The Devil's in the Details:

Using High-Cadence, Multiwavelength Observations to Understand the Disk-Jet Connection in Blazars

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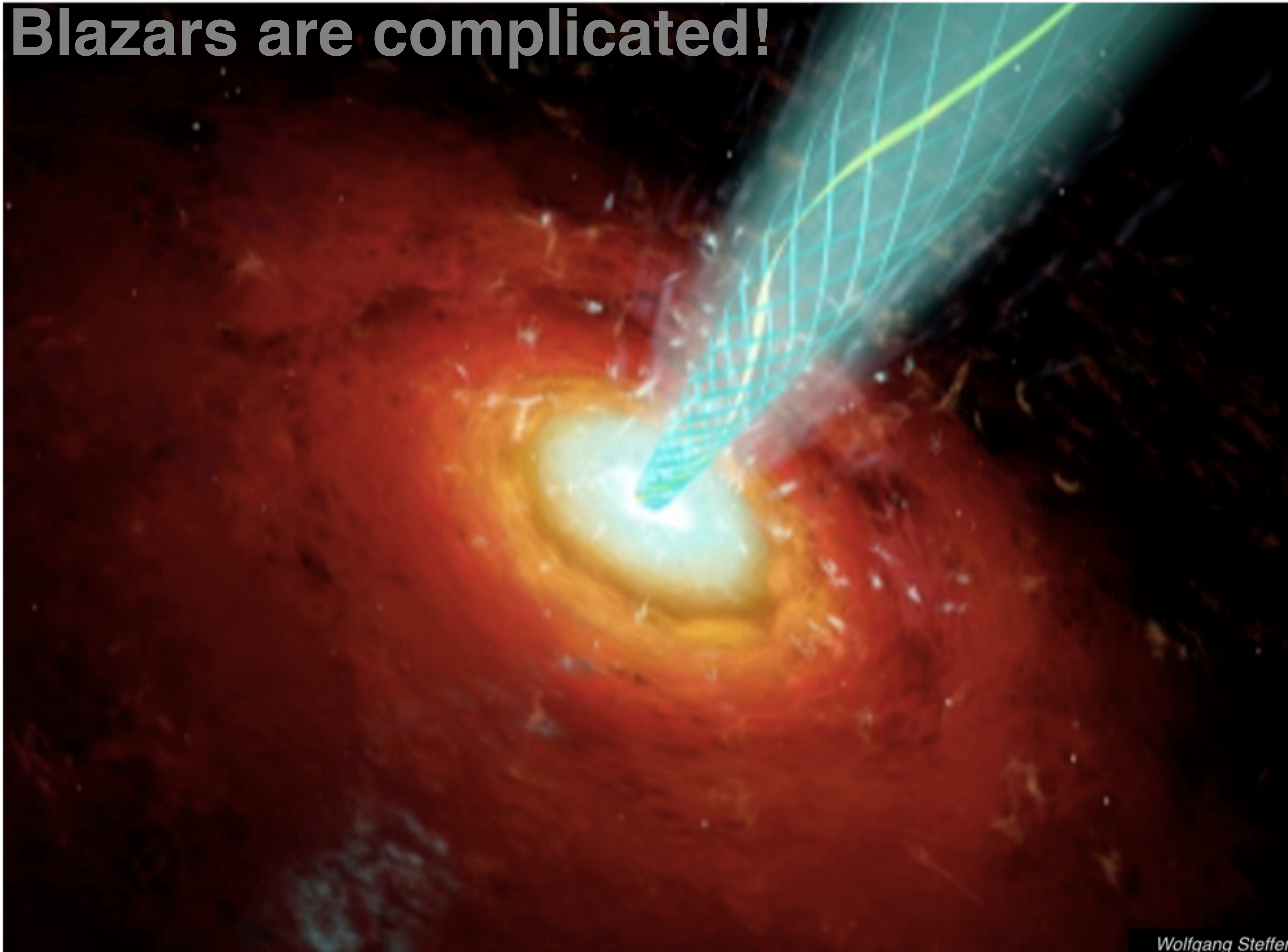
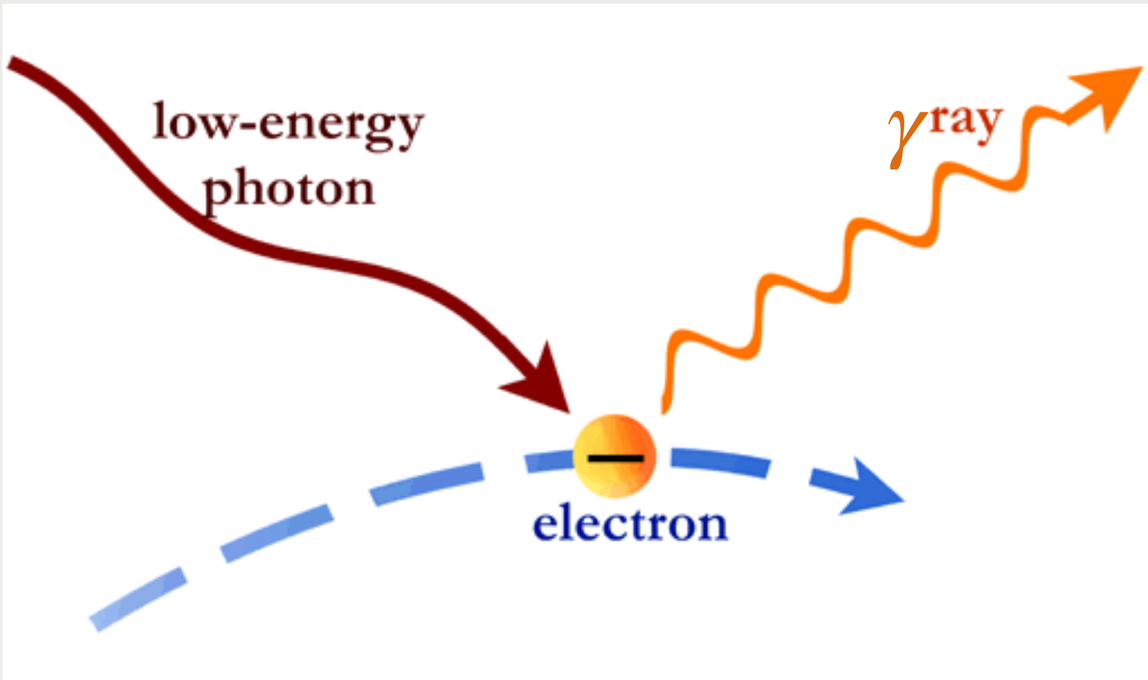
Blazars are complicated!



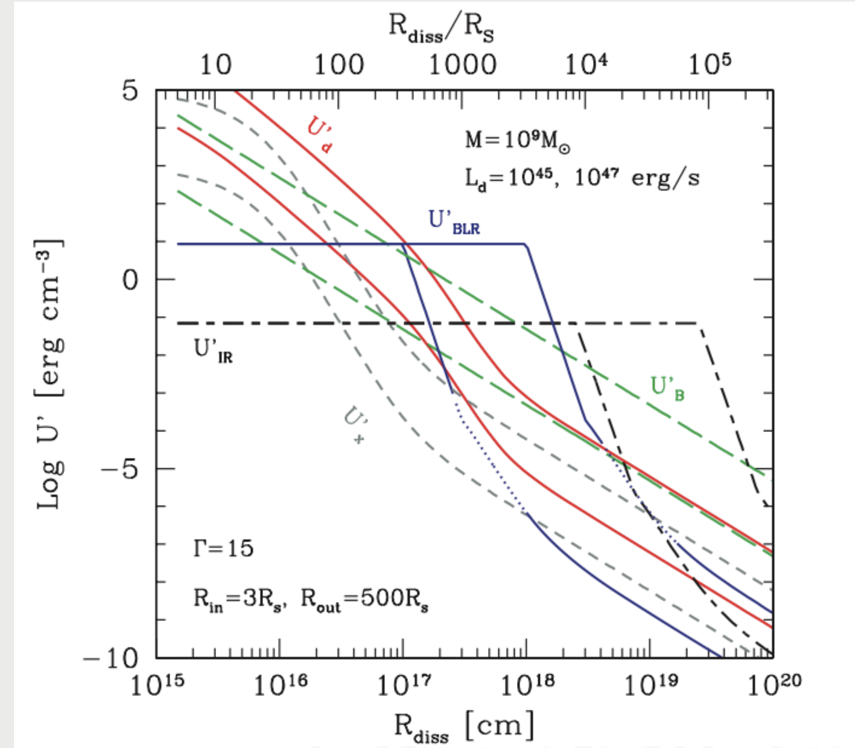
- *Theory:* How do you produce gamma-rays?
- *Experiment:* Can we observationally constrain the location of the γER?
- *Implications:* Is there corroborating evidence?
- *Complications:* Is there contradicting evidence?
- *Questions:* Are we asking enough questions?
- *Next Steps:* Is it time for another test?

Roadmap

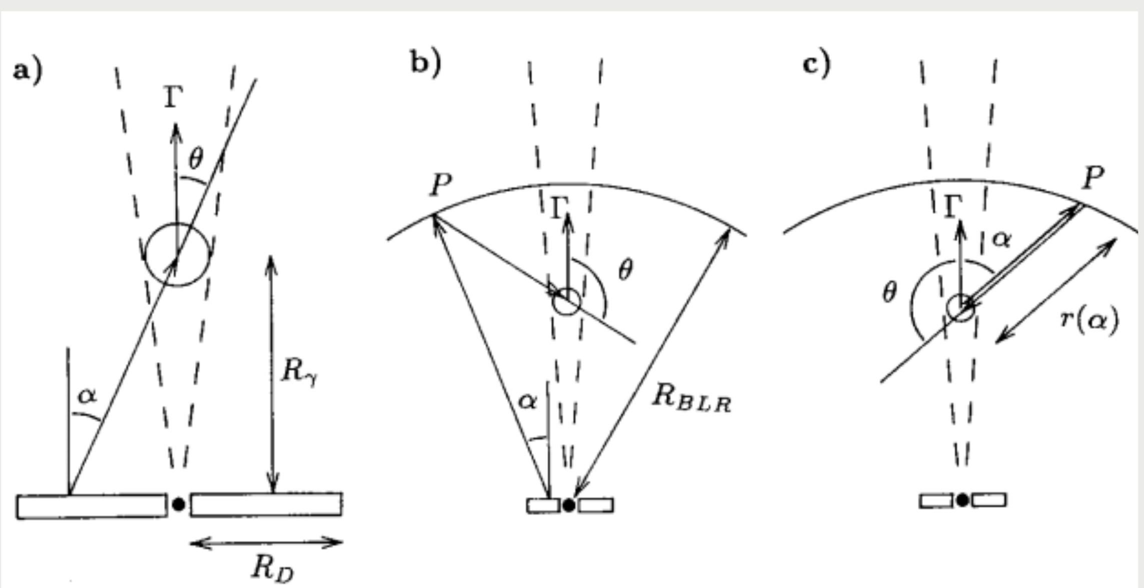
How do you produce gamma-rays?



CXC/S.LEE



GHISELLINI & TAVECCHIO 2009



GHISELLINI & MADAU 1996

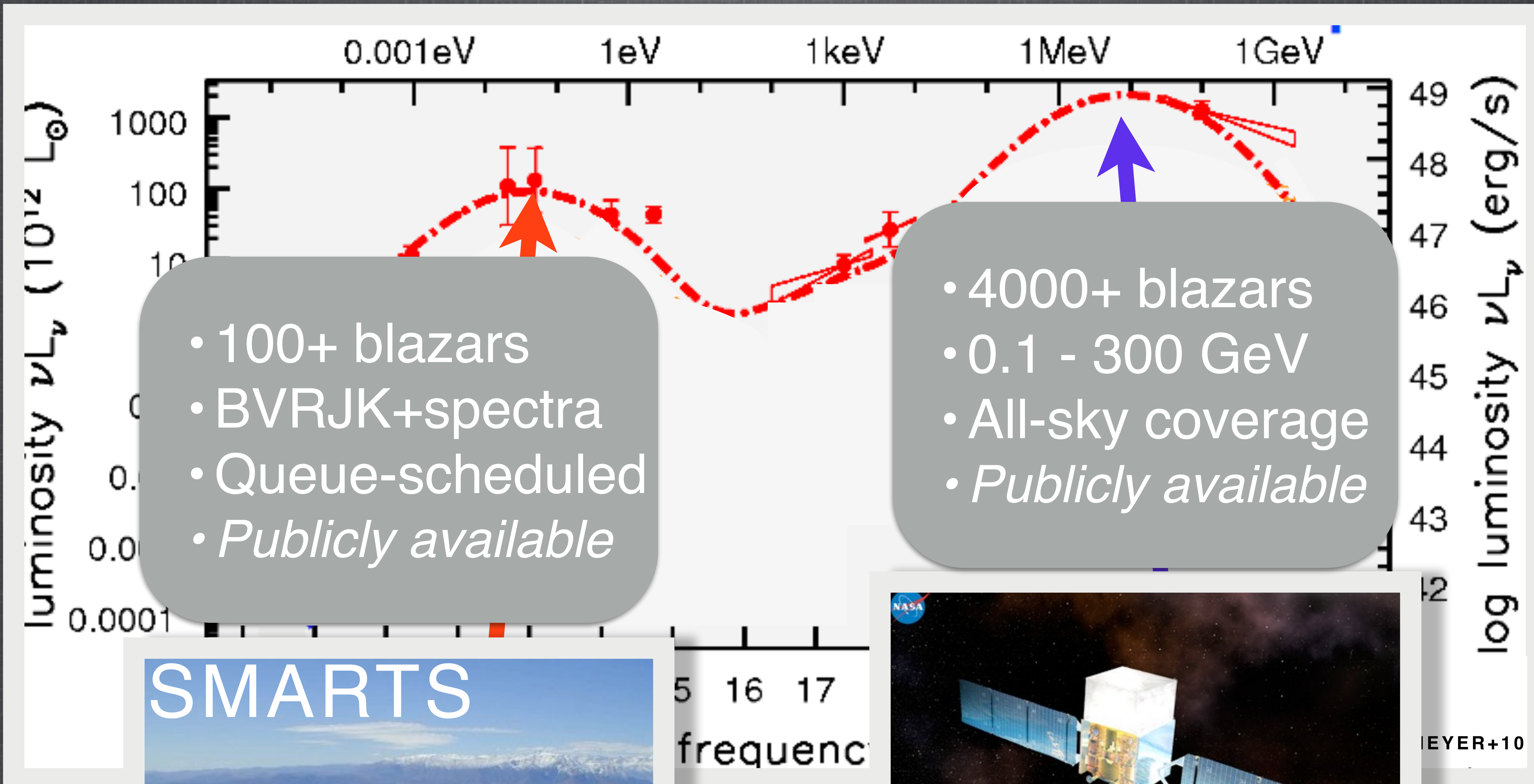
- In leptonic framework: *(Bottcher 2006)*
- IC scattering of lower energy photons *(Ghisellini & Made 1996; Ghisellini & Tavecchio 2009; Sikora, Begelman & Rees 1993,1994)*
- One zone models with distance dependent photon field(s) *(Sikora+ 1994; Dermer +1993; Maraschi+1992)*

Theory

Can we constrain the location of the γER?

- Construct a *mostly* model independent, observationally driven test
- Exploit blazar variability and **assume location of BLR is fixed at sub-pc scales**
- Isolate thermal and non-thermal components with independent measurements
- Monitor a sample of gamma-ray active blazars with high cadence, simultaneous and multiwavelength coverage
- Wait until something interesting happens

Experiment



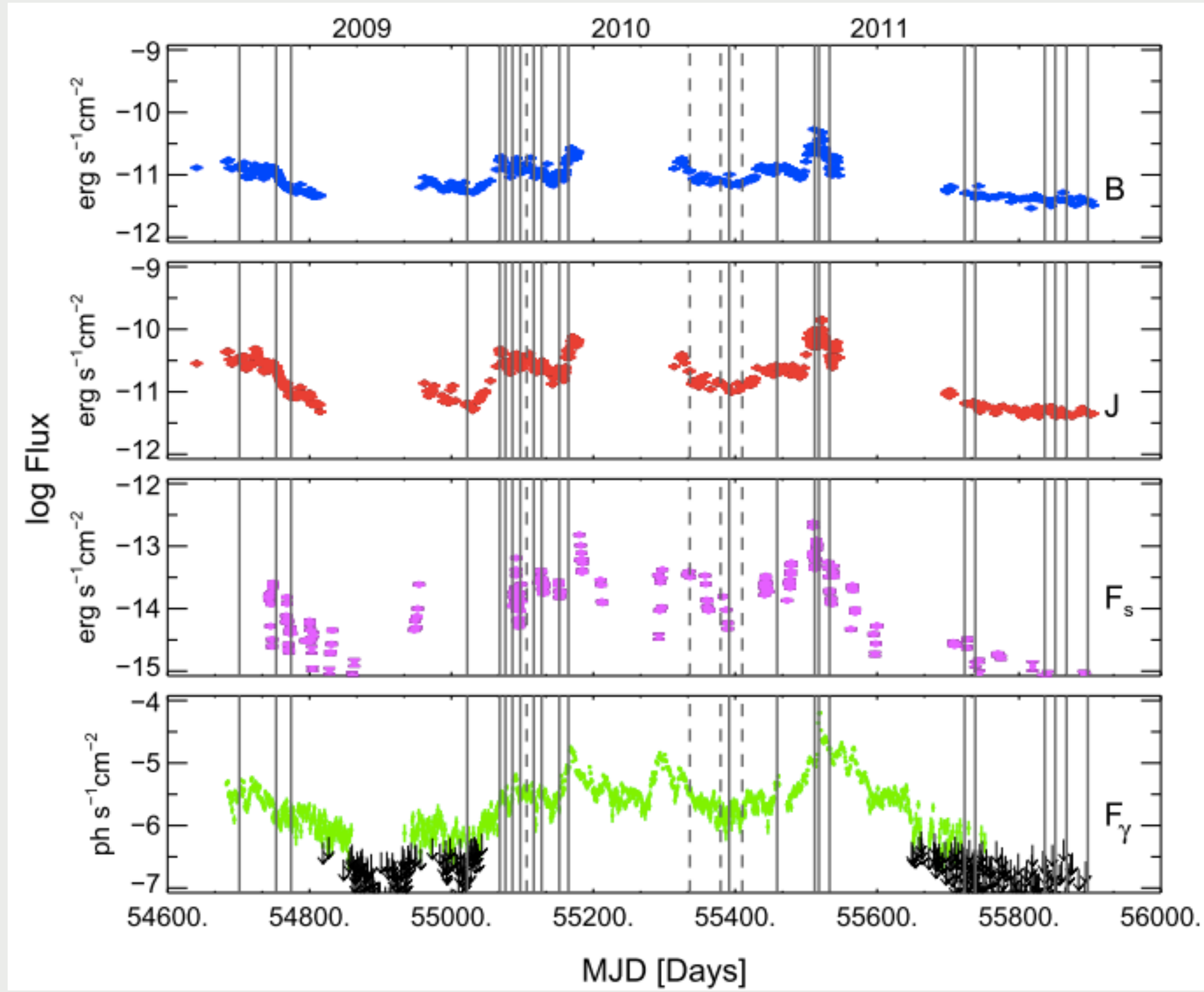
- 100+ blazars
- BVRJK+spectra
- Queue-scheduled
- *Publicly available*

- 4000+ blazars
- 0.1 - 300 GeV
- All-sky coverage
- *Publicly available*

Experiment

3C 454.3

- FSRQ, z = 0.859
- Monitored B, J, synchrotron flux and gamma-ray flux for 3.5 years
- Simultaneously collected optical spectra (vertical solid lines: simultaneous with OIR photometry, vertical dotted lines: 1-2 days maximum offset)

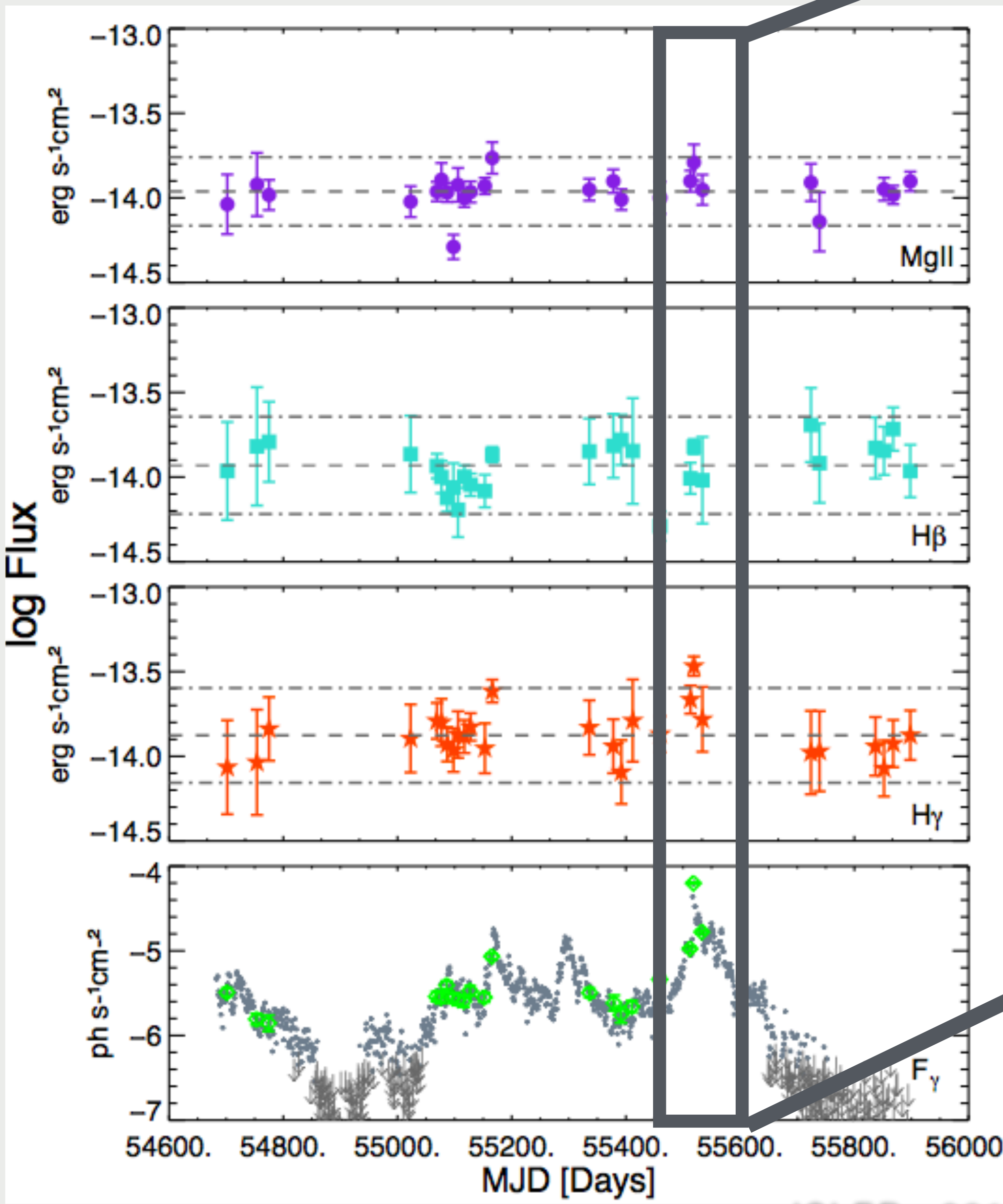


ISLER+ 2013

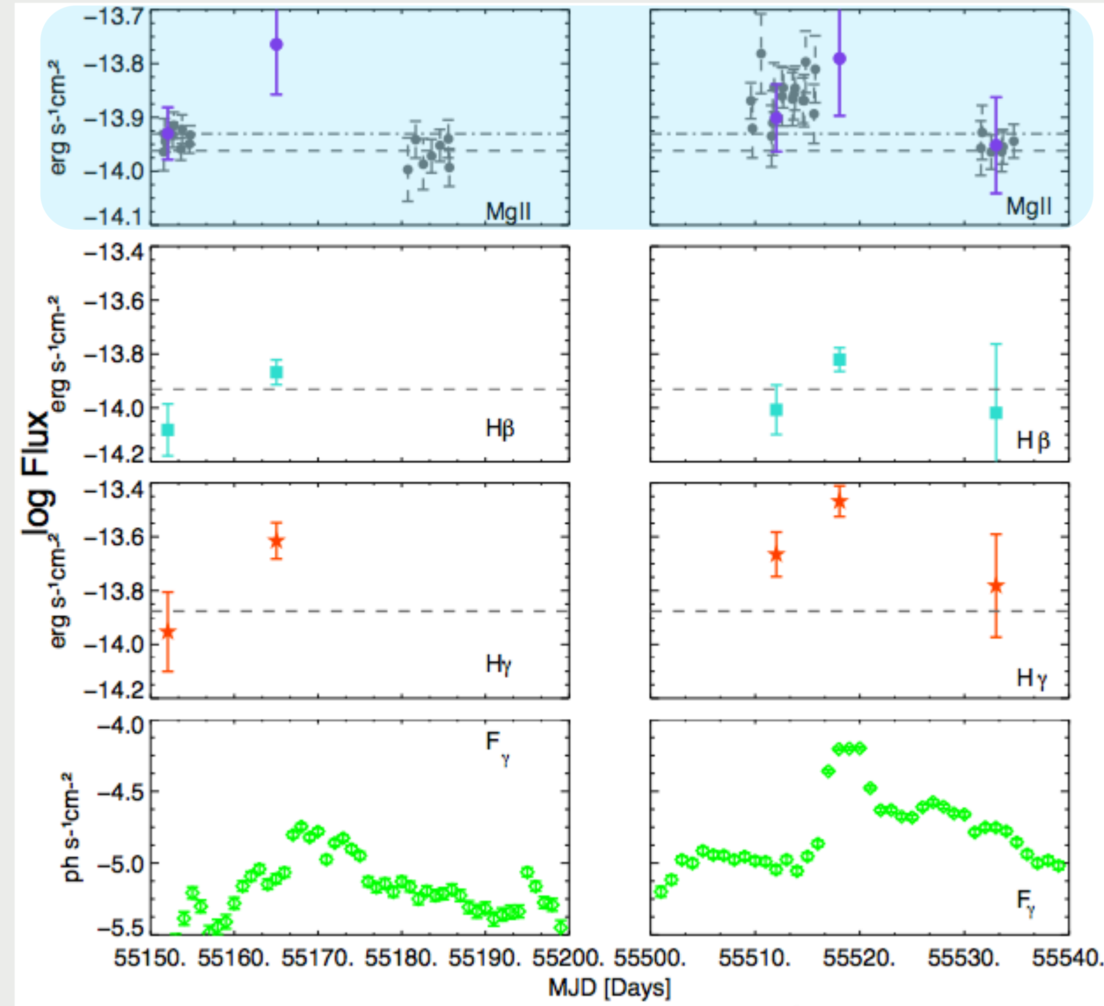
- Optical spectroscopy samples high- and low- gamma-ray activity states, including exceptional 2009 flare

Experiment

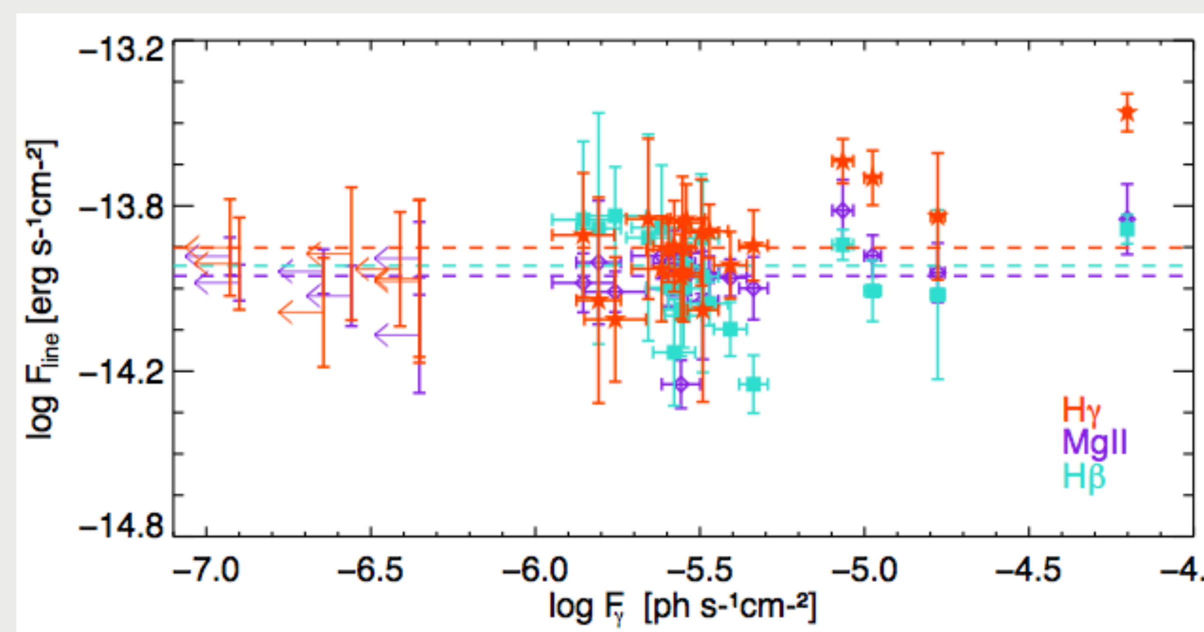
3C 454.3



ISLER+ 2013



(GREY) LEÓN-TAVARES+ 2013

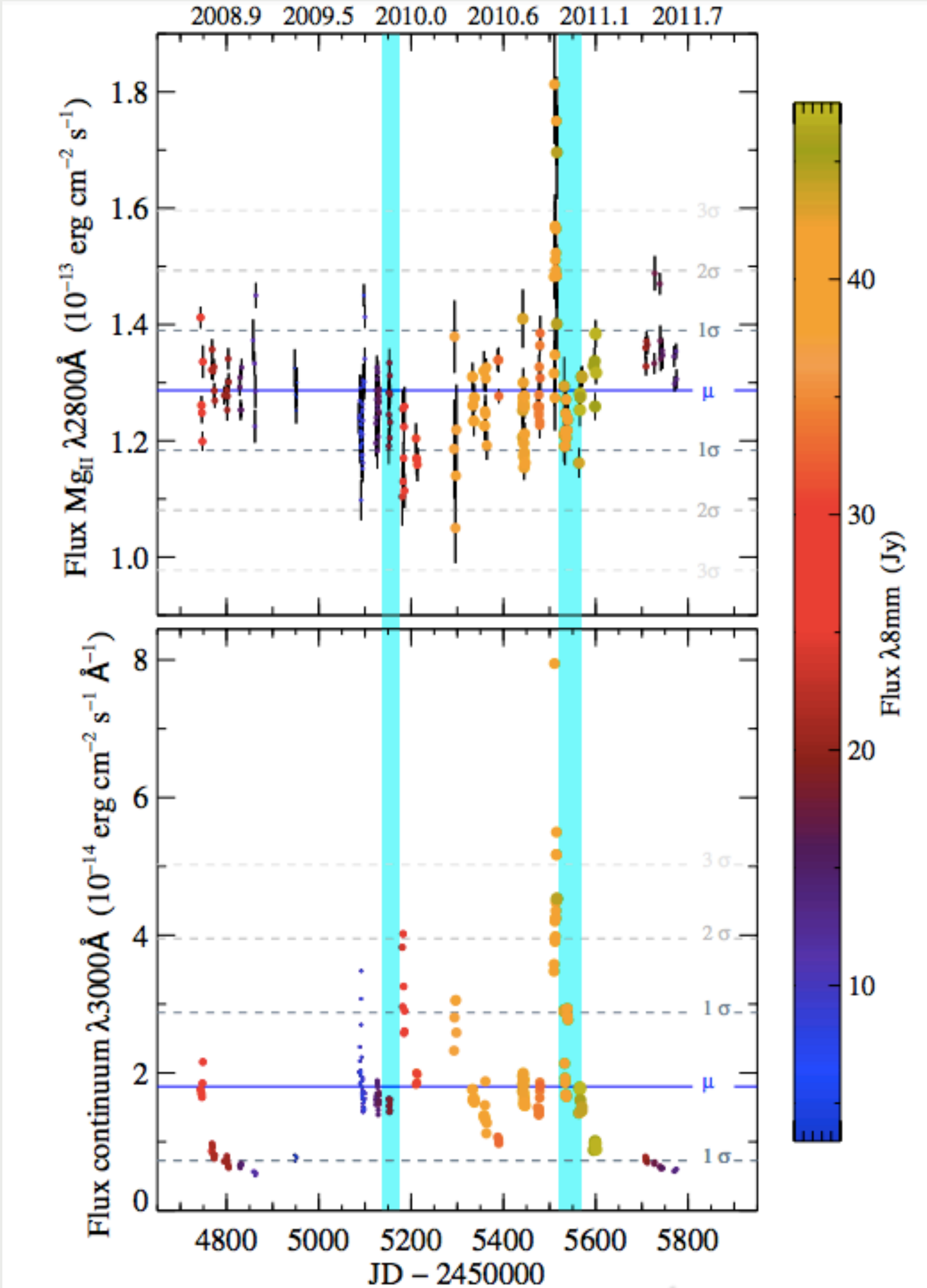


ISLER+ 2013

Optical emission line flux seems to increase contemporaneously with exceptional gamma-ray flare

Experiment

3C 454.3



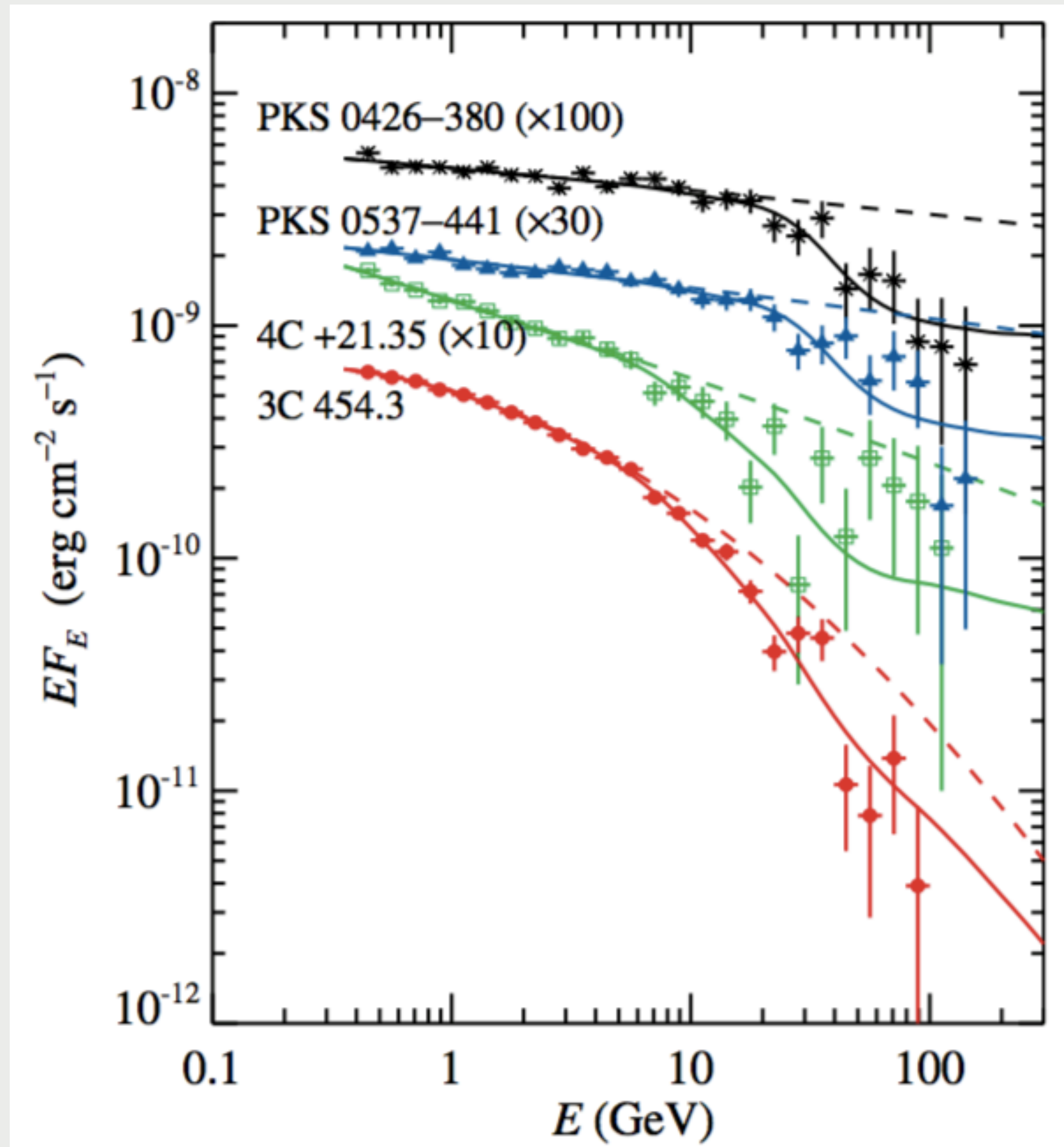
LEÓN-TAVARES+ 2013

- Marginally significant line flux variability detected independently *(León-Tavares+ 2013)*
- Line variability correlated with mm-core flux (color of datapoints) and core ejections (cyan regions)
- mm-core is well constrained at pc scales from central source *(Agudo+2014; Agudo+2013, León-Tavares+ 2011)*
- γER could be on pc scales

Experiment

Is there corroborating evidence?

- $\gamma\gamma$-absorption by pair production on HI and HeII photons in the BLR will cause GeV breaks
- Early $\gamma\gamma$-absorption studies found evidence of both HI and HeII absorption *(Poutanen & Stern 2010)*
- Reanalysis found less significant detections of HeII, but not completely ruled out *(Stern & Poutanen 2014)*
- HI (LyC) absorption is strongly significant in most cases

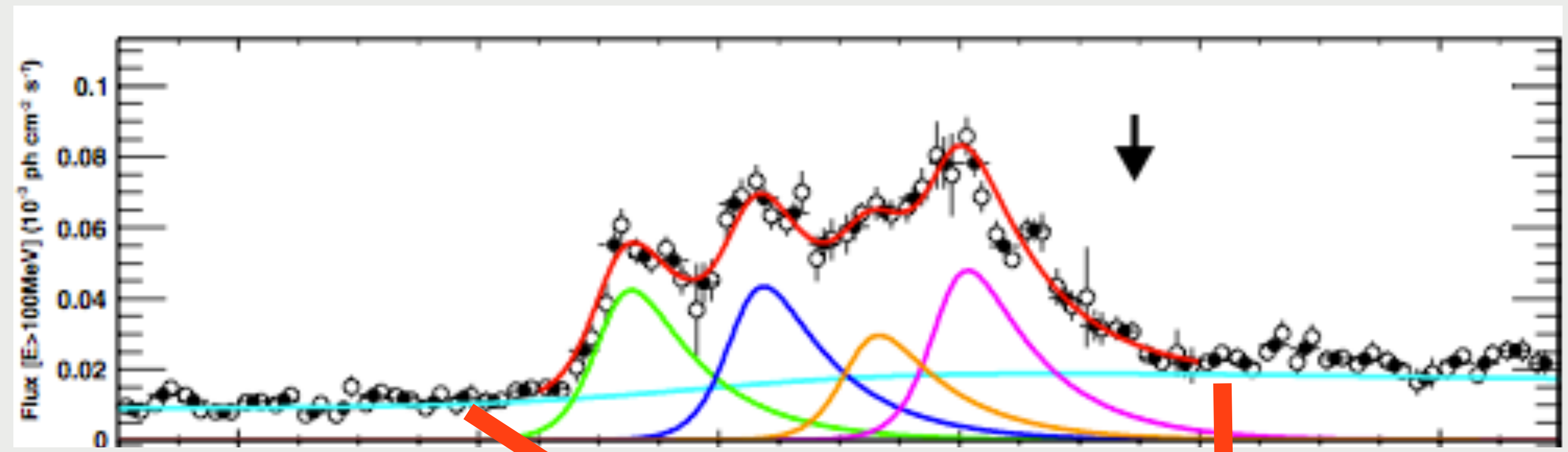


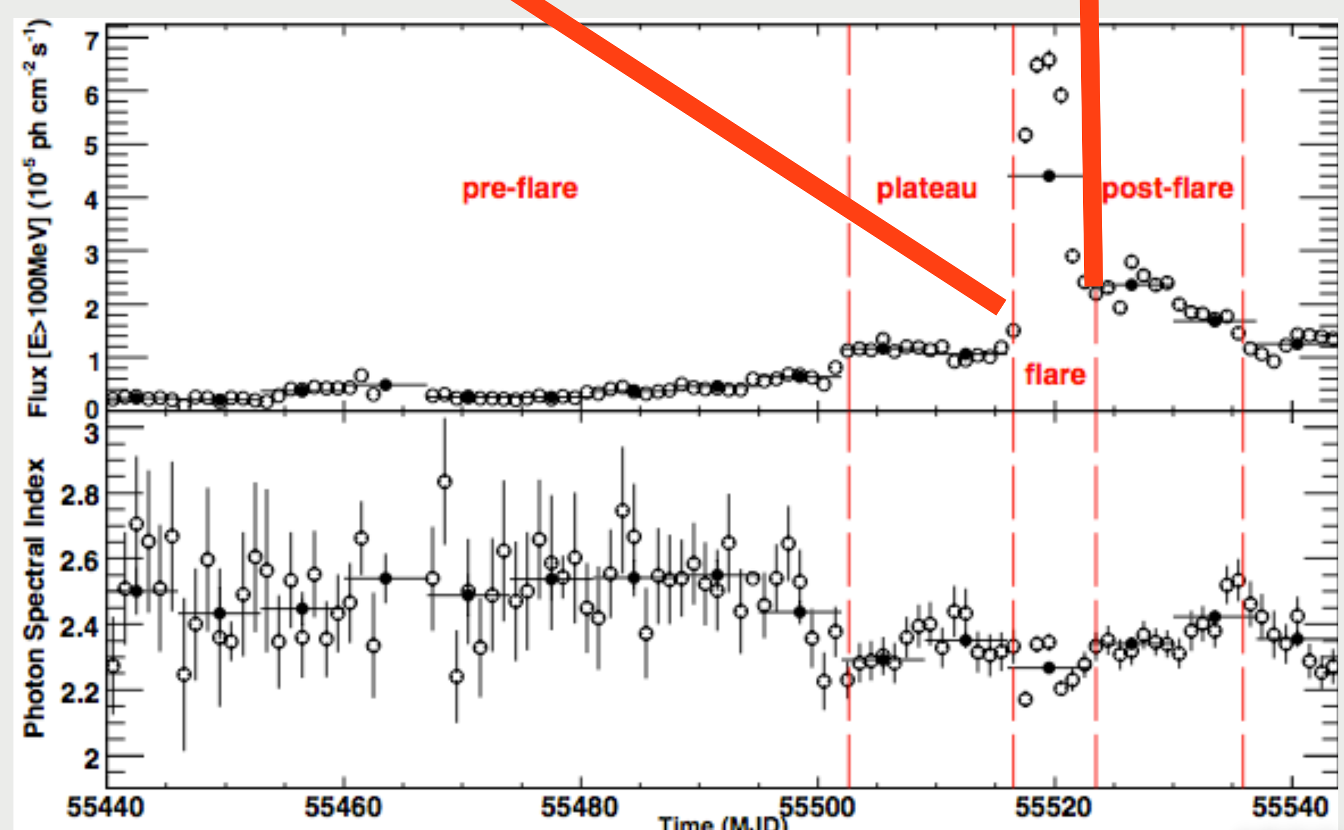
STERN & POUTANEN 2014

Implications

Is there corroborating evidence?

- Ultra-short timescale variability infers small emission region
- Gamma-ray flux doubling times as short as 6 hours have been reported *(Abdo+12)*
- Single-zone models are often sufficient to explain gamma-ray variations



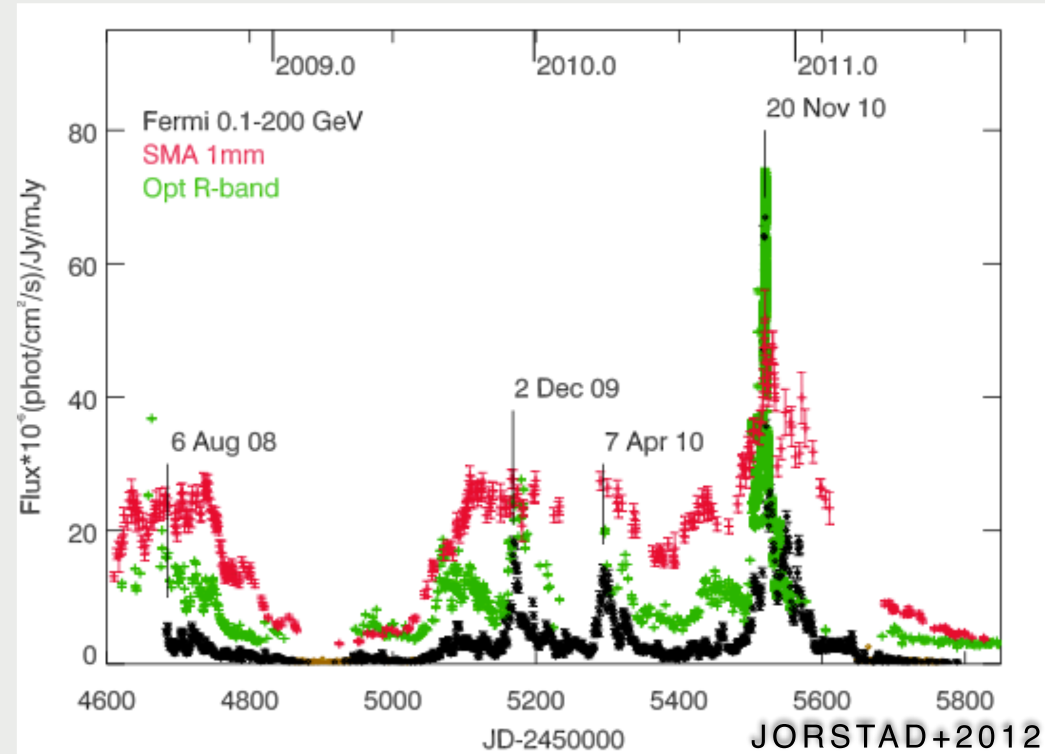


ABDO+12

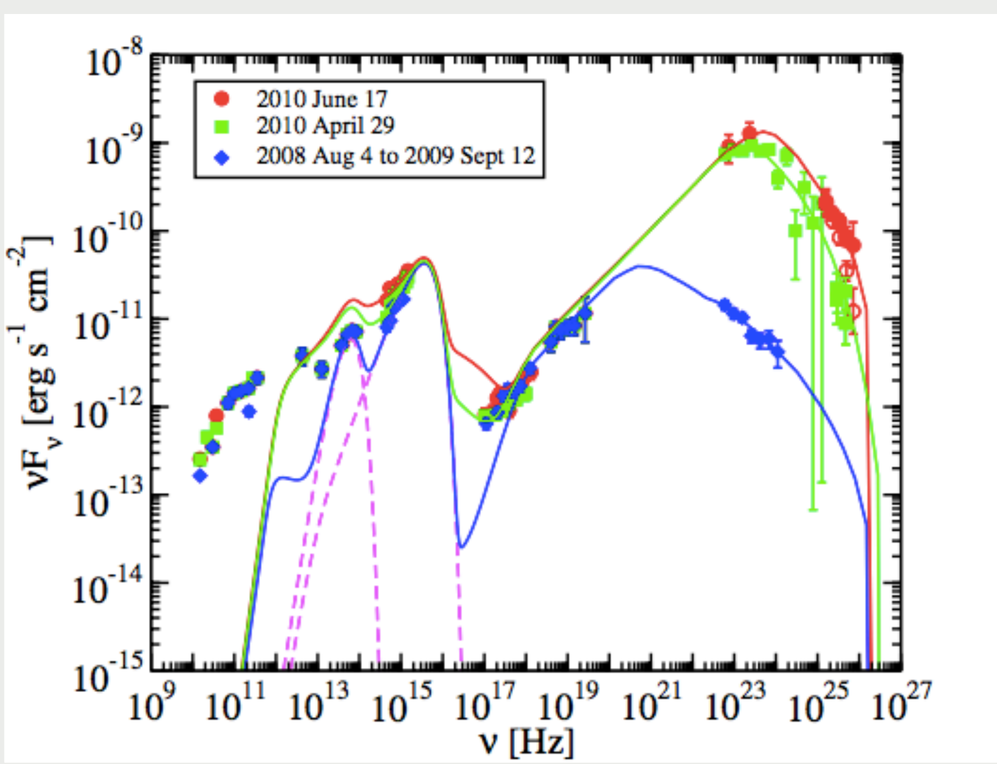
Implications

Is there contradicting evidence?

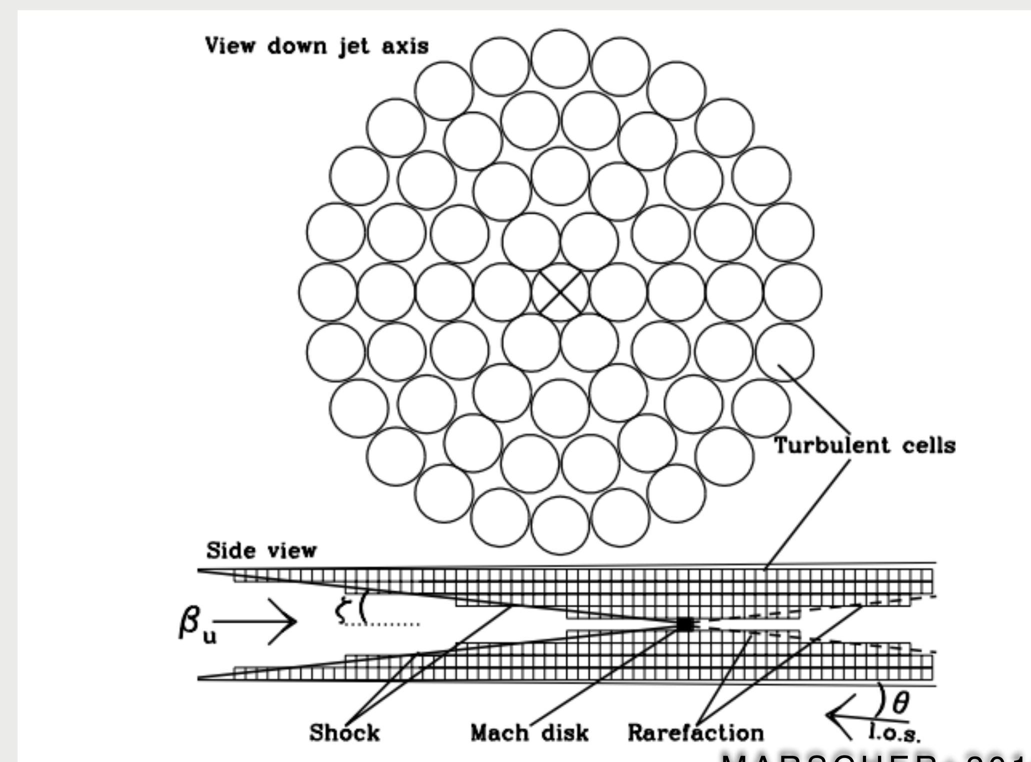
- 1+ day variability in mm, optical and X-ray compatible with more extended emission region
- SSC from optical photons in the jet triggered by conical shock regions
- Correlated VHE must happen far from thermal emission (4C+21.35)
- Ultra-fast high energy variability requires multizone emission region(s)



JORSTAD+2012



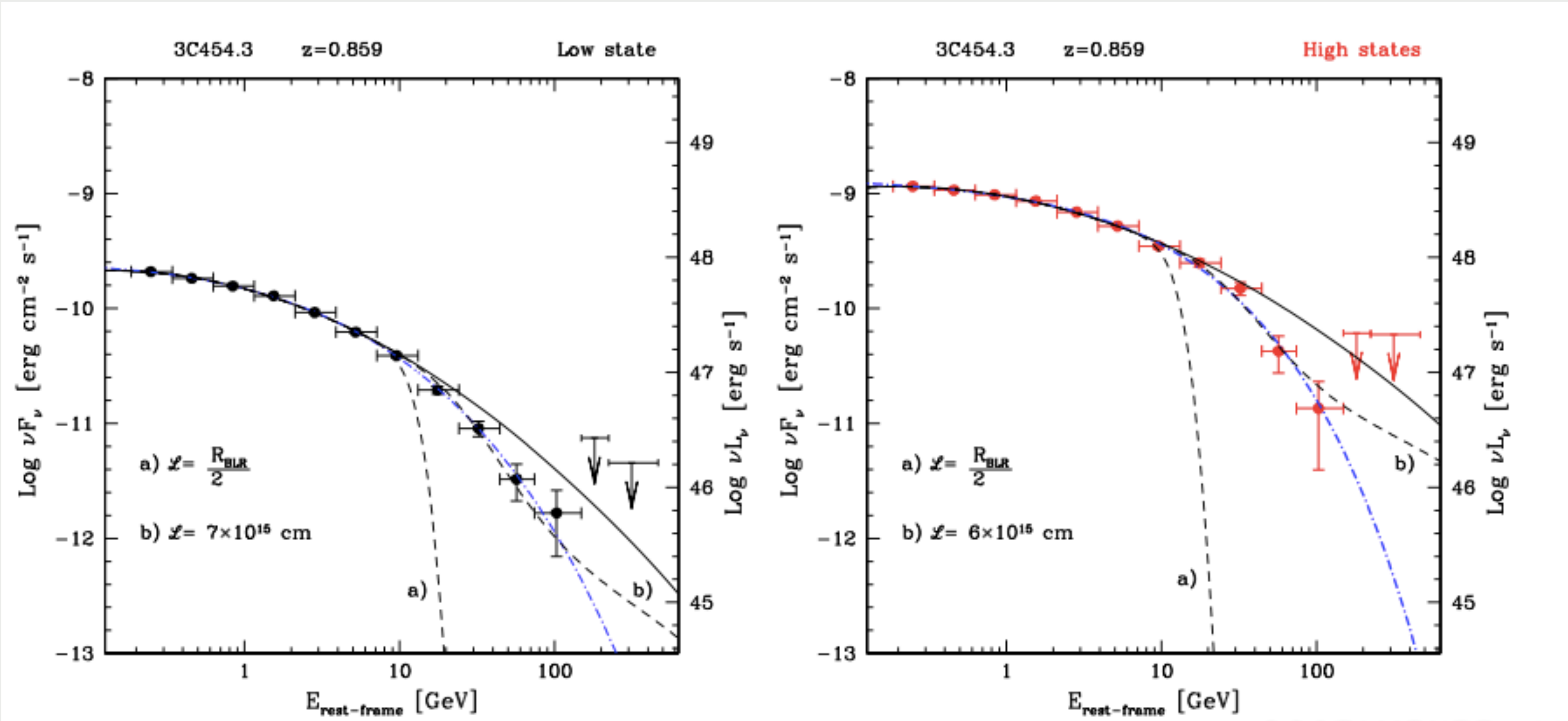
ACKERMANN+2014



MARSCHER+2014

Complications

Is there contradicting evidence?

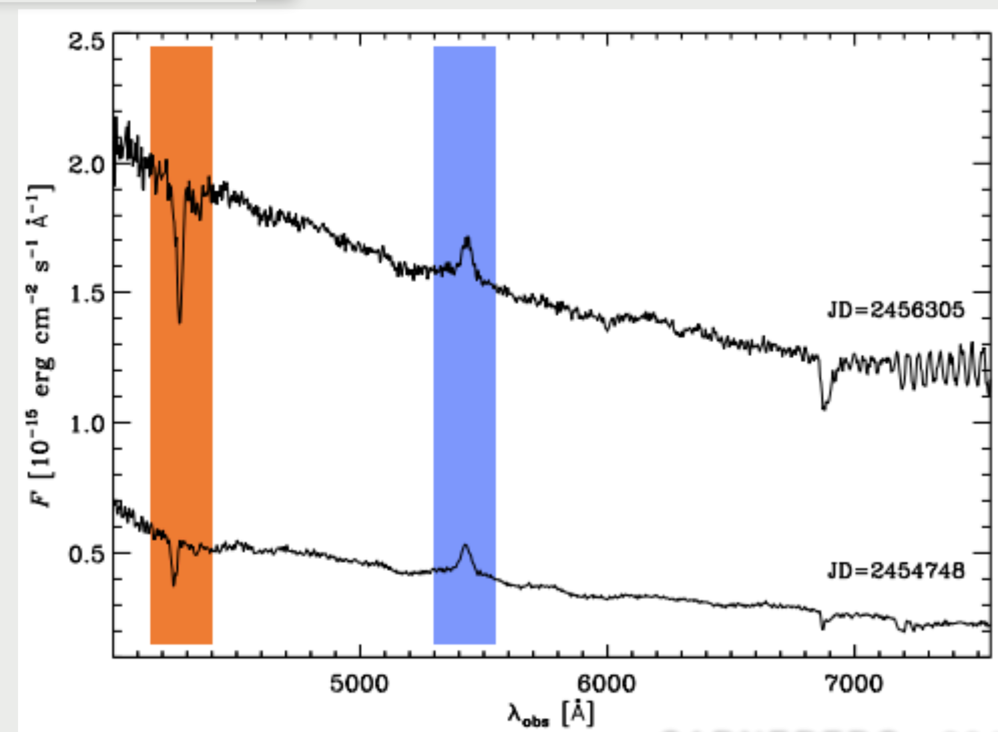


COSTAMENTE+ 2018

- Not all gamma-ray flares have significant emission-line variability *(Isler+ 2015; Carnerero+ 2015)*

- $\gamma\gamma$-absorption is disfavored in the majority of gamma-ray flares in FSRQs; but not ruled out in ~10% of sources *(Costamente+ 2018)*

- Amount and location of $\gamma\gamma$-absorption is strongly model dependent



CARNERERO+ 2015

Complications

What have we learned?

1. Correlated emission-line flux variability has been observed in a few sources at ~2.5σ and correlates w γ-rays, optical polarization fraction and mm-core ejections *(Isler+2015; Isler+2013, León-Tavares+2013; Jorstad+ 2013)*
2. $\gamma\gamma$- absorption has been confirmed and may be rare *(Stern & Poutanen 2014; Poutanen & Stern 2010)*; highly model dependent on seed photon population, BLR constraints *(Costamente+2017; Abolmasov & Poutanen 2016; Britto+2015; Bai+ 2009)*
3. Fast variability can be modeled near and far from the central source *(Marscher+2014, Pacciani+ 2014, Abdo+ 2015; Ackermann+ 2014)*
4. Many flares are correlated with pc-scale variability *(Jorstad+2017; Larionov+ 2016; Agudo+2014; Agudo+2013)*
5. Photon field required and γER interacts with thermal emission at least in some cases

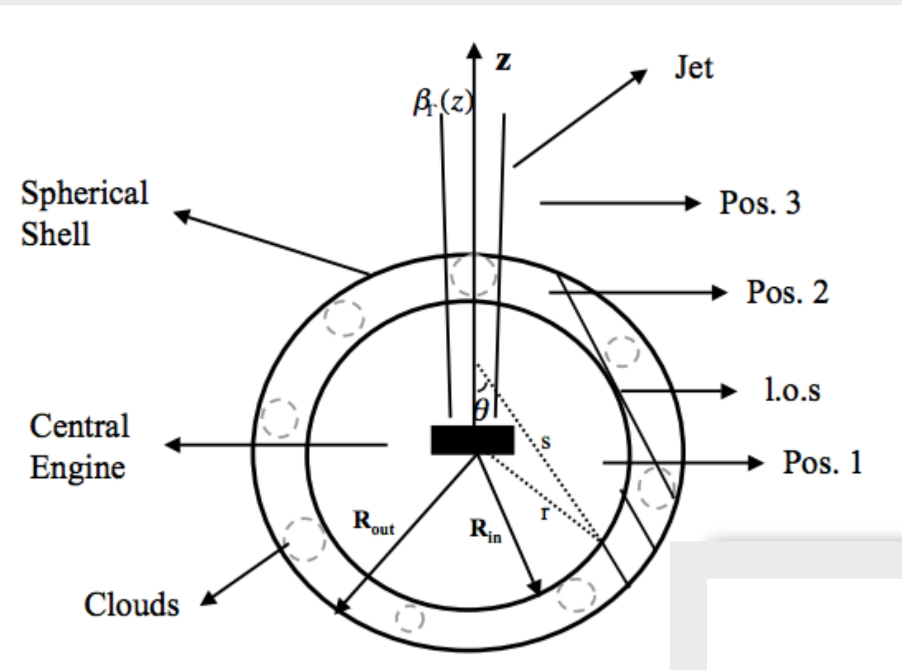
Experiment

Where is the gamma-emitting region??

Not yet enough information… and we probably need to expand our notion of what (and where) the broad-line region is.

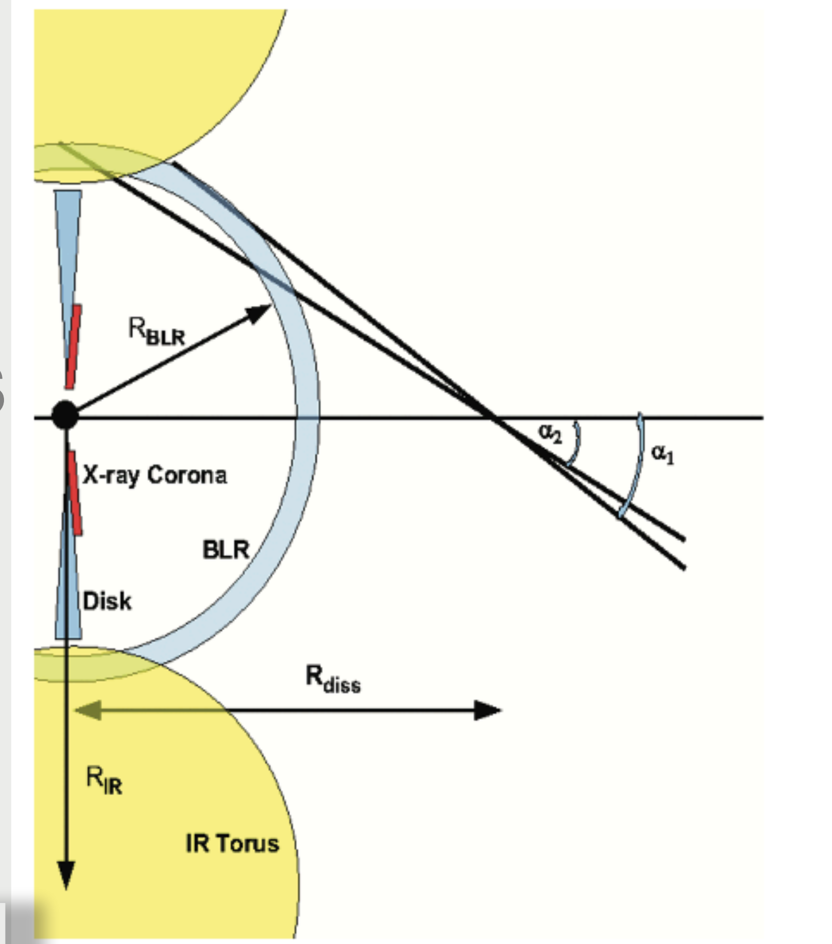
Do we have enough information?

Theory: What is the composition, orientation and extent of the broad line region (BLR)?

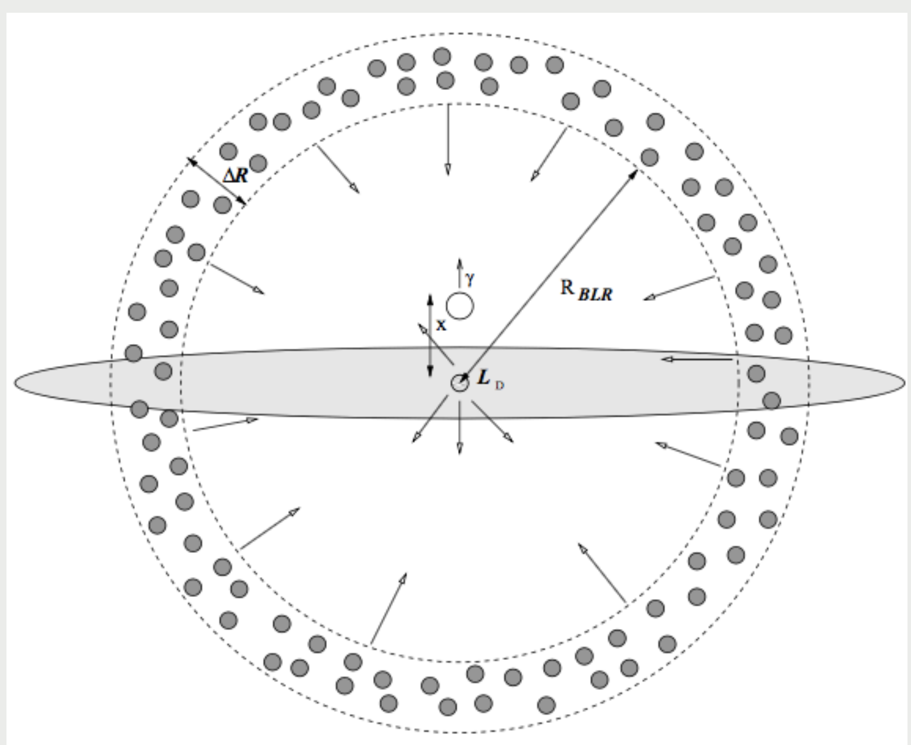


JOSHI+ 2013

Current models only account for very simple BLR configurations.



GHISELLINI & TAVECCHIO 2009

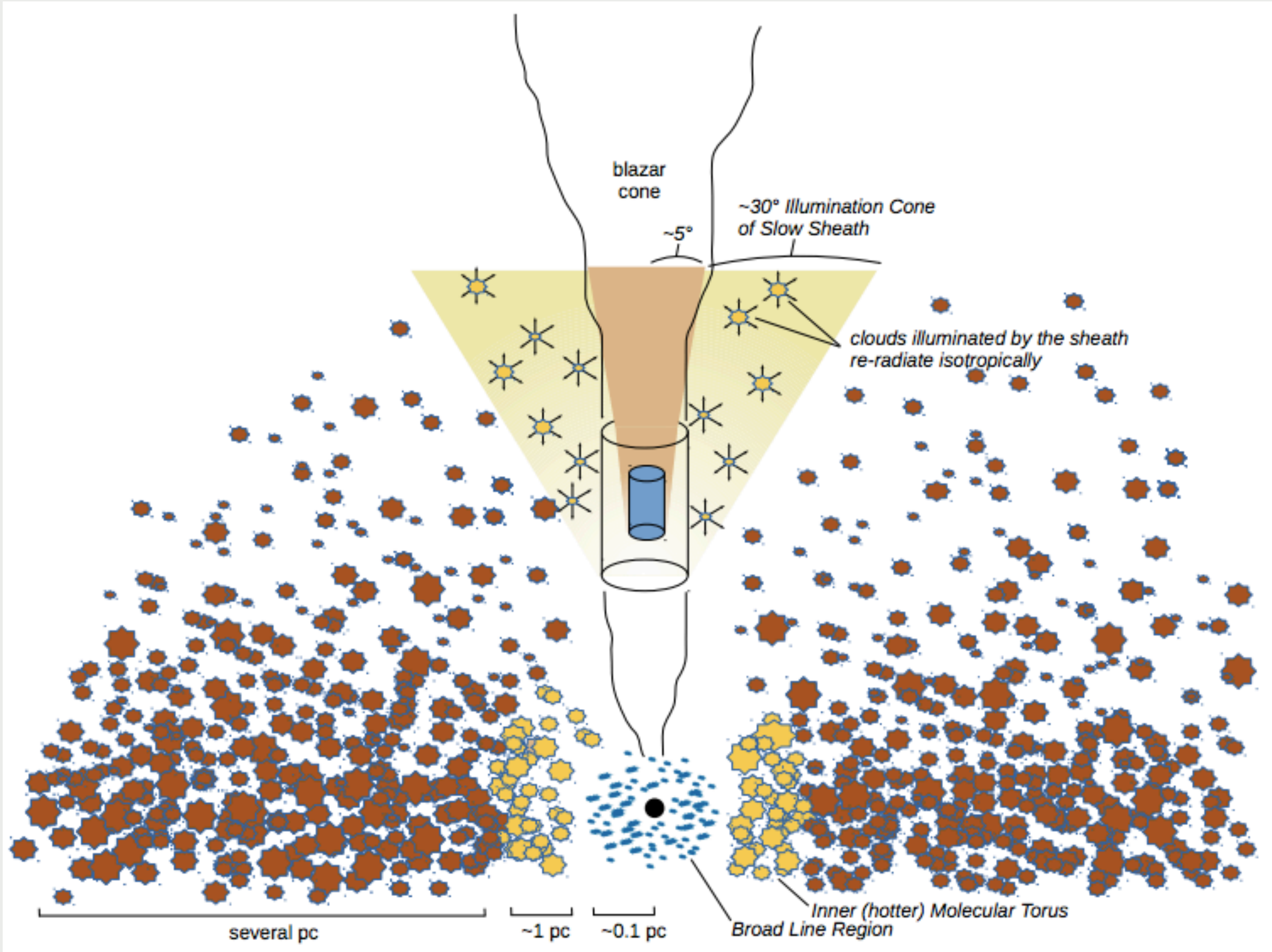


TAVECCHIO & MAZIN+ 2009

What if we allowed for more realistic BLR models?

Questions

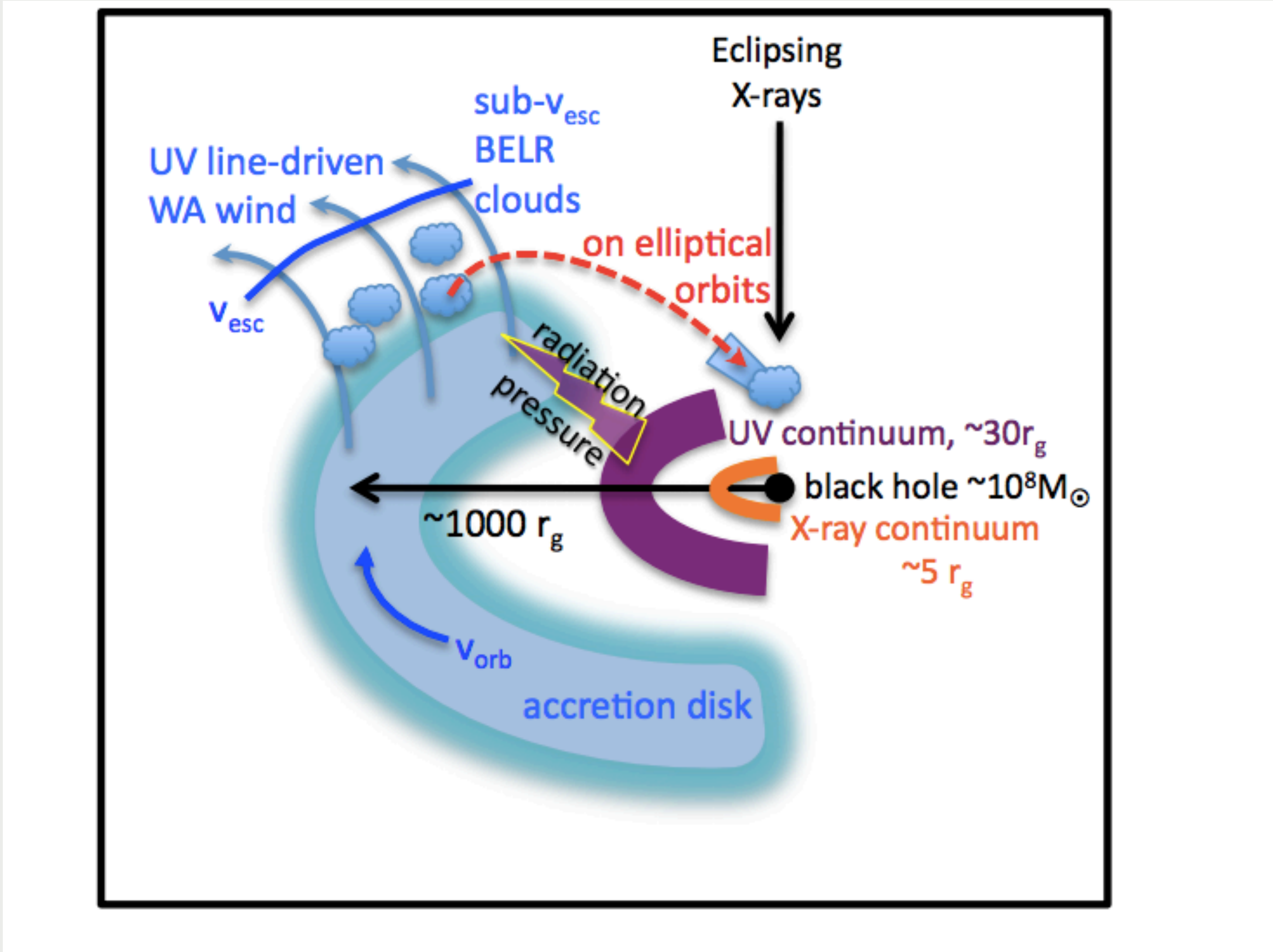
Modified Torus and Jet?



BREIDING+ 2017

A molecular torus that extends a few pc beyond the dust sublimation radius. The wide beaming pattern of synchrotron radiation from the sheath will heat molecular clouds and can dominate over the sheath photons directly entering the spine and produce emission line variability.

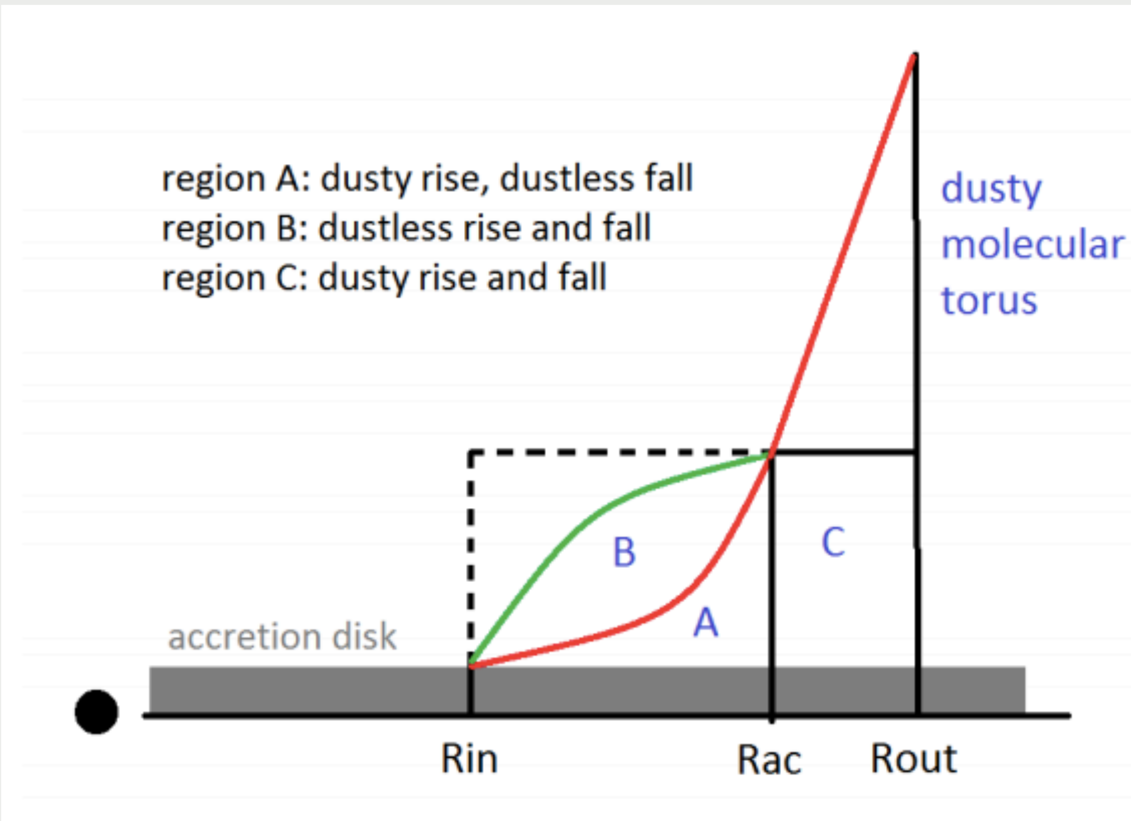
Quasar Rain?

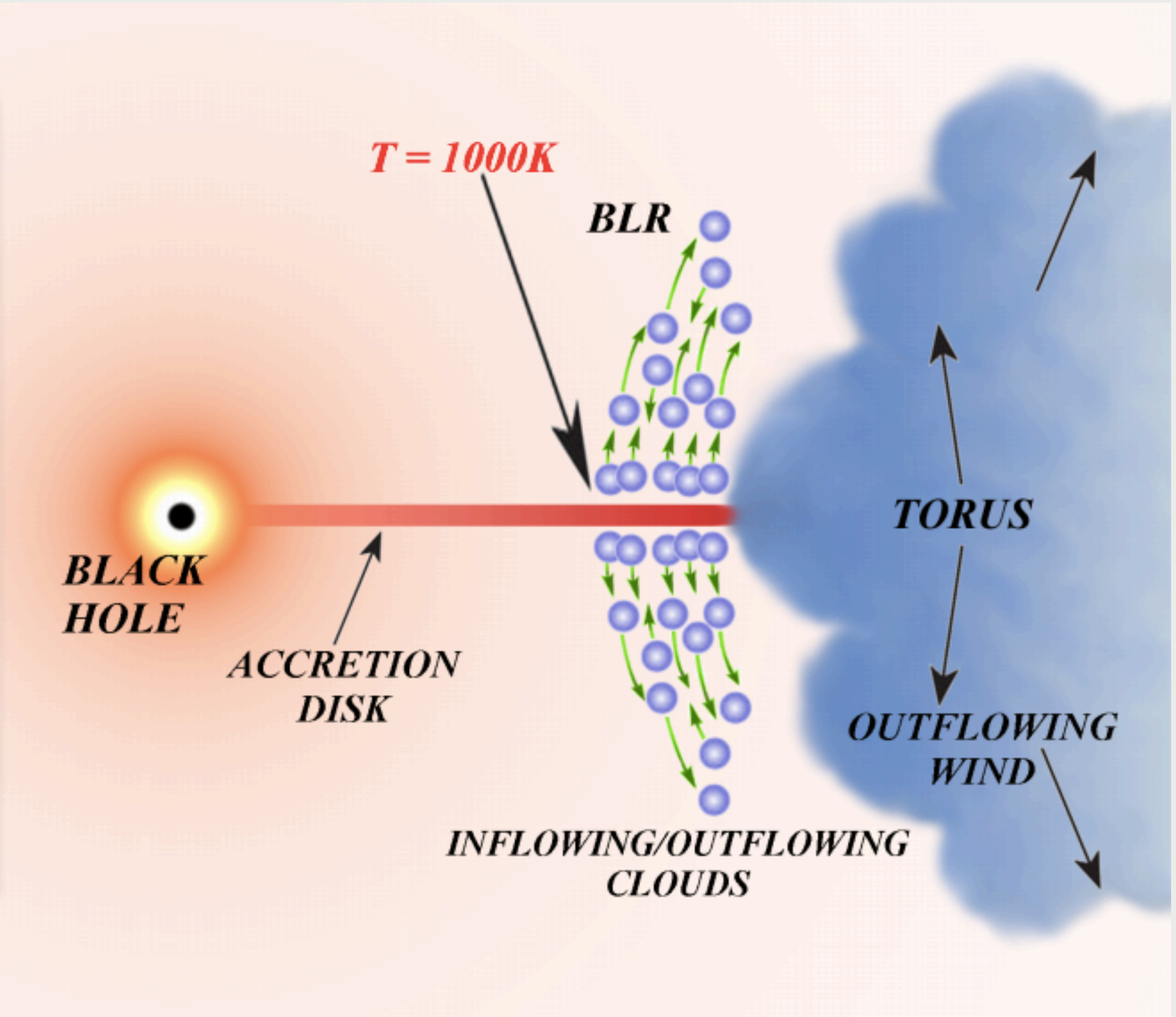


ELVIS 2017

Condensation in the warm accretion disk wind. Cool clouds condense faster than the warm absorber reaches escape velocity and falls back towards central source creating “quasar rain” that can look like an elliptical broad line region.

FRADO?



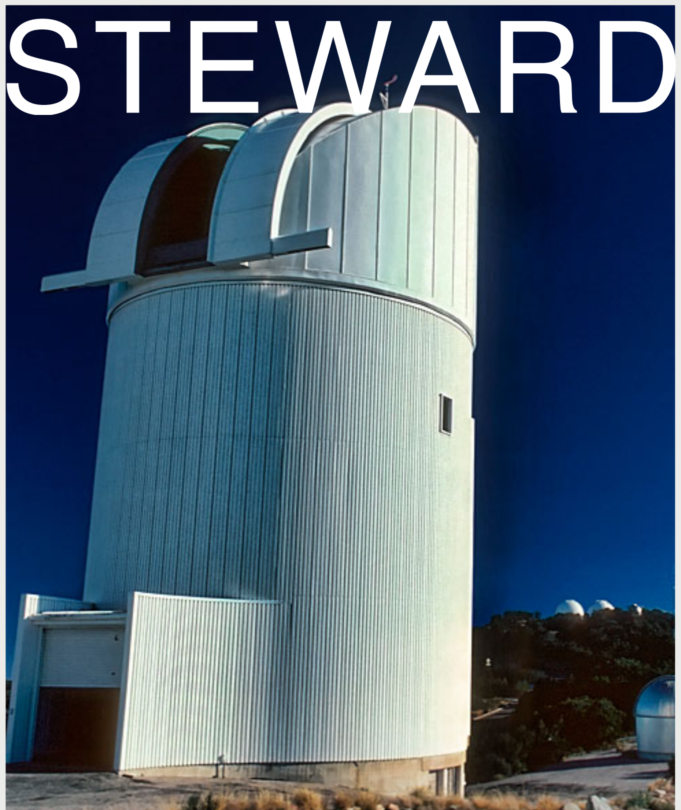


CZERNY+ 2017, 2014

Failed radiatively accelerated, dust-driven outflows. A dust-driven disk wind where the local effective temperature of a non-illuminated accretion disk drops below 1000 K and allows for dust formation. Upon irradiation, dust sublimates and material falls back towards disk.

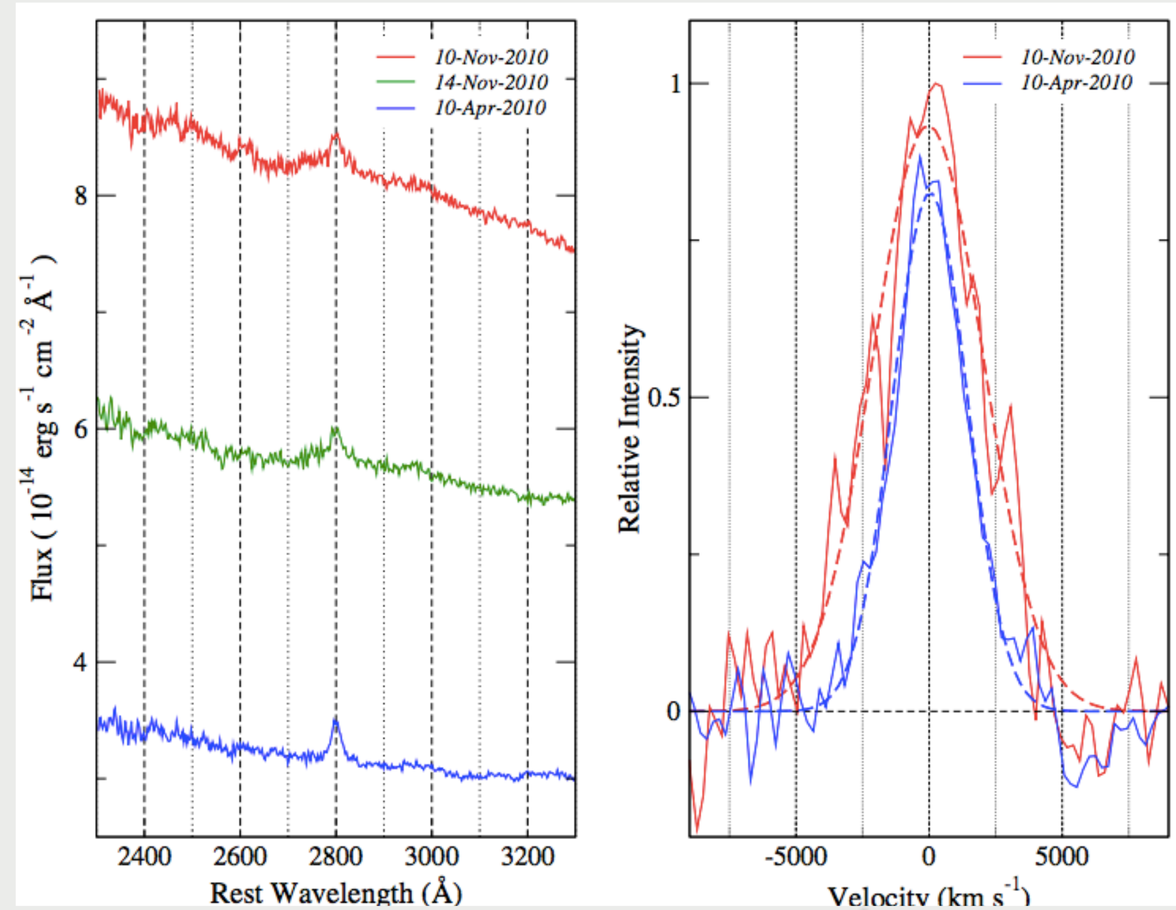
Do we have enough information?

Observations: What is the emission line flux and profile variability?



FRED ESPENEK

Current data lack sufficient spectral resolution to constrain BLR dynamics.



LEÓN-TAVARES+ 2013

What if we could significantly increase the quality of our observations?

Questions

Is it time for another observational test?

YES!

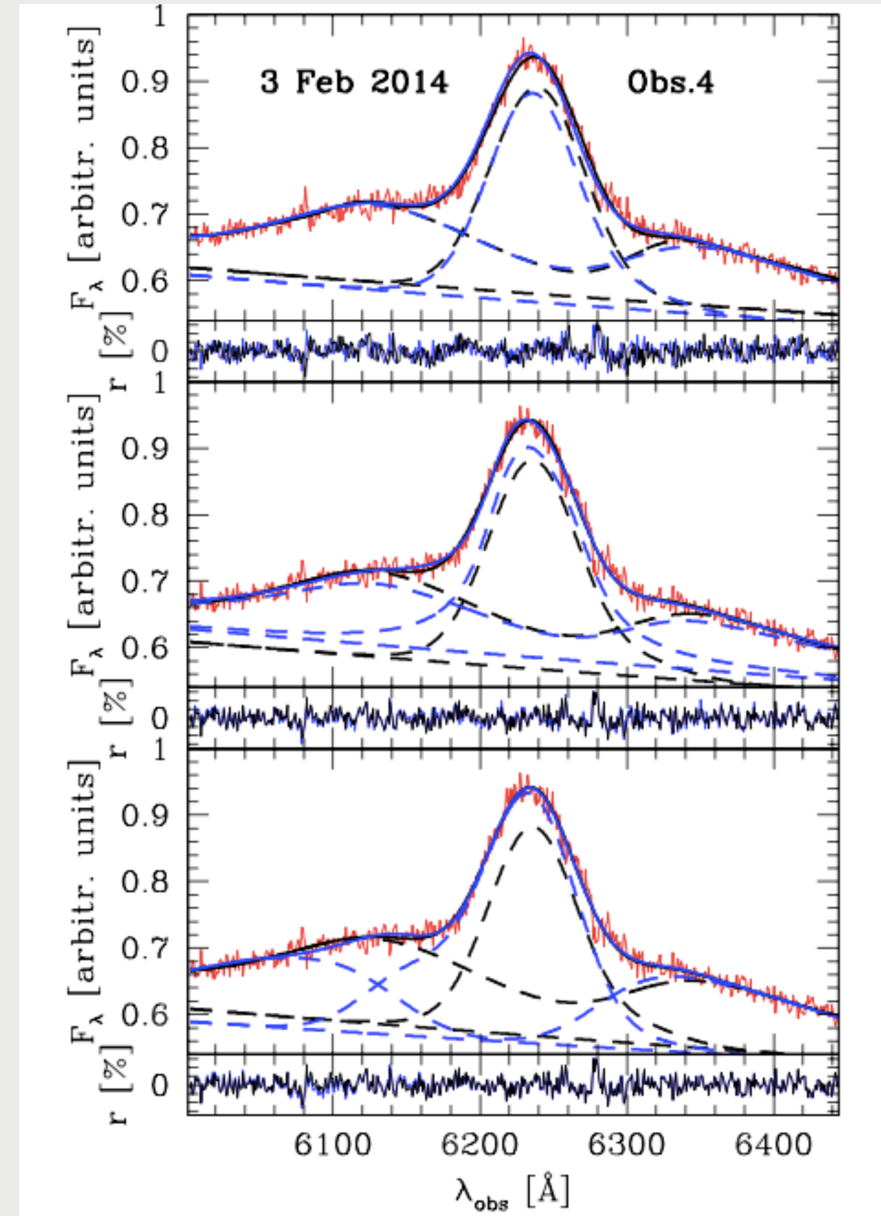
With large aperture, queue-scheduled spectropolarimeters, we can obtain time resolved, simultaneous optical spectral flux and line profile variability.

SALT

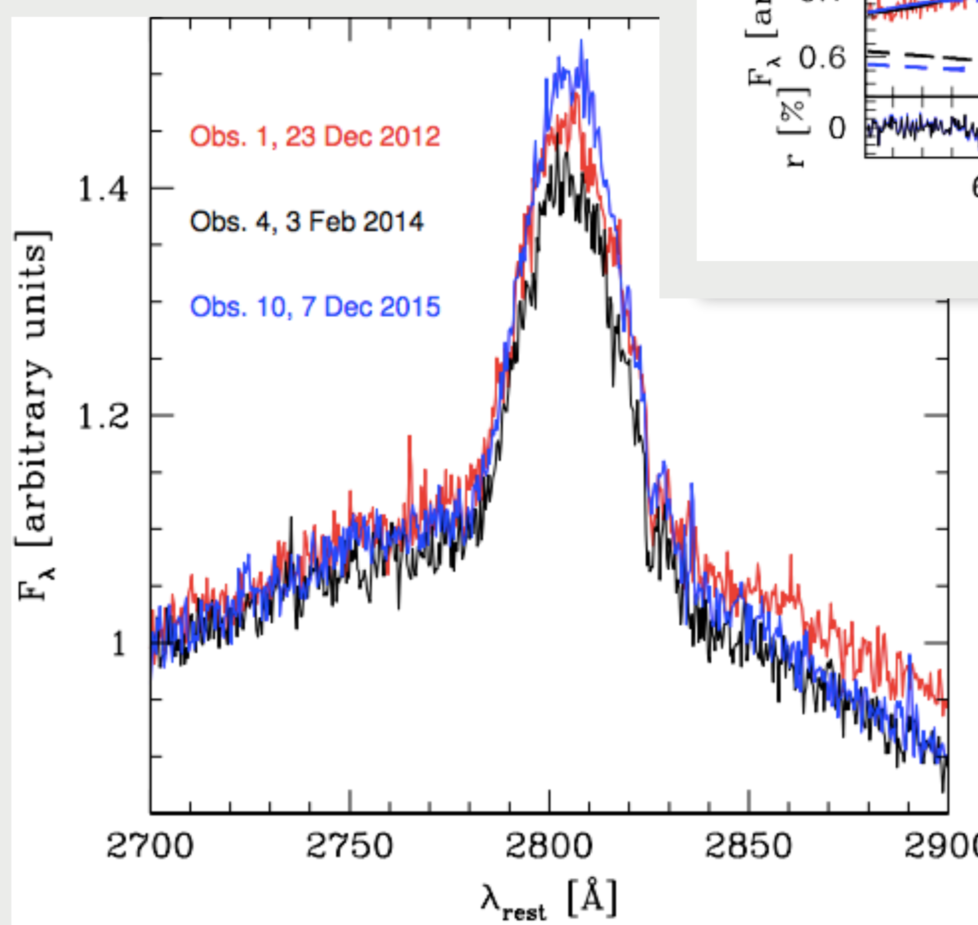
WYNAND BASSON

HE 0435-4312

- Using larger aperture telescopes, e.g. SALT (10m), line profiles can be accurately measured *(see Jorstad's talk!)*
- Equivalent width and line shift variability are observed in quasar HE 0435-4312 (z=1.232) across 10 epochs
- Differences in the MgII and FeII line profiles are detected
- This difference could be due to anisotropies in the illumination of the accretion disk *(Gaskell+ 2011)*
- Such analysis is necessary to understand dynamic processes near line production sites



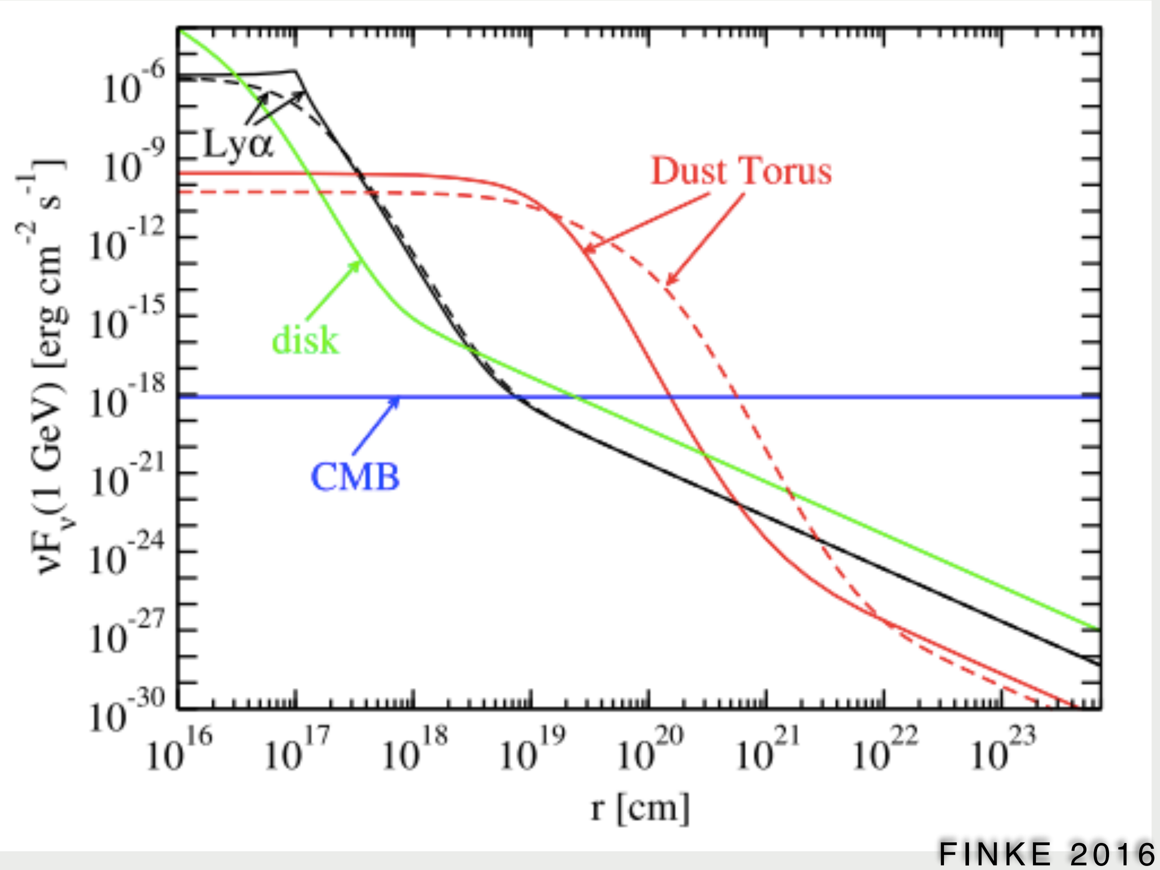
ŚREDZIŃSKA+ 2017



Is it time for another observational test?

- Yes!

- With this higher quality data, we can probe the next generation broad line region models and more robustly constrain where the broad emission lines are produced and how (and when) they interact with the jet.



FINKE 2016

- Next generation models will also take into account more complicated photon fields near the central source and give more realistic constraints on the contribution and evolution of the BLR and whether it is the site of high-energy emission production.

Next Steps