Hints for a Supermassive Black Hole Binary at the center of the blazar J1048+7143

Ilja Jaroschewski
Ruhr University Bochum

TeVPA 2024

Credit:
DESY, Science Communication Lab

Multi-Messenger Picture

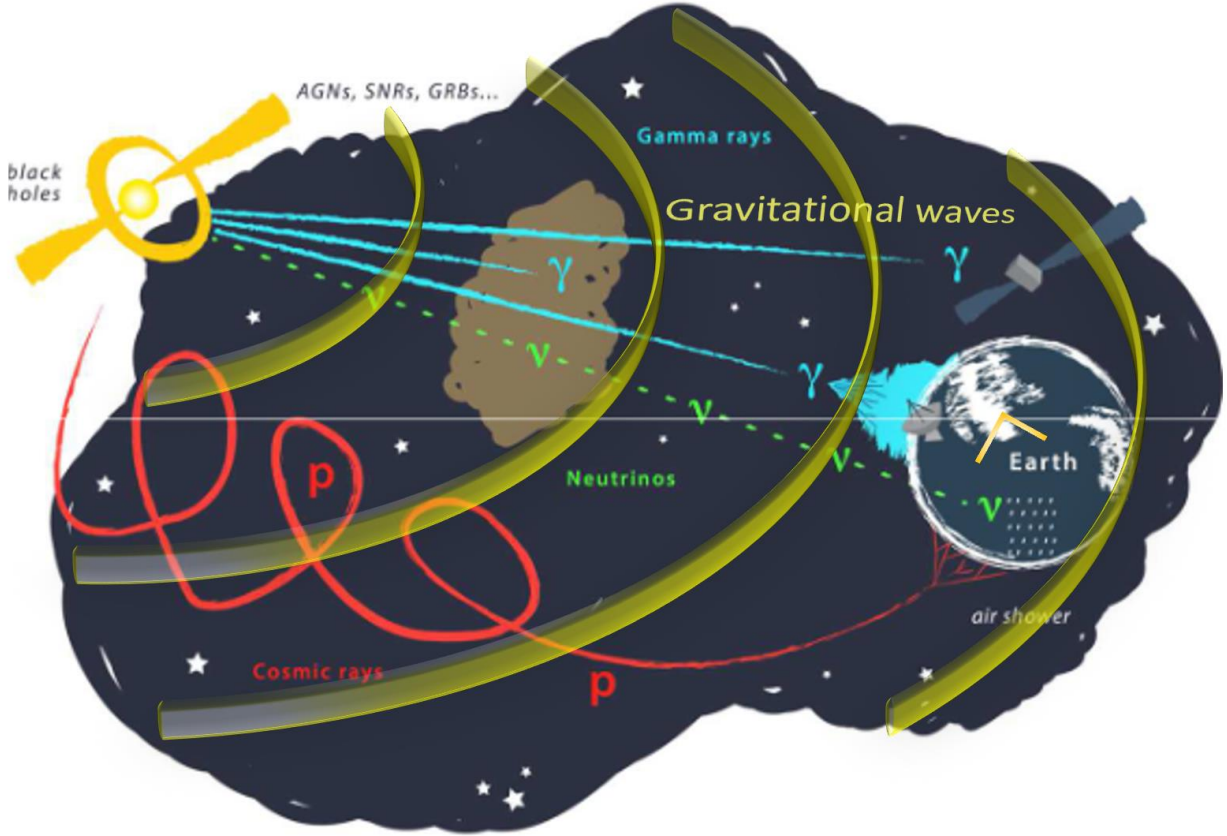

Figure modified after Juan Antonio Aguilar and Jamie Yang, IceCube/WIPAC

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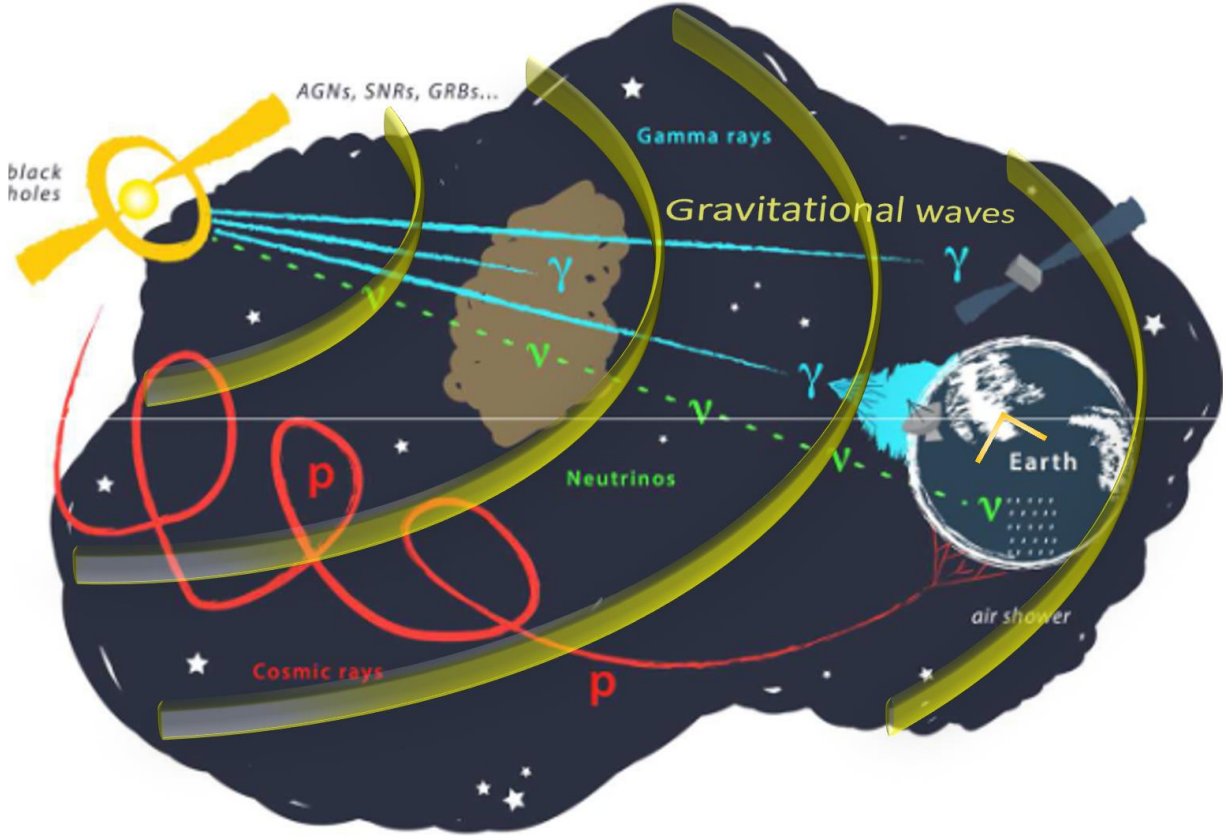


In this talk:

Gamma Rays

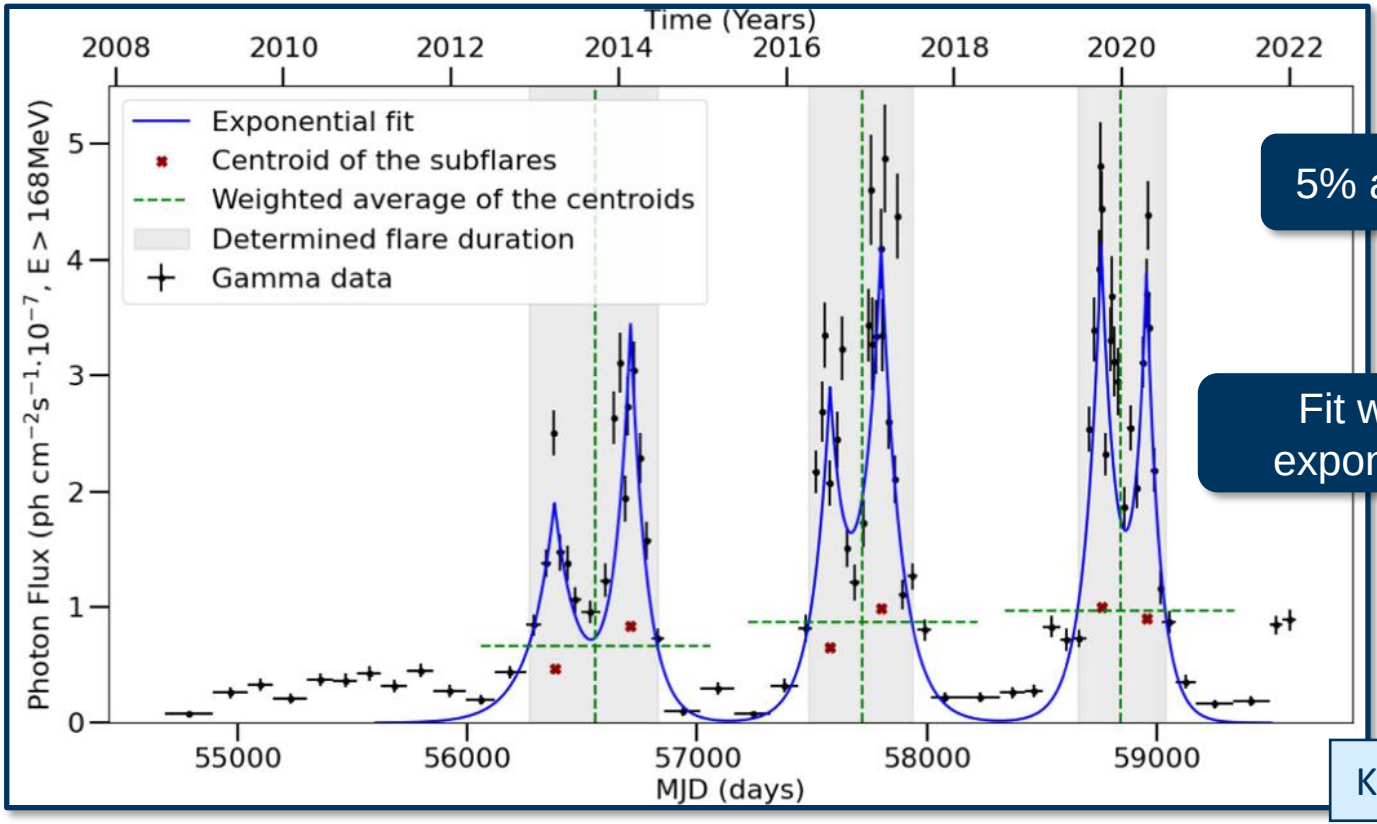
Optical Light

Radio Waves

Gravitational Waves

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

Gamma-Ray Light Curve – End of 2022



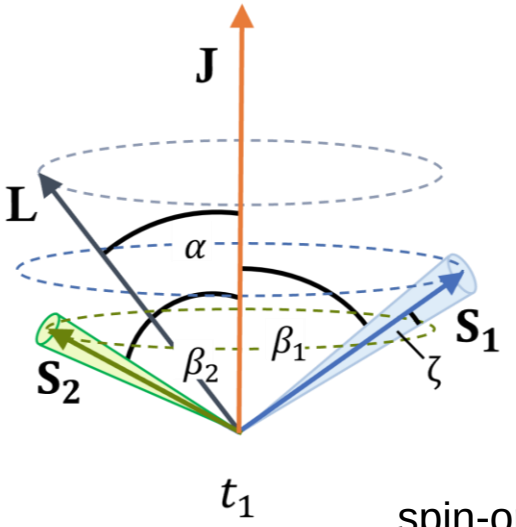
5% adaptive binning

Fit with two-sided exponential function

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

The Jet Precession Model

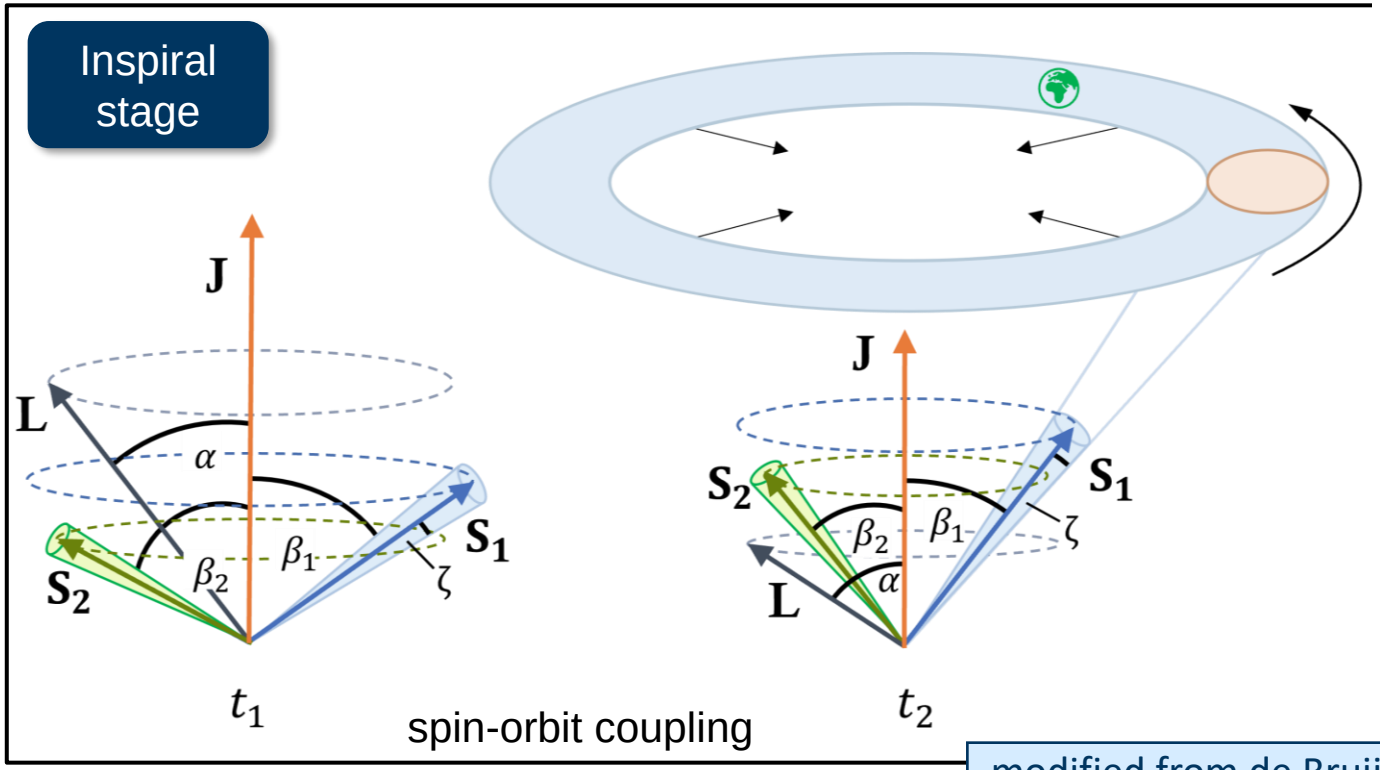
Inspiral stage



spin-orbit coupling

modified from de Bruijn et al. (2020)

The Jet Precession Model



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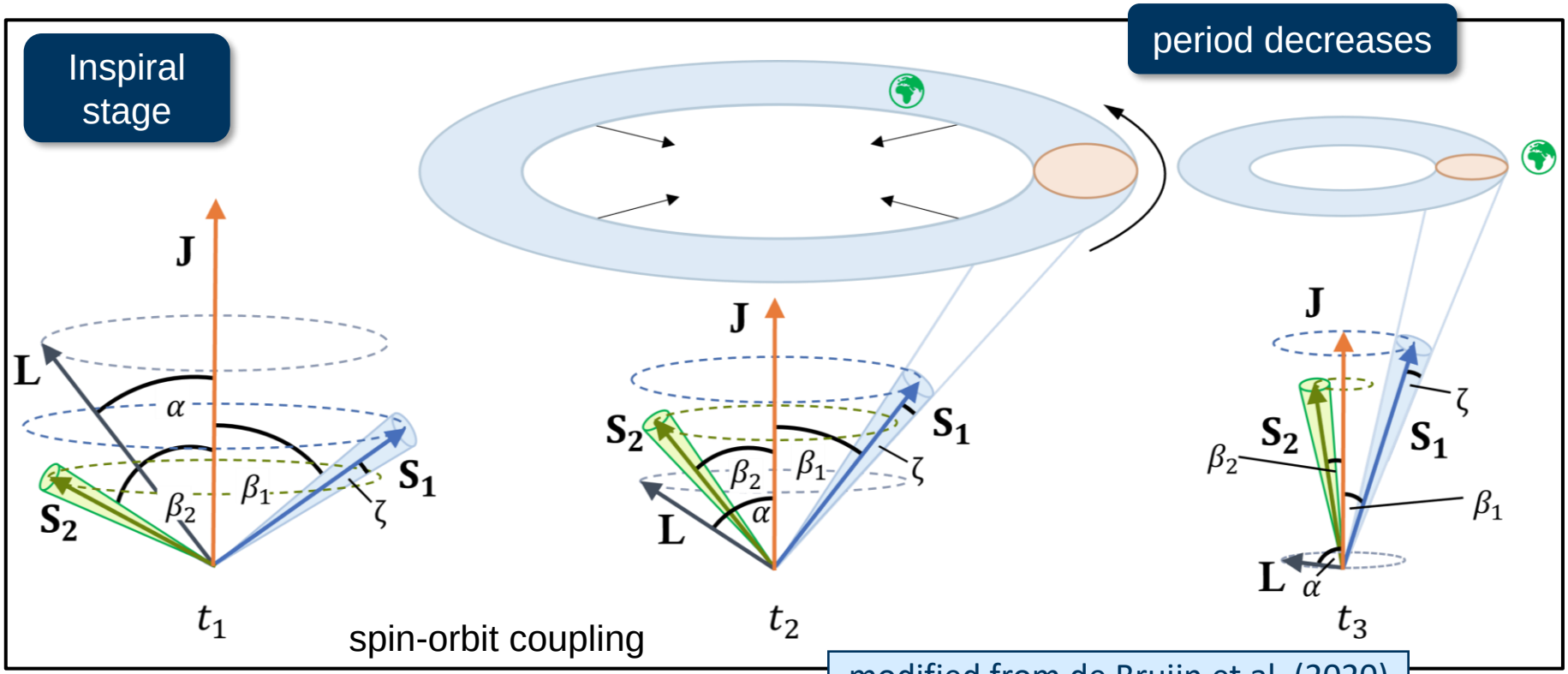
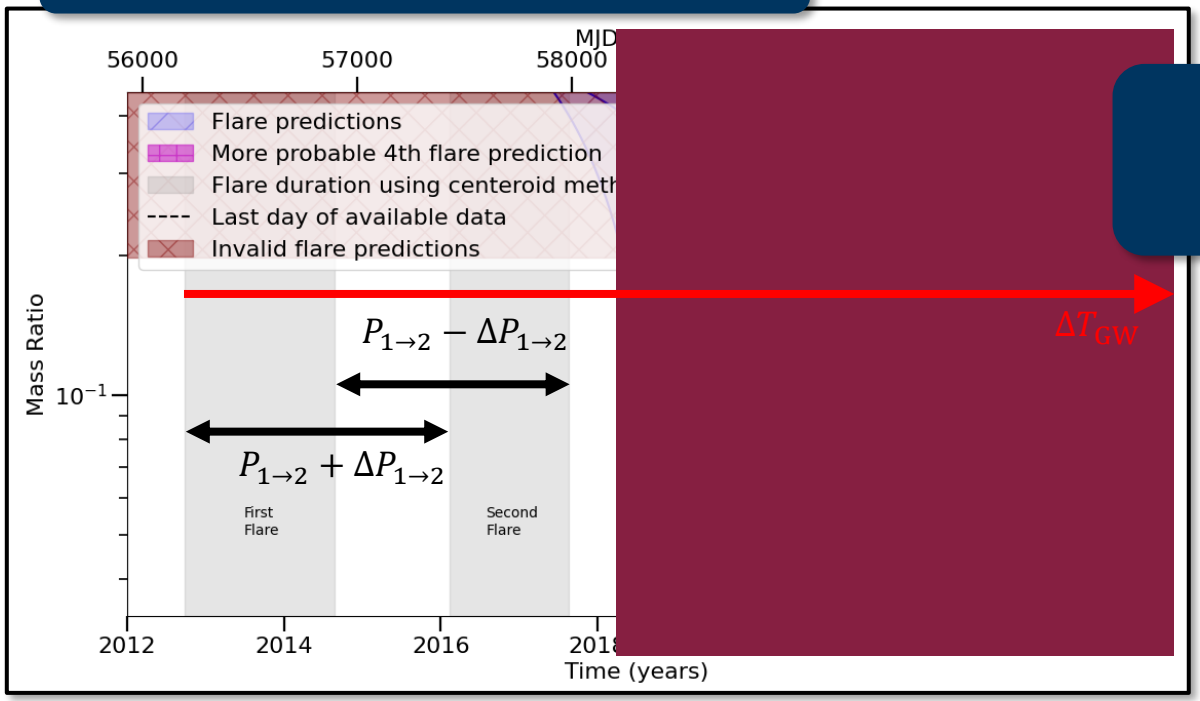


Flare Prediction in Gamma Rays

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



1. Step

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

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

Flare Prediction in Gamma Rays

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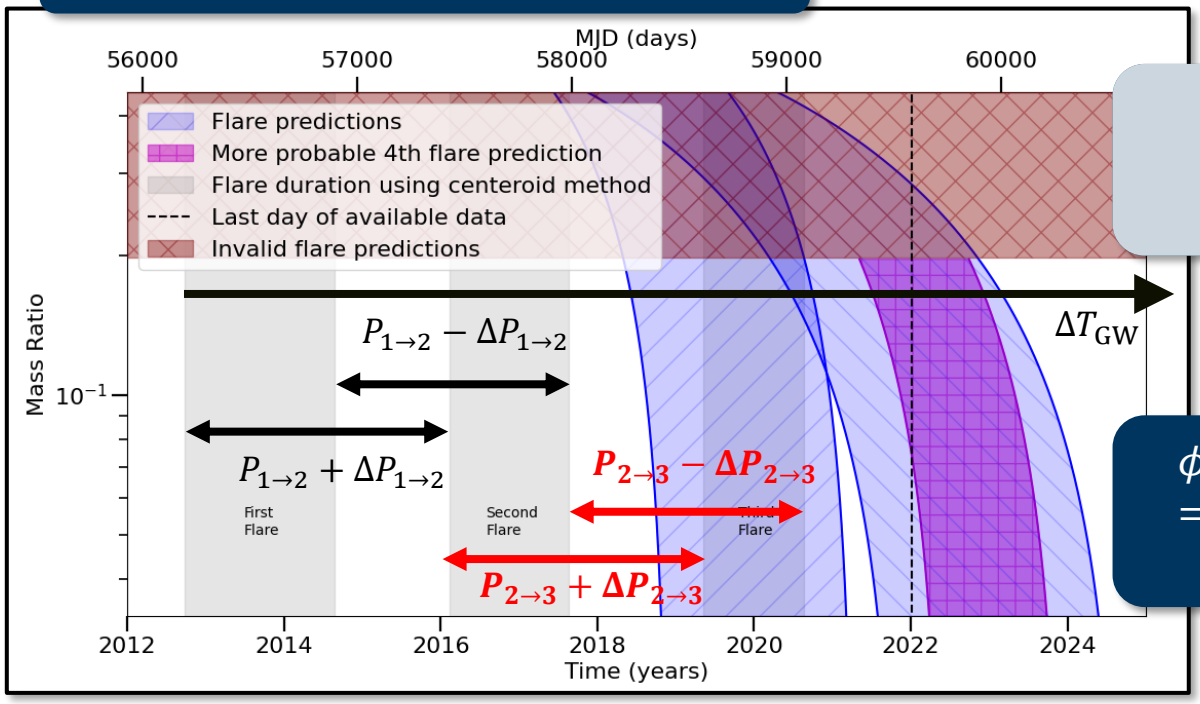


1. Step

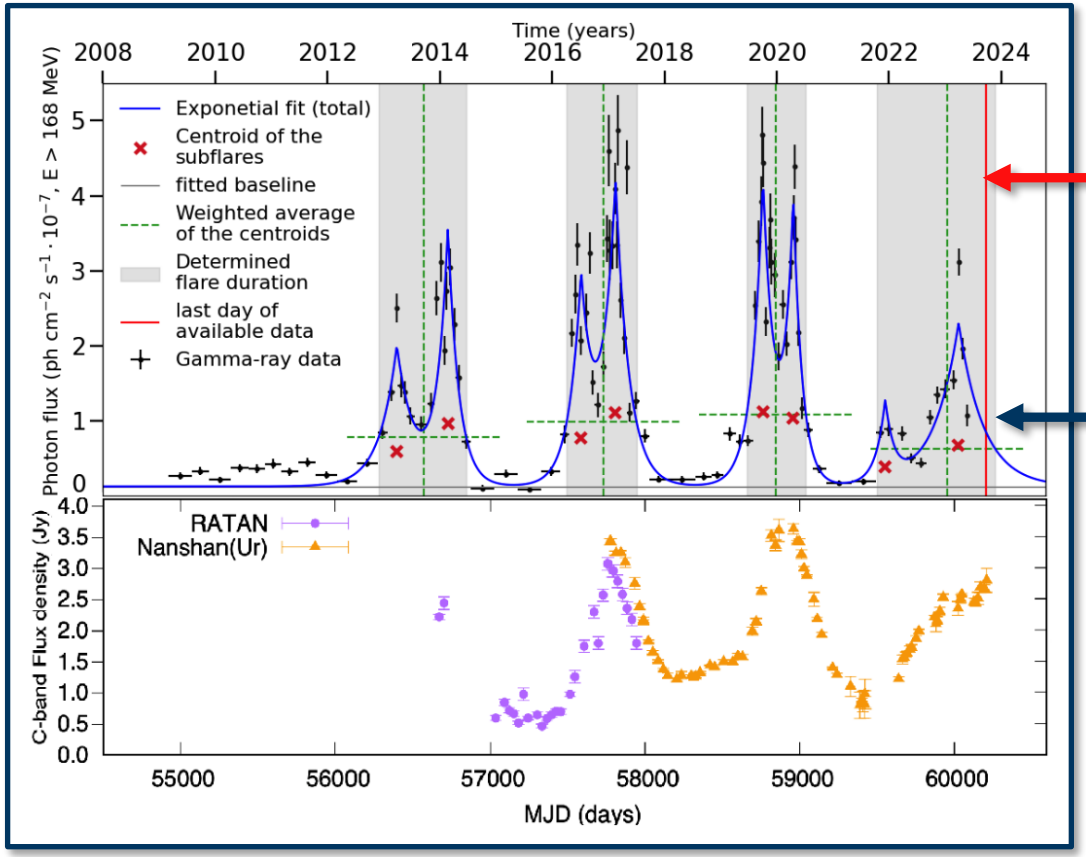
$$\phi(\Delta T_{\mathrm{GW}}, M, q) = \phi(\Delta T_{\mathrm{GW}} - P_{1\to2}, M, q) \pm \zeta + 360°$$

2. Step

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

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

Gamma-Ray + Radio Light Curve



data used until 22.09.2023

flare lasts until 31.10.2023

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

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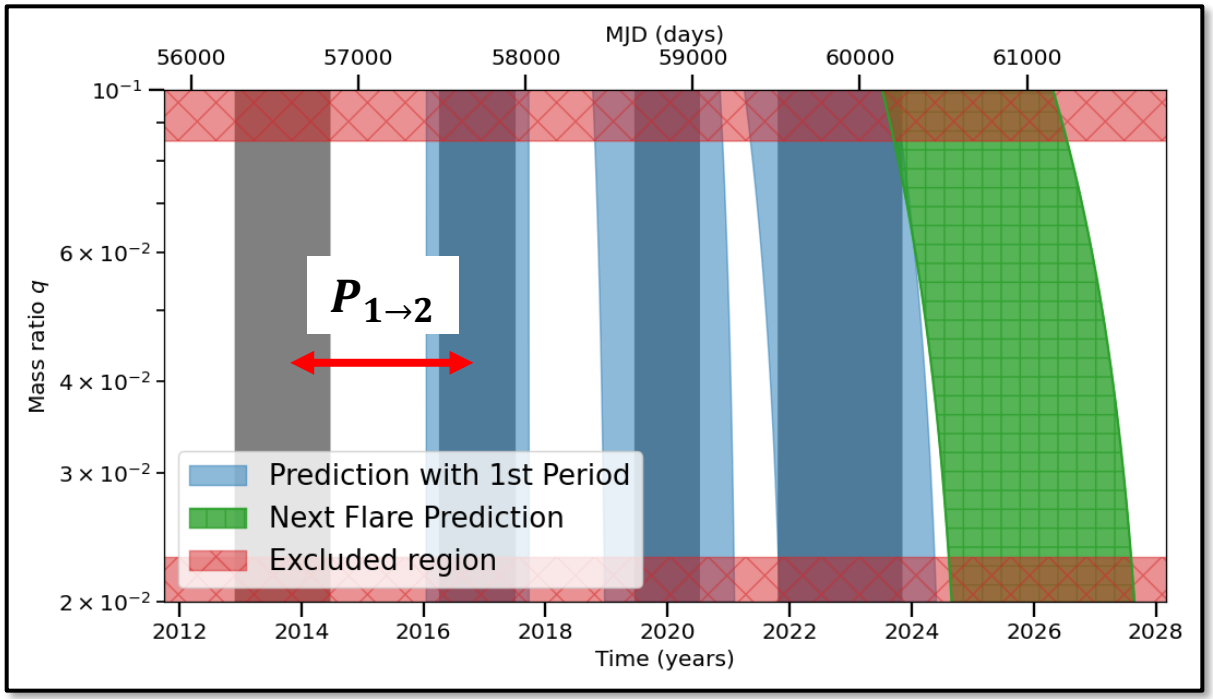
Flare Prediction in Gamma Rays – 4th Flare agrees!

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



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

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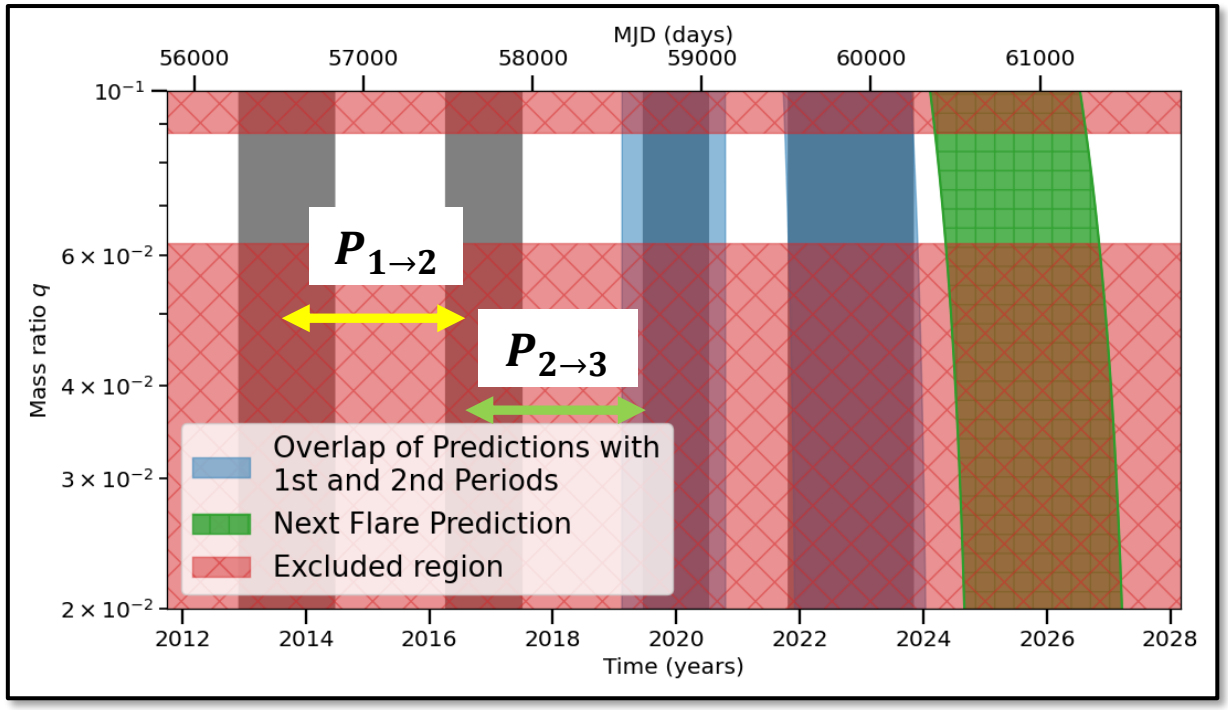
Flare Prediction in Gamma Rays – 4th Flare agrees!

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



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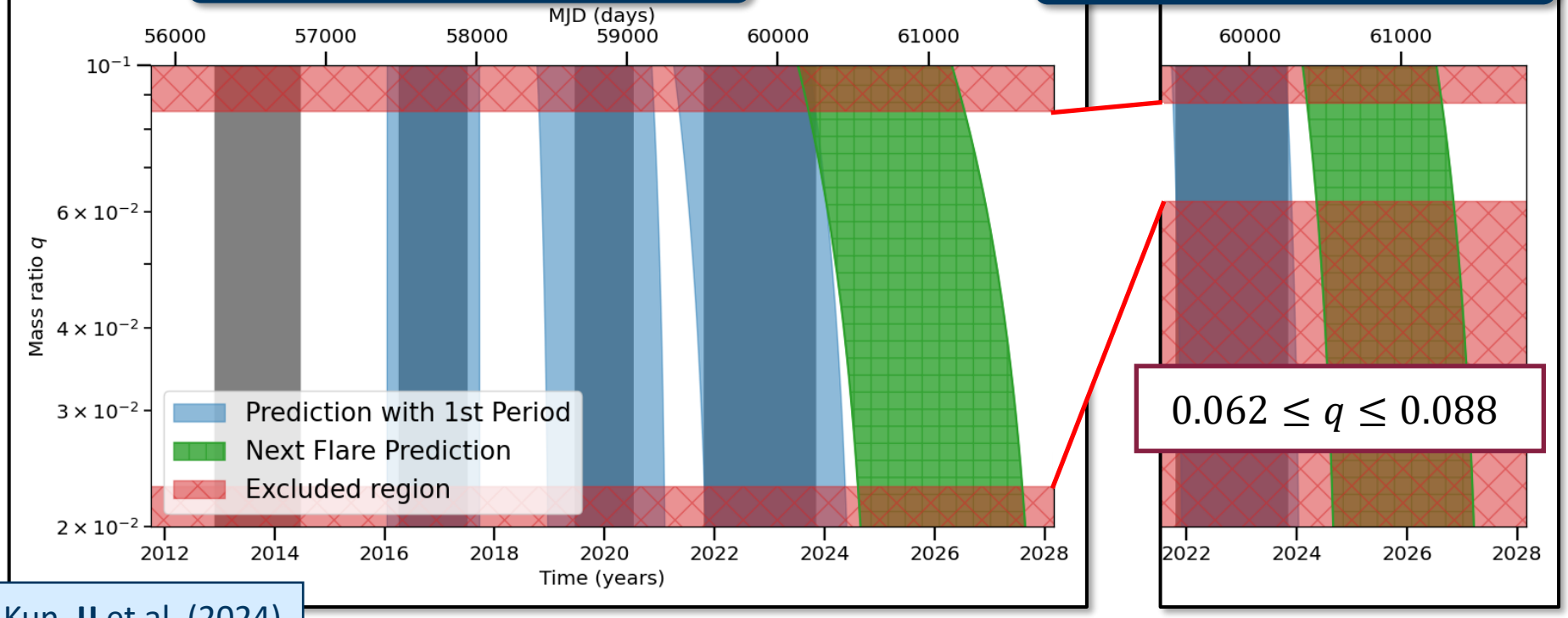
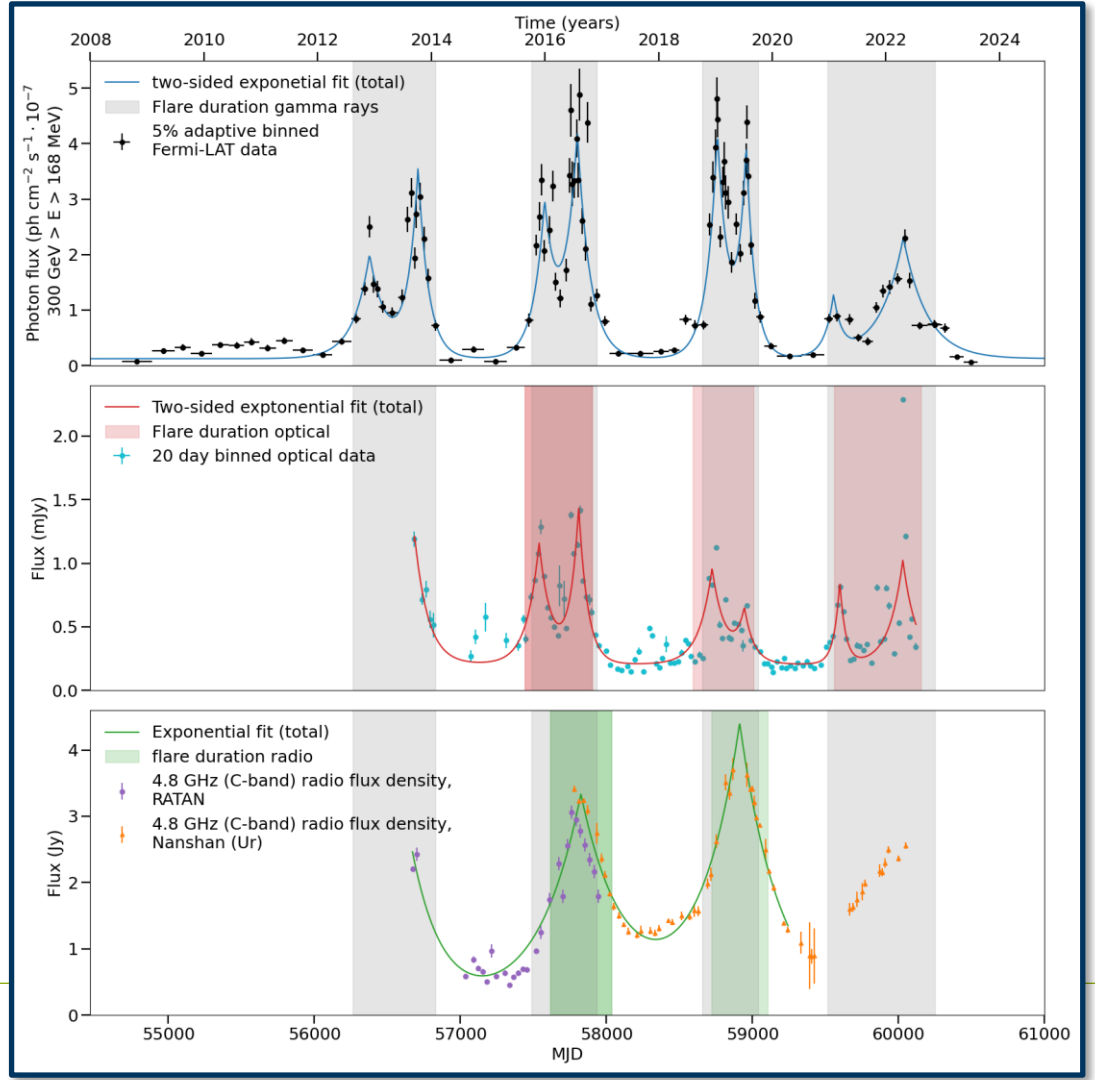
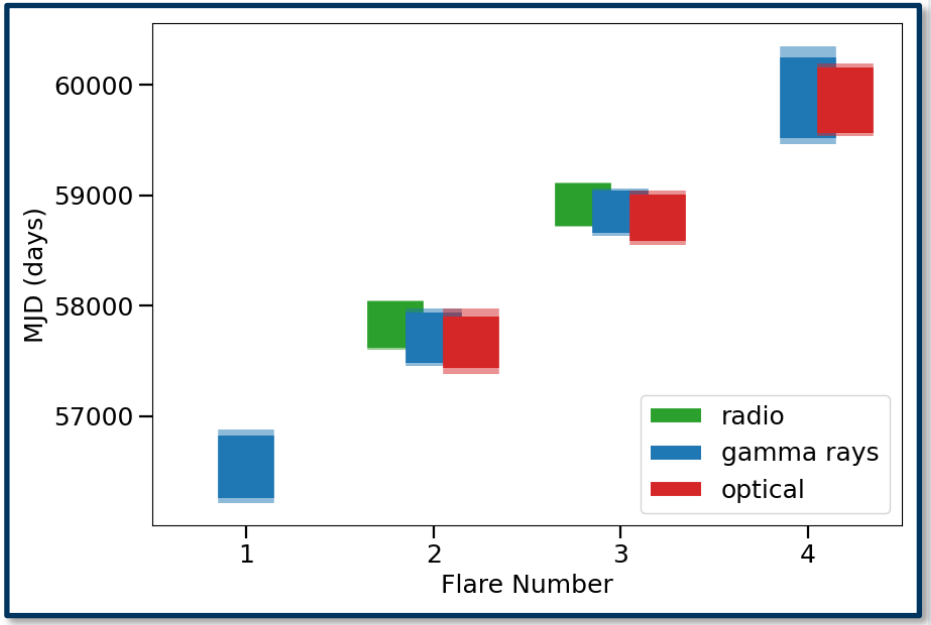


Kun, **IJ** et al. (2024)

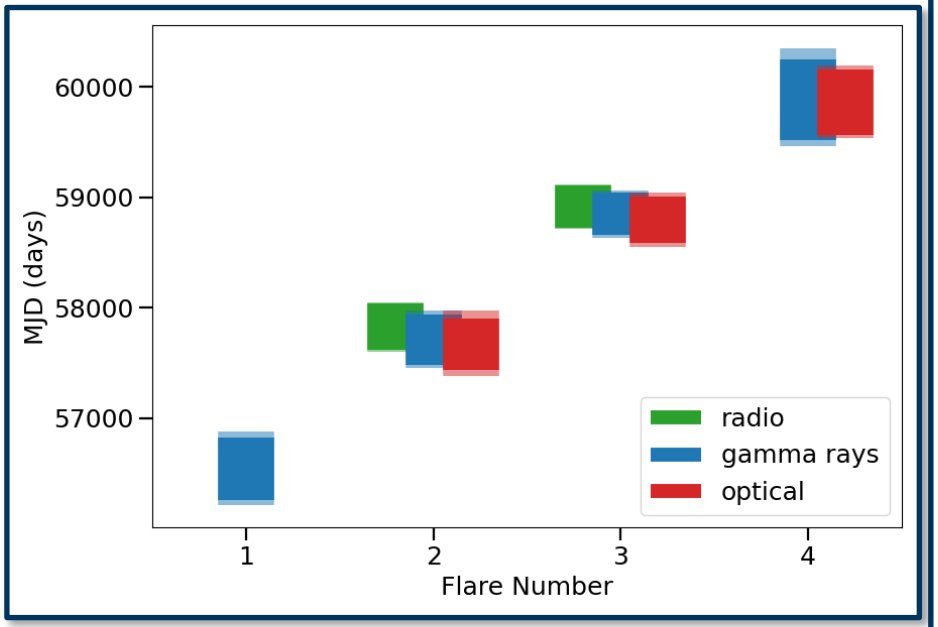
Gamma-Ray Light Curve + Optical + Radio

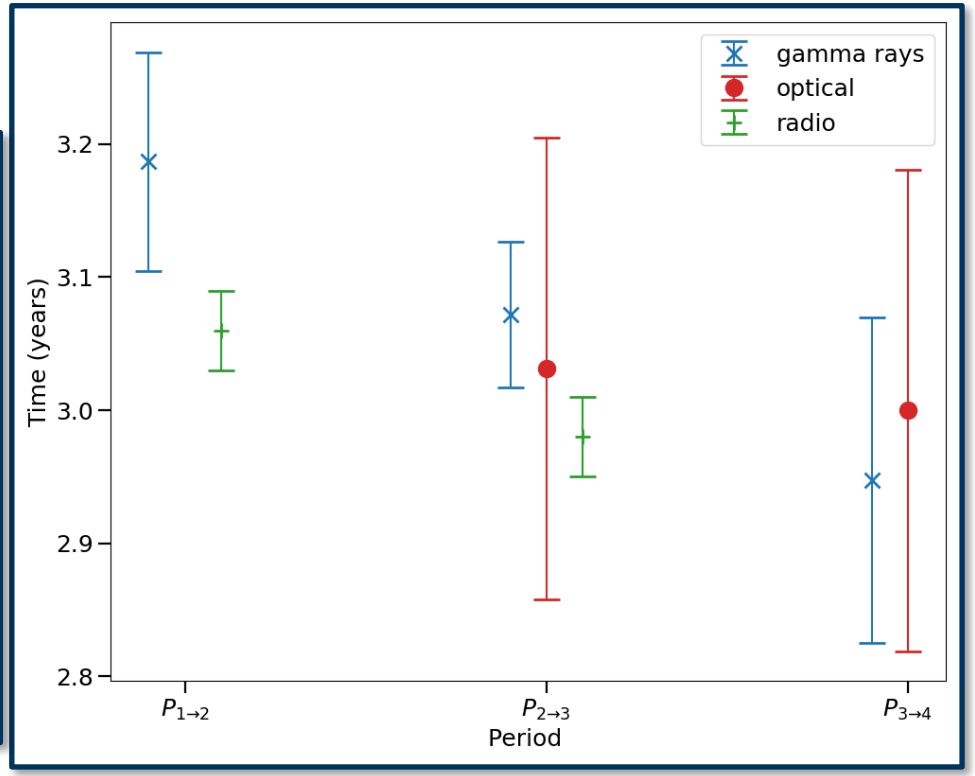


Flare durations

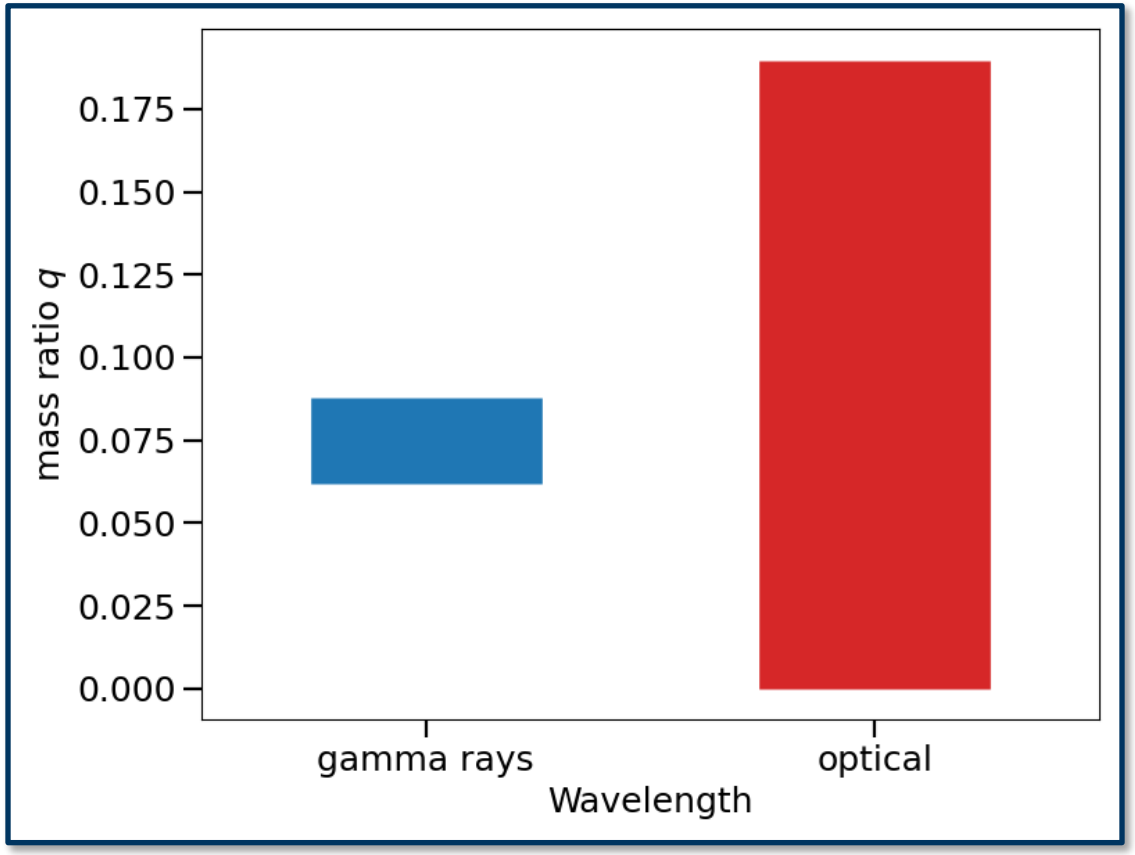


Flare durations + periods

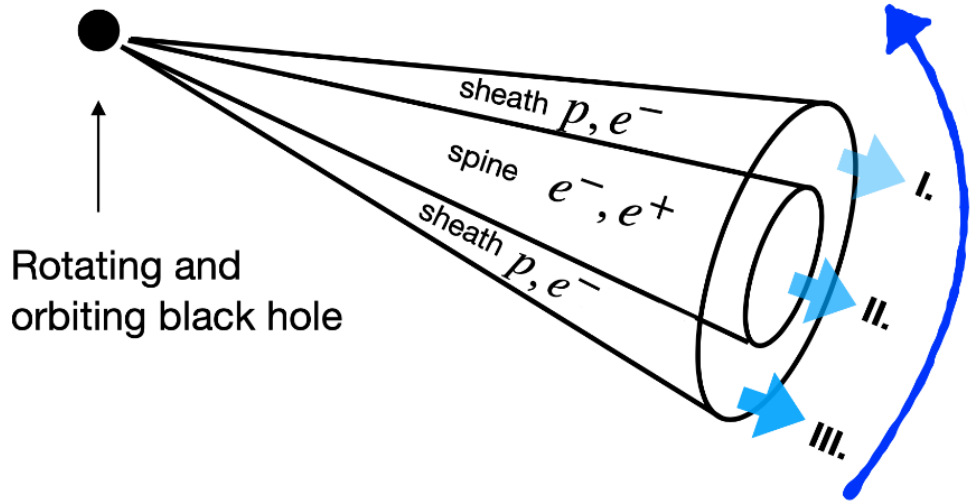




Comparison: Binary Mass Ratios



Double Peak Structure – an Explanation



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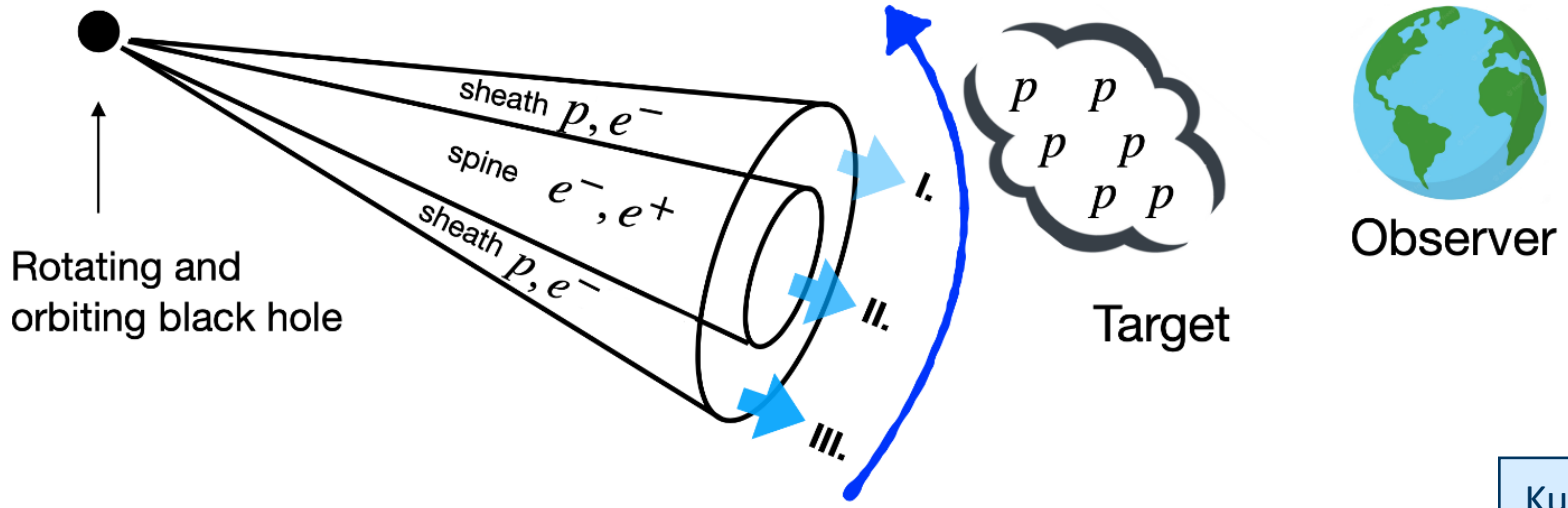

Kun, **IJ** et al. (2024)

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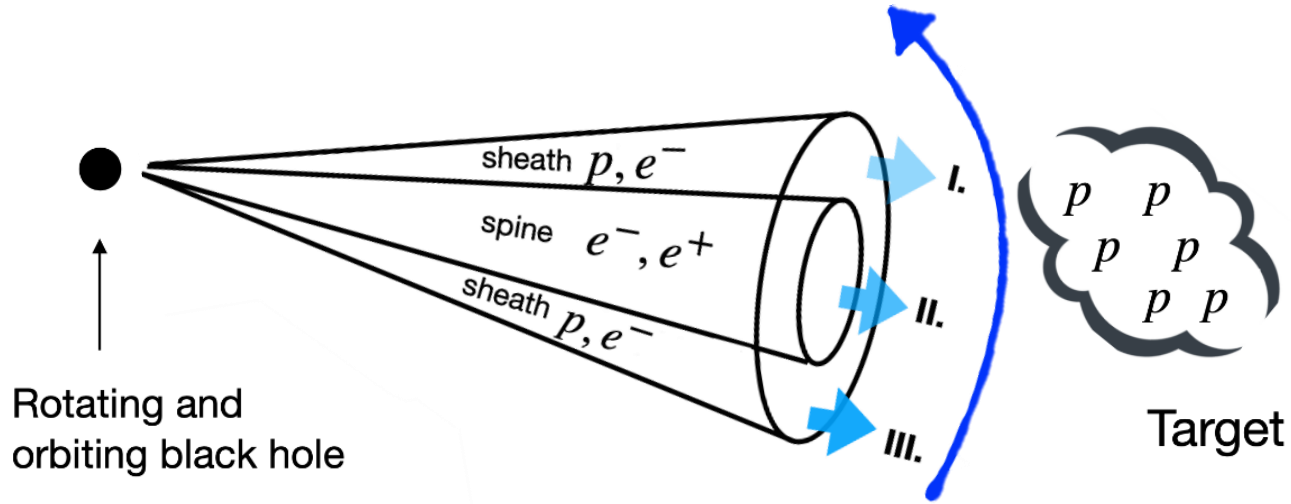

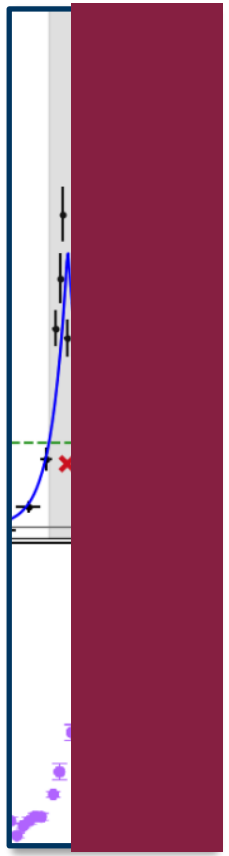

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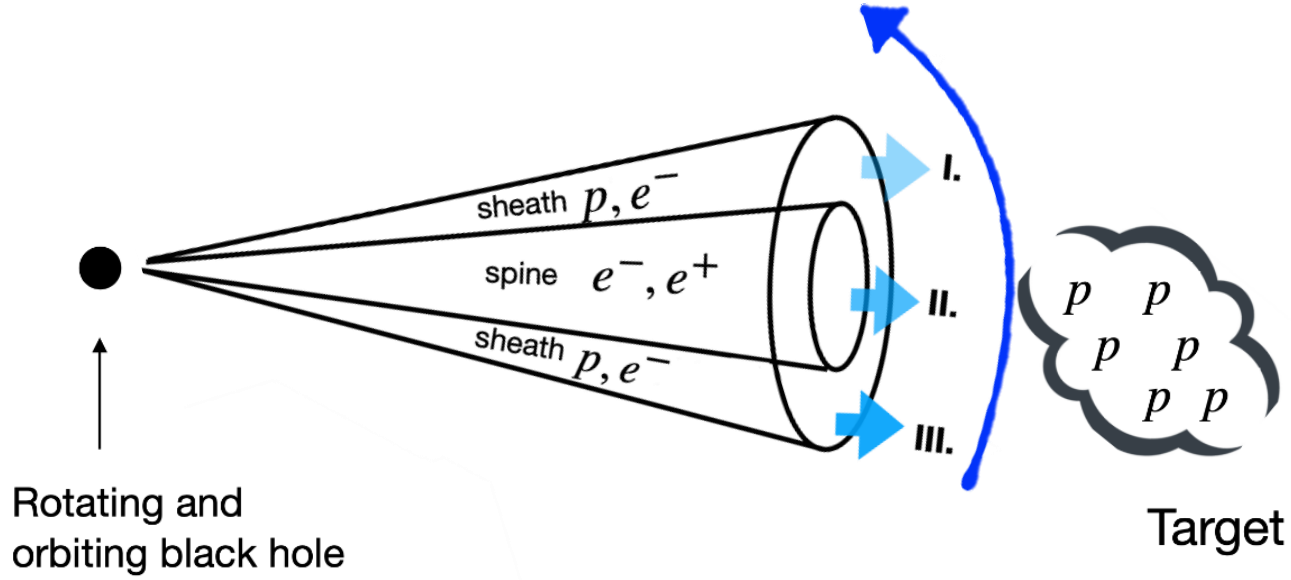

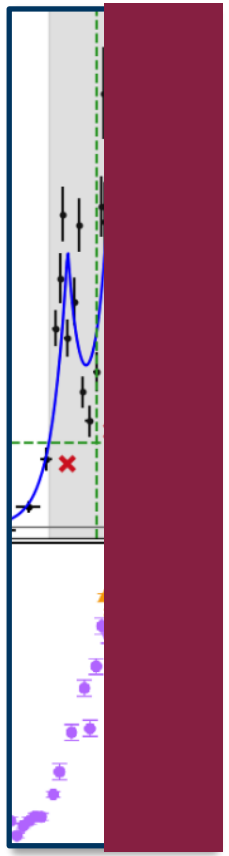

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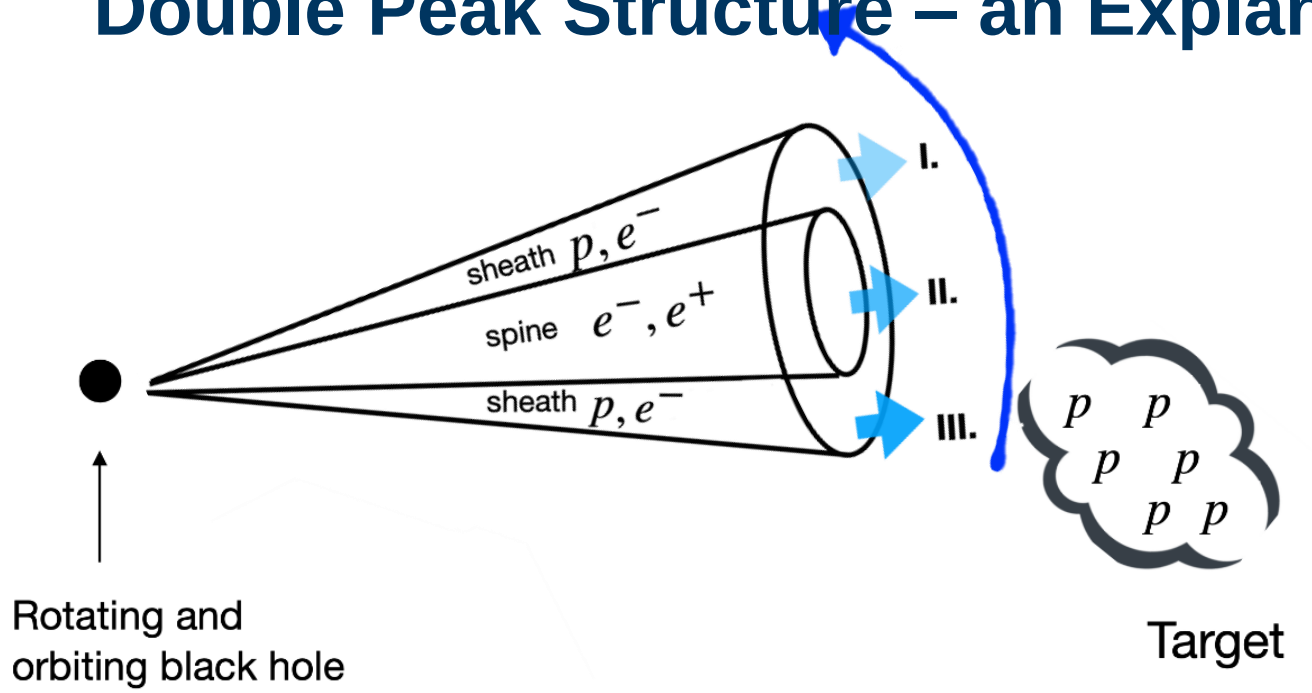
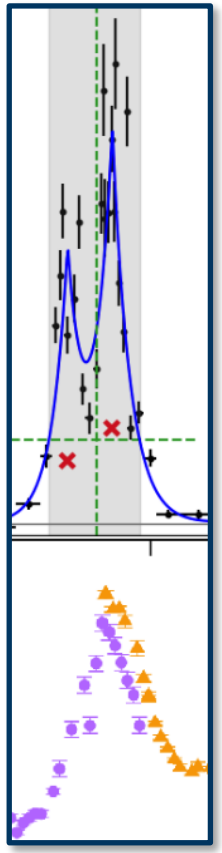
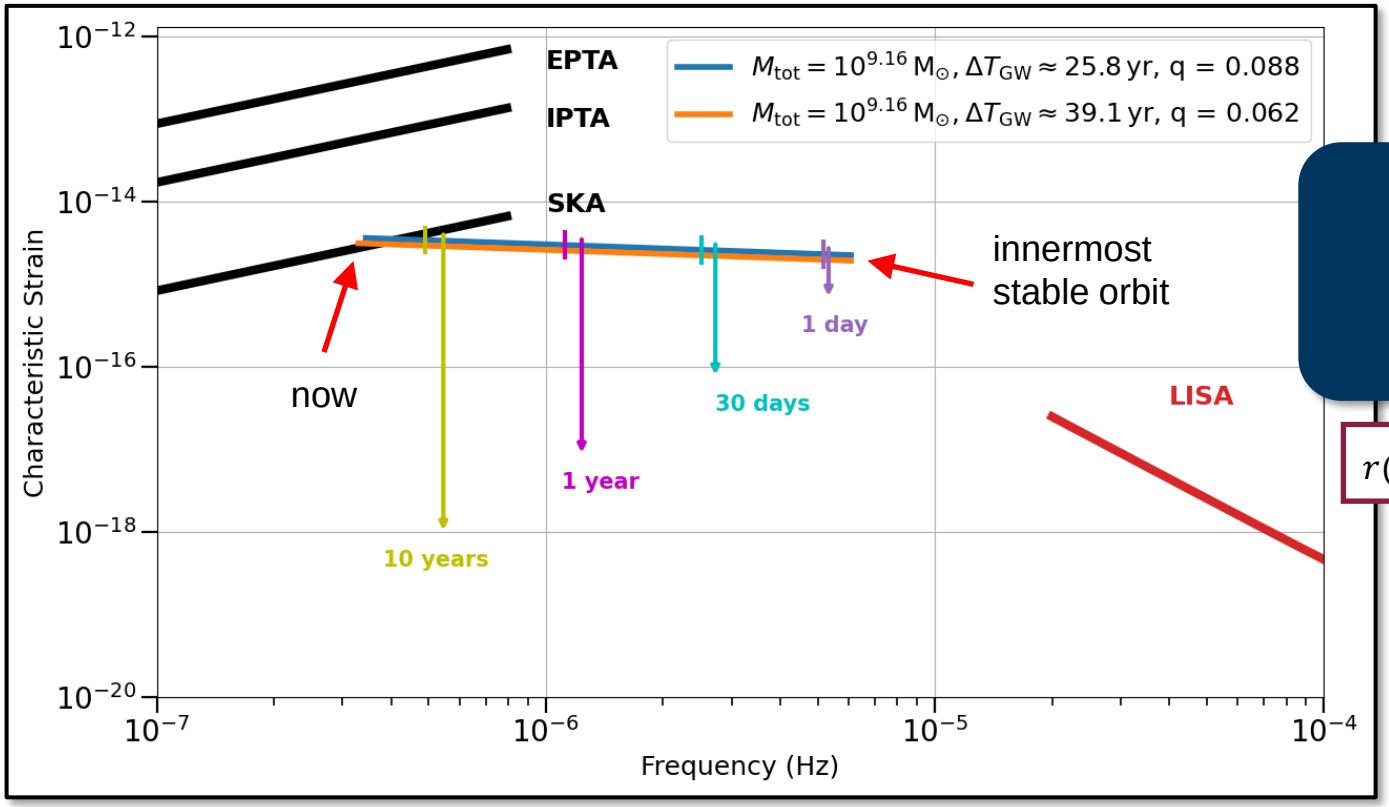




Kun, **IJ** et al. (2024)

Expected Gravitational Wave Signal



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

$r(z)$: comoving distance

Summary

Jet precession due to spin-orbit coupling in a supermassive binary black hole inspiral
→ quasi-periodic multi-messenger signatures with **decreasing periodicities**

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4th Flare predicted successfully

→ Mass ratio range:

$$0.062 \leq q \leq 0.088$$

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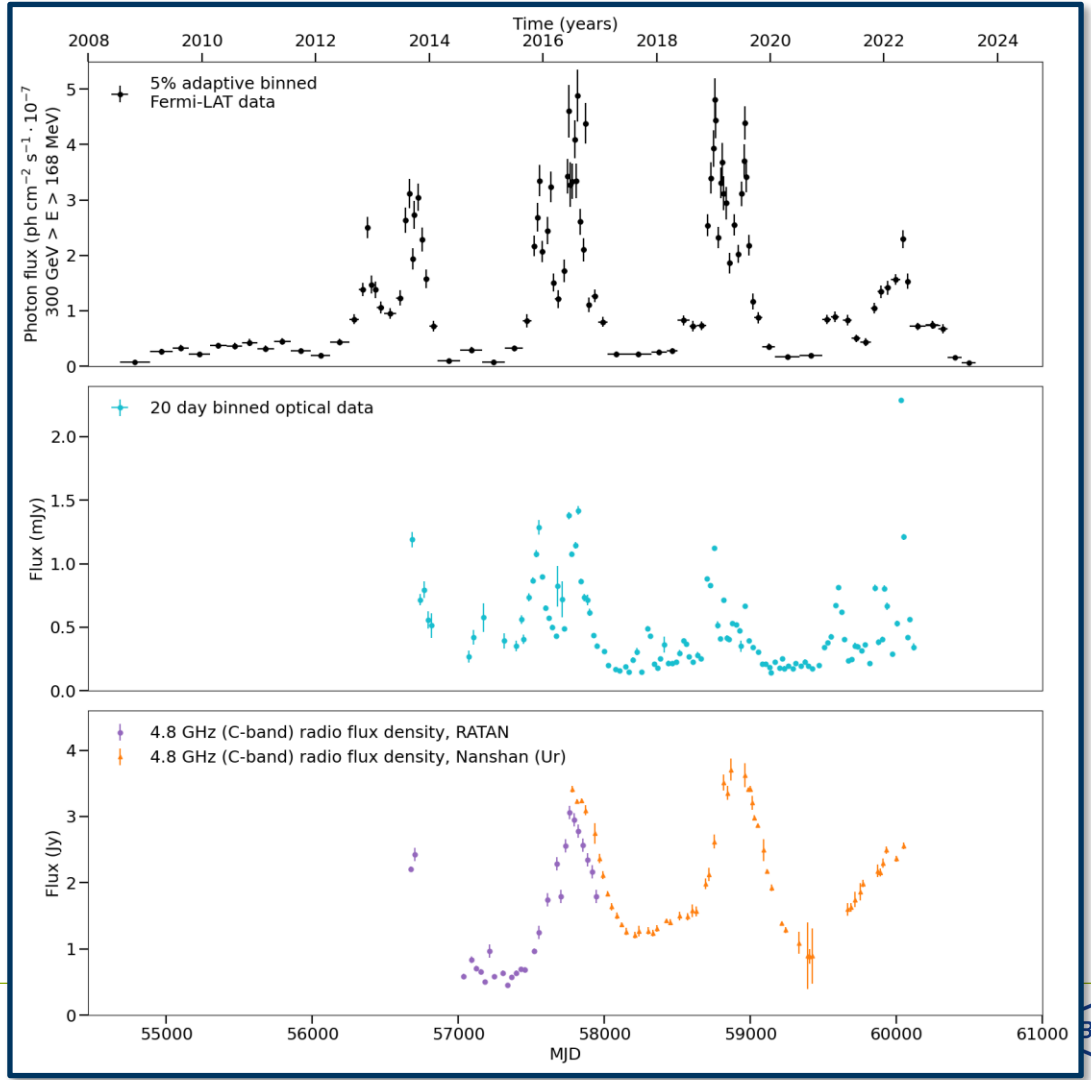
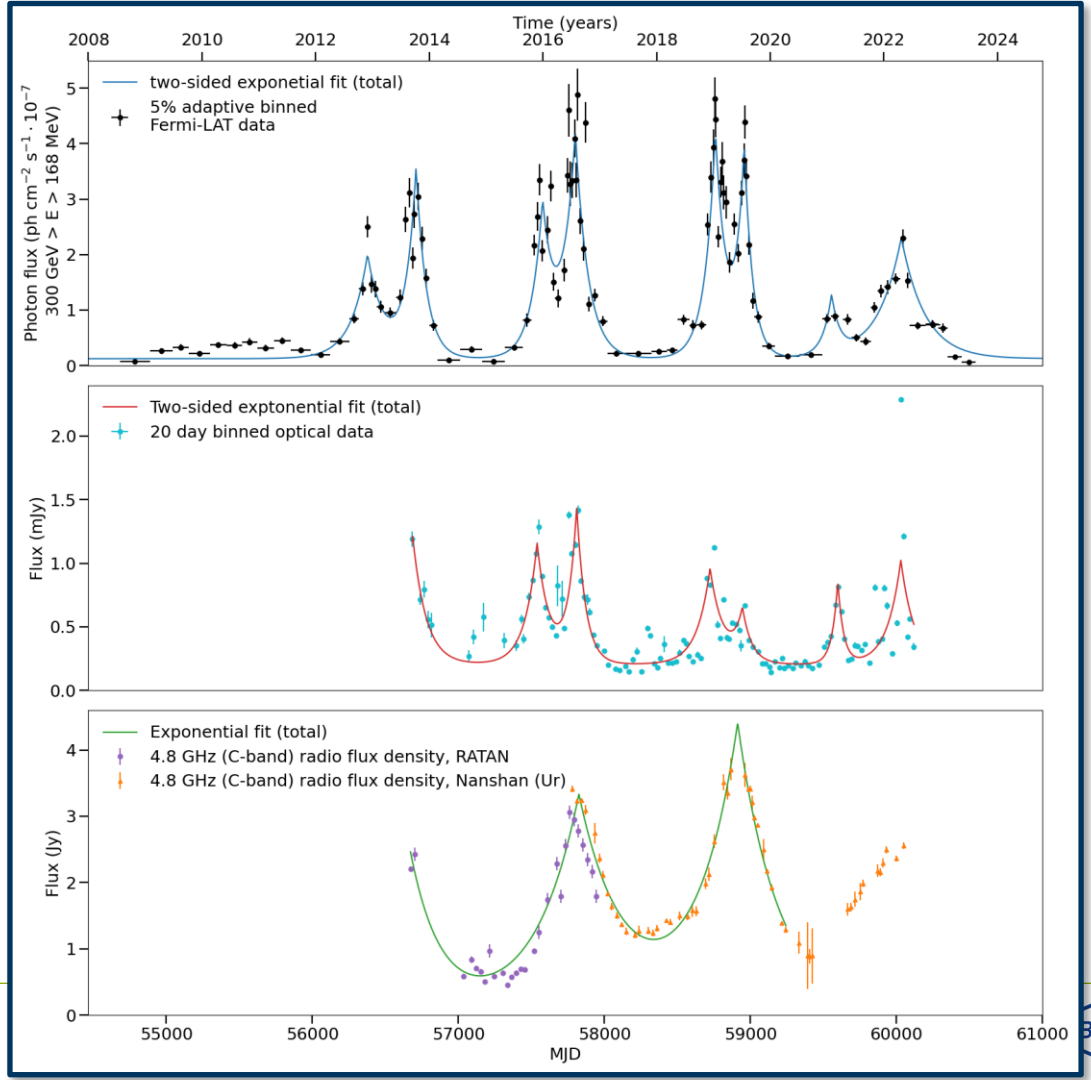
Time range of next flare, if the jet will point at Earth once more:

2024 March 10 - 2026 November 6

Appendix


Time (years)
2008
2010
2012
2014
2016
2018
2020
2022
2024
5% adaptive binned
Fermi-LAT data
Photon flux (ph cm^{-2} s^{-1} · 10^{-7}
300 GeV > E > 168 MeV)
20 day binned optical data
Flux (mJy)
4.8 GHz (C-band) radio flux density, RATAN
4.8 GHz (C-band) radio flux density, Nanshan (Ur)
Flux (Jy)
55000
56000
57000
58000
59000
60000
61000
MJD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55000
56000
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58000
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60000
61000
MJD

Backup: Jet Precession Model

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

$$\phi_{\mathrm{Kun}}(\Delta T_{\mathrm{GW}}, M, q) = \frac{2(4+3q)}{q}\left(\frac{5c}{32}\right)^{\frac{3}{4}}\left(\frac{\eta(q)}{GM}\right)^{1/4}(\Delta T_{\mathrm{GW}})^{1/4} + \psi(\tau, M, q)$$

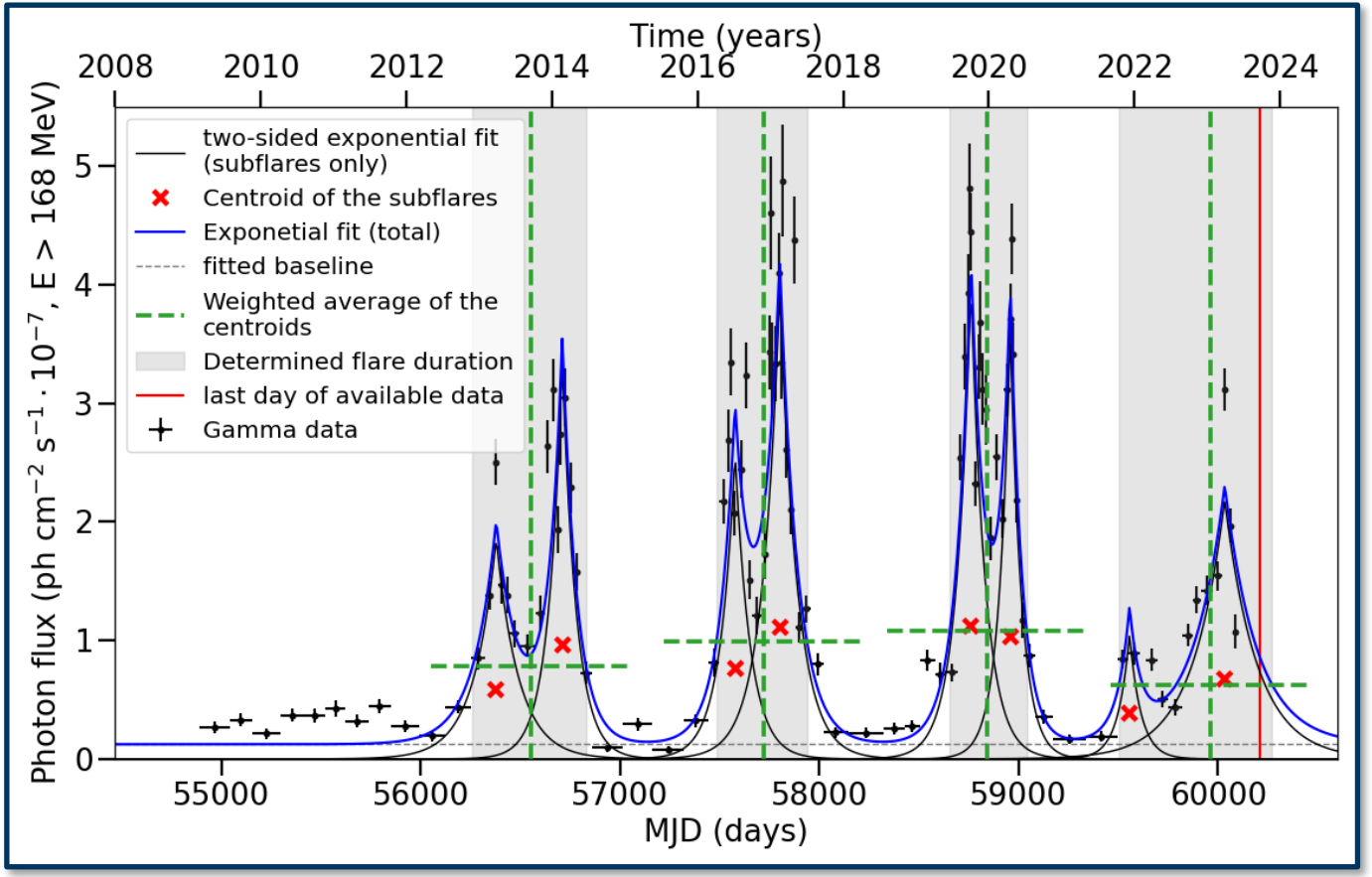
Backup: J1048+7143 – Centroid Method (Kun, IJ et al. 2022)

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

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

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

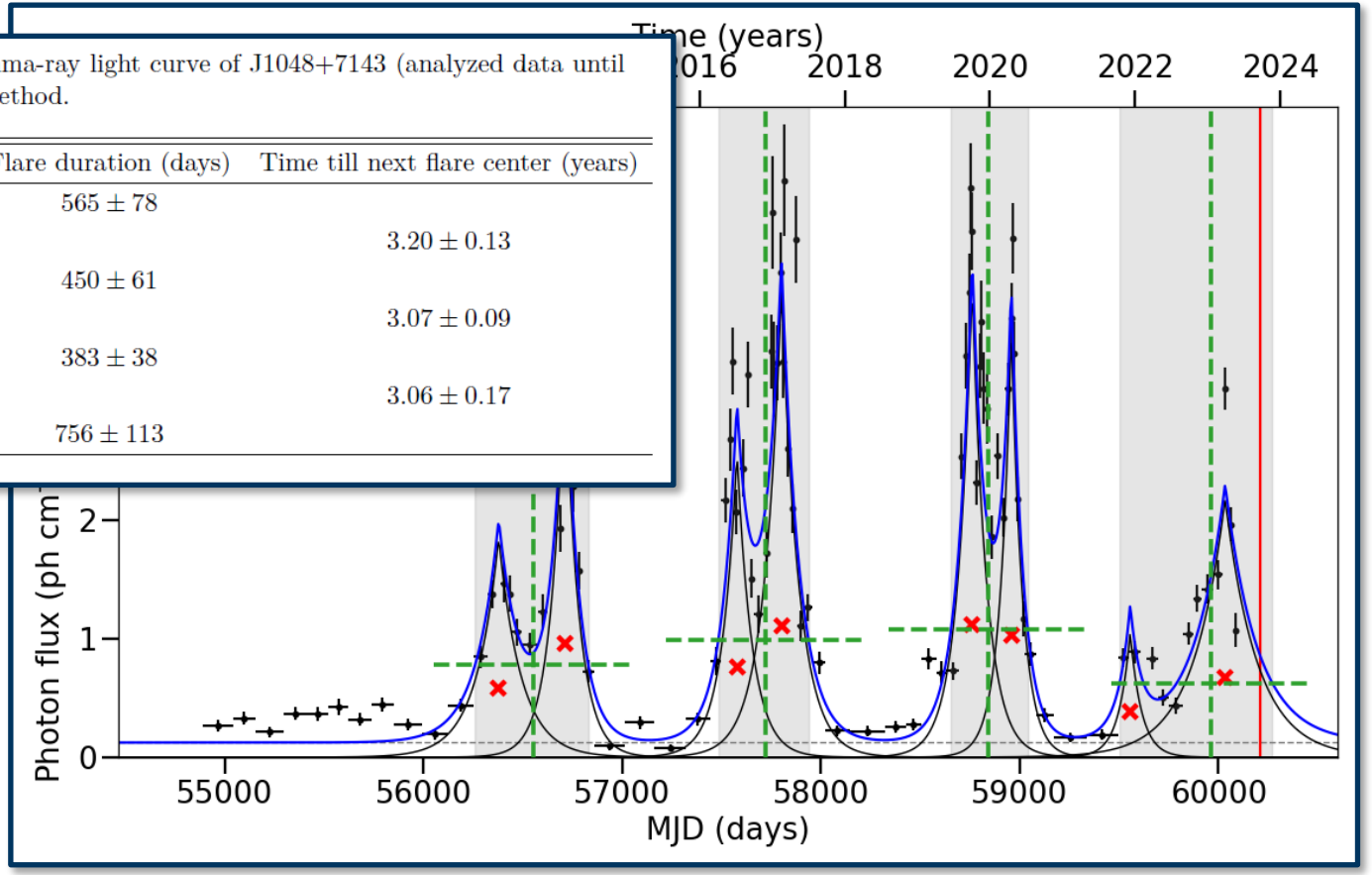
$$Y_i = \frac{A_i}{A_i + B_i} Y_{i,1} + \frac{B_i}{A_i + B_i} Y_{i,2}$$



Backup: J1048+7143 – Flare Characteristics 1/2

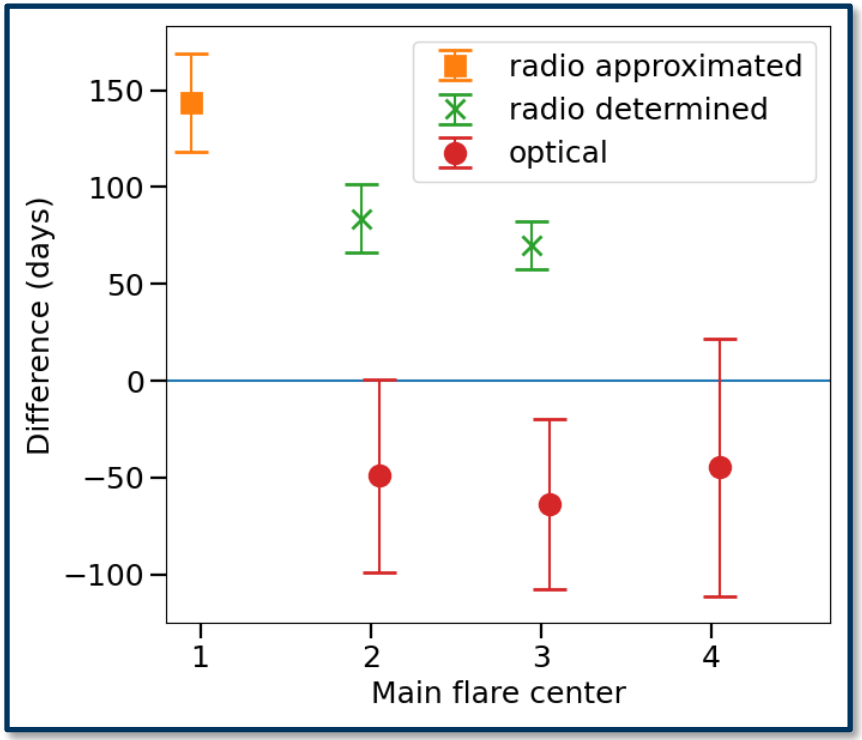
Table 5.1: Characteristics of the gamma-ray light curve of J1048+7143 (analyzed data until MJD 60099) applying the centroid method.

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	

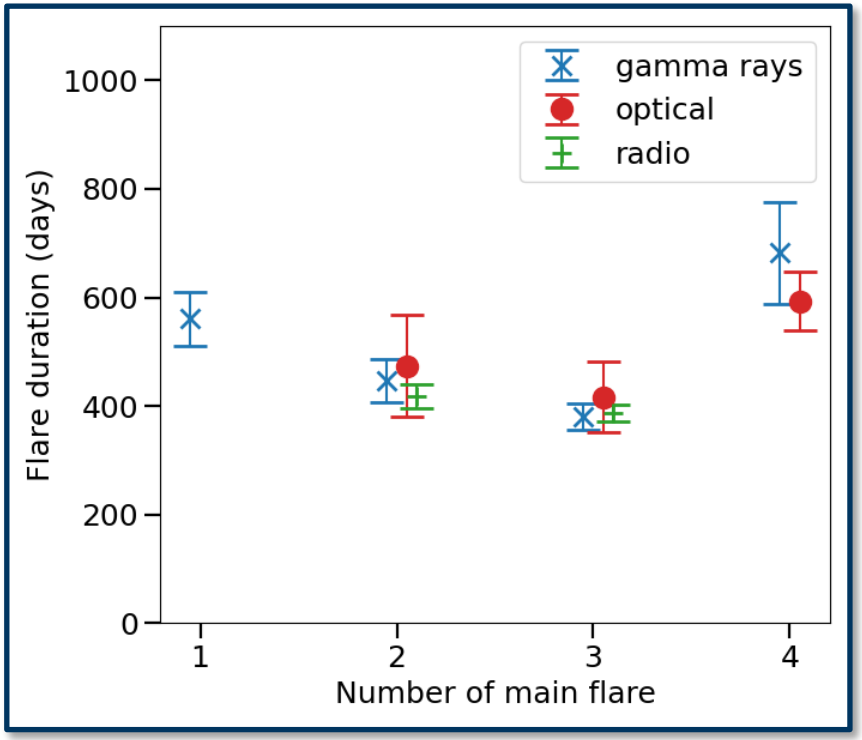


Backup: J1048+7143 – Flare Characteristics 2/2

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



Main Flare durations:



Backup: J1048+7143 – Possible Nutation in Gamma Rays