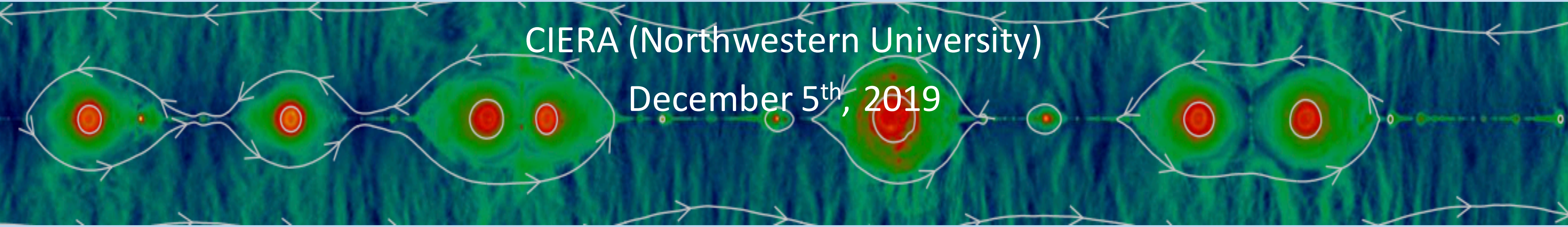
Radiative Signatures of Relativistic Reconnection in Blazar Jets

Ian Christie



CIERA (Northwestern University)

December 5th, 2019

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L. Sironi (Columbia)
D. Giannios (Purdue)
M. Meyer (Stanford)

Blazars

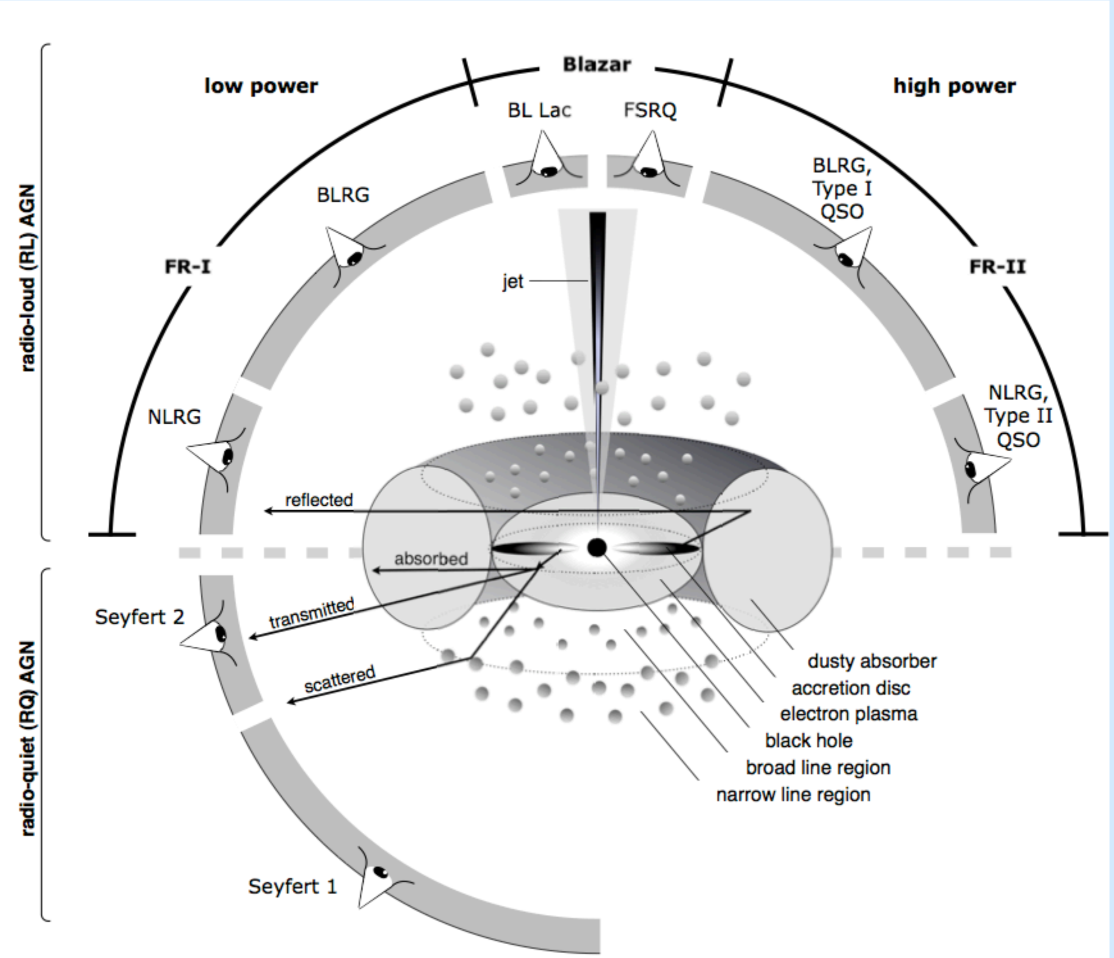
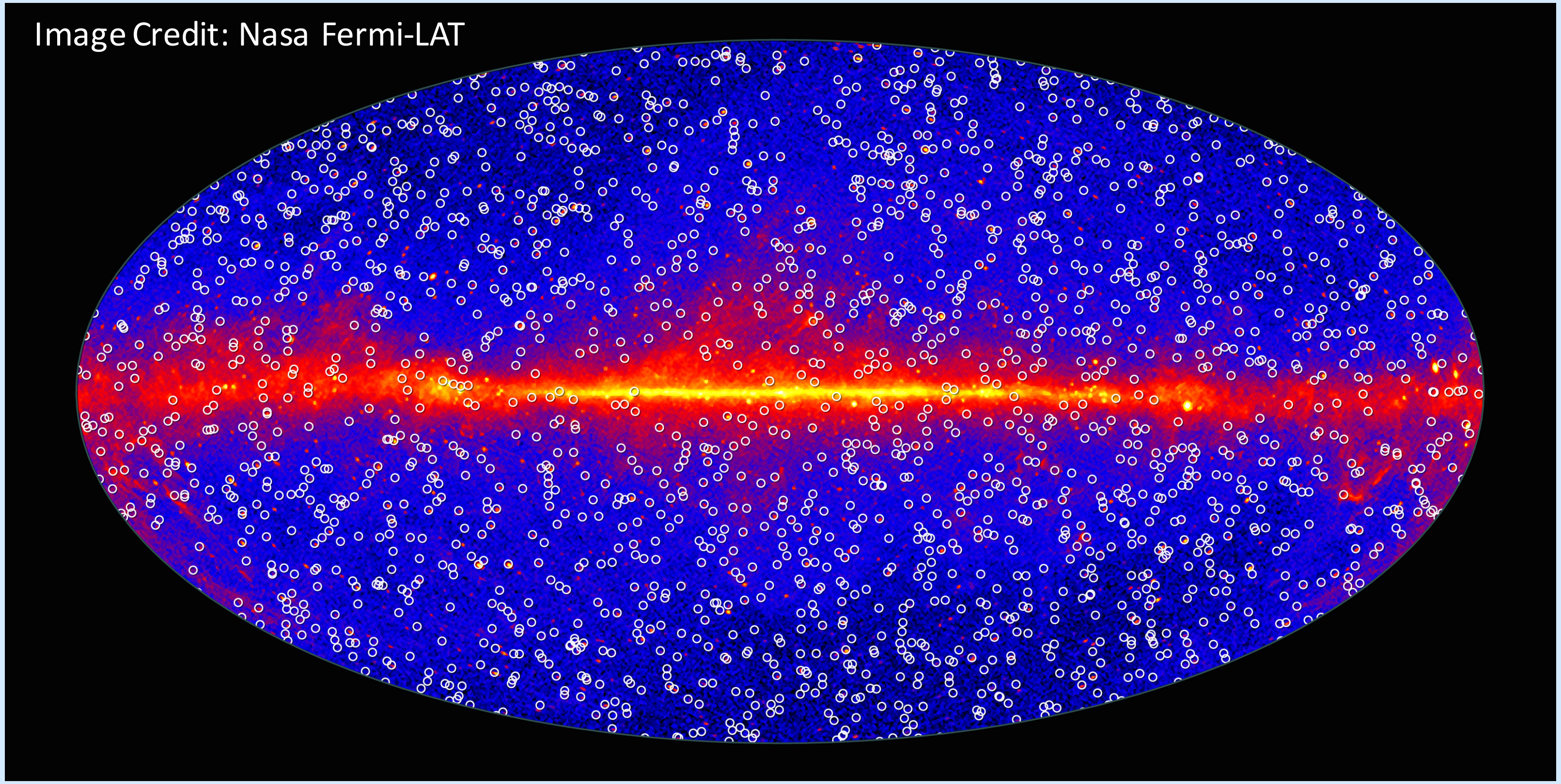


Image Credit: Beckmann & Shrader (2012)

- AGNs with jets pointing towards the observer
- Most abundant sources of extragalactic γ-rays (Ajello et al. 2015)
- Non-thermal, multi-wavelength emission

Blazars

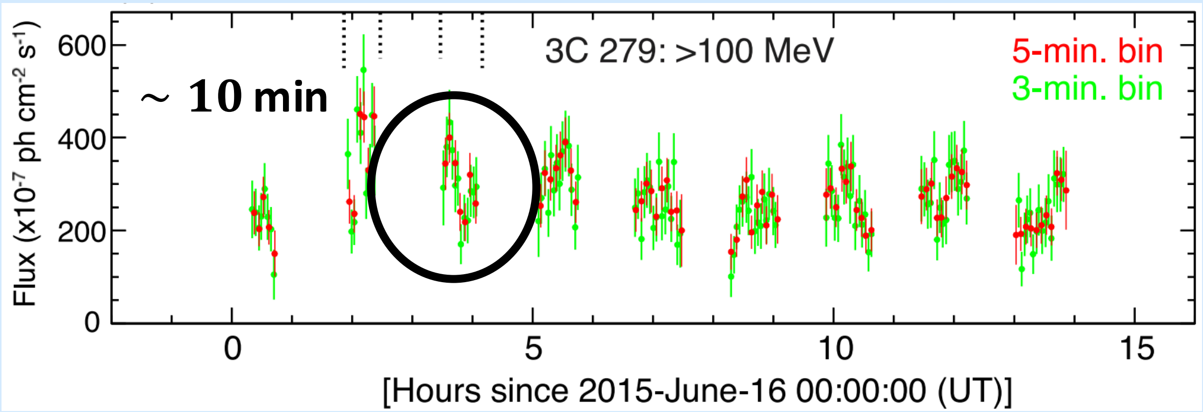
Catalog of Fermi-LAT Detected AGN



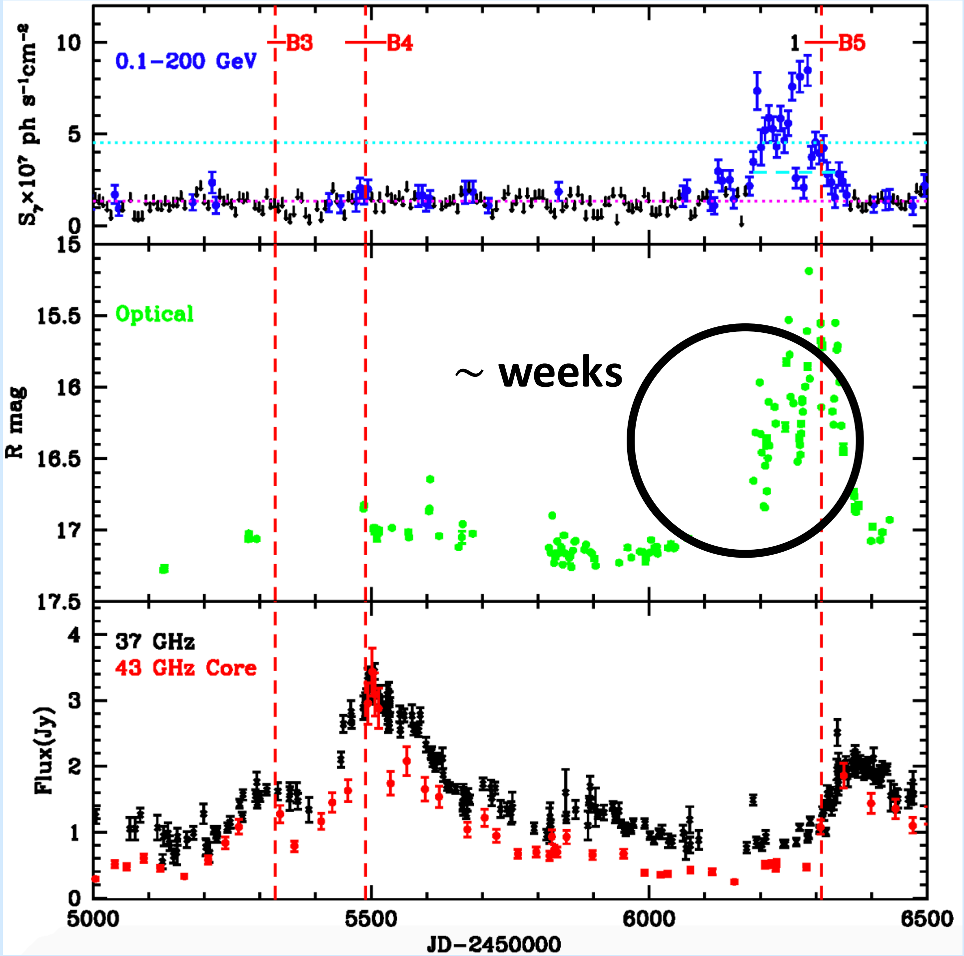
- ❖ AGNs with jets pointing towards the observer
- ❖ Most abundant sources of extragalactic γ-rays (Ajello et al. 2015)
- ❖ Non-thermal, multi-wavelength emission

Blazar Variability

Quasar:
0827+243



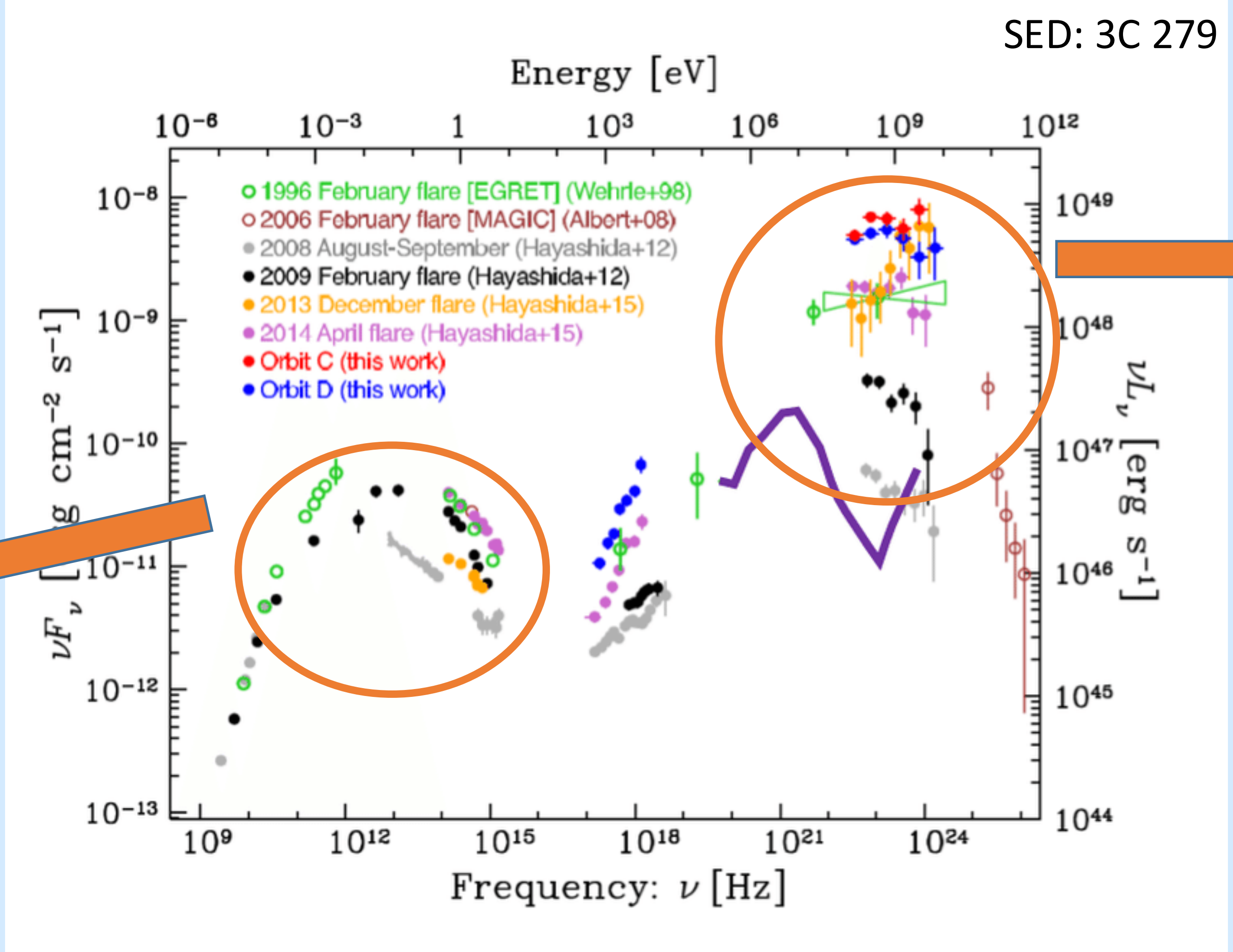
Ackermann et al. 2016



Jorstad & Marscher 2016

- ❖ Multi-wavelength variability lasting from minutes to weeks!

Blazar SED: FSRQ

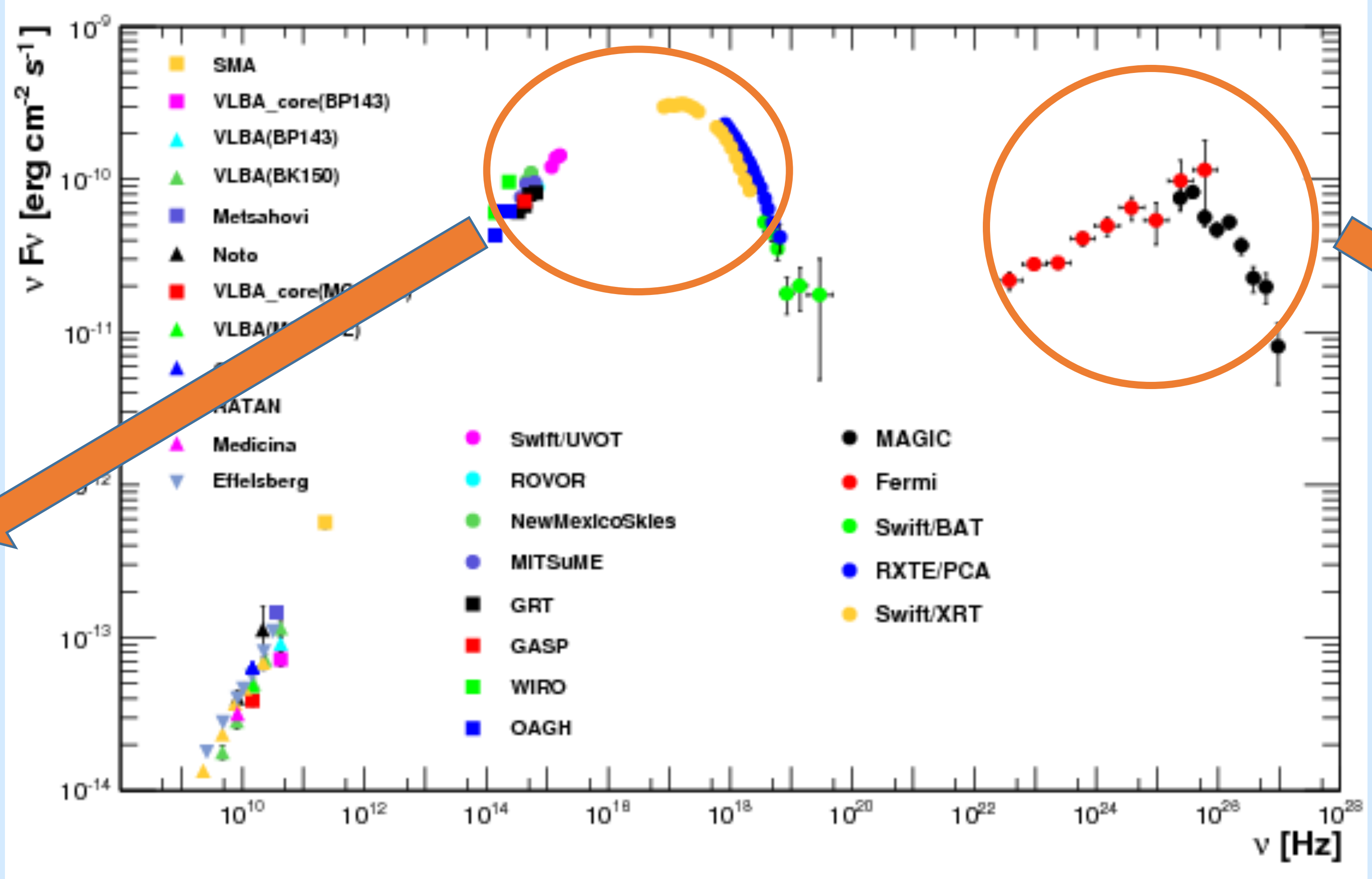


High-energy Bump:
Inverse Compton
(SSC or EC)

Low-energy Bump:
Synchrotron

Blazar SED: BL Lac

SED: Mrk 421



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High-energy Bump:
Inverse Compton
(SSC or EC)

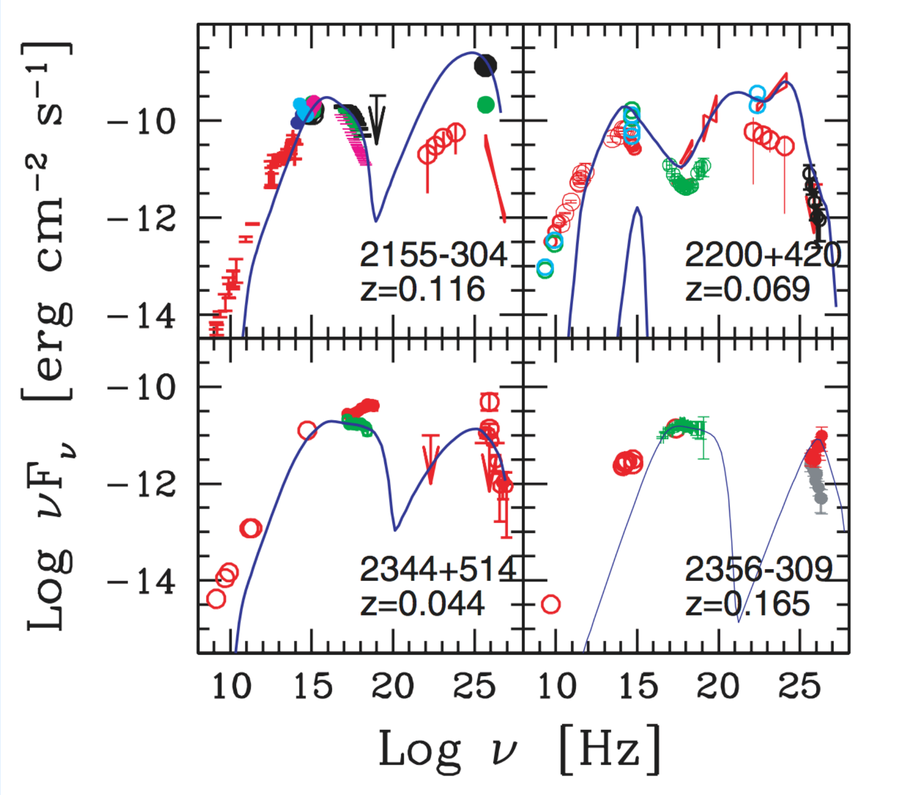
Previous Emission Modeling

- Modeled individual flaring events

- Assumed relativistically moving blob contained magnetic fields and a relativistic, non-thermal particle distribution

(Mastichiadis & Kirk 1995, Bloom & Marscher 1996, Chiaberge & Ghisellini 1999, Celotti & Ghisellini 2008)

1-zone Blazar SED Modeling

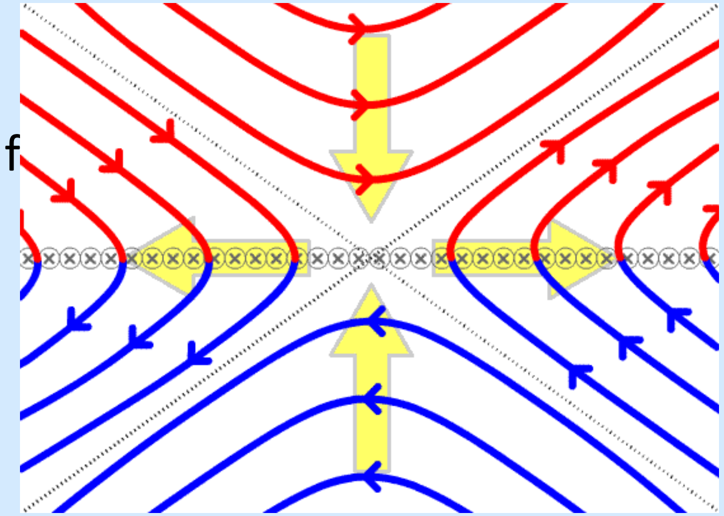


Celotti & Ghisellini 2008

Can we model blazar emission?

- Short-term variability < light-crossing time
- Large Doppler factor of emitting regions > inf bulk Lorentz factor of jet
- How do we obtain relativistic, non-thermal particles?

Animation of Magnetic Reconnection



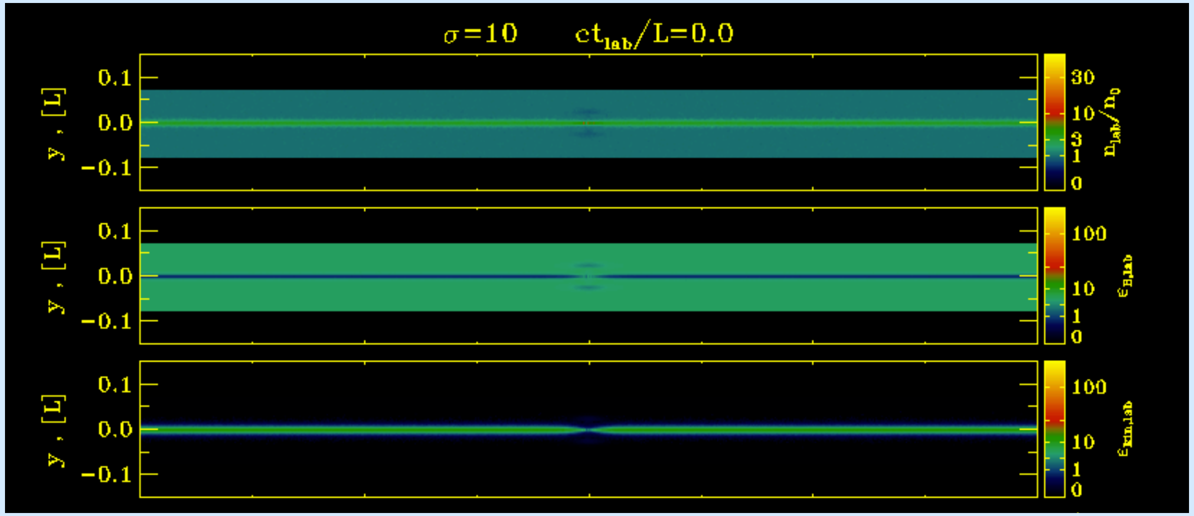
Magnetic Reconnection & PIC

- ❖ Reconnection can:
  - i. accelerate particles to relativistic energy
  - ii. produce relativistically moving *plasmoids*

- ❖ Is simulated through *first-principles* particle-in-cell (PIC) simulations

(Guo et al. 2014, Sironi et al. 2015 & 2016, Werner et al. 2016, Sironi & Spitkovsky 2014)

PIC Simulation of Relativistic Reconnection:
density, kinetic energy, magnetic energy



Sironi et al. 2016

Particle Acceleration in Reconnection

❖ Particles are accelerated at:

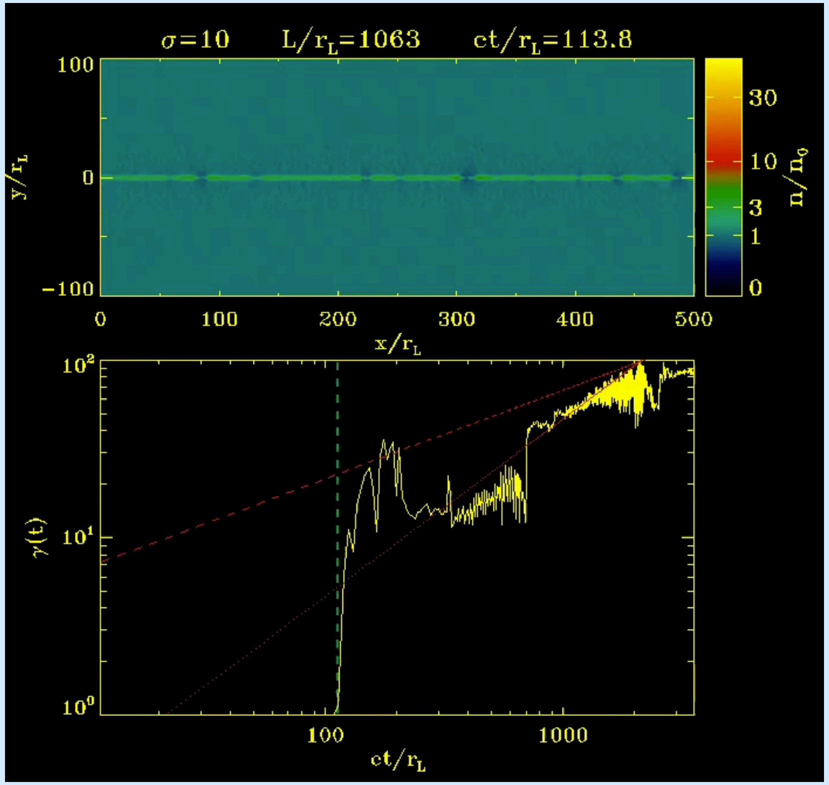
i. X-points

ii. during mergers of plasmoids (i.e. secondary reconnection)

iii. plasmoid compression

(Guo et al. 2014, Sironi et al. 2015 & 2016, Werner et al. 2016, Sironi & Spitkovsky 2014, Petropoulou & Sironi 2018)

Particle Evolution with Reconnection Layer



Petropoulou & Sironi 2018

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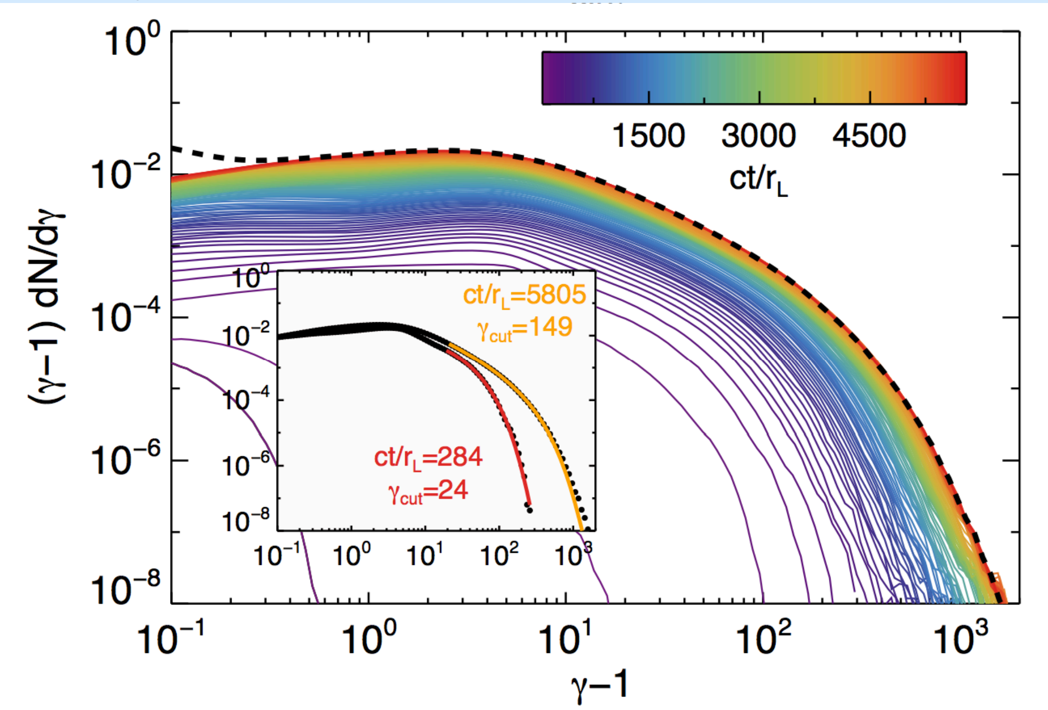
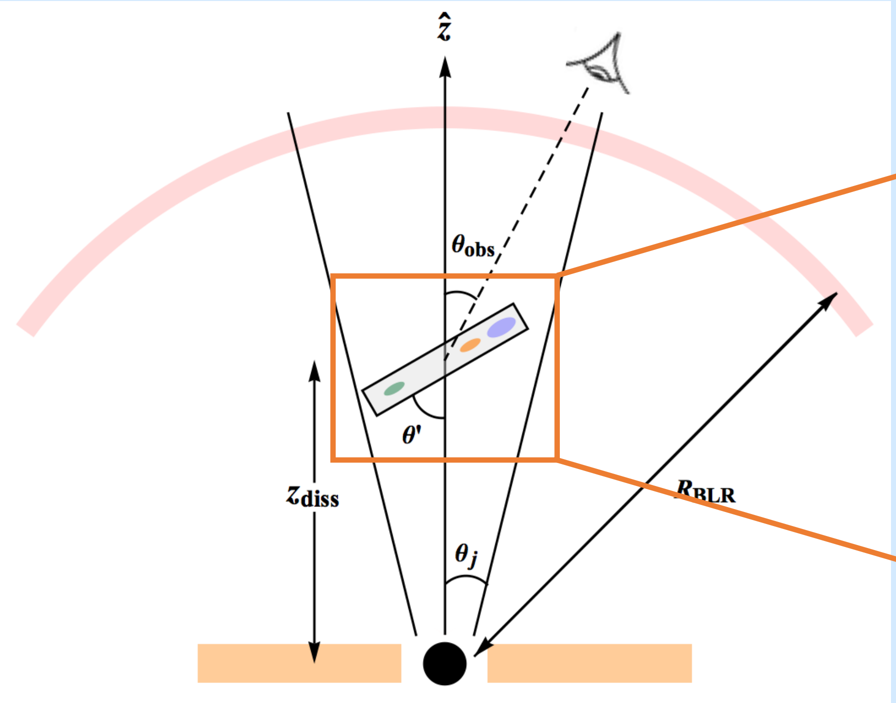
Temporal Evolution of Relativistic Particle Distribution



Petropoulou & Sironi 2018

Blazar Flares Via Plasmoids

Schematic Diagram of Blazar Jet



Christie et al. 2018

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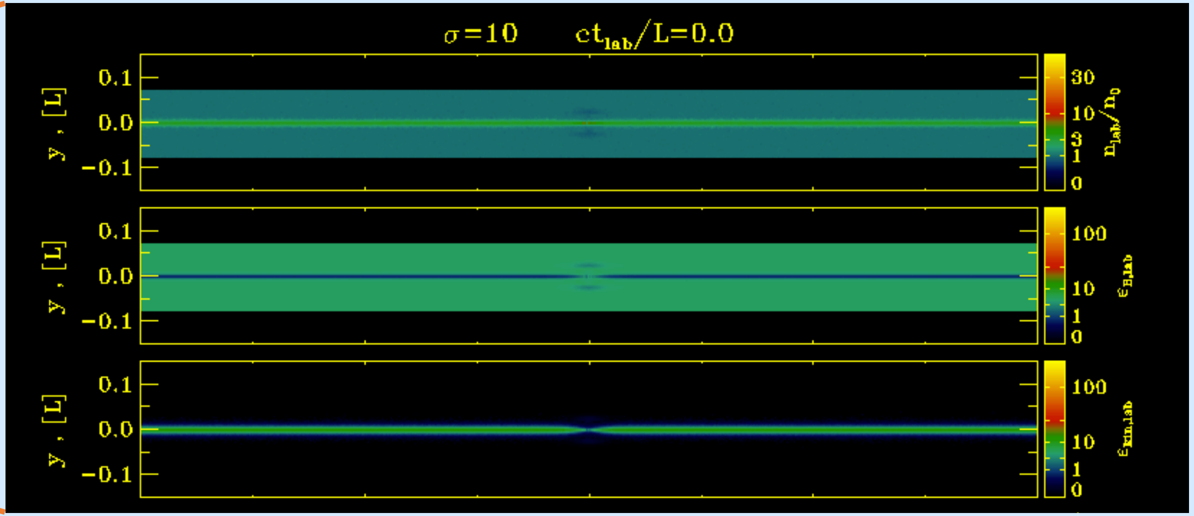


Sironi et al. 2016

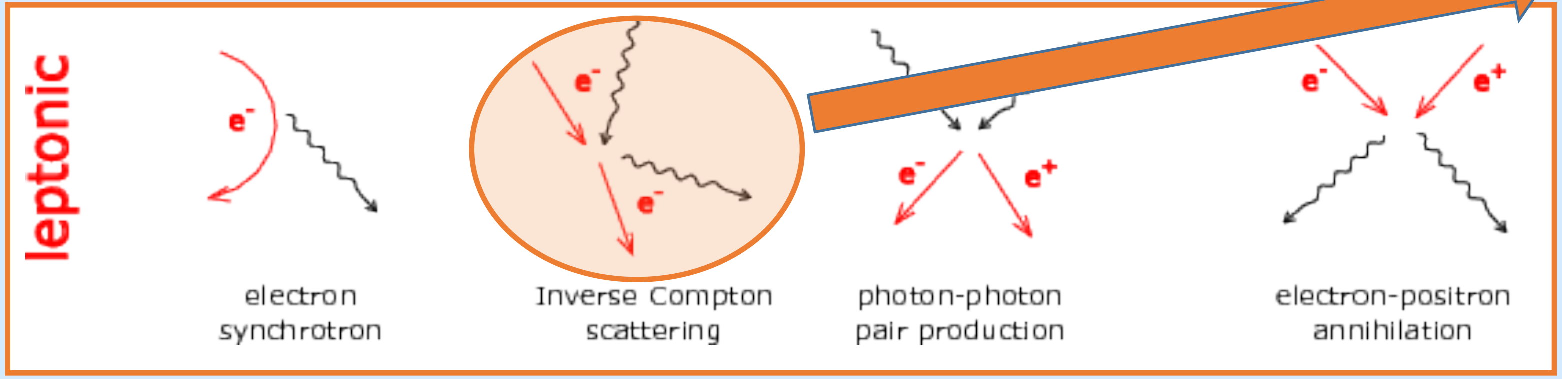
Our Emission Model

- Use 2D PIC simulation results of relativistic magnetic reconnection

- PIC governs majority of model parameter → ***few free parameters (e.g. B-field, size of reconnection layer, strength of external radiation fields, orientation of reconnection layer)***

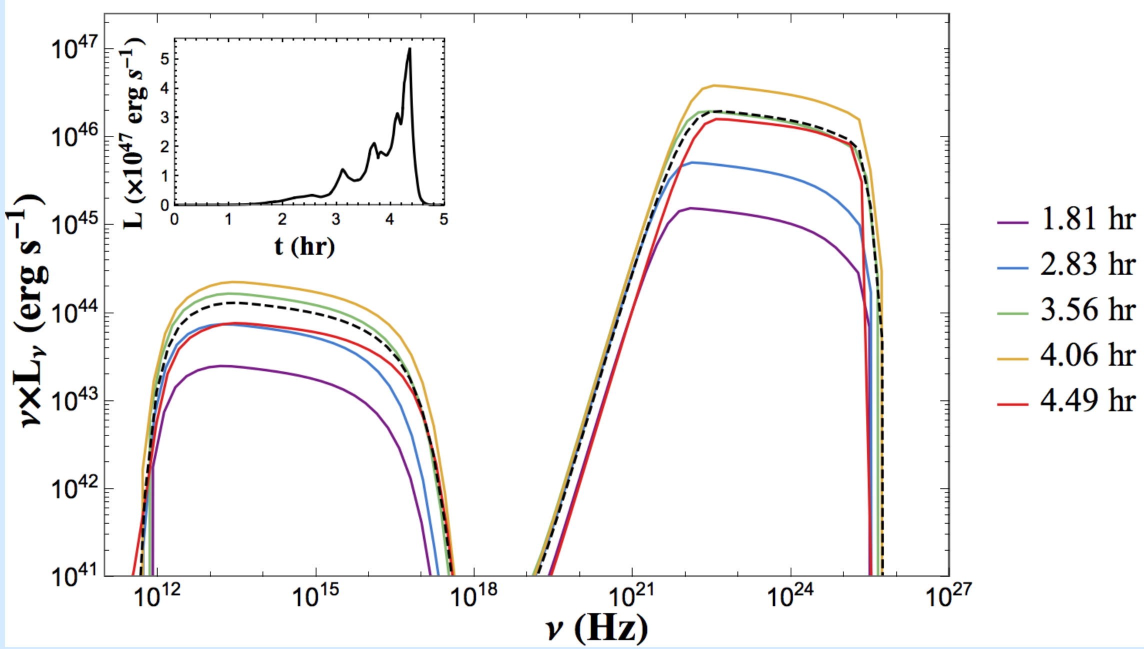
- Compute the emission from the entire reconnection layer → ***model BL Lacs & FSRQs***

Includes emission from Broad Line Region

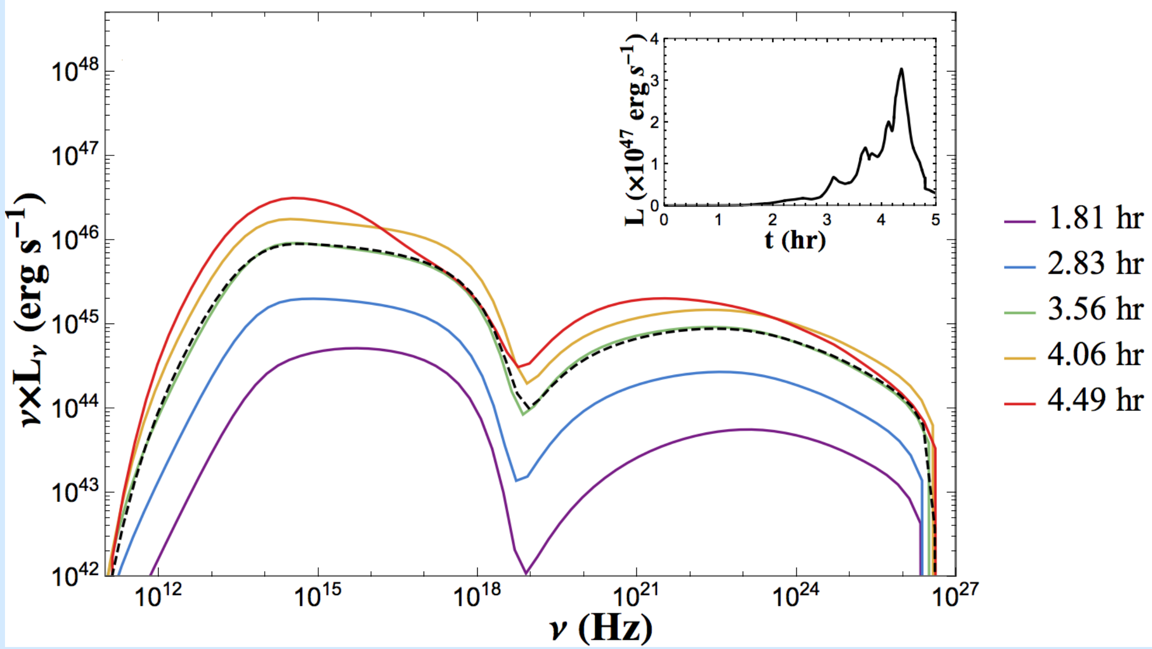


Individual Plasmoid Spectra & Light Curves

FSRQ Modeling



BL Lac Modeling

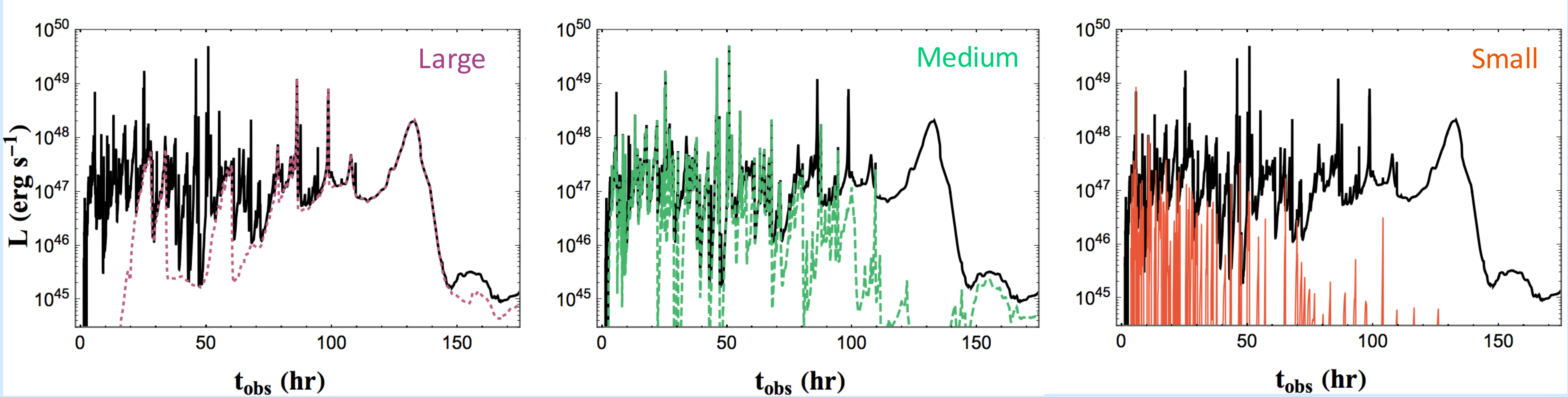


Same Medium Sized Plasmoid
Different External Radiation Fields

Christie et al. 2018

Plasmoid Size Dependence

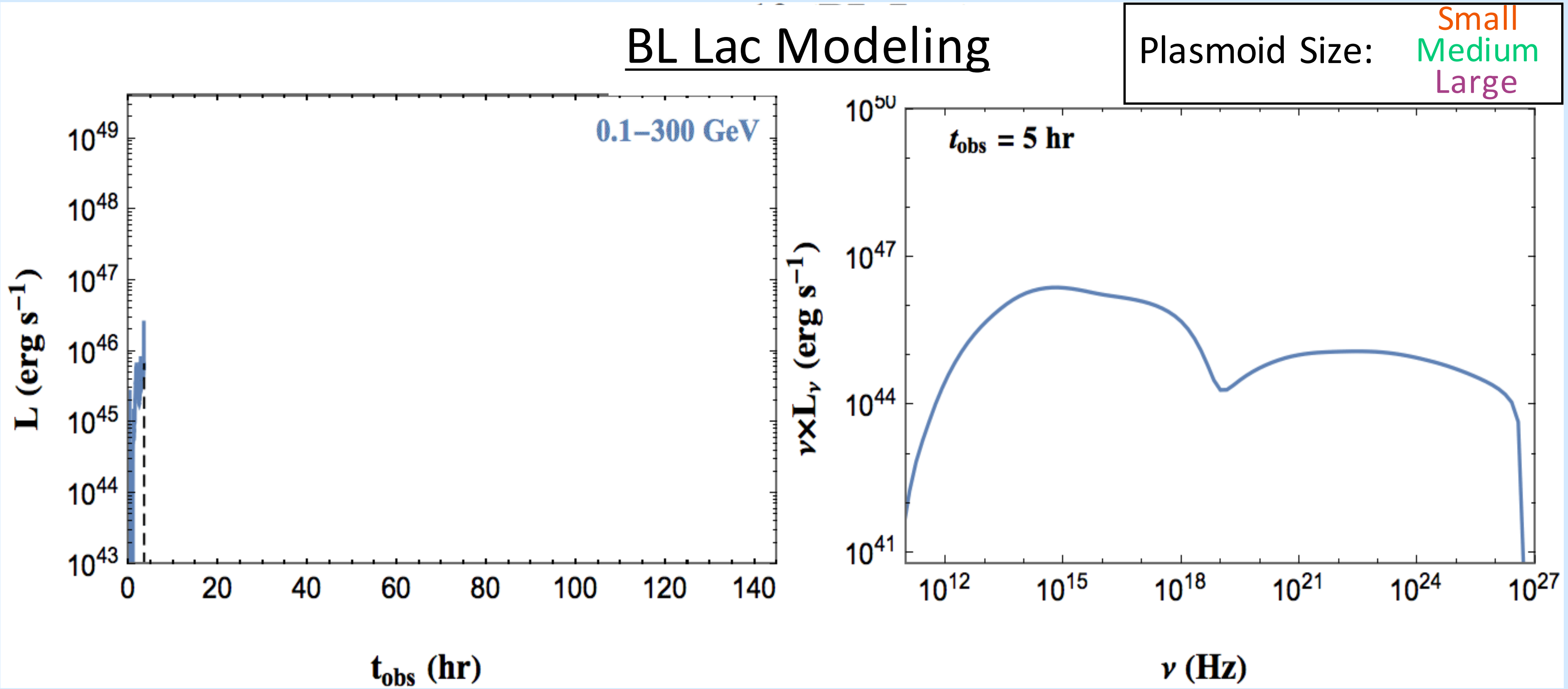
0.1 – 300 GeV Light Curve



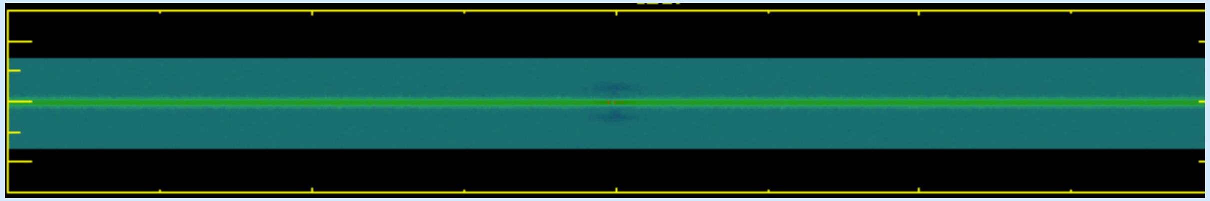
Christie et al. 2018

❖ Fast flares, produced by medium-sized plasmoids, appear on top of a slow-evolving envelope developed by the largest plasmoids

Temporal Evolution of Layer's Spectra

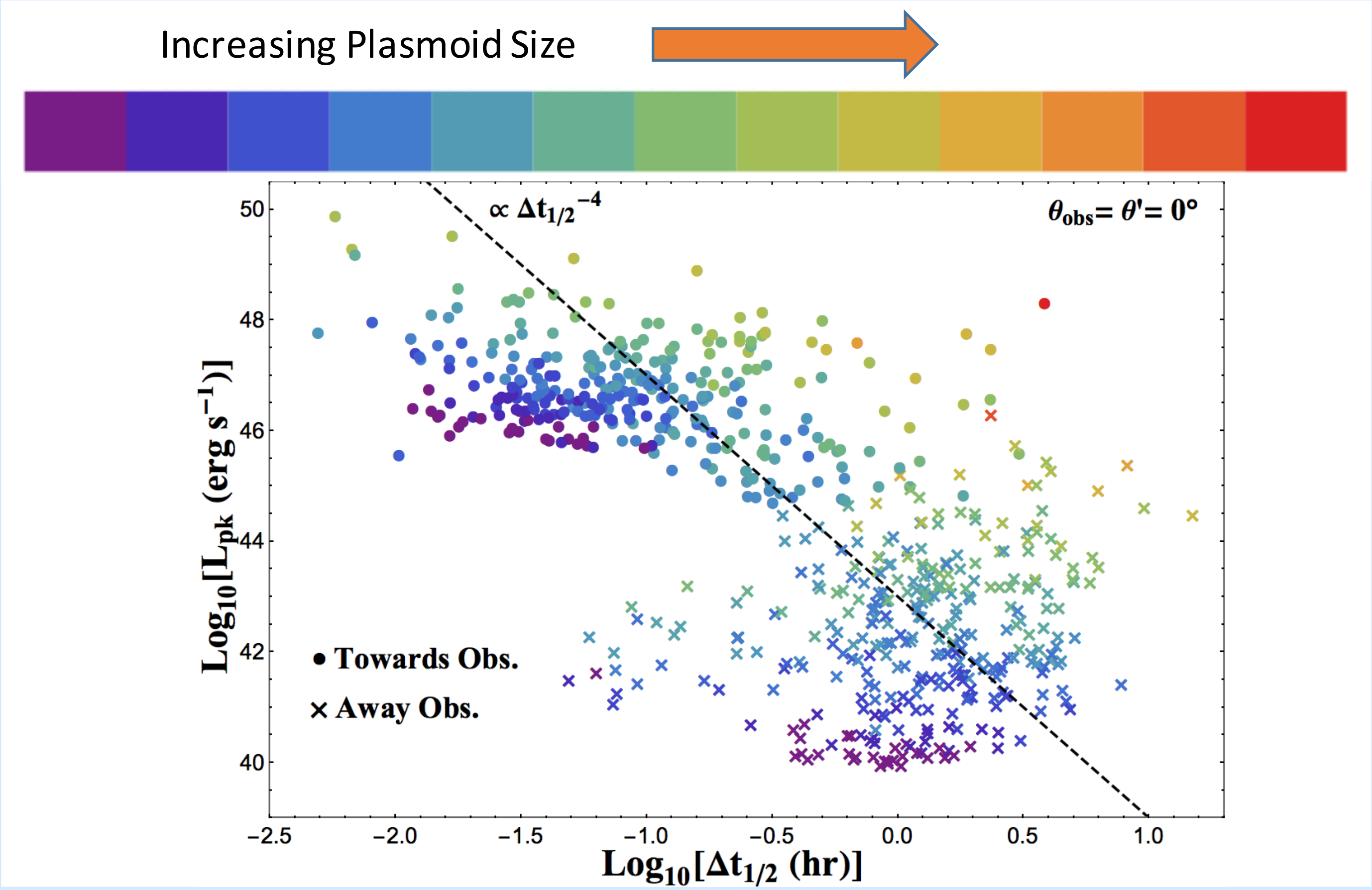


Jet Lorentz factor: 12
Size of Reconnection layer: 10^{16} cm
B-field: $2G$

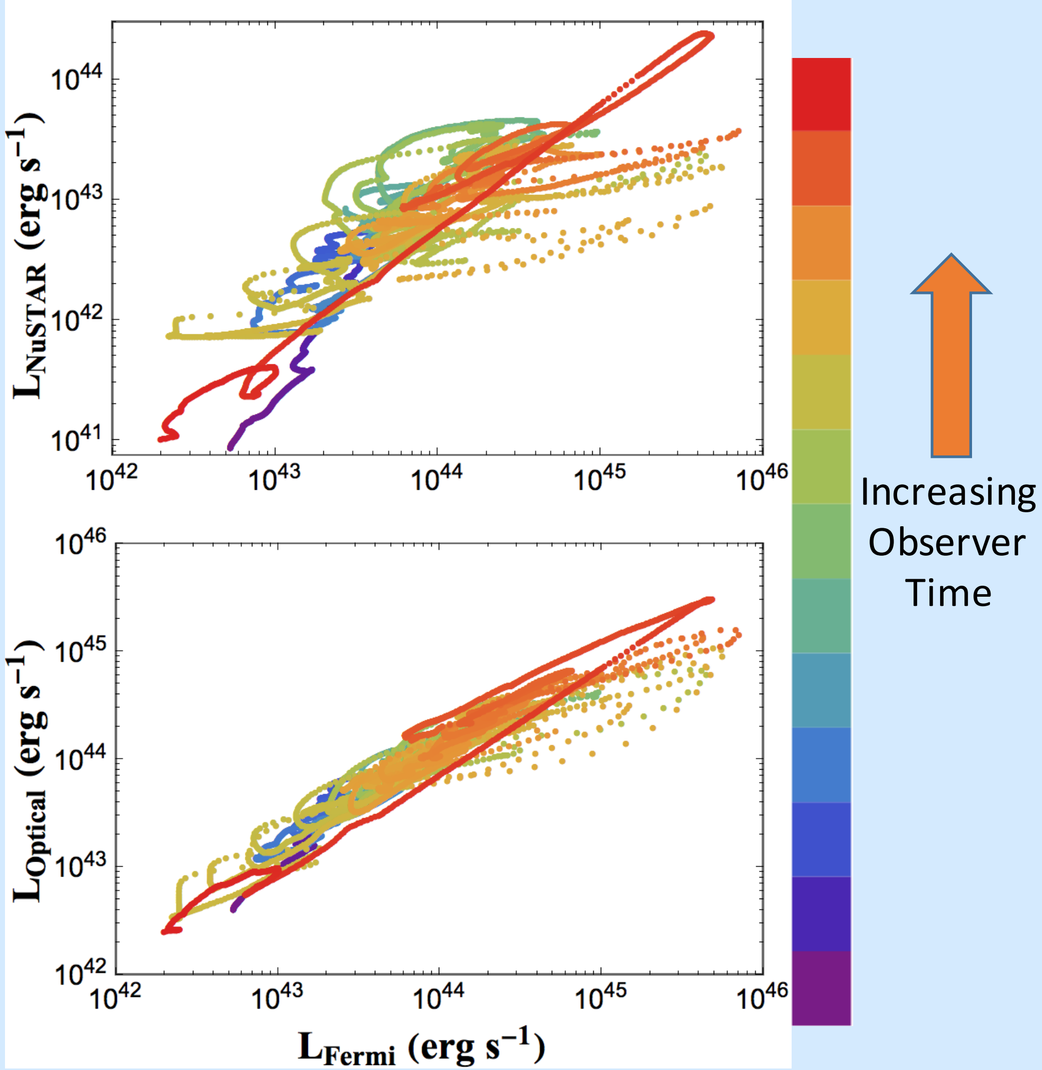


Additional Signatures

Flaring Statistics



Christie et al. 2018

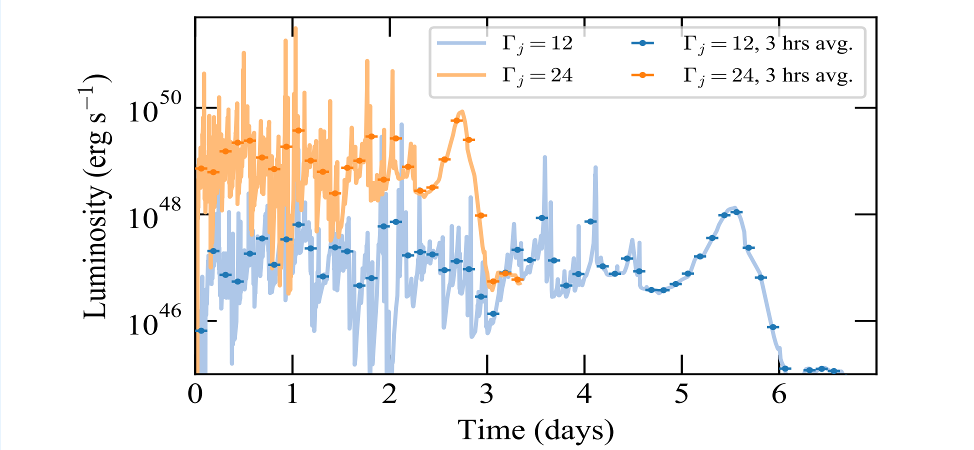


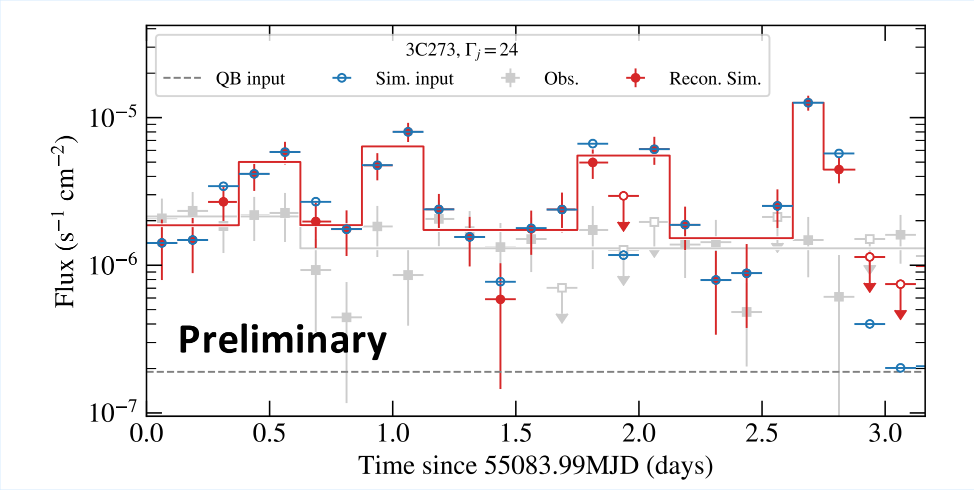
Christie et al. in prep.

Detectability of Model Light Curves

- Conduct a standard Fermi analysis on our simulated light curves → reconstruct source light curves
- Test which features of the model light curves are retained within Fermi observations

Meyer, Petropoulou, Christie, in prep.





Summary

- Our fundamentally-built model displays similar temporal and spectral features in FSRQs and BL Lacs!
- Because of the fundamental nature of PIC, we require few free parameters

Outlook

- Numerous comparisons with observations (e.g. PSDs, correlation, flaring statistics) to come!
- PIC simulations of proton-electron plasmas **+** lepto-hadronic radiative model

<u>arXiv: 1807.08041, 1908.02764</u>

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