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VHE Emission from Blazars:

Counterparts of TeV UIDs???

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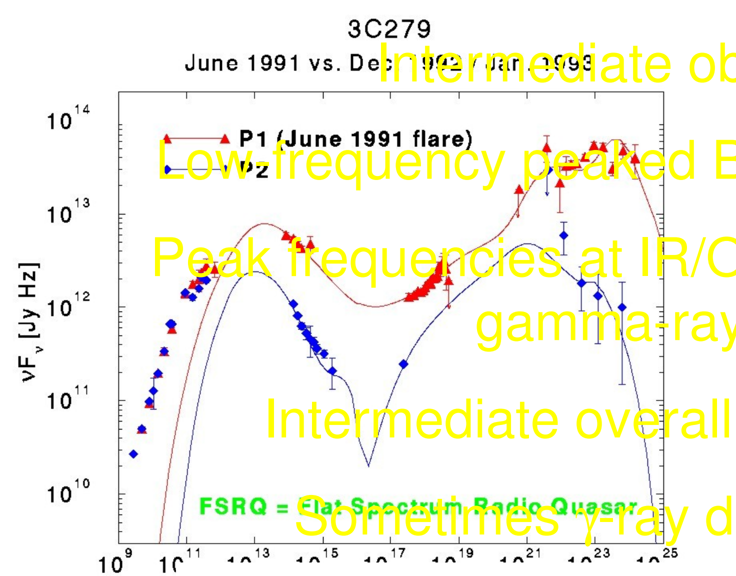
Outline

- Blazar Models along the Blazar Sequence
- 3C279
- W Comae
- Hard VHE spectra of blazars
- Relevance to TeV UIDs (?)

Blazar Classification



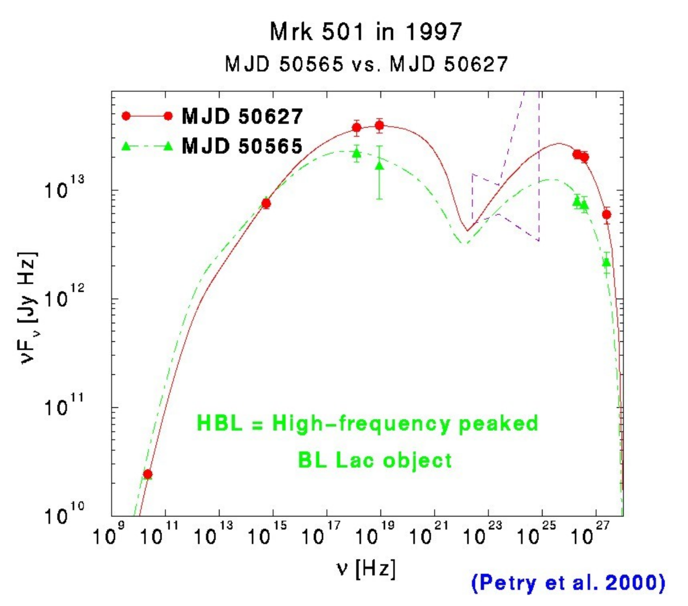
Intermediate objects:

Low-frequency peaked BL Lacs (LBLs):

Peak frequencies at IR/Optical and GeV gamma-rays

Intermediate overall luminosity

Sometimes γ-ray dominated



(Petry et al. 2000)

High-frequency peaked BL Lacs (HBLs):

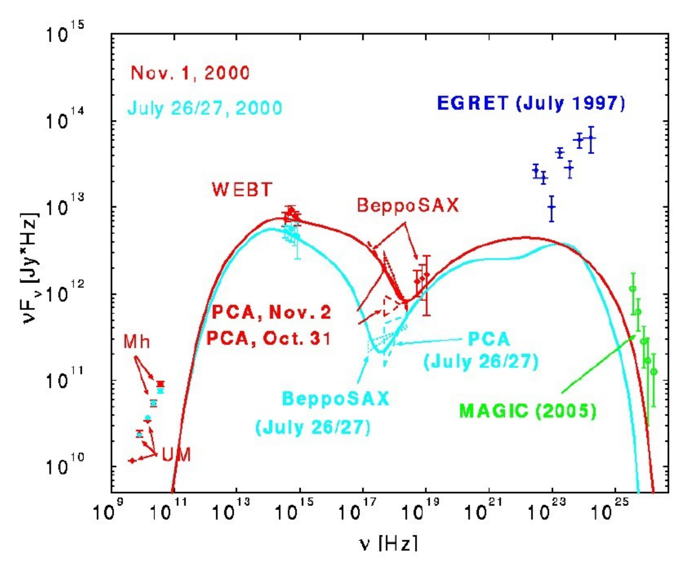
Low-frequency component from radio to UV/X-rays, often dominating the total power

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

Low-fre

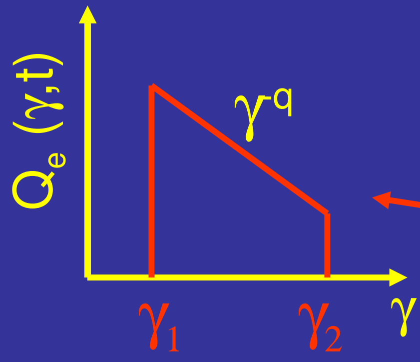
High-fre
to γ-ray

Peak fr

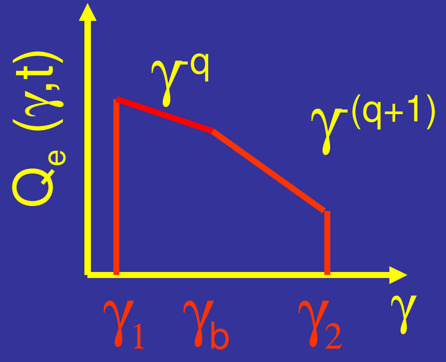


Blazar Models

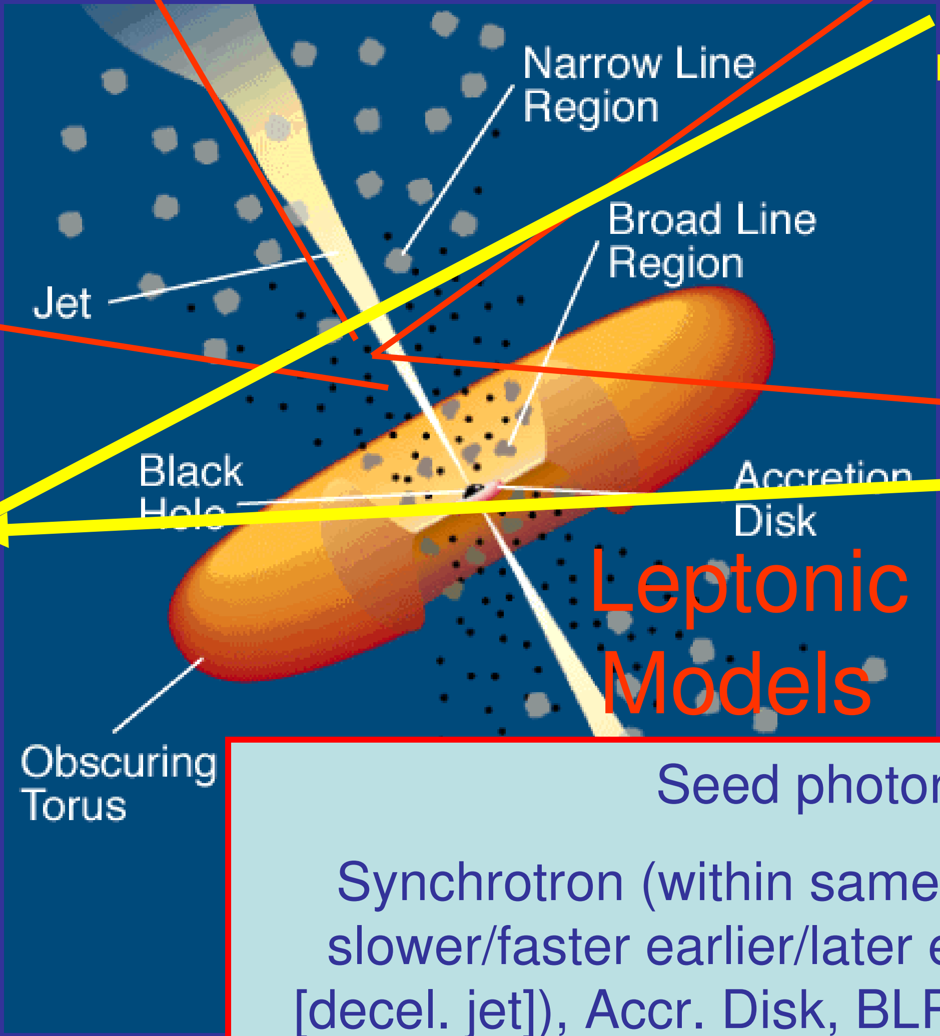
Injection, acceleration of ultrarelativistic electrons



Radiative cooling ↔ escape =>

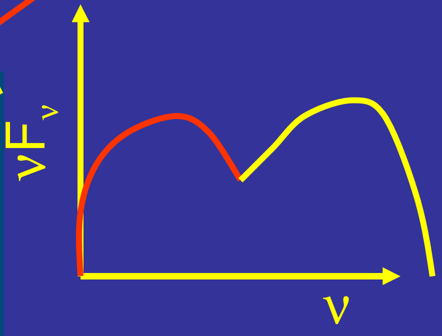


Relativistic jet outflow with $\Gamma \approx 10$

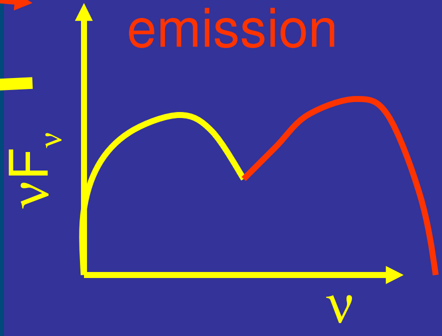


Leptonic Models

Synchrotron emission



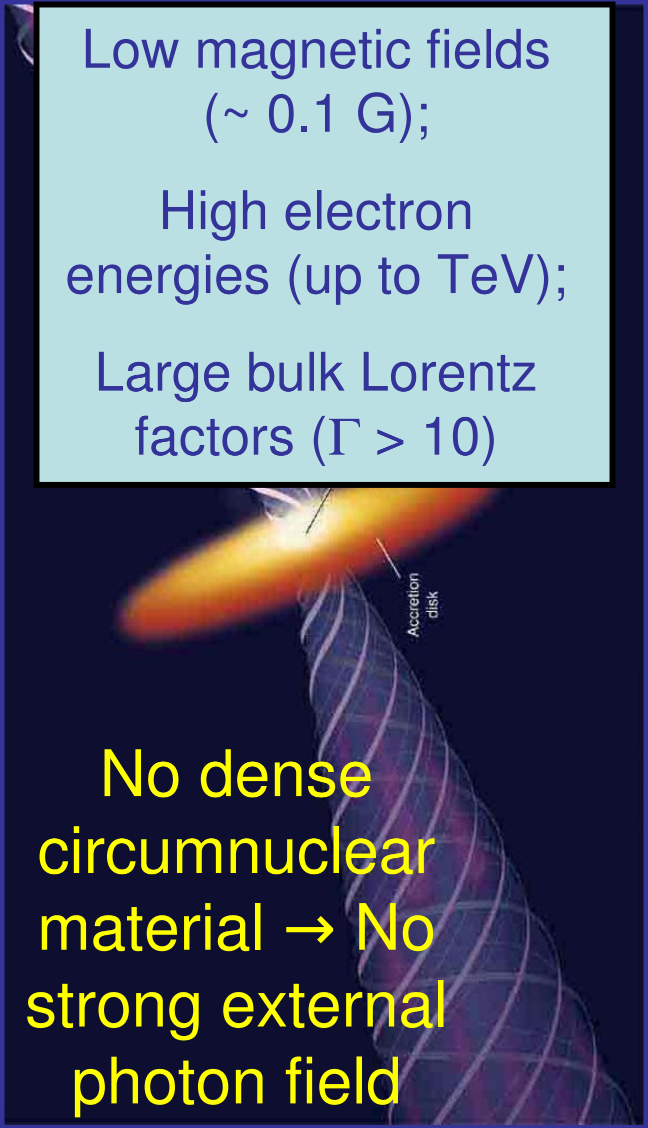
Compton emission



Seed photons:

Synchrotron (within same region [SSC] or slower/faster earlier/later emission regions [decel. jet]), Accr. Disk, BLR, dust torus (EC)

Spectral modeling results along the Blazar Sequence: Leptonic Models



Low magnetic fields (~ 0.1 G);

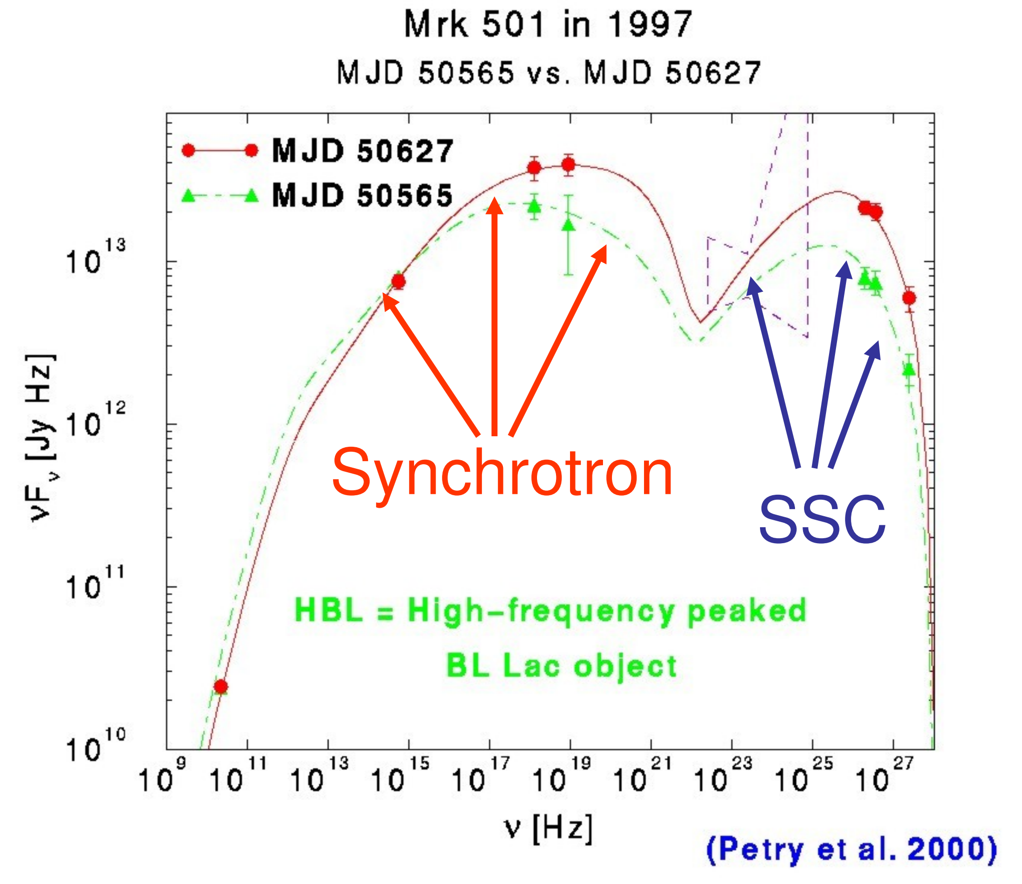
High electron energies (up to TeV);

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

No dense circumnuclear material → No strong external photon field

High-frequency peaked BL Lac (HBL):

The “classical” picture



(Petry et al. 2000)

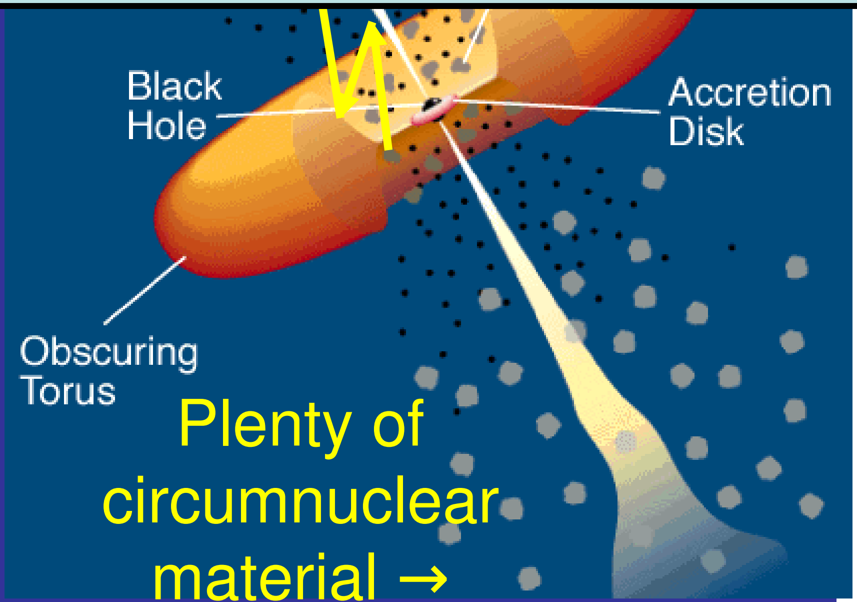
Spectral modeling results along the Blazar Sequence: Leptonic Models

High magnetic fields (~ a few G);

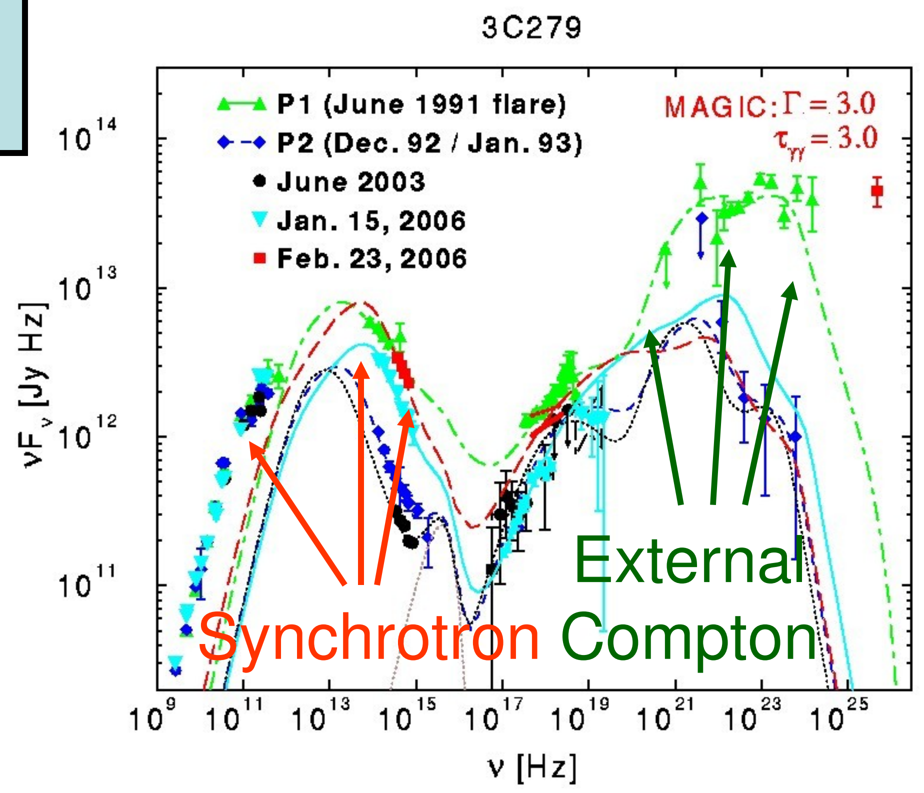
Lower electron energies (up to GeV);

Lower bulk Lorentz factors (Γ ~ 10)

Radio Quasar (FSRQ)



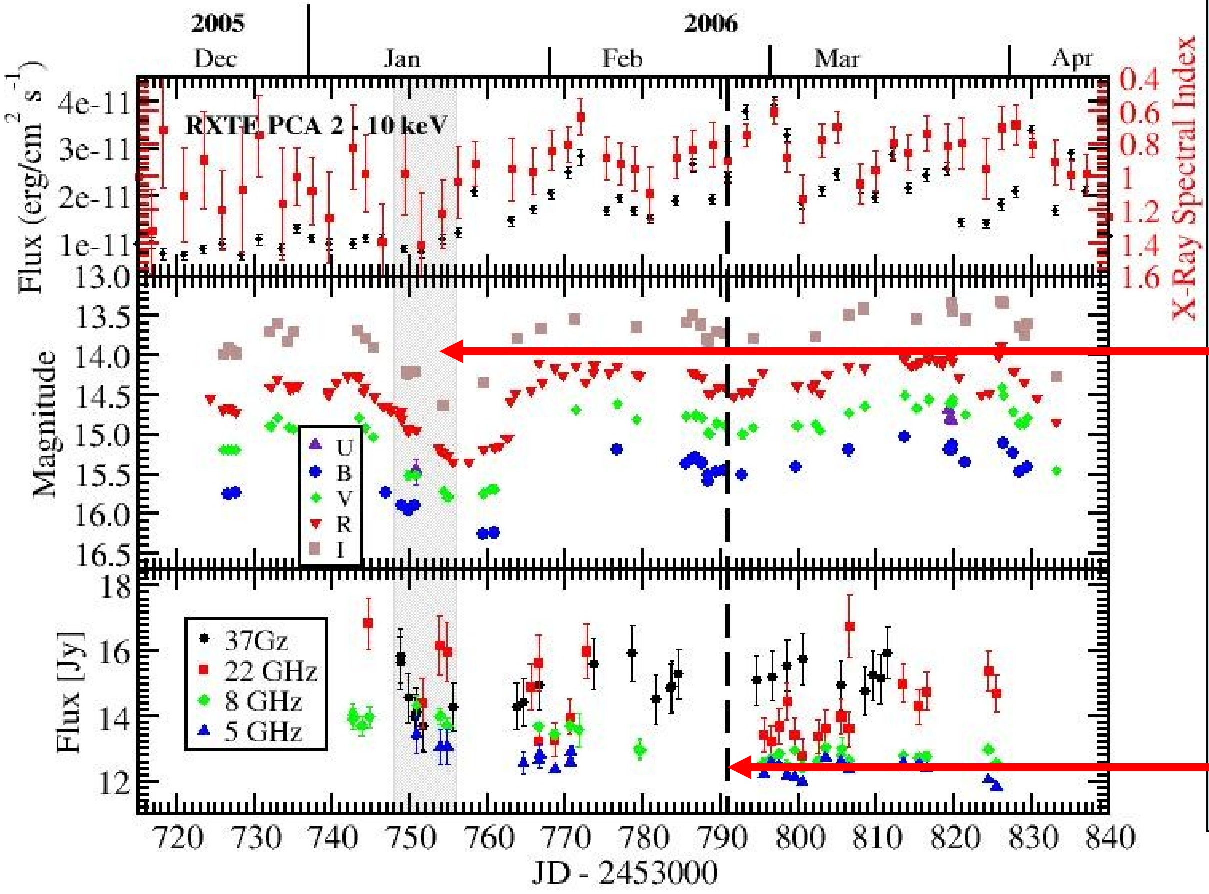
Plenty of circumnuclear material → Strong external photon field



Synchrotron

External Compton

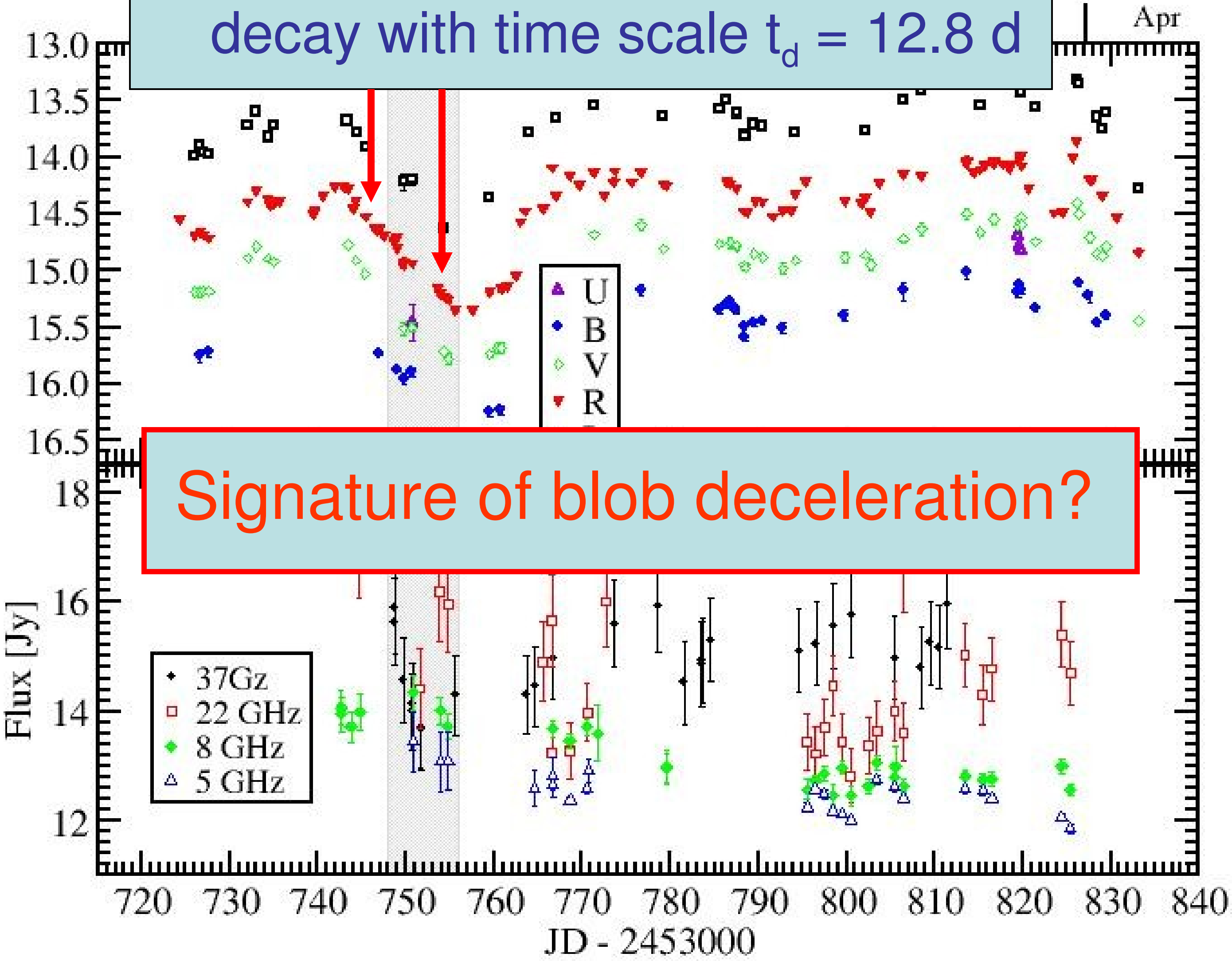
The Multiwavelength Campaign on 3C279 in Spring 2006



- Flat Spectrum Radio Quasar (z = 0.538)
- Persistently detected by EGRET each time it was observed
- INTEGRAL + Chandra ToO observations
- Simultaneous MAGIC observations, with claimed detection on Feb. 23, 2006

Böttcher et al. 2007

Optical Variability

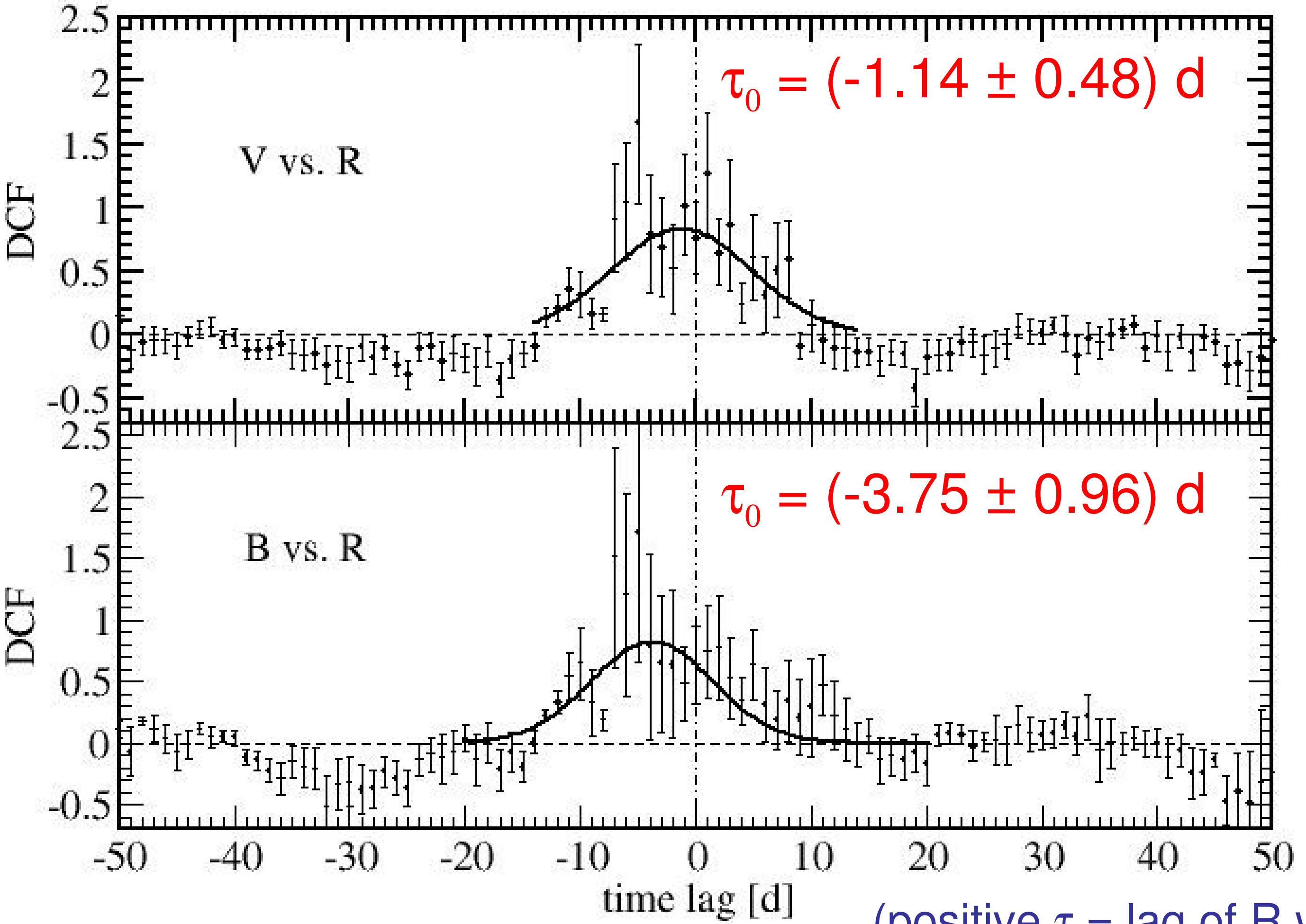


- Remarkably clean exponential decay with time scale t_d = 12.8 d

Signature of blob deceleration?

Discrete Correlation Functions

- Evidence of hard lags in the BVR bands

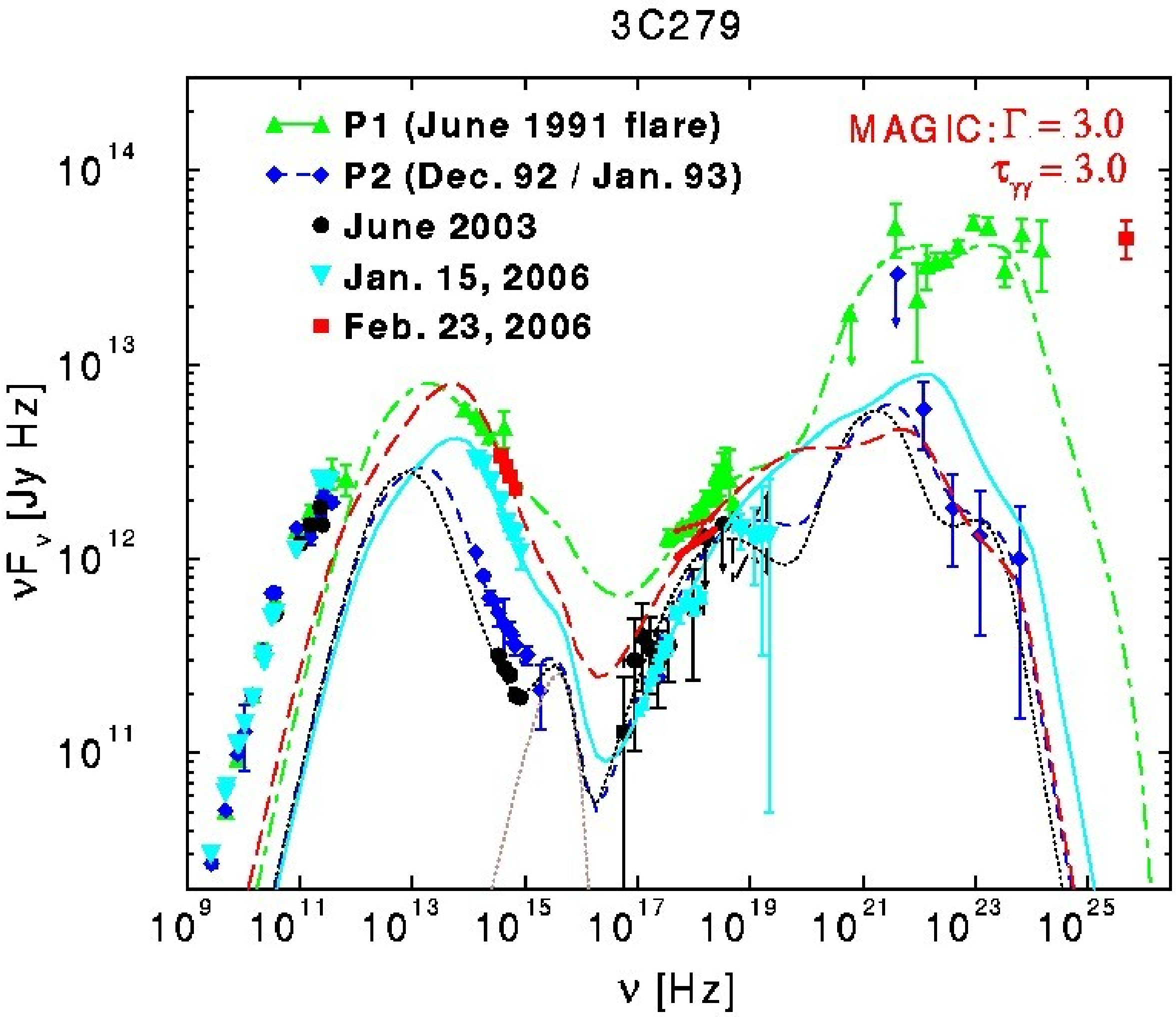


$\tau_0 = (-1.14 \pm 0.48)$ d

$\tau_0 = (-3.75 \pm 0.96)$ d

(positive τ = lag of R w.r.t. V, B)

Spectral Energy Distributions

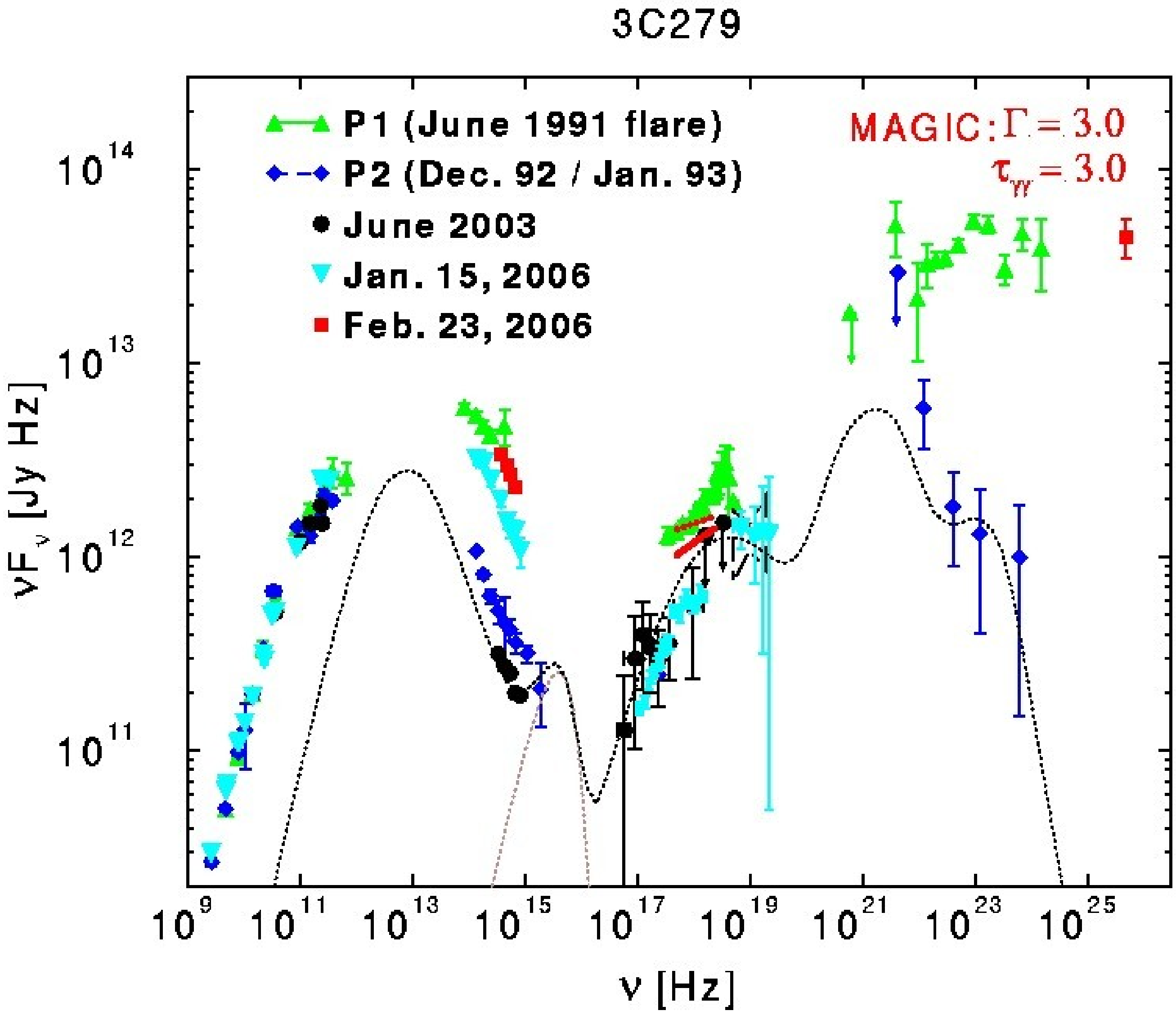


Collmar et al. 2008, in prep.

- SED of Jan 15, 2006, basically identical to low states in 92/93 and 2003 in X- and soft γ-rays
- High optical flux, but steep spectrum

($\alpha_o = 1.64 \pm 0.04$)

Spectral Modeling



Baseline model for lowest state ever observed (June 2003):

$L_{inj} = 1.2\times10^{45}$ erg/s

$\gamma_{min} = 550$

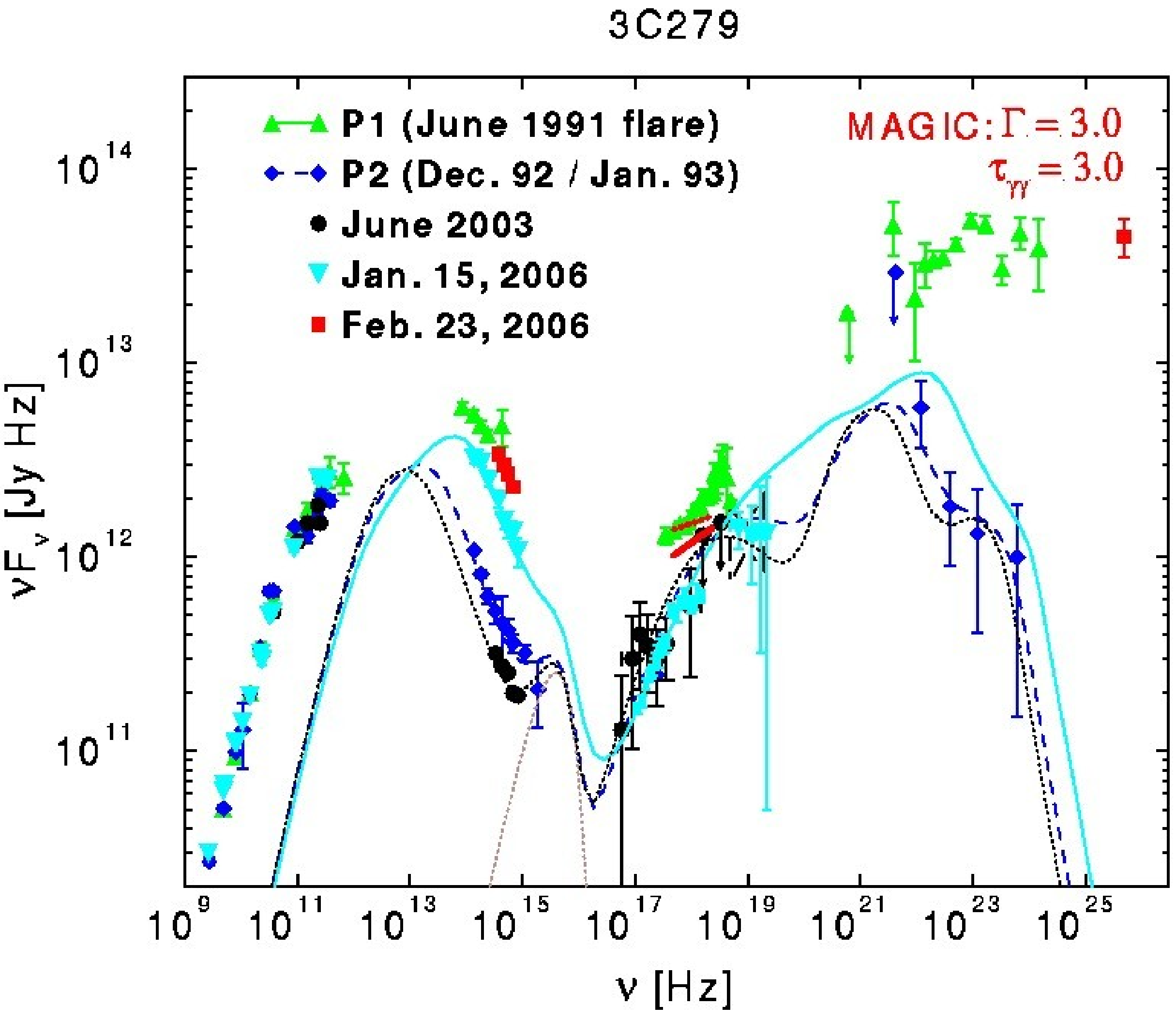
$\gamma_{max} = 10^5$

$q = 3.7$

$B = 0.8$ G

$\Gamma = D = 15$

Spectral Modeling



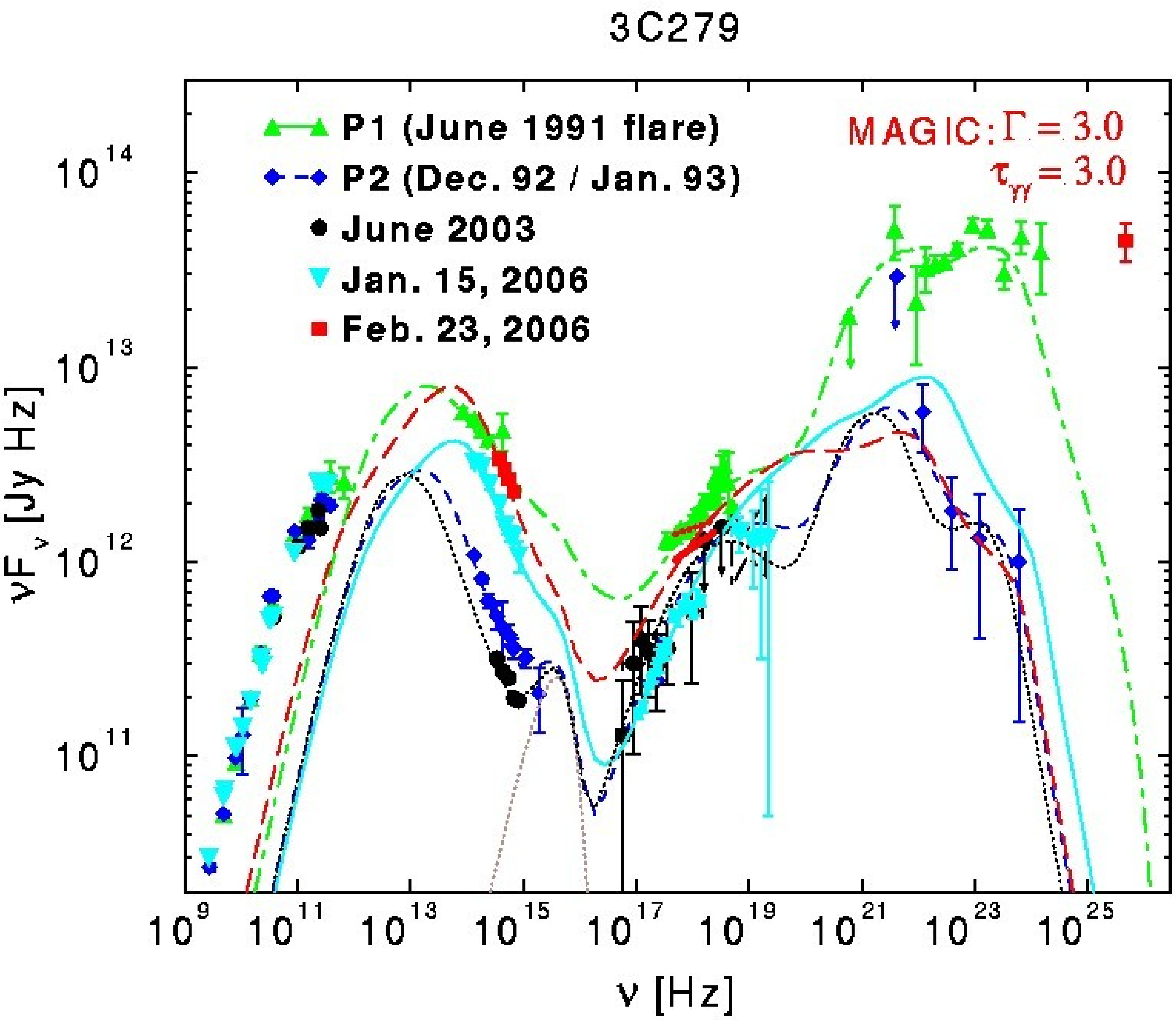
All three low-X-ray states modeled with only changing γ_{min}!

$\gamma_{min} = 550$

$\gamma_{min} = 750$

$\gamma_{min} = 1500$

Spectral Modeling



High X-ray states seem to need higher Doppler factor:

$L_{inj} = 1.8 \times 10^{45}$ erg/s

$\gamma_{min} = 600$

$\gamma_{max} = 10^6$

$q = 2.8$

$B = 0.8$ G

$\Gamma = D = 22$

Leptonic SSC + ERC model with “standard” soft photon sources fails to reproduce the VHE γ-ray (MAGIC) flux

W Comae

- Detected by VERITAS in March 2008 (big flare on March 14)
- One-zone SSC model requires extreme parameters:

Beilicke et al. 2008,
in prep.

Plot censored …

L_{inj} = 2.8*10^{45} erg/s

γ_{min} = 450

γ_{max} = 4.5*10^5

q = 2.2

B = 0.007 G

Γ = D = 30

R_B = 10^{17} cm

Wide peak separation and low X-ray flux require unusually low magnetic field!

W Comae

- Much more natural parameters for EC model
- For Compton scattering in Thomson regime, external photons must have E ~ $(m_e c^2)^2/E_{VHE}$ ~ 0.1 – 1 eV => IR

Plot censored …

Δt_{var} ~ 35 min. allowed with external IR photon field

$L_{inj} = 2*10^{44}$ erg/s

$\gamma_{min} = 700$

$\gamma_{max} = 10^5$

$q = 2.3$

$B = 0.25$ G

$\Gamma = D = 30$

$R_B = 1.8*10^{15}$ cm

$L_{ext} = 1.5*10^{45}$ erg/s

$\tau_{repr} = 0.15$

PKS 2155-304

- Very rapid variability (~ a few minutes; Aharonian et al. 2007)

- One-zone SSC model requires extremely high Doppler factors (>> 50) to lower u_{sy} and Thomson depth of relativistic particles in the emission region in order not to over-produce SSC.

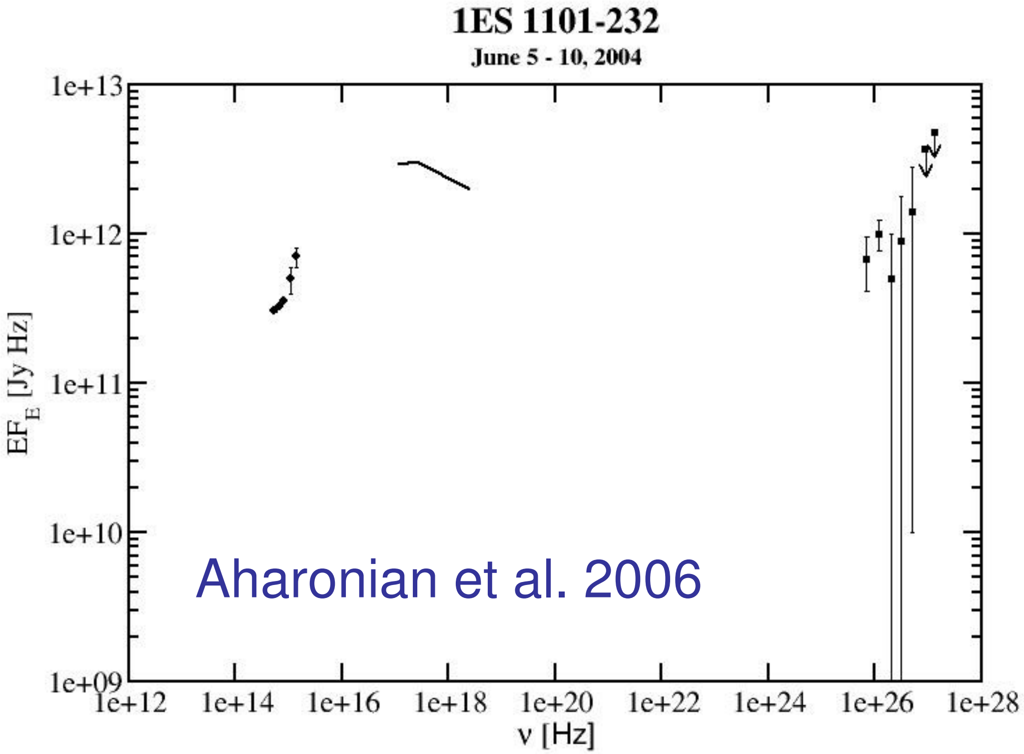
- One-zone SSC model disfavored

(see J. Finke's talk

and Finke et al. 2008)

Hard VHE γ-ray Spectra of HBLs

- Several TeV HBLs (e.g., 1101-232, 0229+200) show very hard (Γ ~ 1.5) spectra after correction for IIBR γγ-absorption.
- Inconsistent with SSC interpretation!



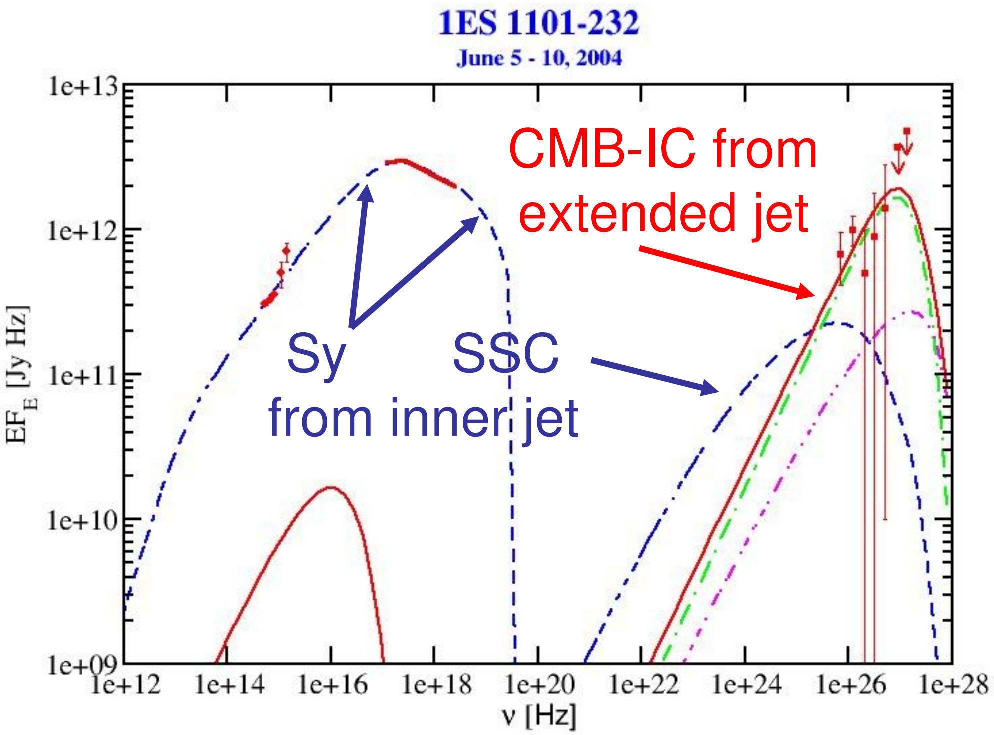
Aharonian et al. 2006

- Requires unusually hard (p ~ 2) ultrarelativistic electron (γ ~ 10^6) spectra
- SSC would show gradual turn-over and can not produce hard VHE spectra.

Hard VHE γ-ray Spectra of HBLs

- Possible solution:

Comptonization of CMB photons



1ES 1101-232

June 5 - 10, 2004

CMB-IC from extended jet

Sy SSC from inner jet

Böttcher et al. 2008

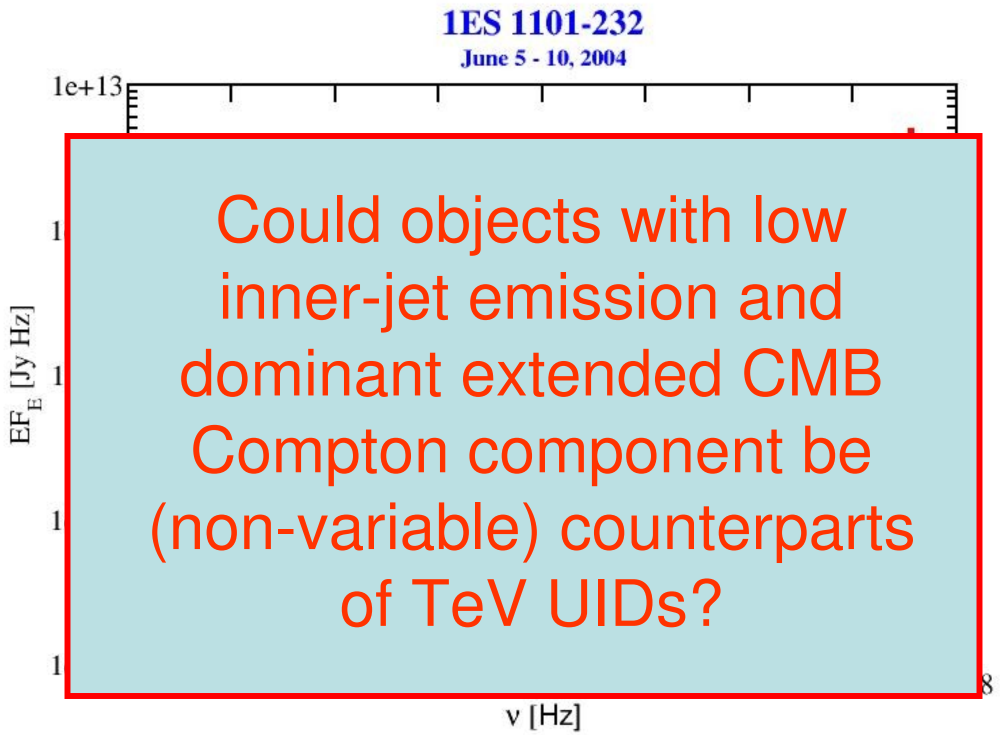
- Inner jet produces sy. + X-ray – GeV γ-ray SSC
- Comptonization of CMB in the outer jet (z ~ pc, R ~ 10^{17} cm, suggested for **non-variable** VHE emission

CMB Comptonization in HBL Jets

- Requires low magnetic fields

$$B < 3.2*10^{-5}\,\Gamma_1\,(1+z)^2\ \mathrm{G}$$

for $u_B < u_{CMB}$ to suppress dominant non-variable synchrotron component


1ES 1101-232

June 5 - 10, 2004

Could objects with low inner-jet emission and dominant extended CMB Compton component be (non-variable) counterparts of TeV UIDs?

- Radiative cooling time scale

$$\tau_{CMB} = 6.3*10^3\ D_1^{1/2}\Gamma_1^{-3/2}(1+z)^{-1}\ \mathrm{yr}$$

for TeV-emitting electrons

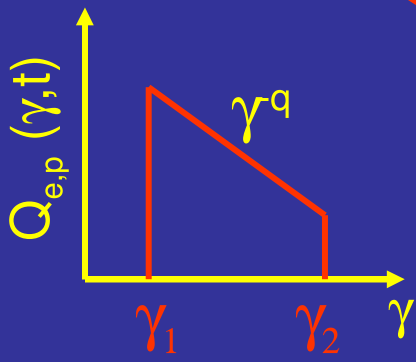
Summary

- If the MAGIC detection of 3C279 is real, an additional spectral component to current leptonic jet models is required.
- SSC model for W Comae requires extreme parameters; external IR photon field allows more natural parameters.
- Spectra and variability of several HBLs (PKS 2155-304, 1101-232, 2200+200) are problematic for one-zone SSC models.
- External radiation fields seem to solve those problems.

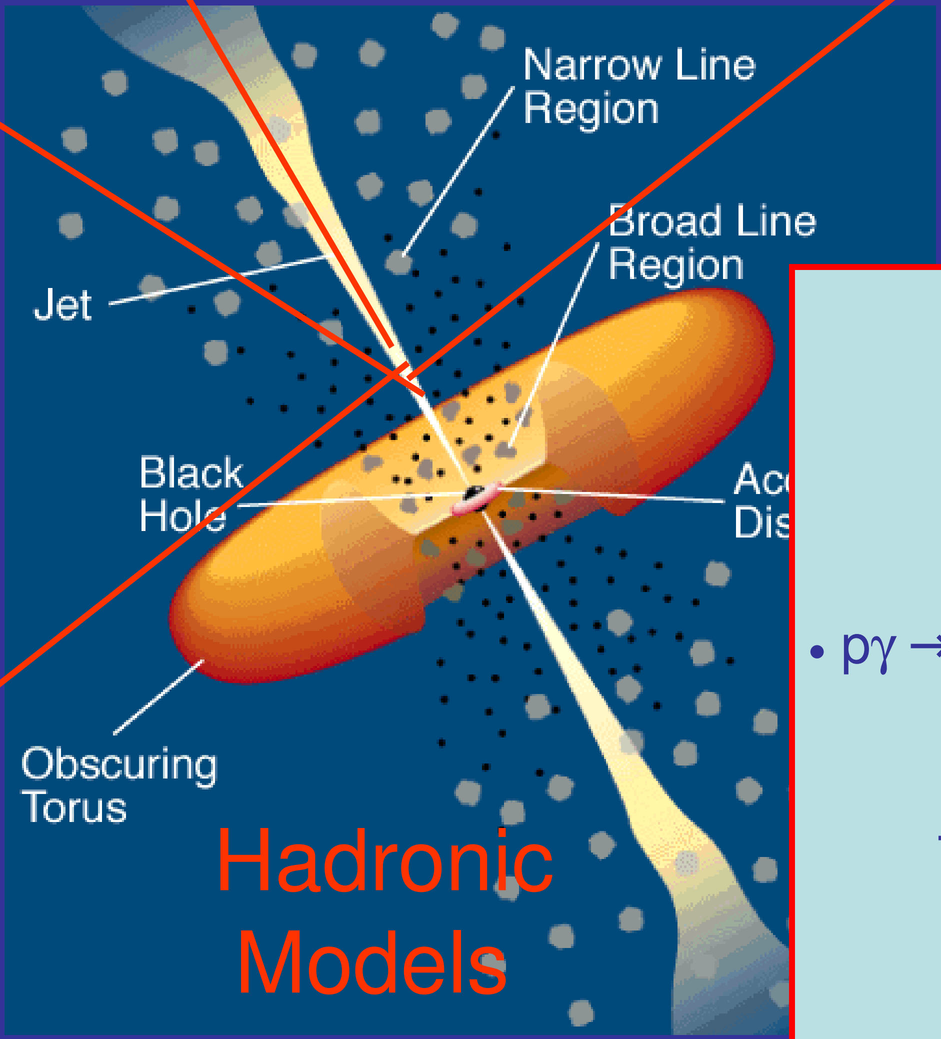
5. Possibility: Comptonization of CMB photons; predicts possibly very hard, but non-variable VHE component.
6. Blazars with CMB Comptonization dominated VHE spectra may be counterparts of some TeV UIDs.

Blazar Models

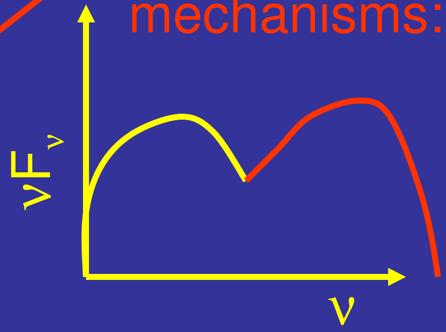
Injection, acceleration of ultrarelativistic electrons and protons



Relativistic jet outflow with $\Gamma \approx 10$

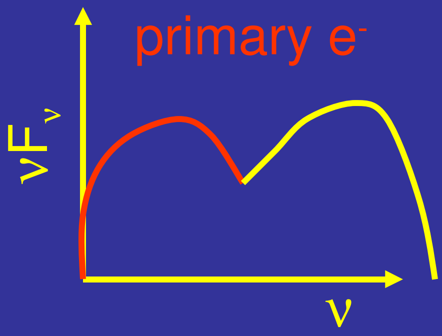


Proton-induced radiation mechanisms:



- Proton synchrotron
- $p\gamma \to p\pi^0$
  $\pi^0 \to 2\gamma$
- $p\gamma \to n\pi^+$; $\pi^+ \to \mu^+\nu_\mu$
  $\mu^+ \to e^+\nu_e\overline{\nu_\mu}$
  $\to$ secondary μ-, e-synchrotron
- Cascades …

Synchrotron emission of primary e^-



Hadronic Models

Spectral modeling results along the Blazar Sequence: Hadronic Models

HBLs: Low co-moving synchrotron photon energy density; high magnetic fields; high particle energies

→ High-Energy spectrum dominated by featureless proton synchrotron initiated cascades, extending to multi-TeV, peaking at TeV energies

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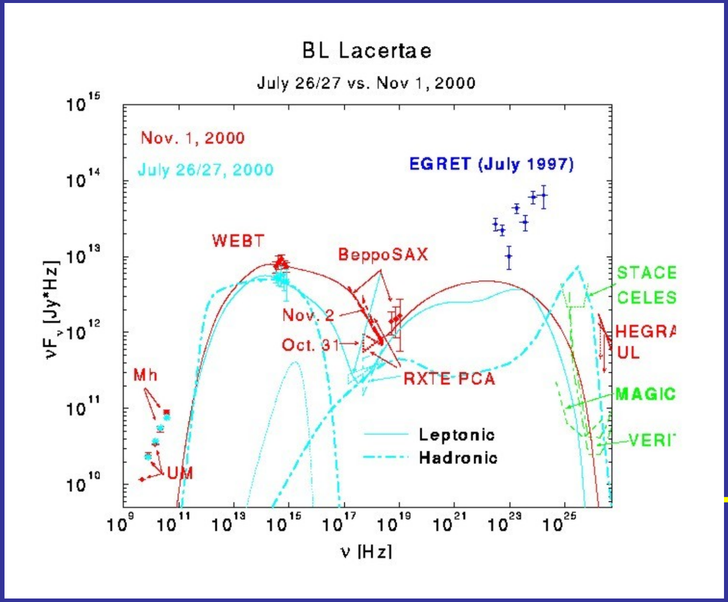
LBLs:



Higher co-moving synchrotron photon energy density; lower magnetic fields; lower particle energies

→ High-Energy spectrum dominated by pγ pion decay, and synchrotron-initiated cascade from secondaries

→ multi-bump spectrum extending to TeV energies, peaking at GeV energies