The Fermi blazar-zone divide

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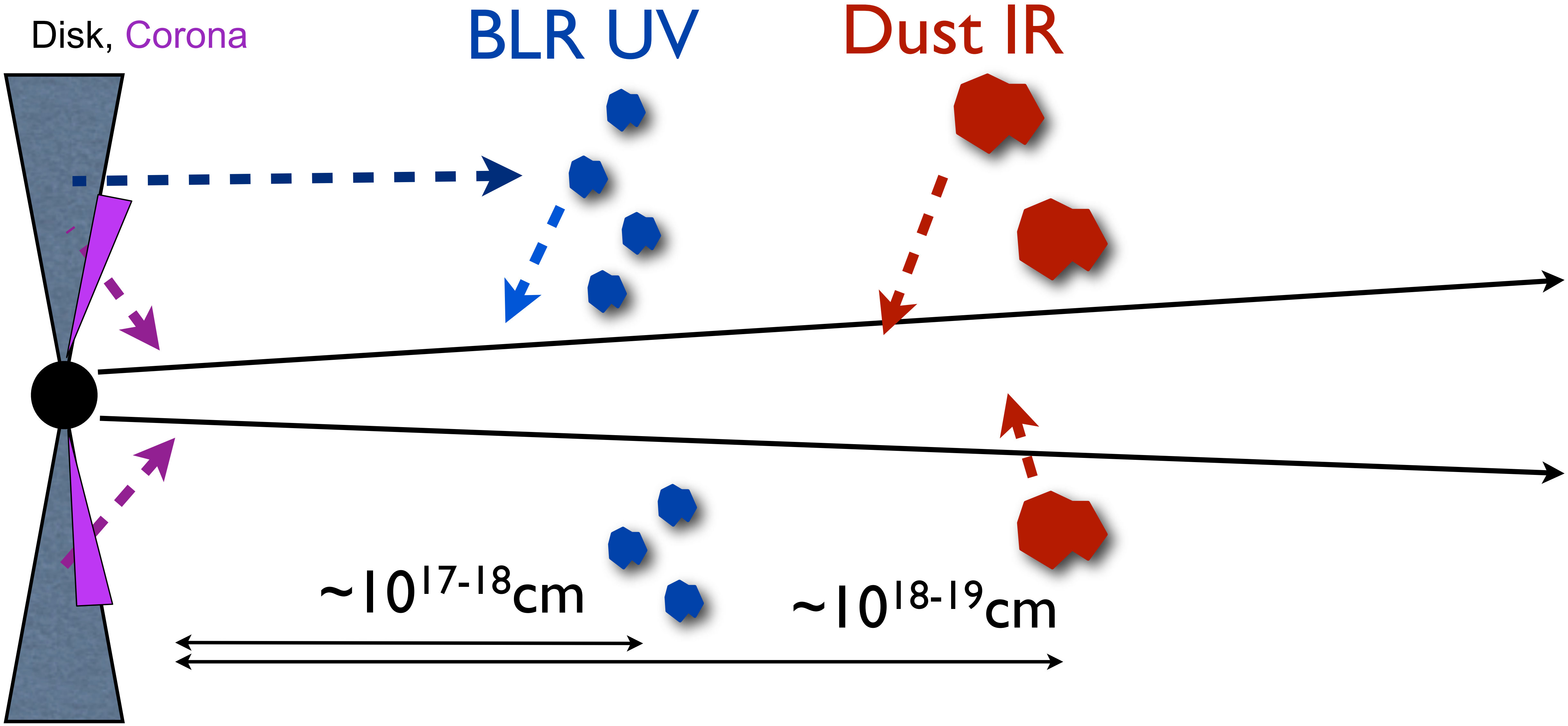
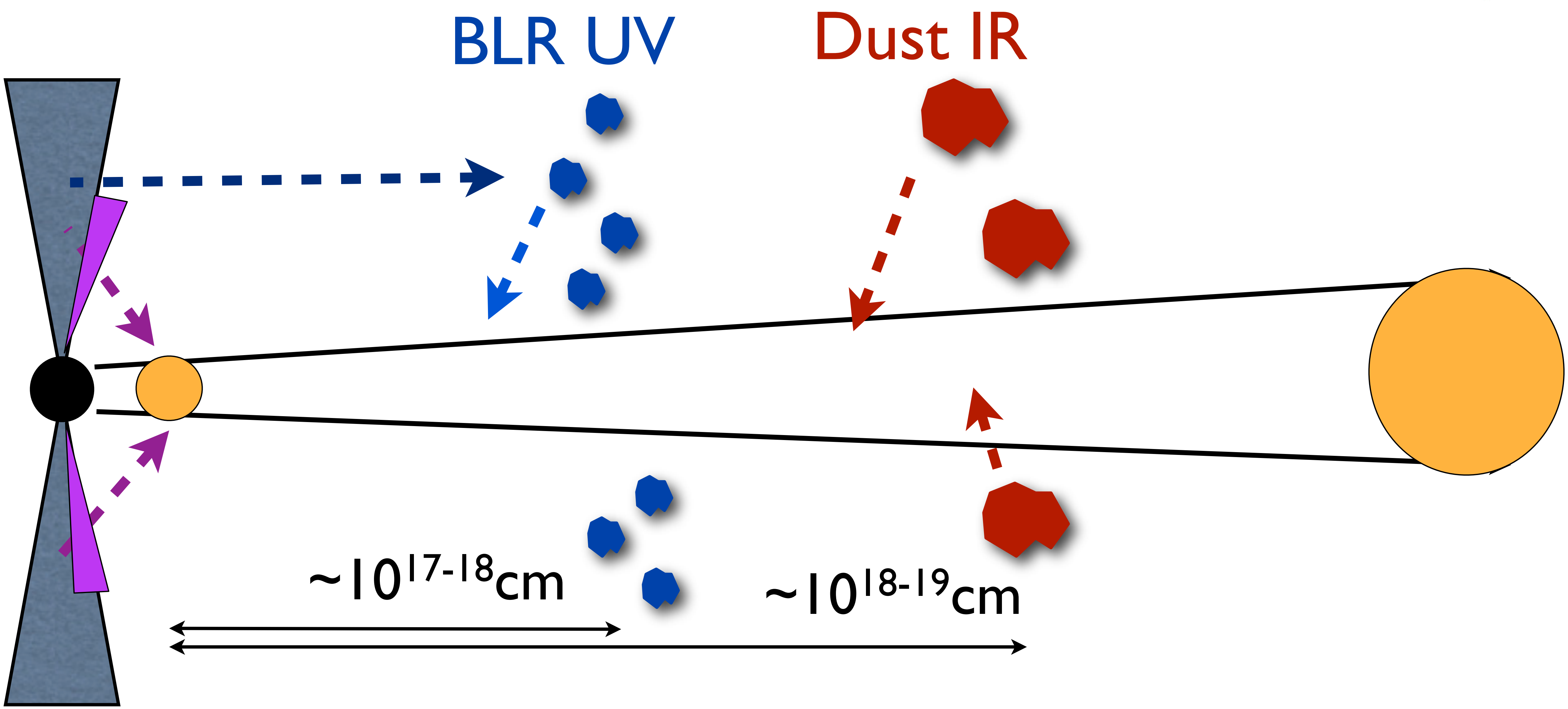
Where the gamma-rays come from ?



NB: Following Arguments valid for FSRQ-like blazars only
(objects with radiatively efficient disk, BLR emission, no or very weak TeV emission);
NOT FOR HBLs / TeV BLLacs !!

Where the gamma-rays come from ?

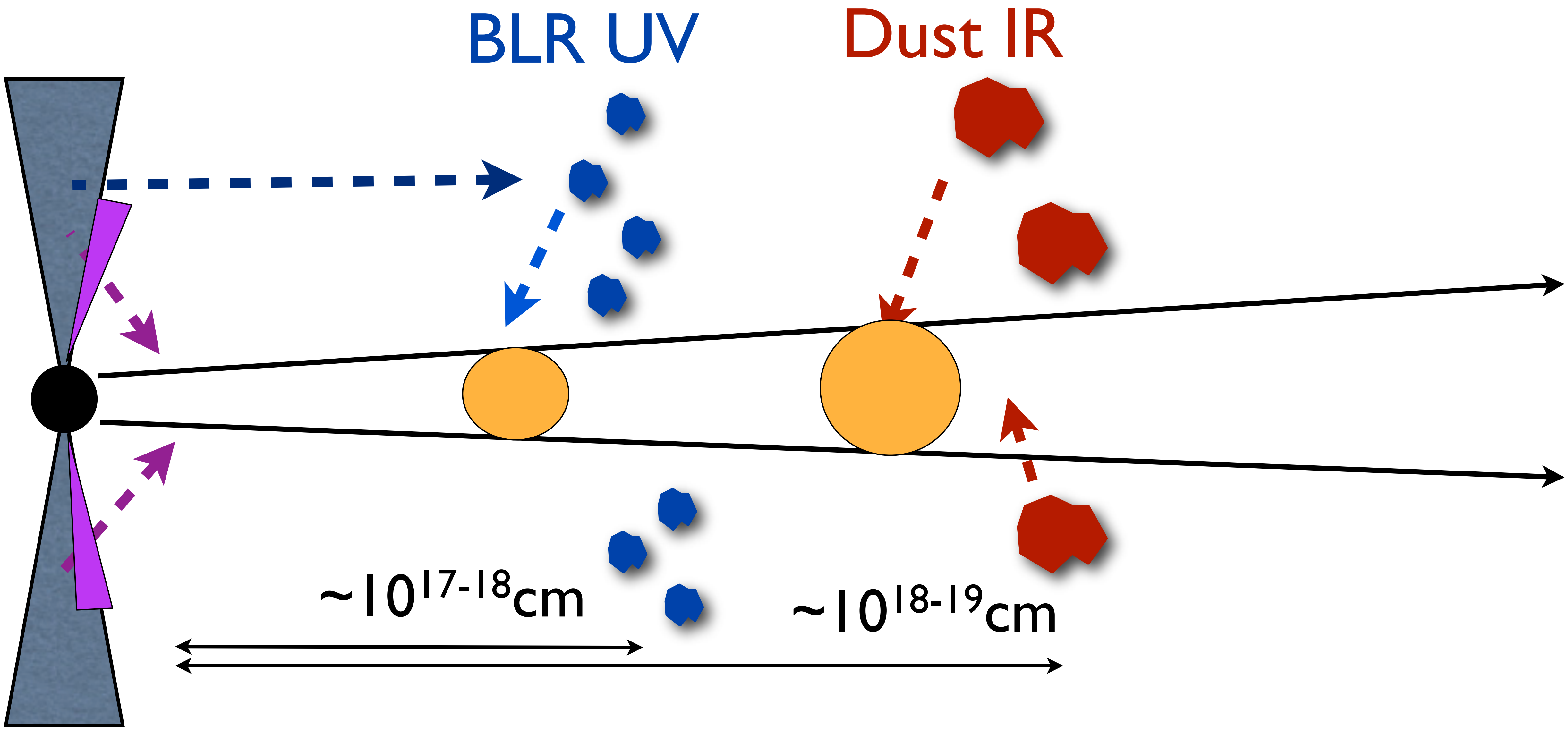


Not too close BH (few Rs): γ - γ absorption and reprocessing $\Rightarrow$ α_X ~0.9-1

Not too far away (~100pc): problems with fast variability (≤ 1-2 days)

(e.g. Ghisellini & Madau 1996)

Seed photons for Inverse Compton (IC)



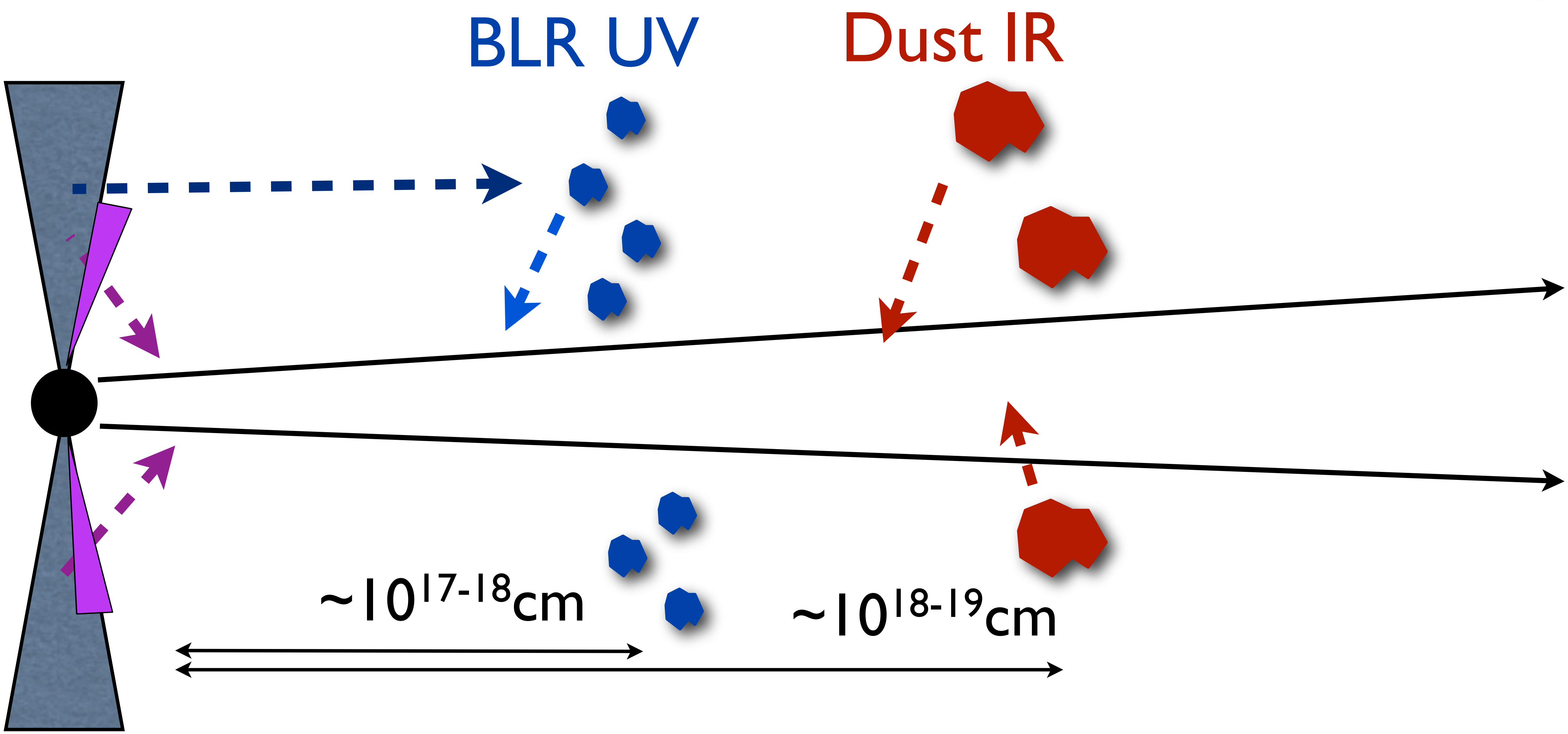
$$\mathbf{R \propto L_{disk}^{1/2}}$$

(Bentz et al. 2006 ; Kaspi et al. 2007)

$$\mathbf{U_{rad} \propto L/R^2 \sim const. \sim 10^{-2} erg/cm^3}$$

External Compton (EC) onto: UV (~9-10 eV) or IR (0.1 eV) (e.g. Ghisellini et al. 2009 Sikora et al. 2009)

Seed photons for Inverse Compton (IC)



$$\mathrm{R} \propto \mathrm{L}_{\mathrm{disk}}^{1/2}$$ (Bentz et al. 2006 ; Kaspi et al. 2007)

$$\mathrm{U}_{\mathrm{rad}} \sim 10^{-2} \mathrm{erg/cm^3}$$

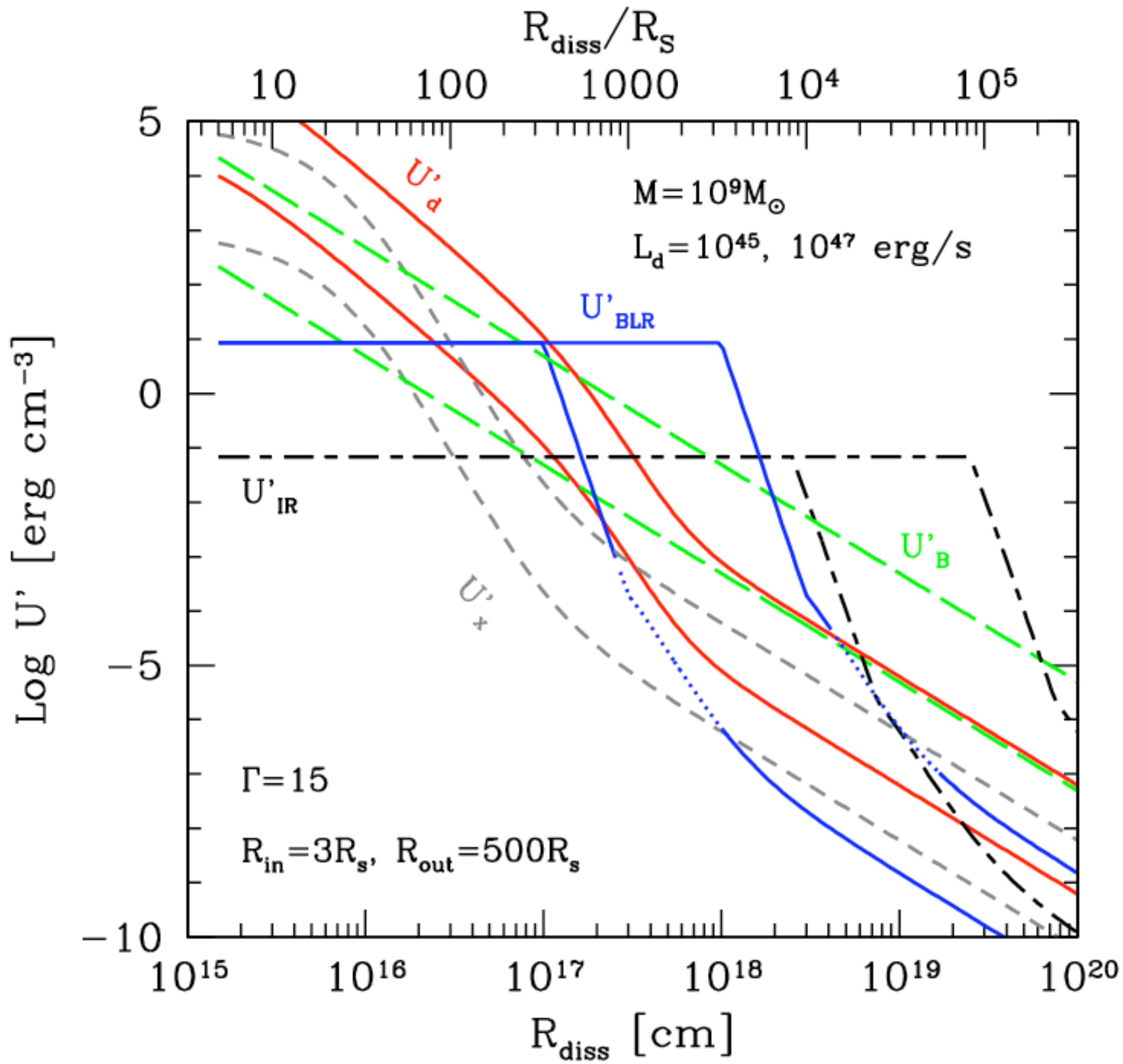
Basic 0th-order assumptions/approximations:

a) $R \sim 10^{17} (L_{disk,45})^{1/2}$ cm **b) isotropic field**

c) BlackBody spectrum @9eV **d) reprocessing factor η~ 10%**

(e.g. Ghisellini et al. 2009
Sikora et al. 2009)

Energy densities in co-moving frame

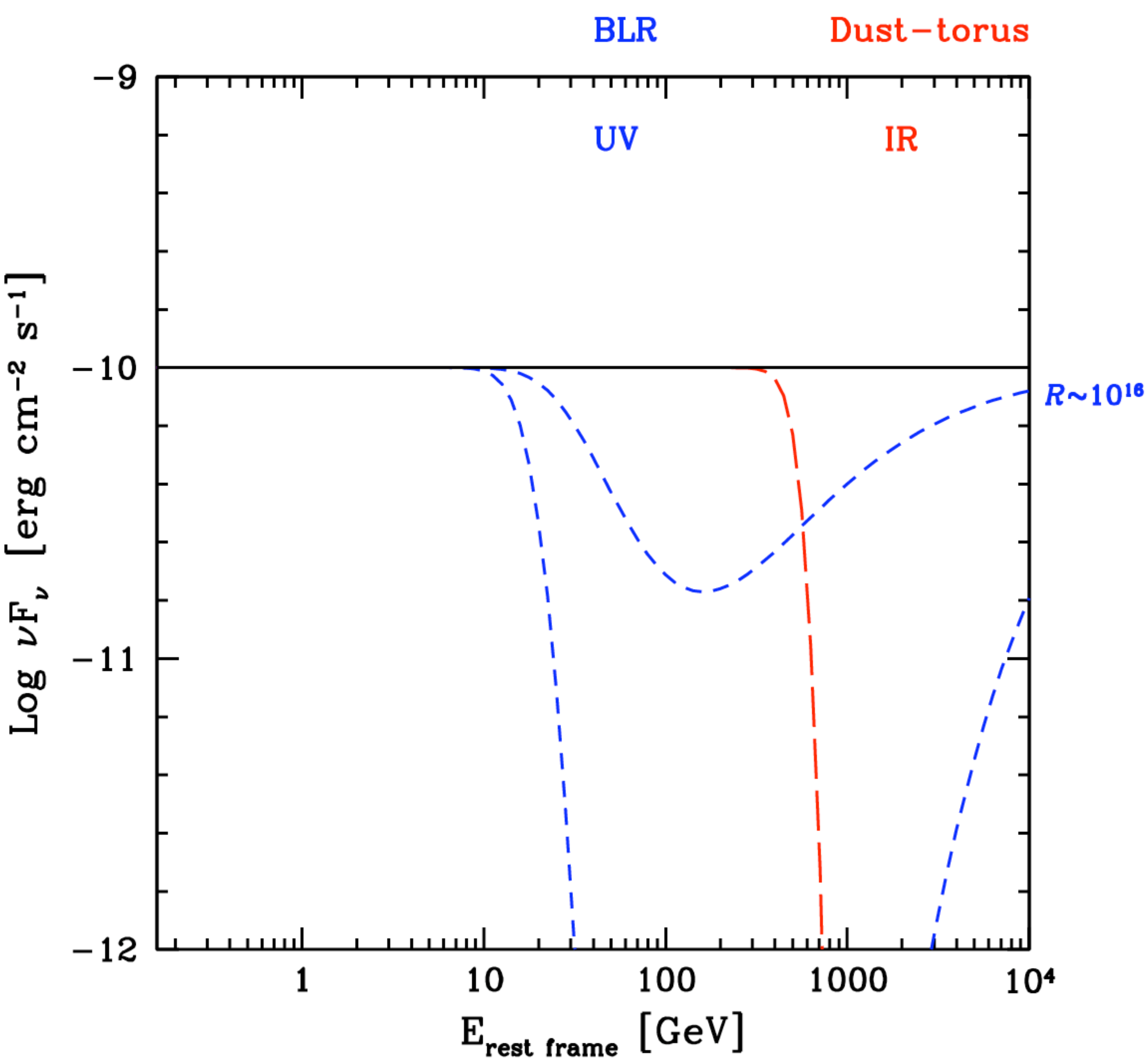


Ghisellini et al. 09
(also in Sikora et at. 09)

Location determines dominant U_{rad}, and thus main IC emission

Absorption feature by γ-γ interactions

But: same seed photons are target for gamma-gamma interactions.
<u>The gamma-rays have to pass through a double "wall" of photons</u>



Optical depth τ is high !

Always not negligible (≥1), even in the minimal case: photon path ~ size of emitting region (typically ~10^{16} cm)

Fermi now samples this energy range for the first time (1-100 GeV rest frame)

Band >10 GeV: lots of diagnostics !

If EC is the main g-ray emission mechanism: @ ~2-10 GeV (restframe), additional possible steepening due to Klein-Nishina effects !

☛ if Lc/Ls~1 **or** Lc/Ls >>1 & BLR spectrum is broad banded
$\Rightarrow$ cooling of e^{+-} in Thomson $\Rightarrow$ steepening

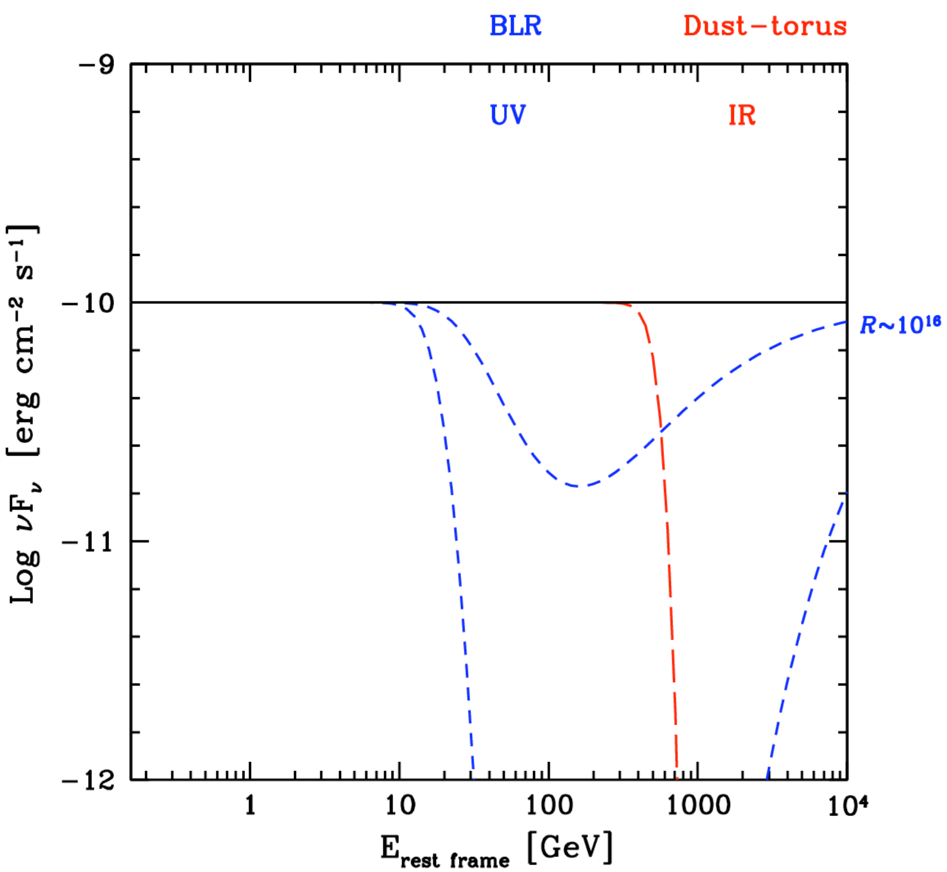
☛ if Lc/Ls >>1 & BLR is narrow banded $\Rightarrow$ no steepening !
compensated by hardening of the particle distribution when cooling is in KN regime
(e.g. Zidjarski 1989, Dermer et al. 2003, Moderski et al. 2005, Ghisellini et al. 2009)

Presence or absence of cut-offs, tells:

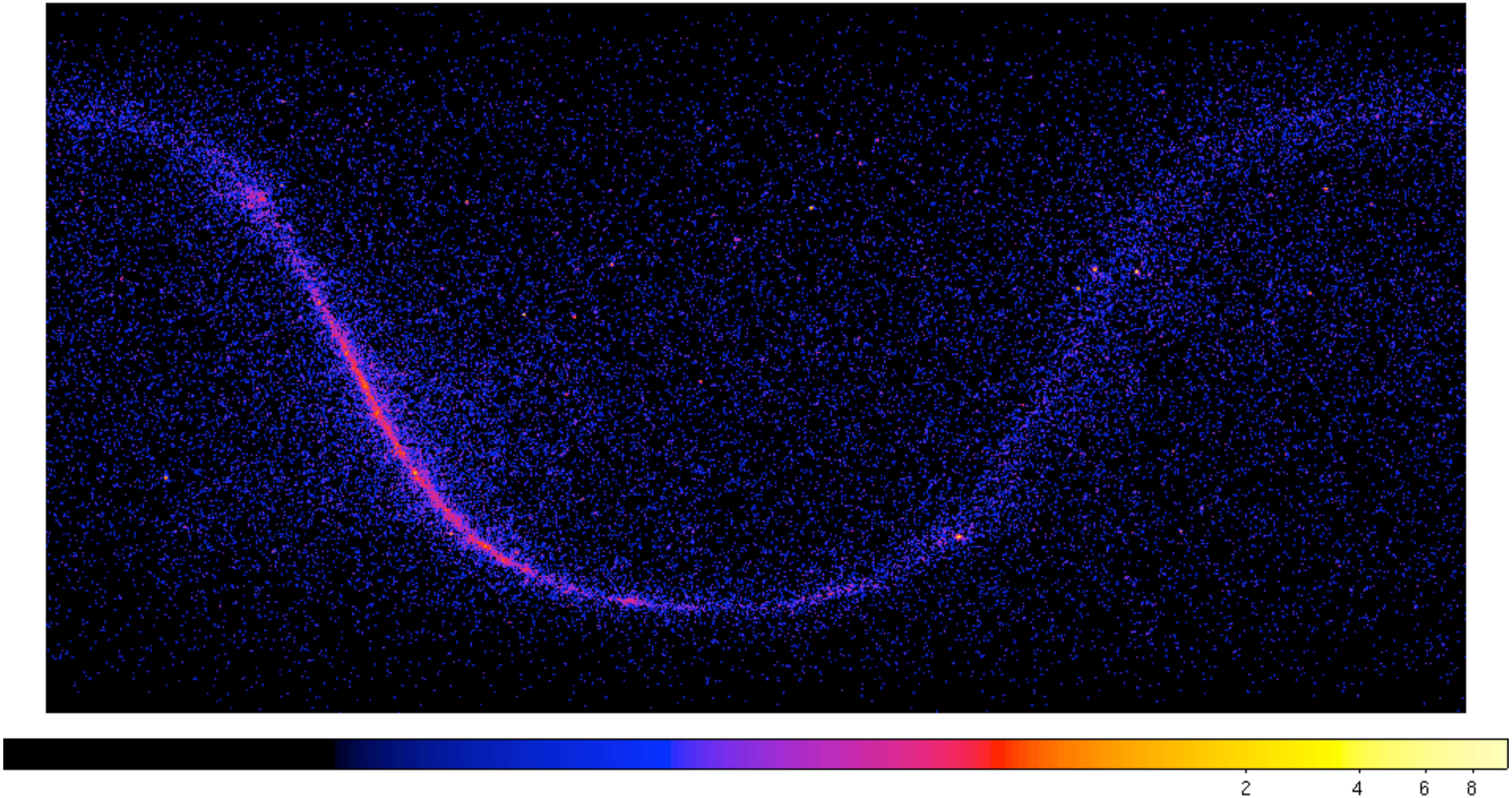
⇛ R_{diss} < or > R_{BLR}

⇛ intensity of cutoff gives an estimate of the photon path inside the BLR

⇛ which EC is viable: UV or IR photons



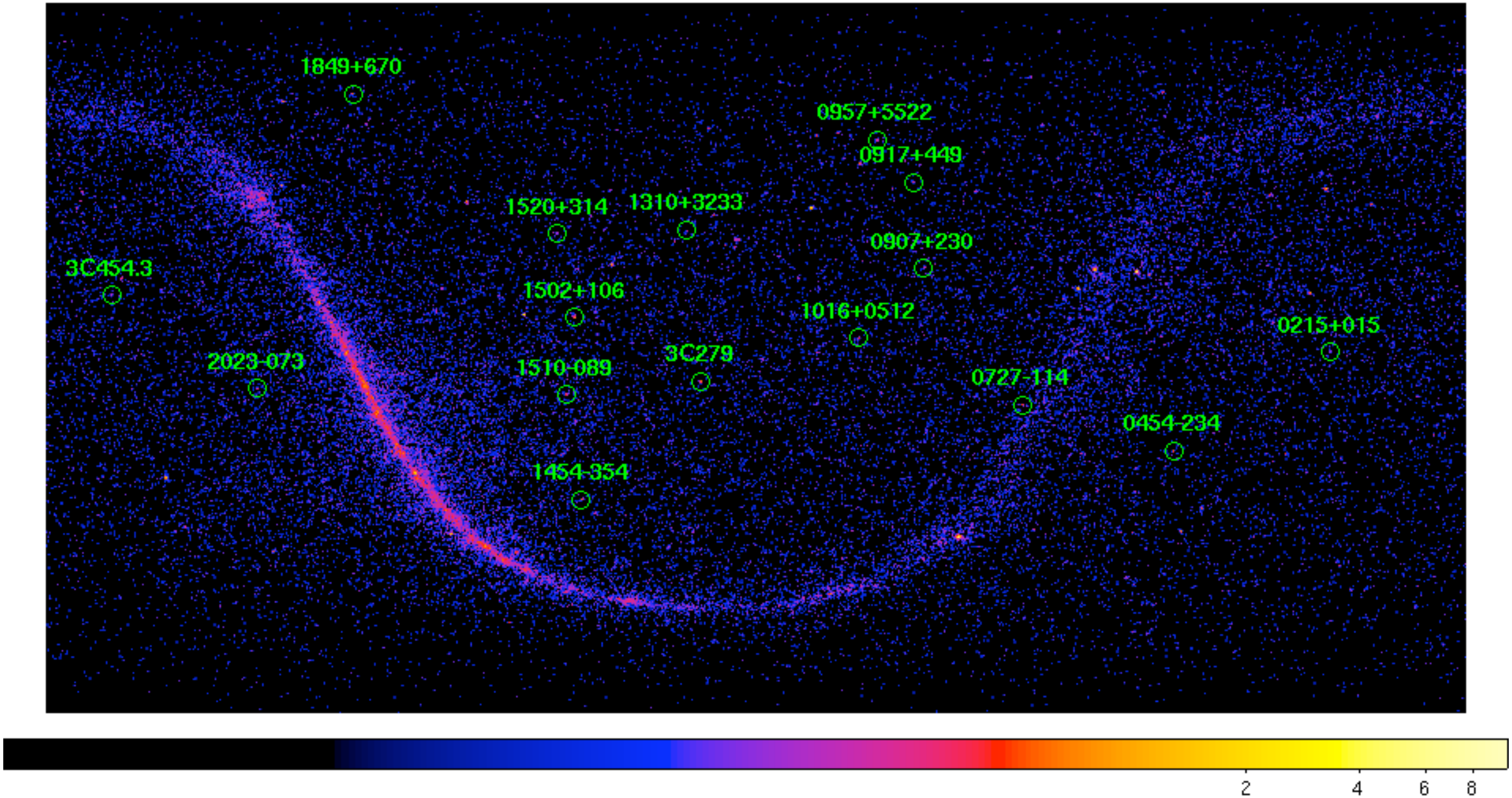
Target selection: FSRQ detected >10 GeV



LAT sky above 10 GeV

Goal: sources with enough photons >10 GeV to see possible spectral features

Target selection: FSRQ detected >10 GeV



We found and analyzed 16 objects. All sources in the preliminary 1-year AGN catalogue, under development by the LAT team.

LAT data analysis

- **Science Tools v9r15p5**
- **E >200 MeV , ROI of 7 deg. from region of 12 deg.**
- **All sources from 1-year catalog inside the 12 deg region included.**
- **Maximum likelihood fit in each energy bin**
- **Obtained Spectra: average from 11-months exposure**
- **All analyses preliminary !!**

Notes:

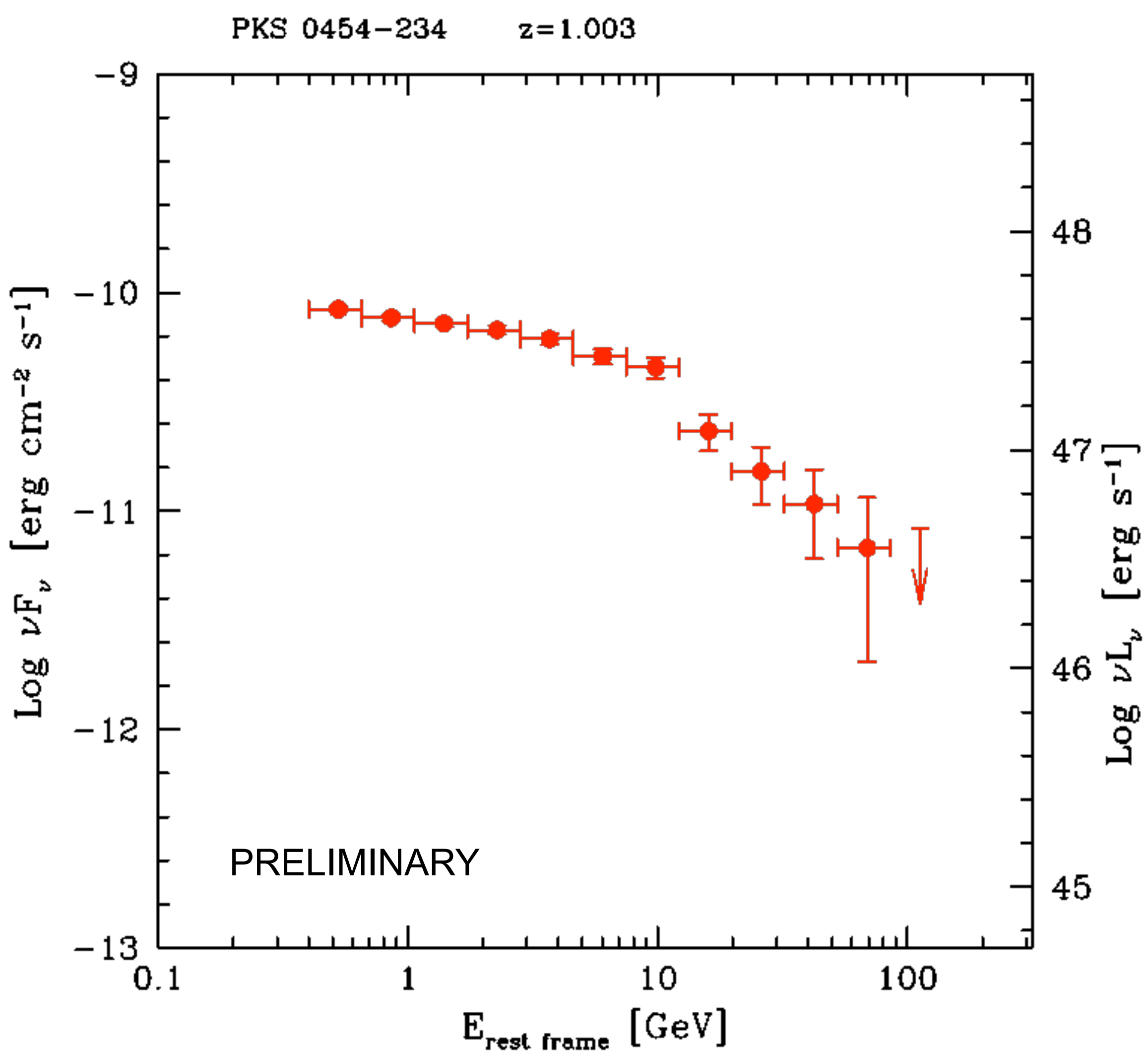
- **All plots have Energy axis in REST FRAME energies**
- **EBL absorption not (yet) relevant at these energies and redshifts** (for most realistic, recent calculations, e.g. Primack, Franceschini)

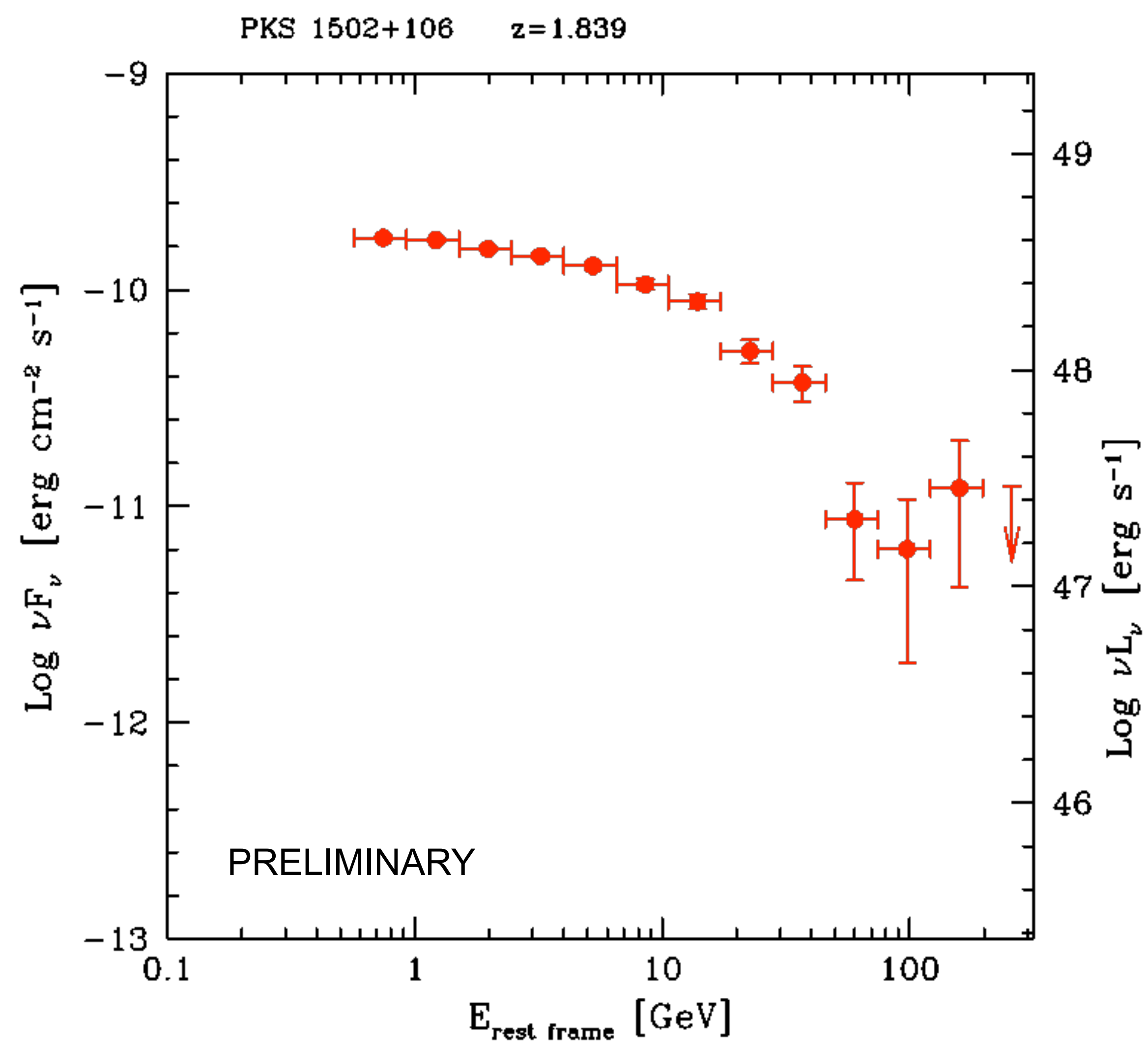
LAT Spectra by Andrea T.

No evidence of strong BLR cut-offs !

τ can be very high (~10 ℓ_{17}), if inside the BLR, and yet:

the sources that do show possible absorption, only moderate (τ ~1.5-3)



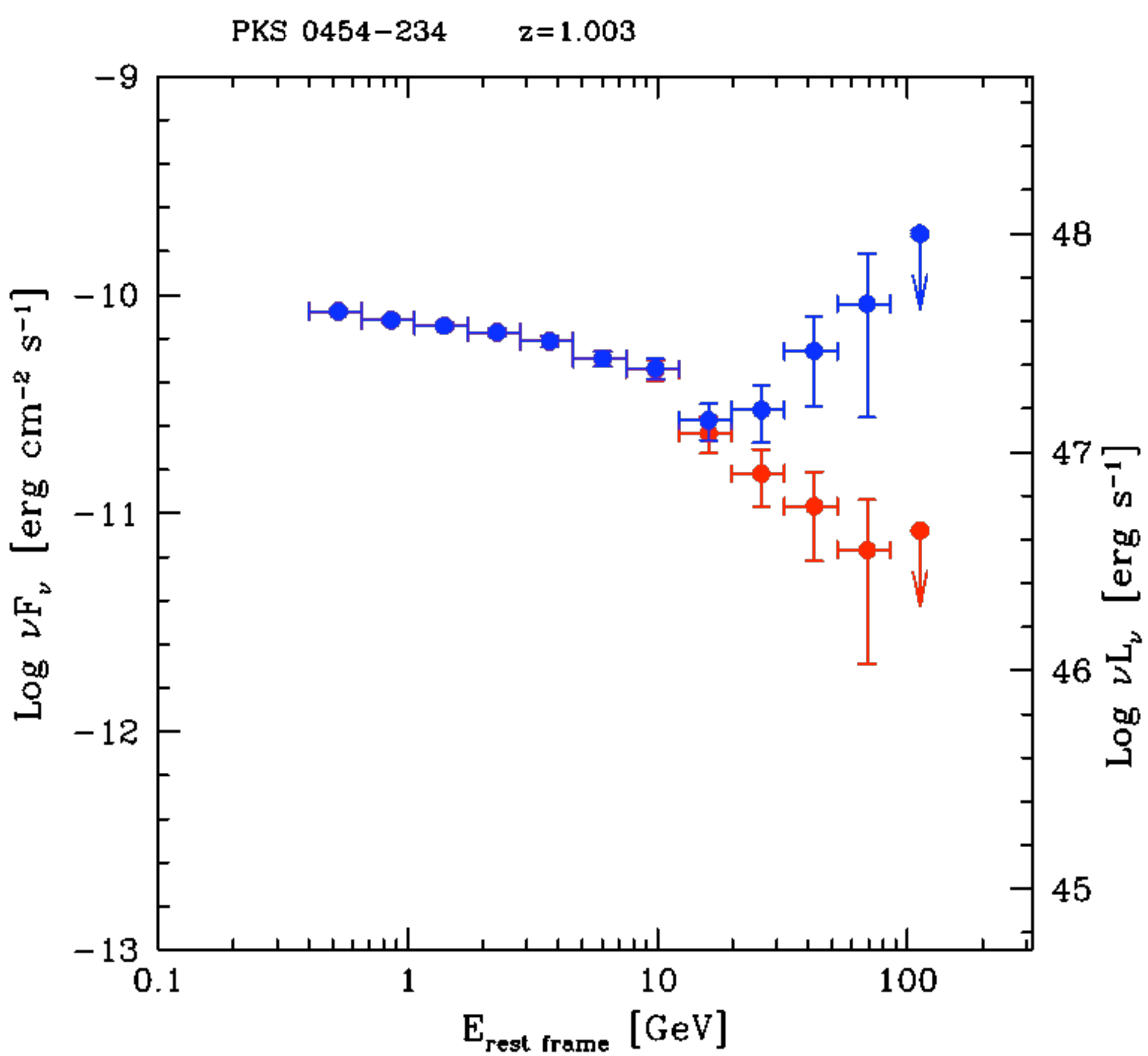


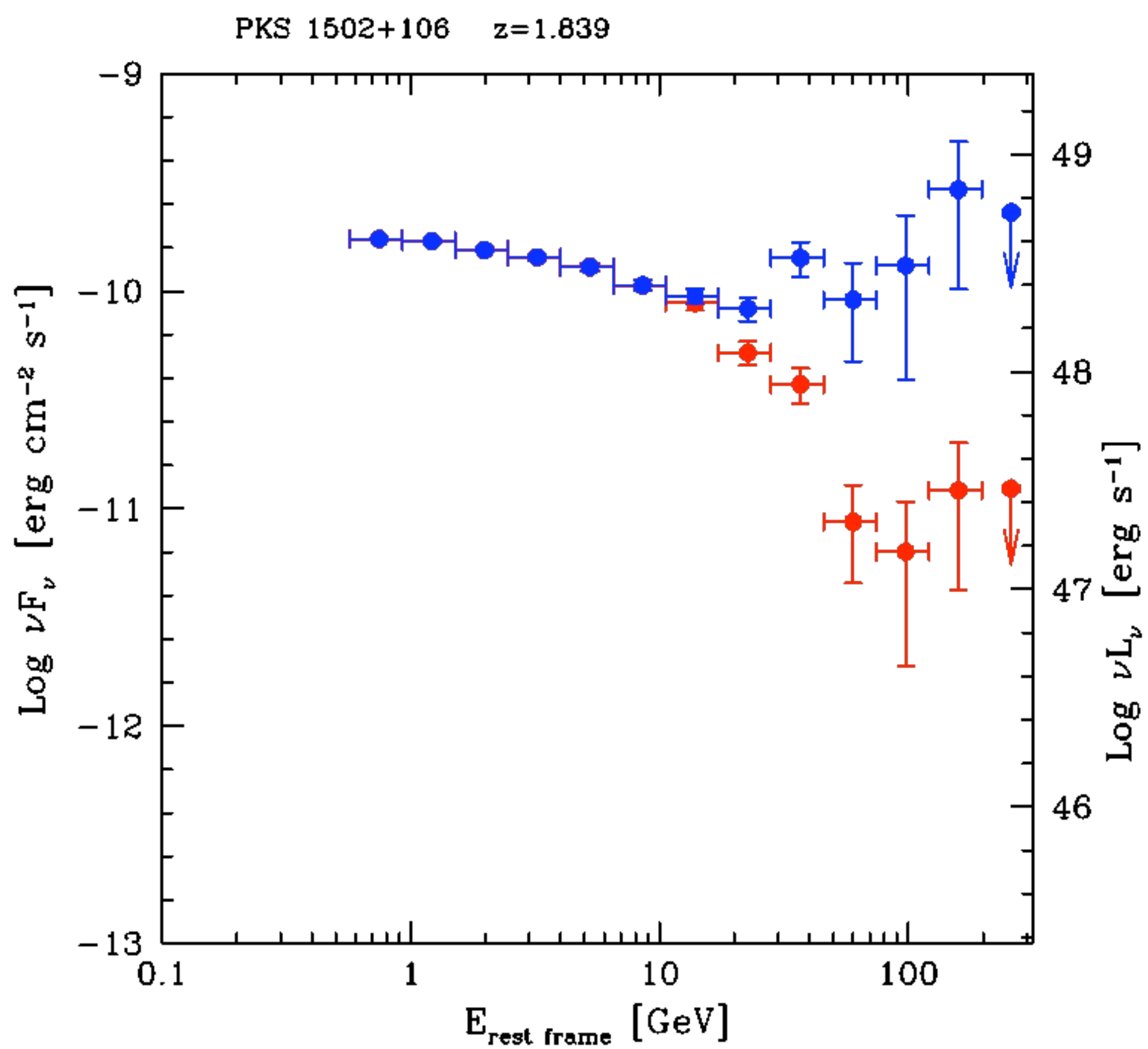
1502: see Benoit's talk and S. Ciprini poster

No evidence of strong BLR cut-offs !

With tau =3 (path a few 10^{16} cm), absorption would already be too strong:

LAT spectra: original, observed ; BLR de-absorbed



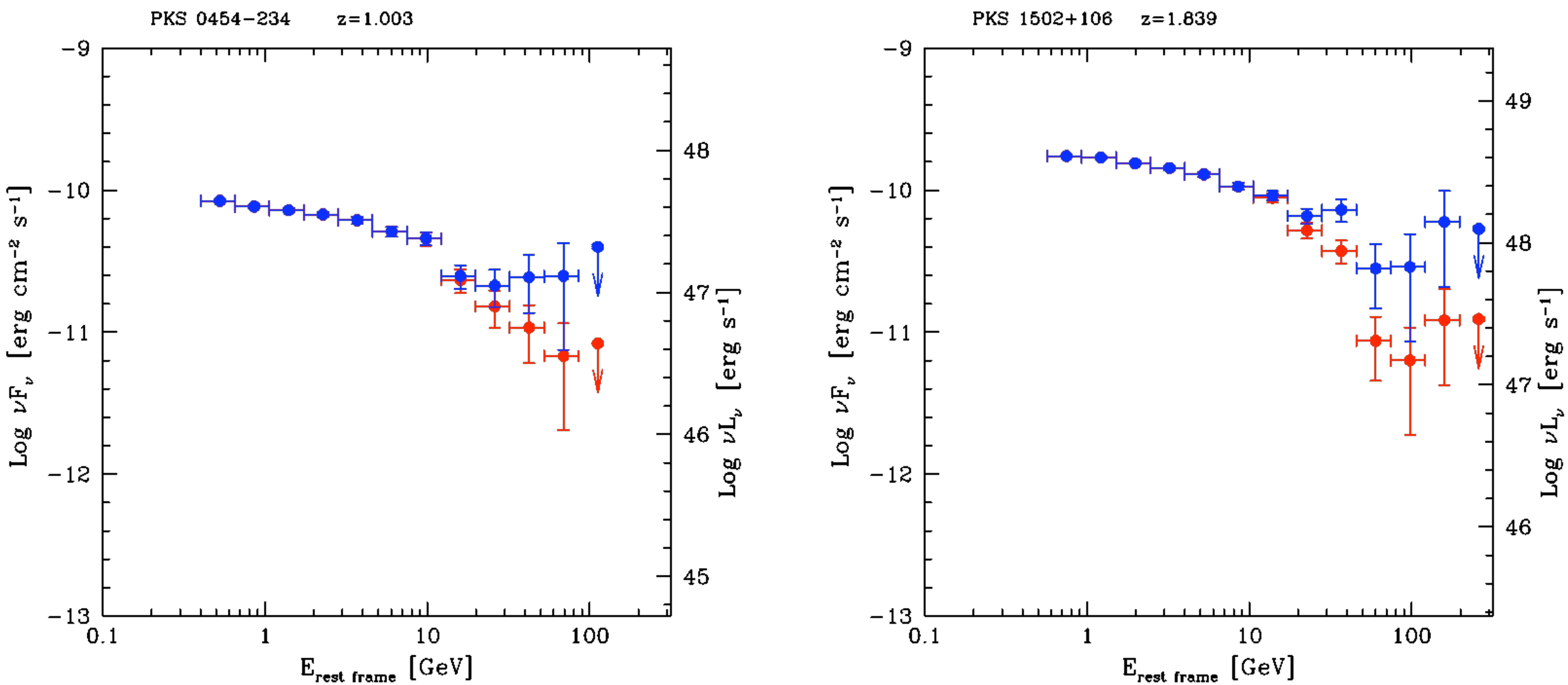


$R_{blr} \sim 4\times10^{17}$ $L_{disk} \sim 2\times10^{46}$

$R_{blr} \sim 0.8\times10^{18}$ $L_{disk} \sim 6\times10^{46}$

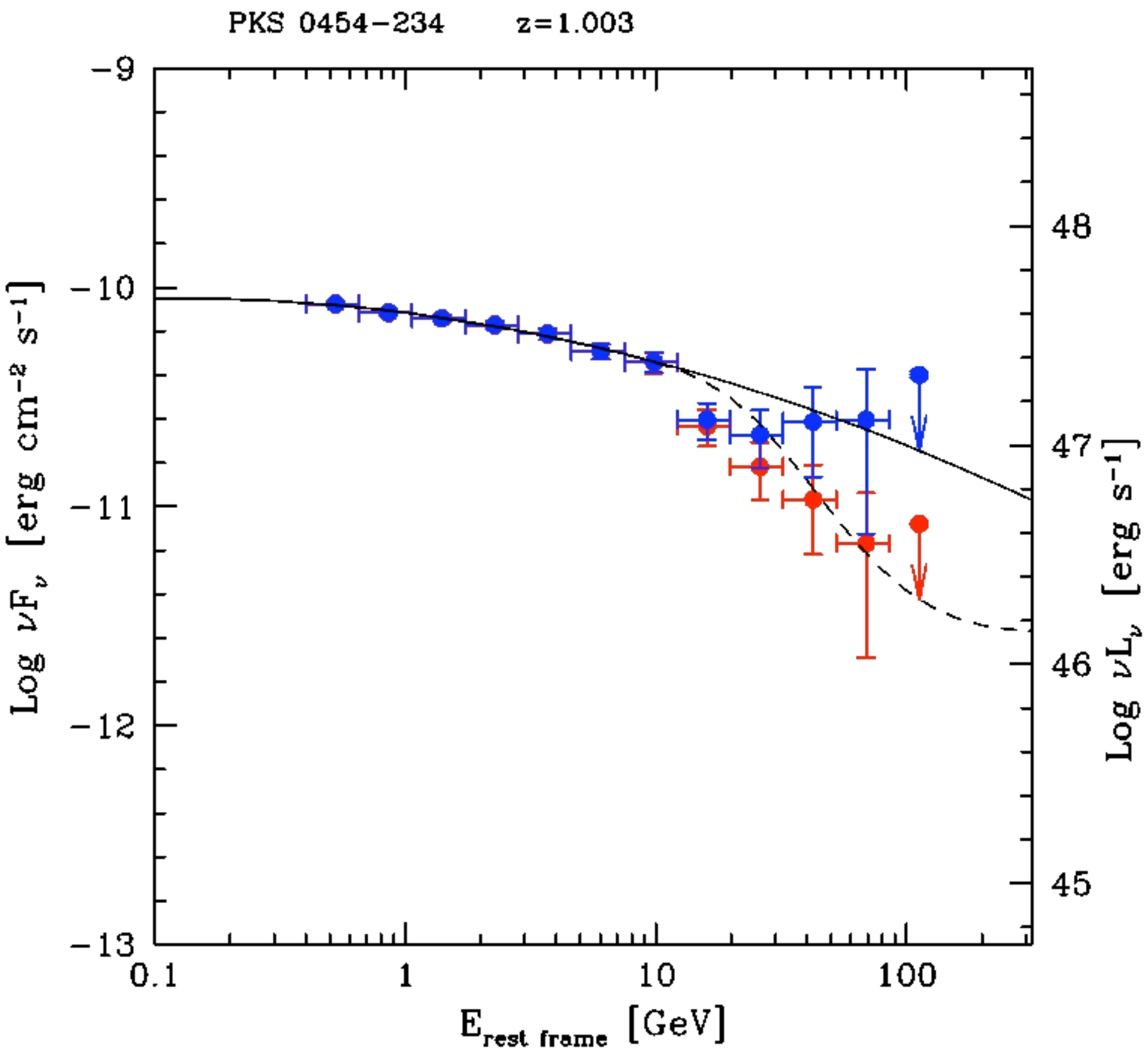
No evidence of strong BLR cut-offs !

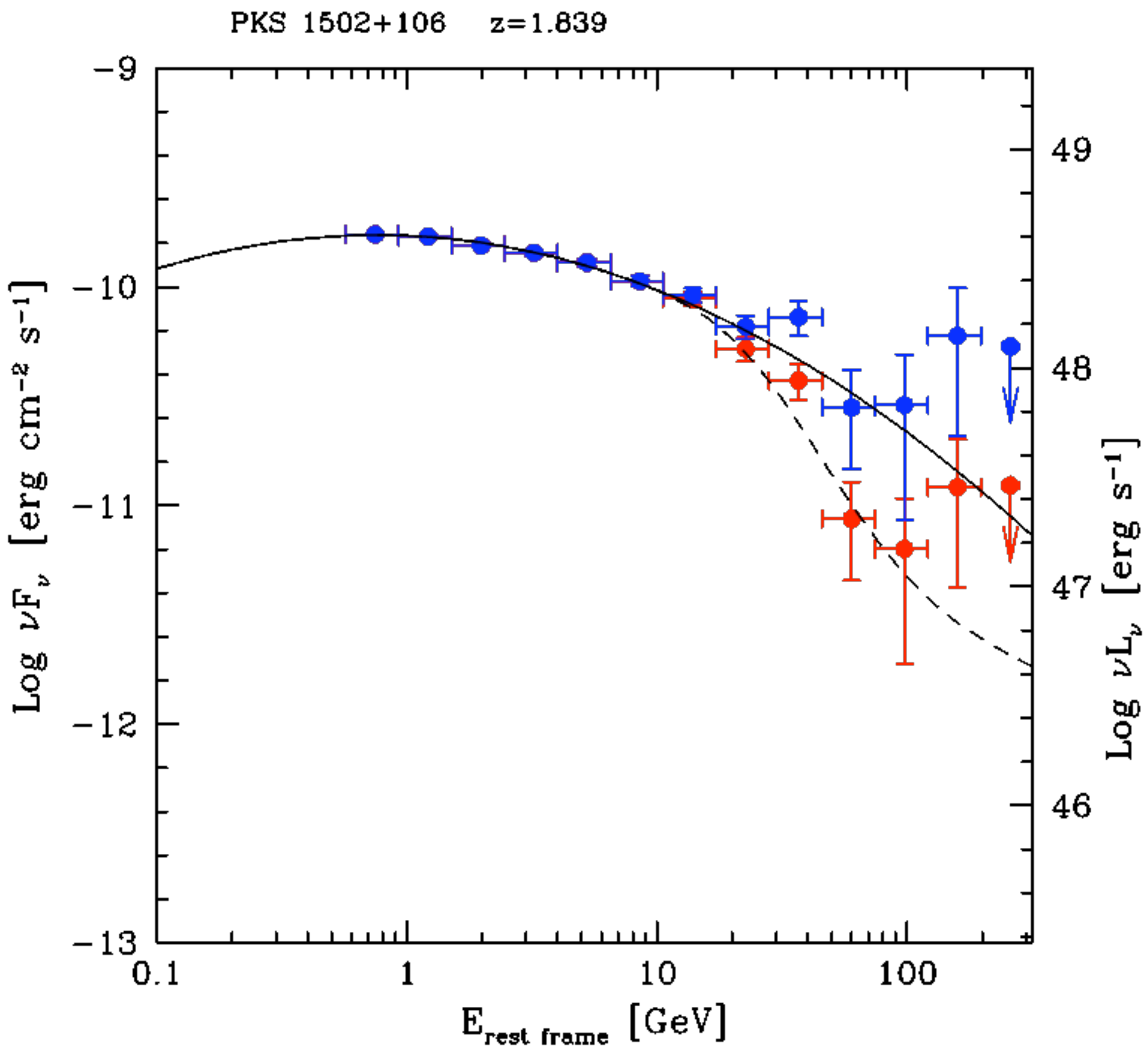
Spectra seems compatible with presence of but minimal absorption ($\sim 10^{16}$ cm, i.e. $R_{diss} \approx R_{blr}$)



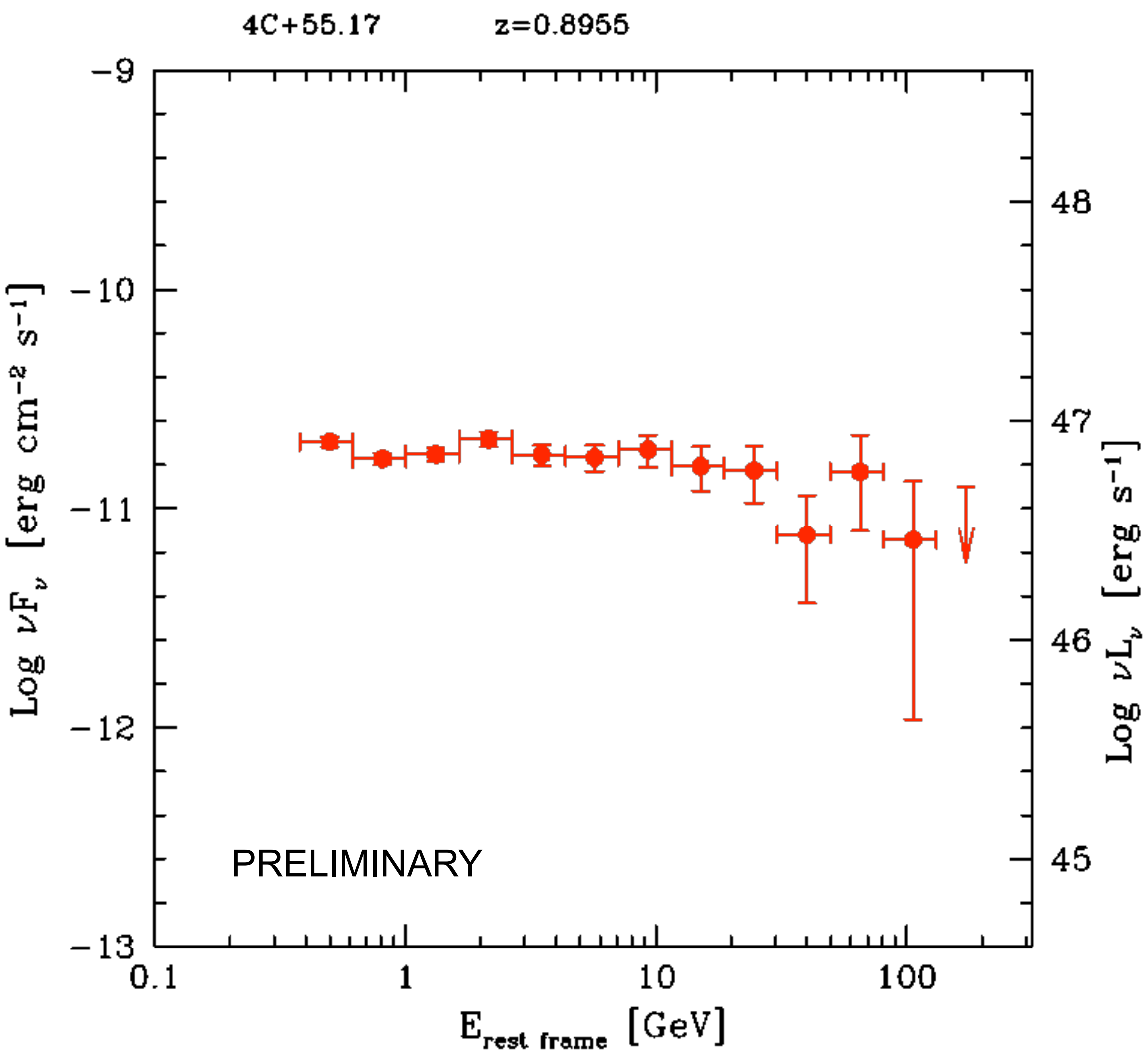
Extrapolation of low energy spectrum

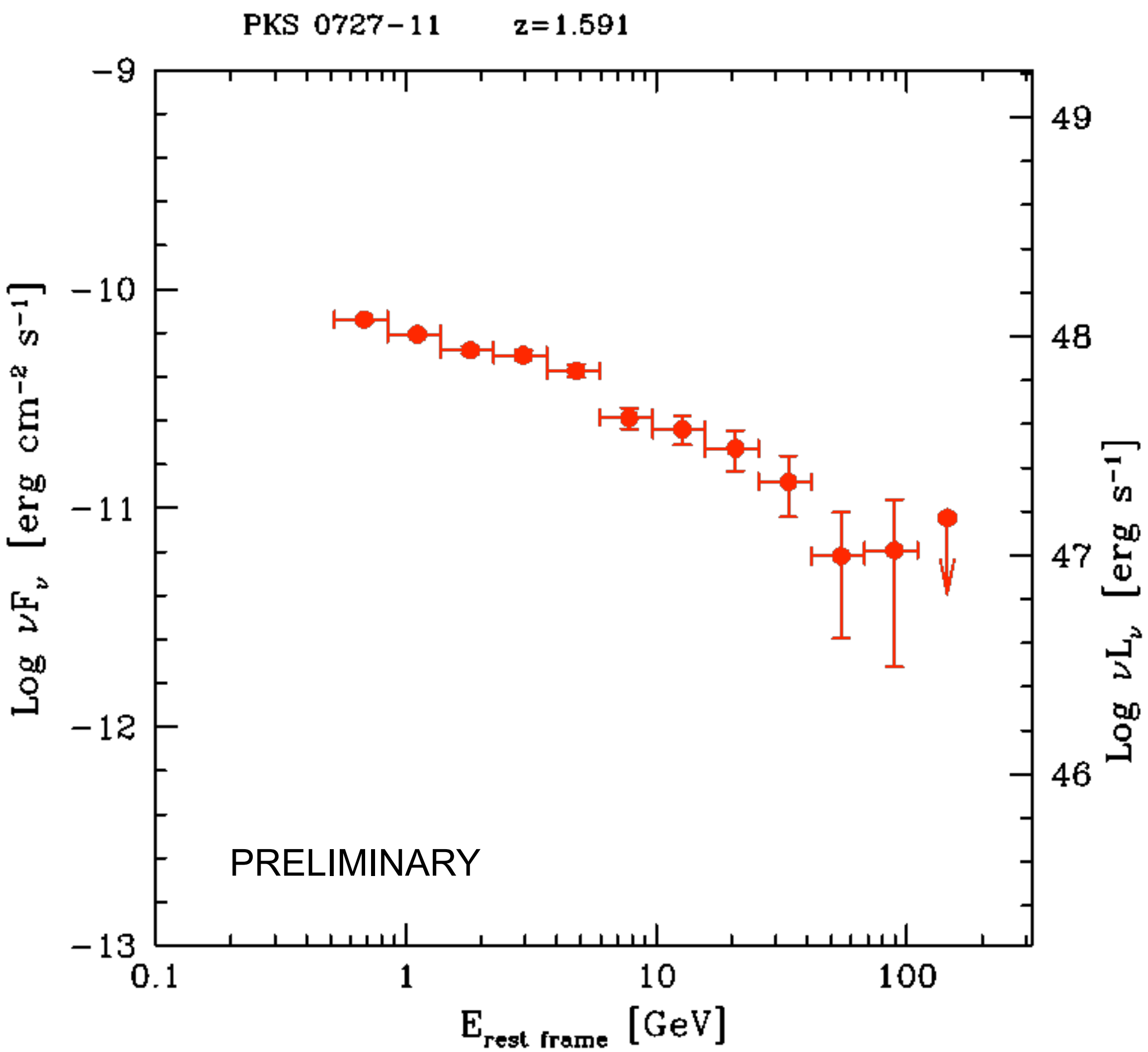
Minimal absorption agrees with shape of the spectrum determined in the low-energy band (e.g. log-parabola; similar for power-law)





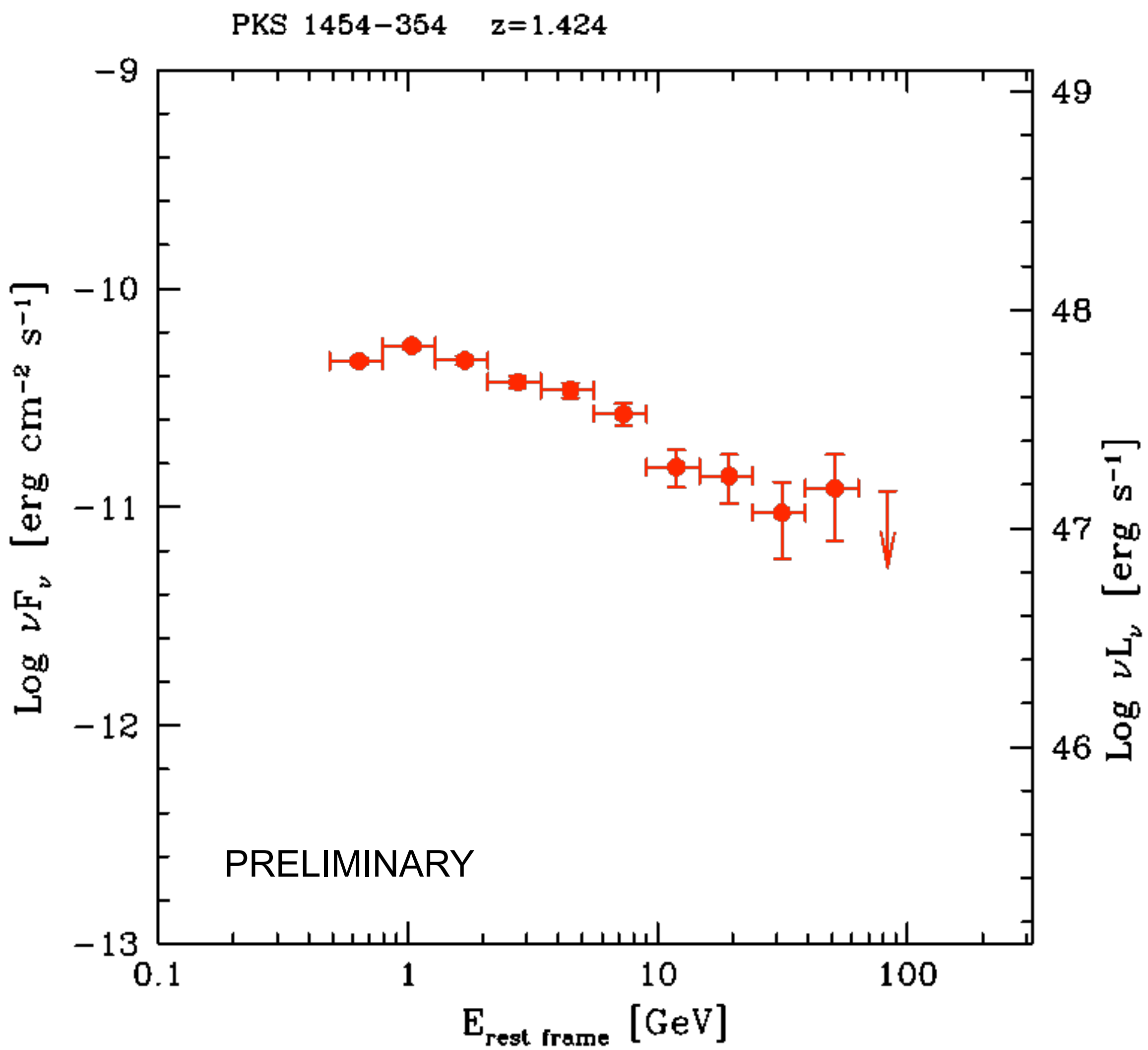
Also NO evidence of absorption at all !

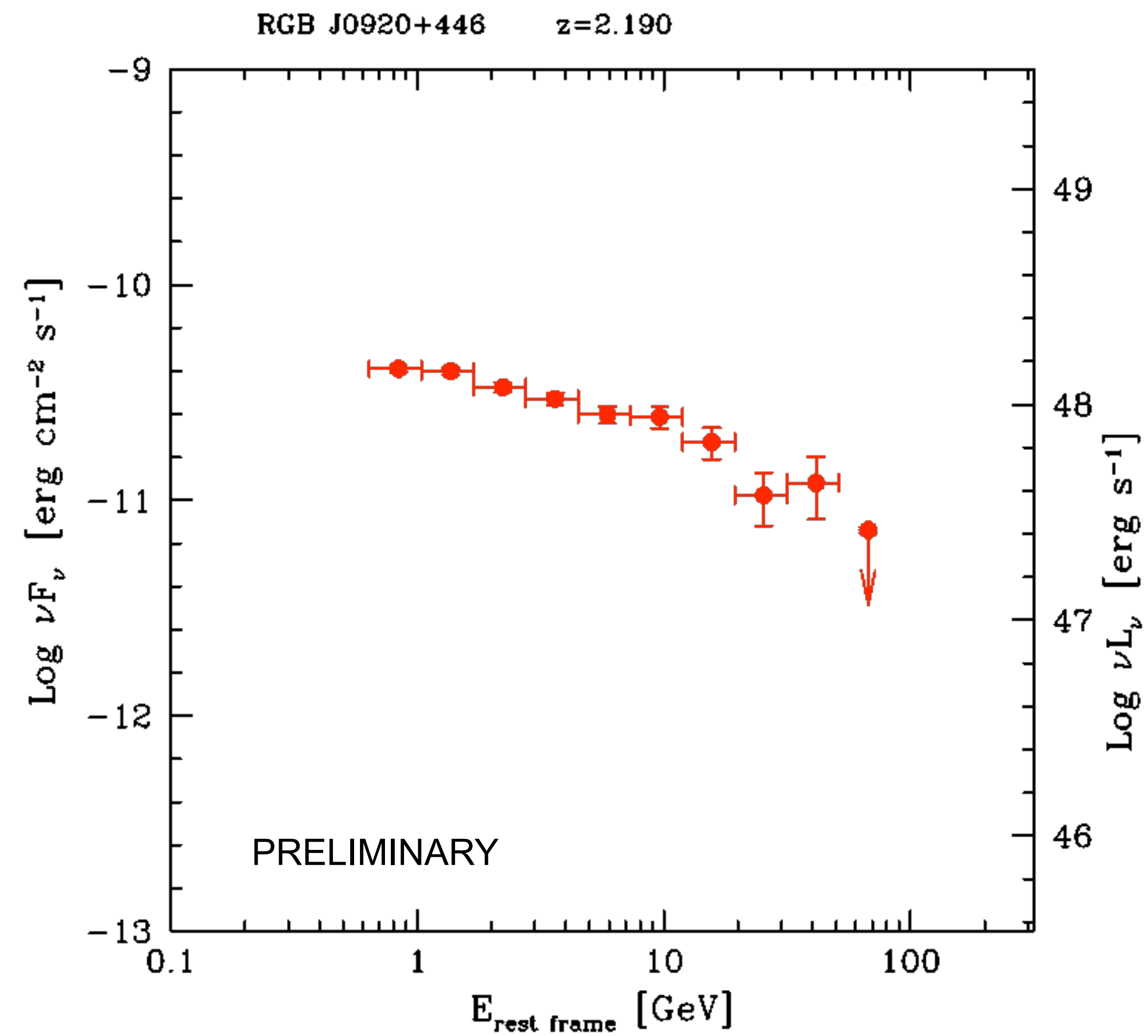




Also NO evidence of absorption at all !

Even in quite powerful objects, with large BLR !



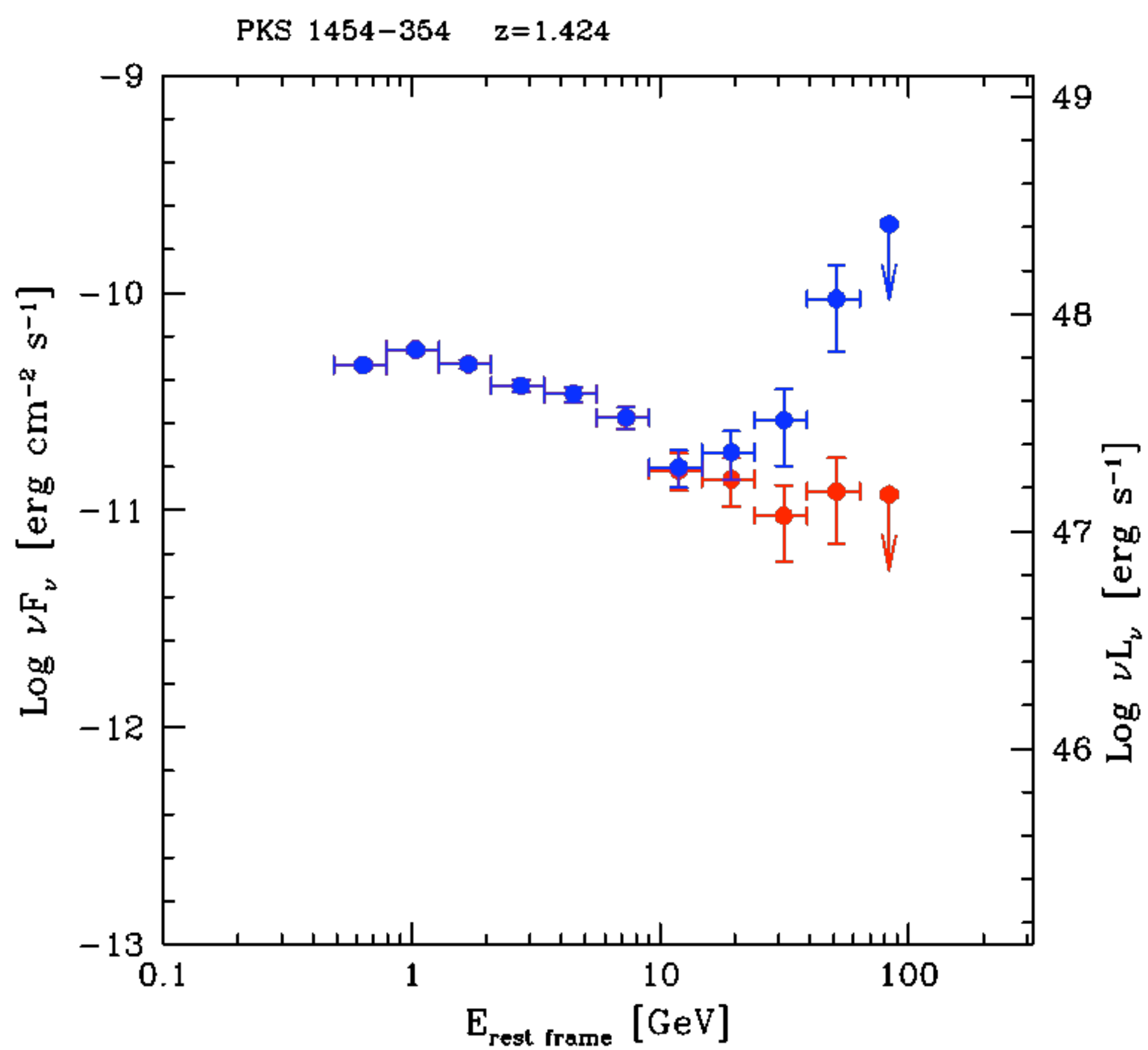


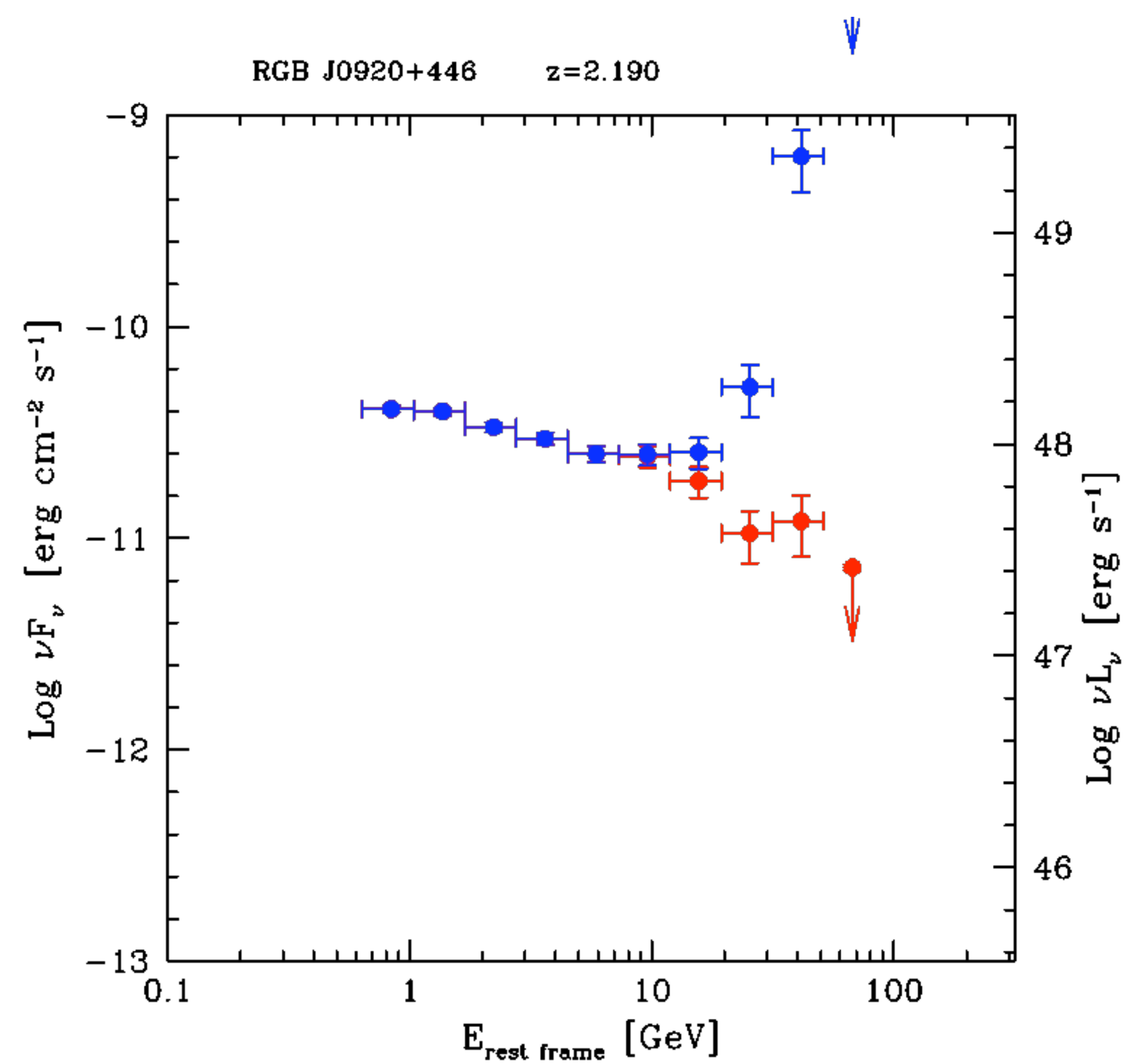
$L_{disk} \sim 5\times10^{46}$ $R_{blr} \sim 7\times10^{17}$
(e.g. $R_{diss} \sim 1.5\times10^{17}$ Ghisellini et al 2009)

$L_{disk} \sim 2\times10^{47}$ $R_{blr} \sim 1.3\times10^{18}$
(e.g. $R_{diss} \sim 5\times10^{17}$)

Also NO evidence of absorption at all !

Even in quite powerful objects, with very large BLR !





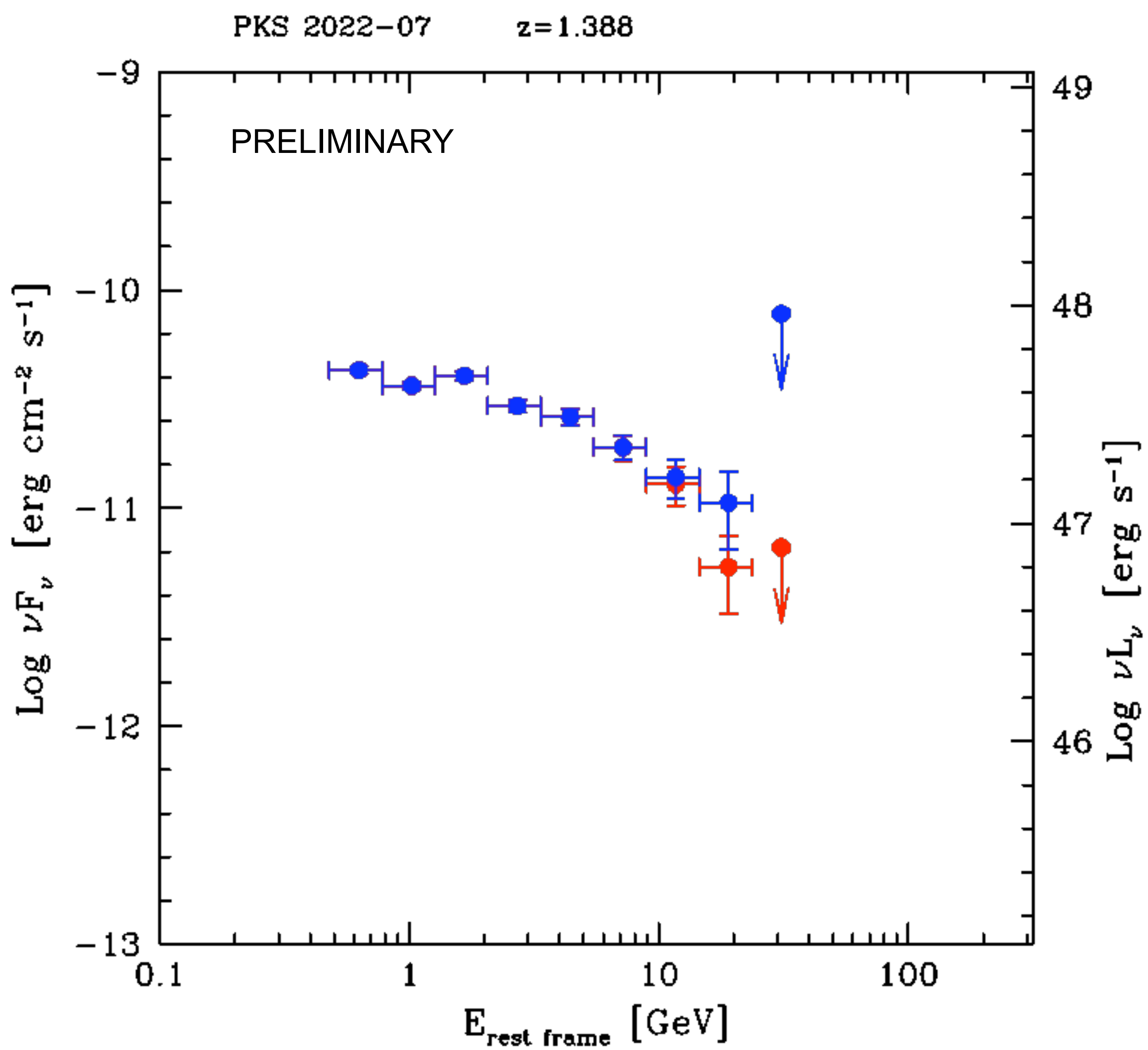
$L_{disk} \sim 5\times10^{46}$ $R_{blr} \sim 7\times10^{17}$
R_{diss} must be $\geq 7\times10^{17}$

$L_{disk} \sim 2\times10^{47}$ $R_{blr} \sim 1.3\times10^{18}$
R_{diss} must be $> 10^{18}$ cm
(or path inside $<< 10^{17}$ cm)

Sources with possible high absorption

Selection effect: FSRQ with very strong cutoff at 20-30 GeV rest frame, are likely not yet detected >10 GeV

Longer LAT exposures will tell which ones present a strong cutoff (by decreasing the high-energy upper limits on the bright sources)



Tau ~8

CAVEATS !

- **Variability**
  - different zones in time, inside or outside BLR
  - absorption features can come and go (should be present during fast flares, ≲1-2 days; if compact means closer to BH)
  - answers from temporal clustering of high energy photons
    NB: expected anti-correlation F>10 GeV vs F<10GeV !!
- **Geometry of BLR region**
  - if flattened onto accretion disk (e.g. Gaskell 2009) ⇒ anisotropic angle
  - $E_{threshold}$ of γ-γ can be shifted at higher energies
    (e.g 25 deg ⇒ 10x shift of γ-γ threshold)
  - This affects EC mechanism as well (lower energy density, redshifted ν_{ext}). EC(UV) might not be so efficient (though it is a way to avoid KN effects)
- **Statistics**
  - still very few photons at highest energies (typically 2-10); results to be confirmed in next months/year with 2x exposures

Conclusions

- Important diagnostics/checks from the band >10 GeV

- Fermi is providing indications that the Blazar-zone for several FSRQ, on average, must lie beyond the BLR ! (~10^{18} cm)
  $\Rightarrow$ variability implications (longer timescales, mm-transparent ??)

- The Fermi blazar-zone divide: dissipation appears to occur both inside and outside the BLR.
  - Fermi can discriminate on a source-by-source and epoch-by-epoch basis !

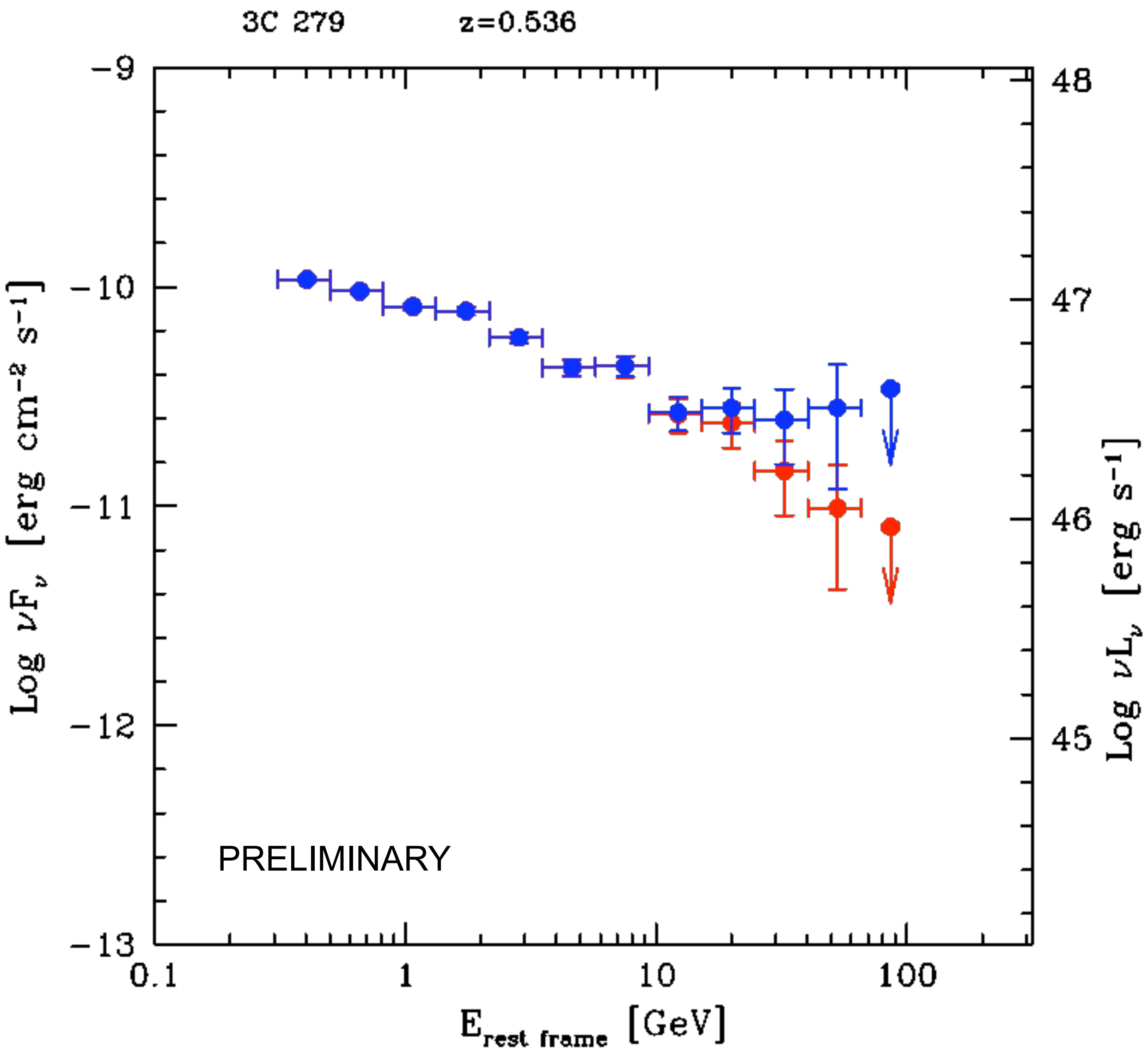
- The absence or presence of absorption/cut-off features constrain the target field to be used for External Compton:
  not a free choice anymore

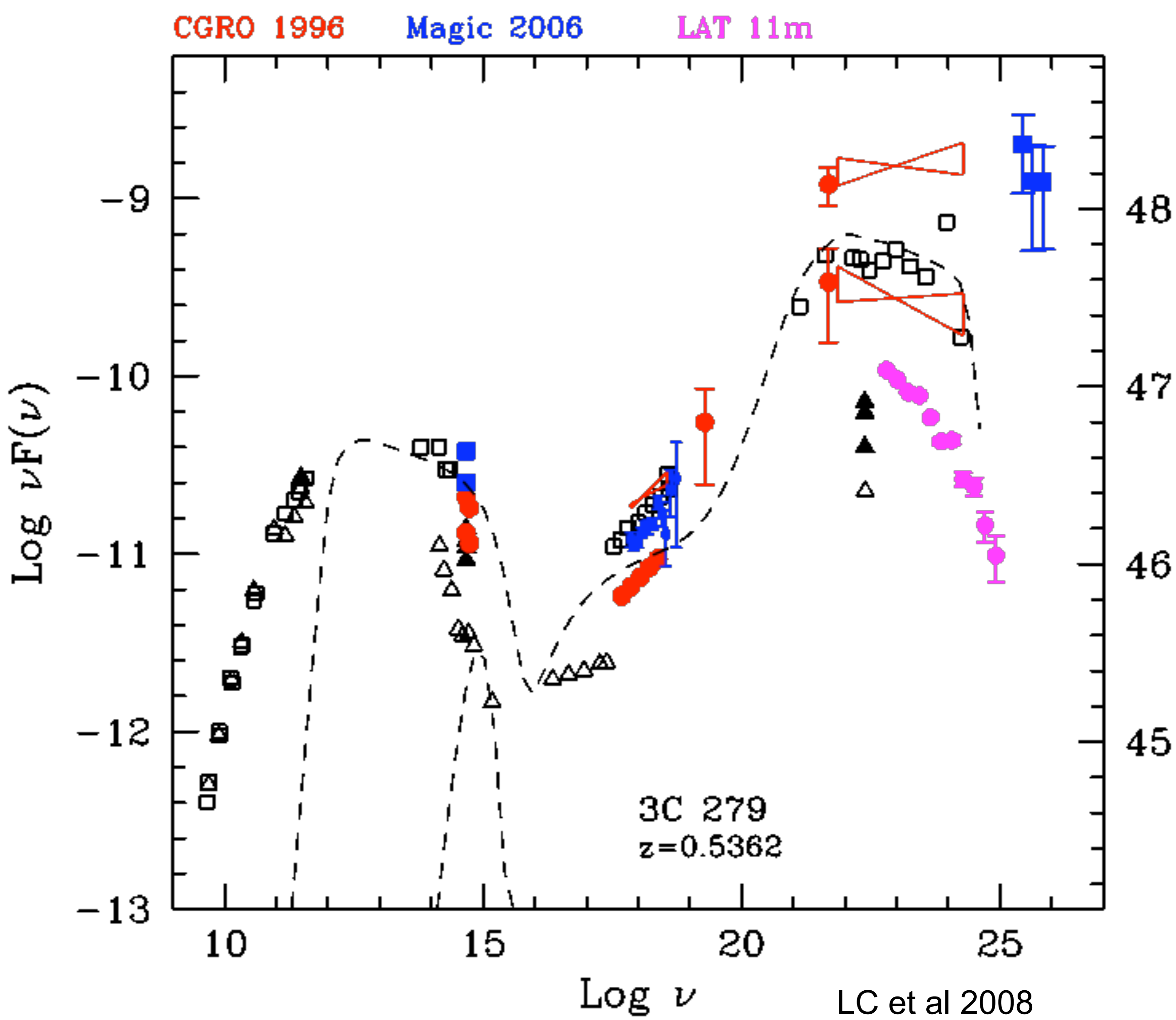
- Objects with strong cut-offs (well inside the BLR) should be uncovered more clearly as exposure increases

back-up slides

The case of 3C 279

$L_{disk} \sim 3x10^{45}$ $R_{blr} \sim 1x10^{17}$

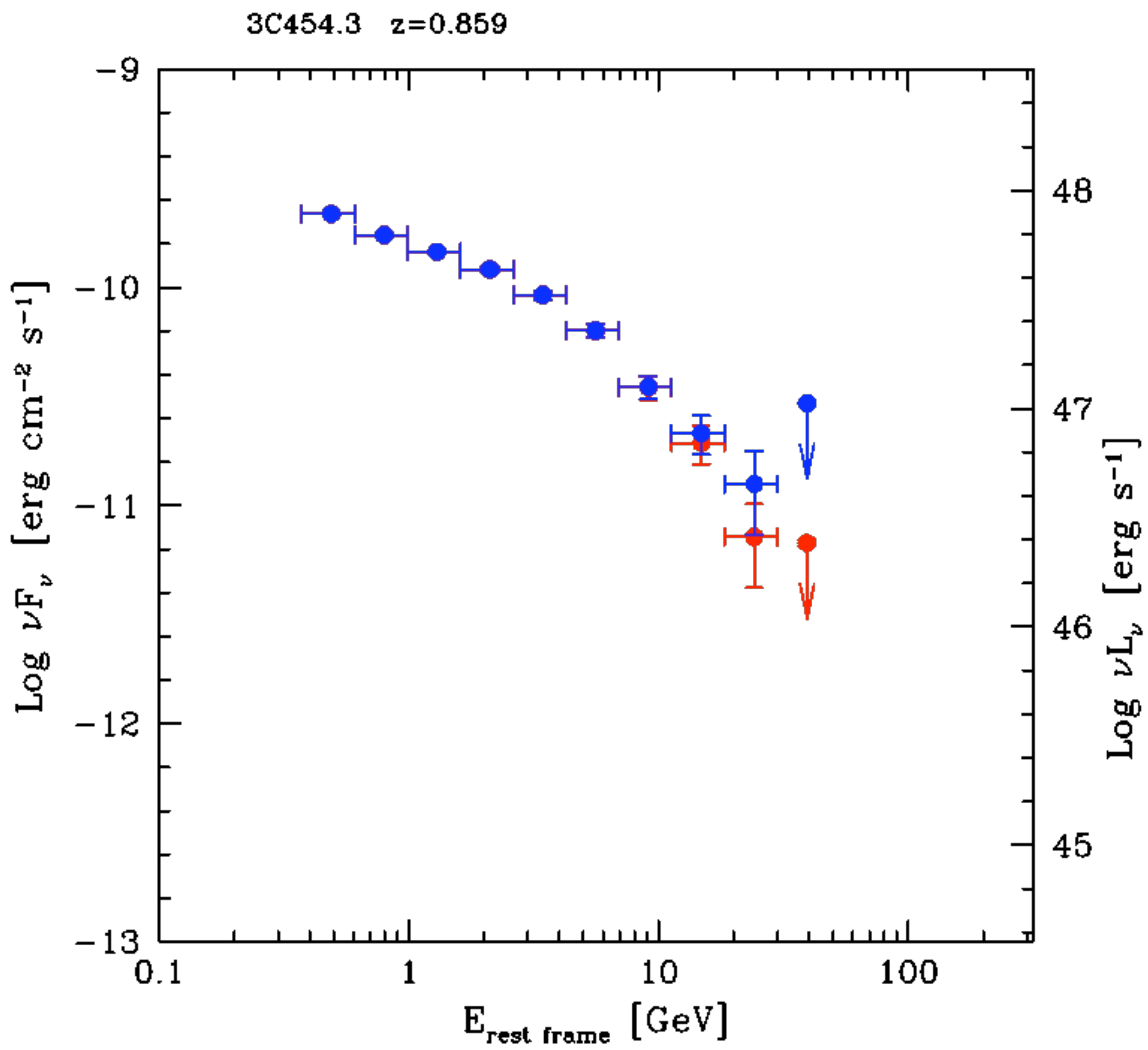




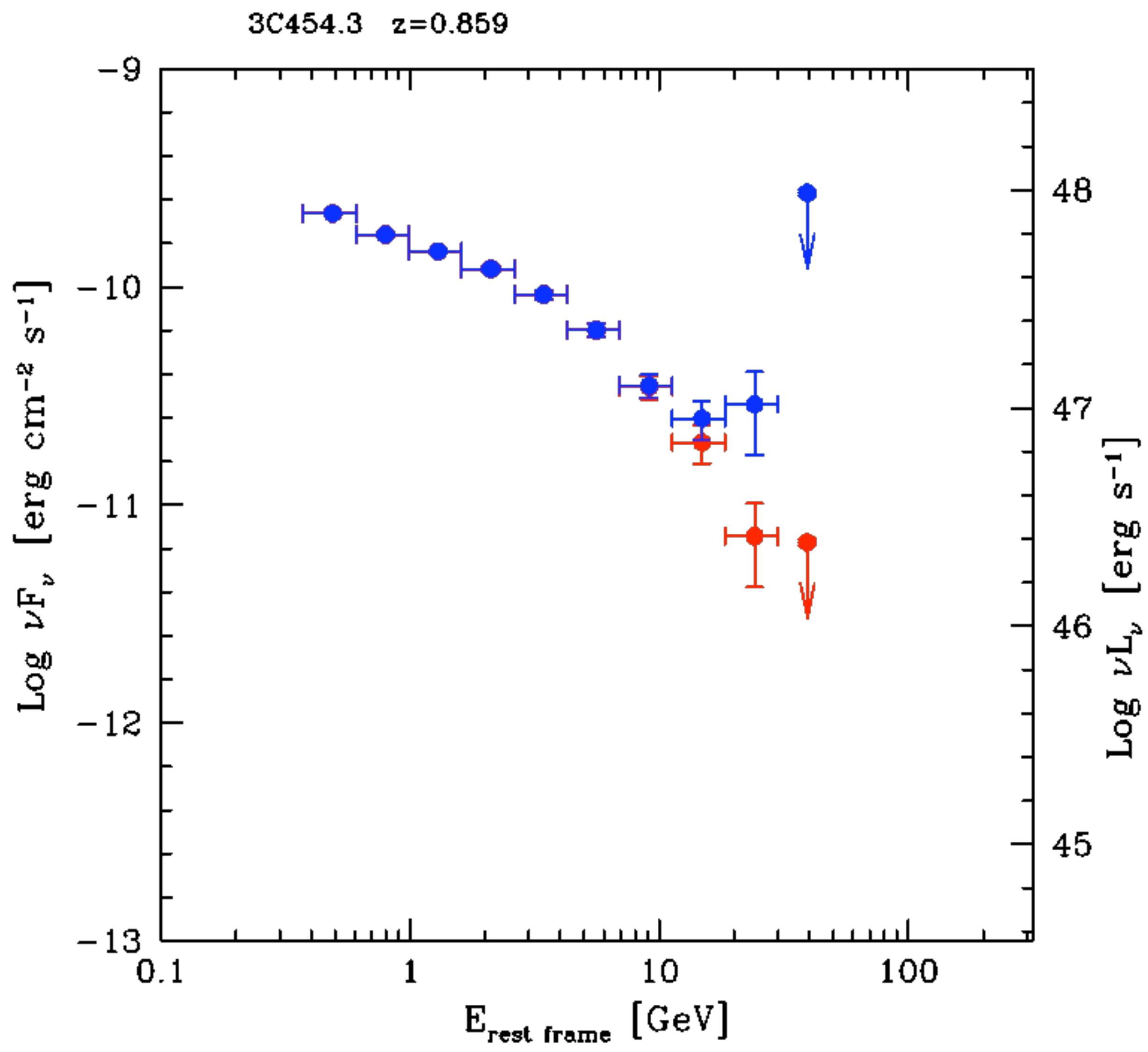
R_{diss} seems > R_{blr}

Average Spectrum ⇒ low Lc/Ls

3C 454.3



tau=3



tau=8