DEPARTMENT OF Physics & Astronomy @ OHIO UNIVERSITY

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Models of the SEDs and Variability of Blazars

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1. Phenomenology of Blazars
2. Jet Model of Blazars
3. X-ray Spectra and Variability of Blazars

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Blazars

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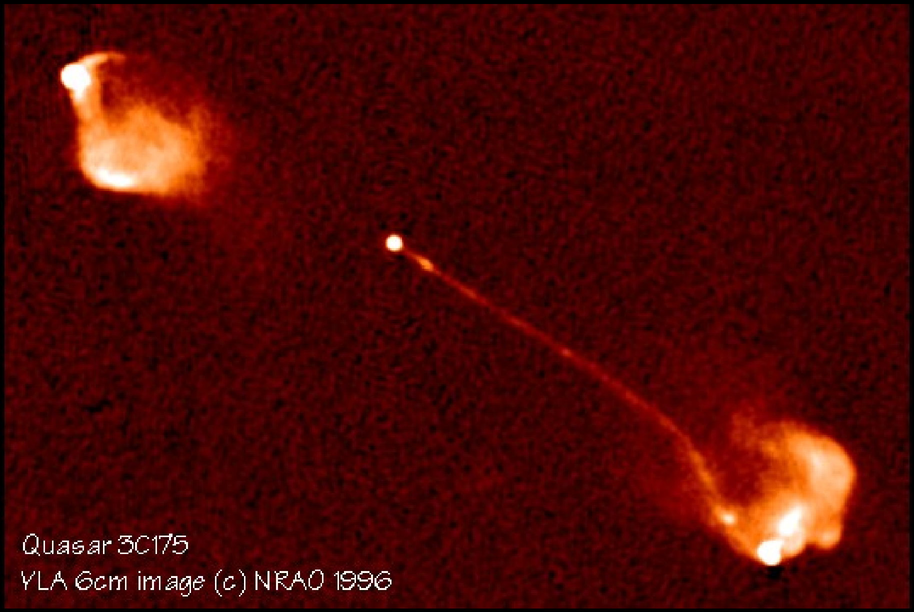

- Class of AGN consisting of BL Lac objects and gamma-ray bright quasars
- Rapidly (often intra-day) variable
- Strong gamma-ray sources
- Radio jets, often with superluminal motion
- Radio and optical polarization

Blazar Classification

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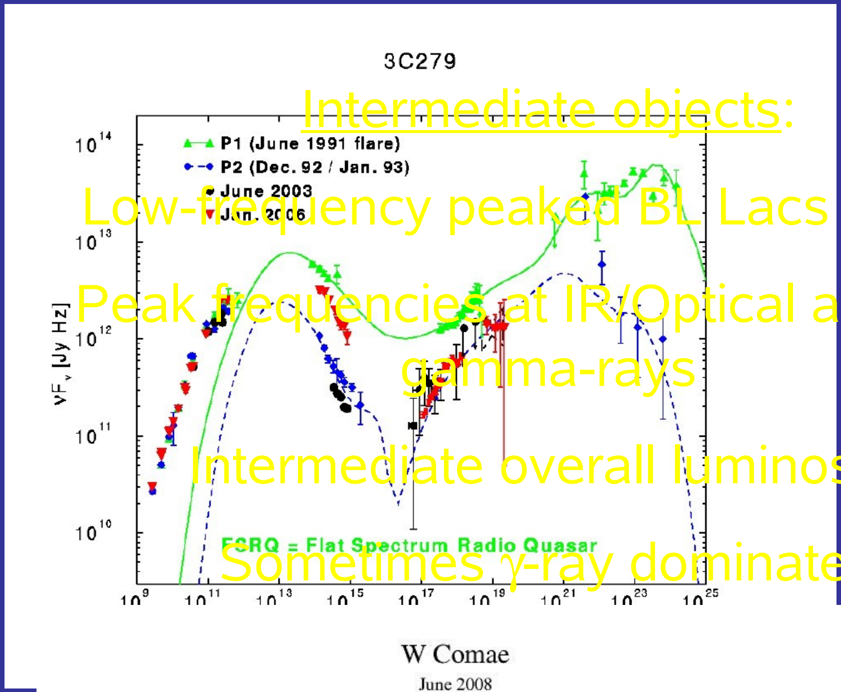


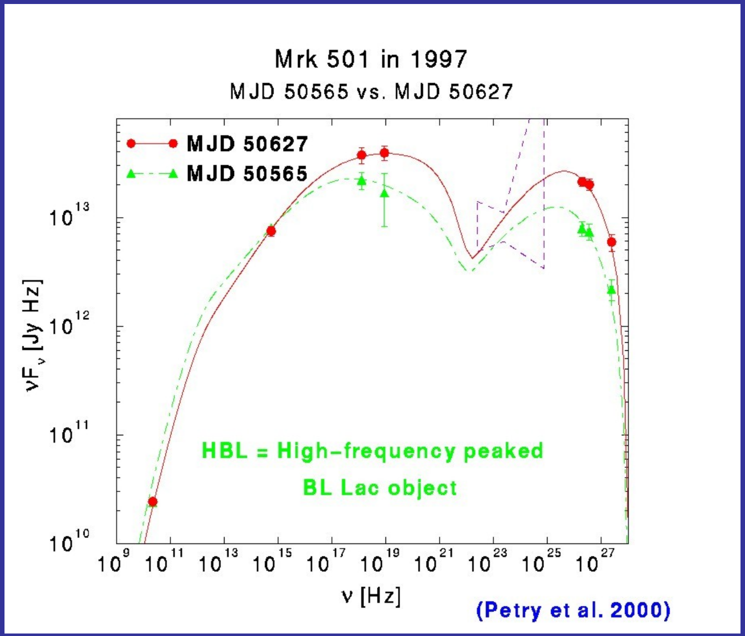
Intermediate objects:

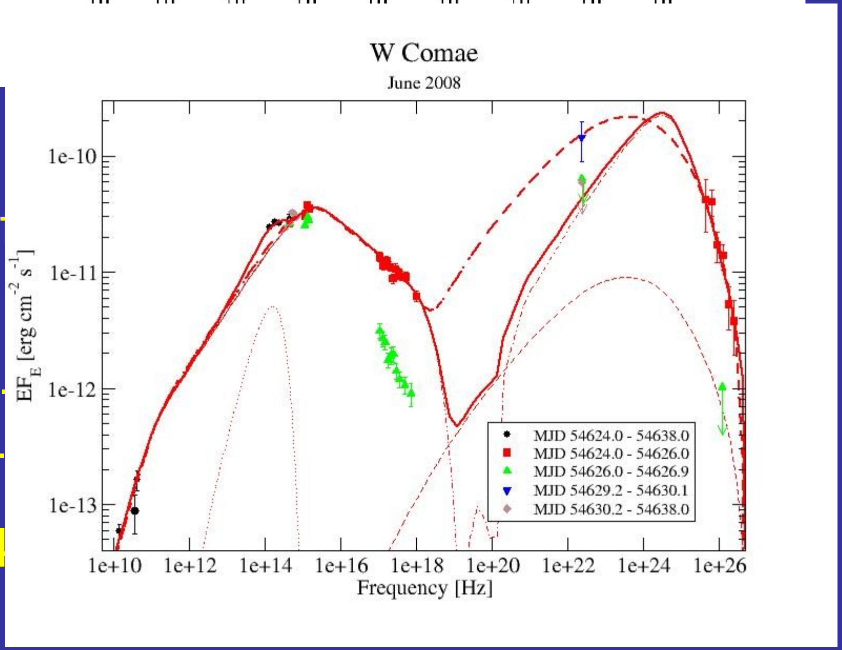
Low-frequency peaked BL Lacs (LBLs):

Peak frequencies at IR/Optical and GeV gamma-rays

Intermediate overall luminosity

Sometimes γ-ray dominated





Low-f

High-

to γ-

Peak

High-frequency peaked BL Lacs (HBLs):

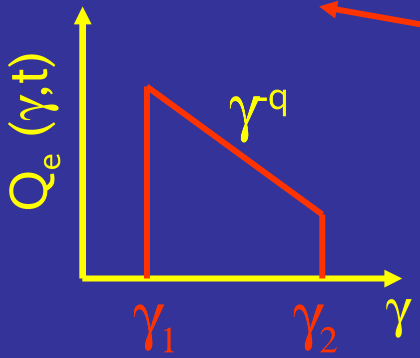
Low-frequency component from radio to UV/X-rays, often dominating the total power

High-frequency component from hard X-rays to high-energy gamma-rays

Leptonic Blazar Models

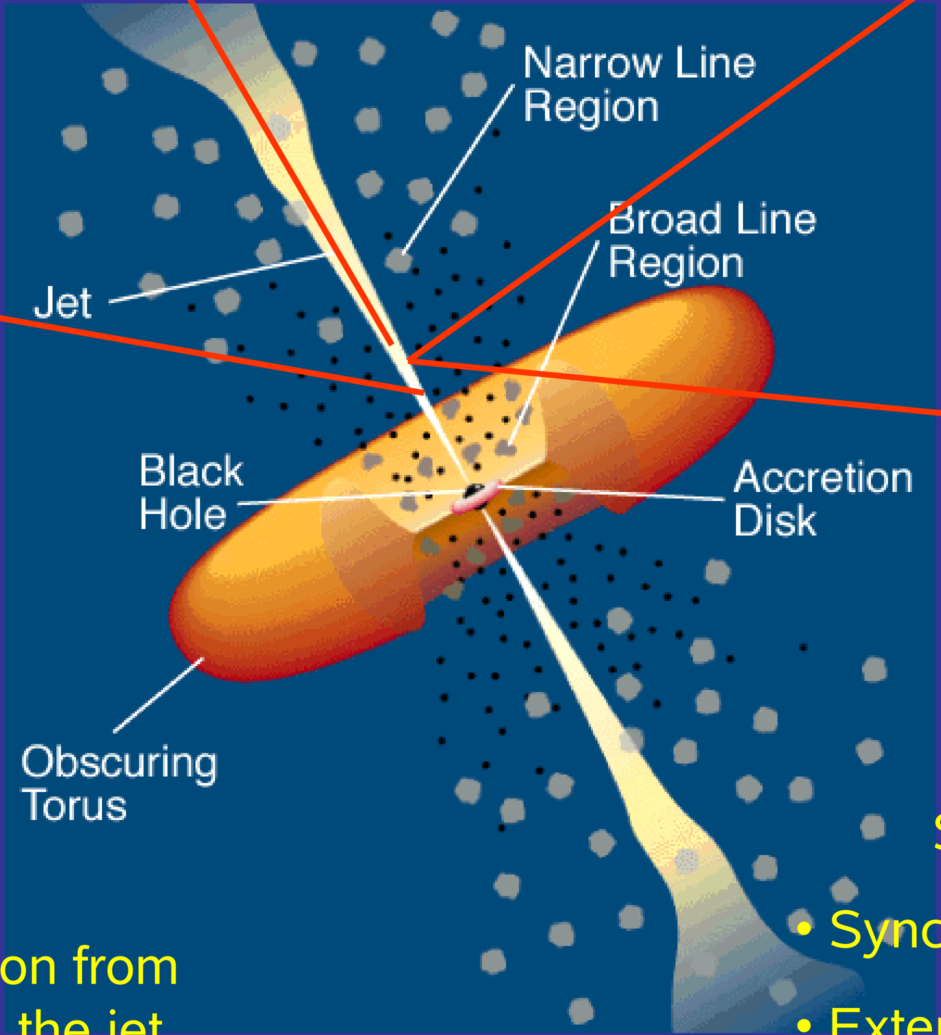
Relativistic jet outflow with $\Gamma \approx 10$

Injection, acceleration of ultrarelativistic electrons

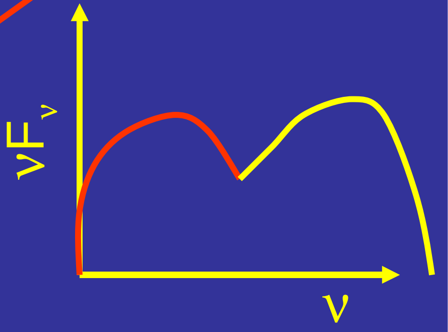


Injection over finite length near the base of the jet.

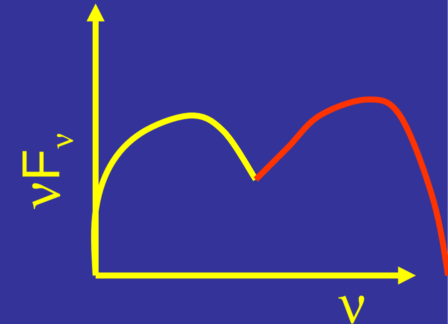
Additional contribution from $\gamma\gamma$ absorption along the jet



Synchrotron emission



Compton emission



Seed photons:

- Synchrotron (SSC)
- External Sources (EC)

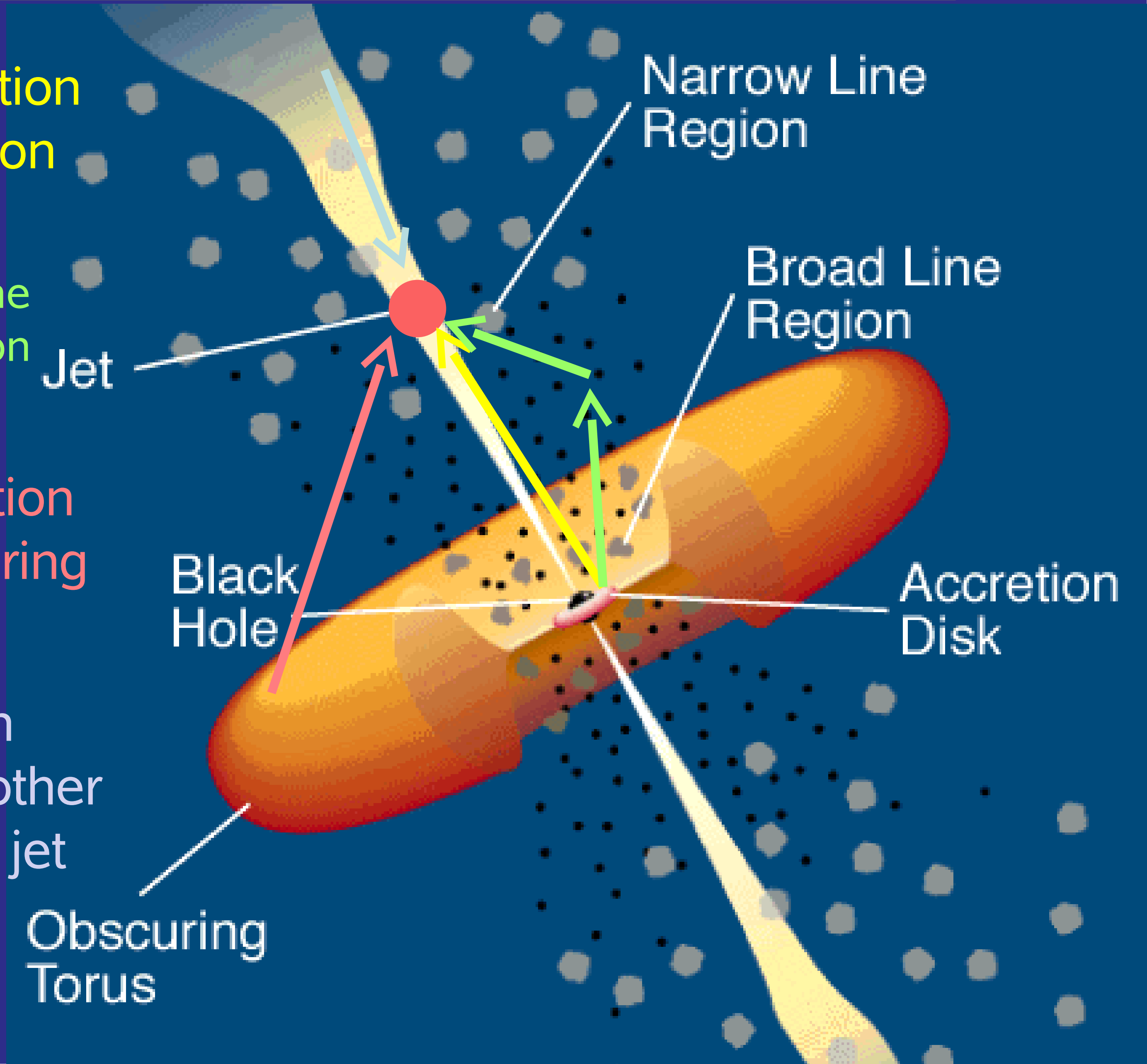
Sources of External Photons

Direct accretion disk emission

Optical-UV Emission from the Broad-line Region (BLR)

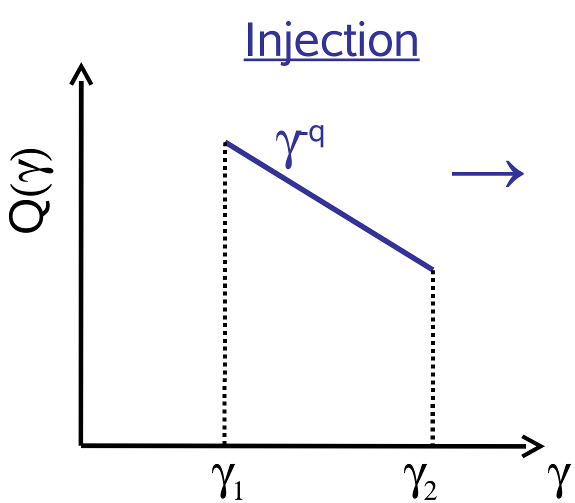
Infrared Radiation from the Obscuring Torus

Synchrotron emission from other regions of the jet



Quasi-Equilibrium Electron Distributions

Balance injection of a power-law distribution of relativistic electrons with radiative cooling and escape from the emission region:



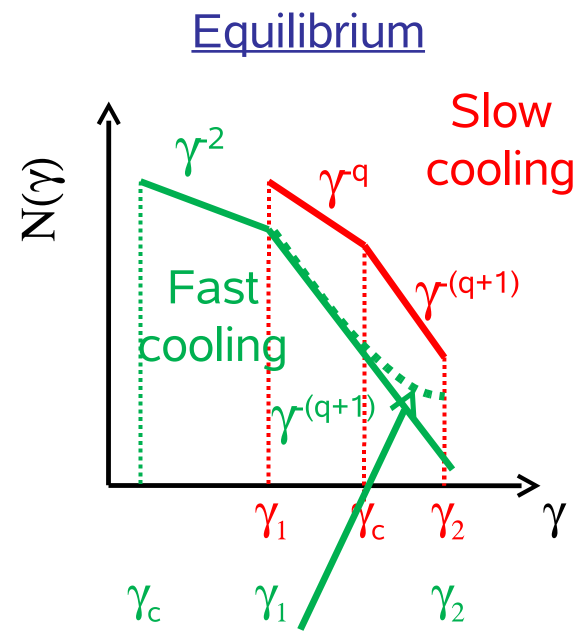
$t_{esc} = \eta\ R/c$

$d\gamma/dt = -\nu_0 \gamma^2$

$t_{cool} = \gamma/|d\gamma/dt| = 1/(\nu_0 \gamma)$

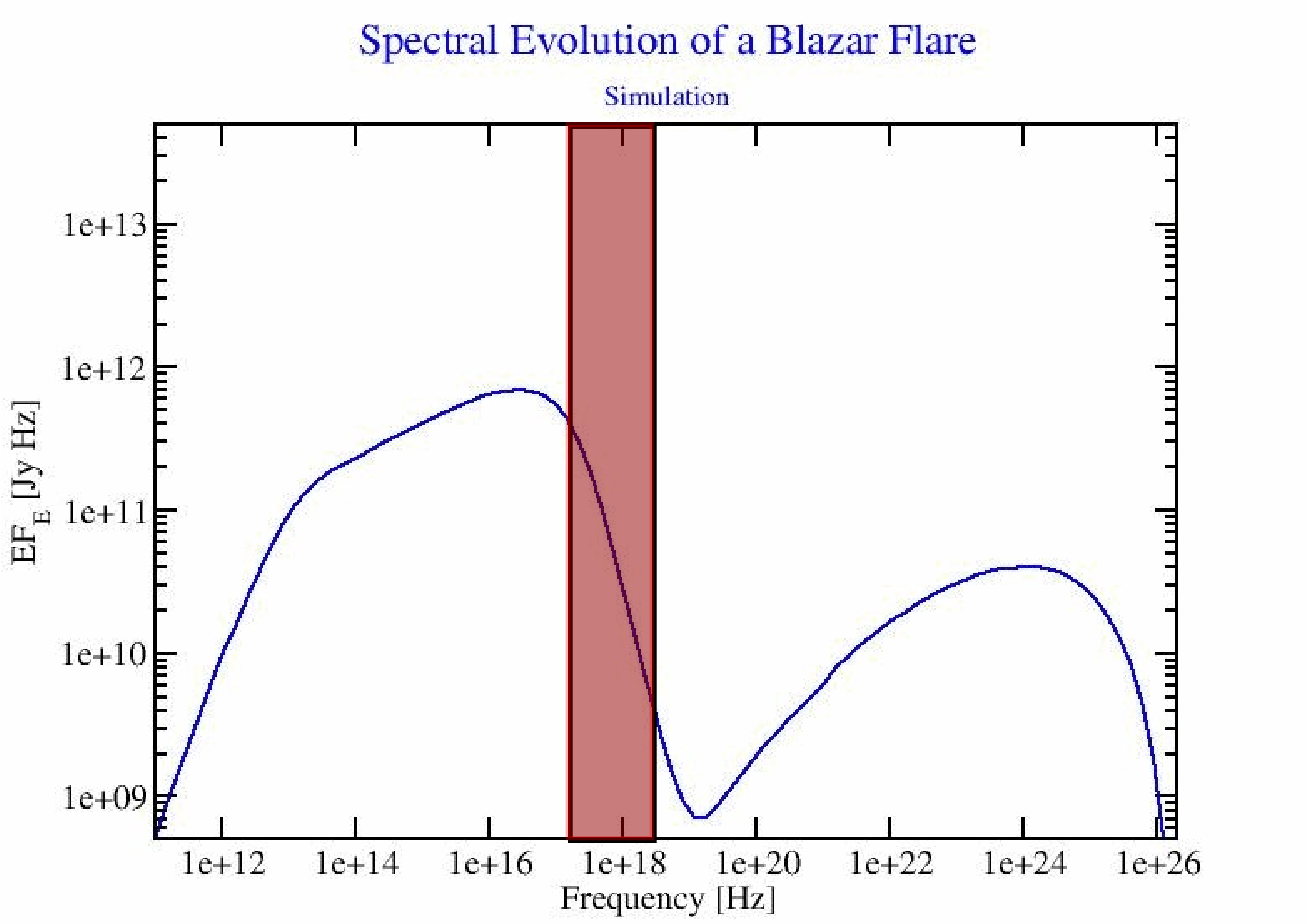
→ Spectral break at γ_c, where $t_{esc} = t_{cool}$

$$\rightarrow \gamma_c = c/(\eta R \nu_0)$$



Compton cooling in KN regime

Spectral Variability

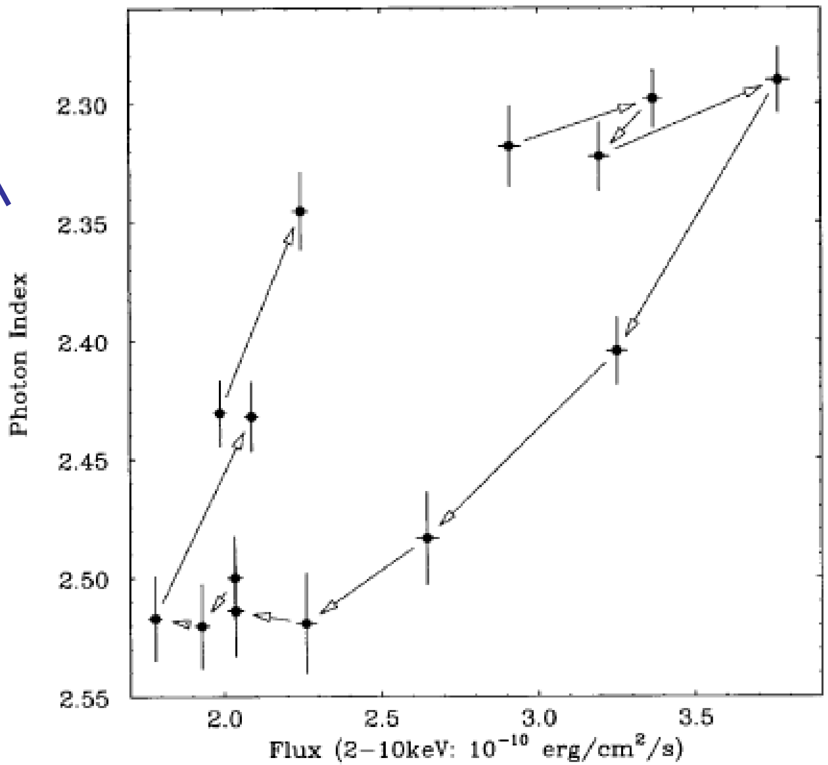


Spectral Variability

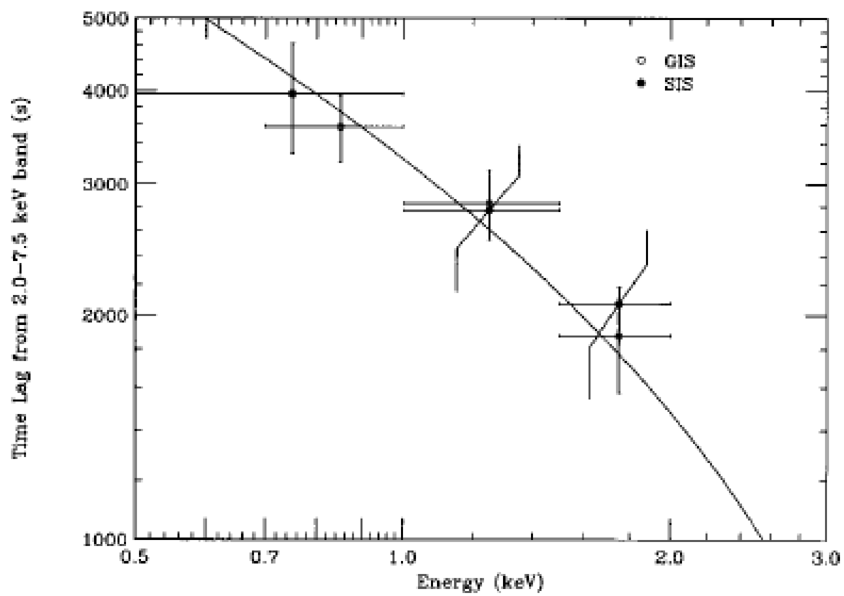
Mrk 421

Hardness-Intensity Diagrams

Spectral Hardness



Spectral Time Lags



(Takahashi et al. 1996)

Parameter Constraints from Observations of Spectral Variability

If energy-dependent (spectral) time lags are related to energy-dependent synchrotron cooling time scale:

$d\gamma/dt = -\nu_0\gamma^2$ with $\nu_0 = (4/3)\, c\, \sigma_T\, u'_B$

$t_{cool} = \gamma/|d\gamma/dt| = 1/(\nu_0\gamma)$

and

$\nu_{sy} = 3.4 * 10^6\, (B/G)\, (D/(1+z))\, \gamma^2$ Hz

$\Rightarrow \Delta t_{cool} \sim B^{-3/2}\, (D/(1+z))^{1/2}\, (\nu_1^{-1/2} - \nu_2^{-1/2})$

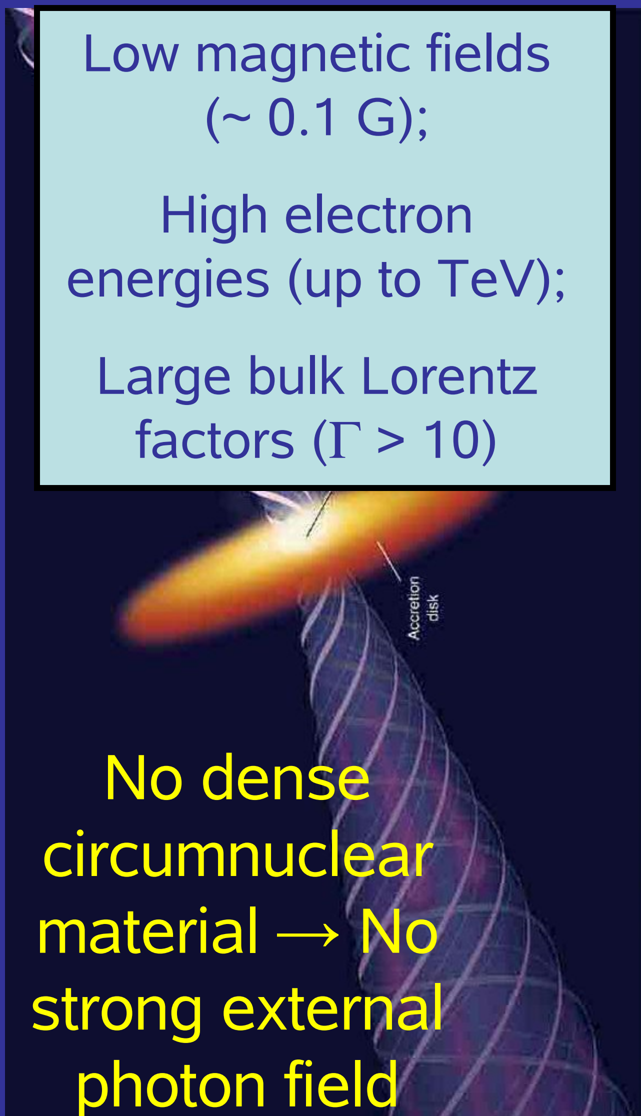
=> Measure time lags between frequencies ν_1, ν_2 → estimate Magnetic field (modulo D/[1+z])!

Spectral modeling results along the Blazar Sequence: Leptonic Models

Low magnetic fields (~ 0.1 G);

High electron energies (up to TeV);

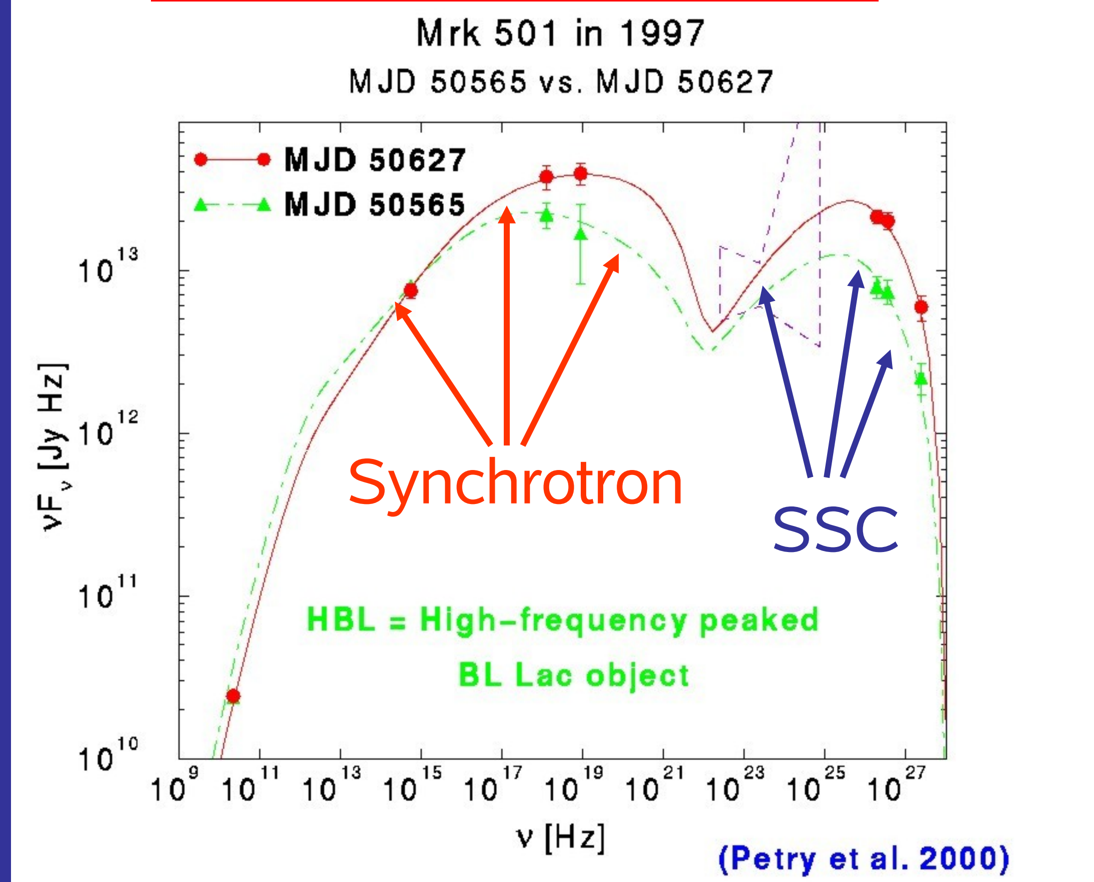
Large bulk Lorentz factors ($\Gamma > 10$)



No dense circumnuclear material → No strong external photon field

High-frequency peaked BL Lac (HBL):

The "classical" picture



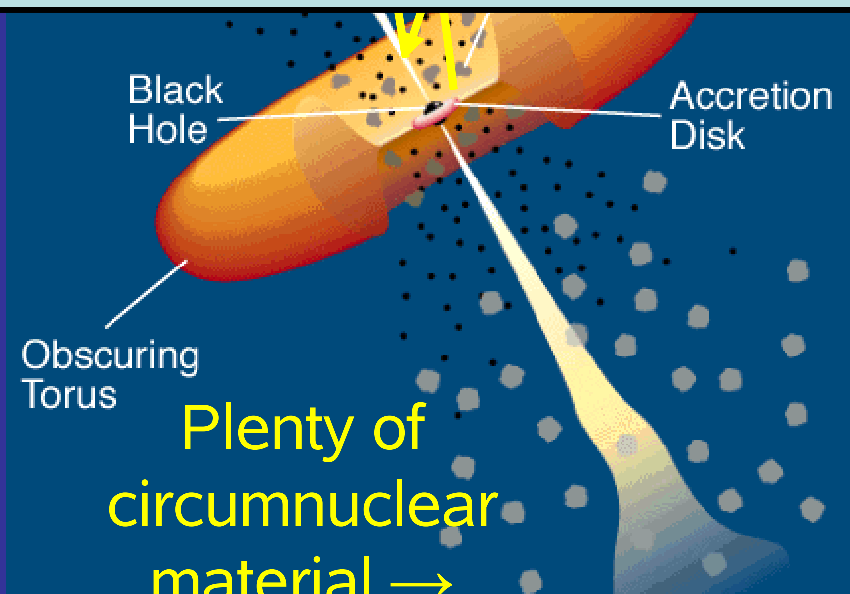
Spectral modeling results along the Blazar Sequence: Leptonic Models

High magnetic fields (~ a few G);

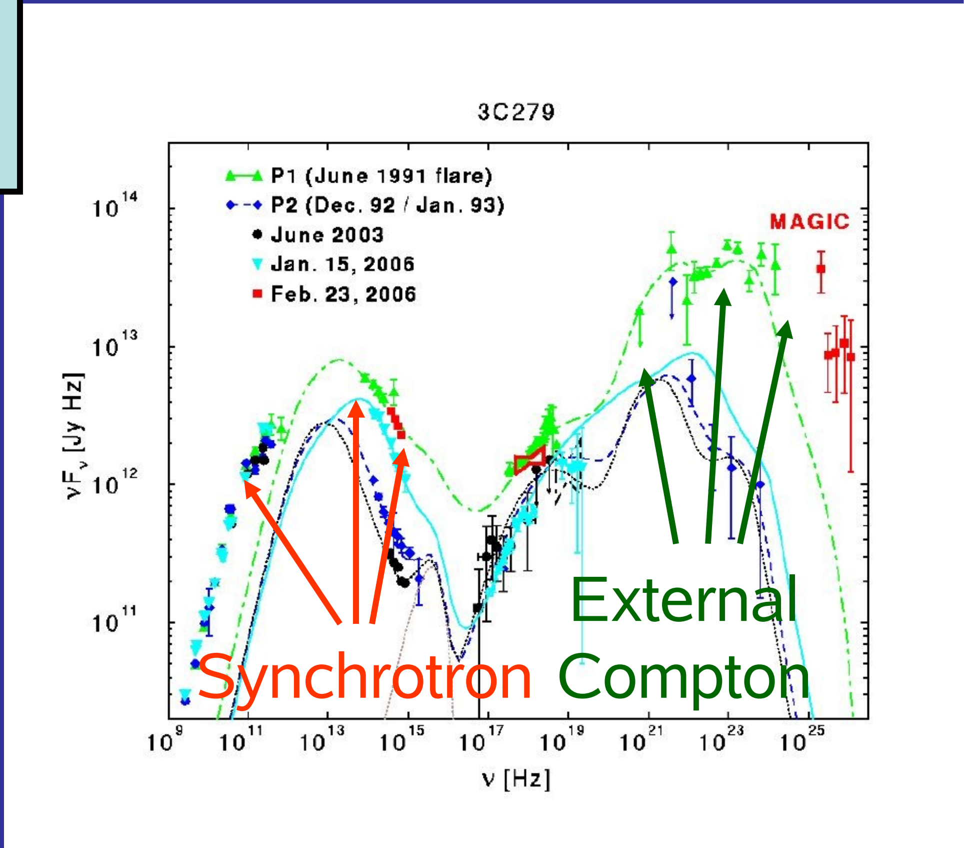
Lower electron energies (up to GeV);

Lower bulk Lorentz factors ($\Gamma \sim 10$)

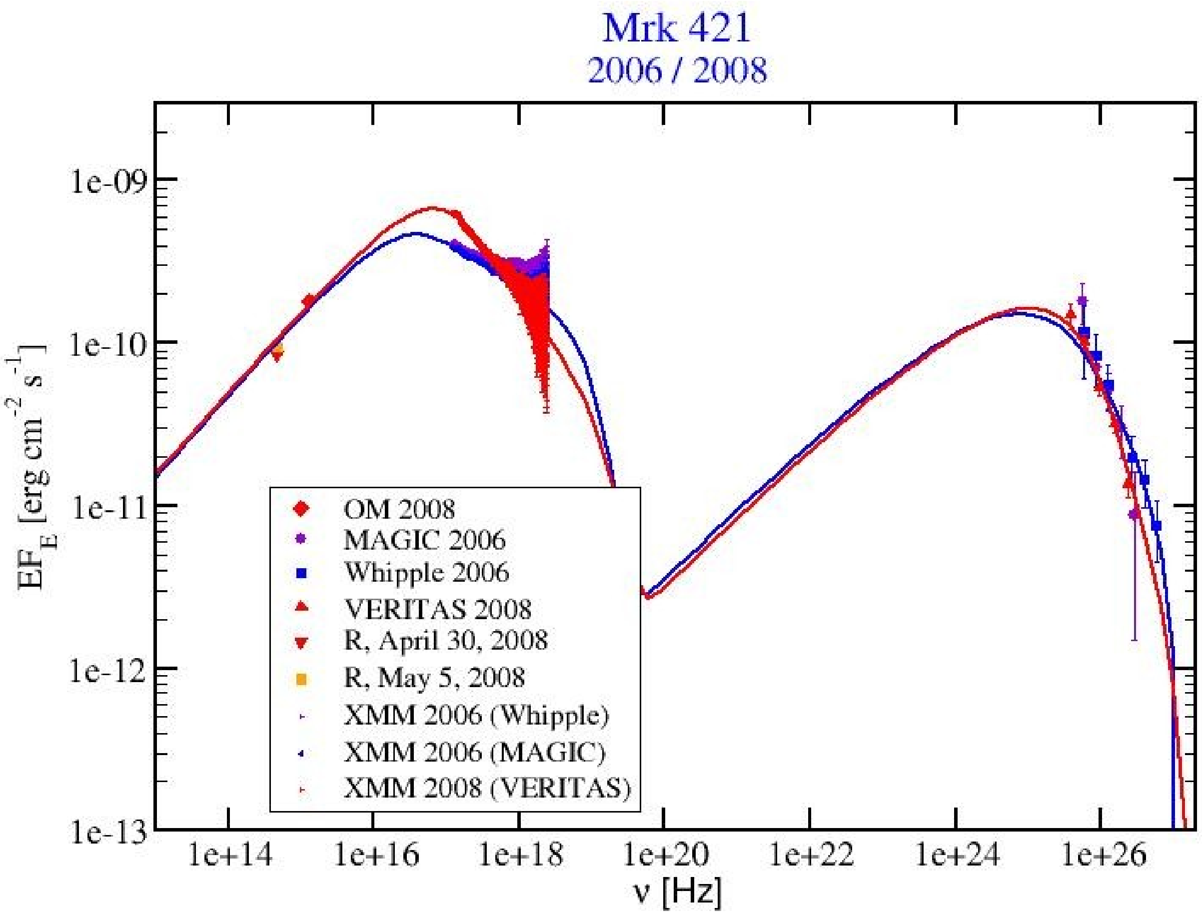
Radio Quasar (FSRQ)



Plenty of circumnuclear material → Strong external photon field



Modeling Mrk421



$L_e = 4.5*10^{43}$ erg/s

$\gamma_1 = 2.5*10^4$

$\gamma_2 = 4.0*10^5$

$q = 2.5$

$R = 3*10^{15}$ cm

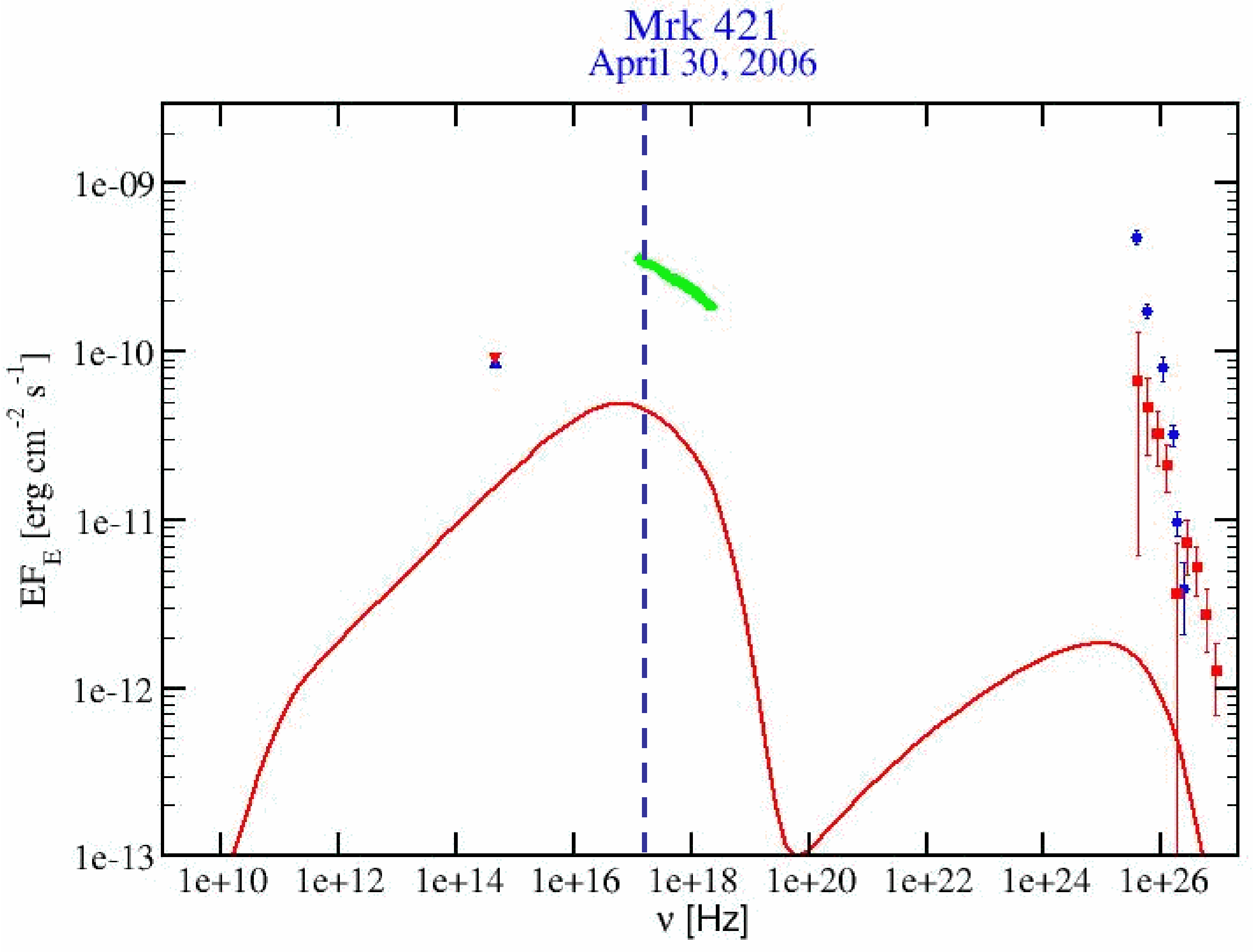
$D = 30$

$B = 0.37$ G

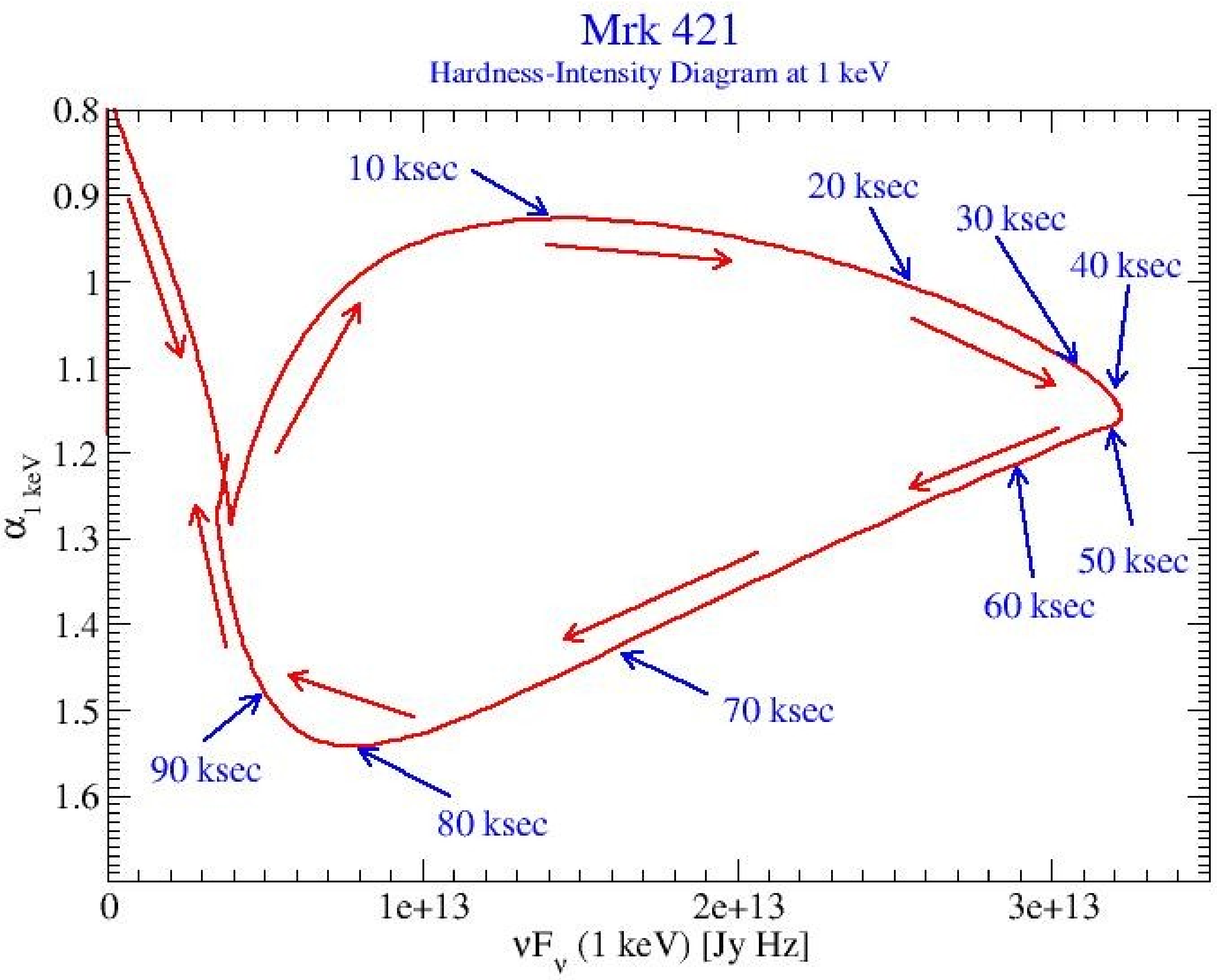
$L_B = 4.2*10^{42}$ erg/s

$\varepsilon_B = 0.093$

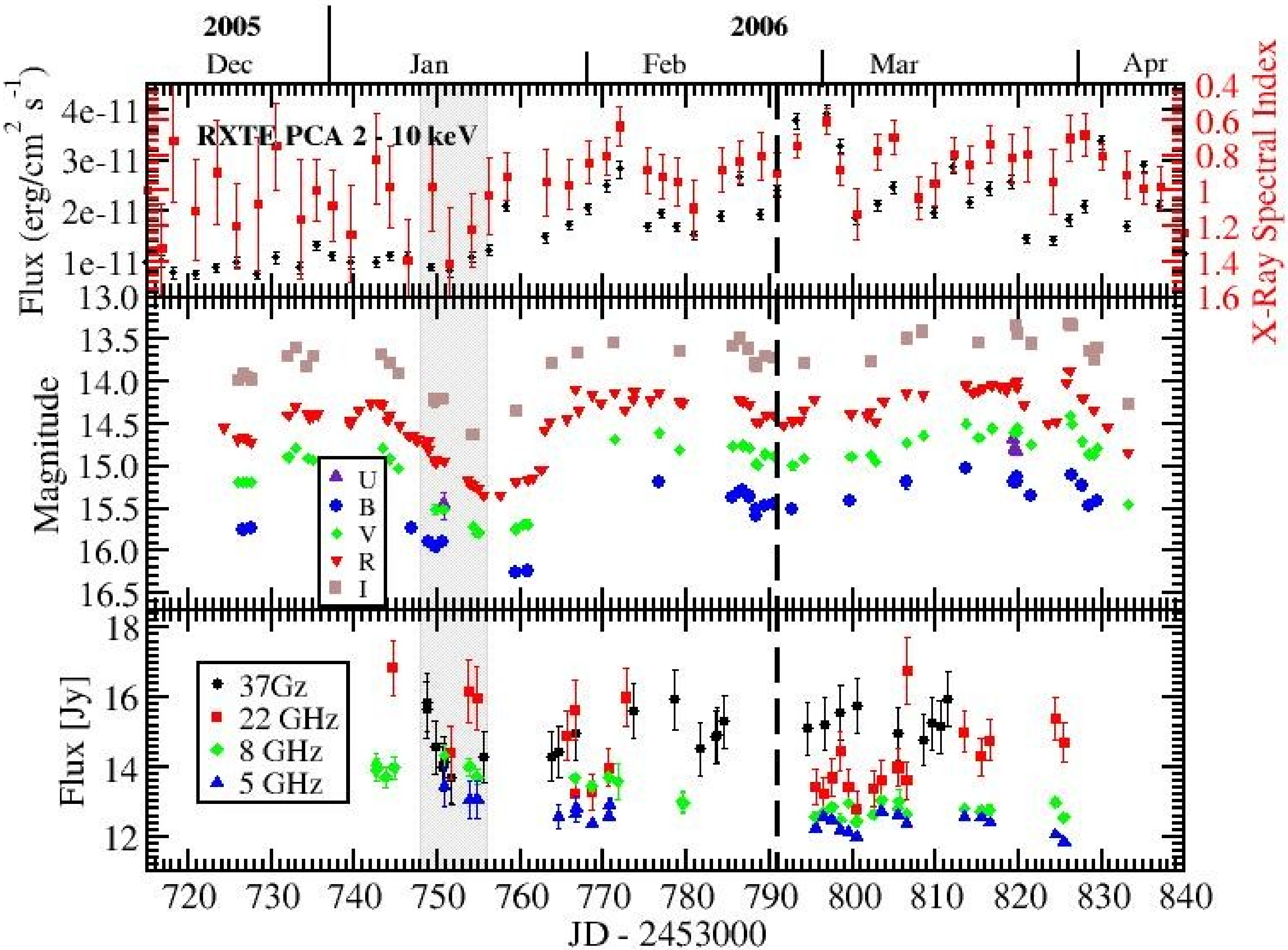
Variability Modeling



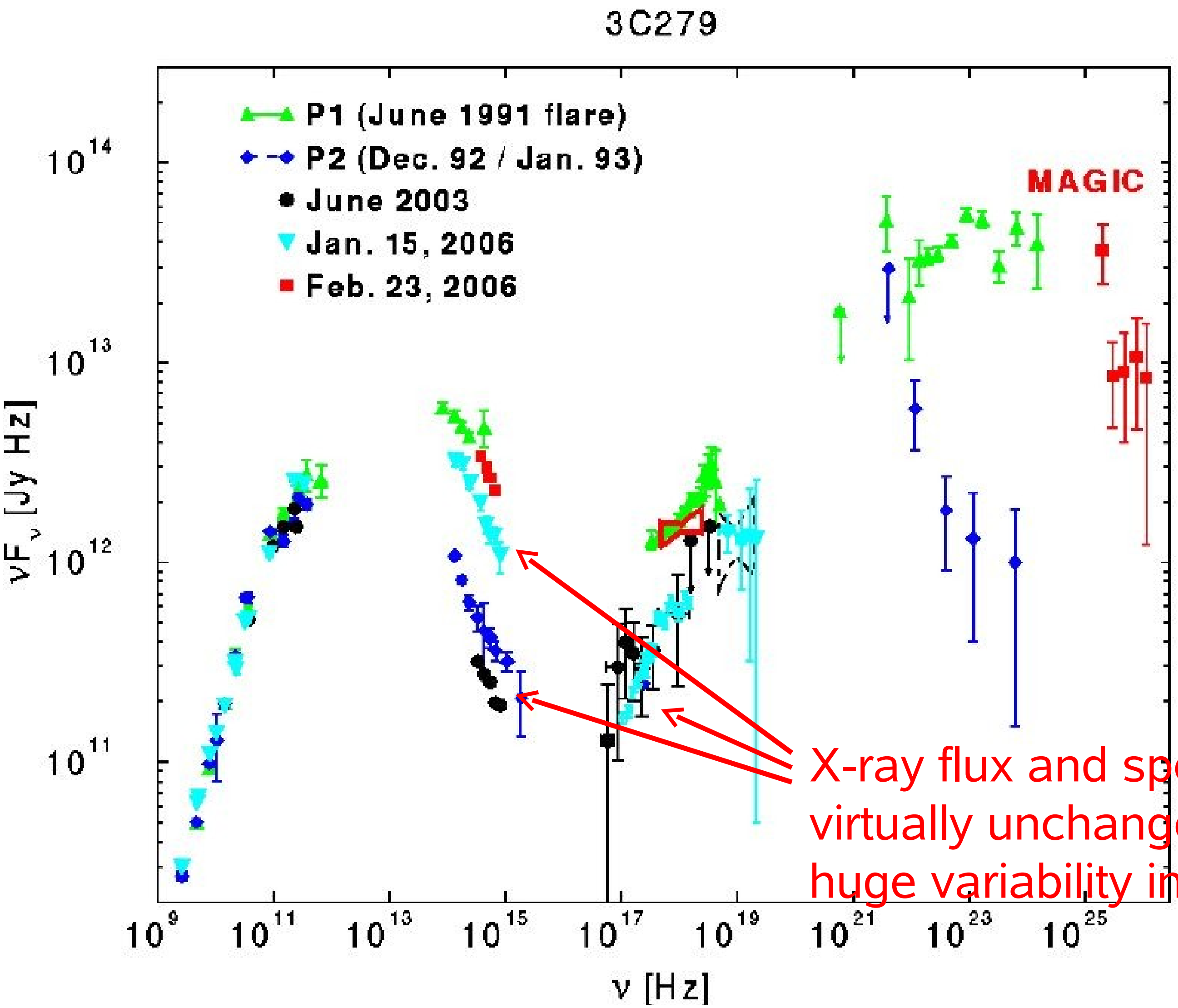
Hardness-Intensity Correlation



X-Ray Variability of the FSRQ 3C279

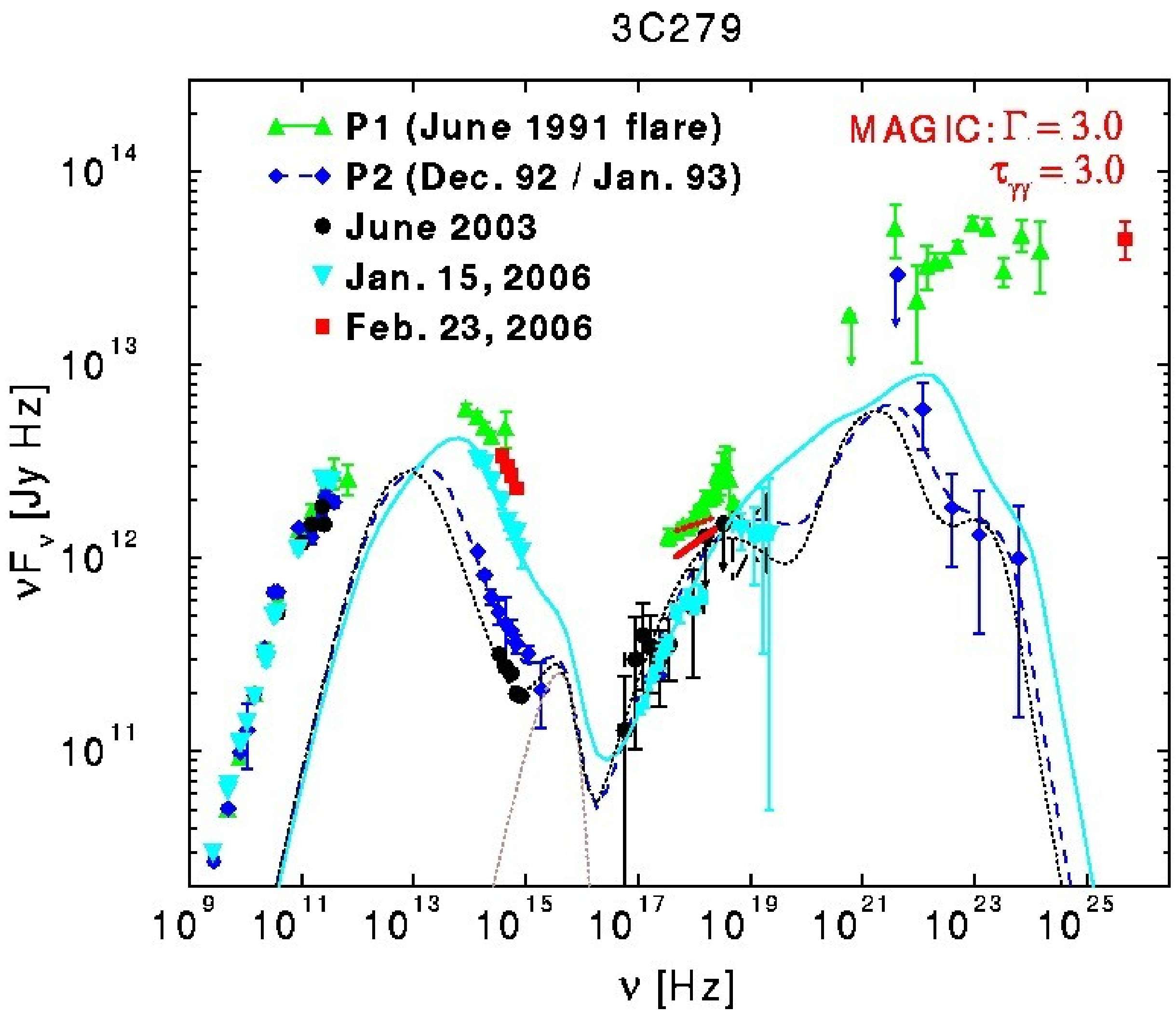


X-Ray Variability of the FSRQ 3C279



X-ray flux and spectrum virtually unchanged in spite of huge variability in the optical!

Spectral Modeling of 3C279



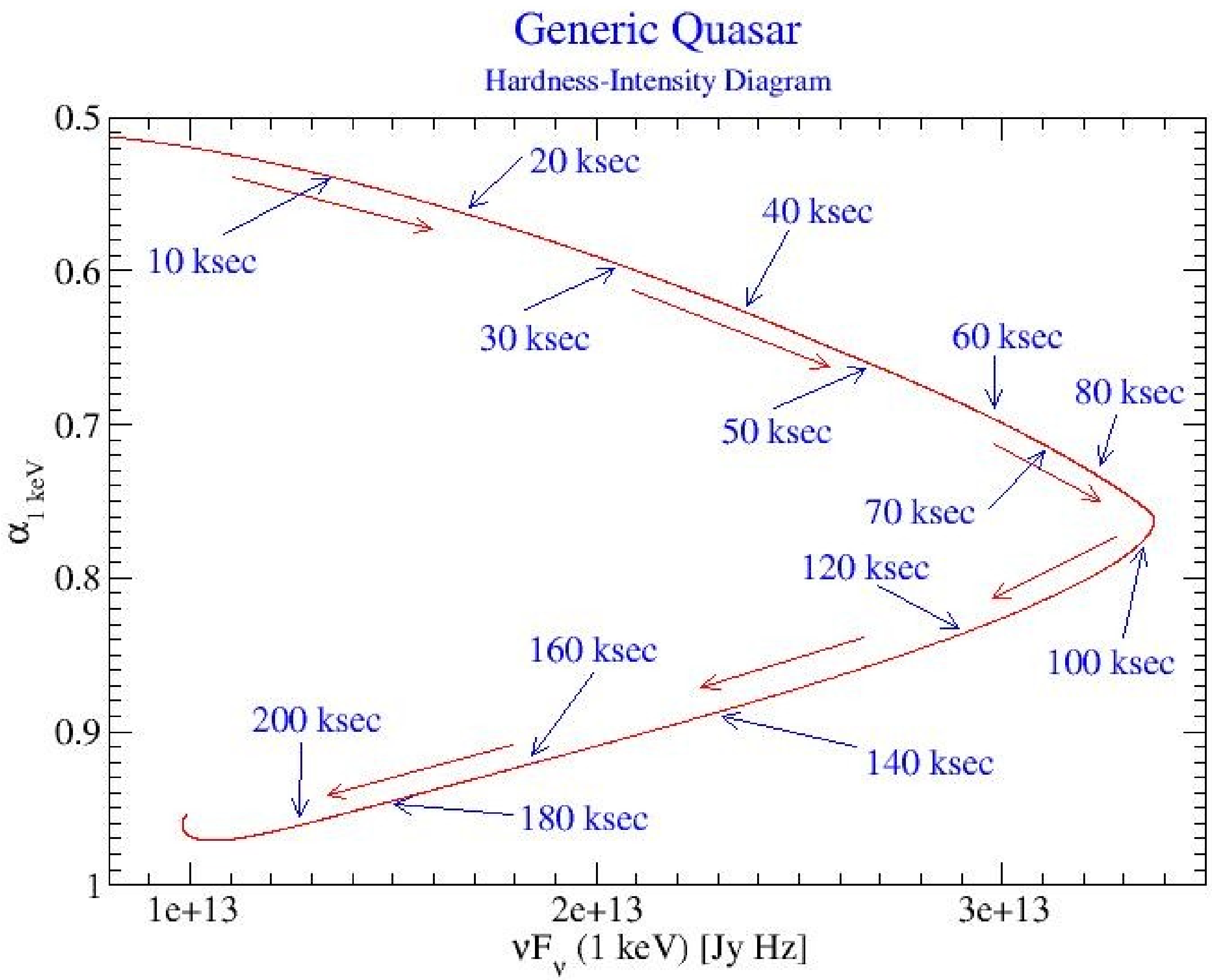
All three low-X-ray states modeled with only changing γ_{min}!

γ_{min} = 550

γ_{min} = 750

γ_{min} = 1500

X-ray Spectral Variability of a Generic FSRQ



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Summary

- Snap-shot X-ray spectra of HBLs (e.g., Mrk 421) and FSRQs are usually well described by featureless power-laws.
- However, HBLs show rapid (intraday) variability in flux **and spectral shape!**
- FSRQs are fainter X-ray sources, but X-ray spectra are more stable, with moderate spectral variability on time scales of ~ days.