南京大學
NANJING UNIVERSITY

A unified model for orphan and multi-wavelength blazar flares

Ze-Rui Wang, Ruo-Yu Liu, Maria Petropoulou, Foteini Oikonomou, Rui Xue, Xiang-Yu Wang

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ONLINE

Outline

- Introduction
- Stochastic dissipation model
- Results
- Conclusion

Introduction

1. Blazars (FSRQ and BL Lac) are the most extreme subclass of AGN with a relativistic jet closely aligned to the observer's line of sight.

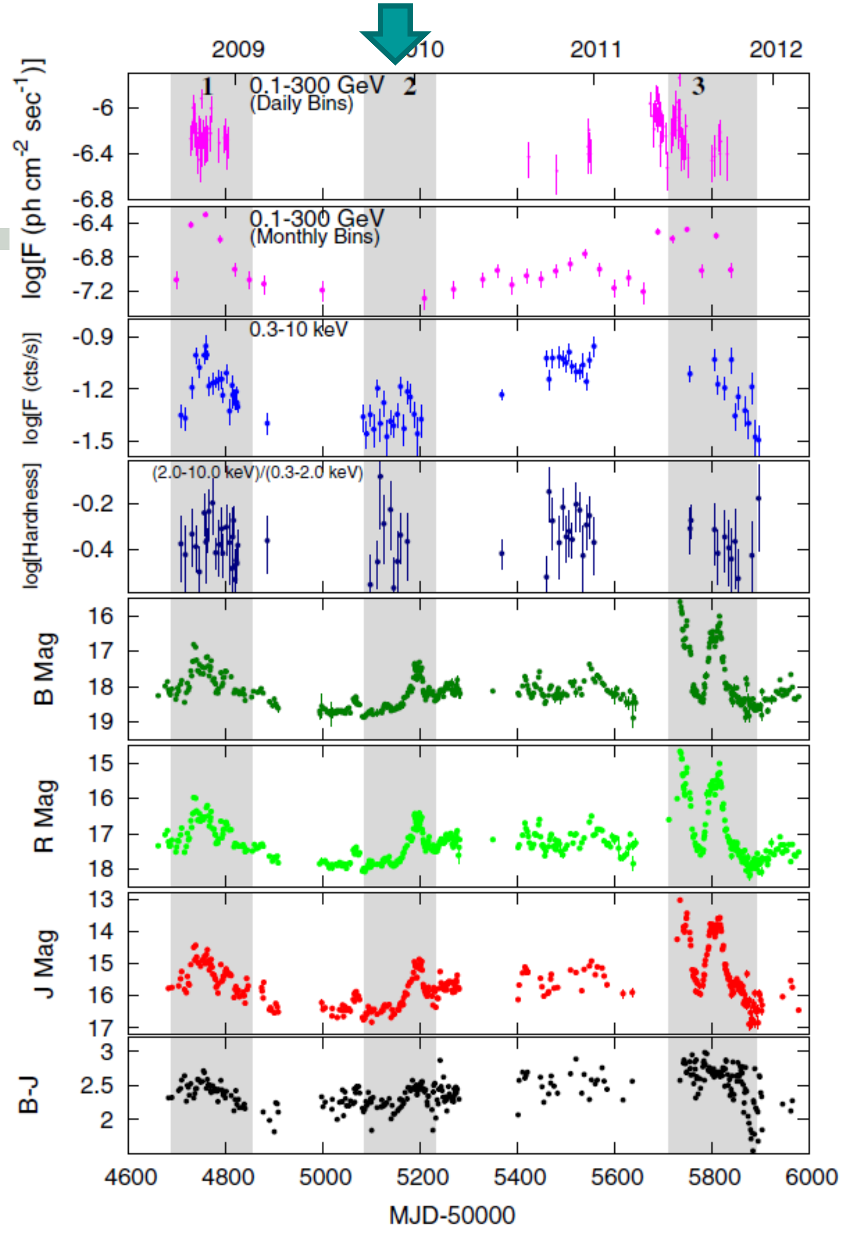
2. Blazar flares have been observed at different energy bands with different duration timescales ranging from several years to few minutes.

3. Different type of blazar flares: multi-wavelength flare, orphan flare.

4. Orphan flare: Radio, optical, GeV, TeV

Introduction

Orphan optical flare



MWL light curve of PKS 0208-512
Chatterjee et al.(2013)

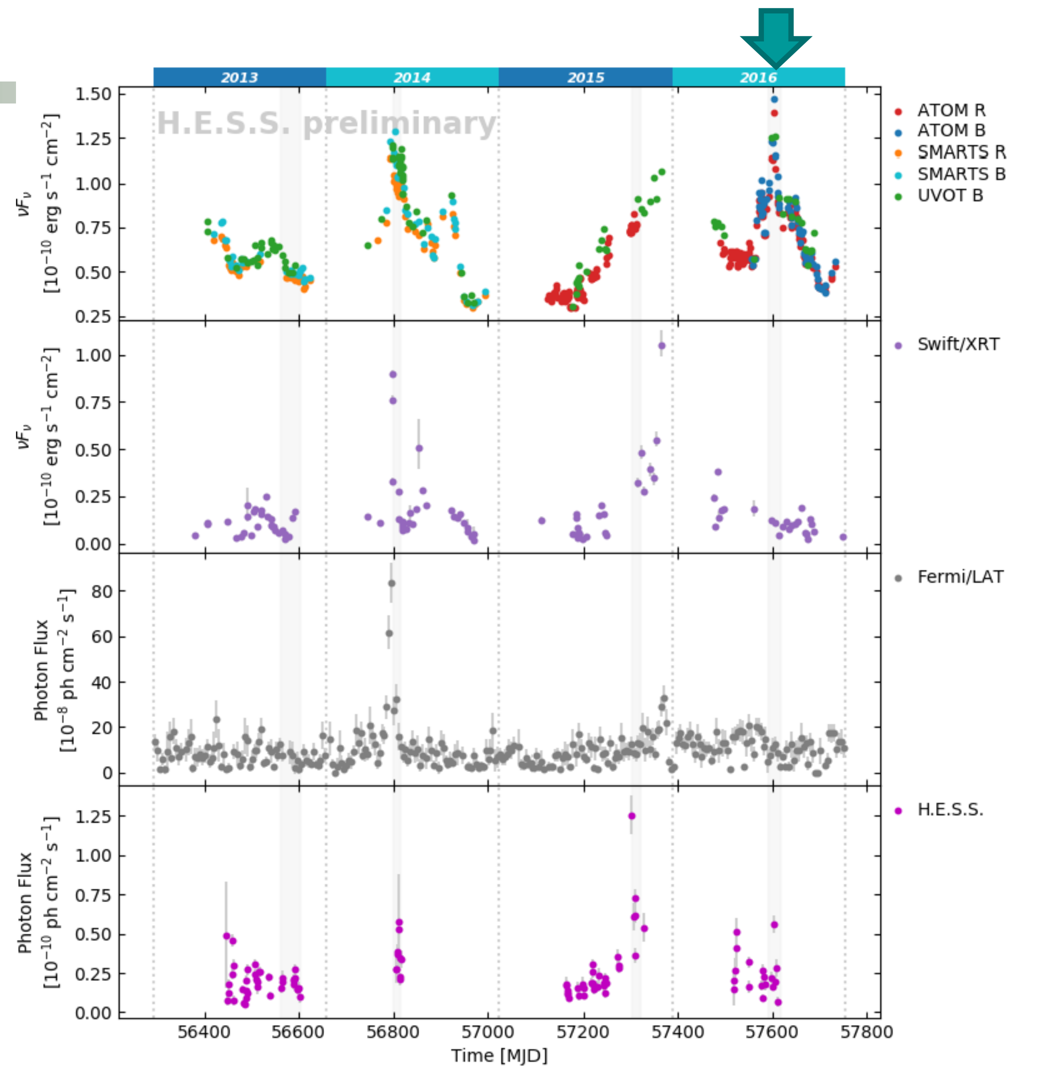
Orphan optical flare in 2010
FSRQ
Lasting for ≥3 months

Introduction

Orphan optical flare

MWL light curve of PKS 2155-304
Wierzcholska et al.(2019)

Orphan optical flare in 2016
BL Lac
Lasting several months



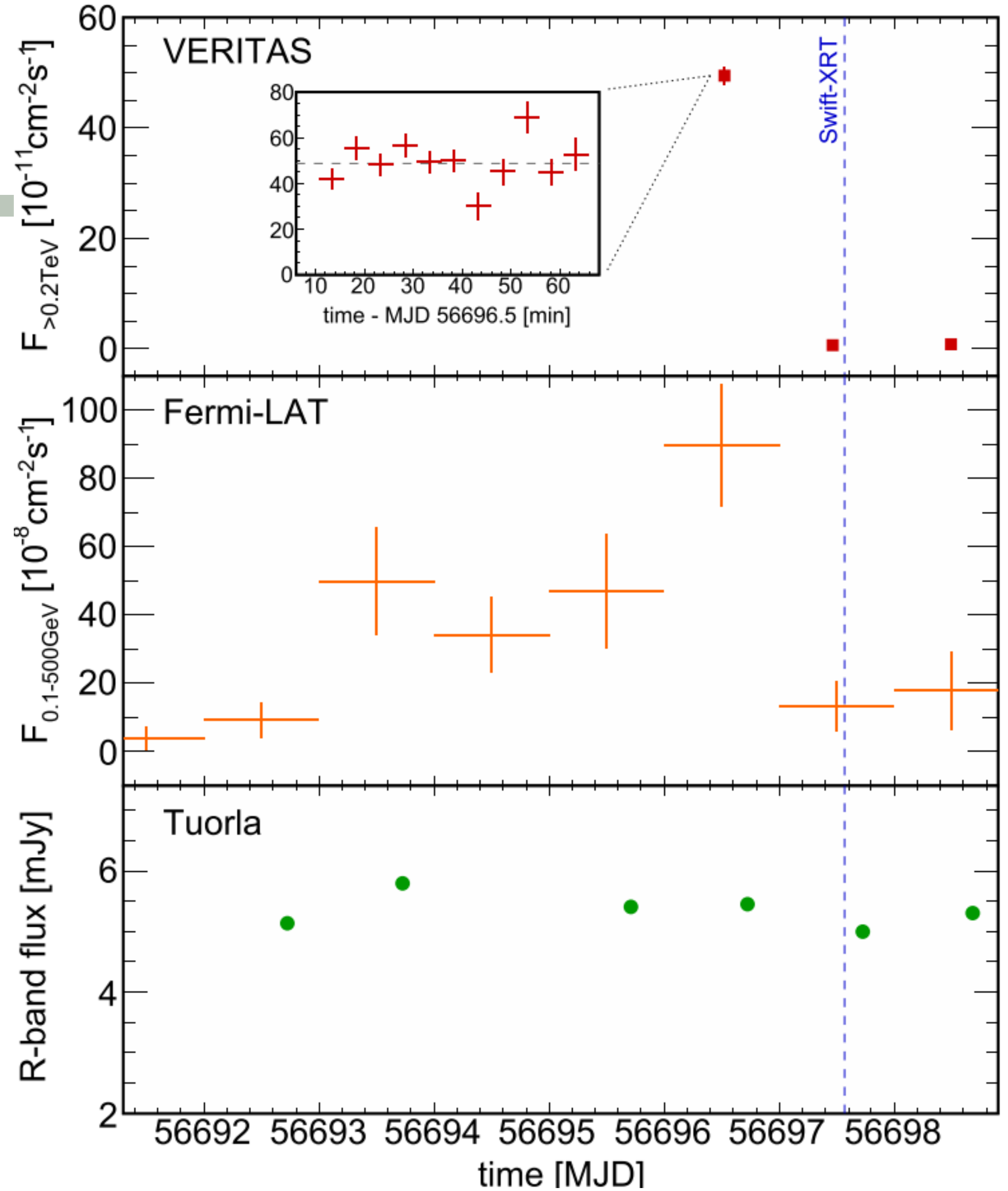
Introduction

Orphan γ-ray flare

MWL light curve of B2 1215+30
Abeysekara et al.(2017)

Orphan γ-ray flare in 2014
BL Lac
Lasting for about 5 days
And have a rapid decay (<8.9 hours)

The TeV flux reached 2.4 times the Crab Nebula flux with a variability timescale of < 3.6 h.



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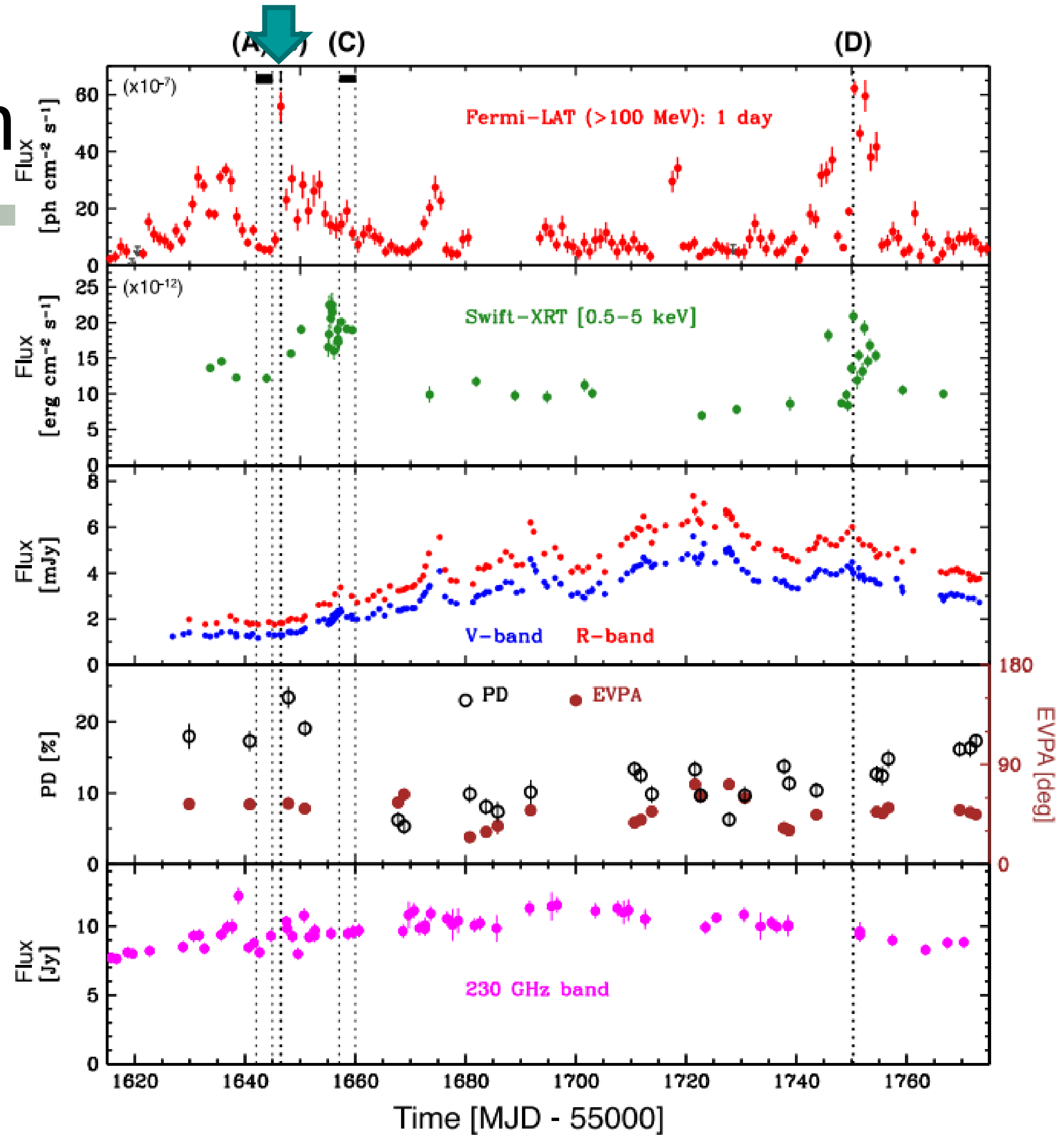
Introduction

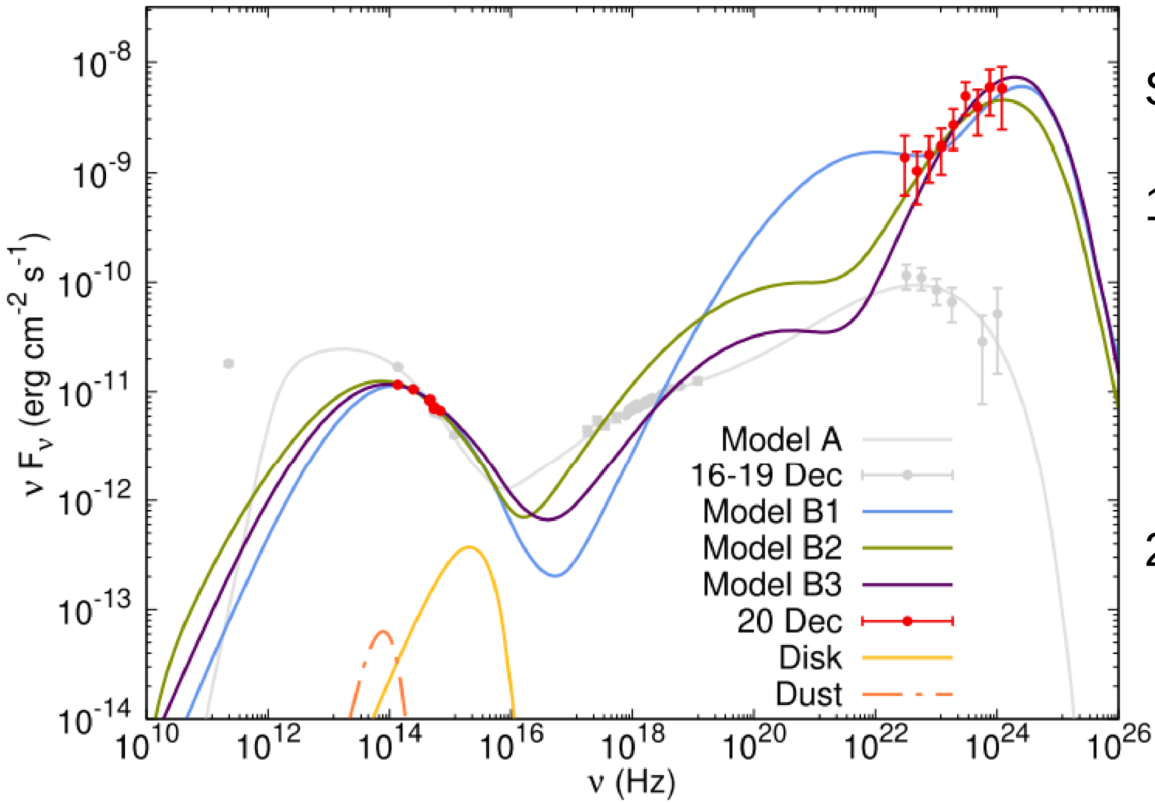
Orphan γ-ray flare

MWL light curve of 3C 279
Hayashida et al.(2015)

Orphan γ-ray flare in interval B
FSRQ
Lasting for 12 hours



Orphan γ-ray flare from 3C 279



SED of 3C 279 (Lewis et al. 2019)

1. Red data represent the orphan γ-ray data which was observed during a 12 hr period on 2013 December 20.

2. Gray data represent the 4 day quiescent period immediately prior to the flare.

Introduction

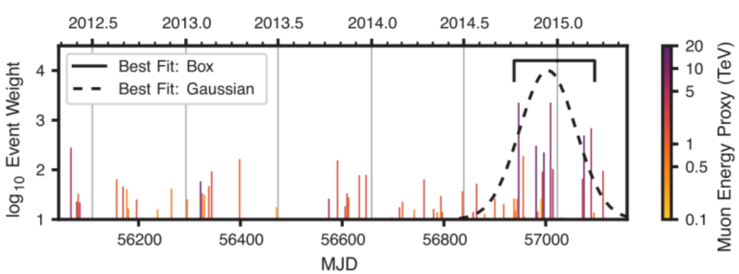
RESEARCH ARTICLE

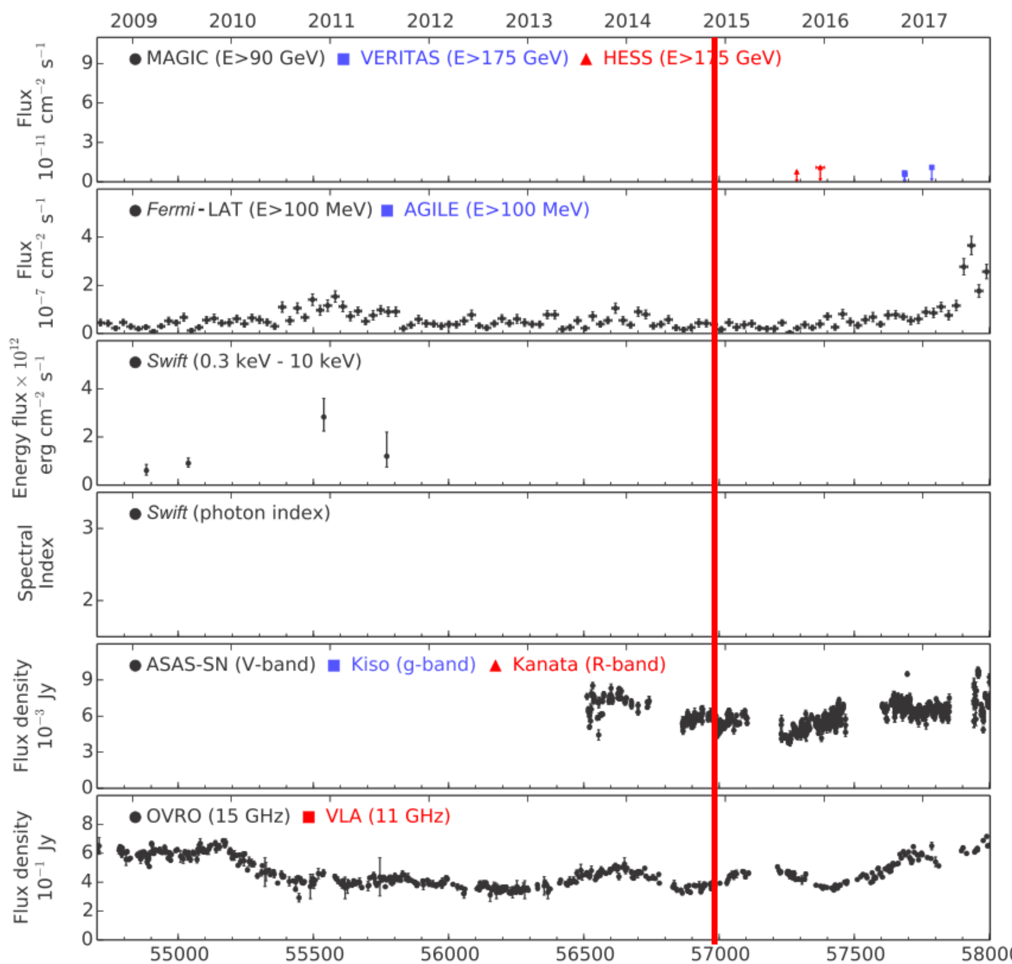
NEUTRINO ASTROPHYSICS

Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

IceCube Collaboration*†

A high-energy neutrino event detected by IceCube on 22 September 2017 was coincident in direction and time with a gamma-ray flare from the blazar TXS 0506+056. Prompted by this association, we investigated 9.5 years of IceCube neutrino observations to search for excess emission at the position of the blazar. We found an excess of high-energy neutrino events, with respect to atmospheric backgrounds, at that position between September 2014 and March 2015. Allowing for time-variable flux, this constitutes 3.5σ evidence for neutrino emission from the direction of TXS 0506+056, independent of and prior to the 2017 flaring episode. This suggests that blazars are identifiable sources of the high-energy astrophysical neutrino flux.





Introduction

1. Blazars (FSRQ and BL Lac) are the most extreme subclass of AGN with a relativistic jet closely aligned to the observer's line of sight.

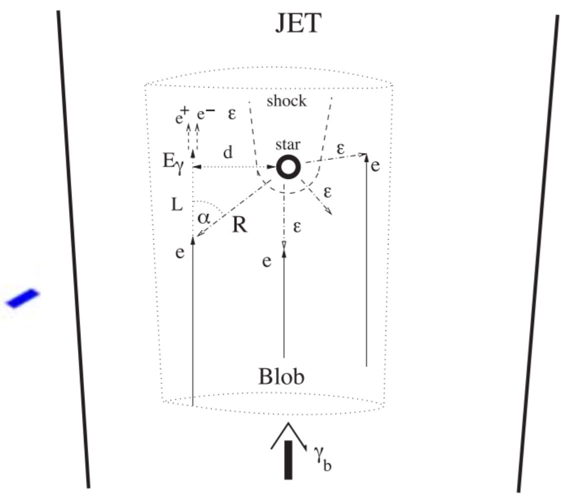
2. Blazar flares have been observed at different energy bands with different duration timescales ranging from several years to few minutes.

3. Different type of blazar flares: multi-wavelength flare, orphan flare.

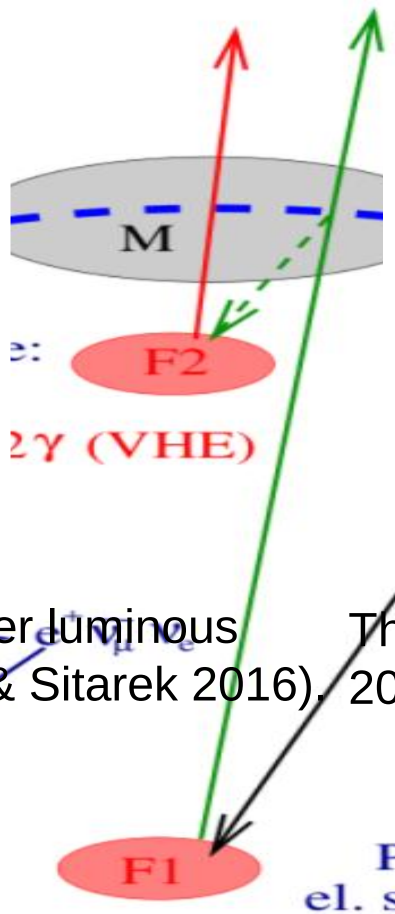
4. Orphan flare: Radio, optical, GeV, TeV, neutrino (TXS 0506+056).

5. True orphan flare rates: 54.5% of optical and 20% of γ-ray flares are orphan events (178 blazars sample from Liodakis et al. 2019).

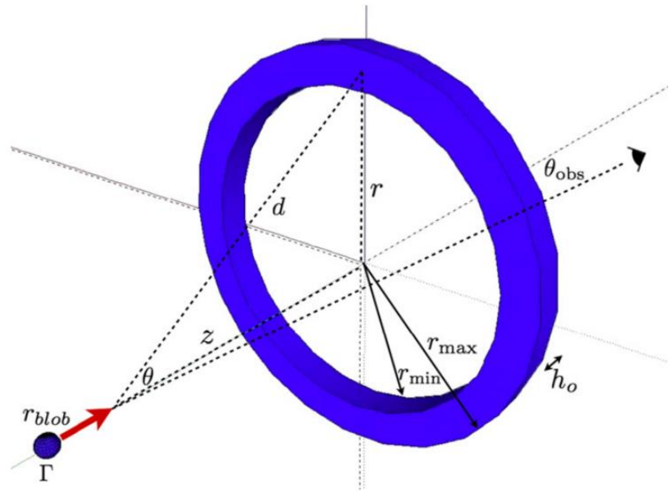
Different model for explaining orphan flare



The relativistic blobs encounter luminous stars (Banasinski, Bednarek & Sitarek 2016).



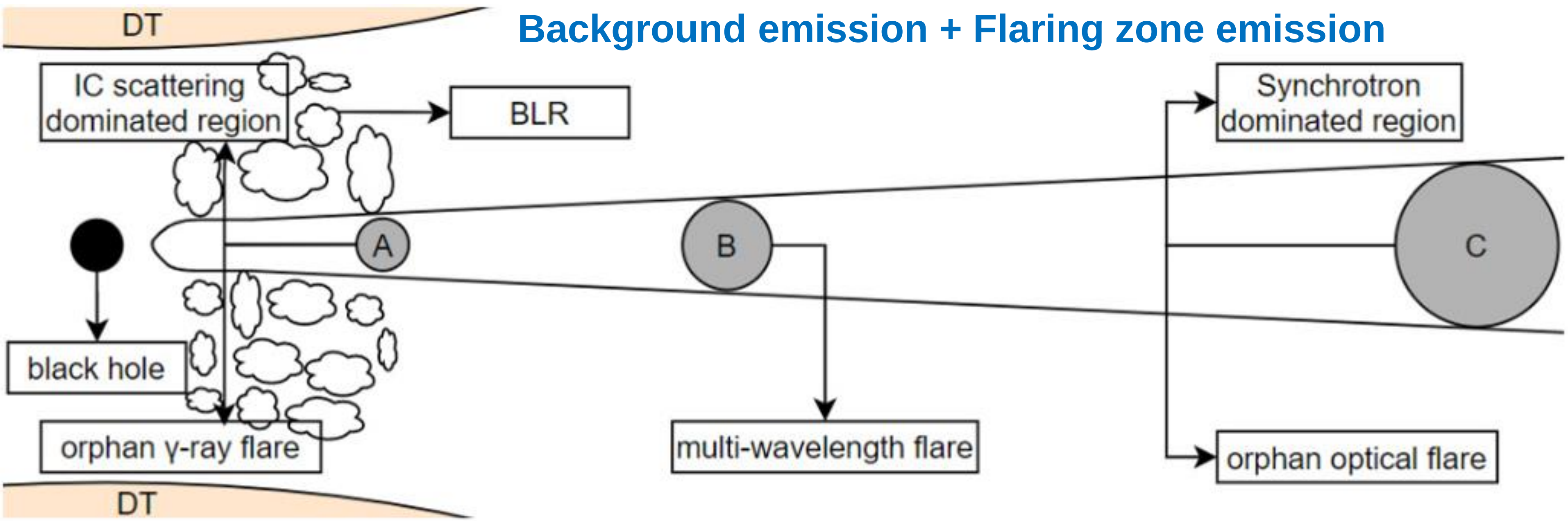
The ring of fire model (Macdonald et al. 2015).



Hadronic Synchrotron Mirror Model (Bottcher 2004).

Schematic view

Background emission + Flaring zone emission



$$R(r) = R_0\left(\frac{r}{0.1\ pc}\right)$$

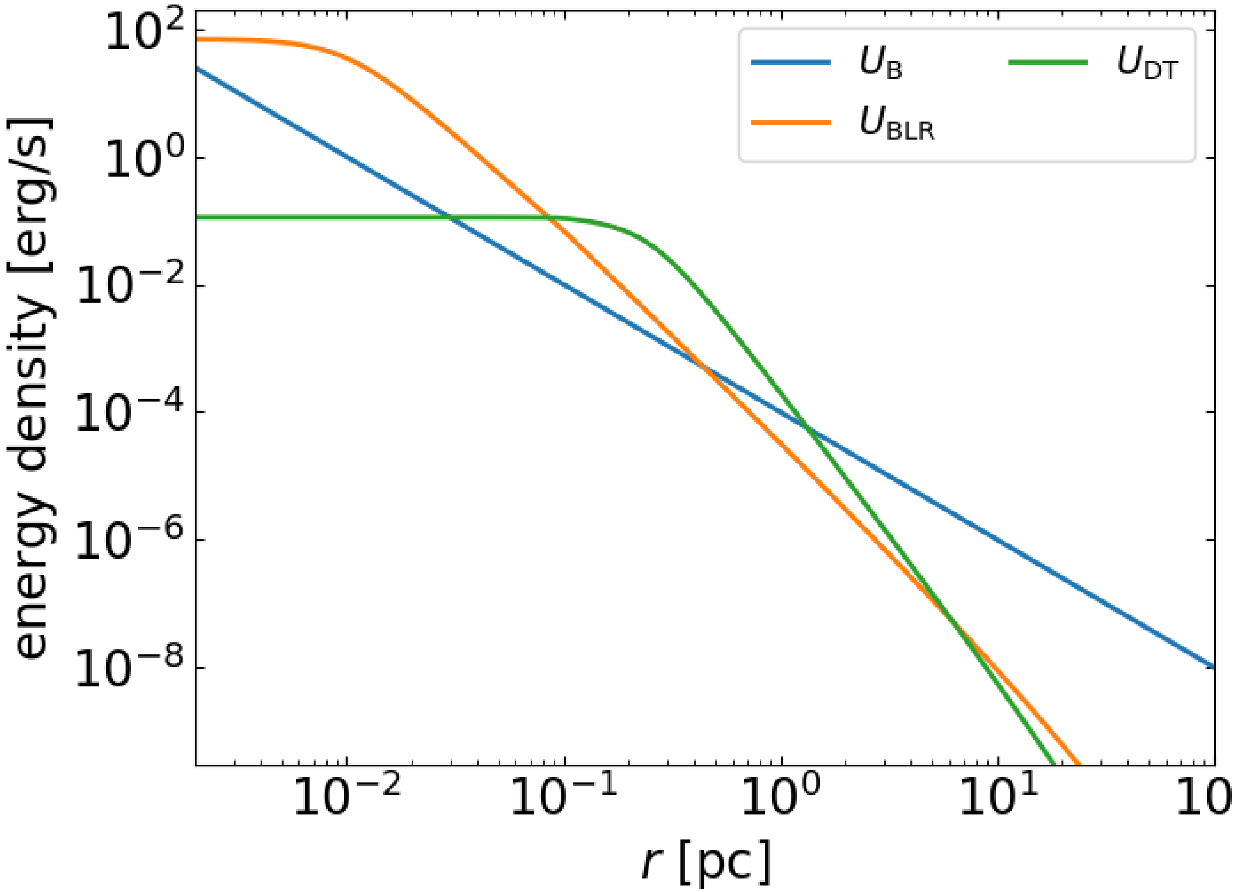
$$B(r) = B_0\left(\frac{R_0}{R(r)}\right)$$

$$\delta_D(r) = \delta_{D,0} - \frac{\delta_{D,0} - 2}{\log\left(\frac{100\ pc}{0.1\ pc}\right)}\log\left(\frac{r}{0.1\ pc}\right)$$

$$u_{syn}(r) = \frac{L_{syn}}{4\pi R(r)^2\Gamma^4}$$

$$u_{BLR}(r) = \frac{\xi_{BLR}\Gamma^2 L_{disk}}{3\pi r_{BLR}^2 c[1 + (r/r_{BLR})^{\beta_{BLR}}]}$$

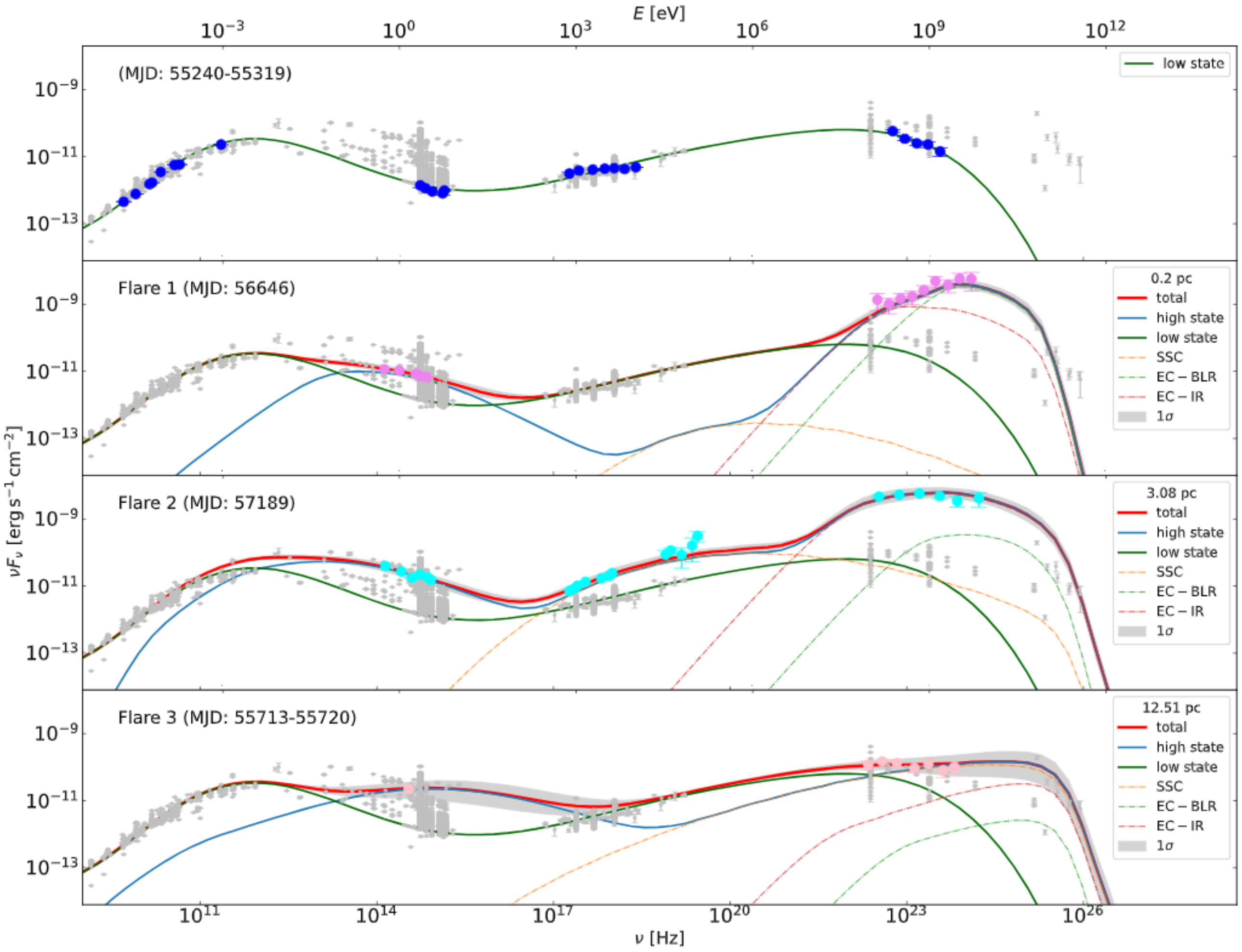
$$u_{DT}(r) = \frac{\xi_{DT}\Gamma^2 L_{disk}}{3\pi r_{DT}^2 c[1 + (r/r_{DT})^{\beta_{DT}}]}$$



$$R(r) = R_0\left(\frac{r}{0.1\,pc}\right) \qquad B(r) = B_0\left(\frac{R_0}{R(r)}\right) \qquad \delta_D(r) = \delta_{D,0} - \frac{\delta_{D,0}-2}{\log\left(\frac{100\,pc}{0.1\,pc}\right)}\log\left(\frac{r}{0.1\,pc}\right)$$

$$u_{syn}(r) = \frac{L_{syn}}{4\pi R(r)^2\Gamma^4} \qquad u_{BLR}(r) = \frac{\xi_{BLR}\Gamma^2 L_{disk}}{3\pi r_{BLR}^2 c[1+(r/r_{BLR})^{\beta_{BLR}}]} \qquad u_{DT}(r) = \frac{\xi_{DT}\Gamma^2 L_{disk}}{3\pi r_{DT}^2 c[1+(r/r_{DT})^{\beta_{DT}}]}$$

Fitting result for 3C 279



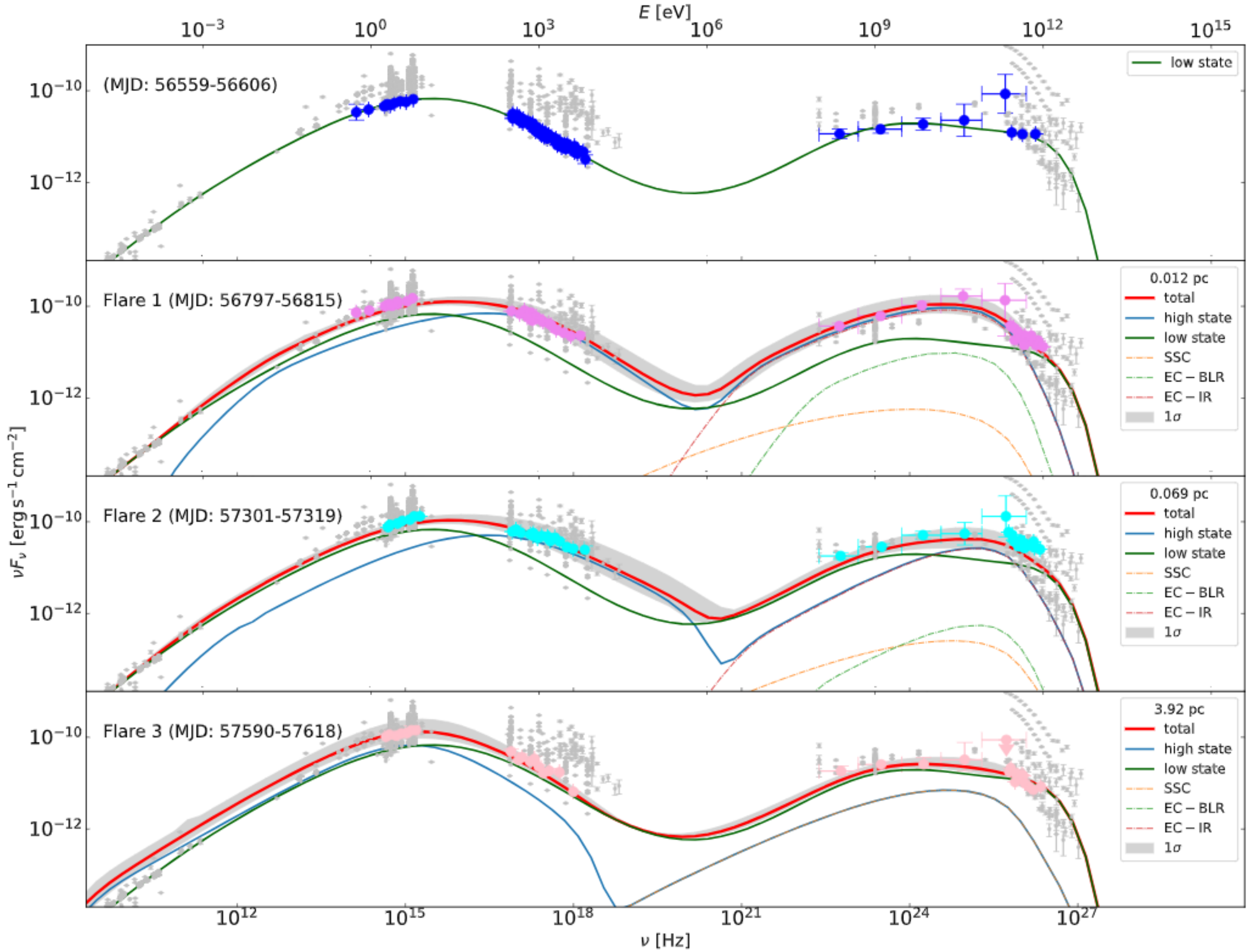
Low state

Orphan γ-ray flare

Multi-wavelength flare

Multi-wavelength flare

Fitting result for PKS 2155-304



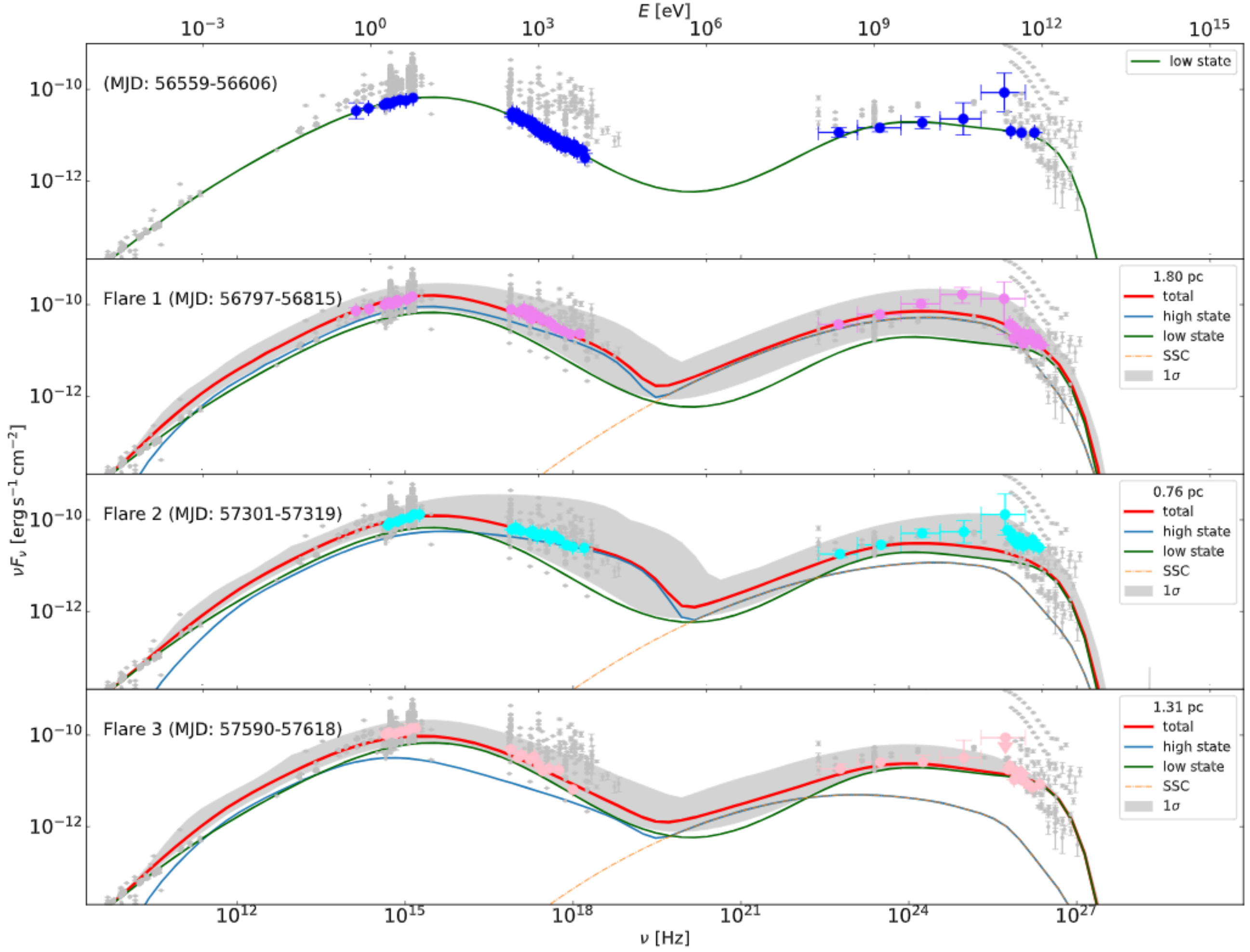
Low state

Multi-wavelength flare

Multi-wavelength flare

Orphan optical flare

PKS 2155-304 without BLR&DT



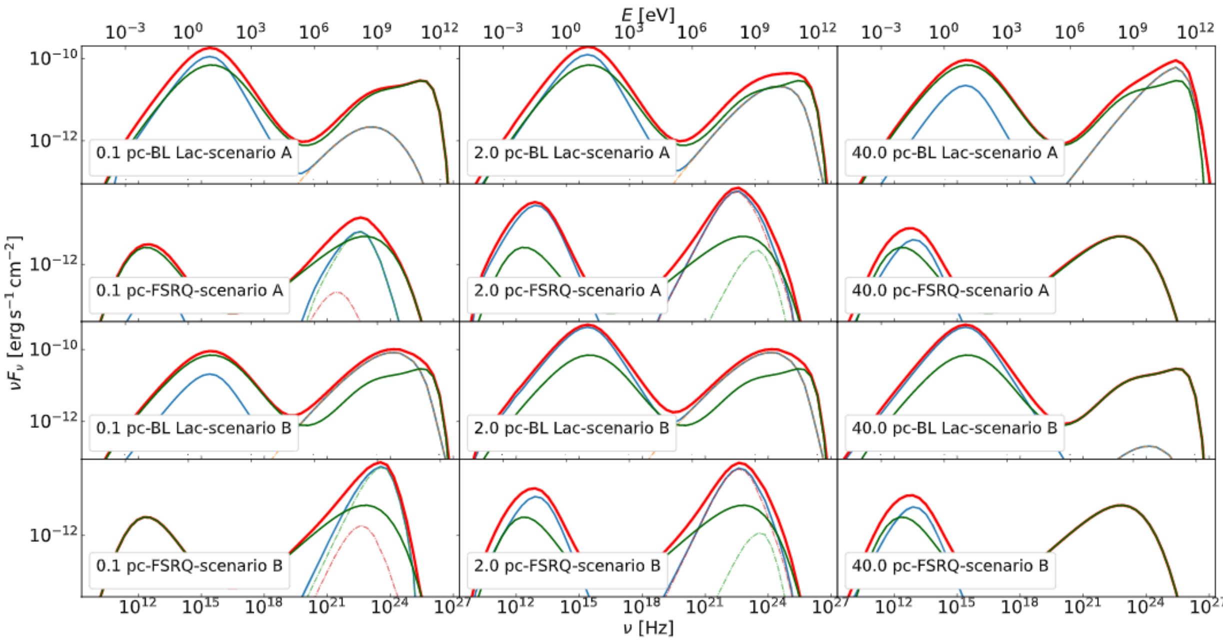
Low state

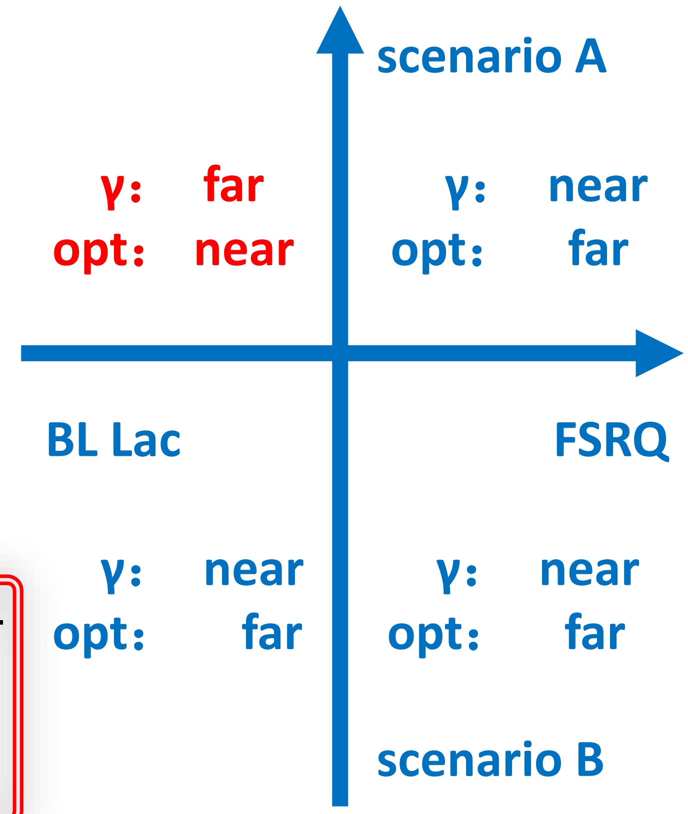
Multi-wavelength flare

Multi-wavelength flare

Orphan optical flare

The general cases





Scenario A: decreasing magnetic field strength B and Doppler factor δ_D.

Scenario B: constant magnetic field strength B and Doppler factor δ_D

Duration of blazar flares

The light-crossing times and observed duration of flaring states for 3C 279 and PKS 2155-304

	3C 279		PKS 2155-304		PKS 2155-304 (no BLR/DT)	
	$t_{\rm lc}$	$\Delta t_{\rm dur}$	$t_{\rm lc}$	$\Delta t_{\rm dur}$	$t_{\rm lc}$	$\Delta t_{\rm dur}$
Flare 1	$0.17^{+0.05}_{-0.04}$ days	0.5 days[a] (G)[b]	$0.03^{+0.02}_{-0.01}$ days	$\sim$ 20 days (X/G)	$0.08^{+0.10}_{-0.03}$ days	$\sim$ 20 days (X/G)
Flare 2	$4.55^{+0.96}_{-0.94}$ days	$\sim$ 2 days (G)	$0.13^{+0.10}_{-0.05}$ days	$\sim$ 20 days (T)	$0.03^{+0.03}_{-0.01}$ days	$\sim$ 20 days (T)
Flare 3	30^{+13}_{-9} days	$\sim$ 23 days (G)	22^{+12}_{-7} days	$\sim$ 108 days (O)	$0.05^{+0.06}_{-0.03}$ days	$\sim$ 108 days (O)

$$t_{lc} = (1+z)R(r)/(c\delta_D)$$

'G' denotes that this duration is estimated from the GeV band,
'O' from the optical, 'X' from the X-ray, and 'T' from the TeV band.

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Conclusion

1. The stochastic dissipation model includes two emission components.
   Background emission: the superposition of radiation from numerous but comparatively weak dissipation zones along the jet.
   Flaring zone: stronger dissipation zone randomly appear at different positions along the jet.

2. The ratio between the Compton dominance of flaring zone and background emission determines the type of blazar flare.

3. FSRQ: orphan γ-ray flare tend to arise when the strong dissipation occurs close to the SMBH, while orphan optical flare arises when the strong dissipation occurs far away from the SMBH.

4. BL Lac: the situation is similar to that of FSRQs in scenario A, but the situation is more complex due to the KN effect in scenario B.

5. The flare duration and the orphan flare rates expected in the model are consistent with orphan flare observations made to date.

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Thank you!