GLAST – NuSTAR synergies in unraveling the structure of jets in active galaxies

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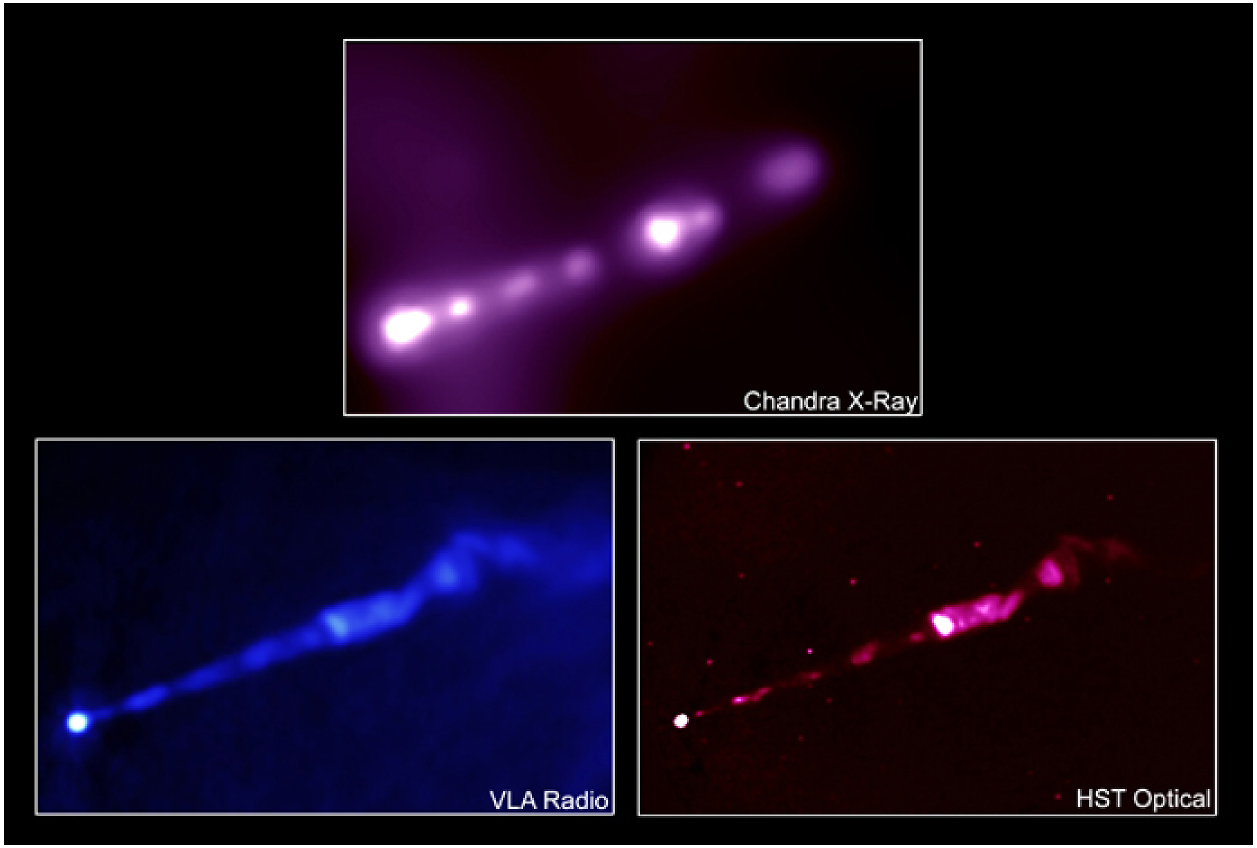
Outline:

- Jet-dominated AGN as gamma-ray sources
- Emission processes and content the relativistic jet
- Future observational prospects in the high energy regime towards the answers: GLAST and NuSTAR

Radio, optical and X-ray images of the jet in M 87



Jets are common in AGN – and radiate in radio, optical and X-ray wavelengths

Astrophysical jets and blazars: what are blazars?

- Blazars are active galaxies with prominent relativistic jets
- Jets are clearly visible in high-resolution radio images
- Blazars are commonly detected as MeV – GeV and even TeV γ-ray emitters (~ 60 detected by EGRET)
- Rapidly variable in all bands including γ-rays
- Variability of γ-rays implies compact source size, where the opacity of GeV γ-rays against keV X-rays to e^+/e^- pair production would be large – sources would be opaque to their own emission!
- Entire electromagnetic emission (γ–rays too!) most likely arises in a relativistic jet with Lorentz factor $\Gamma_j \sim 10$, pointing close to our line of sight
- The observed emission is WAY brighter than would be for a non-relativistic jet (Doppler boosting: $Flux_{obs} \sim Flux_{iso} \times \Gamma_j^{\ 4}$)

Unified picture of active galaxies

- Presumably all AGN have the same basic ingredients: a black hole accreting via disk-like structure

- In blazars the jet is most likely relativistically boosted towards us and thus so bright that its emission masks the isotropically emitting “central engine”

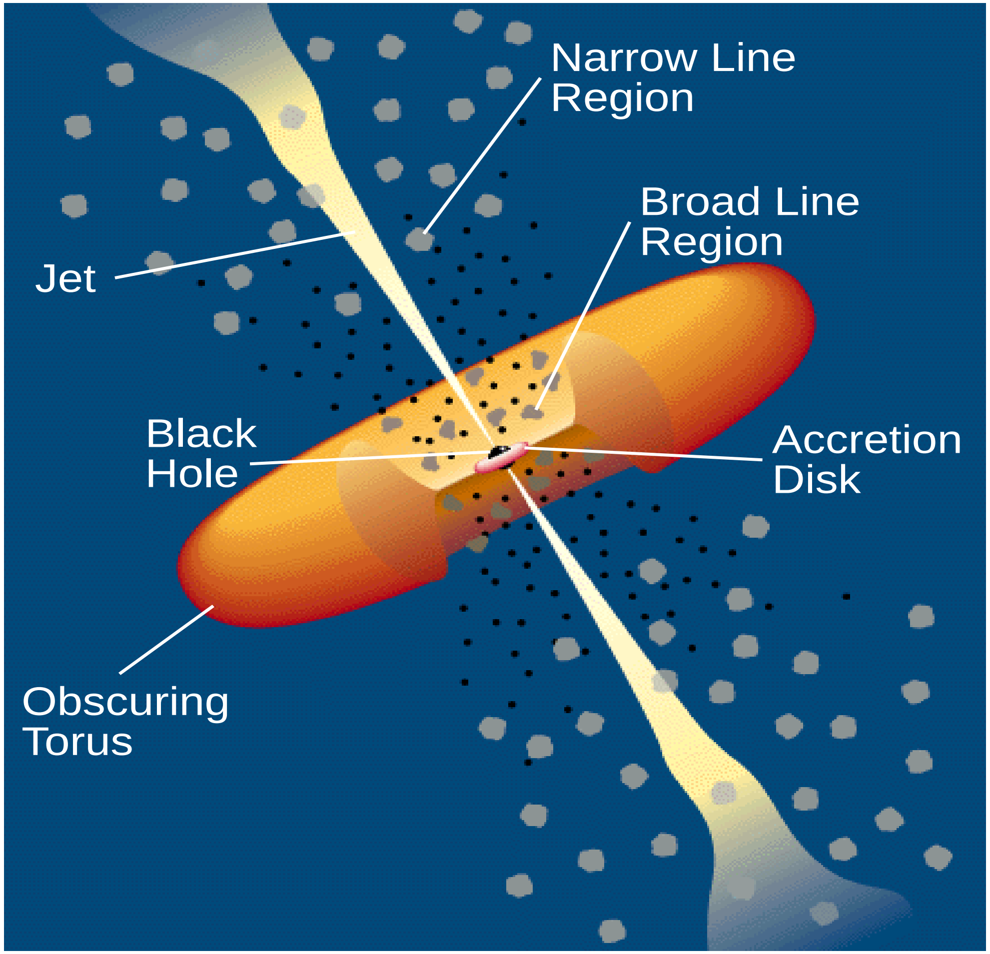
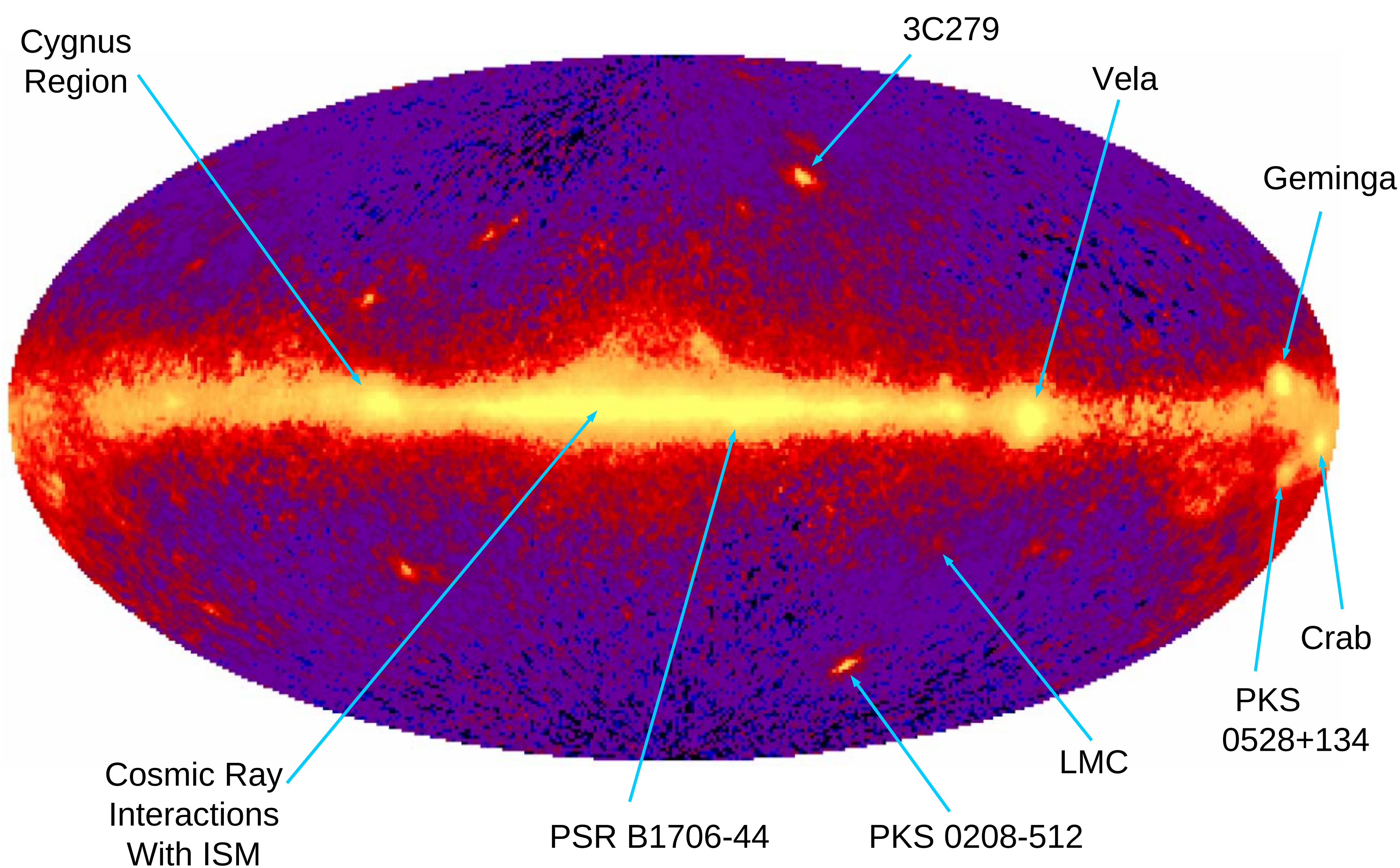


Diagram from Padovani and Urry

EGRET All Sky Map (>100 MeV)

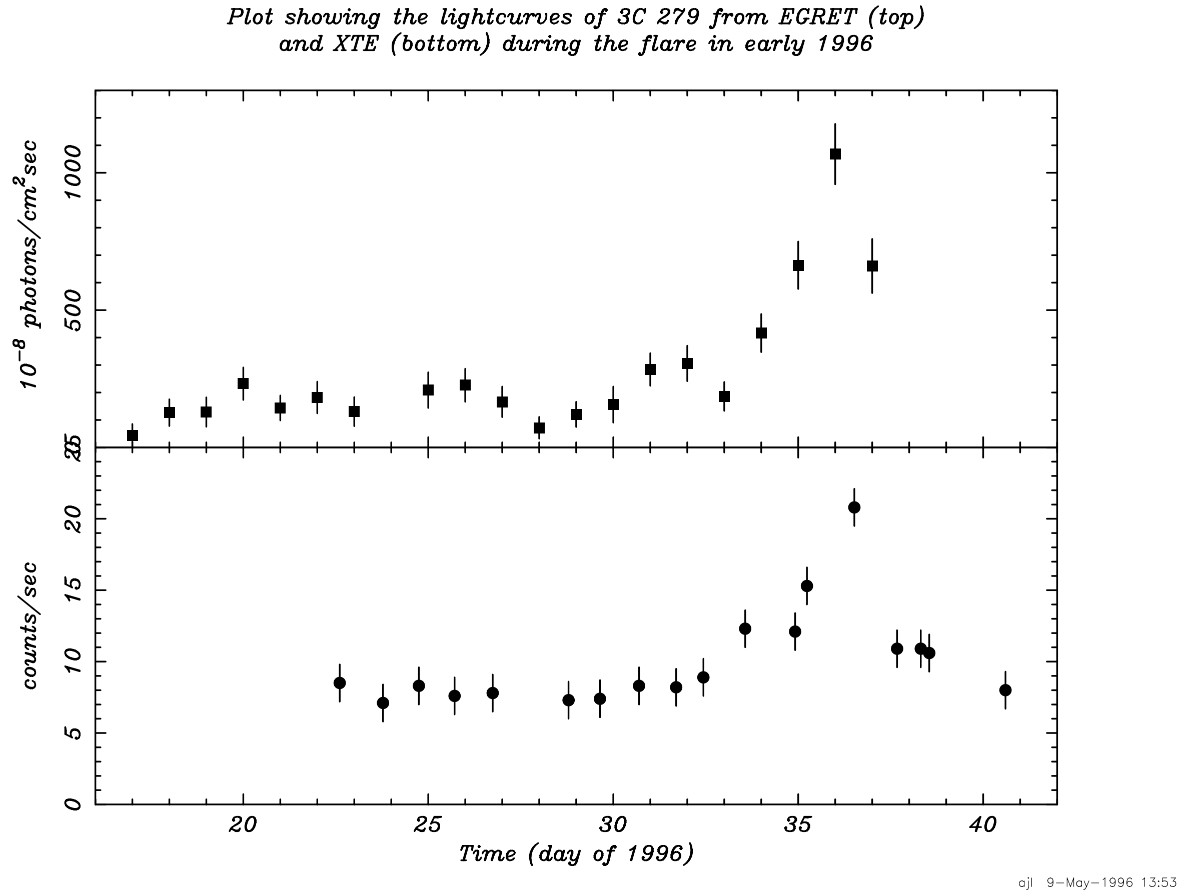


Blazars are variable in all observable bands

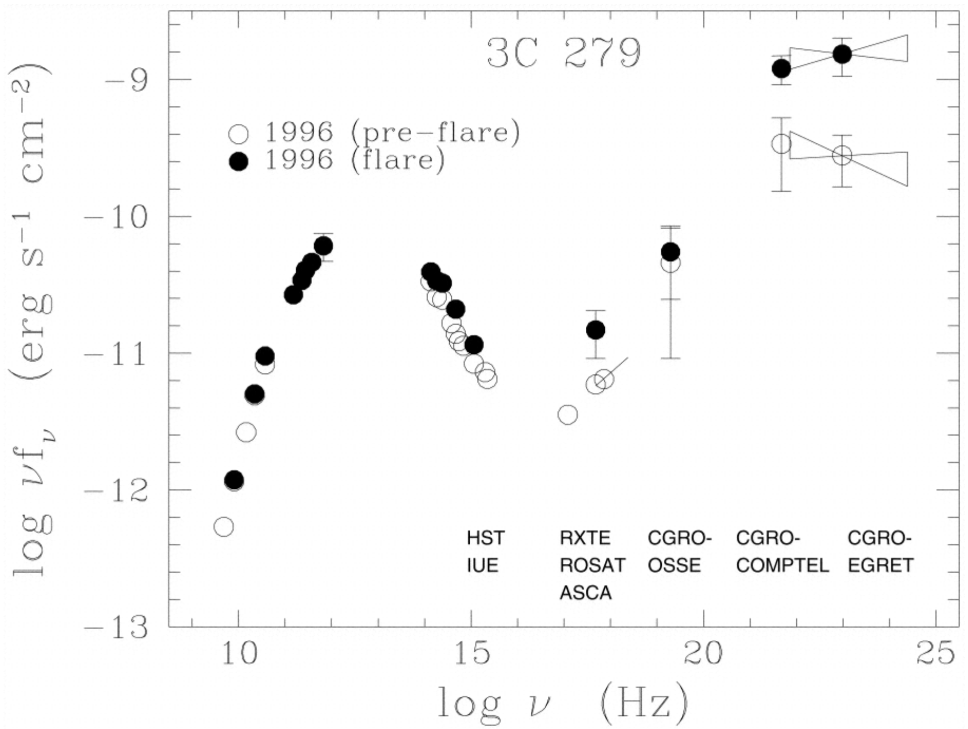
Example: X-ray and GeV γ-ray light curves from the 1996 campaign to observe 3C279

γ–rays

X-rays

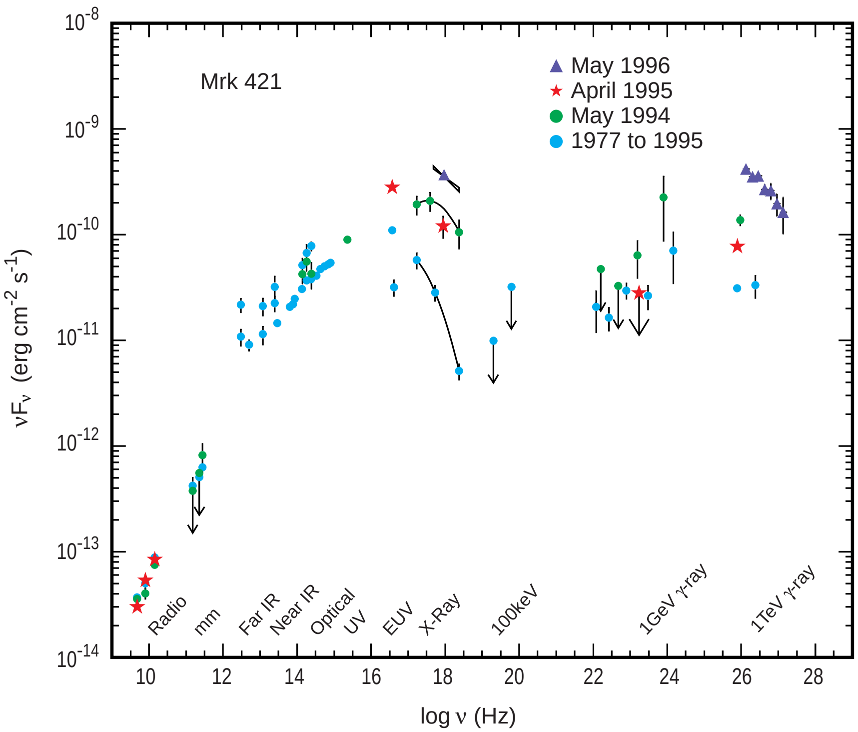


Broad-band spectra of blazars



Example of a spectrum of an EGRET blazar: 3C279

(data from Wehrle et al. 1998)



Example of a spectrum of a TeV blazar: Mkn 421

(data from Macomb et al. 1995)

Radiative processes in blazars

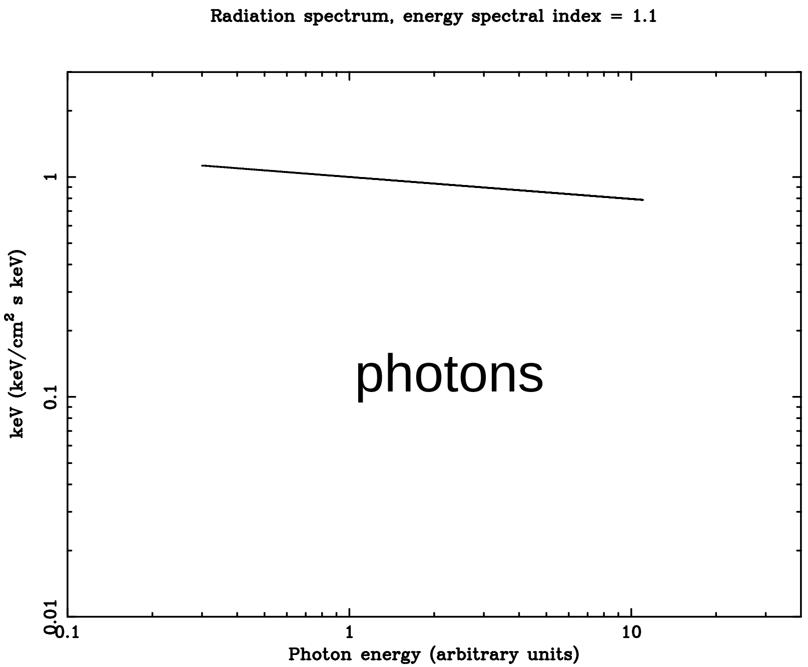
- **What do we <u>infer</u>? We have some ideas about the radiative processes**…
  - Polarization and the non-thermal spectral shape of the *low energy component* are best explained via the synchrotron process: relativistic electrons experience Lorentz force in magnetic field, are accelerated, radiate
  - The *high-energy component* is most likely due to the inverse Compton process by the same relativistic particles that produce the synchrotron emission, Compton-upscatter internal or external radiation
  - Relative intensity of the synchrotron vs. Compton processes depends on the relative energy density of the magnetic field vs. the ambient "soft" photon field
- BUT – WE STILL DON'T KNOW HOW THE JETS ARE LAUNCHED, ACCELERATED AND COLLIMATED – AND WHAT IS THEIR CONTENT
- TO MAKE SOME PROGRESS ON THIS FRONT, WE SHOULD AT LEAST KNOW THE COMPOSITION OF THE JET

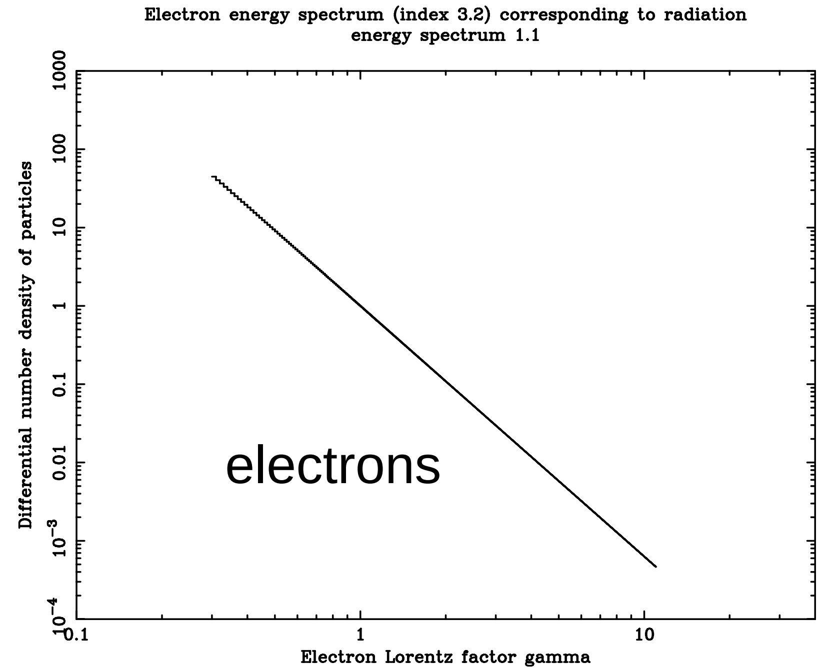
  (electrons-protons? electron-positrons?)

Modelling of radiative processes in blazars

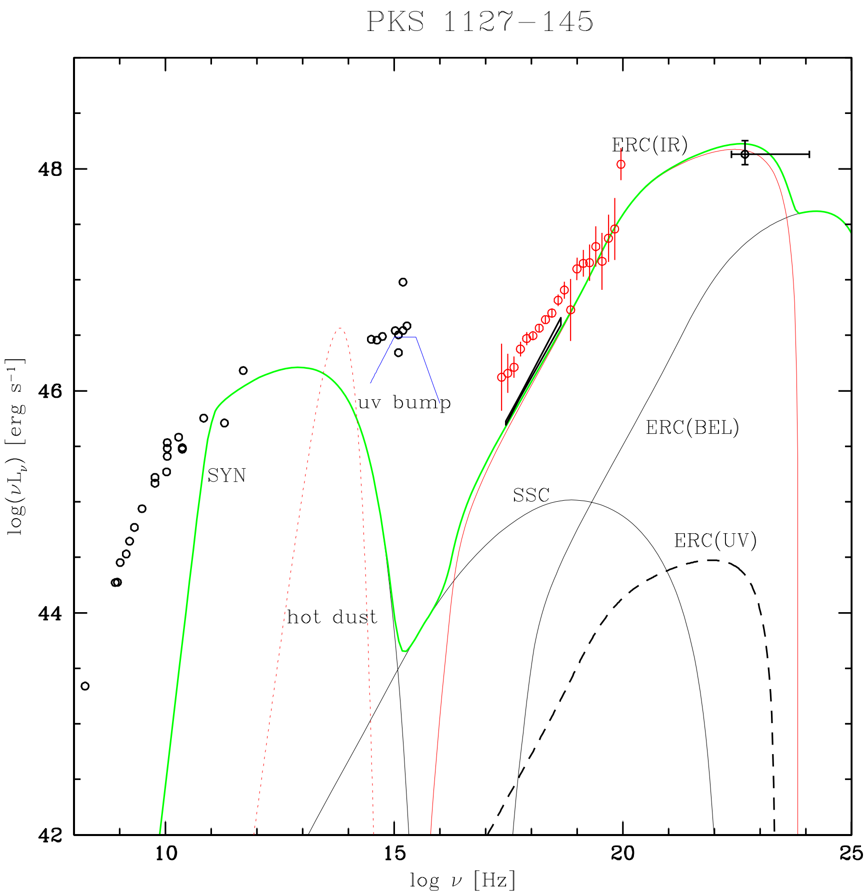
- In the context of the synchrotron models, emitted photon frequency is
  $\nu_s = 1.3 \times 10^6 \, B \times \gamma_{el}^2$ Hz
  where B is the magnetic field in Gauss
  and γ_{el} is the electron Lorentz factor
- The best models have B ~ 1 Gauss, and γ_{el} for electrons radiating at the peak of the synchrotron spectral component of ~ $10^3 - 10^6$, depending on the particular source
- Degeneracy between B and γ_{el} is "broken" by spectral variability + spectral curvature (Perlman et al. 2005)
- The high energy (Compton) component is produced by the same electrons as the synchrotron peak and $\nu_{compton} = \nu_{seed} \times \gamma_{el}^2$ Hz
- Still, the jet Lorentz factor Γ_j is ~ 10, while Lorentz factors of radiating electrons are $\gamma_{el} \sim 10^3 - 10^6$
- Must find a mechanism to convert the "bulk flow" of the jet (Γ_j ~ 10) to "random motion" of electrons (γ_{el} ~ thousands)

Photon and electron spectra





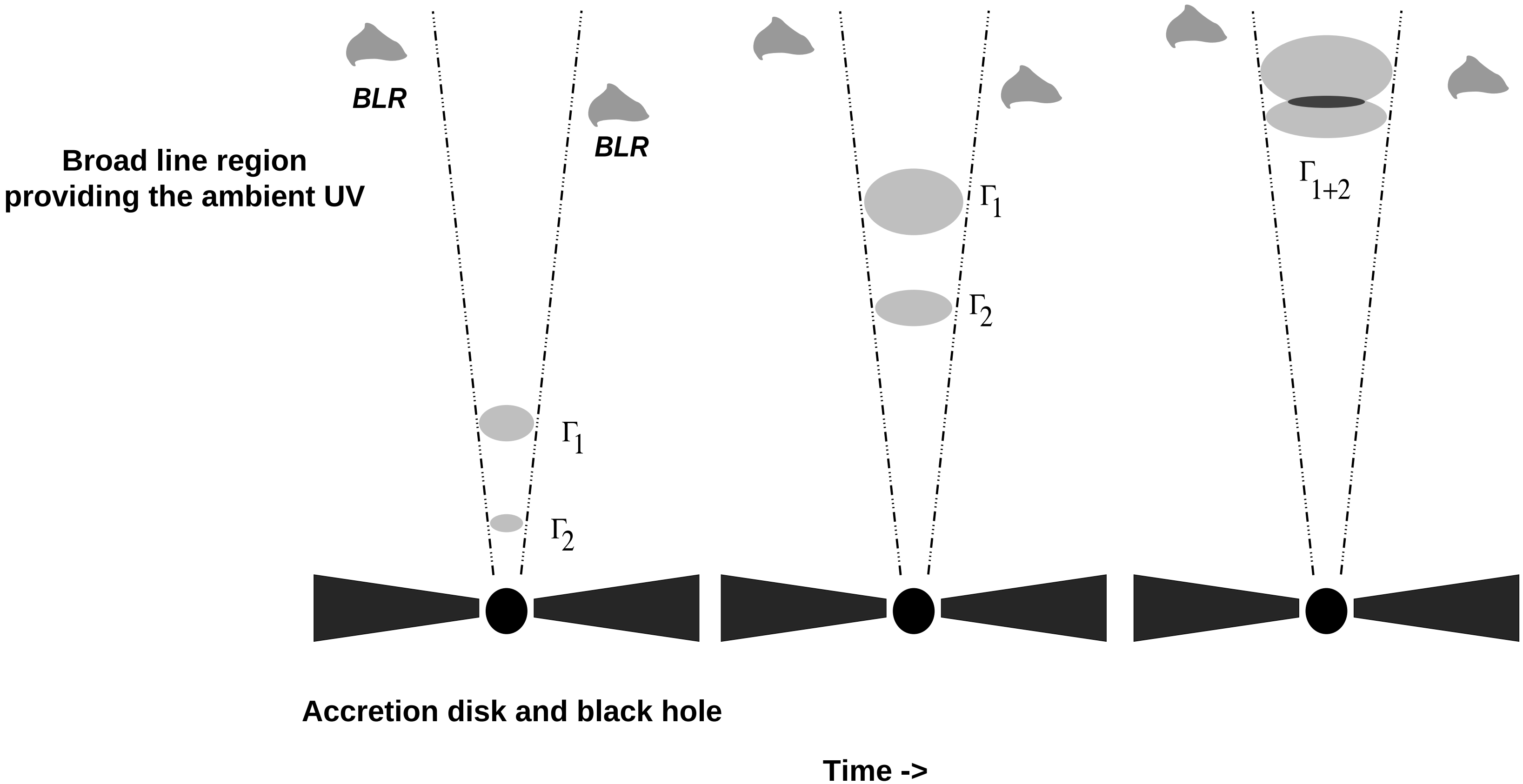
- **Radiation energy spectra often have power-law shape, $P(E) = P_o E^{-\alpha}$**
- **It is easy to show that for synchrotron or inverse Compton radiation, such a spectral form arises from a power-law distribution of the number of radiating electrons, $N(\gamma) = N_o \gamma^{-p}$ where $\alpha = (p-1)/2$**
- **This means that for most typical spectra, the *least-energetic particles are most numerous* – they are the bulk of the jet!**



Even in this extreme case of a very hard X-ray spectrum of a blazar, the lowest energy particles dominate by number

(data from Blazejowski et al. 2004)

- Low-energy (synchrotron) component *cannot* be used to study the lowest end of the electron energy distribution (via “easy” radio observations) – the compact regions are opaque to self-absorption
- The only hope to study the low-energy, most *numerous* particles is the hard X-ray / soft γ-ray regime -> NuSTAR
- Simultaneous observations will be needed as the sources are variable



Viable mechanism for particle acceleration - colliding shells model:

Shells move with Lorentz factors Γ where $\Gamma_2 > \Gamma_1$, shell 2 collides with shell 1, a shock forms, and particles are accelerated via Fermi process in shocks

Content of the jet

- Are blazar jets dominated by kinetic energy of particles from the start, or are they initially dominated by magnetic field (Poynting flux)? (Blandford; Vlahakis; Wiita; Meier; Hardee; …)
- There is a critical test of this hypothesis, at least for quasar-type ("EGRET") blazars:
- *If the kinetic energy is carried by particles*, the radiation environment of the AGN should be bulk-Compton-upscattered to X-ray energies by the cold electrons associated with the bulk motion of the jet
- If Γ_{jet} = 10, the ~10 eV H Lyα photons should appear bulk-upscattered to 10^2 x 10 eV ~ E > 1 keV (E is higher for "hotter" internal electrons)
- X-ray flare should precede the γ-ray flare (form a "precursor")
- X-ray monitoring concurrent with GLAST observations is crucial to settle this
- A lack of X-ray precursors would imply that the jet is "particle-poor" and may be dominated (at least initially) by Poynting flux

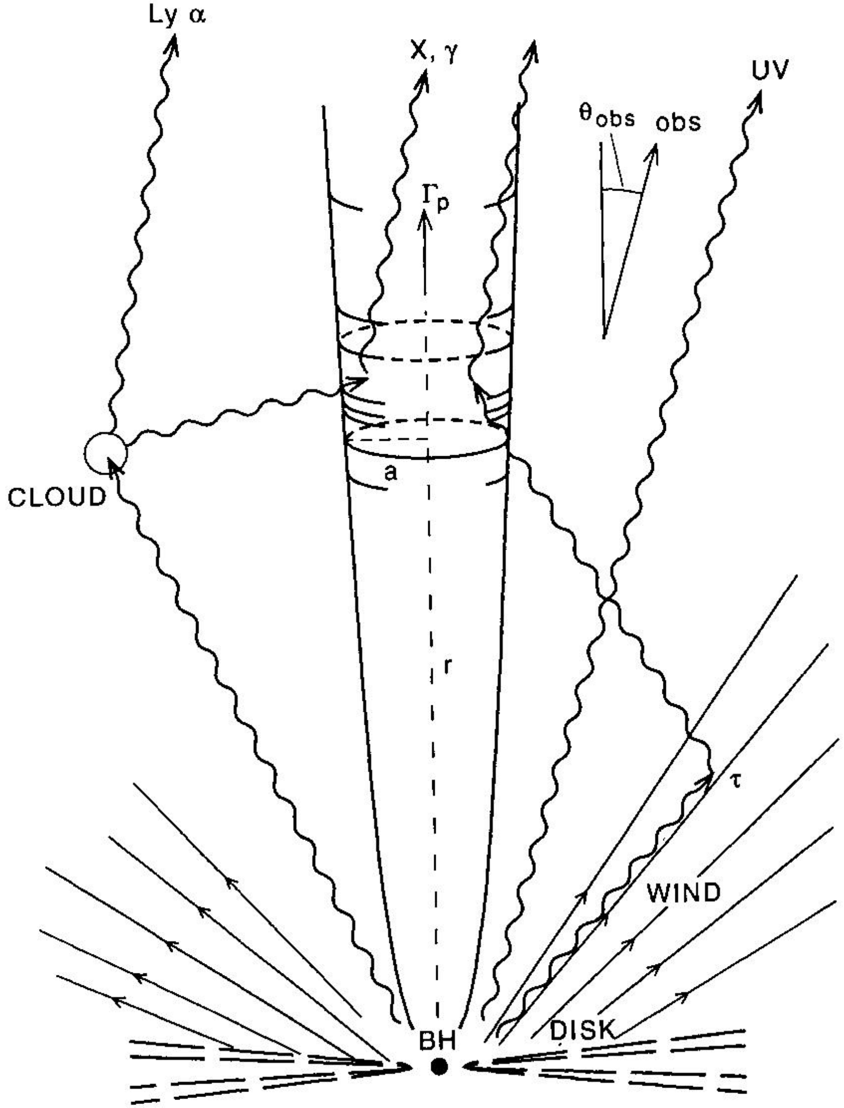


FIG. 2.—Geometry of the source. The radiating region, denoted by short cylinder of dimension a, moves along the jet with pattern Lorentz factor Γ_p. Underlying flow moves with Lorentz factor Γ, which may be different.

From Sikora, Begelman, and Rees 1994

- Source of the “seed” photons for inverse Compton scattering can depend on the environment
- It can be the synchrotron photons internal to the jet (the “synchrotron self-Compton” model
- - This is probably applicable to BL Lac objects such as Mkn 421
- Alternatively, the photons can be external to the jet (“External Radiation Compton” model)
- - This is probably applicable to blazars hosted in quasars such as 3C279

GLAST LAT's ability to measure the flux and spectrum of 3C279 for a flare similar to that seen in 1996 (from Seth Digel)