Alignment of the jet with Black Hole spin: a hint from the TDE Sw J1644+57

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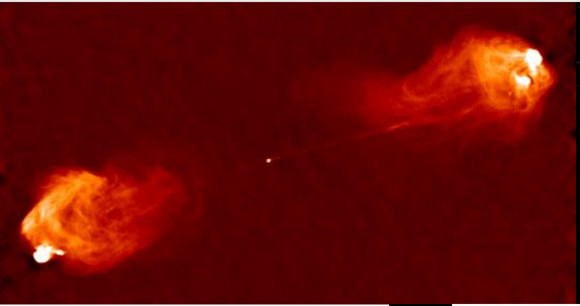
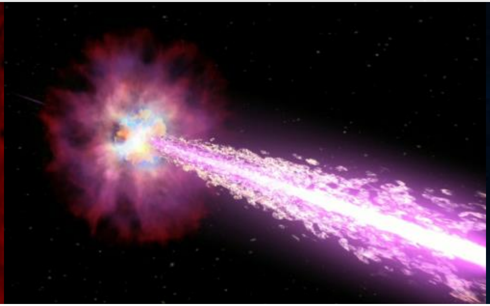
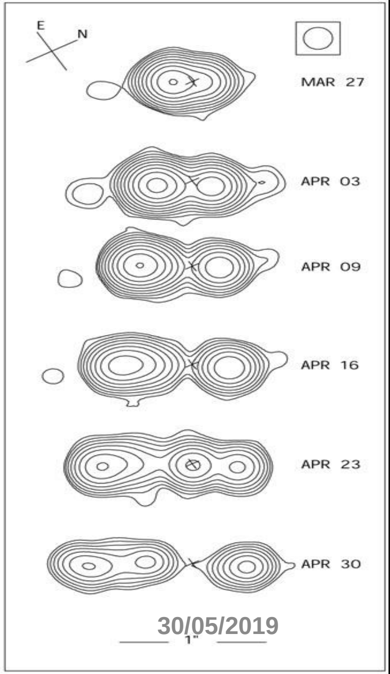
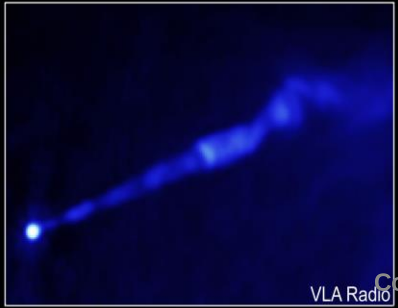
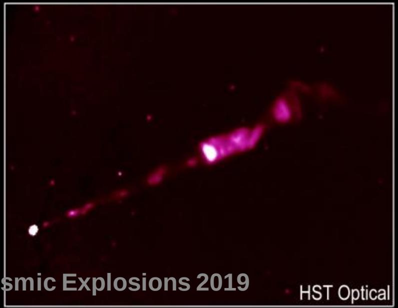
Jets are ubiquitous:

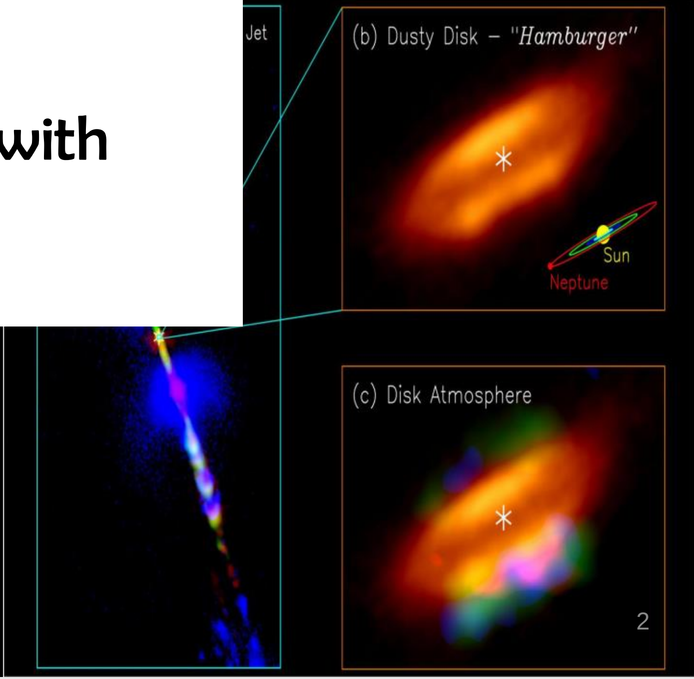



Q: Is the jet axis aligned with the BH spin axis?





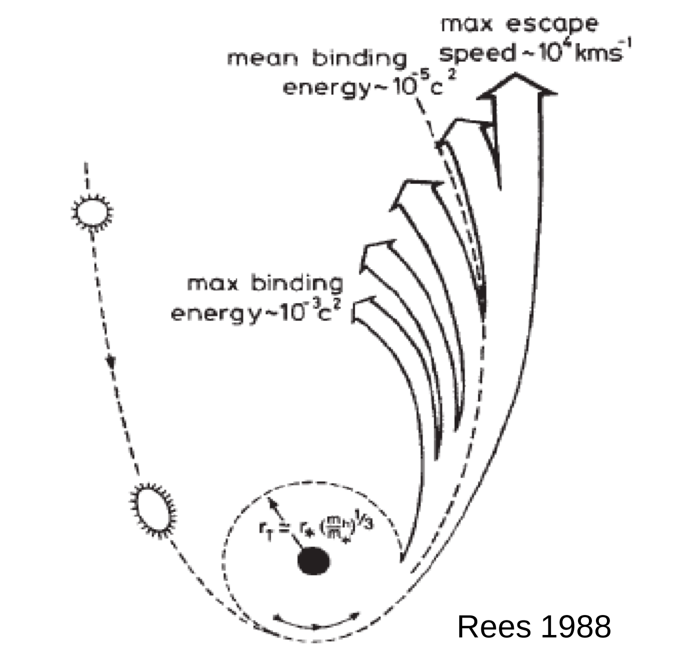


TDE: idea

- If a star passes too close to a BH, it is shredded by the tidal force. The star is partially accreted onto the BH:

  Tidal radius, $R_T \sim R_* \left(\frac{M_{BH}}{M_*}\right)^{1/3}$

- If $R_T \le R_S$, no disruption: star engulfed as a whole.
- For $M_{BH} \sim 10^5 - 10^8 M_\odot$, tidal disruption event (TDE)
- A fraction of the debris becomes bound to the BH, circularizes, and starts accreting.
- Flare of EM radiation, peaking in EUV to soft X-rays, with $T_{eff} \sim 40 - 100\ eV$ and $L_{peak} \sim 10^{42-45}\ erg/s$.
- Accretion rate, $\dot{M} \sim t^{-5/3}$ (canonically)



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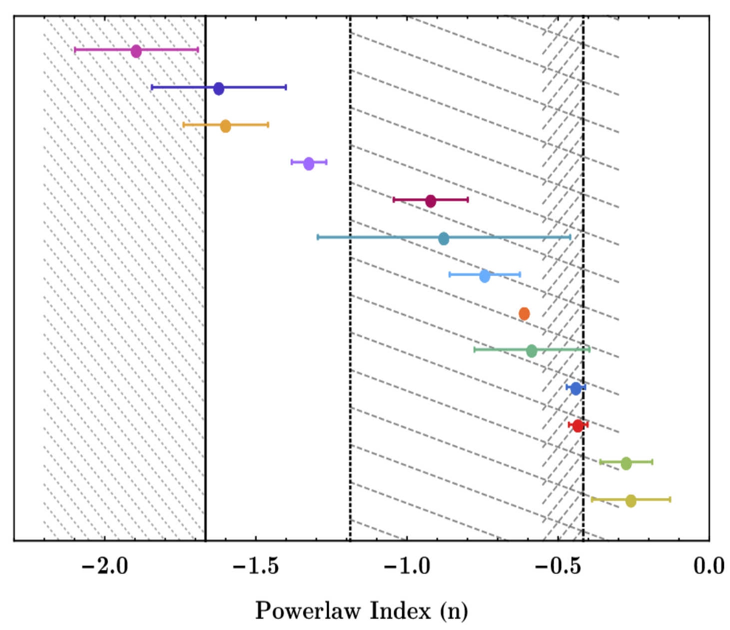
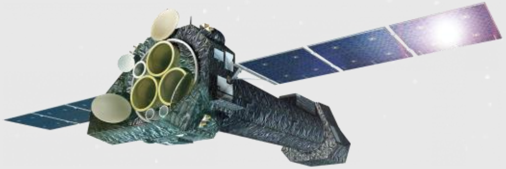
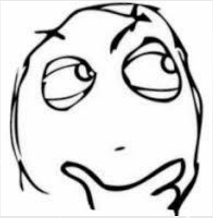
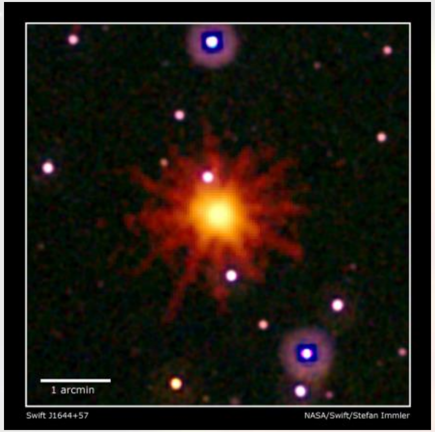


Auchettl + 2017

On 28th March, 2011.........







GRB110328A/SwiftJ164449.3+573451
(Sw J1644+57 hereafter)

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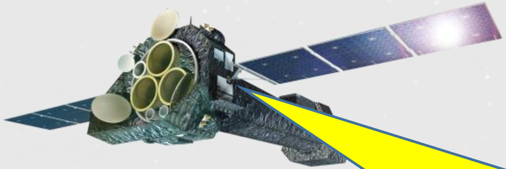
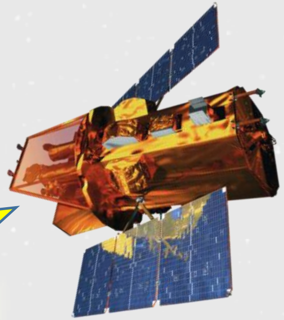
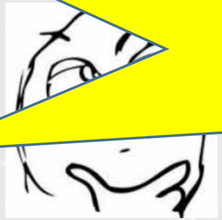
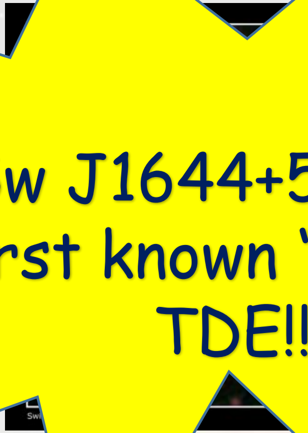




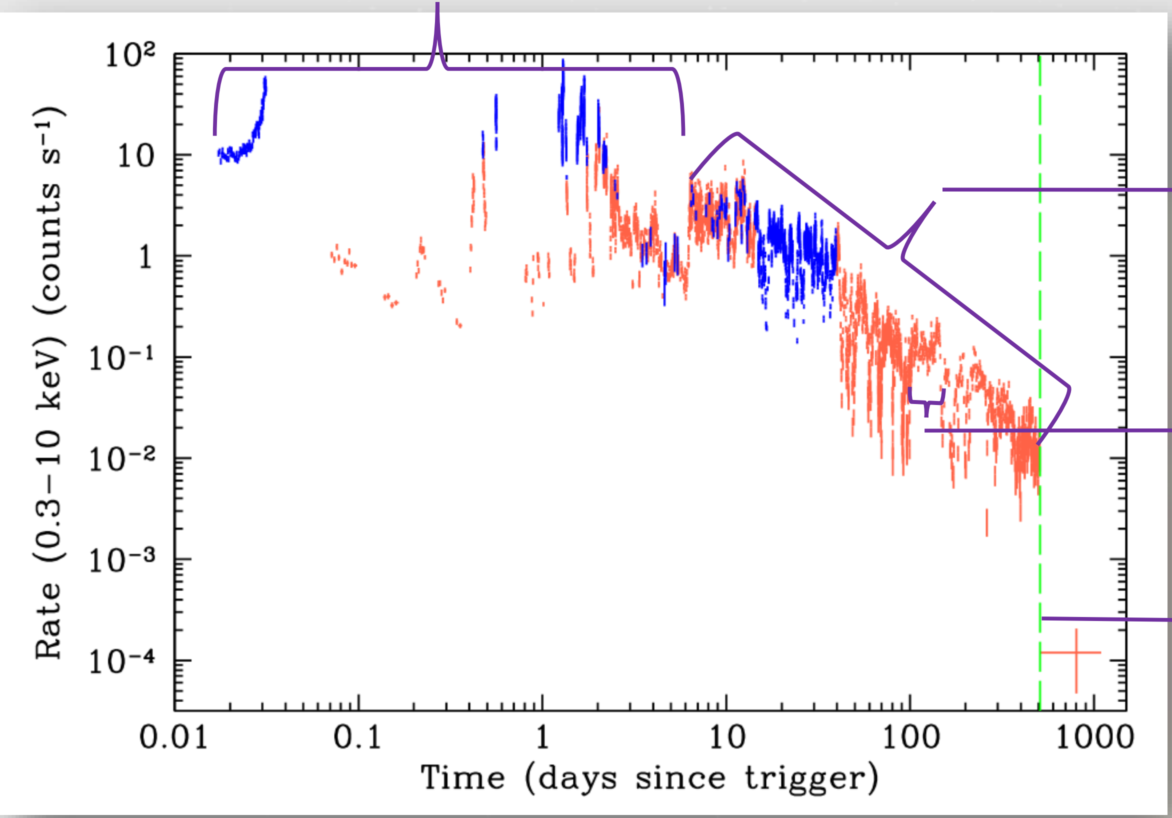
Sw J1644+57 : the first known "jetted" TDE!!!





GRB1103 wiftJ1644 73451
(Sw 44+57 hereaft

J1644+57 : lightcurve



Swift XRT light curve (from UKSSDC): red=PC mode, blue=WT mode

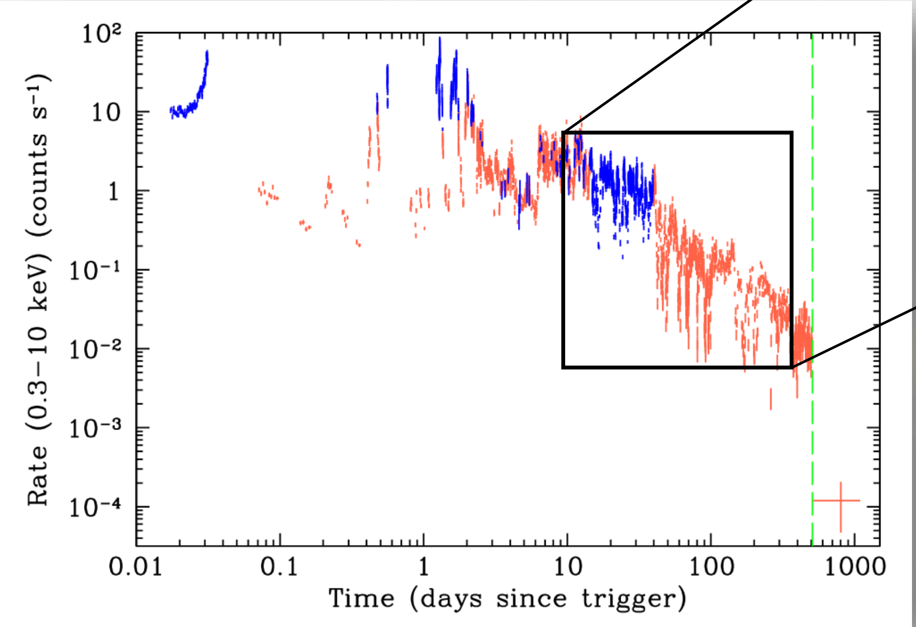
Highly flaring, rapid variability at 100 s timescale, flat secular trend

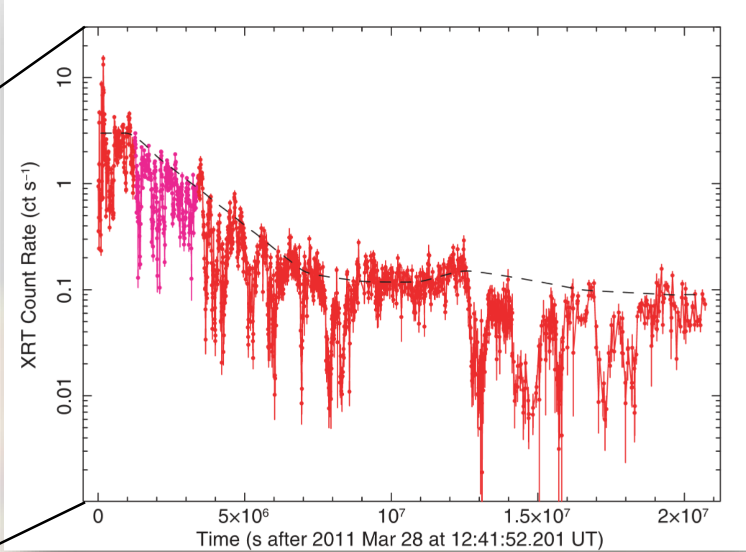
Long term decay, “roughly” following $t^{-5/3}$ trend, lots of dips “Early time”, “Late time” (Saxton + 2012)

“Plateau region”, dips almost vanish

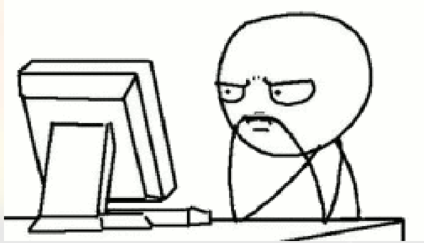
Jet “shut-off” after 508 days

J1644+57 : not the end of the story



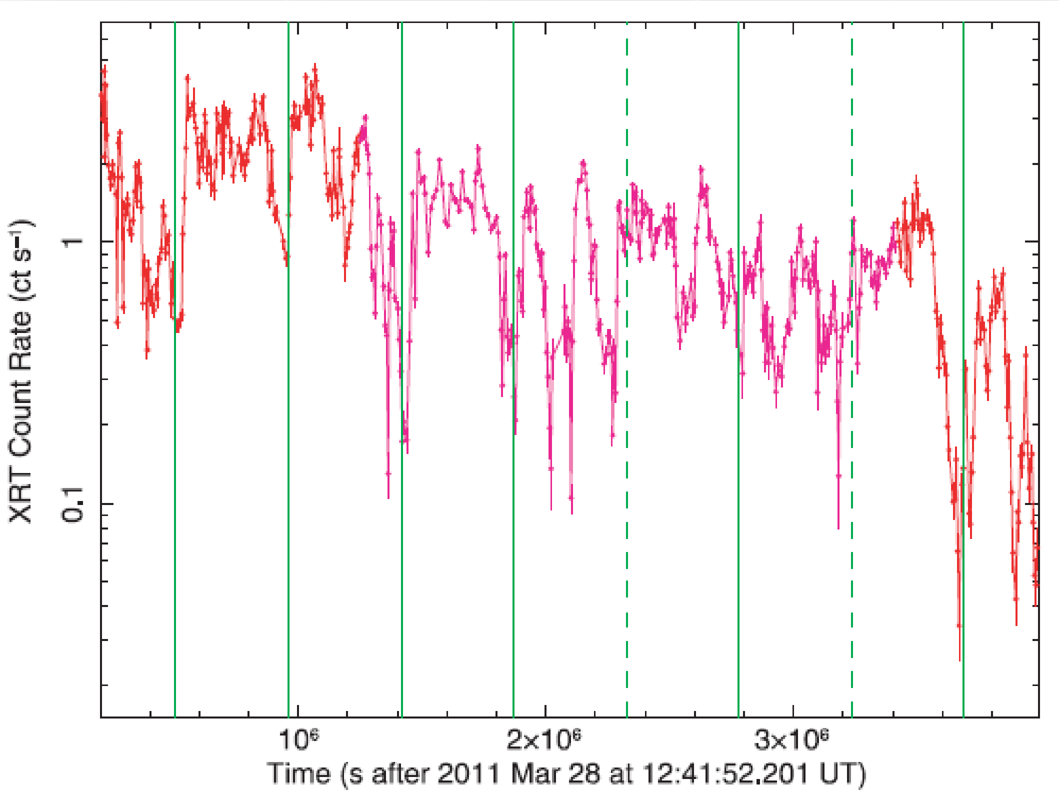


Saxton + 2012



J1644+57 : not the end of the story

- More QPOs / dips at $2.2 - 9 \times 10^5\ s$ before "plateau", after that the dips occur at $1.4 \times 10^6\ s$ timescale
- X-ray continuum (most likely) jet-dominated
- No apparent change in N_H inside or outside the dips
- May be not due to the change in absorption column density within the line of sight
- Jet precession?



Saxton + 2012

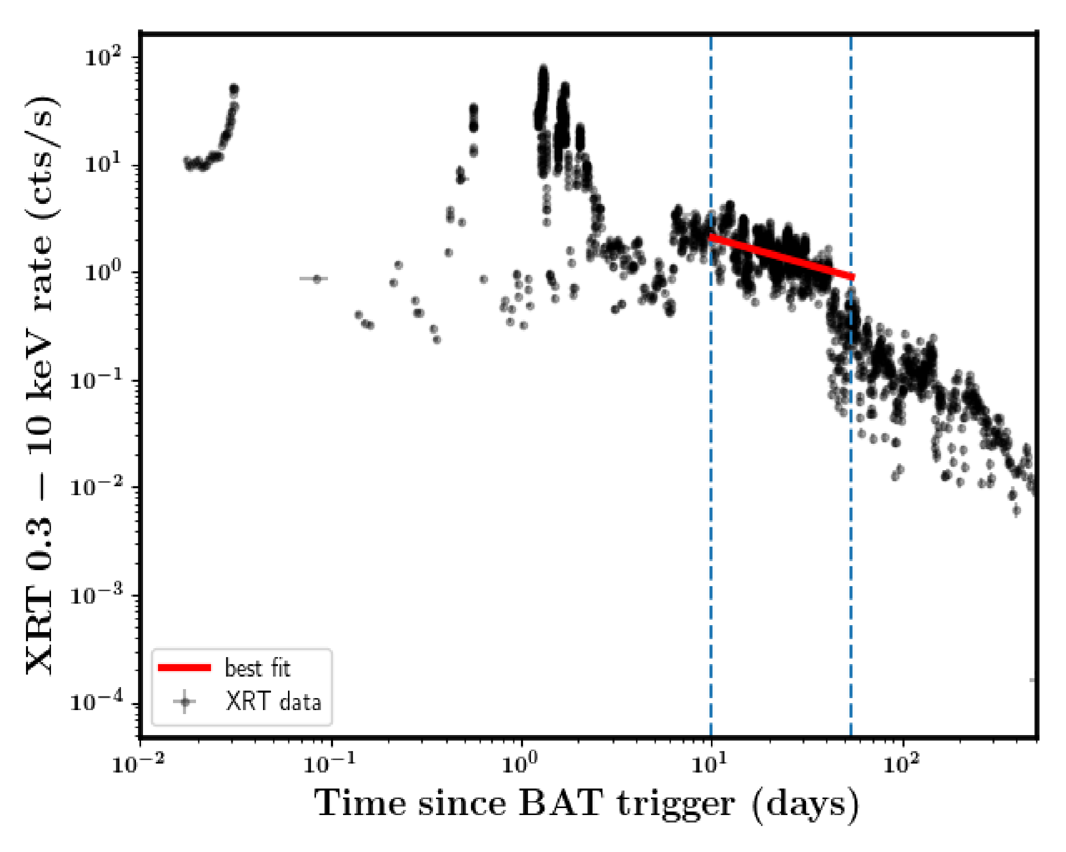
Constraining jet inclination angle β: assumptions

- **Assumptions:**

1. Steady accretion exists
2. Disk is thick

- **Parameters assumed:**

- $r_o = 2\, r_P = r_T$
- $M_* = M_\odot,\ R_* = R_\odot$
- $M_{BH} = 10^6 M_\odot$
- $\theta_{jet} \simeq 6°$
- $R_i = R_{ISCO}$ (for a Kerr BH)
- $\Sigma = \Sigma_i (r/r_i)^{-\zeta}$, with $\zeta = 1,0,..$
- $\Gamma = 5.5$, as suggested by Wang et al (2014), consistant with Lu et al (2017)



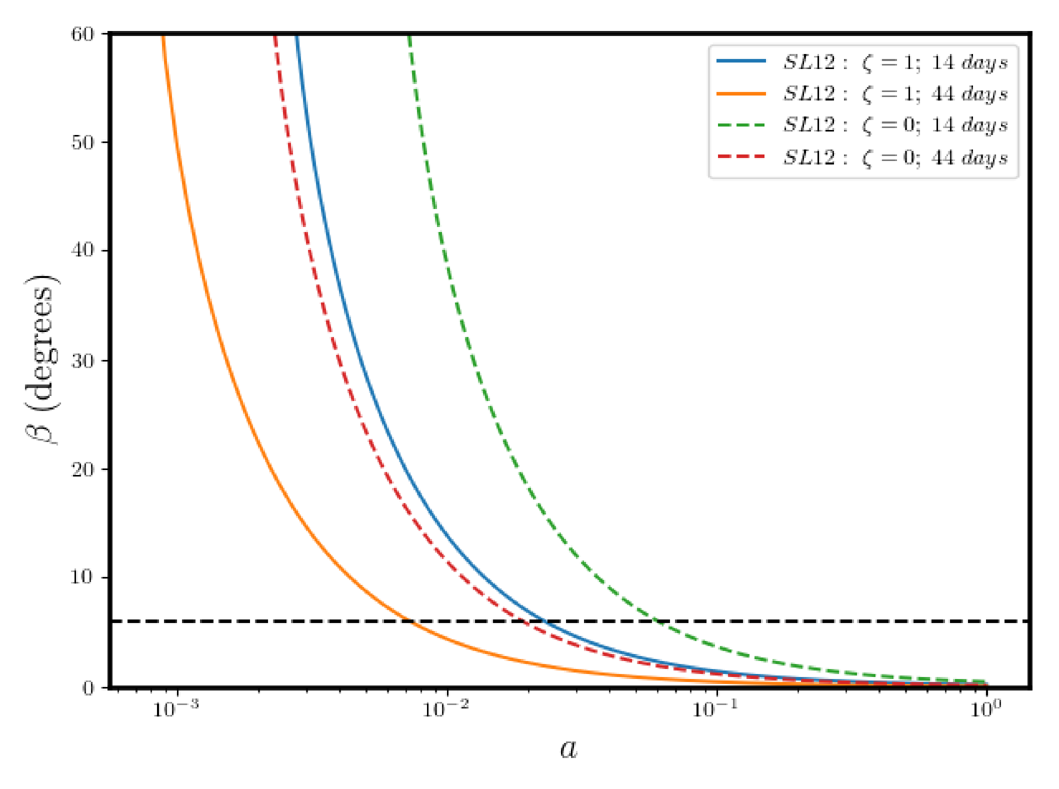
Approach 1: I don't believe in precession (for this)

- Assume **NONE** of the dips are due to jet precession (Stone & Loeb, 2012)

- Within this time $t_{obs} \simeq 54 - 10 = 44\ days$, observer's line of sight remains within the jet opening angle θ_{jet}

- $t_{obs} = \frac{2\theta_{jet}(1+z)T_{prec}}{2\pi \sin\beta}$

- Result: β is quite small for realistic a

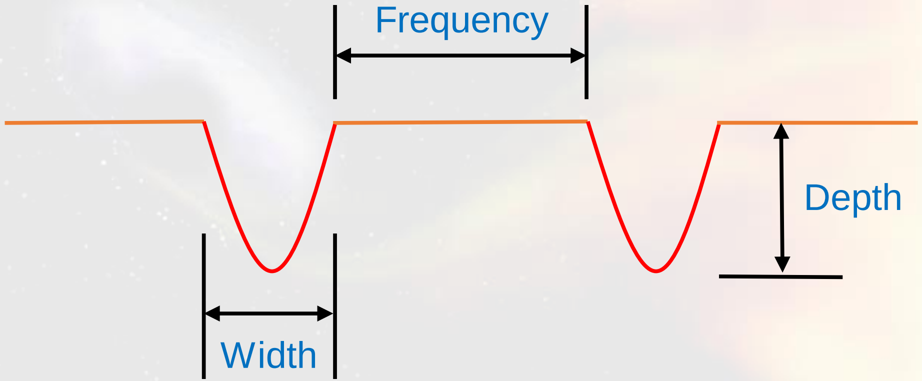


Approach 2: I think I believe in precession

- **Assume ALL of the dips have contributions from jet precession**

- Three quantities related to the dips:

1. Maximum fractional amplitude (f_{max}) as a proxy for depth
2. “Duty cycle” ($\mathcal{R}$) or simply “Ratio” as a proxy for the width/shape
3. Further, $(1+z)T_{prec}$ can be equated to the frequency of occurrence, if we assume LT precession of the disk to be the cause of jet precession



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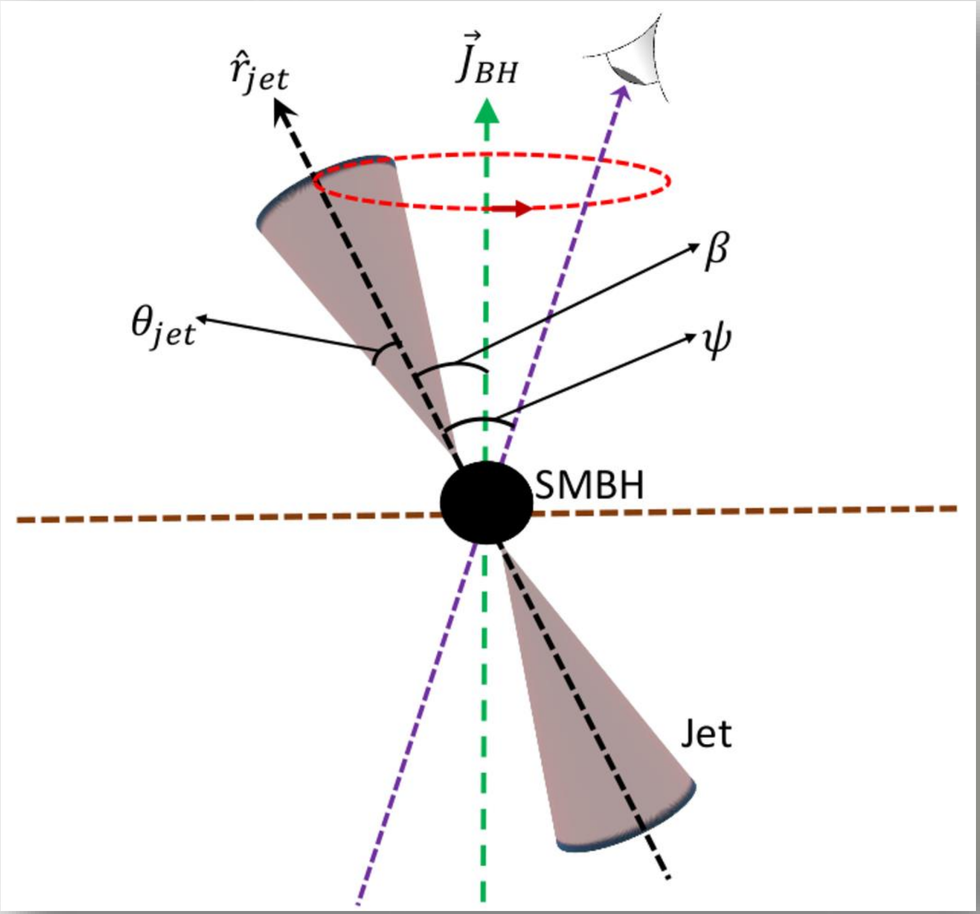

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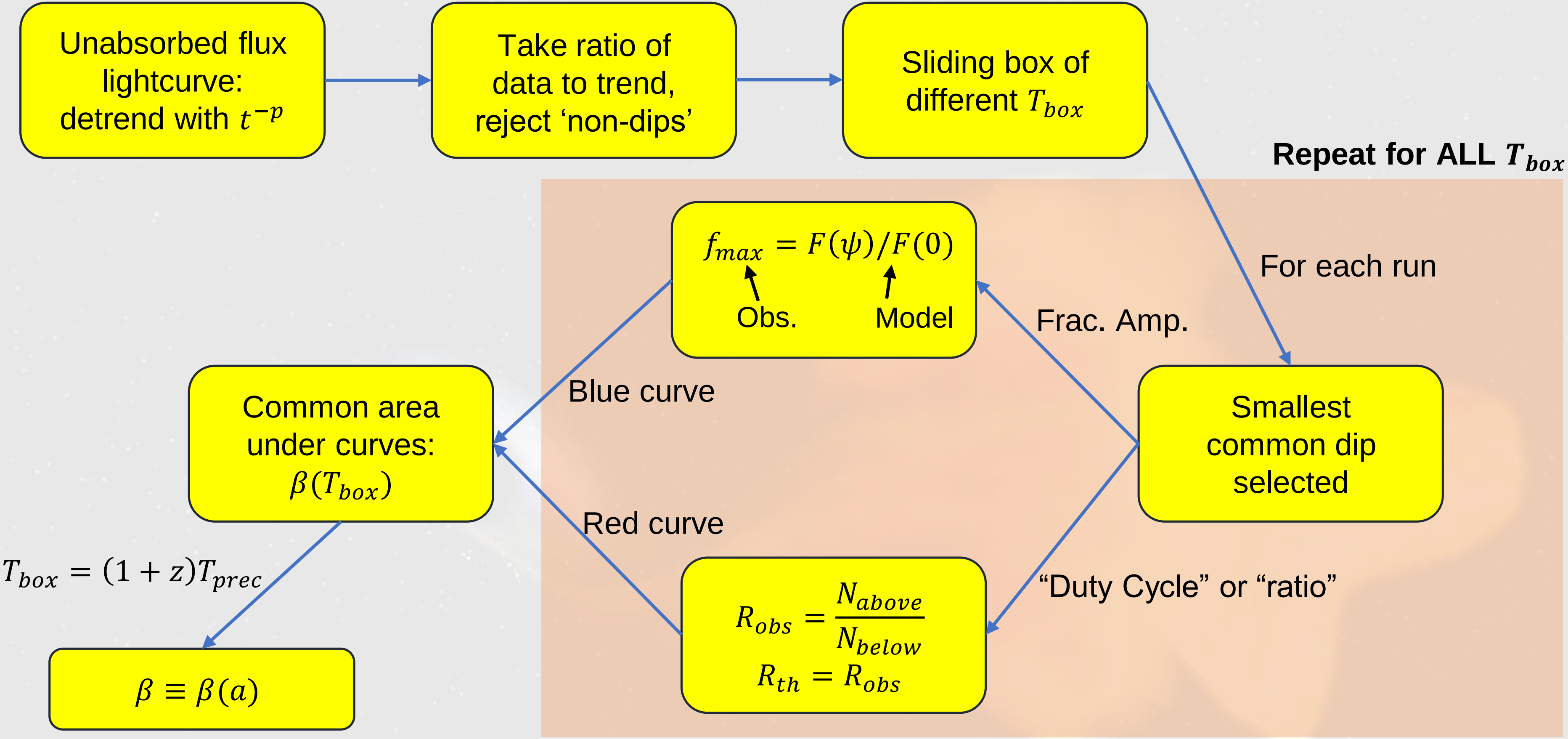
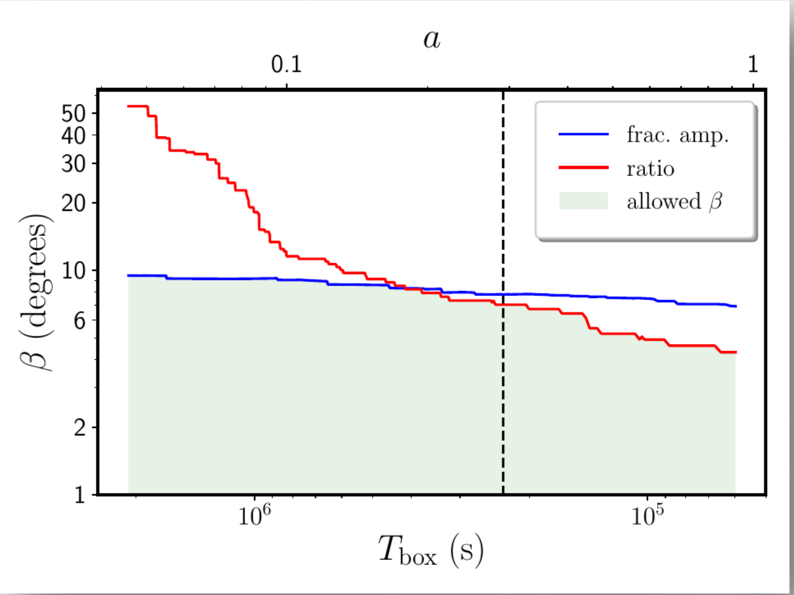


Approach 2: Yeah I believe in precession , now what?



Point-like jet

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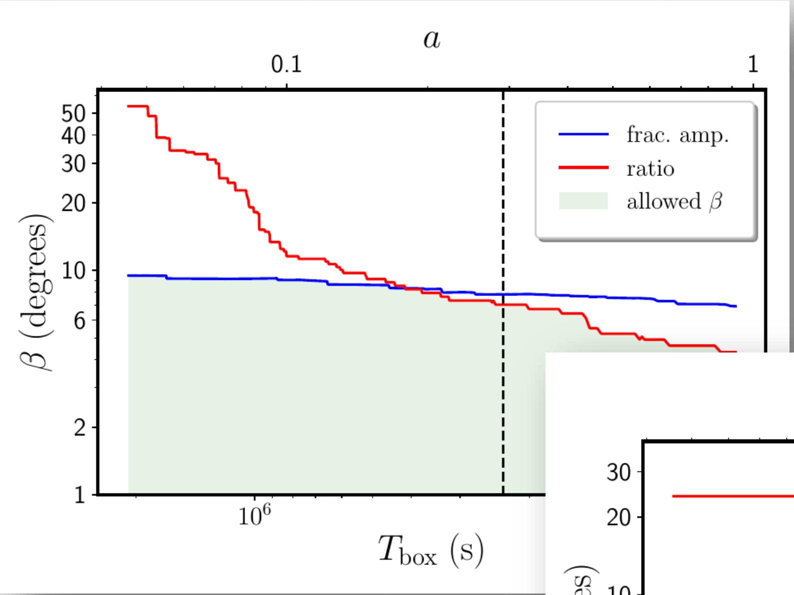

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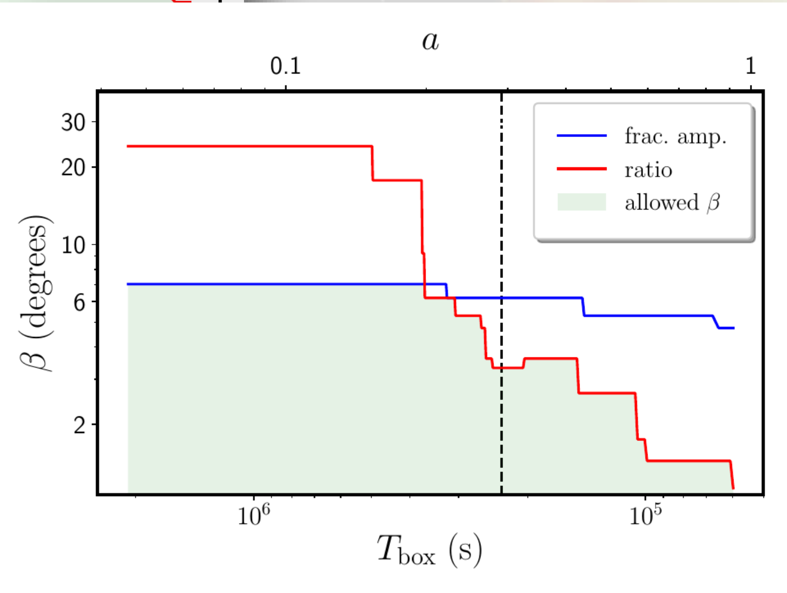

Top-hat jet

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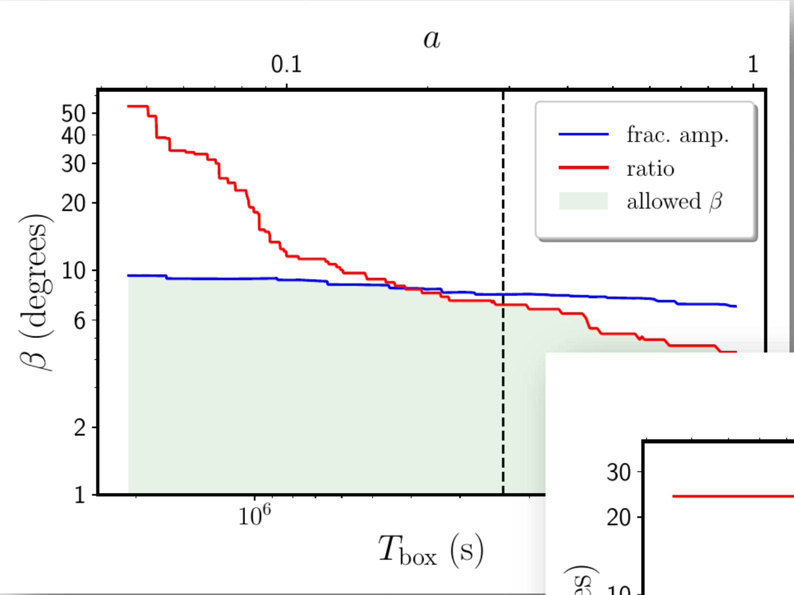

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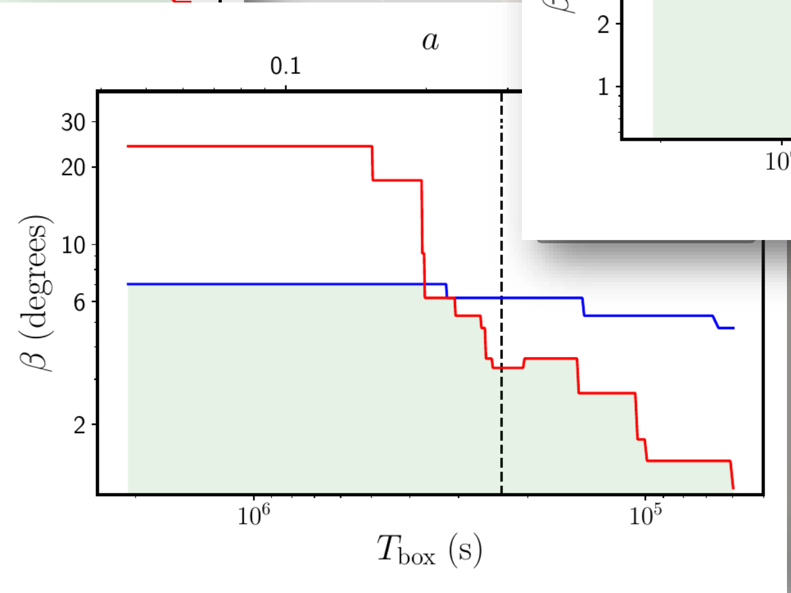

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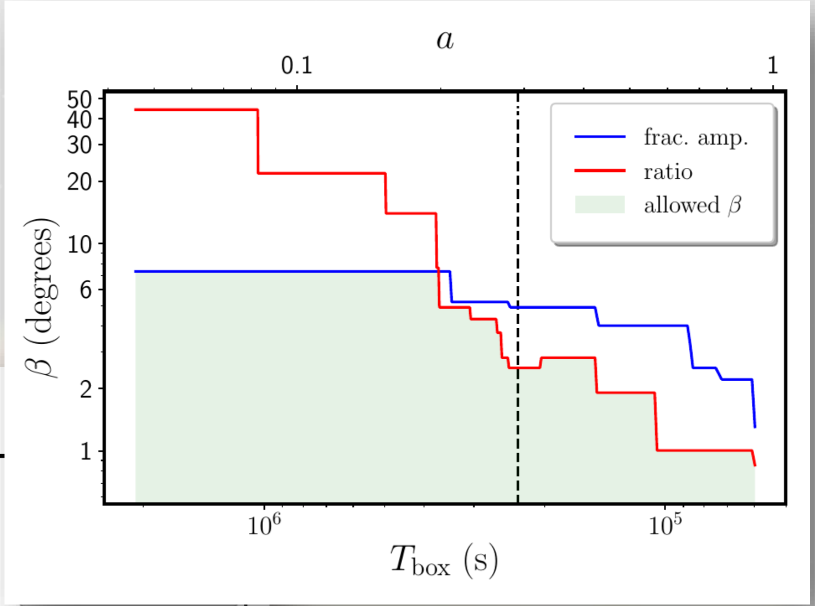


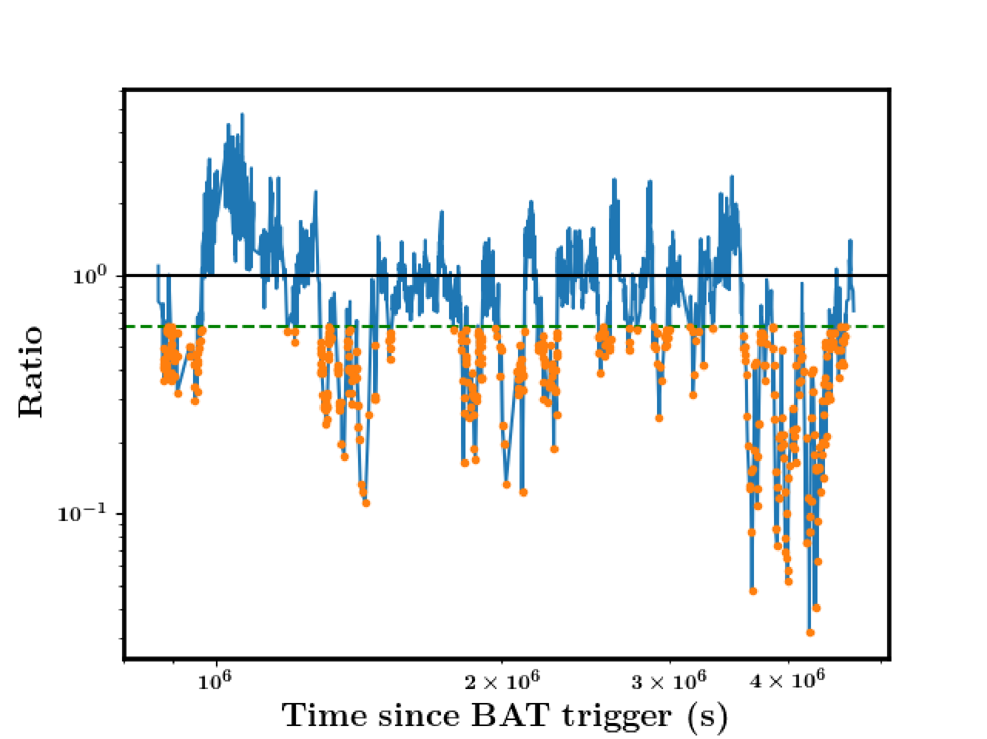
Gaussian jet

Summary and conclusions

- For J1644+57, the jet inclination angle w.r.t. the BH spin axis is systematically low ($<10^\circ$) for the acceptable ranges of BH spin parameter.
- Precession unlikely to be the cause, something else?
- We found this low inclination, so what? (The implications)


THANK YOU
Many of the truths we cling to depend
greatly on our own point of view

Backup slide 1



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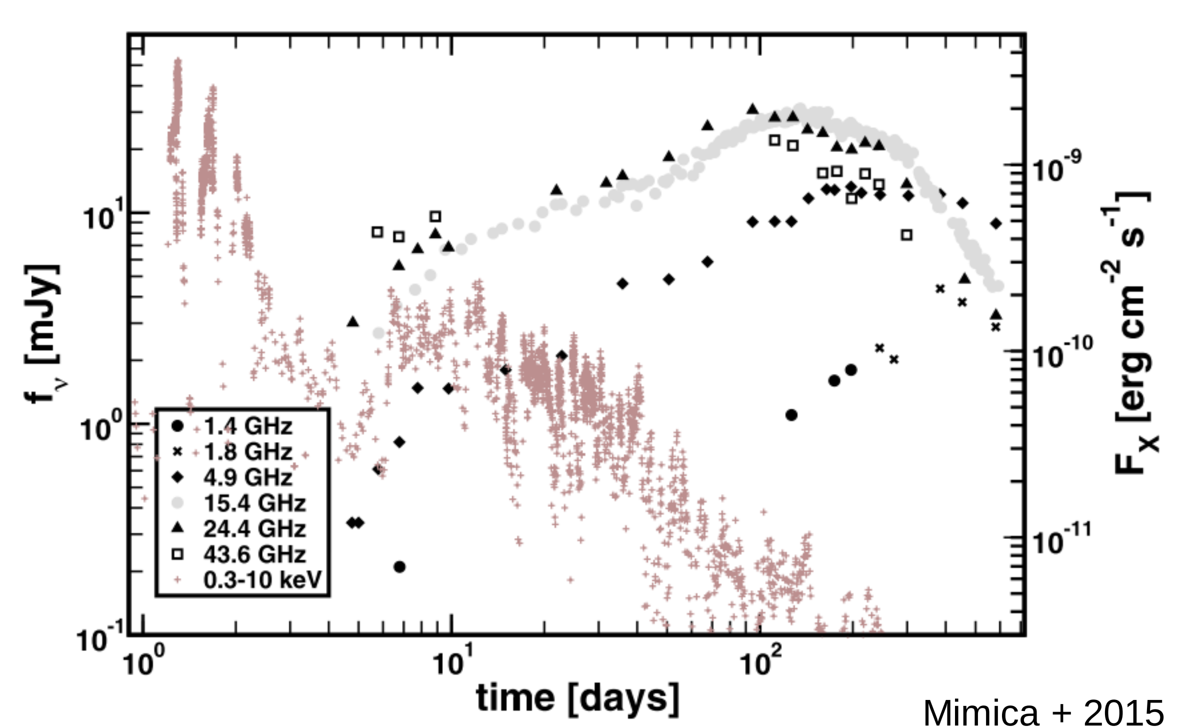
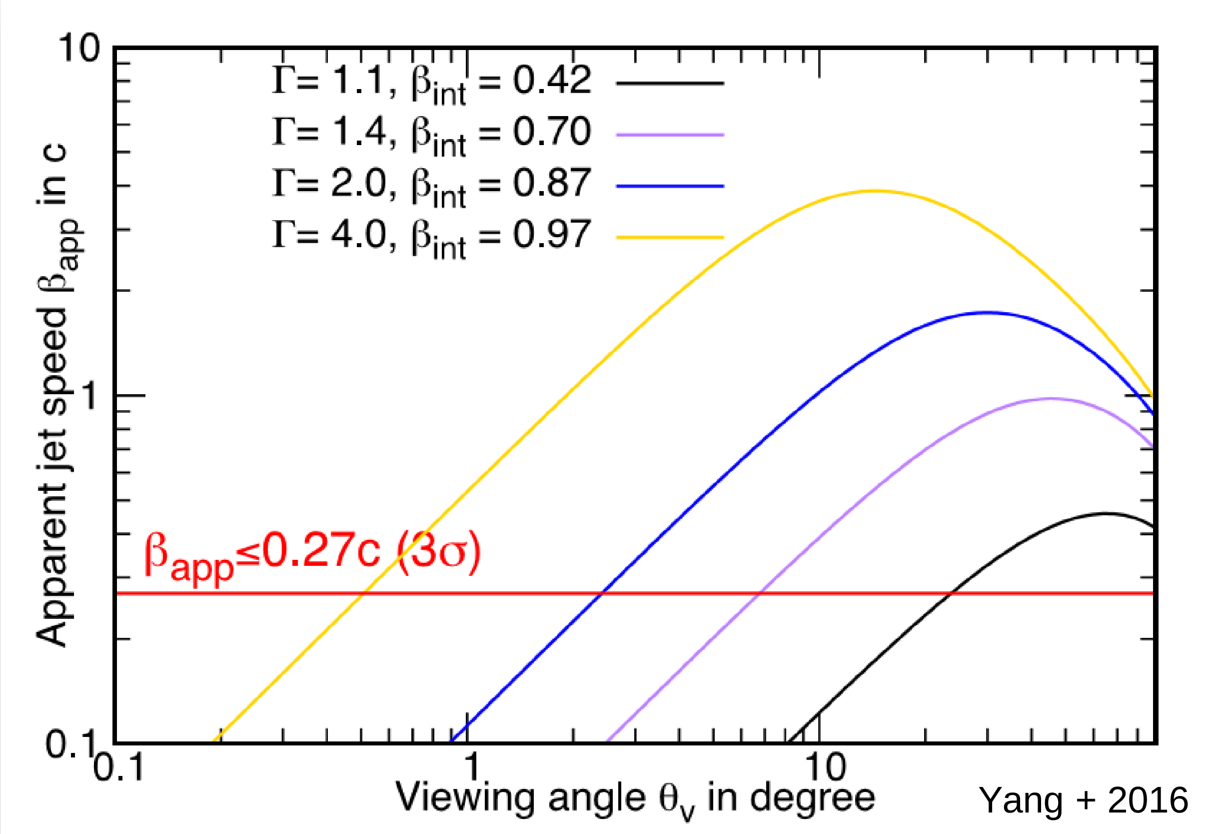


Mimica + 2015

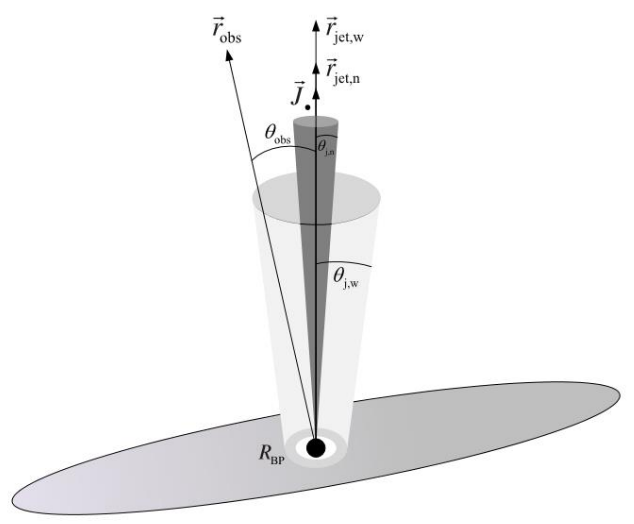
Backup slide 2



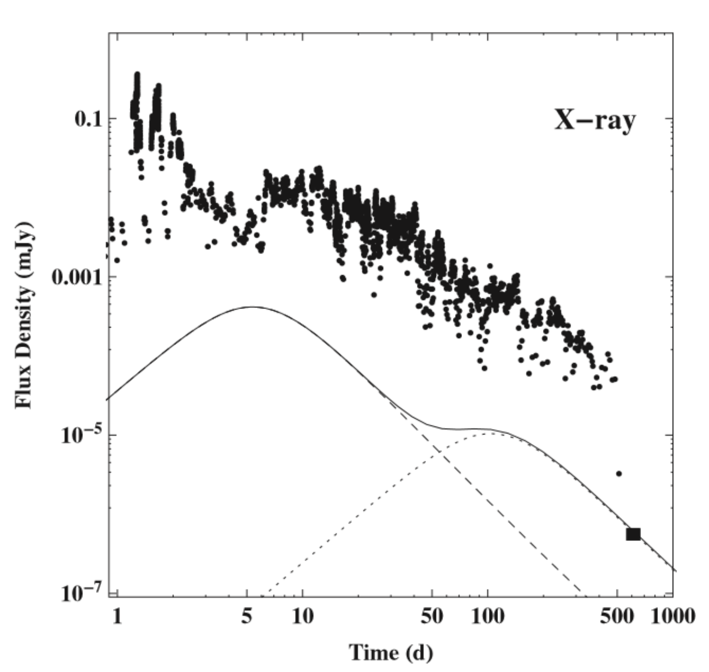
Backup slide 3

Results of Radio Observations Fits

Jet Component	n (cm^{-3})	θ_{obs} (°)	E_{52}	Γ_j	θ_j (°)	p	ϵ_B	ϵ_e
Inner-narrow	0.25	7.0	3.0	5.5	6.0	2.8	0.25	0.2
Outer-wide	0.25	7.0	30.0	2.5	10.0	2.8	0.13	0.15



Wang + 2014



Constraining β: approach 2

- We are assuming that ALL the statistically significant dips are due to jet precession. However, the largest dips need not be the only dips caused by it, as they may have other contamination. In fact, one should look out for smaller dips which may be present throughout the data (as a manifestation of the relentless precession), on which there might be other sources of variability.
- We run a sliding window, with timescales varying from $5 \times 10^4\ s$ to $2.5 \times 10^6\ s$.
- Take only the boxes with ≥ 10 events in it.
- In a given timescale, find the dip (only the statistically significant ones are taken) with maximum fractional amplitude f_{max}
- Now slide the window throughout the data to find out for which window f_{max} becomes minimum. Define this as the minimum variation for that timescale.
- Repeat the same for all the different lengths of sliding window
- We have taken care of the additive effects by choosing the minimum dip. In order to take into account any subtractive effect (flare?), we take the maximum point above the baseline, and add this dispersion to the previously calculated f_{max} value in order to get a more conservative limit on f_{max}
- Compare the f_{max} with the theoretical predictions:

- Maximum angle (ψ_{max}) that the jet subtends from the line of sight (at which some modulation will be visible) is 2β or $(2\beta - 2\theta_{jet})$, depending on which side the line of sight is.
- Depth of the modulation:

$$f_{max} = \frac{F(\psi_{max})}{F(0)} = D^{4-p}$$

- Solve to get the β (can be done analytically) for the considered window length.

Constraining β: approach 2

- The 'duty cycle' of the dips, or the fraction of time the jet is out of sight compared to the total time, puts an independent constraint on β

- Take the f_{max} - selected window from the previous step.
- For each box, set reference point at the midpoint between the maximum and minimum values of the ratios in that box
- Points above this are tabulated as N_{above}, and points below are added in N_{below}

- Define 'Duty Cycle' as: $\mathcal{R}_{obs} = \frac{N_{above}}{N_{below}}$
- Now, we have selected the box with the least fractional amplitude, accounting for the minimum variations in the observed lightcurve.
- For all the other kind of box selections, the larger dips would have lower mid values, and hence higher N_{above}.
- Furthermore even for the same window, as the data is noisy enough, other 'noise' dips also contribute to N_{below}. For a cleaner theoretical data, therefore, N_{below} will lessen.
- So, $\mathcal{R}_{obs}$ is actually the lower limit of the possible 'duty cycles'.

- For all the theoretically calculated scenarios, then $\mathcal{R}_{th} \geq \mathcal{R}_{obs}$
- Then the minimum value of $\mathcal{R}_{th}$ closest to $\mathcal{R}_{obs}$ should give us the required upper limit of β

❖ Note: $\mathcal{R}_{th}$ increases with increasing θ_{jet} and decreasing Γ. As we have already taken the maximum θ_{jet} and minimum Γ allowed, the estimate of β is indeed the upper limit possible in this selection.

Point-like jet:

$$F(\psi, t) = D^{4-p+\alpha} F(0, t)$$

where $D = \frac{1-B}{1-B\cos(\psi)}$ **and** $B = \sqrt{1-\frac{1}{\Gamma^2}}$

In General:

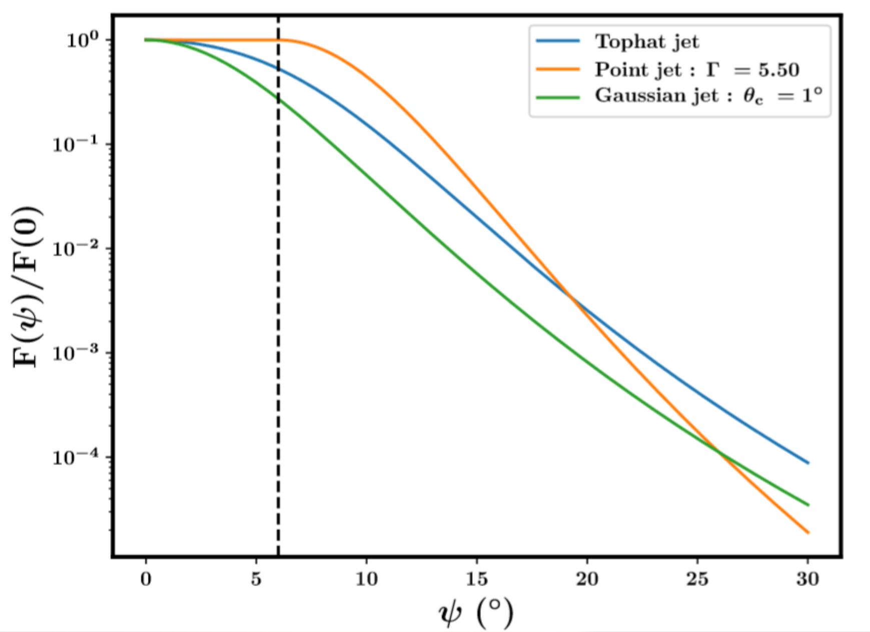
$$\frac{F(\psi)}{F(0)} = \frac{\int_0^{2\pi}\int_0^{\pi/2} \frac{\epsilon(\theta)\sin\theta d\theta d\phi}{[1-B(\cos\theta\cos\psi+\sin\theta\sin\phi\sin\psi)]^{3+\alpha(\theta)}}}{\int_0^{2\pi}\int_0^{\pi/2} \frac{\epsilon(\theta)\sin\theta d\theta d\phi}{[1-B\cos\theta]^{3+\alpha(0)}}}$$

Top-hat jet:

$$\epsilon(\theta) = \begin{cases} 1, & \textbf{for } \theta \le \theta_{jet} \\ 0, & \textbf{for } \theta > \theta_{jet} \end{cases}$$

Gaussian jet:

$$\epsilon(\theta) \propto e^{-(\theta/\theta_c)^2}$$



On 28th March, 2011.........

Komossa 2015

main properties of SwiftJ1644+57

- discovered with *Swift BAT* in March 2011; no detection before March 25
- $L_{x,isotropic} = 10^{45} - 4\ 10^{48}$ erg/s
- lightcurve overally declining, plus rapid variability,up to $\Delta t \sim 100$s
- optically inactive host at $z_{host} = 0.35$
- mass estimates: $M_{BH} <$ few x10^6 M_{sun}
- unresolved, variable, beamed radio emission
- sudden drop in X-rays after ~1.5 yr not seen in the radio