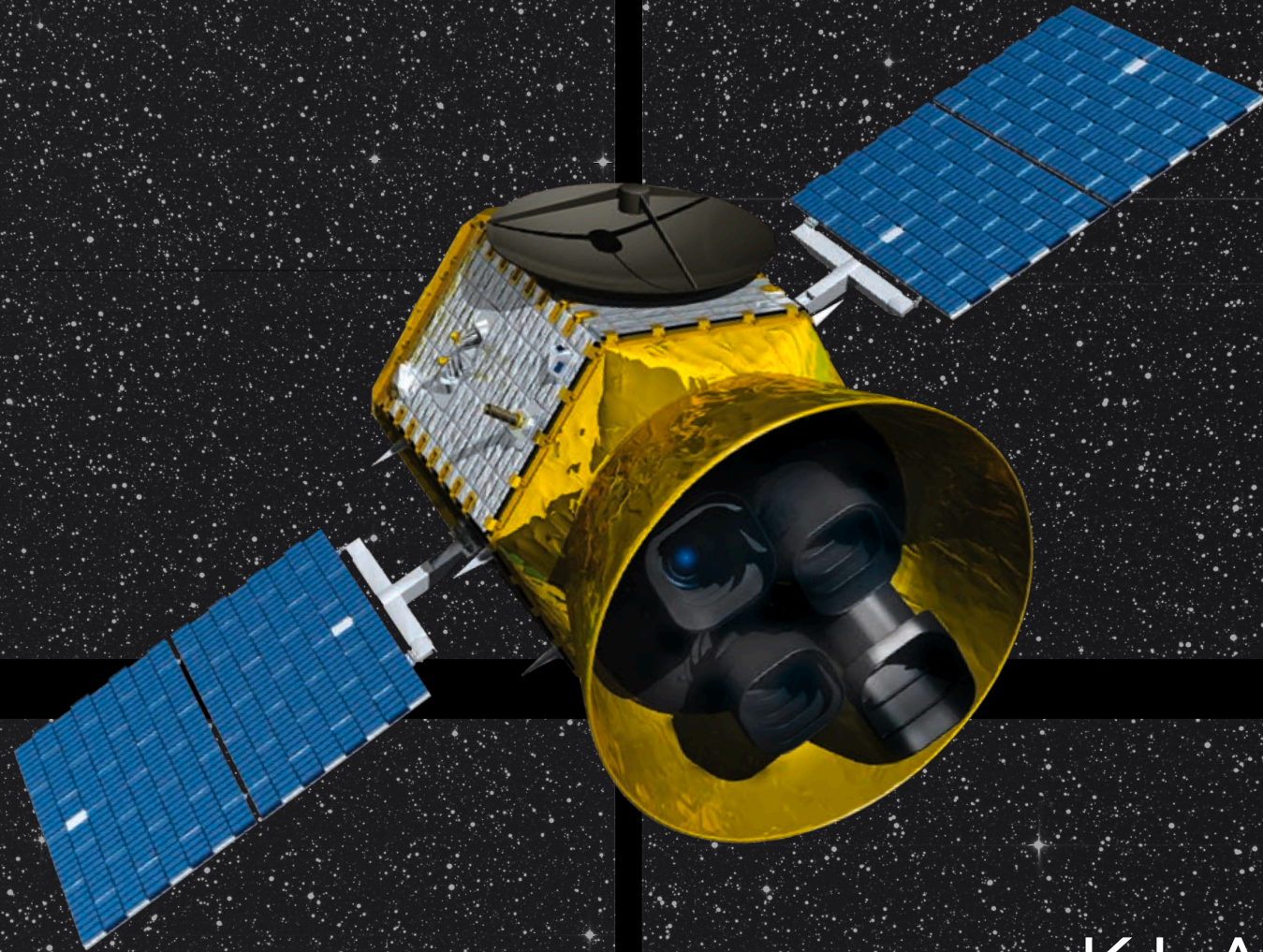


USING TESS AND ZTF TO STUDY EARLY- AND LATE- TIME TRANSIENT BEHAVIOR



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HOT-WIRING THE TRANSIENT UNIVERSE
24 MARCH 2026

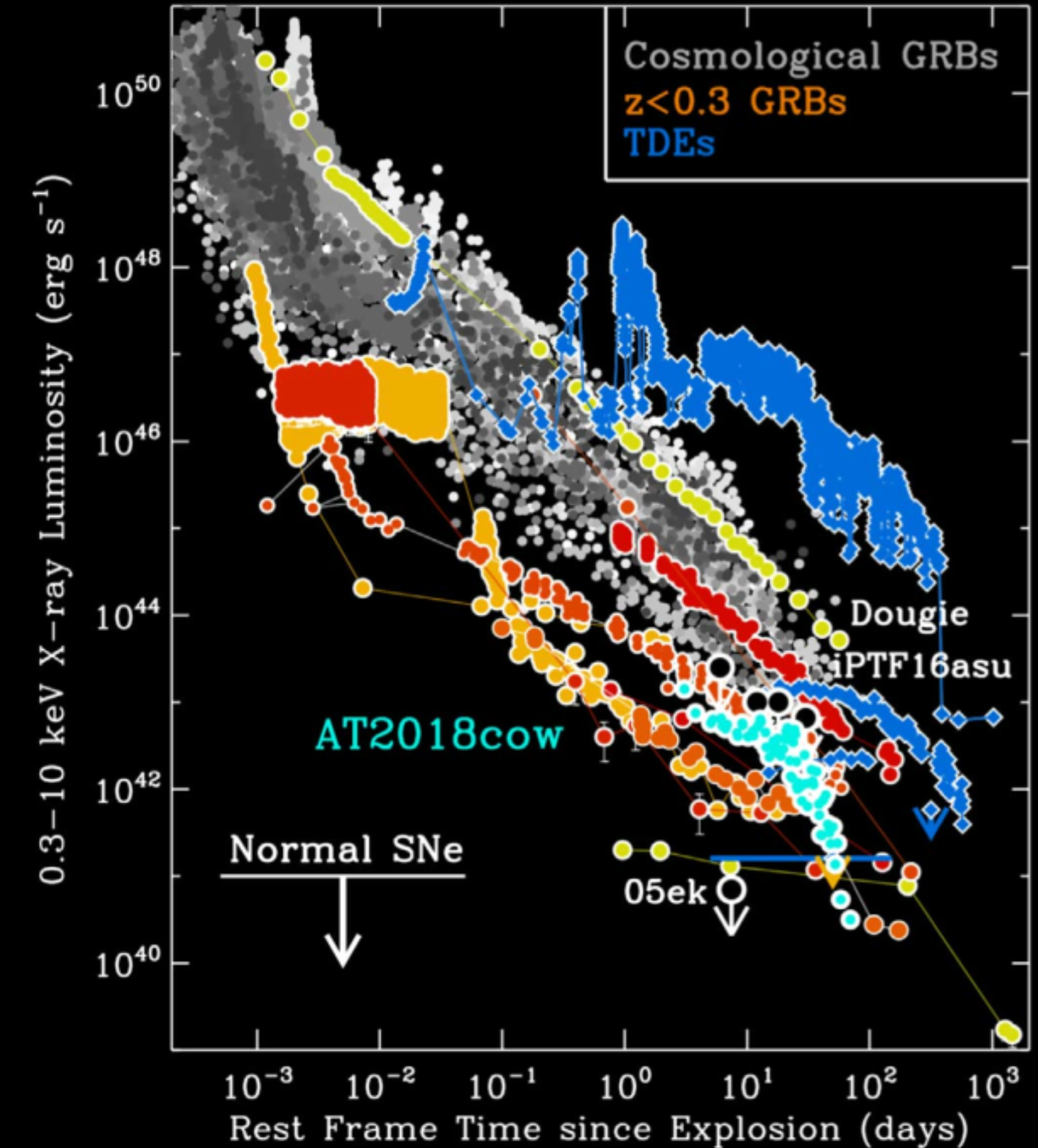
COLLABORATORS: ANNA HO, MICHAEL FAUSNAUGH, ERAN OFEK, RUSLAN KONNO, DANIEL PERLEY, QINAN WANG, RYAN RIDDEN-HARPER, ARMIN REST, K-RYAN HINDS

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LUMINOUS FAST BLUE OPTICAL TRANSIENTS

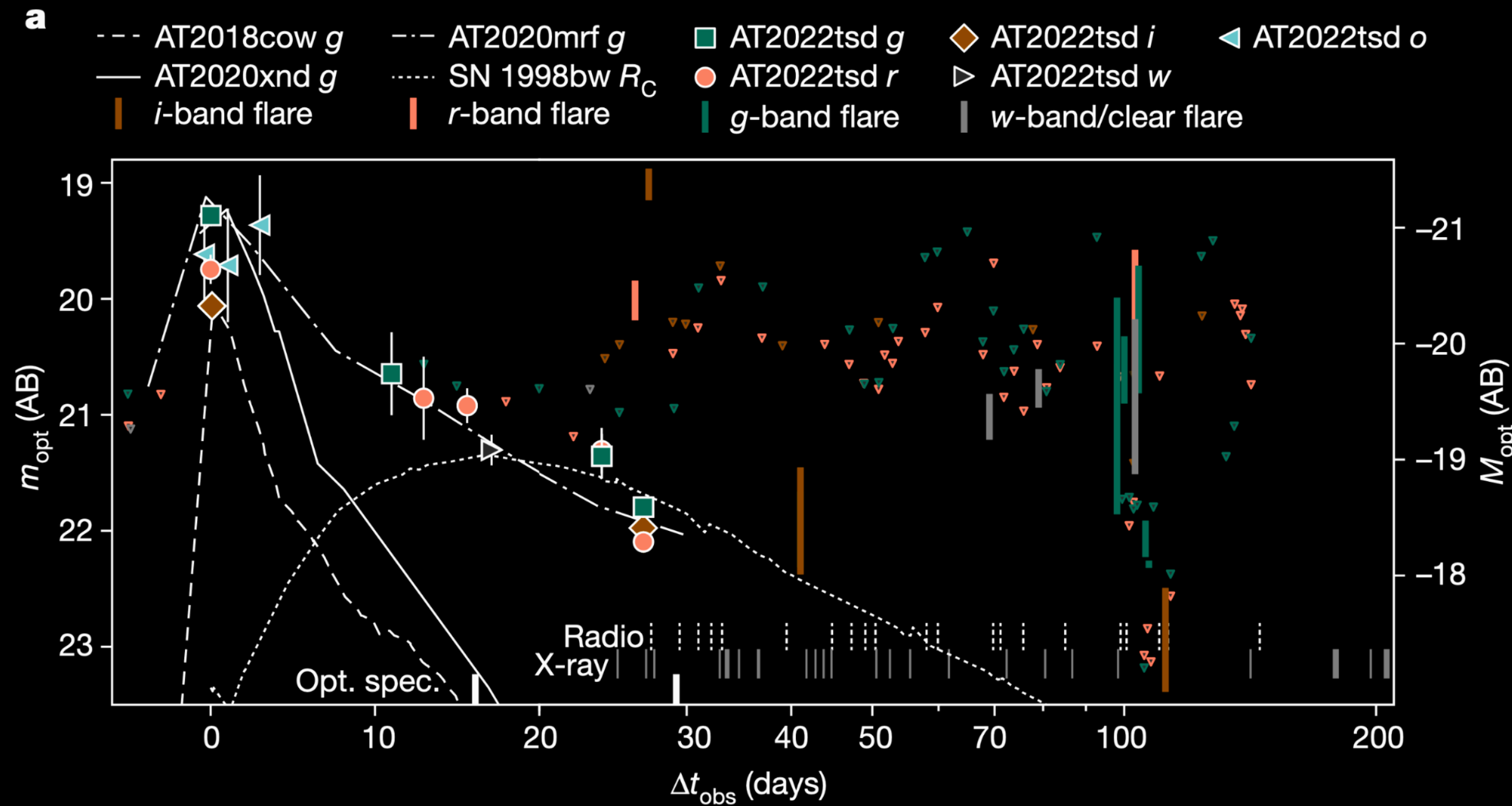
LFBOTs are **L**uminous ($-22 < M < -20$), **F**ast -
(FWHM $\lesssim 5$ days), and **B**lue ($g-r < 0$)

Multi-wavelength events: X-rays at early times and
radio at later times **provides evidence for a central
engine pushing a shock into a dense medium**

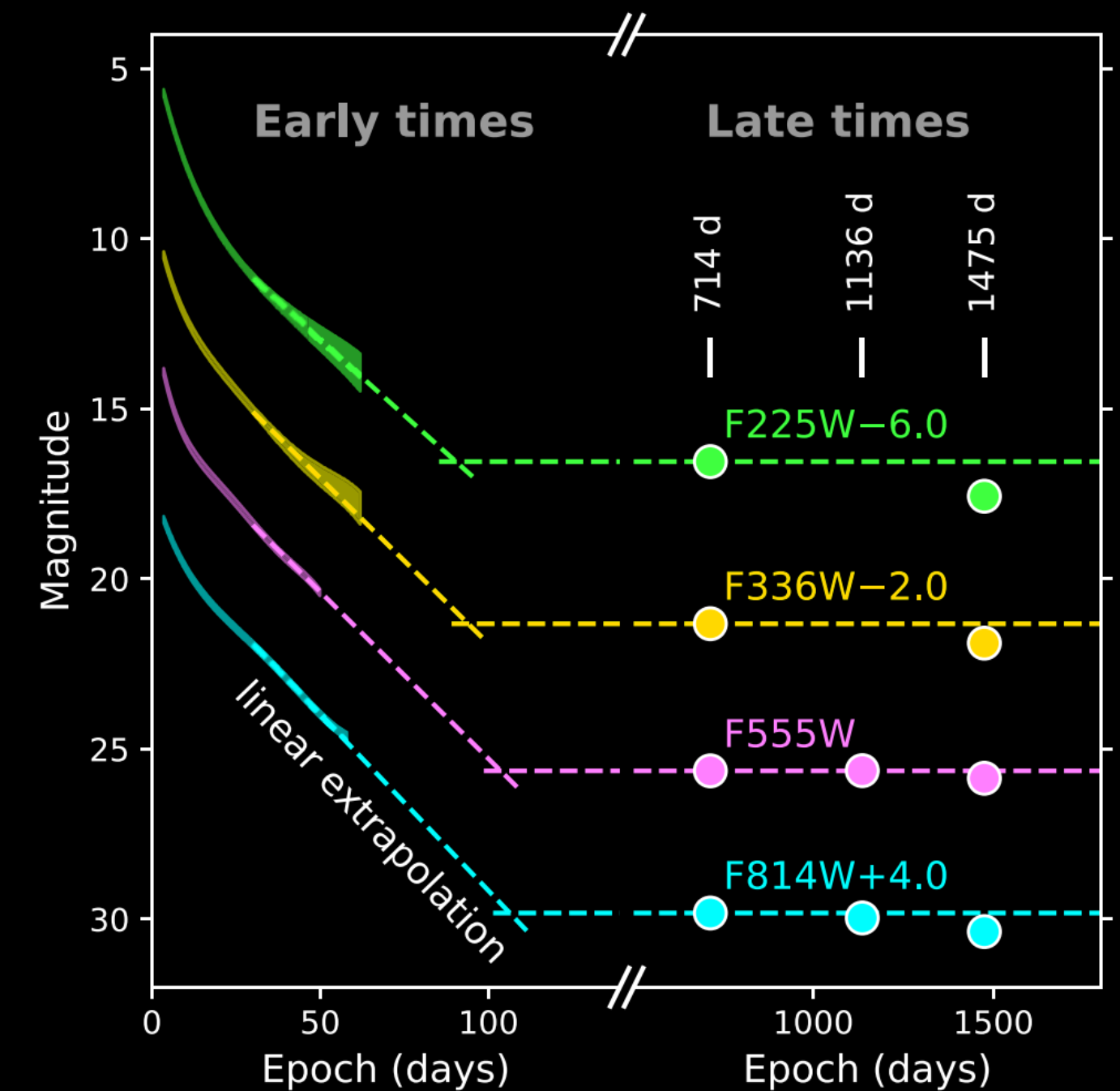


Margutti+2019

(MORE) PROOF FOR CENTRAL ENGINES



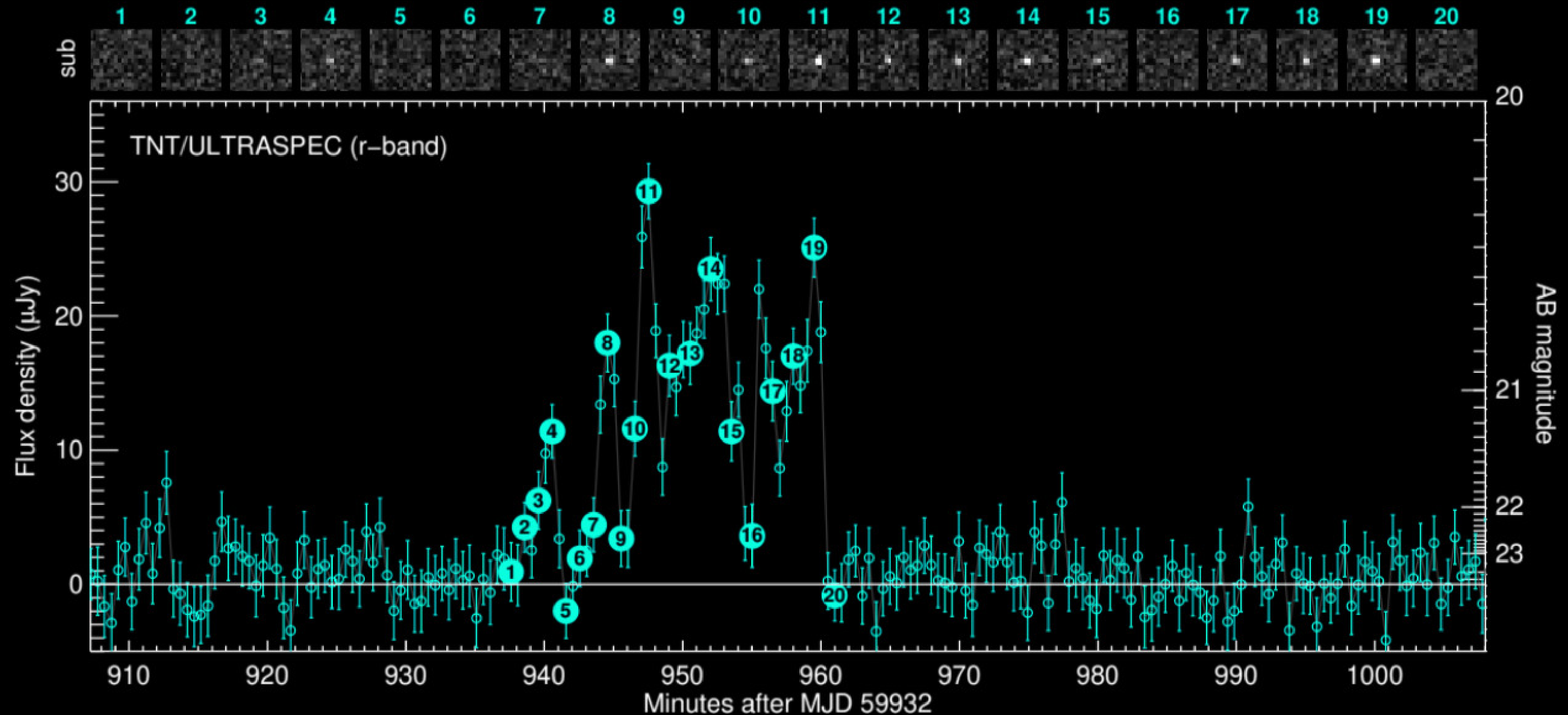
Ho+2023



Sun+2023

Episodic late-time flaring from t_0 to $t_0 + 100$ d points to a compact emitting region ($9 \times 10^{11} \text{ cm} \cdot \Gamma^2$), relativistic outflow velocities and a high brightness temperature, corresponding to **nonthermal emission** (synchrotron?) from a possibly accreting black hole.

Plateau[?] phase (100s-1000s of days after the transient) - implying an accretion disk?
Accepted JWST Cycle 5 program to probe the 2018cow accretion disk SED!

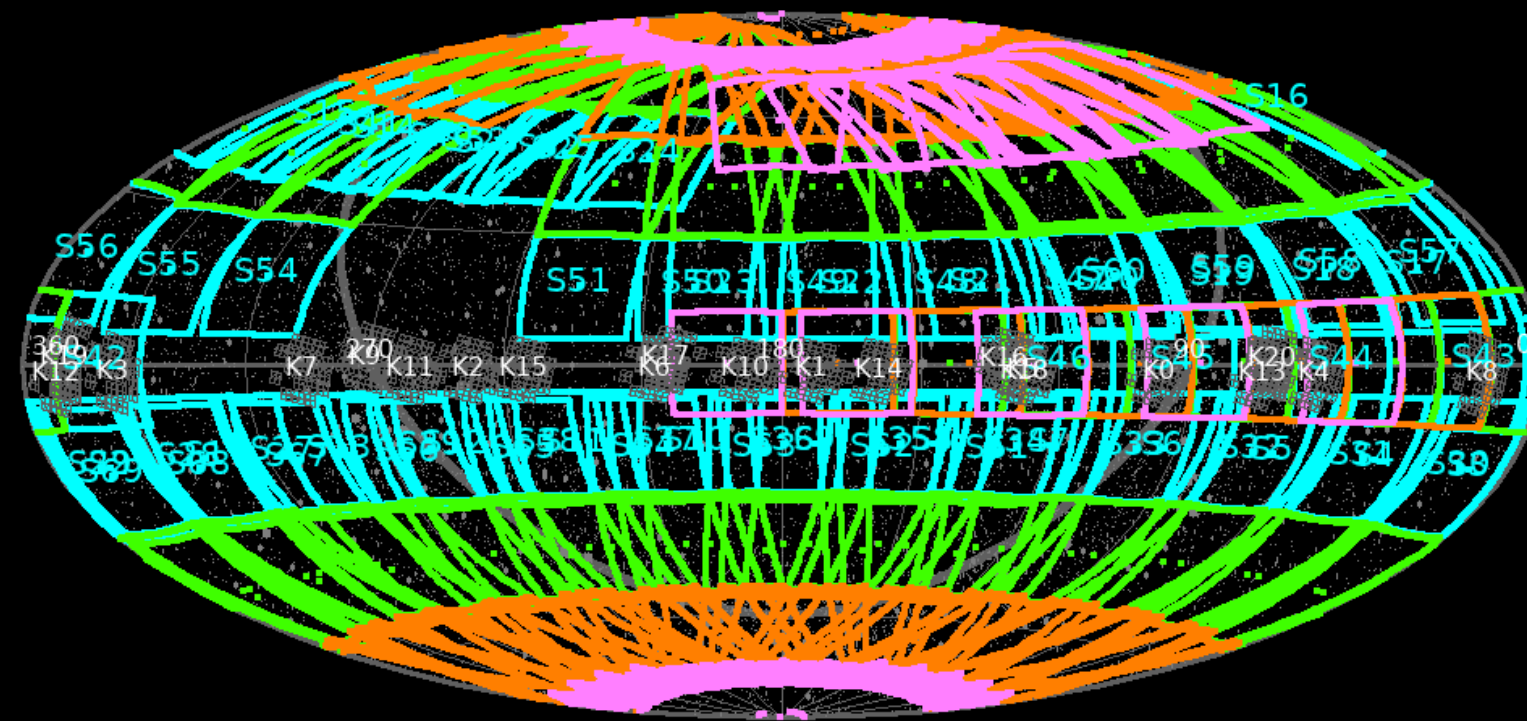
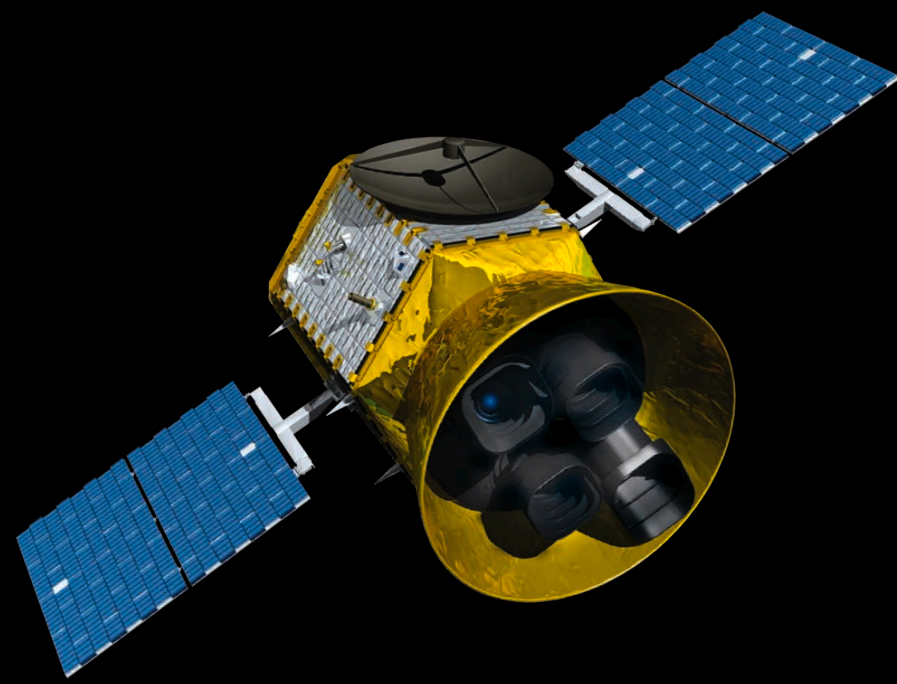
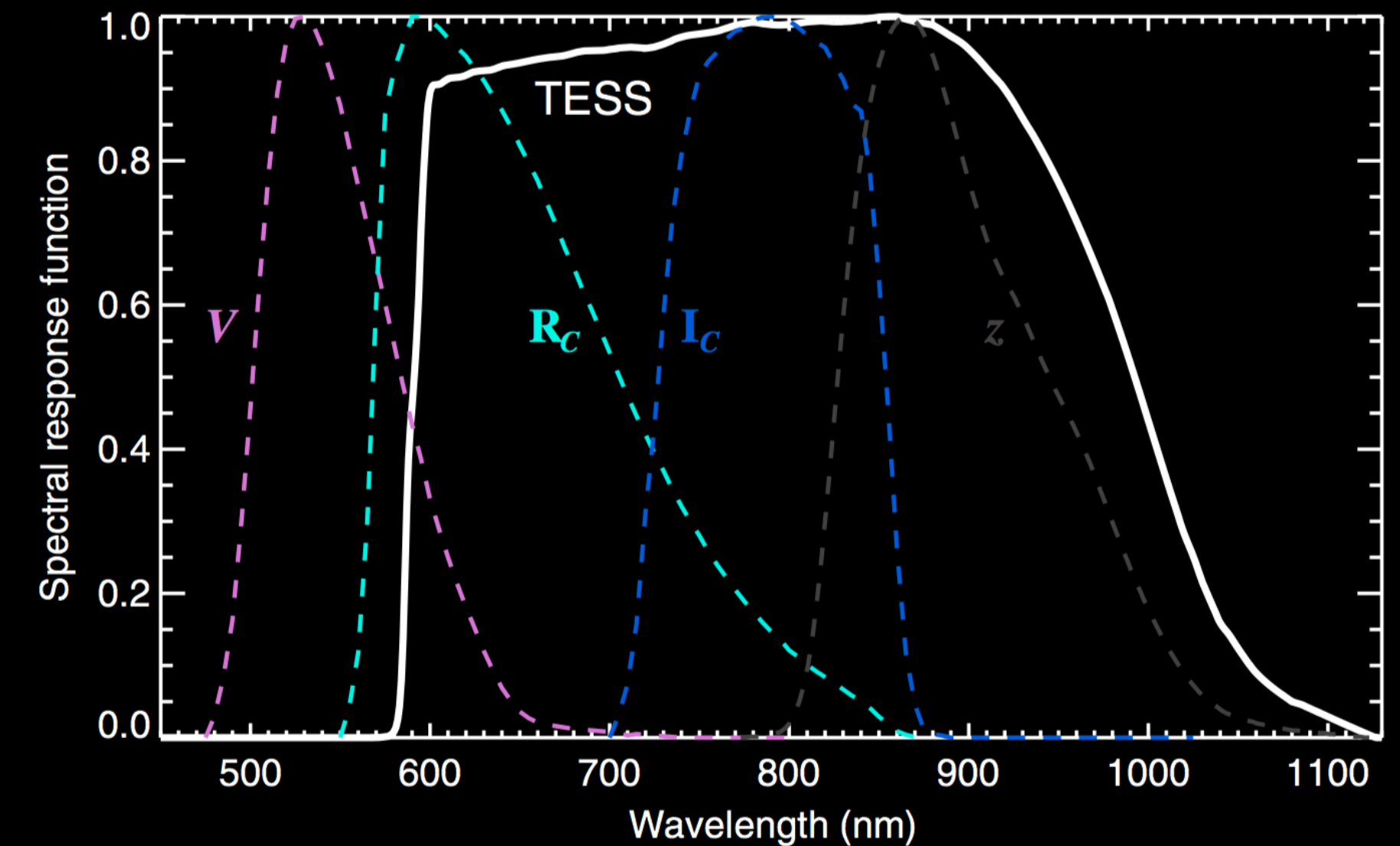


Ho+2023

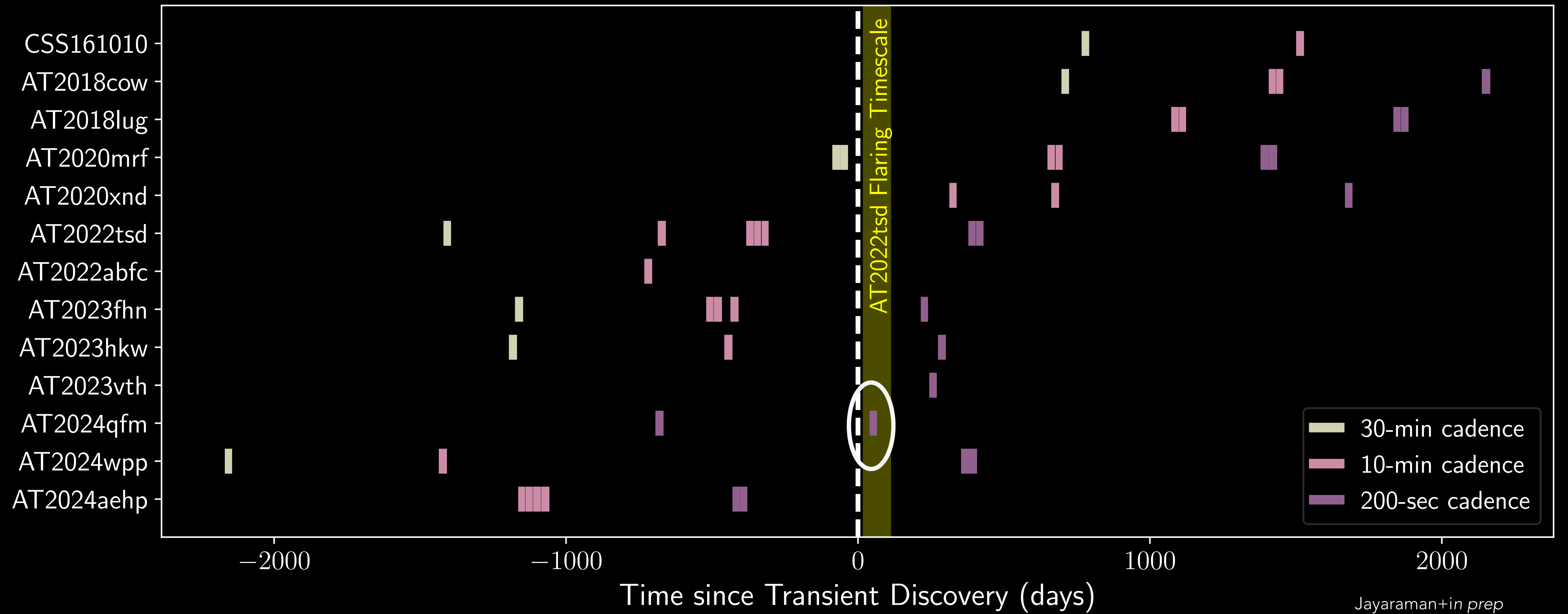
Flaring phase (tens of days after the initial event)—red outbursts ($u-I \sim 1.4$) comparable to the luminosity of the original transient, with rapid variability (minutes-timescale)

Searching for these flares requires a survey that:

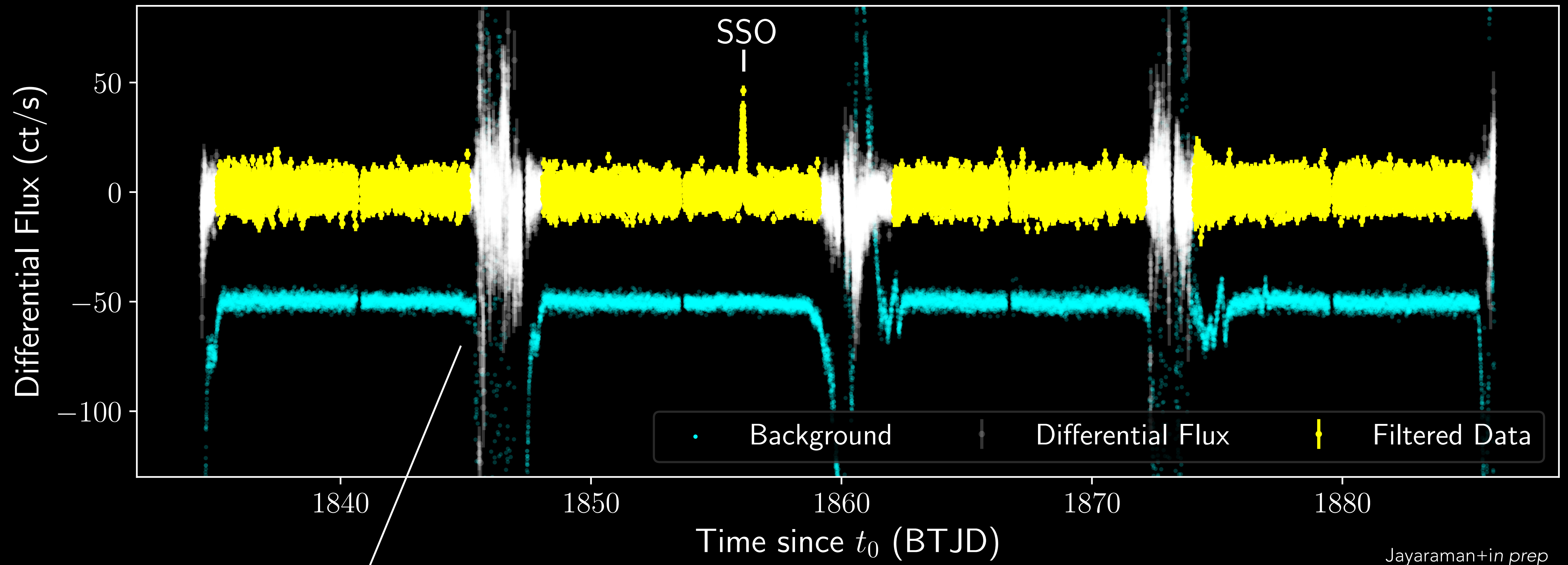
- ✓ has an **observational cadence of minutes**;
- ✓ is able to observe the LFBOT **for a long duration after the initial emission** phase;
- ✓ has a bandpass sensitive to **redder** colors



THE SAMPLE



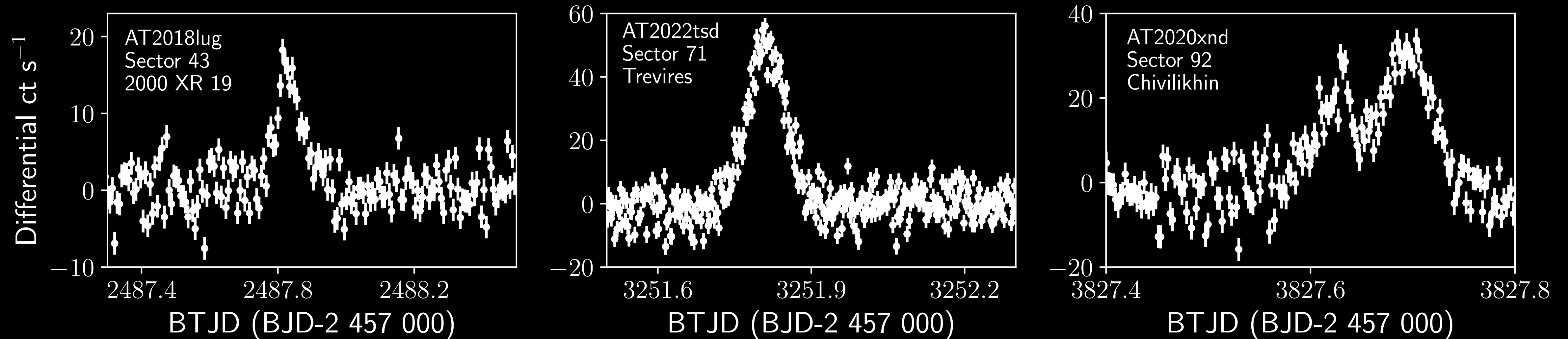
TESS LIGHT CURVES



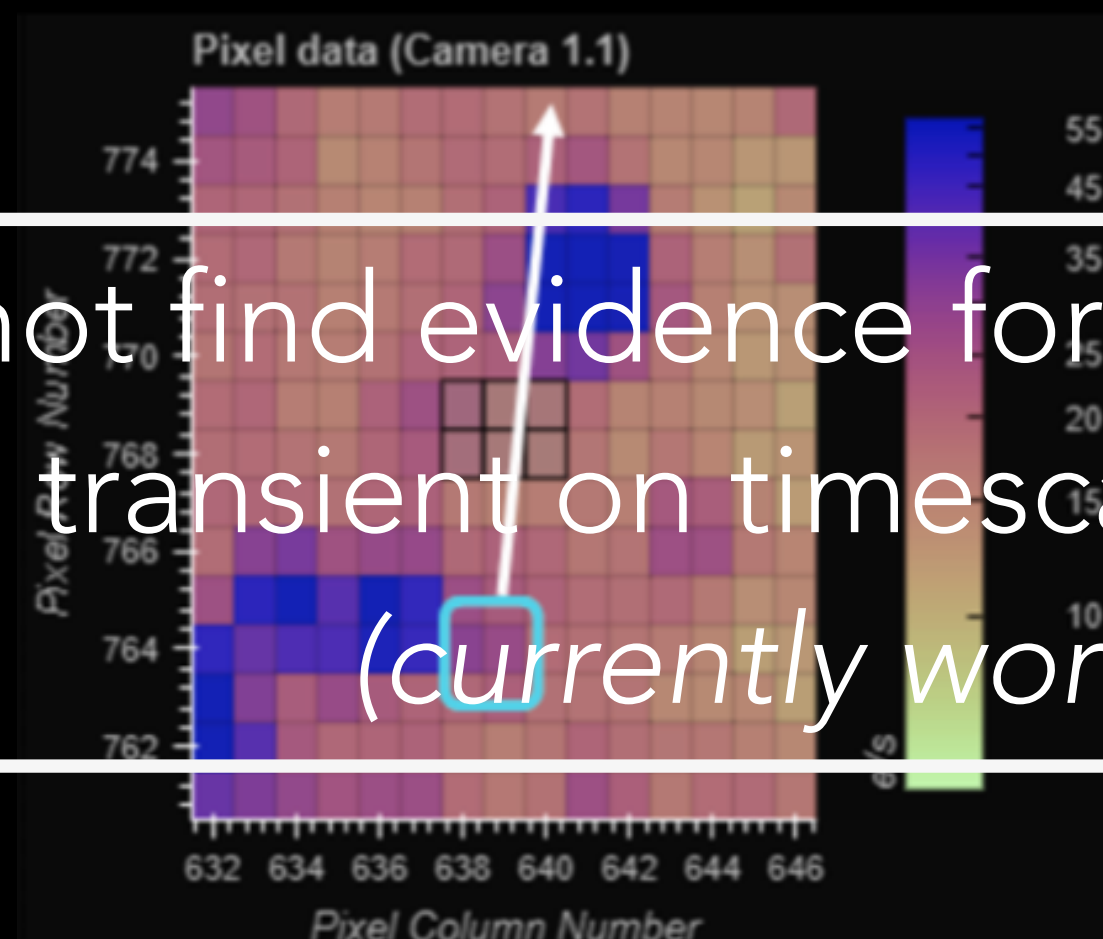
Scattered light from
Earth- and Moonshine

Often, the light curve and background are strongly correlated, suggesting that the signal is not real

TESS LIGHT CURVES: RESULTS



Jayaraman+in prep



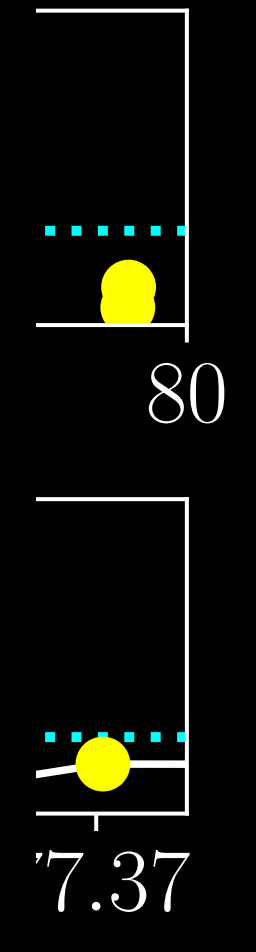
We do not find evidence for flaring in TESS data at luminosities $\sim$ comparable to the original transient on timescales of $\sim$ hundreds to thousands of days after the event. *(currently working to more precisely quantify this claim)*

Rise and fall on timescales of a few hours, with clear evidence of something moving through the aperture during the observation

LOOKING FORWARD...

Flaring similar to AT2022tsd in its structure can be detected by TESS out to $z \sim 0.04$. If we don't want to resolve structure, TESS can detect flares (binned) out to hundreds of Mpc.

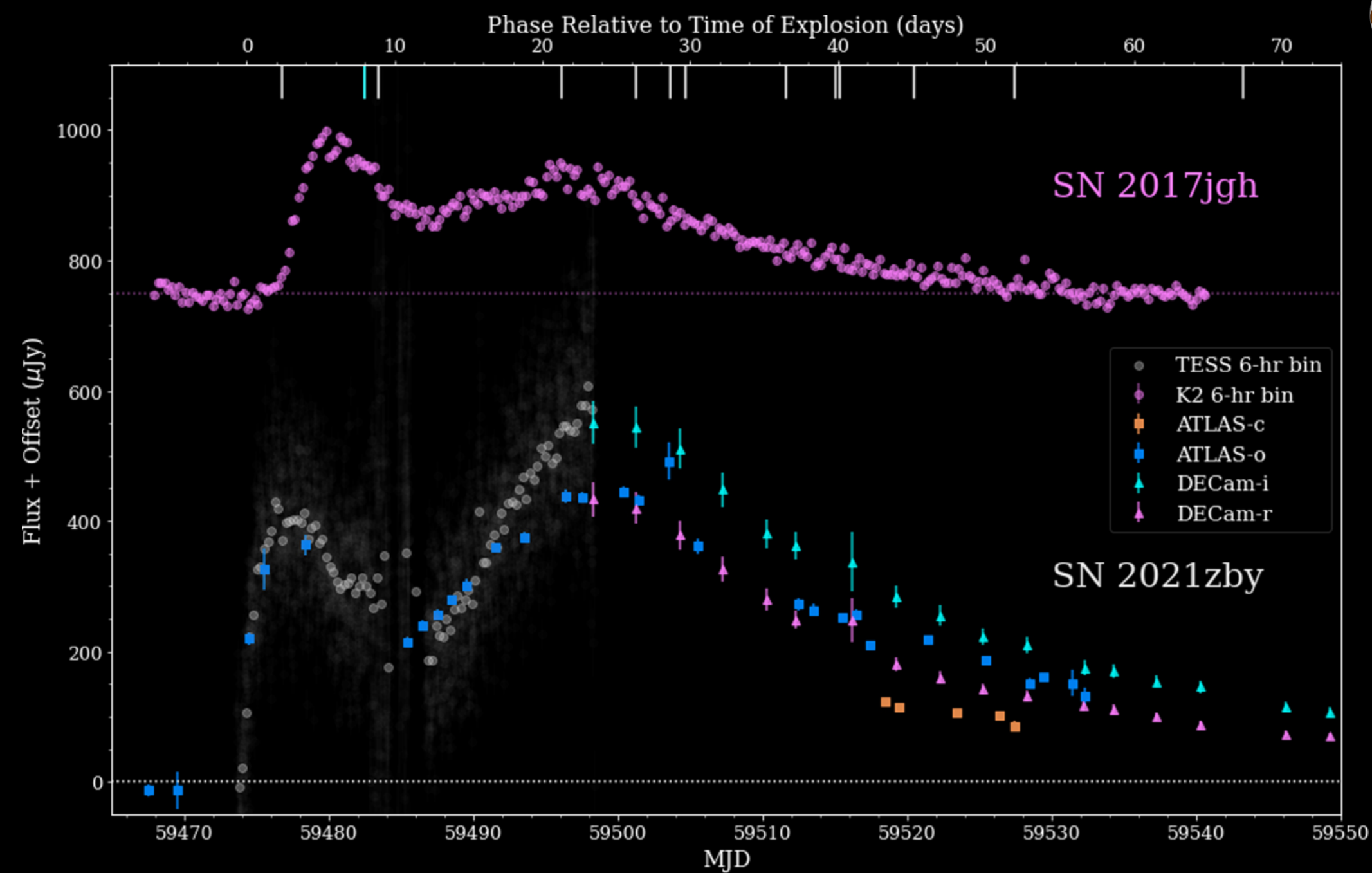
Other surveys, such as **LAST** and **the Argus Array**, have a more optimistic rate; we predict **a few to tens of detections per year** of such flaring!

TESS magnitude	Survey	Exposure (s)	Field of View (deg ²)	Limiting Magnitude	Maximum z	Volume (Gpc ³)	Rate (yr ⁻¹)	
	TESS	200	2 304	18.2	0.19	0.217	0.2–2	
	TESS (<i>binned</i>)	7 200	”	20.2	0.43	3.44	3.4–34	
	LAST	20	355	19.6	0.34	0.23	0.23–2.3	
	ZTF	30	47	20.8	0.55	0.16	0.16–1.6	
	LS4	45	20	21	0.59	0.09	0.09–0.9	
	LSST/Rubin	30	9.6	24.5	2.19	5.45	5.5–55	
	Argus Array	60	8 000	20.5	0.48	18.1	18–180	<i>n prep</i>

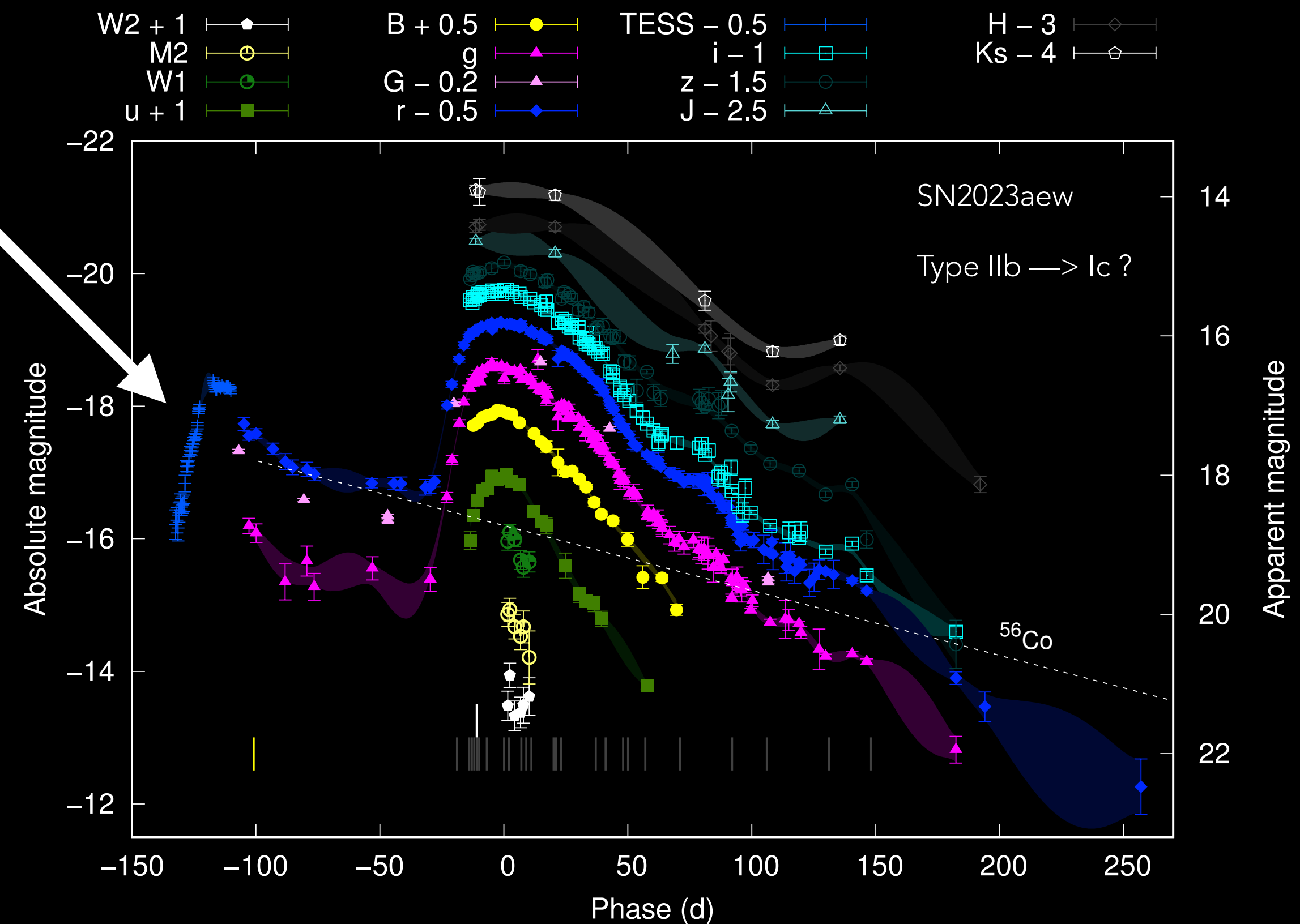


SUPERNOVA SHOCK COOLING

TESS's cadence and continuous monitoring enables **searches for and constraints on shock cooling emission in core-collapse SNe**—these events are also *fast* and **blue**.



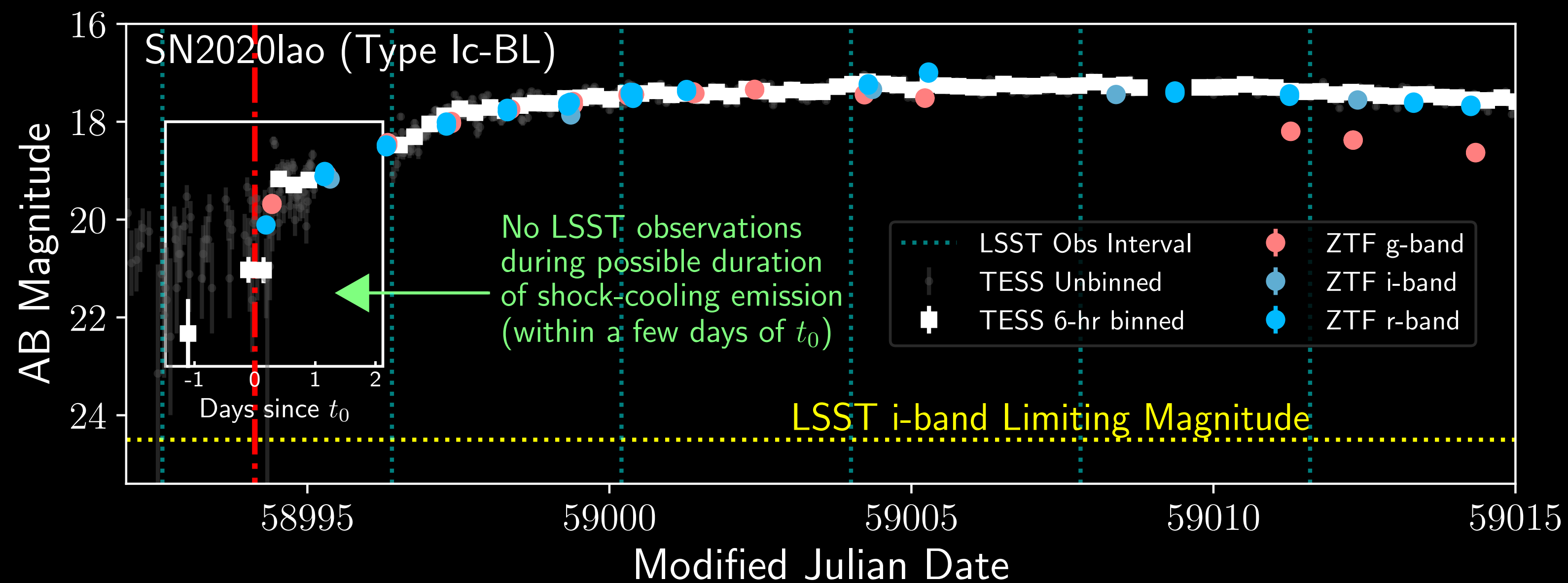
Wang+2023



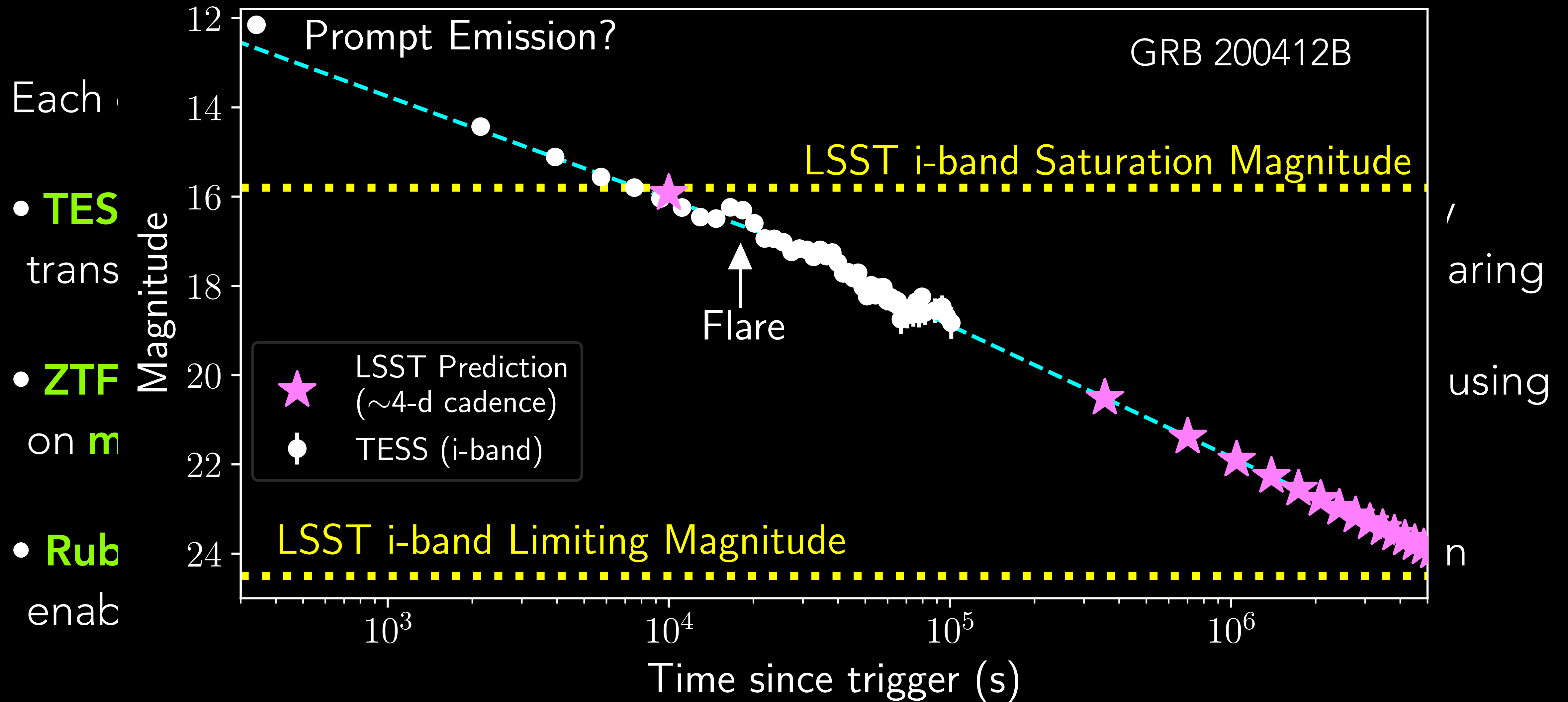
Kangas+2024

SHOCK COOLING IN SUPERNOVAE WITH TESS + ZTF

We do not find any evidence for shock cooling in any of the supernovae from the ZTF Bright Transient Survey (BTS) in TESS, which **helps constrain the progenitor radius**. If we **combine TESS with Rubin and ZTF**, we can search for shock cooling or other flux features in nearby, bright supernovae, with high-cadence light curves! This is interesting for SNe powered by central engines (such as Ic-BL/GRB-SNe), probing pre-explosion mass loss (SN2018gep, Ho et al. 2018; iPTF14gqr, De et al., 2018)



TESS + LSST + ZTF



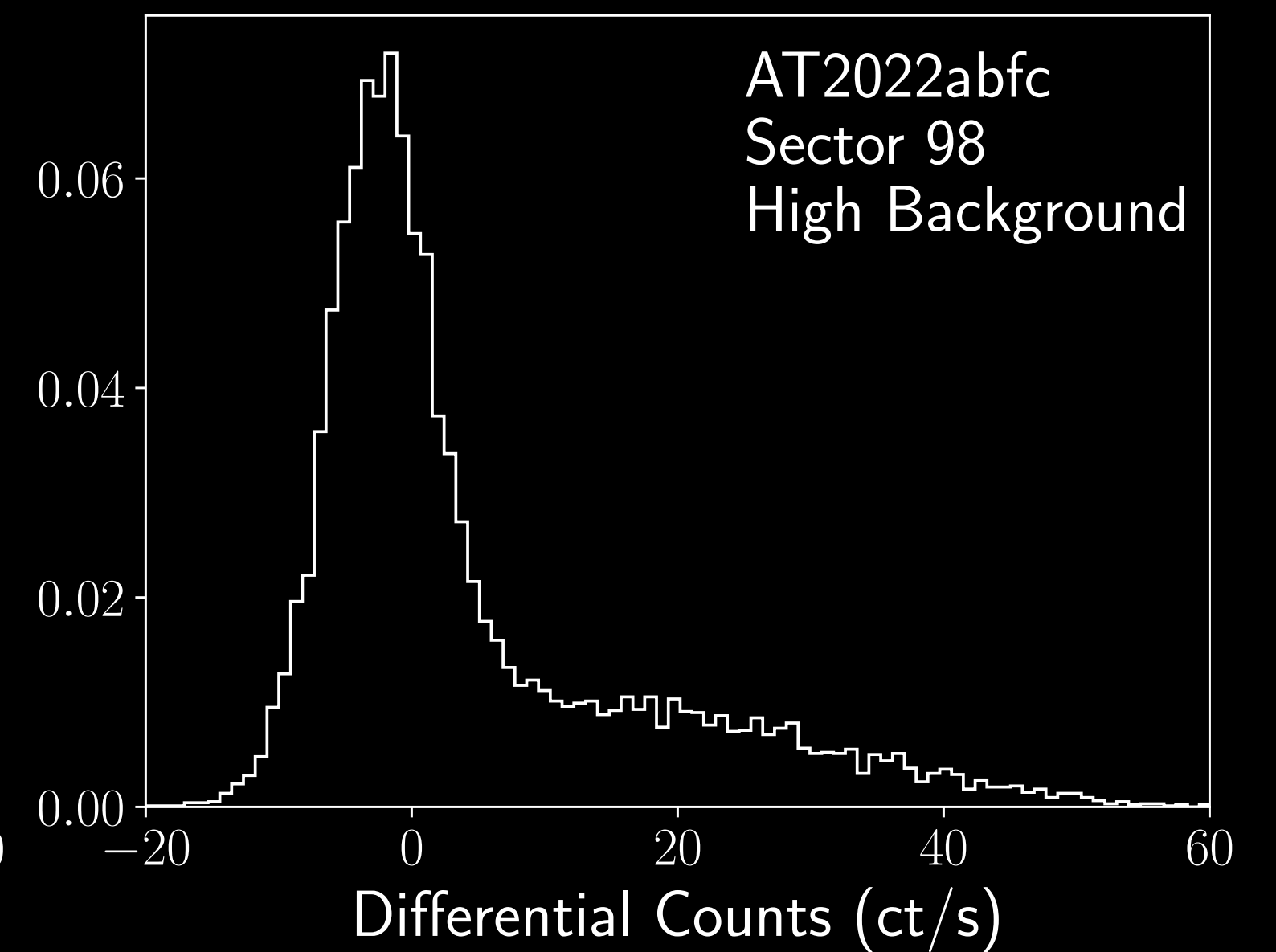
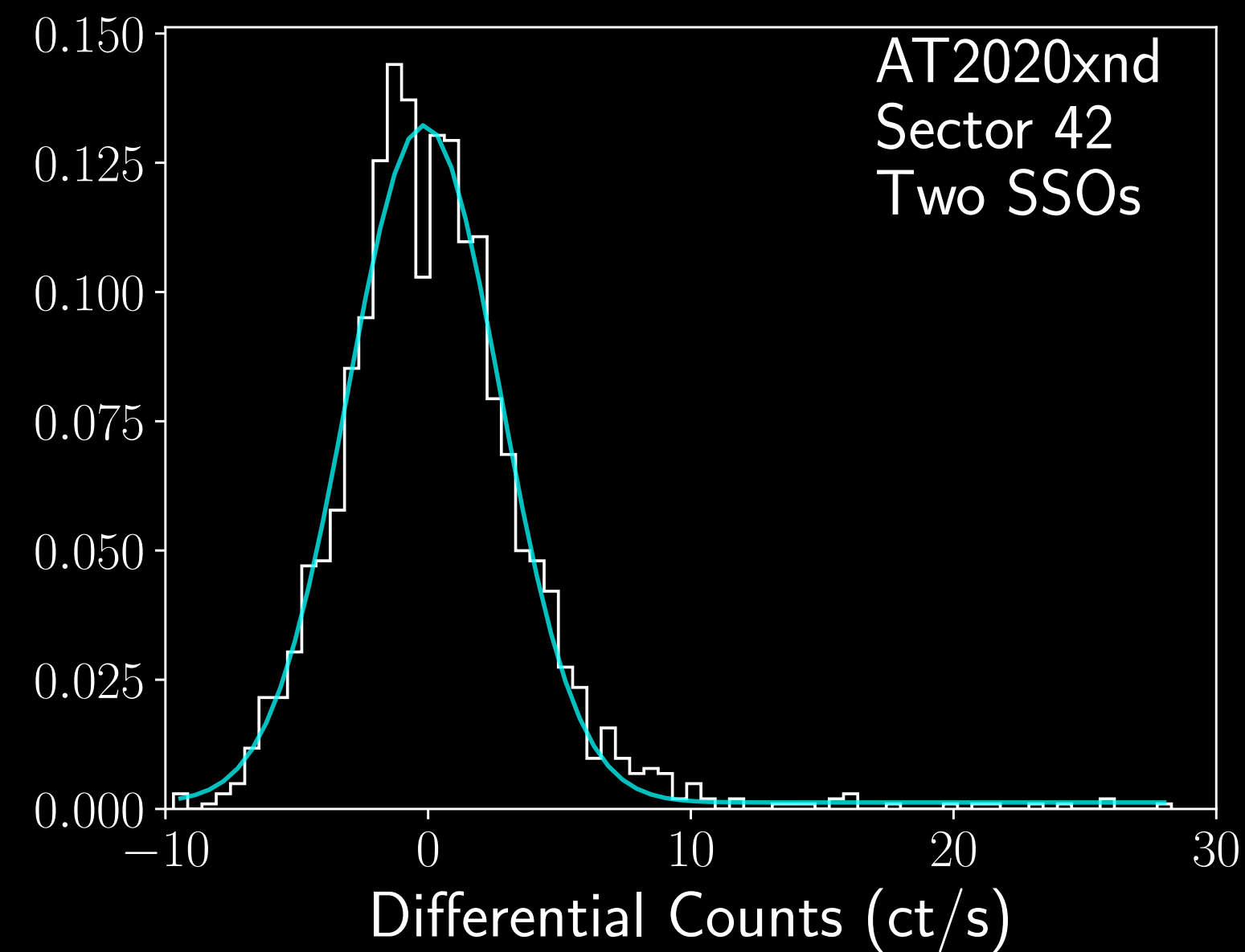
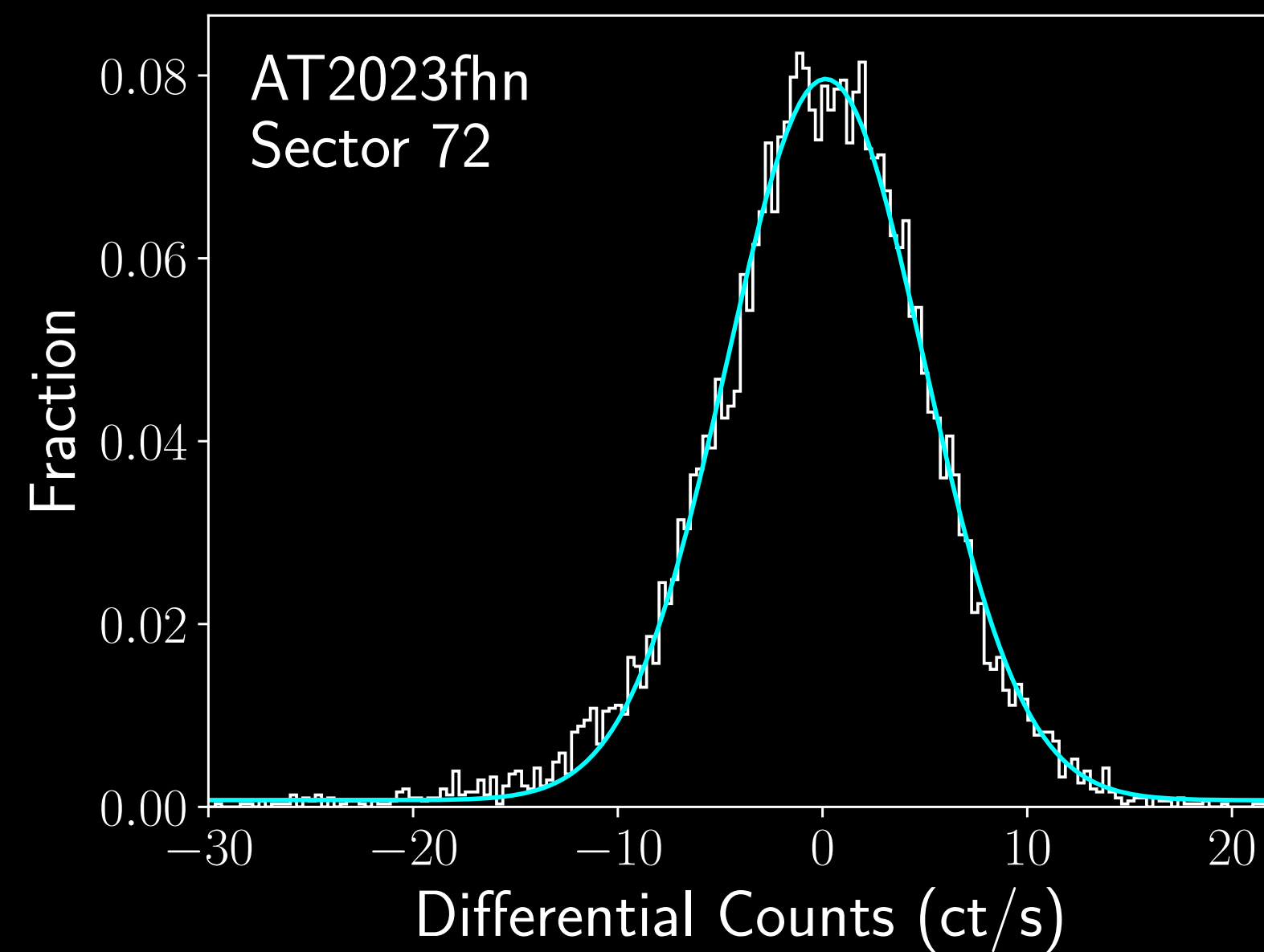
CONCLUSIONS

- We still **lack a good understanding of the rate of late-time flaring in LFBOTs**. We analyzed late-time TESS data for the 13* known LFBOTs and **did not find evidence of such flaring in any such event**. We are working to quantify our limits.
- We searched for **shock cooling emission from the ZTF Bright Transient Survey core-collapse supernova sample in TESS and did not find any evidence for SC**.
- *Future directions:* (1) **Comparing TESS image differencing algorithms** as part of the shock cooling search; (2) Collaborating on **flare searches in other transients** (e.g., TDEs); and (3) Fine-tuning **fast transient filters for ZTF and LSST and integrating them with TESS** photometry

TESS will be best used in conjunction with ZTF and Rubin/LSST to study the early-time behavior of transients, **especially those powered by central engines**, and constrain the late-time behavior of such events—alongside **LAST and the Argus Array**.

BACKUP

TESS LIGHT CURVES: STATISTICAL PROPERTIES



Jayaraman+in prep

"Normal" light curve
with a non-detection

Two solar system objects
("rocks") in the aperture

Considerable scattered
light enters camera

TESS LIGHT CURVES: LIMITS AT THE NATIVE CADENCE

Identifier	TESS Observation Details		Limiting T_{AB}	Luminosity (erg s^{-1})
	Sector	Times		
AT2018cow	25	$[t_0 + 697.72, t_0 + 723.34]$	18.60	$< 2.37 \times 10^{41}$
	51–52	$[t_0 + 1407.01, t_0 + 1457.14]$	18.40	$< 2.84 \times 10^{41}$
	78	$[t_0 + 2148.33, t_0 + 2163.57]$	17.72	$< 5.35 \times 10^{41}$
CSS161010	5	$[t_0 + 766.04, t_0 + 791.81]$	19.06	$< 8.89 \times 10^{41}$
	32	$[t_0 + 1502.28, t_0 + 1528.25]$	18.37	$< 1.67 \times 10^{42}$
	98	$[t_0 + 3322.02, t_0 + 3344.91]$	17.62	$< 3.34 \times 10^{42}$
AT2018lug	42–43	$[t_0 + 1073.79, t_0 + 1124.98]$	18.25	$< 1.69 \times 10^{44}$
	70–71	$[t_0 + 1834.45, t_0 + 1886.06]$	17.74	$< 2.72 \times 10^{44}$
AT2020xnd	42	$[t_0 + 313.03, t_0 + 338.49]$	18.16	$< 1.43 \times 10^{44}$
	55	$[t_0 + 662.44, t_0 + 689.60]$	18.23	$< 1.34 \times 10^{44}$
	92	$[t_0 + 1669.33, t_0 + 1692.63]$	17.55	$< 2.53 \times 10^{44}$
AT2020mrf	50–51	$[t_0 + 649.40, t_0 + 701.66]$	18.34	$< 3.33 \times 10^{43}$
	77–78	$[t_0 + 1379.61, t_0 + 1433.64]$	17.93	$< 4.85 \times 10^{43}$
AT2022tsd	70–71	$[t_0 + 379.03, t_0 + 429.53]^a$	17.75	$< 2.35 \times 10^{44}$
AT2022abfc	98	$[t_0 + 1083.65, t_0 + 1112.04]$	18.00	$< 1.22 \times 10^{44}$
AT2023fhn	72	$[t_0 + 215.47, t_0 + 240.88]$	17.62	$< 2.30 \times 10^{44}$
AT2023hkw	75	$[t_0 + 274.09, t_0 + 301.79]$	17.91	$< 3.97 \times 10^{44}$
AT2023vth	80	$[t_0 + 244.27, t_0 + 270.72]$	17.55	$< 1.94 \times 10^{43}$
AT2024qfm	83	$[t_0 + 40.58, t_0 + 65.53]$	17.60	$< 2.06 \times 10^{44}$
AT2024wpp	97	$[t_0 + 356.13, t_0 + 380.67]$	17.71	$< 2.31 \times 10^{43}$

We do not find evidence of flaring on timescales of minutes at the **native cadence of TESS** at luminosities comparable to that of the original transient

Working on further investigation (binning the light curves to impose a more stringent limit), though higher z complicates things (**we could strengthen these limits up to 3x**)