Multiwavelength variability for external Compton and SSC models with time-dependent multi-zone simulations.

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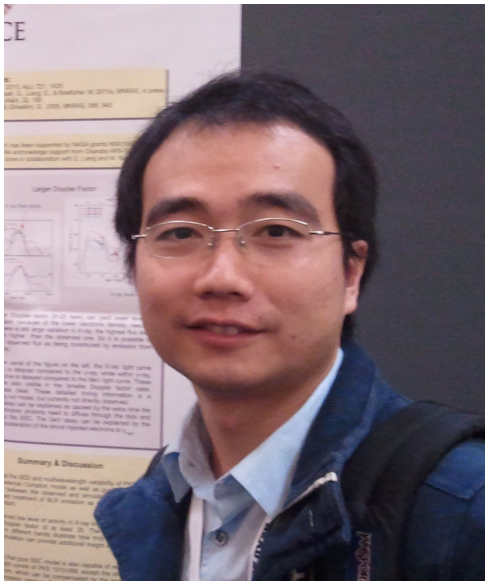
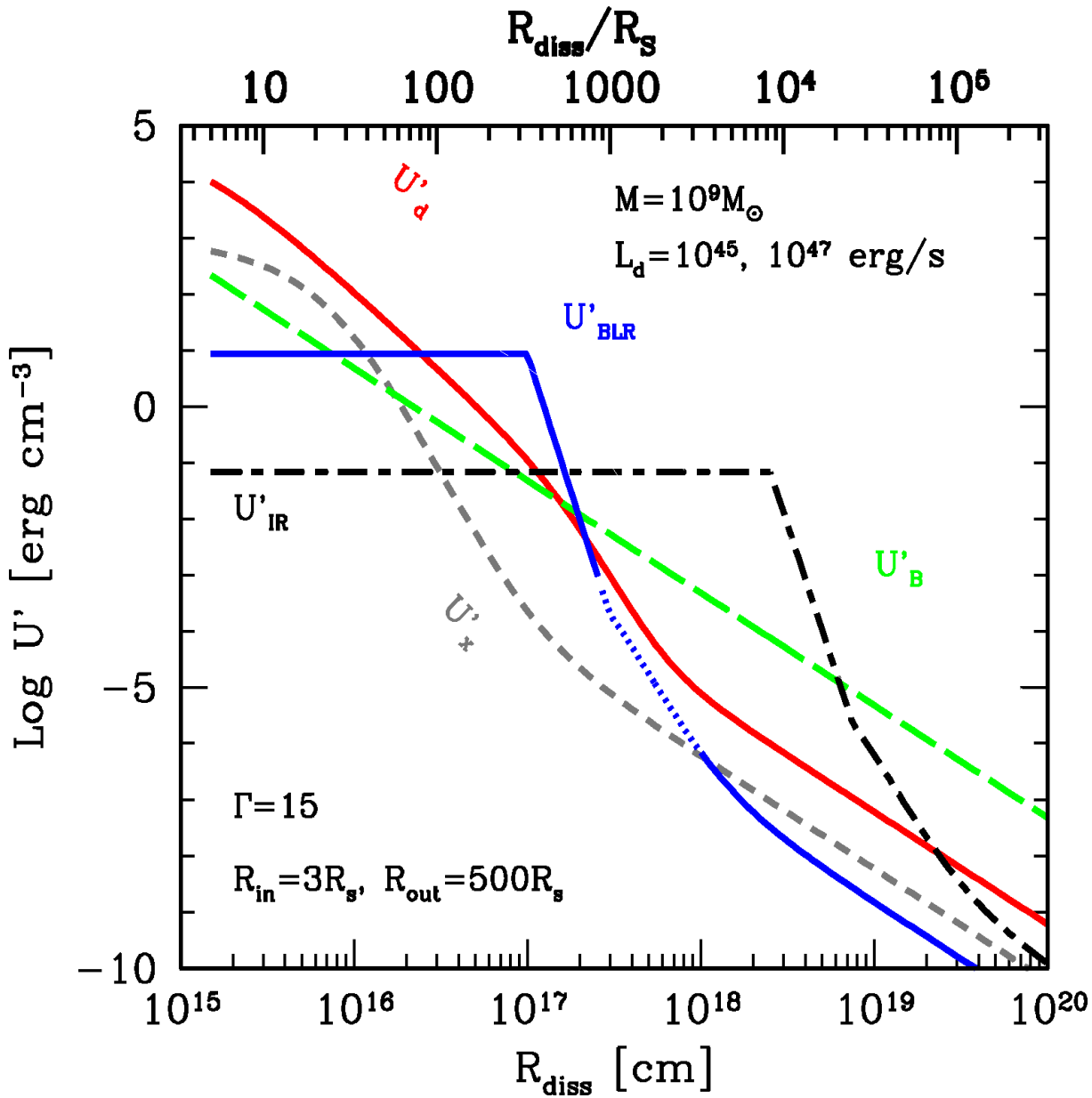


Chen et al. 2012, MNRAS, 424,789
[hot off the presses :-)]

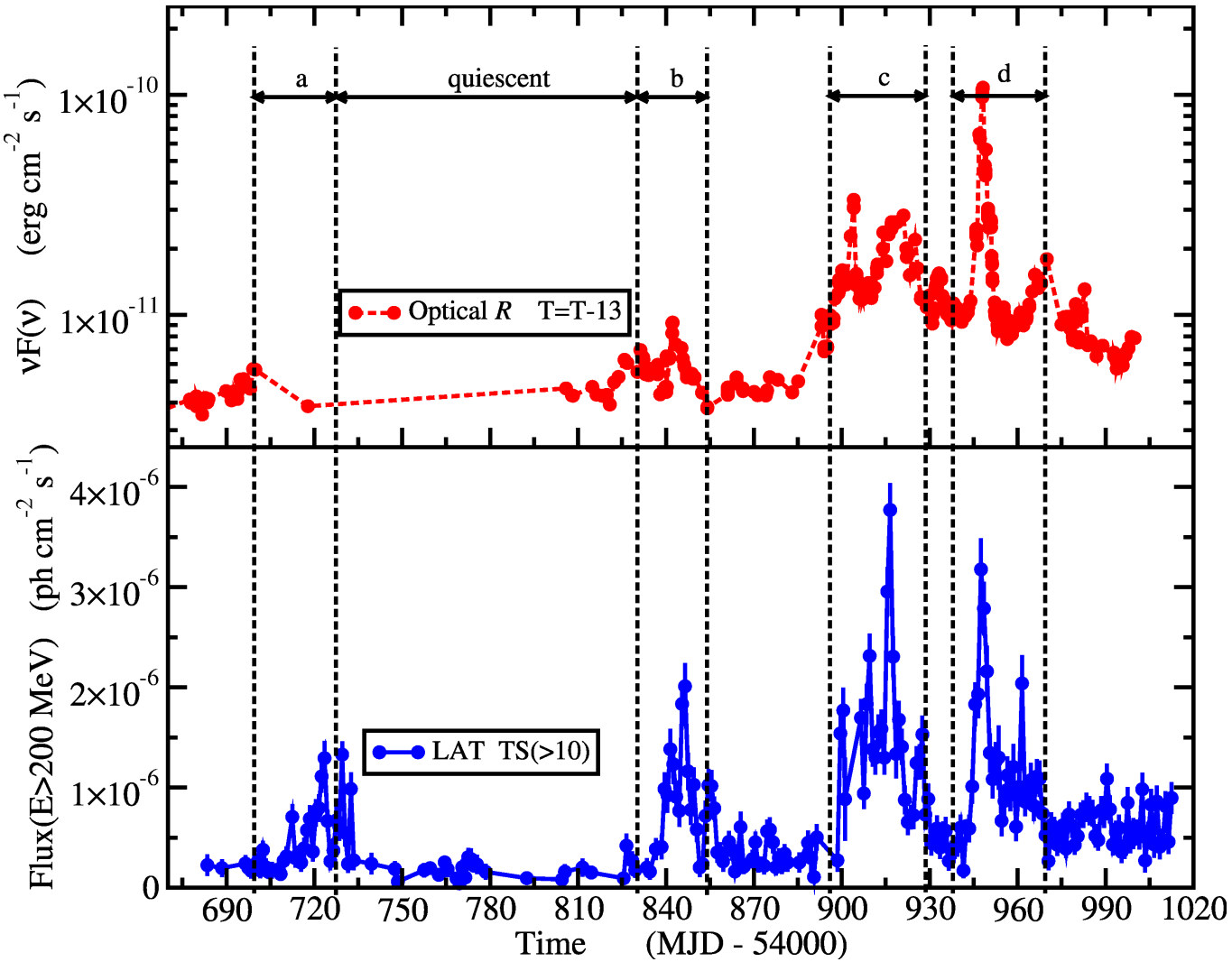
SSC, EC/BLR, EC/torus, and *blob* location

- The type of EC depends on the distance from the black hole of the active, flaring, jet region.
- This can tell us where the flow becomes dissipative and it is a diagnostics of the jet structure and evolution.
- We can identify the source of the external radiation on the basis of temporal and spectral properties.



Ghisellini & Tavecchio 2009

PKS 1510-089



Infrared and gamma-ray (LAT) light curves

[Abdo et al. 2010]

- A powerful FSRQ, at z=0.361.
- Several active phases since the launch of Fermi.
- The spring of 2009 high activity state was intensely monitored (Abdo+ 2010, D'Ammando+ 2011, Marscher+ 2010)
- IR and gamma-ray highly variable and well correlated.

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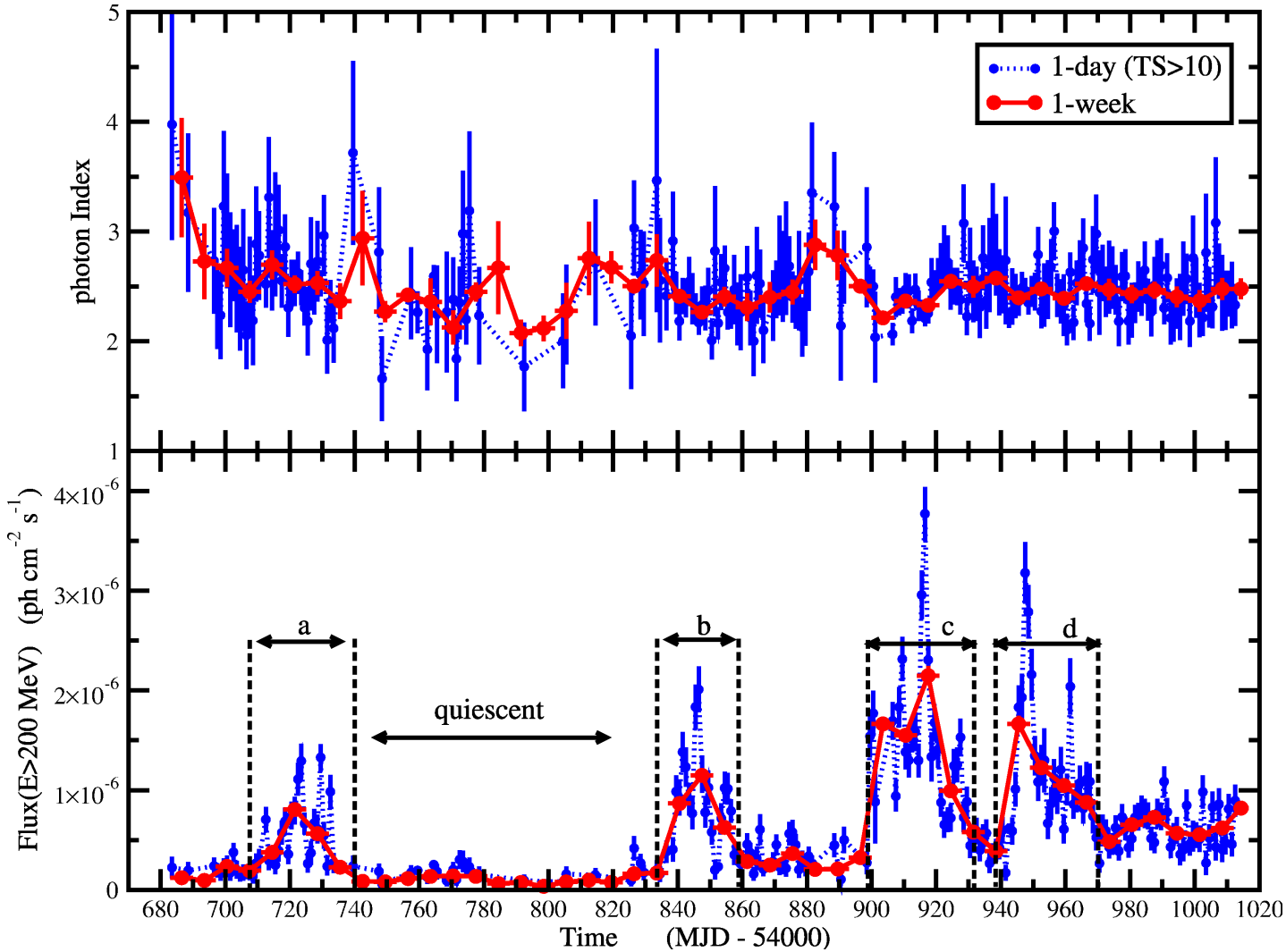

- LAT-band spectrum showing very modest variability even during the strongest flares.

gamma-ray (LAT) photon index (top) and flux (bottom) light curves

[Abdo et al. 2010]

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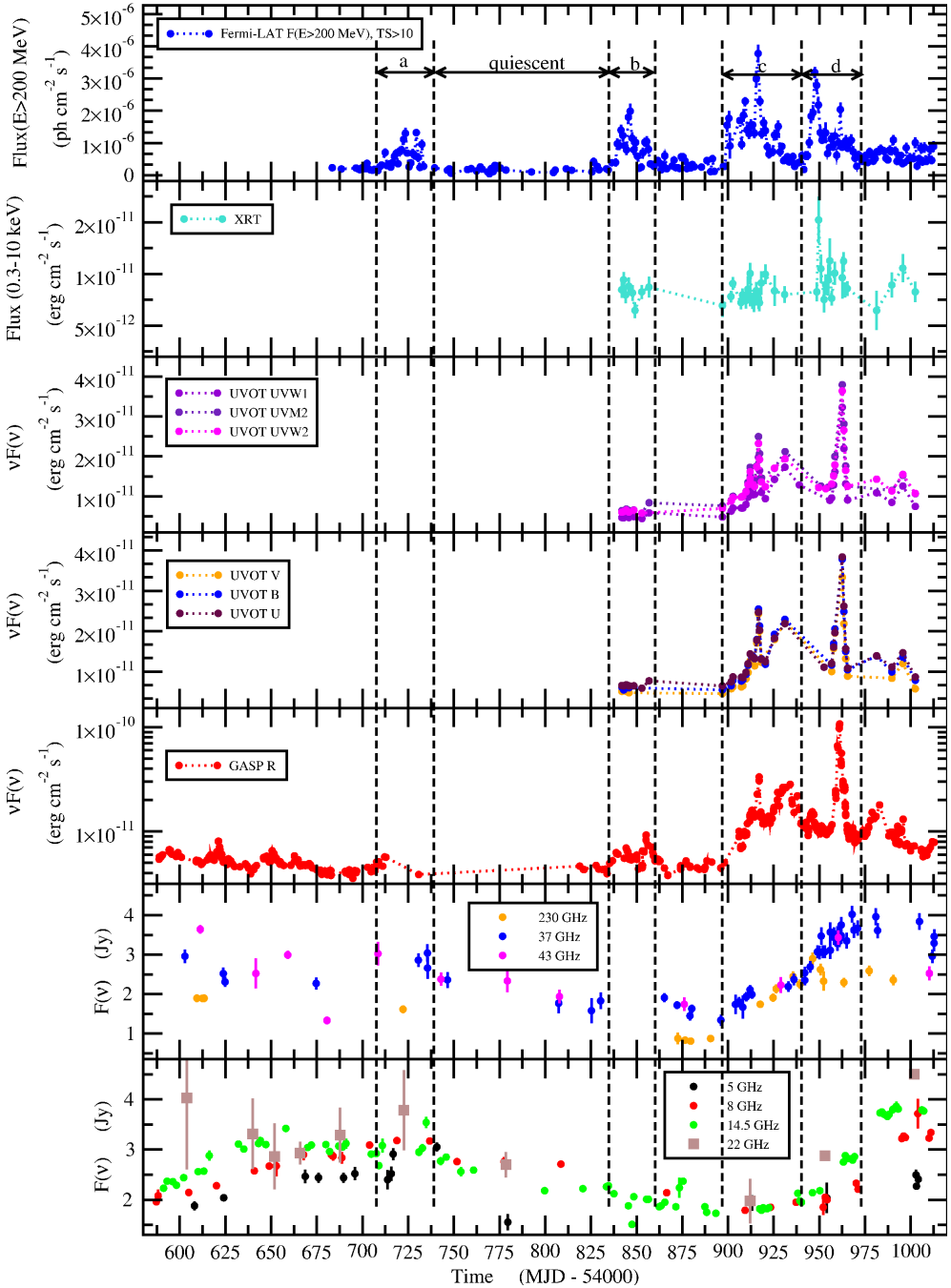


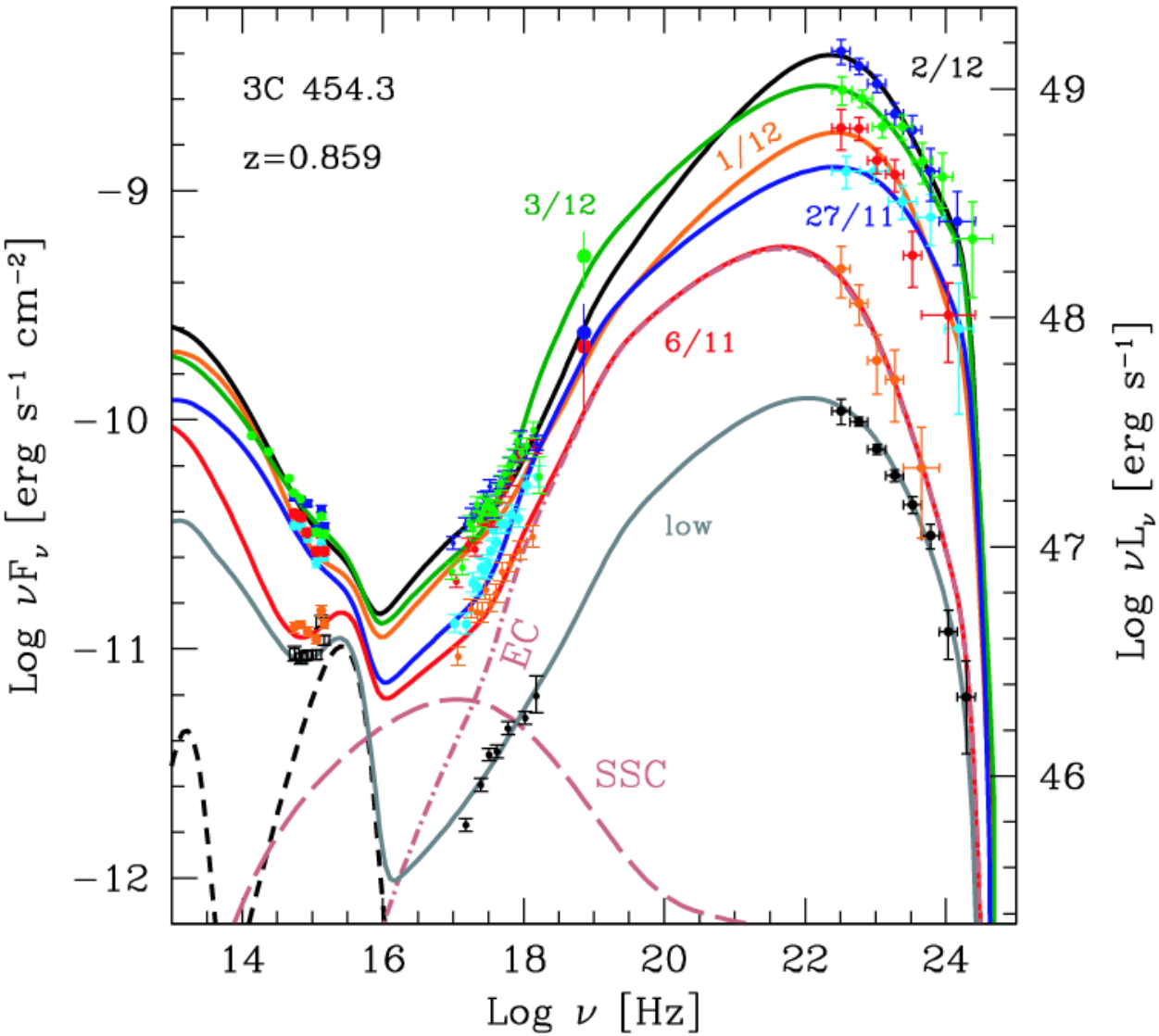
- Observational benchmarks:
  - Visible big-blue-bump, emission from the accretion disk.
  - Close correlation between IR and gamma-ray,with no measurable lag.
  - UV variability modest, consistent with dilution by non-variable disk emission.
  - Weak X-ray variability (< x2), with extremely hard spectrum.
  - Intense gamma-ray flux variability, not accompanied by significant spectral change.

[Abdo et al. 2010]

time-dependent modeling

- State of the art of modeling:
  - Fitting snapshot or time-averaged SEDs, with steady-state one-zone (homogeneous, *point-like,* 0-D) models.
  - No real modeling of multiwavelength light curves, and series of SEDs.
- Some time-dependent codes have been developed (Chiaberge&Ghisellini 1999, Kataoka+ 2000, Katarzynski+ 2008, Sokolov+ 2004,2005, Graff+ 2008, Böttcher&Dermer 2010, also **`poster P2-18`**) but they all have significant limitations:
  - Cooling assumed to be dominated by synchrotron.
  - No internal photon diffusion, internal travel time effects ignored.
  - Effectively not 2-D
- Current multiwavelength datasets allow/demand a major advancement of physical modeling of jet emission: time-dependent and taking into account the finite dimension and geometry of the source.

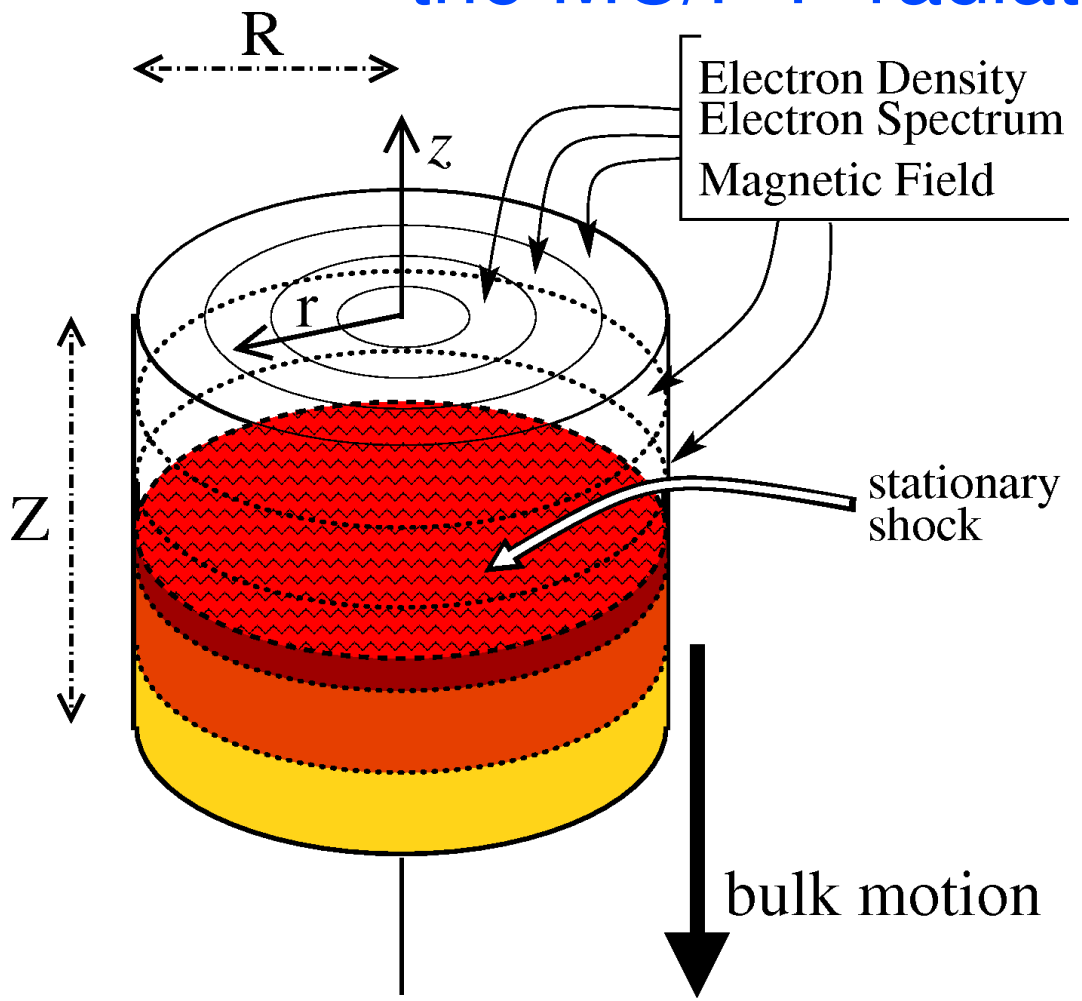
3C 454.3, a powerful FSRQ
one-zone non-time-dependent model



[Bonnoli+ 2010]

- Sequence of SEDs from multiwavelength campaign during a very high flaring state.
- Each SEDs fit with a single-zone, steady state emission model.
- Inference that the flare could be interpreted as due to a change of the power injected in electrons.
- Timescales/sampling of the observations are such that SEDs should be physically related.

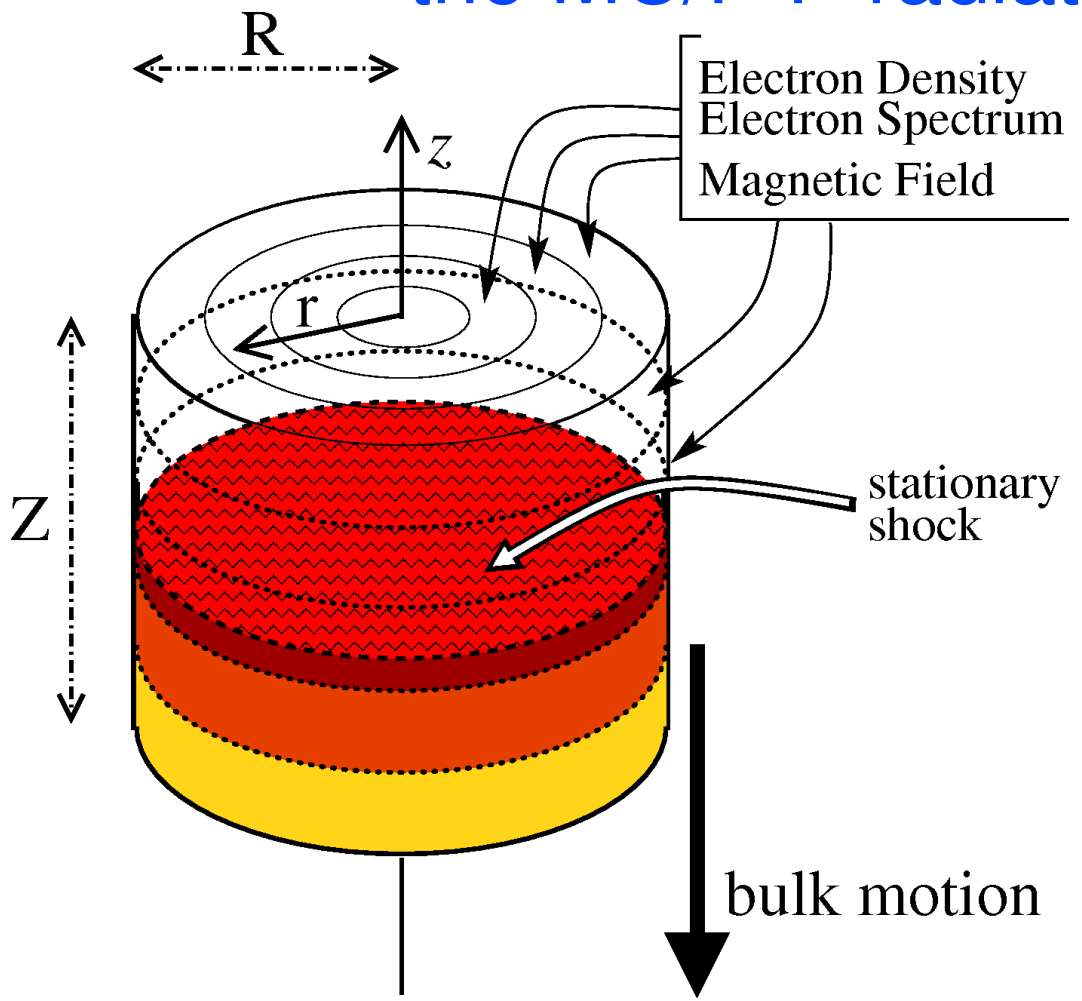
the MC/F-P radiative transfer code



- The hatched layer represents the *shock.* The blob, simulation volume, is moving downward and crossing the shock front.
- Zones affected by the shock at earlier times have had some time to radiate the newly injected energy and are plotted in lighter colors.

- Our code is **time-dependent** and **multi-zone**, two major leaps forward in blazar modeling.
- This code has the unique feature of taking into account all **light crossing time effects.**
  - ***Internal***: crucial to model inverse Compton emission, which depends on radiation coming (at retarded times) from the entire volume.
  - ***External***, i.e. properly accounting for the delays and mixing up of the emission from different part of the blob as seen from the observer point of view.

the MC/F-P radiative transfer code



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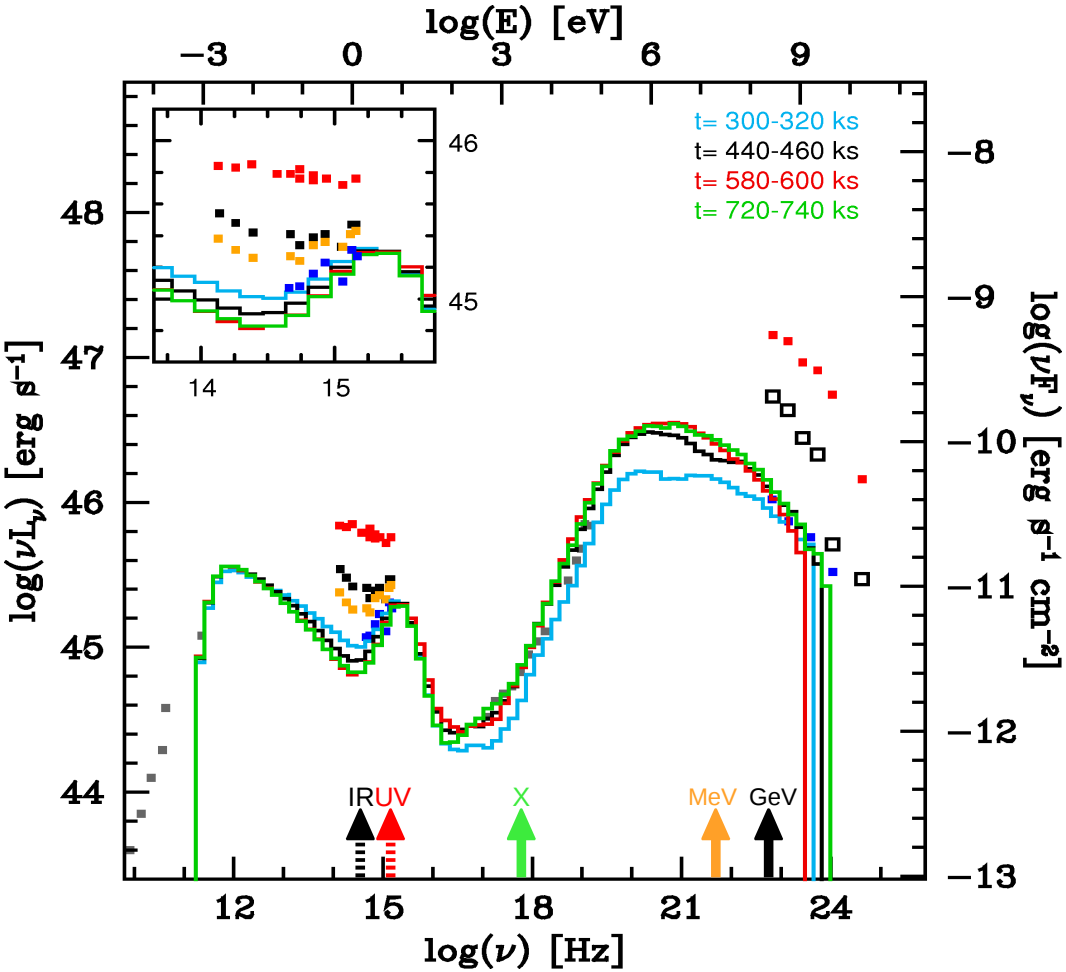
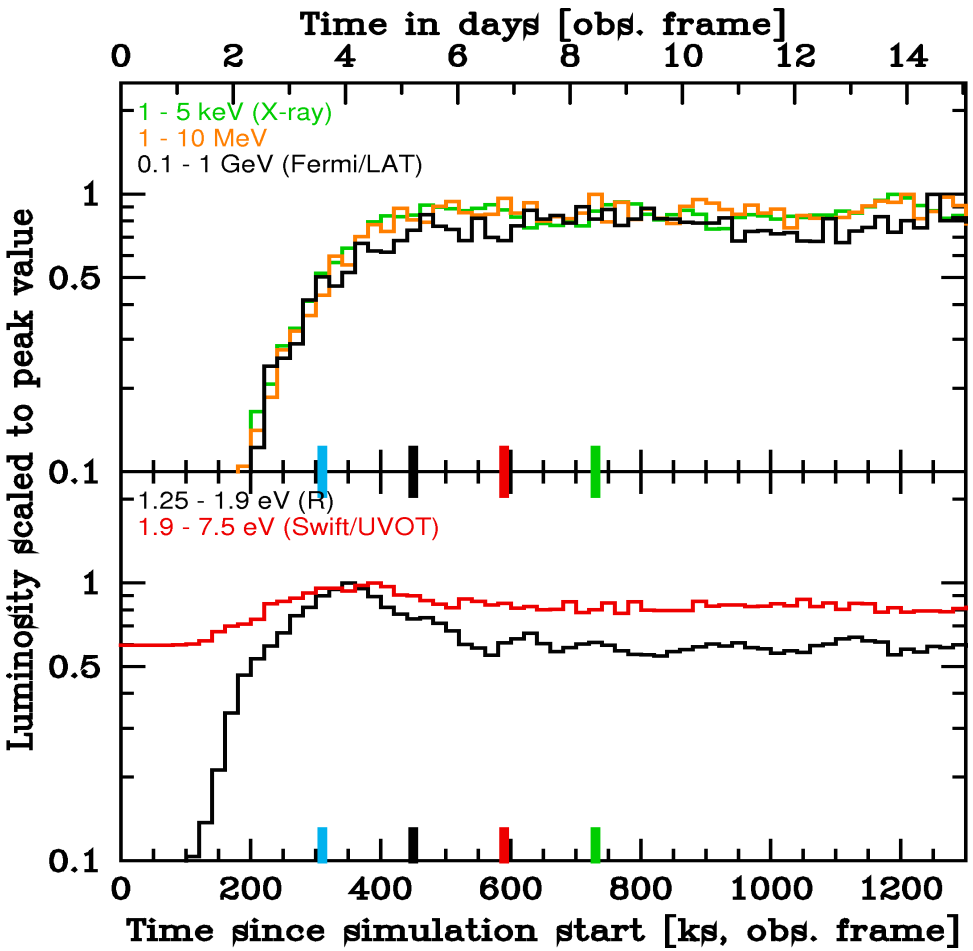
- For this investigation we adopted a scenario with the following elements:
  - *Stochastic* acceleration throughout the blob (e.g., Katarzynski+ 2006, Tramacere+ 2011).
  - The blob constantly *picks up* mildly relativistic electrons which are then energized by the diffuse stochastic acceleration. There is also an *escape* term.
  - The blob encounters a “shock” which injects “instantly” new electrons, with a power law distribution. They also then evolved with the rest of the electrons.
  - The blob can be illuminated by an external radiation field.

about model parameters and constraints

- The model obviously has several parameters *(e.g.* L_{inj}, γ_{min}, γ_{max}, p, t_{acc}, t_{esc}, B, R, Z, Γ , f_{ext}, R_{ext}*)* not all of them actually relevant, and because of the *holistic* nature of non-thermal processes there are relationships between them.
  - For instance some of those characterizing the distribution of picked-up and injected electrons are superceded by the stochastic acceleration.
  - There are then constraints, e.g. Γ, R_{ext}, f_{ext} combine to set U'_{ext}, whose ratio to B^2, sets $L_{EC}/L_{sync} \sim U'_{ext}/B^2$.
  - Some parameters can be set on the basis of empirical findings, for instance the size of the BLR or molecular torus (R_{ext}).
- Finally with high quality sequences of SEDs, we have several basic observables:
  - We have variability timescale, luminosities and peak positions, spectral indices at least in gamma-ray, x-ray and IR/O band, etc.
- Overall within the context of a given adopted framework, the modeling is in fact strongly constrained.

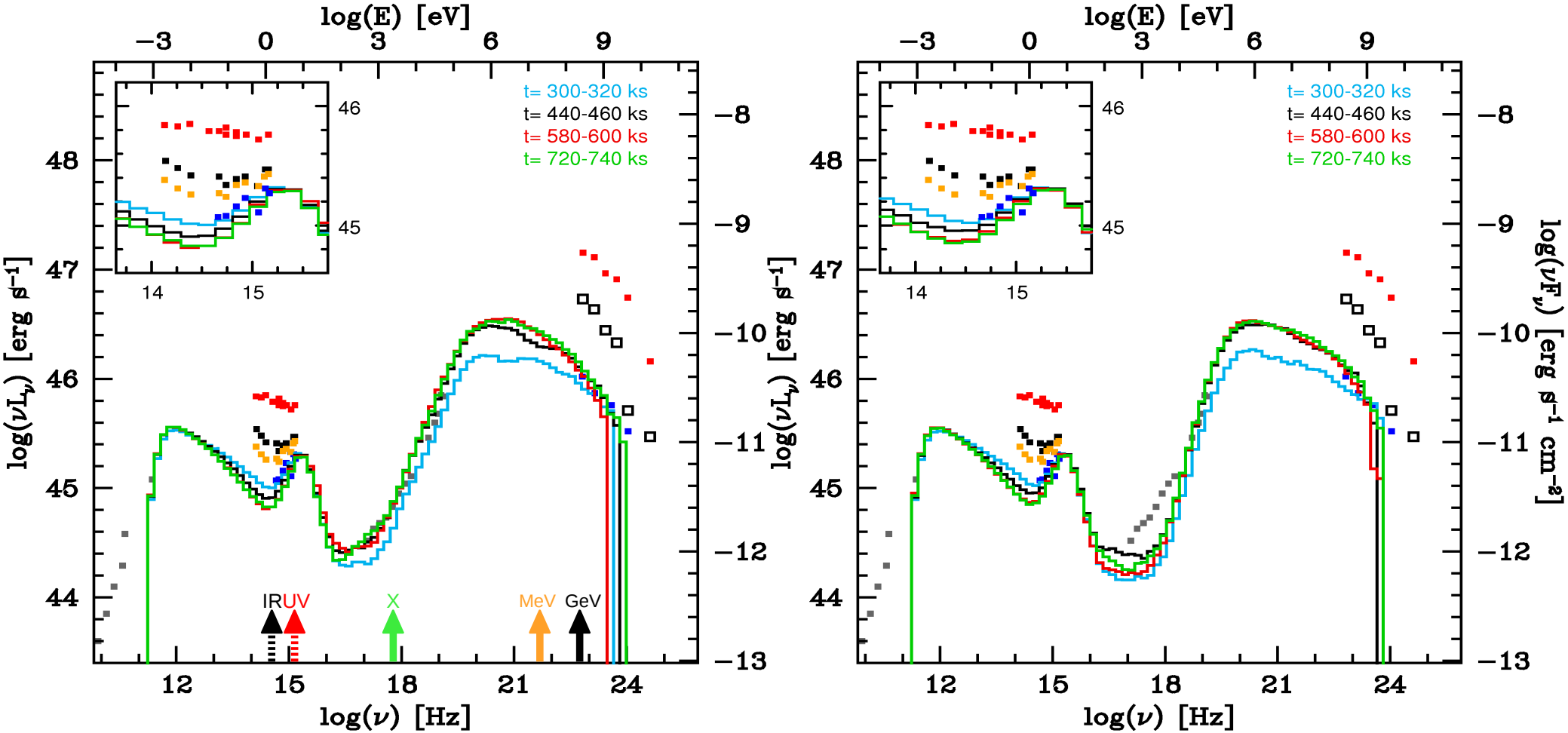
EC/BLR, δ=15, non-flaring





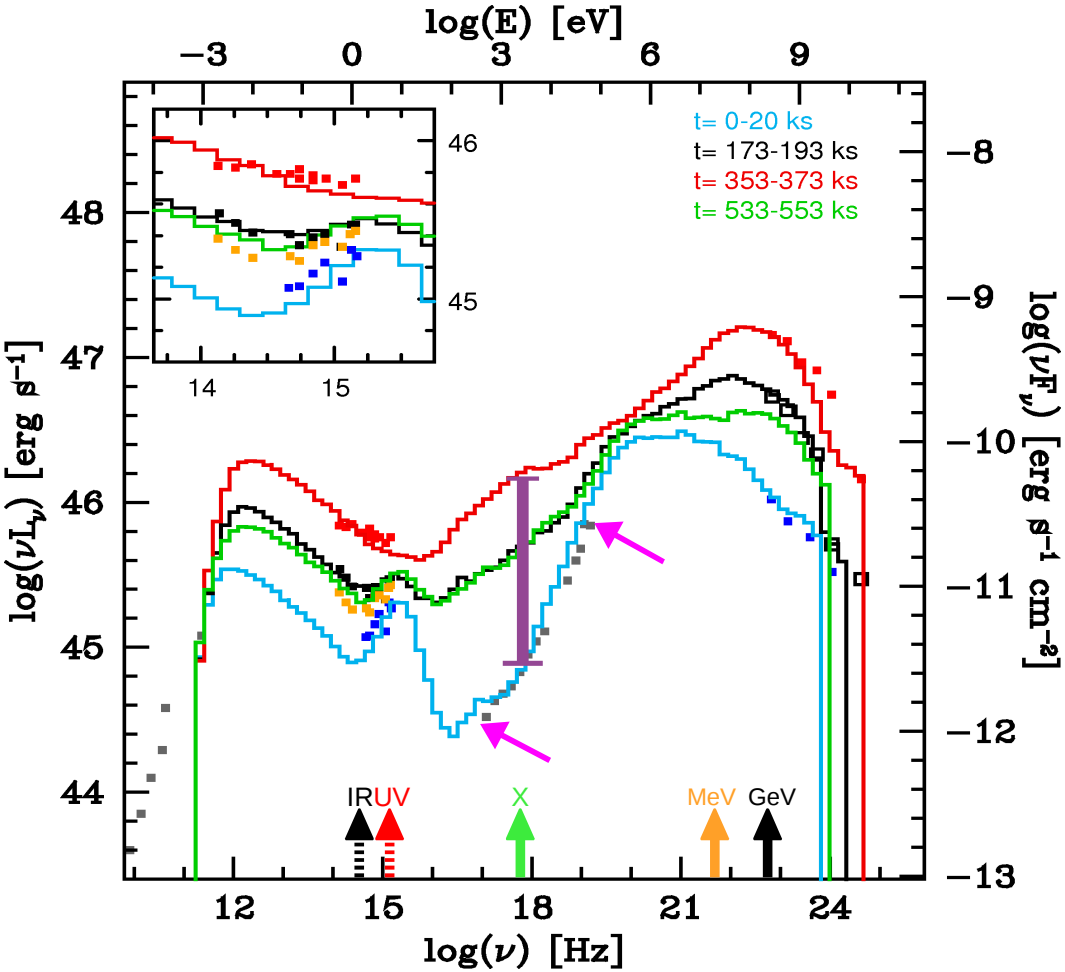
- First we set up the “blob” to reproduce the quiescent (not-very-variable) state.

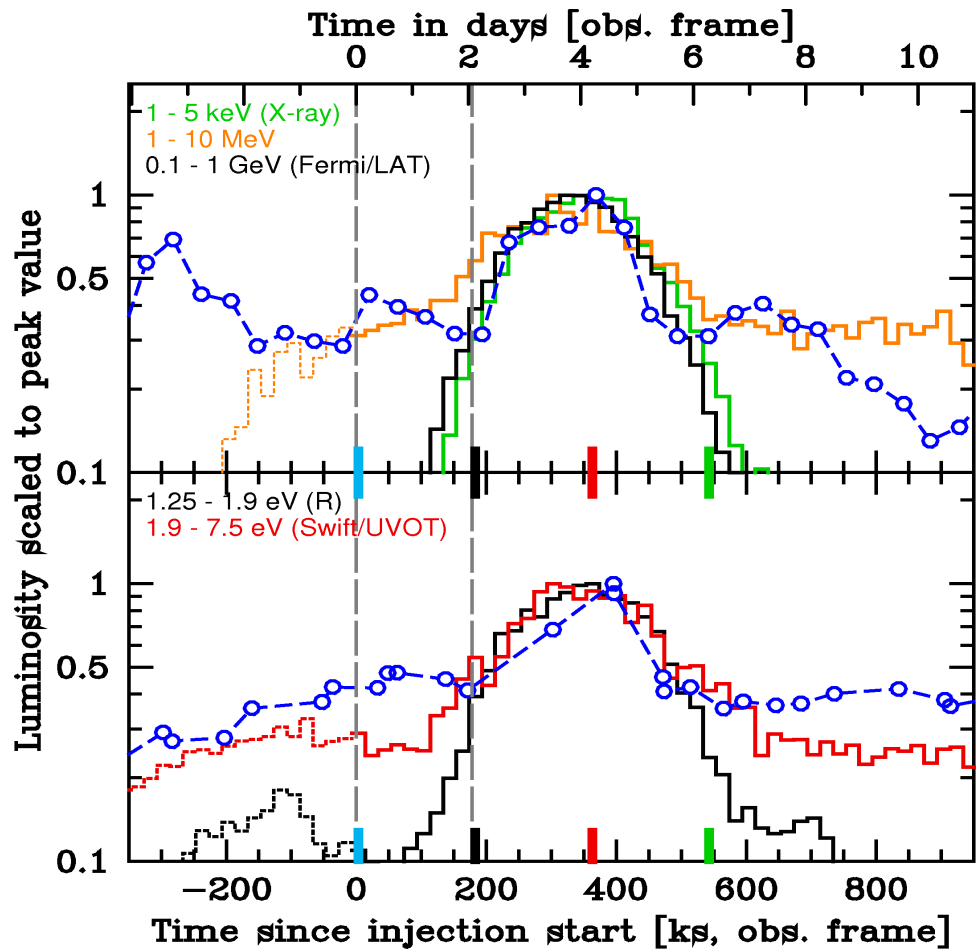
EC/BLR, δ=15, non-flaring, compare BLR spectra



- The results are fairly sensitive to the spectrum used for the external radiation, in particular in the X-ray band, where we often have very good observed spectra, hence very effective constraints.

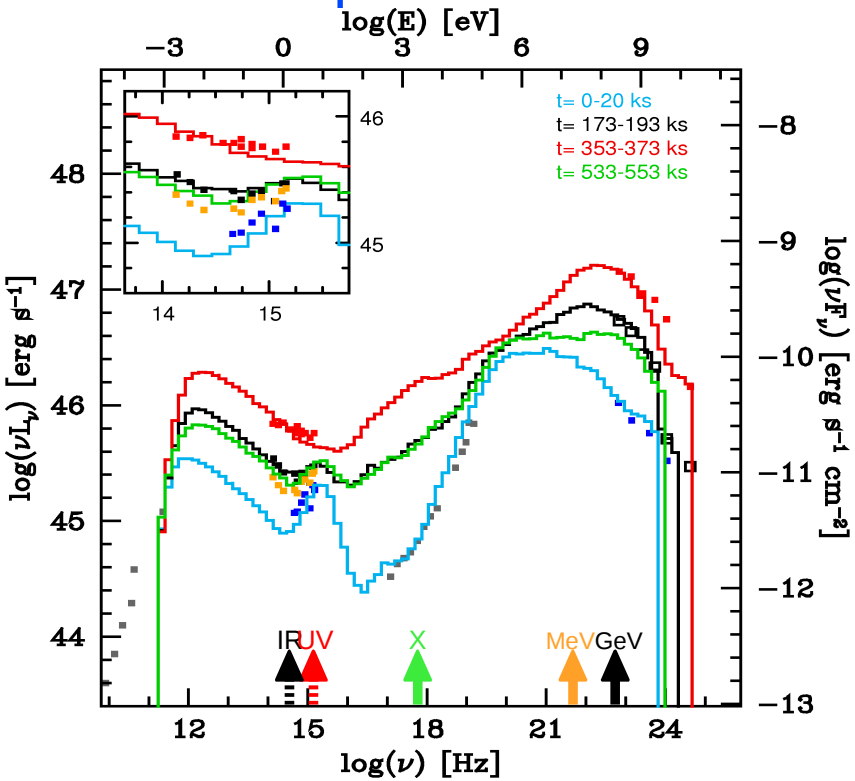
EC/BLR, δ=15 [blr15]

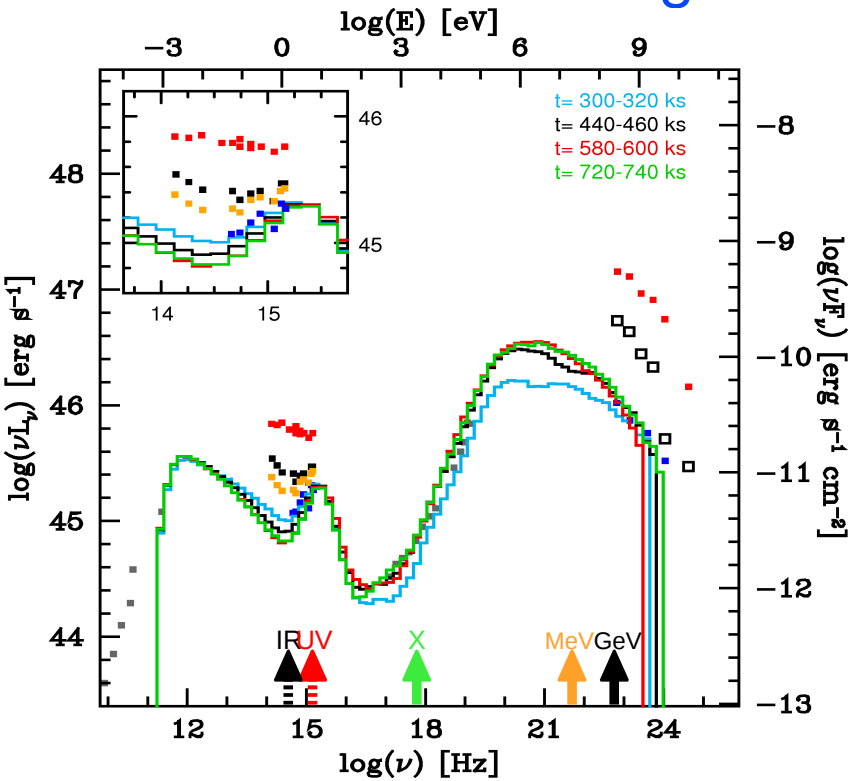




- Very large variation in X-rays, **not observed!**
- It is caused by SSC filling-in (and more) the range between synchrotron and EC emission. SSC varies quadratically with respect to synchrotron, and it can't be avoided, hence any variation in the synchrotron part will be accompanied by a larger increase of the SSC emission.

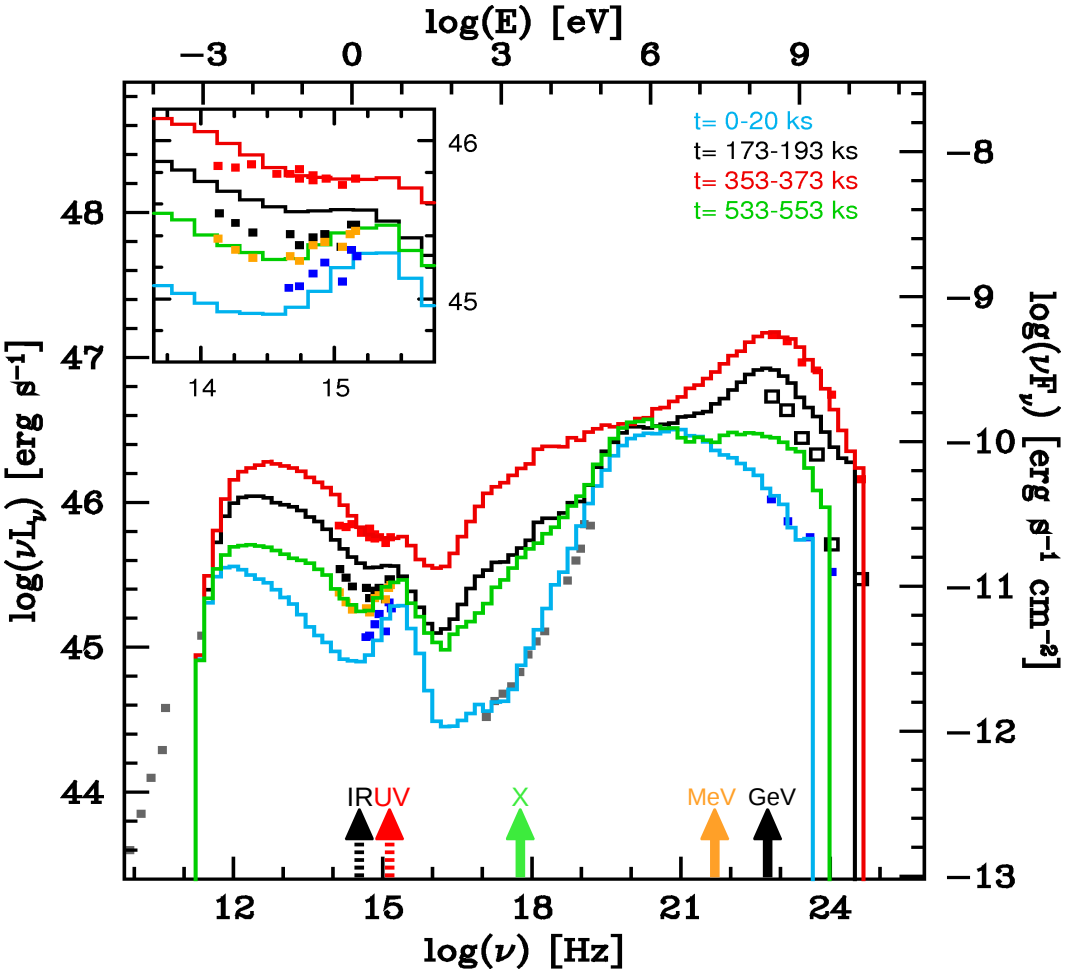
quiescent vs. flaring state and the importance of time-dependent multi-zone modeling

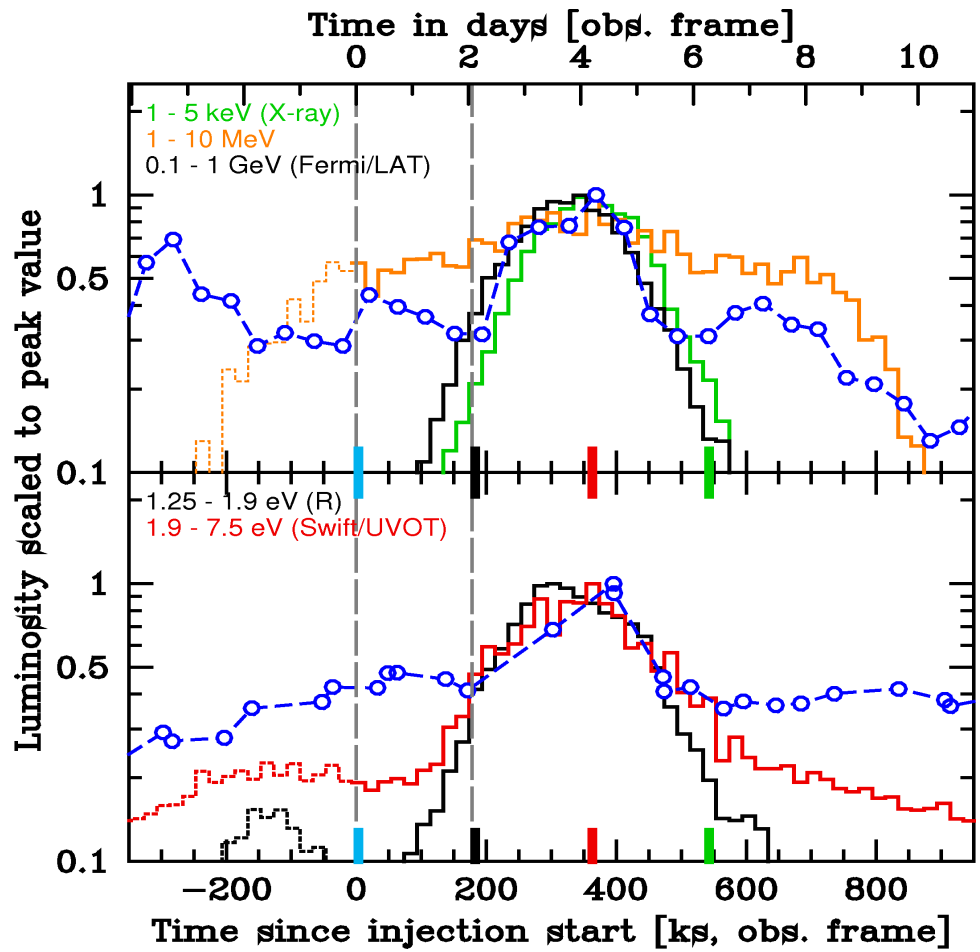




- SEDs are significantly more complex in the shape and variation of the high energy component because we observe a blend of emission produced at different times in zones at different stages of the flare development and with electron distributions at different stages of their evolution.
- Even if locally the processes affecting the electrons are fast and the particle spectrum could be regarded as reaching rapidly a steady state (in the case of injection lasting for a long enough time), the sequence of SEDs produced in a flare is not equivalent to a sequence of steady-state SEDs.

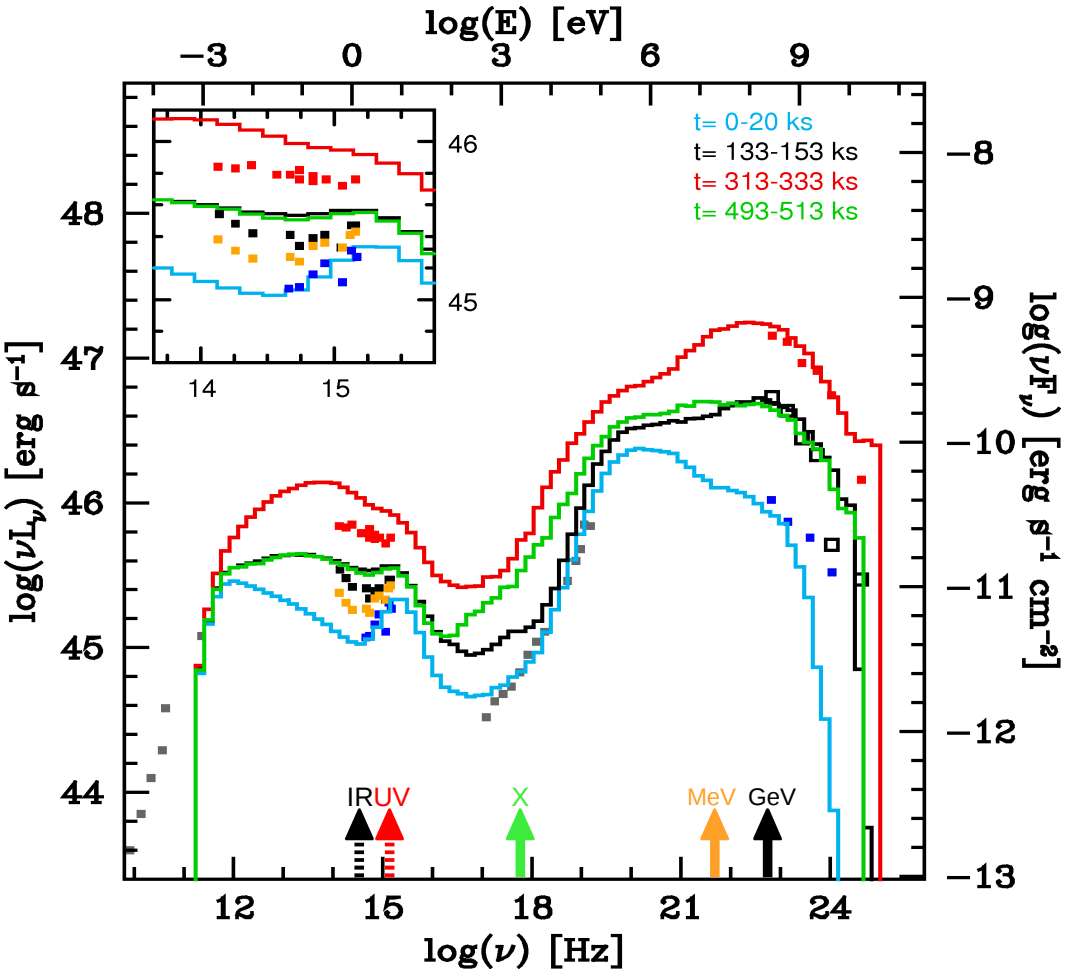
EC/BLR, δ=15, higher $\gamma_{\rm min}$ [blr15high]

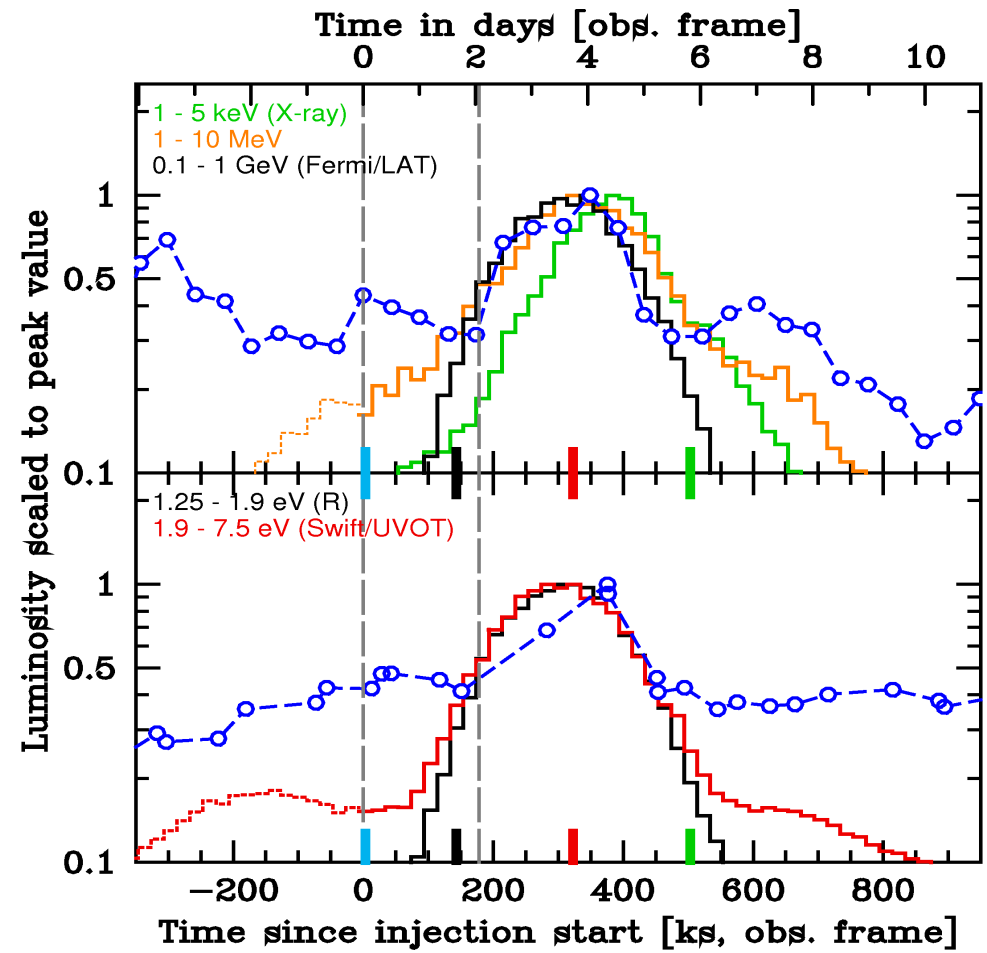




- Increasing the minimum energy of the injected electrons may decrease the SSC emission in the X-ray band.
- However $\gamma_{\rm min}$ is constrained to be below ~100 by the fact that no spectral breaks are observed in the LAT band. No significant improvement could be achieved.

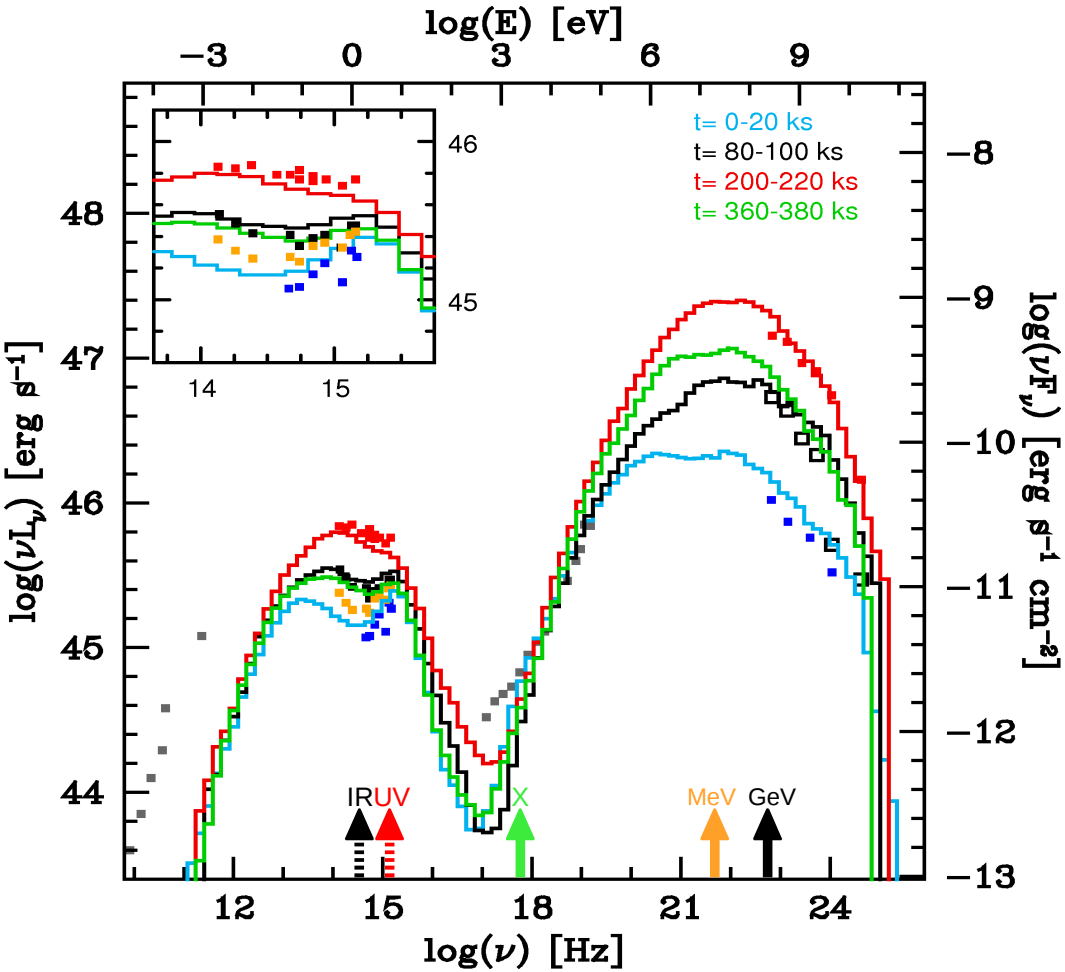
EC/torus, δ=15 [torus15]

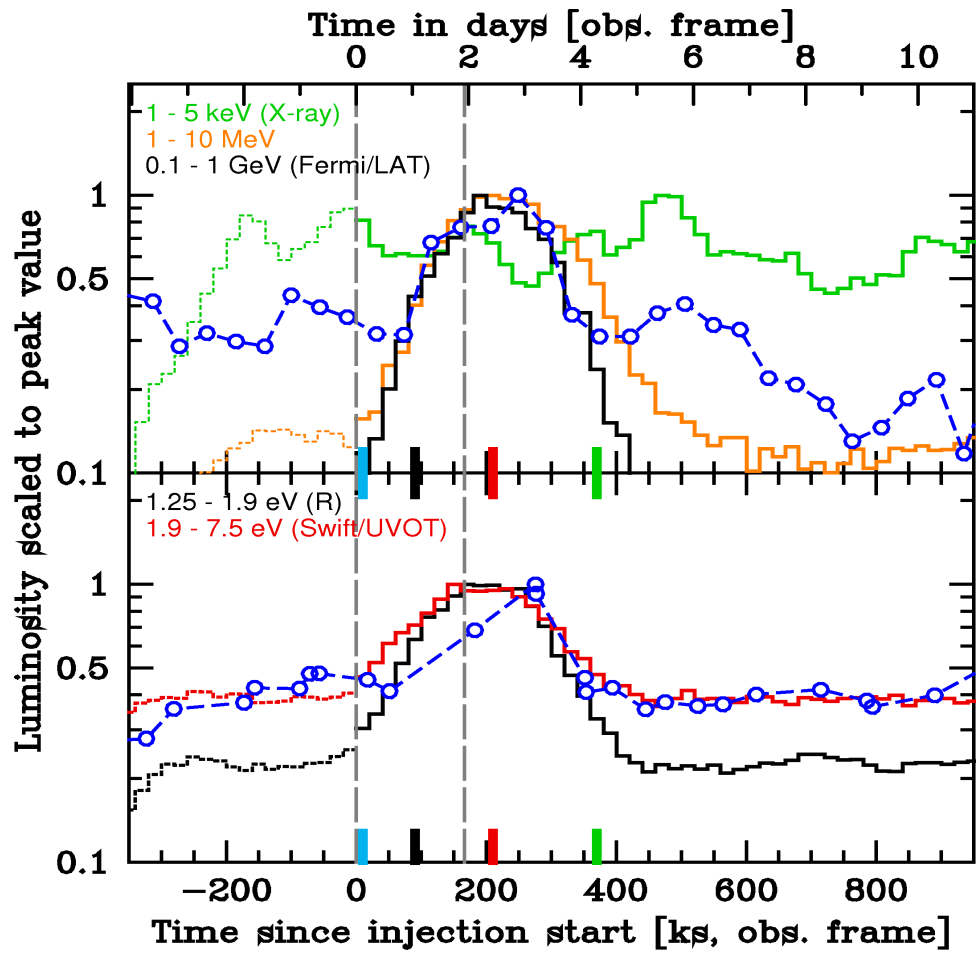




- Overall we can reproduce decently the main observed features, but it proved to be quite difficult to match well the soft FIR-IR-O spectral shape (at the same time of the gamma-ray spectrum)
- Need higher energy electrons because seed photons have lower energy.
- Acceleration and escape timescales become more extreme.

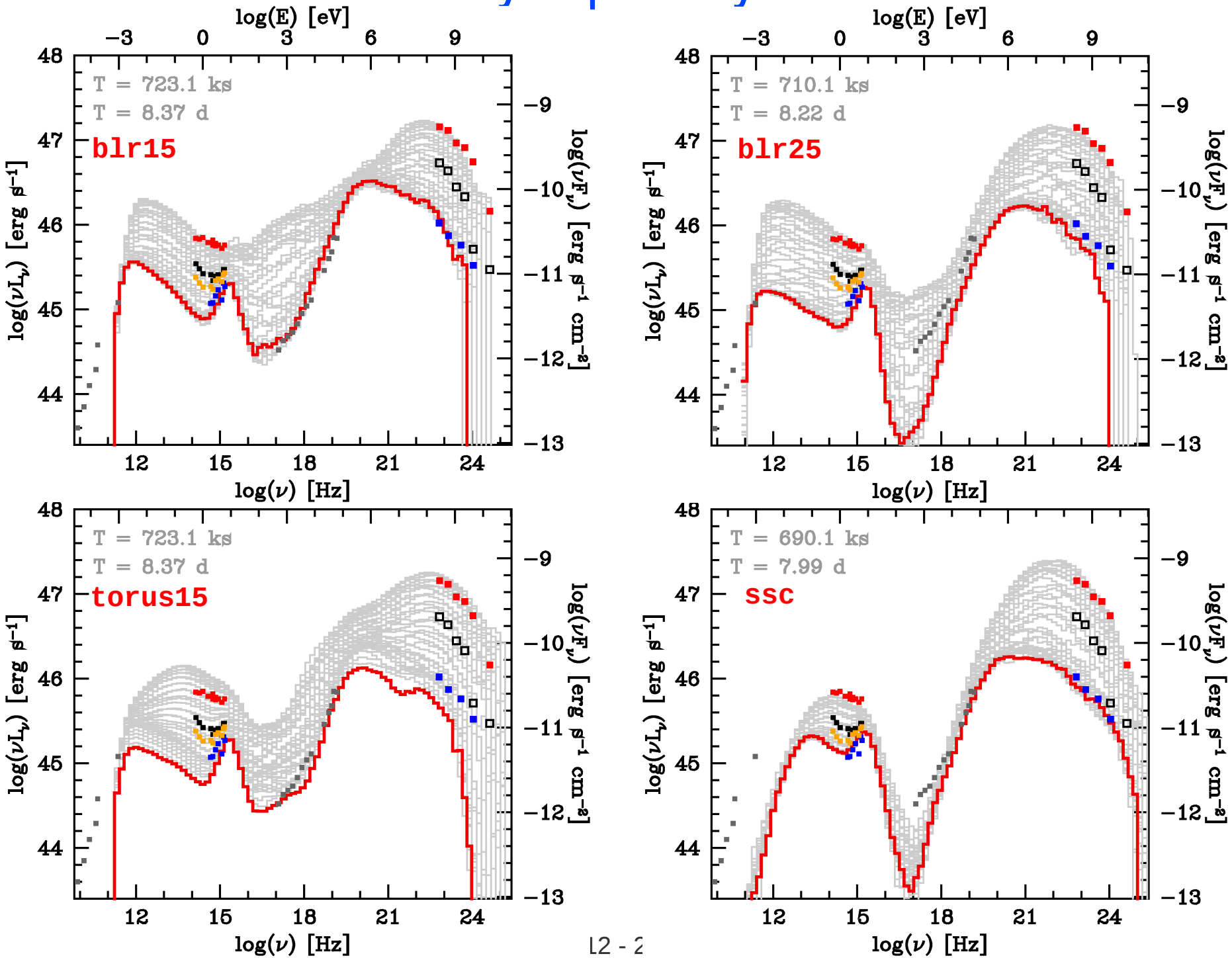
SSC, δ=10 [ssc]





- A pure SSC model could be desirable in light of some recent observations hard to reconcile with the gamma-ray radiation coming from within the BLR.
- Pure SSC does reasonably well, but the X-ray spectrum is too hard, the required $\gamma_{\rm min}$ fairly high (2000), and the IR/O spectrum is not soft enough.

synoptically



summary

- We have developed a time-dependent, multi-zone radiative transfer code, necessary to model multiwavelength variability of blazars.
- In the context of this scenario where the flaring is caused by the increase of the number of relativistic electrons ascribed to the effect of the interaction of a portion of the jet (blob) with a shock, we cannot *firmly* discriminate the three main scenarios for gamma-ray emission (EC/BLR, EC/torus, SSC).
- These initial results show clearly the differences produced by a more realistic treatment of the emitting source in the shape of SEDs and their time variability over relevant, observable time-scales, and demonstrate the crucial importance of time-dependent multi-zone finite-size-blob) models to advance our understanding of the physics of these sources, by taking full advantage of the wealth of information offered by the high-quality data of current multiwavelength campaigns.

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