Constraints on the population of off-axis short gamma-ray bursts

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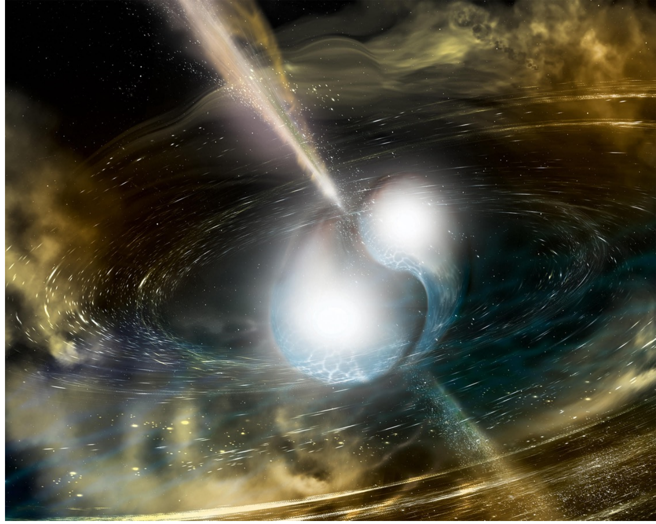
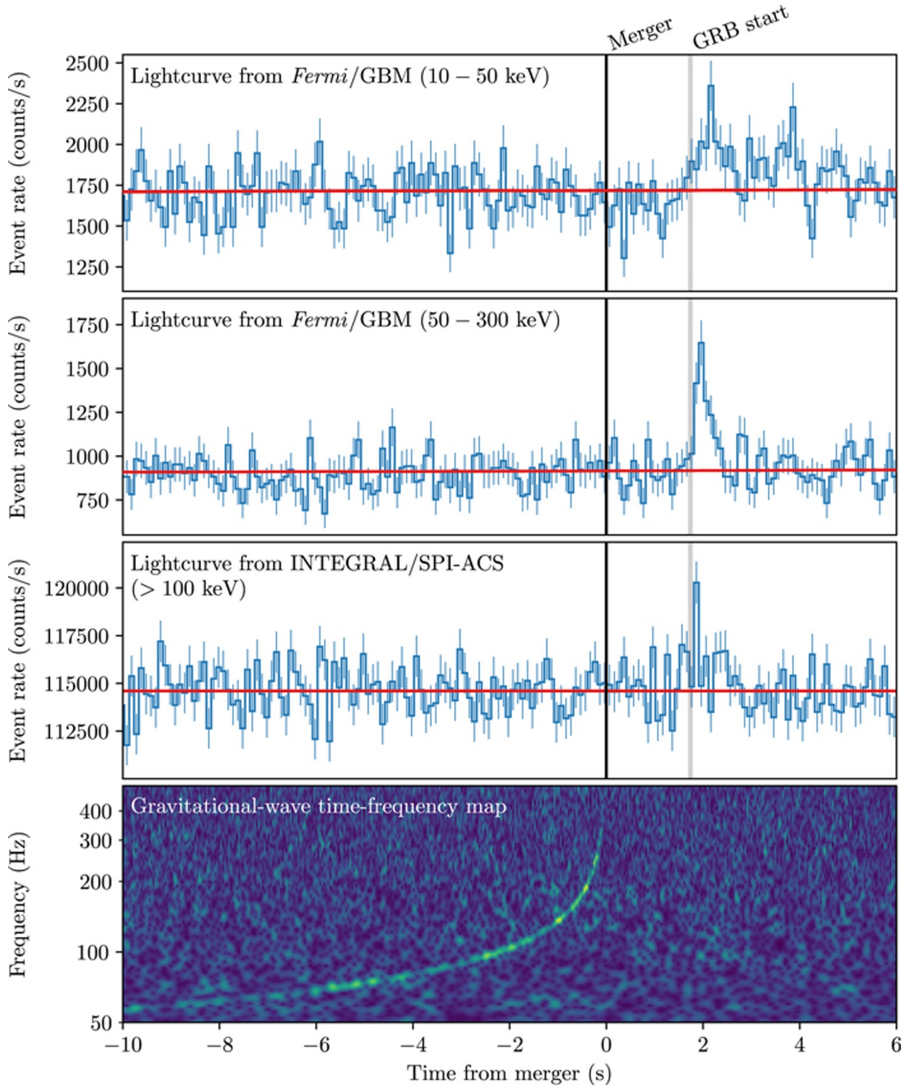
Short Gamma-ray Bursts (sGRBs)





Abbott et al. 2017

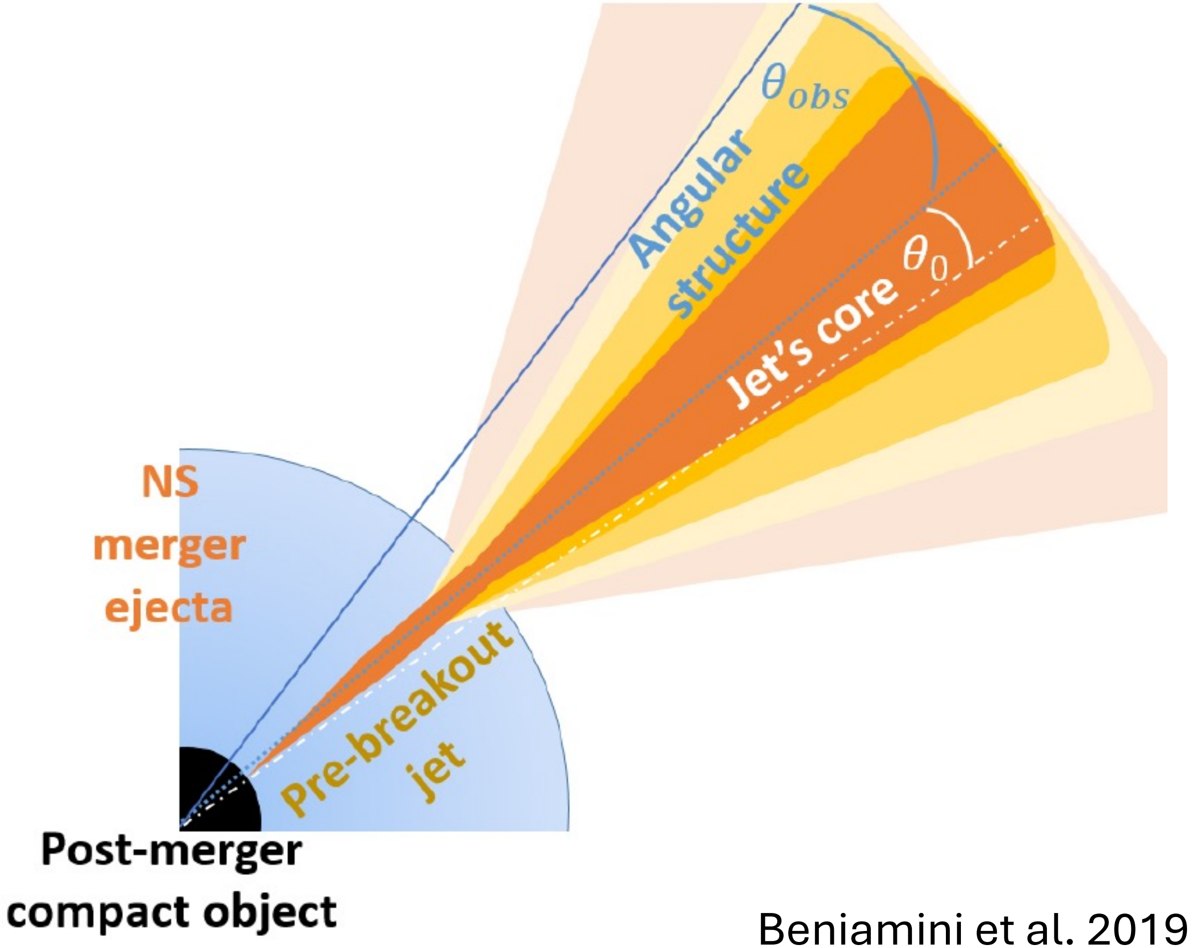
- Prompt gamma-ray duration of < 2 s
- Neutron star mergers are confirmed as a progenitor pathway (GW170817)

- **Afterglow emission** from interaction of relativistic jet with environment
- Jet is initially coasting and decelerates when enough material piles up

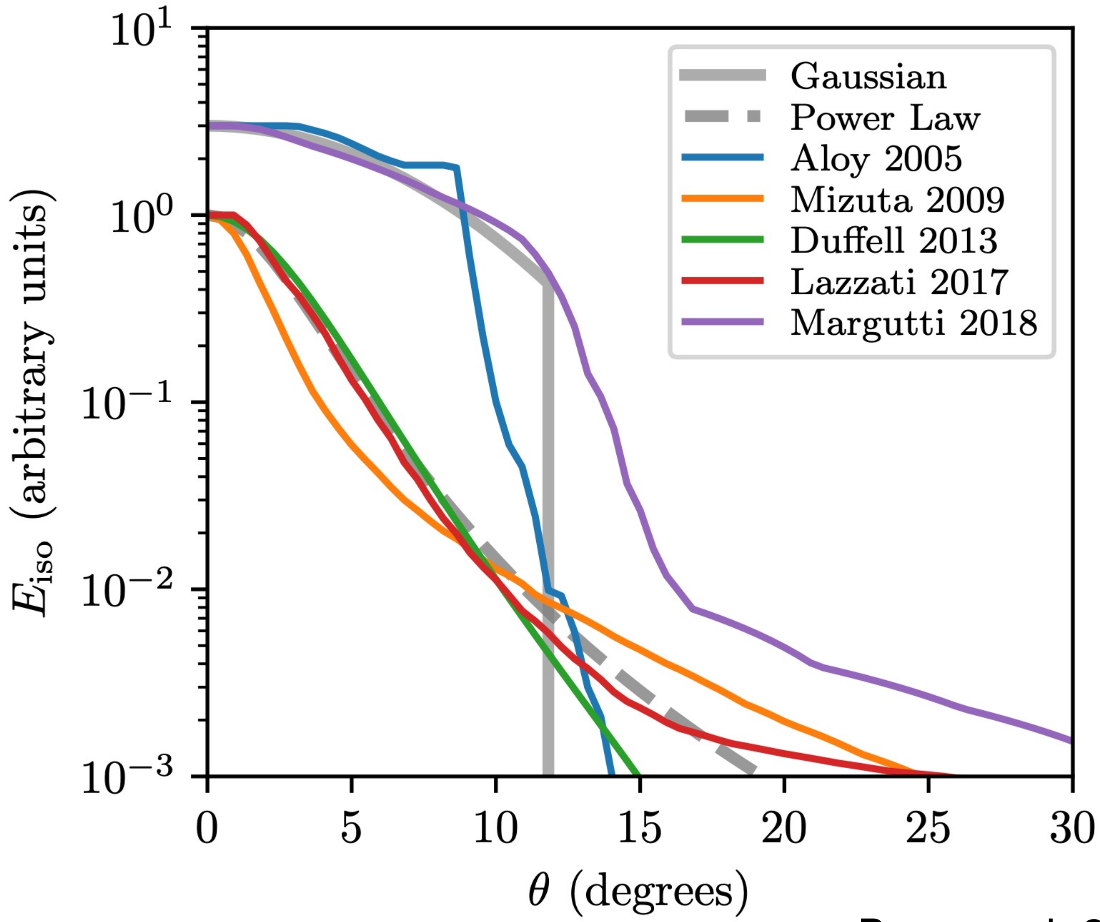
GRB Jet Structure

See previous talk by Paz Beniamini!

- GRB jet's have a structure in both **energy** and **Lorentz factor**
- The structure and viewing angle impacts the observed lightcurve
- We consider both **tophat** jets and **power-law** structured jets



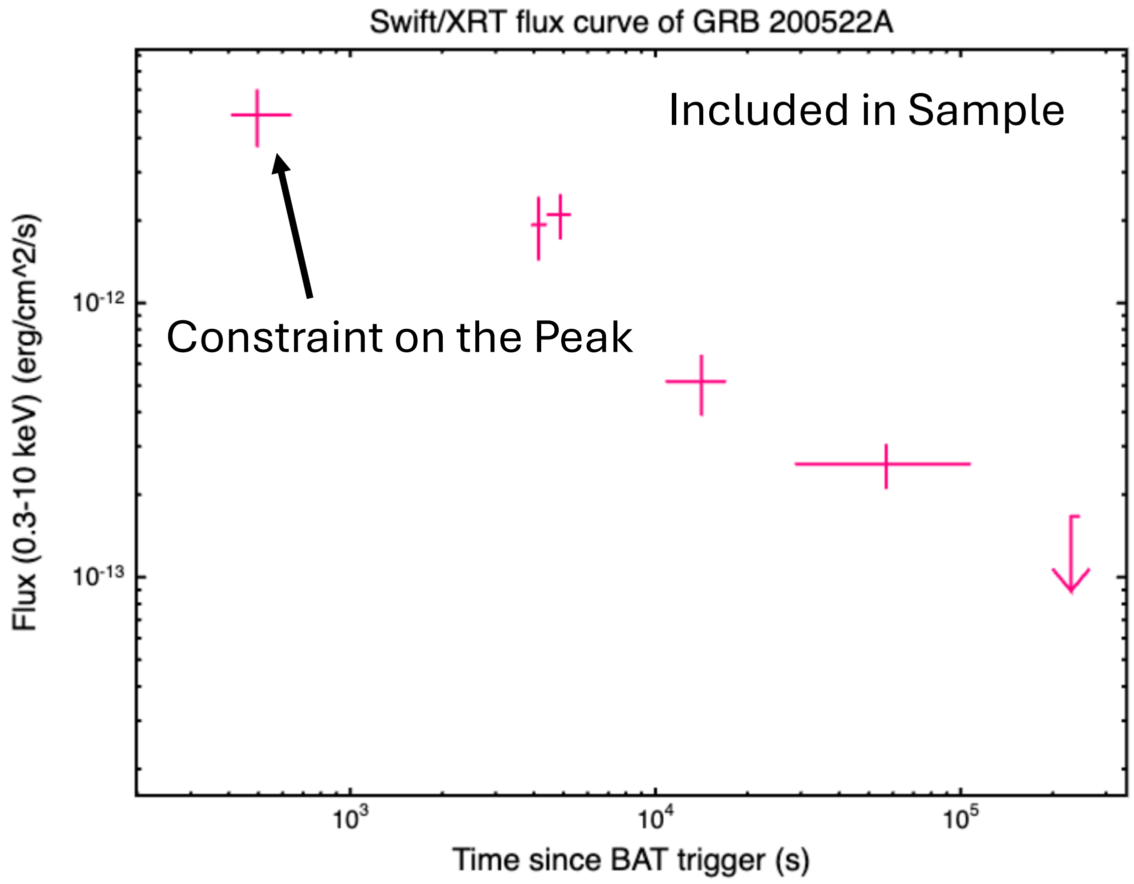
Beniamini et al. 2019

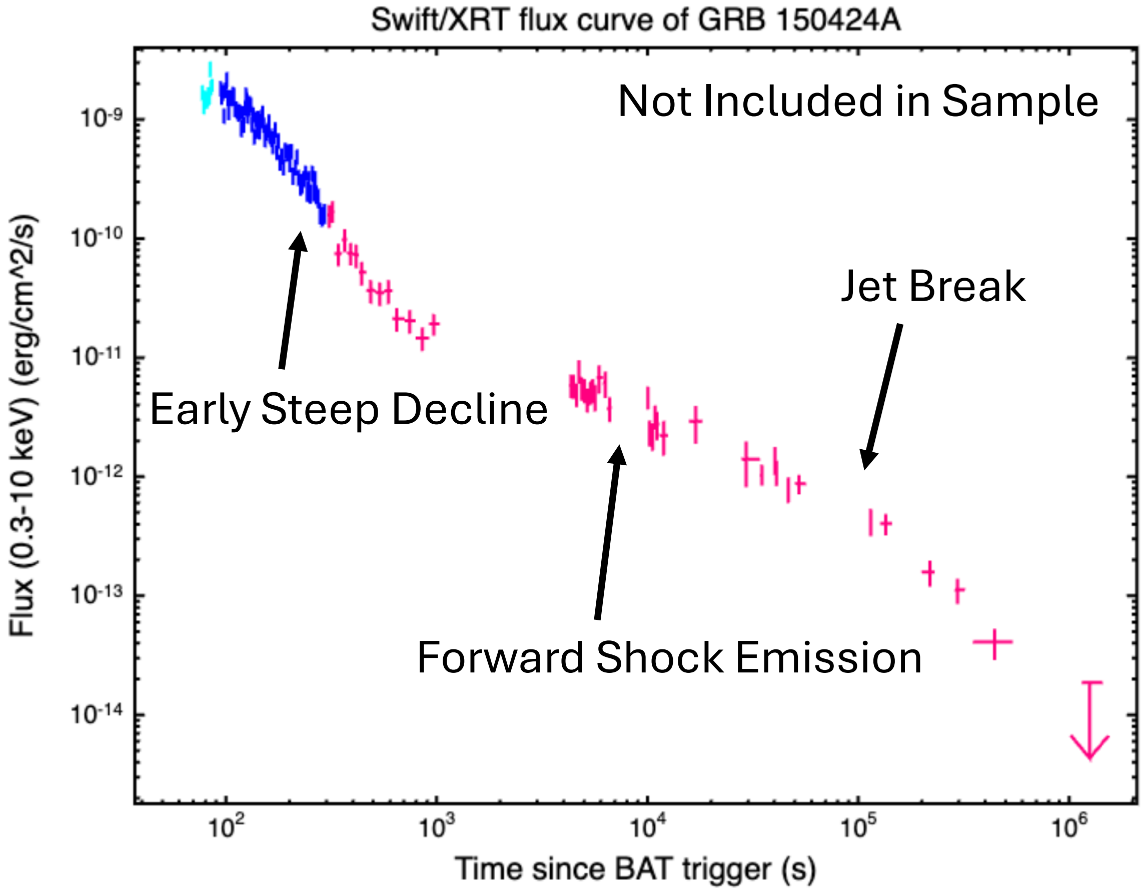


Ryan et al. 2020

Sample Selection

- Sample of 58 short GRBs detected by the *Swift Observatory* (30 with redshift)
- Use **upper limit** on *peak time* and **lower limit** on *peak X-ray flux* for each sGRB





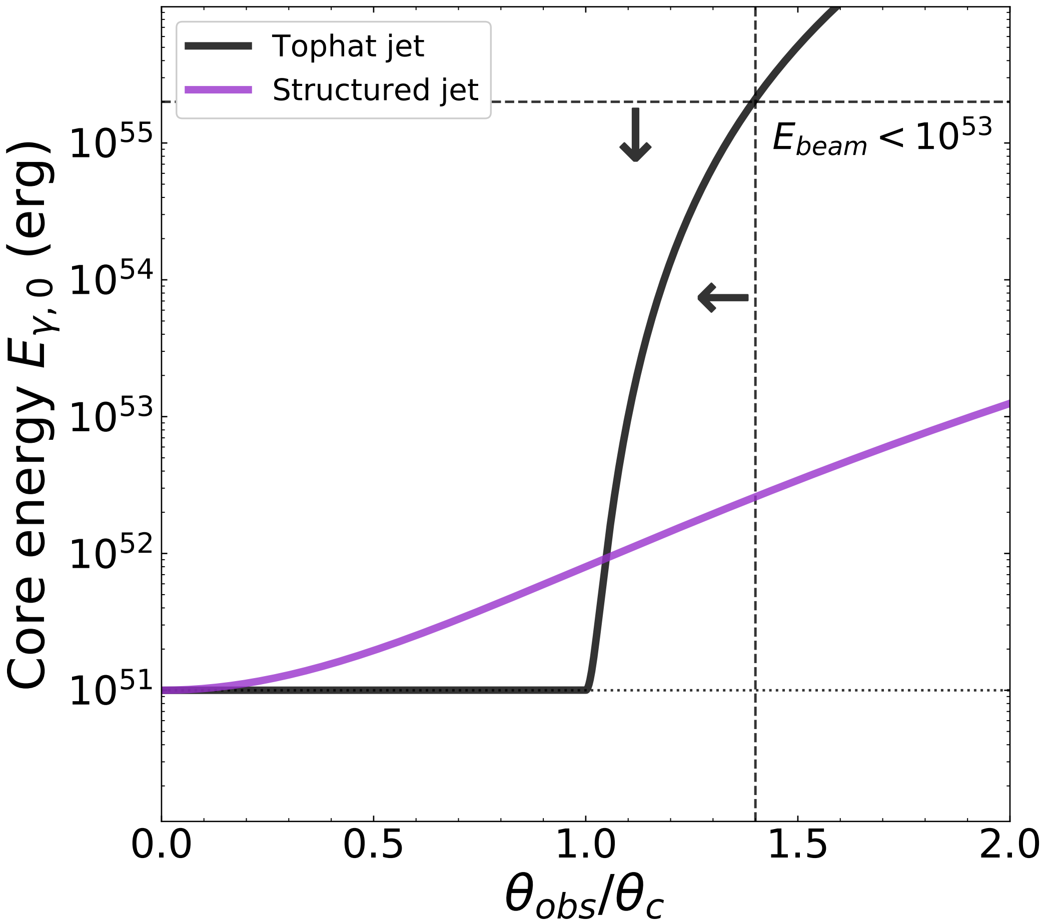
See also O'Connor et al. 2020

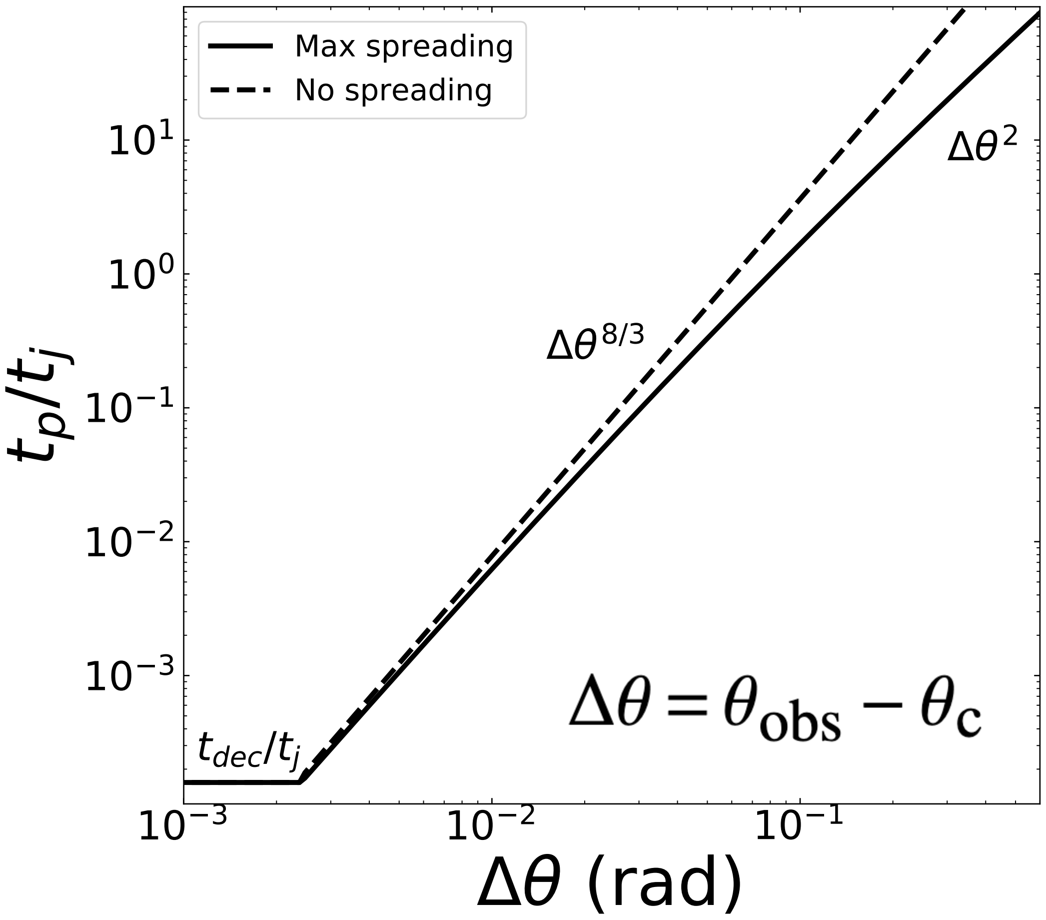
O'Connor, Beniamini, Gill 2024

Tophat Jets

$$E_{\gamma,0} = E_{\gamma,\mathrm{obs}} \begin{cases} 1 & \theta_{\mathrm{obs}} \leqslant \theta_{\mathrm{c}}, \\ q^4 & \theta_{\mathrm{c}} < \theta_{\mathrm{obs}} \leqslant 2\theta_{\mathrm{c}}, \\ q^6(\theta_{\mathrm{c}}\Gamma_0)^{-2} & 2\theta_{\mathrm{c}} < \theta_{\mathrm{obs}}, \end{cases}$$

- An off-axis jet has a **later peak time**
- Constrain viewing angle for our sample based on the time of the first X-ray detection





e.g. Kasliwal et al. 2017, Ioka & Nakamura 2018

Chand et al. in prep.

Constraints for tophat jets

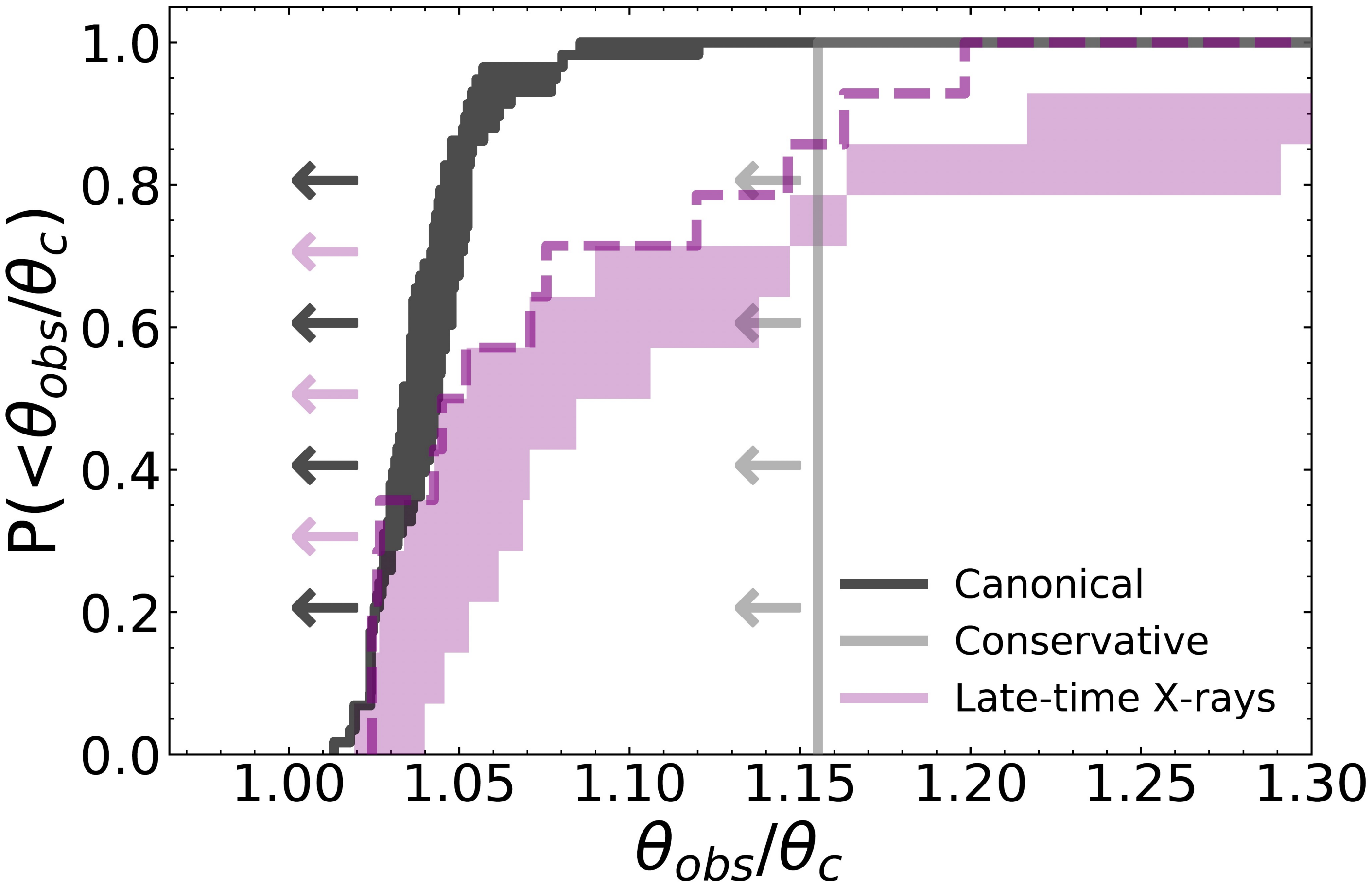
- Test a range of afterglow parameters (e.g., density, Lorentz factor)
- If their jets are tophats short GRBs can **not be viewed far off-axis** $\theta_{obs}/\ \theta_c \leq 1.2$

Label	θ_c (rad)	Γ_0	n (cm^{-3})
Canonical	0.1	300	10^{-2}
Conservative	0.05	100	10^{-1}

High density is more conservative

- Events with a jet break yield independent constraint
(Rouco Escorial et al. 2022; purple region)

$$\theta_{\rm obs}/\theta_{\rm c} \lesssim 1 + (t_{\rm o}/t_{\rm j})^{3/8}$$

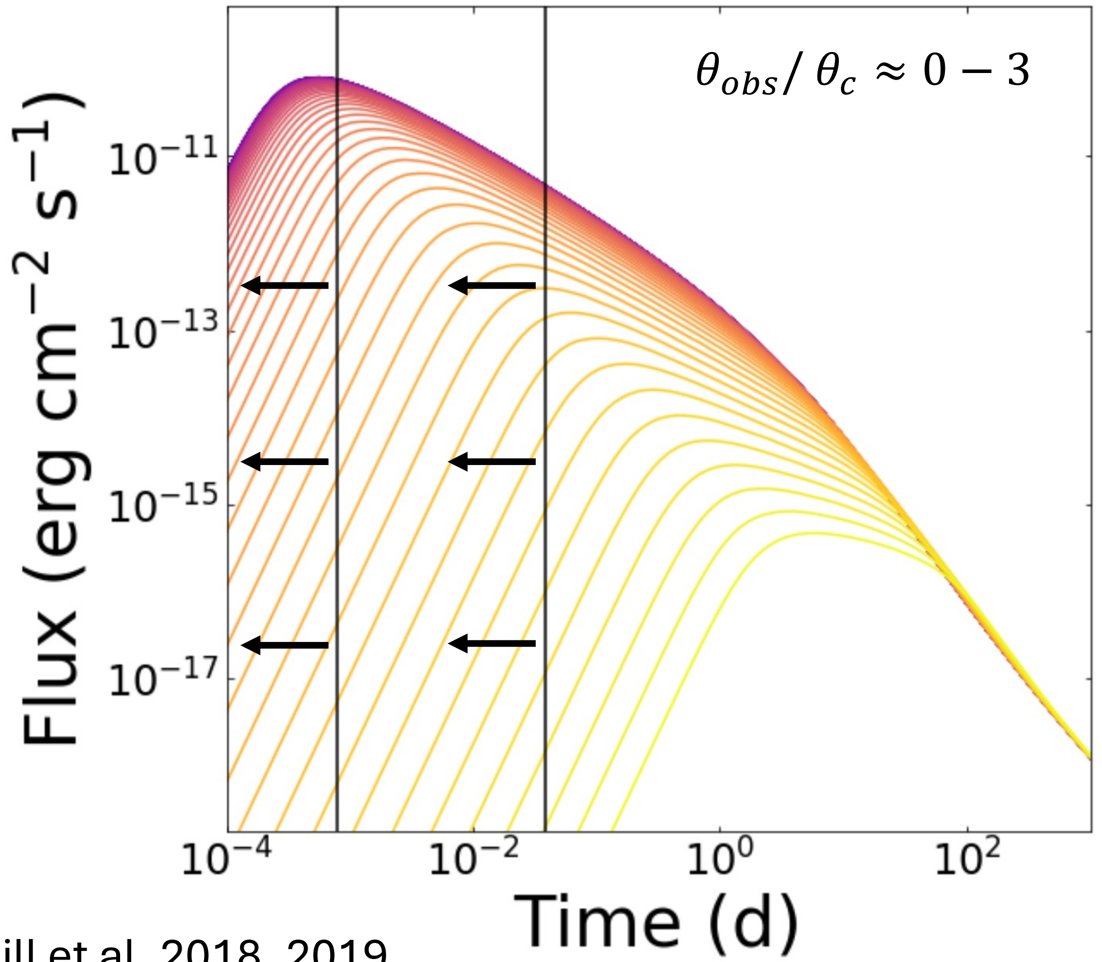


O'Connor, Beniamini, Gill 2024

Structured Jets

$$\frac{\varepsilon(\theta)}{\varepsilon_c} = \Theta^{-a}, \qquad \frac{\Gamma(\theta)-1}{\Gamma_0 - 1} = \Theta^{-b}, \qquad \Theta \equiv \sqrt{1+\left(\frac{\theta}{\theta_c}\right)^2}$$

- Consider power-law structured jets based on numerical simulations (e.g., Lazzati et al. 2017, Nativi et al. 2021, Gottlieb et al. 2021)
- Deceleration of line-of-sight material dominates at early times



Gill et al. 2018, 2019

- **Increasing viewing angle leads to later peak times at lower fluxes**
- We apply observed limits to determine the max viewing angle
- Use analytical equations calibrated to numerical lightcurves (Gill et al. 2018, 2019)

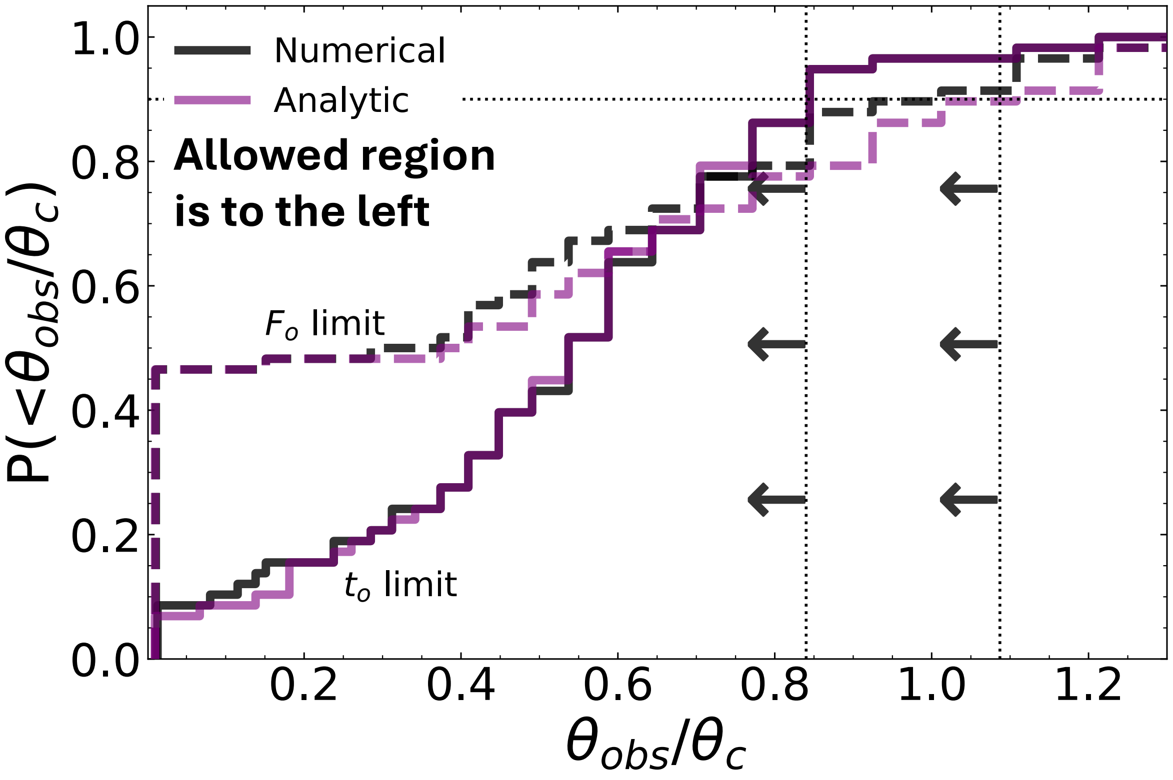
Label	a_{kin}	b
Canonical	3	4
Conservative	4	2

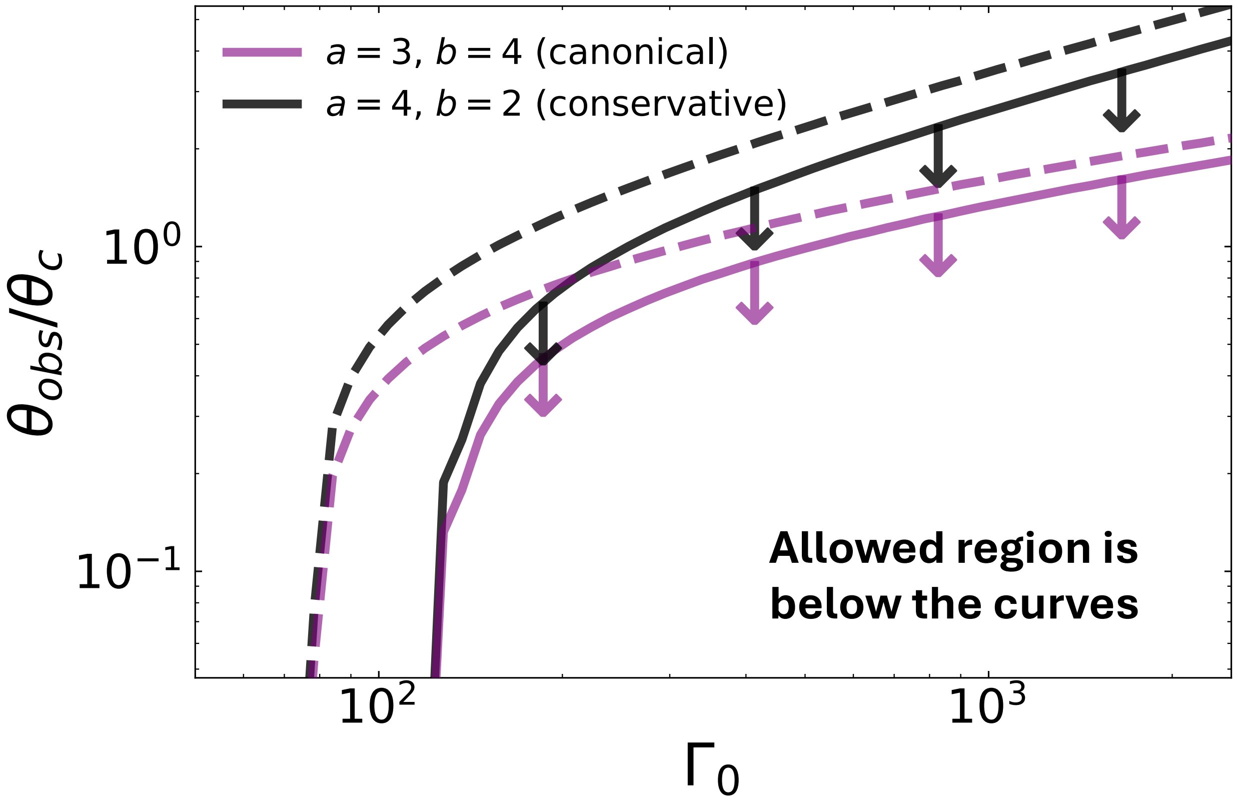
Structure from numerical simulations
e.g. Lazzati et al. 2017, Gottlieb et al. 2021

See also Beniamini et al. 2020, 2022

Constraints for structured jets

- Either our sample is viewed within the core of their jets, or their Lorentz factors are very fast ($\Gamma_0 > 200 - 500$)
- Shallow Lorentz factor profiles are less constraining





O'Connor, Beniamini, Gill 2024

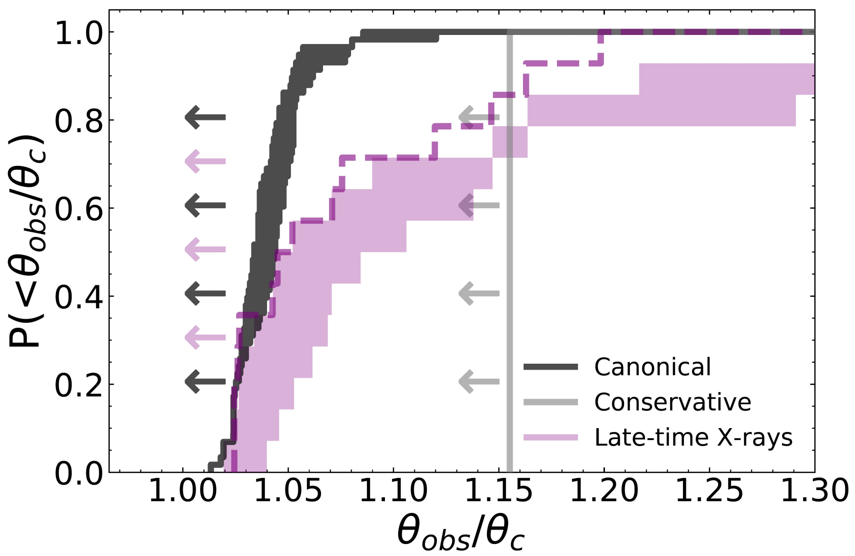
Summary

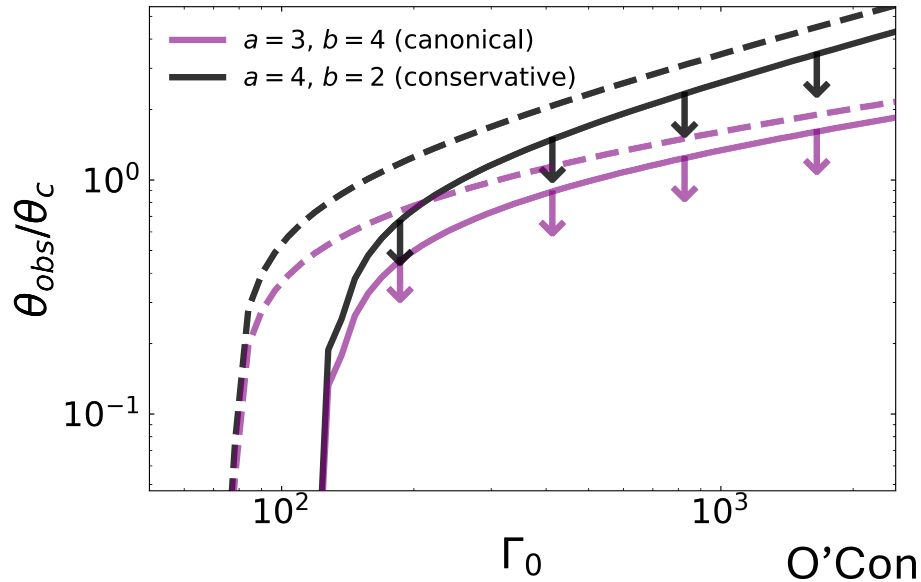
See previous talk by Paz Beniamini!

- For **tophat** jets short GRBs must be viewed within $\theta_{obs}/\ \theta_c \leq 1.2$

- For **structured** jets short GRBs must be viewed close to the jet's core, or the initial Lorentz factor is very fast ($\Gamma_0 > 200 - 500$)

- **Cosmological GRBs are not viewed far off-axis**





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The Peculiar Einstein Probe Transient EP240408a

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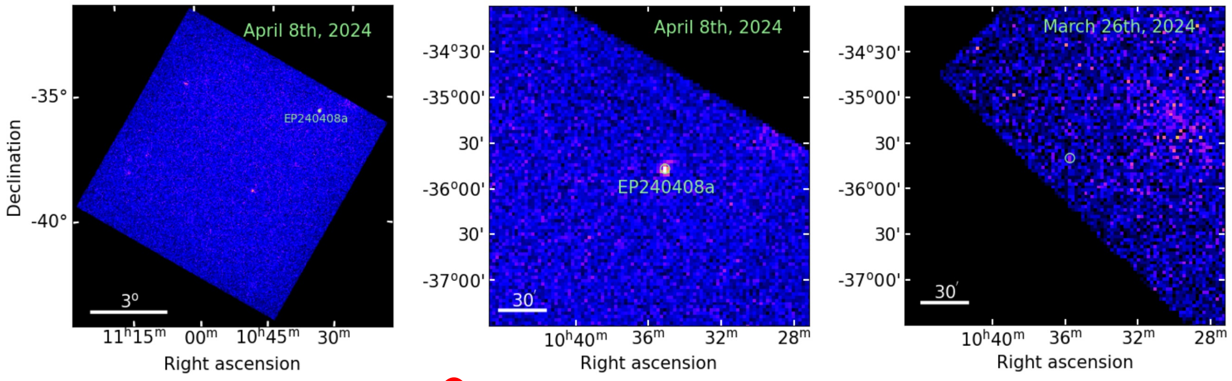
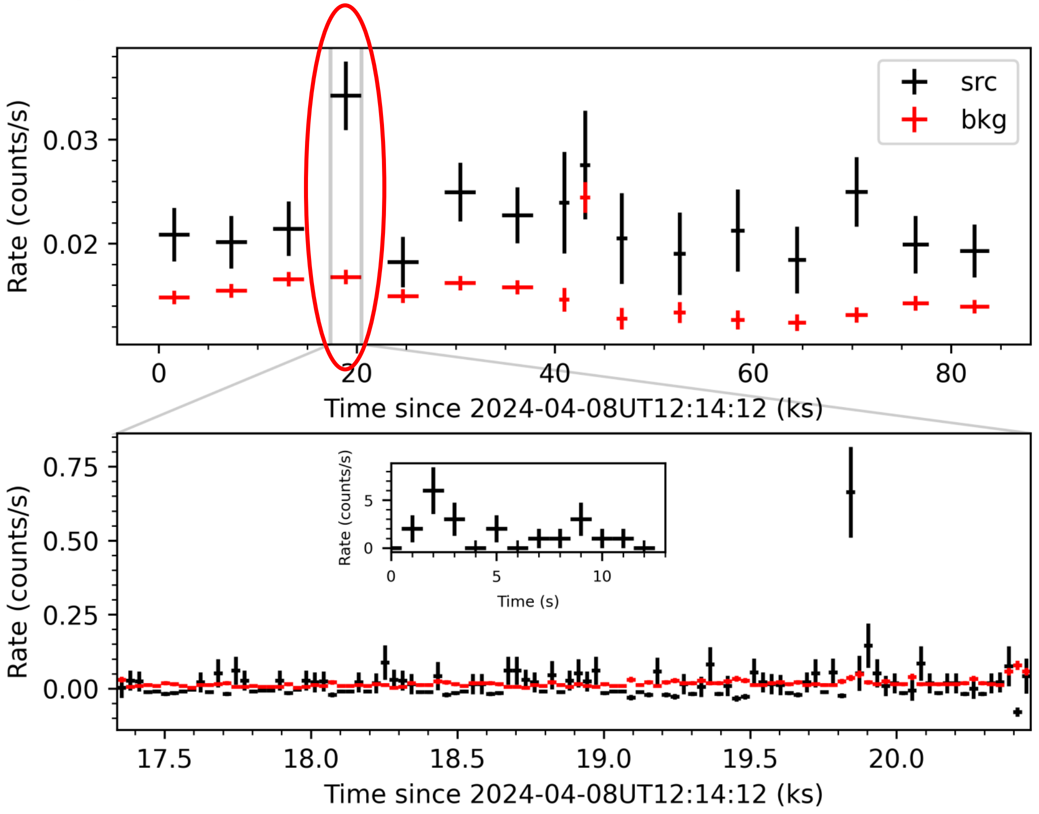
Dheeraj Pasham (*MIT*), ***Igor Andreoni*** (*UNC*), Jeremy Hare (*GSFC*), ***Paz Beniamini*** (*Open University*), et al. (*Submitted to ApJL*)

EP240408a





Credit: ESA

Profiles of the WXT and FXT

	WXT	FXT
X-ray optics	Lobster-eye MPO	Wolter-I
Detector	CMOS	pnCCD
Effective area	~3cm ^{2} @1keV	300cm ^{2} @1.5keV (each)
FoV	~3600 deg ^{2}	~60 arcmin
Angular resolution	~5 arcmin	~20 arcsec HEW @1.5keV
Bandpass	0.5-4 keV	0.3-10 keV

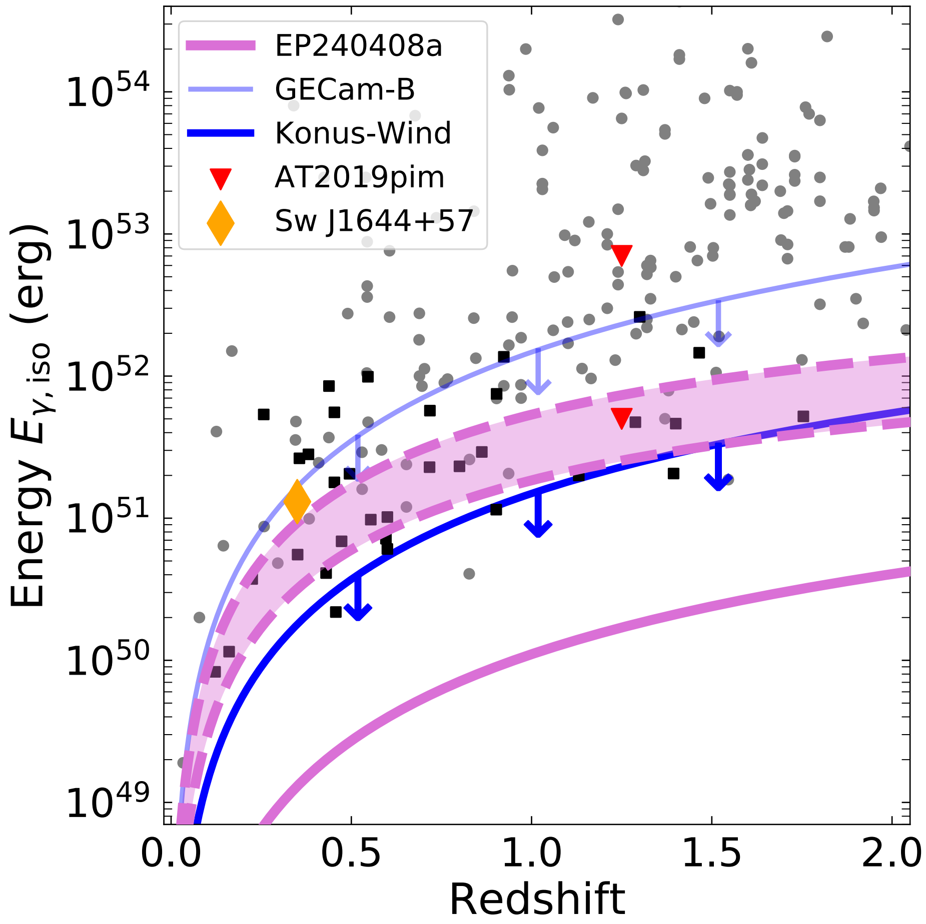
- Detected by EP/WXT as ~10 s trigger.
  - Very bright – peak flux 4e-9 erg/cm^2/s
- **Zhang+2024 report persistent X-ray emission before and after trigger.**
  - Unlikely to be a GRB based on this.
- Not detected ~13 days prior
  - No constraints in that window.
- **No redshift has been identified.**

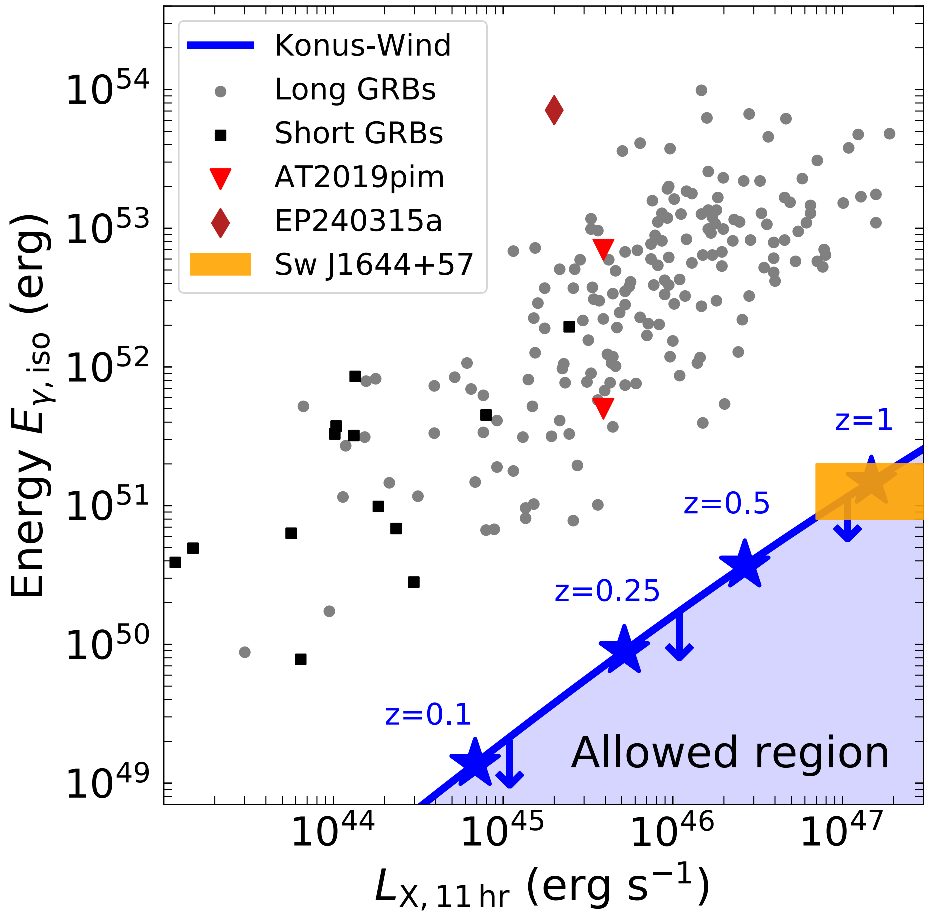
See Zhang, EP Team, et al. 2024

Prompt Gamma-ray Constraints

Gamma-ray limits thanks to Dmitry Svinkin & Jimmy DeLaunay

- **No gamma-ray counterpart.** Not detected by GECam-B, Konus-Wind, and Swift. *Konus-Wind is the most sensitive limit*, as out of BAT field of view.





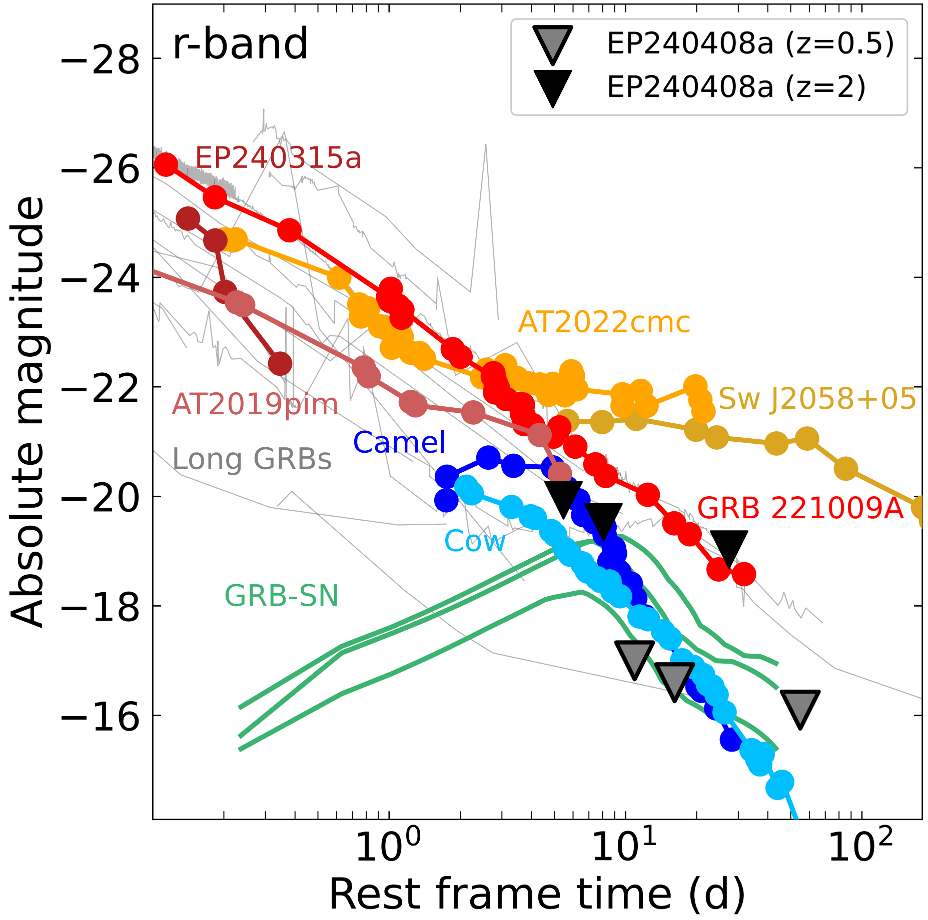
Unlikely to be a gamma-ray burst (GRB), even if off-axis.

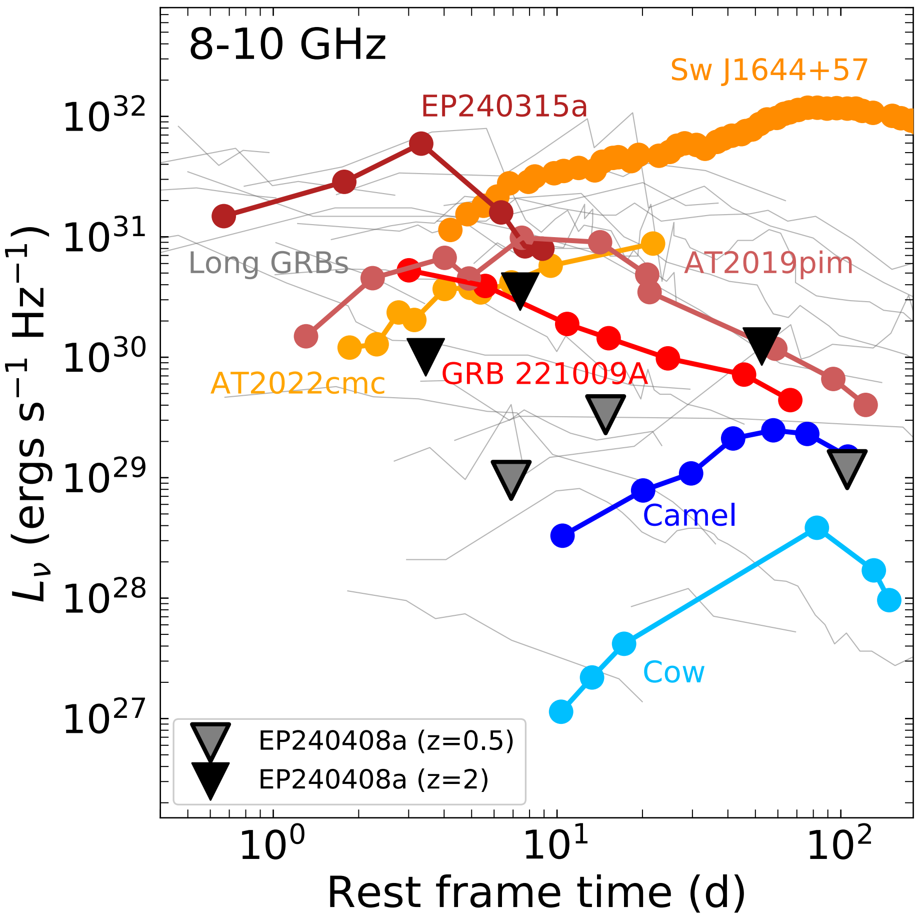
See O'Connor, Pasham, Andreoni, et al. 2024

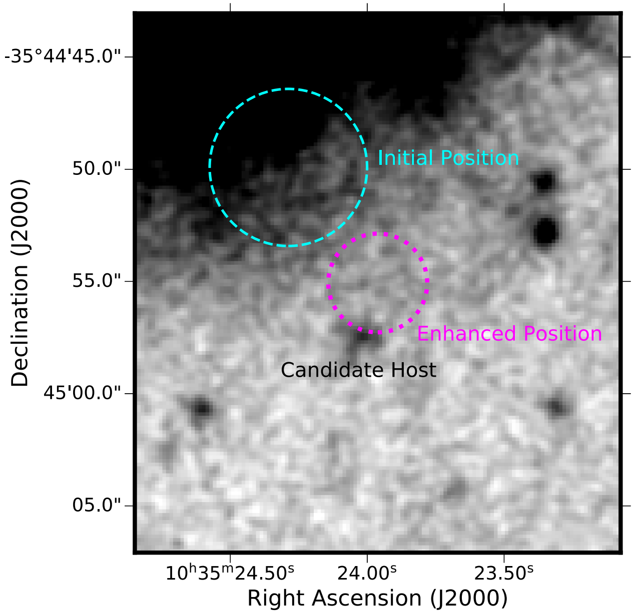
Multi-wavelength Follow-up

See also Igor Andreoni's talk on Friday!

- **Gemini, VLA, ATCA yielded deep upper limits.**
- Gemini uncovered a faint candidate host galaxy; *no redshift* has been acquired.





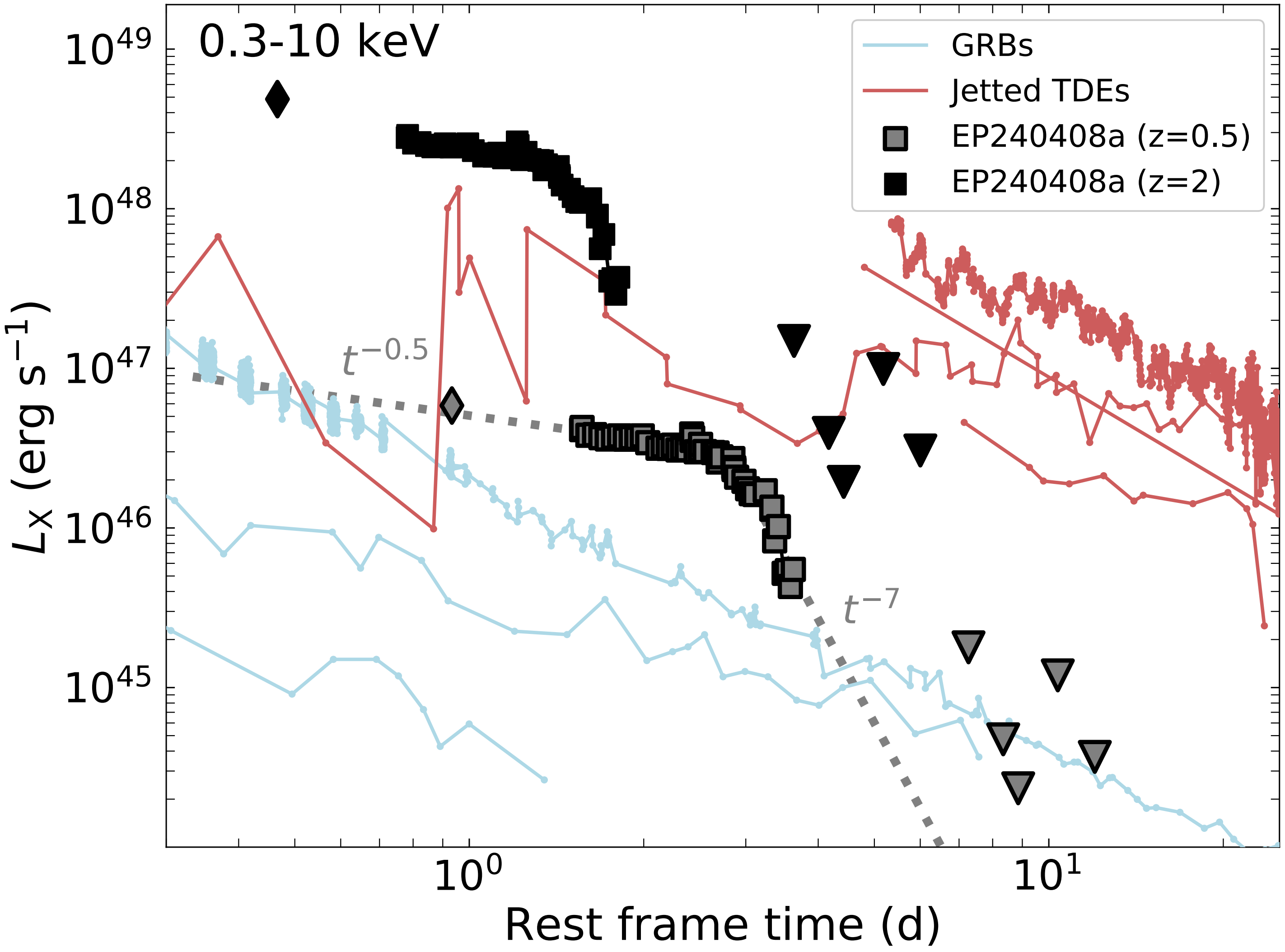


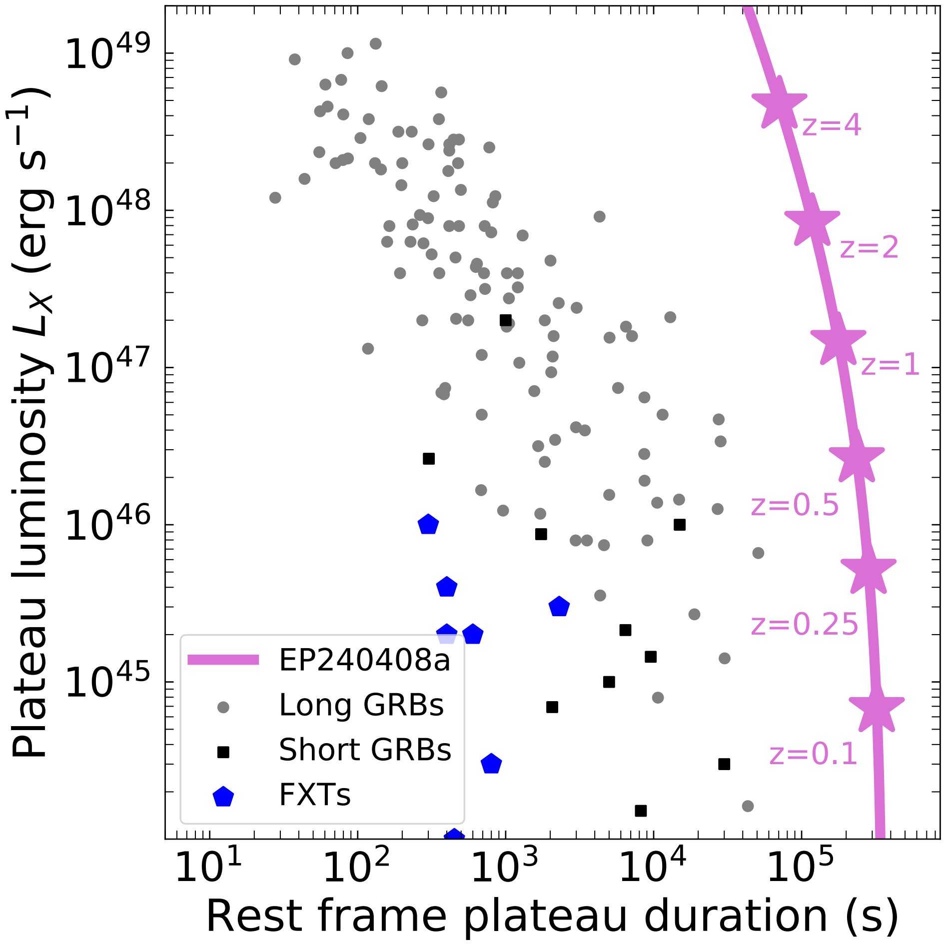
See O'Connor, Pasham, Andreoni, et al. 2024

X-ray Follow-up

See also Igor Andreoni's talk on Friday!

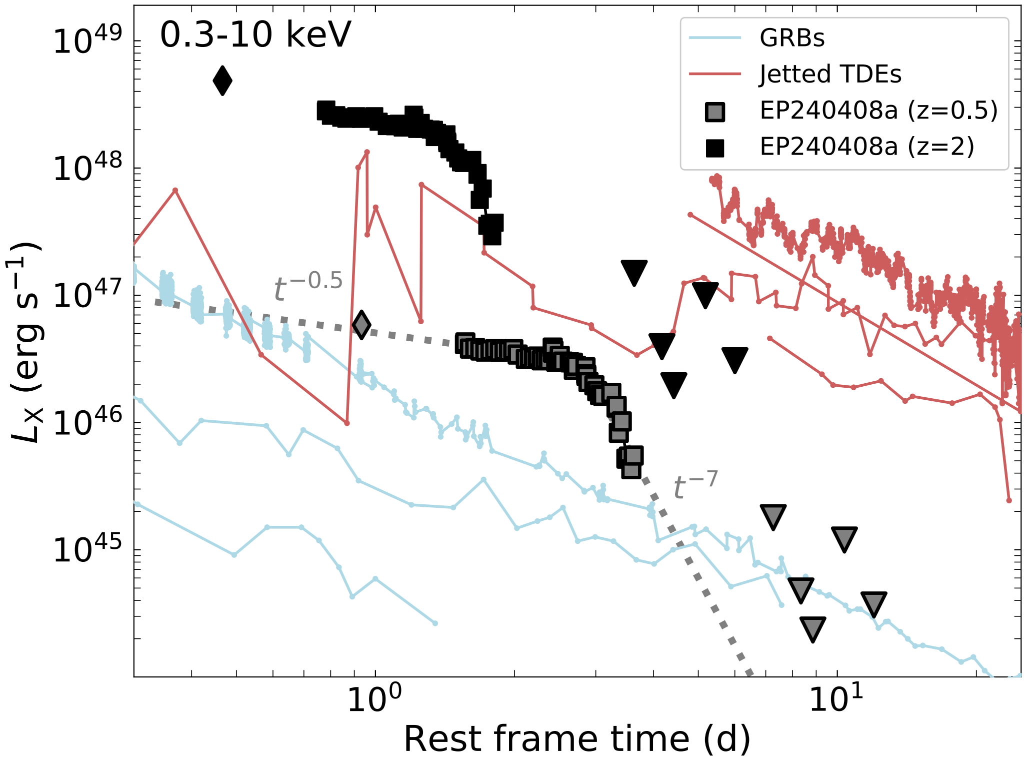
- **Swift provided localization. NICER monitoring revealed long-lived transient.**
- *X-ray lightcurve unlike other high energy transients (e.g., GRBs, TDEs).*





See O'Connor, Pasham, Andreoni, et al. 2024

Possible Interpretations

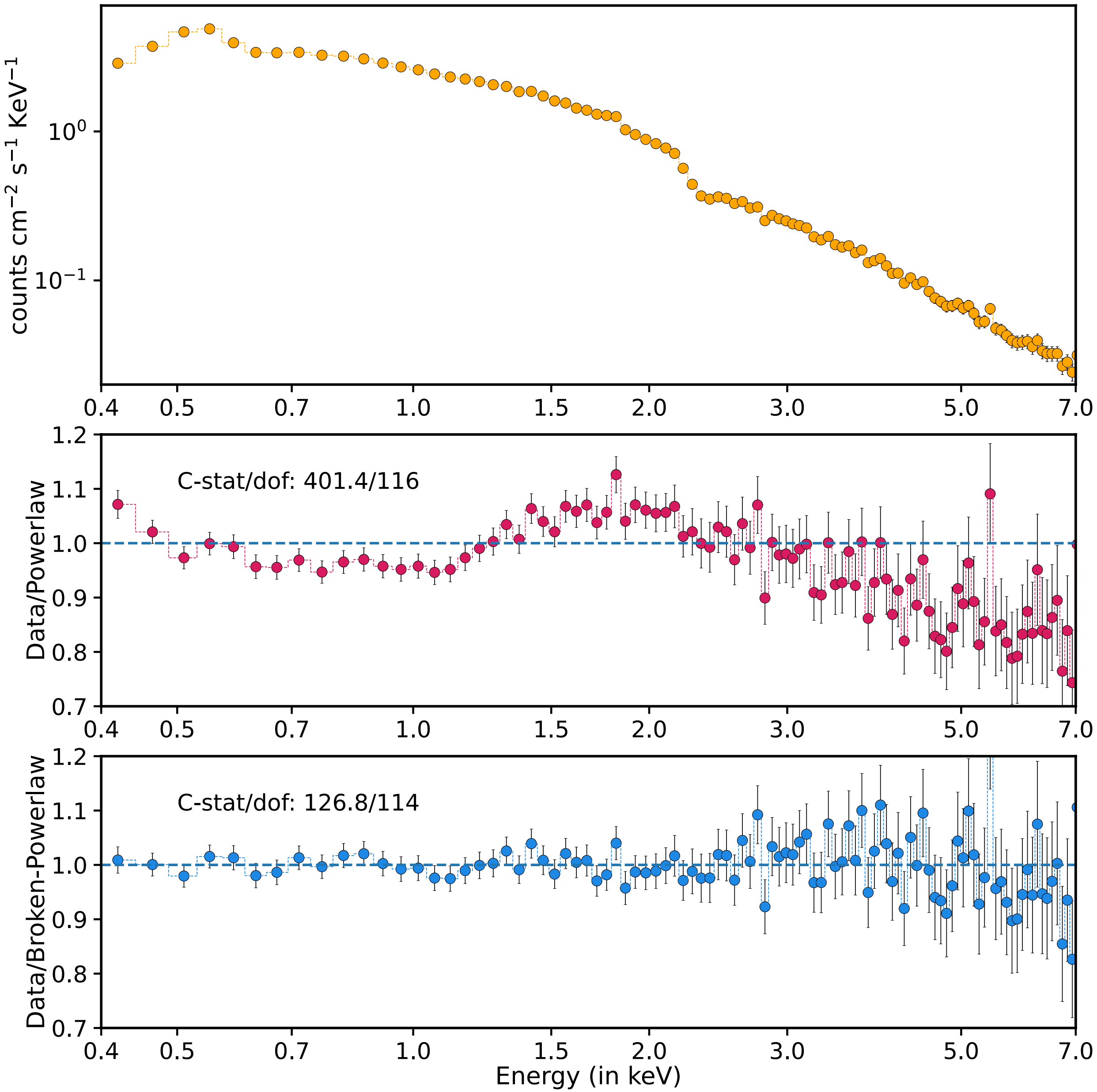


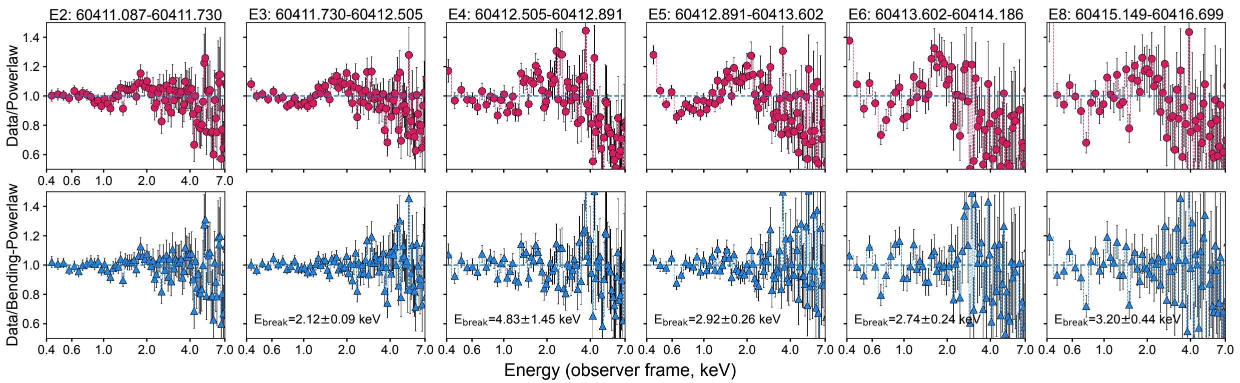
- **A new class of X-ray transient?**
- We exclude:
  - Low redshift transients ($z < 0.5$)
    - e.g., lack of low-*z* host or bright optical/radio emission
  - Galactic X-ray transients (e.g., CVs, HMXBs, LMXBs)
  - Fast Blue Optical Transients (FBOTs)
  - Fast X-ray Transients (FXTs)
- Unlike any known Gamma-ray burst
  - e.g., lack of gamma-rays, plateau duration, persistent emission prior to trigger (Zhang+24)
- **Closest to relativistic jetted Tidal Disruption Events (TDEs) at $z > 1$**
  - Lack of optical/infrared may be intrinsic dust (*no Galactic dust*)
  - Lack of luminous radio may be explained by delayed deceleration of the jet
  - Likely a nearly on-axis jet with a narrow core, to explain the required Eddington ratios
  - *Potentially caused by disruption of a* ***White Dwarf by an Intermediate Mass Black Hole***
  - ***Onset of disruption may have been up to 13 days prior to trigger.***

- **Future observations of similar transients are critical to determine its nature.**


Thank you!

EP240408a NICER X-ray Spectra



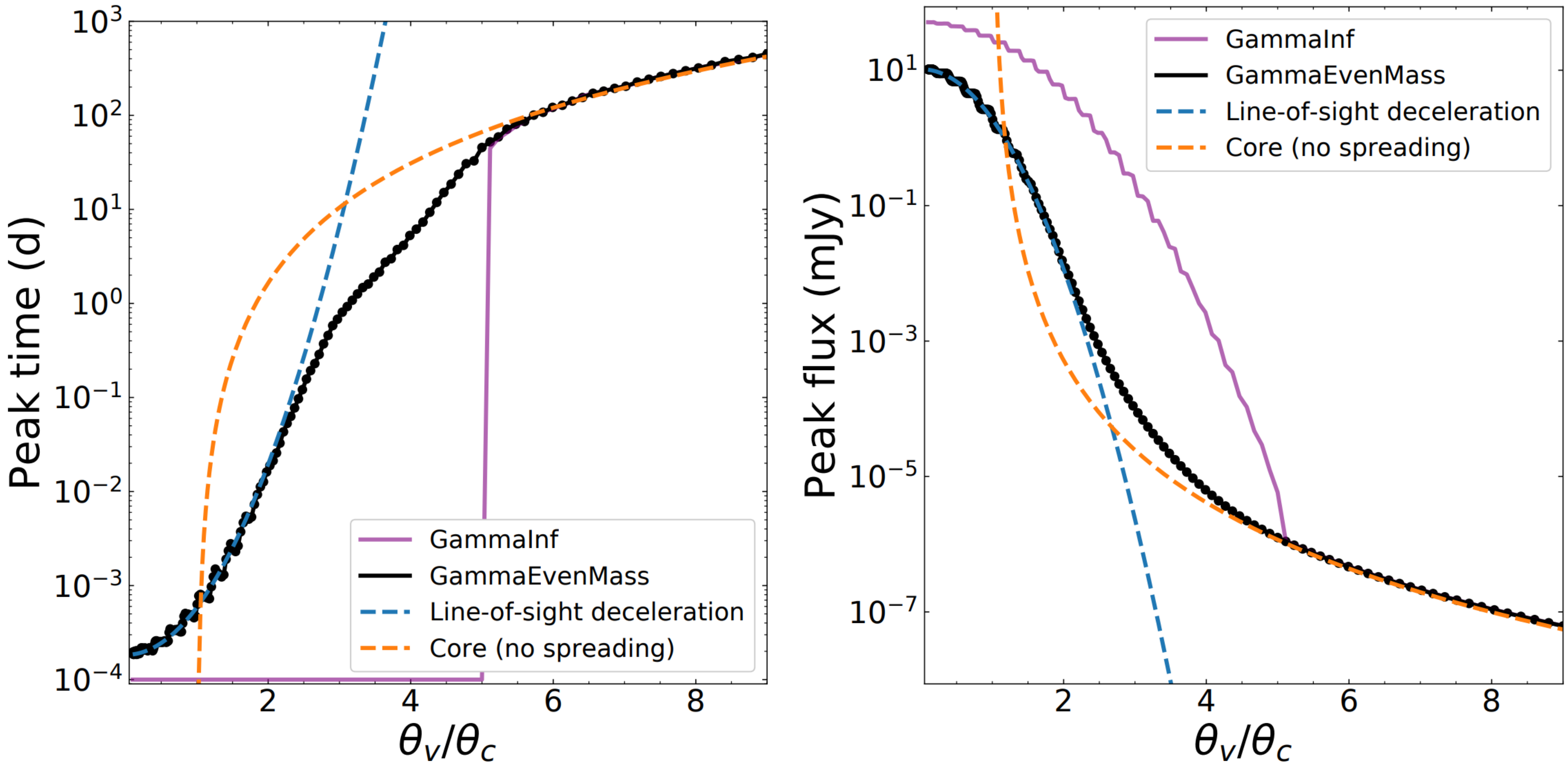


- NICER spectra reveal broken power-law in some epochs.
- Spectral break at ~4 keV in the observer frame.
- Significant Hydrogen column density, implies optical extinction

See O'Connor, Pasham, Andreoni, et al. 2024

Evolution of Peak time and Peak Flux

- Peak time/peak flux as computed with ***Afterglowpy*** (Ryan+20) applying a Gaussian angular profile for both **energy** and **Lorentz factor**



See Kaur, O'Connor, Palmese, et al. 2024