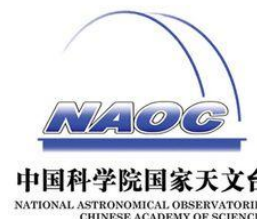


Complex Dynamics Revealed in Stellar Activities by Multi-wavelength Observations

J. Wang

NAOC/GXU

Beijing 2025/05



Content

- Introduction
- Two case studies with high-energy
- Superflares of M-dwarfs detected by GWAC
- Suggestions on Multi wavelength study with EP

Who are active

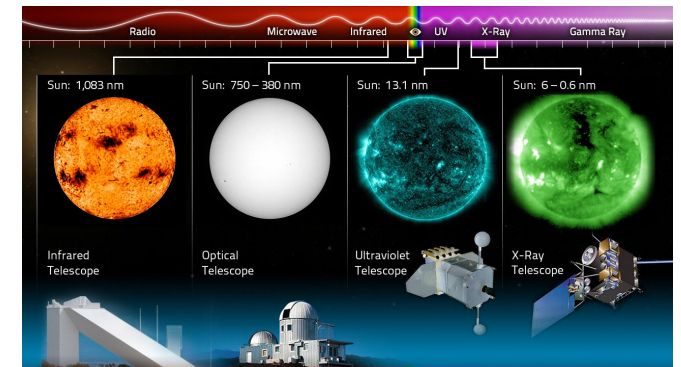
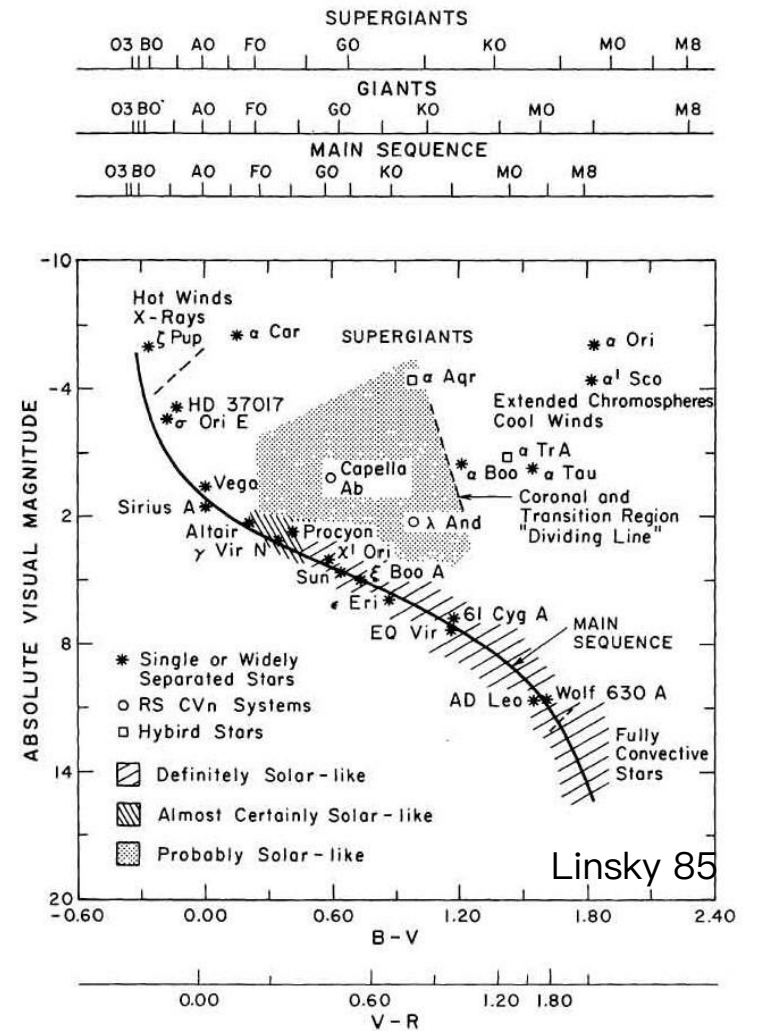
- Activity on H-R diagram

(e.g., Pettersen89; Schmitt94; Osten+05; Huenemoerder+10; Balona+15; Notsu+16; Van Doorselaere+17; Kowalski+13; Davenport+16; Chang+18; Paudel+18; Schmidt+19; Xin+21)

- Evidence of magnetic reconnection in some cases

(e.g., Noyes+84; Wright+11; Shulyak+17).

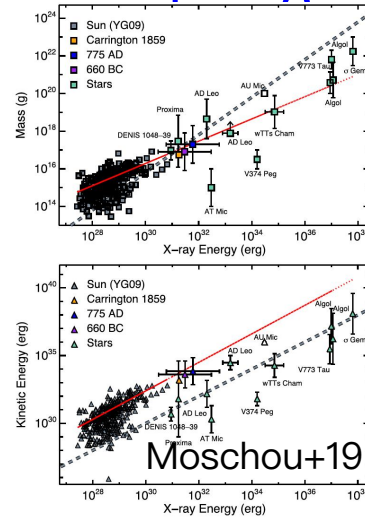
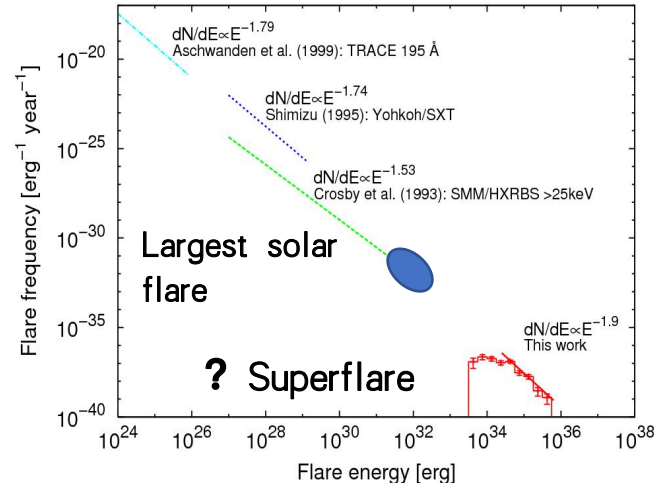
- Total energy: $10^{29} - 10^{32}$ erg
- Time scale : minutes — hours
- Sun
 - Coronal mass ejections (CMEs)
 - Prominence eruption
 - Evaporation & Condensation



Why study activities?

Will superflares occur on Sun?

Do CMEs/evap occur on other

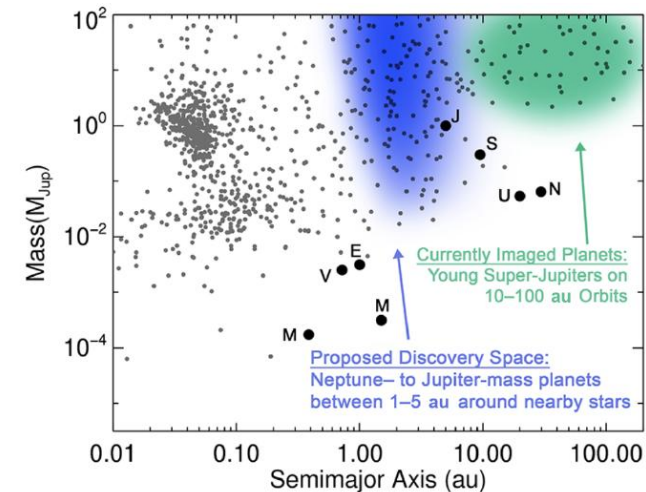
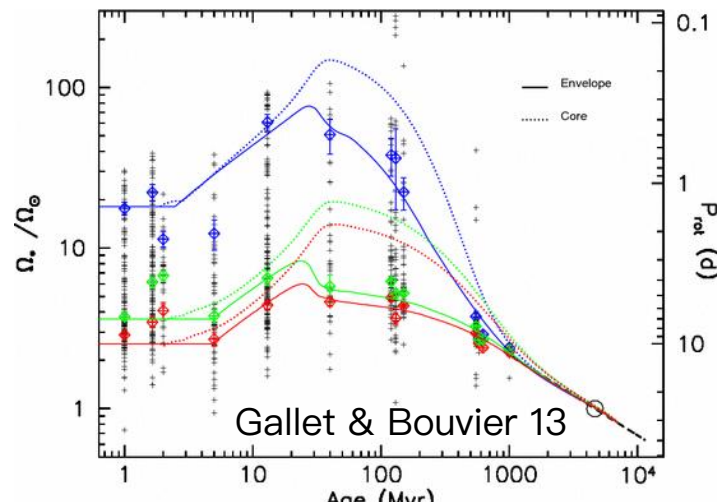
TABLE 1
SUPERFLARES

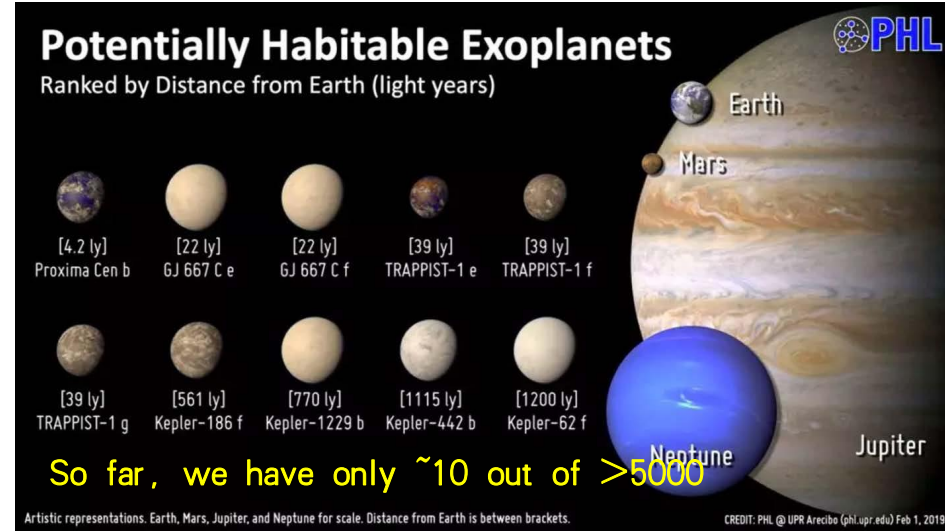
Star	Detector	V_{normal}	Amplitude	Duration	Energy (ergs)
Gmb 1830	Photography	6.45	$\Delta B = 0.62$ mag	18 minutes	$E_B \sim 1 \times 10^{35}$
κ Cet	Spectroscopy	4.83	$\text{EW(He)} = 0.13 \text{ \AA}$	~ 40 minutes	$E \sim 2 \times 10^{34}$
MT Tau	Photography	16.8	$\Delta U = 0.7$ mag	~ 10 minutes	$E_U \sim 1 \times 10^{35}$
π^1 UMa	X-ray	5.64	$L_X = 10^{29}$ ergs s^{-1}	$> \sim 35$ minutes	$E_X = 2 \times 10^{33}$
S For	Visual	8.64	$\Delta V \sim 3$ mag	17–367 minutes	$E_V \sim 2 \times 10^{38}$
BD + $10^\circ 2783$	X-ray	10.0	$L_X = 2 \times 10^{31}$ ergs s^{-1}	~ 49 minutes	$E_X \geq 3 \times 10^{34}$
σ Aql	Photometry	5.11	$\Delta V = 0.09$ mag	~ 5 –15 days	$E_{BV} \approx 9 \times 10^{37}$
5 Ser	Photometry	5.06	$\Delta V = 0.09$ mag	~ 3 –25 days	$E_{BV} \approx 7 \times 10^{37}$
UU CrB	Photometry	8.63	$\Delta I = 0.30$ mag	$> \sim 57$ minutes	$E_{\text{opt}} = 7 \times 10^{35}$

Shaefer+00

Evolution history of stellar rotation

Habitability of exoplanet





Habitable planets:

- $0.2-5M_{\oplus}$ for permanent atmosphere
- Surface temperature $0-80^{\circ}\text{C}$ for liquid water

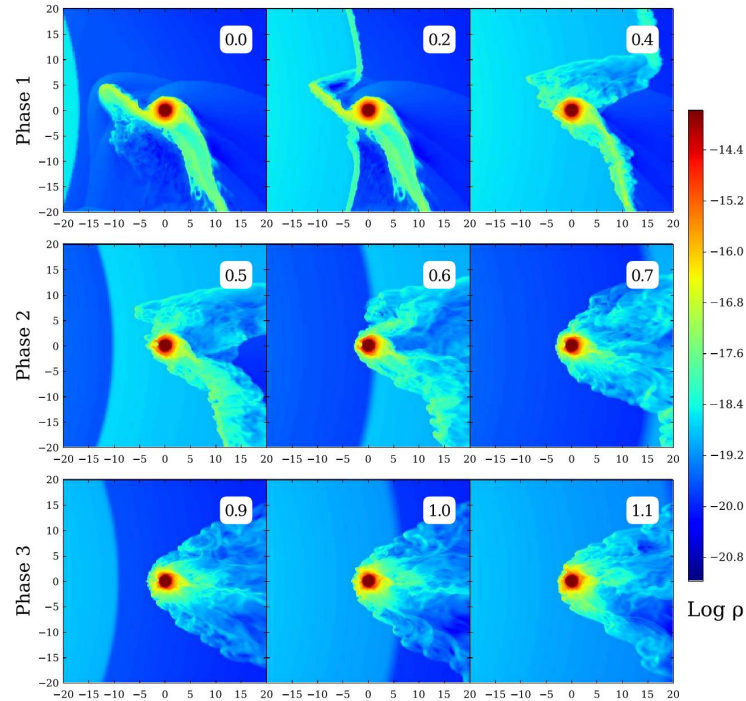
Space weather is expected in these system, which determines the **habitability** (Airapetian+16; Barnes+16)



- The space weather depends on stellar activities, which is lack of observations.
- Monitors of stellar activities, especially **CME**, is a task of top priority

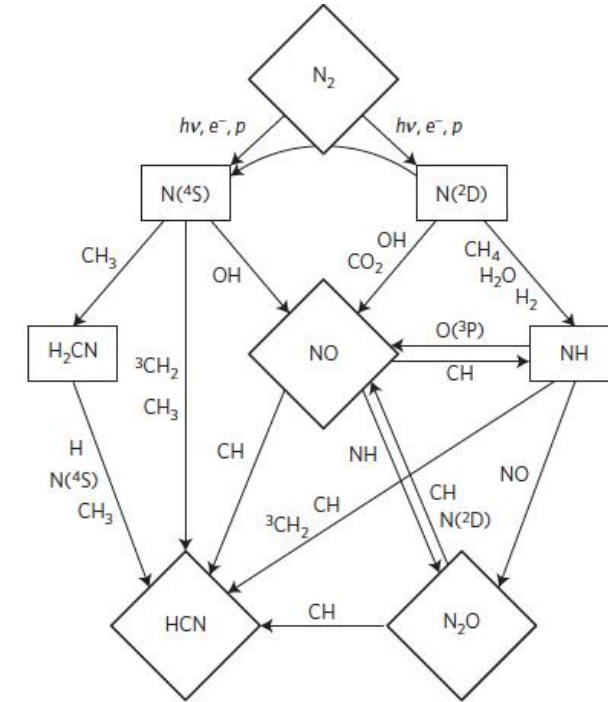
- In principle: habitability depends on stellar activity
- In debate (See talks in May 28)

Phy: negative



Corrosion & detachment
(e.g., Cerenkov+17)

Chem: positive



Greenhouse gases
(e.g., Airapetian+16; Barnes+16)

Direct obs evi: Stellar activity investigation

Potential Chromospheric Evaporation in the M Dwarf's Flare Triggered by Einstein Probe Mission

CROSSIDAR

J. Wang^{1,2,3} , X. Mao^{1,4}, C. Gao^{1,2,4}, H. Y. Liu¹ , H. L. Li¹ , H. W. Pan¹, C. Wu^{1,4}, Y. Liu¹, G. W. Li¹ , L. P. Xin¹ ,
S. Jin^{1,2,4}, D. W. Xu^{1,4}, E. W. Liang^{2,3} , W. M. Yuan¹, and J. Y. Wei^{1,4}

¹ Key Laboratory of Space Astronomy and Technology, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, People's Republic of China; wj@nao.cas.cn, liuheyang@nao.cas.cn

² Guangxi Key Laboratory for Relativistic Astrophysics, School of Physical Science and Technology, Guangxi University, Nanning 530004, People's Republic of China

³ GXU-NAOC Center for Astrophysics and Space Sciences, Nanning 530004, People's Republic of China

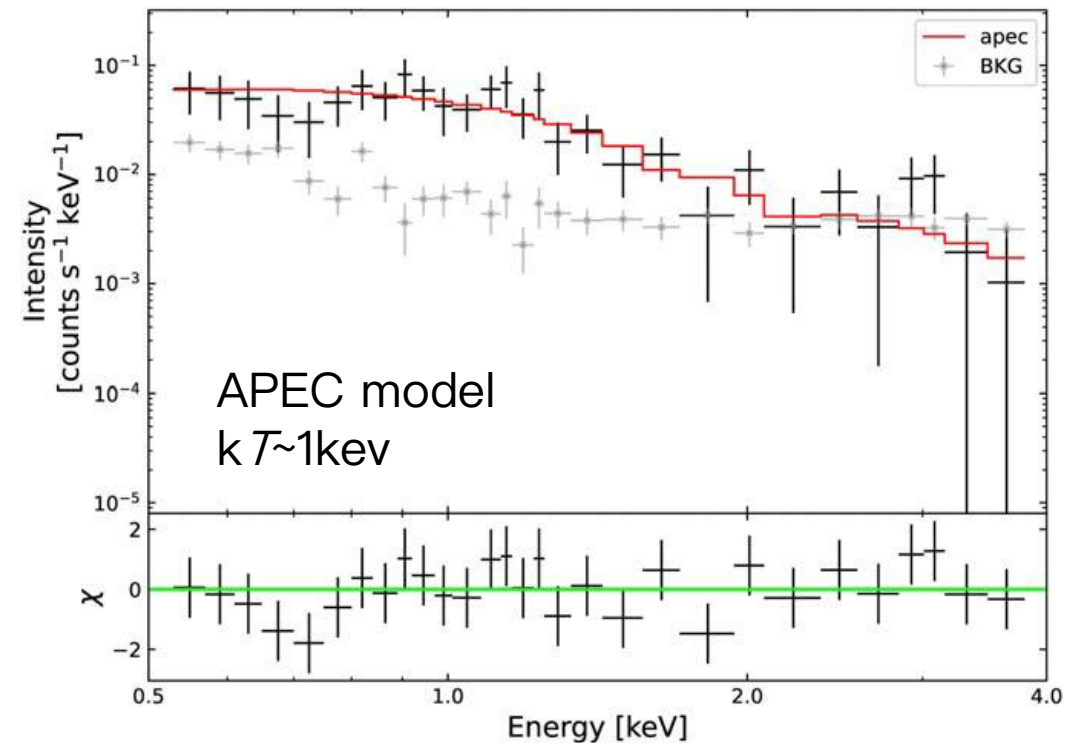
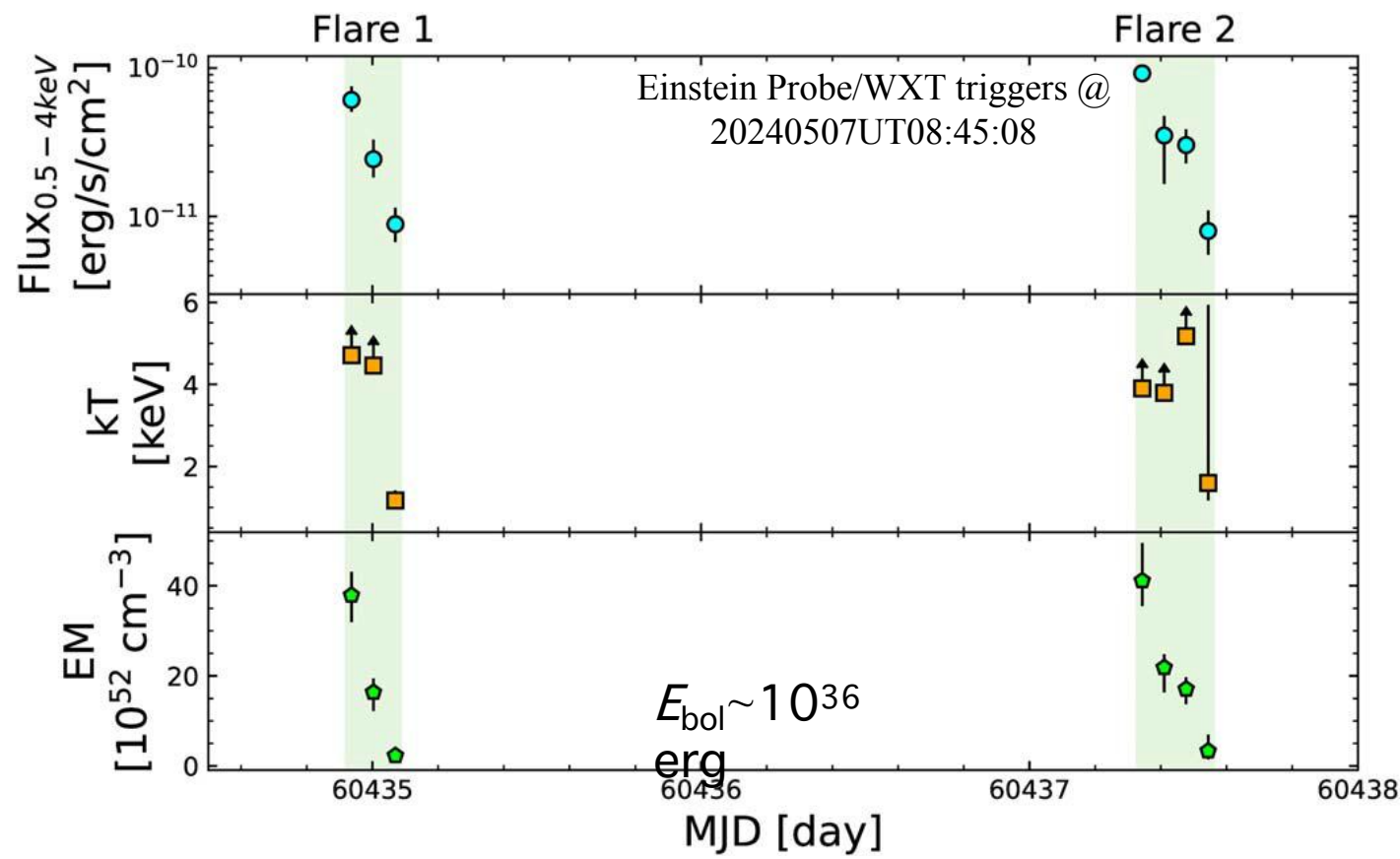
⁴ School of Astronomy and Space Science, University of Chinese Academy of Sciences, Beijing, People's Republic of China

Received 2024 August 25; revised 2024 September 30; accepted 2024 October 1; published 2024 November 14

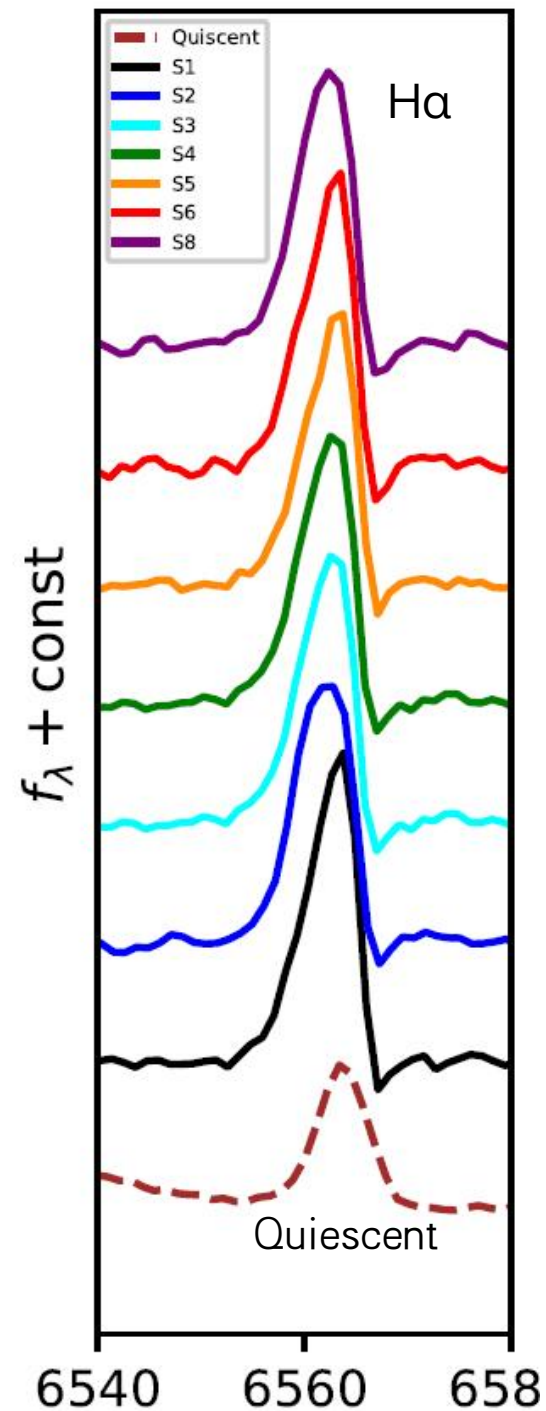
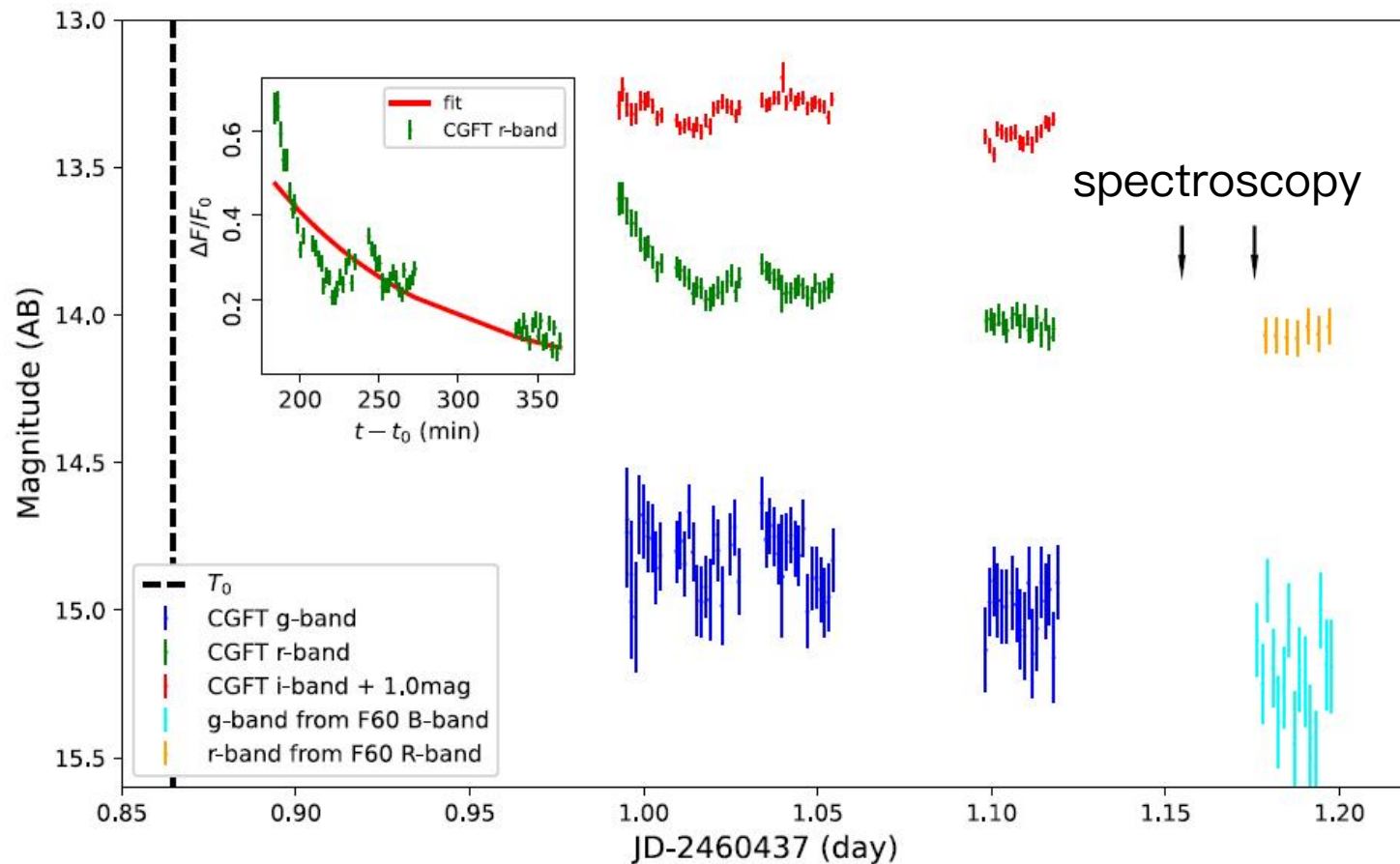


2MASS J12184187–0609123: A High Proper Motion M–dwarf

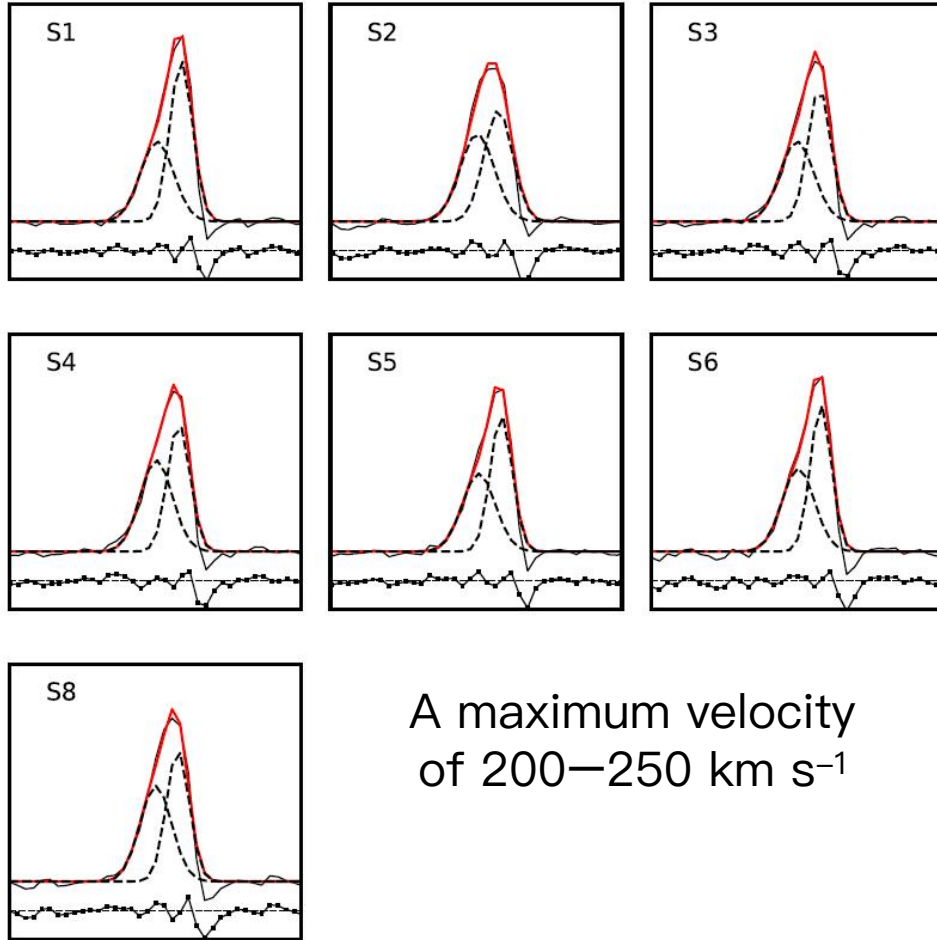
EP240507a



Multi wavelength follow-ups



Blue wing of H α



A maximum velocity
of 200–250 km s⁻¹

Scenario	Mass
chromospheric evaporation	1.2×10^{18} g
prominence eruption	7×10^{15} g $\sim 7 \times 10^{18}$ g

Case 2

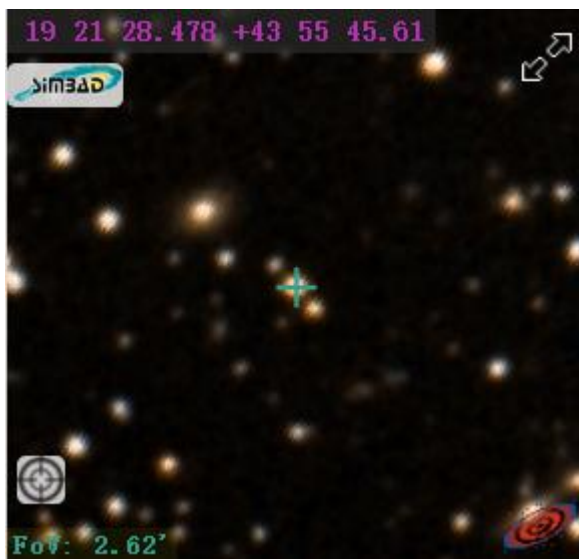
Possible Detection of a Flare-associated Coronal Mass Ejection on an M-dwarf

J. Wang^{1,2}

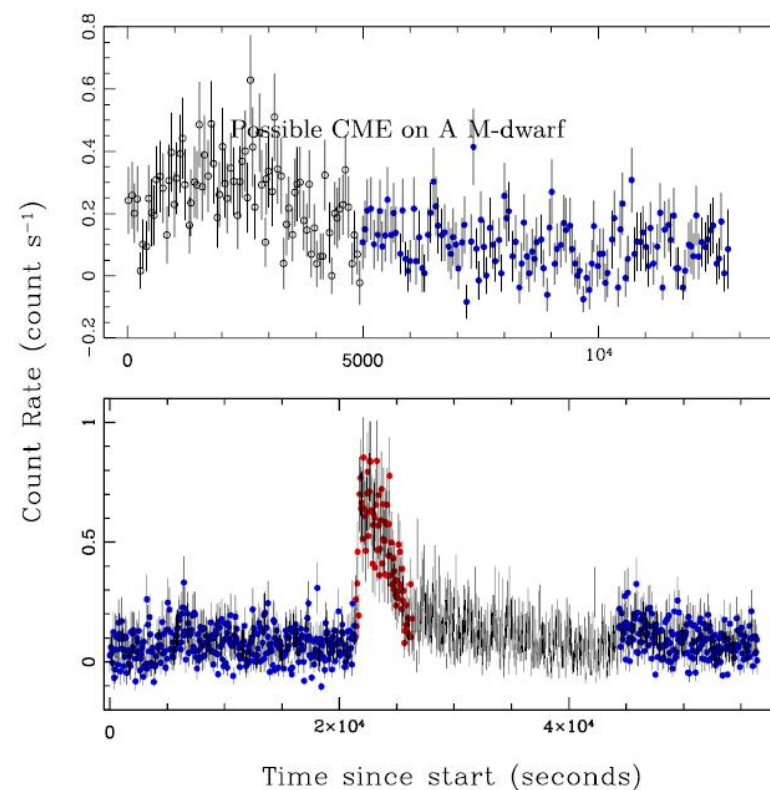
¹ Guangxi Key Laboratory for Relativistic Astrophysics, School of Physical Science and Technology, Guangxi University, Nanning 530004, China; wj@nao.cas.cn

² Key Laboratory of Space Astronomy and Technology, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, China

Received 2023 March 2; revised 2023 April 25; accepted 2023 May 12; published 2023 August 10



KIC 8093473 : BY Dra
Variable



XMM-Newton X-ray light curves in
0.2–12 keV

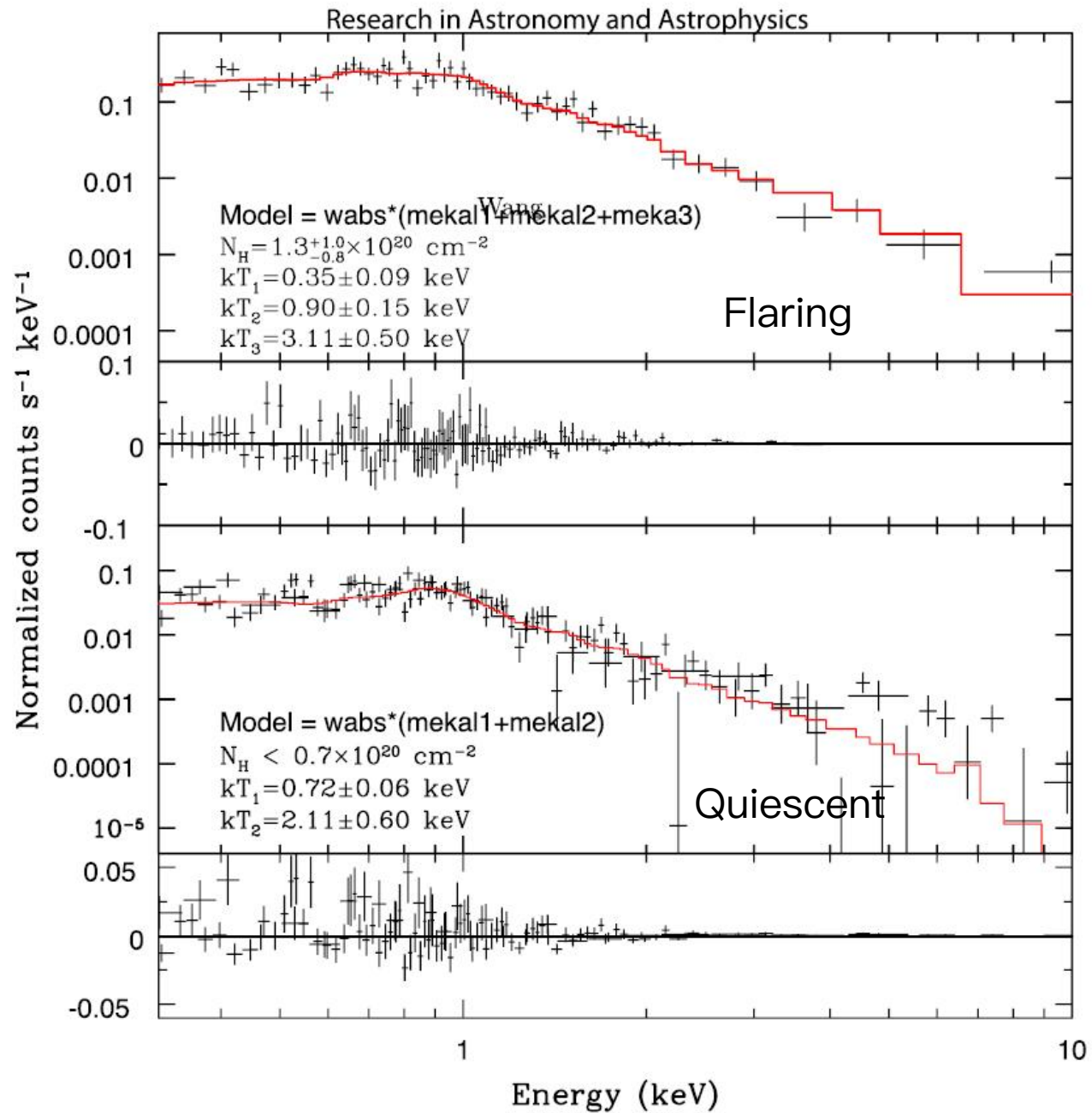
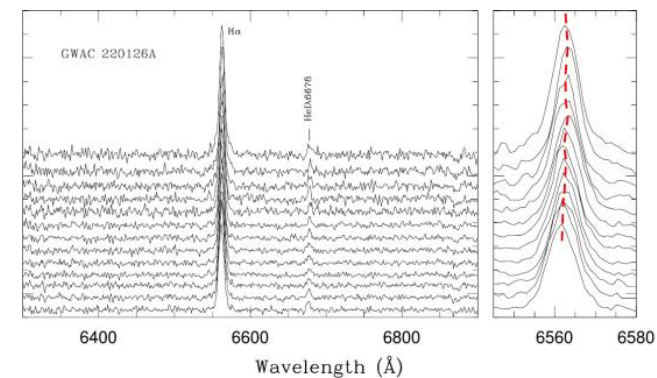
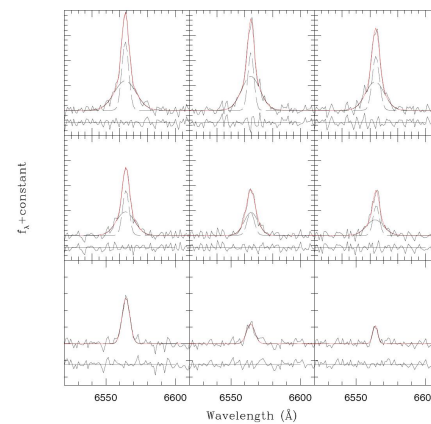
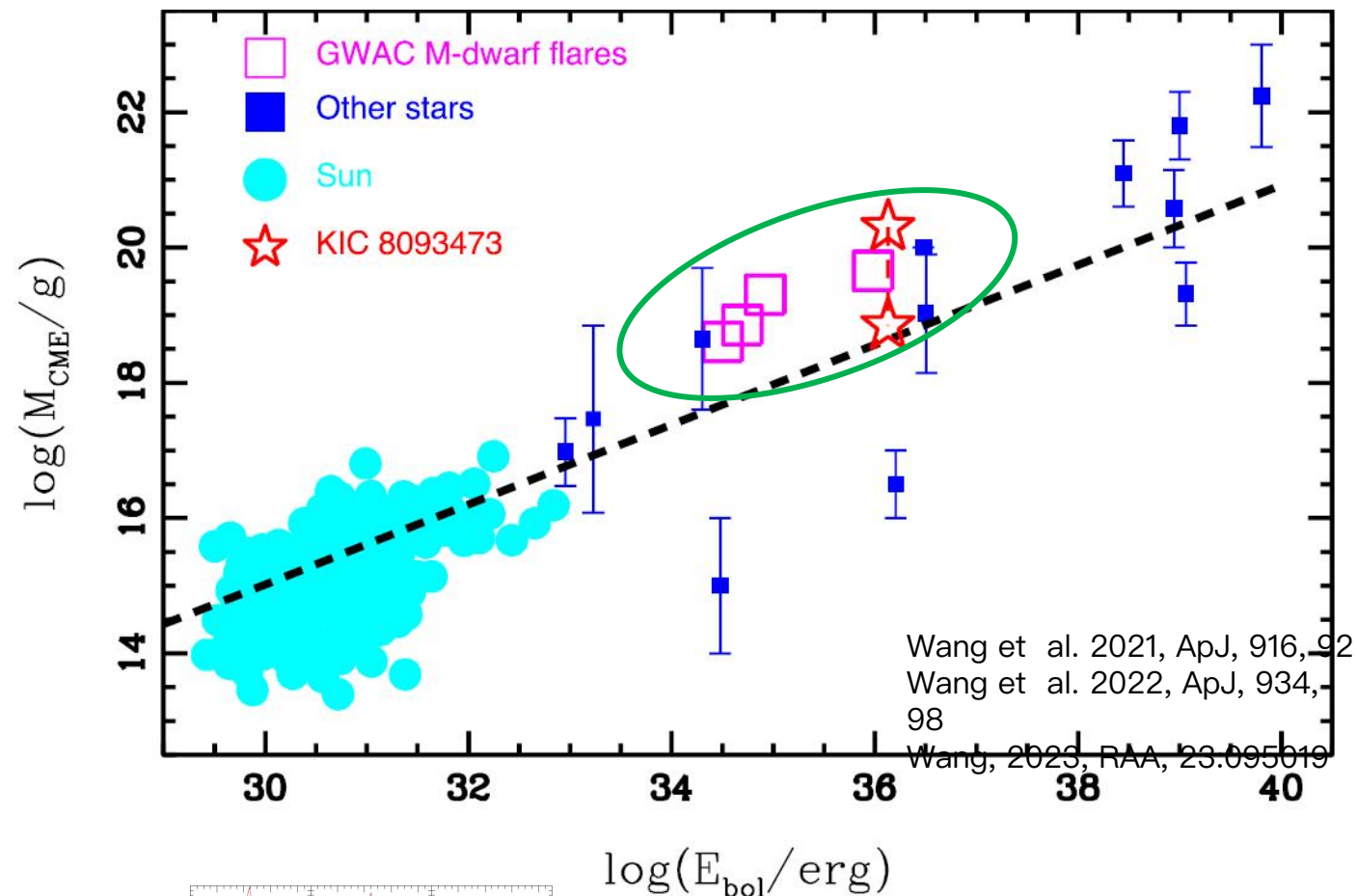
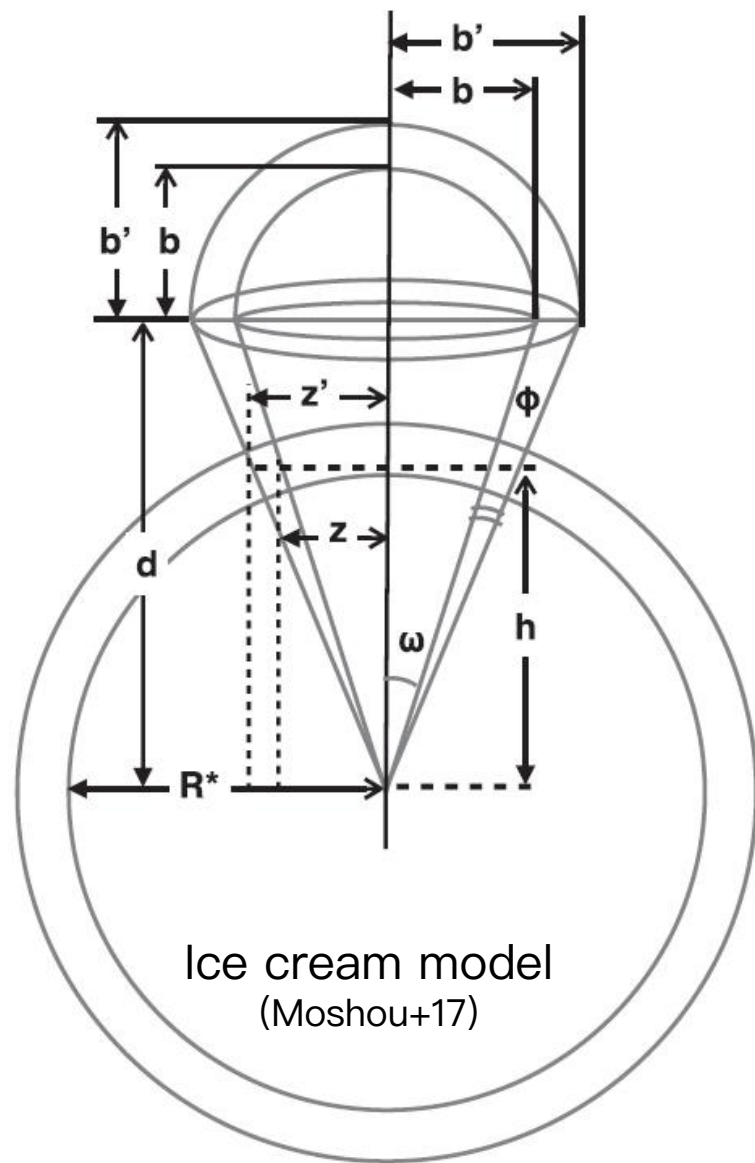


Table 1
XMM-Newton EPIC PN X-Ray Spectral Fit Parameters for the Flaring and Quiescent States of KIC 8093473

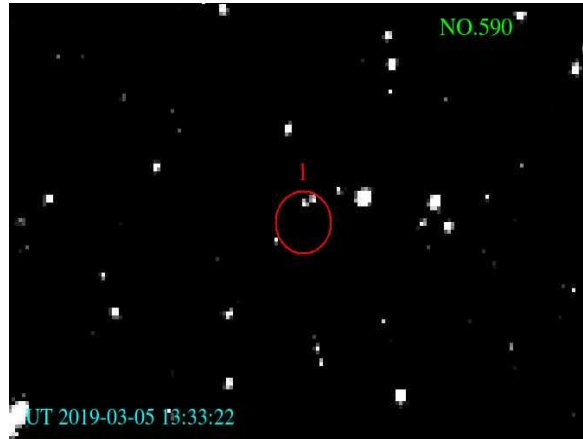
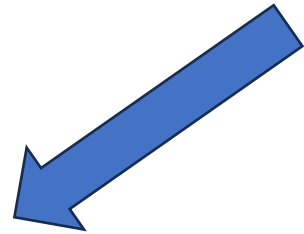
Parameter (1)	Value (2)	Unit (3)	Description (4)
Flare			
N_{H}	$1.3^{+1.0}_{-0.8}$	10^{20} cm^{-2}	Interstellar column density
kT_1	0.35 ± 0.09	keV	Plasma temperature
kT_2	0.90 ± 0.15	keV	Plasma temperature
kT_3	3.11 ± 0.50	keV	Plasma temperature
Cash statistic	$64.16/54 = 1.178$		
Flare+tail			
N_{H}	$0.9^{+0.7}_{-0.7}$	10^{20} cm^{-2}	Interstellar column density
kT_1	0.35 ± 0.06	keV	Plasma temperature
kT_2	0.94 ± 0.16	keV	Plasma temperature
kT_3	2.47 ± 0.40	keV	Plasma temperature
Cash statistic	$114.16/118 = 0.967$		
Quiescent			
N_{H}	<0.7	10^{20} cm^{-2}	Interstellar column density
kT_1	0.72 ± 0.06	keV	Plasma temperature
kT_2	2.11 ± 0.60	keV	Plasma temperature
Cash statistic	$82.39/64 = 1.287$		

Decreasing N_H : Indicator of CME



Superflares of M-dwarfs detected by GWAC

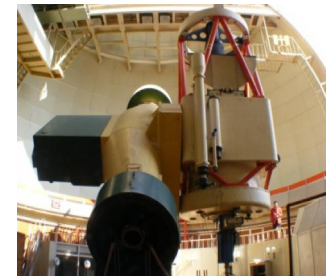
- Fast follow-up in Multi wavelength



→
 $T_0+2\text{min}$



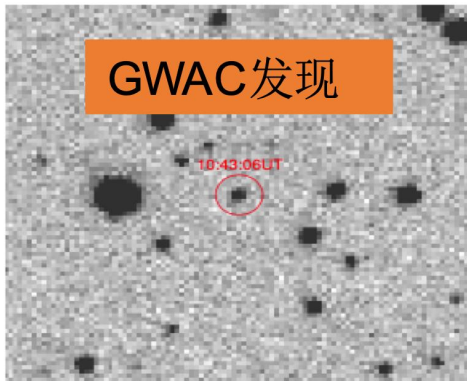
→
 $T_0+5\text{min}$



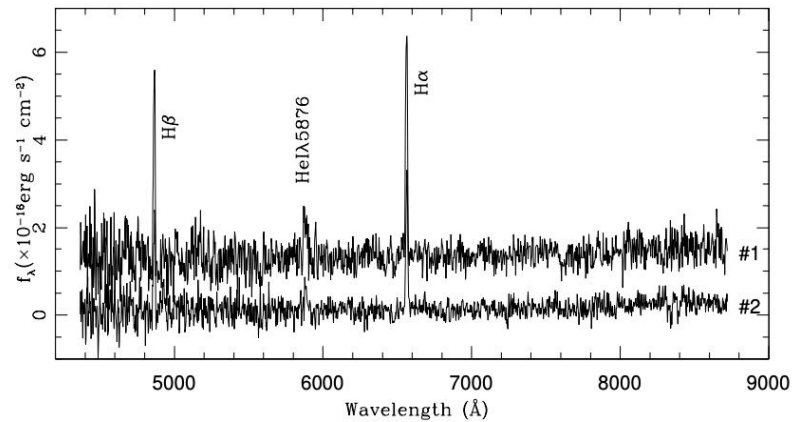
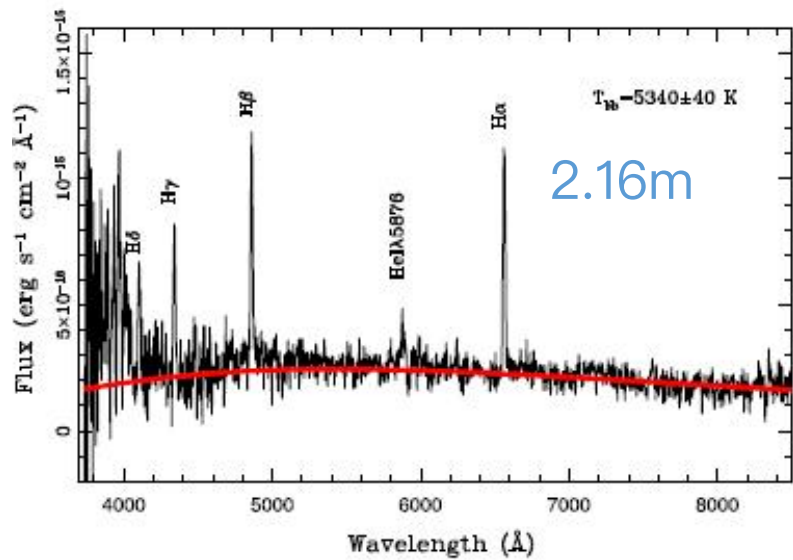
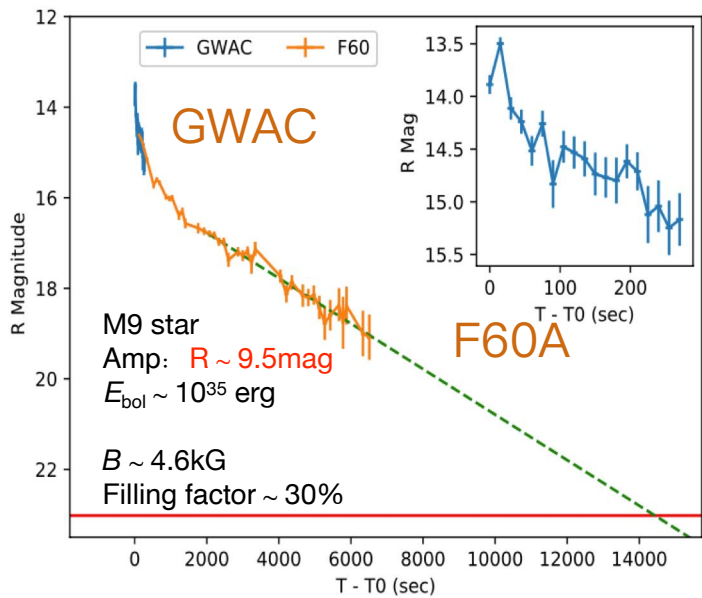
GWAC+F60+2.16

Object	T_0 (BTime)	ΔT_1 (min)	ΔT_2 (min)	ΔT_{tot} (min)	Comments
G201221_C20405	25:50:36	~16	~23	40.55	G8/HaBL
G210108_C12599	24:25:07	~8	~12	~20	G8/No HaBL
G210111_C23283	29:01:45	~8	~12	~20	G8/No HaBL
G210117_C09392	24:06:33	~13	~12	25.50	G8/Weak HaBL
G211104_C09370	24:50:17	~5	~7	~12	False positive (YSO)/Stop loss
G211229_C07135	19:48:49	~11	~20	30.15	G8/HaBL
G220106_C03574	19:19:28	~6	~11	16.30	G8/HaBL
G220126_C05272	20:42:04	~13	~31	43.93	G4/2.3"/abnormal line profile
G220204_C14956	27:38:35	~11	~10	20.12	EW binary, sdMe, No HaBL
EV Lac	23:25:59	~5	~11	~16	False trigger

Superflares of M-dwarfs detected by GWAC



GWAC	ΔR (mag)	Sp. T	Energy (erg/s)	B (kG)
181229A	~9.5	M9	$\sim 10^{35}$	~4.6
220525 A	8.6	L0	$(6.4 \pm 0.7) \times 10^{33}$	~1.3

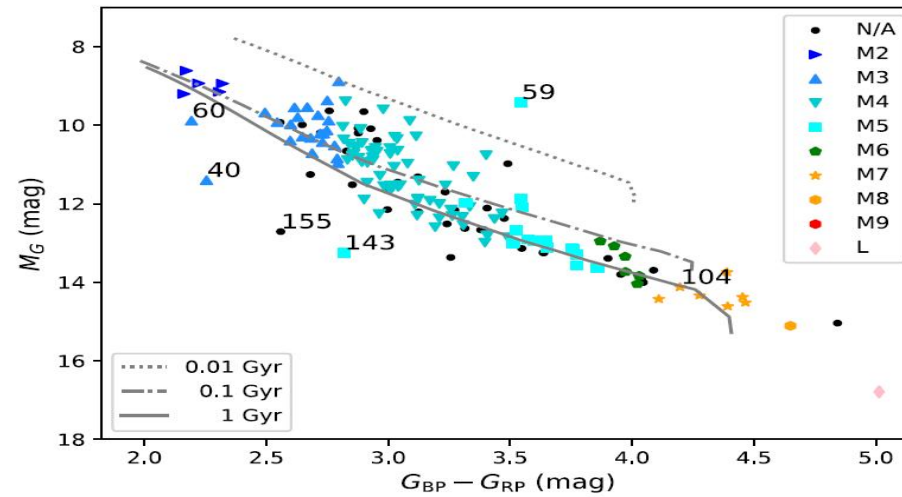
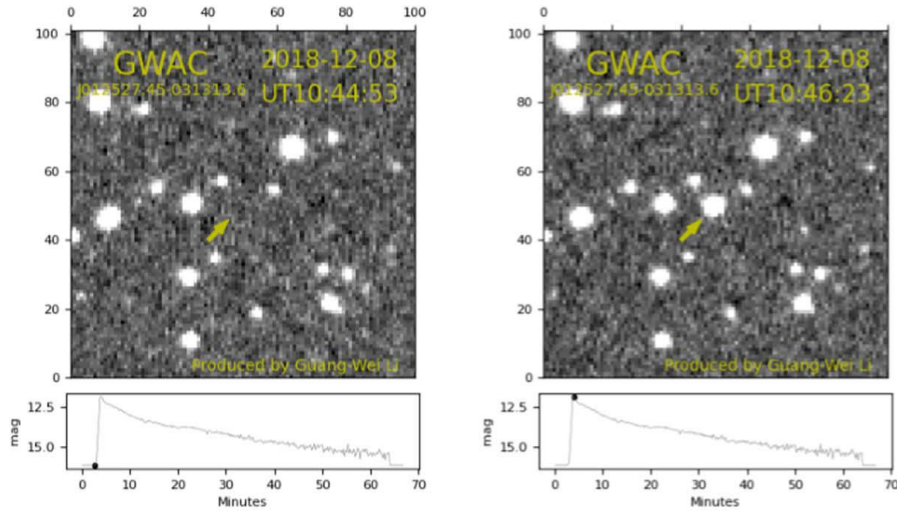


181229A

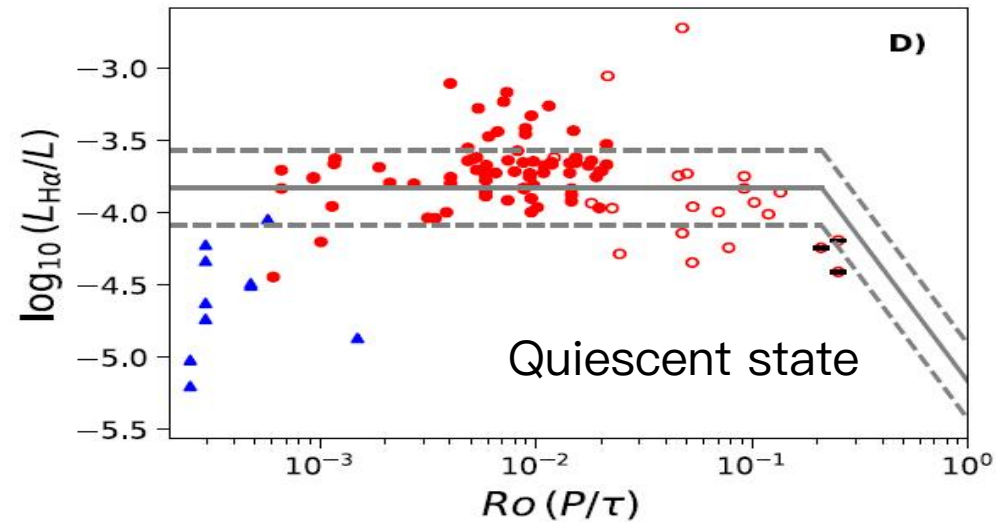
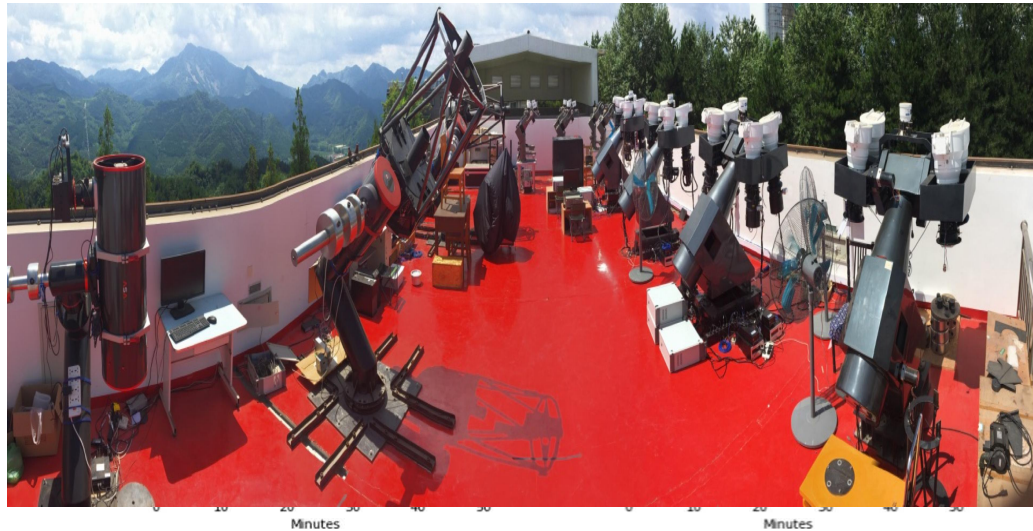
Xin et al. 2021, ApJ
Xin et al. 2024, MNRAS

Superflares of M-dwarfs detected by GWAC

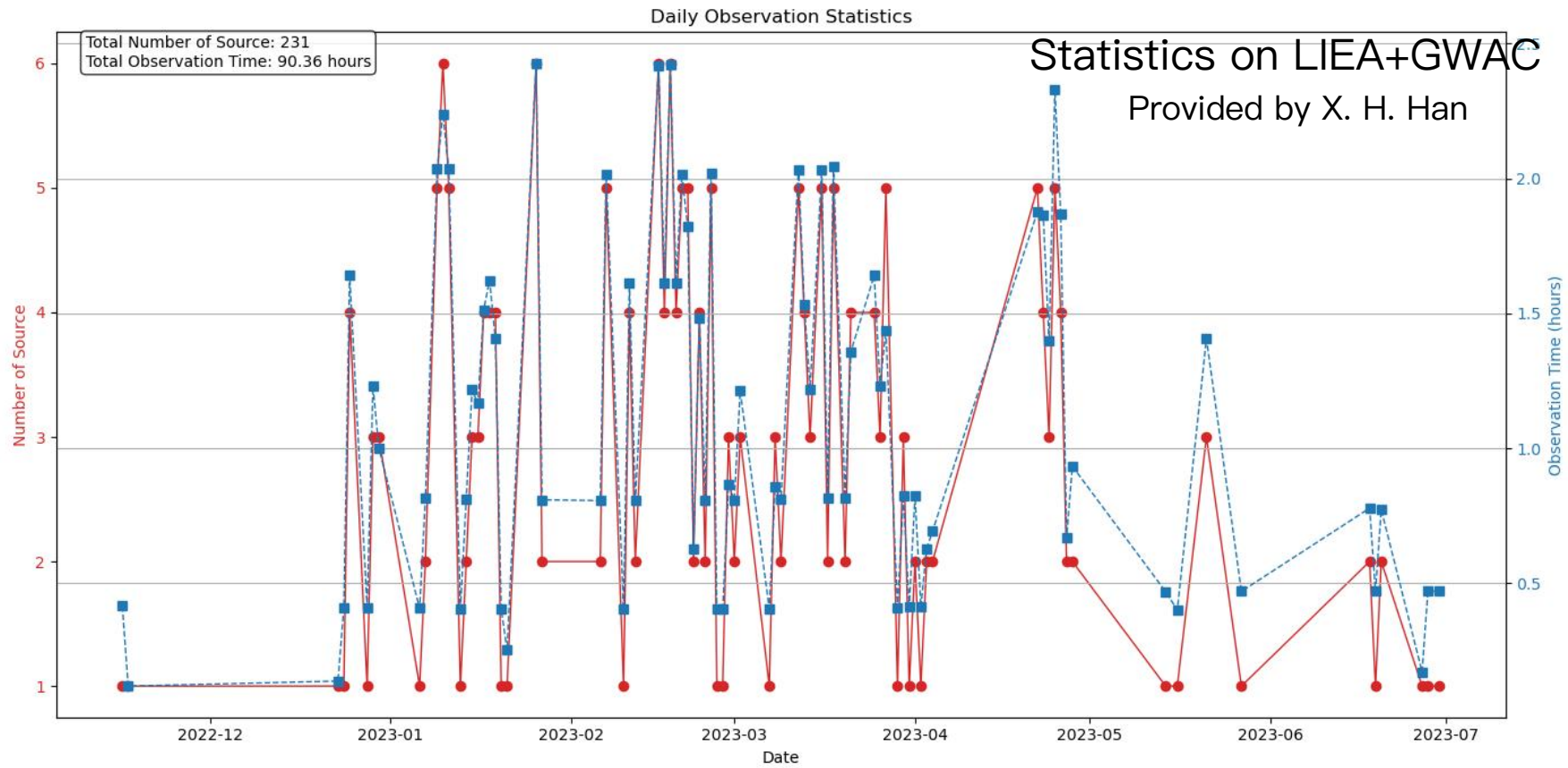
Young & saturated late-type stars
(Li et al. 2024, ApJ)



163 flares from GWAC



Suggestion on Multi wavelength study with EP



231

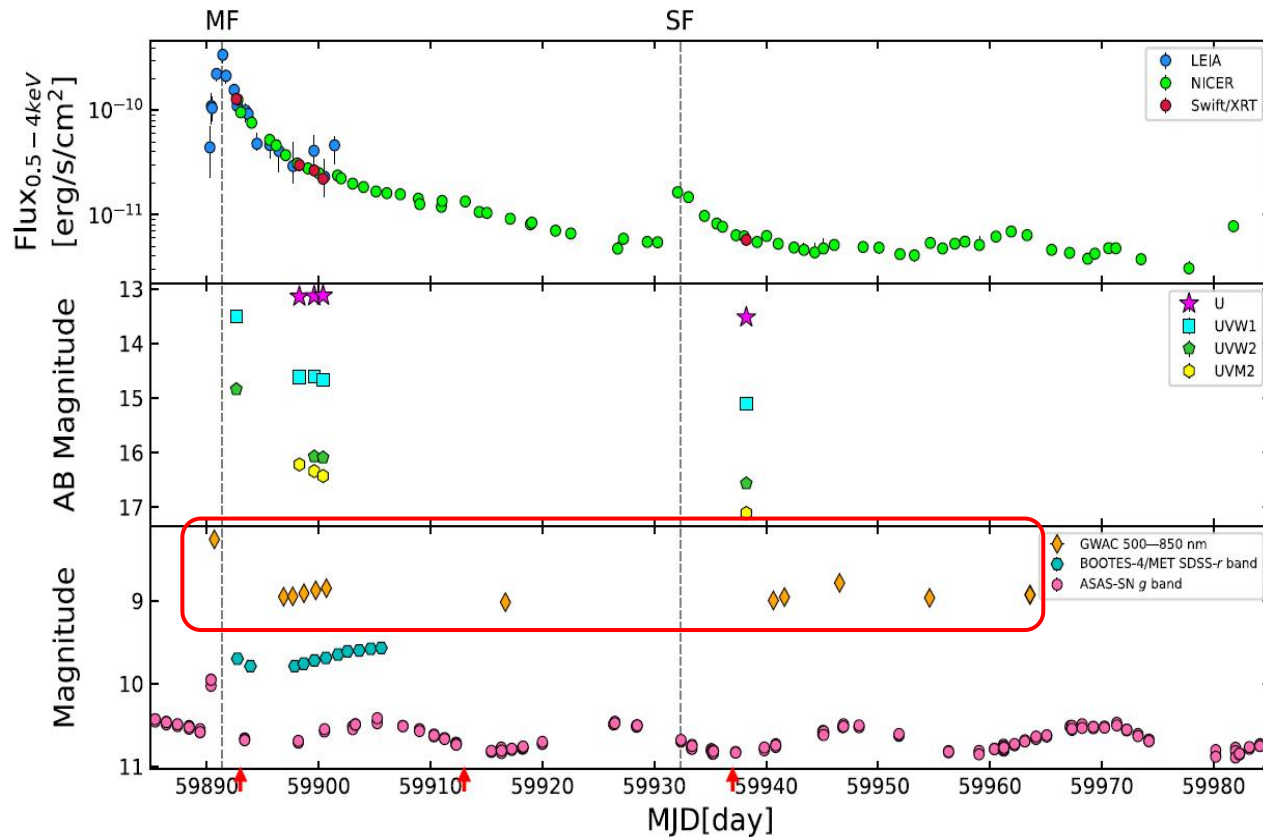
Total pointings

~90hrs

Total duration

Suggestion on Multi wavelength study with EP

- EP + GWAC simultaneous survey

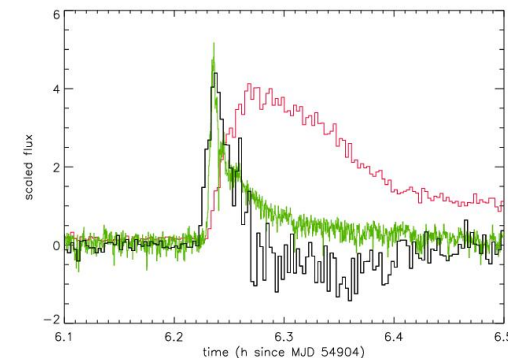


Multi- λ of flare on HD 251108 triggered by LIEA (Mao+ 25)

Scientific motivation

- Relation between X-ray & WL
- Neupert effect or not (Neupert 68)

$$\frac{dI_{SXR}}{dt} = I_{\mu} \quad \frac{dI_{SXR}}{dt} = I_{HXR}$$



Fuhrmeister+11

Conclusion

- Complex dynamics can be revealed in stellar flares including
 - ✓ CME
 - ✓ Chromospheric evaporation
 - ✓ Prominence eruptionby follow-up in multi-wavelength.
- EP + GWAC simultaneous survey is expected to play important role in studying stellar flares.

The End

Thanks