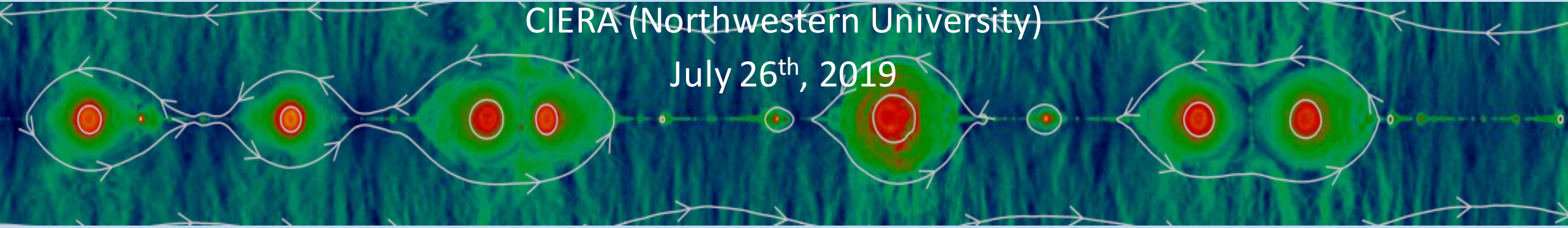
Radiative Signatures of Relativistic Reconnection in Blazar Jets

Ian Christie

CIERA (Northwestern University)

July 26th, 2019



In Collaboration with:

Maria Petropoulou (Princeton)

Lorenzo Sironi (Columbia)

Dimitrios Giannios (Purdue)

Blazars

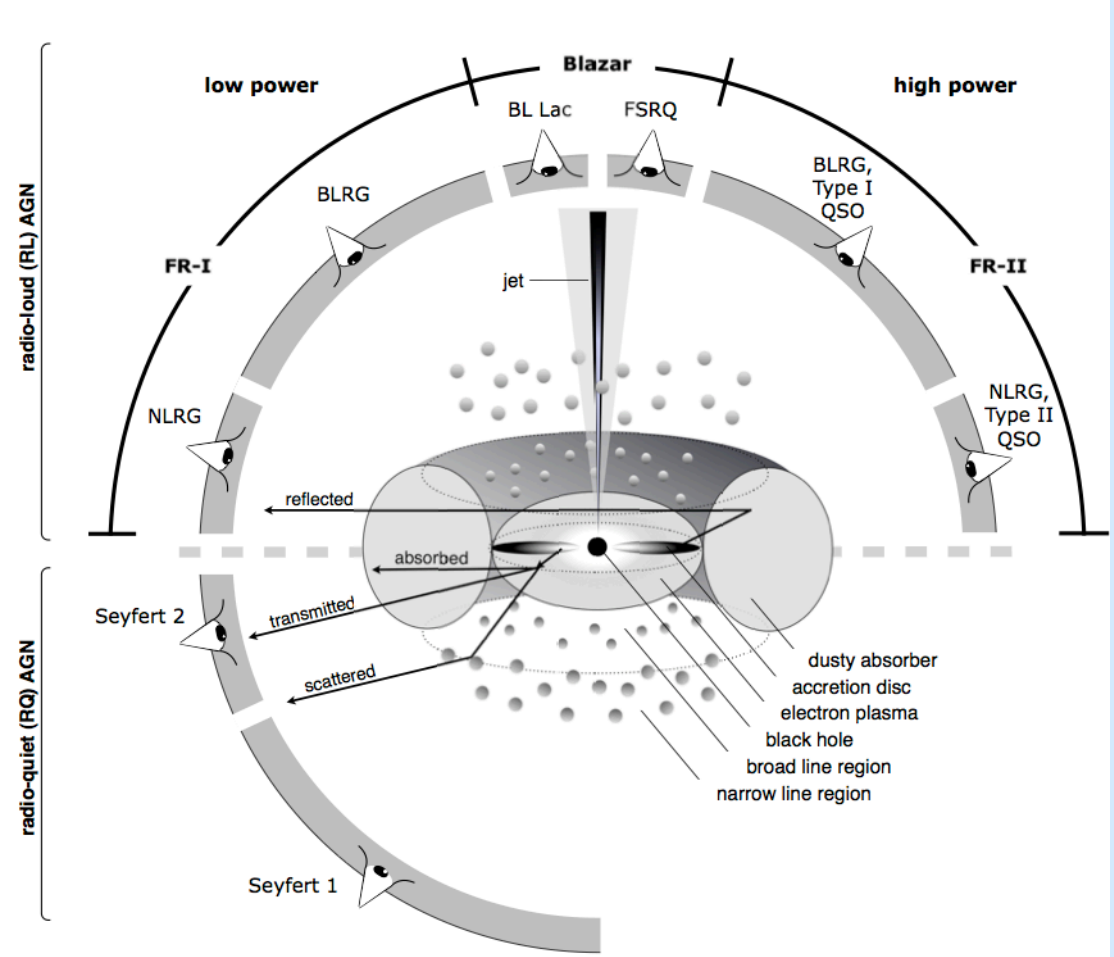
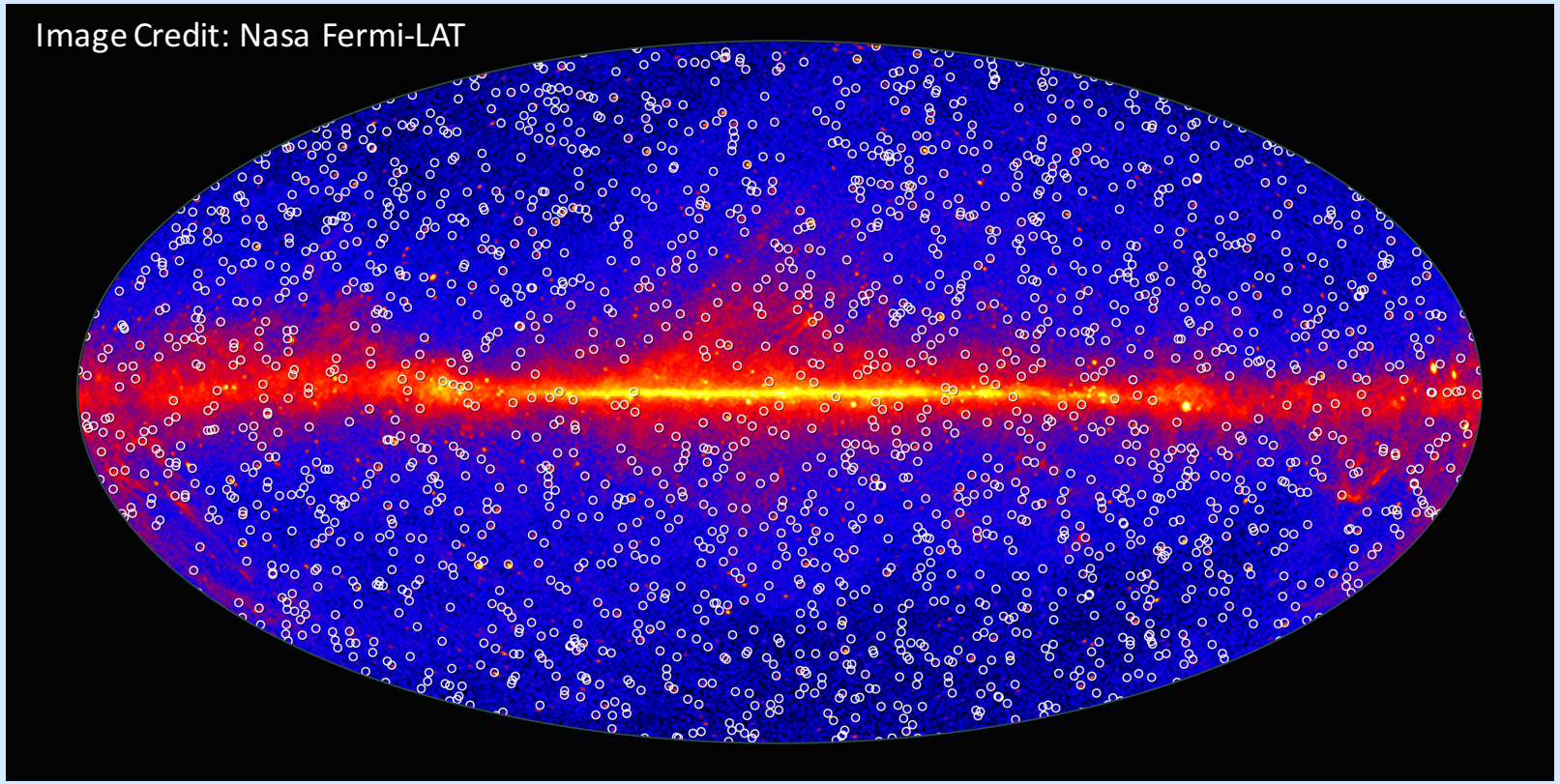


Image Credit: Beckmann & Shrader (2012)

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

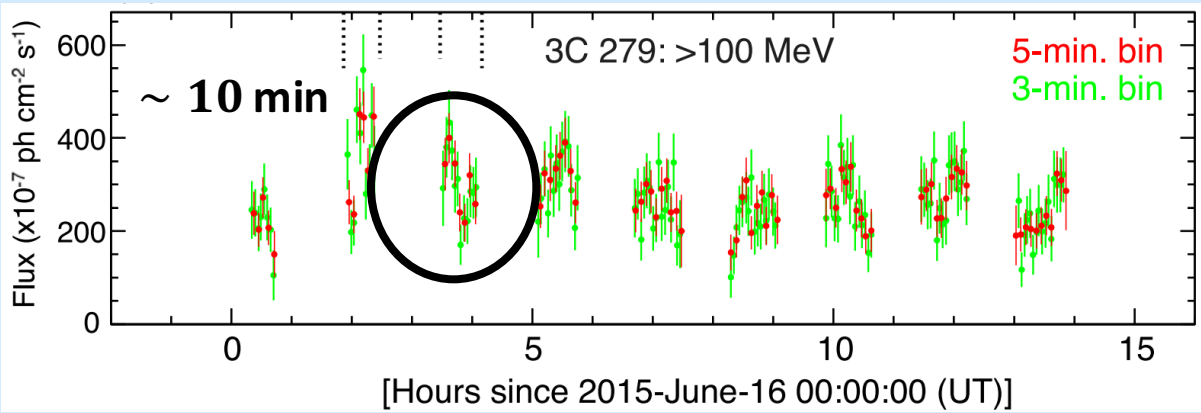
Blazars

Catalog of Fermi-LAT Detected AGN



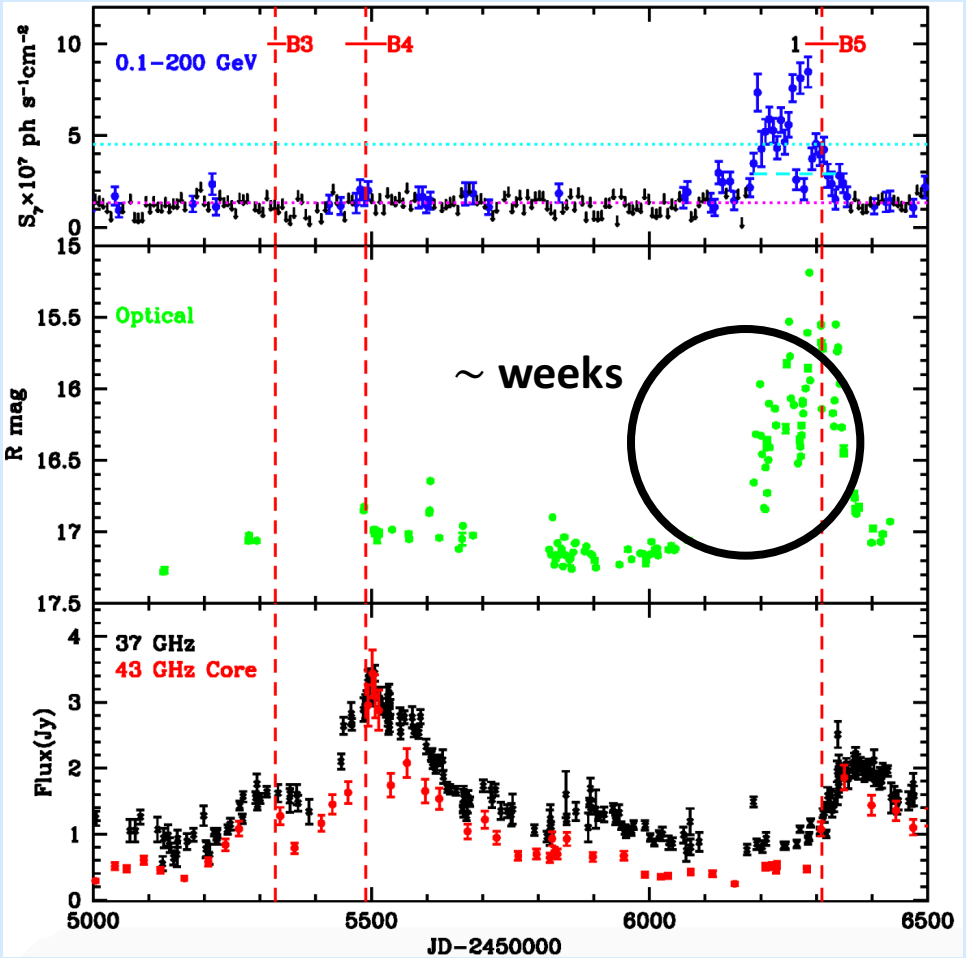
- AGNs with jets pointing towards the observer
- Most abundant sources of extragalactic γ-rays
  (Ajello et al. 2015)
- Non-thermal, multi-wavelength emission

Blazar Variability



Ackermann et al. 2016

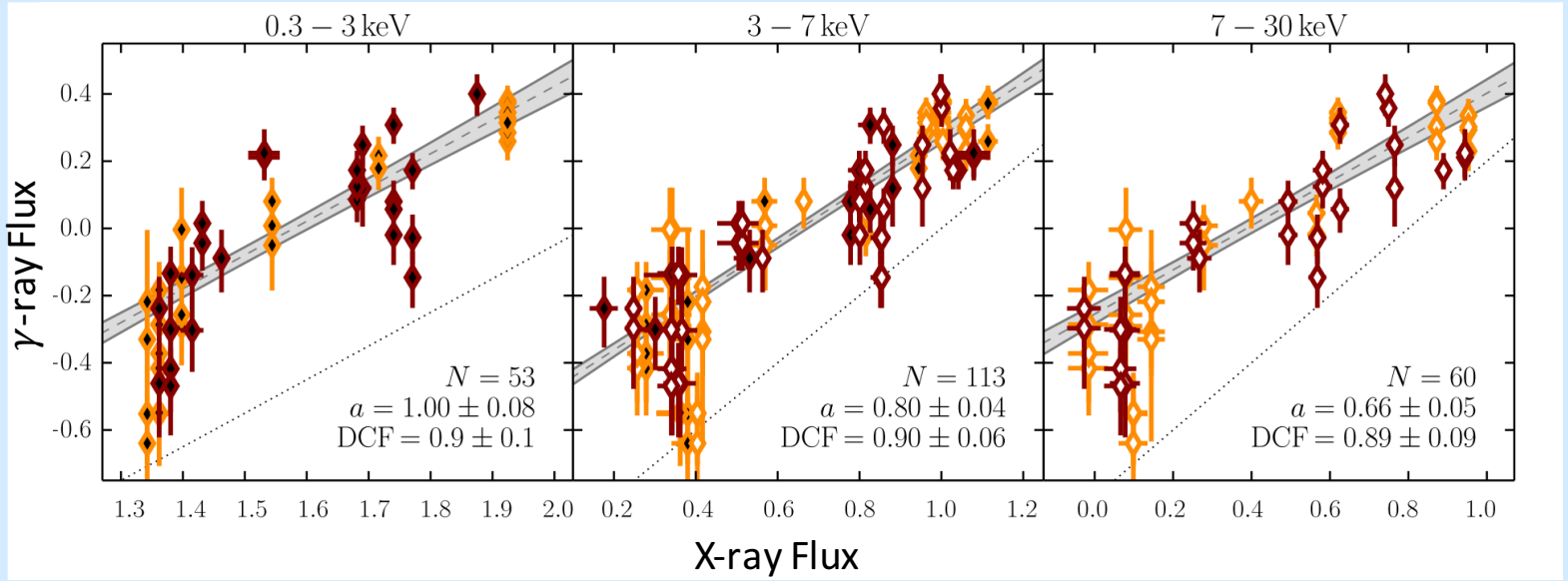
Quasar:
0827+243



Jorstad & Marscher 2016

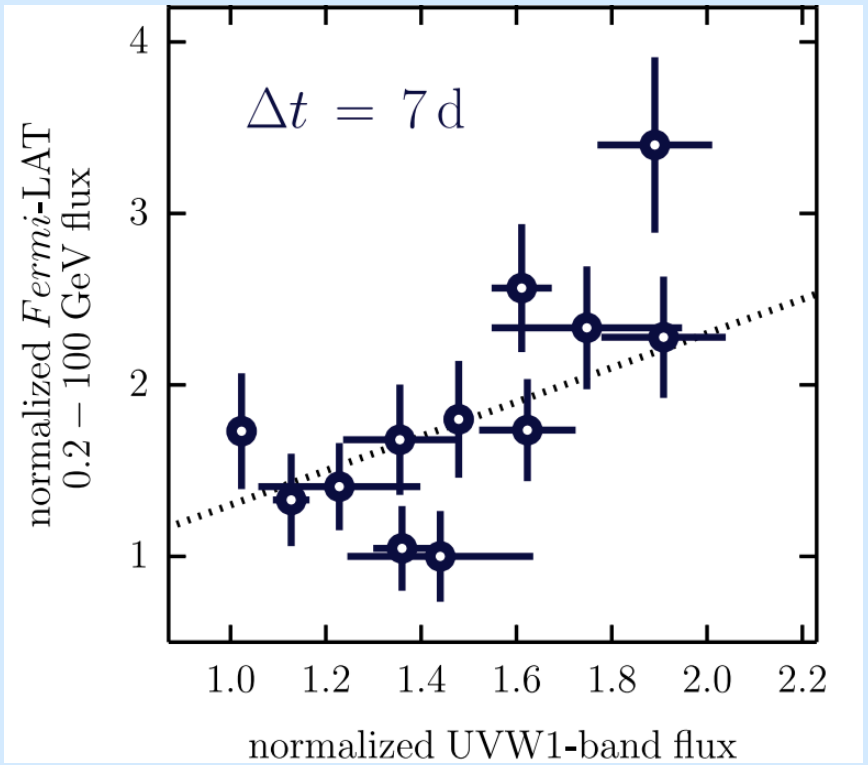
- Multi-wavelength variability lasting from minutes to weeks!

Other Characteristics



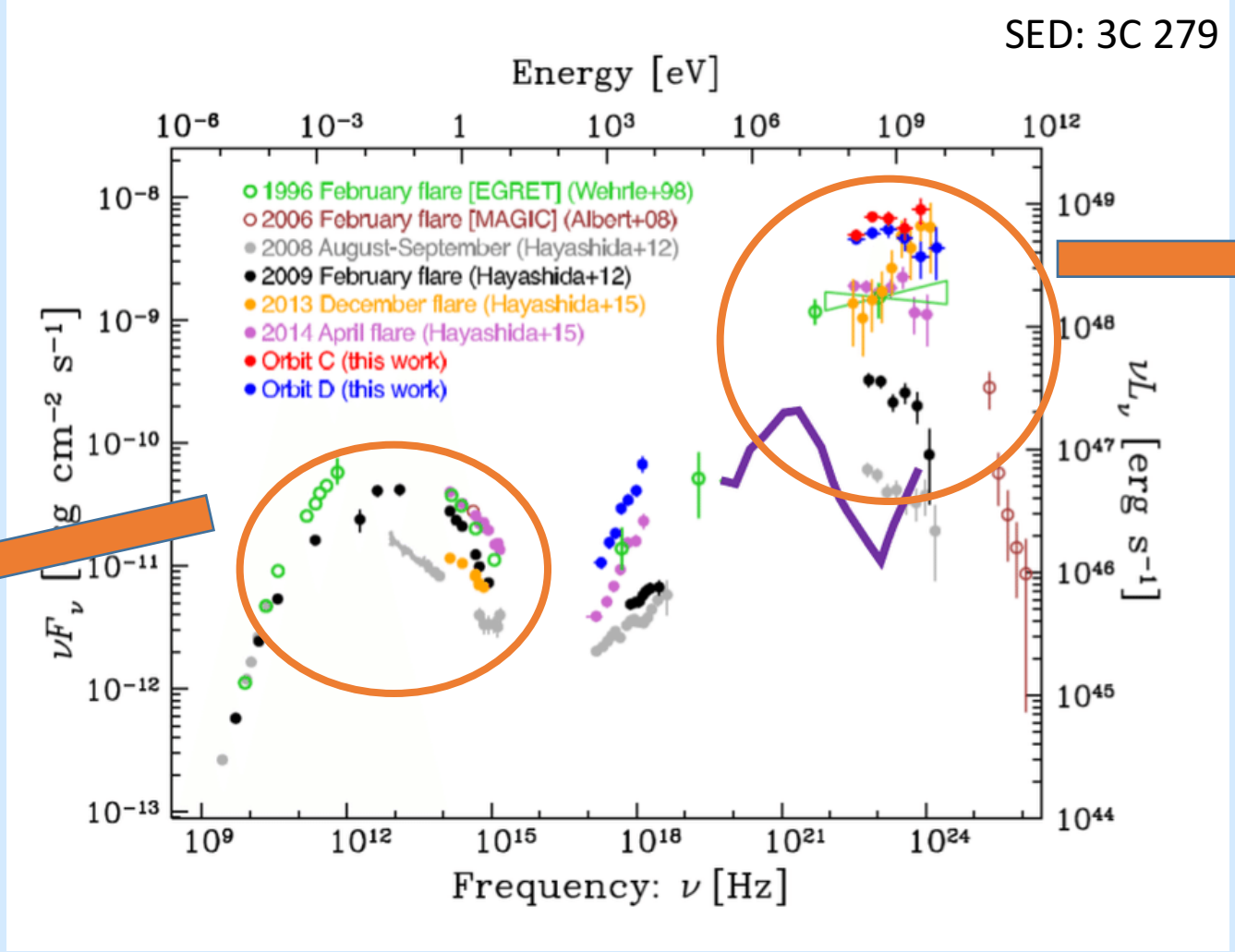
Balokovic et al. 2016

Mrk 421



Jorstad & Marscher 2016

Blazar SED: FSRQ

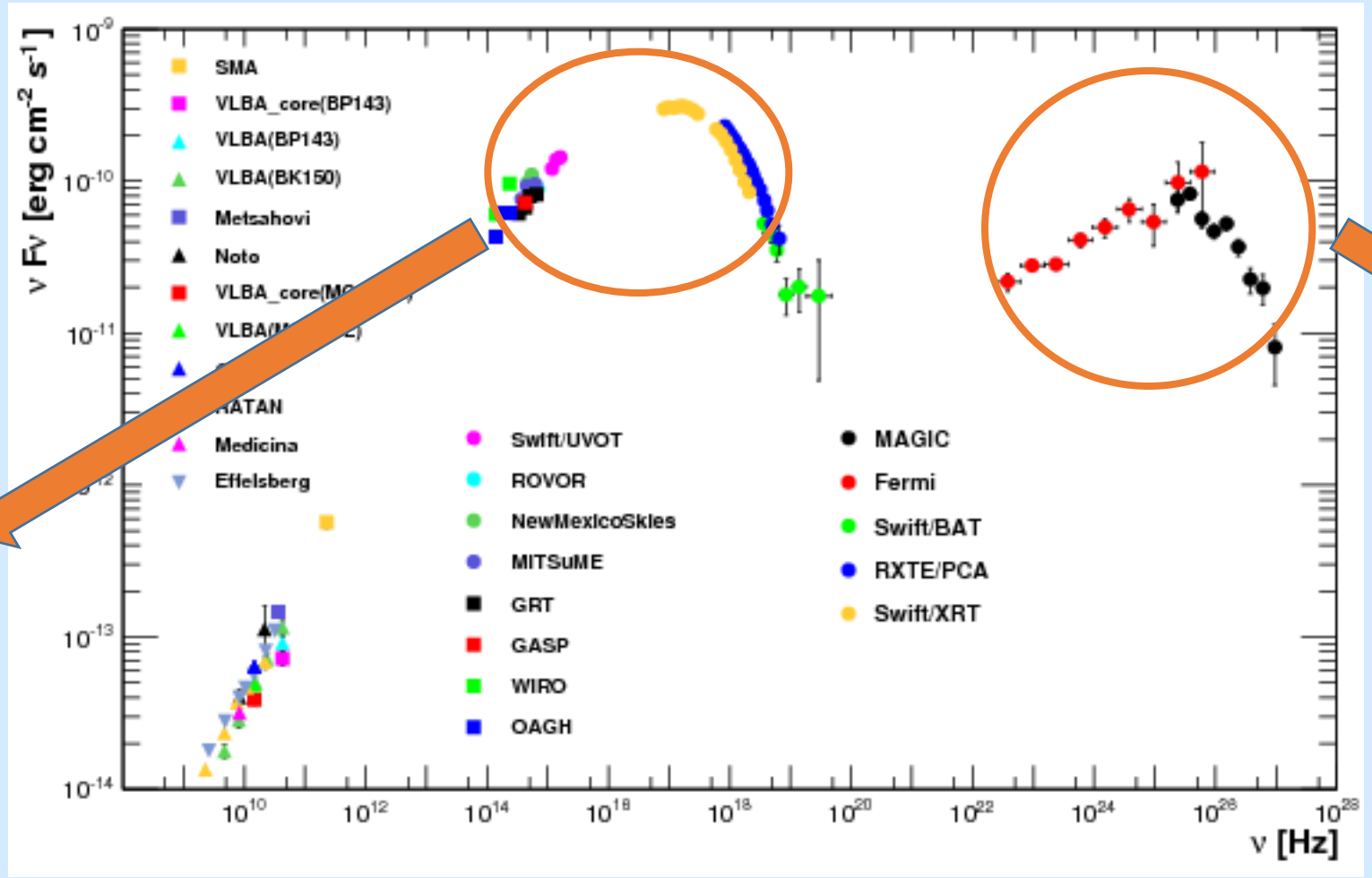


Low-energy Bump:
Synchrotron

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

Blazar SED: BL Lac

SED: Mrk 421



Low-energy Bump:
Synchrotron

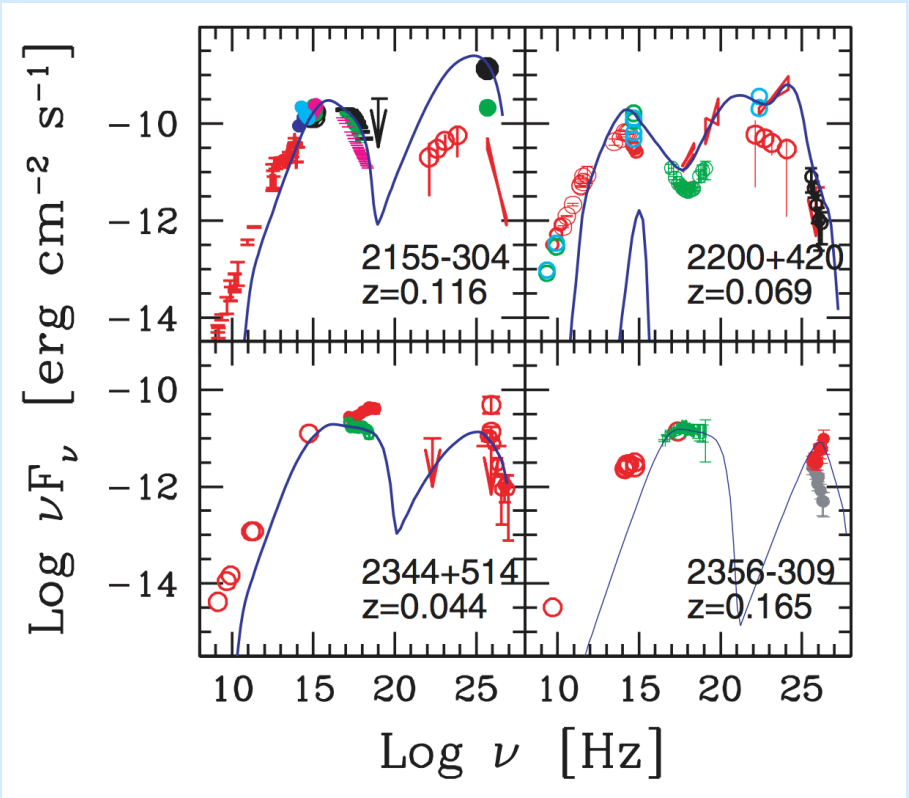
High-energy Bump:
Inverse Compton (SSC or EC)

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

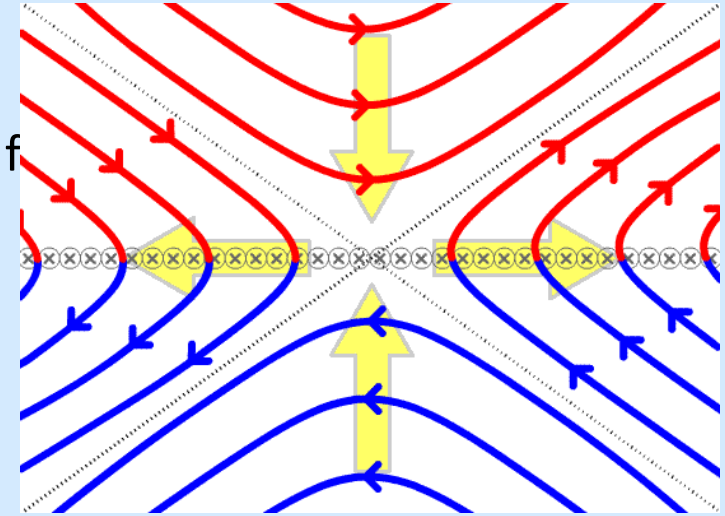


Celotti & Ghisellini 2008

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



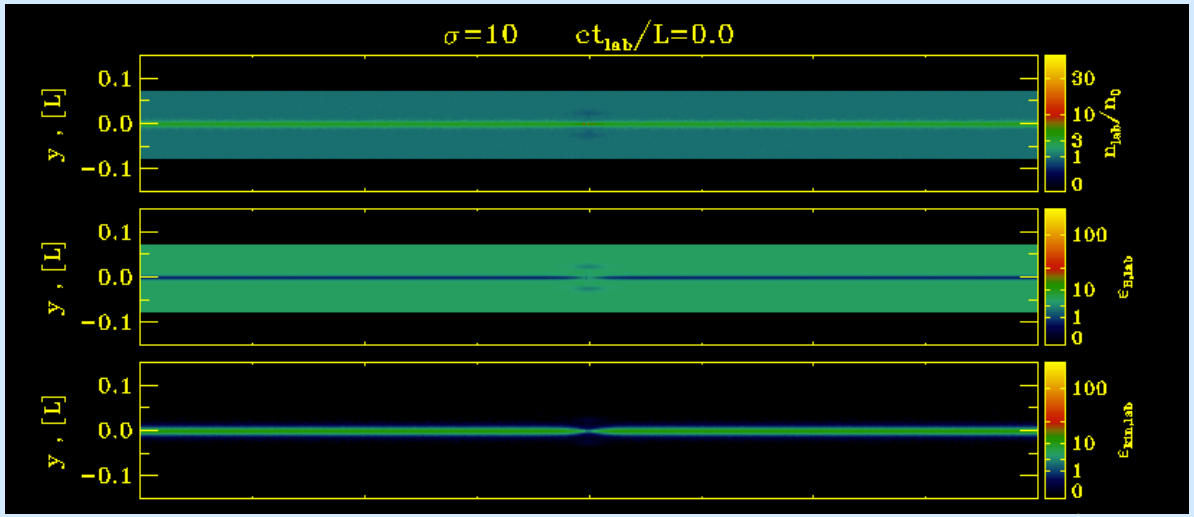
Magnetic Reconnection & PIC

- 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



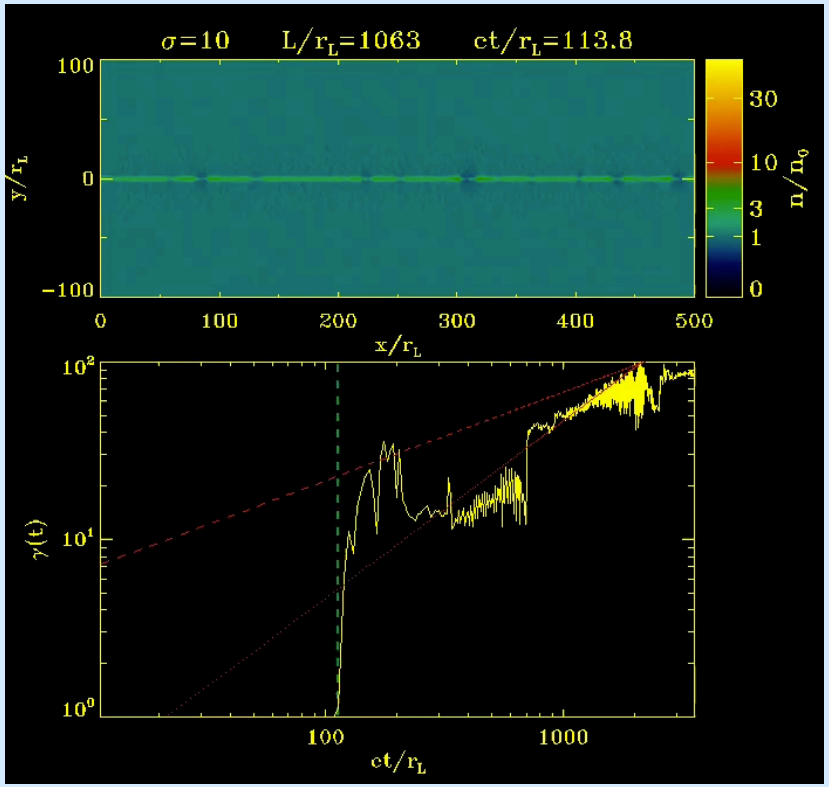
Sironi et al. 2016

Magnetic Reconnection: Particle Acceleration

- 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



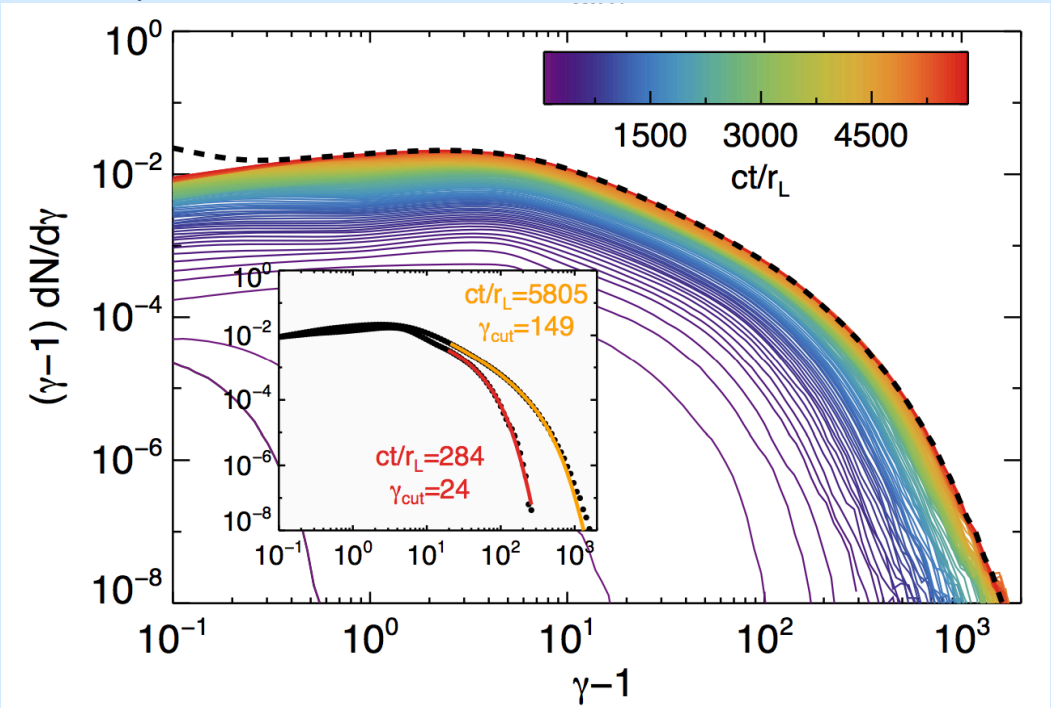
Petropoulou & Sironi 2018

Magnetic Reconnection: Particle Acceleration

- 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)

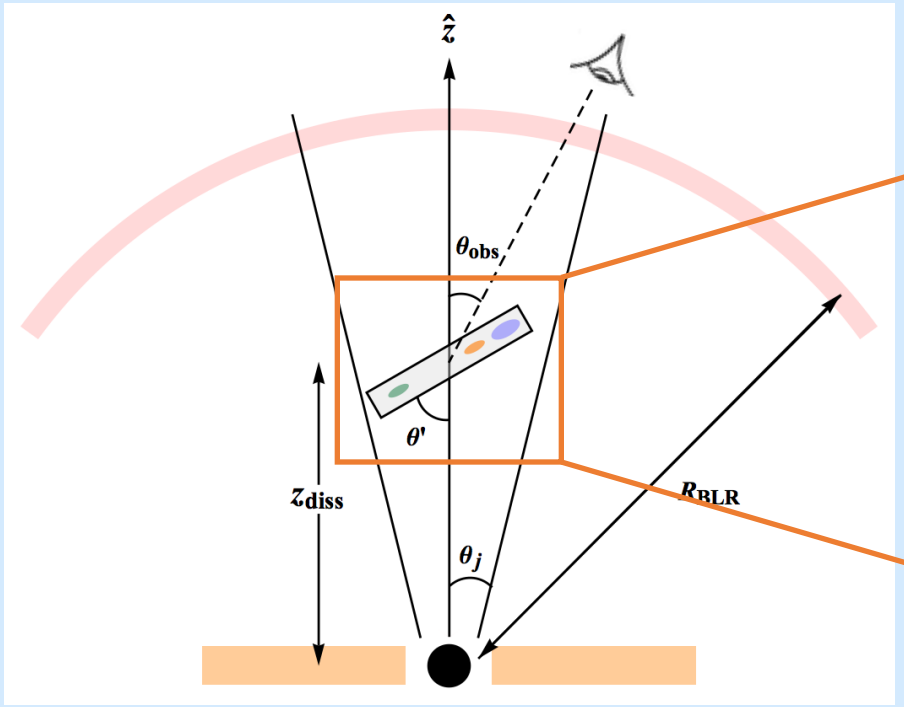
Temporal Evolution of Relativistic Particle Distribution



Petropoulou & Sironi 2018

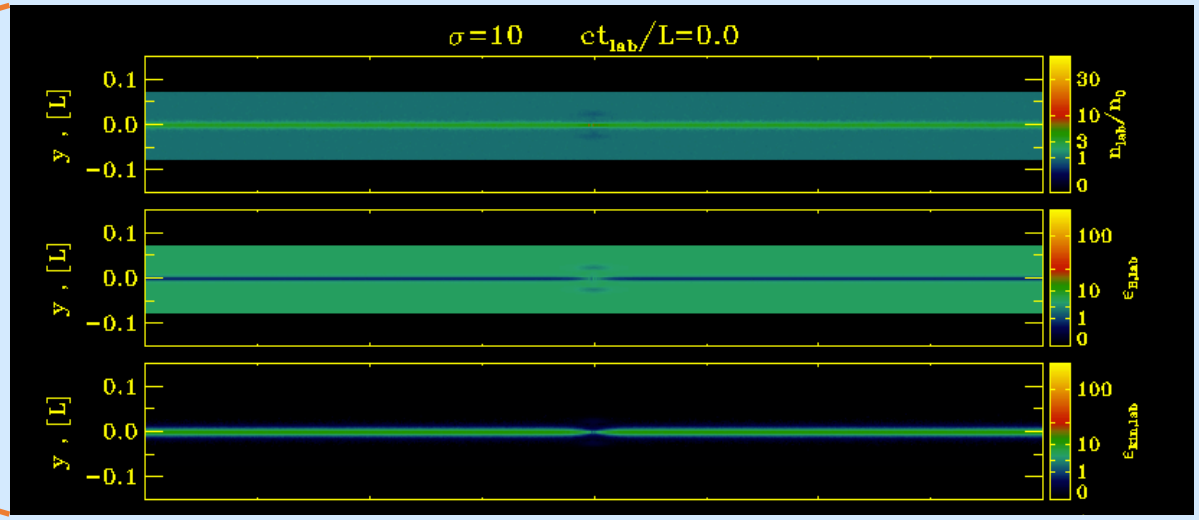
Blazar Flares Via Plasmoids

Schematic Diagram of Blazar Jet



Christie et al. 2019

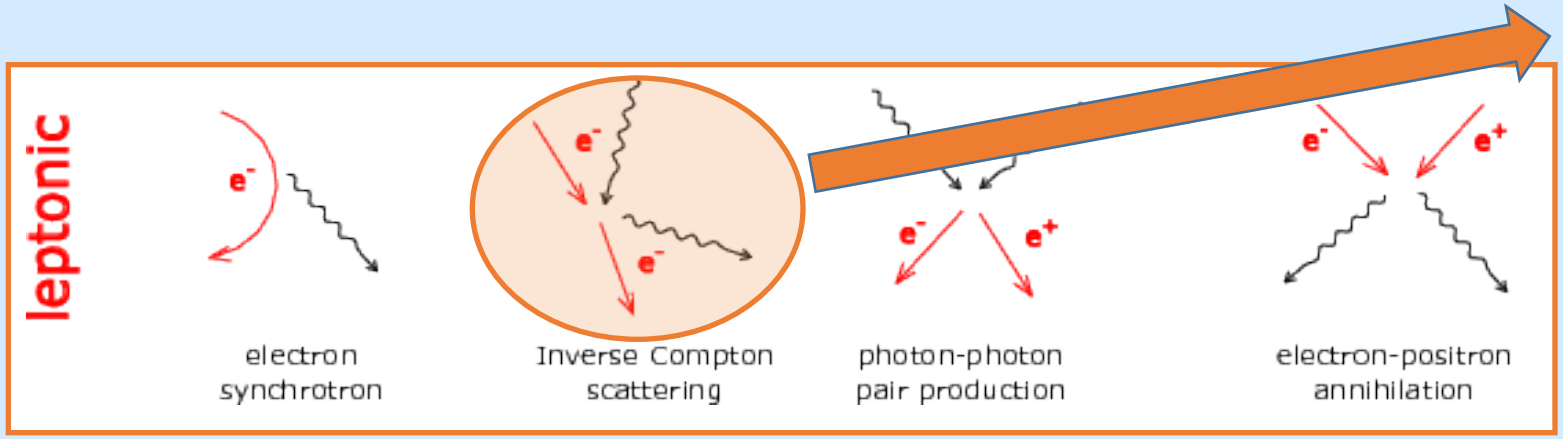
PIC Simulation of Relativistic Reconnection:
density, kinetic energy, magnetic energy



Sironi et al. 2016

Our Emission Model

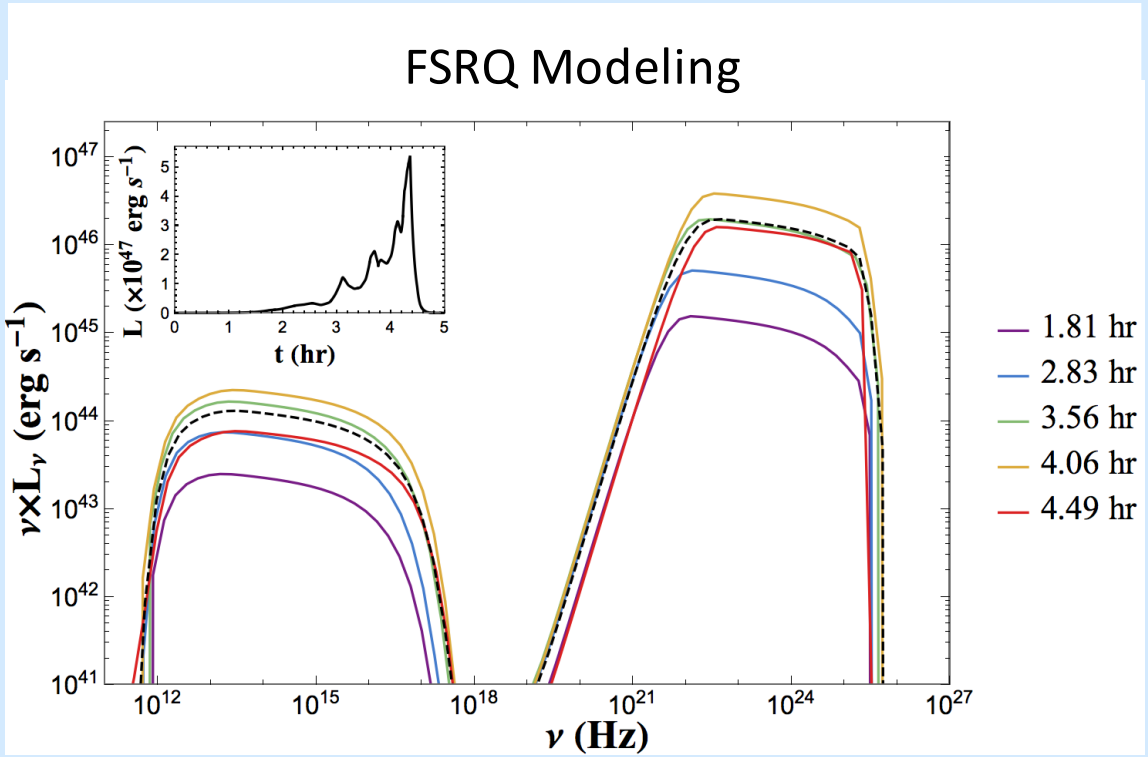
- Use 2D PIC simulation results of relativistic magnetic reconnection
- PIC governs majority of model parameter → ***few free parameters (e.g. B-field, size of reconnection layer, strength of external radiation fields, orientation of reconnection layer)***
- Compute the emission from the entire reconnection layer → ***model BL Lacs & FSRQs***



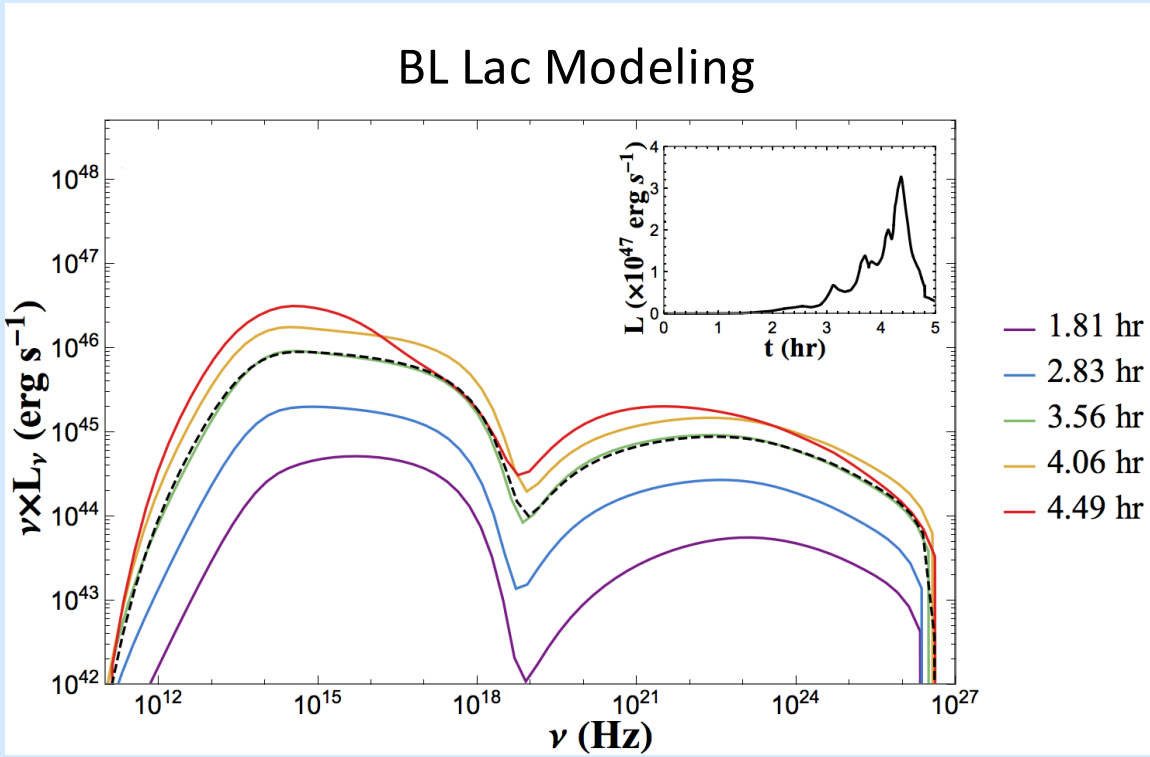
Includes emission from Broad Line Region

Individual Plasmoid Spectra & Light Curves

FSRQ Modeling



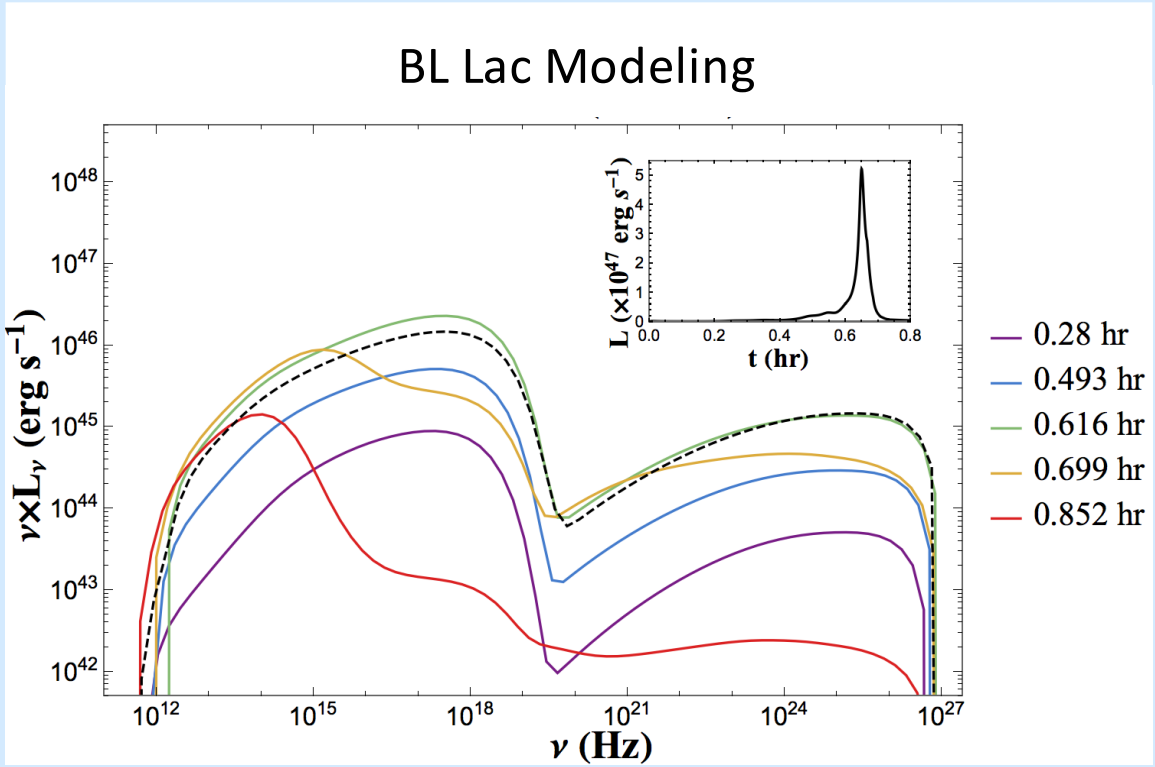
BL Lac Modeling

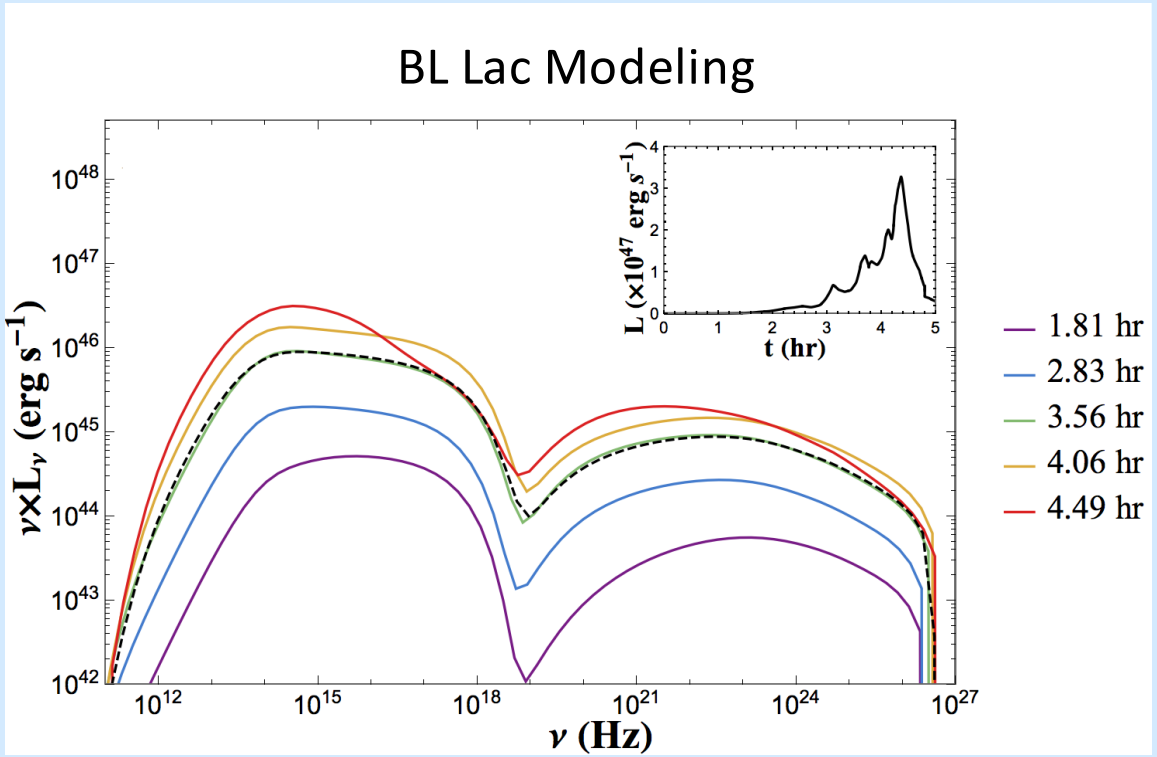


Same Medium Sized Plasmoid
Different External Radiation Fields

Christie et al. 2019

Individual Plasmoid Spectra & Light Curves



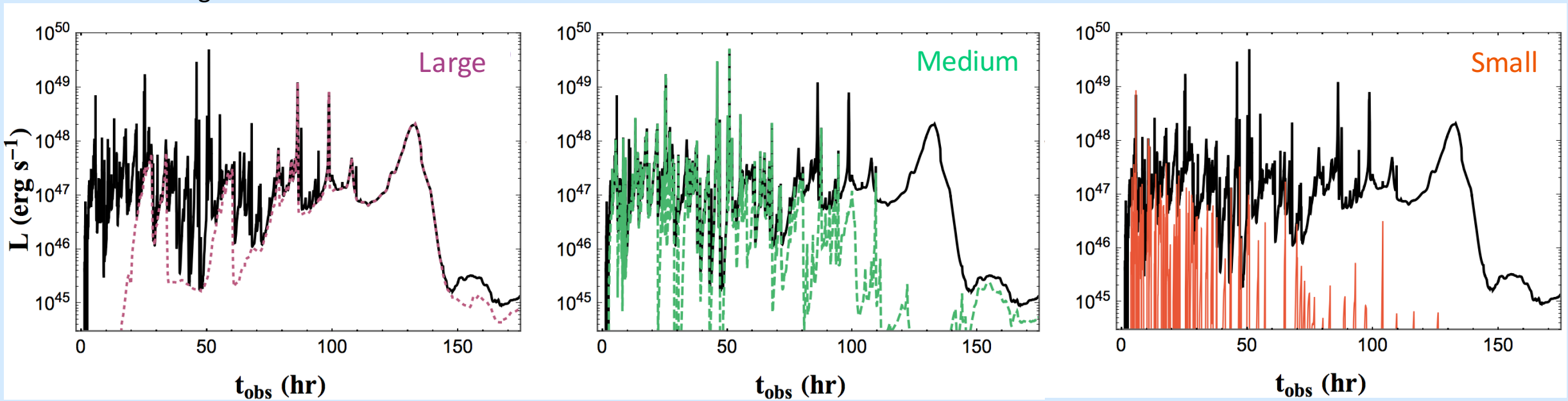


Same Medium Sized Plasmoid
Different Magnetizations (σ)

Christie et al. 2019

Plasmoid Size Dependence

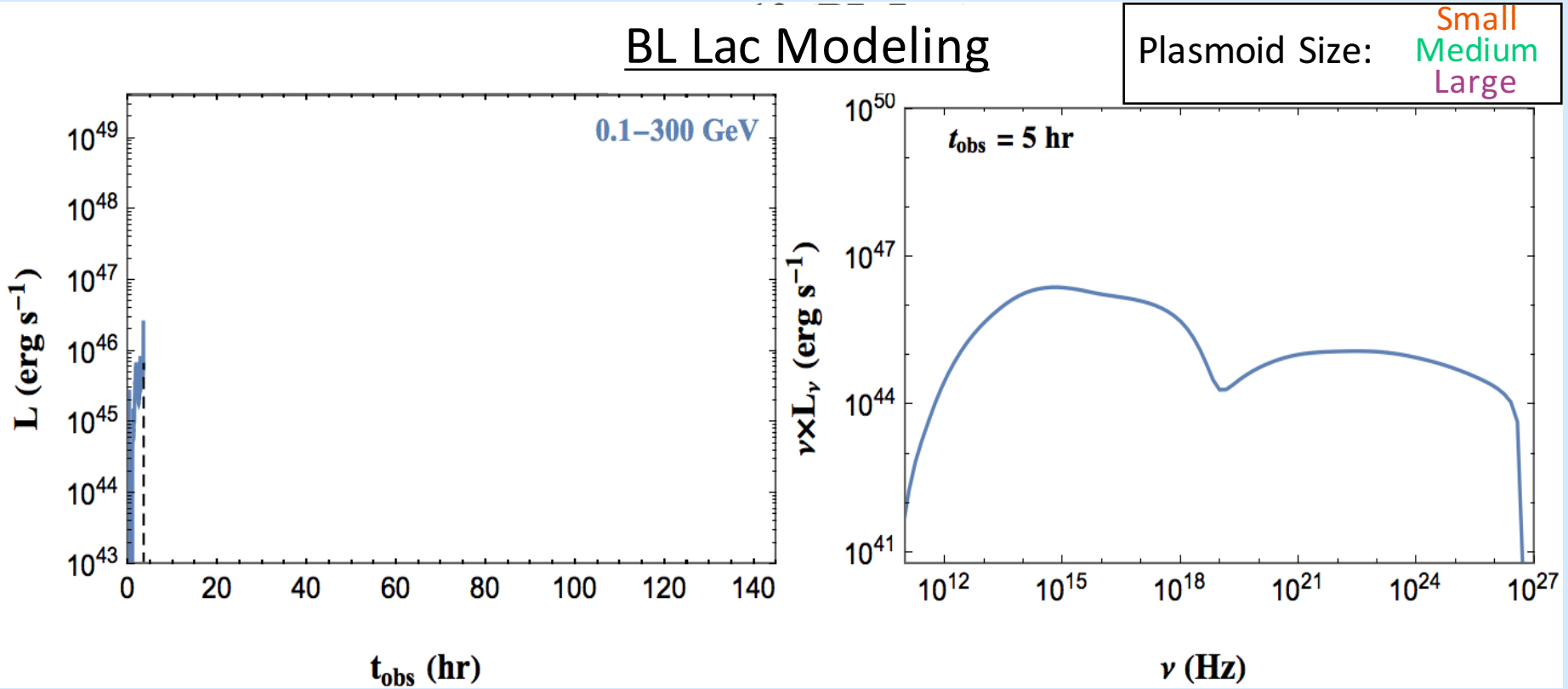
0.1 – 300 GeV Light Curve



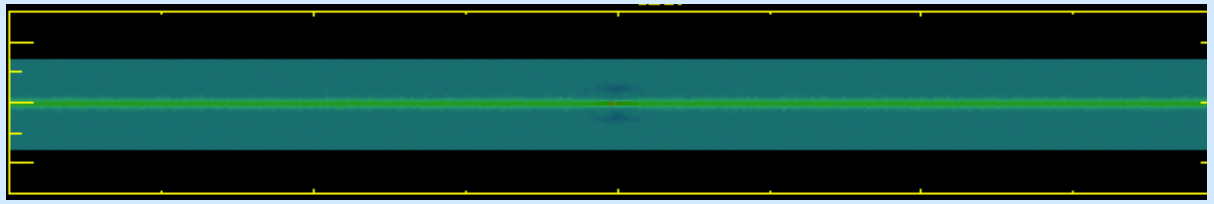
Christie et al. 2019

- 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

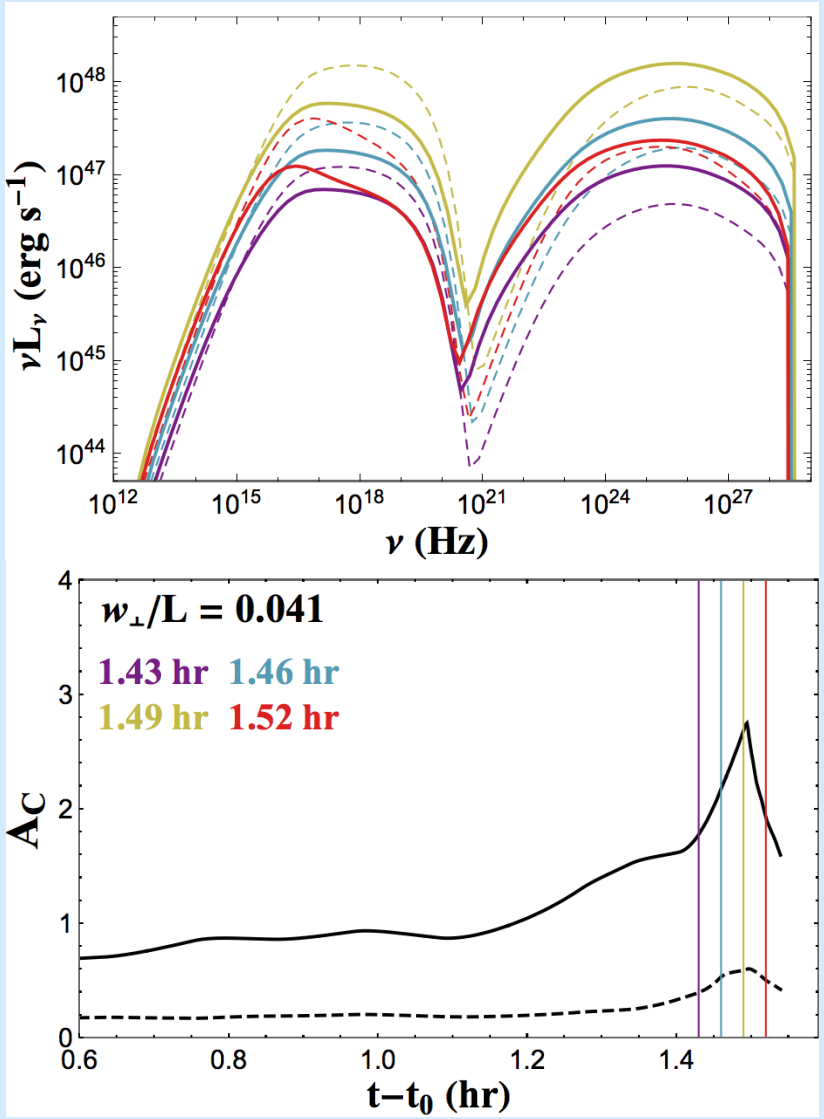


Jet Lorentz factor: 12
Size of Reconnection layer: 10^{16} cm
B-field: $2G$



Inter-Plasmoid Compton Effect

- Since small plasmoids mostly trail behind large plasmoids ⟹ we consider the illumination of the large plasmoid on the smaller ones
- With this natural process, Compton ratios increase to the observed ones!

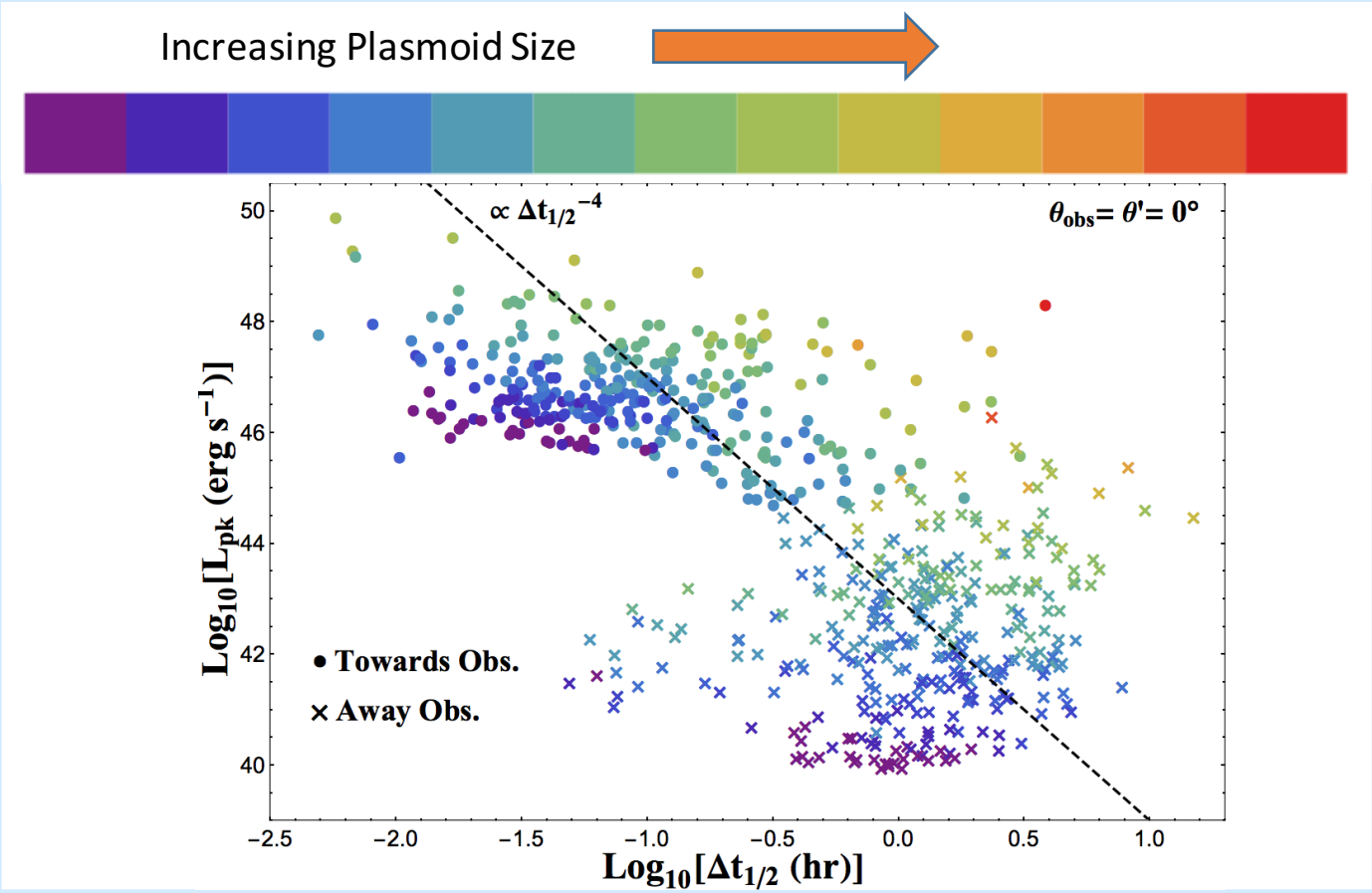


Christie et al. in prep.

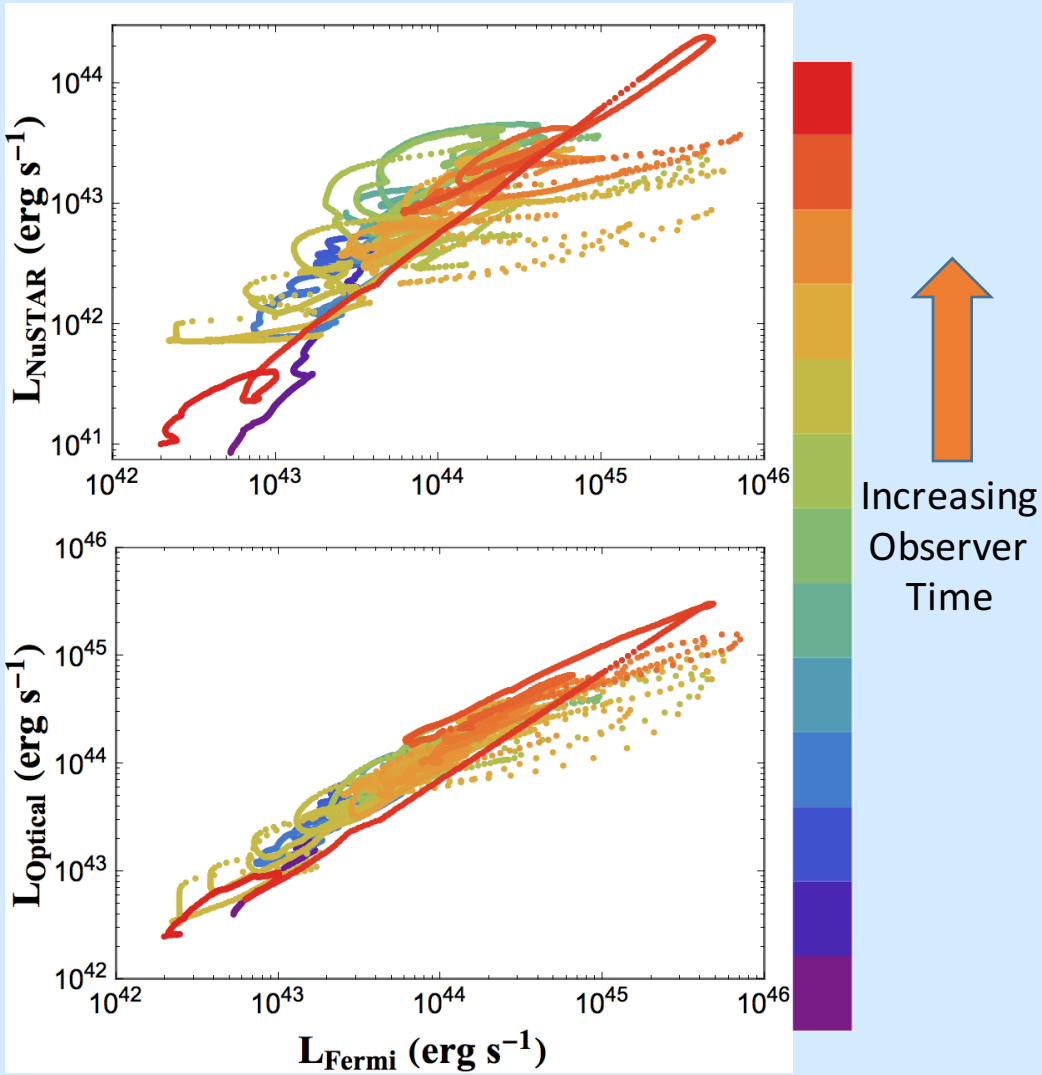
Additional Signatures

Flaring Statistics

Increasing Plasmoid Size



Christie et al. 2019



Christie et al. in prep.

Summary

- Our fundamentally-built model displays similar spectral features in FSRQs and BL Lacs!
- Requires few free parameters
- Can produce the fast (minutes) timescale and long (days) flares observed in many blazars!

Outlook

- Numerous comparisons with observations (e.g. PSDs, correlation, flaring statistics) to come!
- PIC simulations of proton-electron & pair plasmas
- Inclusion of Hadronic components within radiative model

arXiv: 1807.08041

ichristi231@gmail.com