J1048+7143: A Supermassive Black Hole Binary Candidate Close to Merger

Common name:
S5 1044+71

Ilja Jaroschewski

First ACME workshop:
The gravitational wave sky and complementary observations

Collaborators:

Emma Kun,
Julia Becker Tjus,
Johannes Just,
Silke Britzen,
Sándor Frey,
Krisztina Éva Gabányi,
Lang Cui,
Xin Wang,
Yuling Shen

Multi-Messenger Picture

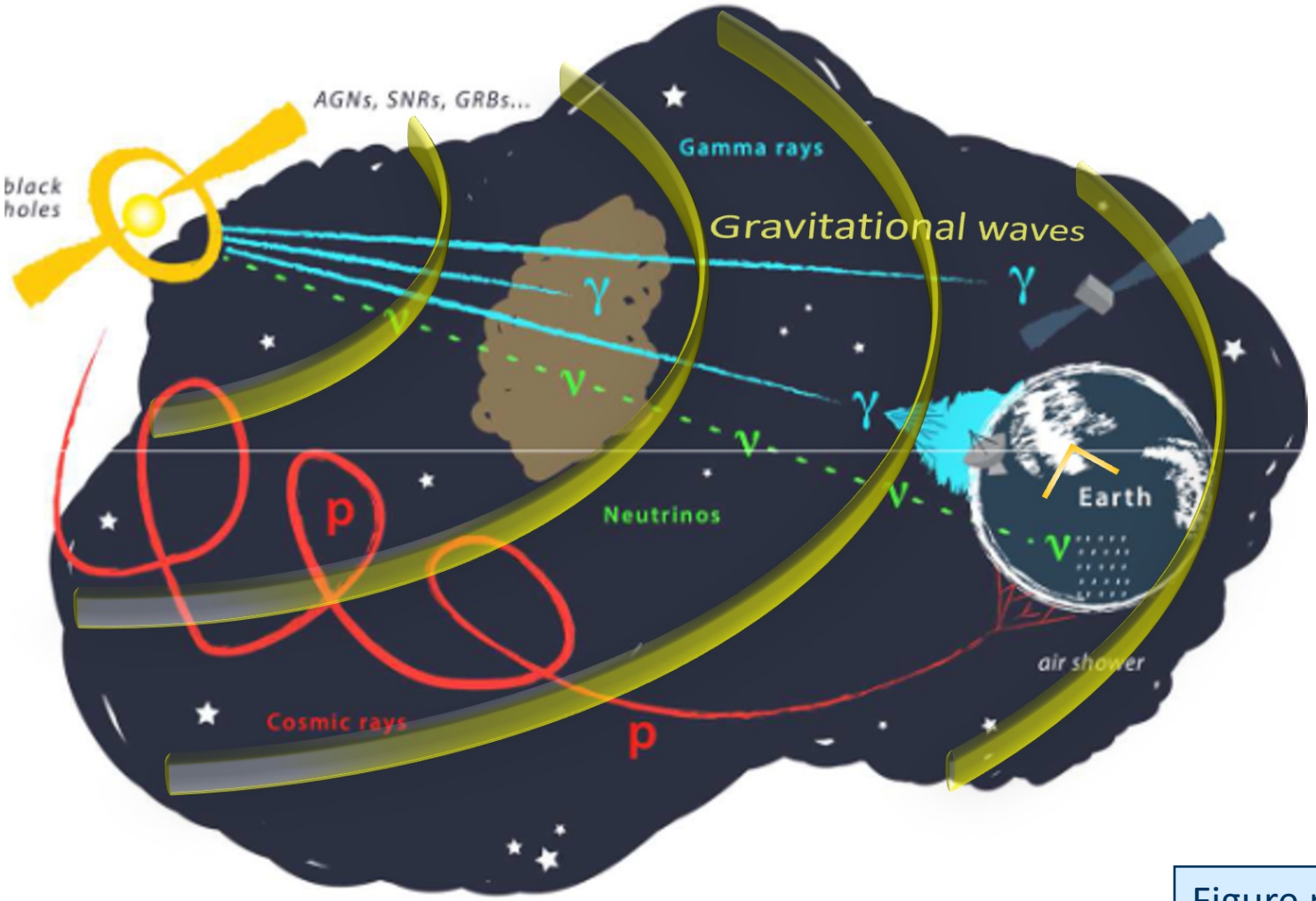
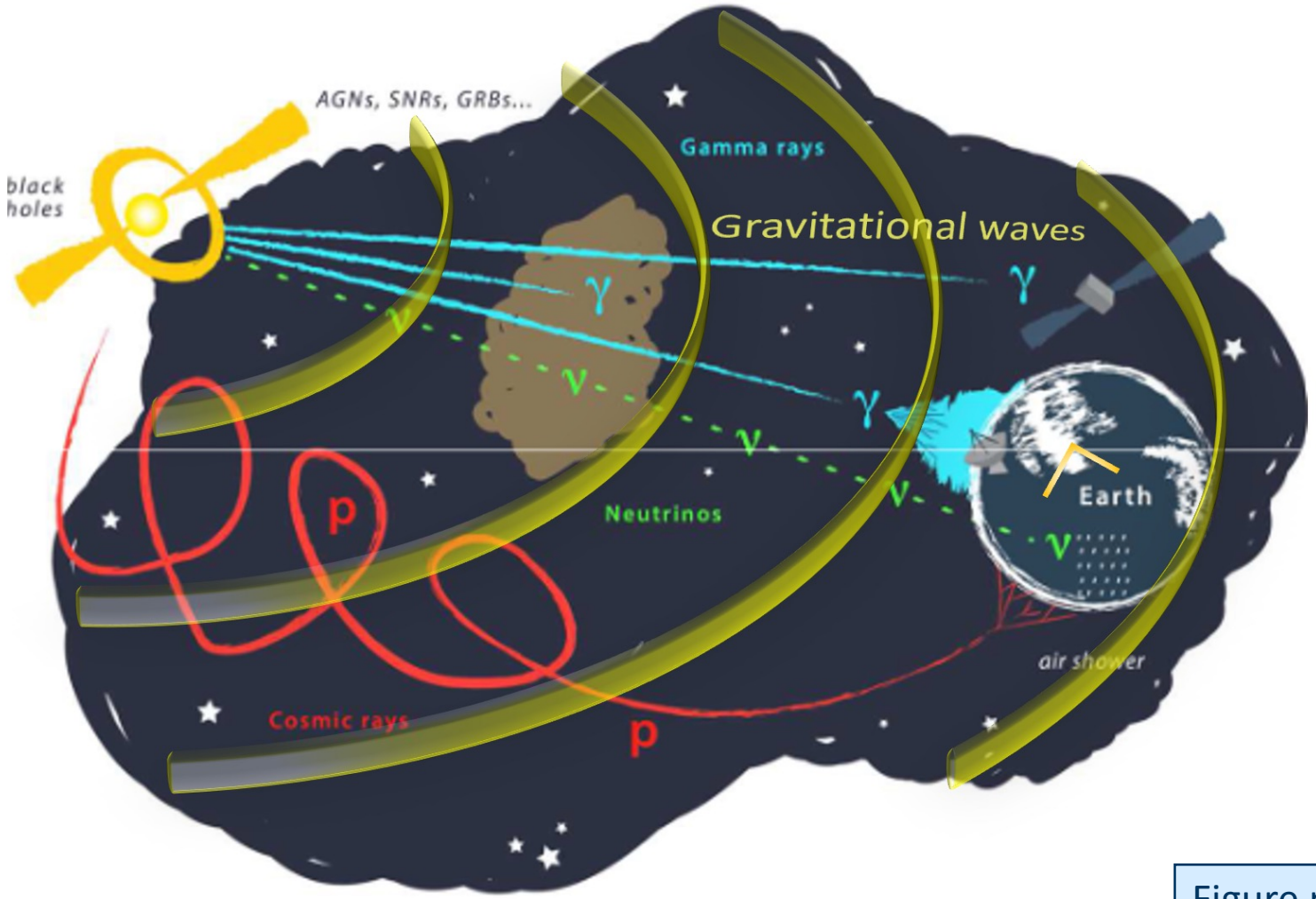


Figure modified after Juan Antonio Aguilar and Jamie Yang, IceCube/WIPAC

Multi-Messenger Picture



In this talk:

Gamma Rays

Optical Light

Radio Waves

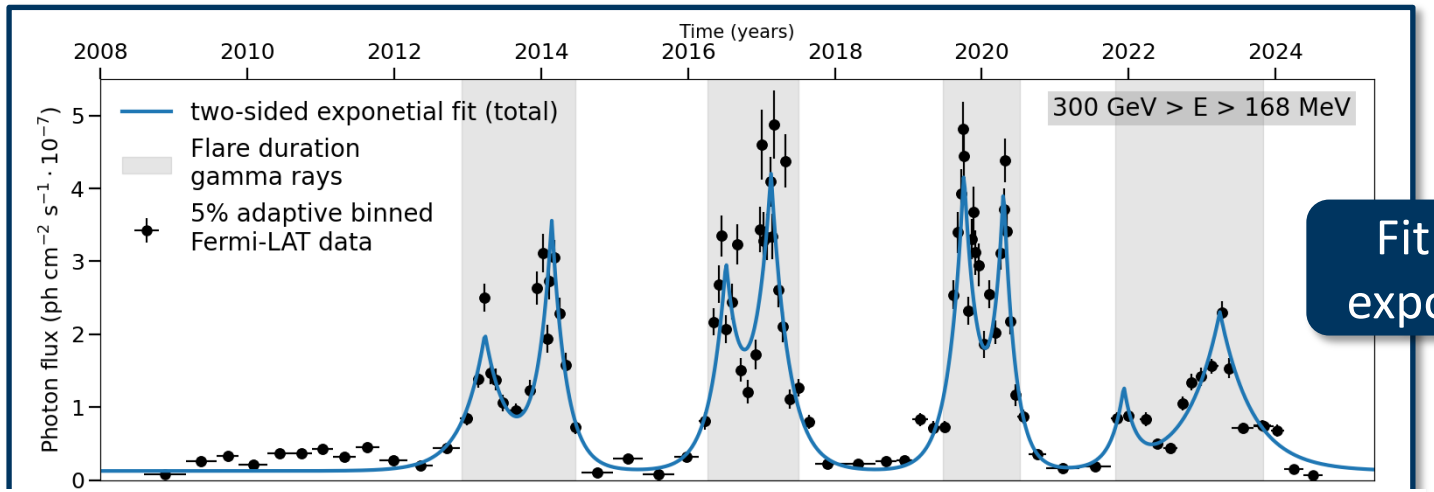
Gravitational Waves

Figure modified after Juan Antonio Aguilar and Jamie Yang, IceCube/WIPAC

cea irfu

Observational Data:

Gamma-Ray Light Curve

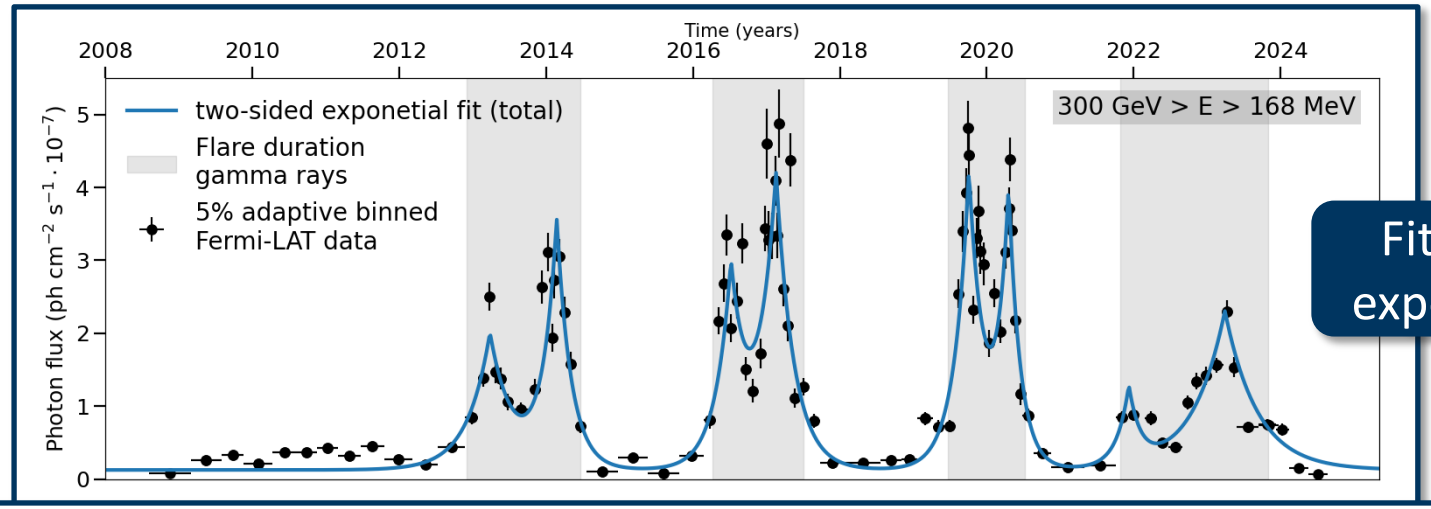


Fit with two-sided exponential function

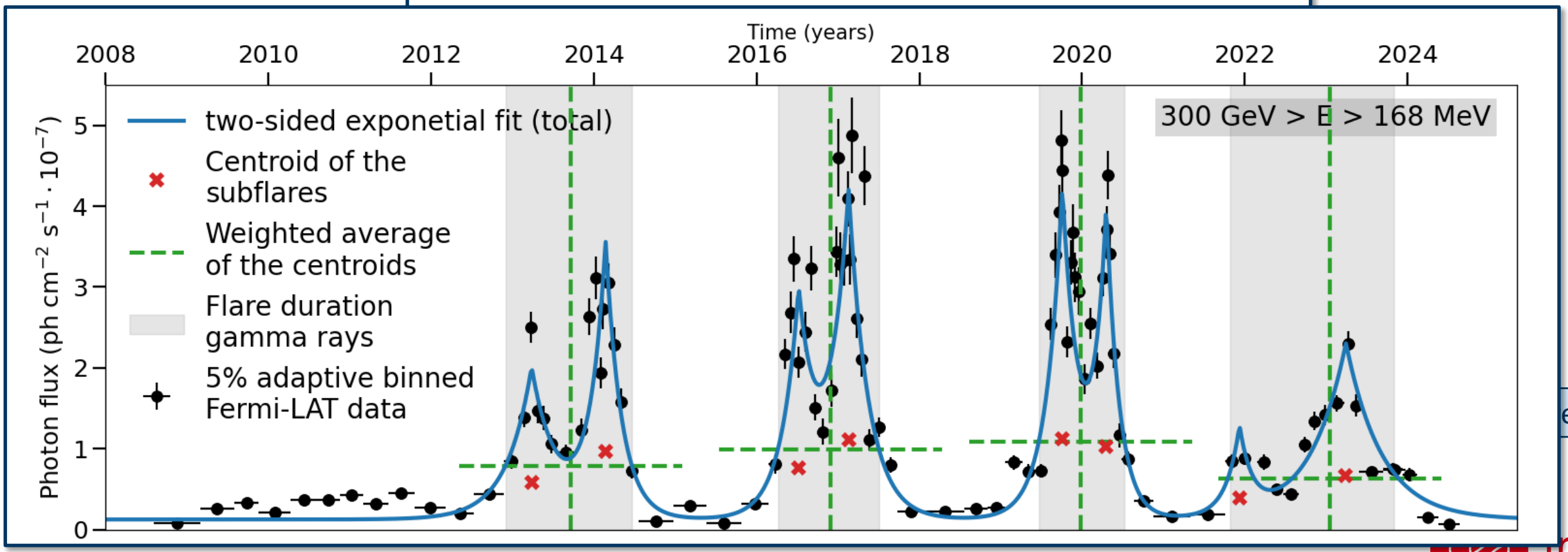
IJ+ in prep.

Observational Data:

Gamma-Ray Light Curve



Fit with two-sided exponential function



ep.

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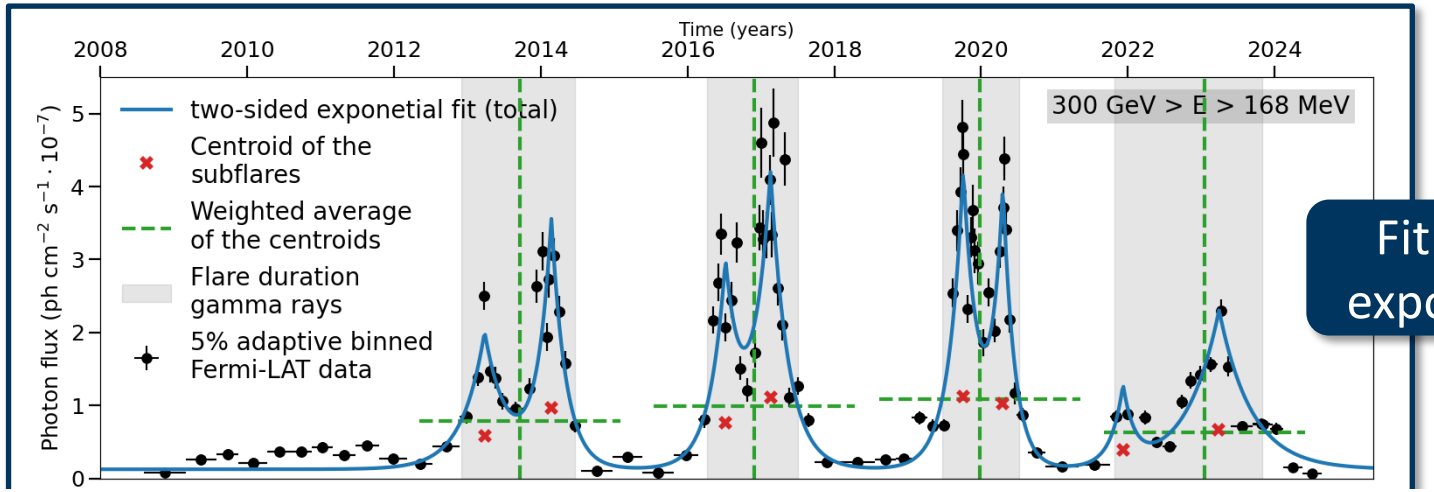
Observational Data:

Gamma-Ray Light Curve



Fit with two-sided exponential function

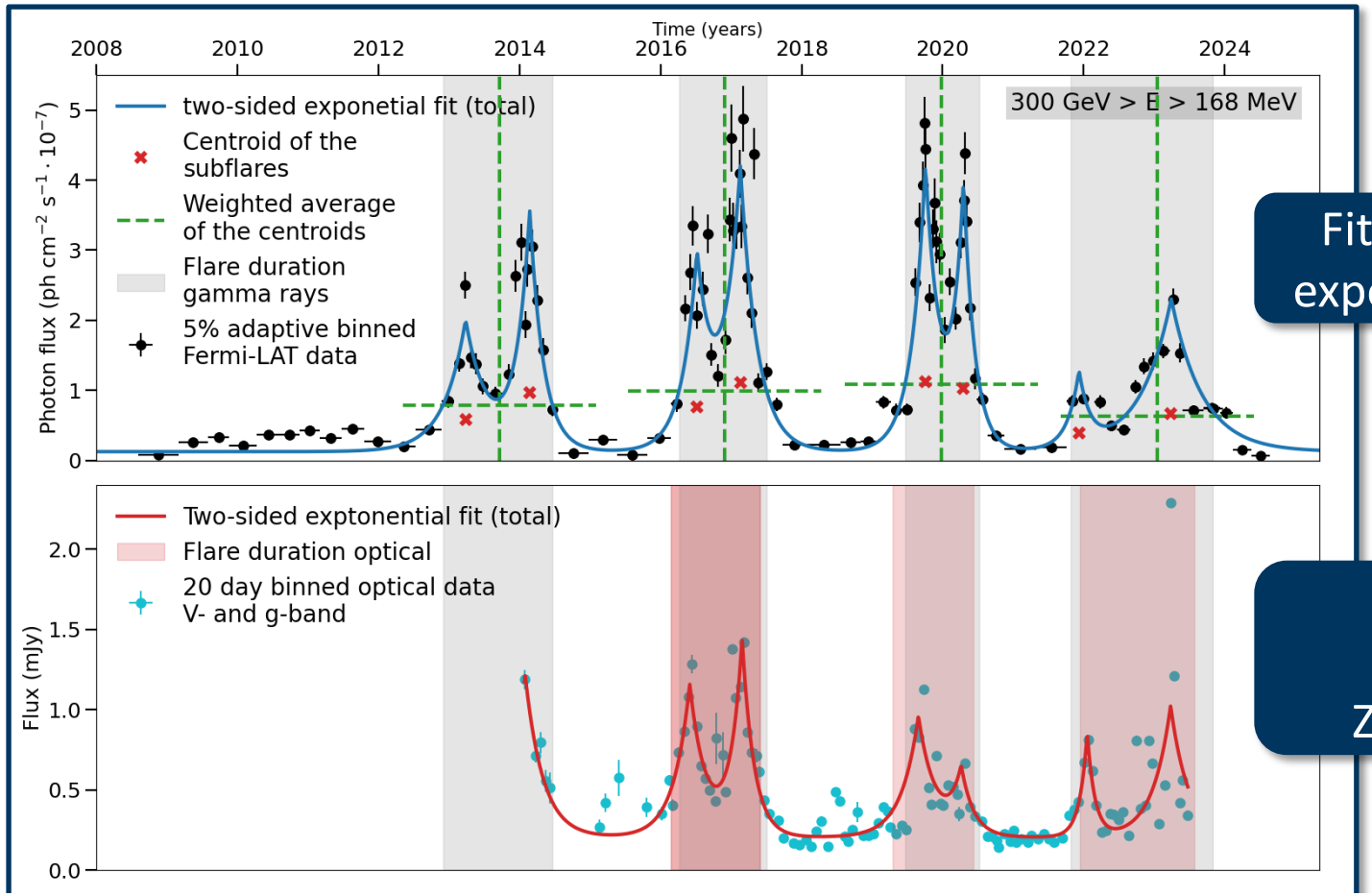
IJ+ in prep.

cea irfu

Observational Data:

Gamma-Ray Light Curve

+ Optical



Fit with two-sided exponential function

ASAS-SN
AAVSO
ZTF in progress

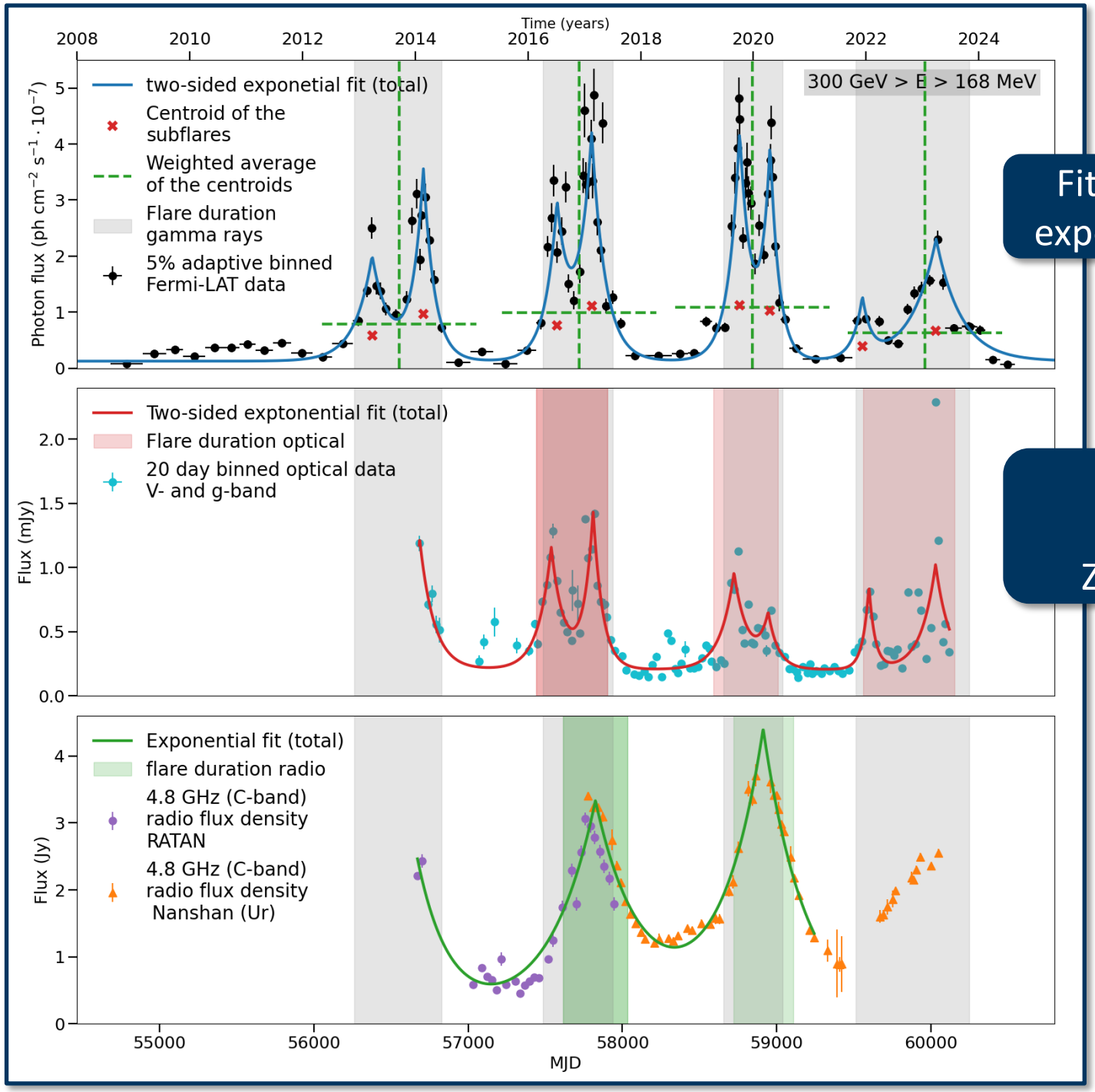
IJ+ in prep.

Observational Data:

Gamma-Ray Light Curve

+ Optical

+ Radio



Fit with two-sided exponential function

ASAS-SN
AAVSO
ZTF in progress

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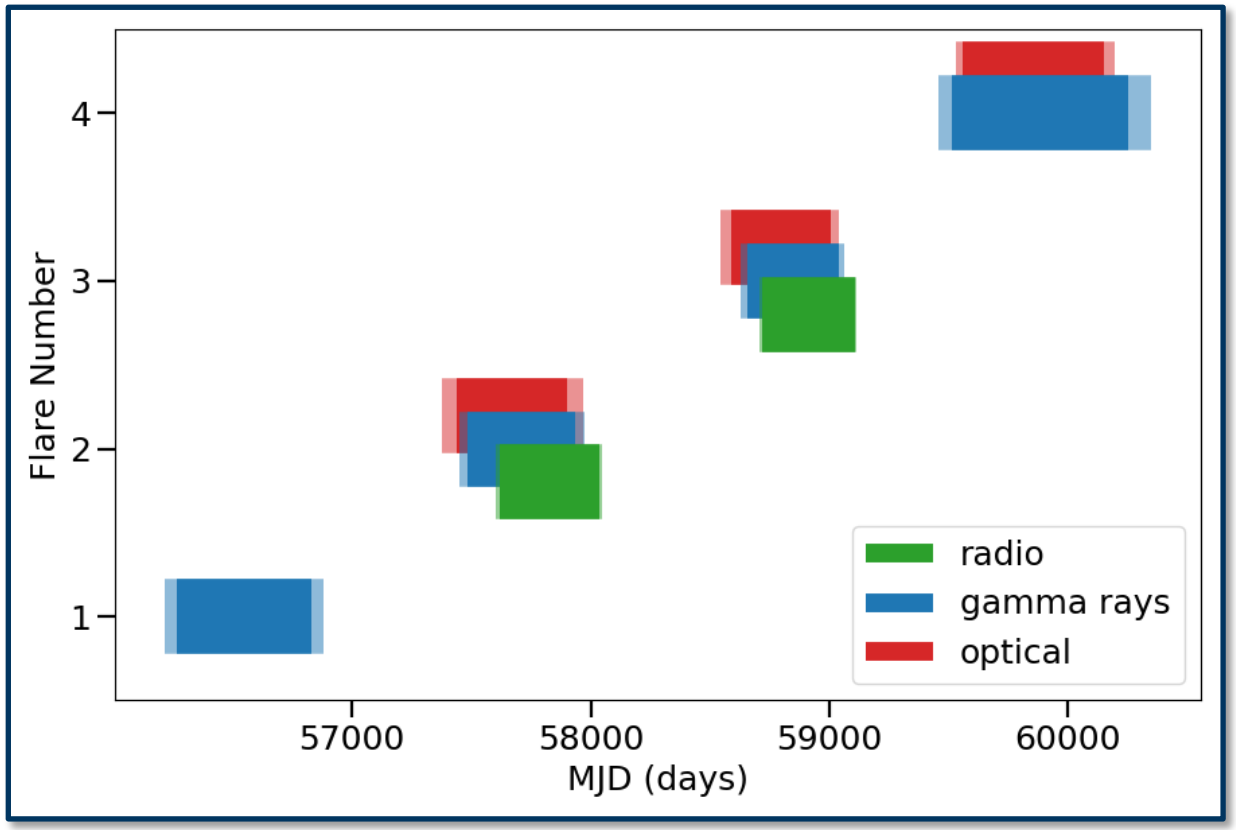
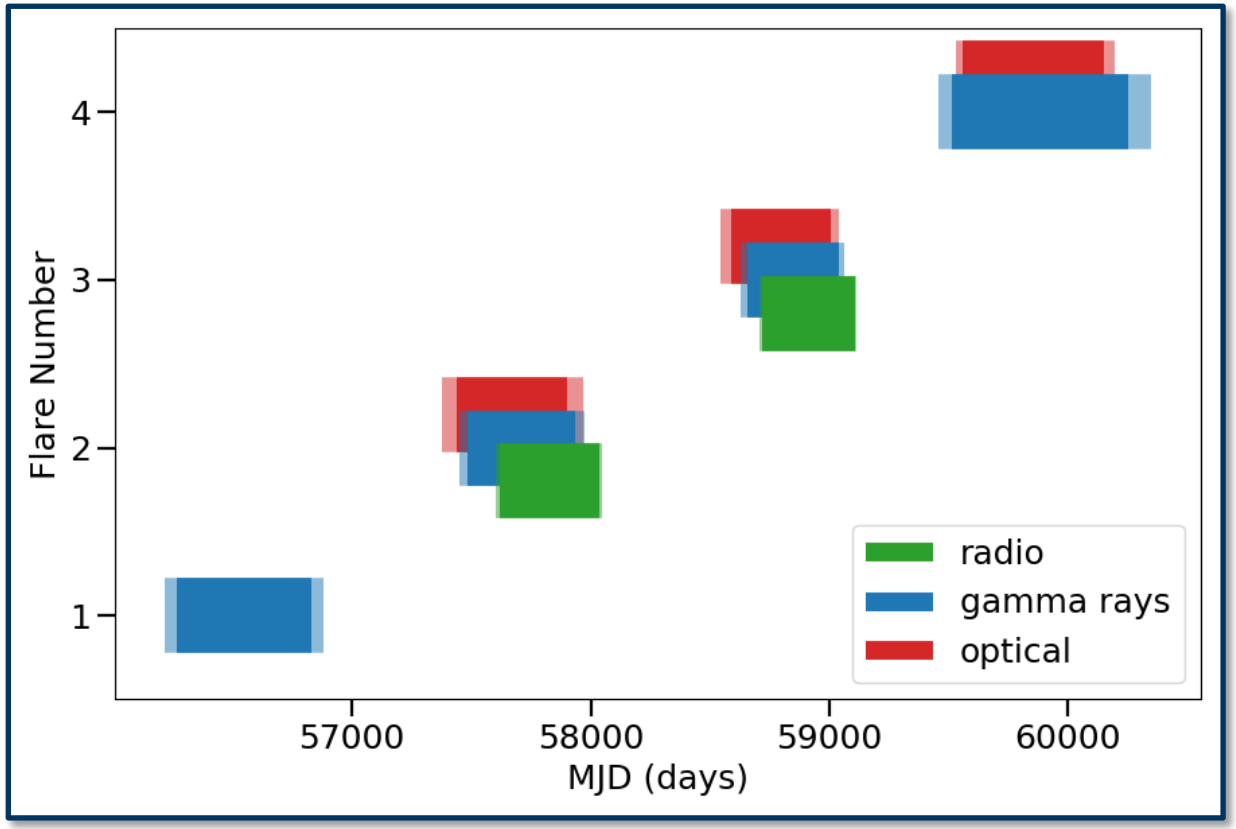
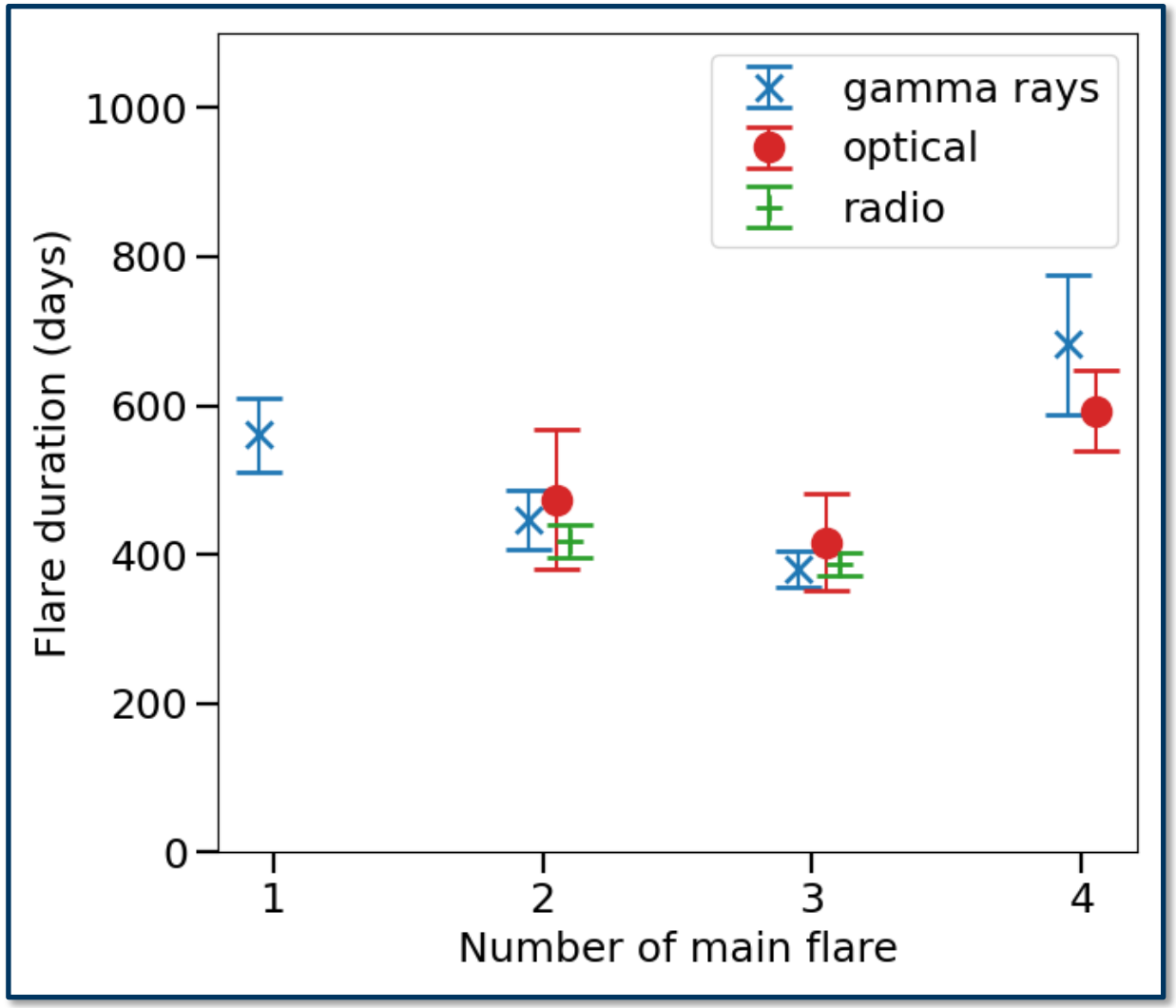
Flare Durations



IJ+ in prep.

Flare Durations

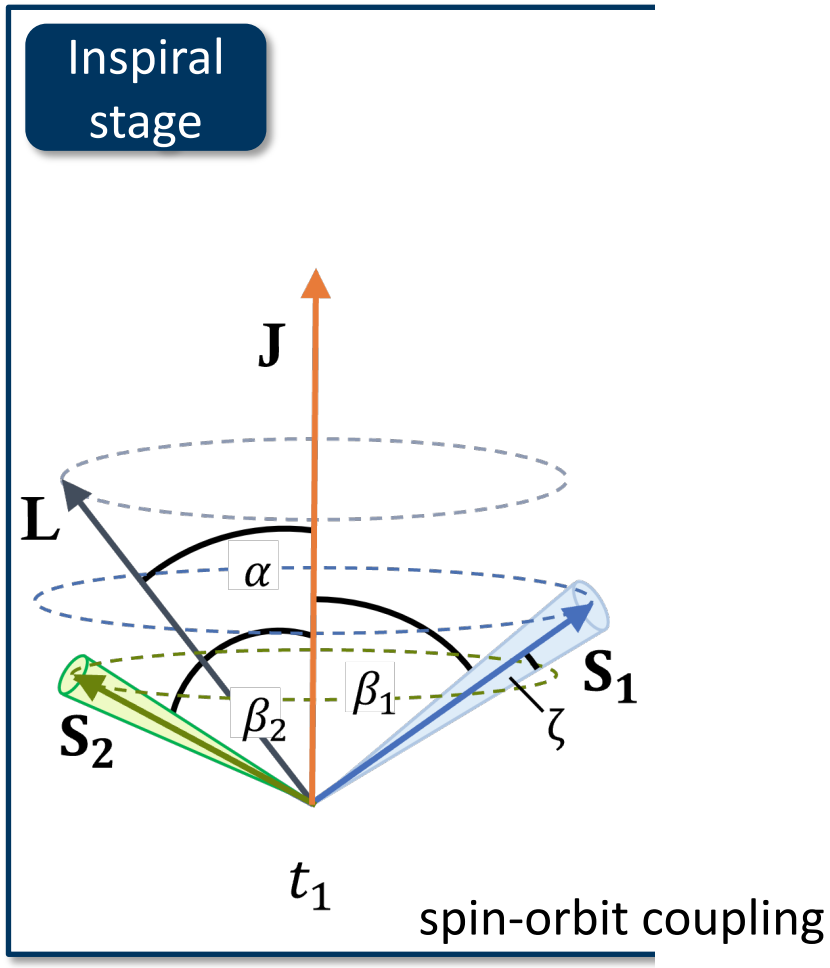




IJ+ in prep.

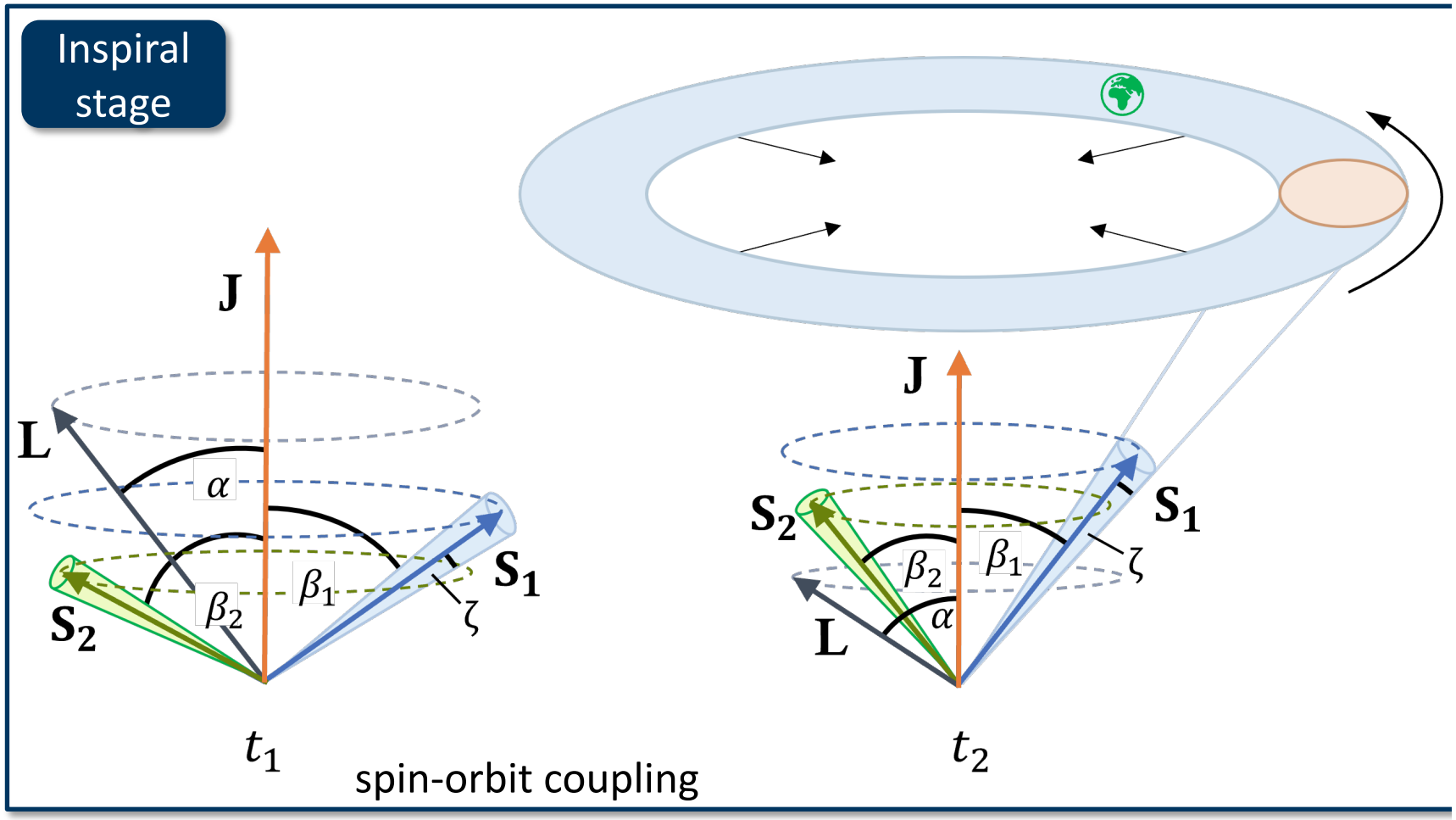
The Jet Precession Model

The Jet Precession Model



modified from de Bruijn et al. (2020)

The Jet Precession Model



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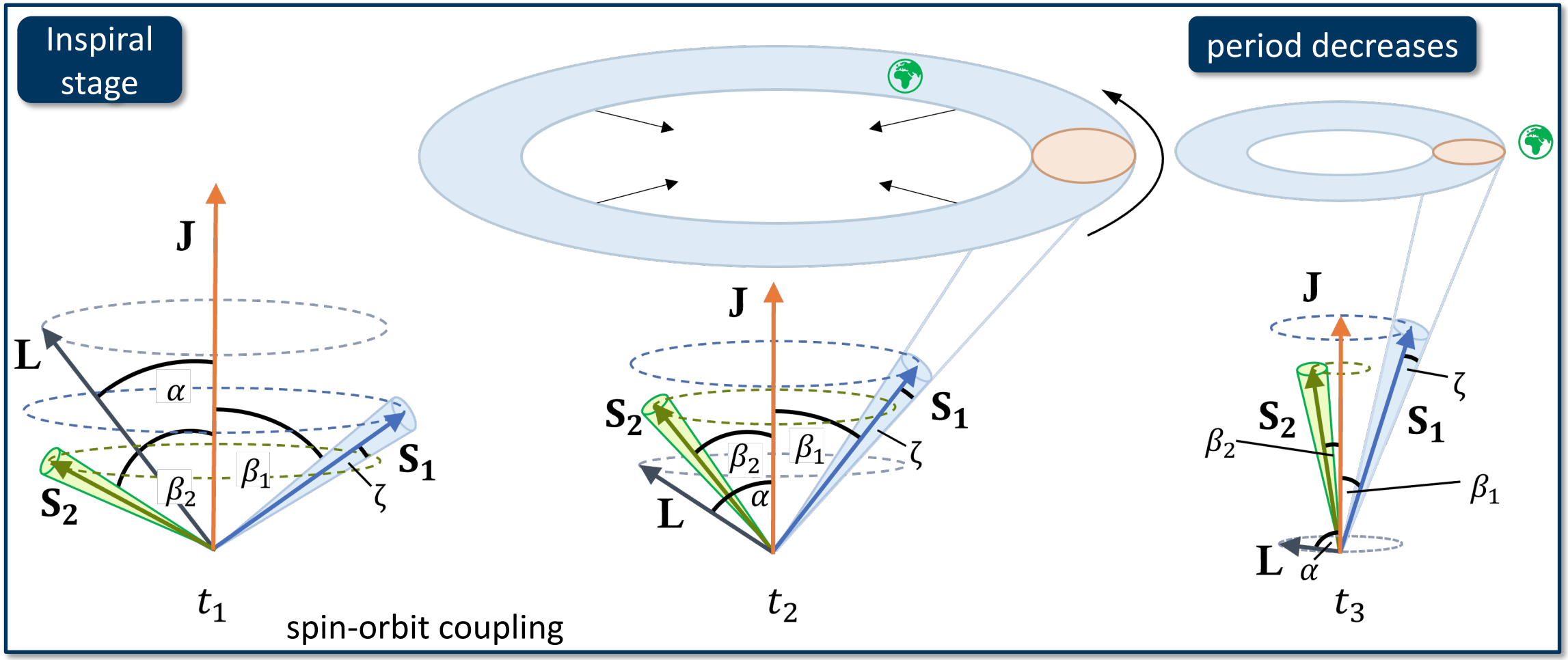
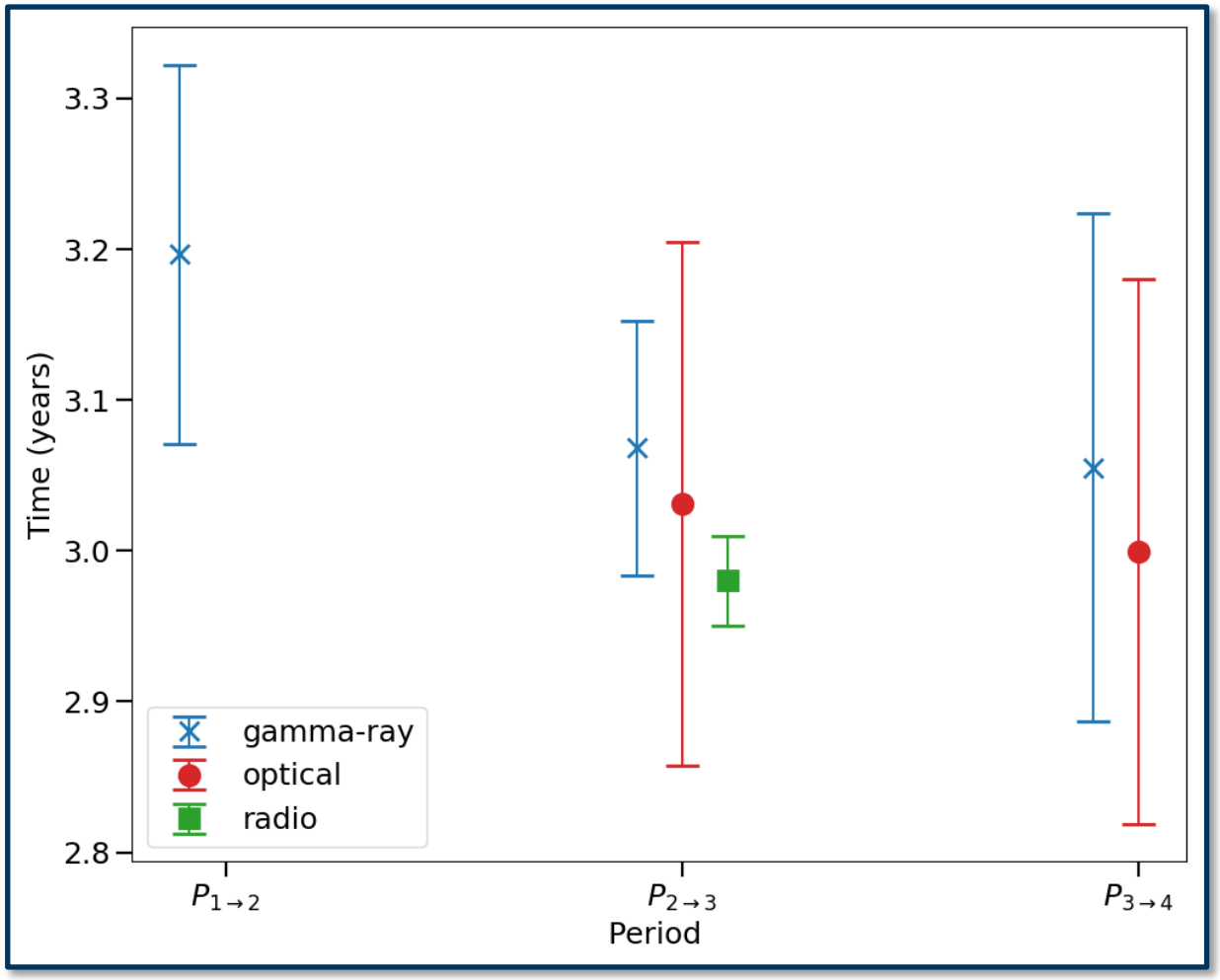
The Jet Precession Model



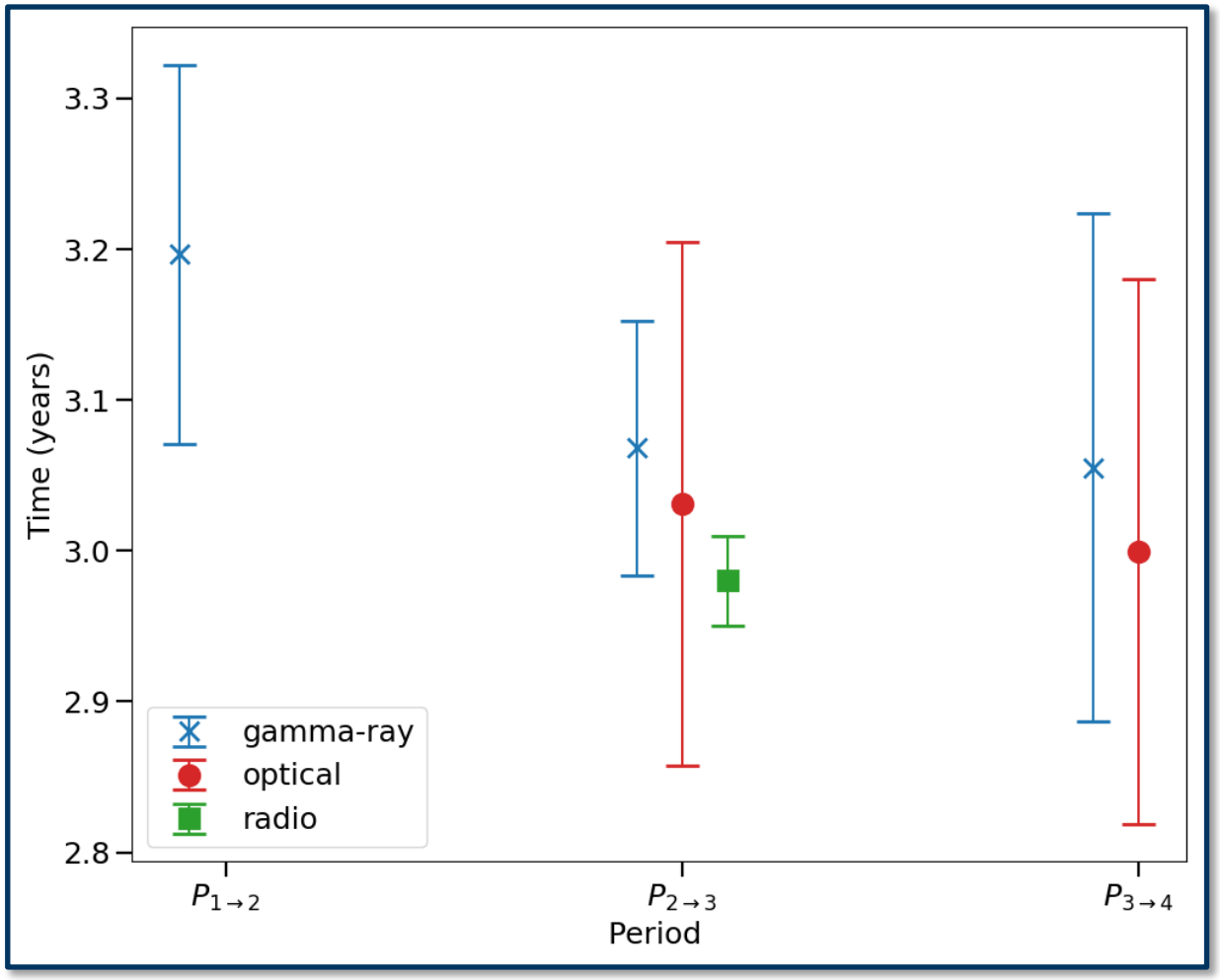
modified from de Bruijn et al. (2020)

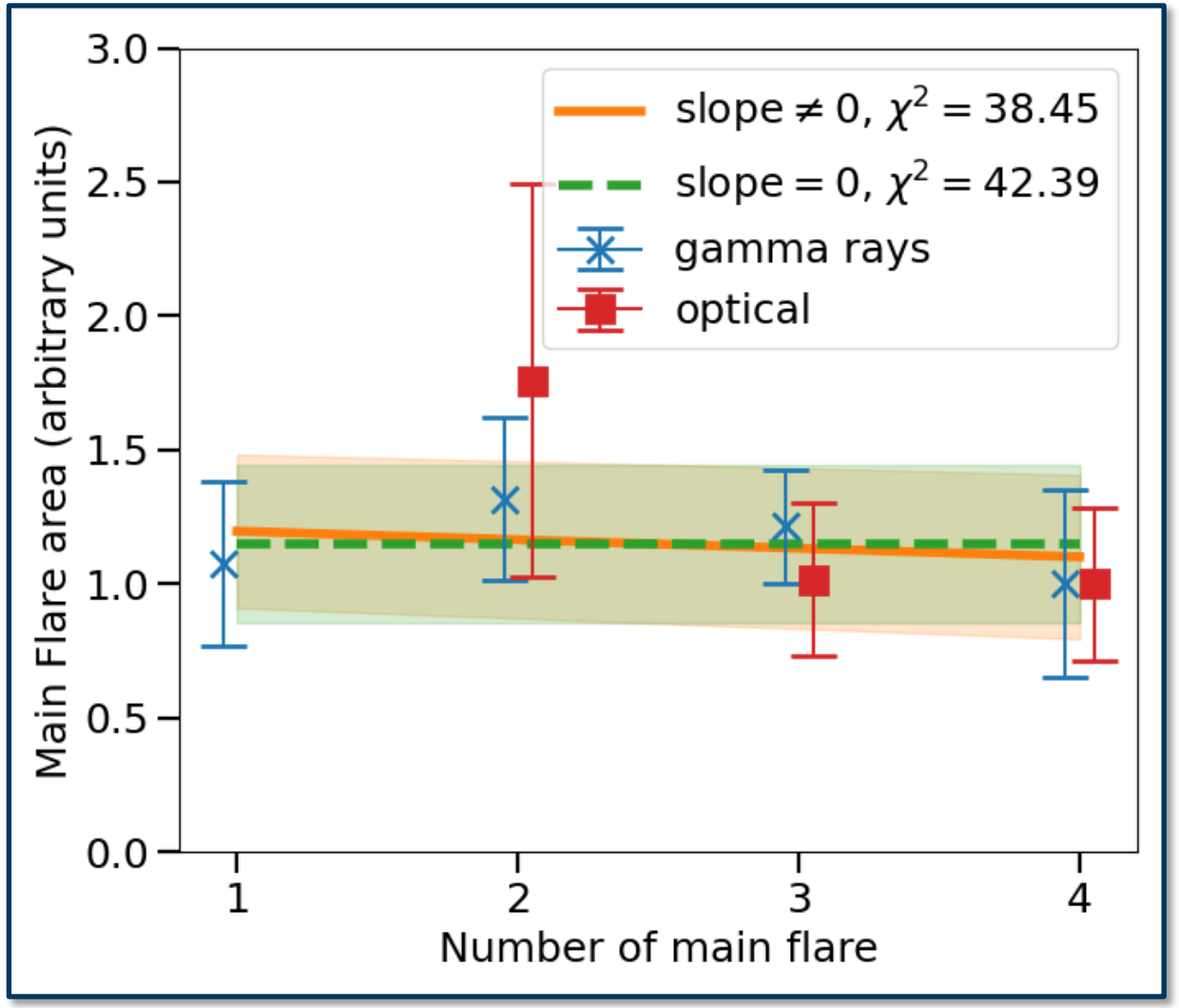
Periods between Flares



IJ+ in prep.

Periods between Flares + Flare Areas





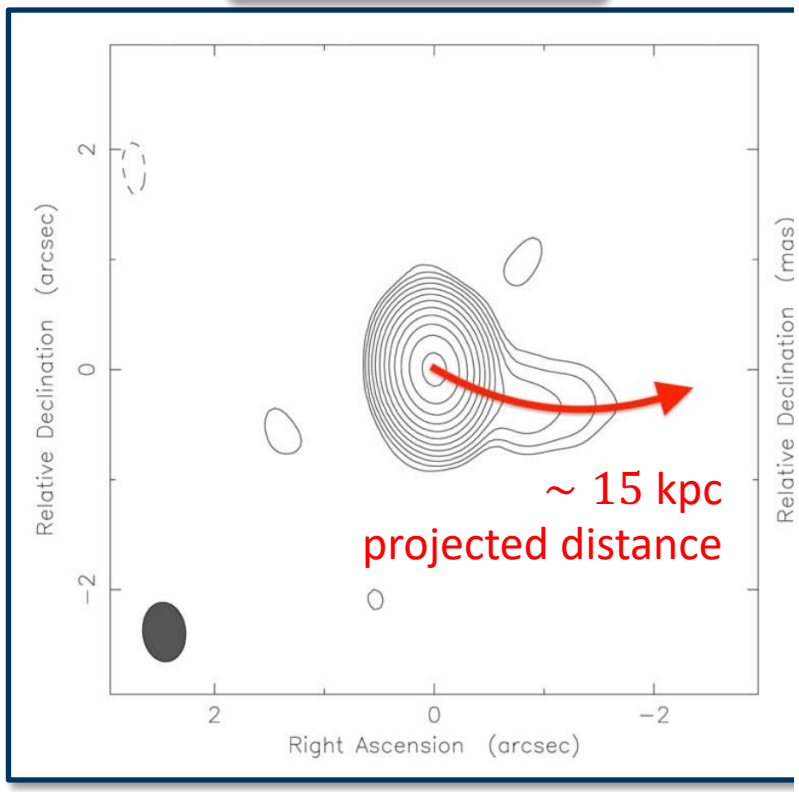
Flare areas normalized to last flare

IJ+ in prep.

Jet Structure at Parsec Scales – Radio Observations

Jet Structure at Parsec Scales – Radio Observations

4.8 GHz VLA

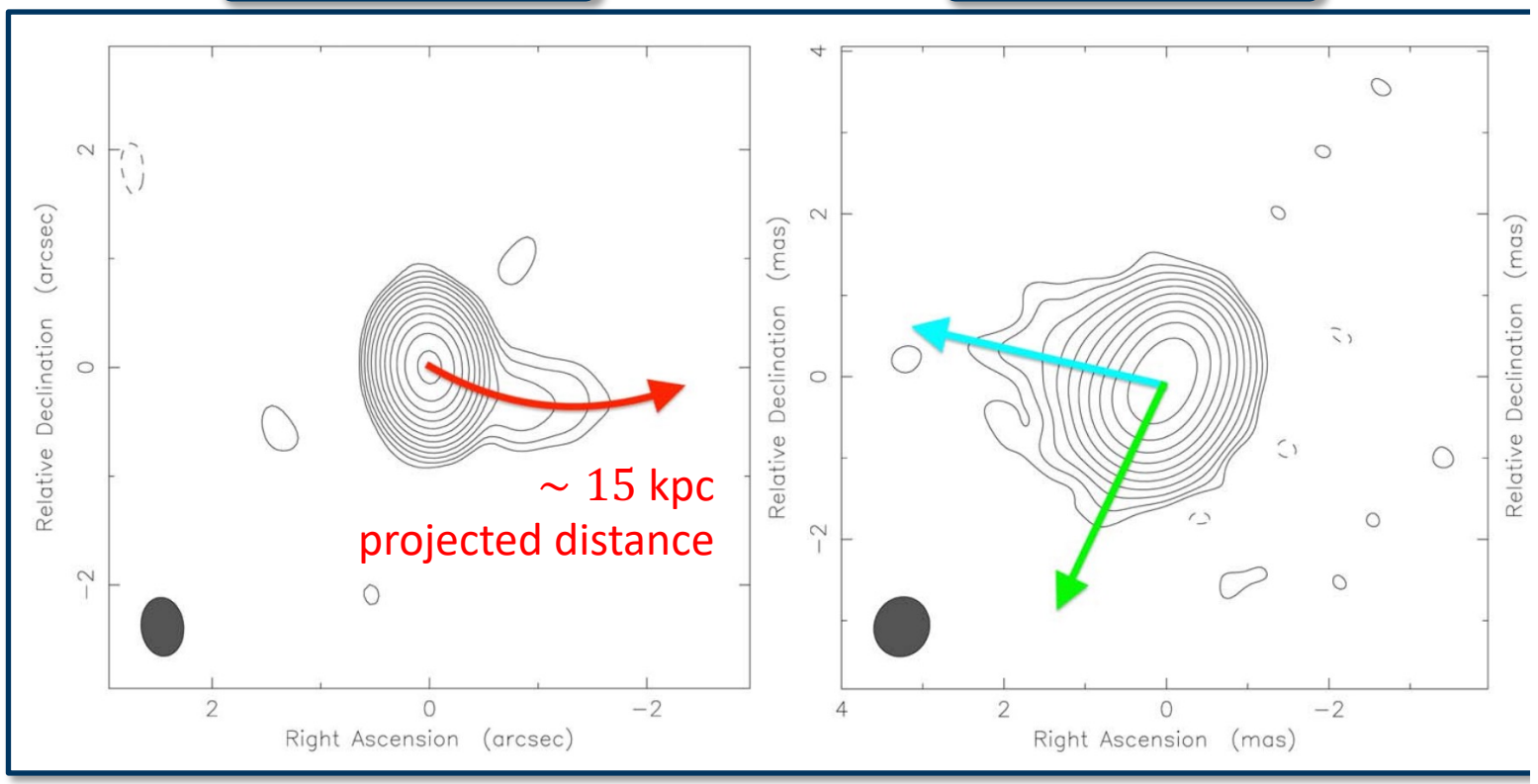


Kun, **IJ** et al. (2022)

Jet Structure at Parsec Scales – Radio Observations

4.8 GHz VLA

8.6 GHz VLBI



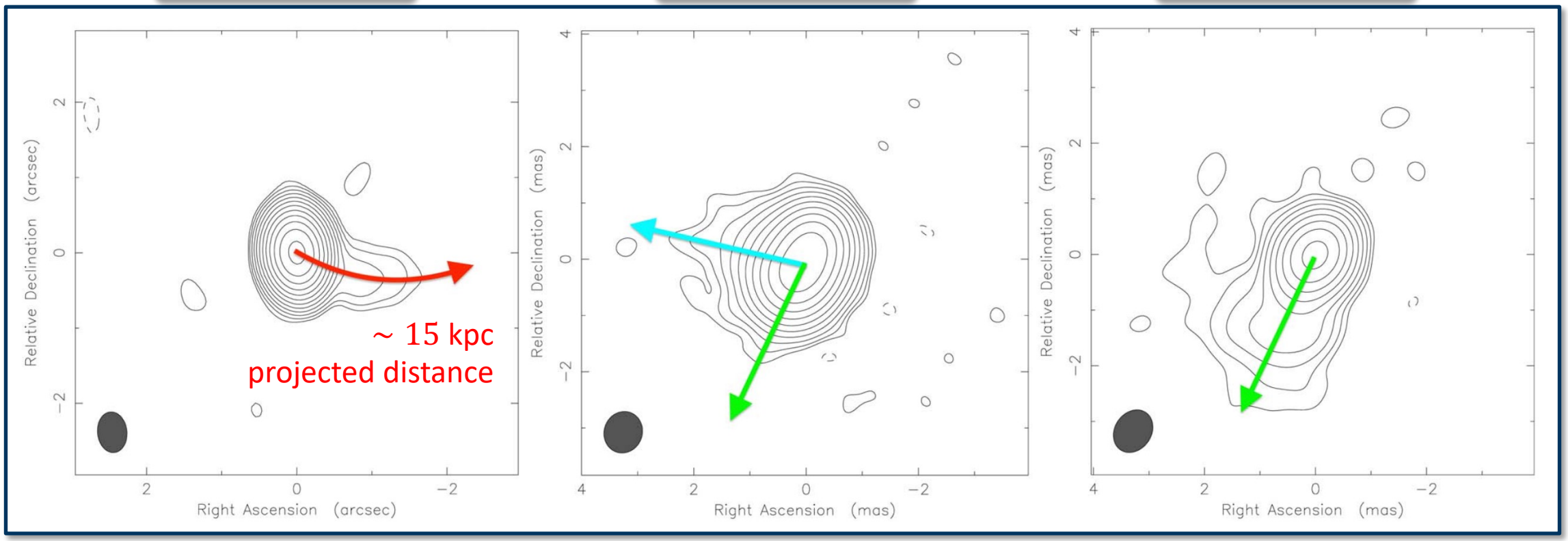
05.07.2001

1 mas ≡ 8.361 pc
projected linear scale

Kun, **IJ** et al. (2022)

Jet Structure at Parsec Scales – Radio Observations

4.8 GHz VLA | 8.6 GHz VLBI | 8.6 GHz VLBI



05.07.2001

23.03.2010

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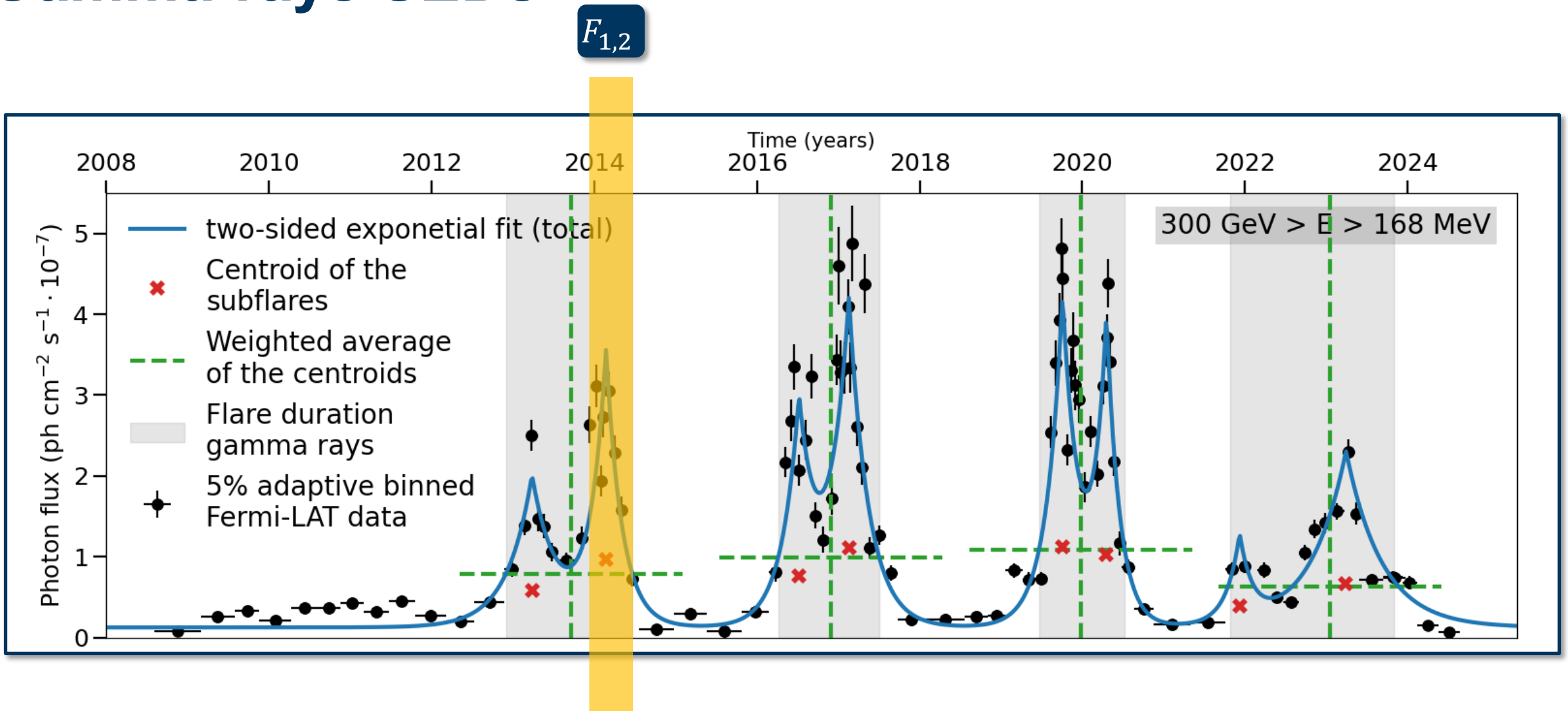
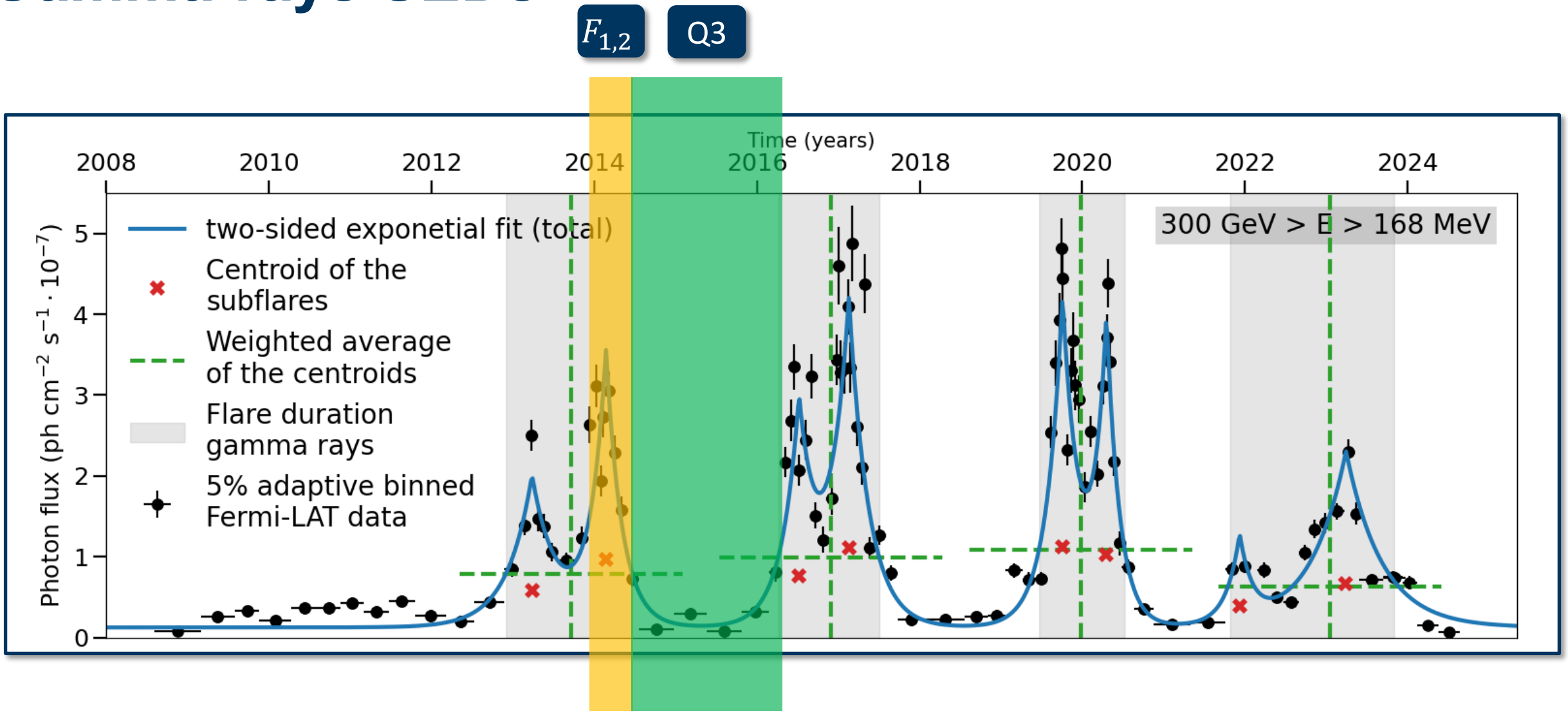
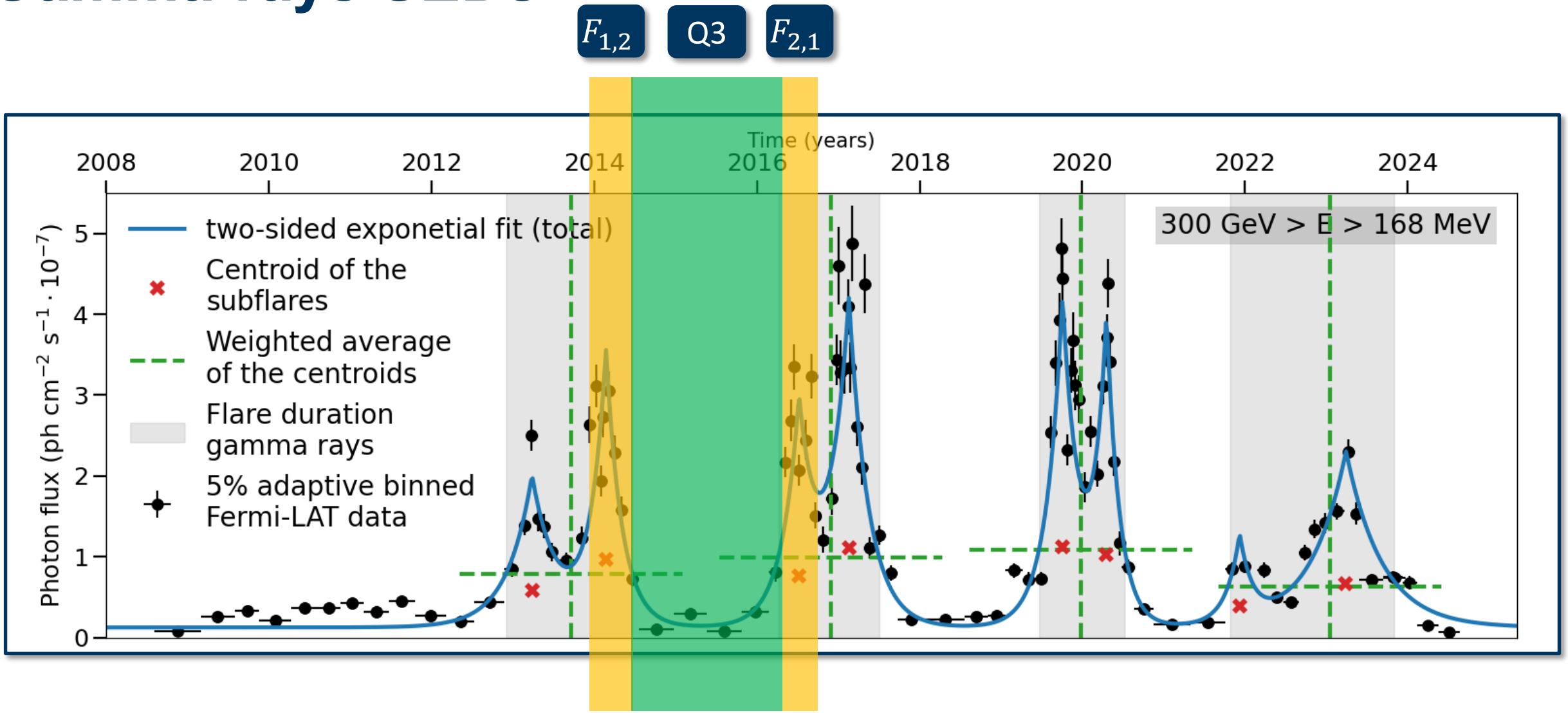
Gamma-rays SEDs



Gamma-rays SEDs

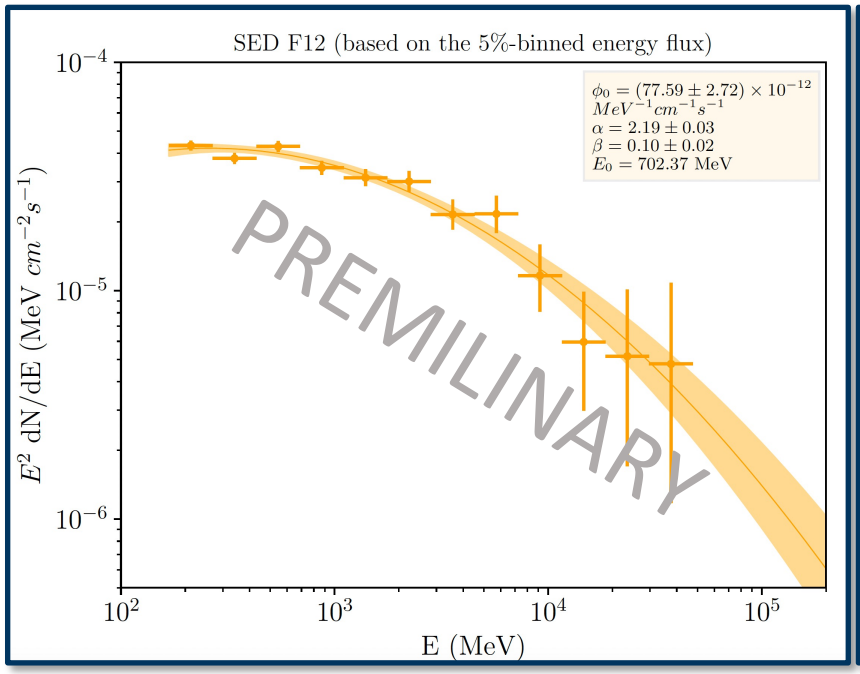


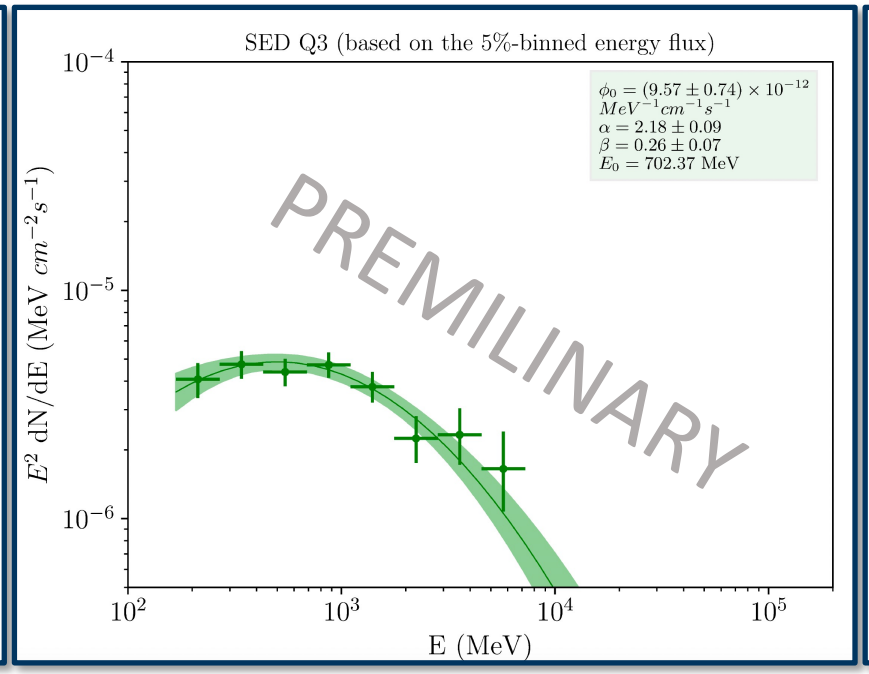
Gamma-rays SEDs

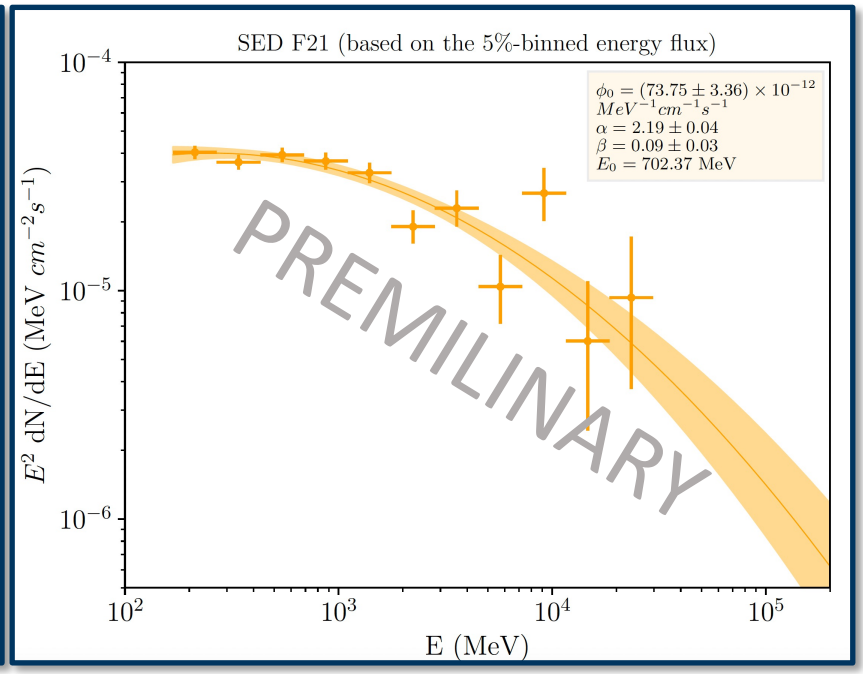


Gamma-rays SEDs – Comparison

$F_{1,2}$ | Q3 | $F_{2,1}$





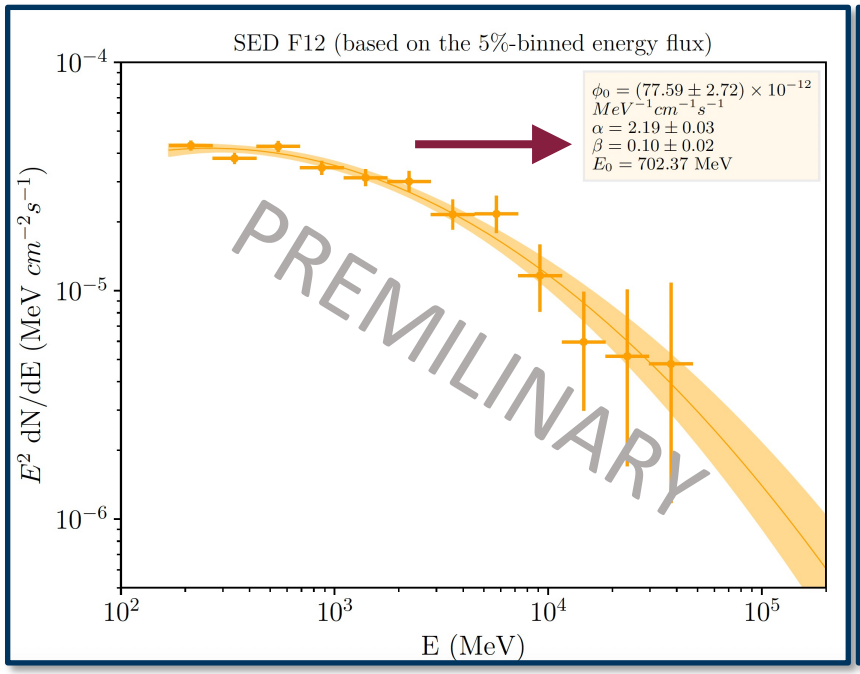


$$\frac{dN}{dE} = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha - \beta \ln(E/E_0)}$$

Doppler Boost

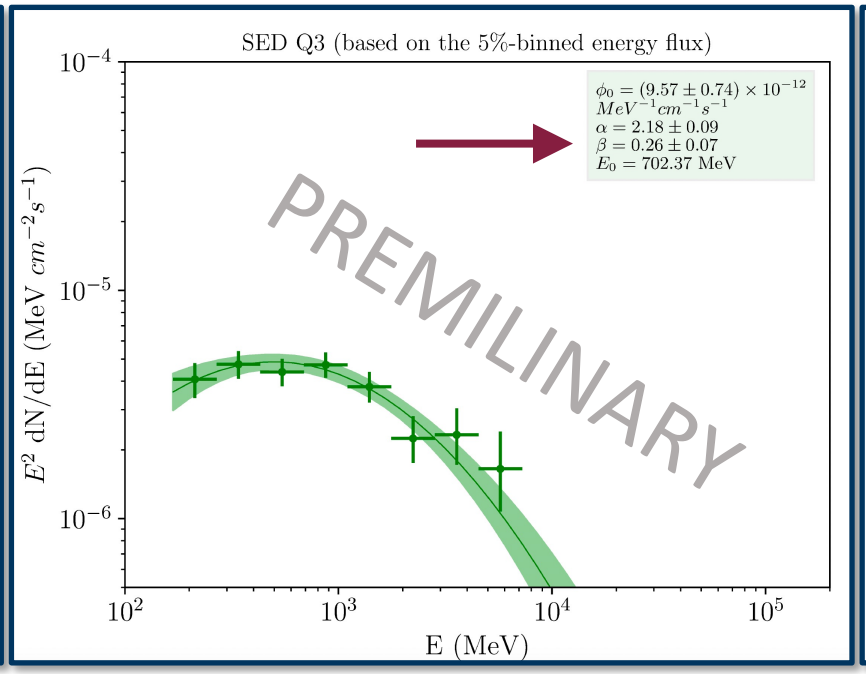
Gamma-rays SEDs – Comparison

$F_{1,2}$



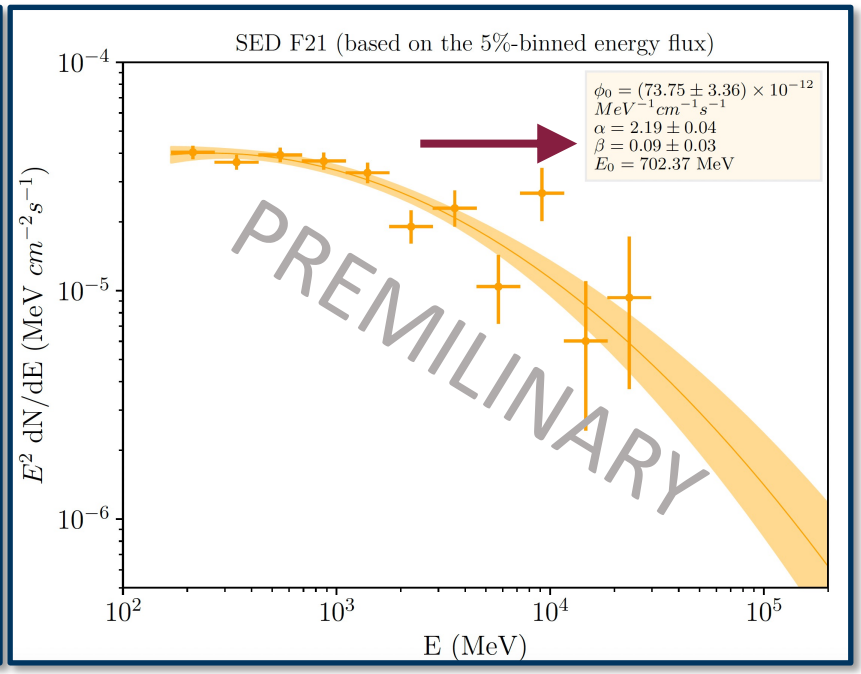
$\beta = 0.10 \pm 0.02$

Q3



$\beta = 0.26 \pm 0.07$

$F_{2,1}$

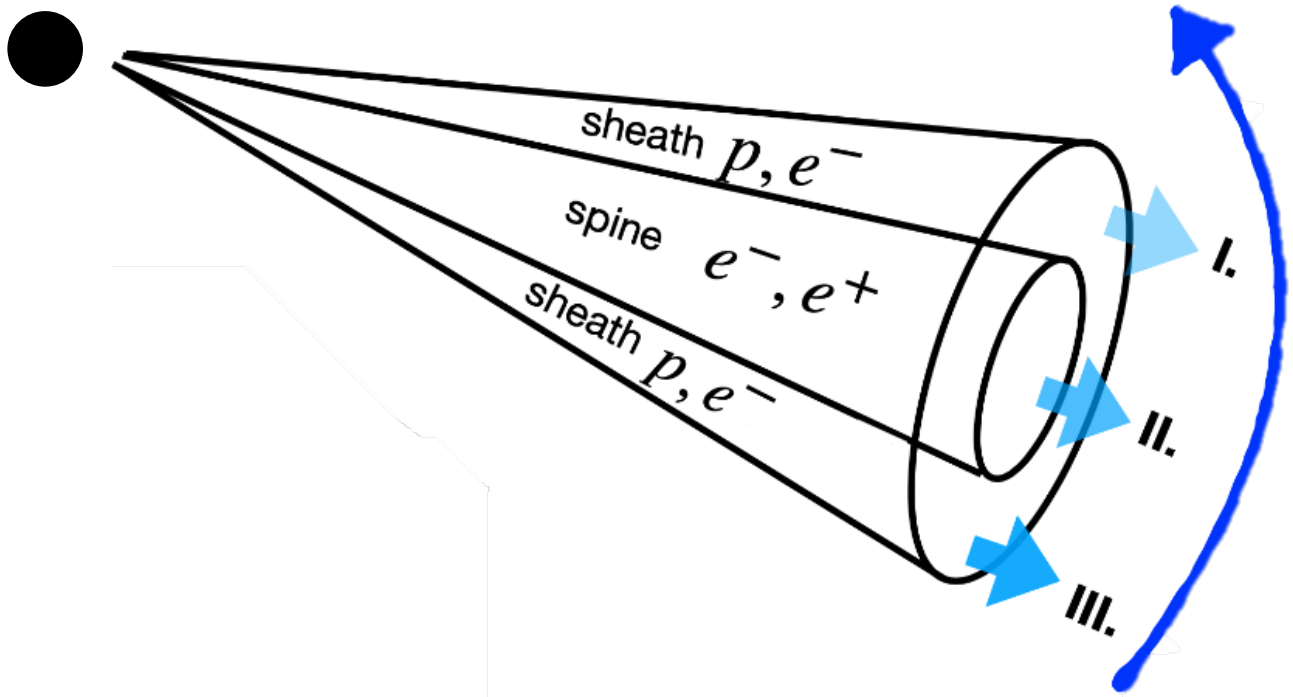


$\beta = 0.09 \pm 0.03$

$$\frac{dN}{dE} = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha - \beta \ln(E/E_0)}$$

Doppler Boost

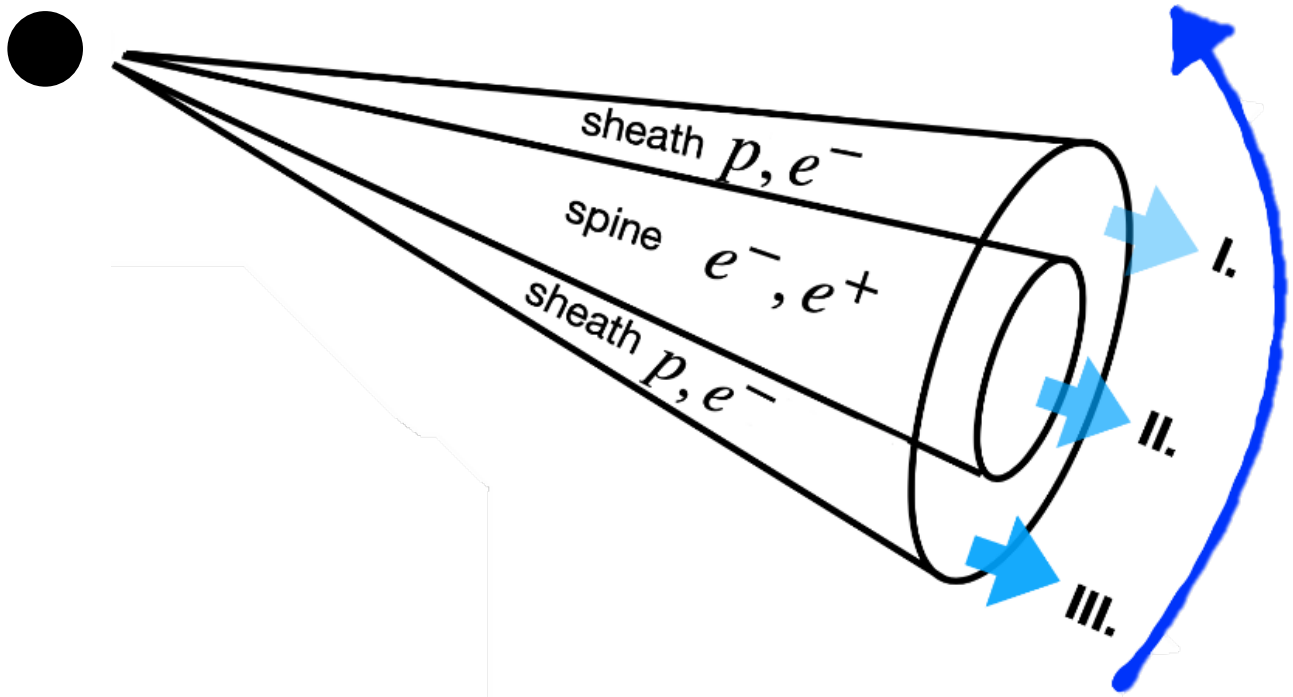
Double Peak Structure – an Explanation: Spine-Sheath Model

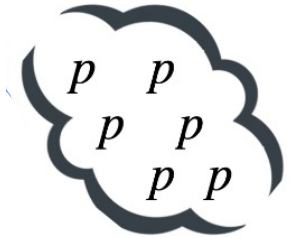


Observer

Kun, **IJ** et al. (2024)

Double Peak Structure – an Explanation: Spine-Sheath Model



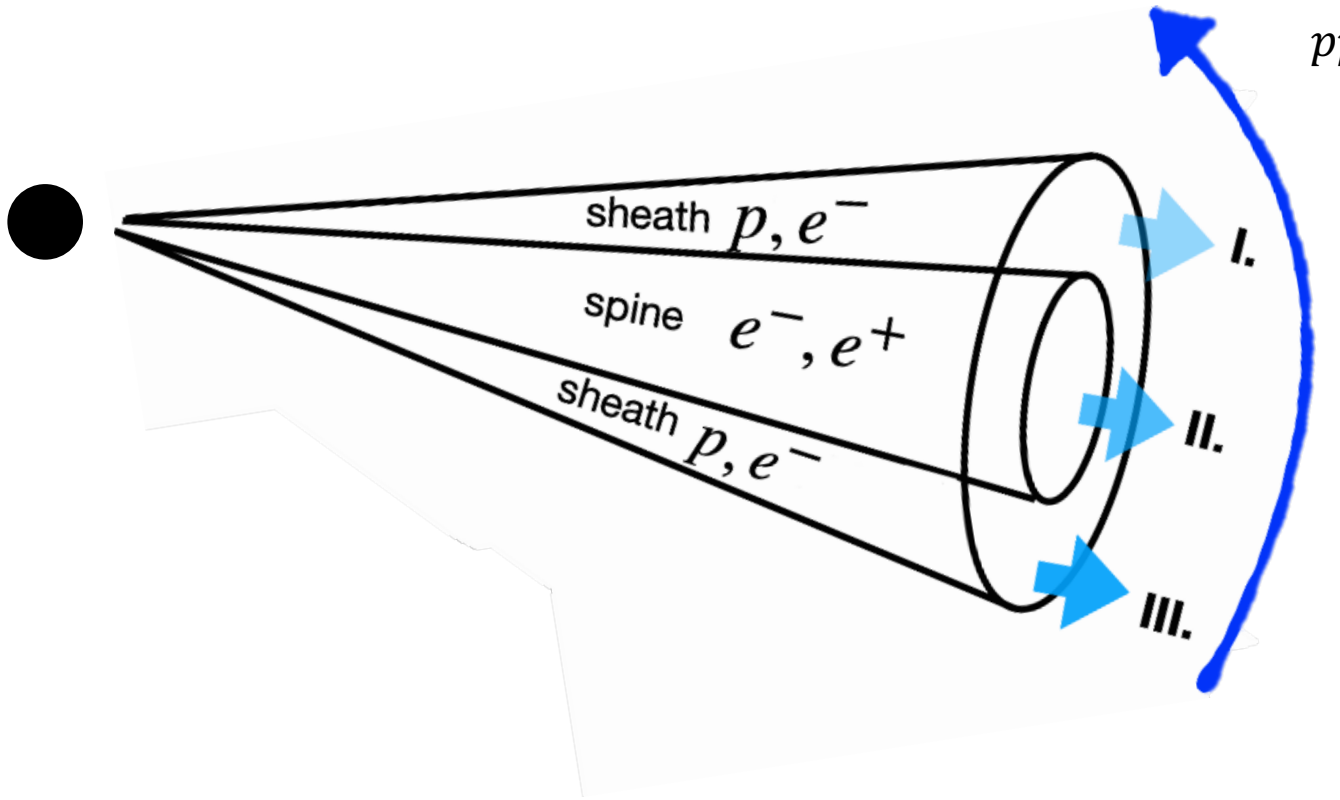


Target

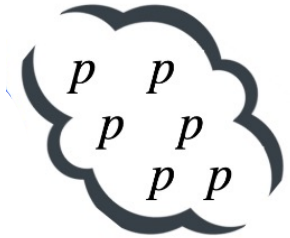
Observer

Kun, **IJ** et al. (2024)

Double Peak Structure – an Explanation: Spine-Sheath Model

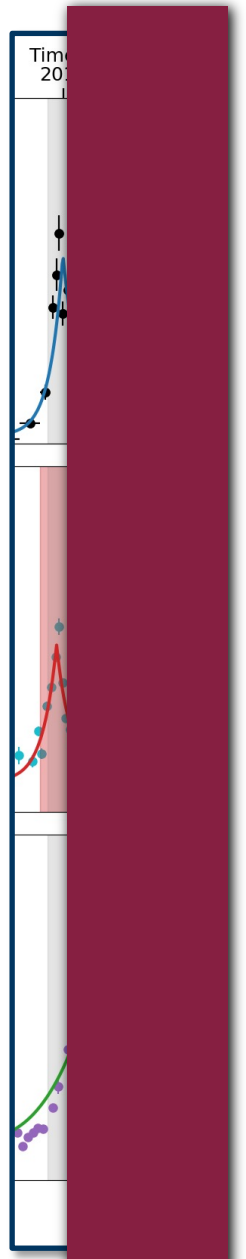


$pp/p\gamma \rightarrow \gamma$



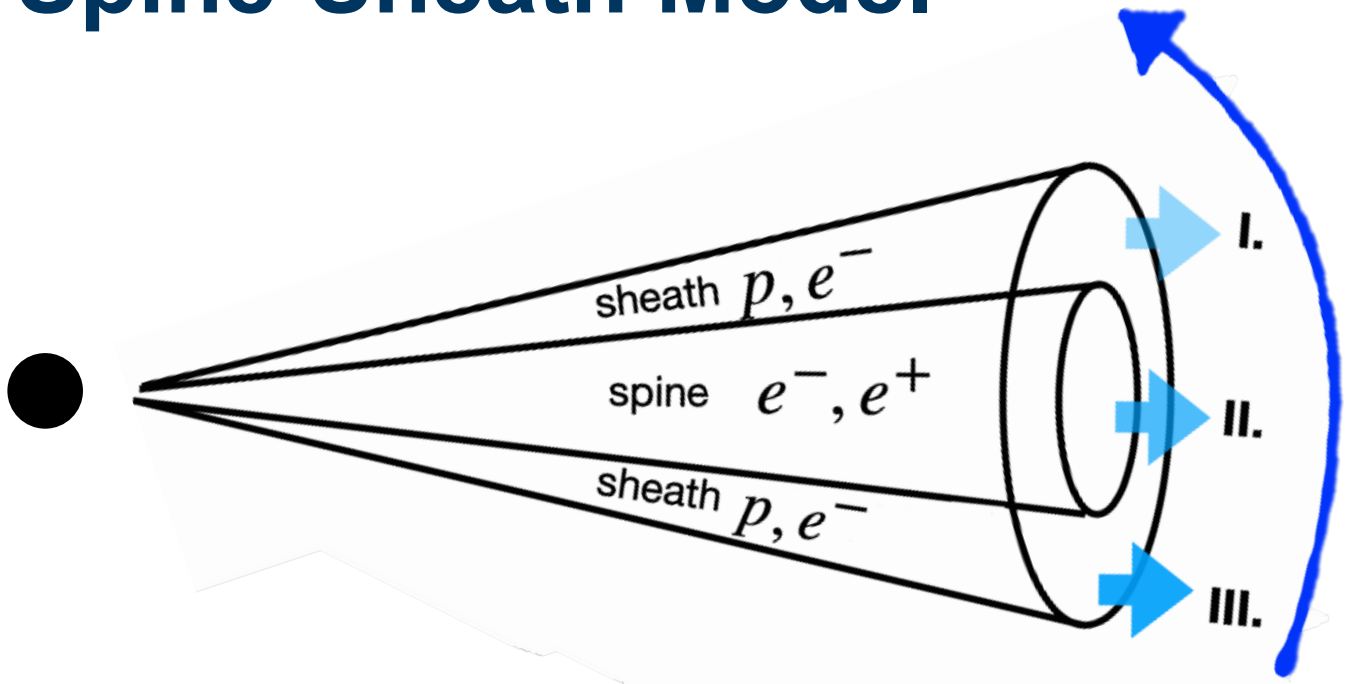
Target

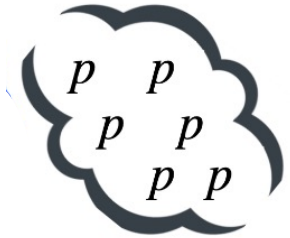
Observer



Kun, **IJ** et al. (2024)

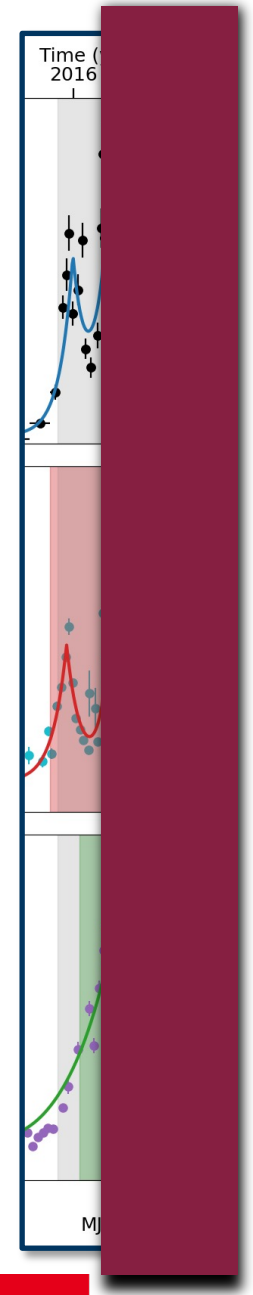
Double Peak Structure – an Explanation: Spine-Sheath Model





Target

Observer



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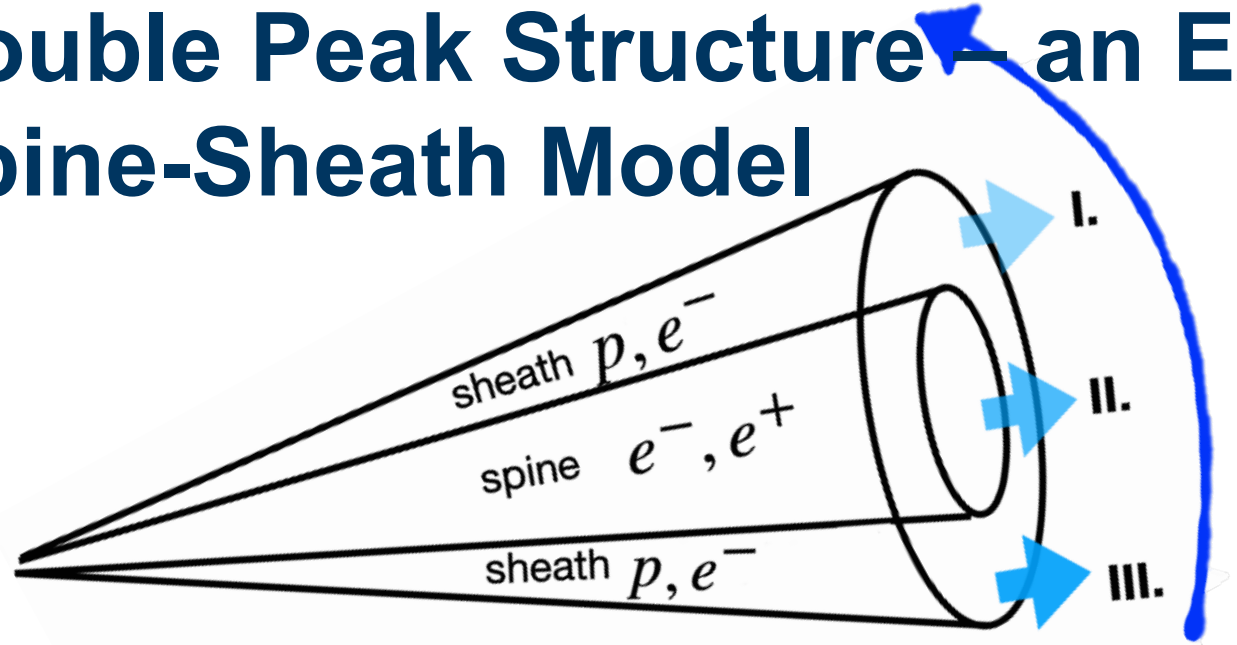
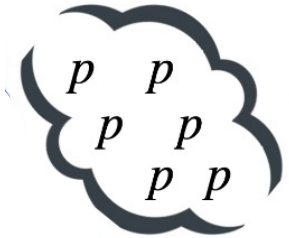
Double Peak Structure – an Explanation: Spine-Sheath Model

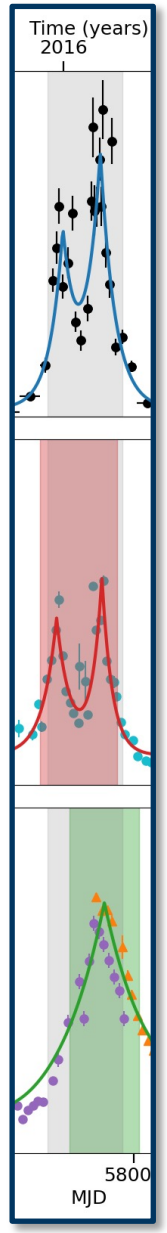




Target

$pp/p\gamma \rightarrow \gamma$

Observer



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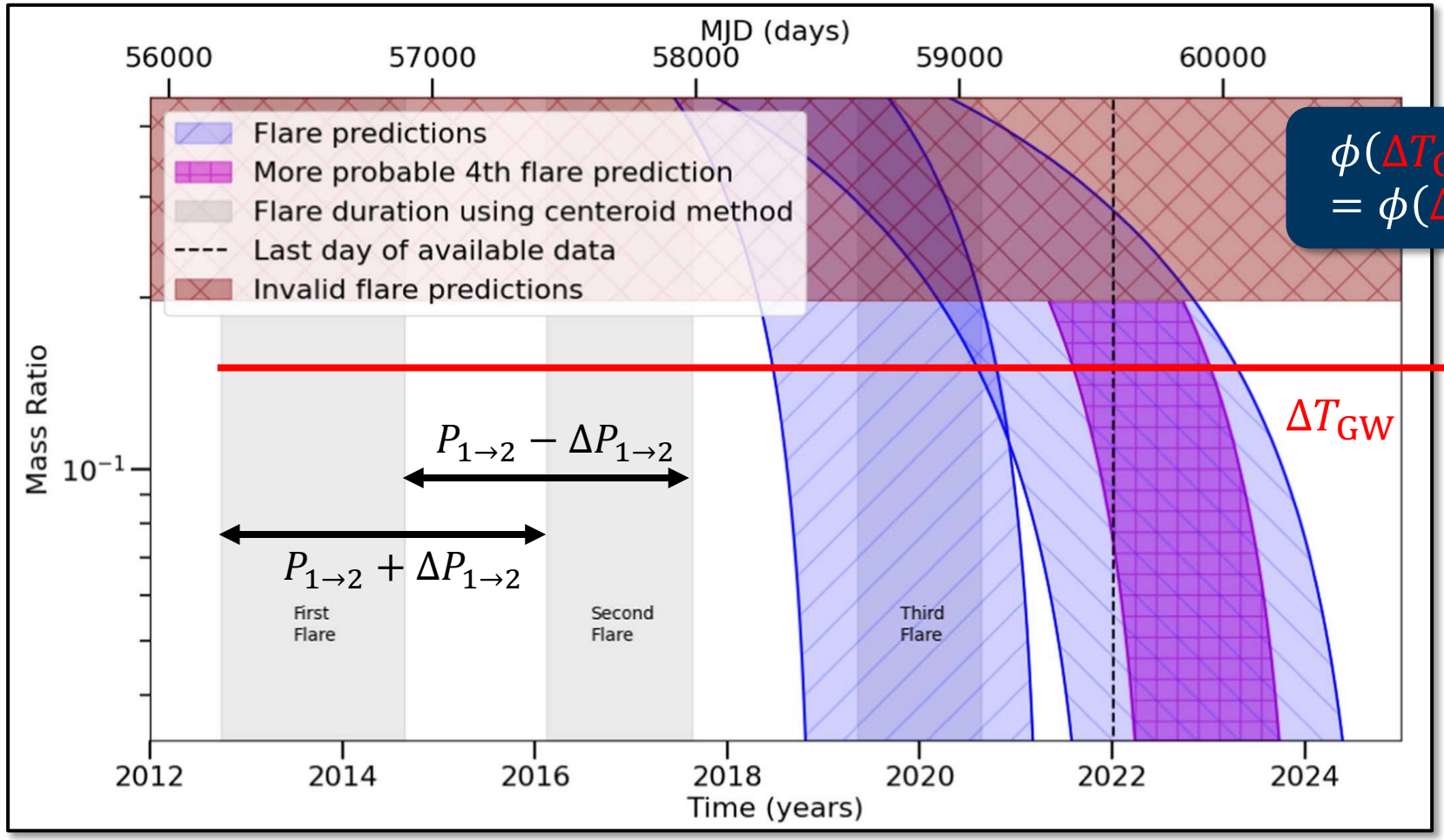
Flare Prediction in Gamma Rays

1. Step

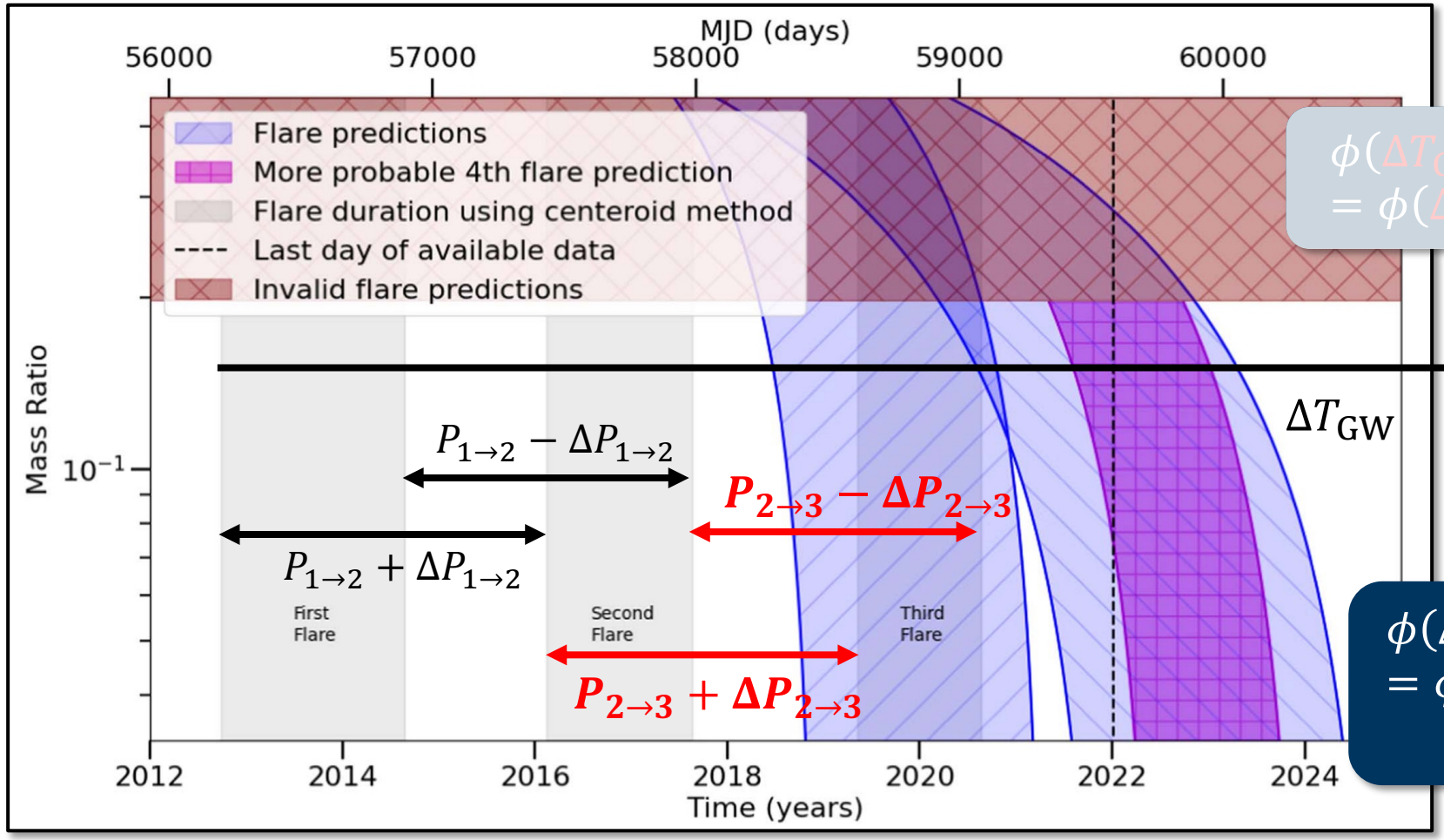


$$\phi(\Delta T_{\mathrm{GW}}, M, q) = \phi(\Delta T_{\mathrm{GW}} - P_{1\to2}, M, q) \pm \zeta + 360°$$

half-opening angle: $\zeta \sim 5.73°$

Kun, **IJ** et al. (2022)

Flare Prediction in Gamma Rays



1. Step

$$\phi(\Delta T_{\mathrm{GW}}, M, q) = \phi(\Delta T_{\mathrm{GW}} - P_{1\to2}, M, q) \pm \zeta + 360°$$

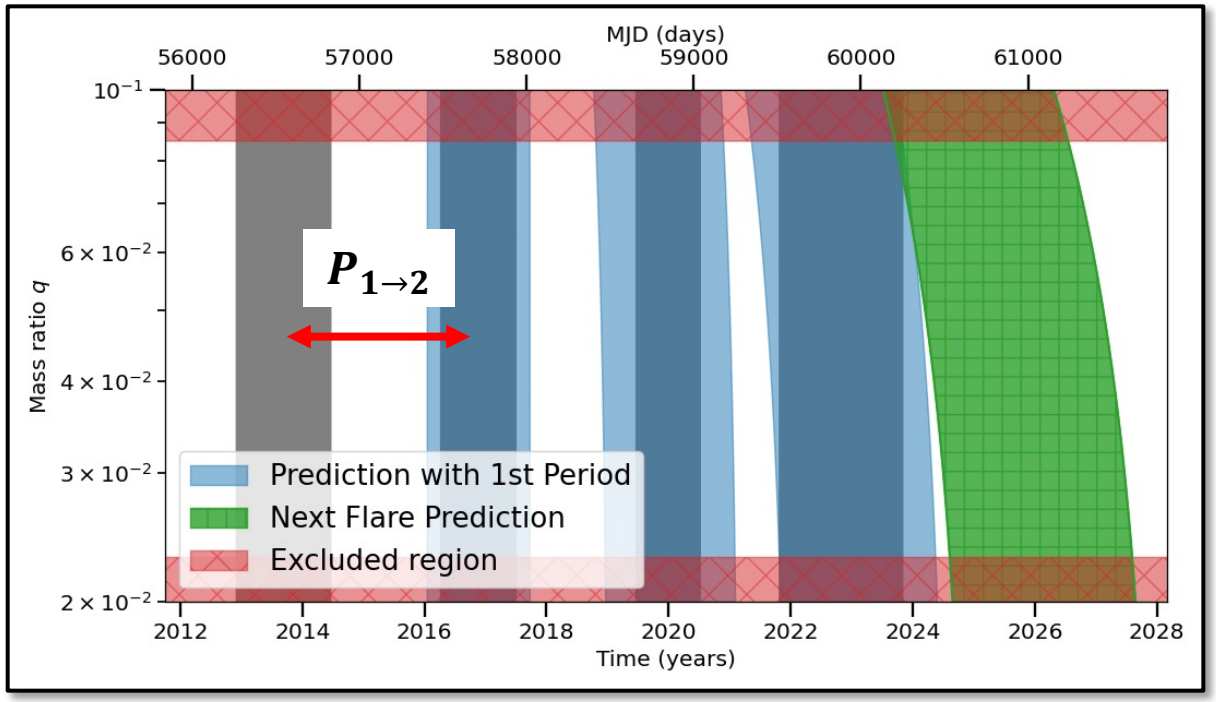
2. Step

$$\phi(\Delta T_{\mathrm{GW}}, M, q) = \phi(\Delta T_{\mathrm{GW}} - P_{1\to2} - P_{2\to3}, M, q) \pm 2\zeta + 720°$$

half-opening angle: $\zeta \sim 5.73°$

Kun, **IJ** et al. (2022)

Flare Prediction in Gamma Rays – 4th Flare agrees!

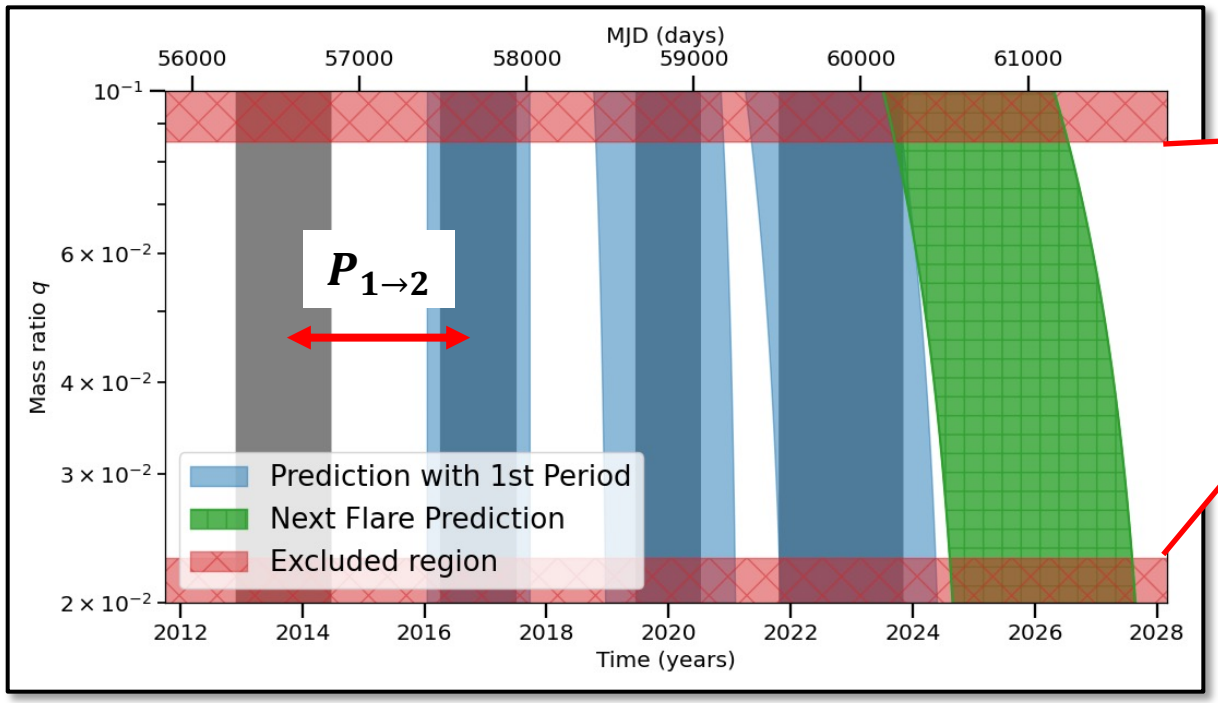


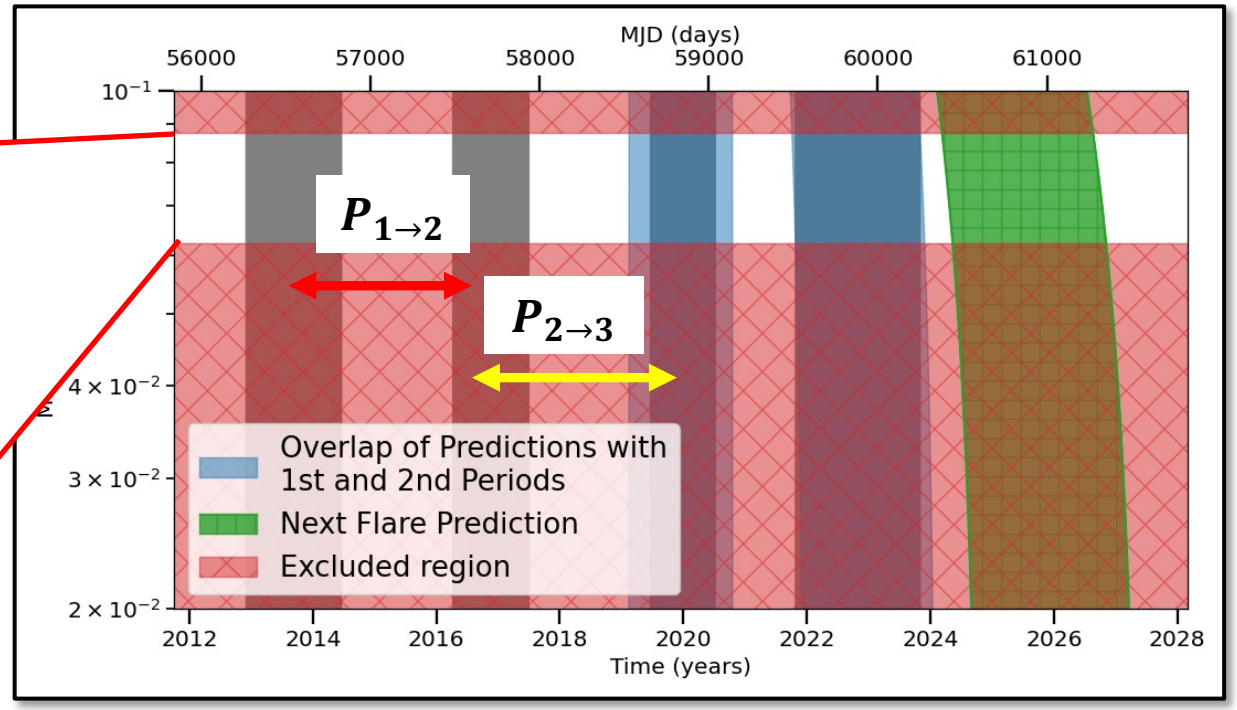
half-opening angle: $\zeta \sim 5.73°$

half-opening angle: $\zeta \sim 8.34°$

Kun, **IJ** et al. (2024)

Flare Prediction in Gamma Rays – 4th Flare agrees!





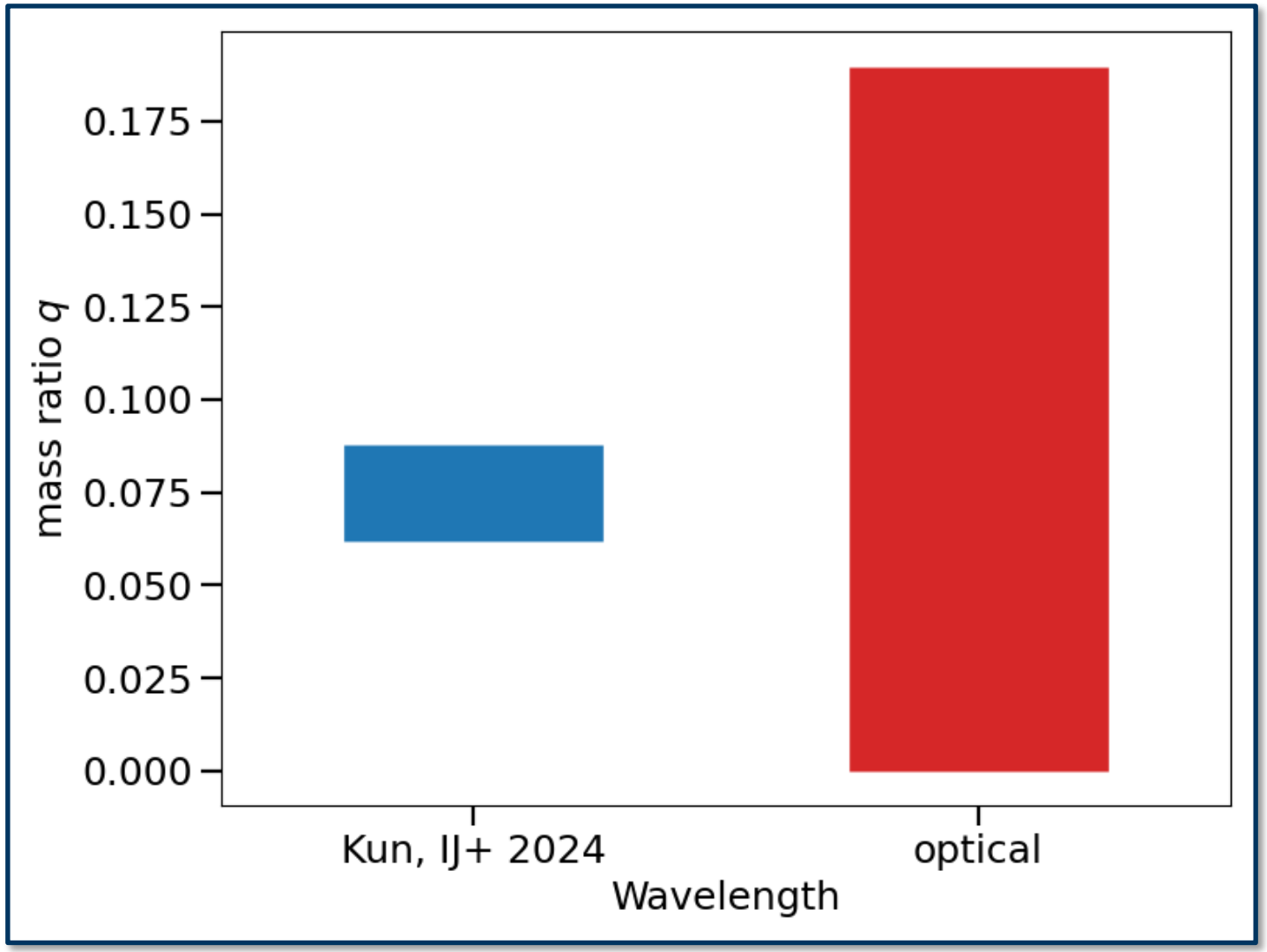
half-opening angle: $\zeta \sim 5.73°$

half-opening angle: $\zeta \sim 8.34°$

$$0.062 \leq q \leq 0.088$$

Kun, **IJ** et al. (2024)

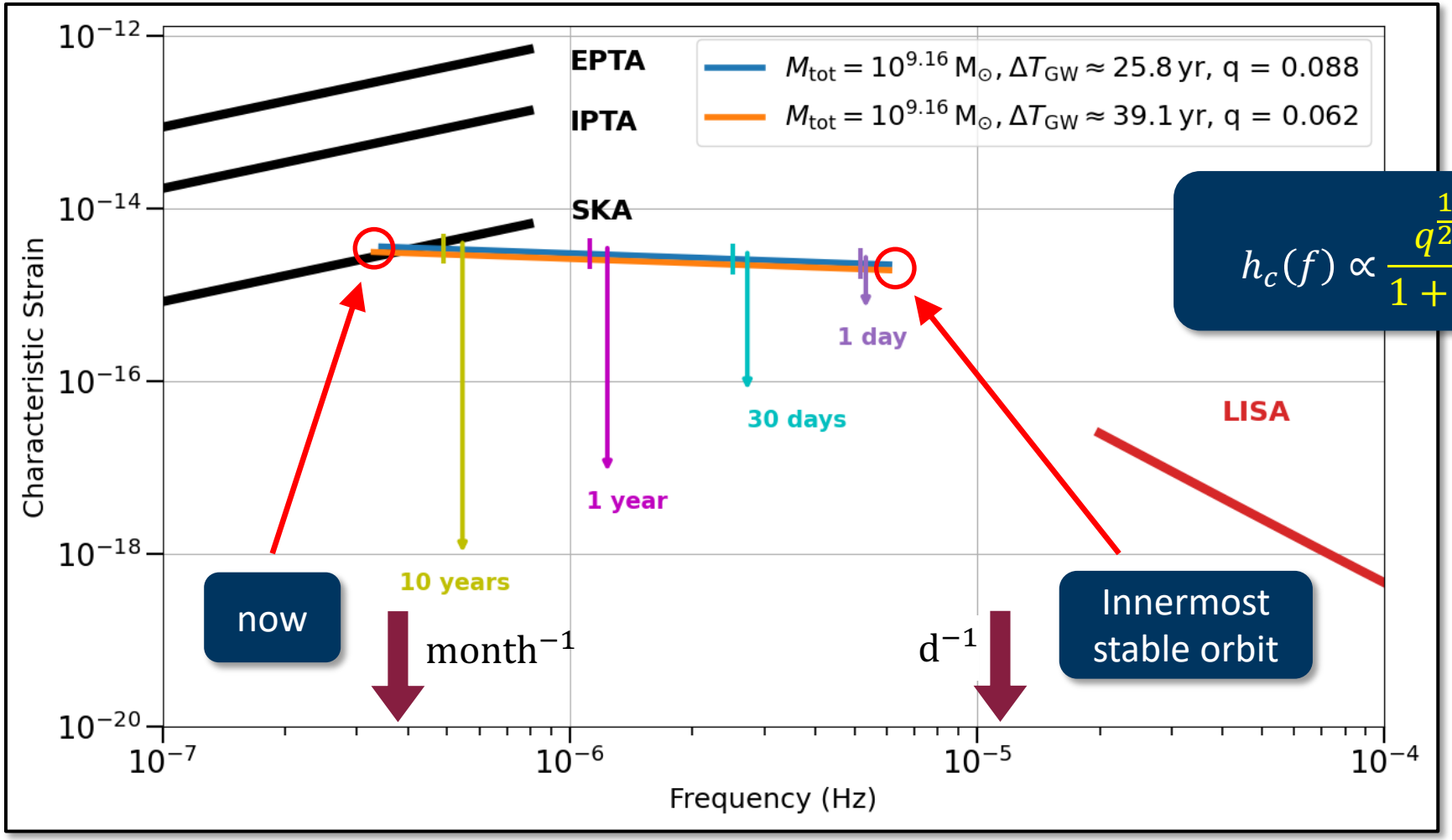
Constrained Binary Mass Ratios



IJ+ in prep.

Expected Gravitational Wave Signal

$z = 1.15$



$$h_c(f) \propto \frac{q^{\frac{1}{2}}}{1+q} M^{\frac{5}{6}} \cdot \frac{1}{r(z)(1+z)^{1/2}} f^{-1/6}$$

$r(z)$: comoving distance

PN parameter:

$$\varepsilon \approx 0.064$$

Kun, **IJ** et al. (2022)

Summary – Blazar J1048+7143

analytical **Jet Precession** model applied with:

1. optical

- 3 flares observed
- Mass ratio constrained from above

$$q \lesssim 0.19$$

- 4 flares observed
- 4th flare (successfully) predicted
- Mass ratio constrained from above **AND** below

$$0.062 \leq q \leq 0.088$$

2. Radio

- 2 flares observed
- 3rd flare: more data necessary

Time range of next flare, if the jet will point at Earth once more: 2024 March 10 - 2026 November 6

ilja.jaroschewski@cea.fr

Summary – Blazar J1048+7143

analytical **Jet Precession** model applied with:

1. optical
   - 3 flares observed
   - Mass ratio constrained from above

   $q \lesssim 0.19$

2. Gamma rays
   - 4 flares observed
   - 4th flare (successfully) predicted
   - Mass ratio constrained from above **AND** below

   $0.062 \leq q \leq 0.088$

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Summary – Blazar J1048+7143

analytical **Jet Precession** model applied with:

1. optical
   - 3 flares observed
   - Mass ratio constrained from above

   $q \lesssim 0.19$

2. Gamma rays
   - 4 flares observed
   - 4th flare (successfully) predicted
   - Mass ratio constrained from above **AND** below

   $0.062 \leq q \leq 0.088$

3. Radio waves
   - 2 flares observed
   - 3rd flare: more data necessary

Time range of next flare, if the jet will point at Earth once more: 2024 March 10 - 2026 November 6

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in combination with **Spine-Sheath** jet model

double-peak structure in gamma rays and optical light curve explainable

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More coming:
- ZTF optical light curve → combined optical light curve
- Expected Neutrino upper limits
- Swift X-Ray light curve

Goal → Combined MM picture!

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ZTF + Fermi-LAT LCR: new flaring episode?

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Back-Up

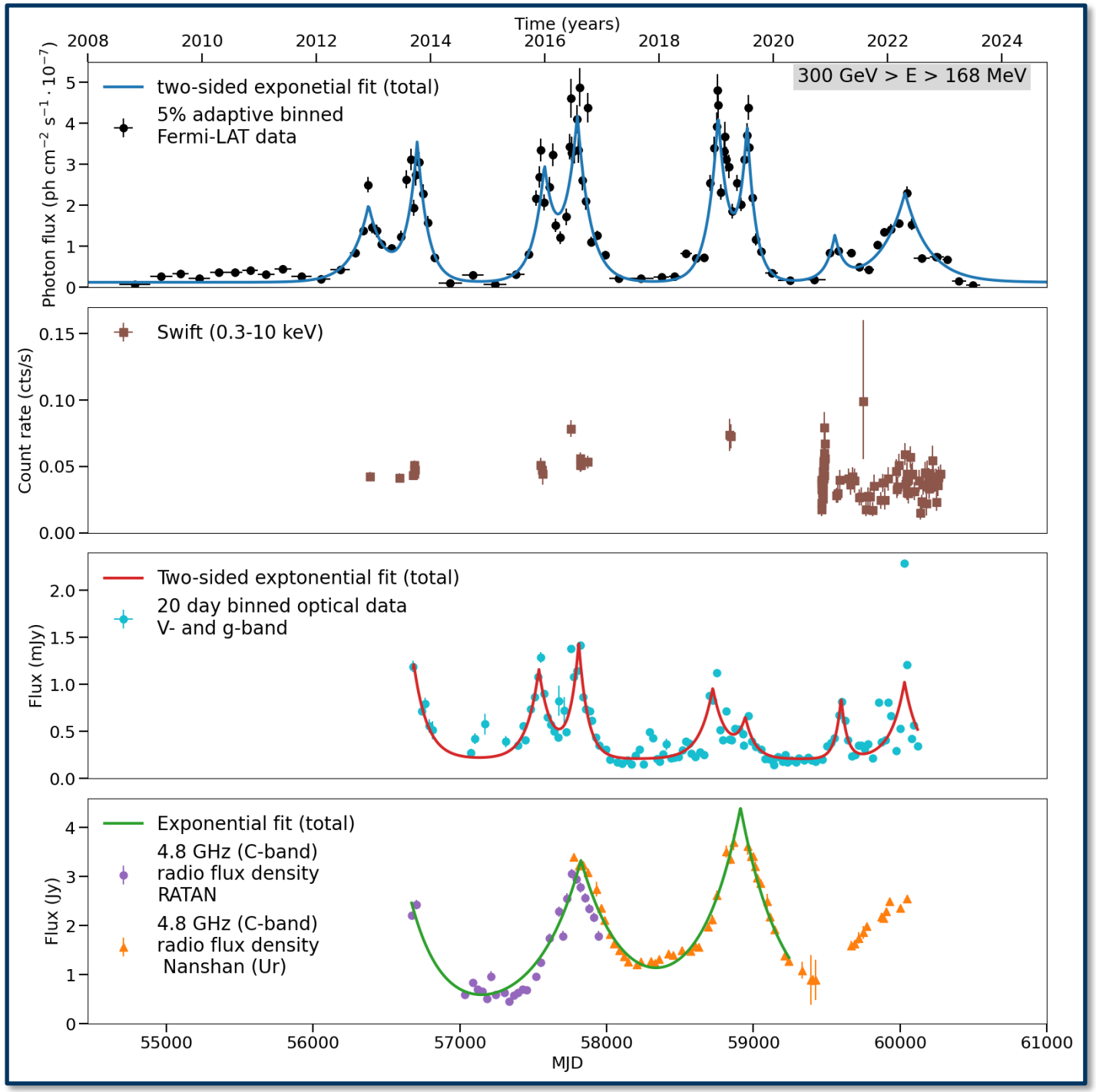
Backup:

Gamma-Ray Light Curve

+ X-Ray

+ Optical

+ Radio



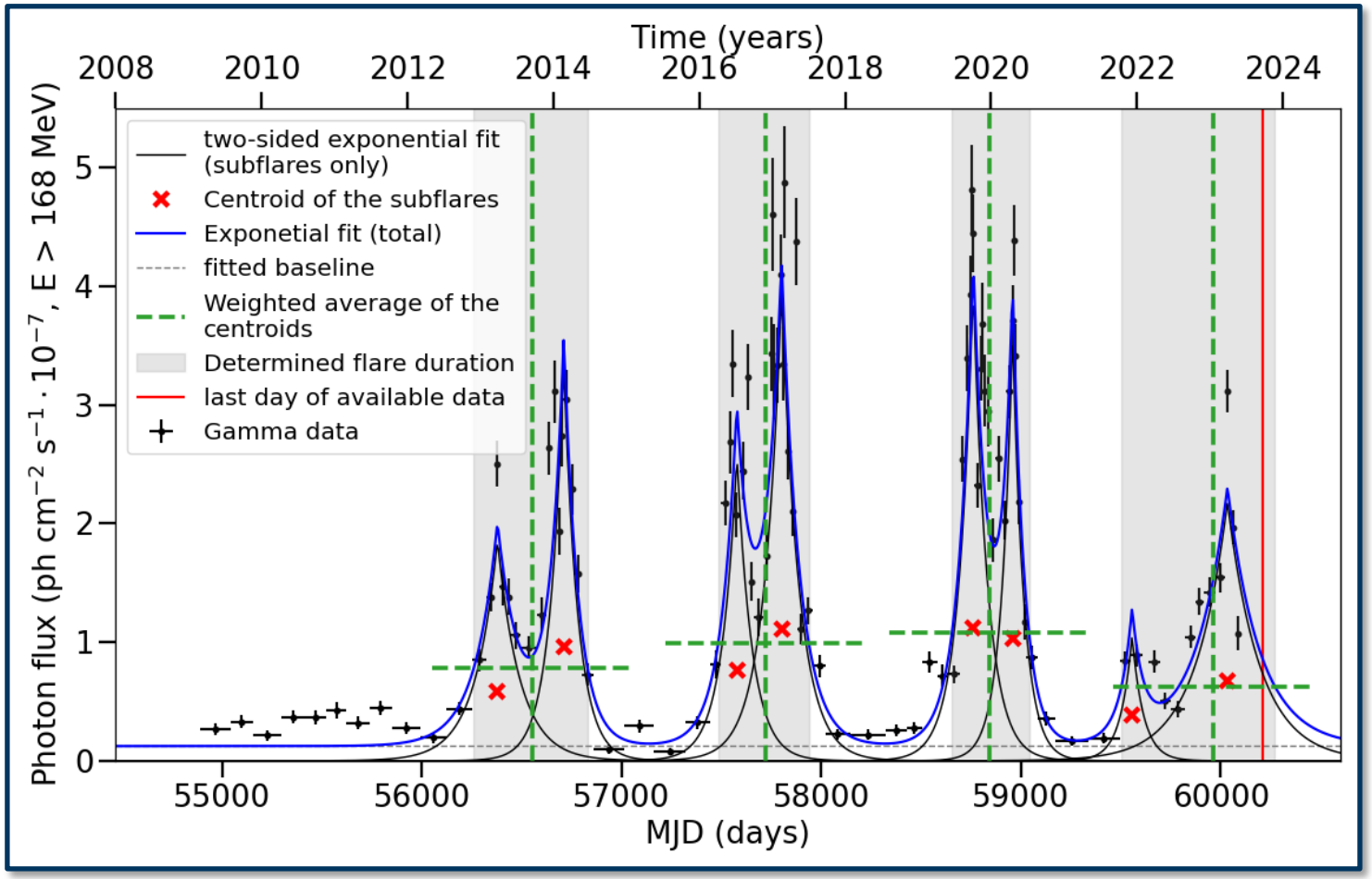
Backup: J1048+7143 – Centroid Method (Kun, IJ et al. 2022)

$$X_{i,j} = \frac{\int t \cdot F_{i,j}(t)\mathrm{d}t}{\int F_{i,j}(t)\mathrm{d}t}$$

$$Y_{i,j} = \frac{1}{2}\frac{\int F_{i,j}^2(t)\mathrm{d}t}{\int F_{i,j}(t)\mathrm{d}t}$$

$$X_i = \frac{A_i}{A_i + B_i} X_{i,1} + \frac{B_i}{A_i + B_i} X_{i,2}$$

$$Y_i = \frac{A_i}{A_i + B_i} Y_{i,1} + \frac{B_i}{A_i + B_i} Y_{i,2}$$



Kun, **IJ** et al. (2024)

Backup: J1048+7143 – Flare Characteristics 1/2

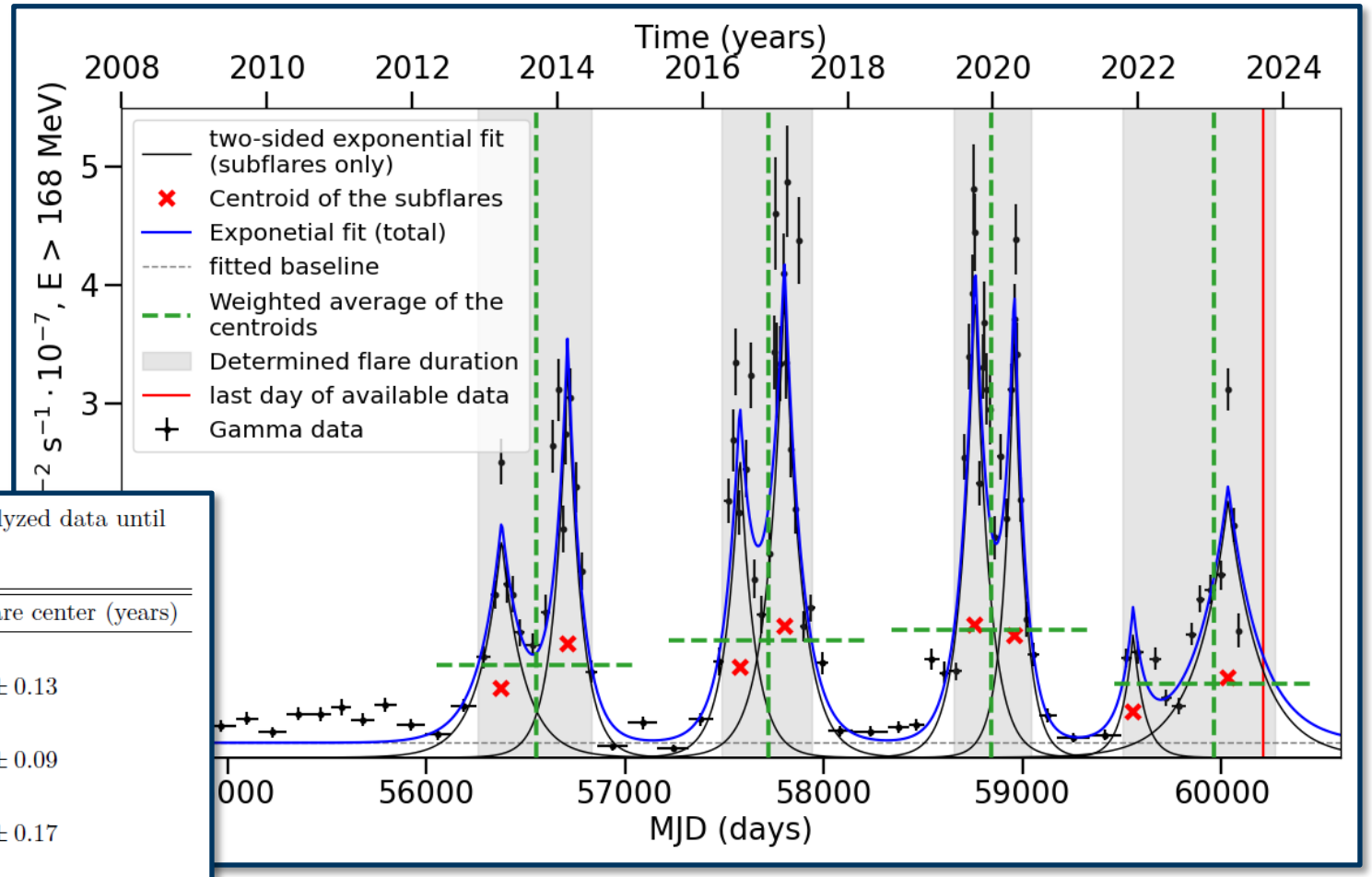


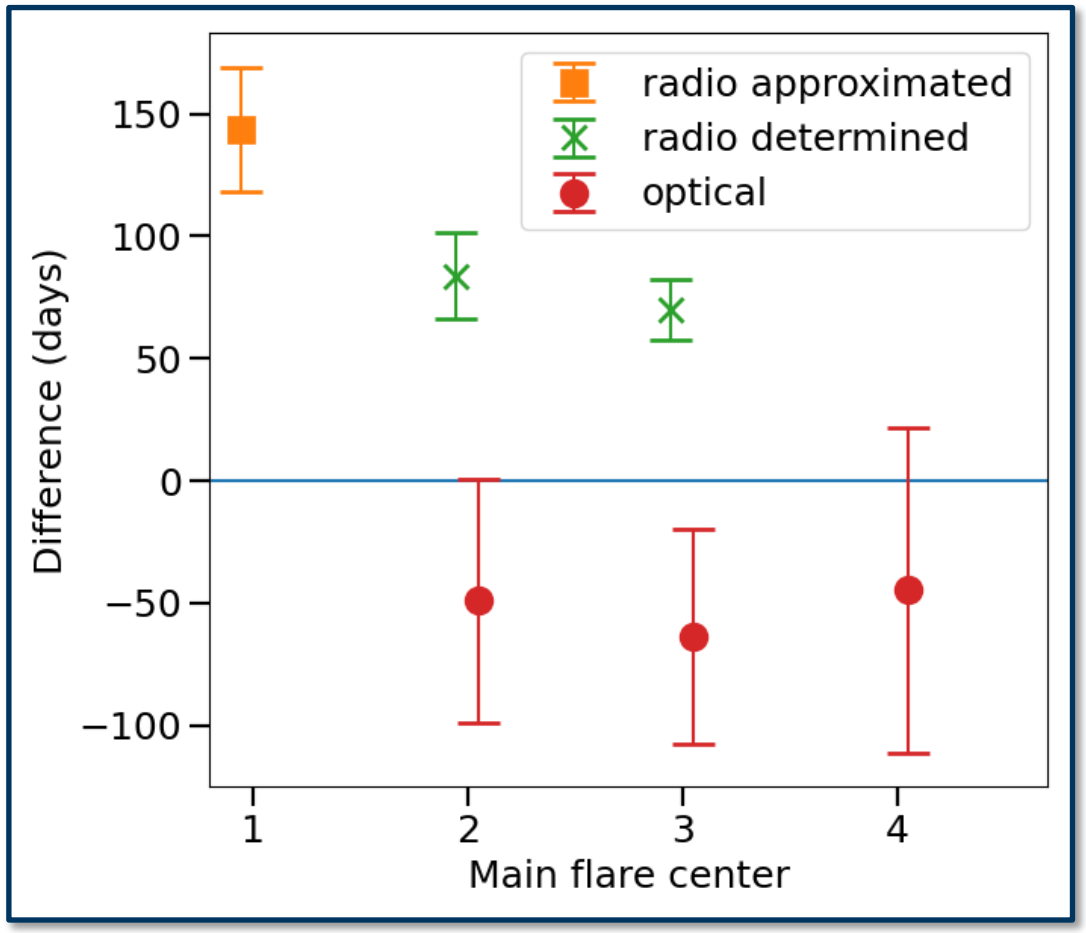
Table 5.1: Characteristics of the gamma-ray light curve of J1048+7143 (analyzed data until MJD 60099) applying the centroid method.

Parameter	Flare center (MJD)	Flare duration (days)	Time till next flare center (years)
F1	56554 ± 38	565 ± 78	
$P_{1\to2}$			3.20 ± 0.13
F2	57722 ± 25	450 ± 61	
$P_{2\to3}$			3.07 ± 0.09
F3	58842 ± 18	383 ± 38	
$P_{3\to4}$			3.06 ± 0.17
F4	59958 ± 59	756 ± 113	

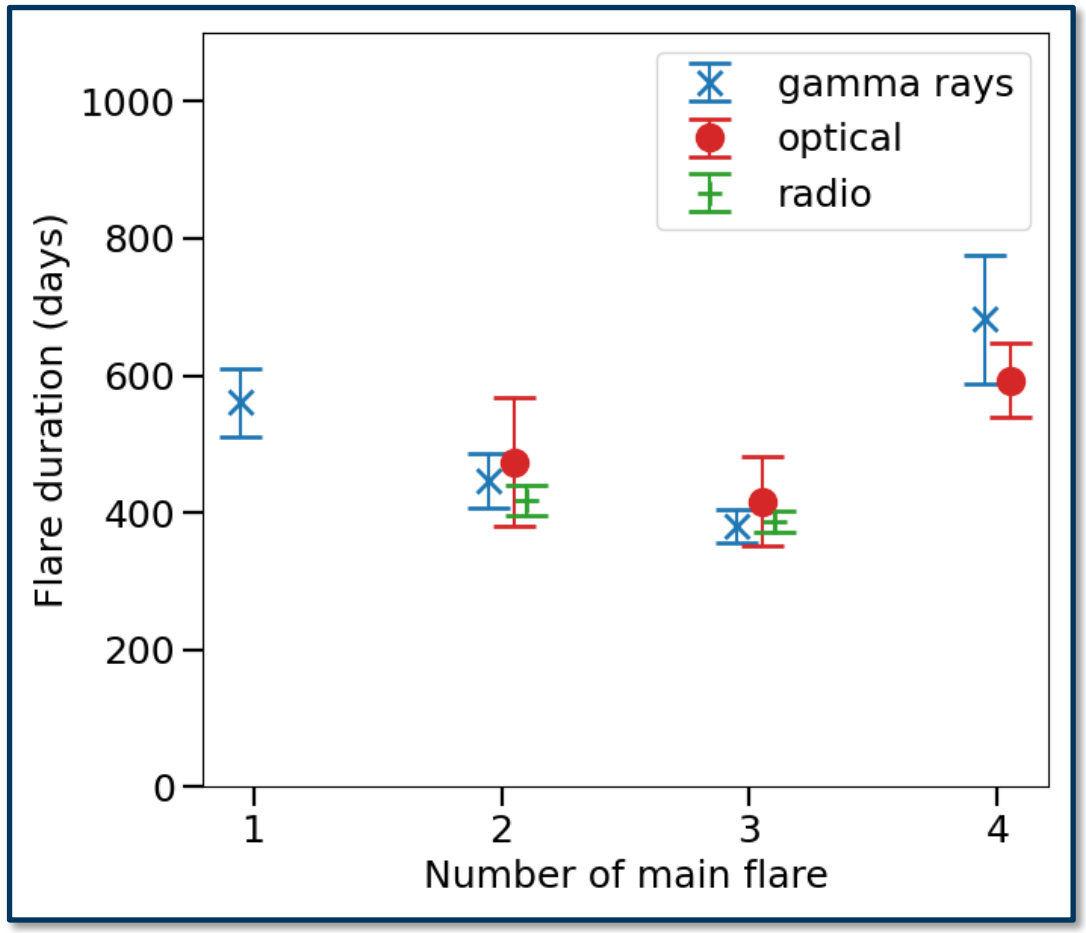
Kun, **IJ** et al. (2024)

Backup: J1048+7143 – Flare Characteristics 2/2

Difference of main flare centers in the gamma-ray and radio light curve:



Main Flare durations:



Backup: J1048+7143 – Possible Nutation in Gamma Rays + Optical

Earth's path through the jet