A γ-ray View on MWL Studies of Blazars

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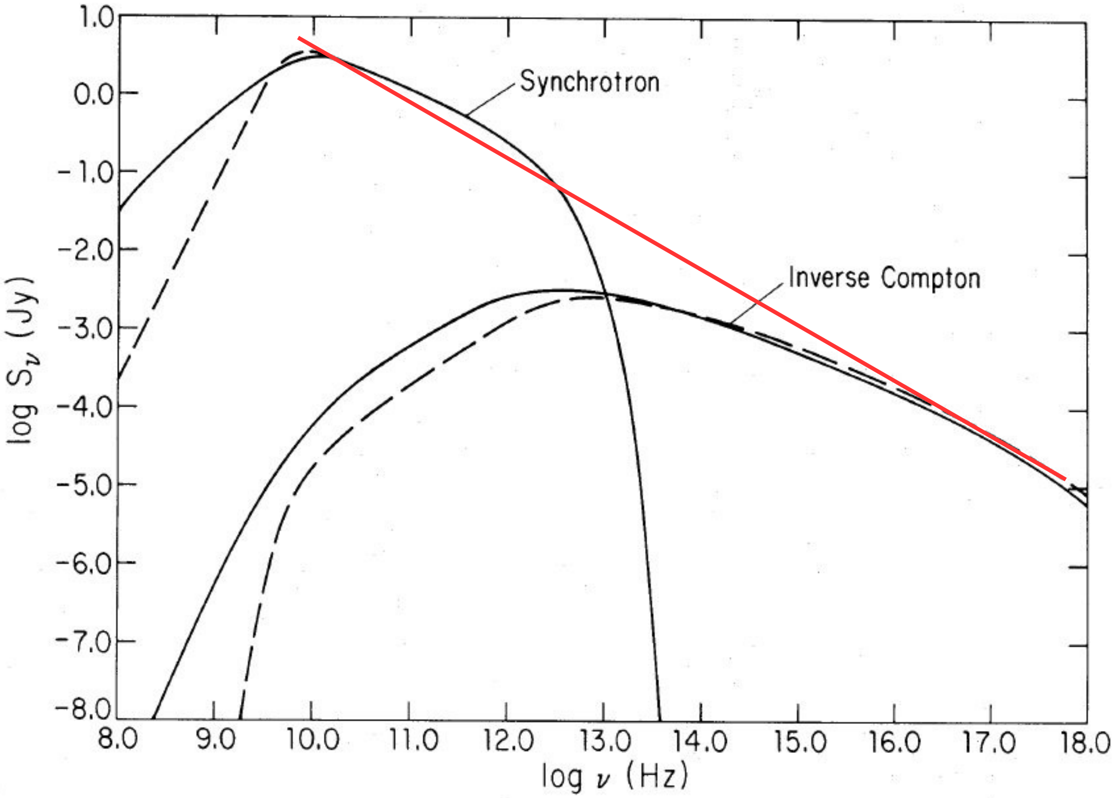
MWL studies of Blazars



Marscher, ApJ 216, 244, 1977

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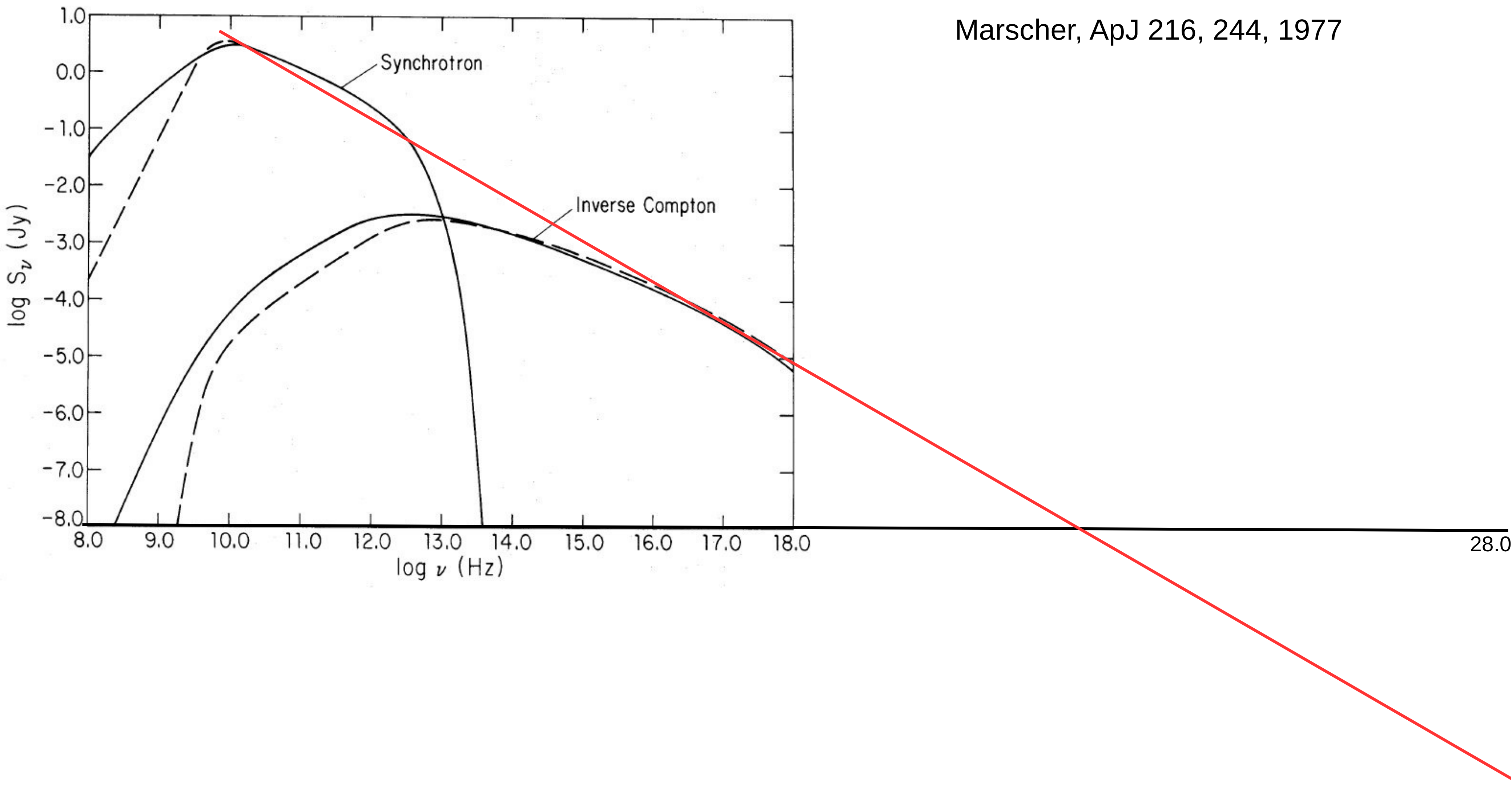
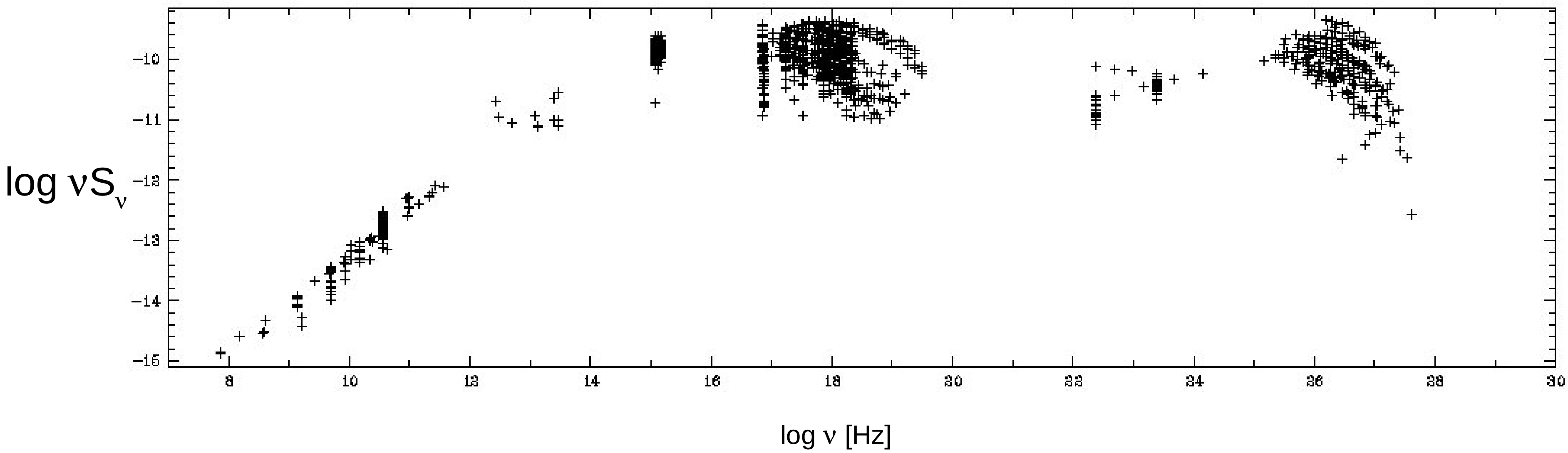


Marscher, ApJ 216, 244, 1977

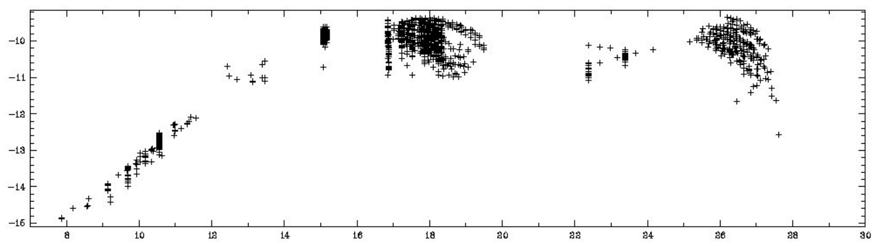
γ rays: Top End and Bottom End



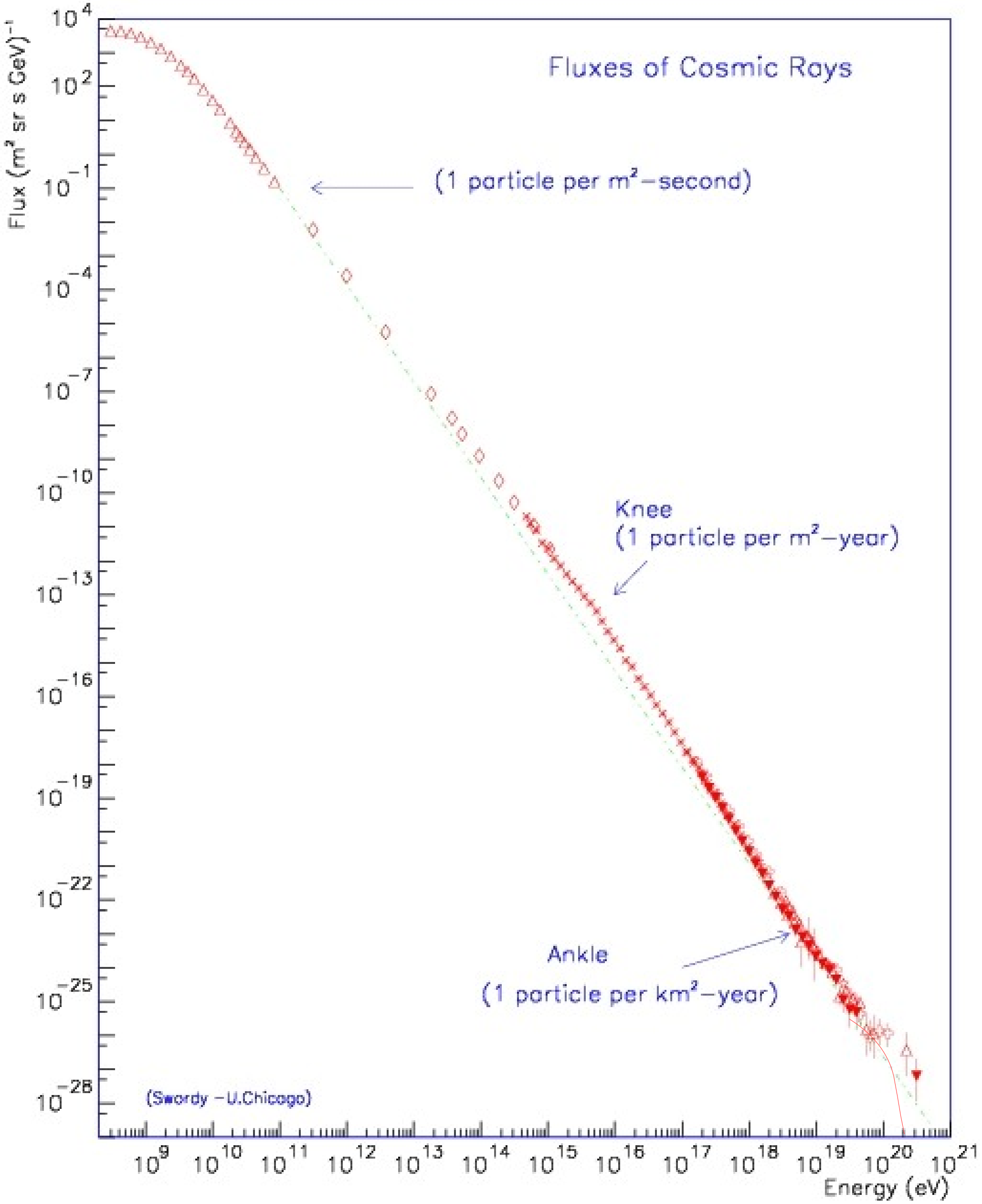
Measured SED (1104+38, a.k.a. Mrk 421)

- Covering an additional 10 orders of magnitude
- XBLs → Synchrotron emission extends to 10^{20} Hz
- Plotting νS_ν rather than S_ν

γ rays: Top End and Bottom End



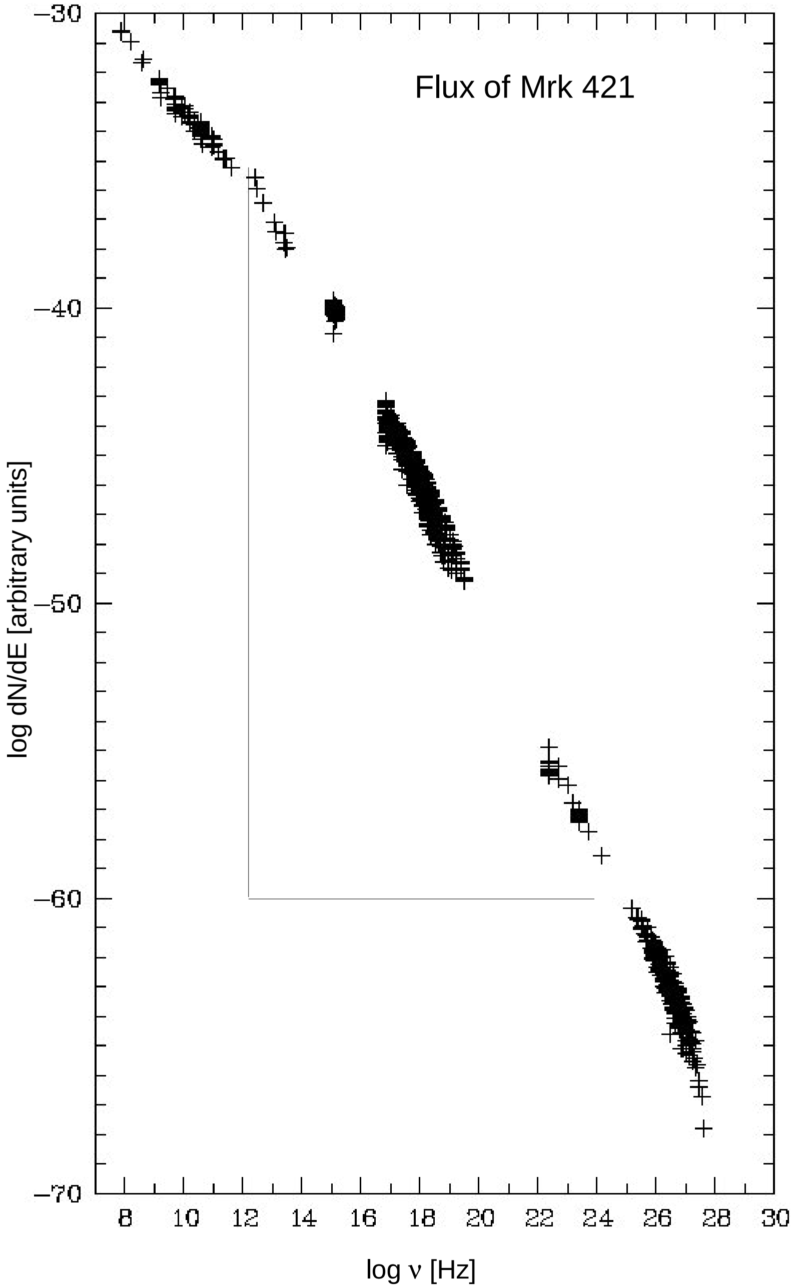
log ν [Hz]

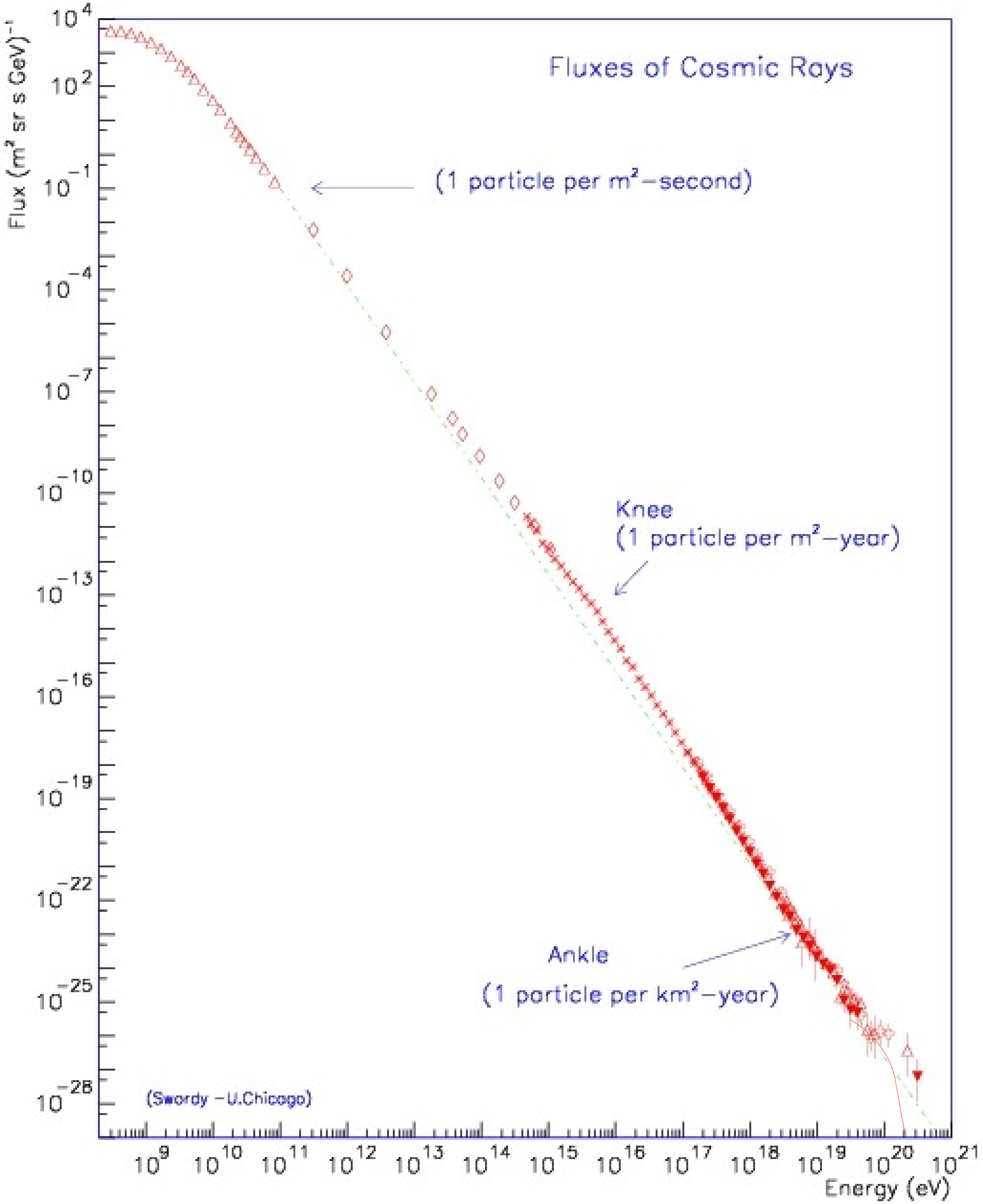


Cosmic Rays (full sky average)
(S. Swordy)

Modified: drop at GZK cutoff

γ rays: Top End and Bottom End





High Energies - Few Photons

TeV: 10 orders of magnitude higher energies compared to X-rays
→ 20 orders of magnitude fewer photons

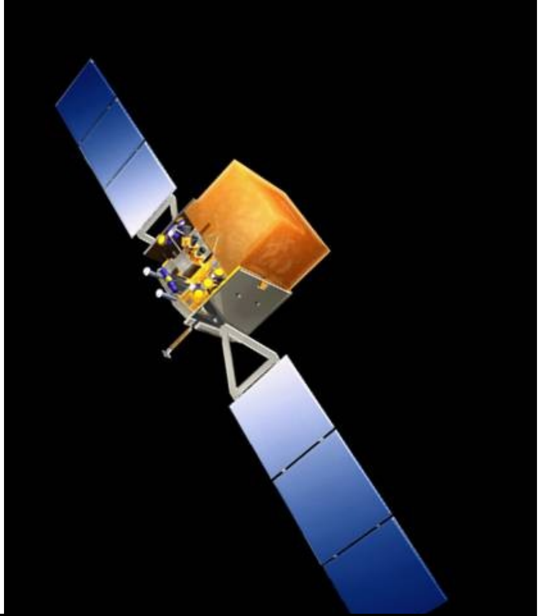
→ (1) Experimental challenges (seeing anything)

→ (2) statistical challenges (poissonian noise in unevenly sampled data)

→ (3) methodological challenges
(few photons and no photons are not very different,
unless few photons get published and no photons get not)

→ upper limits are better then nothing, but flux-data with errors
of the same measurements are much more useful.

Complimentary Techniques



Space-borne Fermi LAT
1 m^2, 100%, 1.5 π sr
10^8 s exposure all sky
Week-decades, very homogeneous
100 MeV – 100 GeV

Ground: HESS MAGIC VERITAS
10^5 m^2, 10%, 0.003 sr
high dynamic range
hours - weeks
100 GeV – 10 TeV

Complementary time-scales and energy ranges

Noise processes and time scales

Variability spectra described by power laws (red noise or 'reddish' noise)

Suggests stochastic processes (what are physics implications?)

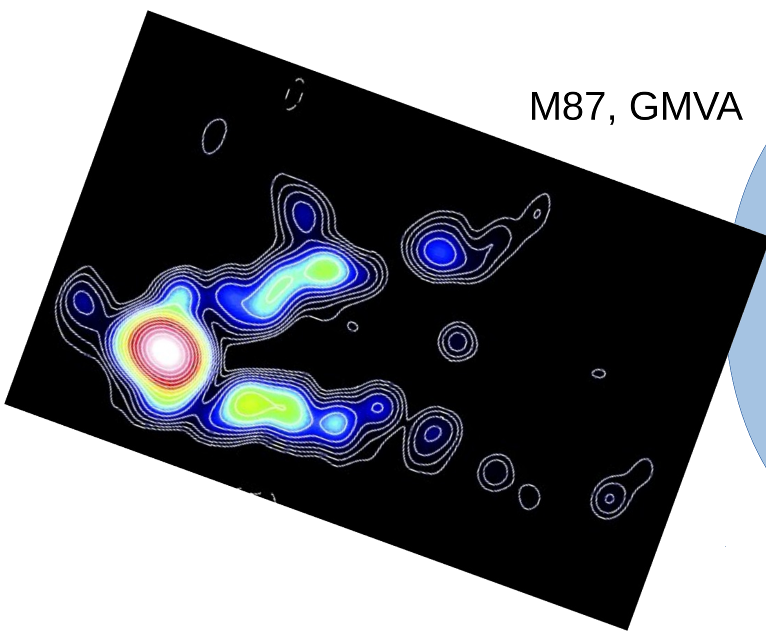
Flare = Increased emission from a distinct volume.
Causality still constrains light-crossing times
(implict assumption of vanishing acceleration times)
Which processes can change fastest?
Acceleration – radiation – amplification – absorption – crossing

In all leptonic models, γ-rays cover high-energy end,
complementing the synchrotron range
→ does this constrain the choices?

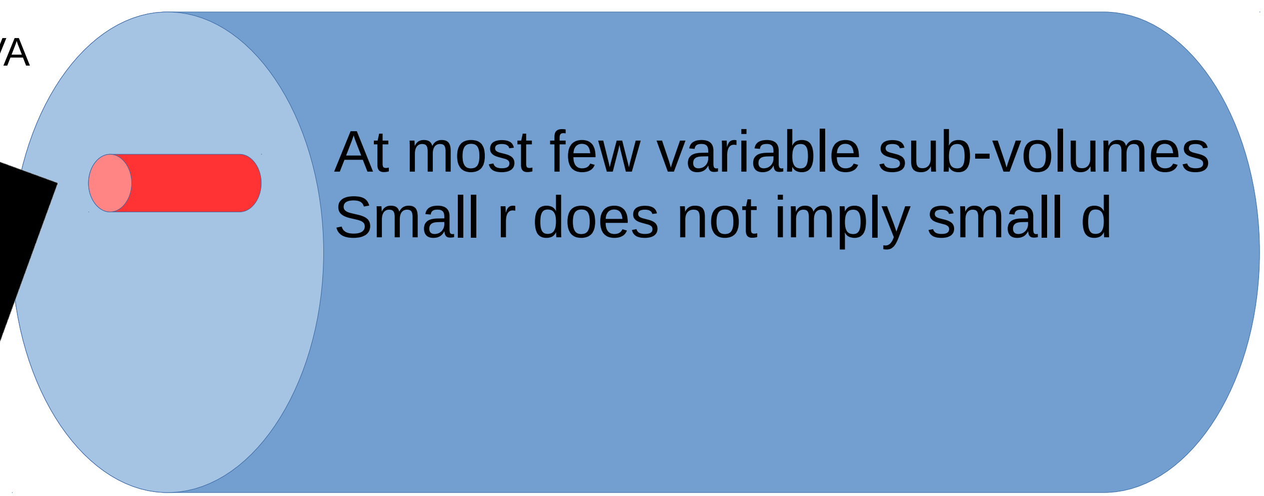
Rapid ('Intraday') variability

The IDV problem: rapid variability implies a compact emission region.
Iteration of the 'Quasar problem':
How to get so much light out of a small volume – beaming uncomfortable

What happens? more light/particle, more particles, (higher energy)?
Cooling/acceleration time scales depend on energy → MWL studies



M87, GMVA



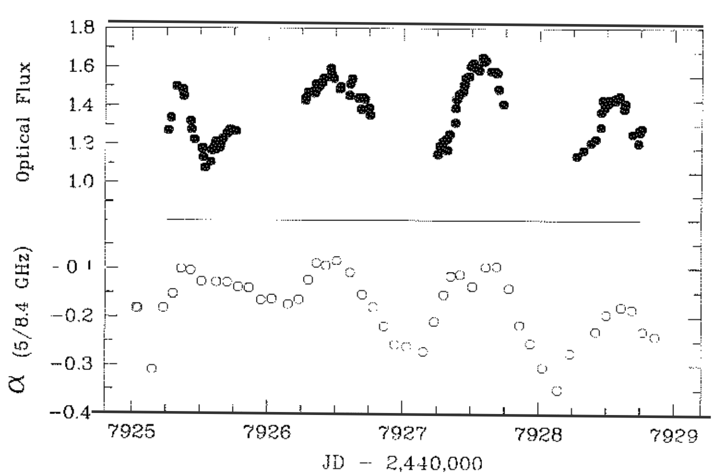
Is GHz IDV intrinsic?

GHz IDV is real (even if it was considered to be impossible).

1) Inferred brightness temperatures exceed IC limit.
Is the limit applicable?

2) Interstellar scintillation is an unavoidable process.
Does it *exclusively* cause IDV ?
(right timescales, right frequency dependence)

→ Trace IDV across the spectrum (many times)



0716+714, WW, ARAA

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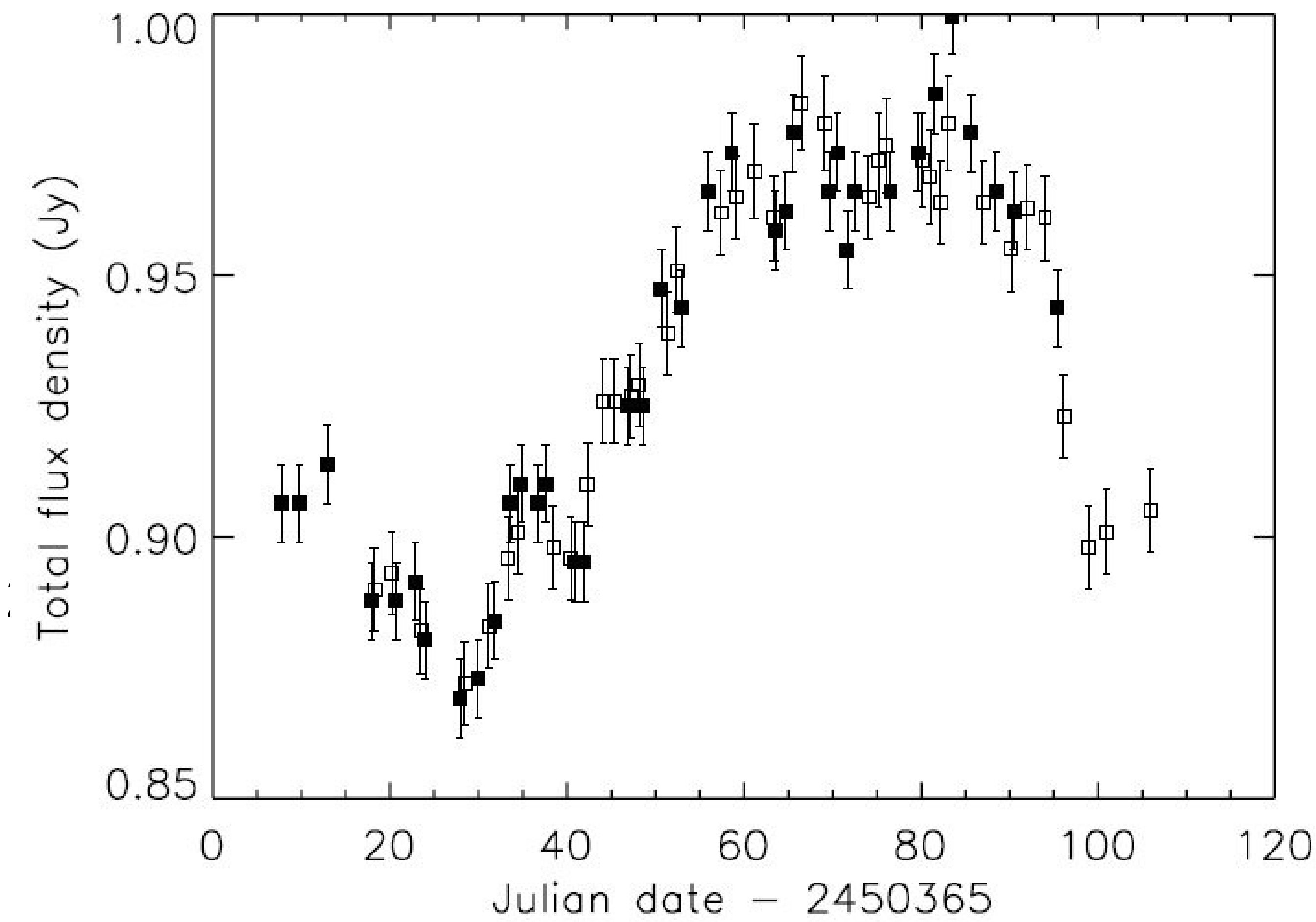
Dave Jauncey: pattern-offset across continents,
annual cycle in IDV timescales.

→ Scintillation causes GHz IDV
But: Scintillation faces the same problem (1)
And: Some IDV is intrinsic (gravitational lensing)



B0218+357 with 10.5d offset between images A & B (15 GHz)

Biggs, Brown, Wilkinson, MN 323, 995 (2001)

And: Some IDV is intrinsic (gravitational lensing)

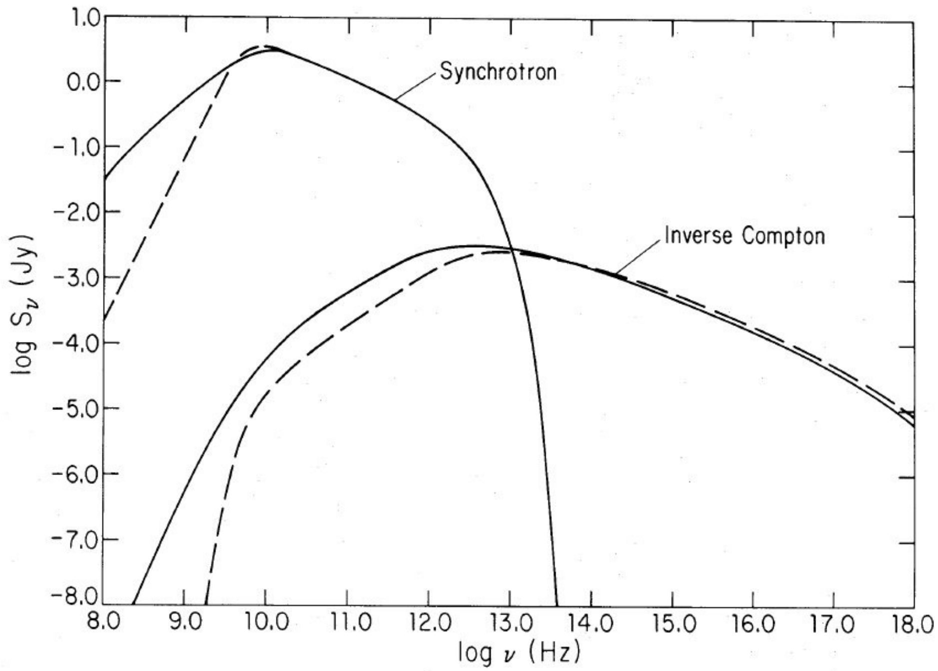
γ rays and Compton catastrophe

Brightness temperature limit 10^{12} K.
For higher T_B (radiation densities) Compton losses are expected:

$$\frac{L_C}{L_S} = 0.5 \left(\frac{T}{10^{12}}\right)^5 \nu \quad \left[1 + 0.5 \left(\frac{T}{10^{12}}\right)^5 \nu\right]$$

(T_B^{10} in 2nd order Compton scattering).
Do we observe this in the gamma-ray domain?

GHz emission due to electrons with $\gamma \sim 1000$. IC boosts photons by γ^2.
1st order/ 2nd order IC boosts GHz into optical / X-ray regime.



γ rays and Compton catastrophe

Brightness temperature limit 10^{12} K set by ratio of synch/IC losses.
T_B^{10} scaling consequence of particle spectra extending to thermal limit.
The high photon densities are due to lowest energy electrons.

Electron spectra with γ_{min} ~100 have lower photon densities/IC losses despite exhibiting similar GHz fluxes → T_B limit increases.

Lowest energy electrons are not seen in synchrotron/IC data
Several lines of arguments suggest $\gamma_{min} > 100$.

Effective TB limit likely to be significantly higher than 10^{12}K in small volumes (with cooled particles diffusing to larger out)

[Irrespective of strong suppression of IC catastrophes by beaming]

Look elsewhere

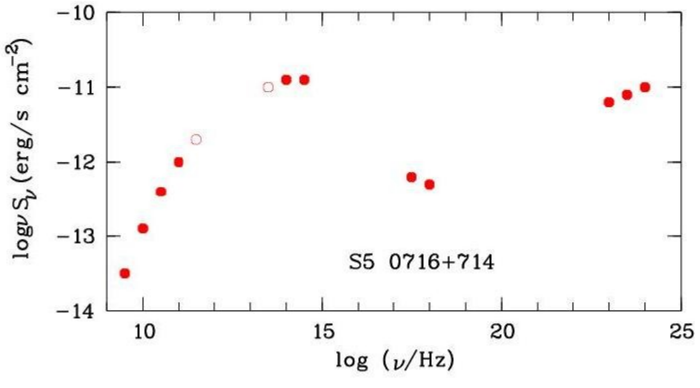
Scintillation (unavoidable) is likely a significant contribution to GHz-IDV
Separating it from all GHz-IDV is difficult.

Can we address the problem in another way?

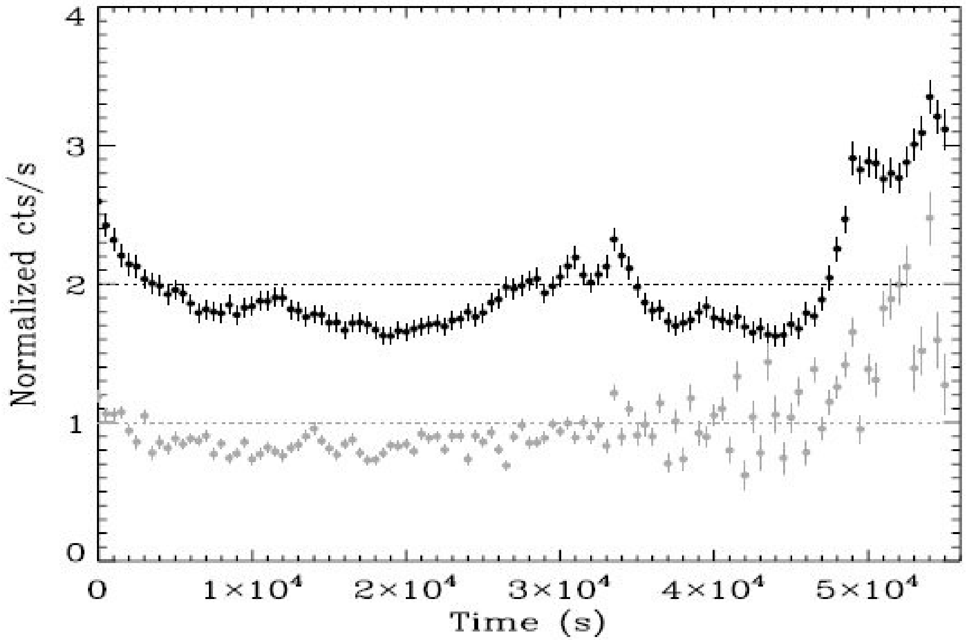
Higher radio frequencies (37 GHz, 230 GHz) do not avoid scintillation.

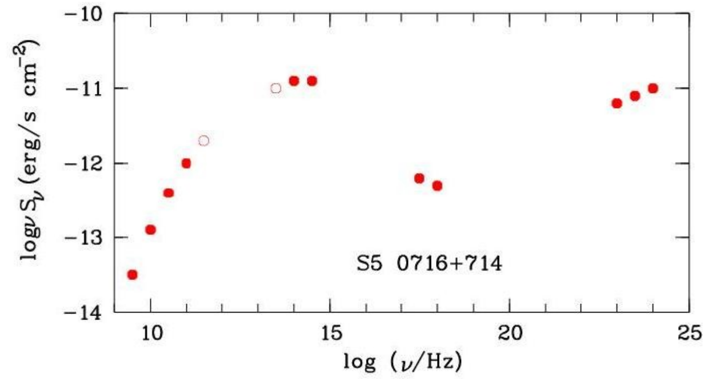
What is happening to low-energy end of particle distribution in compact sub-volumes during flares?

X-ray IDV in sources whose 10^{17} Hz emission is IC dominated (low E)
Cross-correlate high E end (synch, opt) and low E end (IC, X-ray)



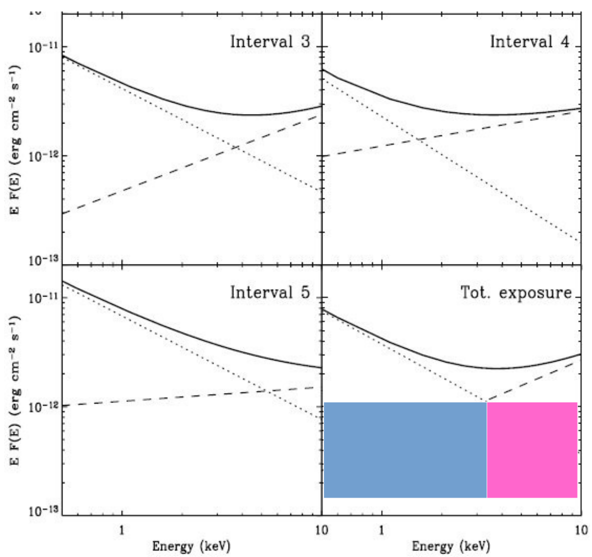
Low E particles and high E photons

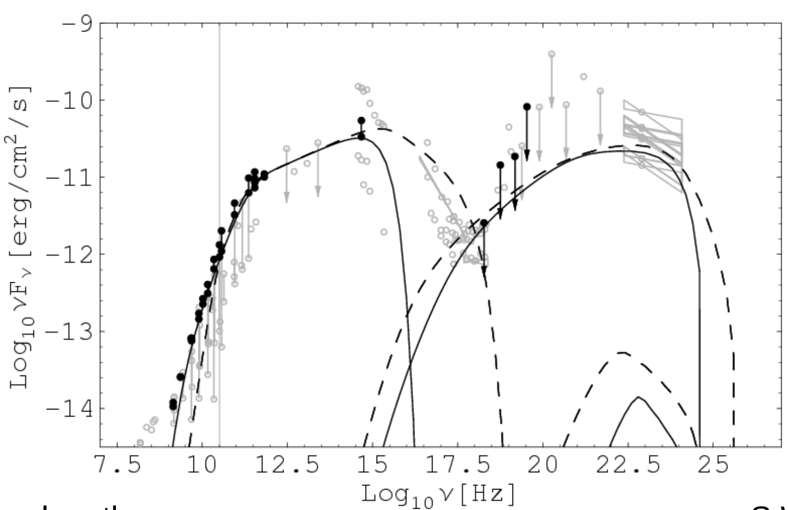




Ferrero & SW, 2005, Ferrero et al., 2006

Low-Energy cut-off Tsang & Kirk, 2007



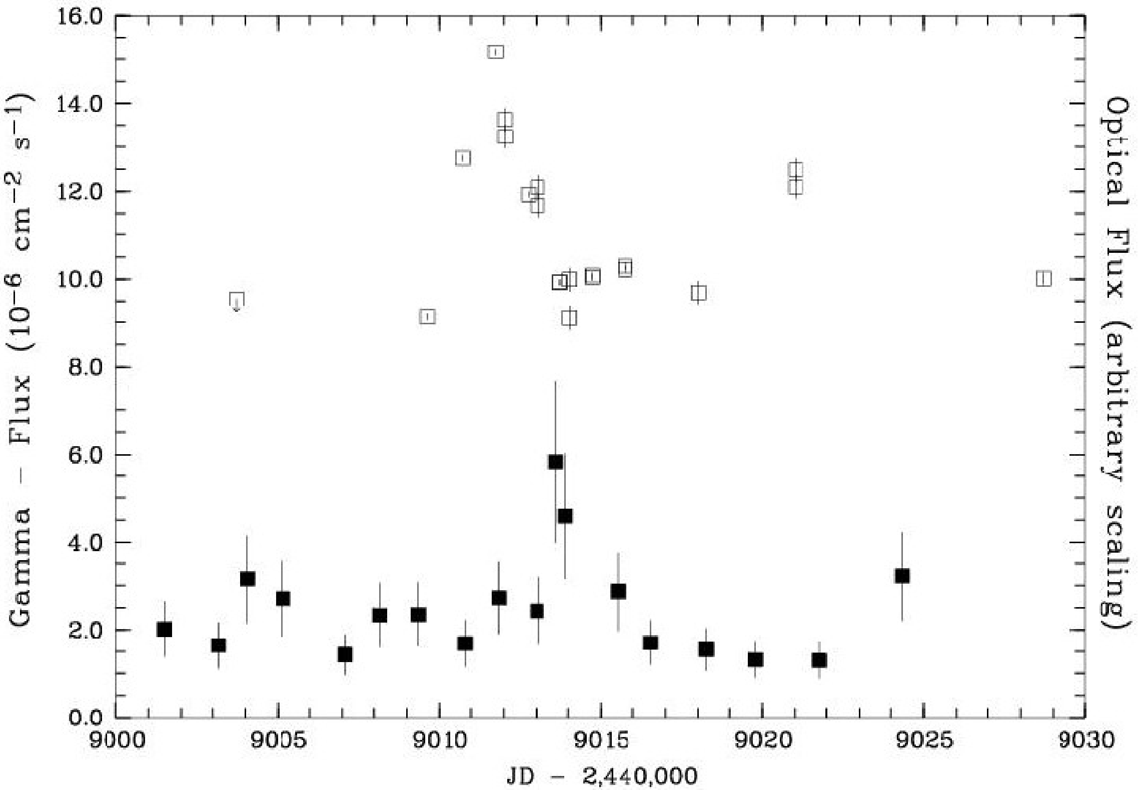


The gamma-ray view

→ IDV by low-energy electrons exists.

Can we trace IDV (particle energy) in IC instead of synchrotron?

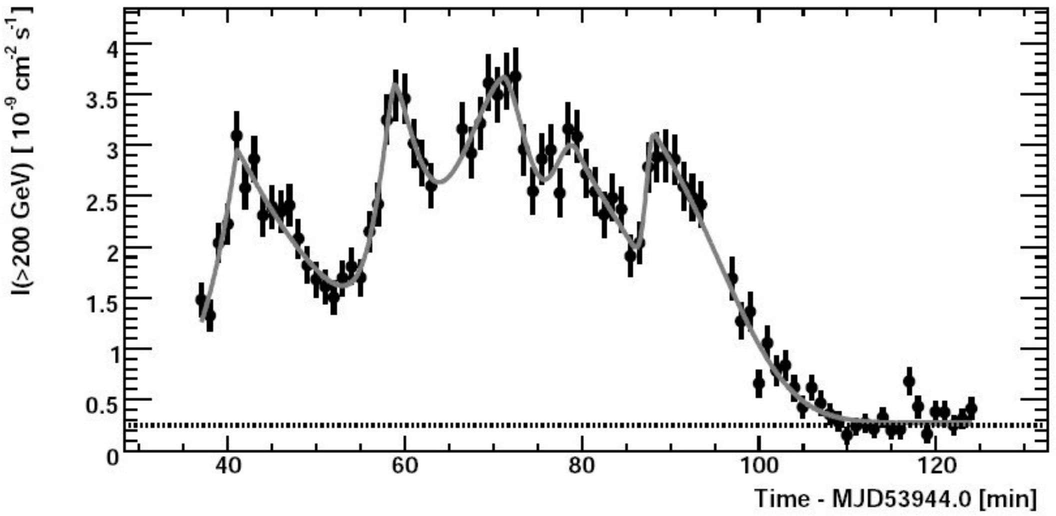
IDV in gamma-ray domain (despite the low photon fluxes)



Rapid γ-ray variability

IDV in gamma-ray domain exists
but it is still unclear whether we can trace IDV (particle energy) in IC:

1: Even at shorter timescales (e.g. PKS 2155-304)



2: Is the IC truly leptonic?

3: Are X-rays in SSC domain?

4: In LBLs the SEDs favor multiple processes.

Leptonic emission

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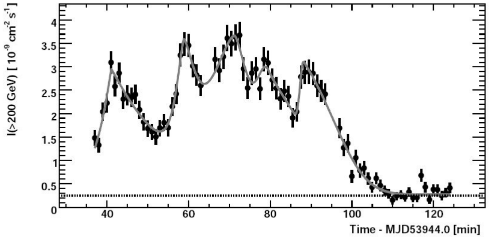


2: Is the IC truly leptonic?
Expect a good match to HE synchrotron

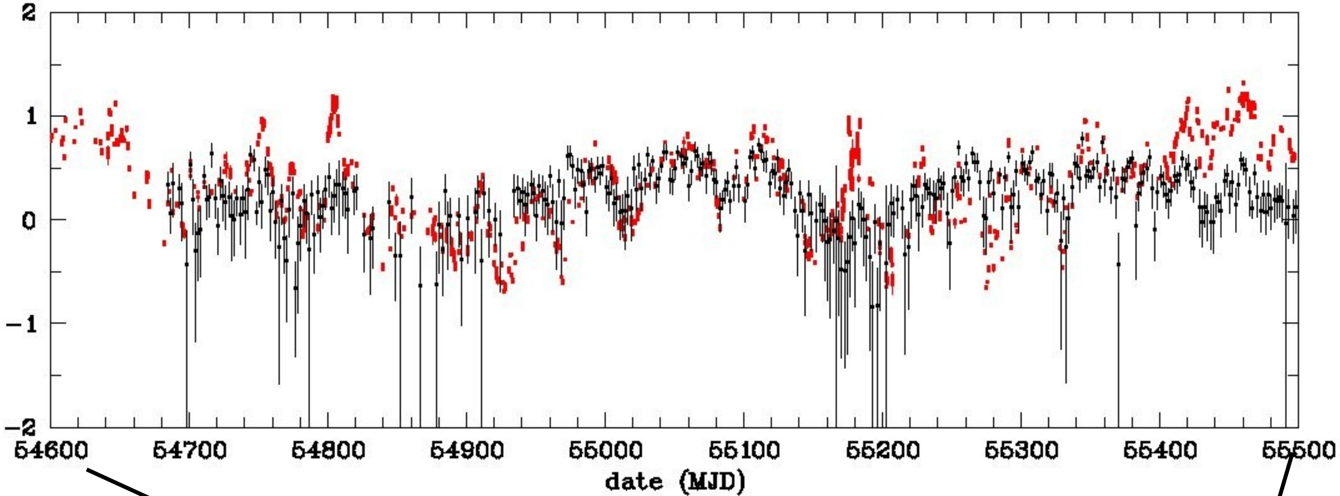
3: Are X-rays in SSC domain?

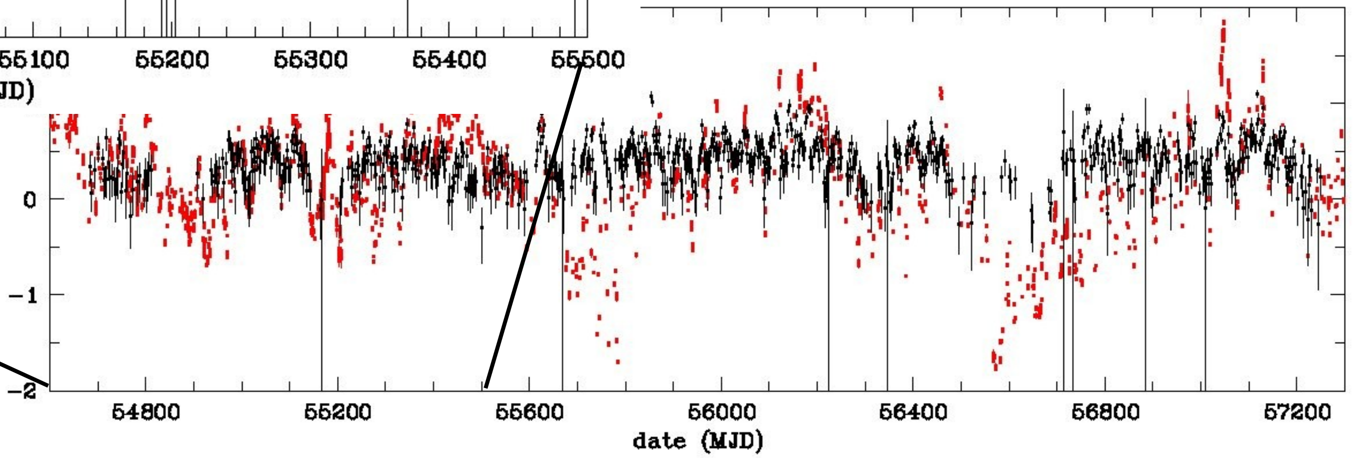
4: In LBLs the SEDs favor multiple processes

Leptoni emission

Continuous optical monitoring of 0716+714 since 2008 and Fermi-LAT:
P8 allows 2d binning with TS>40 for 85% of all bins

Good match on long and short timescales for 70% of all bins
Unique scaling for 60% of all bins
(Wagner, Kurtanidze, Mohamed, in prep.)





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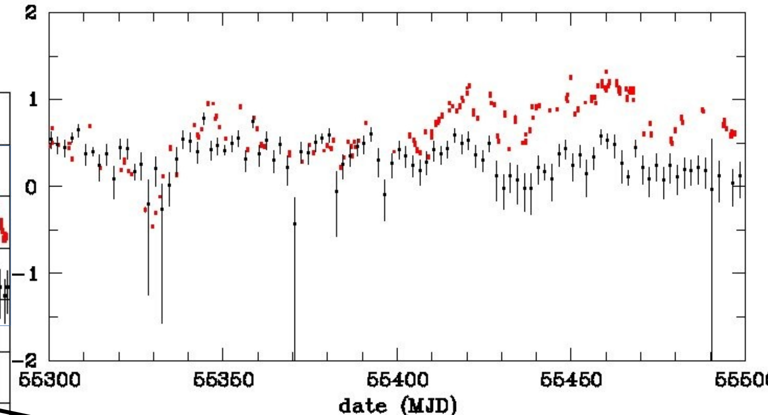

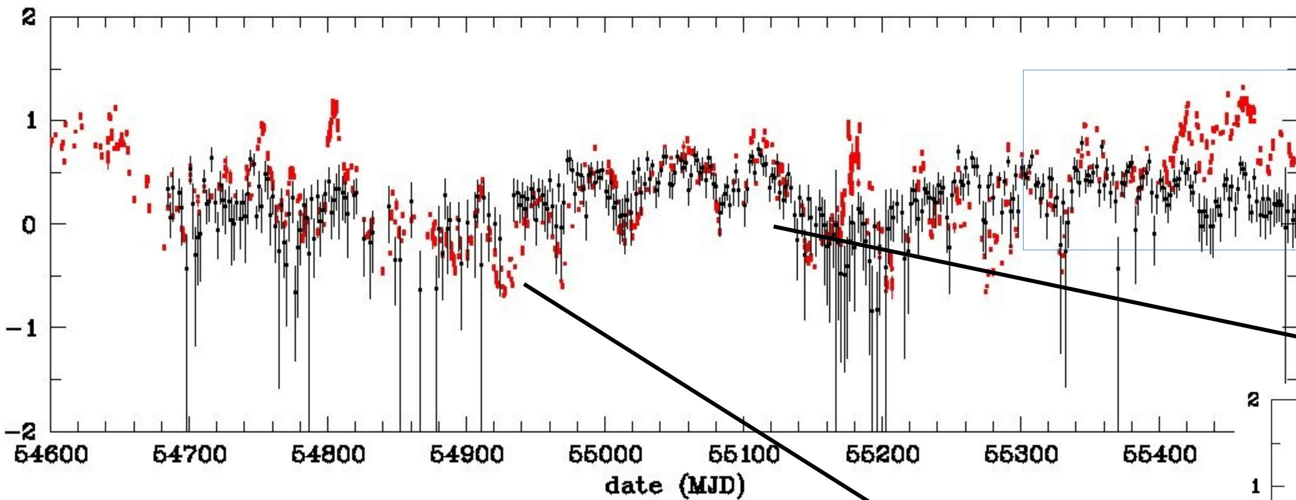

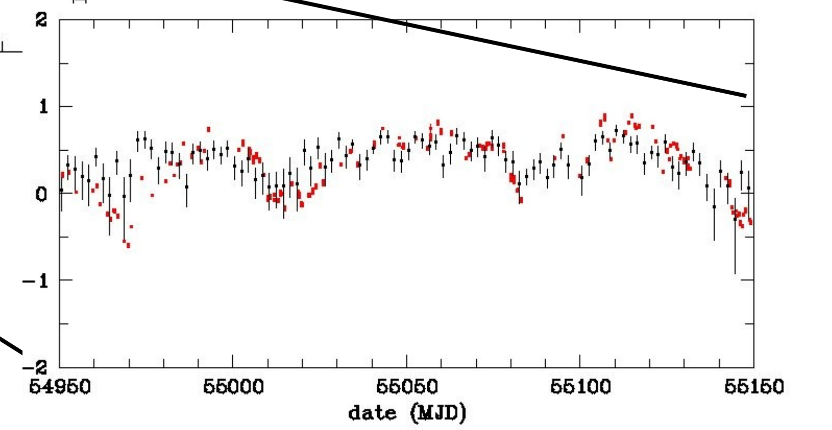

Multiple components

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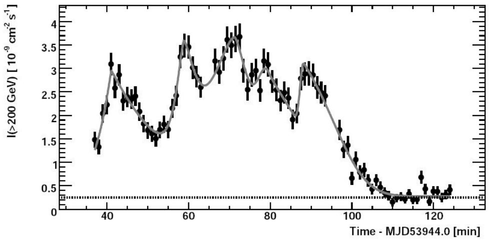

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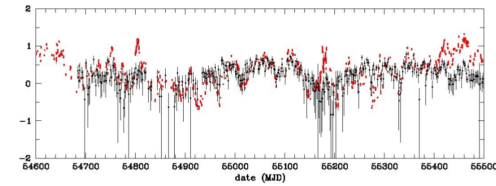
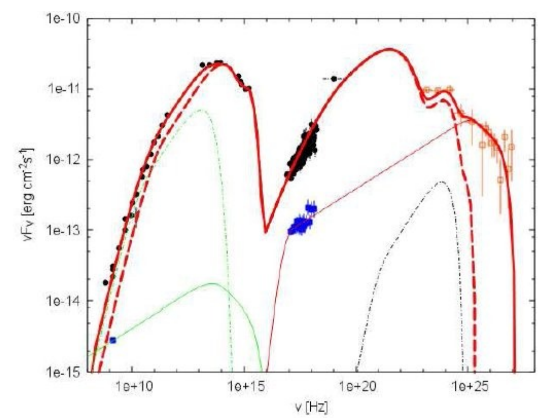


3: Are X-rays in SSC domain?
Most bright gamma-ray sources are HBLs (X-rays are synch.)

4: In some LBLs the SEDs favor multiple components

Zacharias & SW, 2016

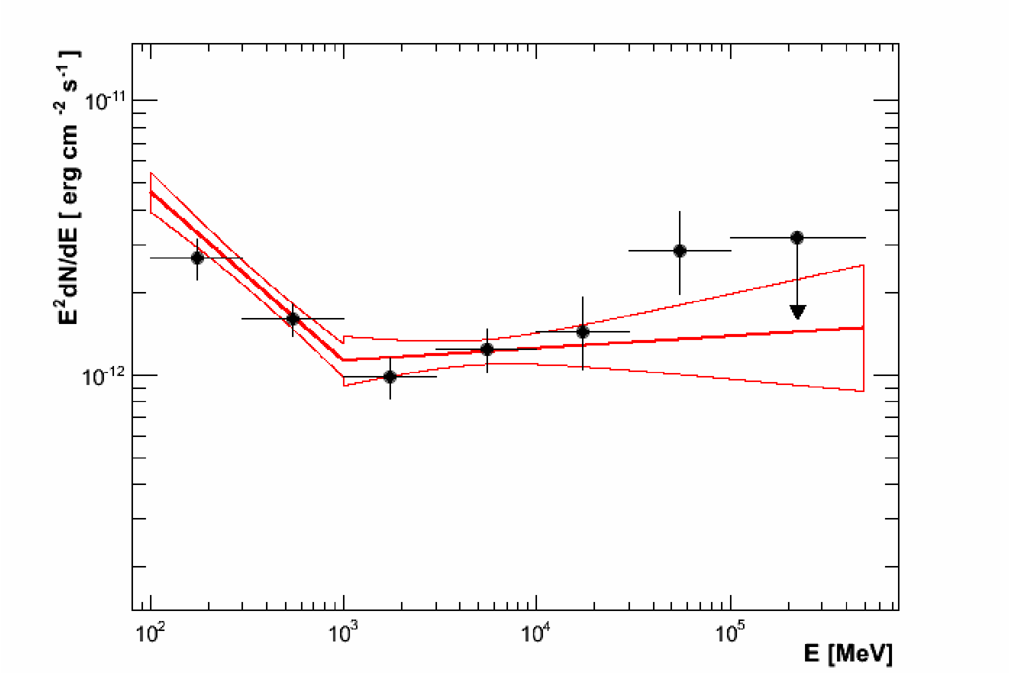


Multiple components

Gamma ray domain displays
multi-component SEDs

(M. Mohamed)

Suggested in many objects in SEDs
Composed of data from
Non-simultaneous observations
(e.g. Fermi LAT and VHE data)



In simultaneous data it is often difficult to cover a sufficiently wide energy range.

Several options to explain hardening, but multi-particle components is often the preferred option.

Multiple components

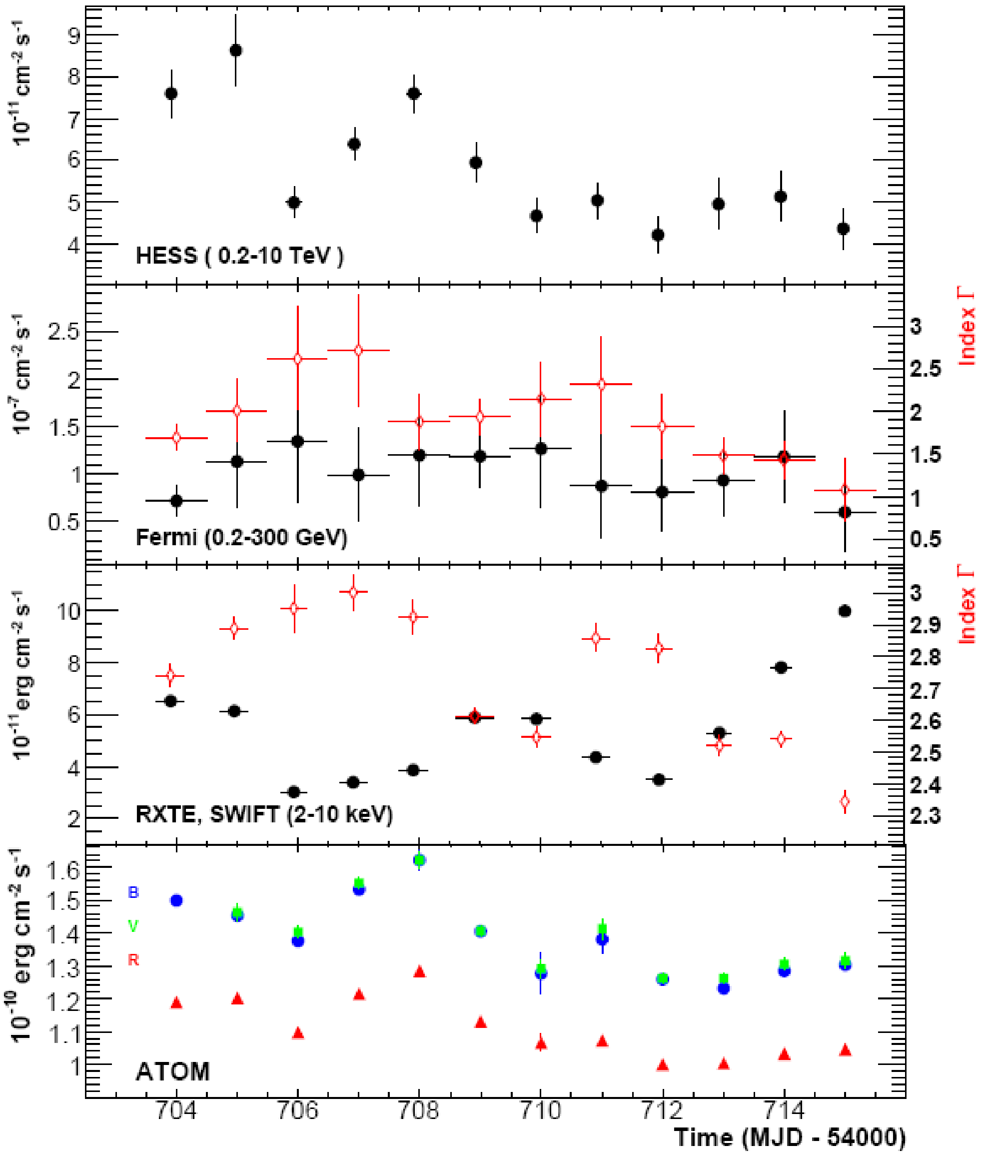
Different components with different variability patterns

PKS 2155-304
(HESS coll. and Fermi coll., 2009)

VHE matches better
to optical synchrotron
than to X-rays
(opposite to LAT)

Inconsistency to simple models.

Flares due to changes in particle spectrum?



Summary

Rapid variability is observed throughout the EM spectrum.

Intrinic variability by low energy particles (direct and indirect)

IC catastrophes are not inevitable; SSC(GHz) not in γ-ray range

Many objects exhibit continuous optical-gamma correlations without lags and little scatter in Compton dominance

However: A growing number shows clear evidence of distinct multi-component particle distribution functions

Advertisement: LAT-0716 photon arrival time project: Talk to me, or email swagner @ lsw.uni-heidelberg.de