LEIA discovery of the longest-lasting and most energetic stellar X-ray flare ever detected

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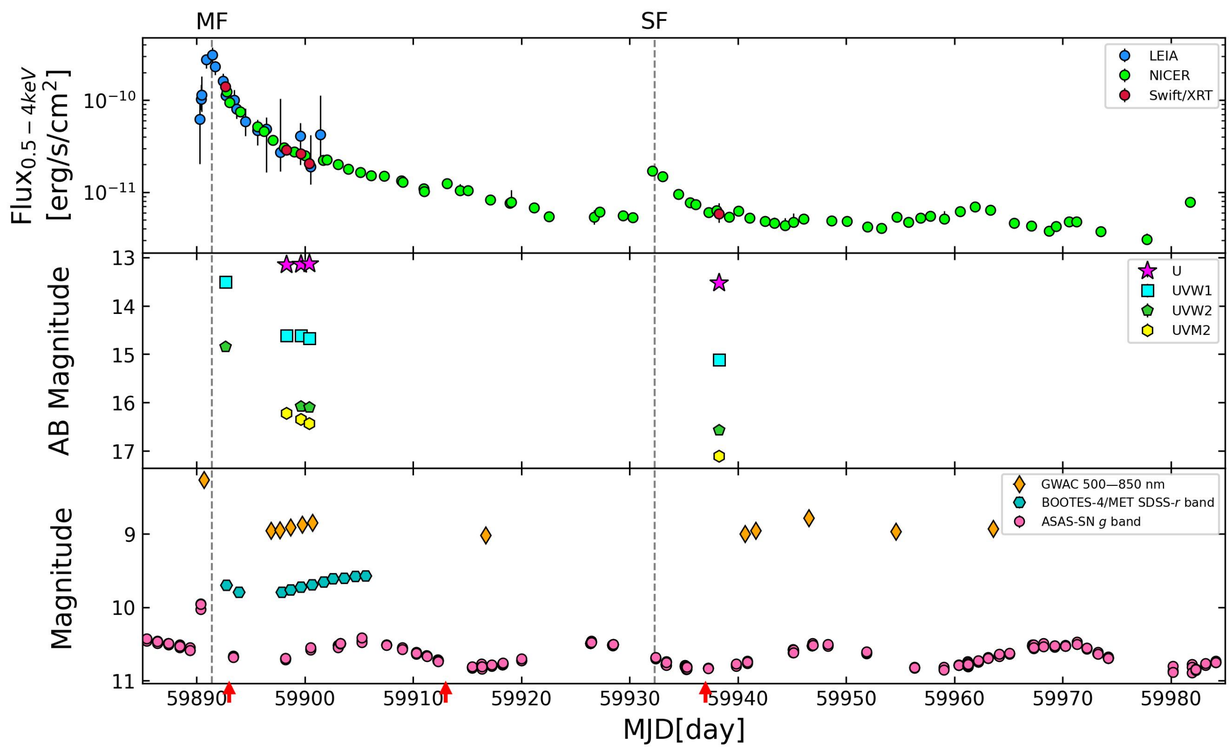
Introduction: *LEIA* (Lobster Eye Imager for Astronomy), as a pathfinder of the *EP* (Einstein Probe) mission, detected a new X-ray transient on November 7, 2022, identified as a superflare event occurring on a nearby K-type giant star HD 251108. The flux increase was also detected in follow-up observations at X-ray, UV and optical wavelengths. The flare lasted for about 40 days in soft X-ray observations, reaching a peak luminosity of ~1.1 × 10^{34} erg s^{-1} in 0.5–4.0 keV, which is roughly 60 times the quiescent luminosity. Optical brightening was observed for only one night. The X-ray light curve is well described by a double "FRED" (fast rise and exponential decay) model, attributed to the cooling process of a loop arcade structure formed subsequent to the initial large loop with a half-length of ~ 1.9 × 10^{12} cm. Time-resolved X-ray spectra were fitted by a four-temperature apec model (with three components being the quiescent background), showing significant evolution of plasma temperature and emission measure over time. The estimated energy released in the LEIA band is ~ 3 × 10^{39} erg, suggesting this is likely the most energetic X-ray stellar flare with the longest duration detected to date.

Observations

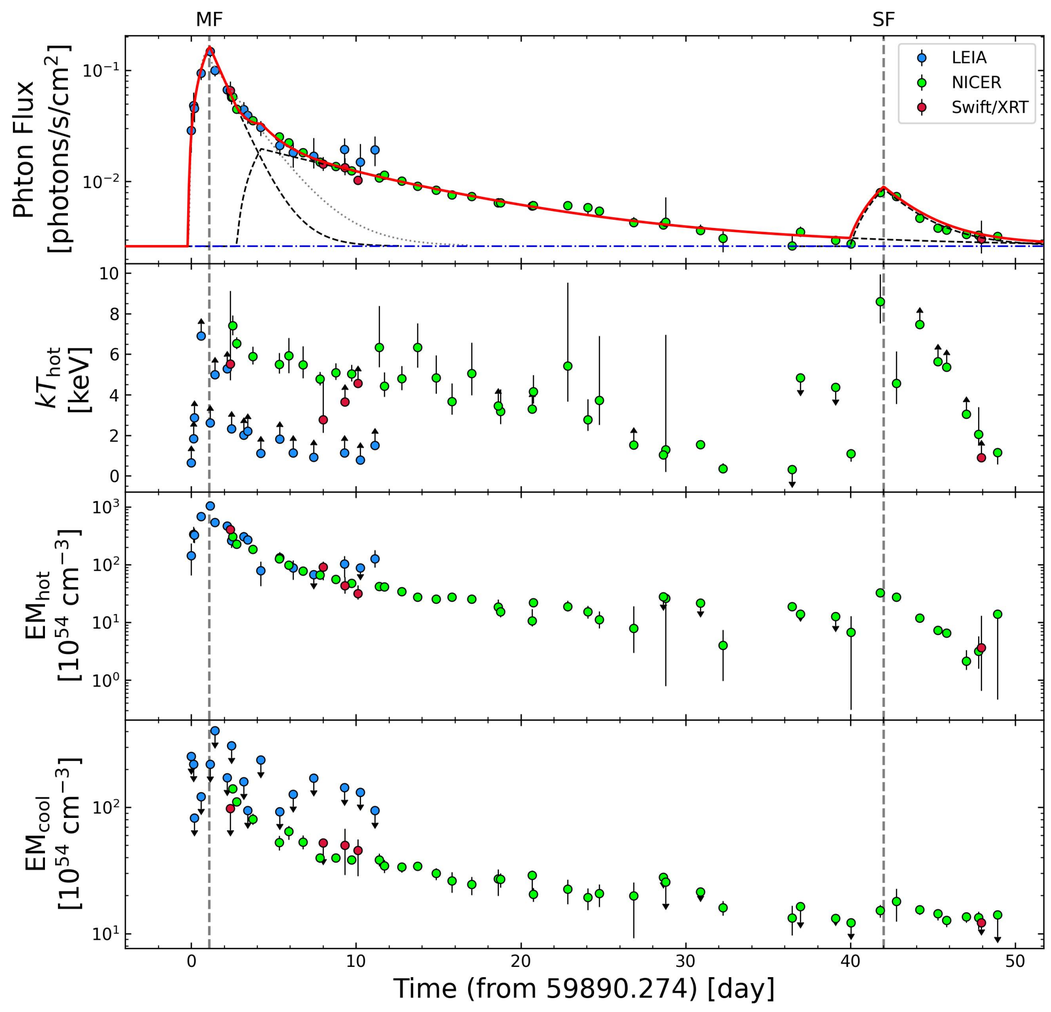


Instrument	Obs-Date	Waveband
LEIA	from 2022-11-07 to 2022-11-18	Soft X-ray
Swift	from 2022-11-09 to 2022-12-25	Soft X-ray/UV
NICER	from 2022-11-09 to 2023-02-06	Soft X-ray
ASAS-SN	from 2022-11-02 to 2023-02-09	optical
GWAC	from 2022-11-07 to 2023-01-19	optical
BOOTES-4/MET	from 2022-11-09 to 2022-11-22	optical
Lijiang 2.4m Telescope	2022-11-10, 2022-11-30 and 2022-12-24	optical

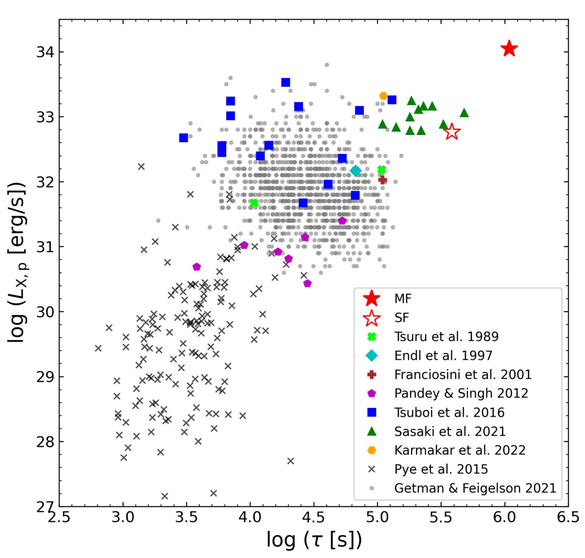
- Duration: ~ 40 days
- Peak luminosity in 0.5-4 keV: ~ 1E34 erg/s
- Energy release in 0.5-4 keV: ~ 3E39 erg/s

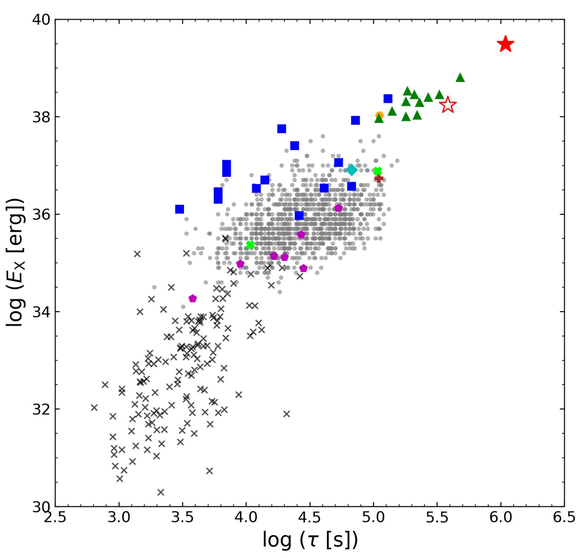
Analysis

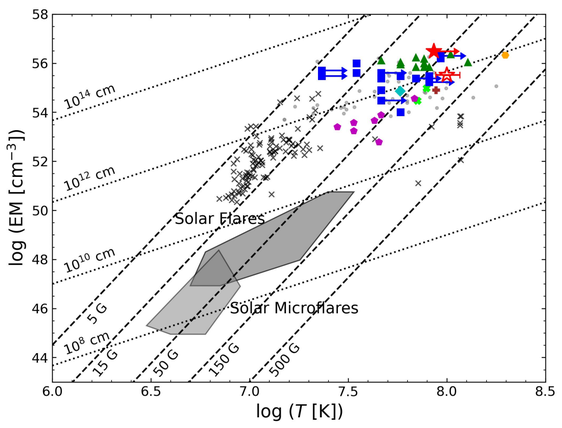
- Fitting model of X-ray quiescent specta: **tbabs*(apec+apec+apec)**
- Fitting model of X-ray flaring specta: **tbabs*(apec+apec+apec+apec)**
- Fitting model of X-ray light curve: **FRED**



Results







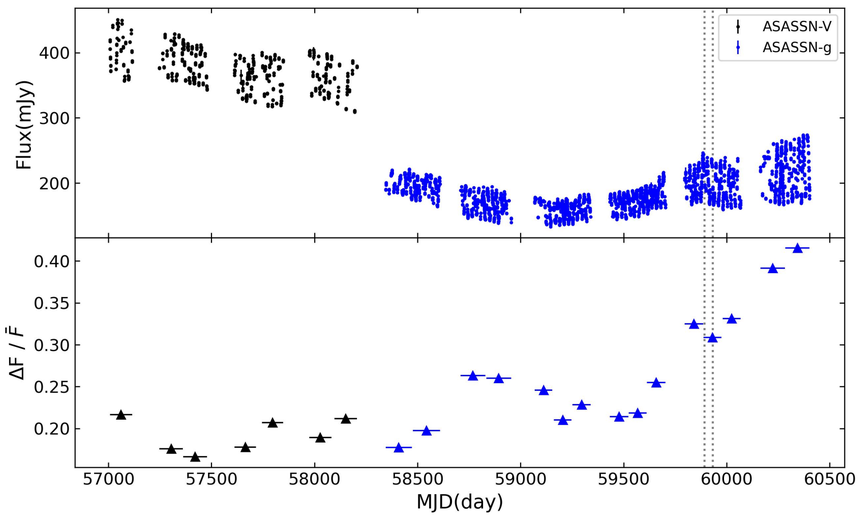
- T_{hot}, EM_{hot}, duration, peak luminosity and released energy are all located at the upper end of the parameter spaces

Discussion

- Flare process: An initial large loop (MF1 phase) followed by a loop arcade structure (MF2 phase)
- Parameters of loop size and flaring plasma

	L^a (10^{12} cm)	$n_e{}^b$ (10^9 cm^{-3})	V^c 10^{36} cm^3	β^d	p^e dyne cm^{-2}	B^f (gauss)
MF1*	1.9±0.2	5.1±0.8	14.0±4.6	0.56±0.12	120±21	54.9±4.8
MF1†	2.2	8.0	19.4	0.53	255	80.0
MF1‡	3.2	22.5	2.4	0.11	1442	190
MF2*	3.8±0.2	1.6±0.1	$61.4^{+11.5}_{-10.1}$	...	$27.3^{+3.9}_{-3.3}$	$26.2^{+1.9}_{-1.6}$
SF*	0.7±0.1	$9.2^{+1.5}_{-1.4}$	0.5±0.1	...	253^{+56}_{-50}	$79.8^{+8.8}_{-7.9}$

- ASAS-SN long-term light curve of HD 251108



Summery

- We reported a superflare event, happened on the star HD 251108, detected by LEIA and followed by multi-wavelength observations. The derived energy release in 0.5–4.0 keV is ~3 × 10^{39} erg, which suggests this is possibly the most-energetic-ever detected X-ray stellar flare.
- With the launch of EP on 9 January 2024, which monitors the X-ray sky with much larger field-of-view and wider range of timescales than LEIA, it is expected to detect a massive amount of stellar flares, which can fundamentally deepen our understanding of this explosive phenomenon.