ion Ring Instability

Wave Resonance & Breaking

But Dad, MHD is so twentieth century …

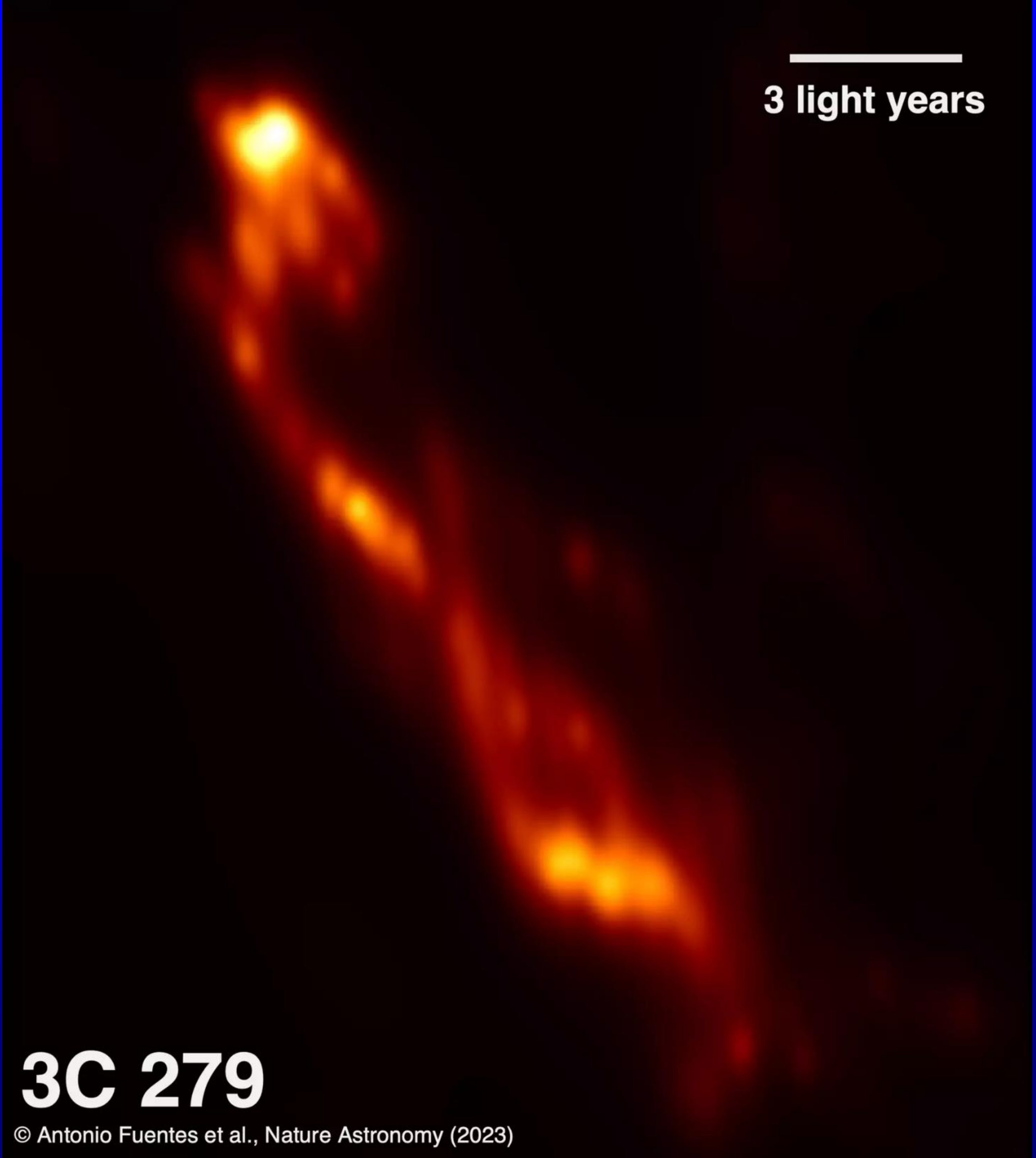
Radiation Re
Feedback/Drag?

m_e vs. m_p still annoying

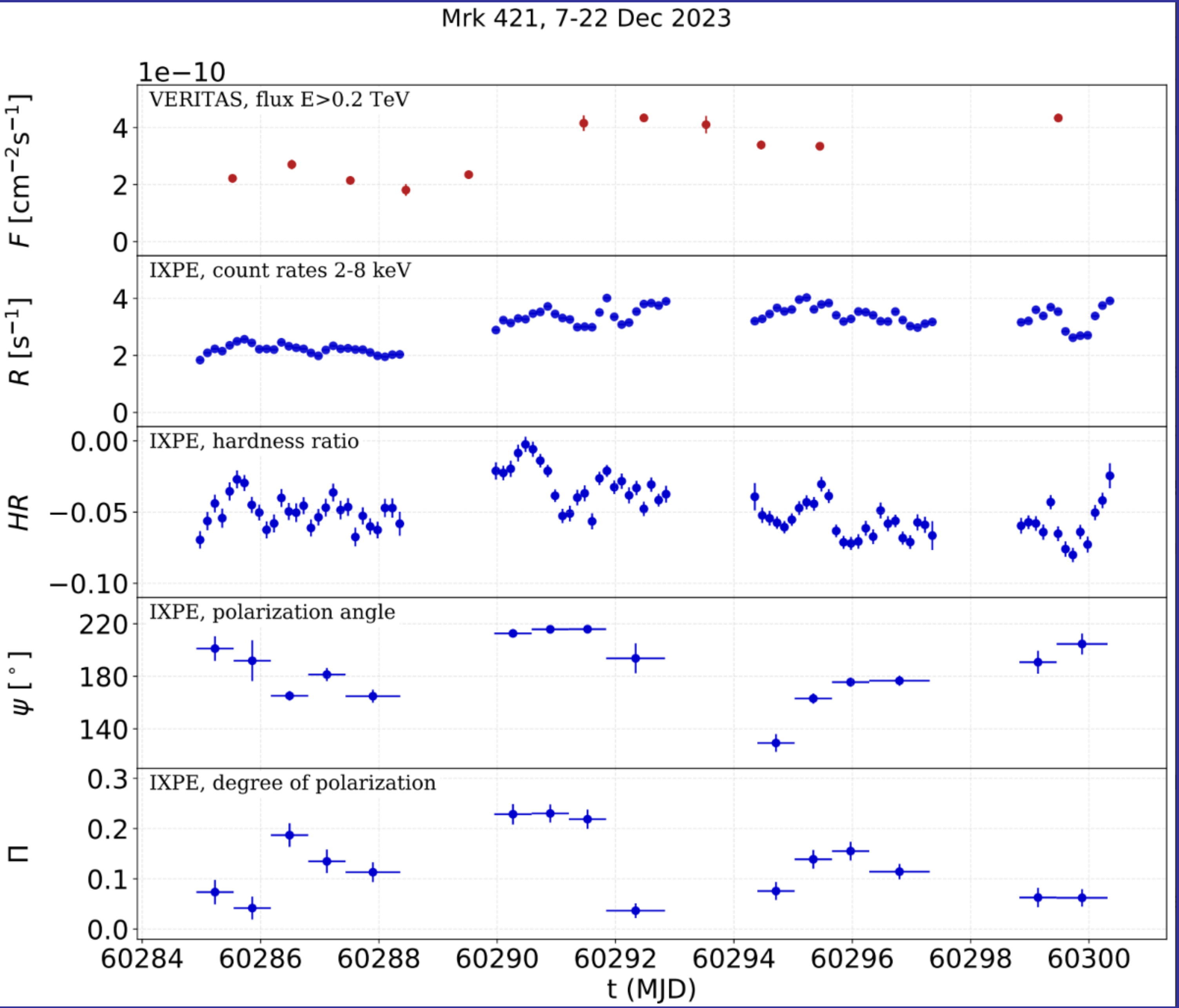
Wi … (1979)

EHT, space VLBI

(extreme VLBI)



From parallel session talk by Errando et al, example of joint VHE-IXPE observation



IXPE – finally have X-ray polarization information for Mkn 501 [Liodakis et al. Nature]

Table 1 | Summary of model properties

Model	Multiwavelength polarization	X-ray polarization variability[a]	X-ray polarization angle
Single zone	Constant[b]	Slow	Any
Multizone	Mildly chromatic	High	Any
Energy stratified (shock)	Strongly chromatic	Slow	Along the jet axis
Magnetic reconnection (kink instability)	Constant	Moderate	Perpendicular to the jet axis
Observed	Strongly chromatic	Slow	Along the jet axis

First, we find an increasing Π towards higher frequencies. Second, we do not find significant variability during the 2–3-day-long IXPE observations, and finally, we find a rough alignment of ψ with the jet axis from radio to X-rays. Therefore, a shock-accelerated, energy-stratified electron population model satisfies all our multiwavelength polarization observations.

[a]Slow variability, a few days to a week; moderate variability, days; high variability, less than 1 day.

[b]There is a slight dependence on the slope of the emission spectrum.

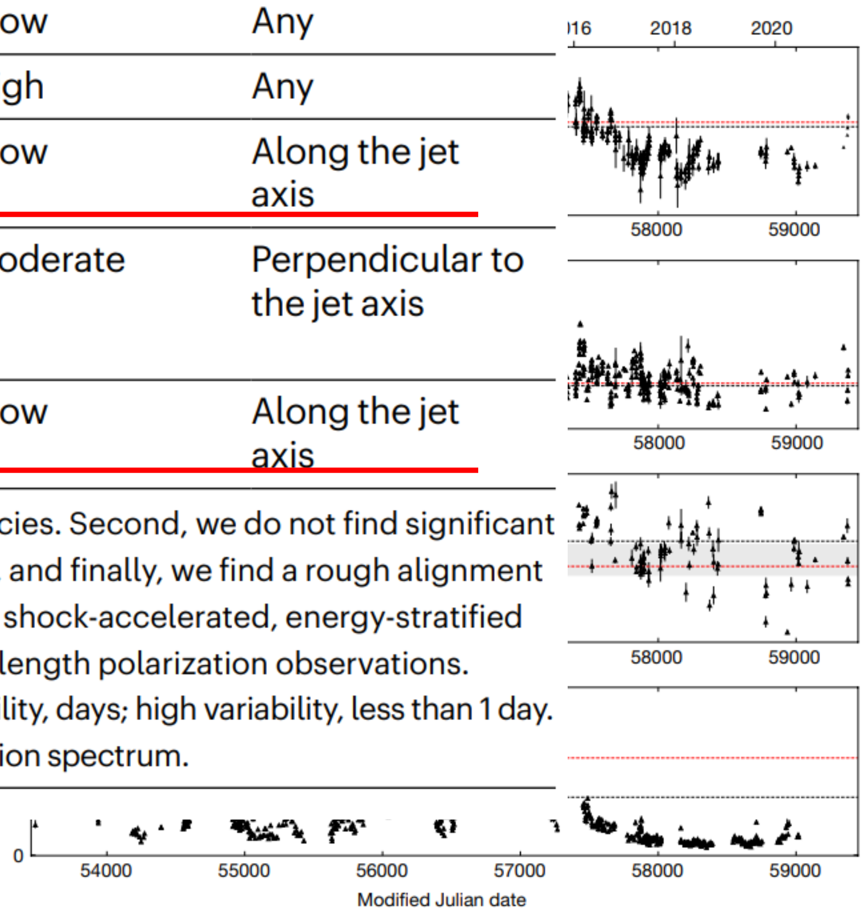
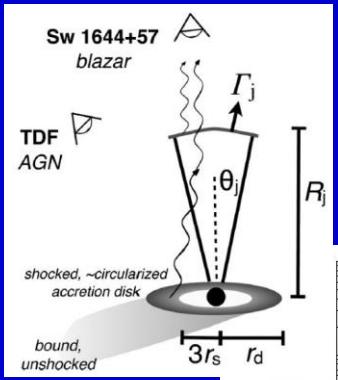


Fig. 2 | Multiwavelength and polarization archival observations of Mrk 501. a–d, Optical brightness (R-band, **a**), observed optical Π in per cent (**b**), observed optical ψ in degrees (**c**) and X-ray flux in $\times 10^{-10}$ erg s^{-1} cm^{-2} (**d**). The black and red dashed lines indicate the level of the source during the 8–10 March and 26–28 March 2022 IXPE observations, respectively. The grey shaded area in **c** shows the direction of the jet axis. In all panels, the error bars denote the 68% CI.

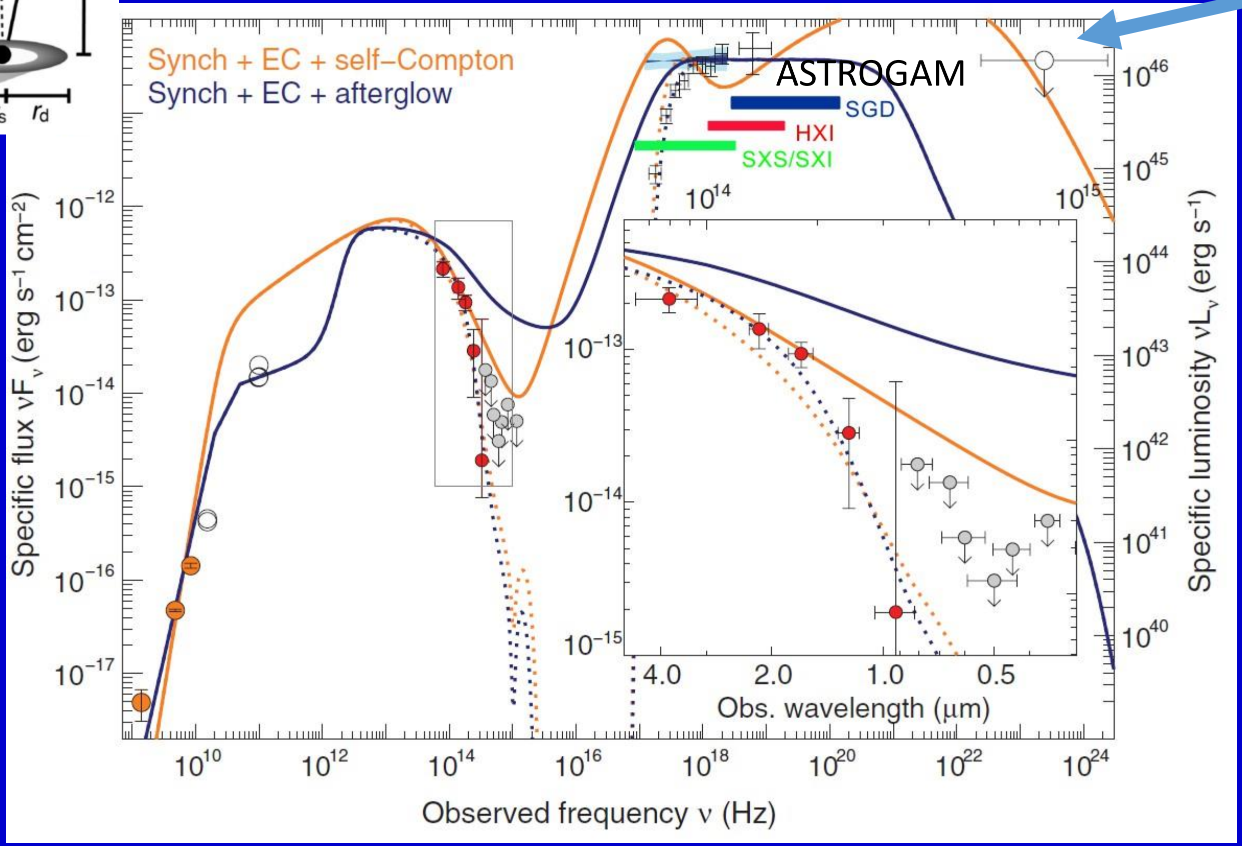
Future Science – Tidal Disruption Events (TDE)

Re-activated Jet?, study evolution as f(dM/dt)

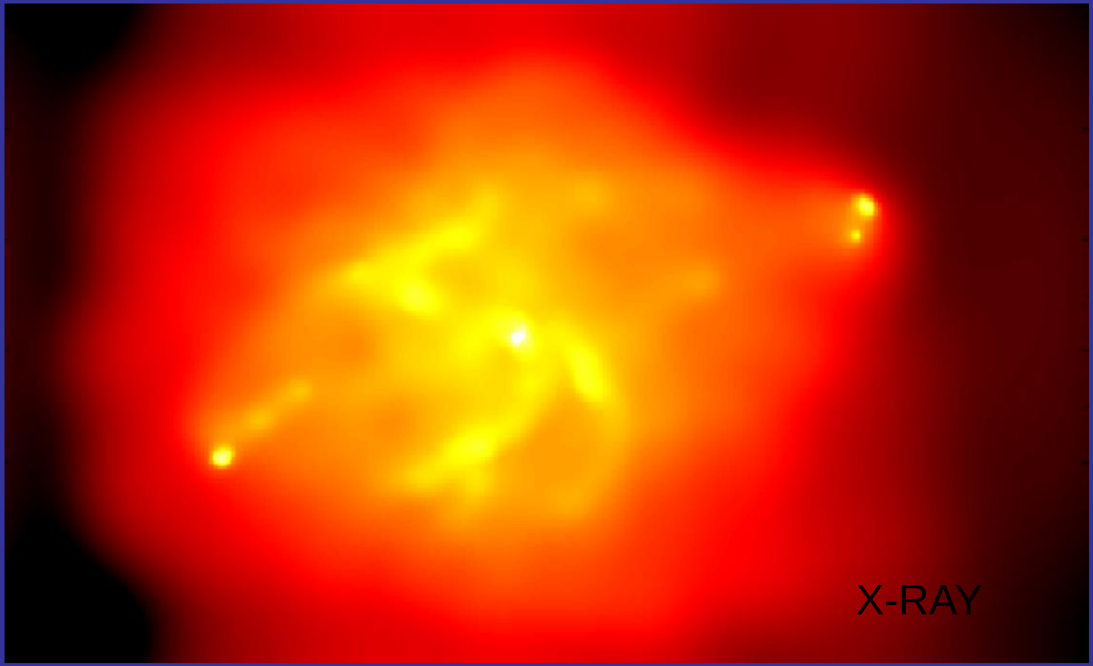


Bloom et al 2012

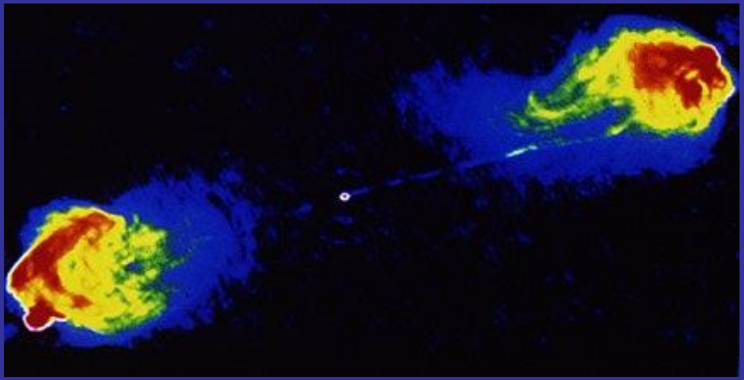
Fermi saw nothing!

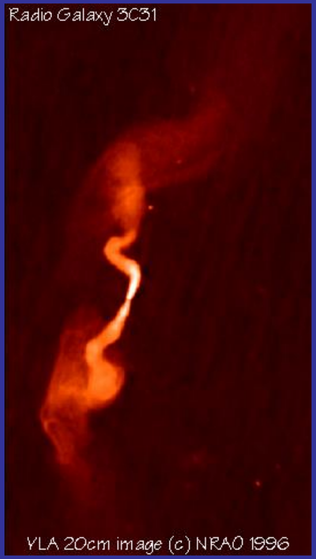


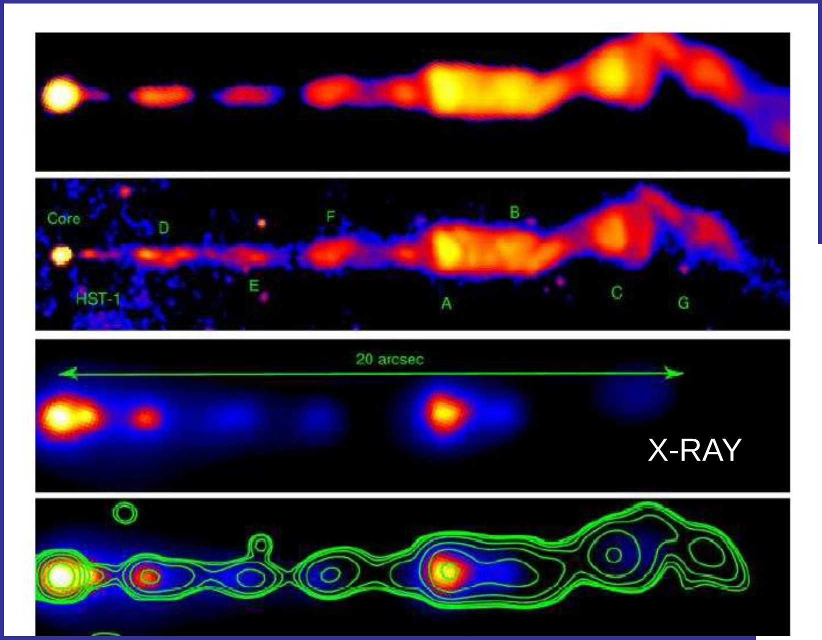
Extended X-Ray Emission from Jets!! [Parent population of blazars] – Potential GeV/TeV Sources!



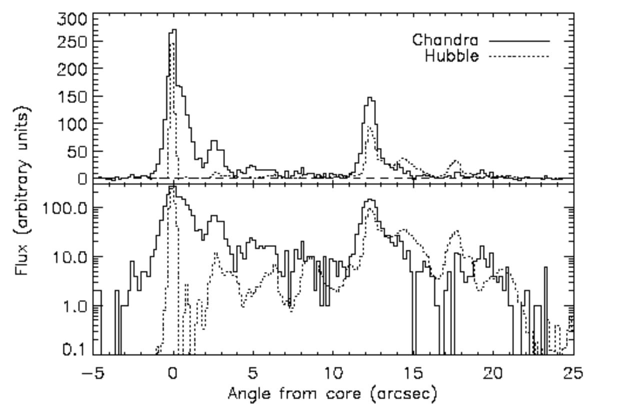
Cygnus A - FRII (powerful jet?)

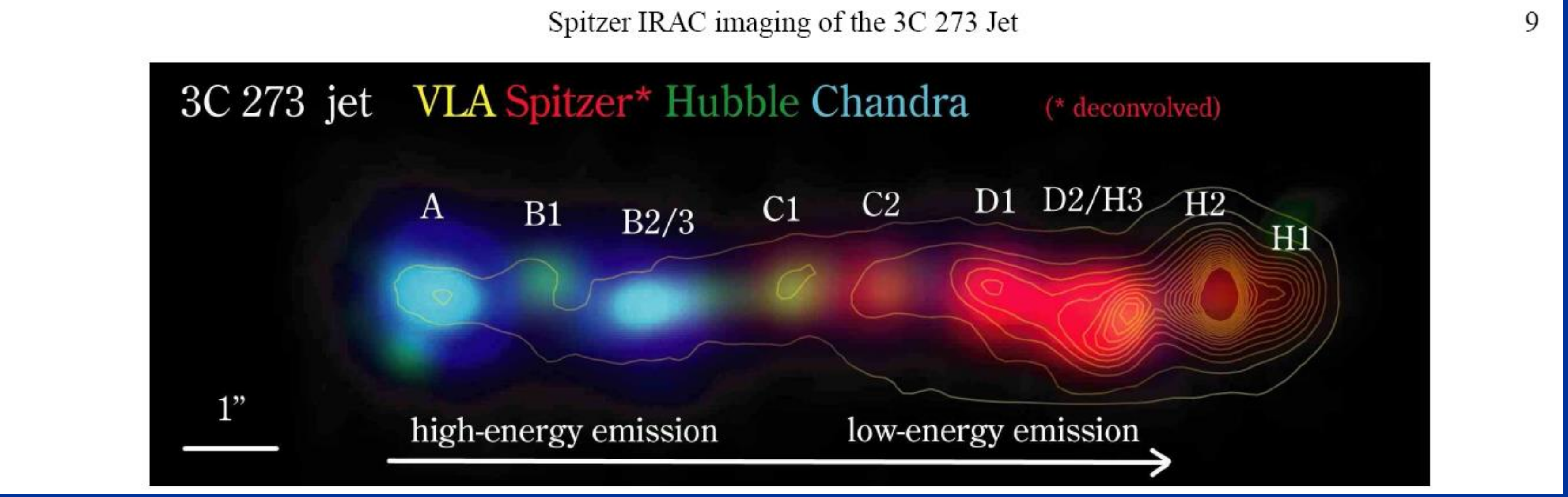


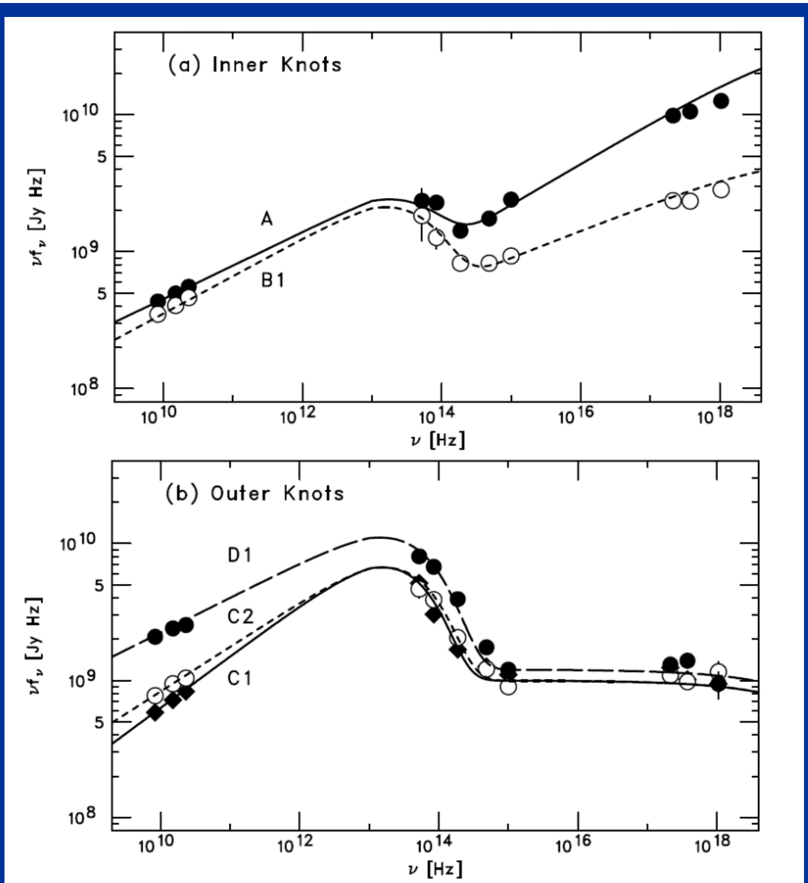




M87 – FRI (weak jet)







Two components!

Optical polarized
⇒Synchrotron
⇒ TeV+ electrons!

Uchiyama et al. 2007

Most AGN (90%) are not radio loud, i.e., have powerful jets, but many (all?) have outflows of some kind that may be quite powerful, e.g, UFOs (UltraFast Outflows, Tombesi et al.).

=> Like Galactic colliding winds!? [And outside of "compact" region], see VHE?

The Astrophysical Journal, 921:144 (14pp), 2021 November 10
https://doi.org/10.3847/1538-4357/ac1bb2

CrossMark

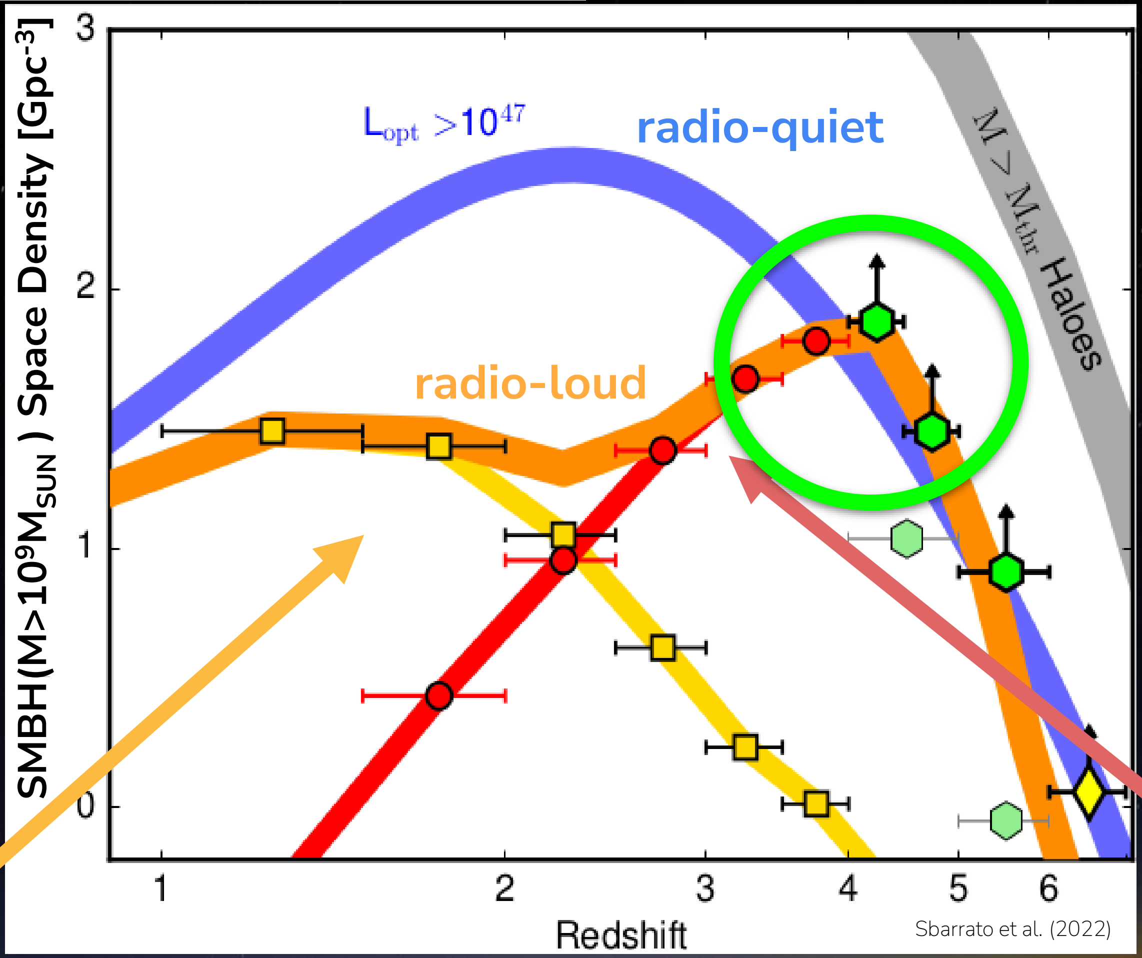
Gamma Rays from Fast Black-hole Winds

M. Ajello[1], L. Baldini[2], J. Ballet[3], G. Barbiellini[4,5], D. Bastieri[6,7], R. Bellazzini[8], A. Berretta[9], E. Bissaldi[10,11], R. D. Blandford[12], E. D. Bloom[12], R. Bonino[13,14], P. Bruel[15], S. Buson[16], R. A. Cameron[12], D. Caprioli[17], R. Caputo[18], E. Cavazzuti[19], G. Chartas[20], S. Chen[6,21], C. C. Cheung[22], G. Chiaro[23], D. Costantin[24], S. Cutini[25], F. D'Ammando[26], P. de la Torre Luque[10], F. de Palma[27,28], A. Desai[29], R. Diesing[17], N. Di Lalla[12], F. Dirirsa[30], L. Di Venere[10,11], A. Domínguez[31], S. J. Fegan[15], A. Franckowiak[32], Y. Fukazawa[33], S. Funk[34], P. Fusco[10,11], F. Gargano[11], D. Gasparrini[35,36], N. Giglietto[10,11], F. Giordano[10,11], M. Giroletti[26], D. Green[37], I. A. Grenier[3], S. Guiriec[18,38], D. Hartmann[1], D. Horan[15], G. Jóhannesson[39,40], C. Karwin[1], M. Kerr[22], M. Kovačević[25], M. Kuss[8], S. Larsson[41,42,43], L. Latronico[13], M. Lemoine-Goumard[44], J. Li[45], I. Liodakis[46], F. Longo[4,5], F. Loparco[10,11], M. N. Lovellette[22], P. Lubrano[25], S. Maldera[13], A. Manfreda[2], S. Marchesi[47], L. Marcotulli[1], G. Martí-Devesa[48], M. N. Mazziotta[11], I. Mereu[9,25], P. F. Michelson[12], T. Mizuno[49], M. E. Monzani[12], A. Morselli[35], I. V. Moskalenko[12], M. Negro[50,51], N. Omodei[12], M. Orienti[26], E. Orlando[12,52], V. Paliya[53,54], D. Paneque[37], Z. Pei[7], M. Persic[4,55], M. Pesce-Rollins[8], T. A. Porter[12], G. Principe[4,5,26], J. L. Racusin[18], S. Rainò[10,11], R. Rando[6,21,56], B. Rani[18,57,58], M. Razzano[8,72], A. Reimer[12,48], O. Reimer[48], P. M. Saz Parkinson[59,60,61], D. Serini[10], C. Sgrò[8], E. J. Siskind[62], G. Spandre[8], P. Spinelli[10,11], D. J. Suson[63], D. Tak[18,64], D. F. Torres[65,66,67], E. Troja[18,68], K. Wood[69,70], G. Zaharijas[52,71], and J. Zrake[1]

Blazars and SMBH Evolution

Lea Marcotulli | lea.marcotulli@yale.edu

$2\Gamma^2$ CORRECTION!



γ-ray blazars

JETS ↔ SMBH GROWTH

X-ray blazars

ALP, LIV, and Hadron Beams … ! (Other possible propagation effects)

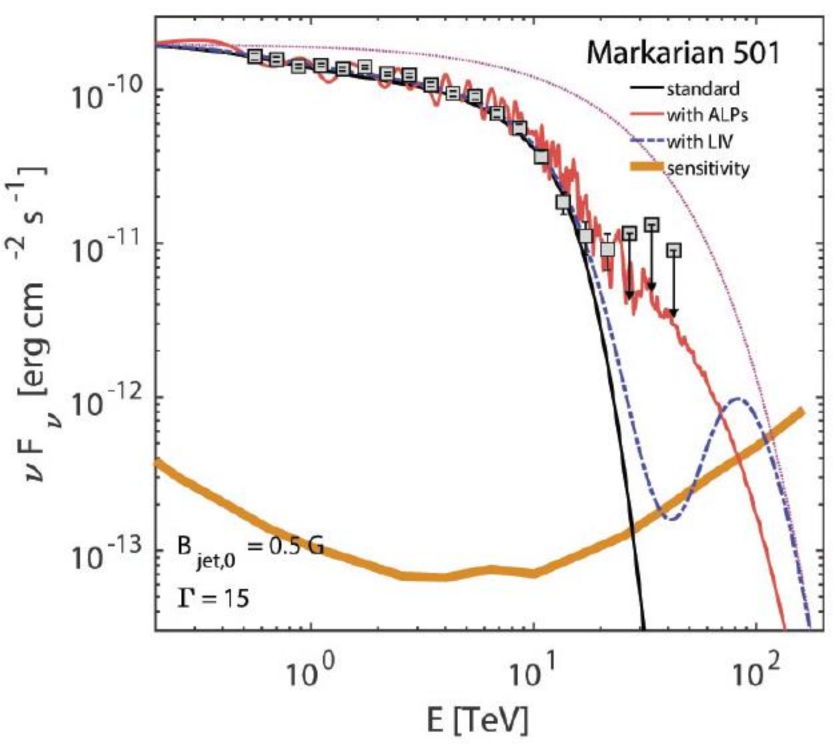


Figure 1. Behaviour of the observed spectrum of Markarian 501 versus the observed energy E. The solid black line corresponds to conventional physics, the solid red line to the scenario of the photon-ALP oscillations and the dot-dashed blue line to the LIV model. The dotted purple line is the intrinsic exponentially truncated power law spectrum, and the solid orange line represents the CTA sensitivity for the south site and 50 h of observation. We take $B_{\rm jet,0} = 0.5\,{\rm G}$ and $\Gamma = 15$. See the text for more details. The grey squares are the observational data detected by HEGRA (Aharonian et al. 2001).

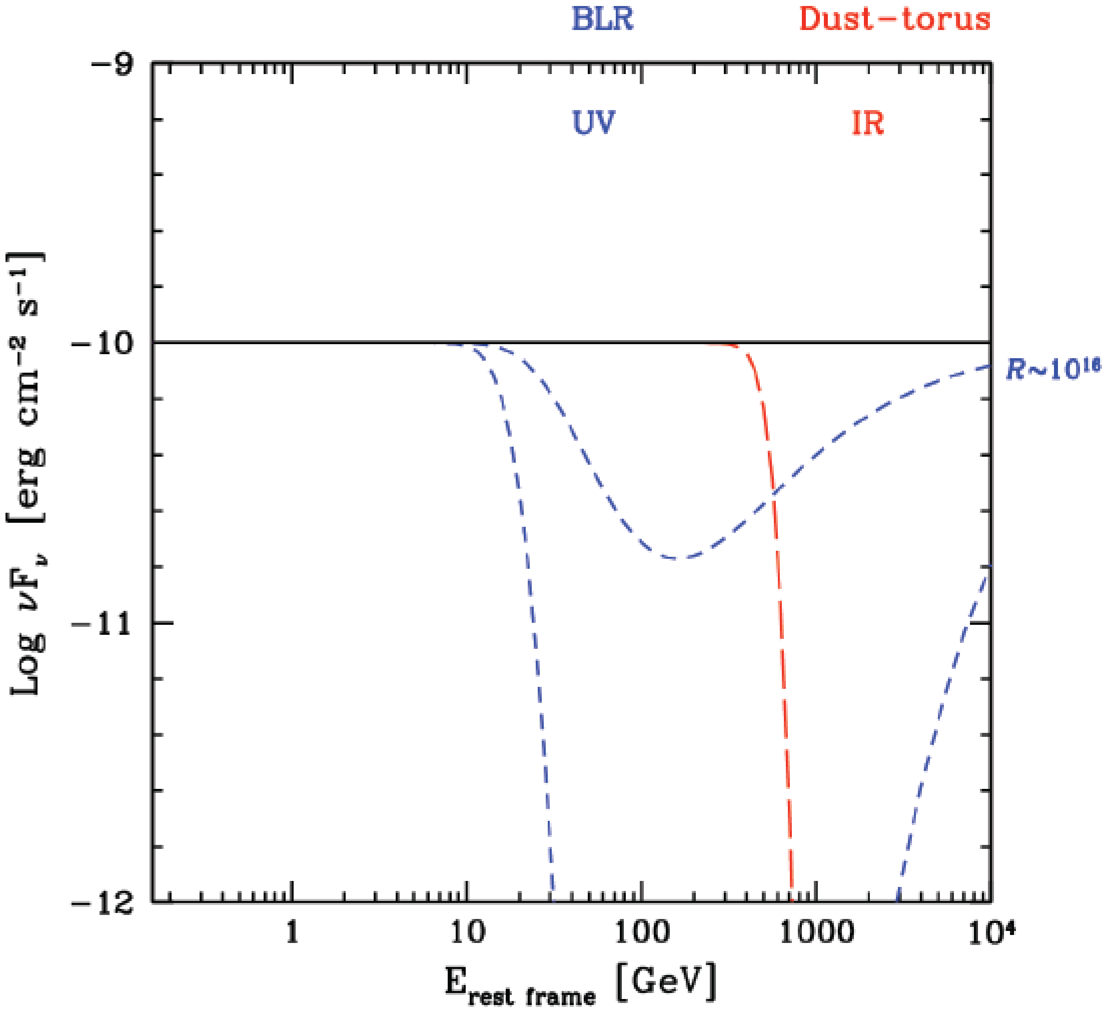
E.g., Galanti, Tavecchio, & Landoni 2019

General Conclusions:

- AGN, both jetted and non-jetted, are more interesting/extreme than we had thought. EGRET showed us we were only seeing the tip of the iceberg. With 2000+gamma-ray blazars, Fermi has shown a lot more of the iceberg, but there are still only ~30 flare events bright enough to probe the shortest variability timescales at GeV energies… More to discover! [Polarization too?]
- Lots more TDE/changing look AGN coming – gamma-rays important to unraveling what is going on… (both in corona + jet)
- To address variability issues, need photon bucket. APT? Low-threshold IACT? (in principle could go down to ~10 GeV) STARLINK approach – launch lots of Fermi's?
- Time coverage gaps = bad. For IACT, spread in longitude so can provide *CONTINUOUS time coverage?*
- There is other cool science can do at gamma-rays like nuclear astrophysics, and follow-up of multi-messenger sources (LIGO) and low-duty cycle AGN flaring => don't try to do everything with one mission?!

Absorption feature by γ-γ interactions

But: same seed photons are target for gamma-gamma interactions.
<u>The gamma-rays have to pass through a double "wall" of photons</u>



Optical depth τ is high !

Always not negligible (≥1), even in the minimal case: photon path ~ size of emitting region (typically ~10^{16} cm)

Fermi now samples this energy range for the first time (1-100 GeV rest frame)

Band >10 GeV: lots of diagnostics !

If EC is the main g-ray emission mechanism: @ ~2-10 GeV (restframe), additional possible steepening due to Klein-Nishina effects !

☛ if Lc/Ls~1 **or** Lc/Ls >>1 & BLR spectrum is broad banded
⇒ cooling of e^{+-} in Thomson ⇒ steepening

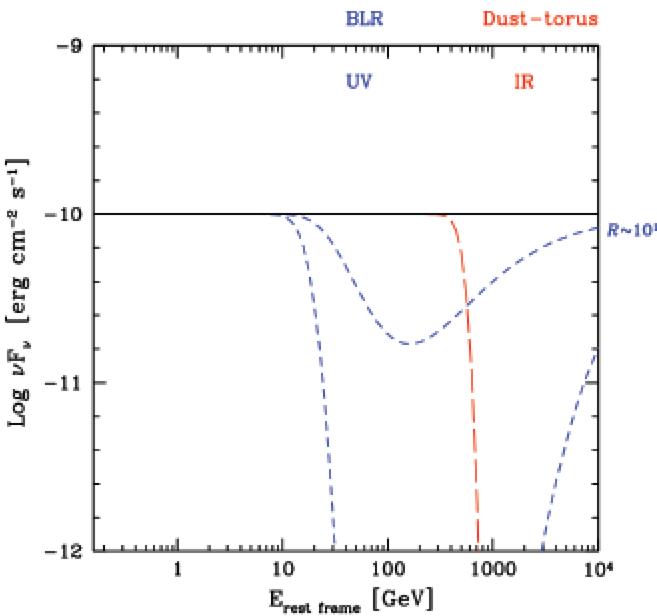
☛ if Lc/Ls >>1 & BLR is narrow banded ⇒ no steepening !
compensated by hardening of the particle distribution when cooling is in KN regime
(e.g. Zidjarski 1989, Dermer et al. 2003, Moderski et al. 2005, Ghisellini et al. 2009)

Presence or absence of cut-offs, tells:

⇒ R_{diss} < or > R_{BLR}

⇒ intensity of cutoff gives an estimate of the photon path inside the BLR

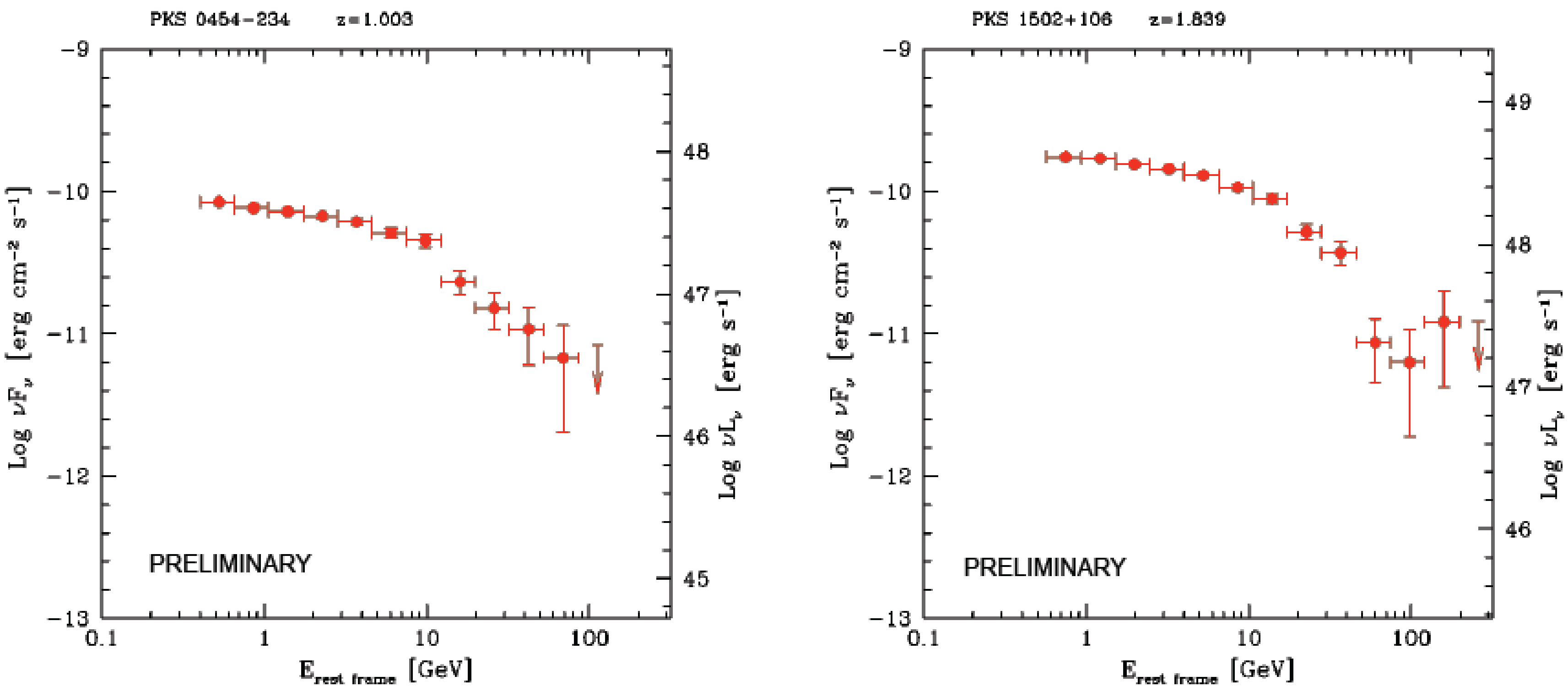
⇒ which EC is viable: UV or IR photons



No evidence of strong BLR cut-offs !

τ can be very high (~10 ℓ_{17}), if inside the BLR, and yet:

the sources that do show possible absorption, only moderate (τ~1.5-3)



1502: see Benoit's talk and S. Ciprini poster

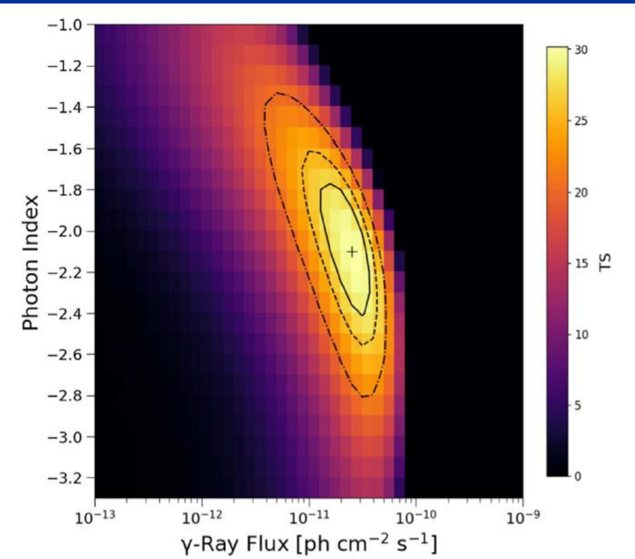


Figure 2. Stacked TS profile for the sample of UFOs. The color scale indicates the TS, and the plus sign indicates the location of the maximum value, with a TS = 30.1 (5.1σ). Significance contours (for 2 degrees of freedom (dof)) are overlaid on the plot showing the 68%, 90%, and 99% confidence levels, corresponding to Δ TS = 2.30, 4.61

Ajello et al. stacked Fermi data for ~11 AGN known to have UFOs. Compared to control sample made to look as much as like UFO sample, except for lack of UFOs in X-ray spectra.

Stacked UFO AGN show signal!
Stacked control sample doesn't.

The Astrophysical Journal, 921:144 (14pp), 2021 November 10 Ajello et al.

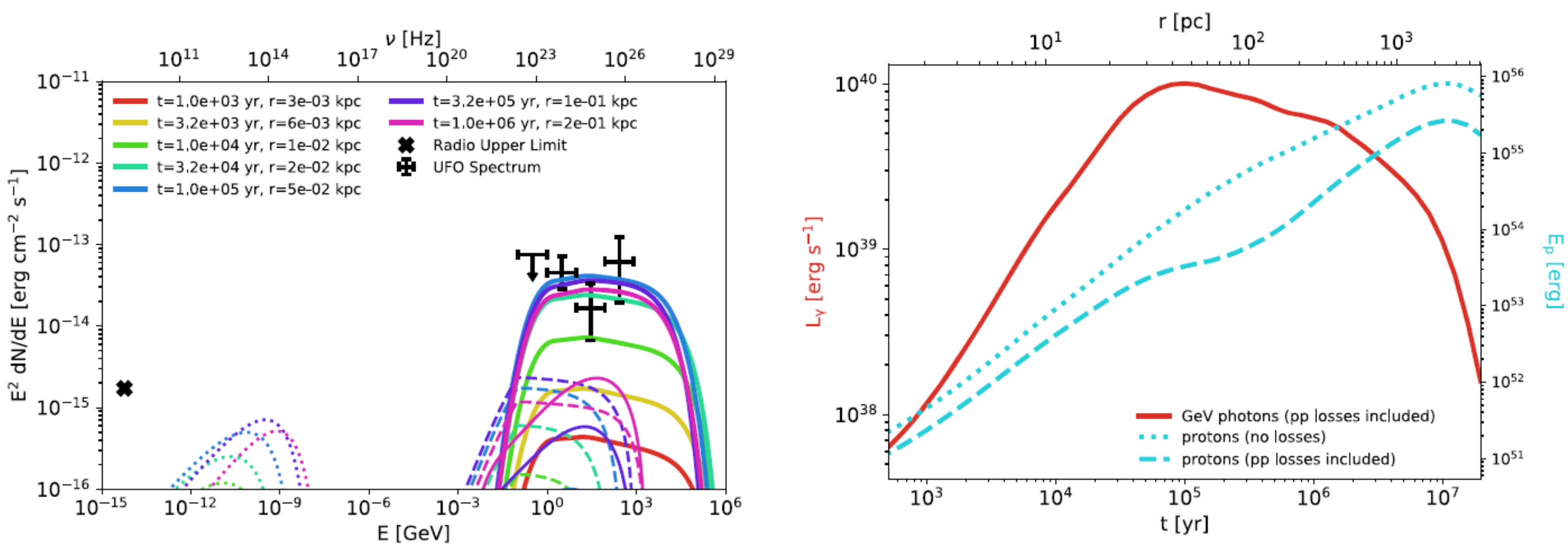
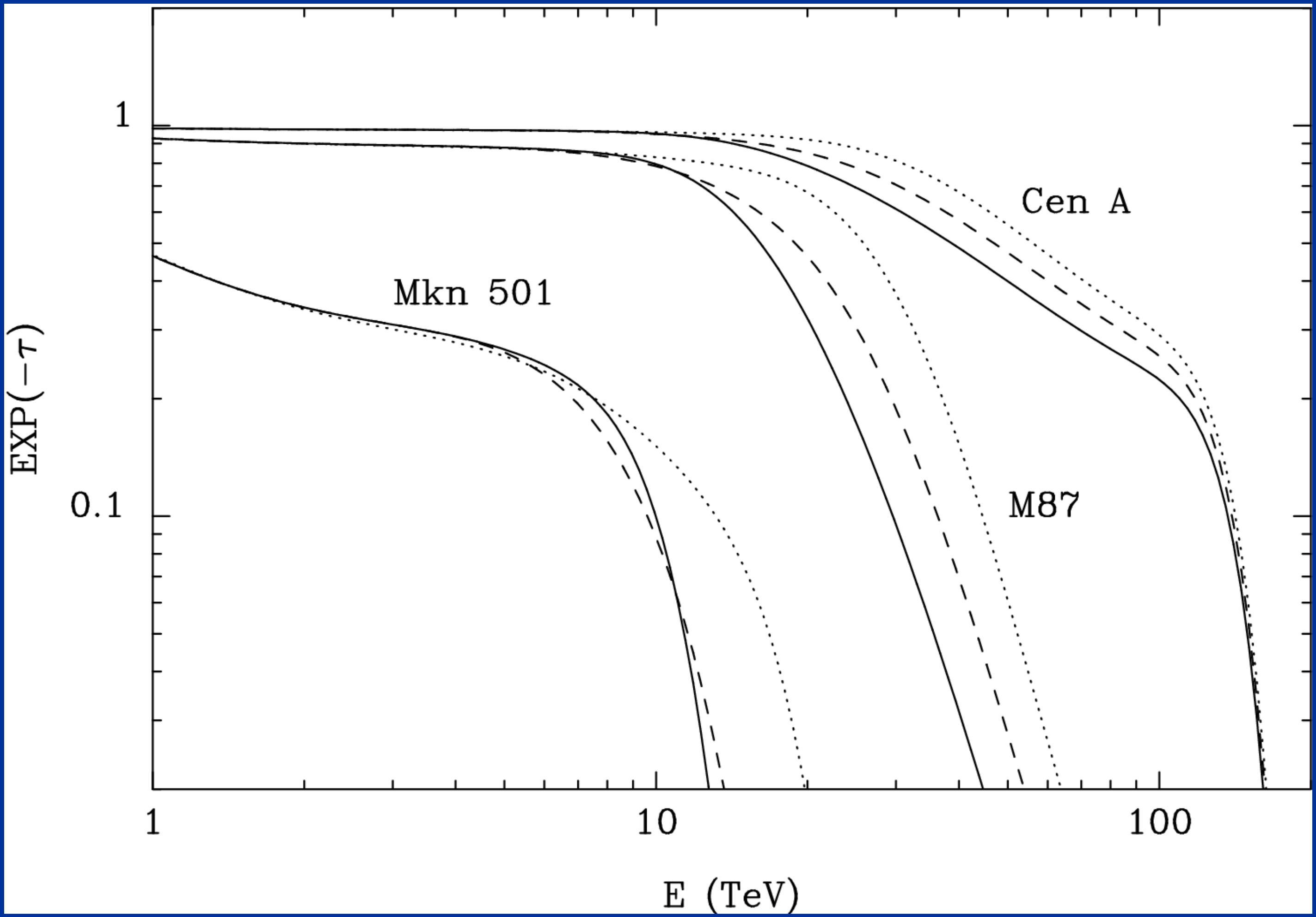


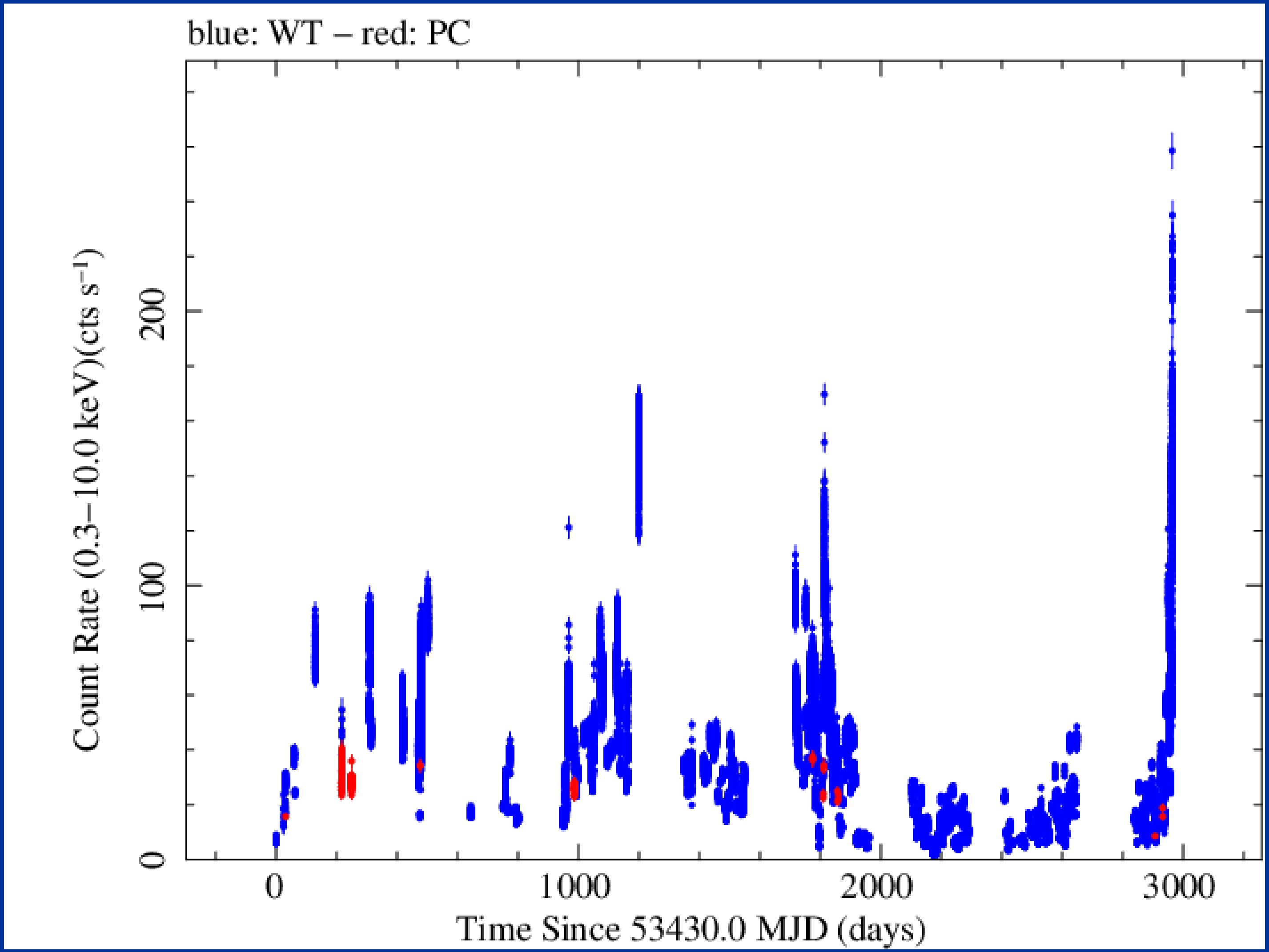
Figure 11. Left: predicted multiwavelength SED of the UFO's nonthermal emission as a function of time. Synchrotron emission (dotted curves), bremsstrahlung emission (dashed curves), inverse-Compton emission (thin solid curves), and emission from π^0 decay (thick solid curves) are shown. The inverse-Compton emission remains subdominant despite assuming an artificially enhanced stellar radiation field of energy density 100 eV cm^{-3}. Also overlaid is the observed γ-ray flux as shown in Figure 3 and the average radio upper limit from Table 2. Note that the leptonic emission produced at early times often does not appear as it falls below the plot range. Right: light curve of a UFO-powered forward shock moving through a representative galaxy. The total energy in CRs is shown before and after proton–proton losses are included (blue dotted and dashed lines, respectively), as is the γ-ray luminosity at 1 GeV (red solid line).

Can use M87 [Cen A?] to probe diffuse background at MIR /FIR wavelengths with E_γ > 10 TeV γ-rays!



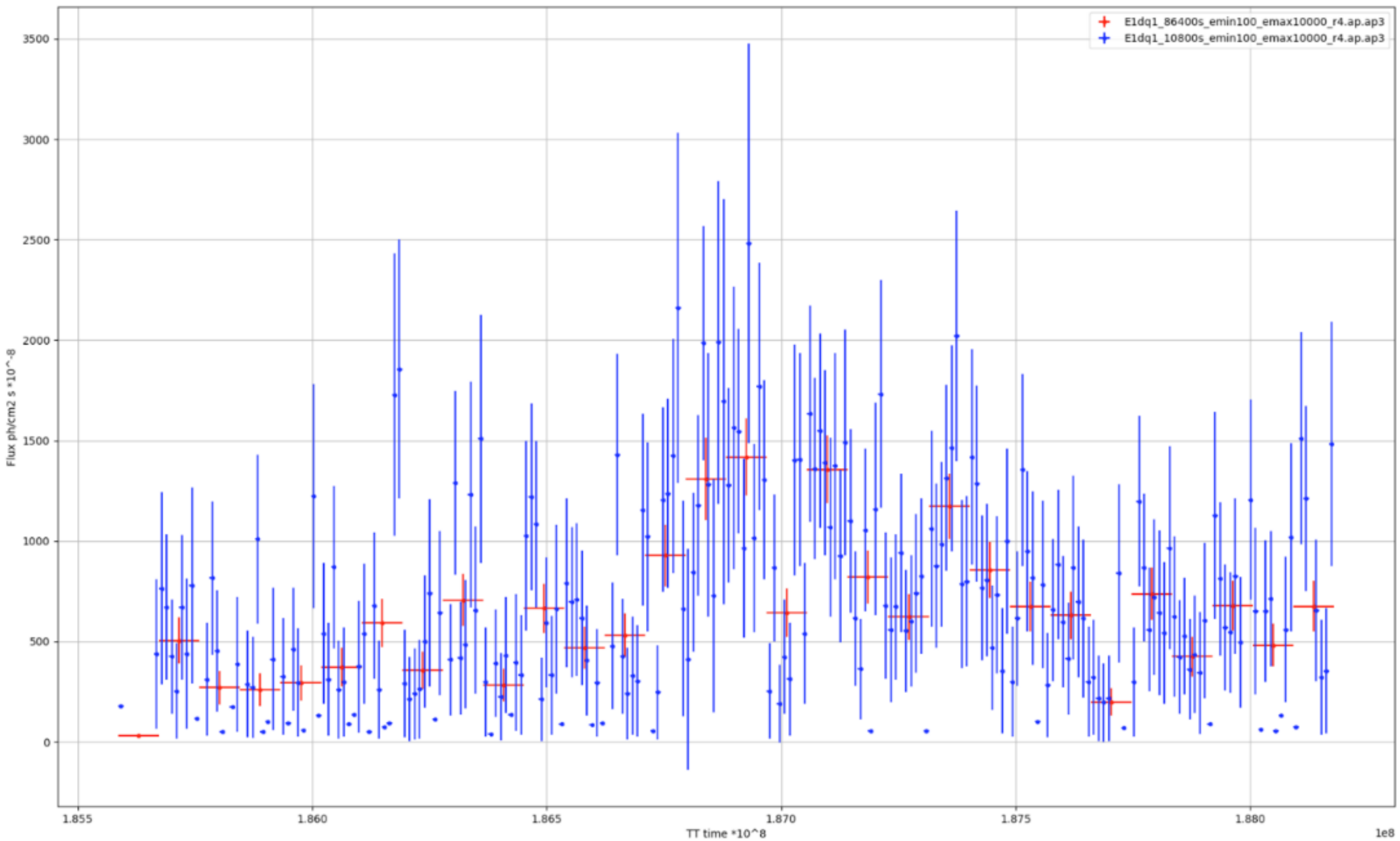
F. Aharonian

Mkn 421 goes haywire! Multiple Personalities…



Public SWIFT XRT lighcurves (Falcone et al. 2012)

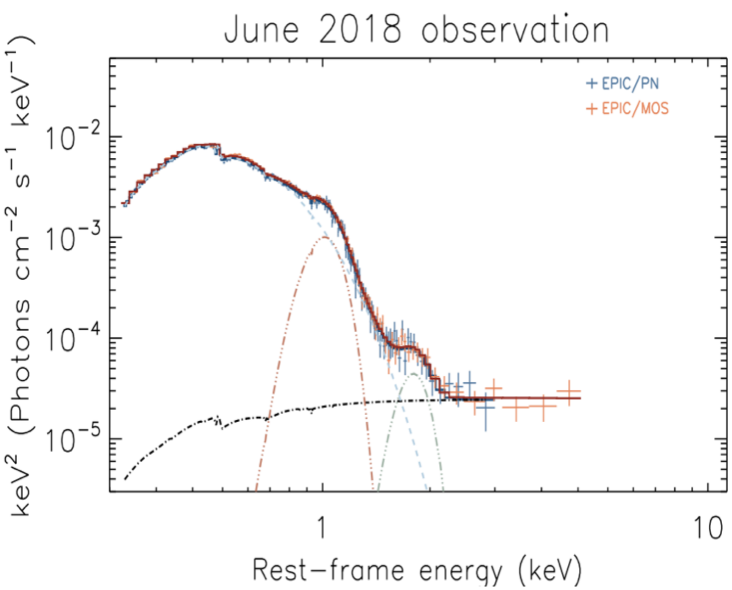
Big complication – even in FSRQ, rapid variability present at GeV energies on 5 min (3C279) - ~hour timescales!

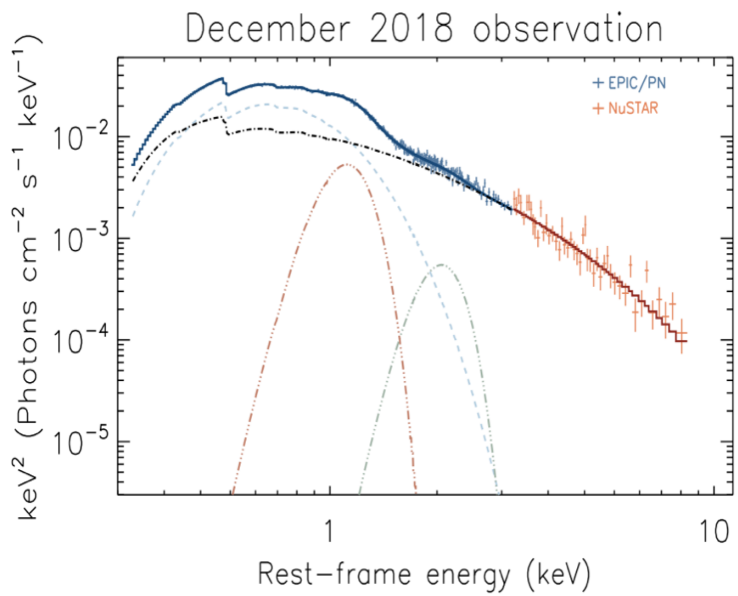


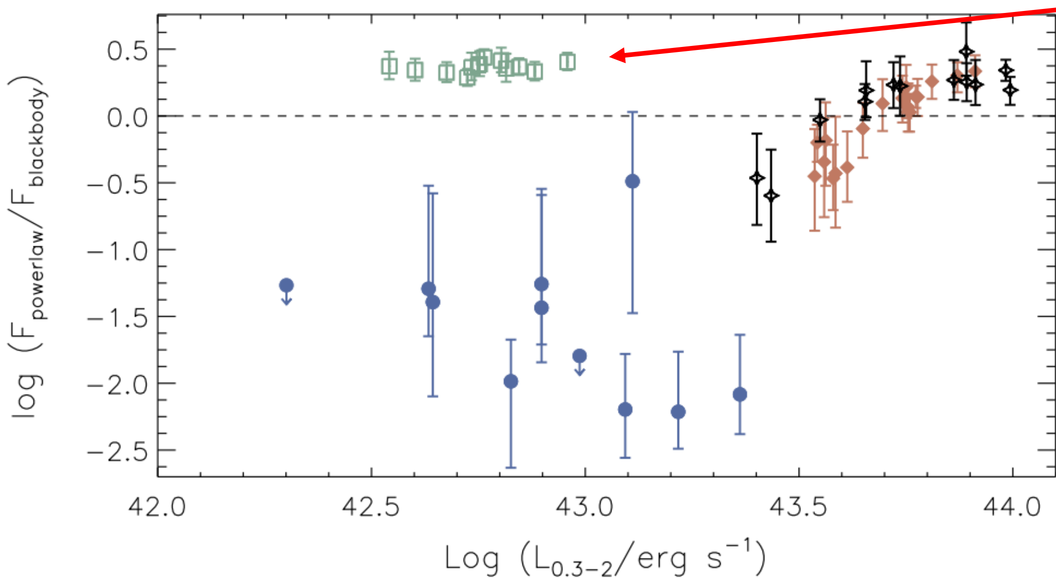
Bulgarelli et al., In prep.

Preliminary aperture photometry analysis of AGILE data for 3C 454.3 flare data,
blue = 3hr binning,   red =daily binning … N.B. is continuous, pointed observation!
(Not Fermi scanning.) Now imagine we only had one 3hr observation/day
(not atypical for IACT), i.e., we dropped 7/8 of the blue points … GAPS=BAD!

Changing look/state AGN(!) – Ricci et al. (2021), 1ES 1927+654







Archival observations

Entire corona disappears then reappears?

Not supposed to happen on such short (month-year) timescales…

Lots more candidates to come from optical surveys …

Even though LHAASO may not be able to track details of variability, it has one big advantage over IACT: ~continuous monitoring for most sources.

Besides catching unexpected flares => one can derive much more easily time-averaged spectra – directly comparable to Fermi 4FGL fluxes. Much better for determining *luminosity functions*, average opening angle of emission, connection to radio power (which usually comes from larger, effectively time-averaged scales).
If one is forced to base conclusions on individual flares,
variable Doppler boosting can be a very very big problem.

Time-averaged flux/luminosity is also the relevant one for cascade background calculations propagation calculations where IGMF-induced time delays are significant.

As VERITAS discovered recently, low duty cycle of blazar emission means have to go 5-10+ years to get multiple flares. So either observe many, many objects or observe fewer (hopefully representative) sources for longer time. Can't use measurements triggered by MAGIC flare, etc. ☹ Much cleaner and simpler with LHAASO [clean selection function].

Because of broad and ~*uniform* sky coverage, LHAASO should be also able to do a lot with .

How to handle extra-galactic transients

LSST/Rubin operating mode – strengths and weaknesses

As LSST [a narrow field instrument] tiles the sky every night, individual exposures quickly (~minutes-hour) differenced against reference image that is periodically updated [how often is subject of ongoing debate]. Transients that exceed a 5 sigma variability threshold are sent out in real time on alert stream, along with 30 days of lightcurve history.

After that no other data on the transient is publicly available until ~yearly data release that contains lightcurves for the previous year. Strategy partly motivated by desire to keep alert data flow manageable (10+ million triggers per night).

Strength: follow-up facilities get access to transients as quickly as LSST can determine something happened. Can catch objects that fade quickly.

Weakness: Interesting classes of objects like ``changing look'' AGN are missed because their variability timescale does not match combination of difference imaging timescale and alert threshold. (These objects change by 5 sigma on ~several week-month timescales).If have to wait a year to follow-up object, completely miss transitions – *science is lost forever.* Also 30 days of lightcurve history sometimes is not sufficient.

Ideally, LHAASO would have similar alert stream (as real time as possible) *and* trigger on range of timescales. Not trivial, but not as hard as for LSST because VHE sky is much darker less crowded than optical sky.

Note: LSST cannot afford to trigger on multiple timescales across the whole sky, but individual science collaborations can have ``watch lists'' (up to ~million object that are monitored in custom manner – NOT possible via brokers, which only collect alerts). If LHAASO can't process fast enough, setup similar watch lists, e.g., for known X-ray binaries and AGN? Or like RXTE/MAXI, publish daily lightcurves for lists of "interesting" objects.

Mechanism for equivalent of DDT/TOO [obtaining lightcurve for a random piece of sky before publication]? E.g., radio and LSST discover transient that may be "jetted" tidal disruption event. Depending on whether LHAASO sees something, follow-up strategy for other observatories changes. Could be automated and access restricted to``partner'' observatories?

Given known GeV-TeV variability patterns (fractal behavior, "non-linear" fast flares), don't repeat initial Fermi mistake and trigger on just daily or weekly fluxes. Lost a lot of flares. Use Bayesian blocks or simply look for clusters in photon arrival times.

Apologies for stating obvious, but have been in collaborations where lost science because hadn't prepared before experiment started. Treat AGN flares like GRBs!

What sources could I put on a watch list?

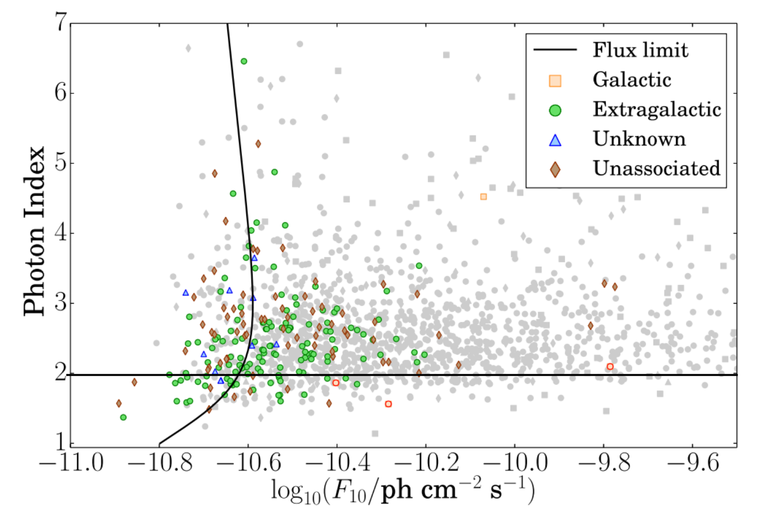
THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 232:18 (23pp), 2017 October
https://doi.org/10.3847/1538-4365/aa8221

CrossMark

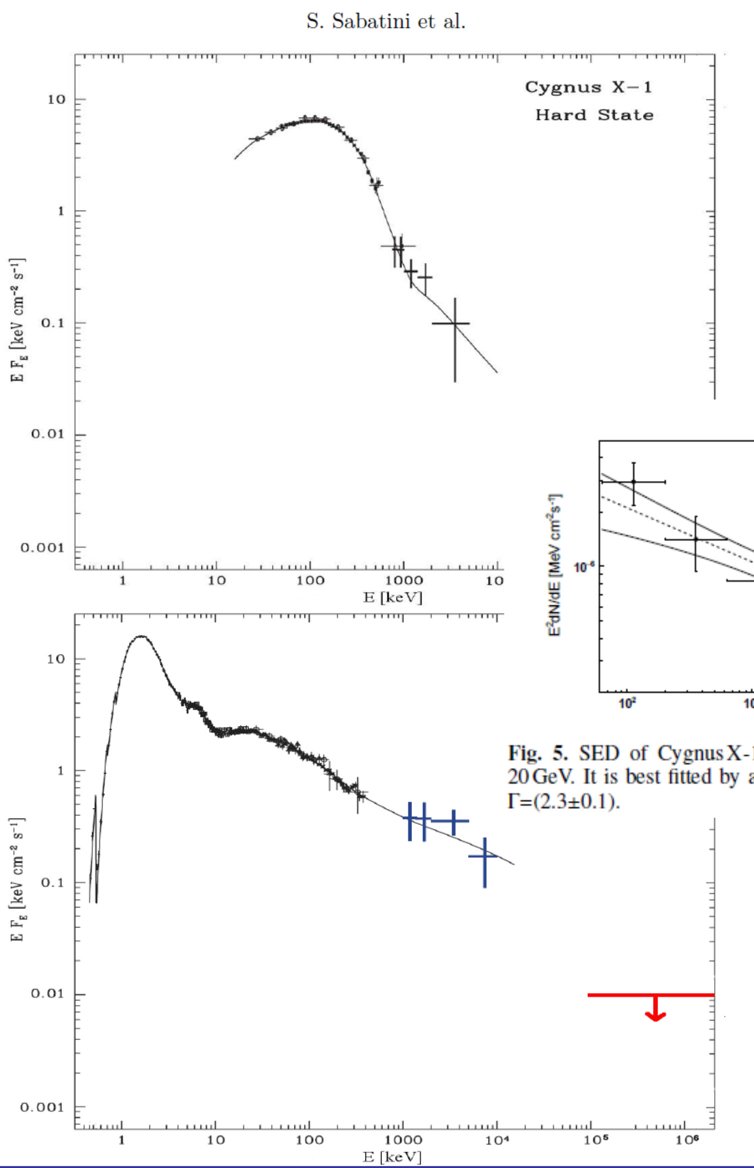
3FHL: The Third Catalog of Hard *Fermi*-LAT Sources

M. Ajello[1], W. B. Atwood[2], L. Baldini[3], J. Ballet[4], G. Barbiellini[5,6], D. Bastieri[7,8], R. Bellazzini[9], E. Bissaldi[10,11],

We present a catalog of sources detected above 10 GeV by the *Fermi* Large Area Telescope (LAT) in the first 7 years of data using the Pass 8 event-level analysis. This is the Third Catalog of Hard *Fermi*-LAT Sources (3FHL), containing 1556 objects characterized in the 10 GeV–2 TeV energy range. The sensitivity and angular resolution are improved by factors of 3 and 2 relative to the previous LAT catalog at the same energies (1FHL). The vast majority of detected sources (79%) are associated with extragalactic counterparts at other wavelengths, including 16 sources located at very high redshift ($z > 2$). Of the sources, 8% have Galactic counterparts and 13% are unassociated (or associated with a source of unknown nature). The high-latitude sky and the Galactic plane are observed with a flux sensitivity of 4.4 to 9.5×10^{-11} ph cm^{-2} s^{-1}, respectively (this is approximately 0.5% and 1% of the Crab Nebula flux above 10 GeV). The catalog includes 214 new γ-ray sources. The substantial increase in the number of photons (more than 4 times relative to 1FHL and 10 times to 2FHL) also allows us to measure significant spectral curvature for 32 sources and find flux variability for 163 of them. Furthermore, we estimate that for the same flux limit of 10^{-12} erg cm^{-2} s^{-1}, the energy range above 10 GeV has twice as many sources as the range above 50 GeV, highlighting the importance, for future Cherenkov telescopes, of lowering the energy threshold as much as possible.



In stellar mass black hole systems, there is HE/VHE emission (!)



Detection of gamma rays of likely jet origin in Cygnus X-1

R. Zanin[1], A. Fernández-Barral[2], E. de Oña Wilhelmi[3], F. Aharonian[1,4,5], O. Blanch[2], V. Bosch-Ramon[6], and D. Galindo[6]

(Affiliations can be found after the references)

September 21, 2021

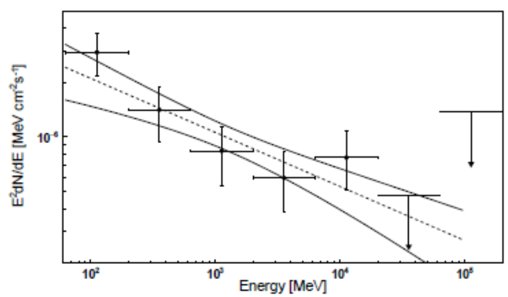
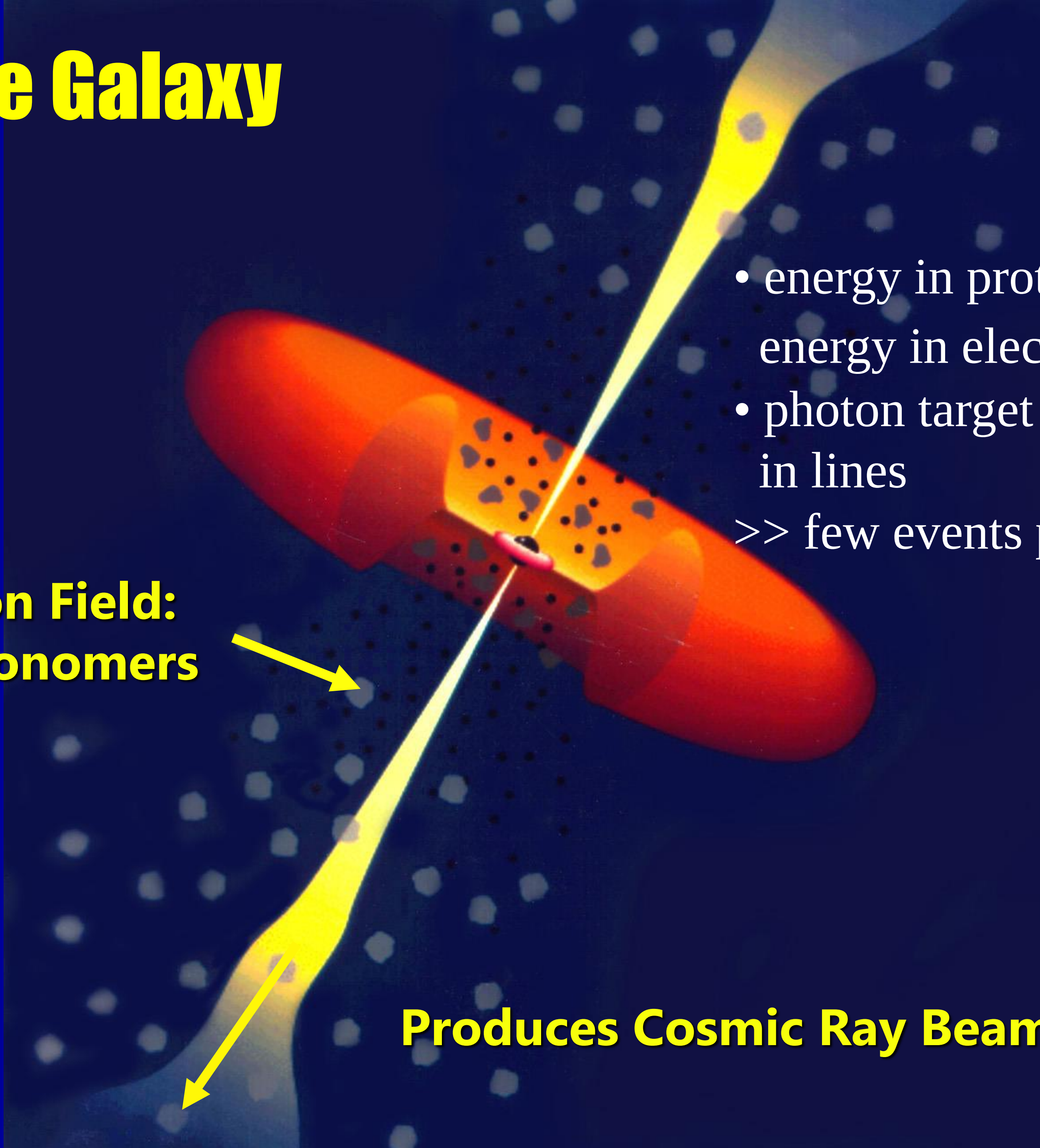


Fig. 5. SED of Cygnus X-1 in the HS, extending from 60 MeV to 20 GeV. It is best fitted by a power-law function with a photon index Γ=(2.3±0.1).

Some may be from extendend jet, but some could be from "corona" (base of jet). Cyg X-1 is not really microquasar
(bulk Lorentz factor of jet < 2, no huge jet outbursts like Cyg X-3, GRS 1915)

Same for AGN? [~3C273 level emission o.k. for EGRB]

Active Galaxy



- energy in protons ~ energy in electrons [??]
- photon target observed in lines

>> few events per year km^2

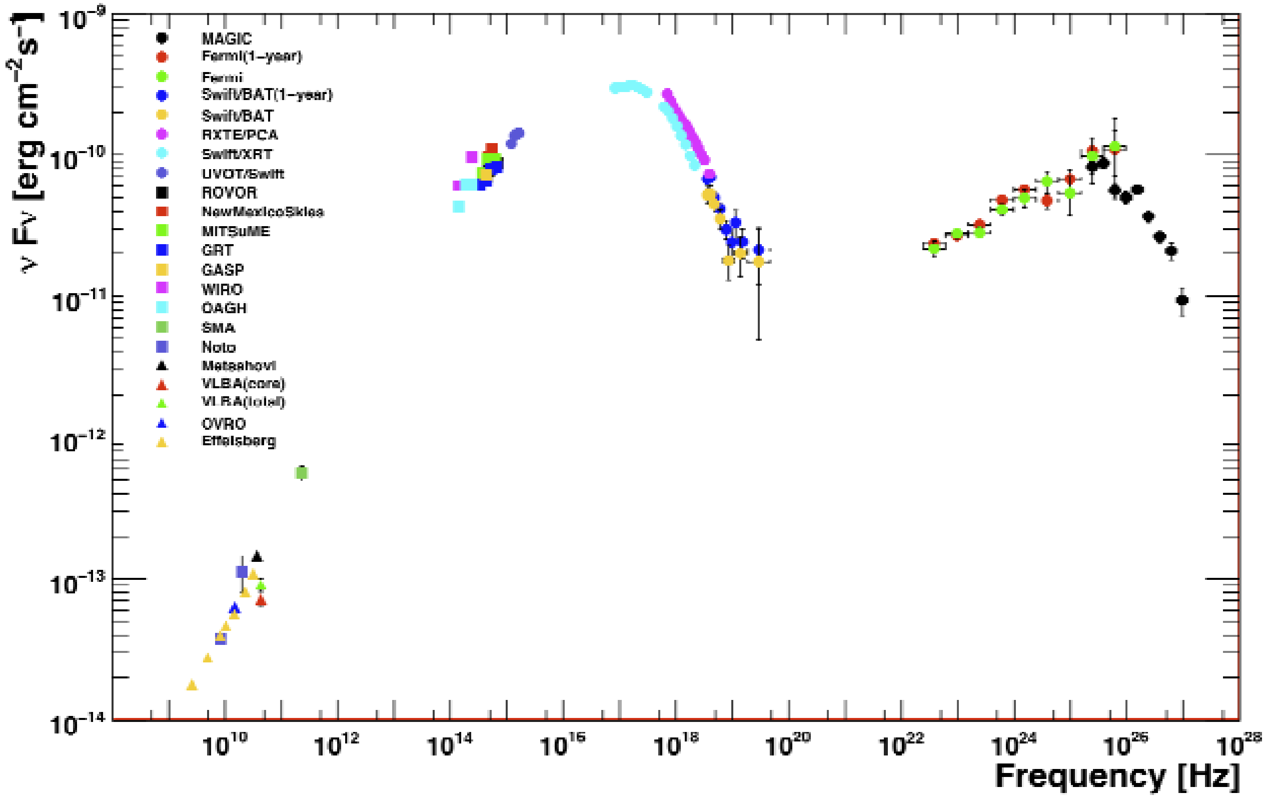
Radiation Field: Ask Astronomers

Produces Cosmic Ray Beam?

F. Halzen, 2004

MW campaign on Mrk421

- 4.5 months long (Jan 20th – June 1st , 2009)
- ~20 instruments participated covering frequencies from radio to TeV
- 2-day sampling at at optical/X-ray and TeV (when possible: breaks due to moon, weather…)

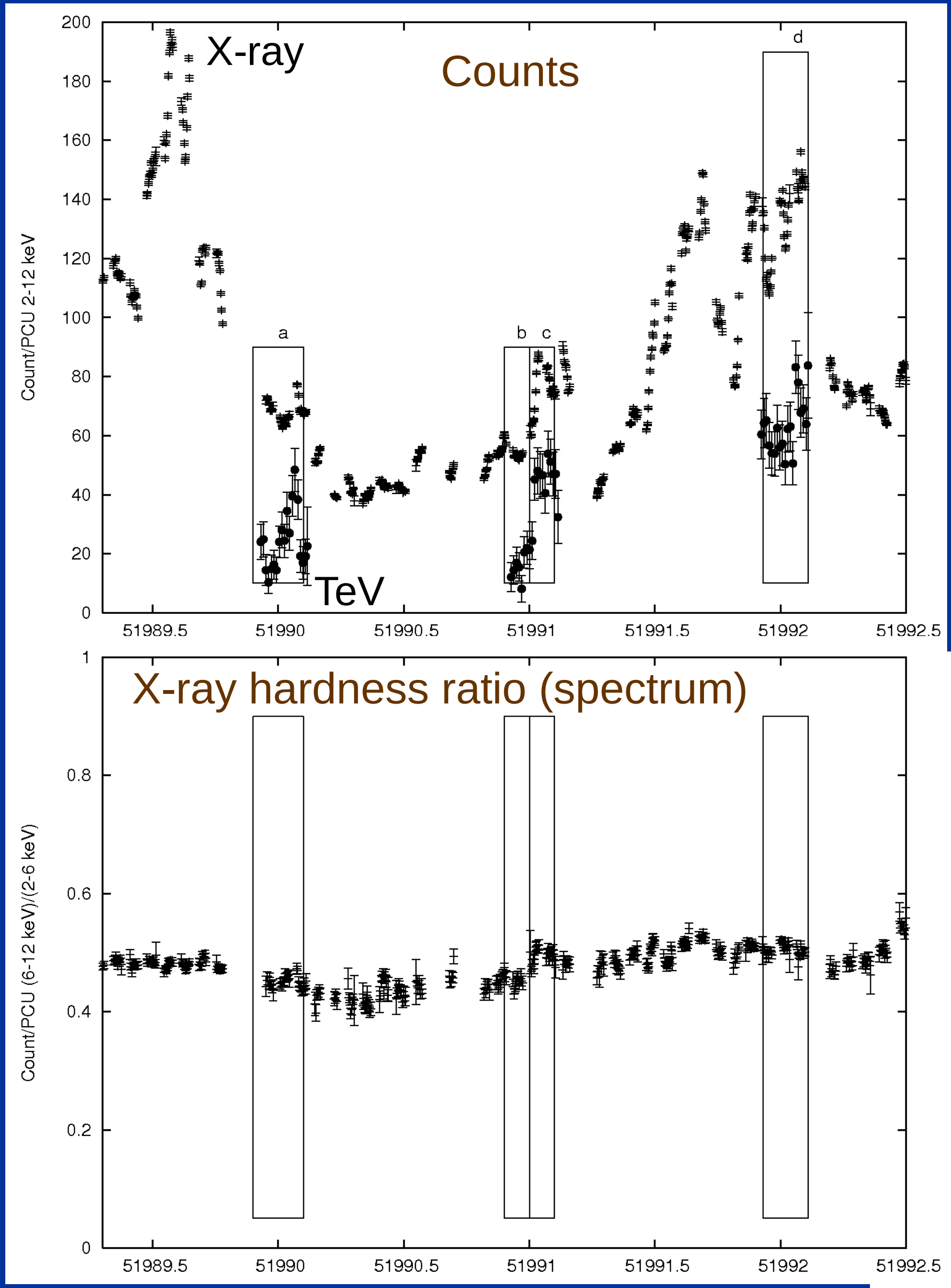


Most complete SED collected for Mrk421 until now

First time that the high energy bump is resolved without gaps from 0.1 GeV to almost 10 TeV

Poster P1-53, D. Paneque et al.

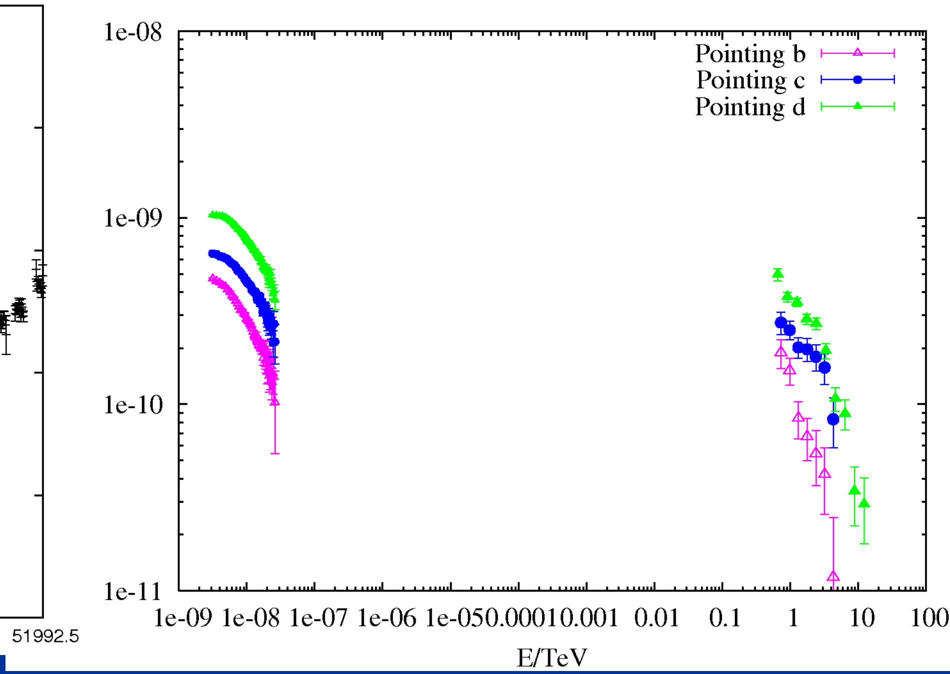
Preliminary



In case you still thought things were simple…

Mkn 421 2002 X-ray/TeV campaign

(Dieter Horns, preliminary)



Theoretical Considerations [Complications] III.

If electrons/pairs are primary particles, what is acceleration energy spectrum?

$$\frac{dN}{dE} \propto E^{-\alpha}\ ?$$

$$E_{\max}\ ?$$

$$E_{\min} / E_{peak}\ ?$$

$$(\text{or just } t_{\text{cool}} \text{ vs. } t_{\text{escape/expansion}})$$

If they are instead secondary particles, similar considerations for primary protons ….
(relativistic e/p behave in same way for given energy)

Good questions!!

Relativistic shock theory $\Rightarrow \alpha \approx 2$, but $\exists$ range (1.7-2.4), depends on details like pitch angle diffusion ... (messy).

$$E_{\max} = f(B, R_{shock}, t_{cool})$$

e.g., if particle too energetic, $r_g > R_{shock}$ and particle escapes

often before get to this, though,

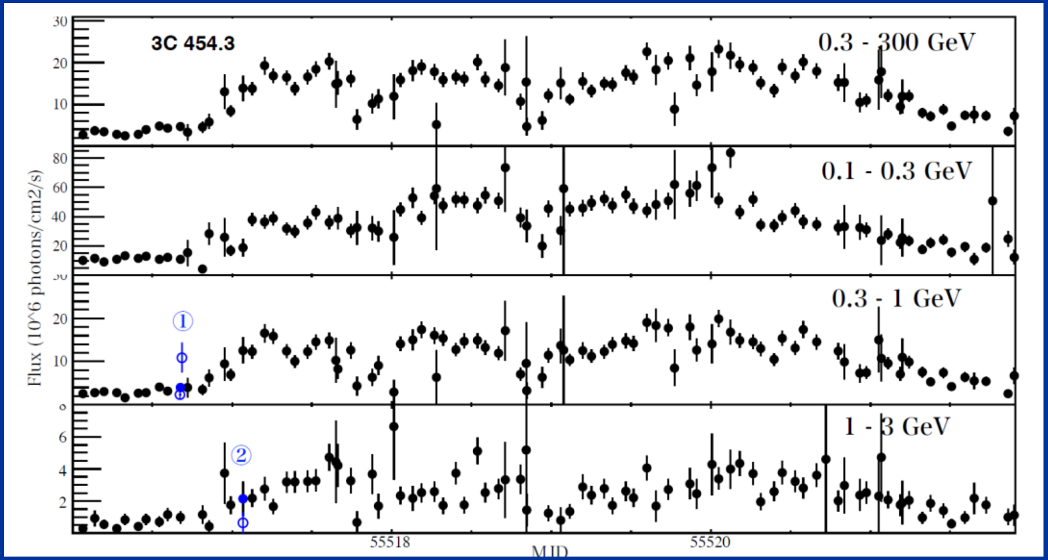
$$t_{accel} \sim r_g / c \sim t_{cool} \propto E^2 B^2 (\text{synch. radn.})$$

□ (Bohm limit, $r_g = eB / mc$)

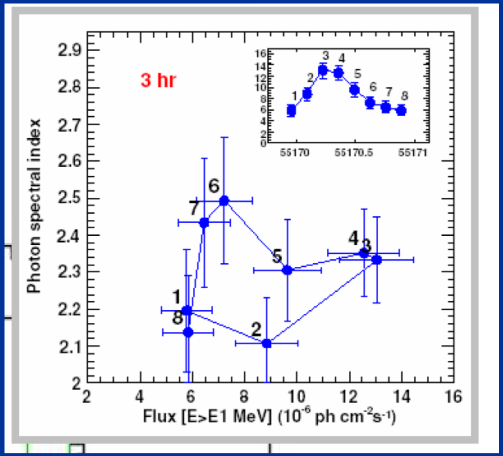
Maybe α reaches asymptotic value during strong flare, but would not be surprising to see $E_{\max}$ vary as source region varies....

This is what we really need to fit ☺

Saitoh, in prep.



From Ciprini 2014 talk



Need to solve time-dependent equations (+ allow spatial inhomogeneities)!

Fact (??) that rapid [<day] optical variability amplitude in FSRQ never as great as gamma amplitude

=> (i) dilution of optical? Multi-zone

(ii) Compton dominance of short flares even larger than already large Compton dominance of time-averaged spectrum (one zone: rest-frame $U_{rad} >> U_B$)

=> Klein-Nishina [cutoff ?] complications [E.g., Moderski et al. 2005]

Now let's play some with physics expressed in these units...

Compton Scattering: $\epsilon' = \frac{4}{3}\gamma^2\epsilon_0, \quad \frac{dn}{dt}_{scat} = \sigma_T cn(\epsilon_0) \rightarrow \frac{d\gamma}{dt} = -\frac{4}{3m_e c^2}\gamma^2\sigma_T c(\epsilon_0 n(\epsilon_0))$

$$\frac{dn'}{dt'} = \mathrm{n}'(\epsilon_0'), \quad \frac{d\gamma}{dt'} = -\frac{4}{3}\gamma^2[\epsilon_0' n'(\epsilon_0')]$$

Now integrate over ϵ_0' (seed target photon distribution):

$$\frac{d\gamma}{dt'}_{total} = -\frac{4}{3}\gamma^2 U'_{rad} = -\frac{4}{3}\gamma^2\frac{\sigma_T R}{m_e c^2}\left(\frac{3}{4\pi R^2 c}\right)L_{seed} = -\frac{4}{3}\gamma^2 l_{seed}\,!$$

And characteristic electron energy loss time is

$$t'_{cool,C} = \frac{\gamma}{|\frac{d\gamma}{dt'}|} = \frac{3}{4}\gamma^{-1}l^{-1}_{seed}$$

Synchrotron Losses: $\frac{d\gamma}{dt} = -\frac{4}{3m_e c^2}\gamma^2\sigma_T cU_B$ where $U_B = \frac{B^2}{8\pi}$

$$\rightarrow \frac{d\gamma}{dt'} = -\frac{4}{3}\gamma^2\left(\frac{\sigma_T R}{8\pi m_e c^2}B^2\right) = -\frac{4}{3}\gamma^2 l_B,$$

$$t'_{cool,S} = \frac{\gamma}{|\frac{d\gamma}{dt'}|} = \frac{3}{4}\gamma^{-1}l^{-1}{}_B$$

Coulumb losses suffered by high-energy electron scattering of low-energy (Maxwellian) electrons:

$$t'_{exch} = \frac{\gamma}{|\frac{d\gamma}{dt'}|_{Coul}} = \frac{\gamma}{\tau_{T,Max}\ln\Lambda}$$

Now, some simple inferences:

What's another reason "hybrid" plasmas may be important for "compact" (:-)) sources?

$$t'_{cool} \propto \gamma^{-1} \text{ while } t_{exch} \propto \gamma \;\Rightarrow\; \text{for } \gamma > \gamma_{th} = (\pi \ln \Lambda \frac{\tau_{T,Max}}{l_{seed,B}})^{1/2} \text{ electrons lose energy to photons}$$

before can share it with Maxwellian electrons, stay in non-thermal tail!

For AGN/GBHC, $\tau_T \sim 1$, $l_{seed} \approx 10$, $\ln \Lambda \approx 20$, so γ_{th} 2...

Now, let's say source/electrons are unconfined and after R/c source or electrons are gone:

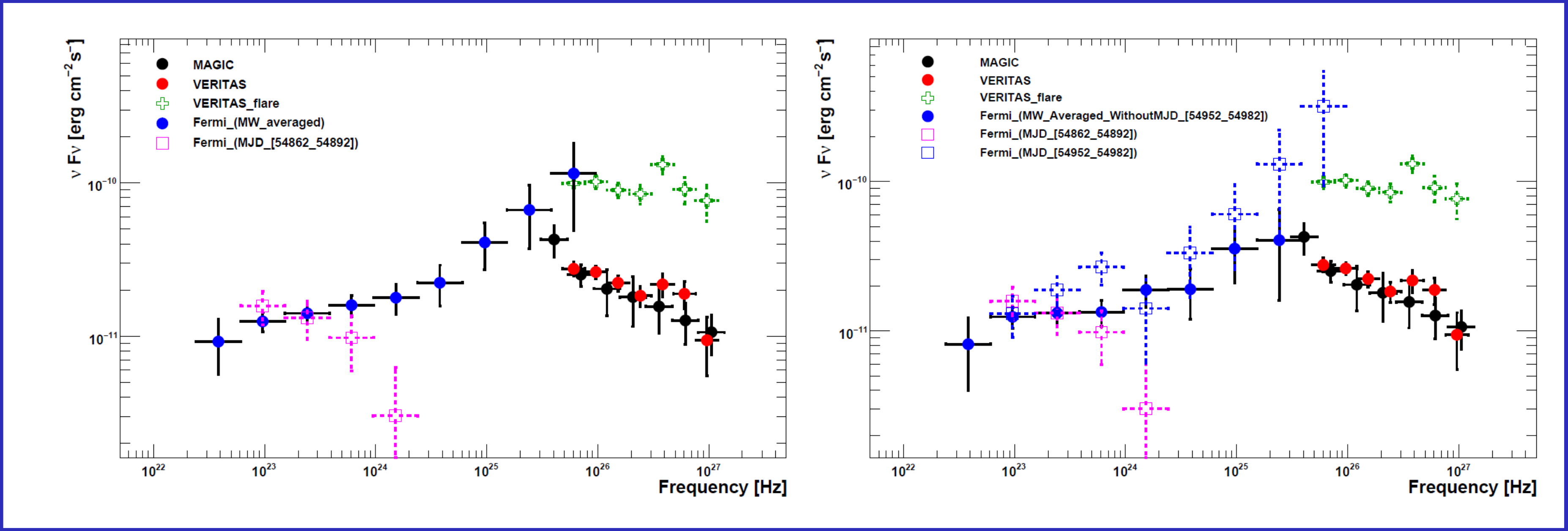
If $t'_{cool} << 1$, electrons radiate effectively (lose most of energy in time); If $t'_{cool} > 1$, don't.

Assuming $t'_{cool} << 1$, what is ratio of Compton to synchrotron power of the source (ratio of two "humps")?

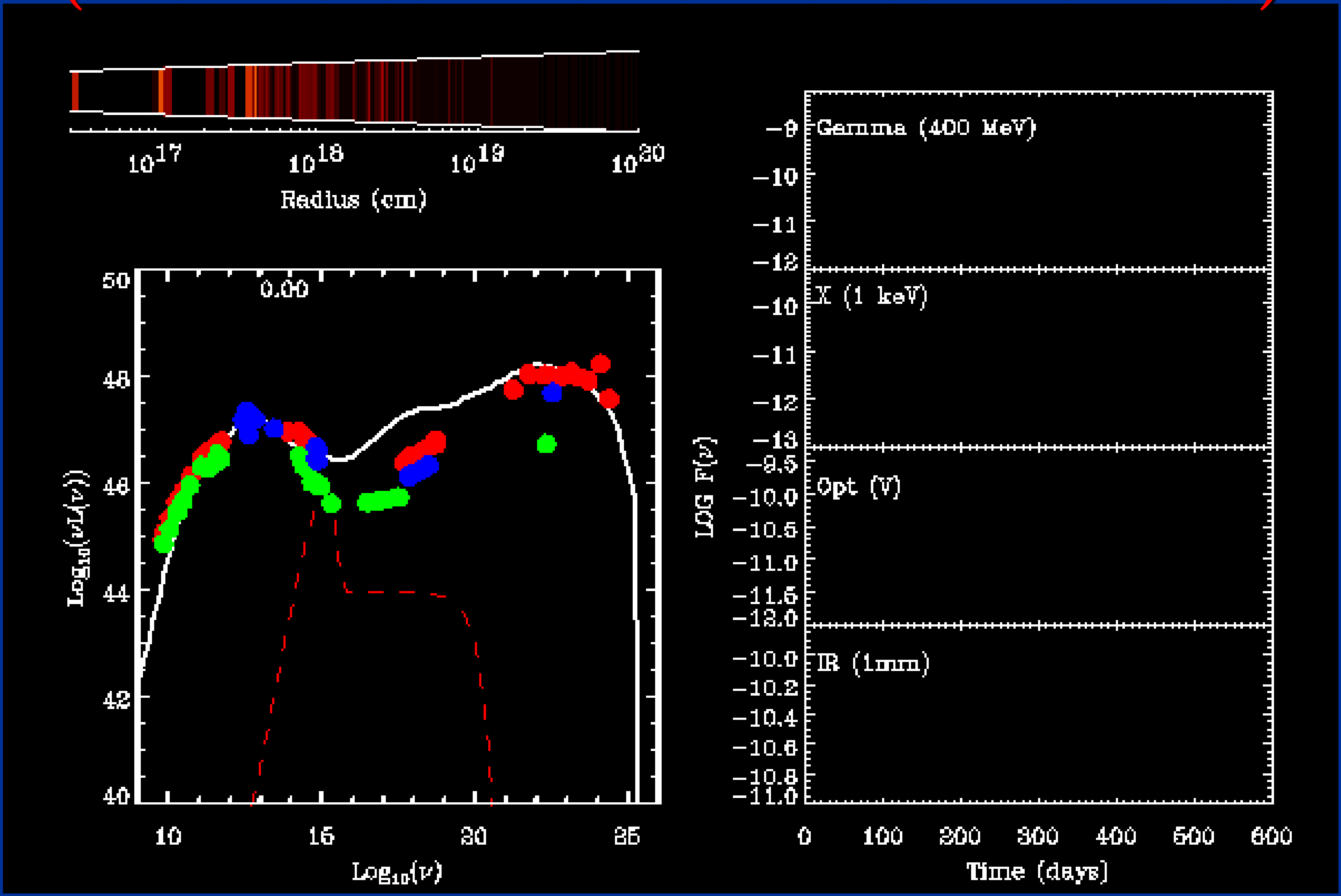
$$\frac{L_c}{L_S} = \frac{U_{rad}}{U_B} = \frac{t'_{cool,S}}{t'_{cool,C}} = \frac{l_{seed}}{l_B}!$$

Now I'm trying to model an *observed* blazar and want to know effect of changing source size R ...

Well, $l_{seed} \propto R^{-1}$, $l_B \propto R$, so $\frac{L_c}{L_S} \propto R^{-2}$ ... done, very sensitive to R (as we will see is L_{SSC}).


MAGIC
VERITAS
VERITAS_flare
Fermi_(MW_averaged)
Fermi_(MJD_[54862_54892])
ν Fν [erg cm^{-2}s^{-1}]
Frequency [Hz]
MAGIC
VERITAS
VERITAS_flare
Fermi_(MW_Averaged_WithoutMJD_[54952_54982])
Fermi_(MJD_[54862_54892])
Fermi_(MJD_[54952_54982])
ν Fν [erg cm^{-2}s^{-1}]
Frequency [Hz]

Numerical simulations for 3C 279. Spada et al. 2001 (Internal shock – "Christmas tree"-like model)



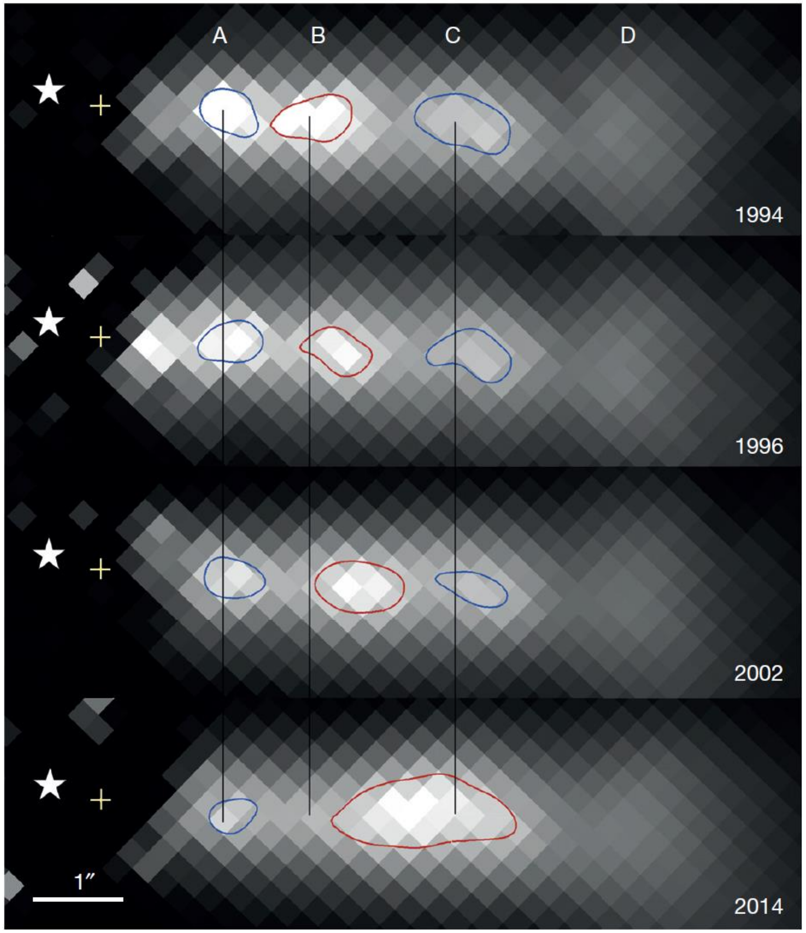
LETTER

doi:10.1038/nature14481

A kiloparsec-scale internal shock collision in the jet of a nearby radio galaxy

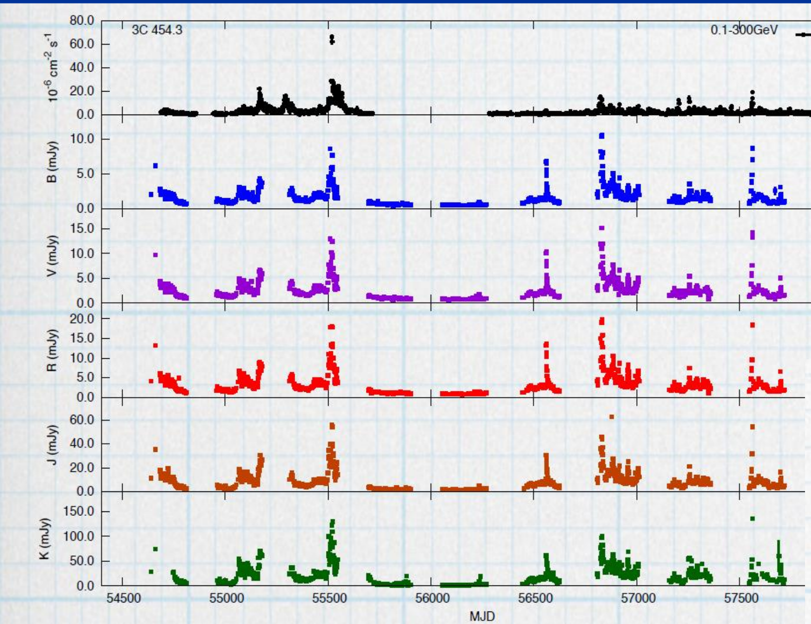
Eileen T. Meyer[1,2], Markos Georganopoulos[2,3], William B. Sparks[1], Eric Perlman[4], Roeland P. van der Marel[1], Jay Anderson[1], Sangmo Tony Sohn[5], John Biretta[1], Colin Norman[1,5] & Marco Chiaberge[1,5,6]

Jets of highly energized plasma with relativistic velocities are associated with black holes ranging in mass from a few times that of the Sun to the billion-solar-mass black holes at the centres of galaxies[1]. A popular but unconfirmed hypothesis to explain how the plasma is energized is the 'internal shock model', in which the relativistic flow is unsteady[2]. Faster components in the jet catch up to and collide with slower ones, leading to internal shocks that accelerate particles and generate magnetic fields[3]. This mechanism can explain the variable, high-energy emission from a diverse set of objects[4–7], with the best indirect evidence being the unseen fast relativistic flow inferred to energize slower components in X-ray binary jets[8,9]. Mapping of the kinematic profiles in resolved jets has revealed precessing and helical patterns in X-ray binaries[10,11], apparent superluminal motions[12,13], and the ejection of knots (bright components) from standing shocks in the jets of active galaxies[14,15]. Observations revealing the structure and evolution of an internal shock in action have, however, remained elusive, hindering measurement of the physical parameters and ultimate efficiency of the mechanism. Here we report observations of a collision between two knots in the jet of nearby radio galaxy 3C 264. A bright knot with an apparent speed of (7.0 ± 0.8)*c*, where *c* is the speed of light in a vacuum, is in the incipient stages of a collision with a slower-moving knot of speed (1.8 ± 0.5)*c* just downstream, resulting in brightening of both knots—as seen in the most recent epoch of imaging.

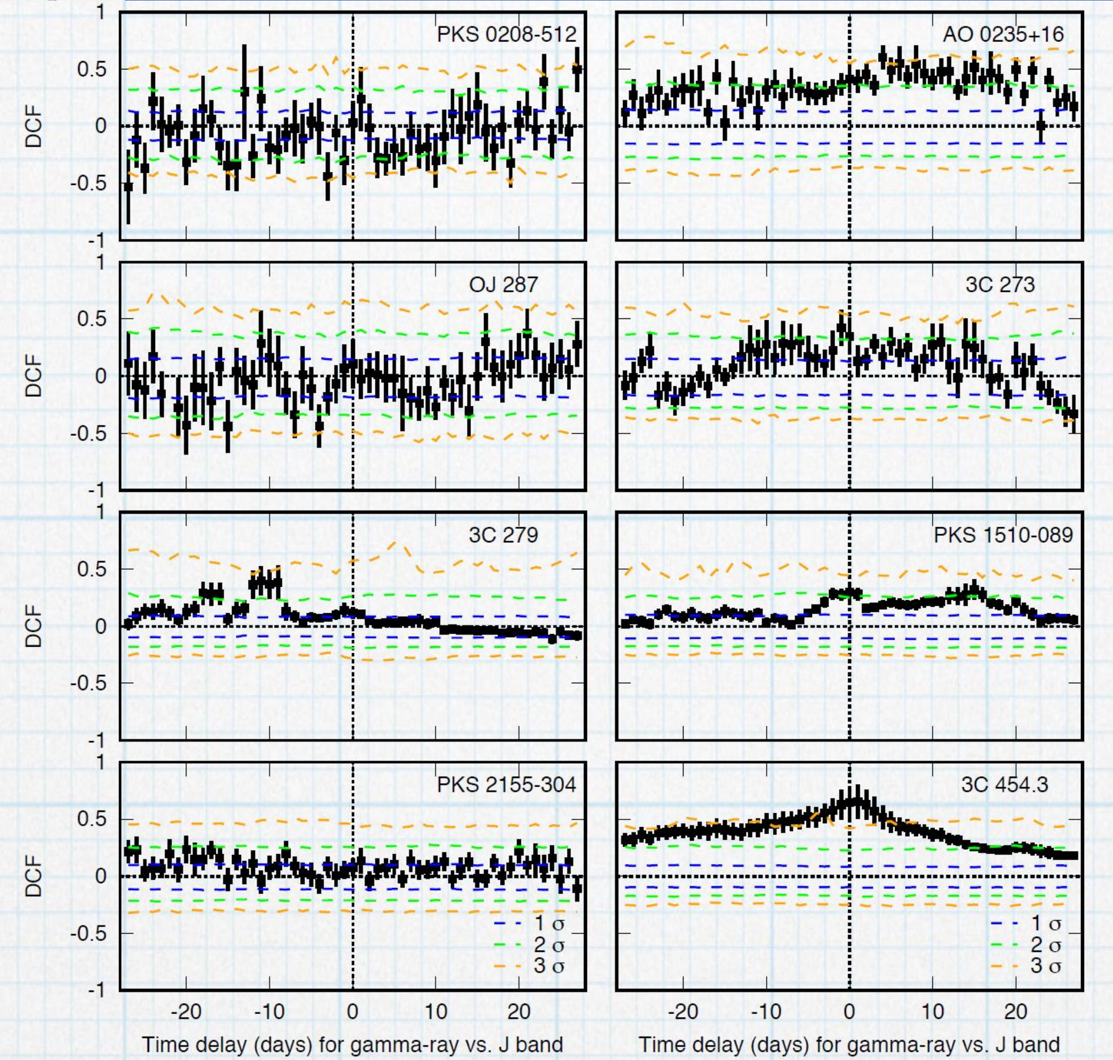


Now have ~10 years of gamma-ray/MW data on behavior of two humps ….

And the answer is ….. [SMARTS data]!



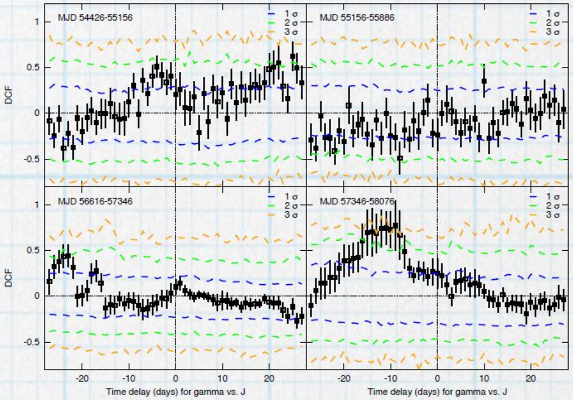
SMARTS optical/infrared (B:blue, V:dark-violet, R:red, J orange, and K:dark-green points) light curves and Ferm gamma-ray light curves in 0.1–300GeV [1] for 3C 454.3.



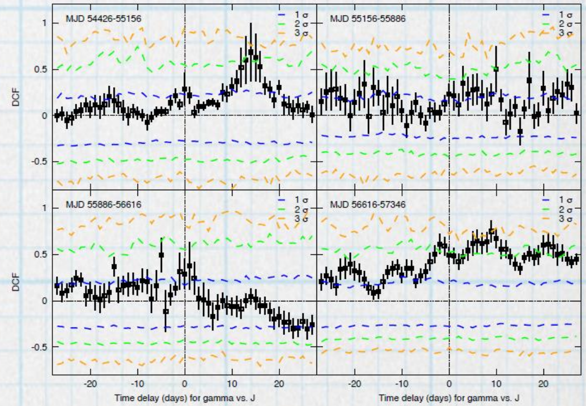
Uh, oh…

No correlation at ~0 lag except for 3C454.3!

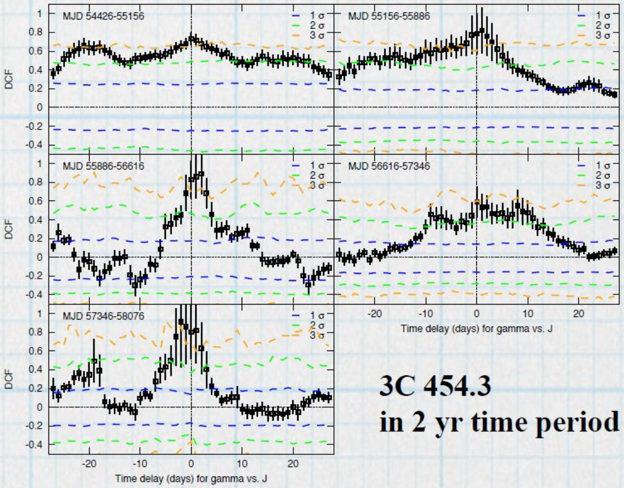
In fact, no correlations…



3C 279 in 2 yr time period



PKS 1510-089 in 2 yr time period



3C 454.3 in 2 yr time period

DCFs between gamma-ray and J-band fluxes of 3C 279, PKS 1510-089, and 3C 454.3 for every 2 year period.

Sources change nature!

[= correlation function not well-defined…]

On shorter timescales, can see borderline significant correlations in objects besides 3C454.3 .. But at ~2 weeks…???

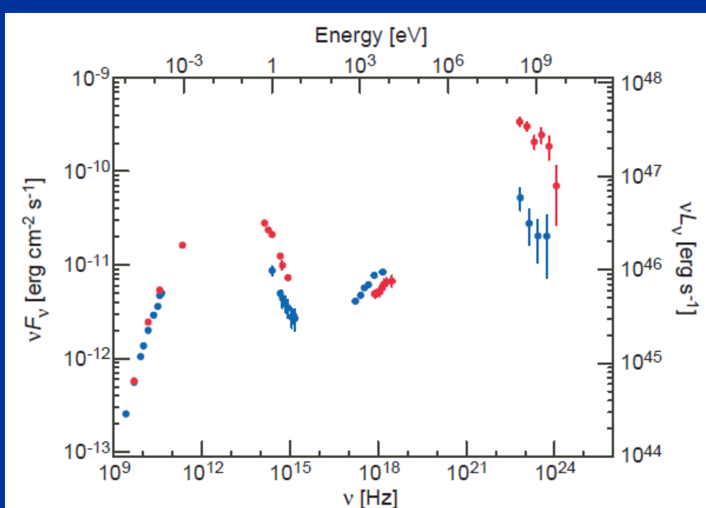
3C279 Fermi Multi-Wavele ngth Campaign

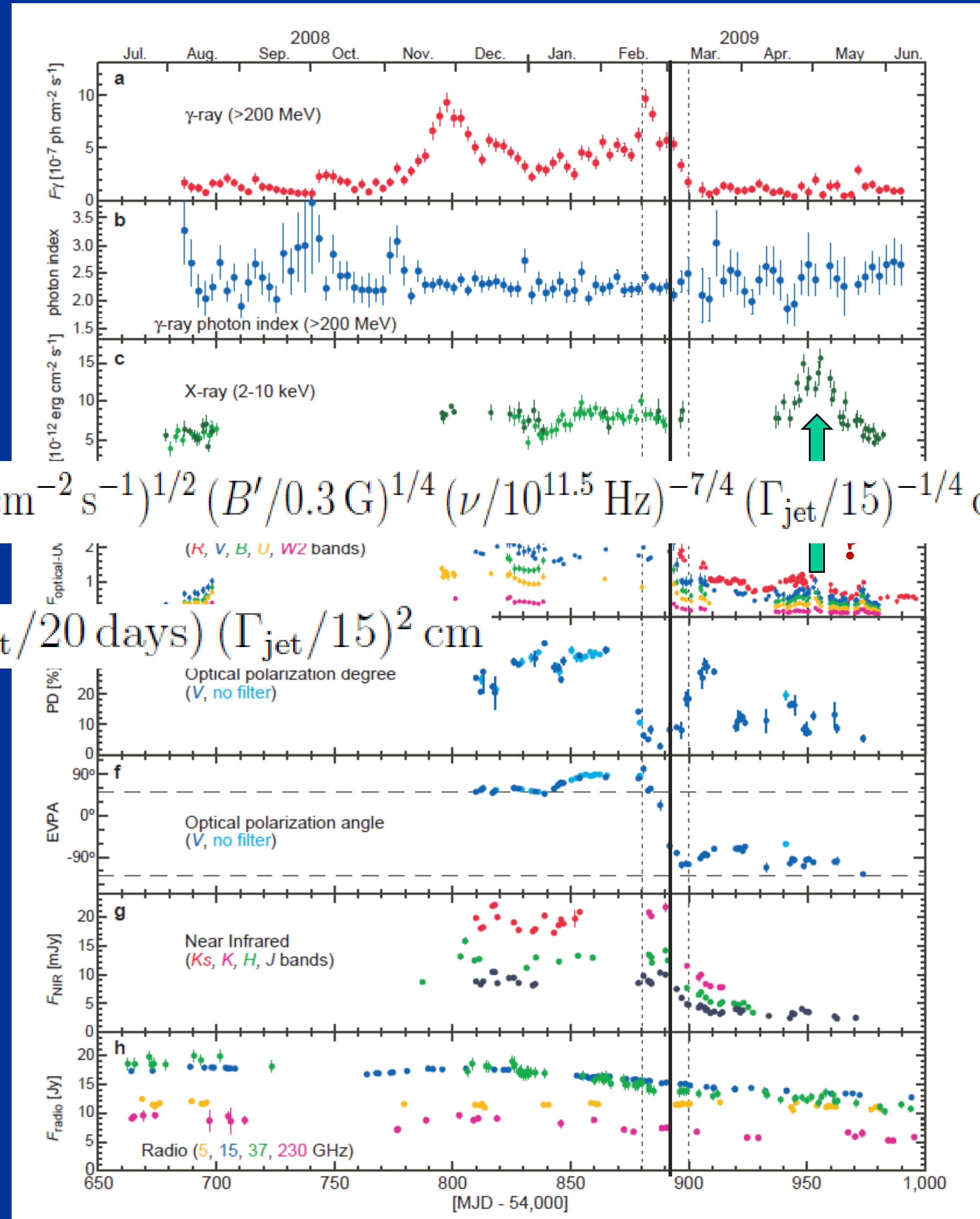
(Polarization Swing)

Abdo et al. (Hayashida) 2010

$$R_{\rm blazar} < 5\times10^{16}\,(\nu F_\nu/2\times10^{-11}\,{\rm erg\,cm^{-2}\,s^{-1}})^{1/2}\,(B'/0.3\,{\rm G})^{1/4}\,(\nu/10^{11.5}\,{\rm Hz})^{-7/4}\,(\Gamma_{\rm jet}/15)^{-1/4}\,{\rm cm}$$

$$r_{\rm event} \geq \Delta r_{\rm event} \sim 10^{19}\,(\Delta t_{\rm event}/20\,{\rm days})\,(\Gamma_{\rm jet}/15)^2\,{\rm cm}$$





A different kind of flare from the "canonical" 3C 454.3….

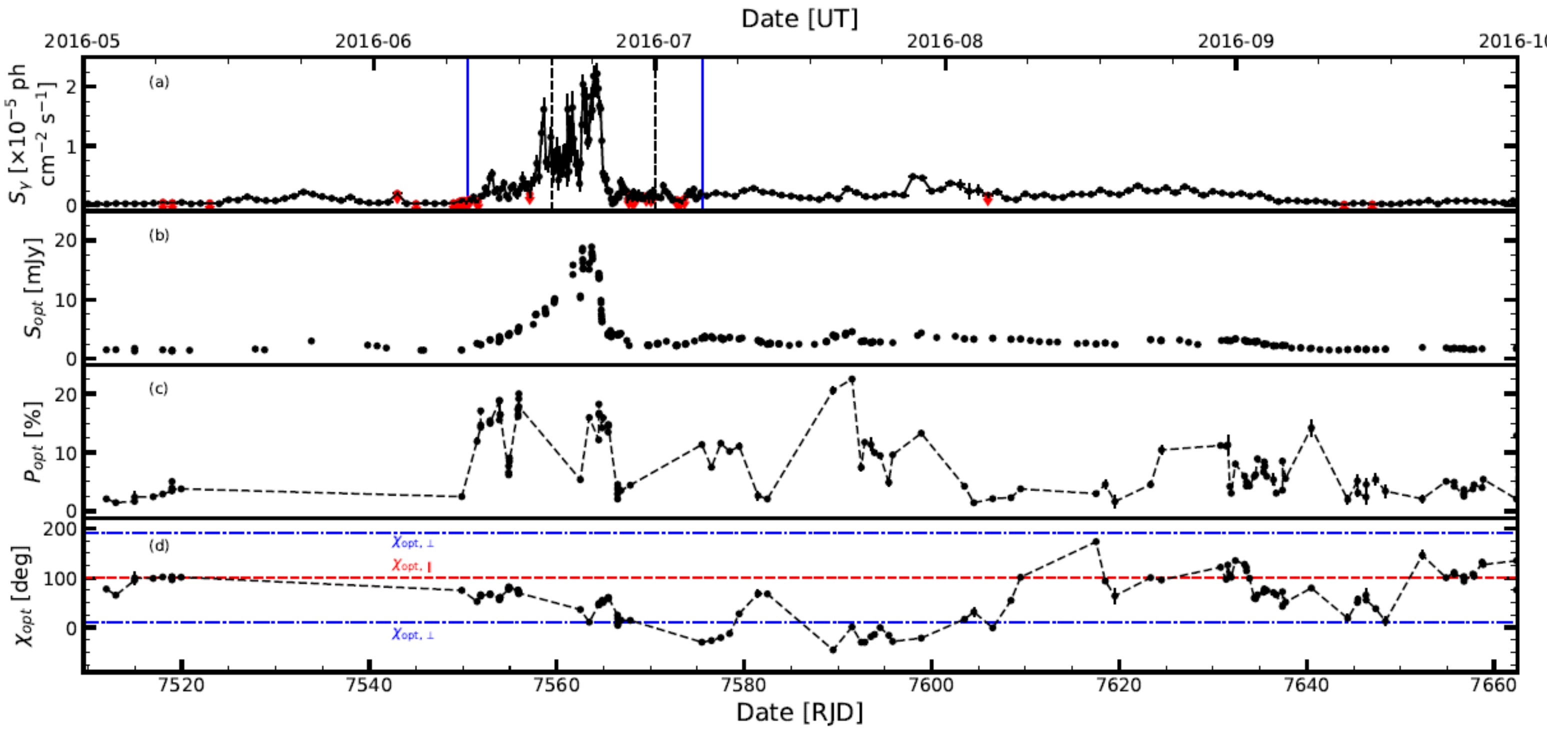
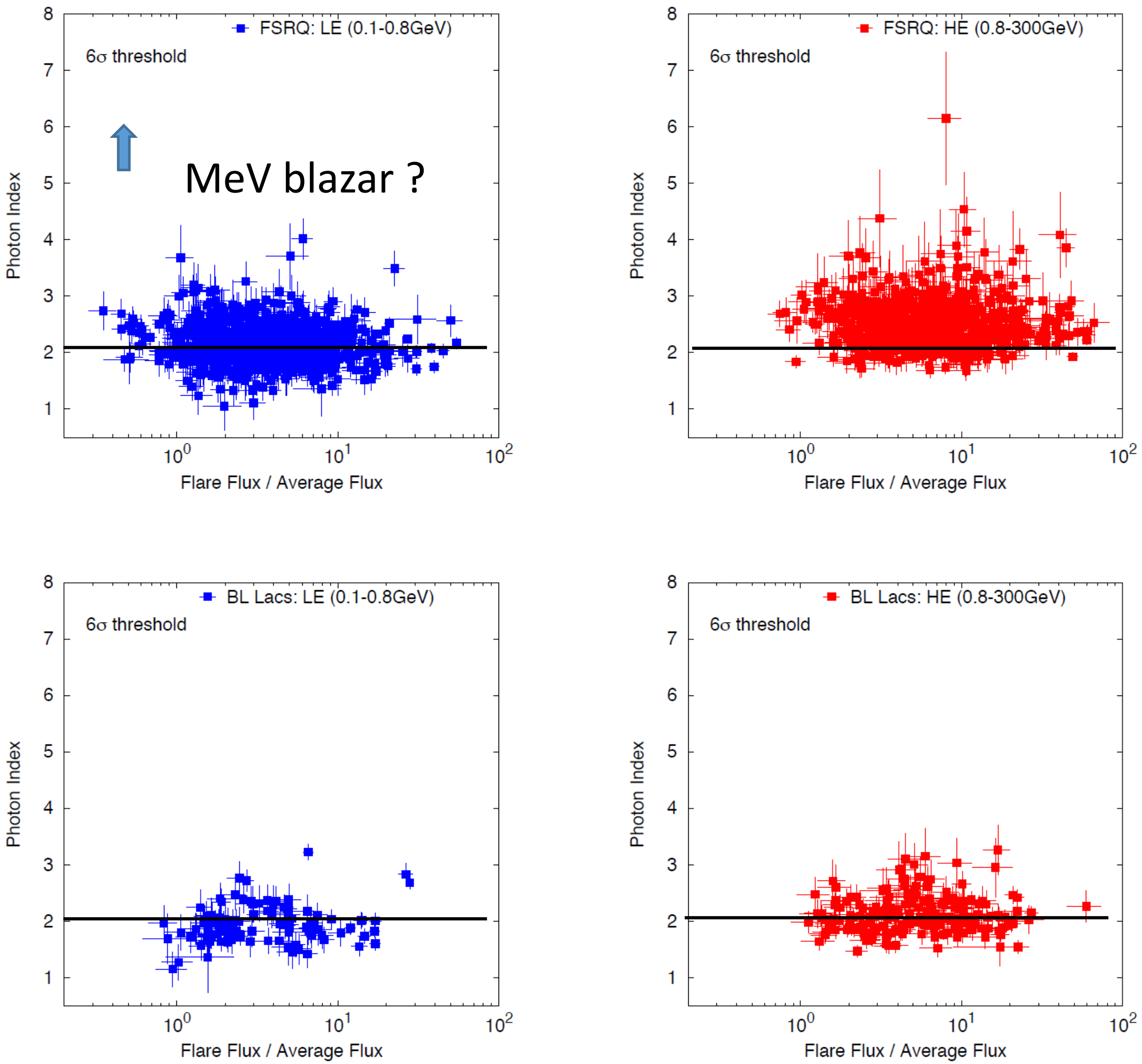


Figure 1. Flux and polarization vs. time of 3C454.3. The date 2016 July 1 is RJD: 7570.5. (a) *Fermi*-LAT γ-ray flux with varying time bins; (b) optical light curve in R band; (c) degree of optical linear polarization; (d) position angle ($\chi_{\rm opt}$) of optical polarization. In (a), the outer, blue, vertical, solid lines mark the division between one-day and six-hour γ-ray binning, while the inner pair of black, vertical, dashed lines mark the division between six-hour and three-hour binning. Upper limits on 24 *Fermi*-LAT data points are marked with a downward-facing, red arrow. In (d), the horizontal lines correspond to polarization angles that are parallel ($\chi_{\rm opt,\parallel}$, red dashed) and perpendicular ($\chi_{\rm opt,\perp}$, blue dash-dot) to the average parsec-scale jet direction of -79° determined using 43 GHz VLBA imaging of the blazar between Jan 2016 and Jun 2017 (see §5.1.1).

Yoshida et al., in prep - Use FAVA to look at flares in objects (much more scatter!)

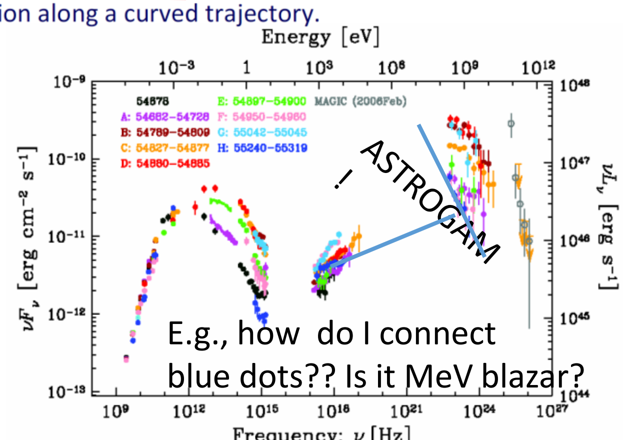
Photon Index with Flare Flux/Average Flux

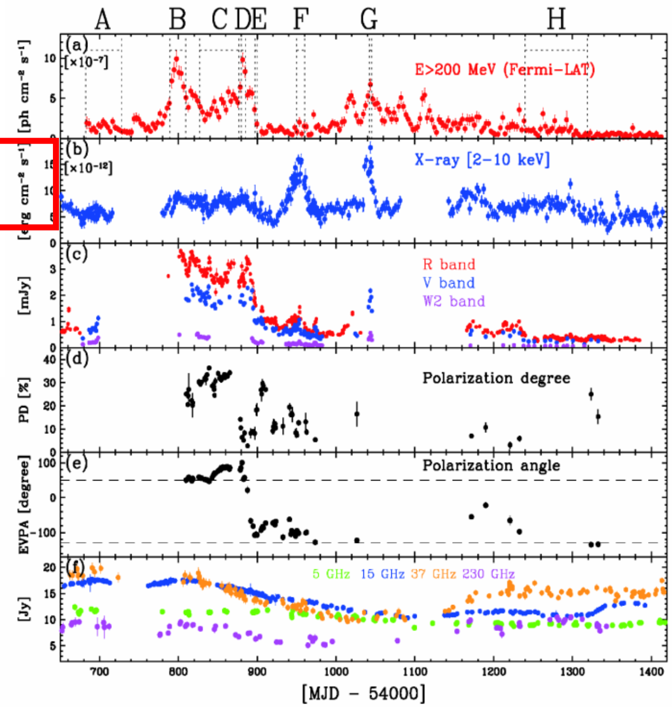


The archetypal EGRET FSRQ violates most standard assumptions…

Individual sources, example (7): flares of 3C 279

- ❑ 2-year multi-wavelength campaigns.
- ❑ Discovery of a change in the optical polarization associated with a LAT gamma-ray flare in 3C 279.
- ❑ Optical emission delayed with respect to gamma-ray emission (about 10 days).
- ❑ Pair of (almost "orphan") flares in X-rays separated by 90 days, with only weak gamma-ray/optical counterparts.
- ❑ SED peak frequency variations (mid-/far-infrared and mm/sub-mm bands).
- ❑ ERC SED modeling (dusty torus too).
- ❑ Polarization swing involving propagation of the emitting region along a curved trajectory.

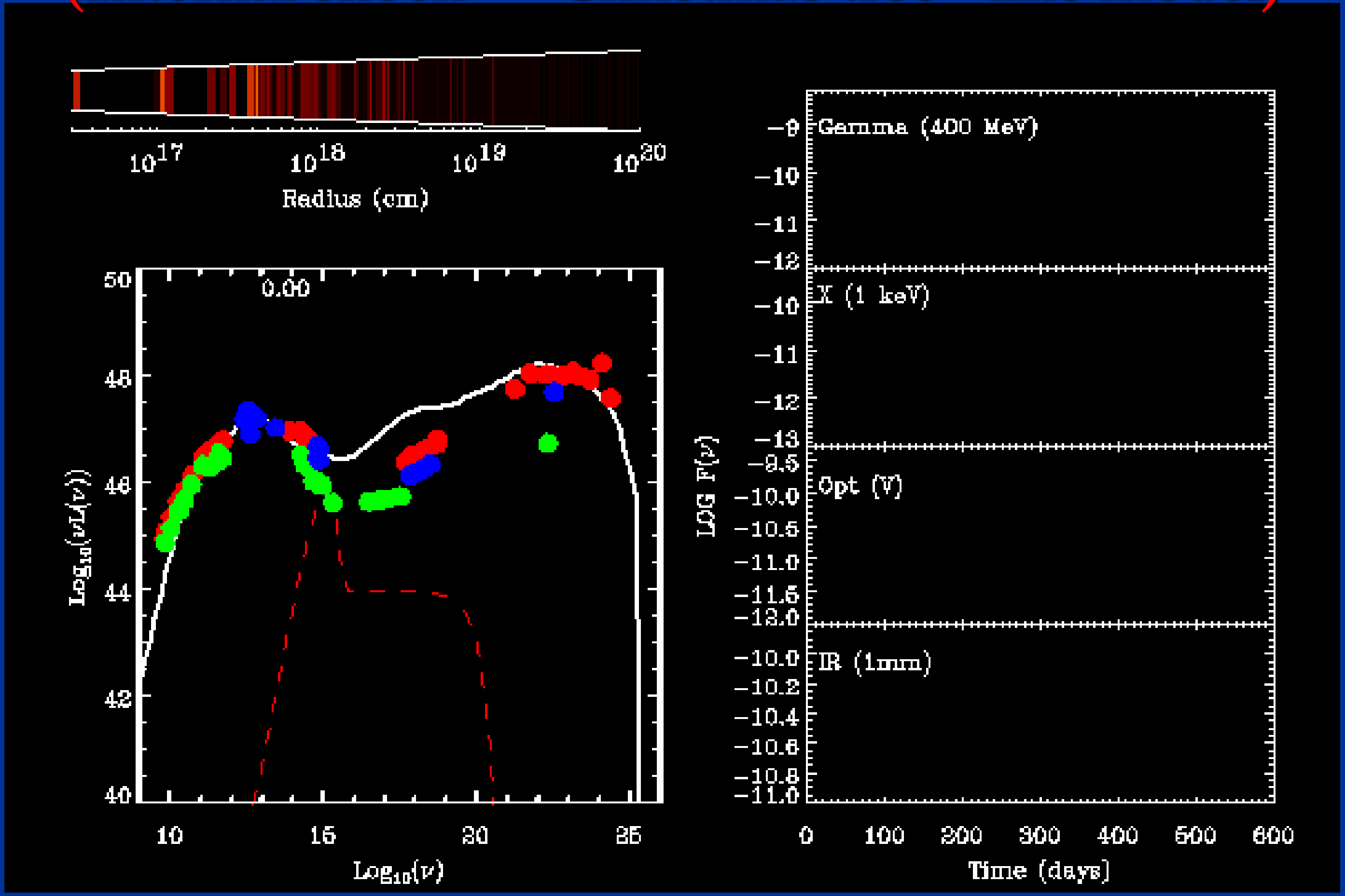




Complex object, w/multiple emission Components, Peak energy changes, possible detection even at TeV… without ASTROGAM, we will remain pretty clueless no matter how many more multi-wavelength we carry out!

- Abdo et al. 2010, Nature 463, 919
- Hayashida et al. 2012 ApJ 754 114

Numerical simulations for 3C 279. Spada et al. 2001 (Internal shock – "Christmas tree"-like model)



Rapid Gamma-Ray and Optical Variability in Bright Fermi Blazars

P. Coppi, Yale
S. Saito, Rikkyo
L. Stawarz, Jagellonian

Using an “aperture photometry" technique to generate Fermi lightcurves on minute timescales, we have carried out a Bayesian Block analysis of the brightest blazar flares to search for variability down to ~15 minute timescales. There is moderate evidence for one such fast flare in PKS 1510-089, but 9 other flare events we examined do not show it, i.e., very rapid variability as found in TeV blazars is probably not common. However, all flare events *do* show evidence strong (factor 2) gamma-ray variability down to ~1 - 2 hour timescales, and we show evidence in 3C 454.3 for spectral evolution on these short timescales. Using SMARTS and optical/NIR data, we are searching for correlated rapid optical variability on similar timescales. While variability on these very short timescales is seen in a few cases, the optical variability amplitude is typically much *smaller* than the gamma-ray one. Interestingly, on ~1-3 day timescales the optical and gamma-ray variability are instead well-correlated and of similar amplitude.

Rapid Variability Example: PKS 1510-089

Using standard daily time bins doesn't tell the whole story …

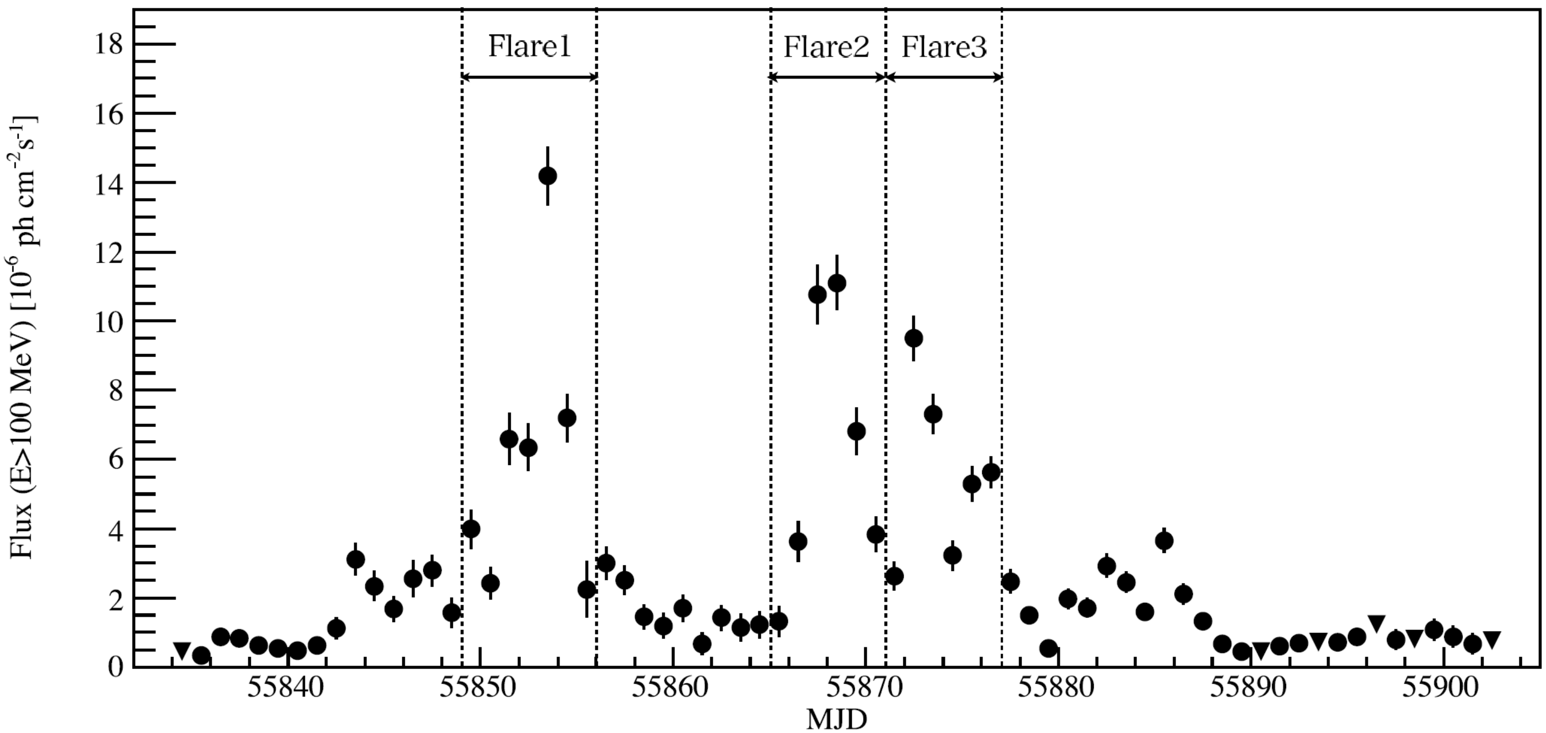
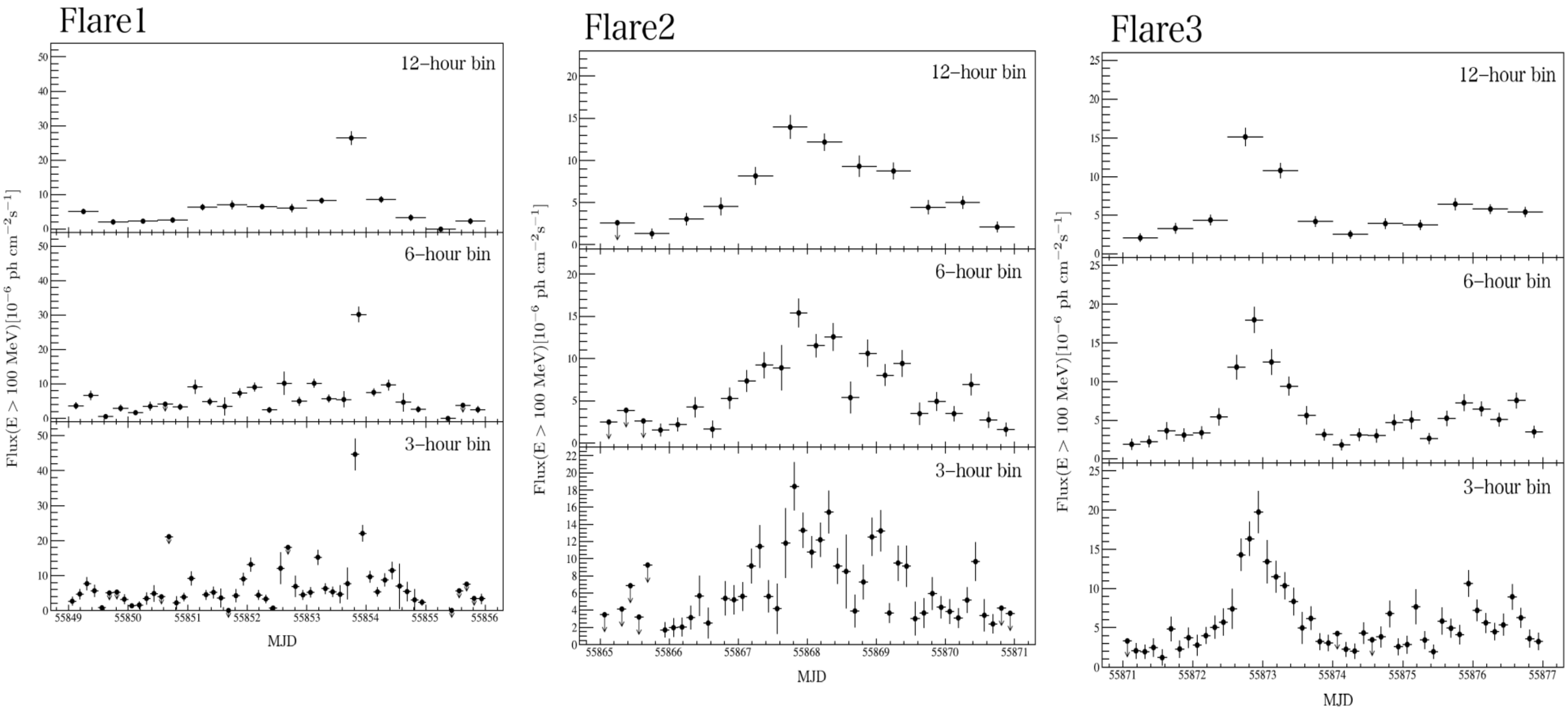


Figure 5.5: Daily γ-ray light curve of PKS 1510$-$089 during the period MJD 55834–55903 analyzed in this paper. 95% flux upper limits are represented by triangles. Horizontal lines separating the three major flares are chosen arbitrarily just to guide the eye.



- N.B. Amplitudes of flares increases as go to shorter time binning.
- There are >2x flares on even three hour timescales … !

=> DON’T USE DAILY LIGHTCURVES

Bayesian block analysis inside individual Fermi exposure windows, example for PKS 1510-089.

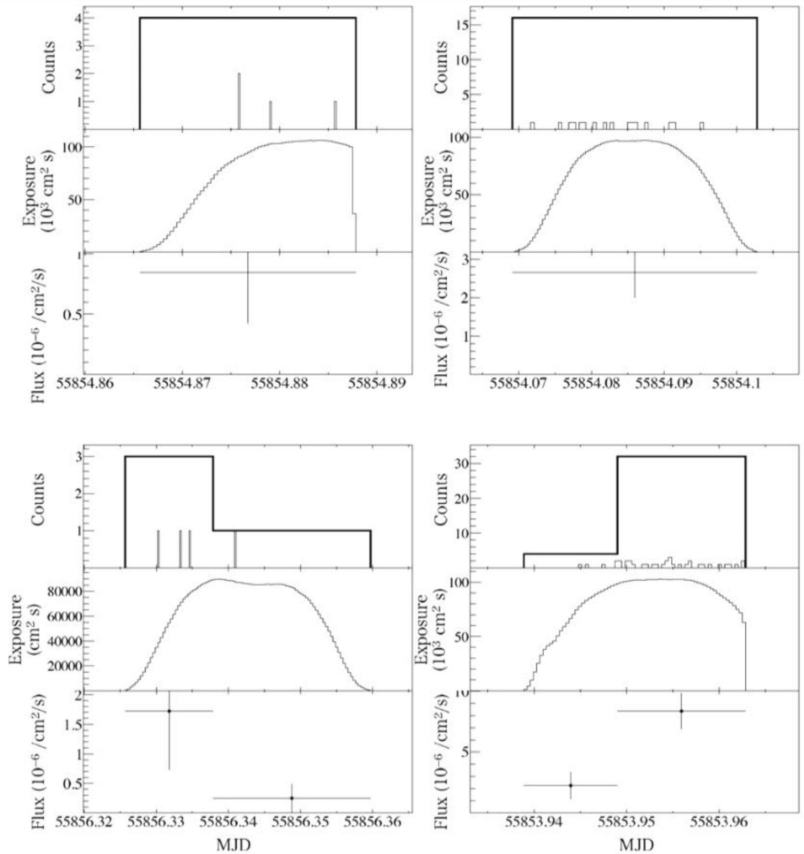
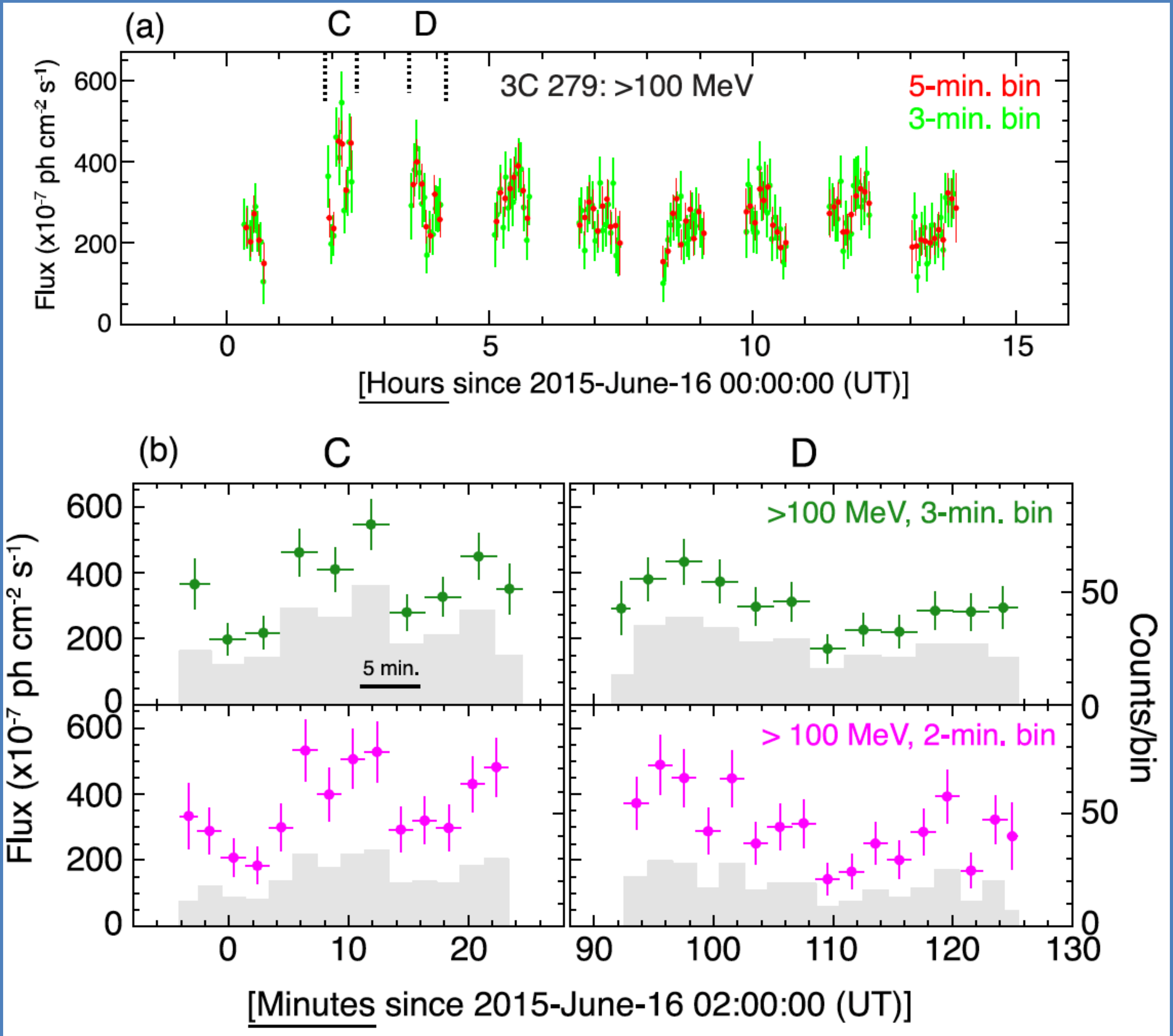
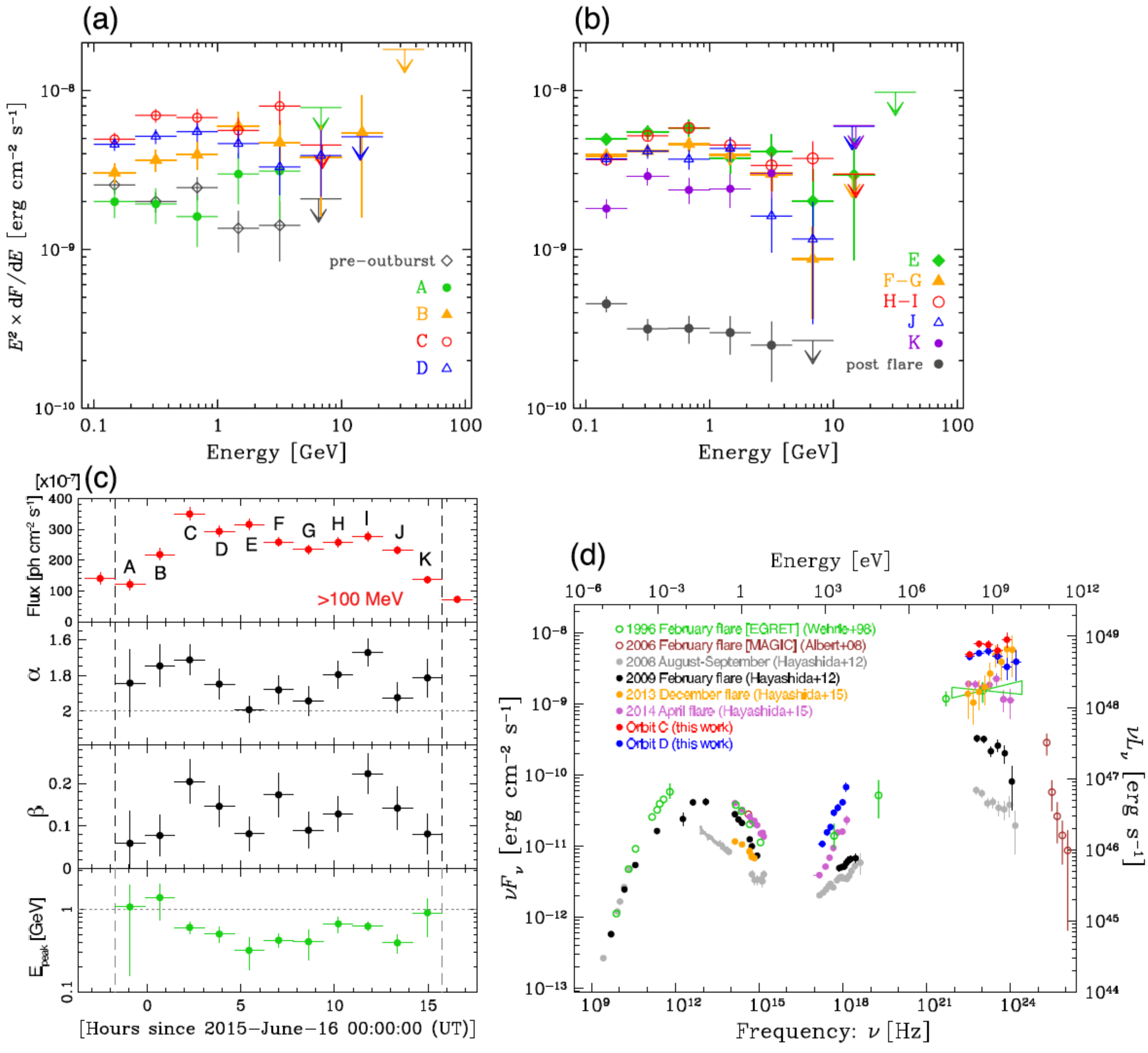


Figure 6.9: Examples illustrating how the *Bayesian block* works to detect sub-orbit variability for different statistics. Four examples of orbits presented were taken from flare #5 in PKS 1510–089, and analysed with $fp = 0.1$. Each exposure typically lasts ~30 minutes. (*upper panels*) Raw count histogram with piecewise constant blocks obtained with *Bayesian* blocks. (*middle panels*) Exposure variation during a single orbit. (*lower panels*) Flux values calculated by dividing counts by exposure.

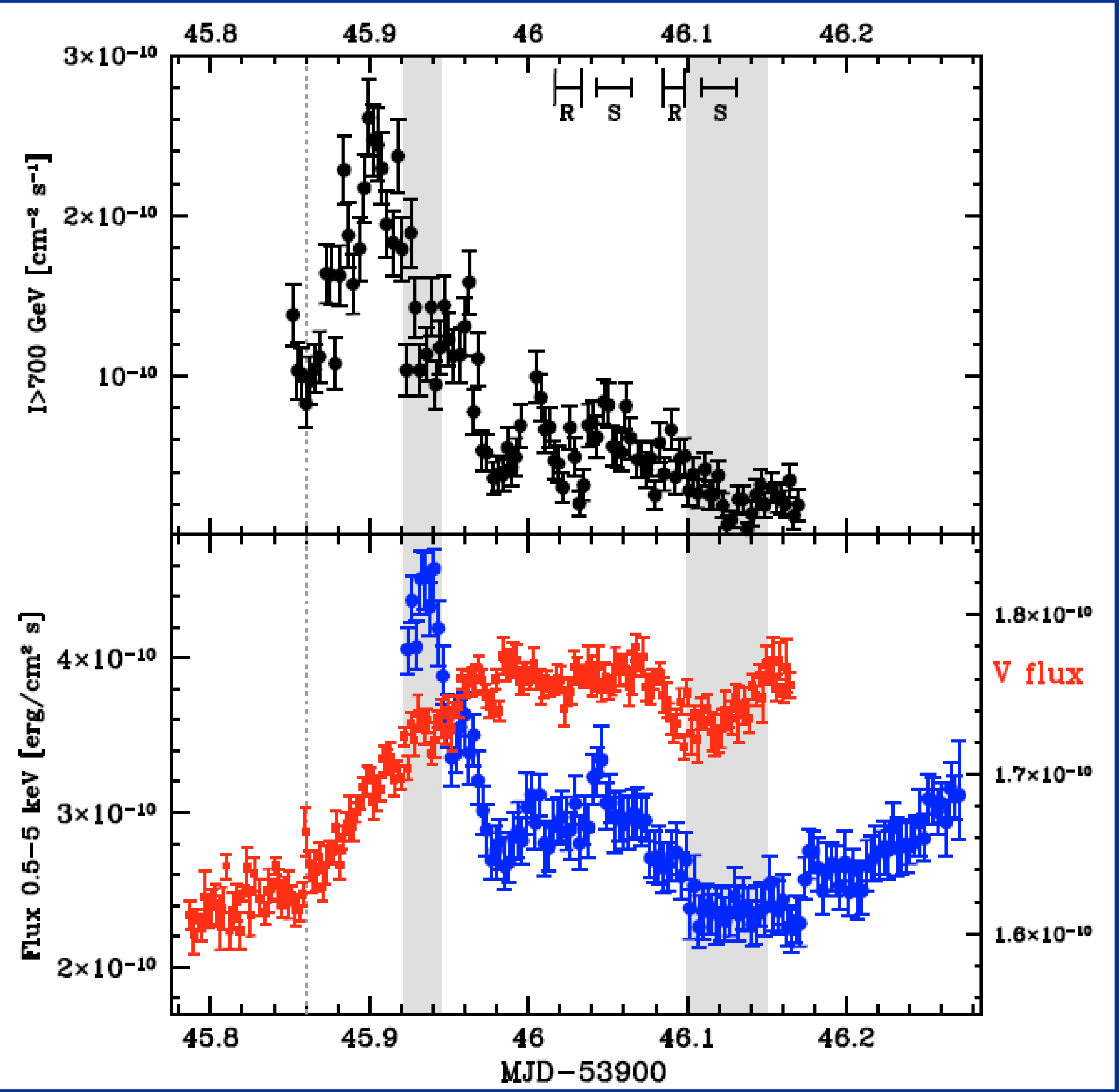
3C 279 in 2015, Fermi, arXiv:1605.05324, Ackerman et al. 2016





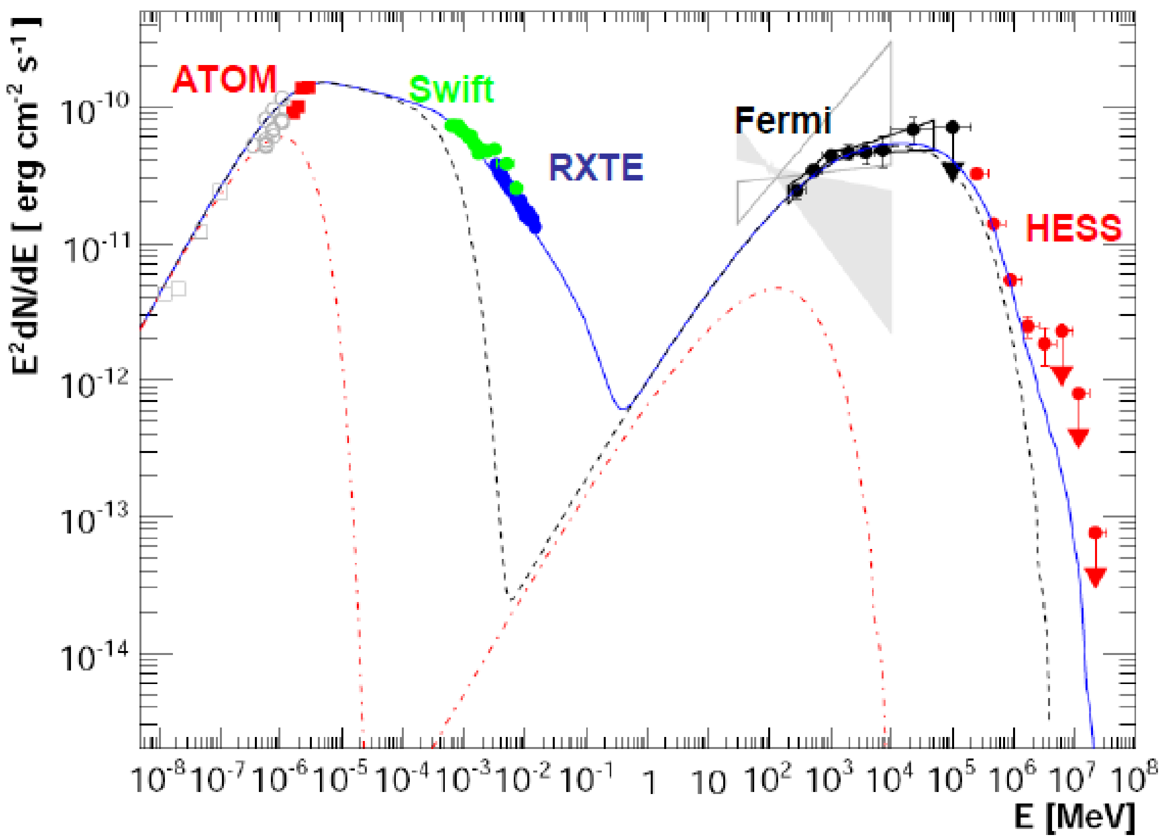
(a)
(b)
(c)
(d)
pre-outburst
A
B
C
D
E
F−G
H−I
J
K
post flare
Energy [GeV]
$E^2 \times dF/dE$ [erg cm^{-2} s^{-1}]
[x10-7]
Flux [ph cm-2 s-1]
>100 MeV
α
β
Epeak [GeV]
[Hours since 2015−June−16 00:00:00 (UT)]
Energy [eV]
1996 February flare [EGRET] (Wehrle+98)
2006 February flare [MAGIC] (Albert+08)
2008 August-September (Hayashida+12)
2009 February flare (Hayashida+12)
2013 December flare (Hayashida+15)
2014 April flare (Hayashida+15)
Orbit C (this work)
Orbit D (this work)
νF_ν [erg cm^{-2} s^{-1}]
νL_ν [erg s^{-1}]
Frequency: ν [Hz]

Lesson: PKS 2155, X-ray-optical-gamma-ray correlations?



MW campaign on PKS 2155–304 (with HESS)

HSP-BLLac, z=0.116
nonflaring,low/quiescent state
First simultaneous SED including GeV-TeV
Unexpected correlations:
• strong correlation between optical and TeV fluxes
• X-ray flux varies independently of TeV flux
• correlation between X-ray flux and GeV photon index
Challenge simple SSC models



Aharonian, F. et al. 2009, ApJL, 696 L150
contact authors: B. Giebels & J. Chiang

Marshall et al. 2010 Pictor A rapid X-ray Variability?

102 *Hardcastle et al.*

Centaurus A - Chandra

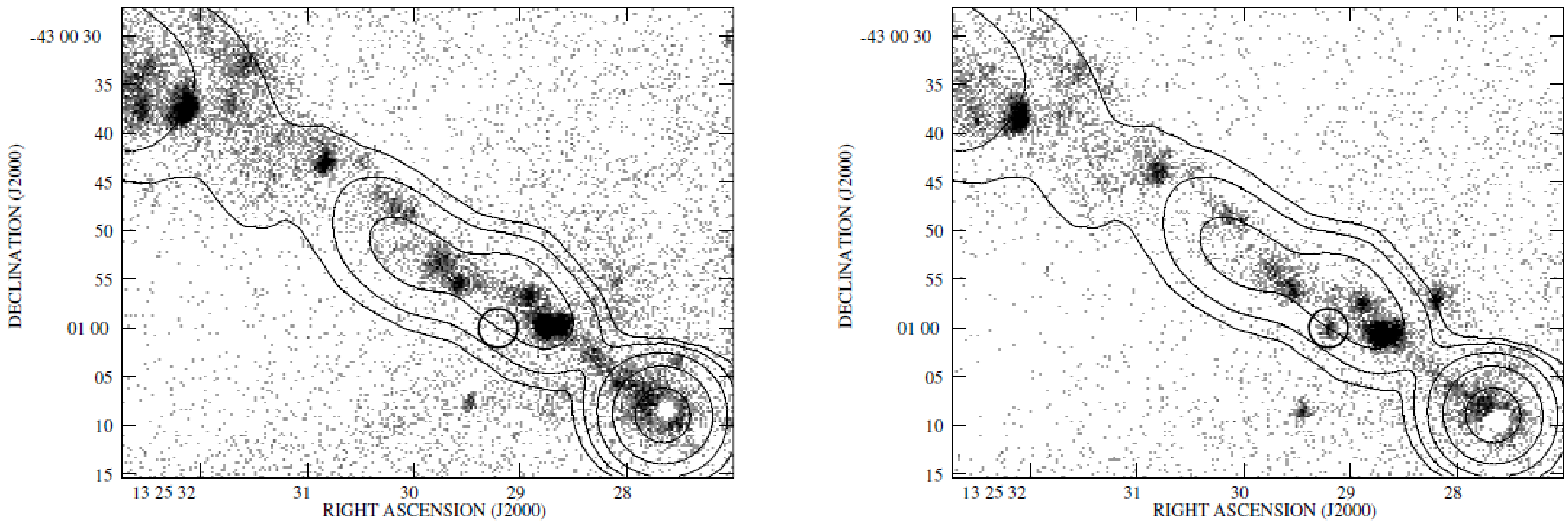
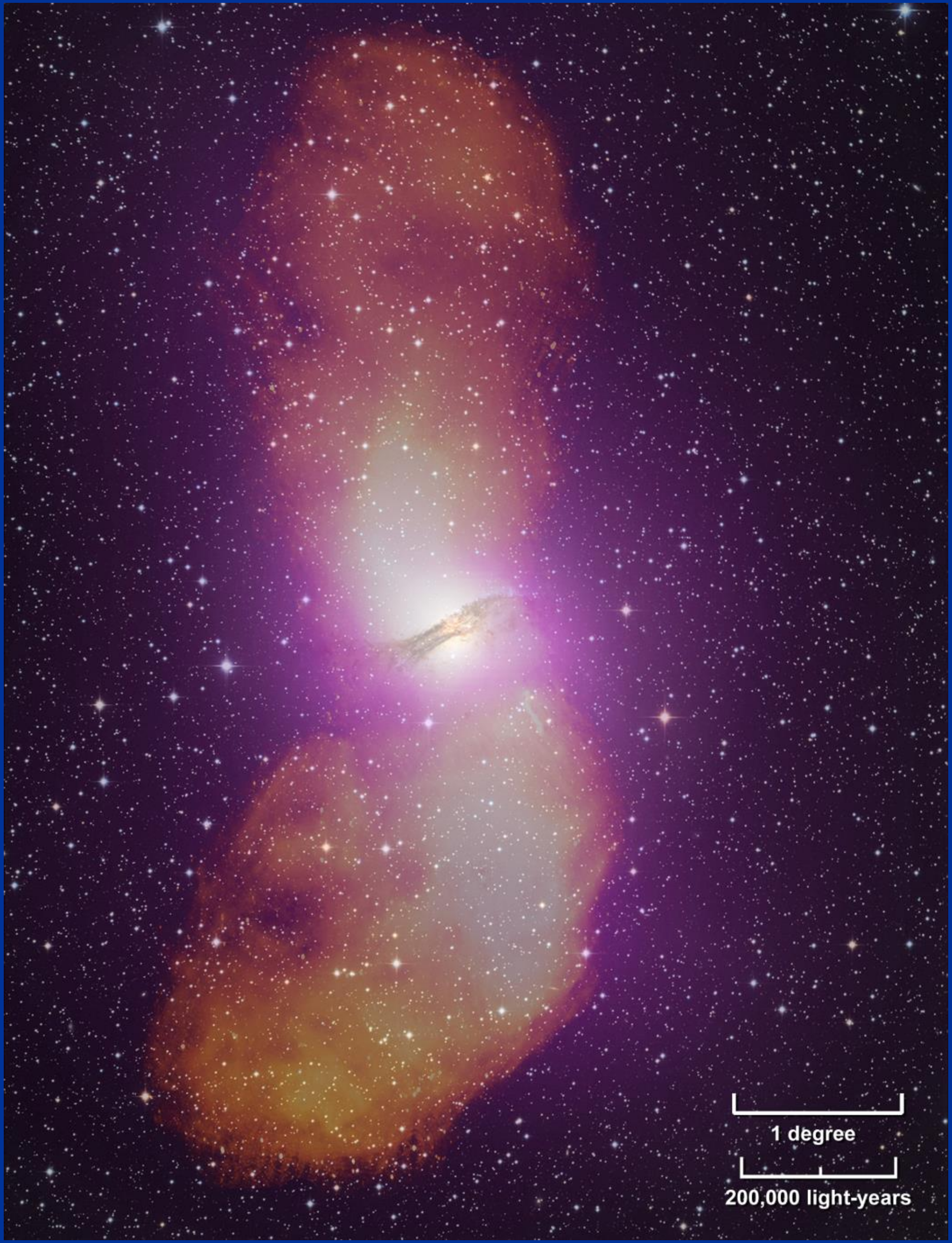


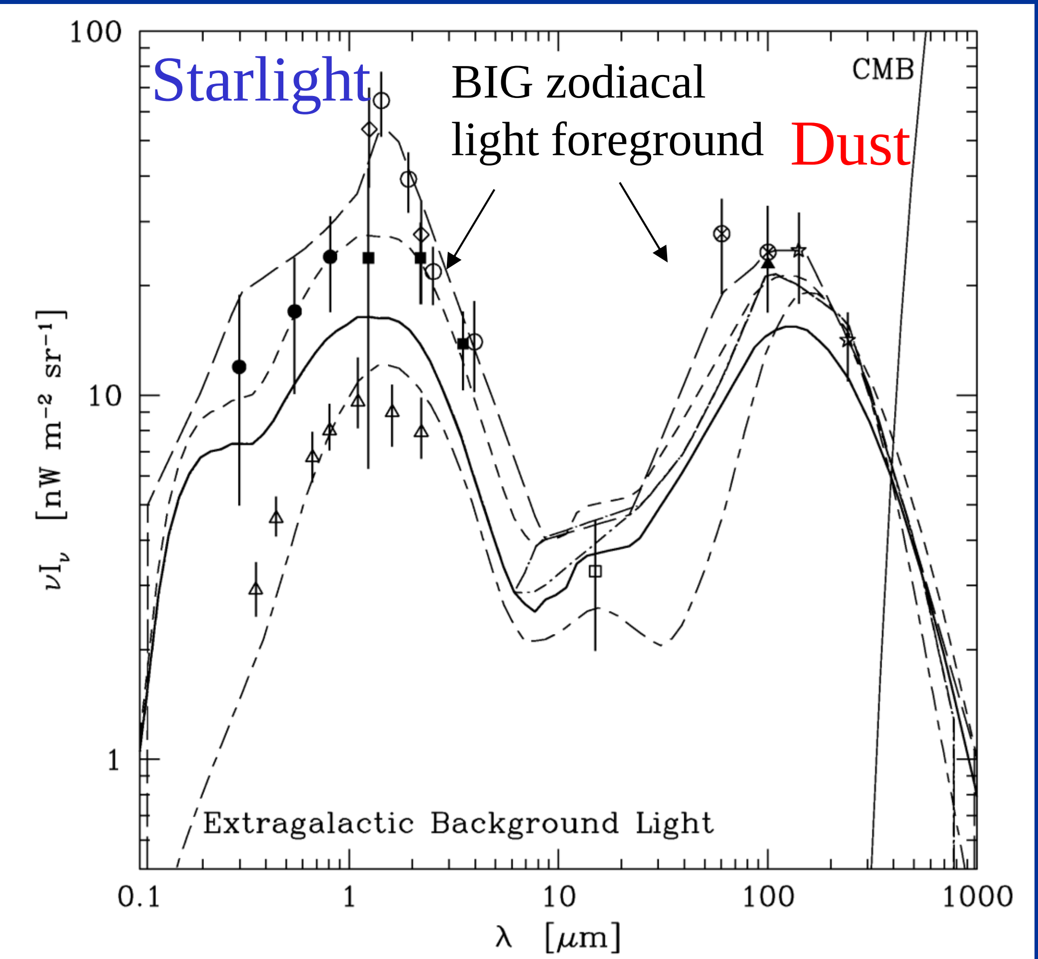
Figure 3. Variability of an X-ray feature close to the jet. The greyscales show (left) 100 ks of *Chandra* data taken in 2003/4 and (right) 90 ks taken in May 2007. The solid circle shows the significantly variable knot. Contours are from the 6-arcsec VLA map

Fig. 2.— X-ray images of the Pictor A jet at several epochs: 2000 (top), 2002 (second from top) 2009 (second from bottom), and the total (bottom). All are rotated by 11.2° to orient the jet to the right. The images were smoothed by a 2D Gaussian with a σ of 0.8″. The 2002 image has a readout streak at about 10° to the jet. Possible knot flares are indicated with magenta arrows.

Another “boring” nearby elliptical … Cen A (radio + optical + Fermi)



So, why do "low energy" astrophysicists care about VHE astronomy?



$\sigma_{\gamma\gamma} = f(E_\gamma E_t)$,

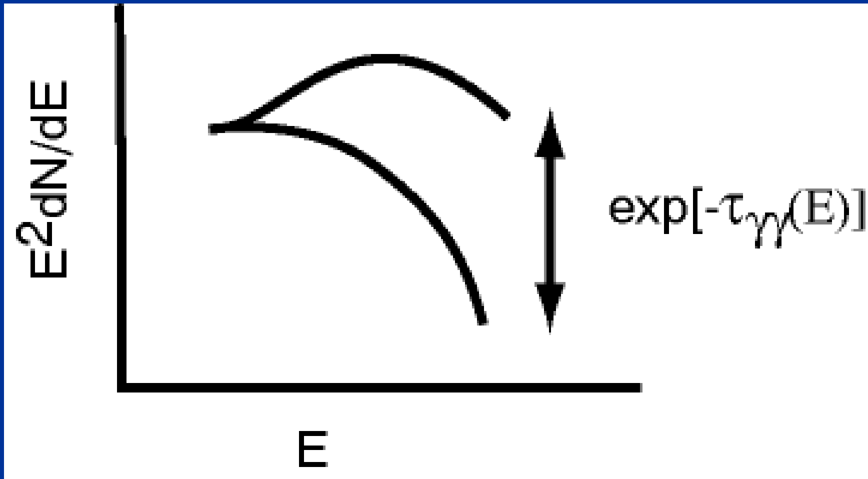
peaks at $E_\gamma E_t \approx 3.4(m_e c^2)^2$

$\Rightarrow$ largest for

$\lambda_{EBL} \approx 1.3\mu$ (E_γ/1 TeV)

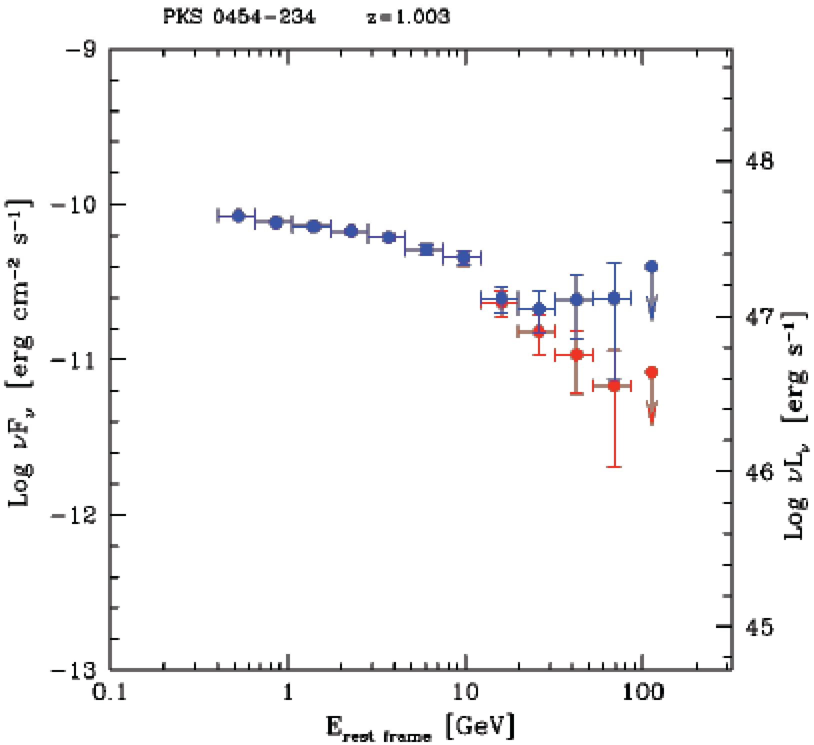
If measure $\tau_{\gamma\gamma}(E_\gamma)$ and know d_{source},

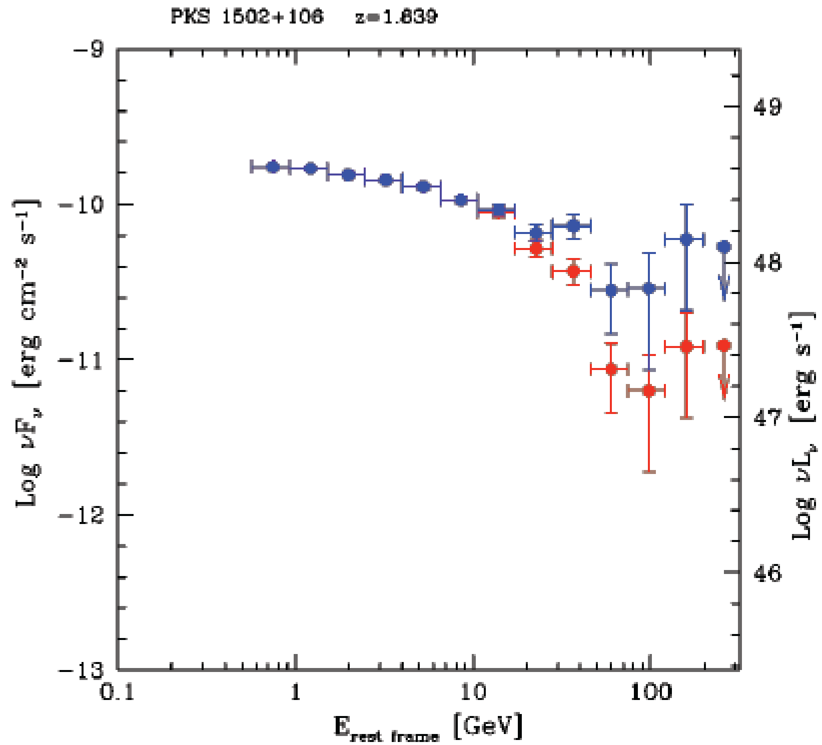
then constrain $n(\lambda_{EBL})$!



No evidence of strong BLR cut-offs !

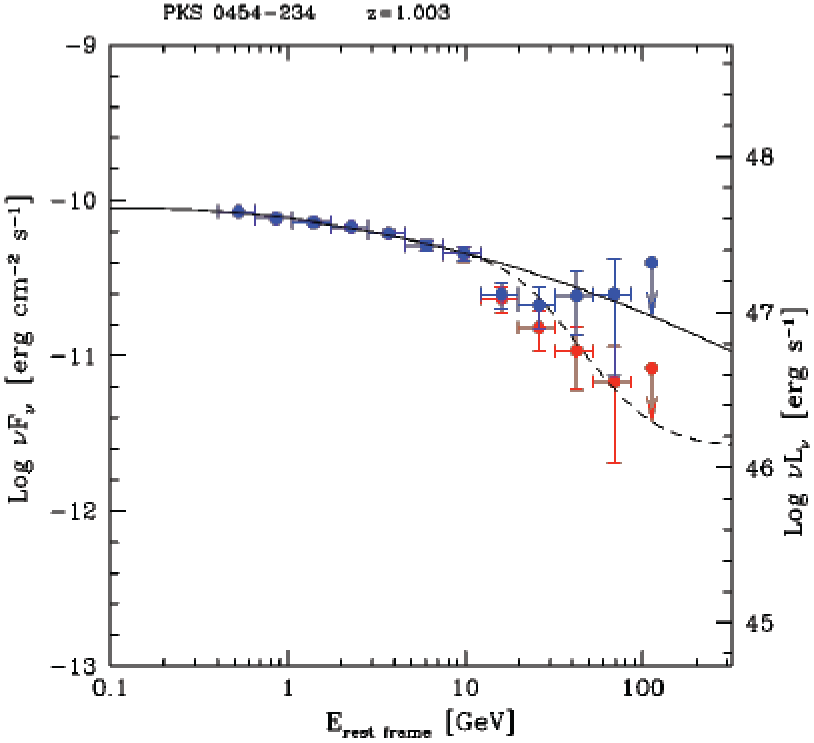
Spectra seems compatible with presence of but minimal absorption ($\sim 10^{16}$ cm, i.e. $R_{diss} \approx R_{blr}$)

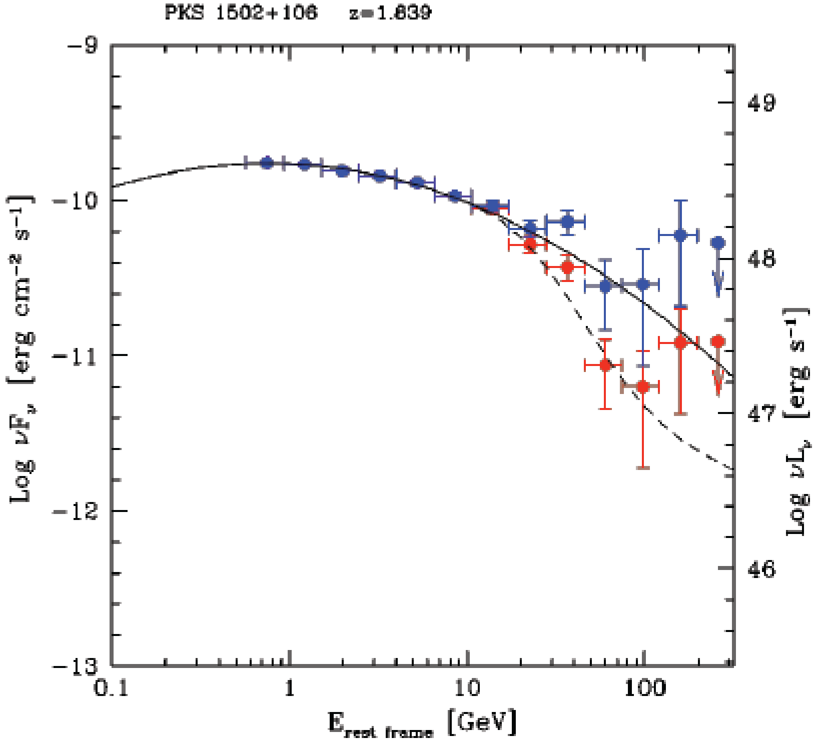




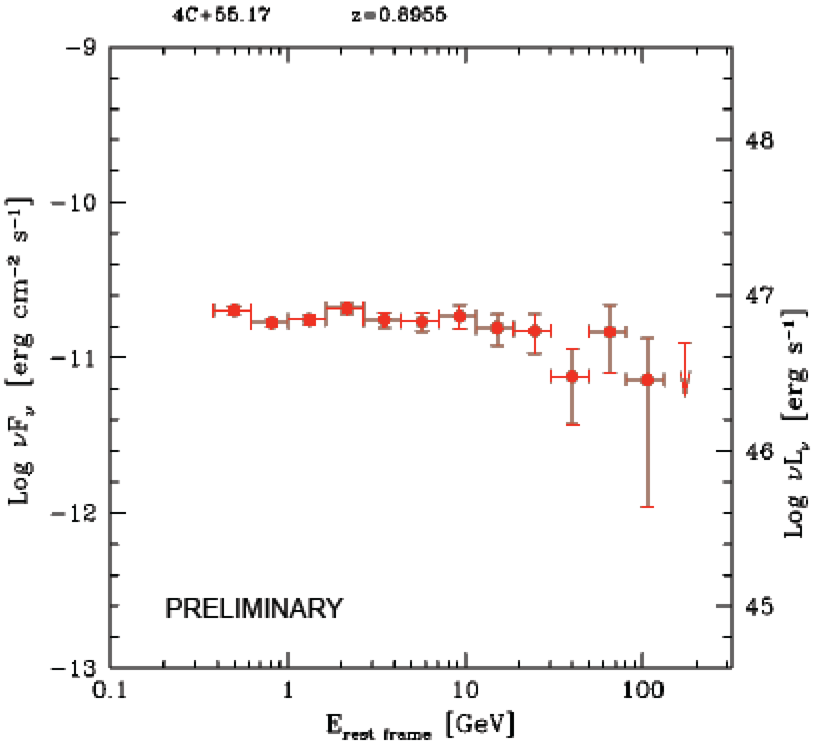
Extrapolation of low energy spectrum

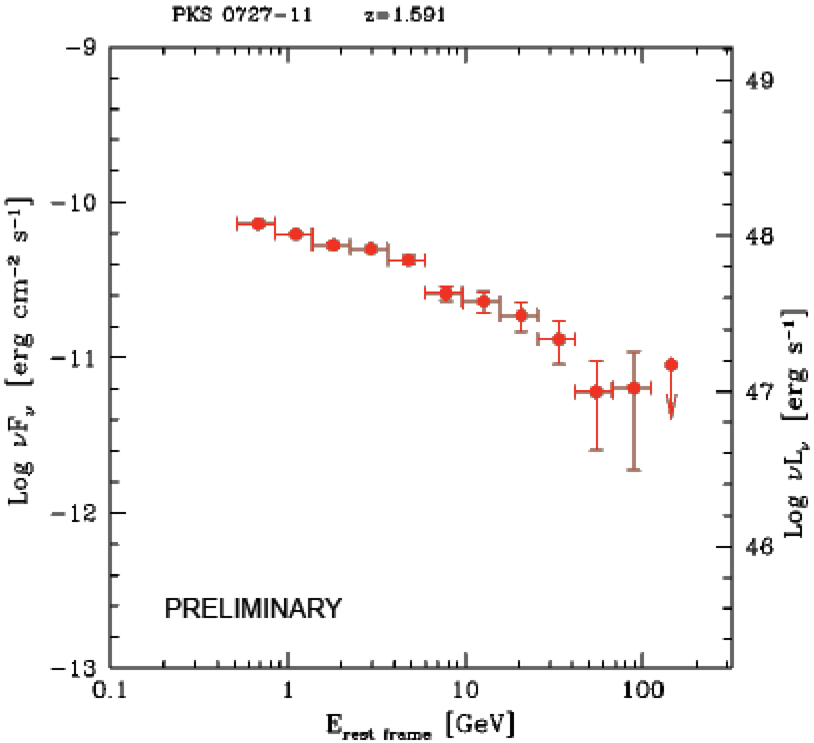
Minimal absorption agrees with shape of the spectrum determined in the low-energy band (e.g. log-parabola; similar for power-law)





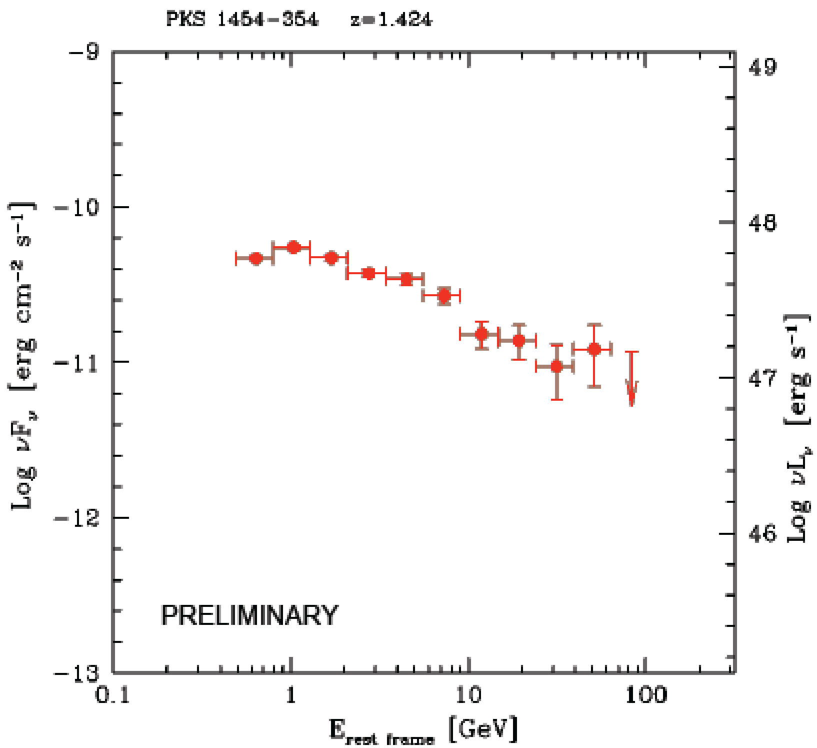
Also NO evidence of absorption at all !

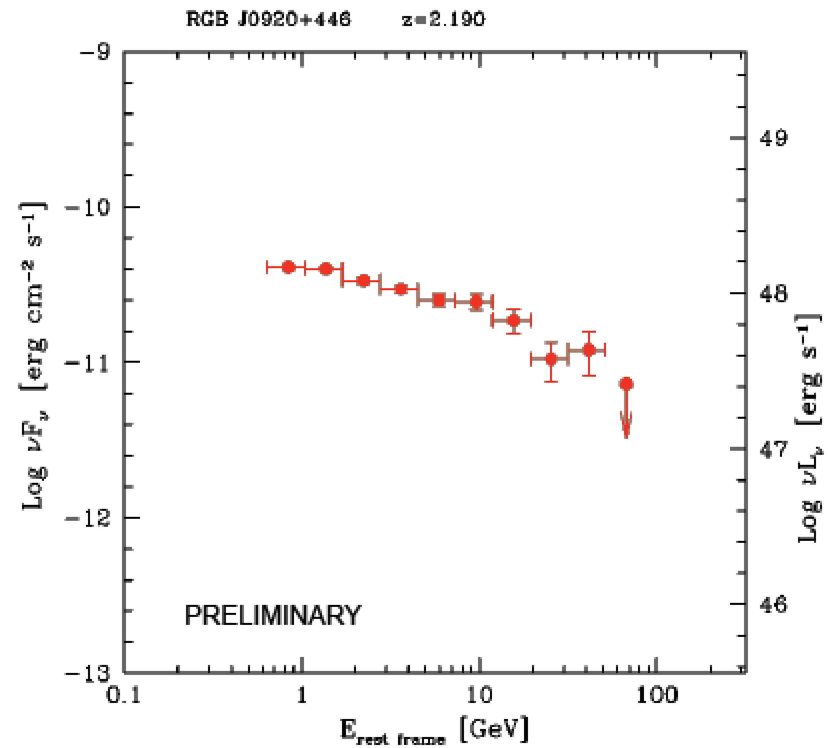




Also NO evidence of absorption at all !

Even in quite powerful objects, with large BLR !



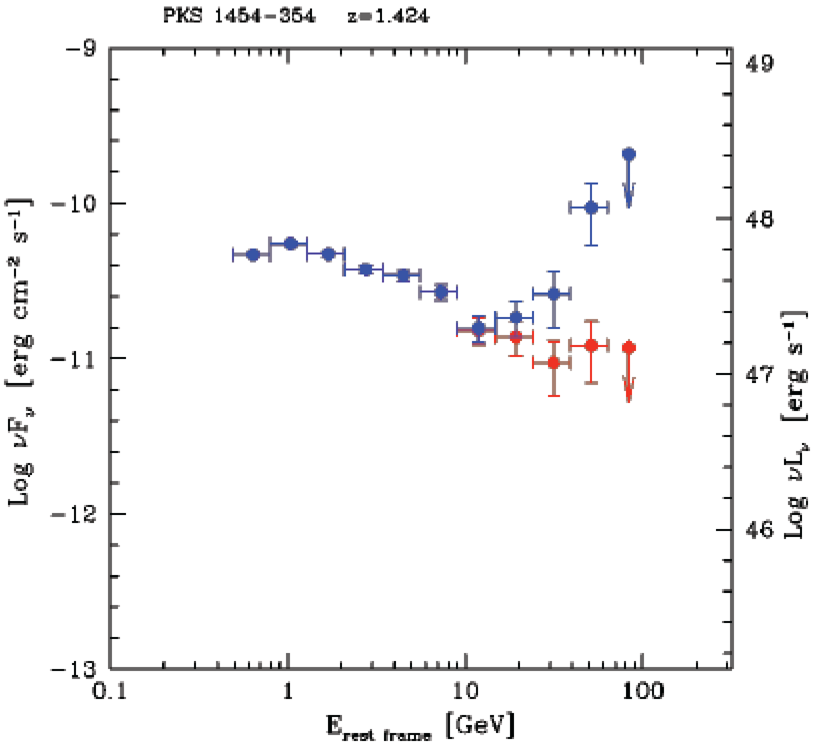


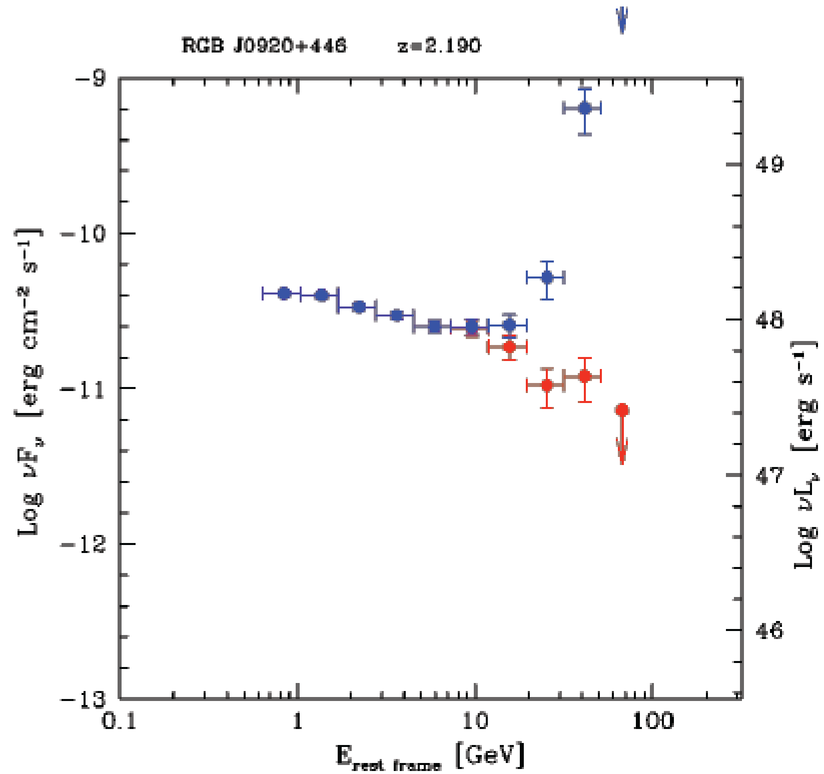
$L_{disk} \sim 5\times10^{46}$ $R_{blr} \sim 7\times10^{17}$
(e.g. $R_{diss} \sim 1.5\times10^{17}$ Ghisellini et al 2009)

$L_{disk} \sim 2\times10^{47}$ $R_{blr} \sim 1.3\times10^{18}$
(e.g. $R_{diss} \sim 5\times10^{17}$)

Also NO evidence of absorption at all !

Even in quite powerful objects, with very large BLR !



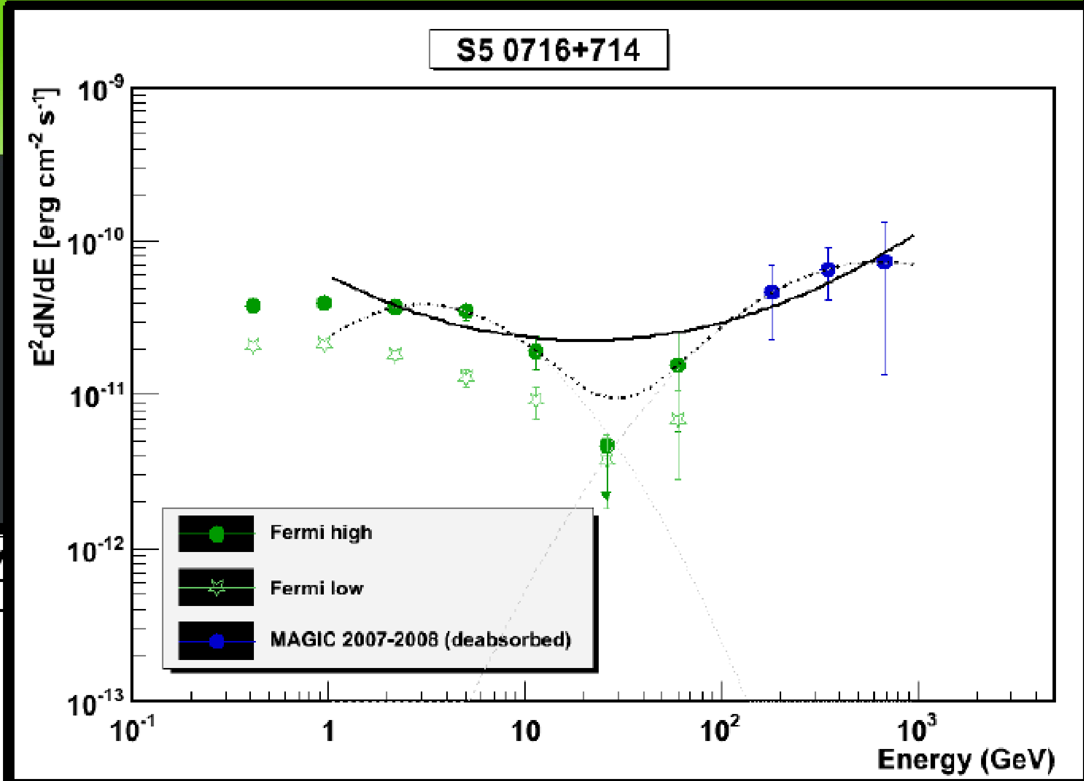


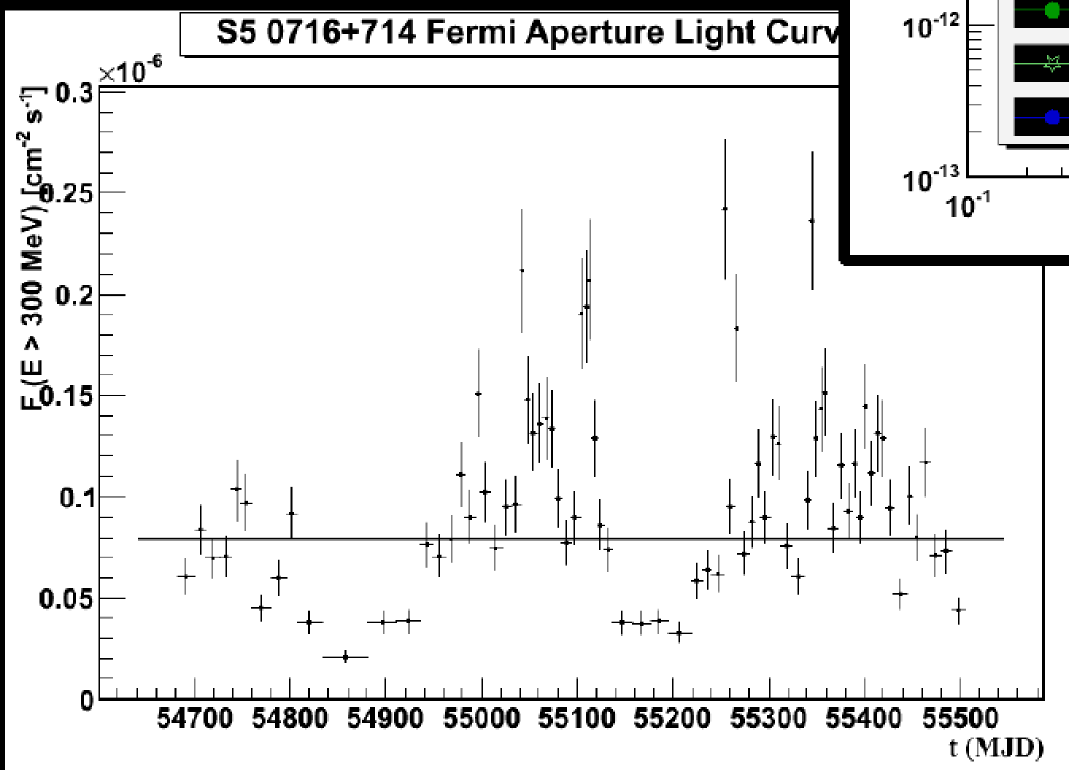
$L_{disk} \sim 5\times10^{46}$ $R_{blr} \sim 7\times10^{17}$
R_{diss} must be $\geq 7\times10^{17}$

$L_{disk} \sim 2\times10^{47}$ $R_{blr} \sim 1.3\times10^{18}$
R_{diss} must be $> 10^{18}$ cm
(or path inside $<< 10^{17}$ cm)

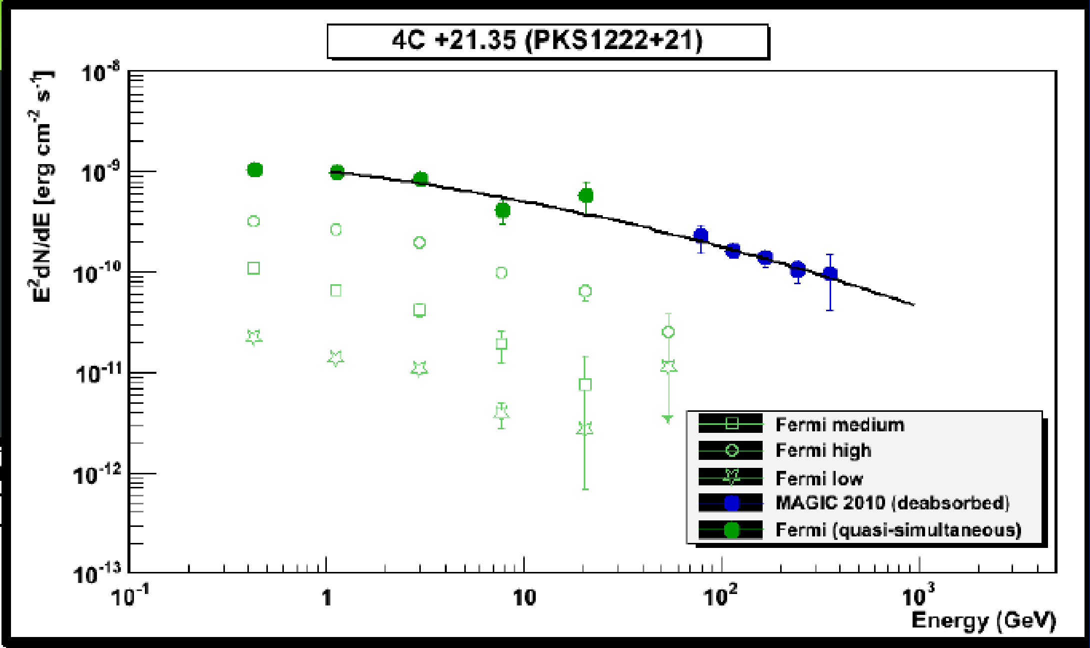
S5 0716+714

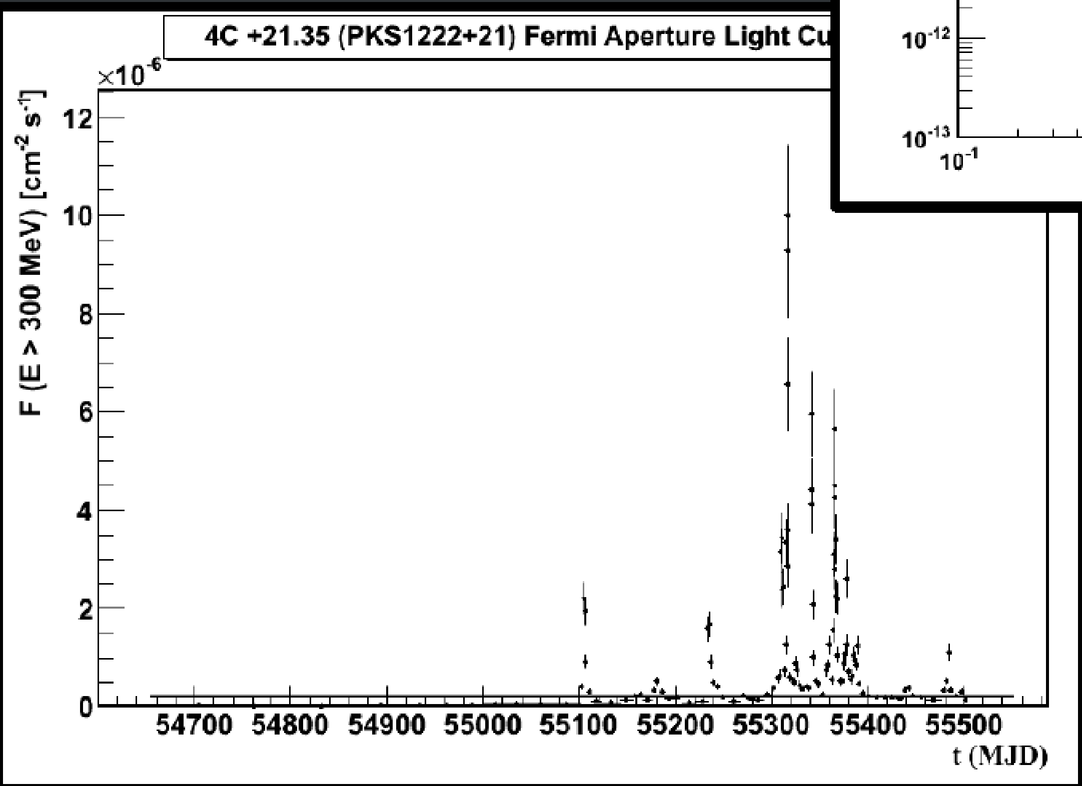
G. Senturk et al. 2011



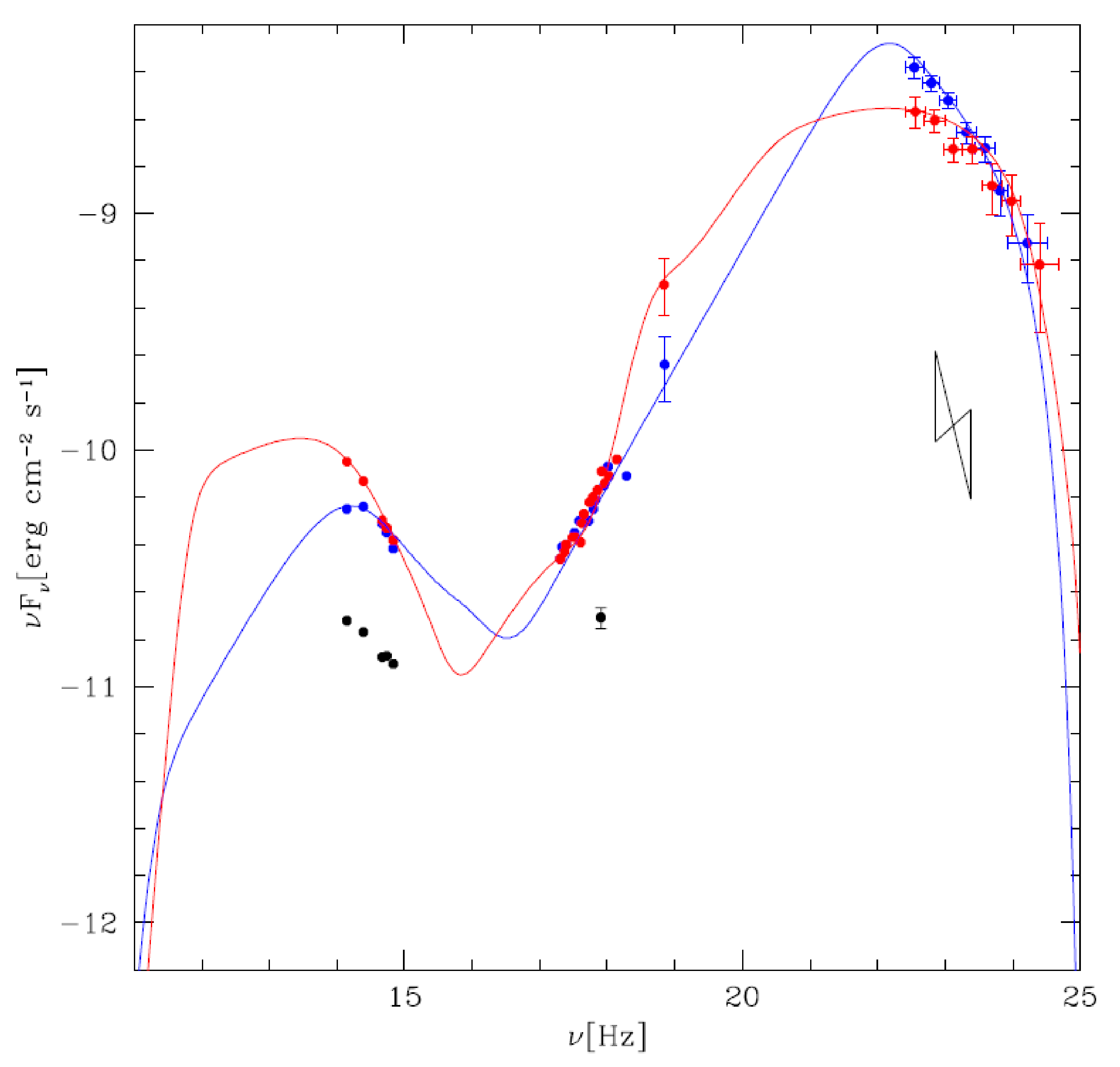


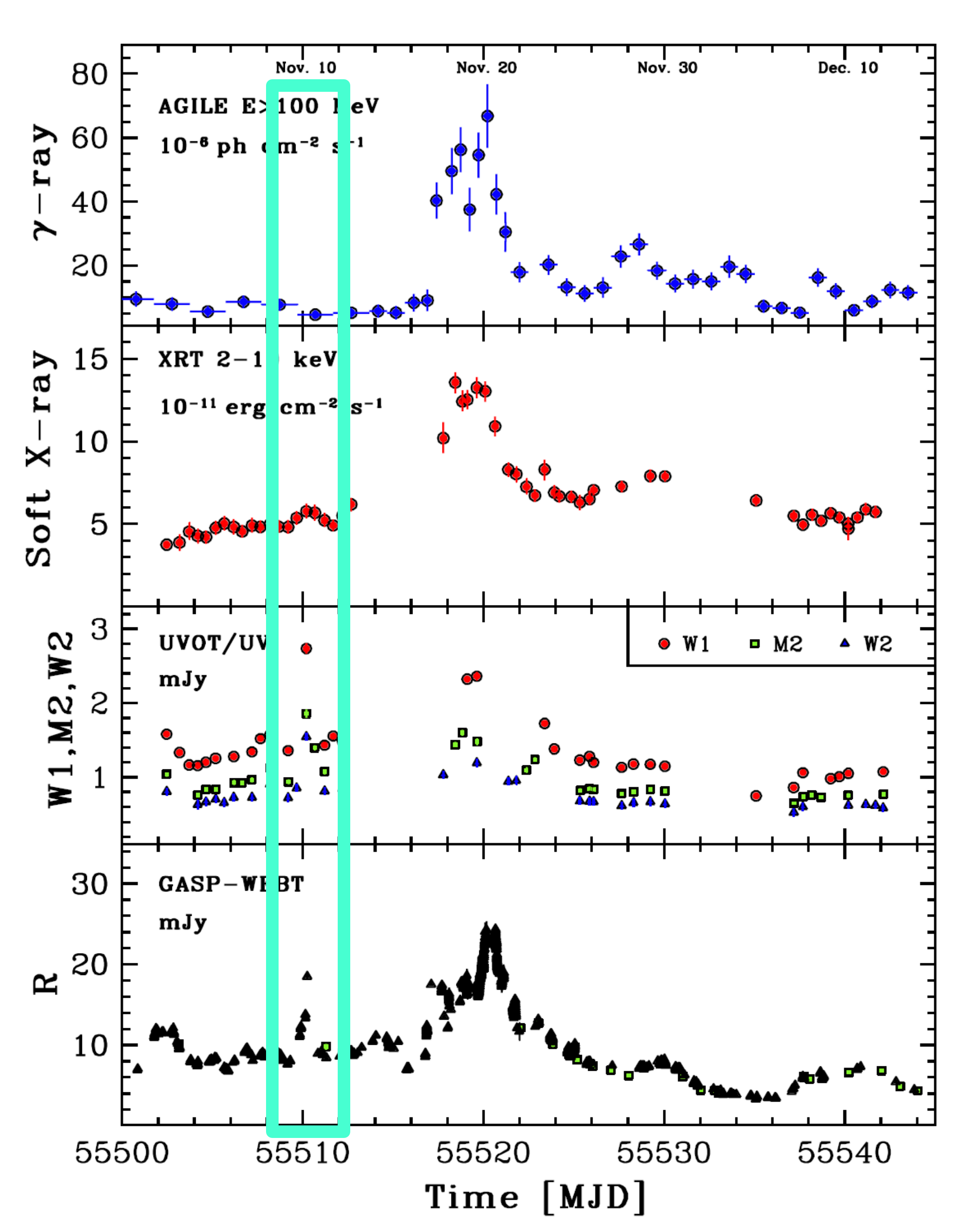
4C +21.35 (PKS 1222+216)





One zone fit to 3C 454.3 Dec 2-3 2009, Bonoli et al. X-gamma + SMARTS NIR/opt




Nov. 10
Nov. 20
Nov. 30
Dec. 10
AGILE E>100 MeV
10^{-6} ph cm^{-2} s^{-1}
γ−ray
XRT 2−10 keV
10^{-11} erg cm^{-2} s^{-1}
Soft X−ray
UVOT/UV
mJy
W1,M2,W2
W1
M2
W2
GASP−WEBT
mJy
R
Time [MJD]
55500
55510
55520
55530
55540

Isler et al. 2013, submitted [see also Leon-Tavares 2013]

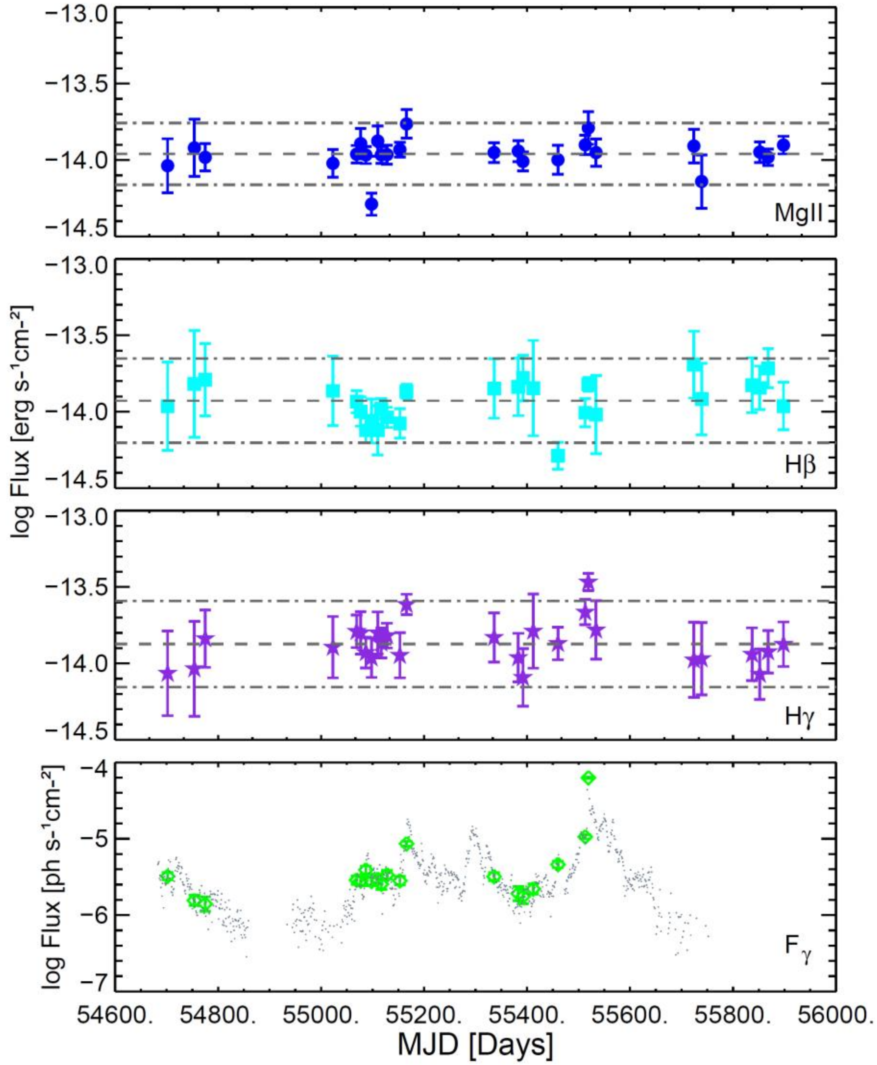


FIG. 4.— Broad emission line flux light curves for Mg II (blue circles), $H\beta$ (cyan squares) and $H\gamma$ (purple stars). The bottom panel shows the *Fermi* γ-ray light curve (TS >25) for the same MJD (filled diamonds) and over the total observed interval (grey points). The average flux of each emission line is represented by the dashed lines and 2σ deviations are marked by dot-dashed lines. Over the 3.3 years of observation, the line fluxes deviate by more than 2σ above the mean only on MJD 55165 and 55518 in Mg II and $H\gamma$. This lack of strong detectable variability in the line emission is in stark contrast to the factor of nearly 100 variations in gamma-ray flux over the same time period, as seen in the bottom panel. However, the highest γ-ray flare phases (MJD 55167 and 55520) correspond to the greatest deviation in the $H\gamma$ and Mg II line fluxes. The rise and fall of the $H\gamma$ line flux, in particular, appears to trace the rise and fall of the γ-ray flux. Both epochs during which the $H\gamma$ and Mg II emission lines deviate from the mean are also coincident with 7mm core ejections (Jorstad et al. 2012).

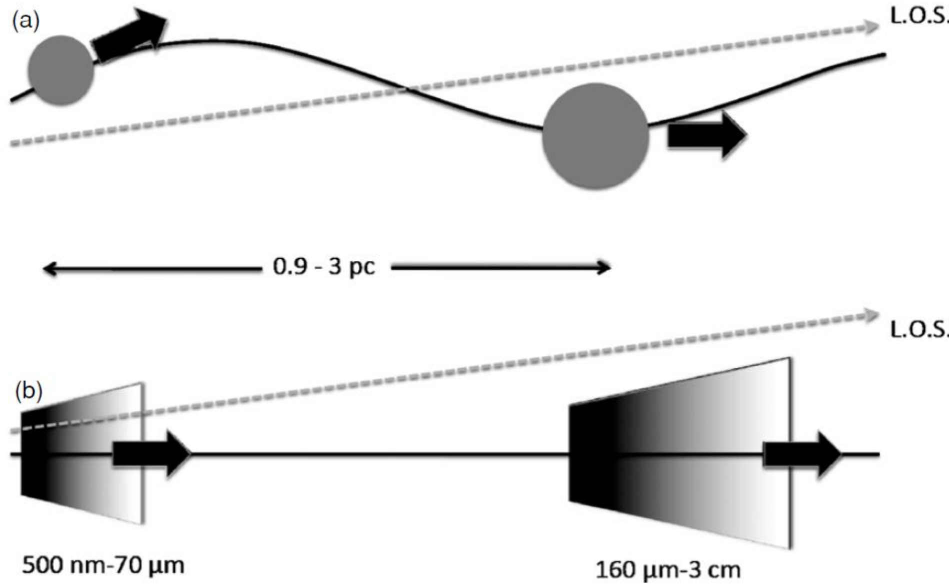


Figure 13. (a) Helical jet model. The two synchrotron peaks are produced by two relativistic blobs moving at different angles to the line of sight. The IR–optical peak is produced closer to the base of the jet, while the sub-mm peak is produced further out. (b) Inhomogeneous jet model. Two radially separated synchrotron emission regions give rise to the IR and sub-mm synchrotron emission peaks. The IR emission region comes from the base of the jet, while the sub-mm emission region comes from a shock (possibly a jet recollimation shock) at a radius of ∼0.9–3 pc. The direction to the observer's line of sight is marked "L.O.S."

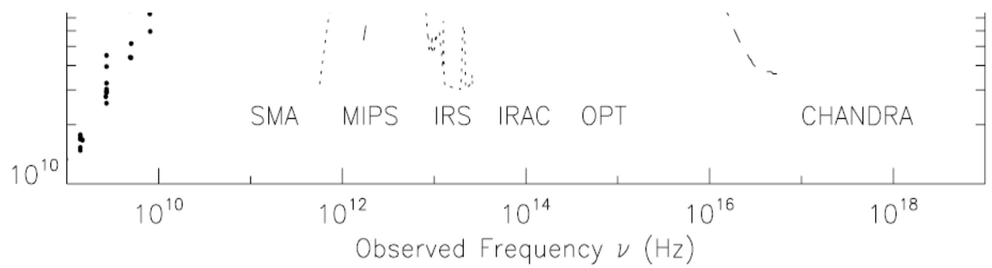


Figure 12. 3C 454.3 SED. *Spitzer* MIPS 160, 70, and 24 μm photometry (triangles), IRS spectra (solid lines), and IRAC 3.6 μm and optical photometry (diamonds) are plotted together with other multiwavelength data. The millimeter and sub-mm points are SMA calibration data. Optical photometry in 2005 is from Foggy Bottom Observatory and the automated Palomar 1.5 m telescope. *XMM*-OM (*UVM2*, *UVW1*, *U*, *B*) photometry for 2006 December 18–19 are from Raiteri et al. (2007, Table 3). *V*, *R*, and *I* photometry for 2006 December 20 are from WEBT data provided by M. Villata (Raiteri et al. 2007; Villata et al. 2007). Both sets have been corrected for extinction. *Chandra* X-ray data for the 2007 minimum are indicated by the error box. The scattered small black dots are radio and optical photometry from the NED database, gathered from 1979–1995. The mean Richards et al. (2006) QSO SED (dashed line) and the Rieke et al. 10^{13} $L_\odot$ ULIRG template (dotted line) are scaled and overplotted for comparison. Neither of these SEDs is compatible with the shape of the IR bump in the low-state 3C 454.3 SED, indicating a dominant nonthermal contribution from the jet. Note the presence of two synchrotron peaks, at IR and sub-mm wavelengths, in both the low and high states.

constrain, but still often several model degeneracies, really start to
constrain if measure simultaneously

take advantage of big flares, single component

FRB example
plug into various brokers
dedicated follow-up facilities

pair cascade
swift ng decadal

Extremely fast acceleration of cosmic rays in a supernova remnant

(Nature 2007)

Yasunobu Uchiyama[1], Felix A. Aharonian[2,3], Takaaki Tanaka[1,4], Tadayuki Takahashi[1] & Yoshitomo Maeda[1]

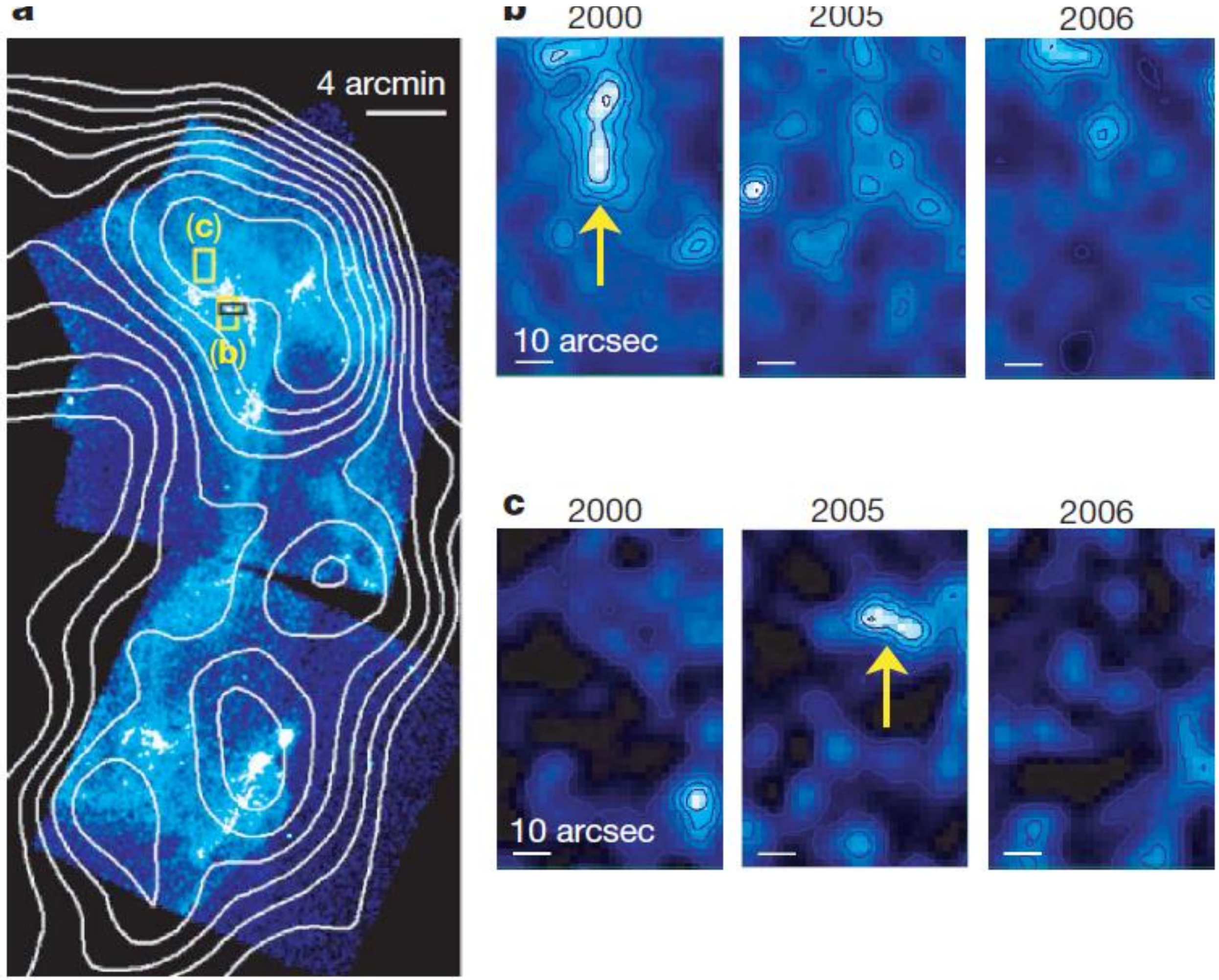
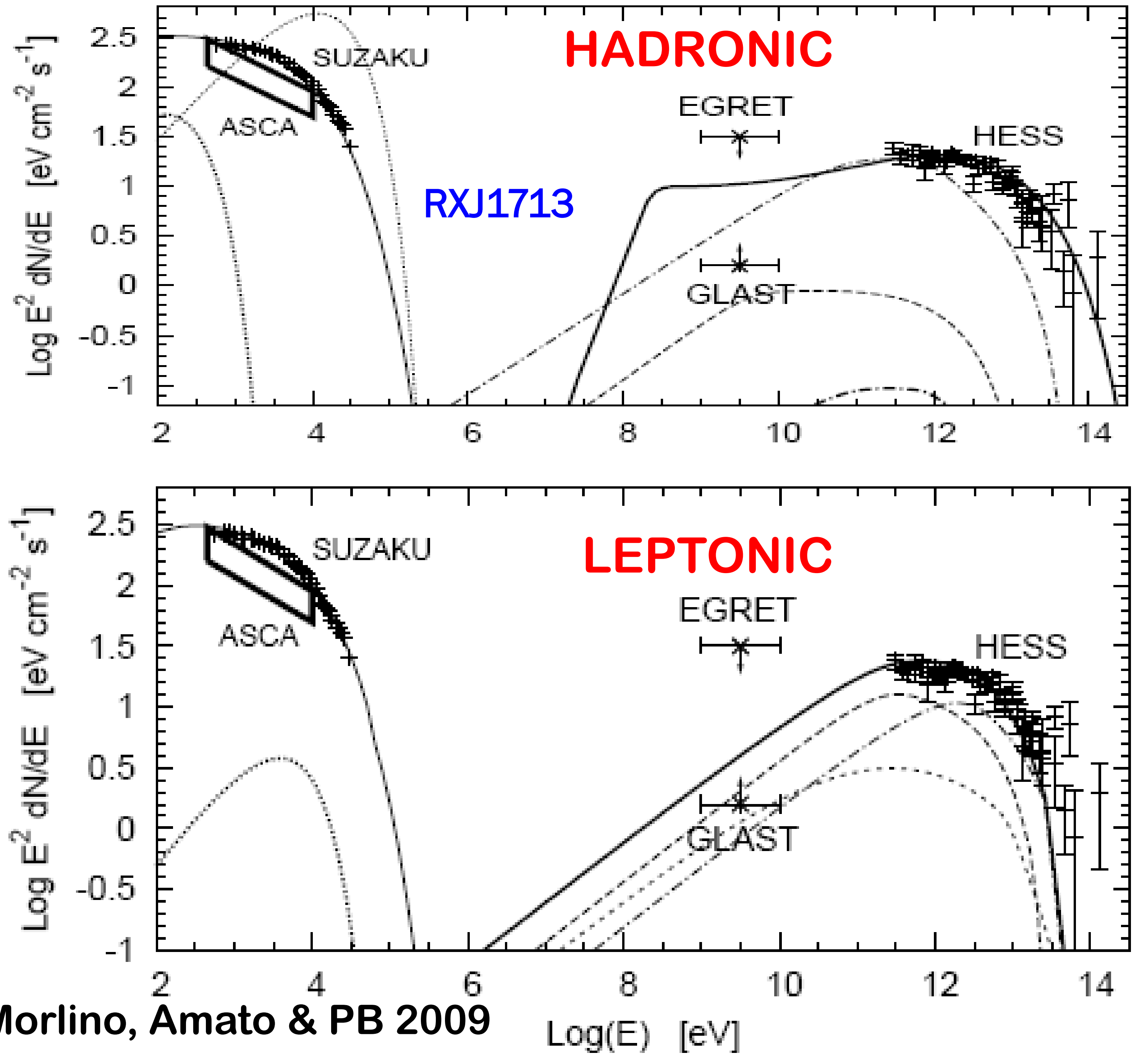


Figure 1 | Chandra X-ray images of the western shell of SNR RX J1713.7−3946. a, A Chandra X-ray mosaic image is overlaid with TeV

From P. Blasi, Brasil lectures

RXJ1713



Morlino, Amato & PB 2009

How to effectively probe the Universe: use the right messenger particles!

[Ideally use as many different kinds and at different energies as possible.]

- Optical/UV: characteristic (z=0) stellar energy, *worst* in terms of obscuration, but do see lots of useful atomic features [your eyes]
- Radio: mainly non-thermal, relatively good at penetrating intervening matter [currently highest spatial resolution, e.g., VLBA interferometry].
- Infrared: see energy absorbed and re-emitted by dust [Spitzer, ALMA].
- Soft X-Ray: hot gas, atomic features still available but not completely understood, still easily *obscured.*
- Hard X-ray (>10 keV): very little gas/stellar contamination, very penetrating, lose atomic features, hard to focus – sensitivity starts to plummet.
- Soft Gamma-Ray (>500 keV): pair annihilation line, nuclear lines, but subject obscuration again due to photon-photon pair production, even harder to stop in detector and image, lots of background.
- VHE Gamma-Ray (>GeV): obscuration in source/during propagation big worry (double-edged sword), but clearly indicates presence of very energetic particles and "extreme" processes and physical conditions (and new physics?)!

All, straight line propagation from source!

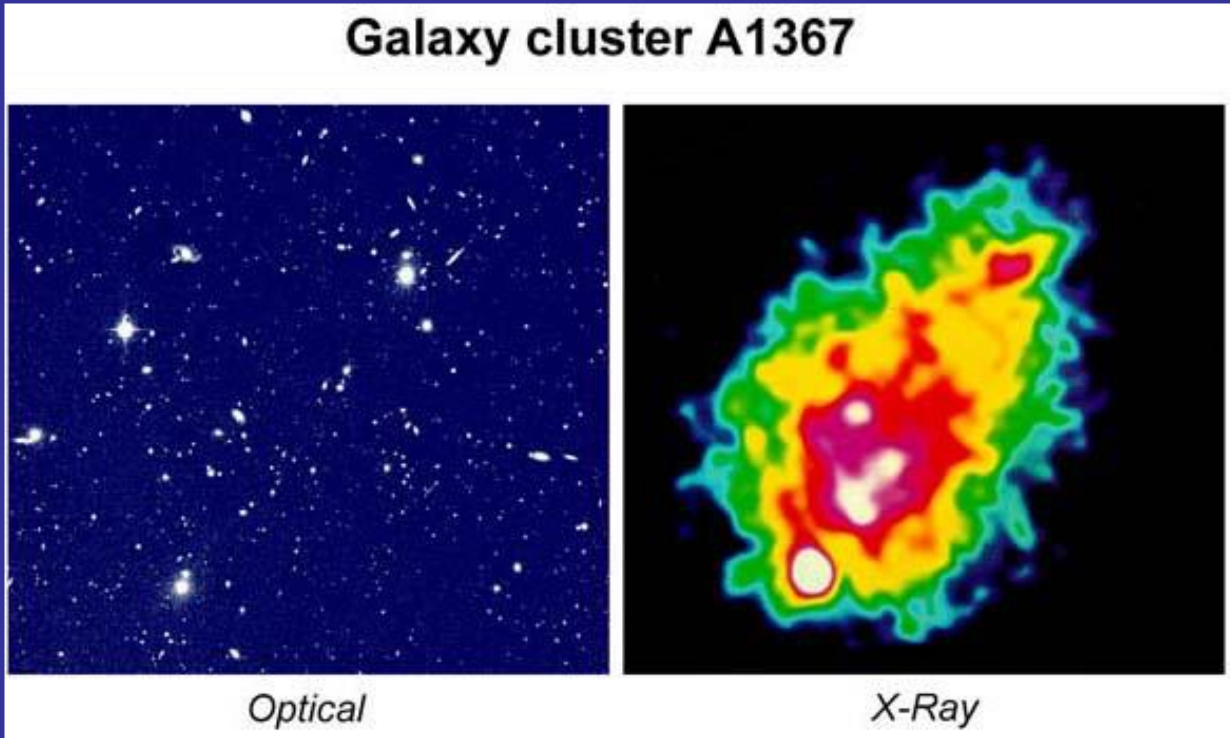
Messenger particles II.

- Protons, Electrons (cosmic rays): subject to energy losses, deflection by magnetic field.

- Neutrinos: straight line propagation, usually impossible to stop in source and almost equally impossible to detect ☺, smoking gun probe for hadronic processes. [ICECUBE, right sensitivity level to finally start seeing something besides nearby supernova]

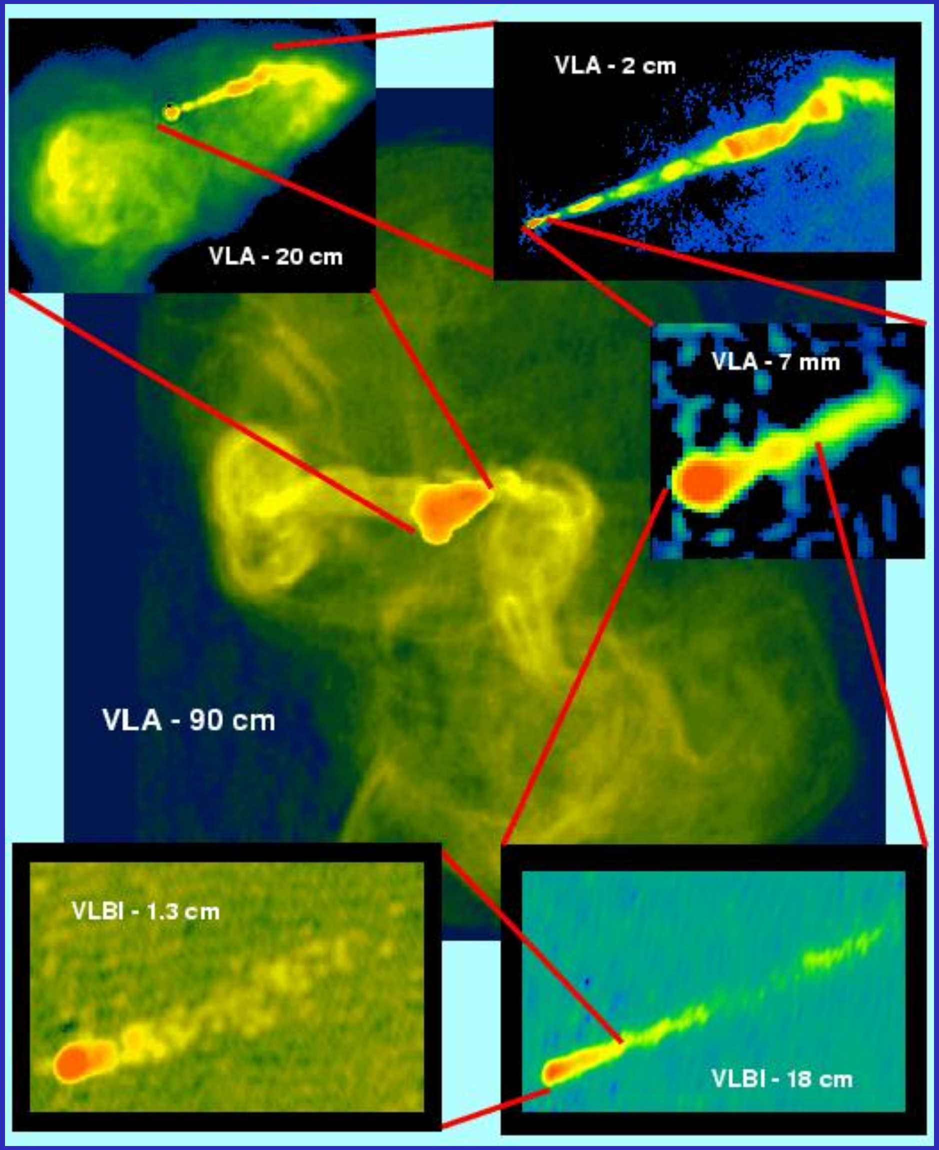
- Gravitons (gravity waves): straight line propagation, need only to detect strain (amplitude not power) => can see to high redshift, but expected strains miniscule, no convincing detections yet [LIGO, LISA]

When you look in new ways …



A “boring” object in the sky: the nearby elliptical galaxy M87

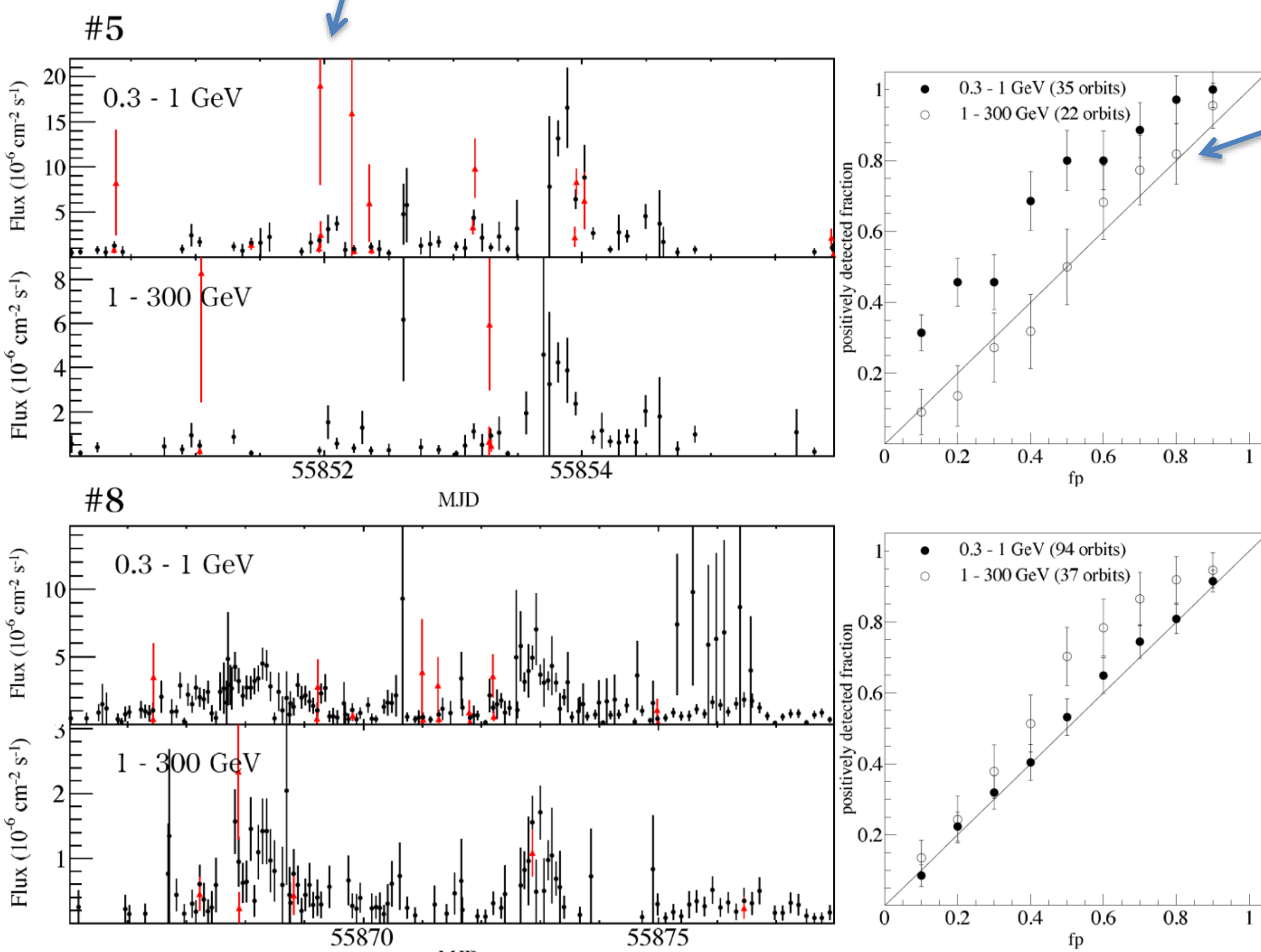
Opt



Radio

Bayesian Block Analysis – PKS 1510-089, Flare 5 shows 3.5 sigma excess of orbits where saw possible flux change (vs. expected number of false positives, solid line in right panels)

Red interval – Bayesian blocks favors 2+ intensity levels during orbit



Solid line = Number of expected false positives

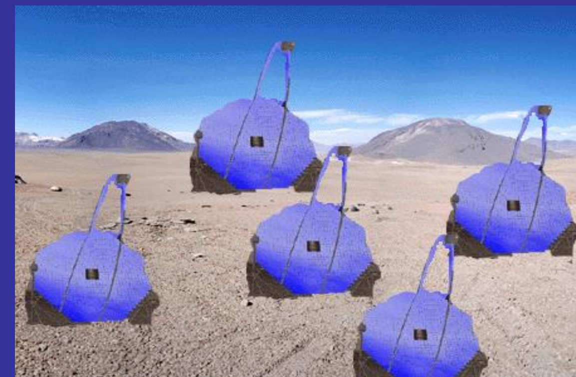
Light curve points shown are averaged over each Fermi exposure window (~30 min long).

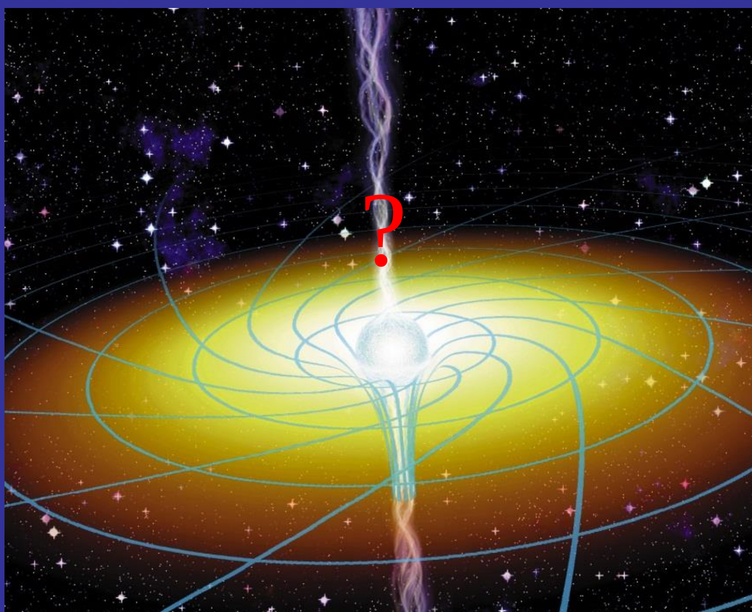
Time Domain Studies of AGN: How to Use Gamma-Rays Properly(?)

P. Coppi, Yale

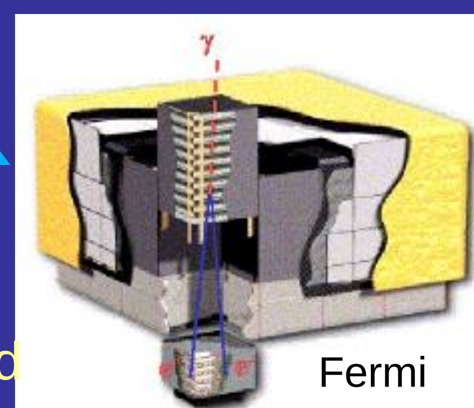
λλ

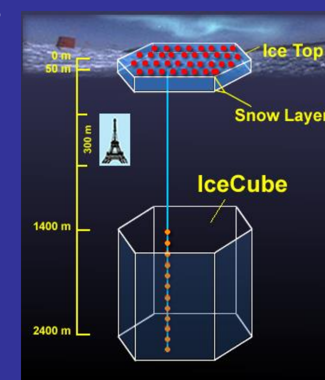
Ground-Based γ-Ray Detectors





Space-Based γ-Ray Detectors





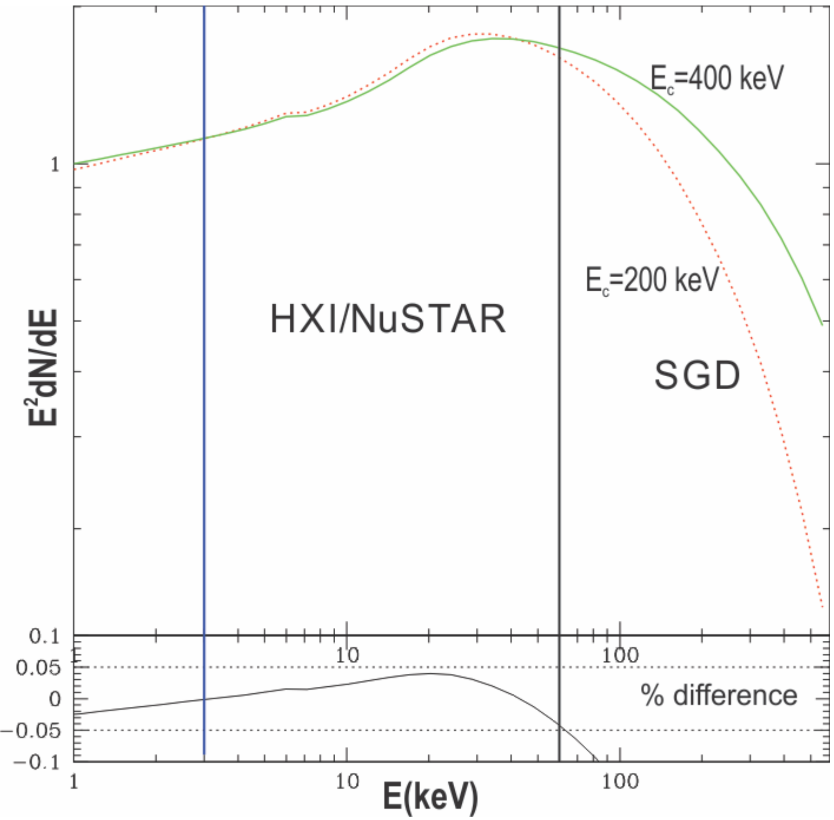
?? neutrinos

I. Why Gamma-Rays for AGN?

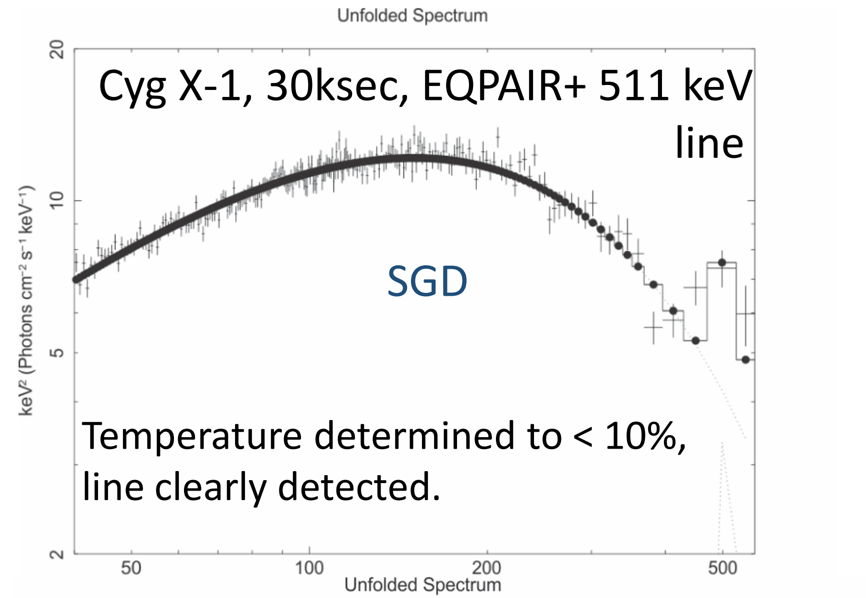
II. The Problem: (Extreme) Variability, Low Duty Cycle – Where Things Stand

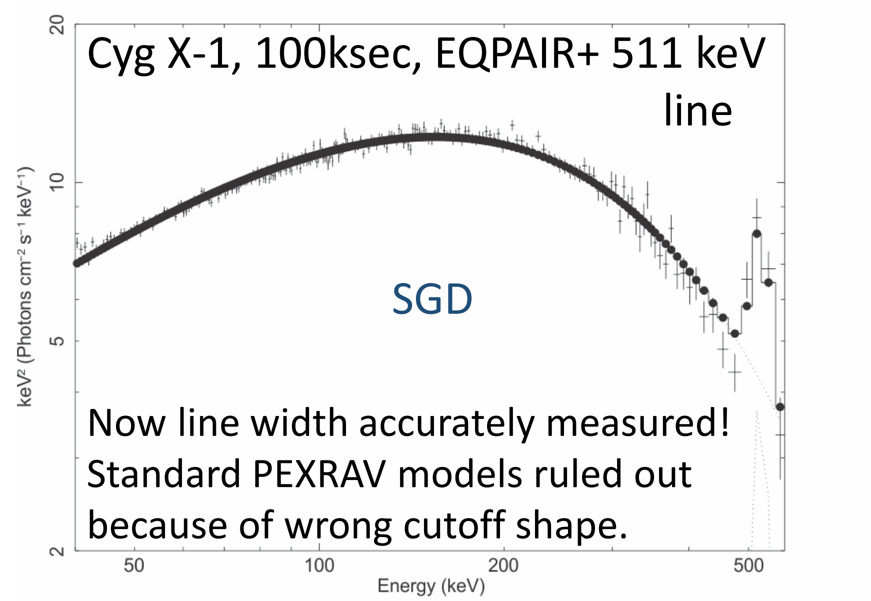
III. Future Prospects & Suggestions

The high-energy break in the hard state of Cyg X-1: Another example of how the SGD/ASTRO-H comes into its own for brighter sources ($>10^{-10}$ erg cm^{2} s^{-1}), e.g., enabling science that cannot be done by NuSTAR alone.



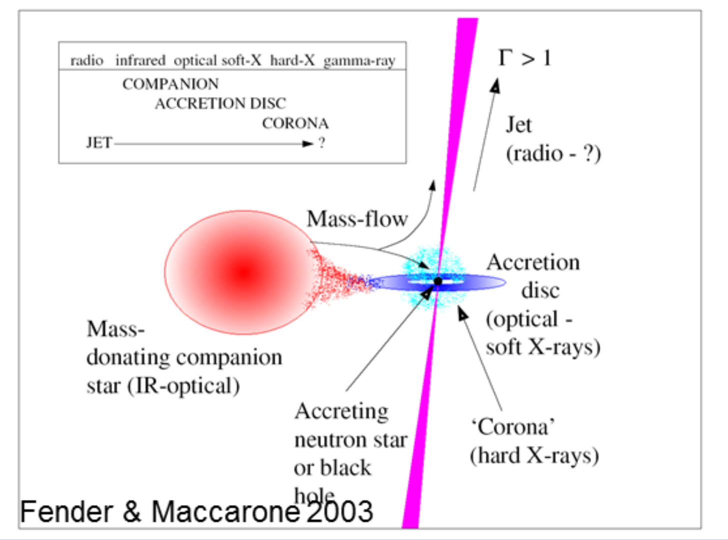
Even with sensitivity to ~60 keV, i.e., past the peak of the Compton reflection hump, modeling degeneracies remain for NuSTAR/HXI alone. Above, the temperature of the Comptonizing electrons cannot be constrained to better than a factor 2.

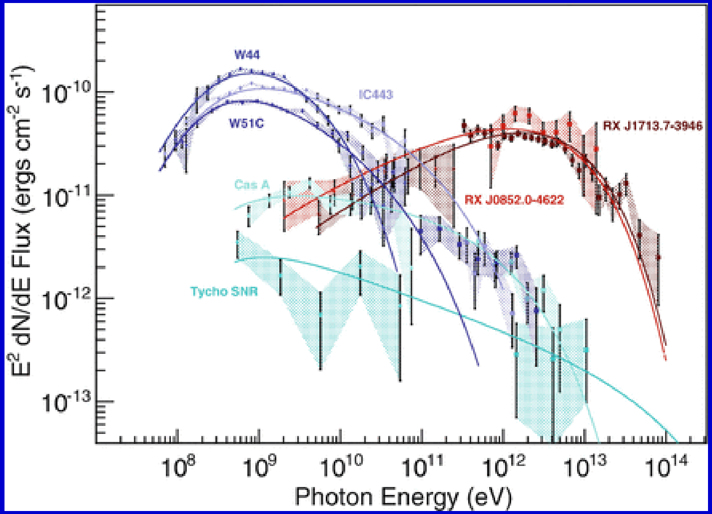


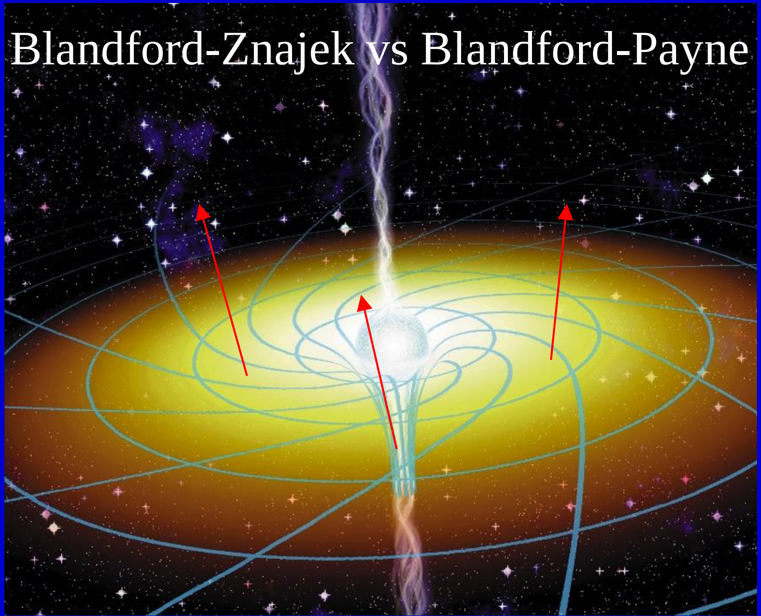


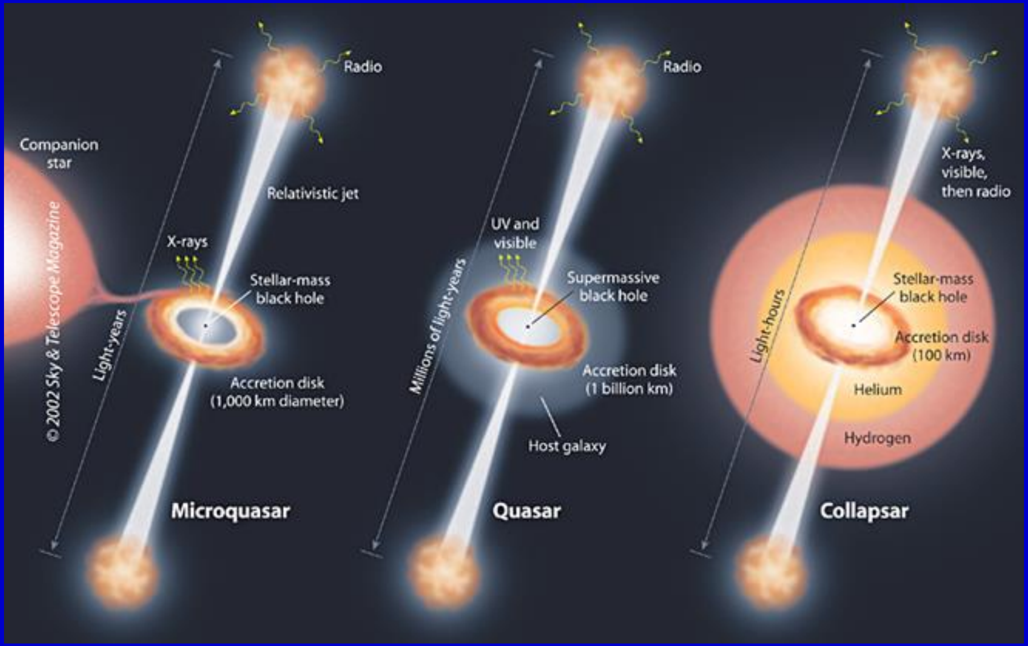
Gamma-Ray Emitting AGN

P. Coppi, Yale









Bla

a blazar sequence??

Lee et al., U Wash.

?

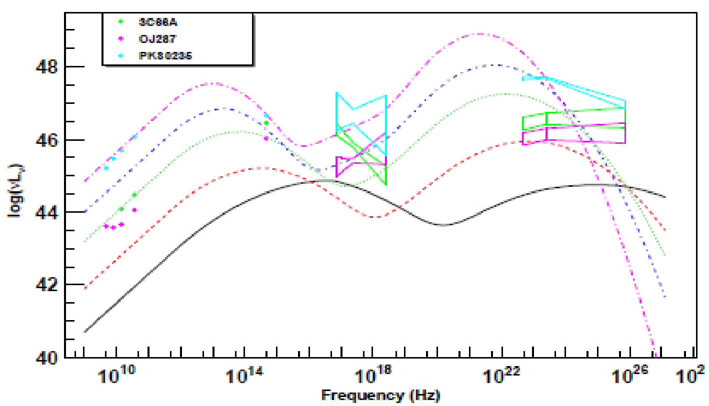
Model Parameters

	B [G]	δ	R [10^{15}cm]	n_e [ergs cm^{-3}]	E_{break} [log eV]	E_{max} [log eV]
3C 66A	0.05	50	28	0.03	9.8	10.8
0235+164	0.05	50	58	0.04	9.3	10.8
OJ 287	0.05	50	16	0.1	9.5	10.8
3C 273	0.05	50	16	0.6	8.8	9.7
3C 279	0.05	50	2.8	15	9.4	10
1502+106	0.05	50	13	0.9	10	10
1510-089	0.05	50	2.5	15	9.7	9.8
3C 454.3	0.05	50	11	5	9.3	9.8

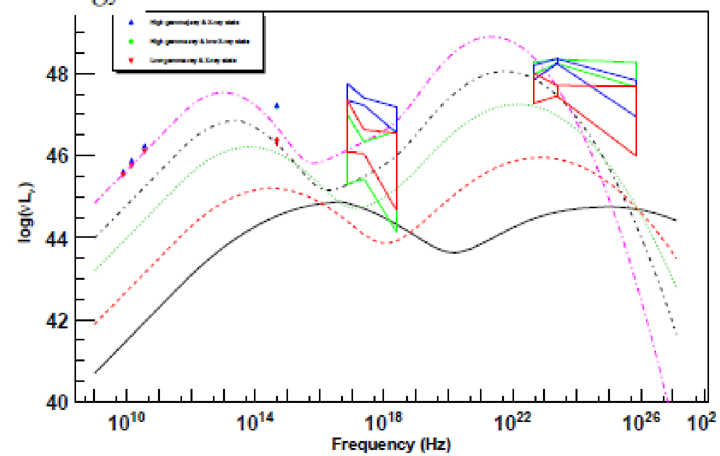
B: magnetic field; δ: Doppler factor; R: radius of the emission region; n_e: electron energy density; E_{break}: break energy; E_{max}: maximum energy

The time-av
the blazar s
while some

Different Gamma-ray and X-ray Emission States



The time-averaged SEDs of the three BL Lac sources are superimposed on the blazar sequence. The three BL Lac sources do not fit well into the blazar sequence. The observed low energy component extends to X-ray energies.



The SEDs of PKS 0235+164 in three different gamma-ray and X-ray emission states are superimposed on the blazar sequence. The variability is more pronounced at X-rays than at gamma-rays, and the observed gamma-ray energy spectra are harder than expected.

Code units for leptonic source, recap

Good choice allows us to scale code to many environments, keep variables ~ unity (helps with numerical precision), and often let's us quickly do order of magnitude estimates.

Convenient choice: $E' = \text{Energy} = E/m_e c^2$, $T' = \text{Time} = T/(R/c)$,

$L' = \text{Length} = L/(\sigma R)^{1/3}$, $N' = \text{Density} = N(\sigma R) = \tau$.

Makes kinetic equations >dimensionless!

$$L_{source,iso} = 4\pi D^2 F_{obs}.$$

$$L_{source} = (Source\ Volume) \times U_{rad} \times (c/R) = (4\pi/3)R^2 c \times U_{rad}$$

$$U_{rad} = \frac{3}{4\pi R^2 c} L_{source}$$

$$N = U_{rad}/(m_e c^2 < \varepsilon >) = \frac{3}{4\pi R^2 m_e c^3 < \varepsilon >} L_{source}$$

Compactness

$$\tau = N' = (\sigma_T R)N = \frac{3\sigma_T R}{4\pi R^2 m_e c^3 < \varepsilon >} L_{source} = \frac{3\sigma_T}{4\pi m_e c^3 < \varepsilon >}\left(\frac{L_{source}}{R}\right) = \frac{1}{< \varepsilon >} l!$$

Given previous SEDs, and high compactness of coronal region, one might think Cyg X-1 could never be significant TeV source… but

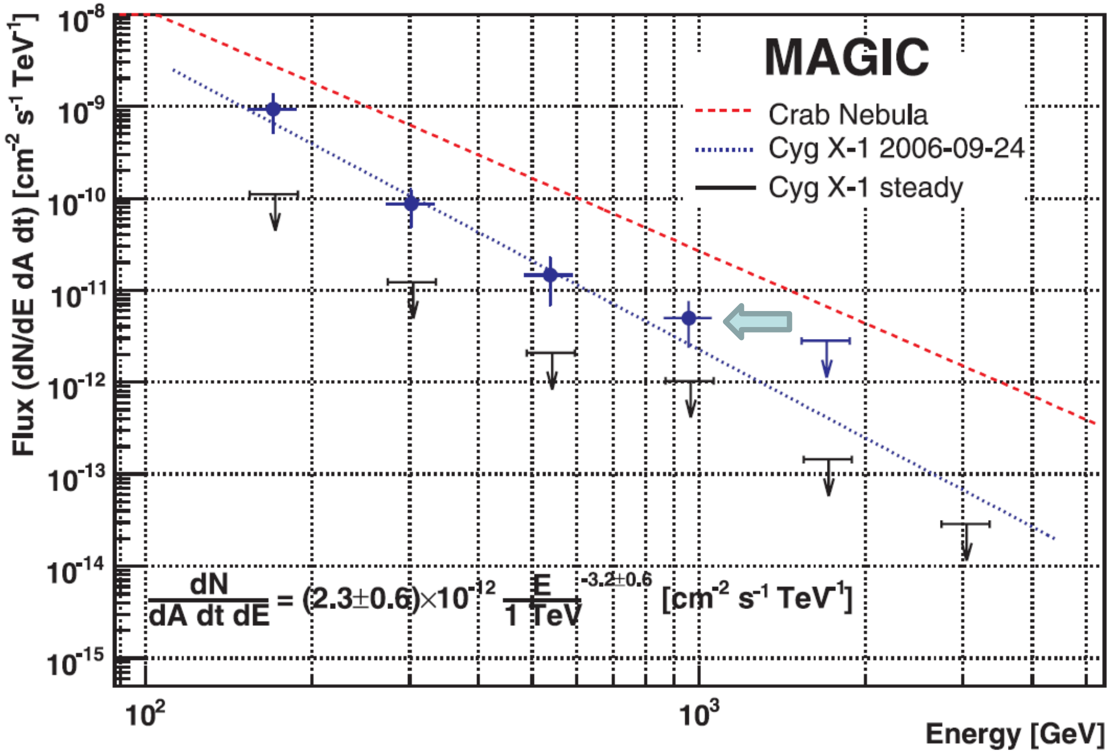


FIG. 1.—Differential energy spectrum from Cygnus X-1 corresponding to 78.9 minutes of EOT between MJD 54,002.928 and 54,002.987 (2006 September 24). Also shown are the Crab Nebula spectrum, the best fit of a power law to the data, and the 95% confidence level upper limits to the steady γ-ray flux (Rolke et al. 2005).

Albert et al 2007