



Fermi
Gamma-ray Space Telescope

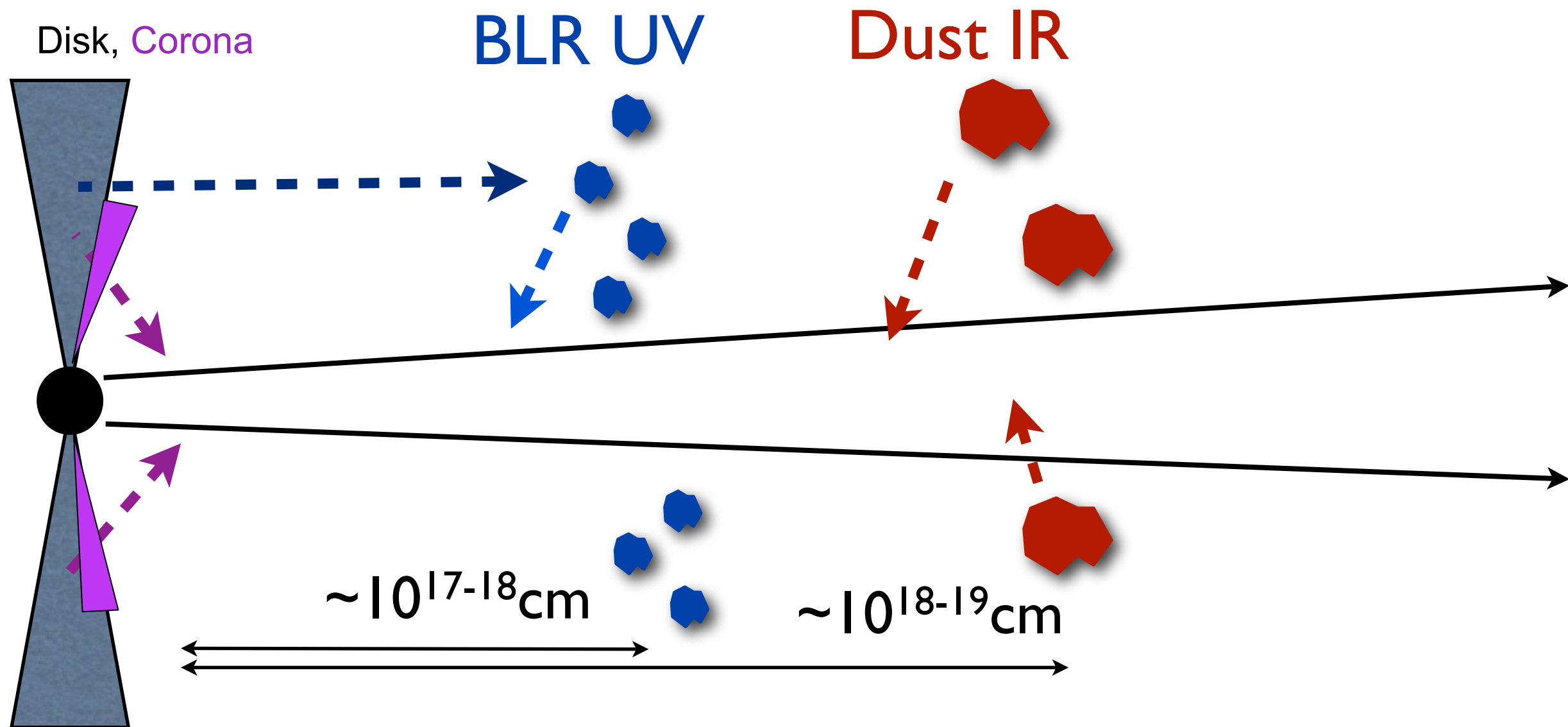
The Fermi blazar-zone divide

Luigi Costamante

HEPL/KIPAC Stanford University

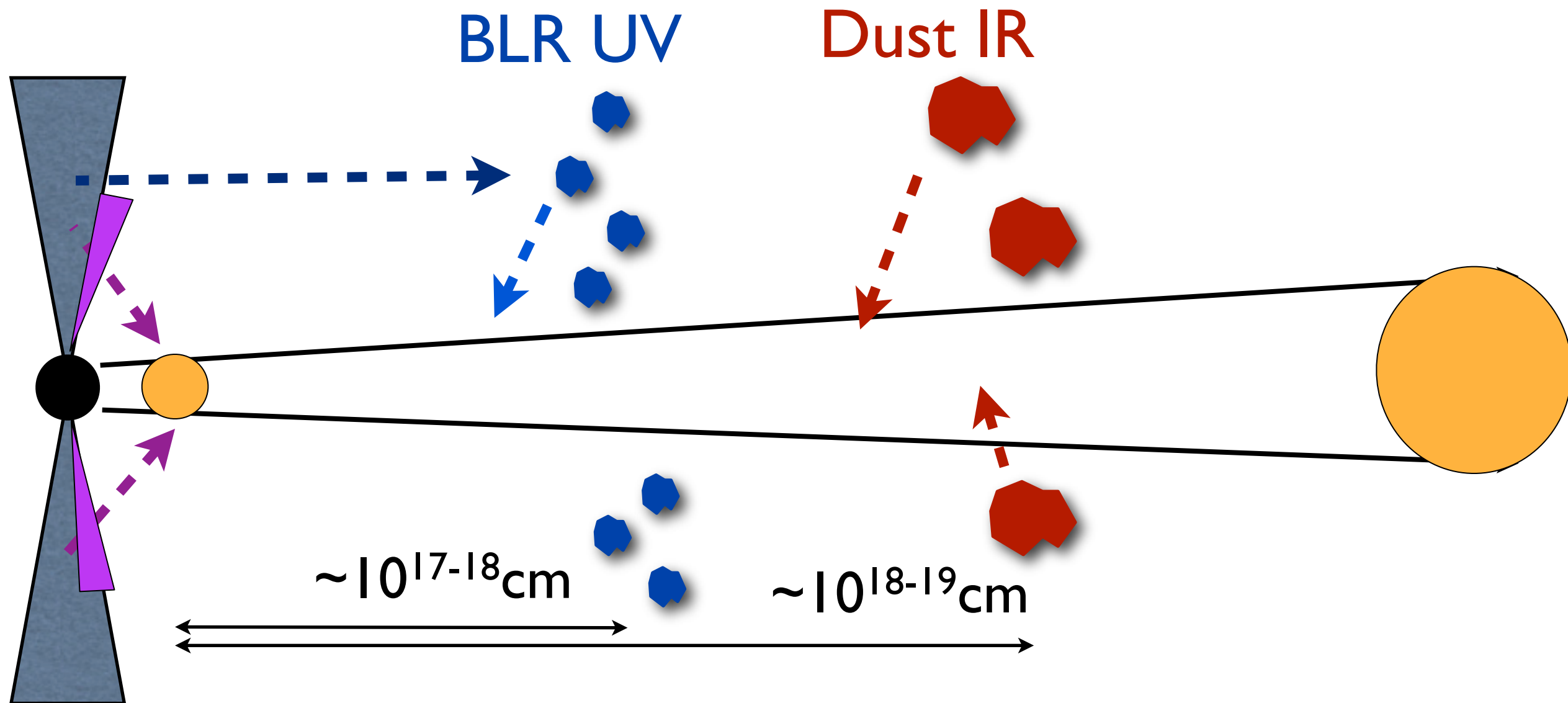
**Andrea Tramacere, Gino Tosti,
on behalf of the Fermi-LAT Collaboration**

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 !!

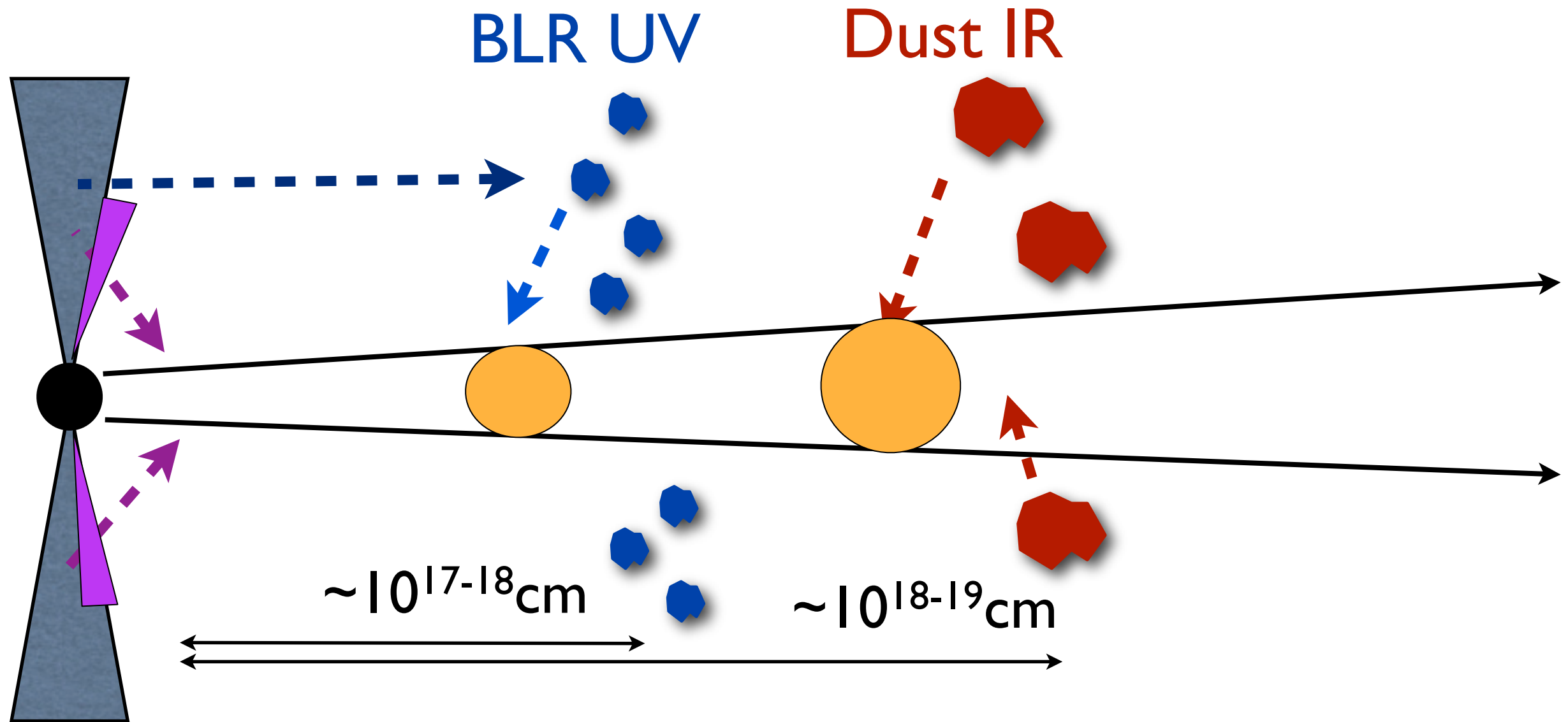
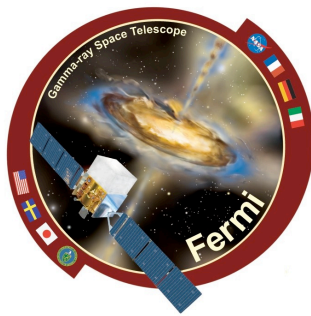
Where the gamma-rays come from ?



Not too close BH (few R_s): $\gamma - \gamma$ absorption and reprocessing $\Rightarrow \alpha_x \sim 0.9-1$

Not too far away ($\sim 100 \text{ pc}$): problems with fast variability ($\leq 1-2$ days)

Seed photons for Inverse Compton (IC)

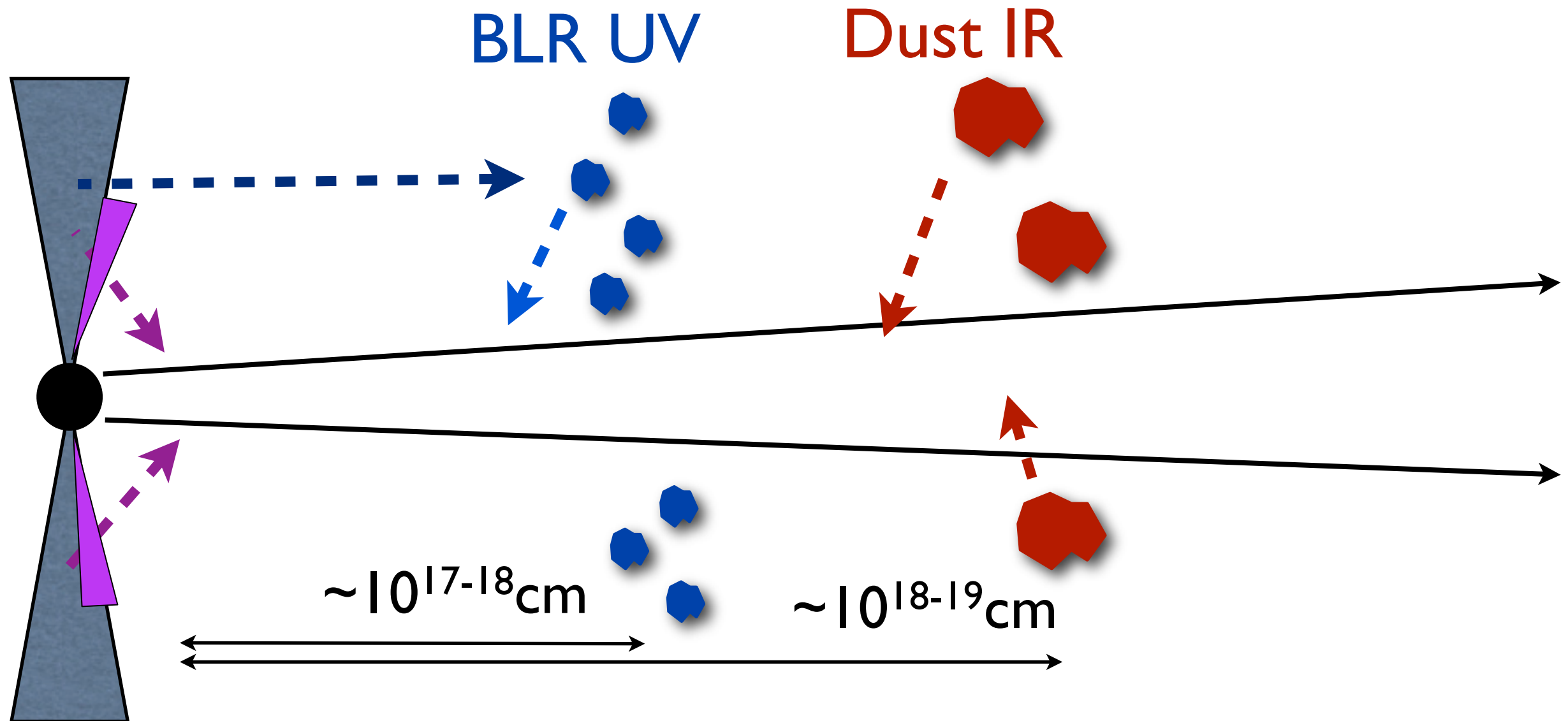
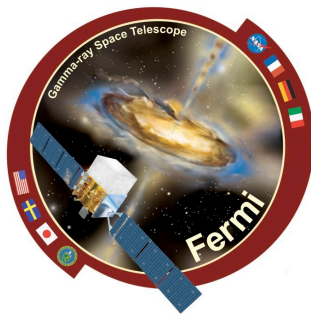


$$R \propto L_{\text{disk}}^{1/2} \quad (\text{Bentz et al. 2006 ; Kaspi et al. 2007})$$

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

External Compton (EC) onto: **UV** ($\sim 9-10$ eV) or **IR** (0.1 eV) (e.g. Ghisellini et al. 2009 ; Sikora et al. 2009)

Seed photons for Inverse Compton (IC)



$$R \propto L_{\text{disk}}^{1/2} \quad (\text{Bentz et al. 2006 ; Kaspi et al. 2007})$$

$$U_{\text{rad}} \sim 10^{-2} \text{erg/cm}^3$$

Basic 0th-order assumptions/approximations:

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

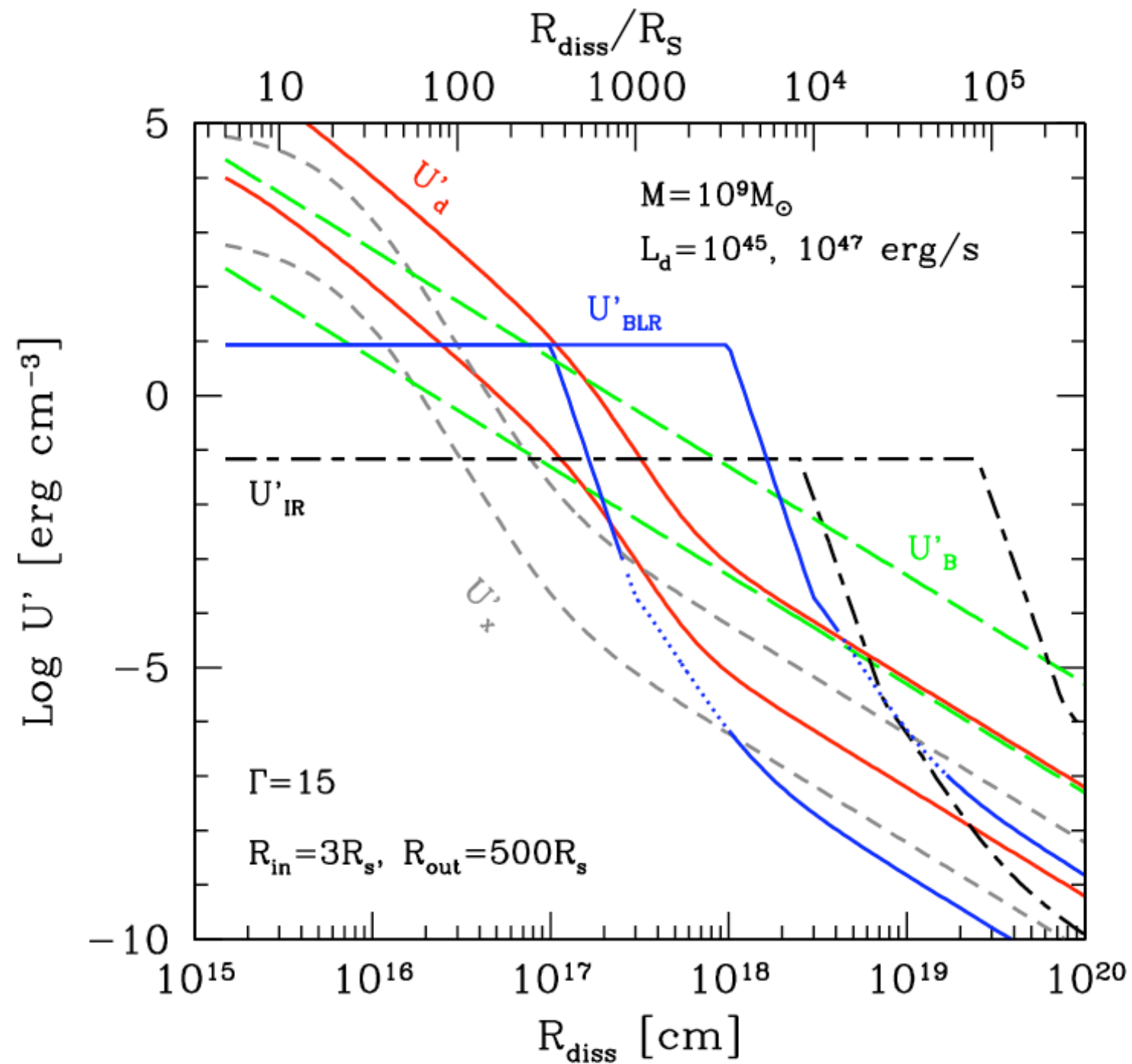
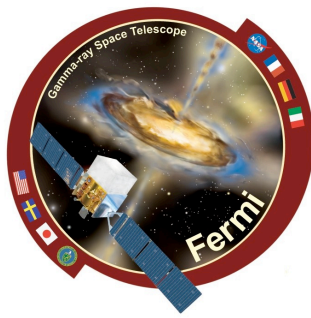
b) isotropic field

c) BlackBody spectrum @9eV

d) reprocessing factor $\eta \sim 10\%$

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

Energy densities in co-moving frame



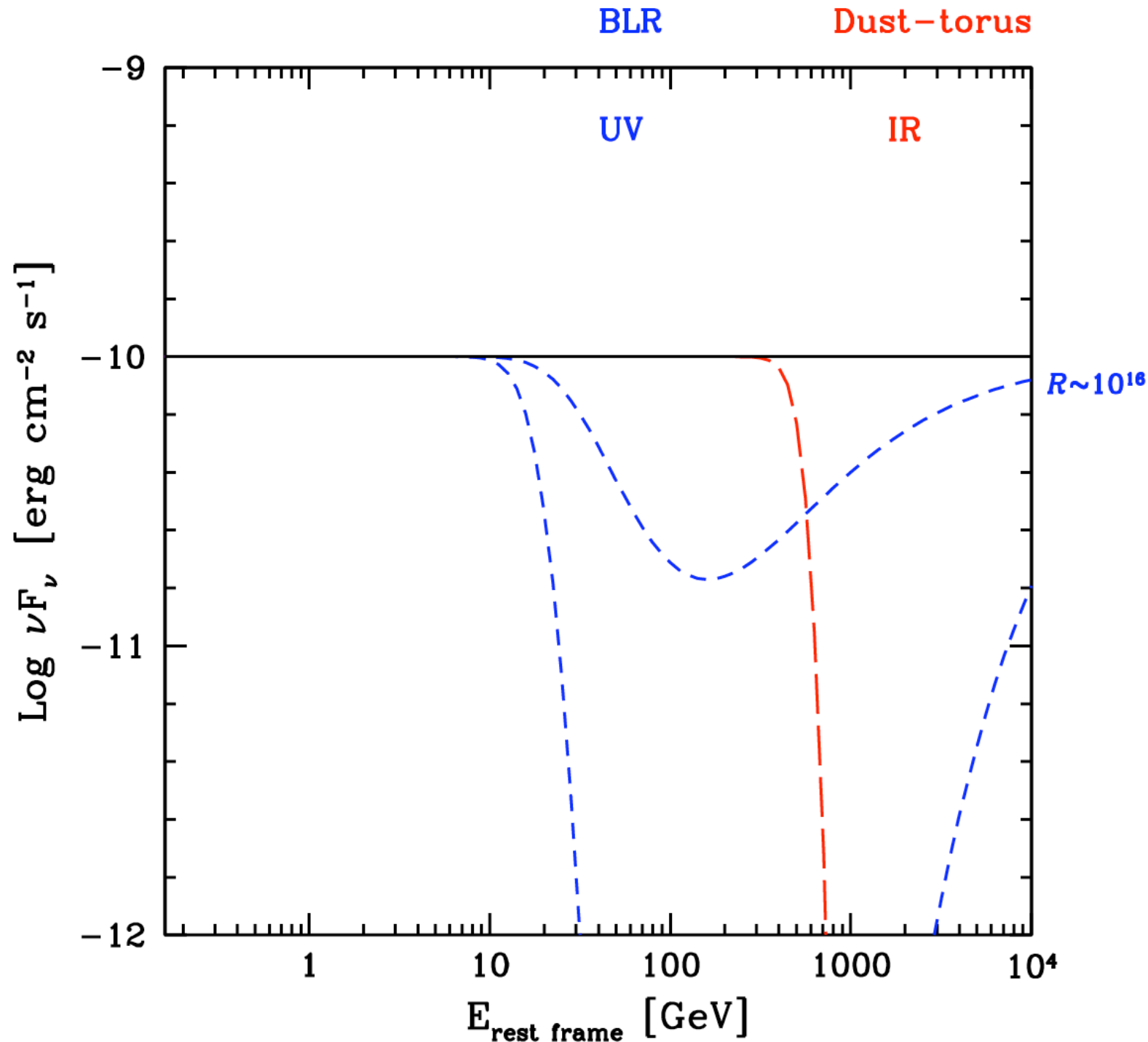
Ghisellini et al. 09
(also in Sikora et al. 09)

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.
The gamma-rays have to pass through a double “wall” of photons



Optical depth τ is high !

Always not negligible (≥ 1),
 even in the minimal case:
 photon path \sim size of
 emitting region
 (typically $\sim 10^{16}$ 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 $L_c/L_s \sim 1$ or $L_c/L_s \gg 1$ & BLR spectrum is broad banded \Rightarrow cooling of e^\pm in Thomson \Rightarrow steepening

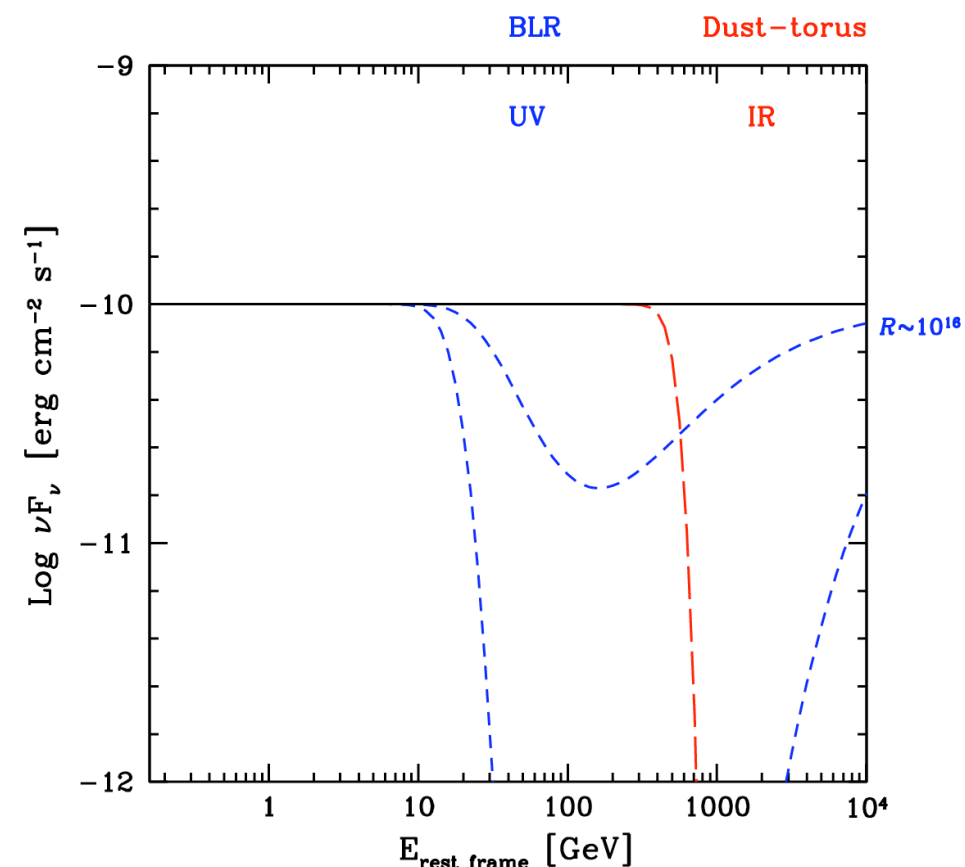
☛ if $L_c/L_s \gg 1$ & BLR is narrow banded \Rightarrow no steepening !
compensated by hardening of the particle distribution when cooling is in KN regime
(e.g. Zidjarski 1989, Dermer et al. 2003, Moderski et al. 2005, Ghisellini et al. 2009)

Presence or absence of cut-offs, tells:

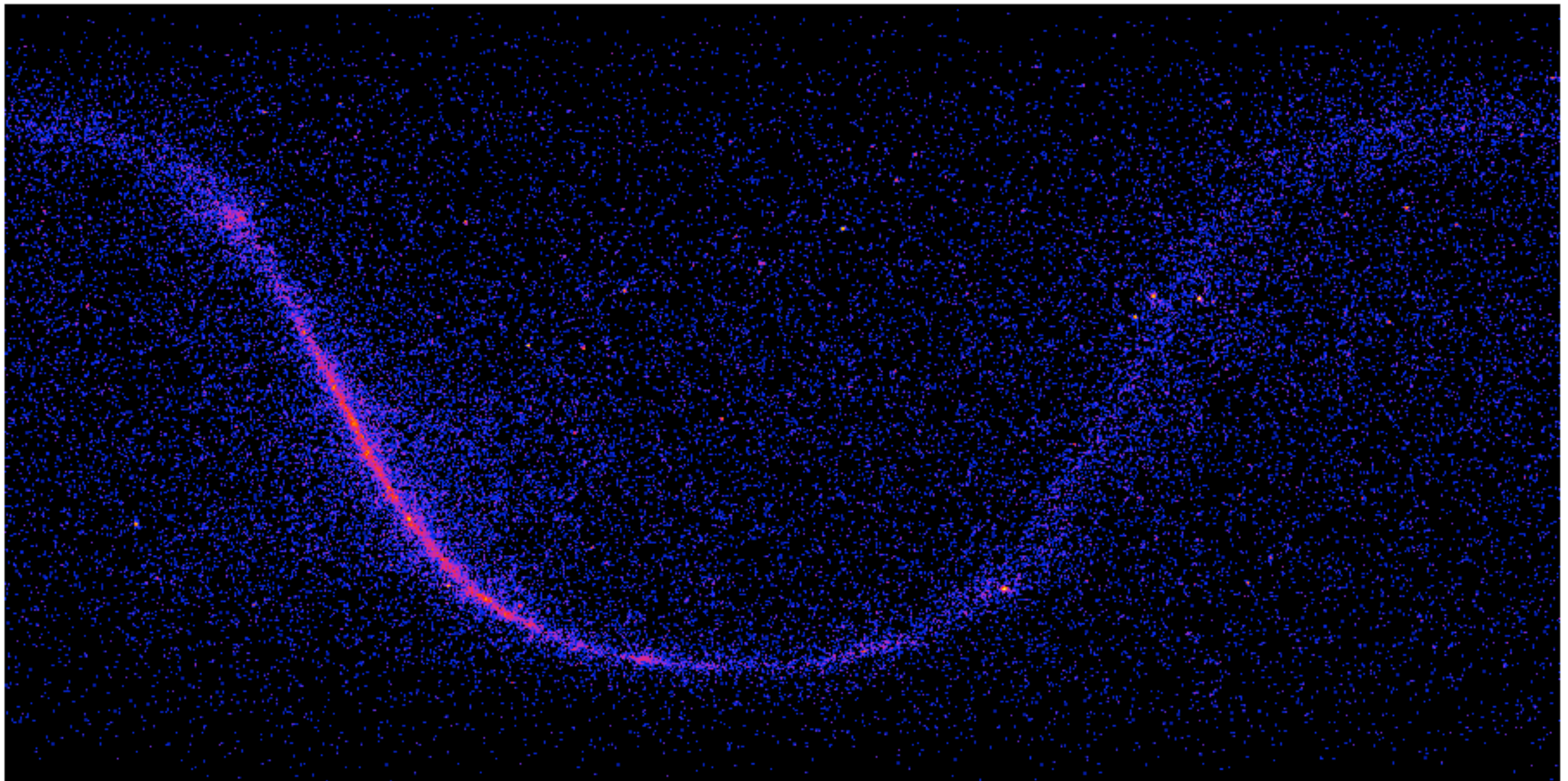
$\Rightarrow R_{\text{diss}} < \text{or} > R_{\text{BLR}}$

\Rightarrow intensity of cutoff gives an estimate of the photon path inside the BLR

\Rightarrow which EC is viable: UV or IR photons



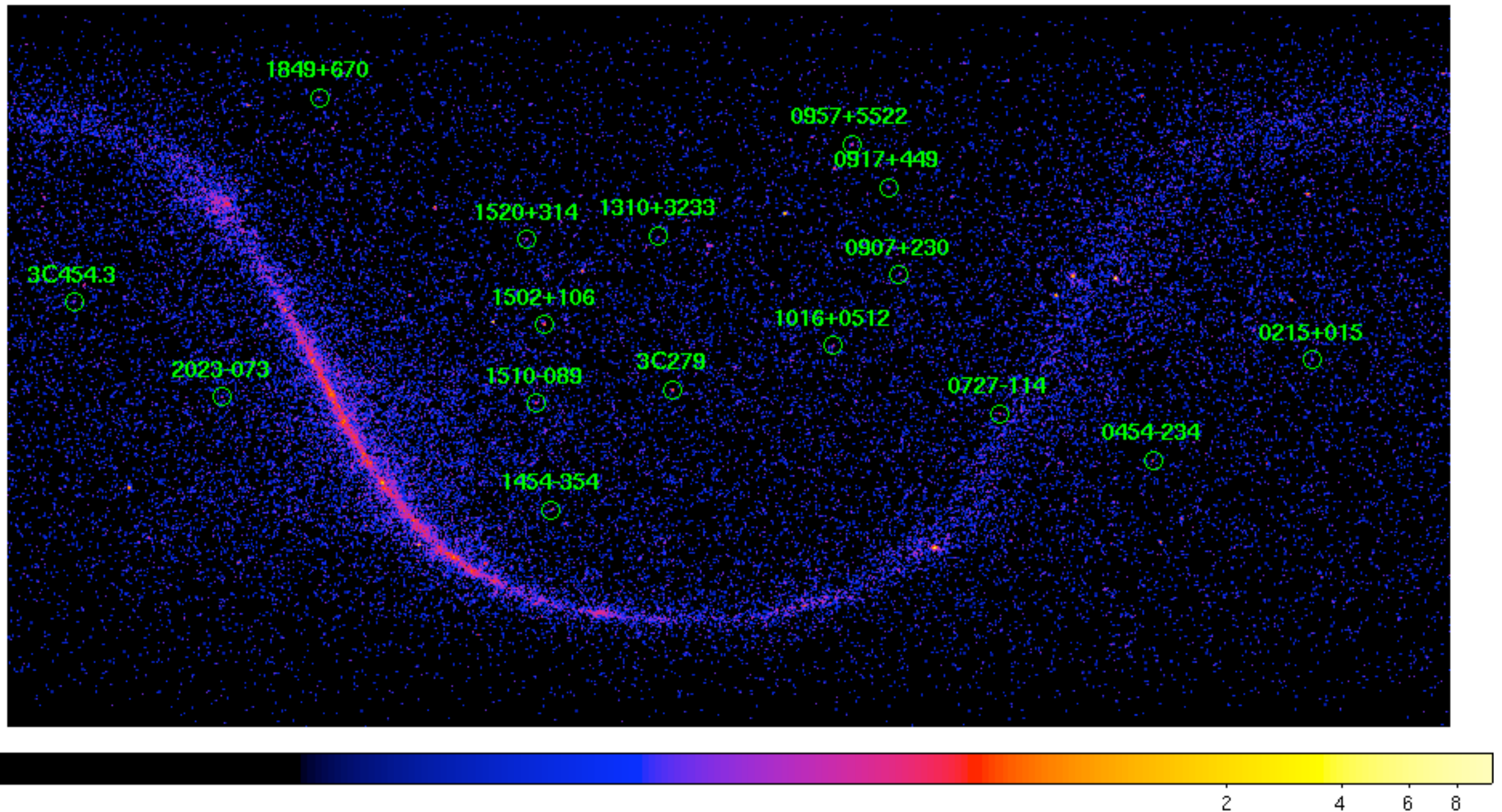
Target selection: FSRQ detected >10 GeV



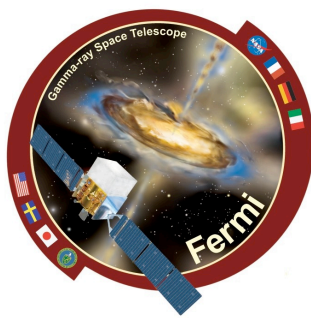
LAT sky above 10 GeV, 9 months exposure

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.



- **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:

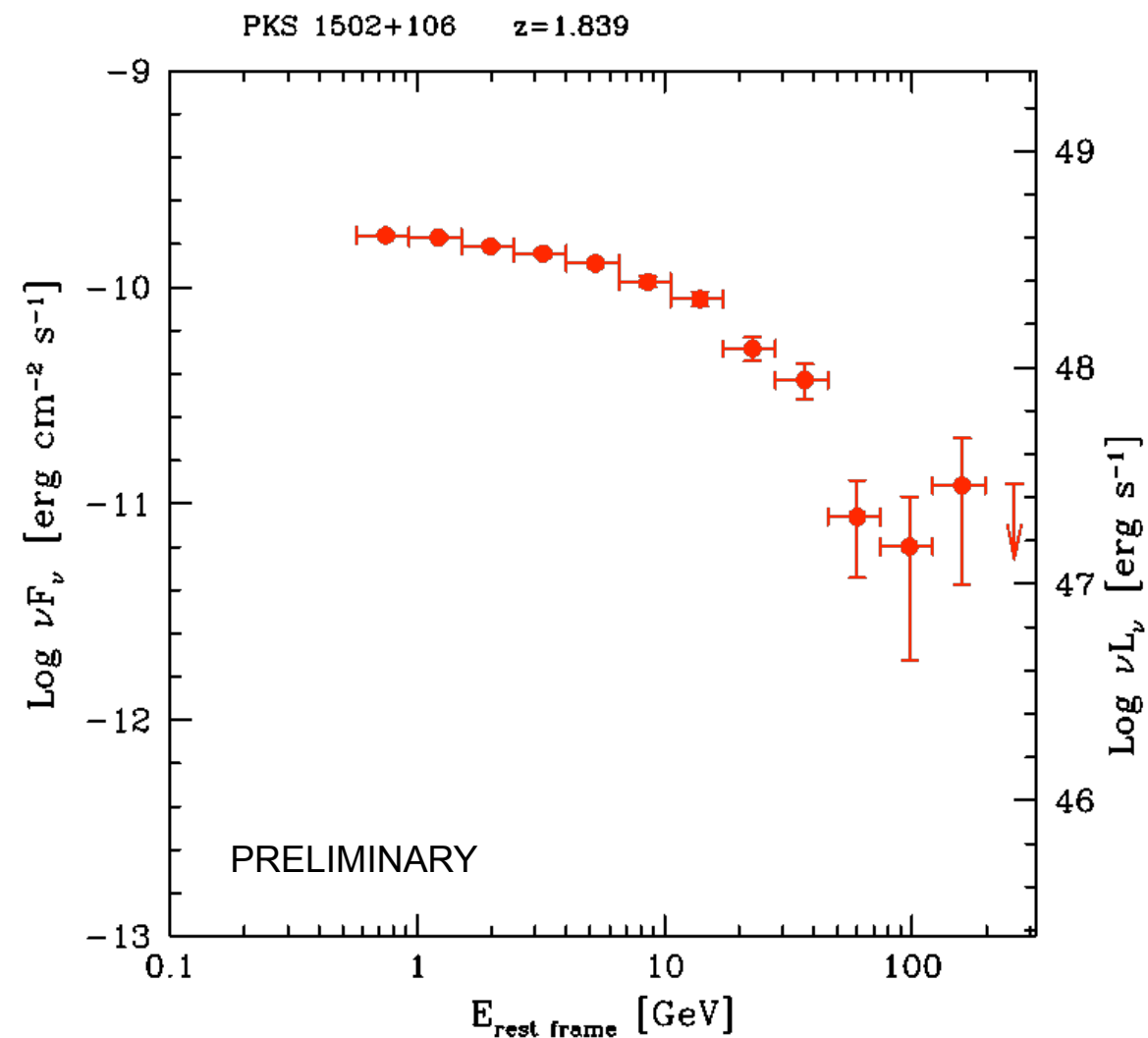
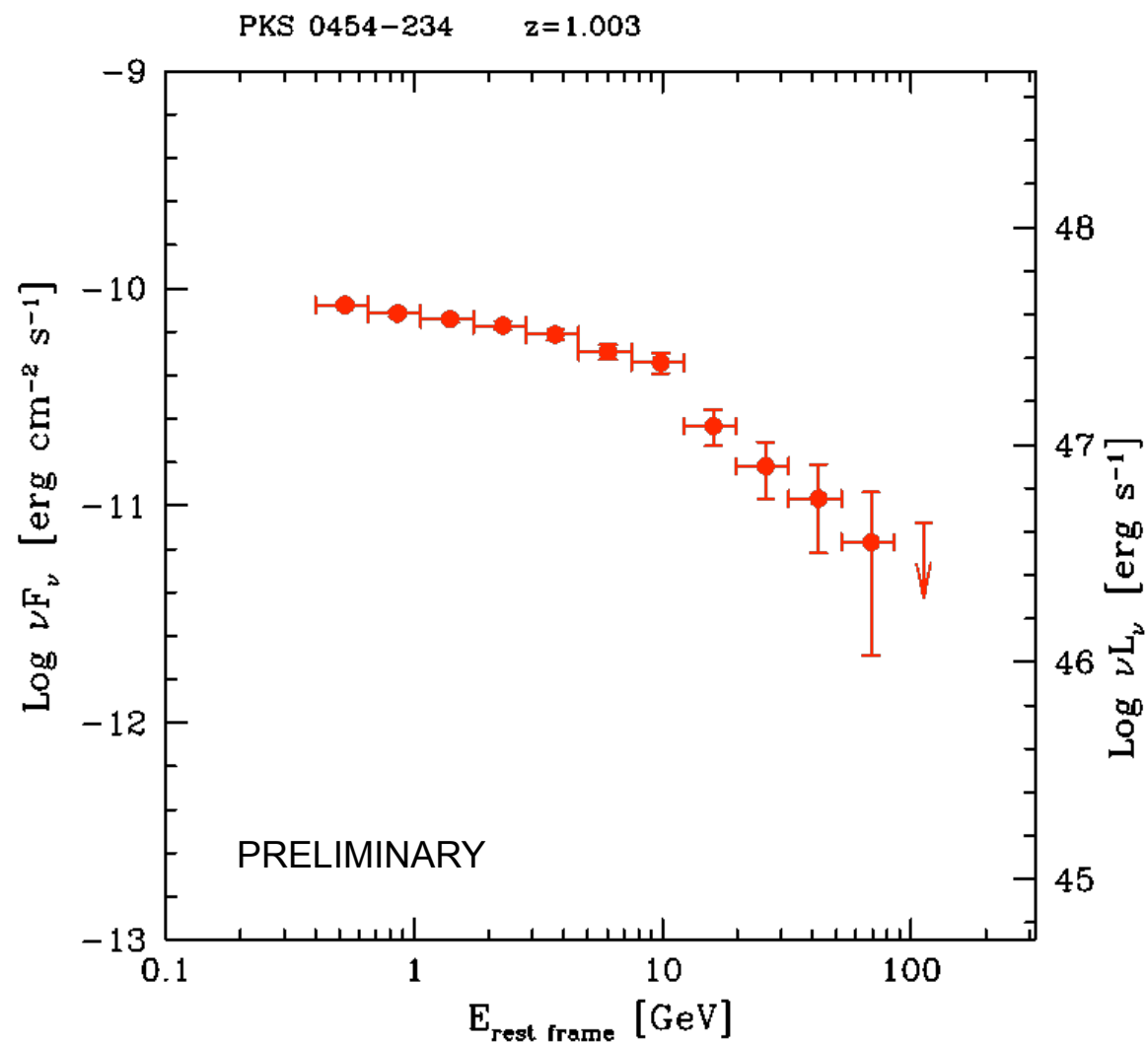
- **All plots have Energy axis in REST FRAME energies**
- **EBL absorption not (yet) relevant at these energies and redshifts**
(for most realistic, recent calculations, e.g. Primack, Franceschini)

Analysis and Spectra by Andrea T.

No evidence of strong BLR cut-offs !



τ can be very high ($\sim 10 \ell_{17}$), if inside the BLR, and yet:
the sources that do show possible absorption, only moderate ($\tau \sim 1.5-3$)



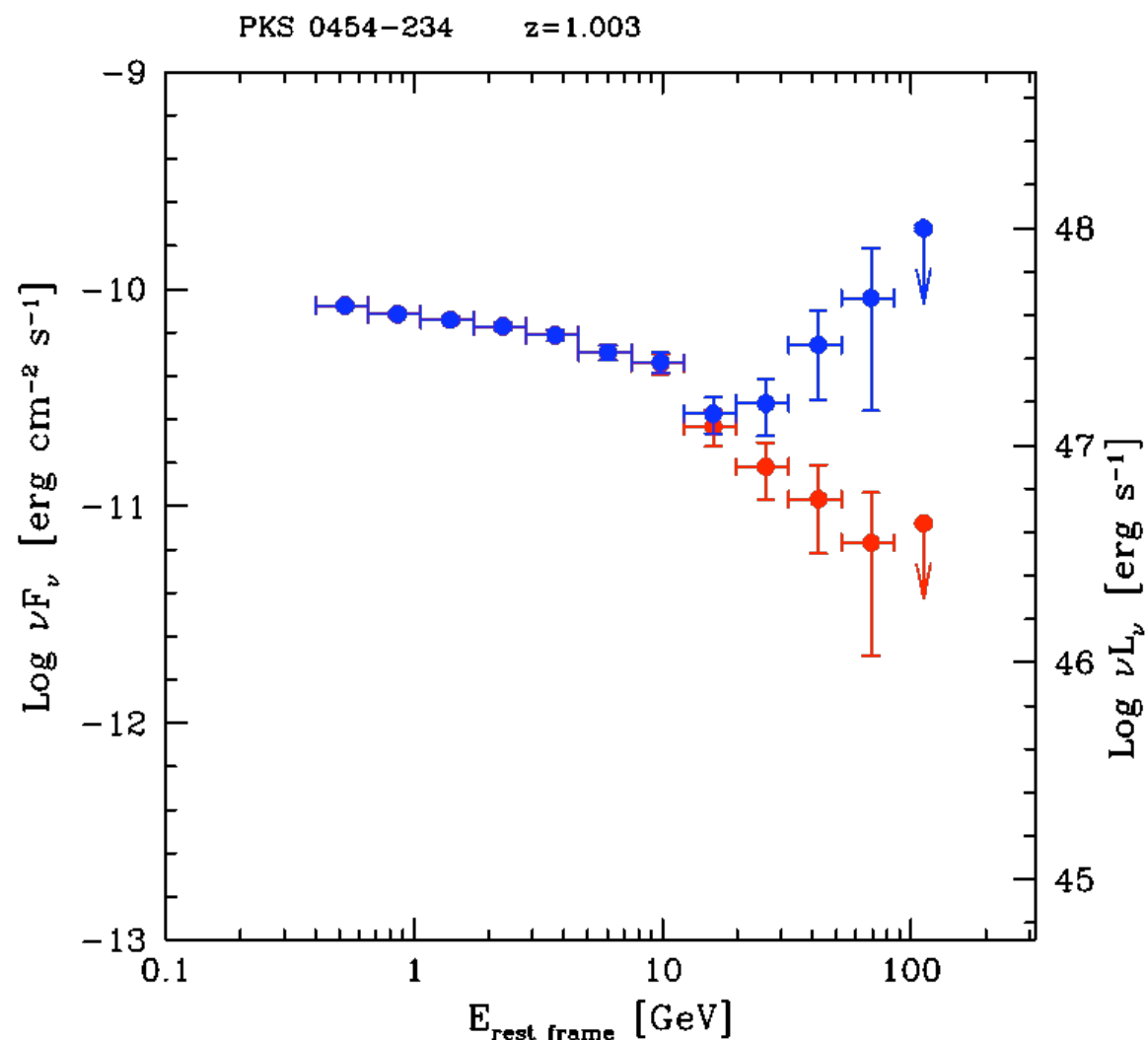
1502: see Benoit's talk here and
S. Ciprini at Fermi symposium

No evidence of strong BLR cut-offs !

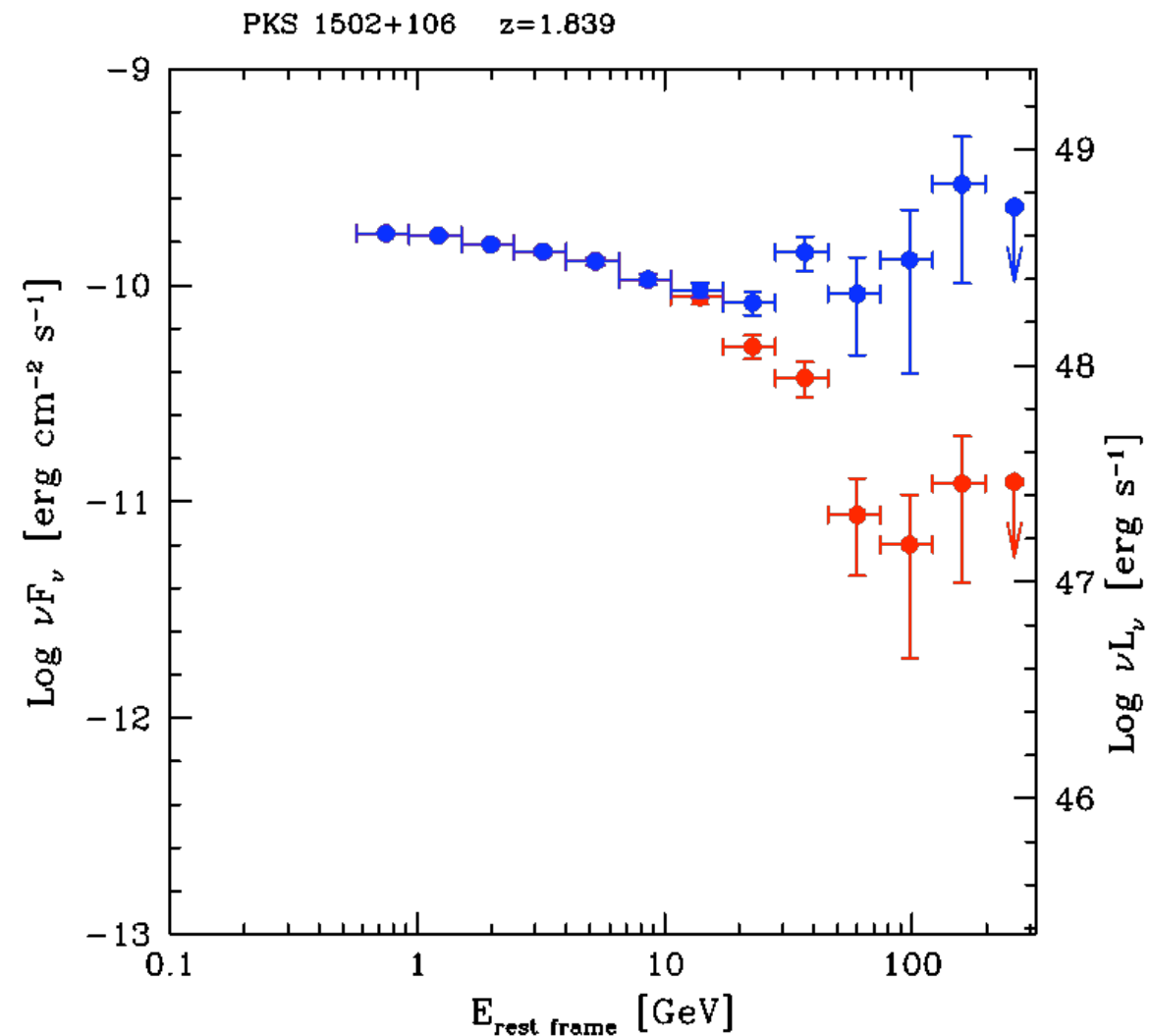


With $\tau = 3$ (path a few 10^{16} cm), absorption would already be too strong:

LAT spectra: **original, observed** ; **BLR de-absorbed**



$$R_{\text{blr}} \sim 4 \times 10^{17} \quad L_{\text{disk}} \sim 2 \times 10^{46}$$

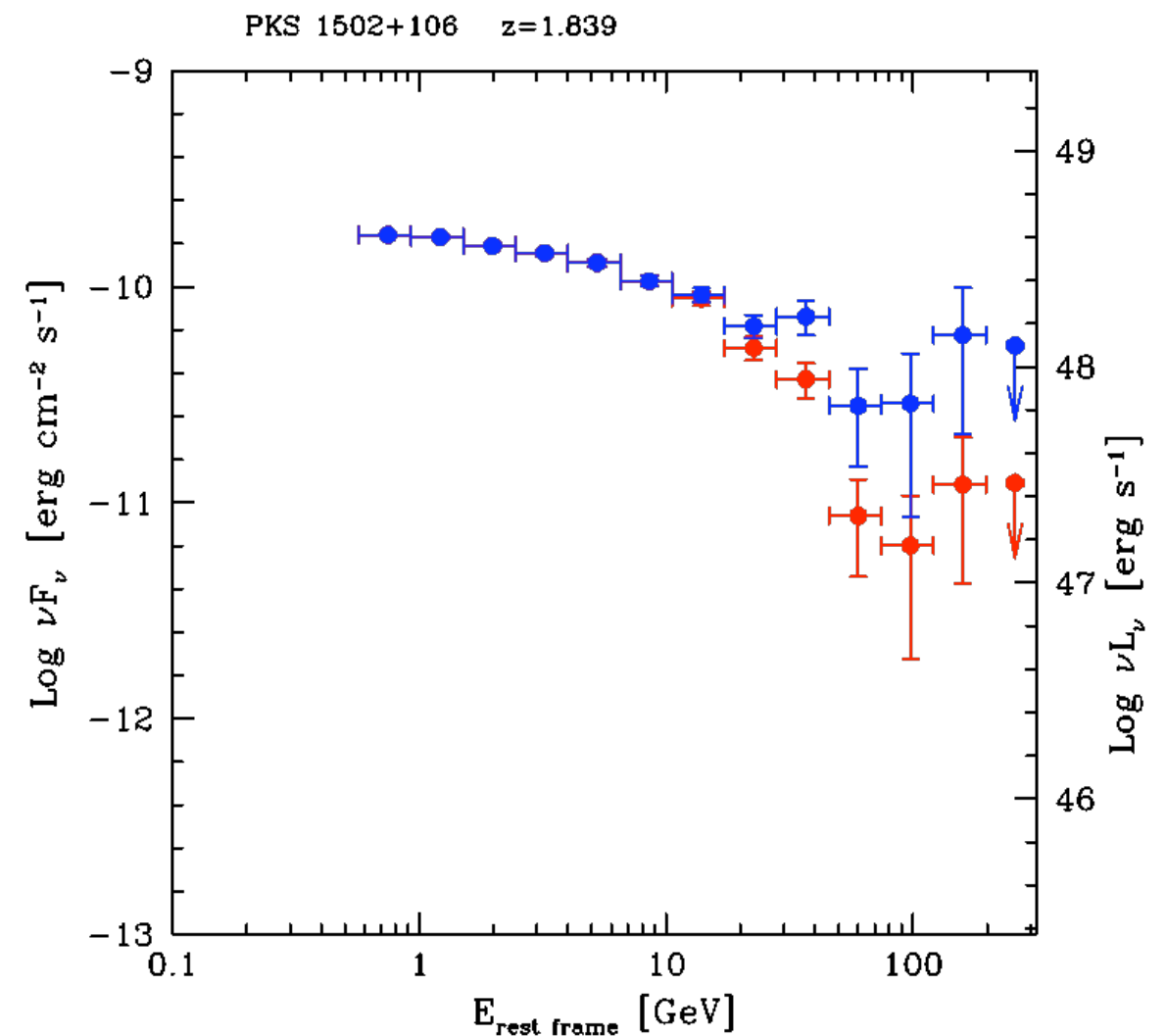
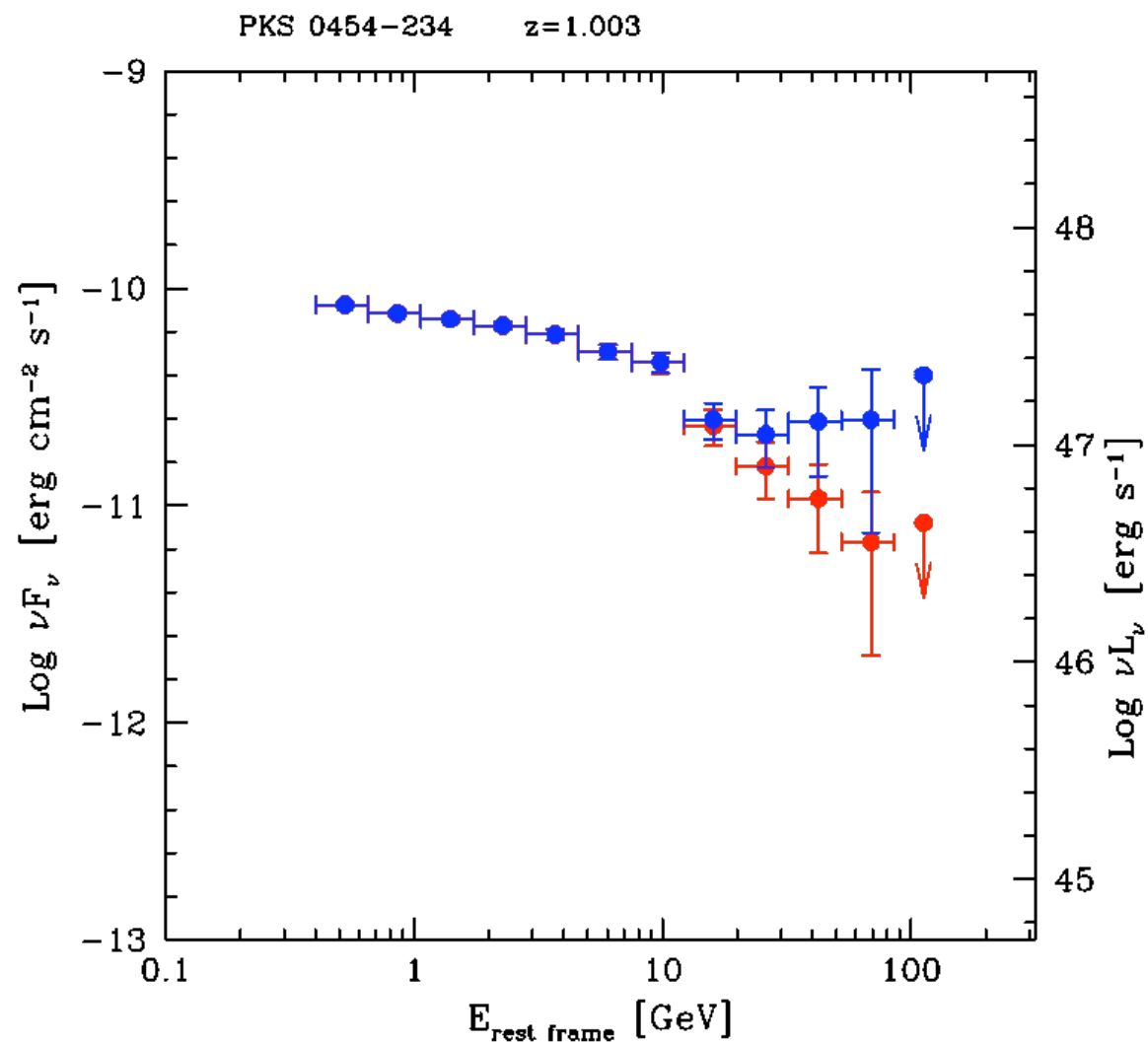


$$R_{\text{blr}} \sim 0.8 \times 10^{18} \quad L_{\text{disk}} \sim 6 \times 10^{46}$$

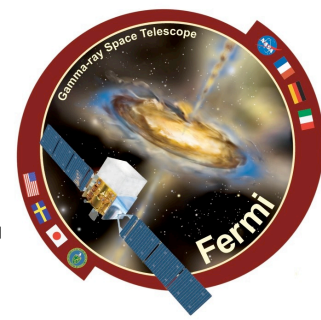
No evidence of strong BLR cut-offs !



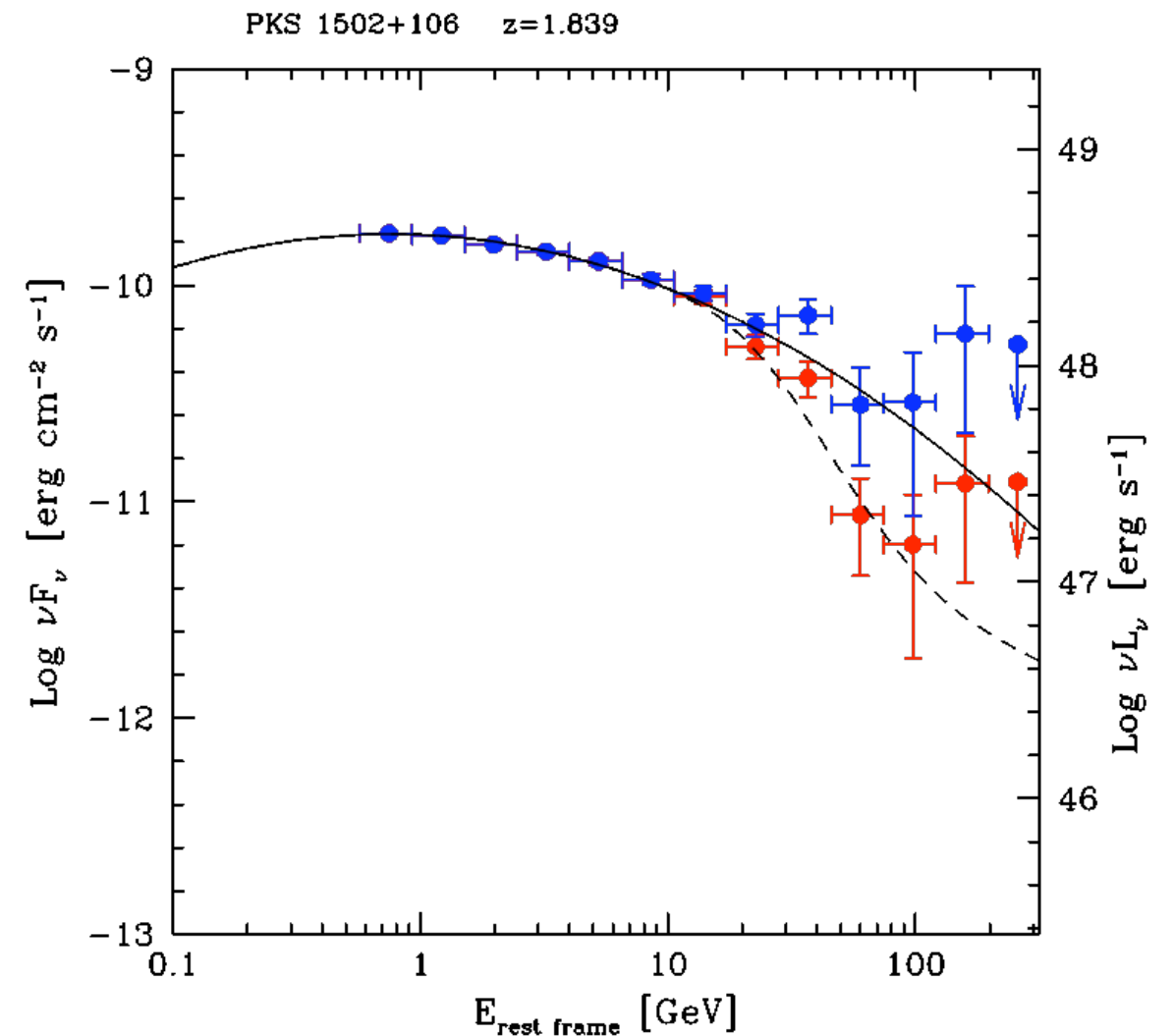
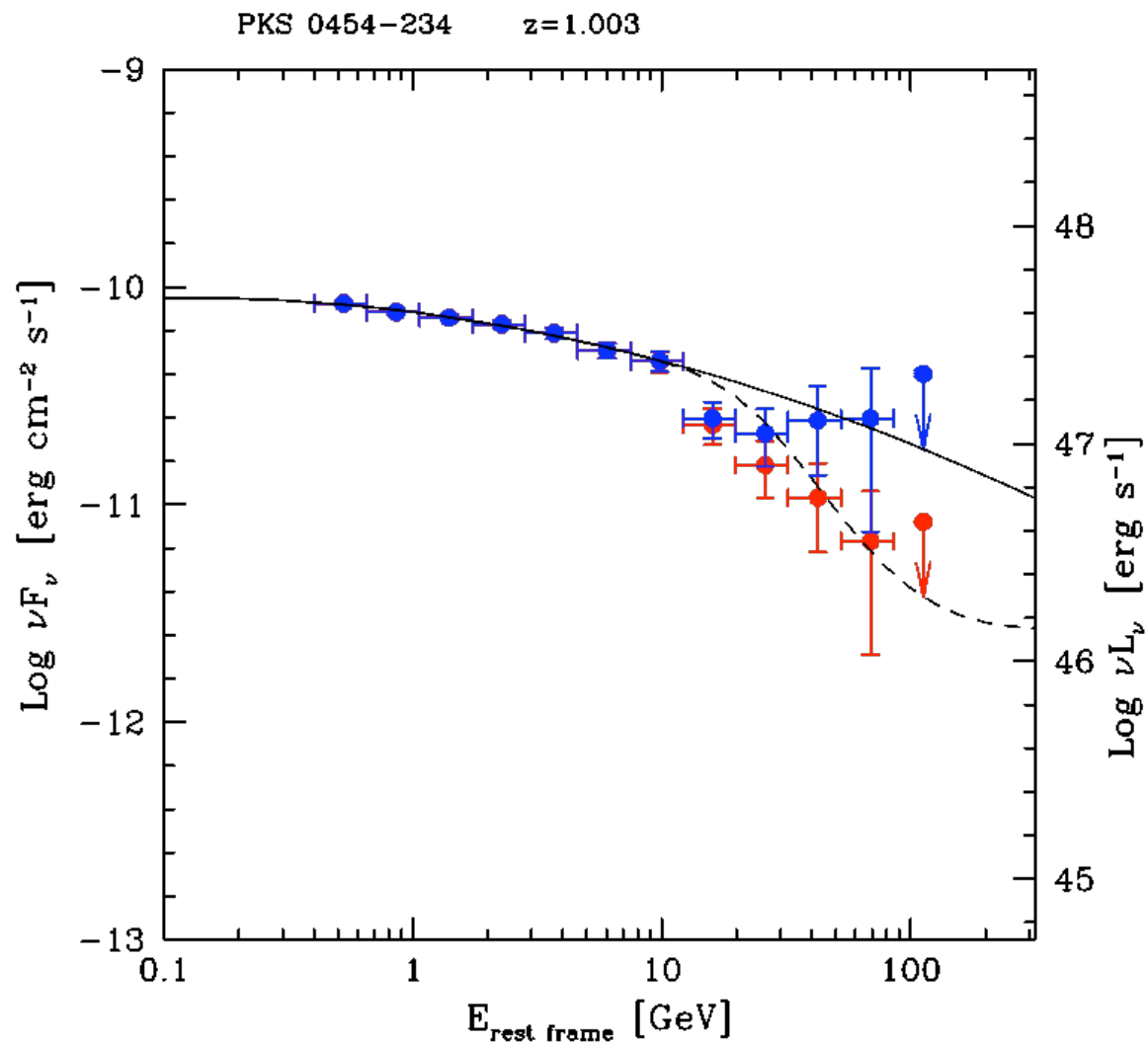
Spectra seems compatible with presence of but minimal absorption
($\sim 10^{16}$ cm, i.e. $R_{\text{diss}} \approx R_{\text{blr}}$)



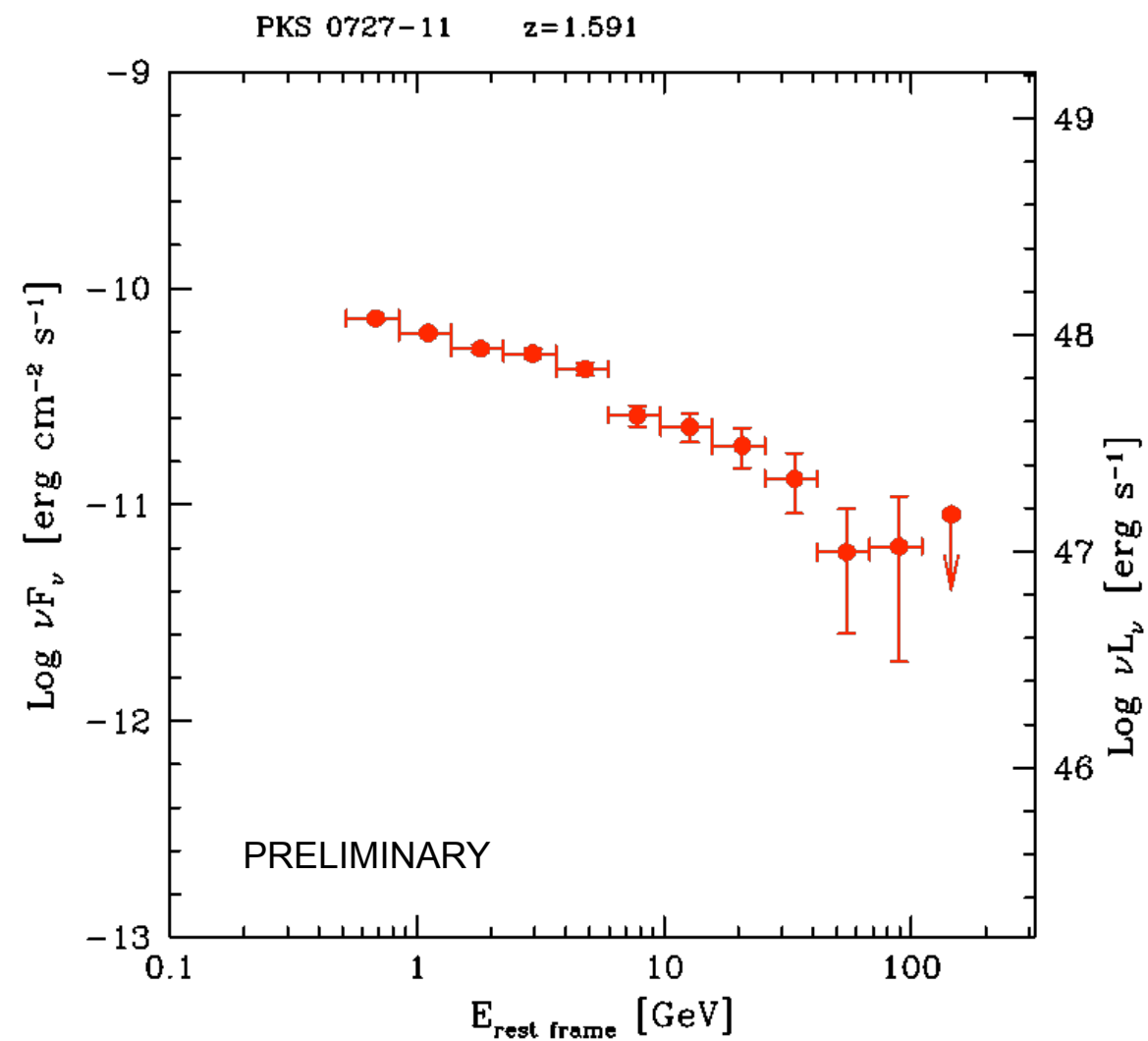
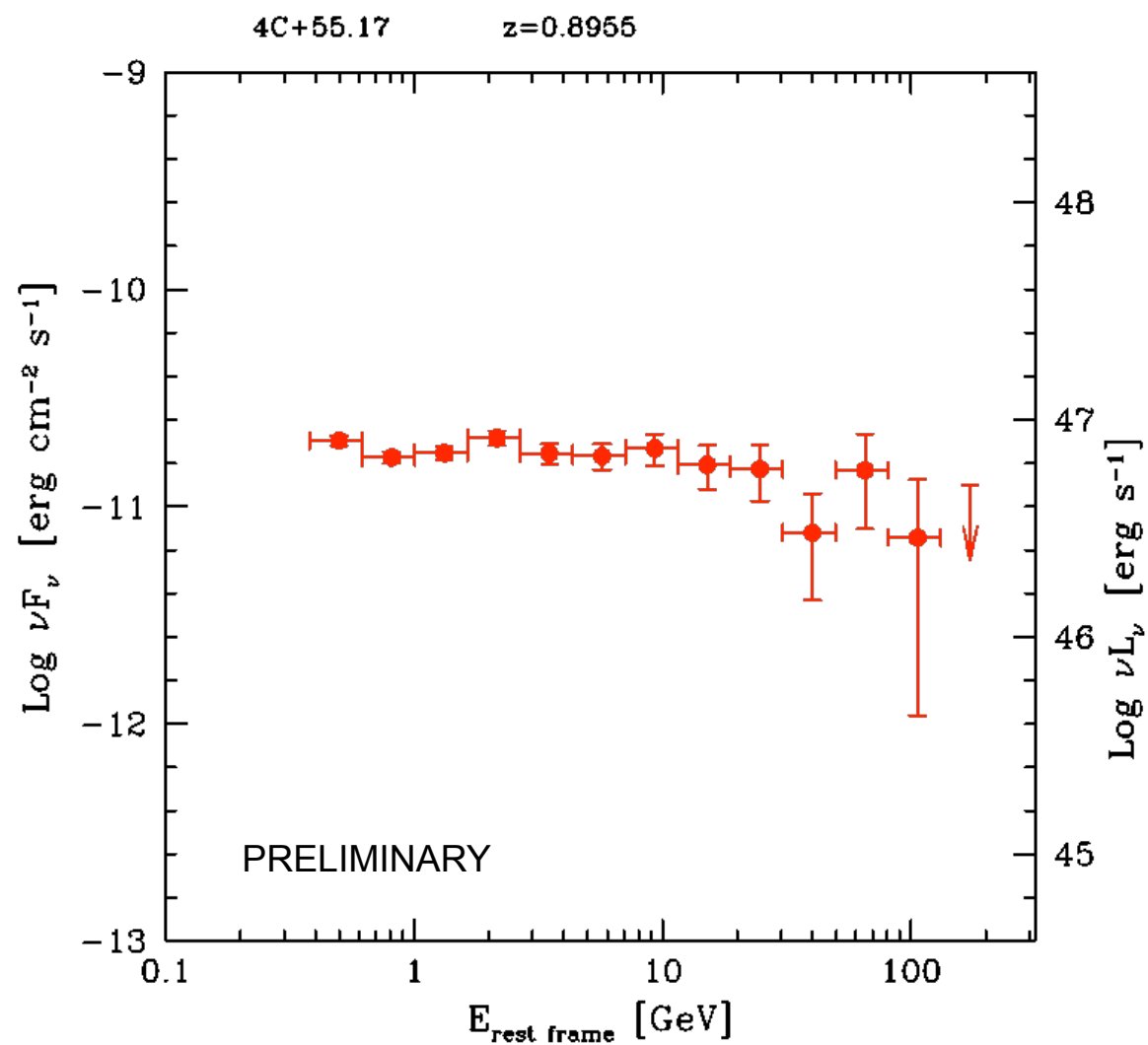
Extrapolation of low energy spectrum



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



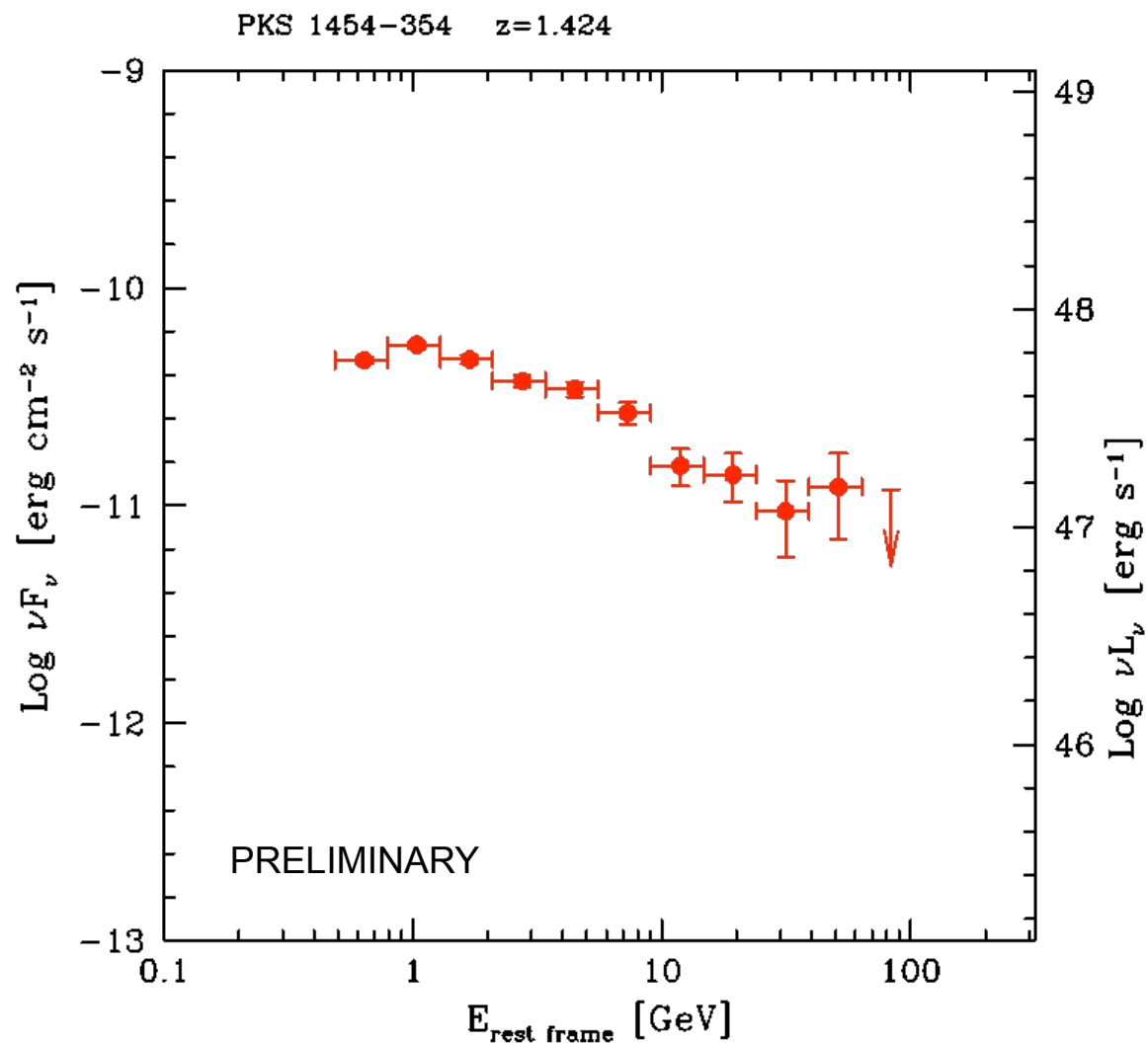
Also NO evidence of absorption at all !



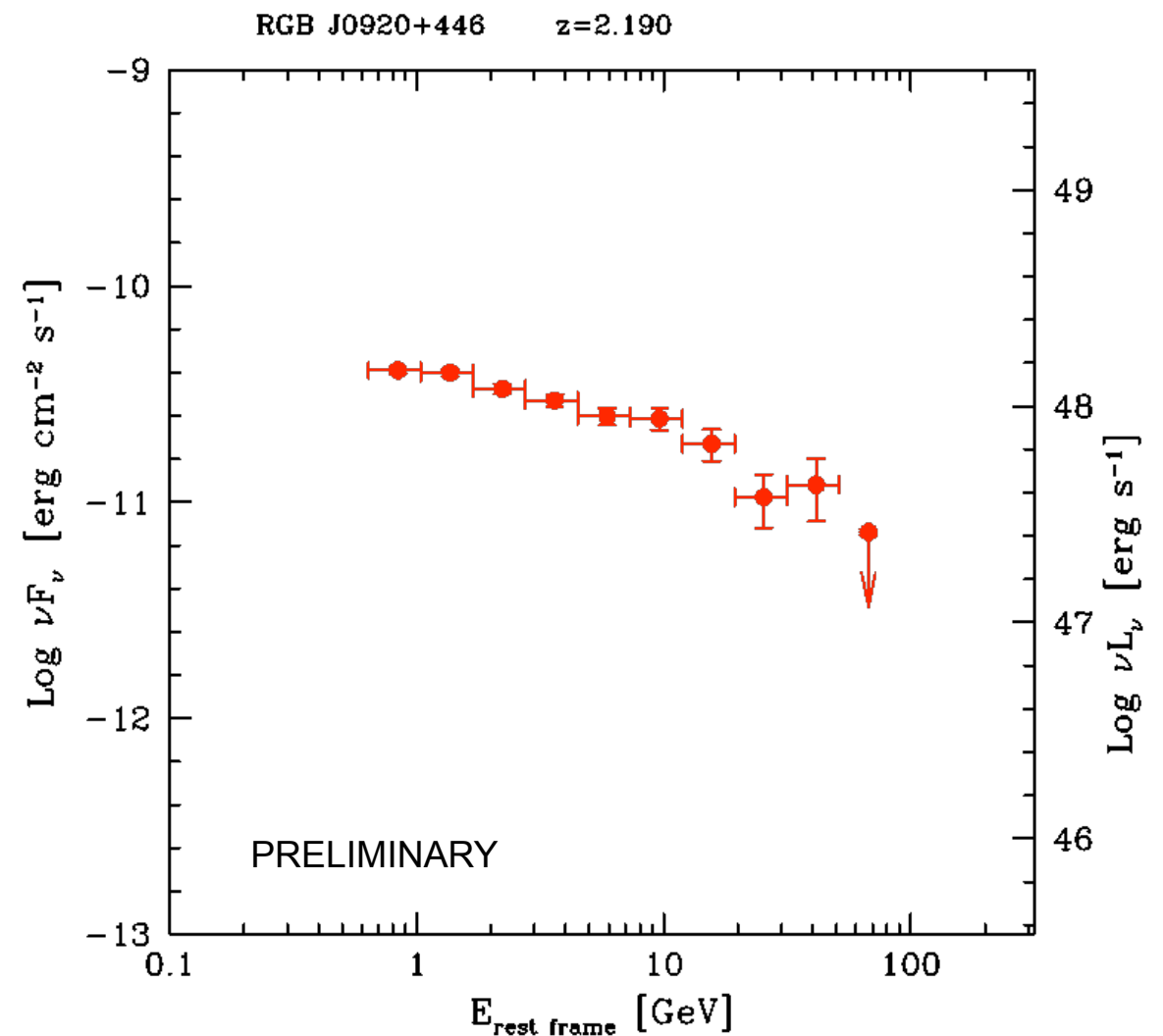
Also NO evidence of absorption at all !



Even in quite powerful objects, with large BLR !



$L_{\text{disk}} \sim 5 \times 10^{46}$ $R_{\text{blr}} \sim 7 \times 10^{17}$
(e.g. $R_{\text{diss}} \sim 1.5 \times 10^{17}$ Ghisellini et al 2009)

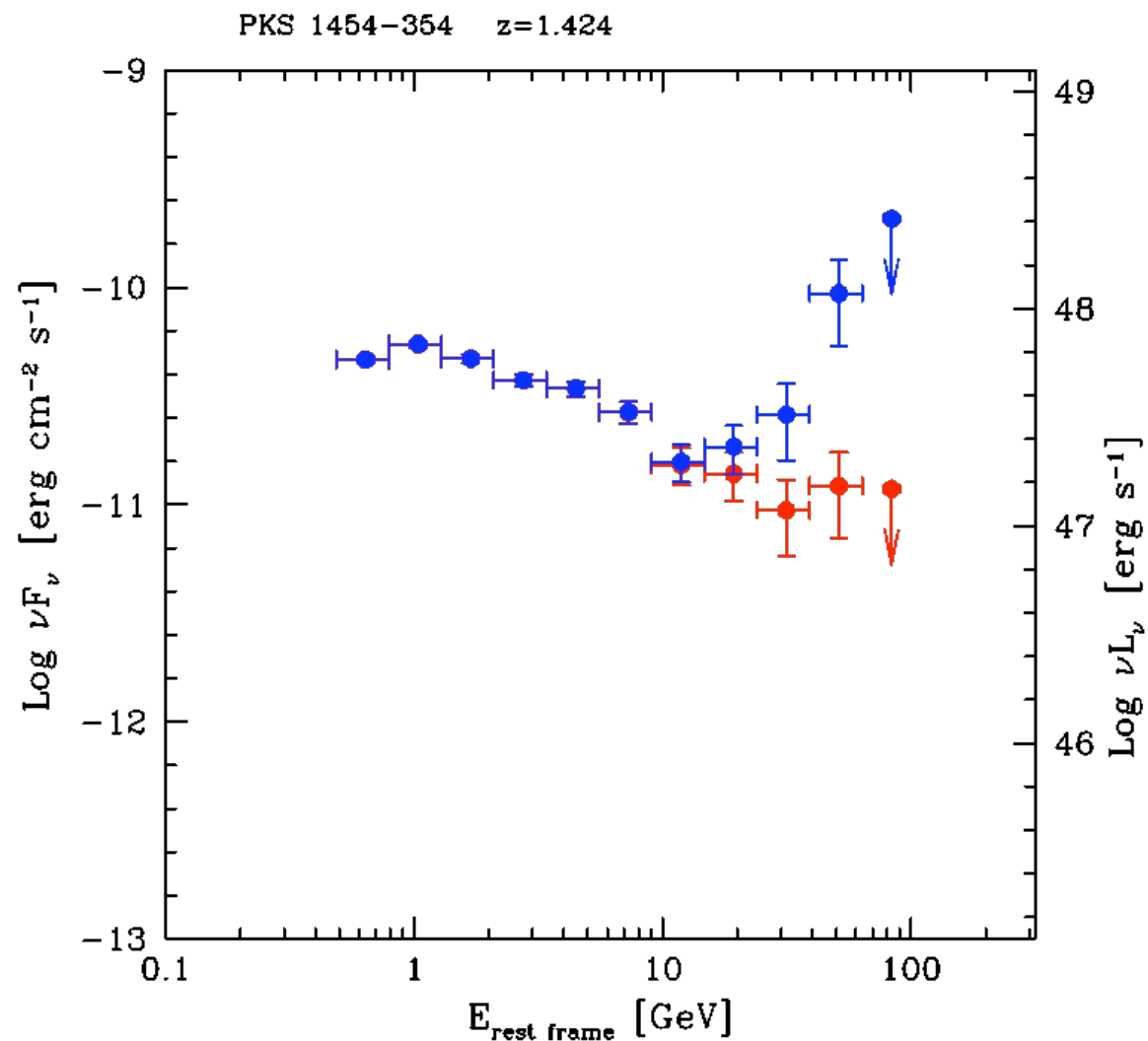


$L_{\text{disk}} \sim 2 \times 10^{47}$ $R_{\text{blr}} \sim 1.3 \times 10^{18}$
(e.g. $R_{\text{diss}} \sim 5 \times 10^{17}$)

Also NO evidence of absorption at all !

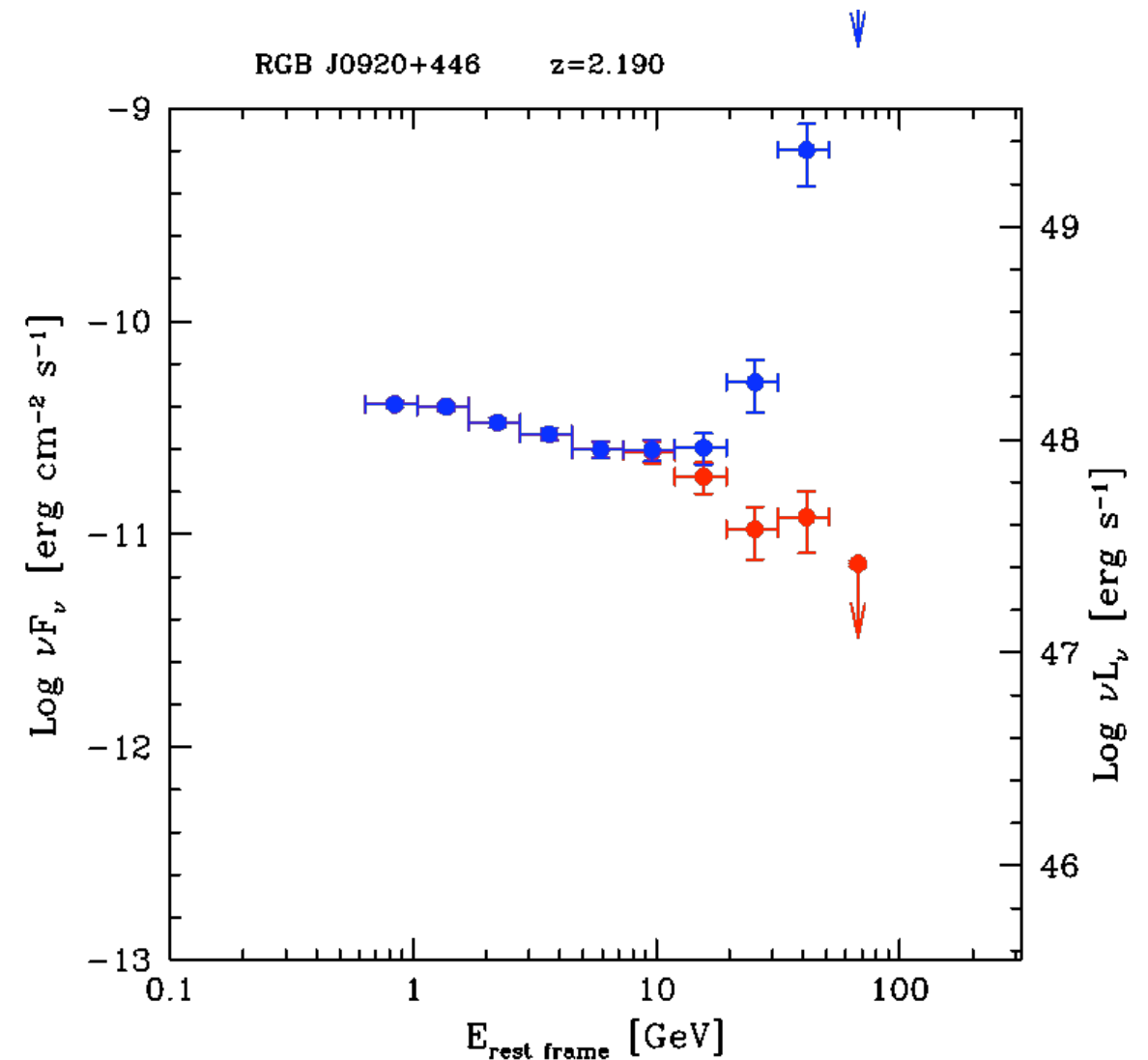


Even in quite powerful objects, with very large BLR !



$$L_{\text{disk}} \sim 5 \times 10^{46} \quad R_{\text{blr}} \sim 7 \times 10^{17}$$

$$R_{\text{diss}} \text{ must be } \geq 7 \times 10^{17}$$



$$L_{\text{disk}} \sim 2 \times 10^{47} \quad R_{\text{blr}} \sim 1.3 \times 10^{18}$$

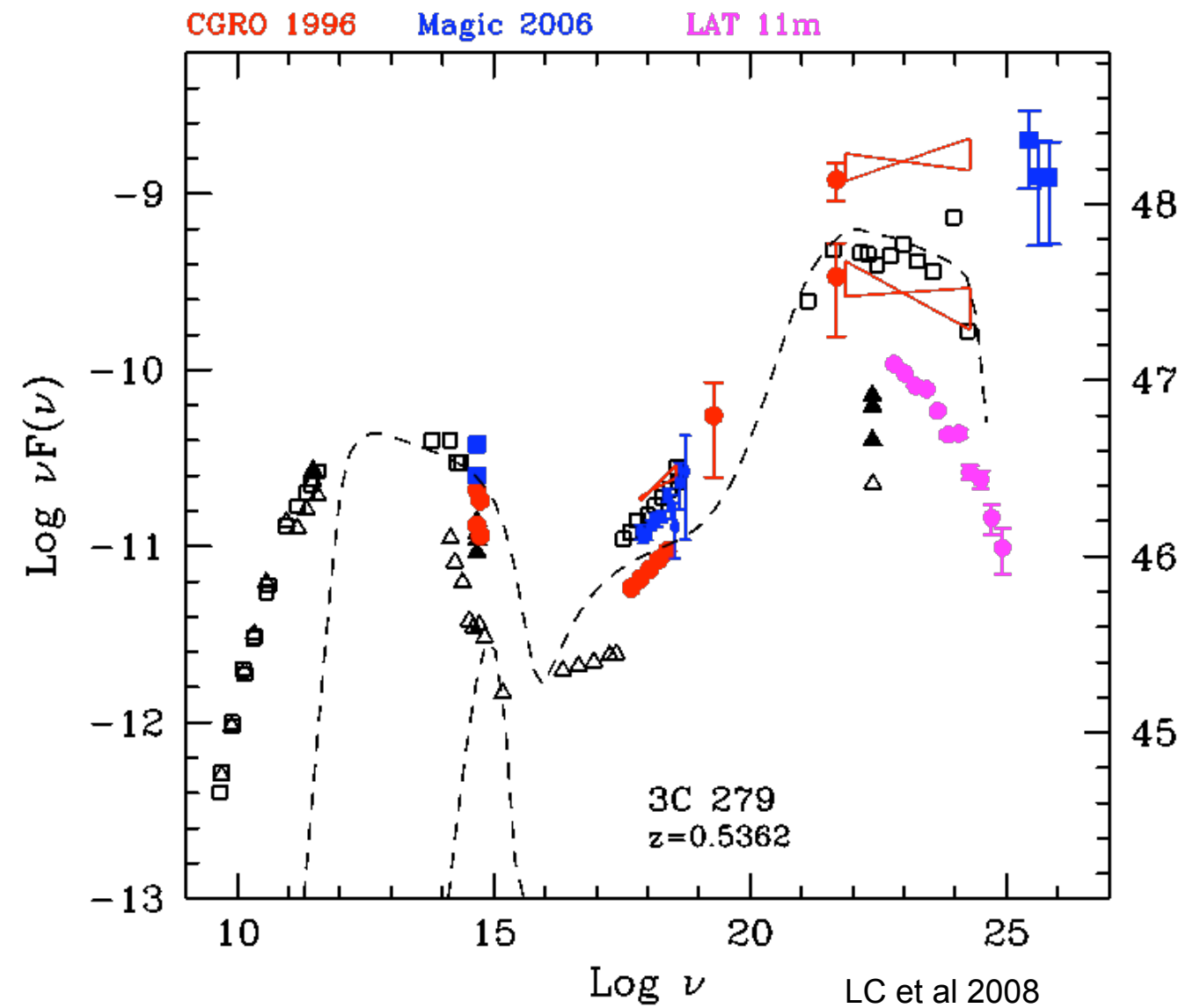
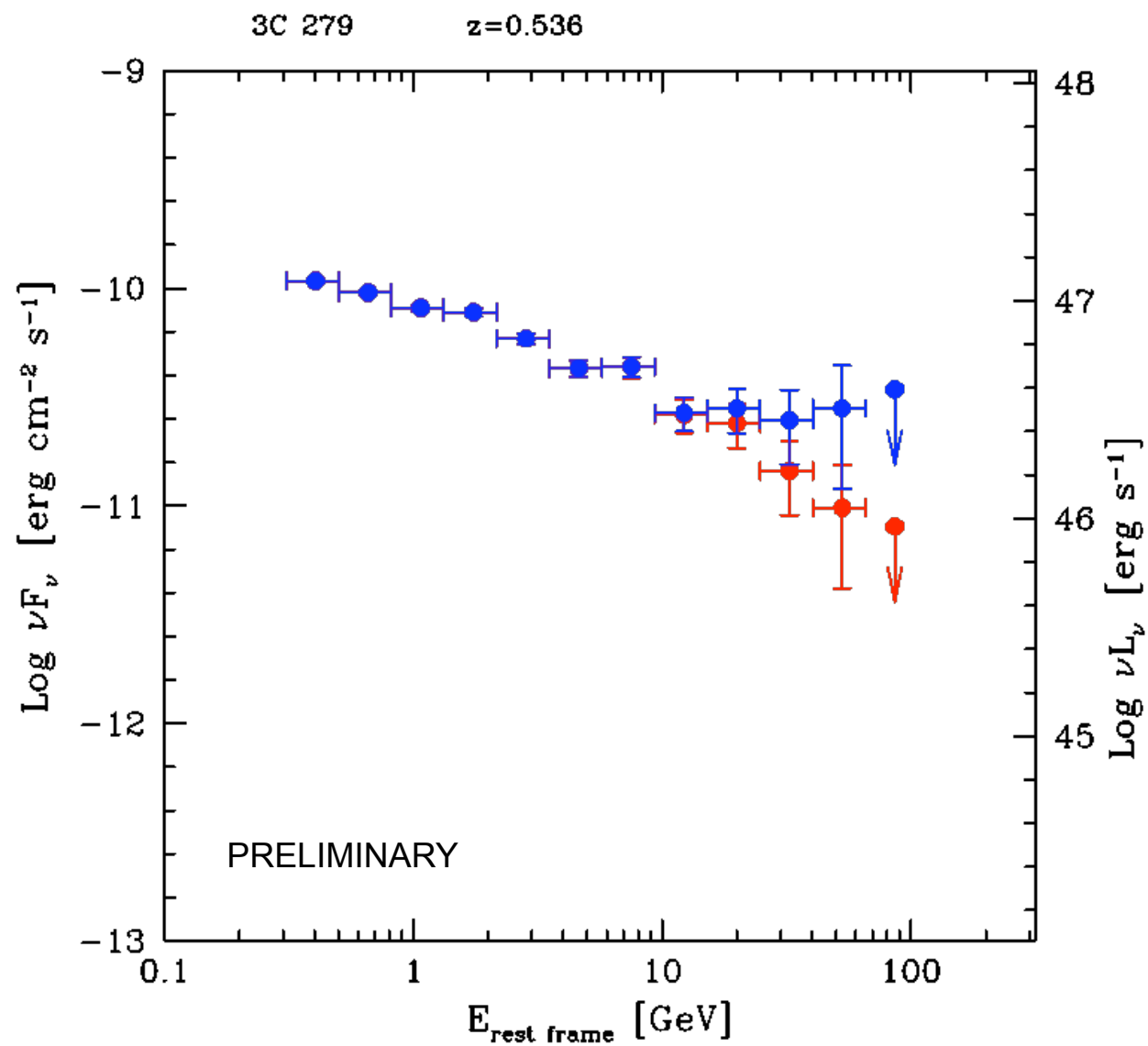
$$R_{\text{diss}} \text{ must be } > 10^{18} \text{ cm}$$

$$(\text{or path inside } \ll 10^{17} \text{ cm})$$

The case of 3C 279



$$L_{\text{disk}} \sim 3 \times 10^{45} \quad R_{\text{blr}} \sim 1 \times 10^{17}$$



R_{diss} seems $> R_{\text{blr}}$

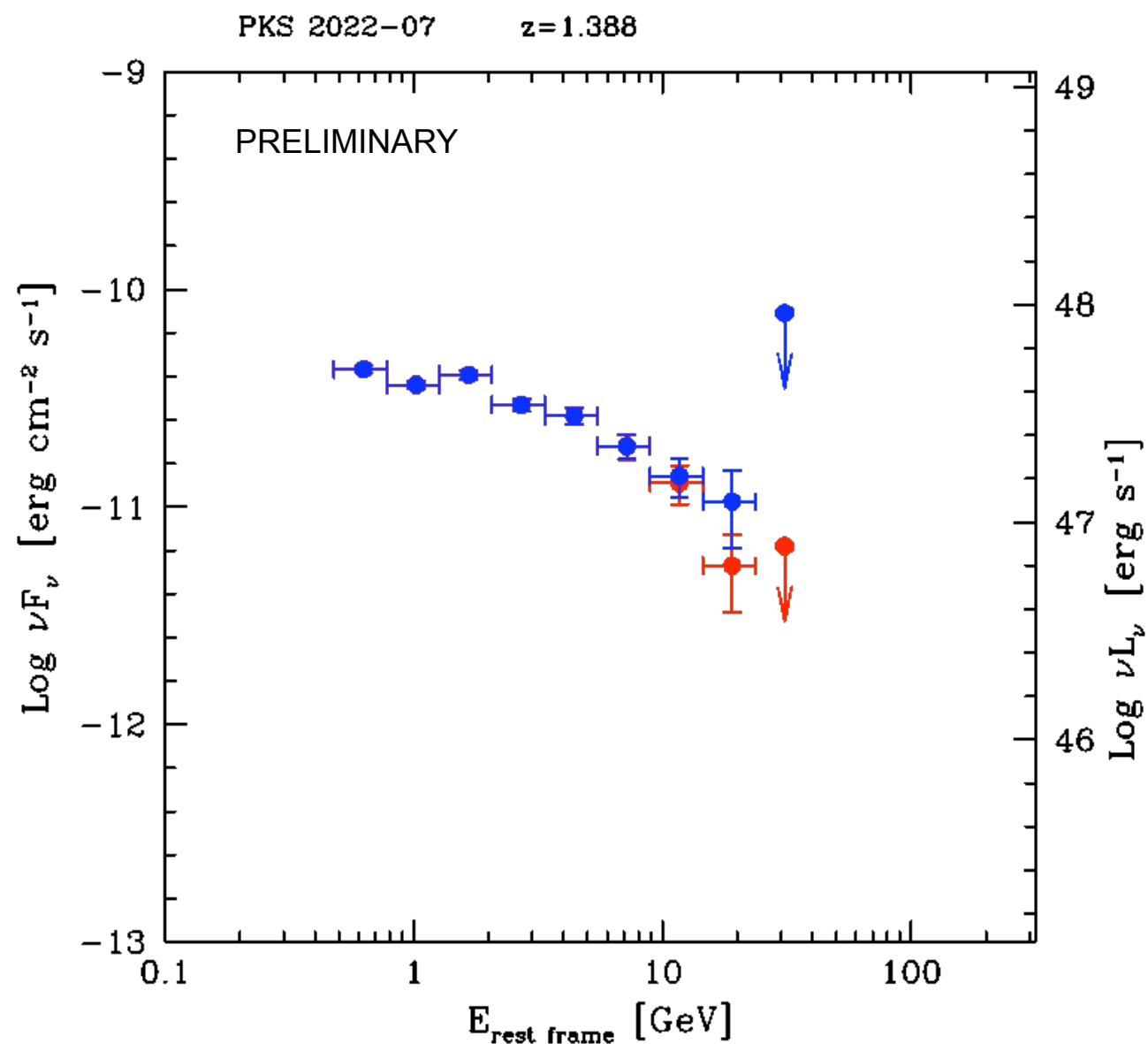
Average Spectrum \Rightarrow low L_c/L_s

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

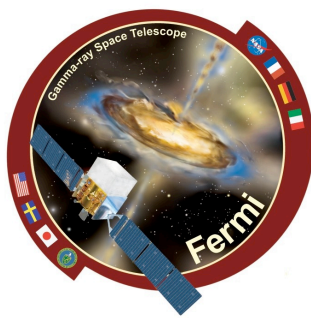
Longer LAT exposures will tell which ones present a strong cutoff (by decreasing the high-energy upper limits on the bright sources)



$\tau \sim 8$



- **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 $F < 10$ GeV !!
- **Geometry of BLR region**
 - if flattened onto accretion disk (e.g. Gaskell 2009) \Rightarrow anisotropic angle
 - $E_{\text{threshold}}$ of γ - γ can be shifted at higher energies
(e.g 25 deg \Rightarrow 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



- 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 ! ($\sim 10^{18}$ cm)
⇒ 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) will be uncovered more clearly as exposure increases