Correlation between Emission-Line Luminosity and Gamma-Ray Dominance in 3C279

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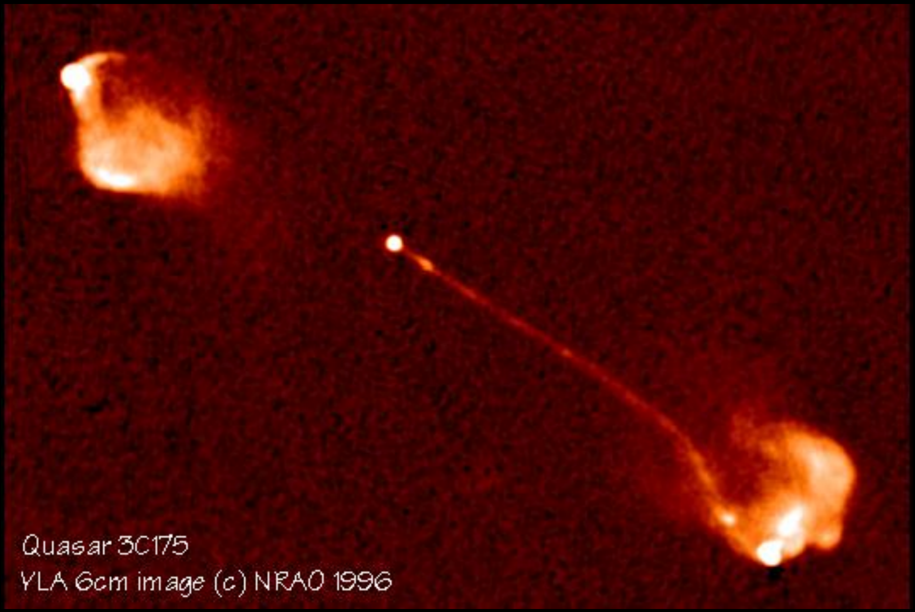
Based on: Dmytriiev, Böttcher & Machipi, 2023, ApJ 949, 28

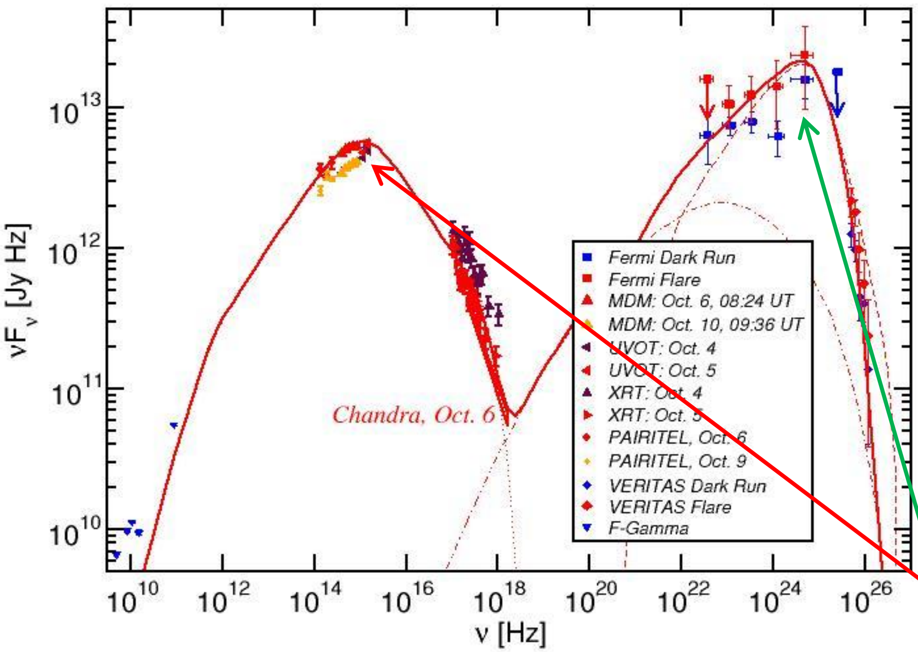
Blazars



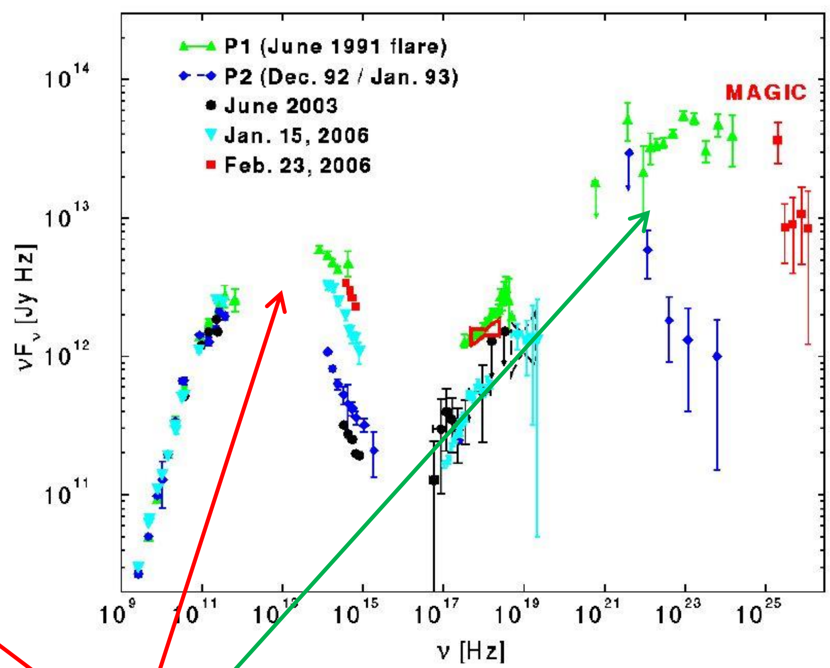
- Class of AGN consisting of BL Lac objects and gamma-ray bright quasars with relativistic jets pointing close to our line of sight
- Rapidly (often intra-day) variable
- Strong gamma-ray sources
- Radio knots often with superluminal motion
- Radio and optical (and X-ray?) polarization

Blazar Spectral Energy Distributions (SEDs)

3C66A



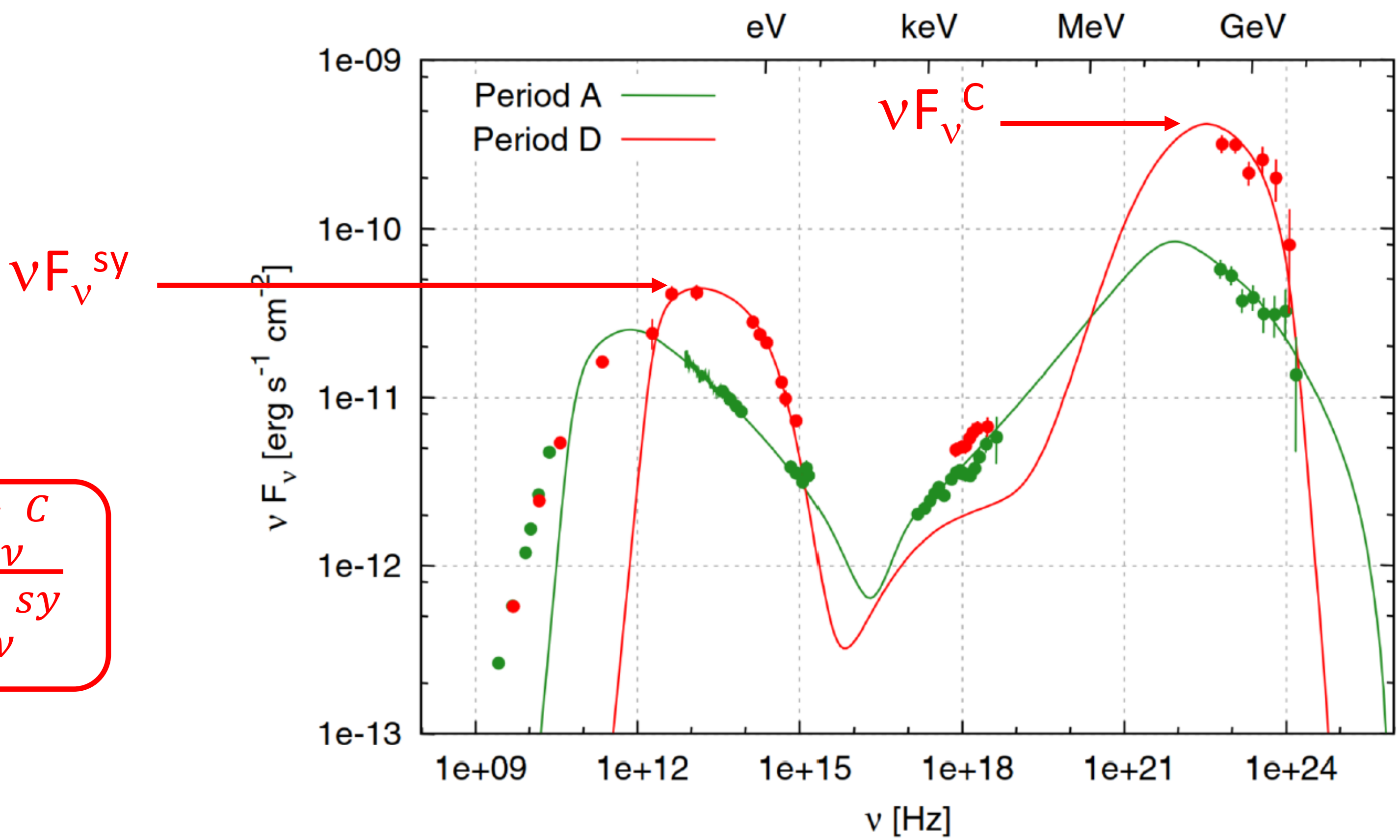
3C279



Non-thermal spectra with two broad bumps:

- Low-energy (probably synchrotron): radio-IR-optical(-UV-X-rays)
- High-energy (X-ray – γ-rays)

Gamma-Ray (Compton) Dominance

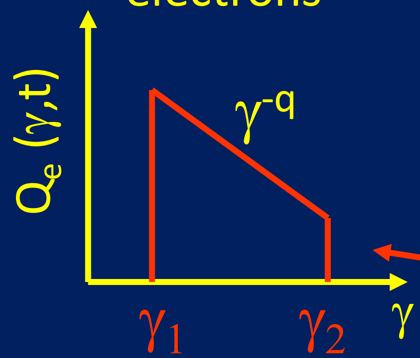


$$CD = \frac{\nu F_\nu^{\,C}}{\nu F_\nu^{\,sy}}$$

(3C279: Hayashida et al. 2012)

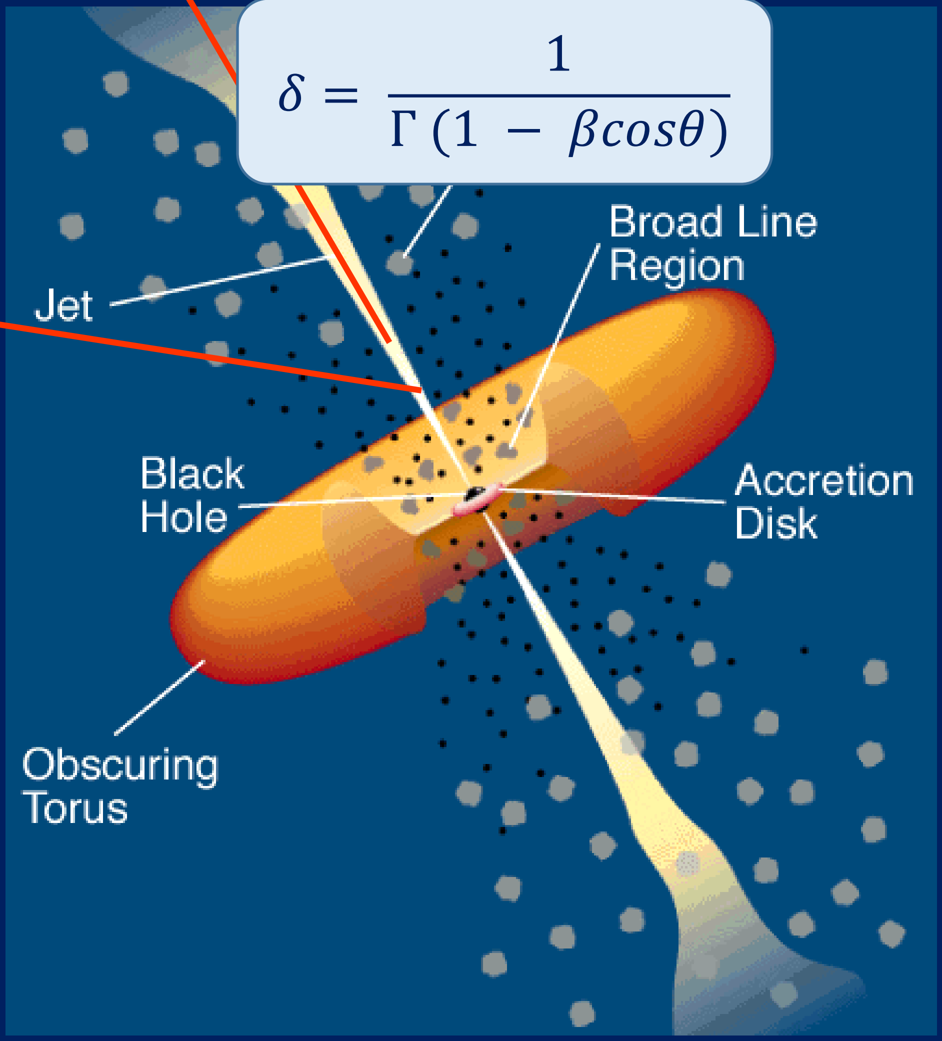
Leptonic Blazar Model

Injection, acceleration of ultrarelativistic electrons



Relativistic jet outflow with $\Gamma \approx 10$

$$\delta = \frac{1}{\Gamma\,(1 - \beta\cos\theta)}$$



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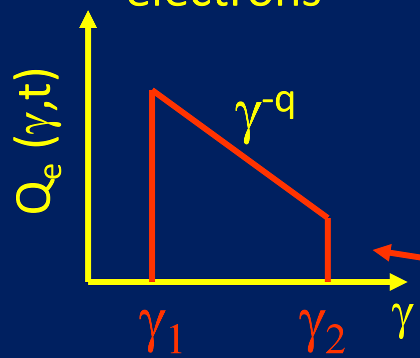

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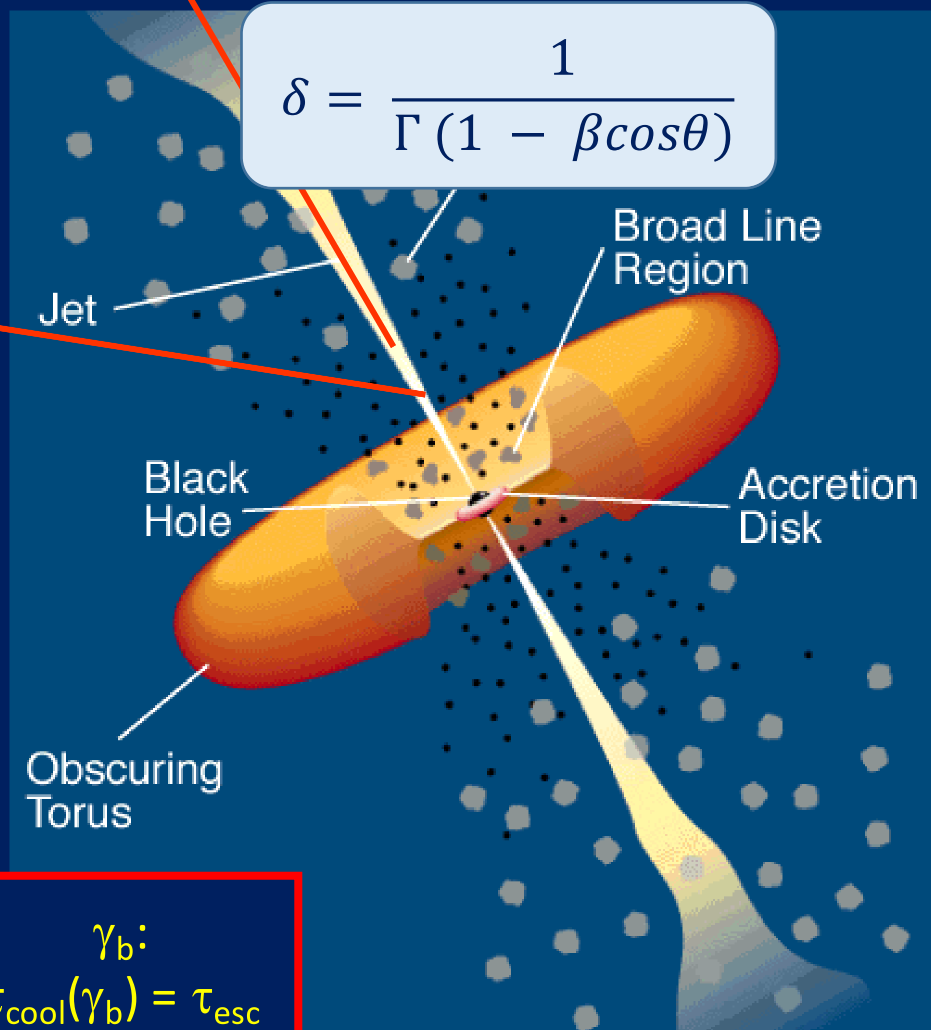
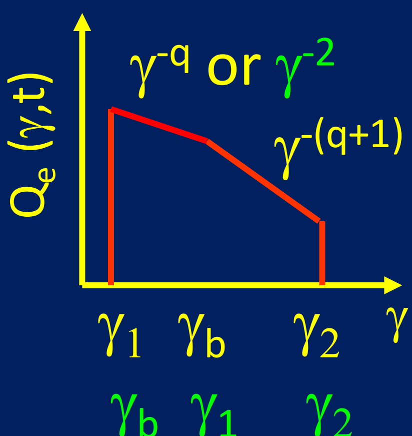


Radiative cooling ↔ escape =>



γ_b:
$\tau_{cool}(\gamma_b) = \tau_{esc}$

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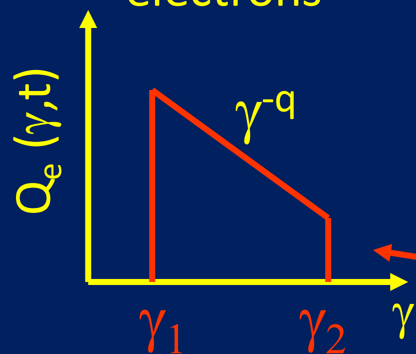

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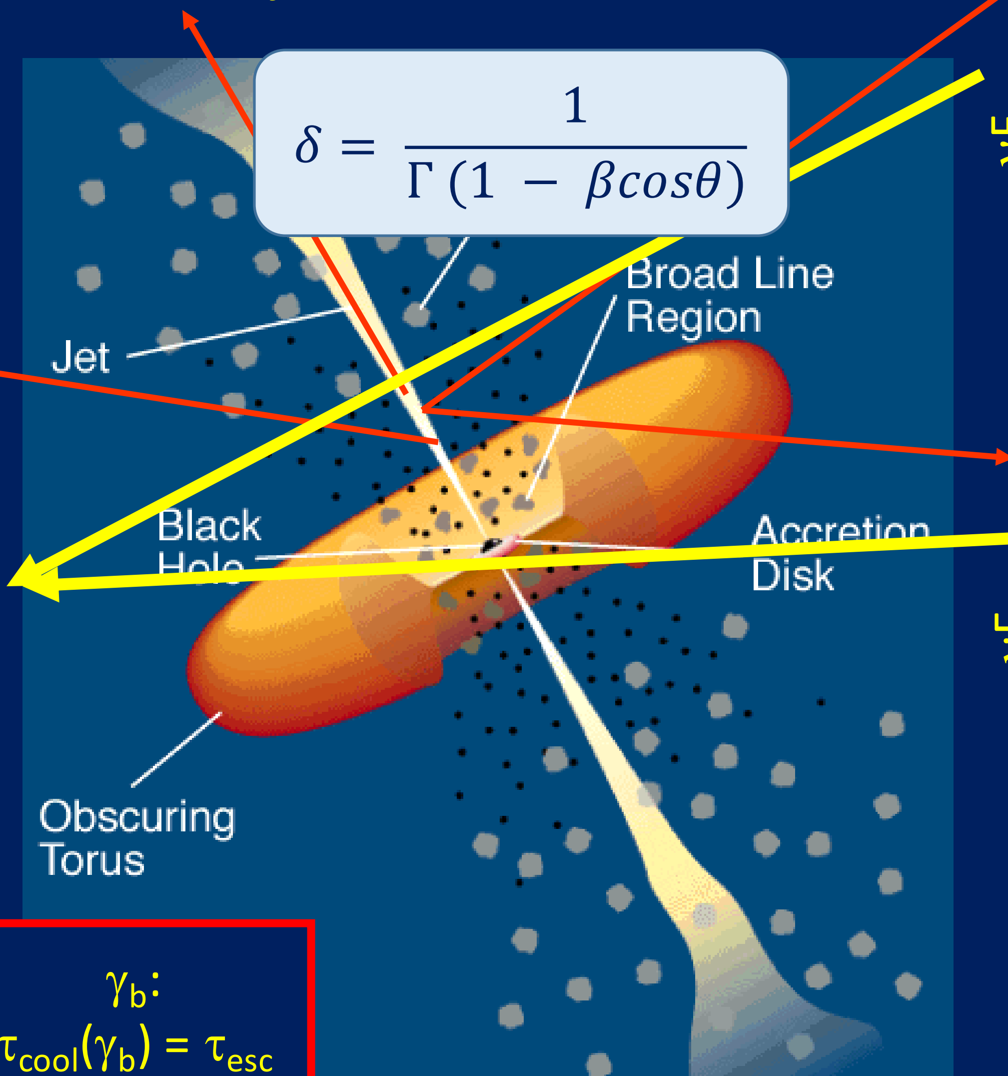

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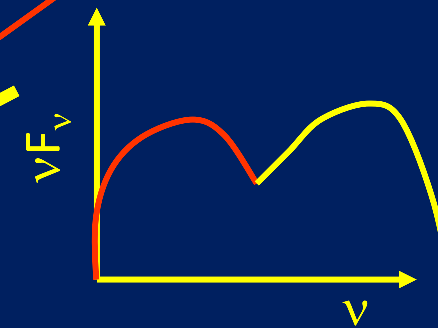
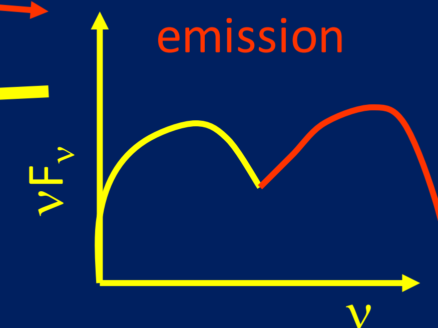
Synchrotron emission



Compton emission



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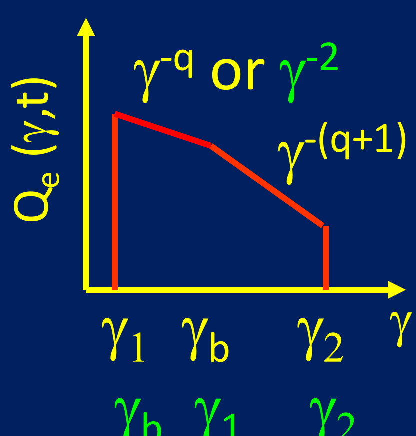

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Leptonic Blazar Model

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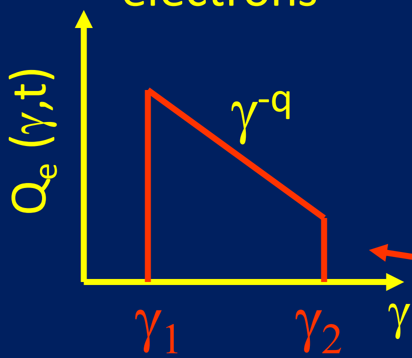

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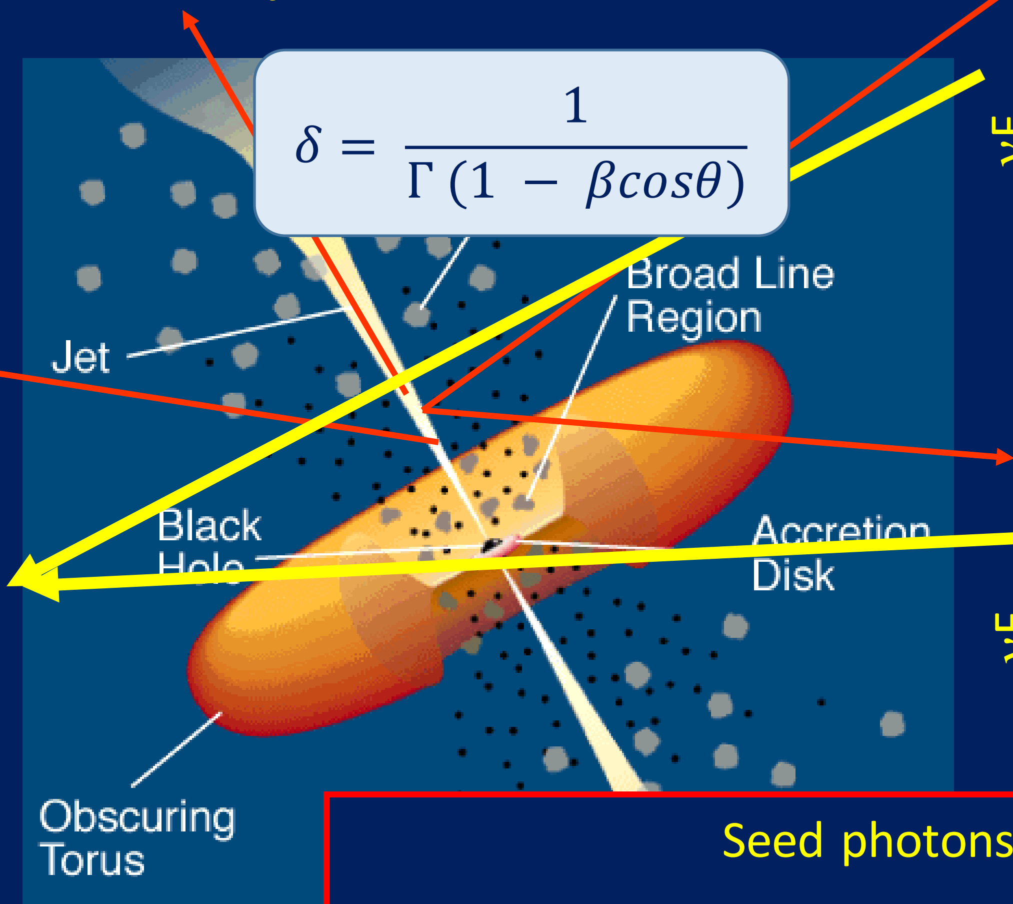
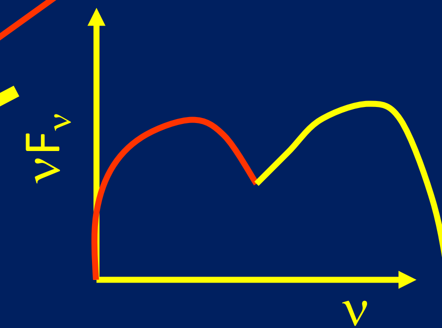
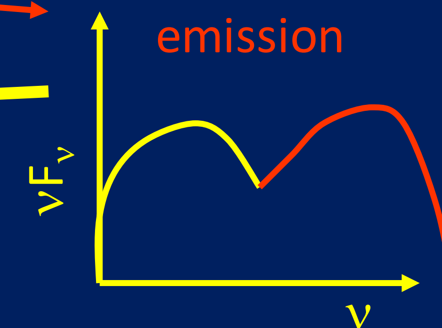


Synchrotron emission



Compton emission



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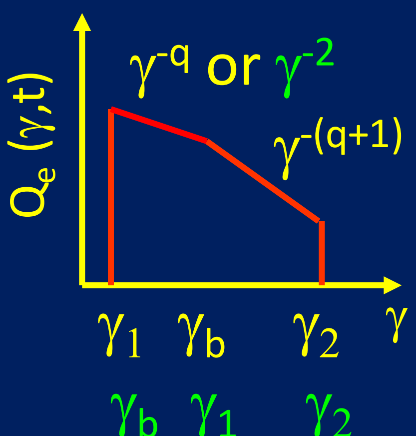


γ_b: $\tau_{cool}(\gamma_b) = \tau_{esc}$

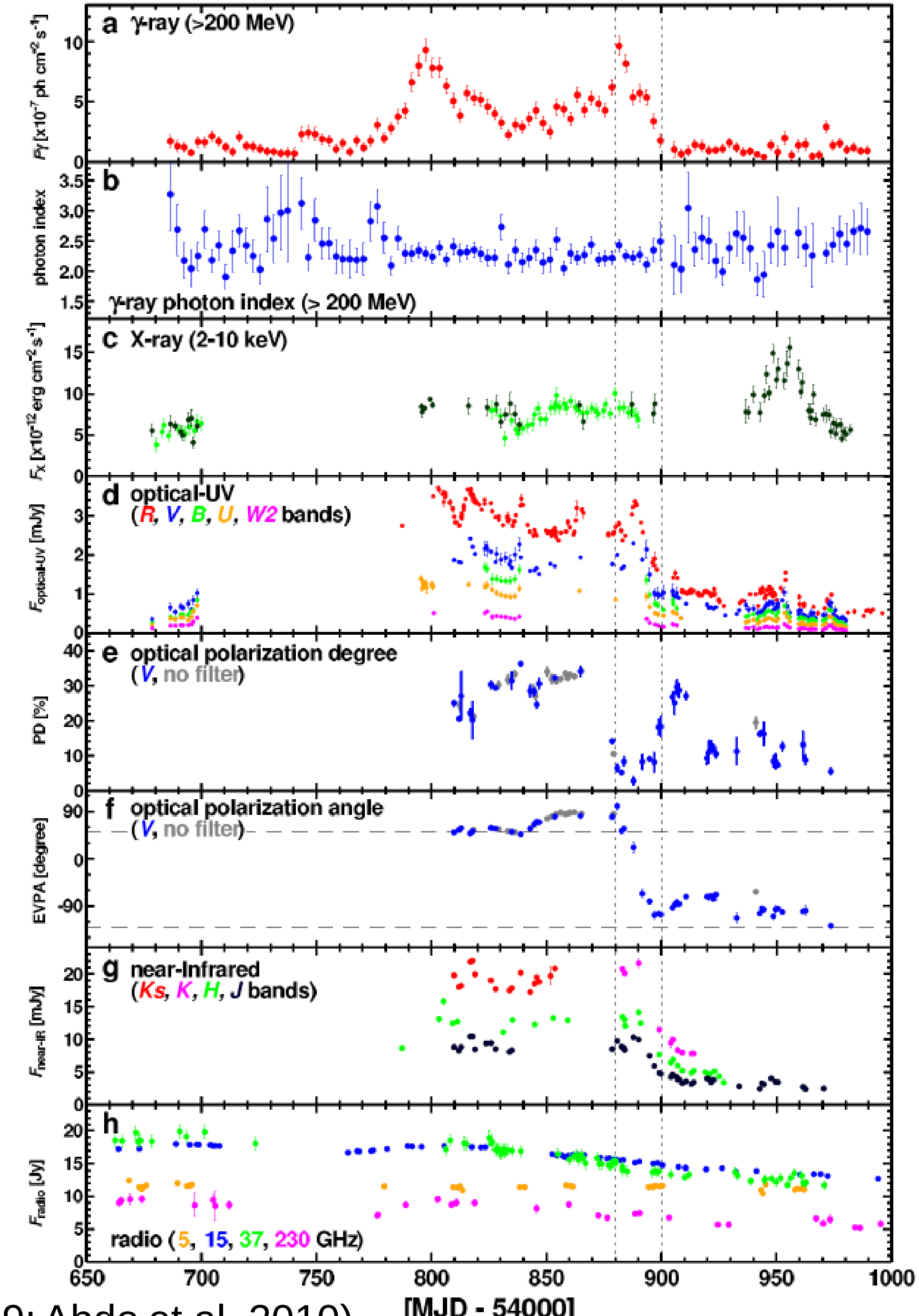
Seed photons:

Synchrotron (within same region [SSC]) or external sources, e.g., accretion disk, BLR, dust torus (EC = External Compton)

Multi-wavelength Variability

Multi-wavelength variability on various time scales (months – minutes)
Sometimes correlated, sometimes not

Different variability amplitudes in different wavelength regimes
→ Change of γ-ray dominance.



(3C279: Abdo et al. 2010)

Gamma-Ray (Compton) Dominance

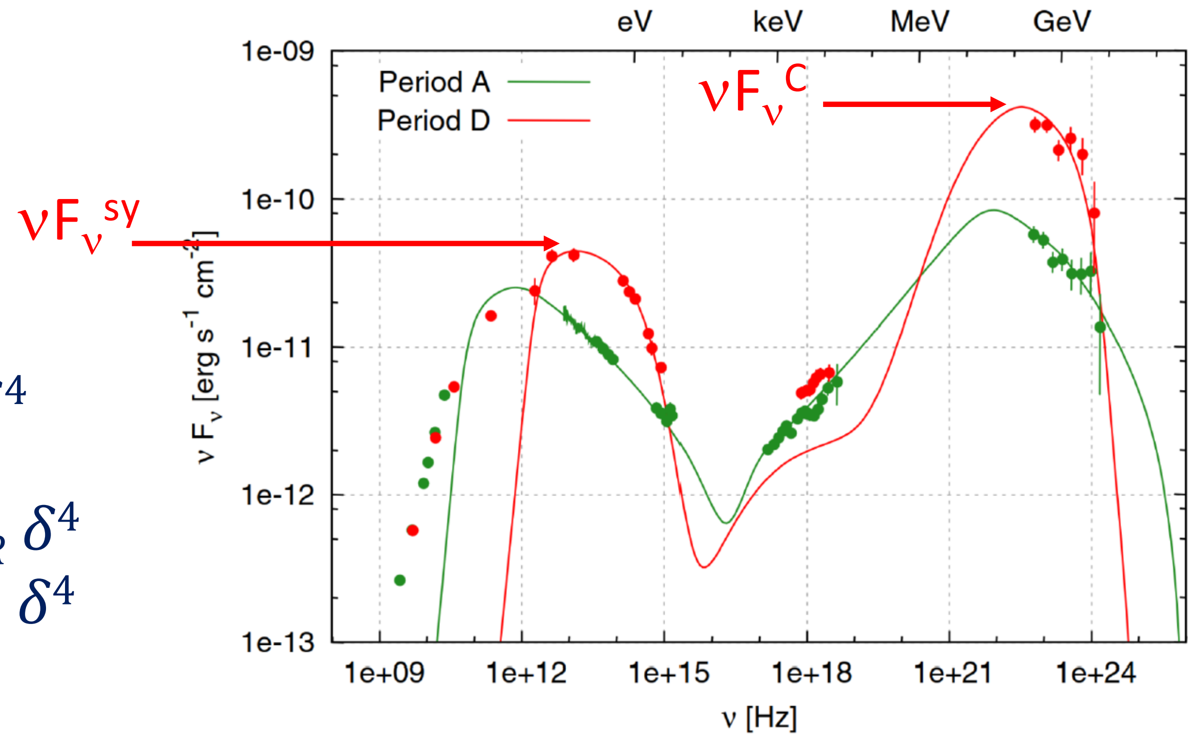
Hypothesis: γ-ray flux dominated by EC on BLR photons (?)

$$CD = \frac{\nu F_\nu{}^{C}}{\nu F_\nu{}^{sy}}$$

$$\nu F_\nu{}^{sy} \propto N_e\, B^2\, \delta^4$$

$$\nu F_\nu{}^{C} \propto N_e\, \Gamma^2\, u_{BLR}\, \delta^4$$
$$\propto N_e\, \Gamma^2\, L_{BLR}\, \delta^4$$

$$\rightarrow CD \propto \frac{\Gamma^2\, L_{BLR}}{B^2}$$



(3C279: Hayashida et al. 2012)

=> If Γ and B are not significantly changing, expect a correlation between LBLR and CD!

3C279

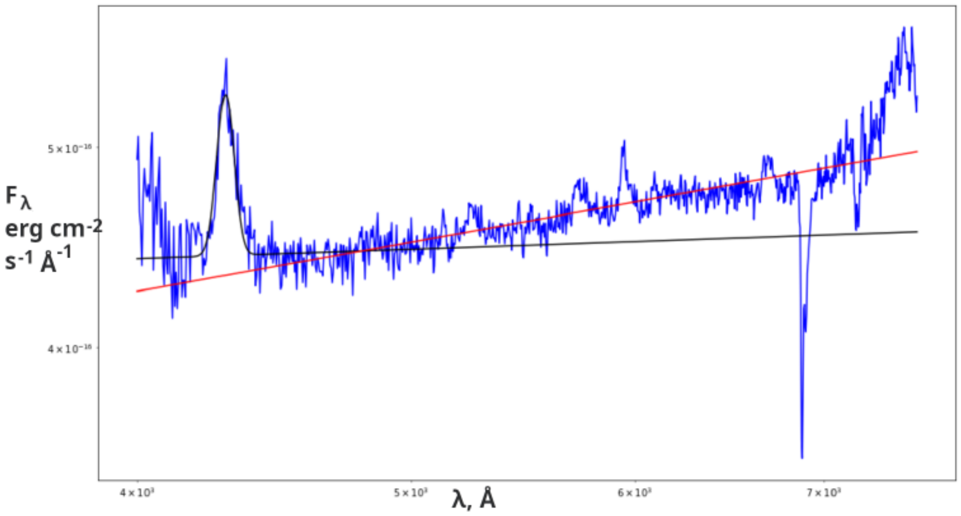
- One of the best studied γ-ray bright FSRQs across the EM spectrum (incl. Fermi-LAT since 2008 and optical spectroscopy monitoring by Steward Observatory)
- First FSRQ detected by EGRET (when 3C73 was expected to be seen)
- First FSRQ detected in VHE γ-rays
- $z = 0.536$
- Typically high CD

Data

- Optical spectroscopy from Steward Observatory monitoring program[1] (2008 – 2018)

- Fit continuum (power-law) + Gaussian emission lines

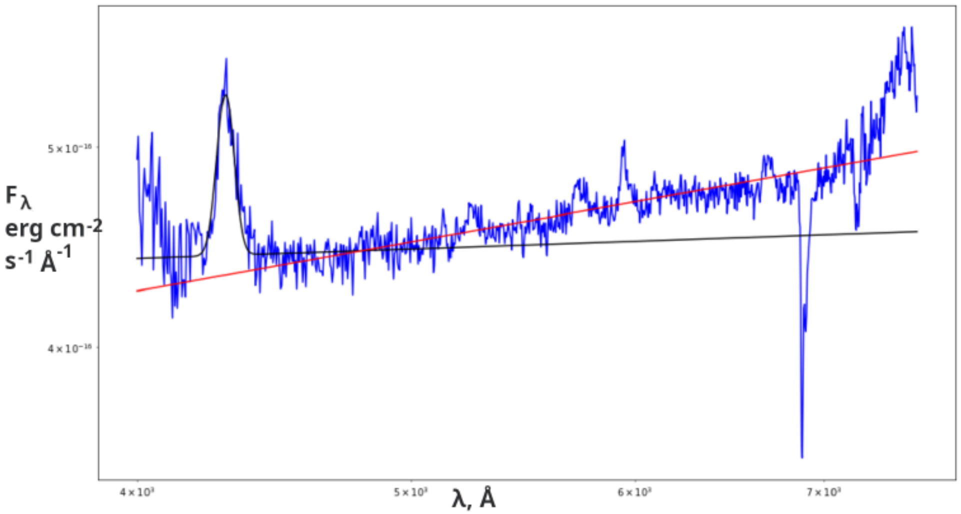
- MgII line (2798 Å, redshifted to 4298 Å) as proxy for emission-line luminosity



[1]http://james.Arizona.edu/~psmith/Fermi/

Data

- Optical spectroscopy from Steward Observatory monitoring program[1] (2008 – 2018)
- Fit continuum (power-law) + Gaussian emission lines
- MgII line (2798 Å, redshifted to 4298 Å) as proxy for emission-line luminosity
- Fermi-LAT data 2008 – 2018
- Fermipy, maximum-likelihood
- Adaptive time binning (1 week, 3 day, 1 day), depending on flux state



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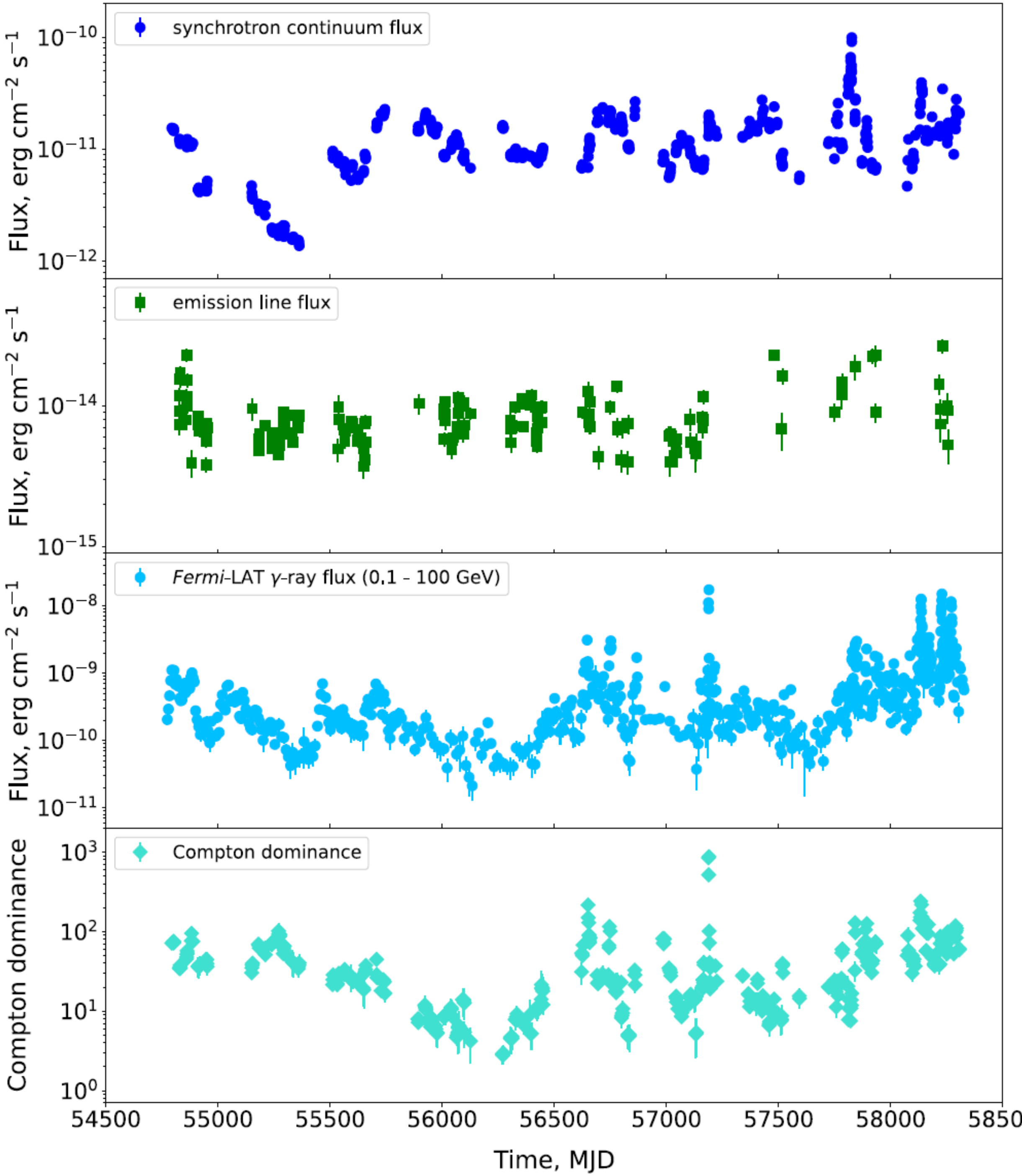
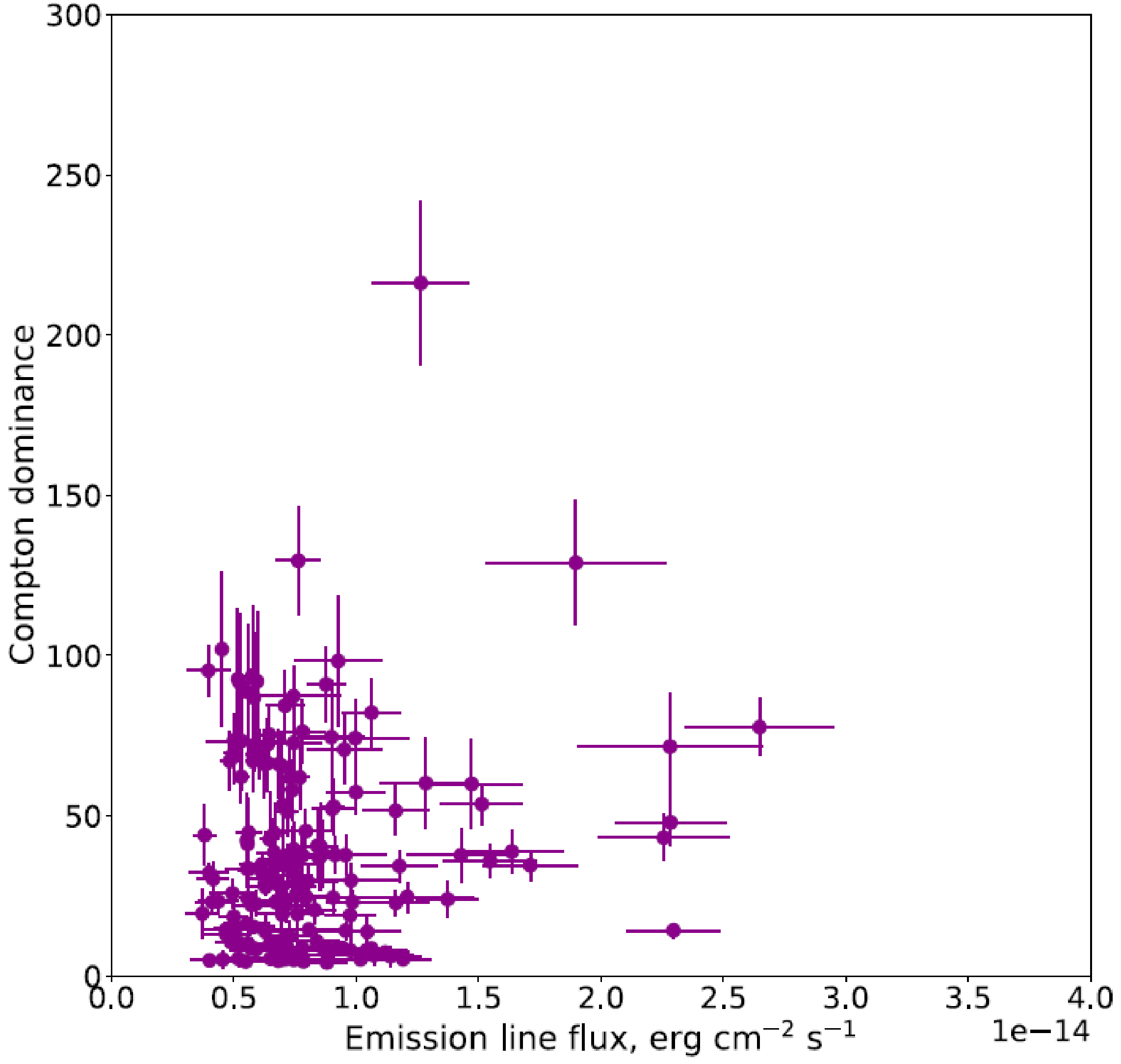
Light curves

No obvious correlation of emission-line flux with optical / γ-ray continuum



Correlation analyses

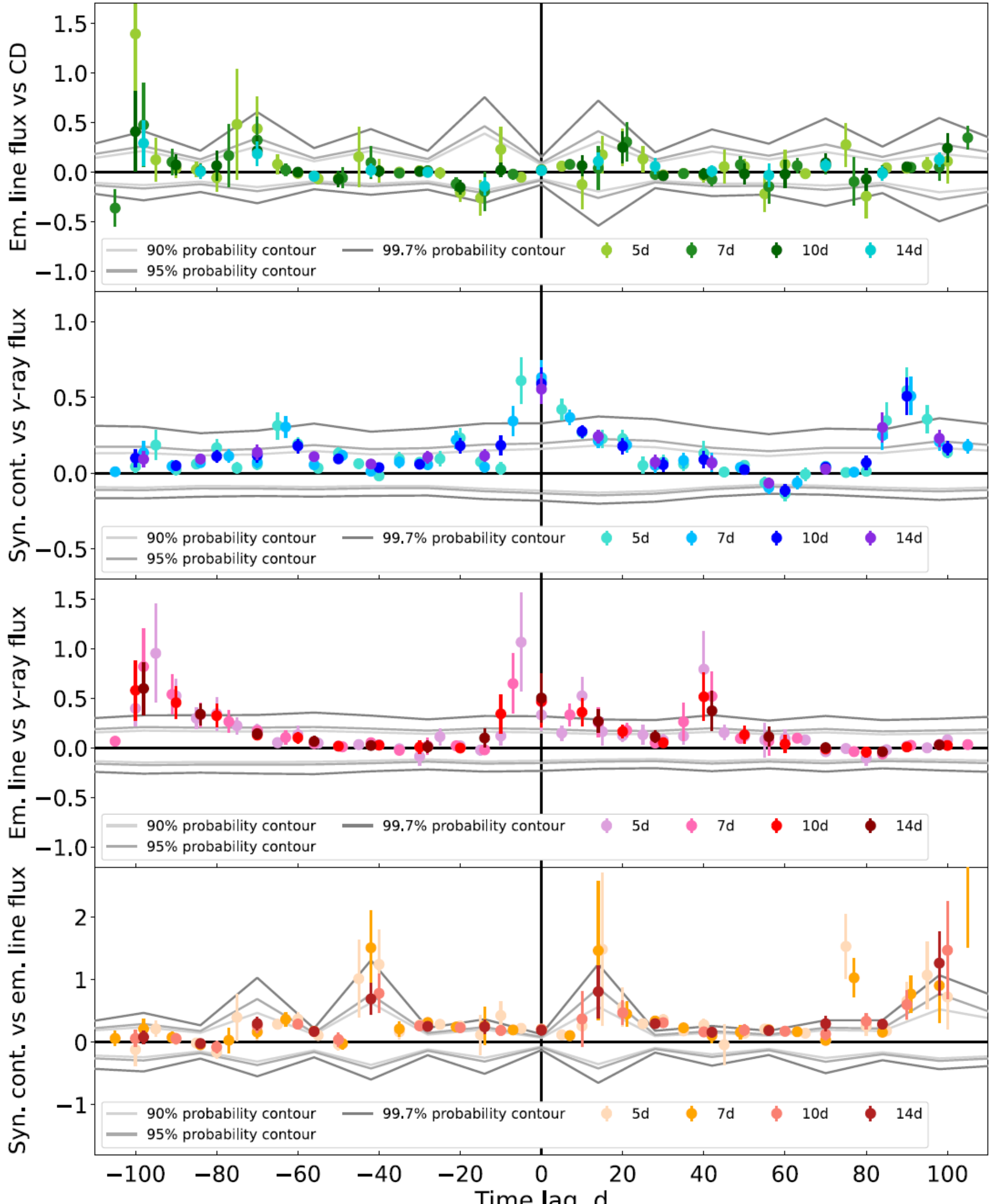
Scatter plot (simultaneous measurements) shows no correlation.



Correlation analyses

Discrete Correlation Function (DCF – Edelson & Krolik 1988):

- Significant correlations:



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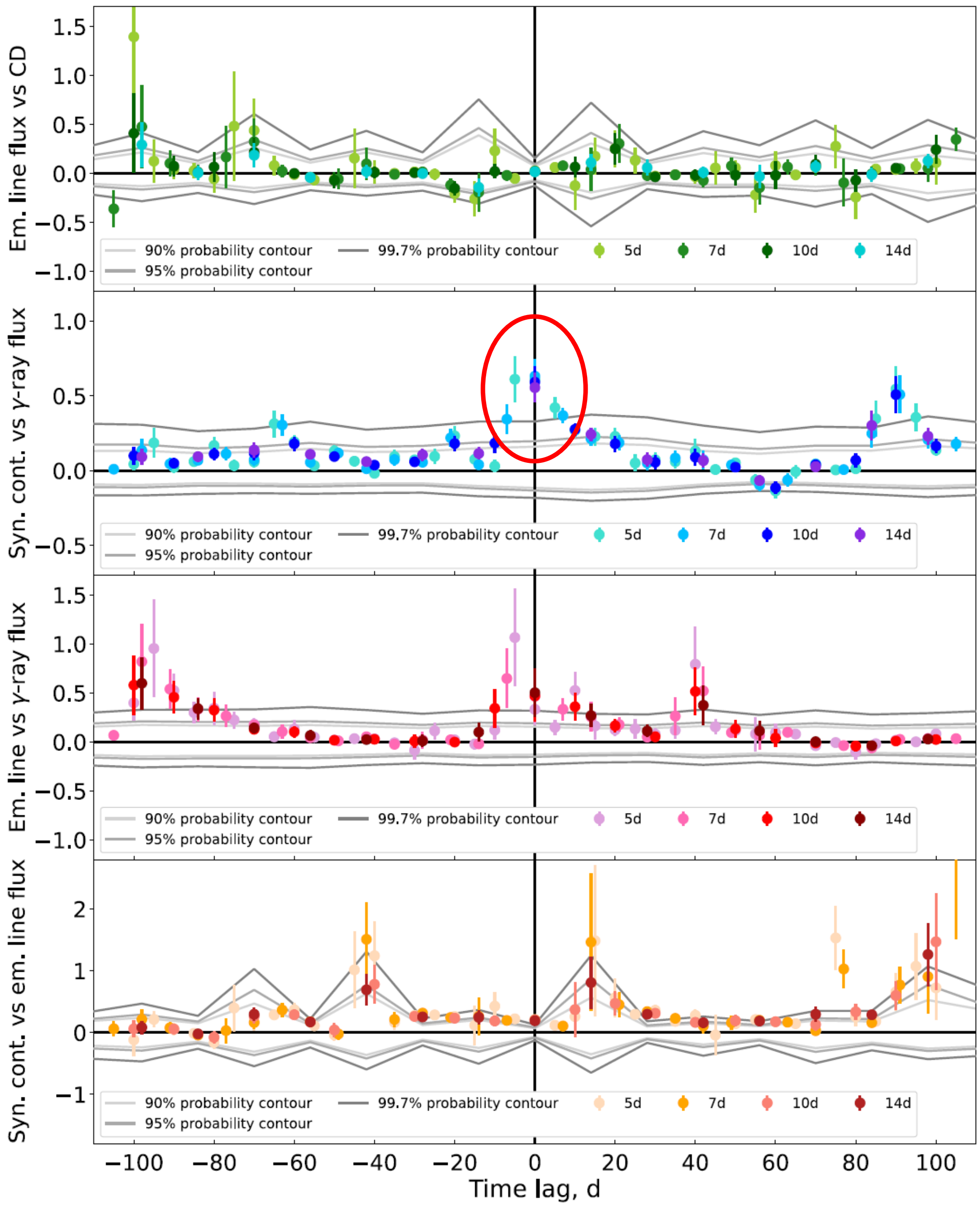
Discrete Correlation Function (DCF – Edelson & Krolik 1988):

- Significant correlations:
  - Synch. cont. vs. γ-ray flux (~ 0 lag)



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Discrete Correlation Function (DCF – Edelson & Krolik 1988):

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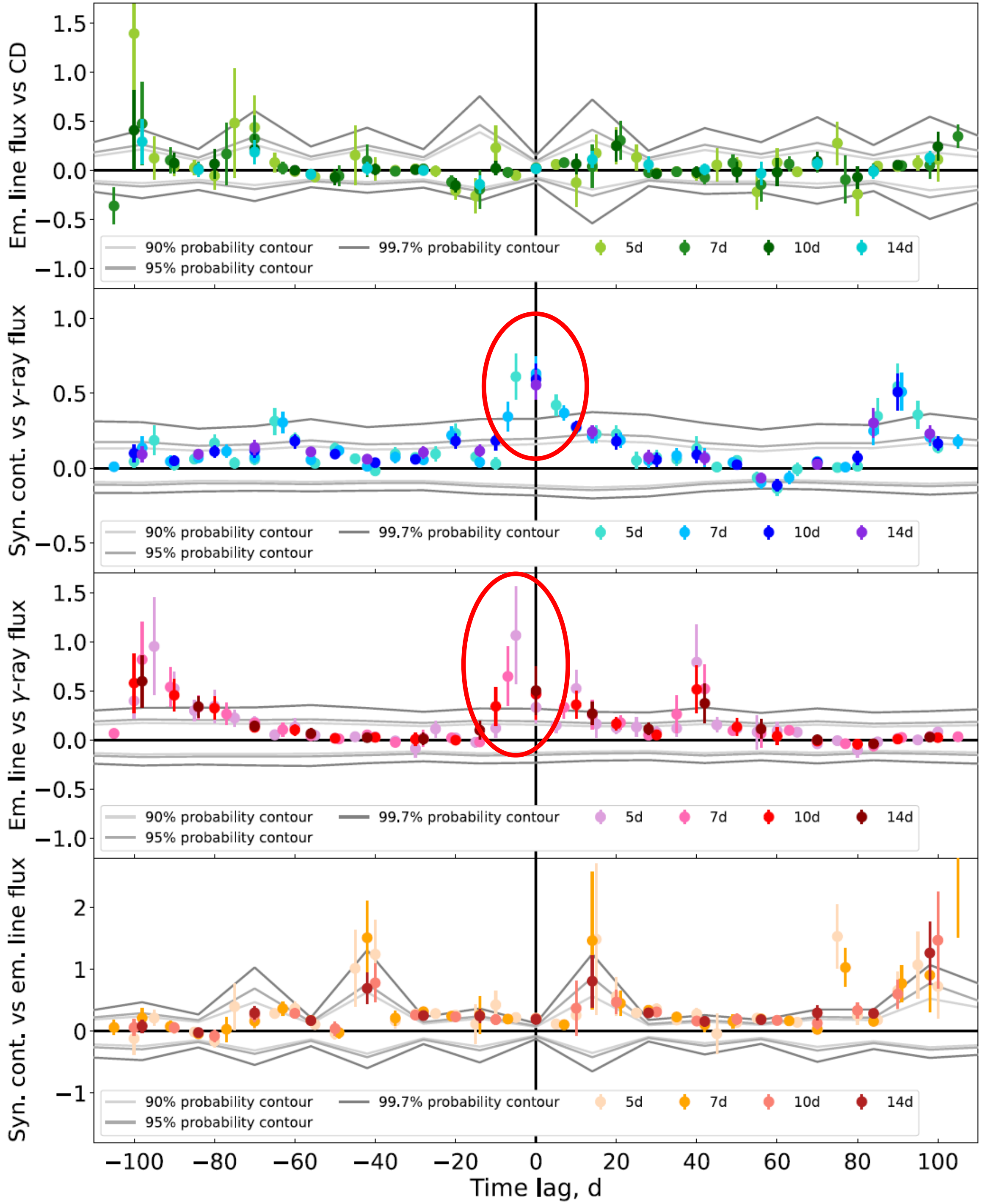
  - Em. line vs. γ-ray flux (~ 5 day lag of γ-rays behind em. lines)



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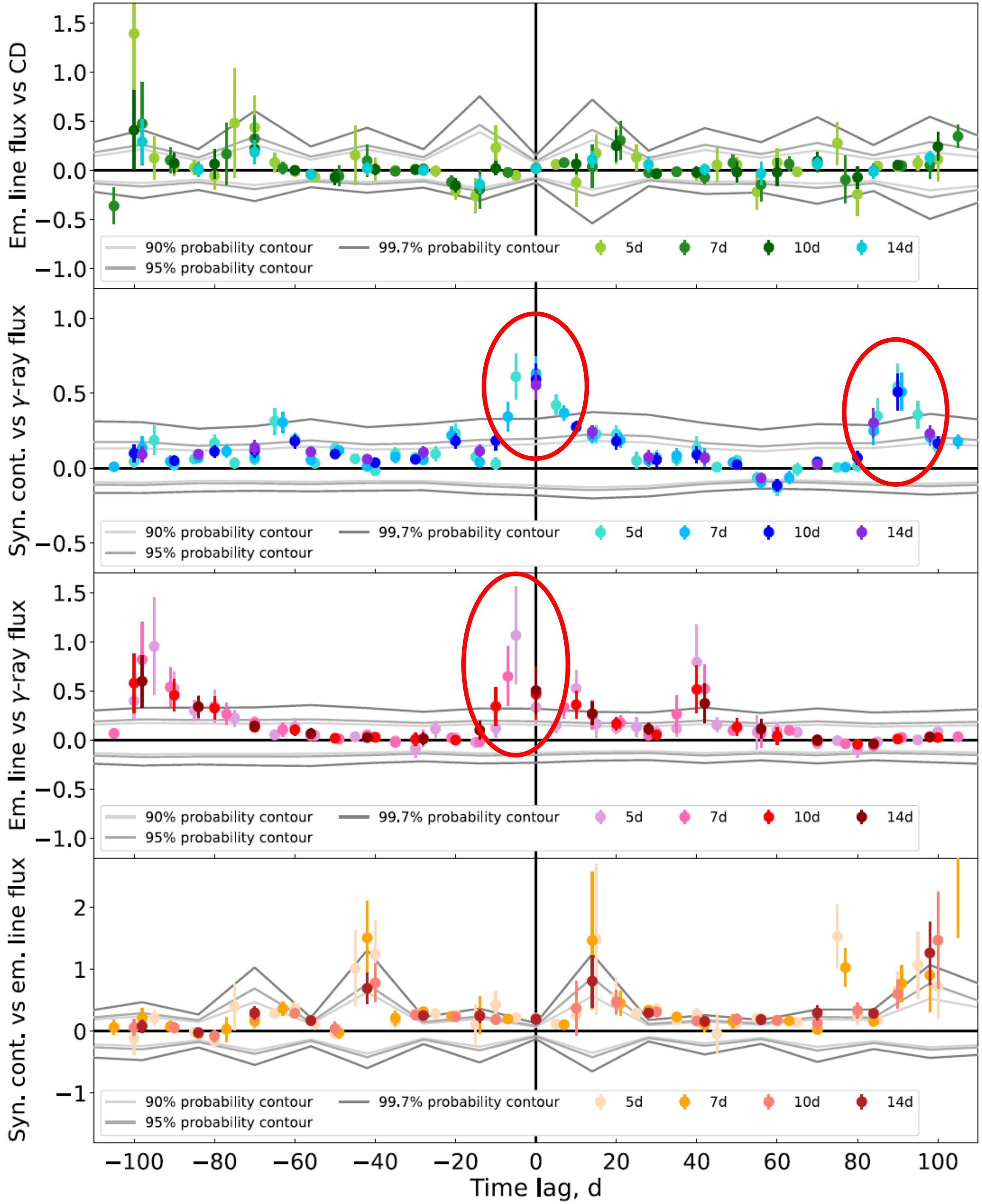
Discrete Correlation Function (DCF – Edelson & Krolik 1988):

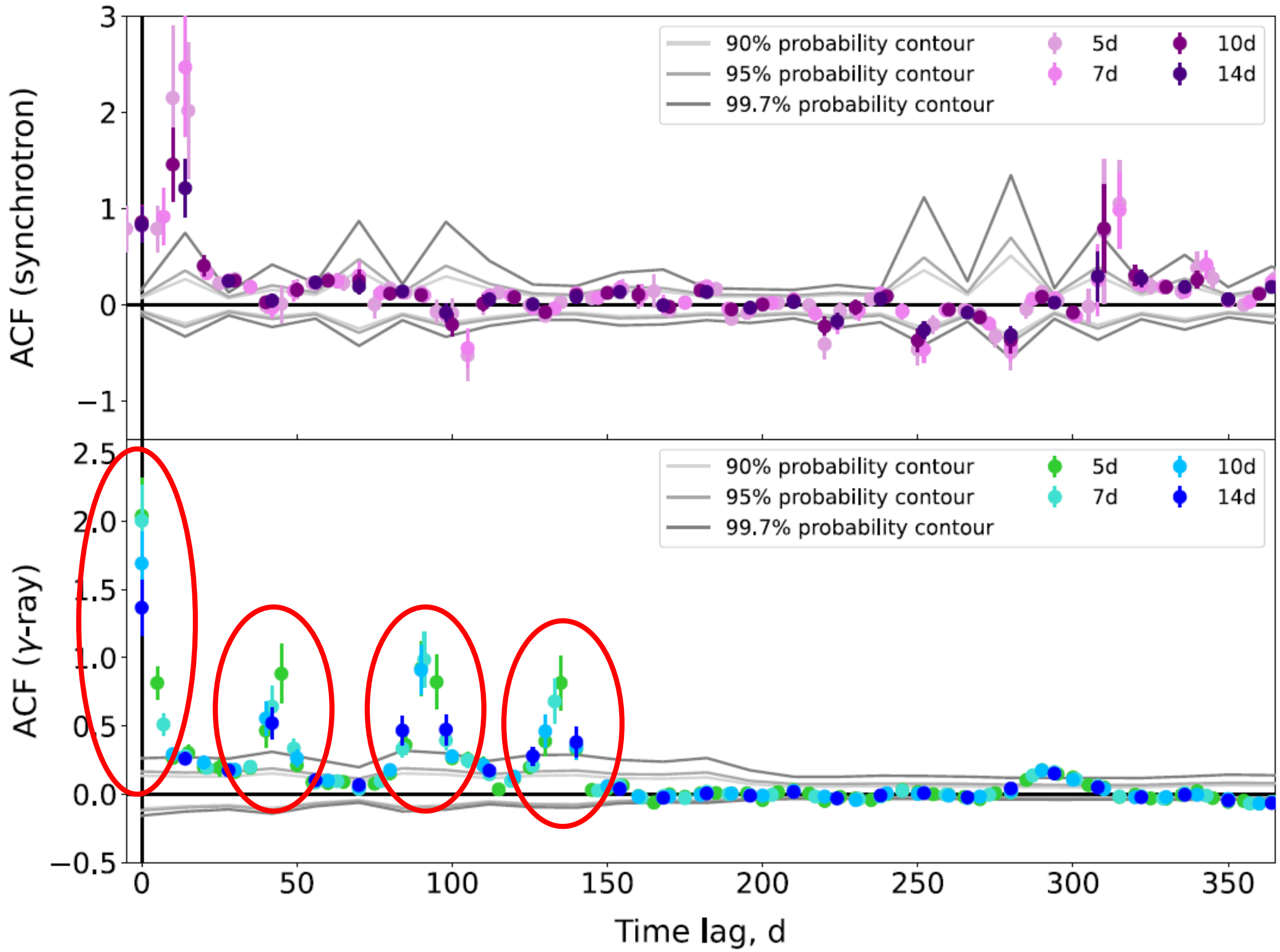
- Significant correlations:
  - Synch. cont. vs. γ-ray flux (~ 0 lag)
  - Em. line vs. γ-ray flux (~ 5 day lag of γ-rays behind em. lines)
  - Possible feature at ~ 90 days in synch. cont. vs. γ-ray flux



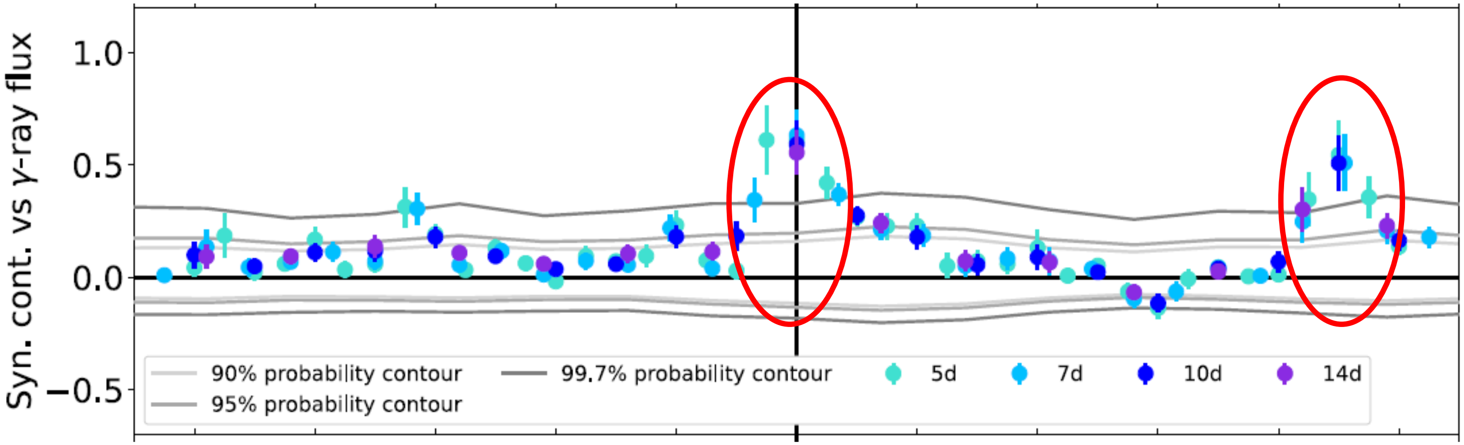
Auto-correlation functions (ACFs)

Apparent quasi-periodic feature in γ-rays

(0, 45, 90, 135 days)



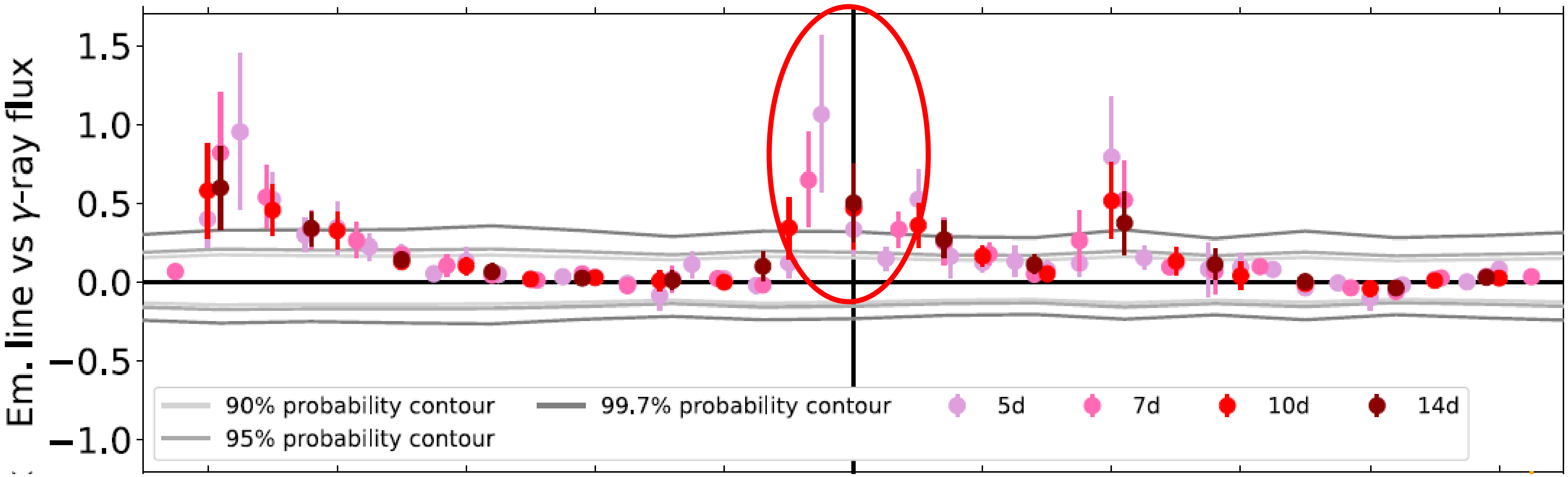
Interpretation: Synch. cont. vs. γ-rays



- Direct correlation: co-spatial production of optical and γ-rays → Support for leptonic scenario (?)

- ~ 90 day lag: γ-rays after synch. cont.?
  - 90 days → Travel distance: d ~ 7.5 $\delta_1 \Gamma_1$ pc
  - Possible interaction of emitting plasma with a second obstacle (standing shock?) ~ 7 – 8 pc down the jet (?)
  - Much lower B-field → Synchrotron suppressed; "Compton-only" flare (?)

Interpretation: Em. lines vs. γ-rays



- Direct correlation (γ-rays lagging behind by ~ 5 days): Support for leptonic EC/BLR scenario

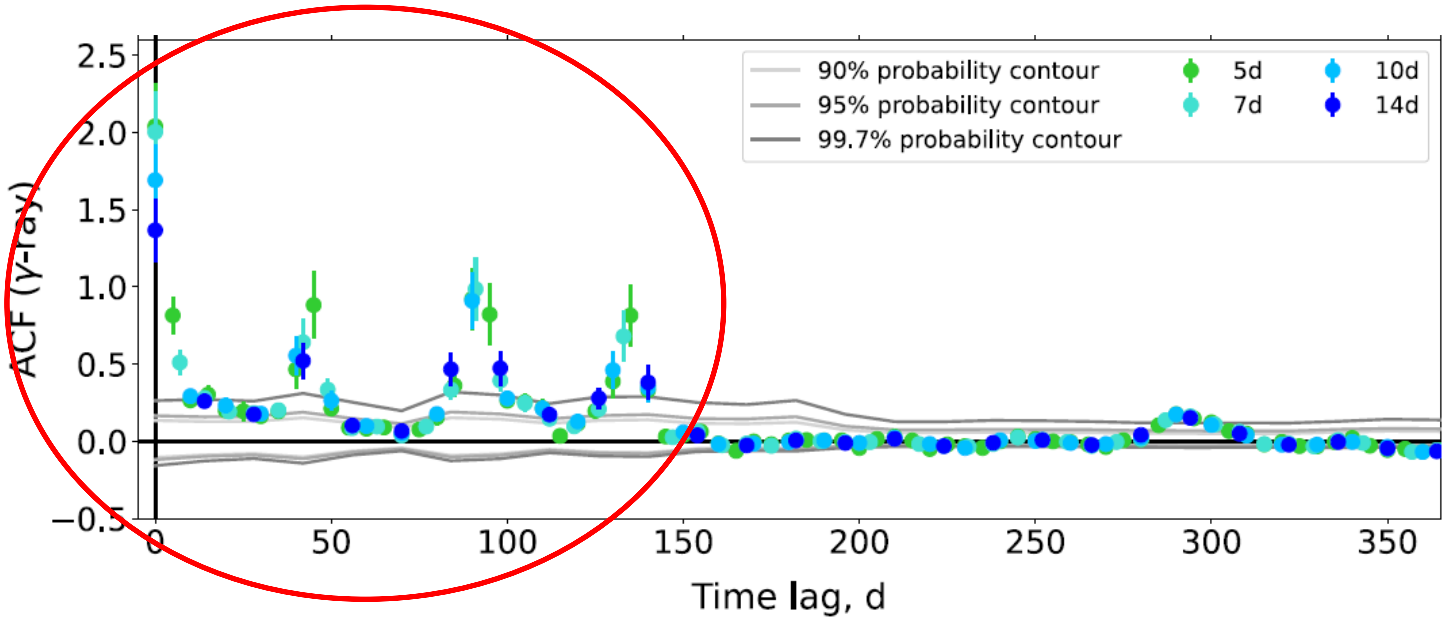
- ~ 5 day lag → Size of BLR ~ 5 light days ~ 1.3×10^{16} cm

- However, no correlation between em. lines and CD!

$$CD \propto \frac{\Gamma^2 L_{BLR}}{B^2}$$

→ Likely changes in Γ, B contribute significantly to mwl variability.

Interpretation: γ-ray ACF



- Quasi-periodic feature: Multiples of ~ 45 days

→ Possible signature of multiple recollimation shocks ~ 4 pc apart (Hervet et al. 2017)?

Summary

- 3C279 shows no clear correlation between CD and BLR luminosity. → Likely other parameters (Γ, B) are changing and have significant impact on multi-wavelength variability.

- Significant correlations:
  - Synch. cont. vs. γ-ray flux → Support for leptonic models (?)
  - Em. line luminosity vs. γ-ray flux → Support for EC/BLR
  - Delayed γ-ray feature ~ 90 days after direct synch cont. vs. γ-ray correlation
    → Possible jet interaction with standing feature ~ 7 – 8 pc down the jet.

- Quasi-periodic feature in γ-ray ACF (multiples of ~45 days)

  → Possible signature of multiple recollimation shocks
  ~ 4 pc apart?


Thank you!