Extragalactic results from Fermi:

LAT observations of blazars and implications on their structure

Fermi GST / LAT collaboration
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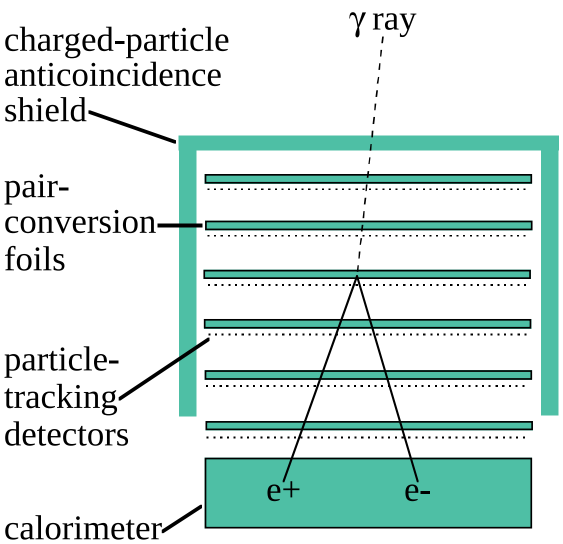
Fermi (a.k.a. GLAST) Large Area Telescope is in orbit



* Principle of operation:

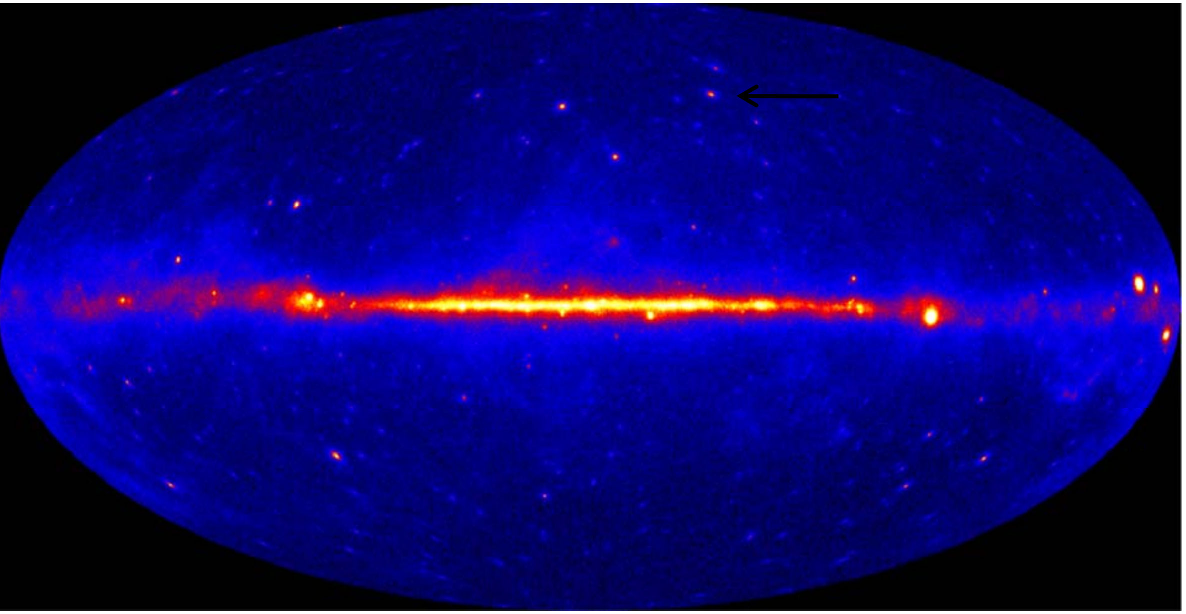
* γ-rays interact with the hi-z material in the foils, pair-produce, and are tracked with silicon strip detectors

* The instrument “looks” simultaneously into ~ 2 sr of the sky

* Energy range is ~ 30 MeV – 300 GeV, with the peak eff. area of ~ 12,000 cm^2 - overlap with TeV observatories

* Point-spread function is energy dependent

* Silicon strip detectors: GLAST is a transistor, vs. EGRET – a vacuum tube



Fermi sky after ~ six months:
Projection in Galactic coordinates

As expected, Fermi / GLAST is detecting many jets in active galaxies (a.k.a. “blazars” – observational classification)

A number (all?) of those are showing rapid variability, flare-like behavior

Several results of objects measured early in Fermi operations: 3C454.3, PKS 1502+106, …

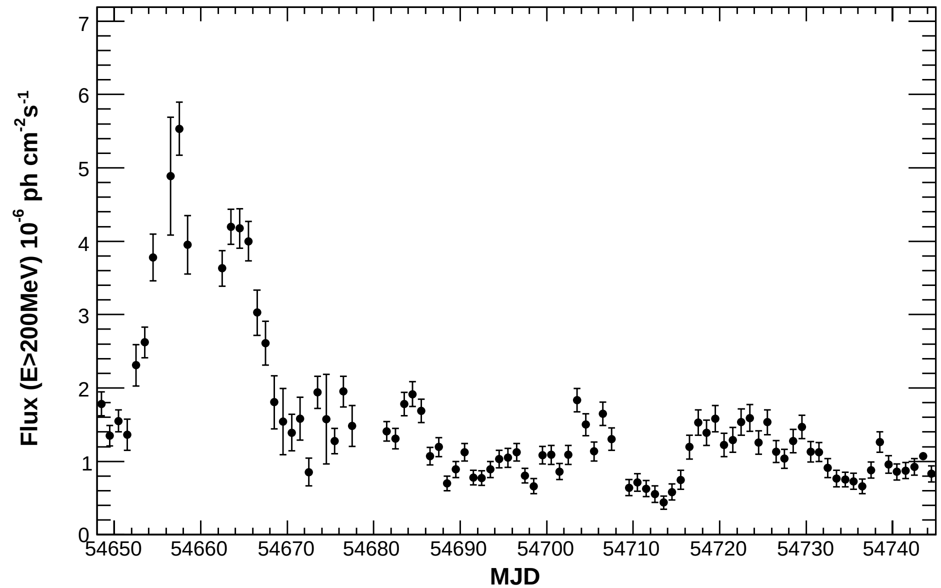
First list of gamma-ray bright AGN is in press (the “LBAS” paper, Abdo et al. 2009)

Blazars are sources of radiation in all measured bands: many are known for their strong TeV gamma-ray emission

What is the nature/structure of blazars? Approach to their study is like peeling an onion: study the broad-band spectrum and variability, understand the radiation process, deduce the process that energizes the radiating particles, infer the ultimate energy source

-> relativistic jet pointing close to our line of sight powered by accretion of matter onto a black hole in the center of the host galaxy

3C454.3 with LAT



Vital statistics:

* Well-known radio source, identified with an OVV quasar at z = 0.859

* Good multi-epoch VLBI data, superluminal expansion, $\delta = 25$, $\Gamma_{jet} \sim 15$, $\theta \sim 0.8^{o}$

* Detected by EGRET, AGILE

• Very active (bright, rapidly variable) since 2000

• Results appeared in Abdo et al. 2009

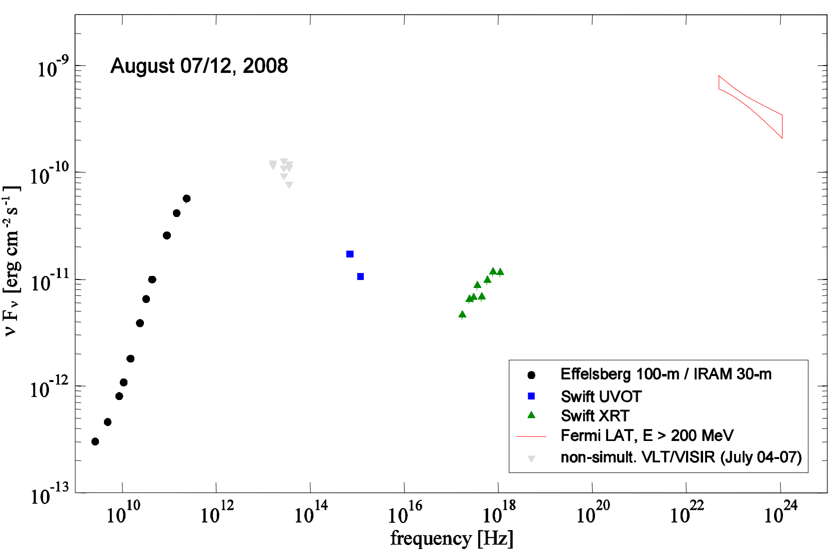
• 3C454.3 has been clearly detected in the early Fermi LAT data, and showed rapid flares, with the risetime on a scale of ~3 days

• Such rapid variability by itself implies a very compact emission region which would be optically thick to the escape of γ-rays via e+/e- pair production -> another way to determine

• Doppler factor

• Here, $\delta > 6$ – consistent with the VLBI-measured jet geometry

• Broad-band spectrum generally well-described by synchrotron-Compton models



Snapshot of the broad-band spectrum for Aug 7-12 2008

3C454.3 with LAT

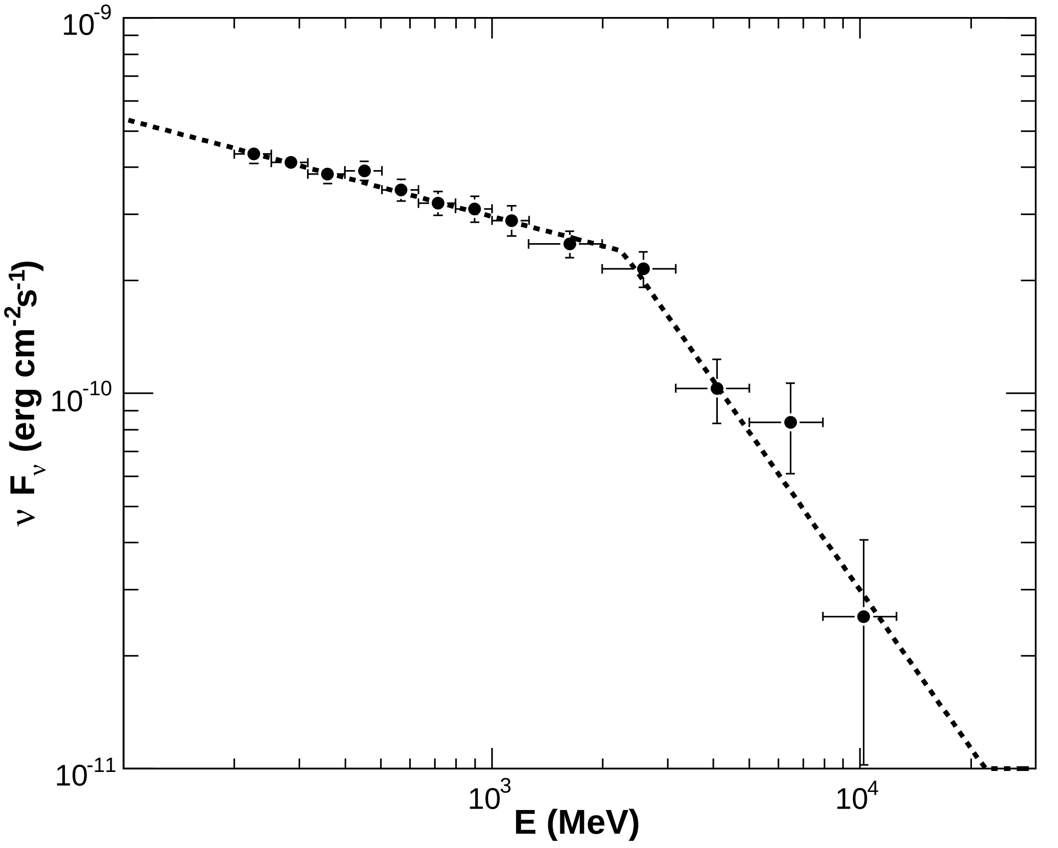
• The quality of Fermi LAT data is good enough to measure departures from simple spectral forms

• 3C454.3 LAT spectrum is not a simple power law

• It steepens to higher energy – can be described as a broken power law with a break, Γ_1 ~ 2.3 to Γ_2 ~3.5 at E_{br} ~ 2 GeV

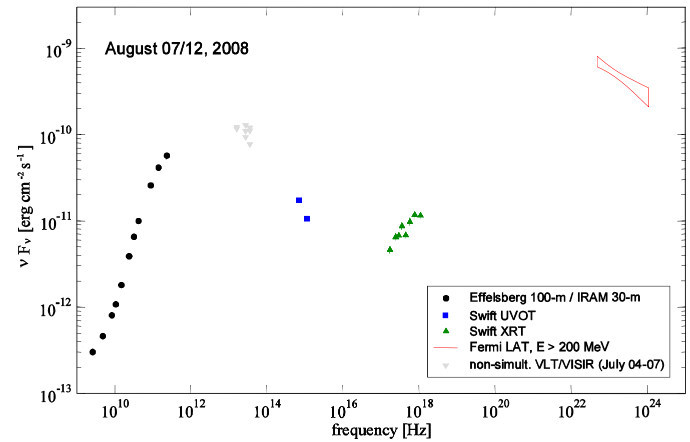
• Broken power law isn't a unique description

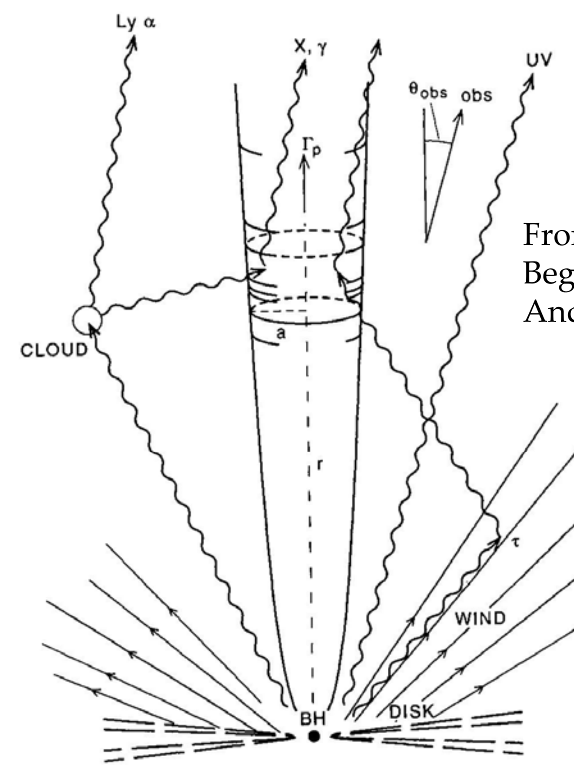
* Very important to measure the details of steepening: Fermi I vs. Fermi II? (Stawarz's talk)



3C454.3 with LAT

- Best description of the broad-band spectrum is via synchrotron + Compton models invoking distribution of relativistic electrons
- Origin of the spectral break?
- Not a simple "cooling break" (expected $\Delta\alpha=0.5$)
- Instead, it can be either due to γ–γ absorption on "local photons" due to the accretion disk, or a signature of intrinsic break in the electron distribution
- First explanation is possible, but, given the comparably weak X-ray emission expected from the accretion disk – somewhat unlikely
- Broken power law of the electron distribution is a better explanation: that would indicate the break at Lorentz factor of radiating electrons of γ_{br} ~ a few x 1000
- There, the cooling time scales are quite short, much shorter than the source crossing time - imply distributed acceleration throughout the jet volume





From Sikora, Begelman And Rees 94

FIG. 2.—Geometry of the source. The radiating region, denoted by short cylinder of dimension a, moves along the jet with pattern Lorentz factor Γ_p. Underlying flow moves with Lorentz factor Γ, which may be different.

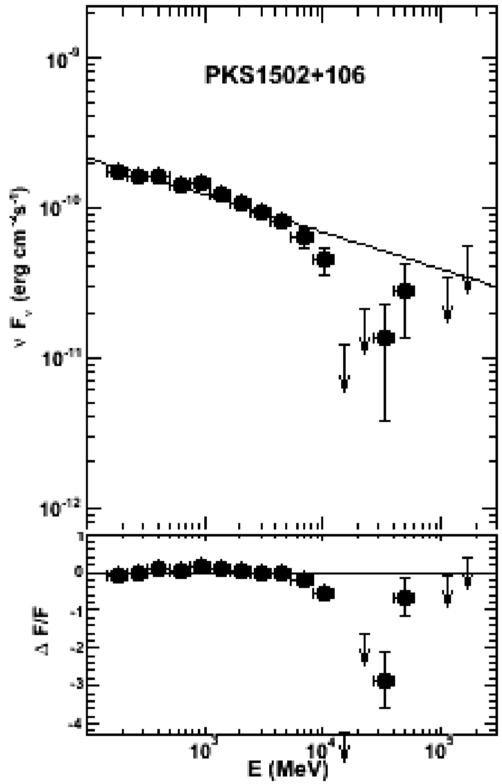
PKS 1502+106

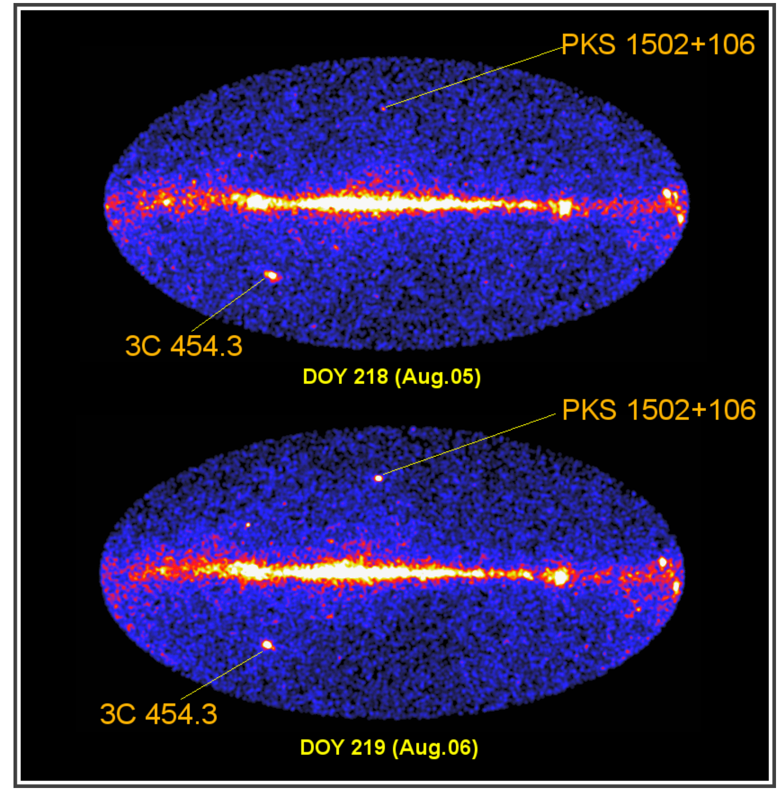
* Another example:
  PKS 1502+106 (aka
  OR 103), at z=1.84 (SDSS)

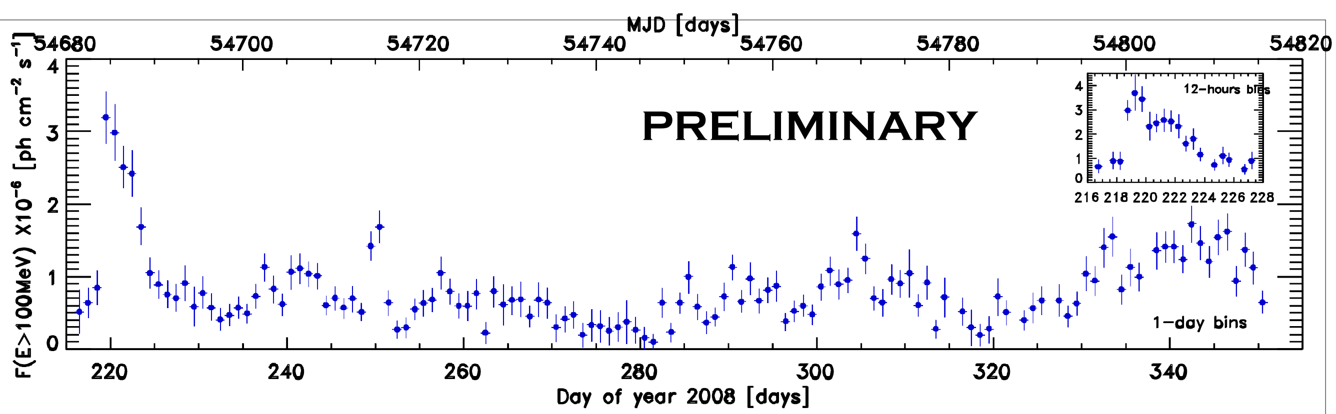
* Extremely rapid flare,
  possibly the highest
  $\Delta L/\Delta t$ detected to date
  in the GeV band (see
  insert in the light curve)

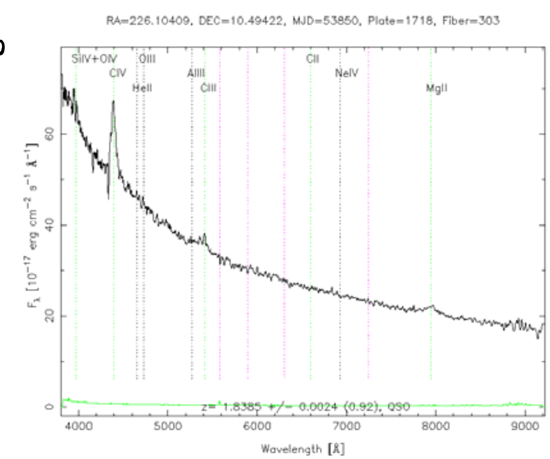
* Allows us to provide
  the independent measure
  of the Doppler factor

* LAT gamma-ray spectrum
  also steepening to higher
  energies



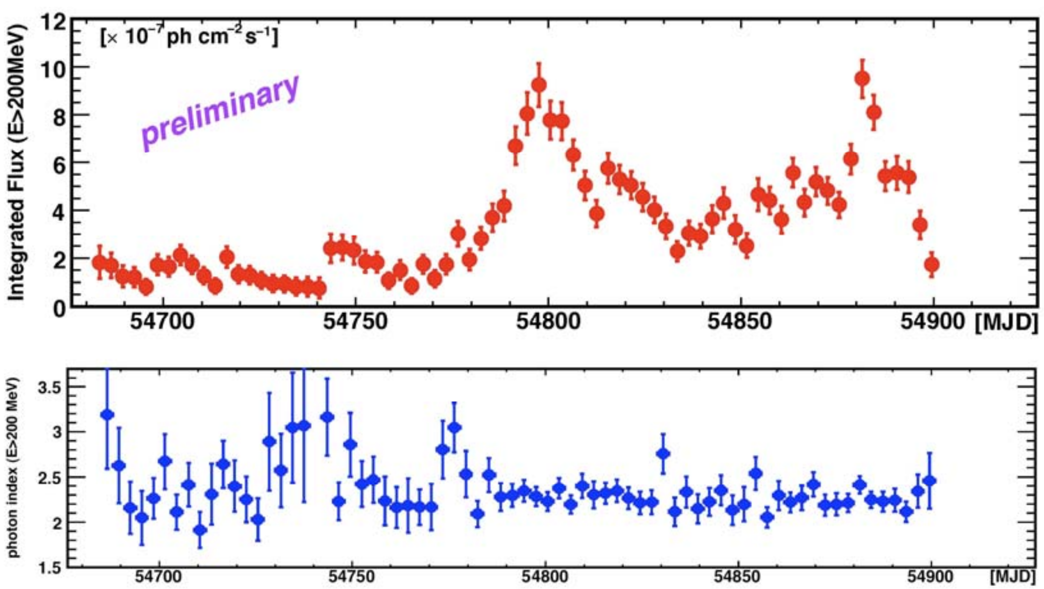




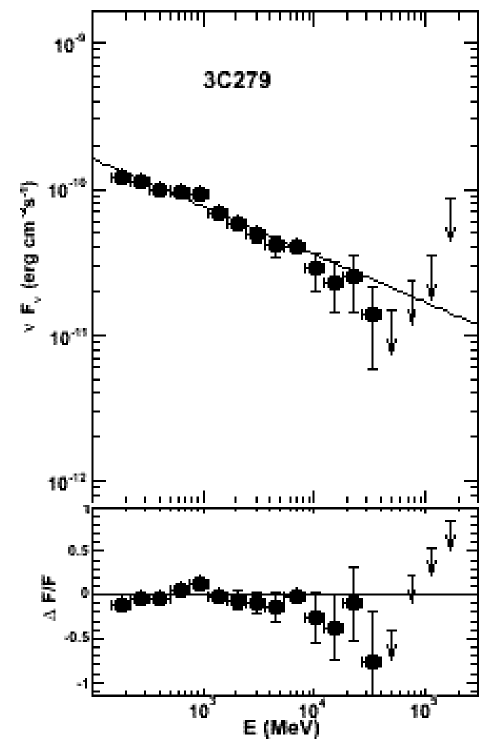


Gamma-ray spectral (in)variability

* Simplest way to study spectral variability is to describe them as a power law,
  plot the time history of index
- Equivalent would be plotting the time-history of the hardness ratio
- Generally, we do not detect significant spectral variability as a function of flux
  (an example - 3C279 – is shown below)
- If flares were "injection -> cooling" would expect spectral evolution
- Instead – distributed, rapid, nearly instantaneous acceleration throughout the volume of the jet might be more appropriate



Gamma-ray flux and spectrum history of 3C279



Spectral diversity

Gamma-ray spectra are quite diverse
(based on the 3-month "LAT Bright AGN Survey" (LBAS): Abdo et al. 2009)

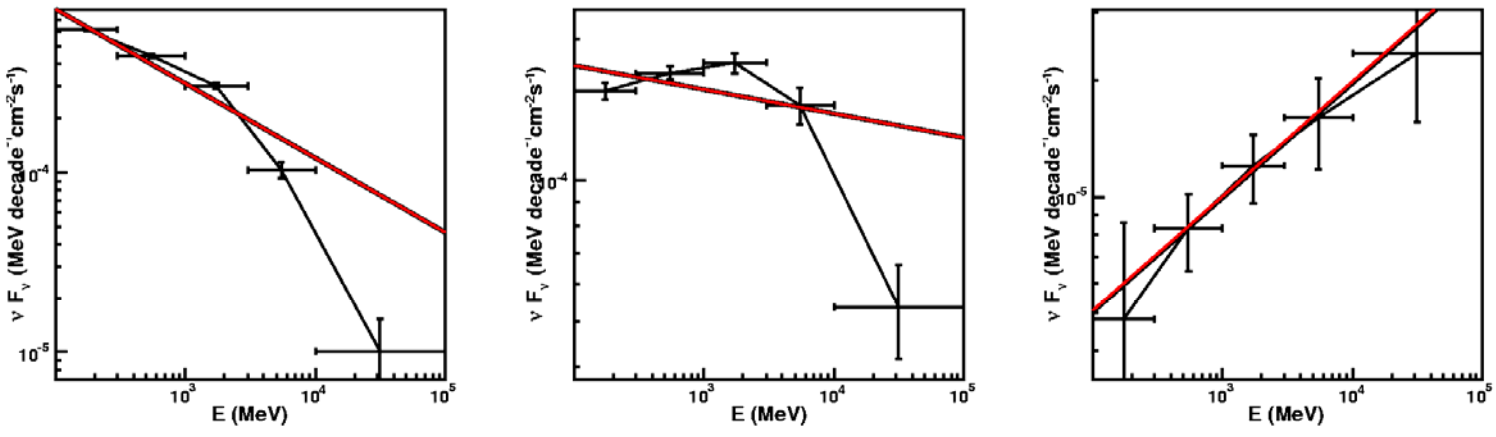


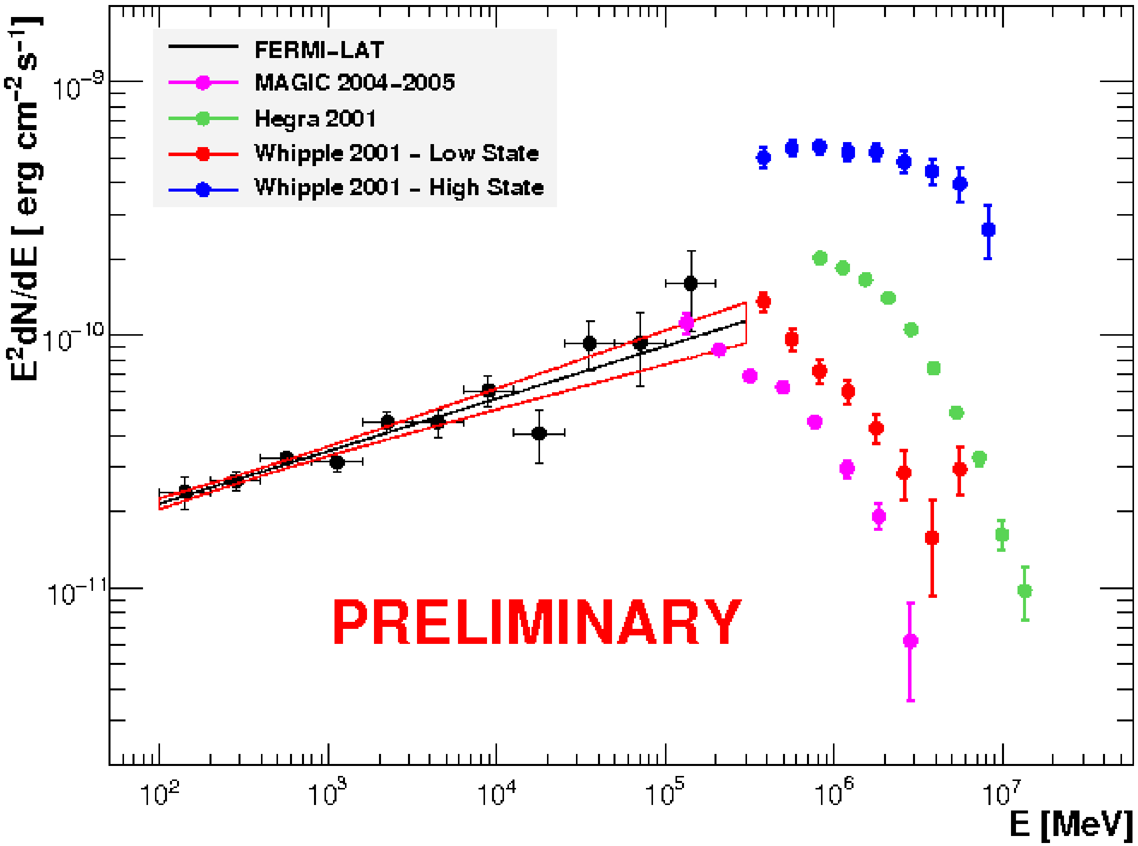
Fig. 10.— Gamma-ray SED of 3 bright blazars calculated in five energy bands, compared with the power law fitted over the whole energy range. Left: 3C454.3 (FSRQ), middle: AO 0235+164 (IBL), right: Mkn 501 (HBL)

<- High luminosity sources **low luminosity sources ->**

- The spectra are diverse – clear association with blazar sub-class
- This has strong implications on contribution of blazars to the diffuse extragalactic gamma-ray background: still work in progress, but we expect both types would contribute at some level
- Are luminous BL Lacs – LBLs – just objects with preferentially higher Doppler factor -> highest bulk Lorentz factors, quasar-like otherwise? 0235+164 above

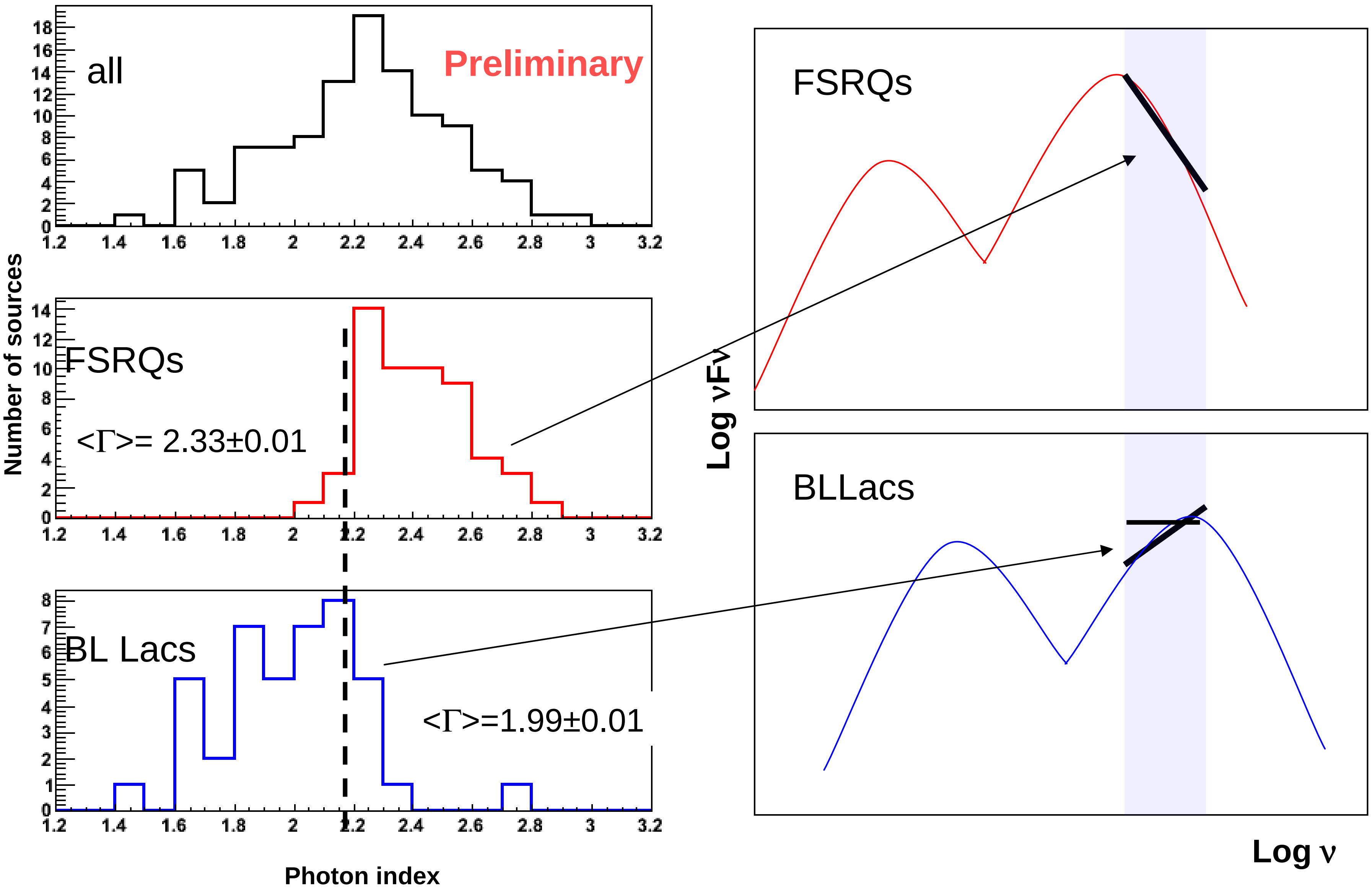
Gamma-ray spectra of HBL blazars

- Example of broad-band gamma-ray spectrum of an HBL-type blazar: Mkn 421
- Spectrum is hard, roughly connects to that measured by TeV instruments
  – but the emission in the TeV band is highly variable
  - the need to measure spectra simultaneously is clear…



Gamma-ray spectrum of Mkn 421

Fermi LAT spectra of blazars in the context of broad-band spectra
Clear spectral diversity!



Origin of spectral diversity of blazars / implication on their structure

- Inference from broad-band spectra:

  -> Electrons producing spectral peaks of HBL blazars have higher energy than those in FSRQ blazars – *Why?*

- HBL-type blazars (bright TeV emitters) have different important characteristic properties as compared to quasar-type blazars (“FSRQ”):
  * HBLs have relatively lower luminosity than FSRQs
  * HBLs have relatively high black hole mass: those, estimated for a number of them, are relatively high, ~ 10^9 Solar masses (probably comparable or slightly greater than FSRQs)

    -> lower luminosity in Eddington units ->

    lower accretion rate in Eddington units
- This trend would imply:

  * Luminous, quasar-type, FSRQ blazars have cold, luminous accretion disks

  * low-luminosity, HBL-type blazars have hot, advective, undeluminous accretion flows

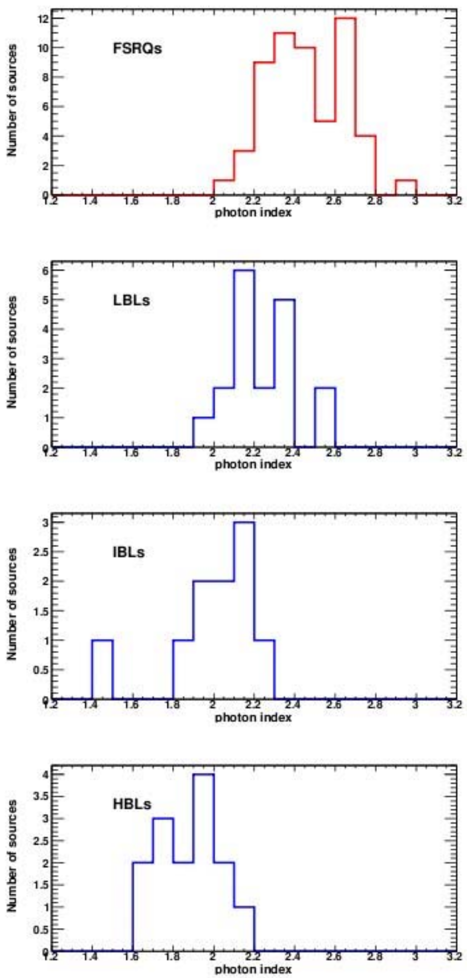
- This scenario can explain the difference in electron energies in the two classes of objects – since:
- Maximum electron energy is determined by the competition of acceleration and cooling of electrons

  * In FSRQs, luminous accretion disk provides ample external photons that are in turn seeds for Compton-upscattering by energetic electrons

    -> Max electron energy is limited

  * In HBL blazars, such external photon field is much weaker

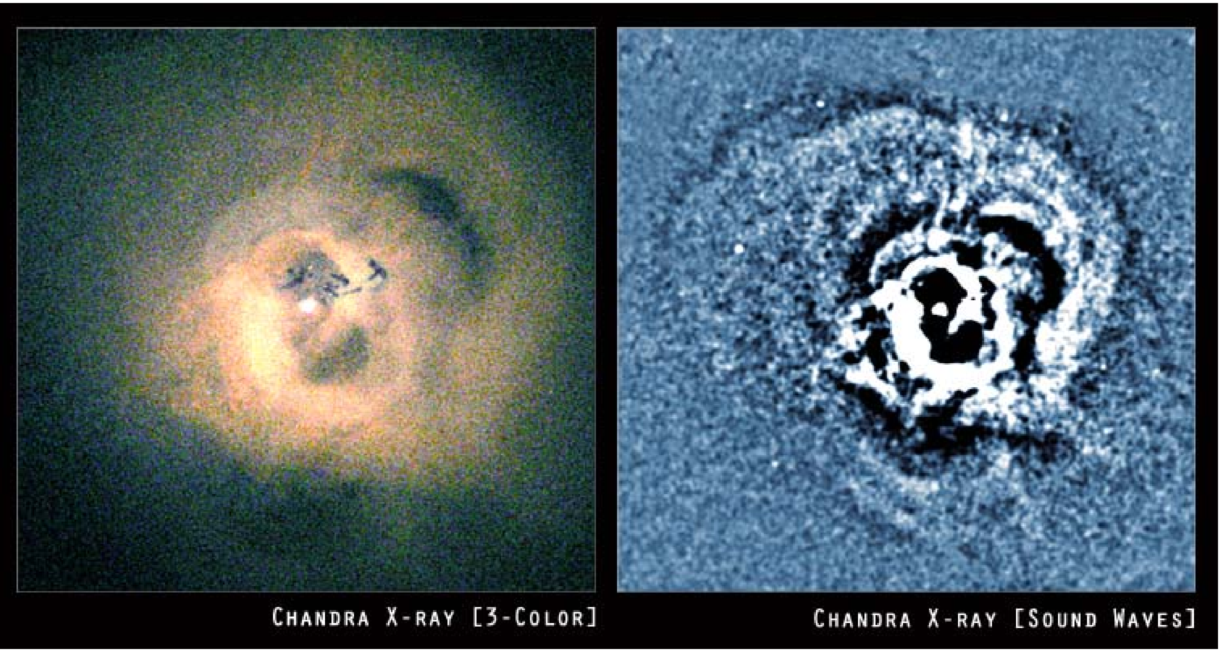
    -> electrons can attain higher energies



Photon index distribution
In 6-month Fermi data:
Similar to that in the LBAS pa

Compact radio source in Perseus Cluster: NGC 1275

- NGC 1275, a.k.a. 3C84 or Perseus A, is a nearby radio galaxy containing a flat-spectrum, compact (VLBI-scale) blazar-like, variable radio source
- It has been detected in the Fermi LAT data, at a much higher level than the upper limit from EGRET -> *variable* (on ~ year time scales)
- It is located in the Perseus cluster of galaxies, but variability clearly excludes the association of γ-rays with the cluster



The jet associated with the active galaxy is most likely responsible for inflating the “cavities’’ seen in the Chandra images of the Perseus cluster

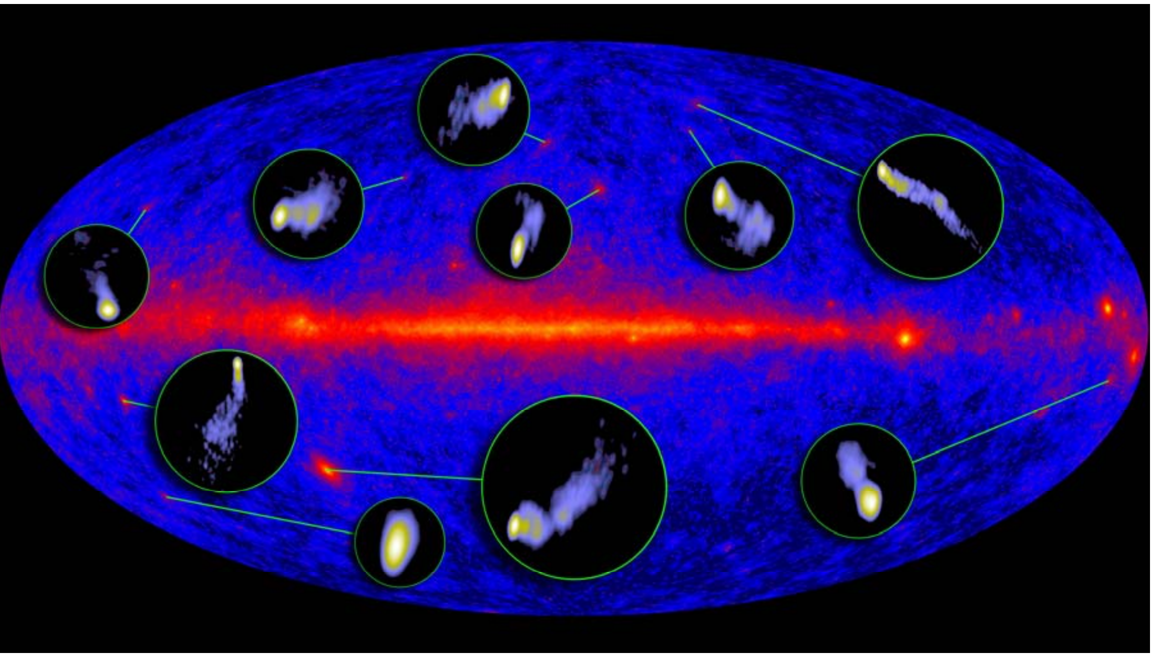
* Gamma-ray spectrum a power law with photon index = 2.1

* Jet is not pointing close to the line of sight

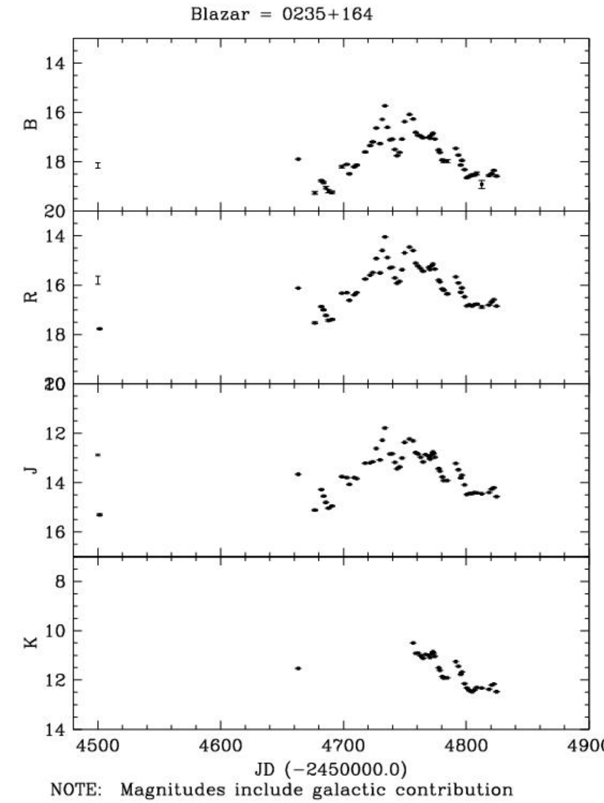
* Seyfert-like characteristics of the nucleus

Blazar-like behavior does not require jet pointing close to the line of sight!

Multi-band observations of blazars are crucial – and already on-going



VLBI maps of bright Fermi blazars:
image courtesy of M. Kadler, Sternwarte Bamberg
on behalf of the MOJAVE - and Fermi-LAT teams



Example of a blazar monitoring efforts:
the Yale University SMARTS program
Illustrated is the AO 0235+164 optical /
near IR light curve