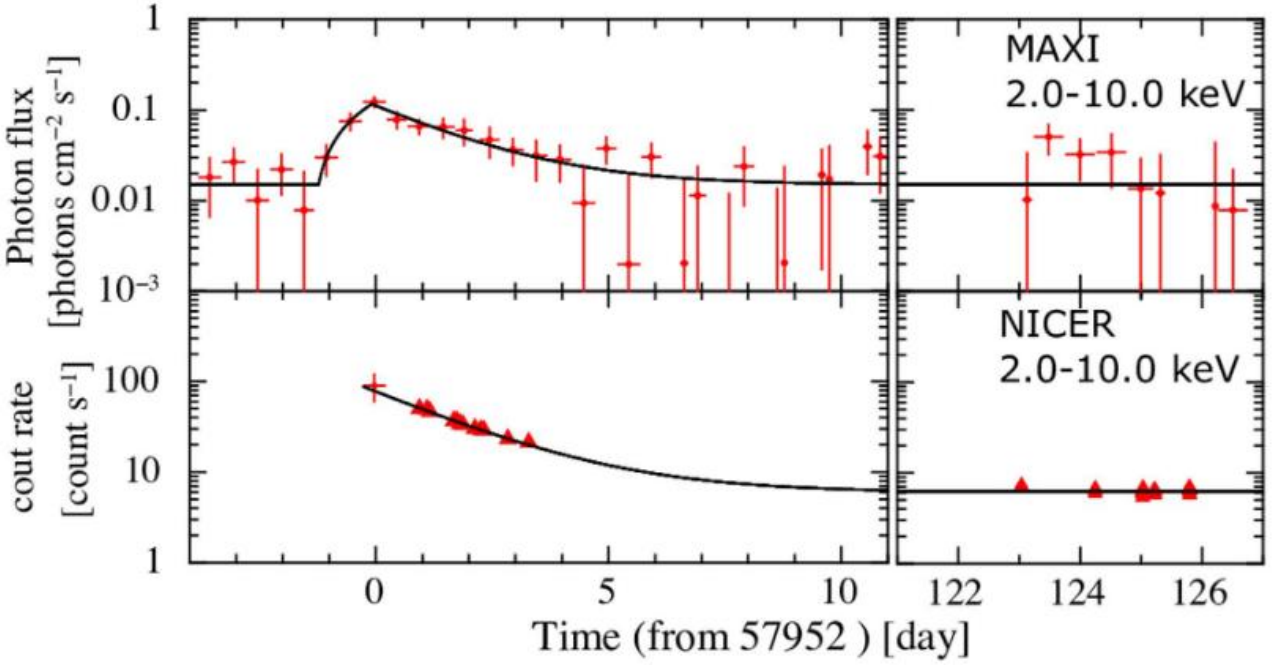
天关对恒星 X 射线耀发大样本观测的初步结果

报告人：毛选　　单位：国家天文台

2025年5月27日

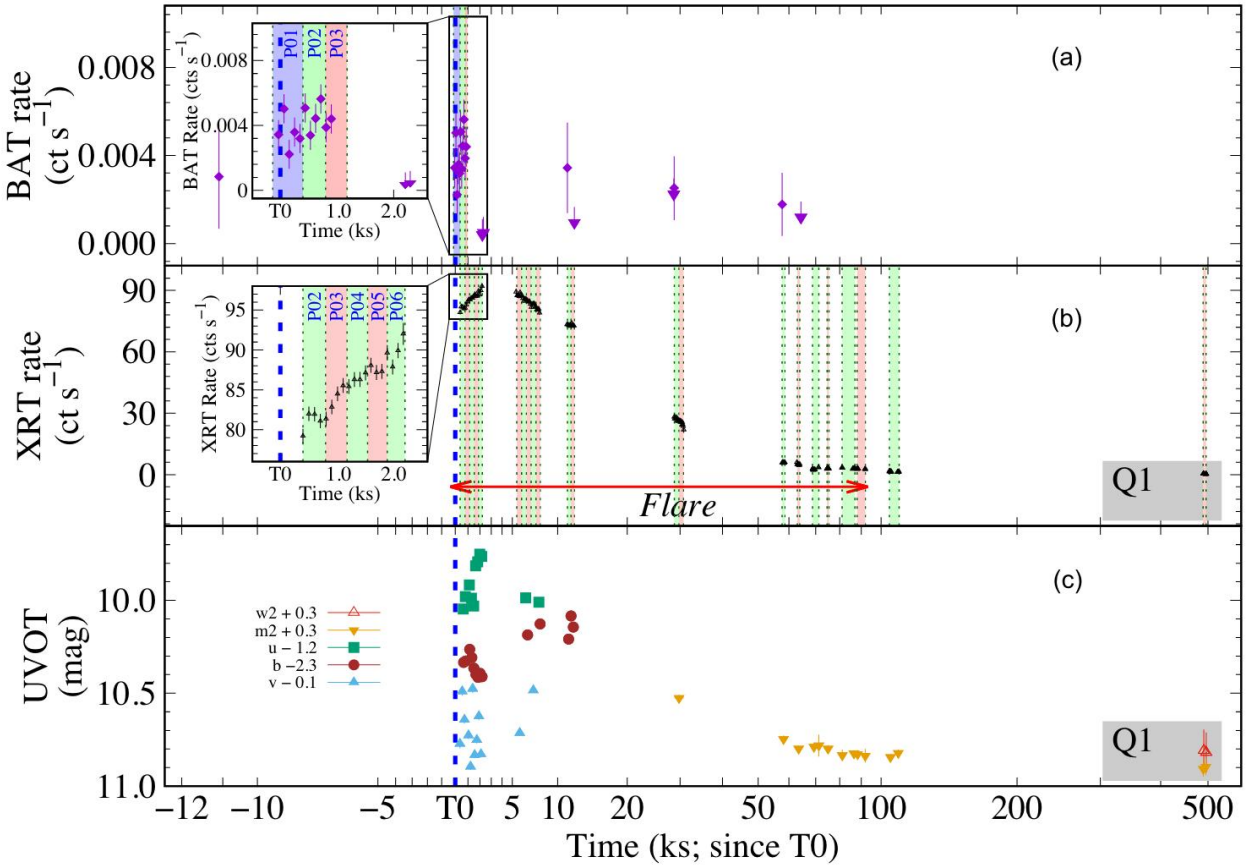
EP之前的恒星X射线耀发探测：个源研究

- MAXI/Gas Slit Camera(GSC)



Sasaki+ 2021

- Swift/Burst Alert Telescope(BAT)



Karmakar+ 2022

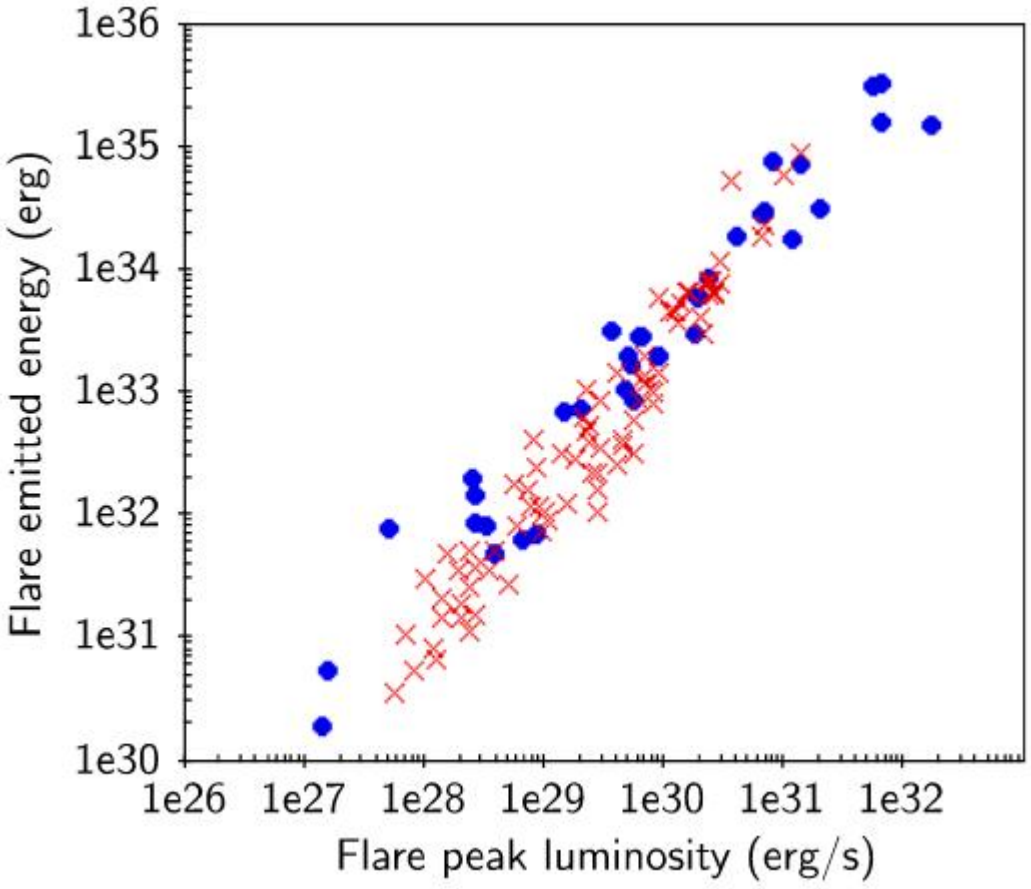
EP之前的恒星X射线耀发探测：样本研究

1．巡天中的偶发探测

Variability type	Sample	Number of stars	Number of light-curves	Number of events Total	Number of events Completely observed
Flare	CVS	63 (30)	76 (32)	133 (39)	116 (34)
	CLVS	8 (4)	8 (4)	11 (4)	11 (4)
	CVS+CLVS	70 (34)	84 (36)	144 (43)	127 (38)
Trend	CVS	10 (1)	11 (1)	11 (1)	
Gradual	CVS	3 (1)	3 (1)	3 (1)	
	CLVS	1 (0)	2 (0)	2 (0)	
Indeterminate	CVS	6 (5)	6 (5)	6 (5)	
	CLVS	2 (0)	2 (0)	2 (0)	
Poor bgd sub?[a]	CVS	2 (0)	2 (0)	2 (0)	
All	CVS	76 (36)	96 (39)		
	CLVS	11 (4)	12 (4)		
	CVS+CLVS	84 (40)	108 (43)		

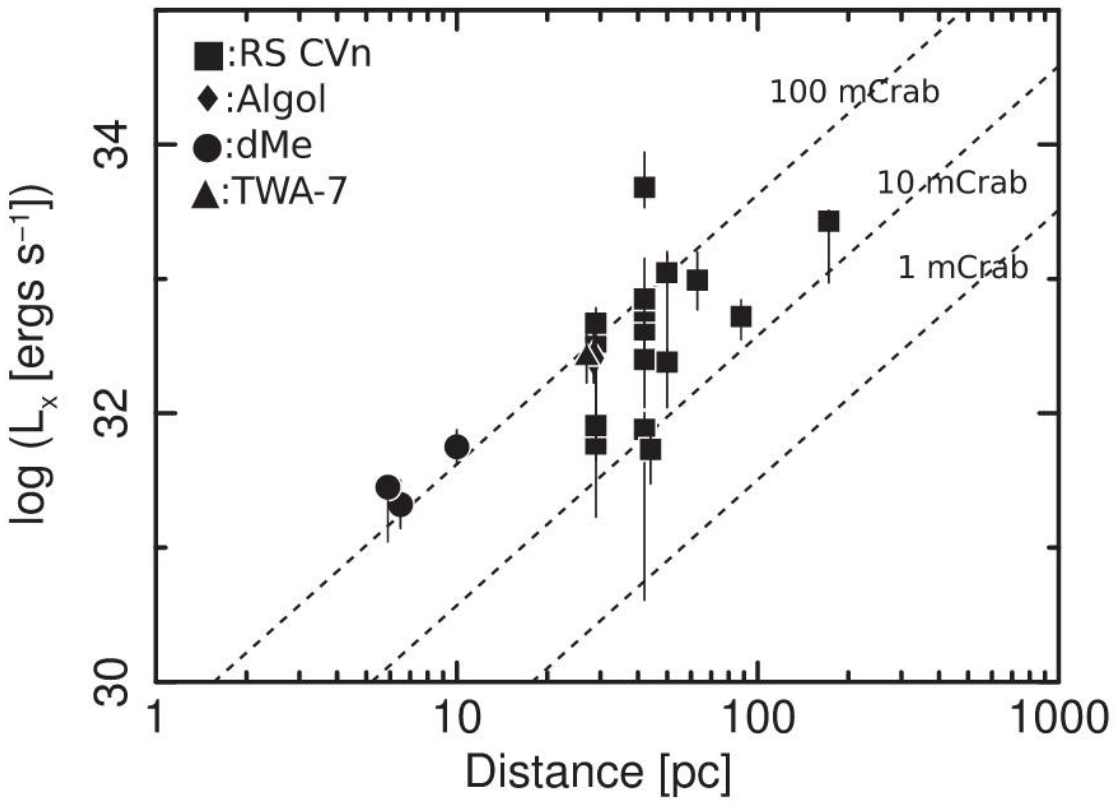
Pye+ 2015

- ~70颗恒星
- ~130次耀发

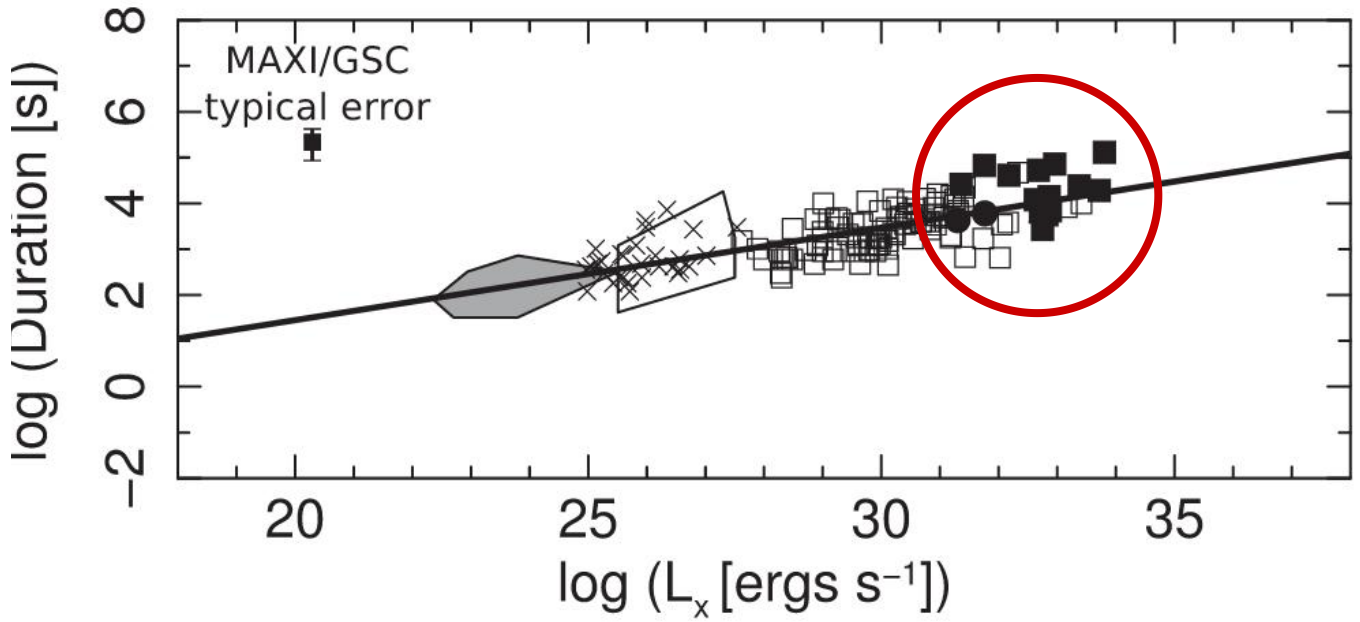


EP之前的恒星X射线耀发探测：样本研究

2. 全天监测设备的探测



- 2年间探测到23次耀发，峰值10^{31-34} erg/s（2-20keV）



Tsuboi+ 2017

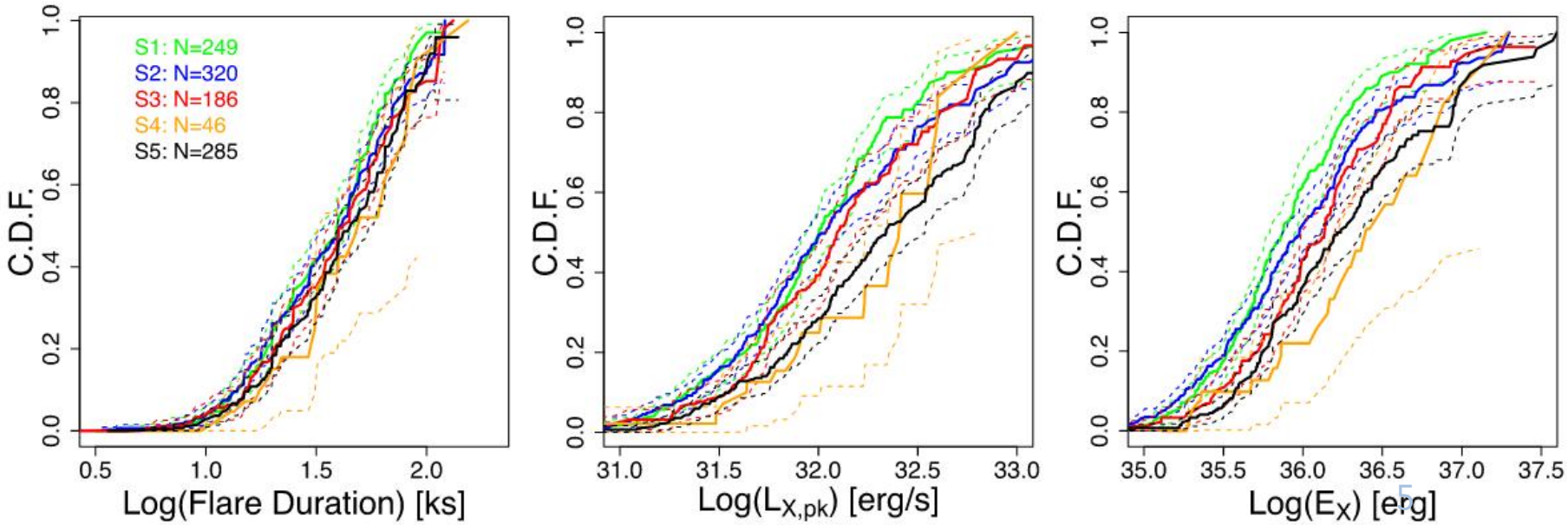
EP之前的X射线恒星耀发探测：样本研究

3．恒星密集区的探测

Table 1
MYStIX and SFiNCs Regions

Region	R.A. (deg)	Decl. (deg)	Dis. (pc)	$N_{X,obs}$	N_{tot}	Region	R.A. (deg)	Decl. (deg)	Dis. (pc)	$N_{X,obs}$	N_{tot}
(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Be 59	0.6	67.4	1100	464	1703	NGC 2264	100.3	9.6	738	898	1837
BRC 2	1.0	68.5	1100	42	142	NGC 2362	109.7	−25.0	1332	467	512
Carina Neb.	161.2	−59.7	2620	6751	37899	NGC 3576	168.0	−61.2	2800	1131	12235
Cep A	344.1	62.0	868	194	534	NGC 6334	260.1	−35.9	1770	1385	12661
Cep B	343.9	62.6	868	1032	1773	NGC 6357	261.4	−34.3	1770	1952	12581
Cep C	346.5	62.5	868	95	247	NGC 7160	328.5	62.6	961	134	157
DR 21	309.8	42.3	1500	594	3907	OMC 2–3	83.9	−5.1	390	287	402
Eagle Neb.	274.7	−13.8	1740	2065	7762	ONC Flank N	83.8	−4.8	392	198	230
Flame Neb.	85.4	−1.9	414	422	596	ONC Flank S	83.8	−5.7	395	223	261
GGD 12–15	92.7	−6.2	830	141	300	Orion Neb.	83.8	−5.4	405	1414	1700
IC 348	56.1	32.1	324	307	284	RCW 120	258.1	−38.5	1680	262	1570
IC 5146	328.4	47.3	783	161	272	RCW 36	134.9	−43.8	930	337	1228
IRAS 20050	301.8	27.5	700	213	308	RCW 38	134.8	−47.5	1700	813	5750
LDN 1251B	339.7	75.2	300	39	39						
Lagoon Neb.	271.0	−24.4	1336	1828	5058						
Lkhα 101	67.5	35.3	564	197	311						
M17	275.1	−16.2	1680	2296	13412						
Mon R2	91.9	−6.4	948	410	882						
NGC 1333	52.3	31.3	296	116	111						
NGC 1893	80.7	33.4	3790	1110	5977						
NGC 2068	86.7	0.1	414	231	335						

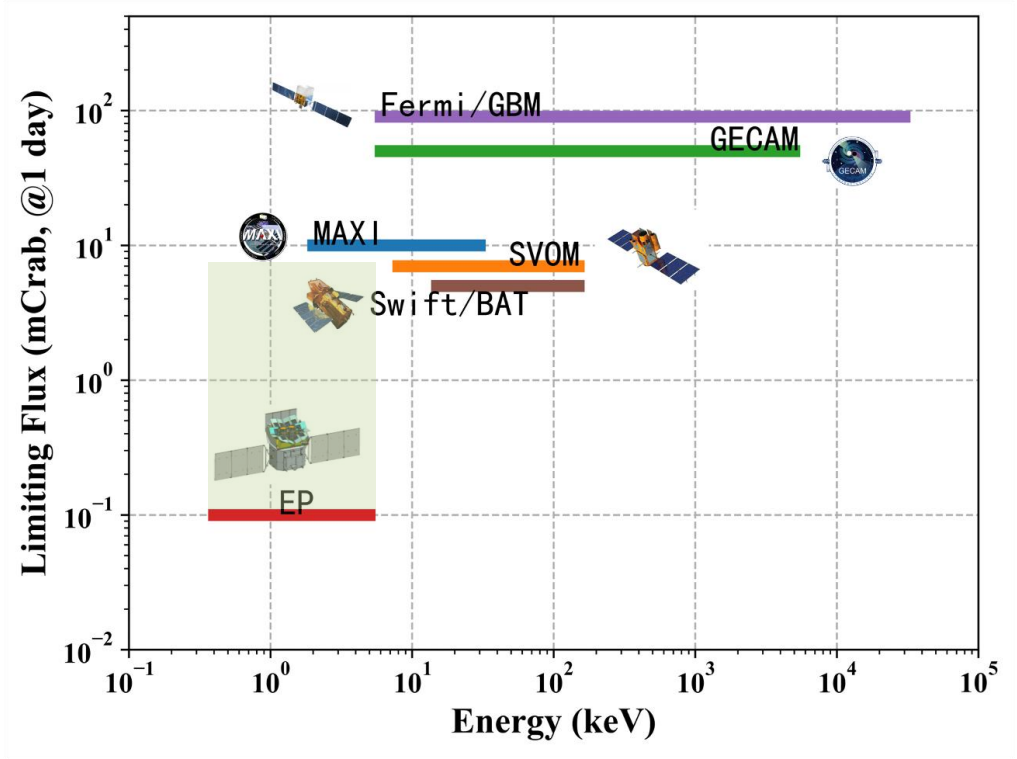
- 主序前星的1086次耀发

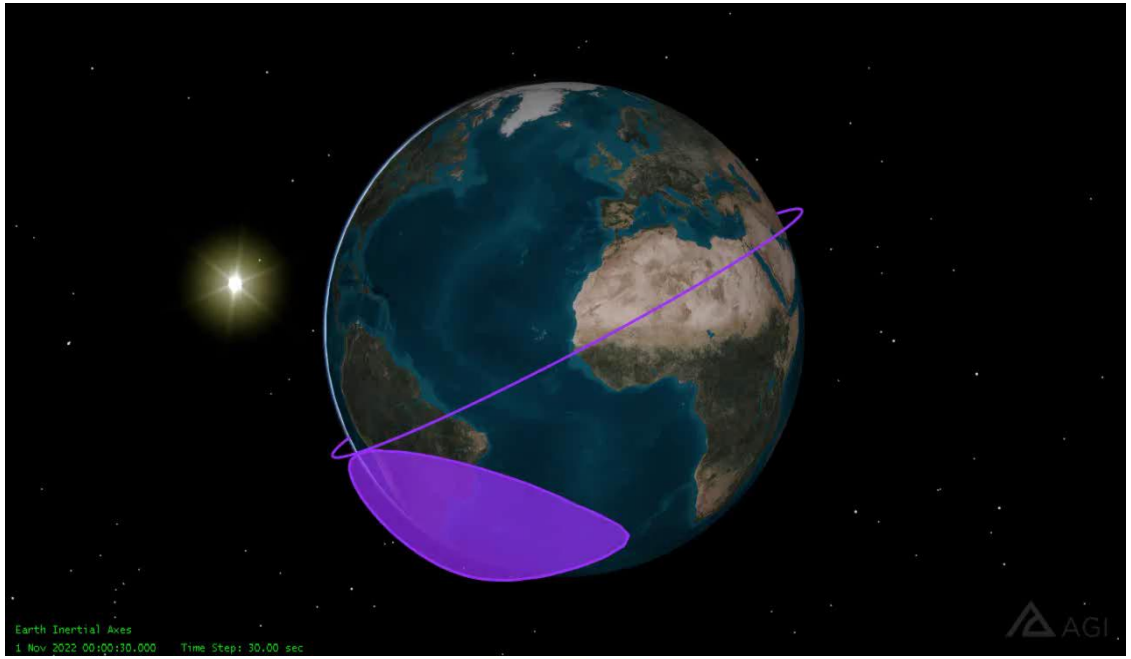


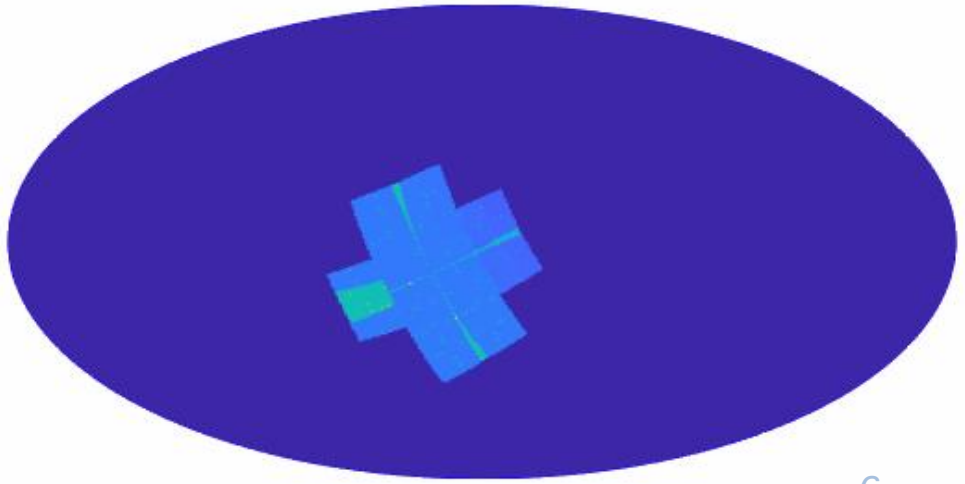
Getman&Feigelson 2021

EP观测模式

- 轨道
  - 高度592 km, 轨道周期 96min
- 巡天模式
  - 每轨**3**个指向，每个指向 **~20min**
  - **3**轨覆盖夜天区 （约**5**个小时）
  - 半年覆盖全天







耀发恒星列表

Stellar Flare List

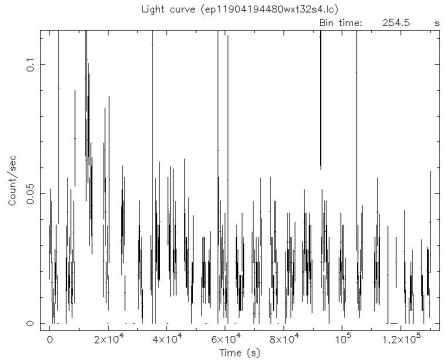
Export CSV

	Common Name	RA	Dec	Pos Err	Alert Time (UTC)	Goto	Detail	Tags	Category	CL	R_Flux
1	BD+44 2051	166.369	43.527	0.015	2024-12-16 23:59:33	◎	ℹ	known_source,stellar_flare	Star	High Proper Motion Star	3.12e-12
2	HD 028907	69.076	55.027	0.02	2024-03-01 10:11:10	◎	ℹ	known_source,stellar_flare	Star	Spectroscopic Binary	6.42e-12
3	LP 705-28	6.462	-9.961	0.042	2024-07-29 18:02:32	◎	ℹ	known_source,stellar_flare	Star	Eruptive Variable	
4	PM J17581-2222	269.526	-22.373	0.037	2024-09-17 07:40:43	◎	ℹ	known_source,stellar_flare	Star	Rotating Variable	
5	GR Mus	194.405	-69.289	0	2025-05-16 05:53:03	◎	ℹ	stellar_flare	XRB	LMXB	3.81e-12
6	HD 181321	290.374	-34.983	0.014	2025-05-11 00:20:11	◎	ℹ	known_source,stellar_flare	Star	Spectroscopic Binary	4.16e-11
7	StKM 1-2018	338.344	-9.615	0.01	2024-09-12 04:29:07	◎	ℹ	known_source,stellar_flare	Star	Double or Multiple Star	8.74e-12
8	BS Ind	320.249	-52.478	0.005	2025-05-23 00:14:34	◎	ℹ	known_source,stellar_flare	Star	Spectroscopic Binary	9.67e-12
9	TYC 3904-65-1	274.031	54.13	0.04	2024-11-03 00:04:59	◎	ℹ	known_source,stellar_flare	Star	Star	1.21e-11
10	V1362 Tau	80.543	24.536	0.018	2024-01-26 00:41:33	◎	ℹ	stellar_flare,known_source	Star	RS CVn Variable	3.92e-12
11	HD 22468	54.197	0.588	0	2024-11-25 03:08:02	◎	ℹ	known_source,stellar_flare	Star	RS CVn Variable	3.72e-12
12	EP250207a	356.902	27.027	0.037	2025-02-07 15:48:27	◎	ℹ	known_source,stellar_flare	Star	Star	
13	PM J02146+3121	33.66	31.363	0.041	2024-11-26 03:04:02	◎	ℹ	known_source,stellar_flare	Star	High Proper Motion Star	3.33e-12
14	V335 Peg	343.151	10.22	0.019	2024-12-04 09:28:47	◎	ℹ	known_source,stellar_flare	Star	Spectroscopic Binary	1.34e-11
15	UPM J1217-3644	184.448	-36.747	0.039	2025-02-06 20:16:56	◎	ℹ	known_source,stellar_flare	Star	High Proper Motion Star	4.47e-13

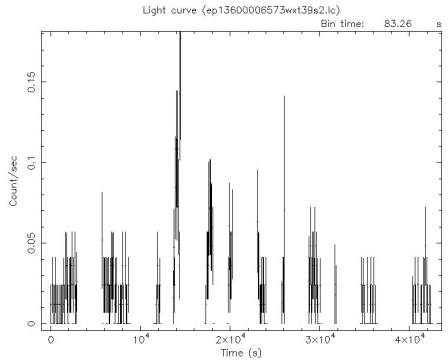
Showing 1-15 of 1134 rows

First Prev 1 2 3 4 5 Next Last

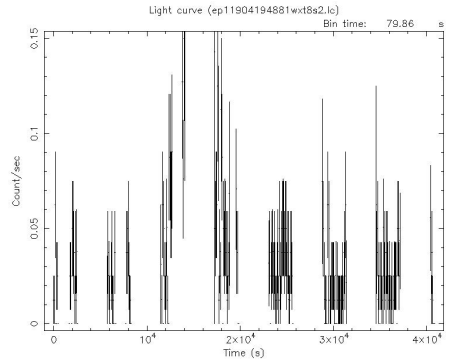
单次观测光变曲线中的恒星耀发



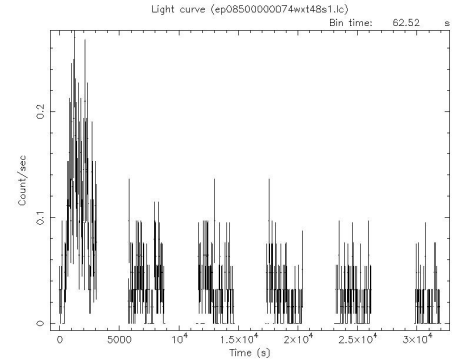
Start Time 20473 14:22:20:288 Stop Time 20475 2:29:54:485



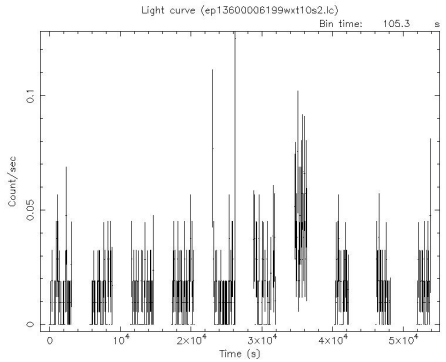
Start Time 20560 18:34:05:662 Stop Time 20561 6:23:09:510



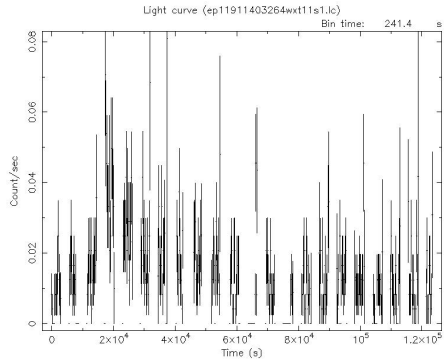
Start Time 20522 0:11:37:964 Stop Time 20522 11:31:46:020



Start Time 20421 10:17:52:345 Stop Time 20421 19:10:21:286



Start Time 20449 19:04:18:707 Stop Time 20450 10:01:30:569



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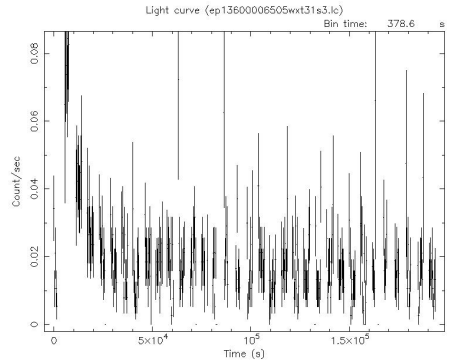

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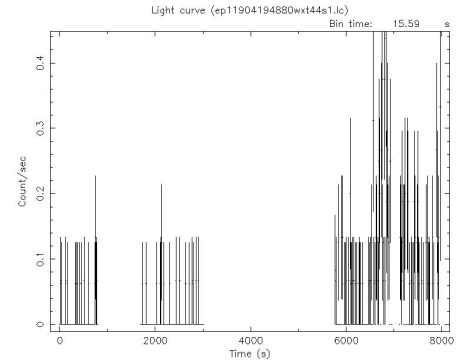
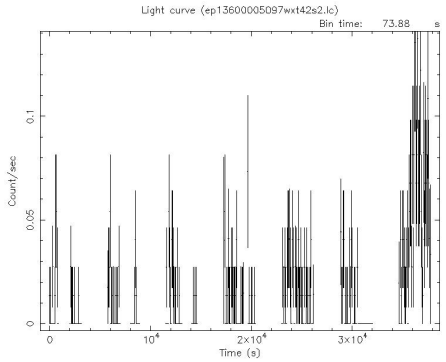
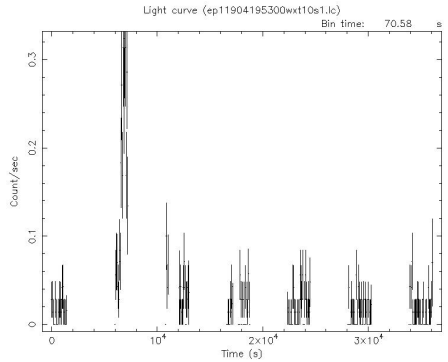


Start Time 20521 5:08:13:781 Stop Time 20521 7:21:02:543



Start Time 20375 1:27:19:973 Stop Time 20375 11:56:31:422



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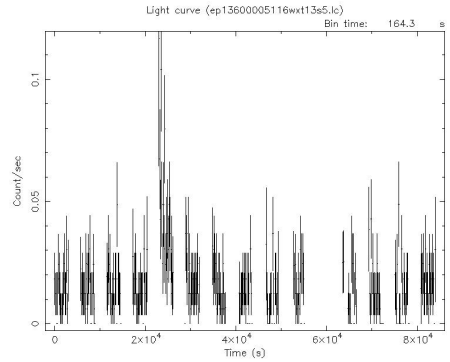
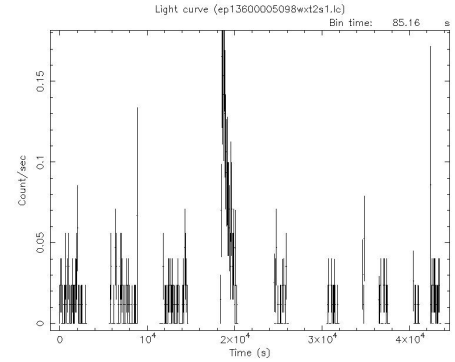
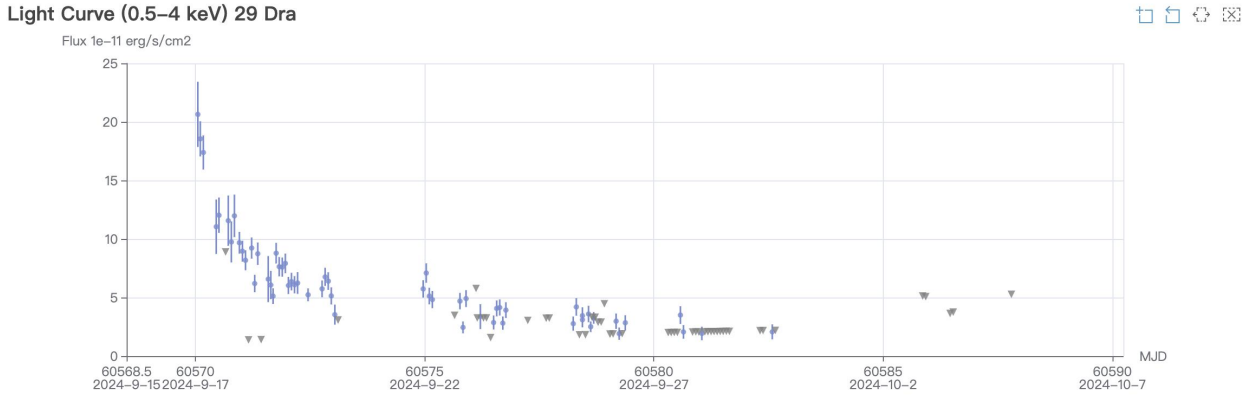


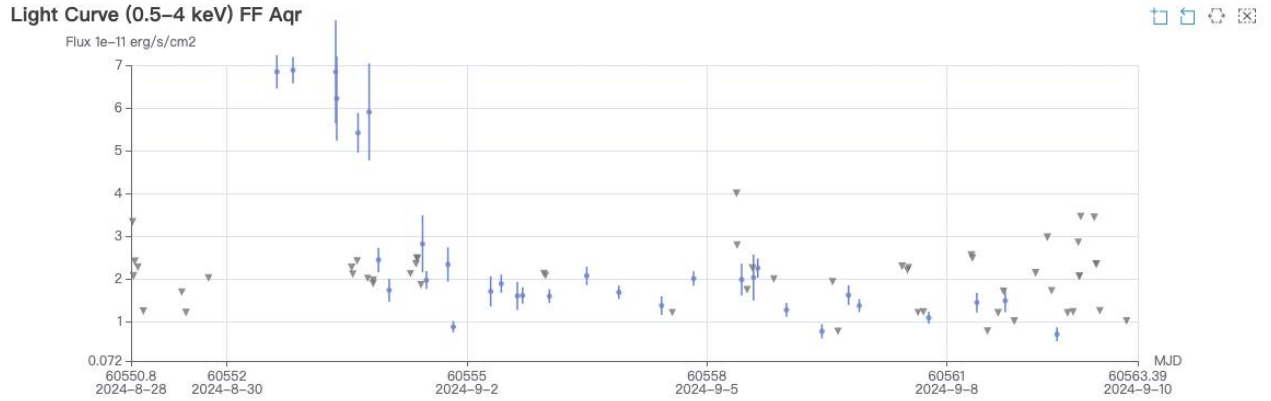
Start Time 20381 8:35:32:172 Stop Time 20382 7:54:37:612

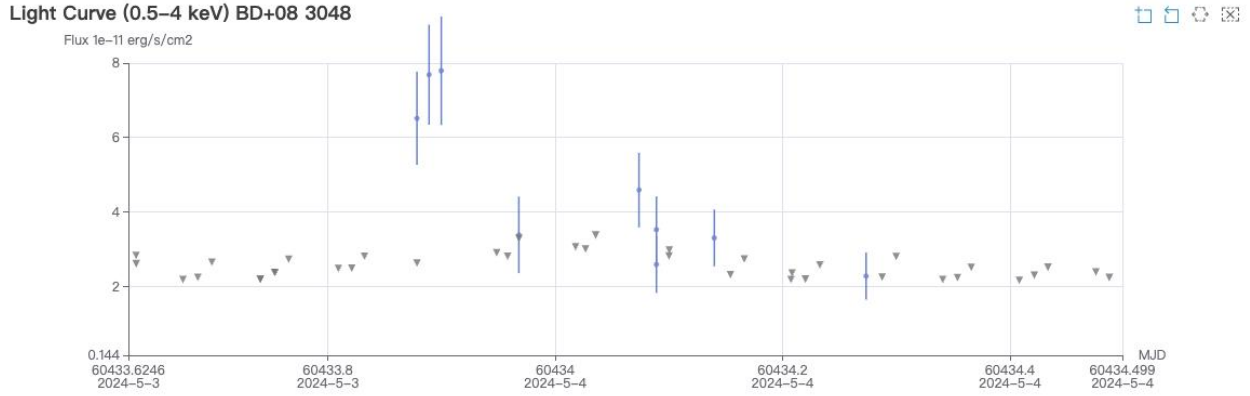


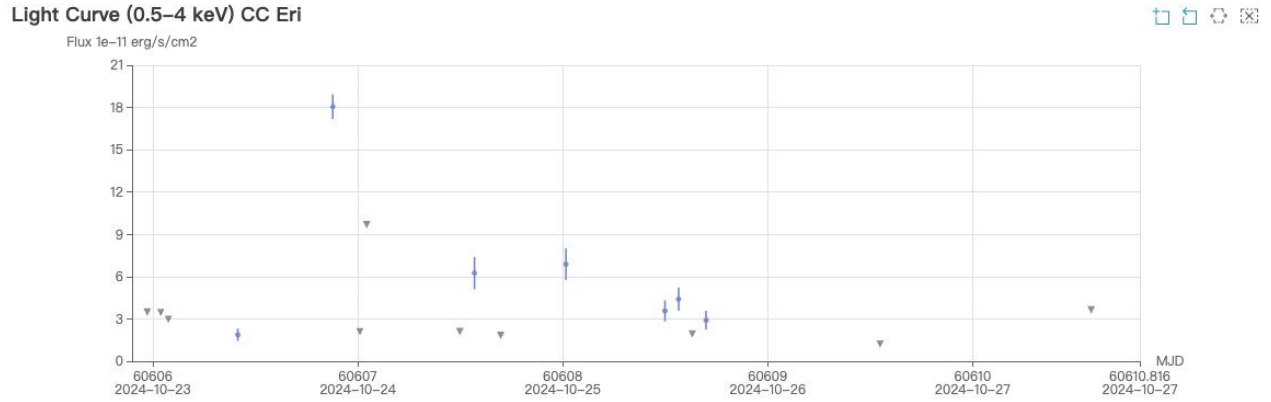
Start Time 20375 12:38:10:613 Stop Time 20376 0:43:26:550

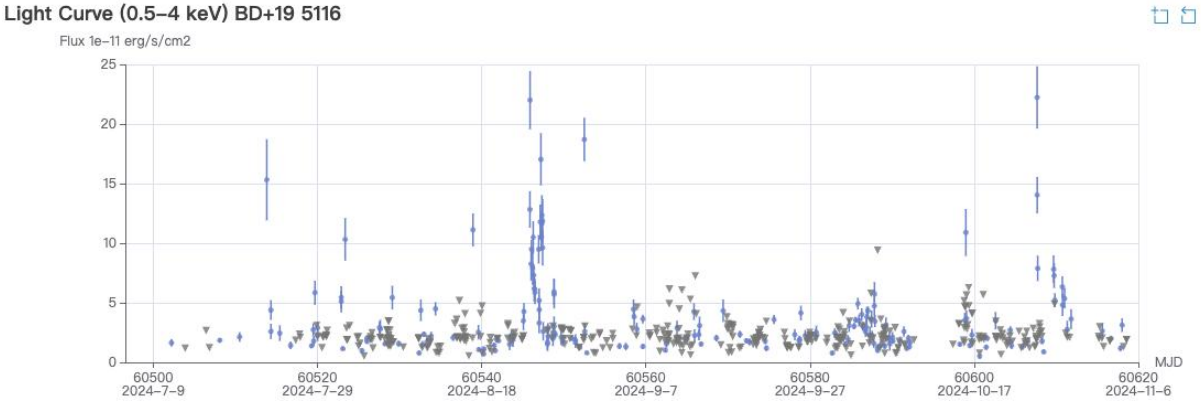
长期光变曲线中的恒星耀发

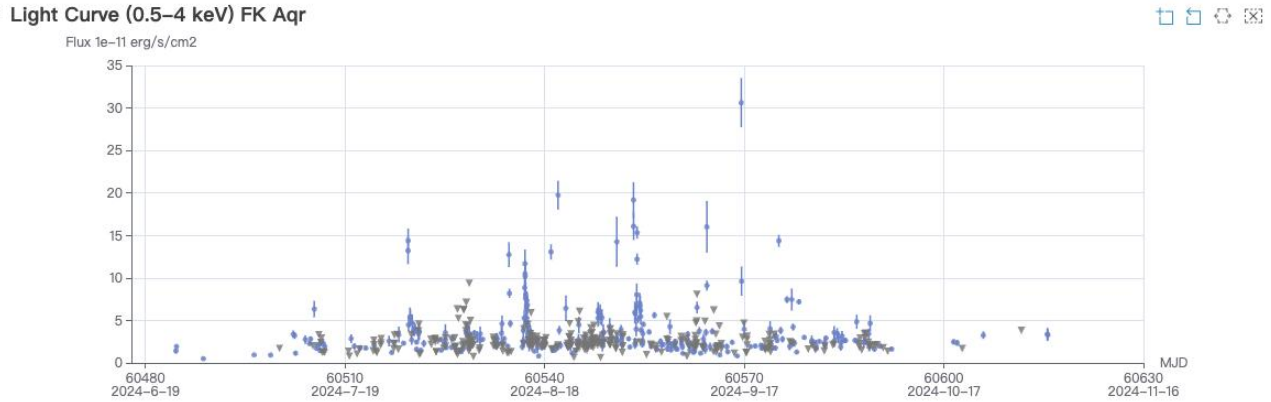




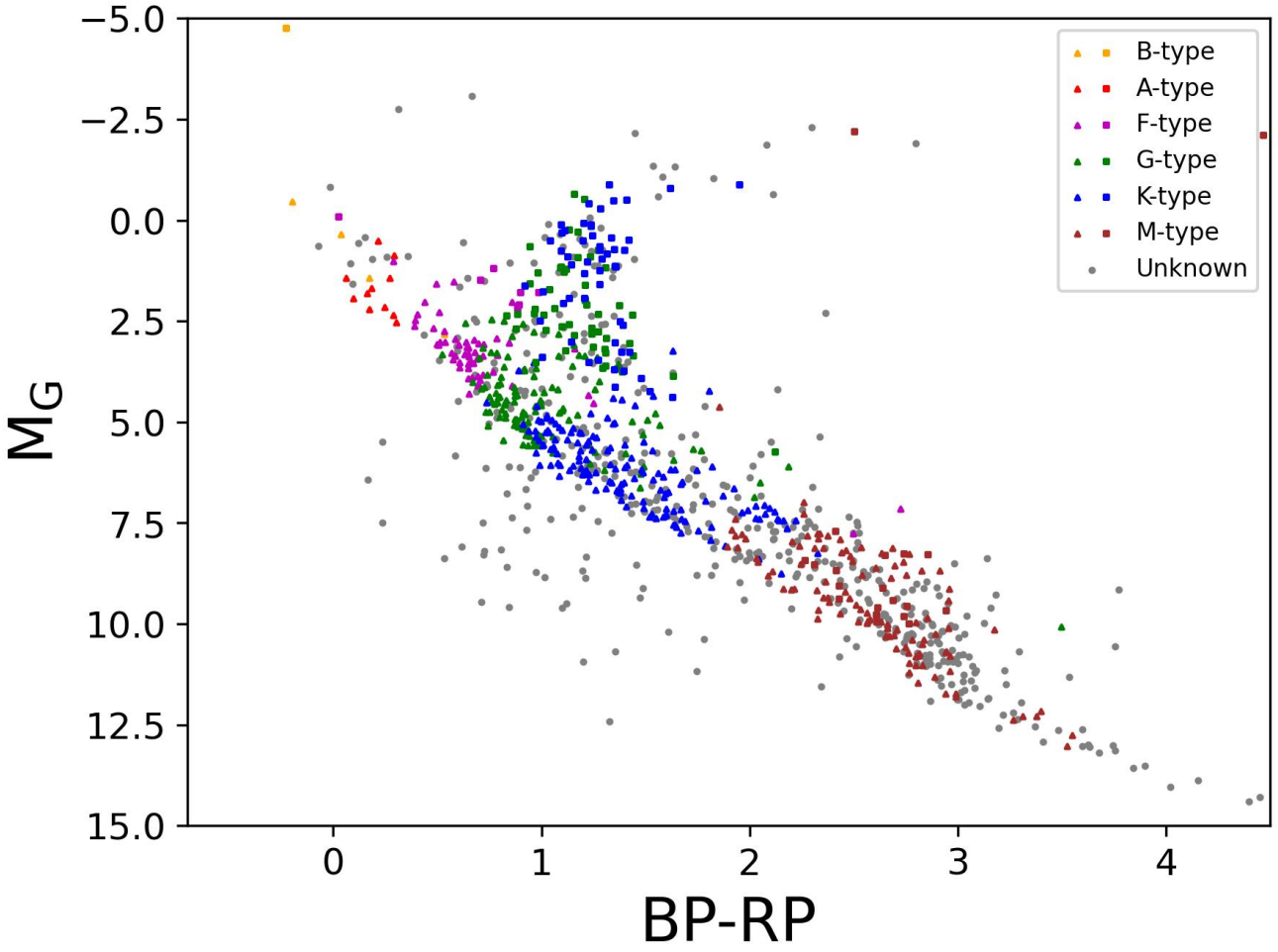








H-R Diagram



总 计： 1101 stars
有距离和测光数据： 1036 stars
有温度和logg信息： 577 stars

- 平均每天探测到2-3颗恒星的耀发！

	O-type	B-type	A-type	F-type	G-type	K-type	M-type
T	>30000	10000-30000	7500-10000	6000-7500	5200-6000	3700-5200	<3700

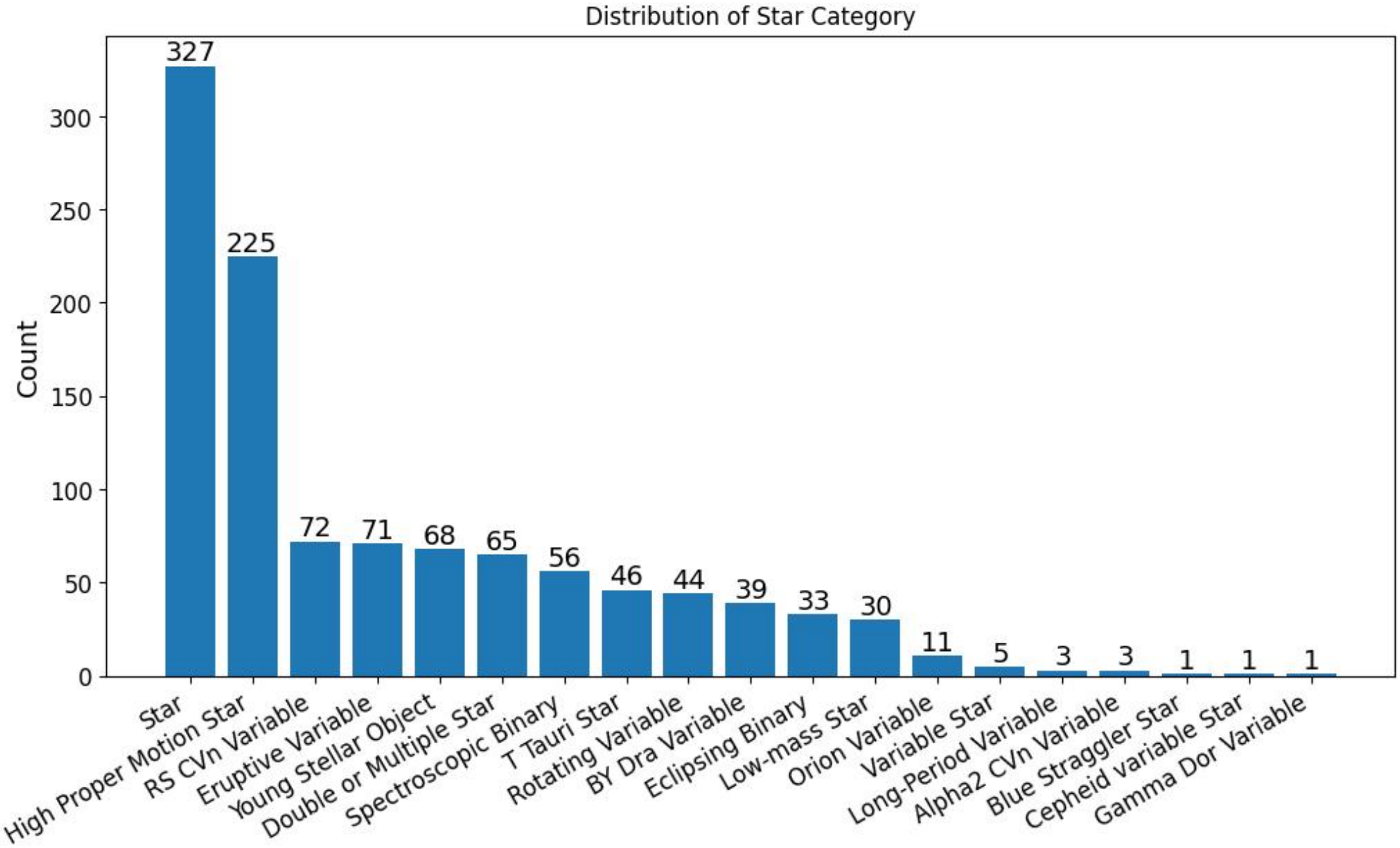
Giant:

$$\log g < \begin{cases} 3.5 & \text{if } T_{\rm eff} \geqslant 6000, \\ 4.0 & \text{if } T_{\rm eff} \leqslant 4250, \\ 5.2 - 2.8 \times 10^{-4} T_{\rm eff} & \text{if } 4250 \leqslant T_{\rm eff} \leqslant 6000. \end{cases}$$

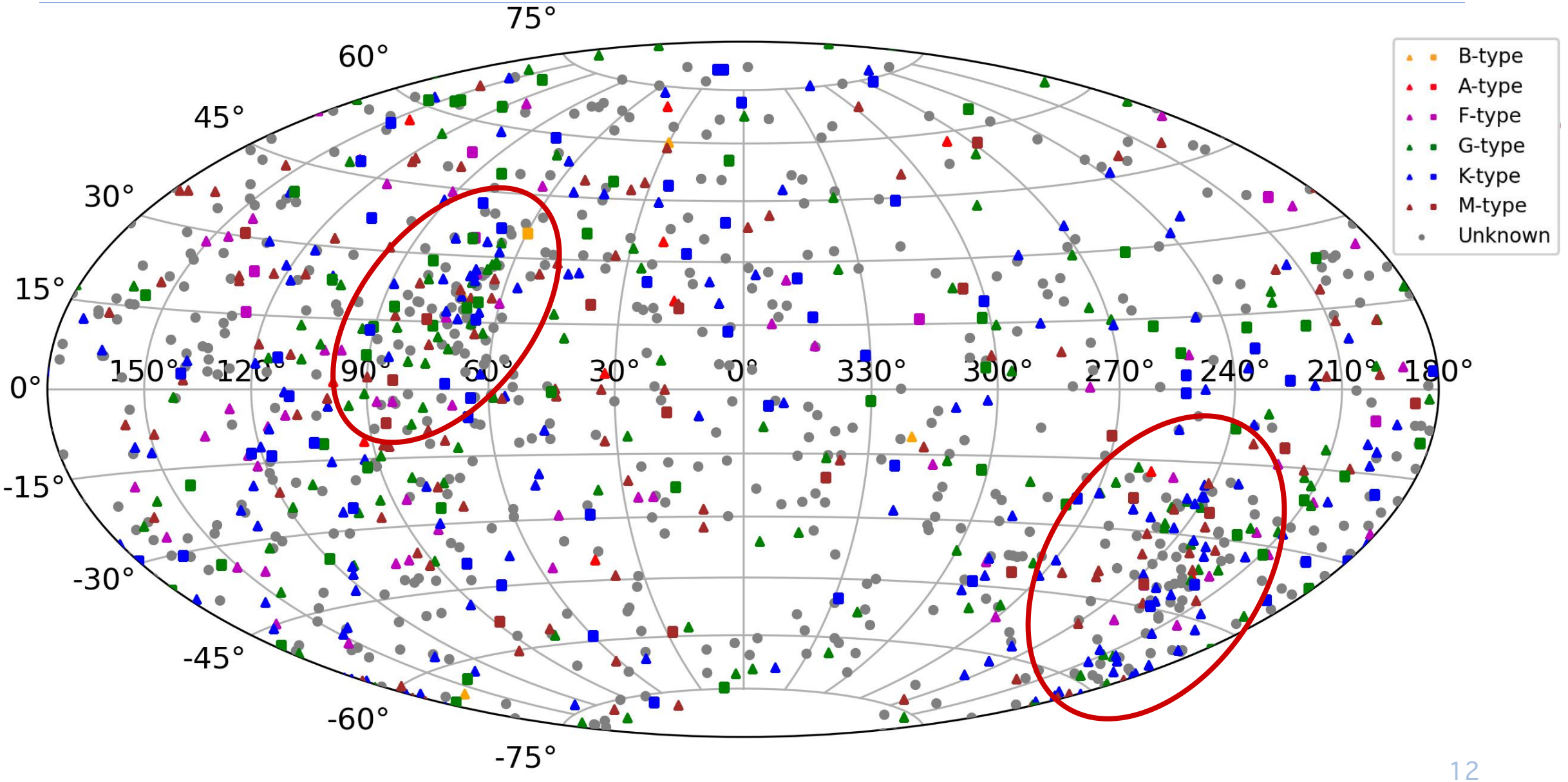
Ciardi+ 2011

	O-type	B-type	A-type	F-type	G-type	K-type	M-type	SUM
Dwarf /YSO	0	4	11	58	118	148	106	445
Giant	0	1	0	7	51	54	19	132
SUM	0	5	11	65	169	202	125	577

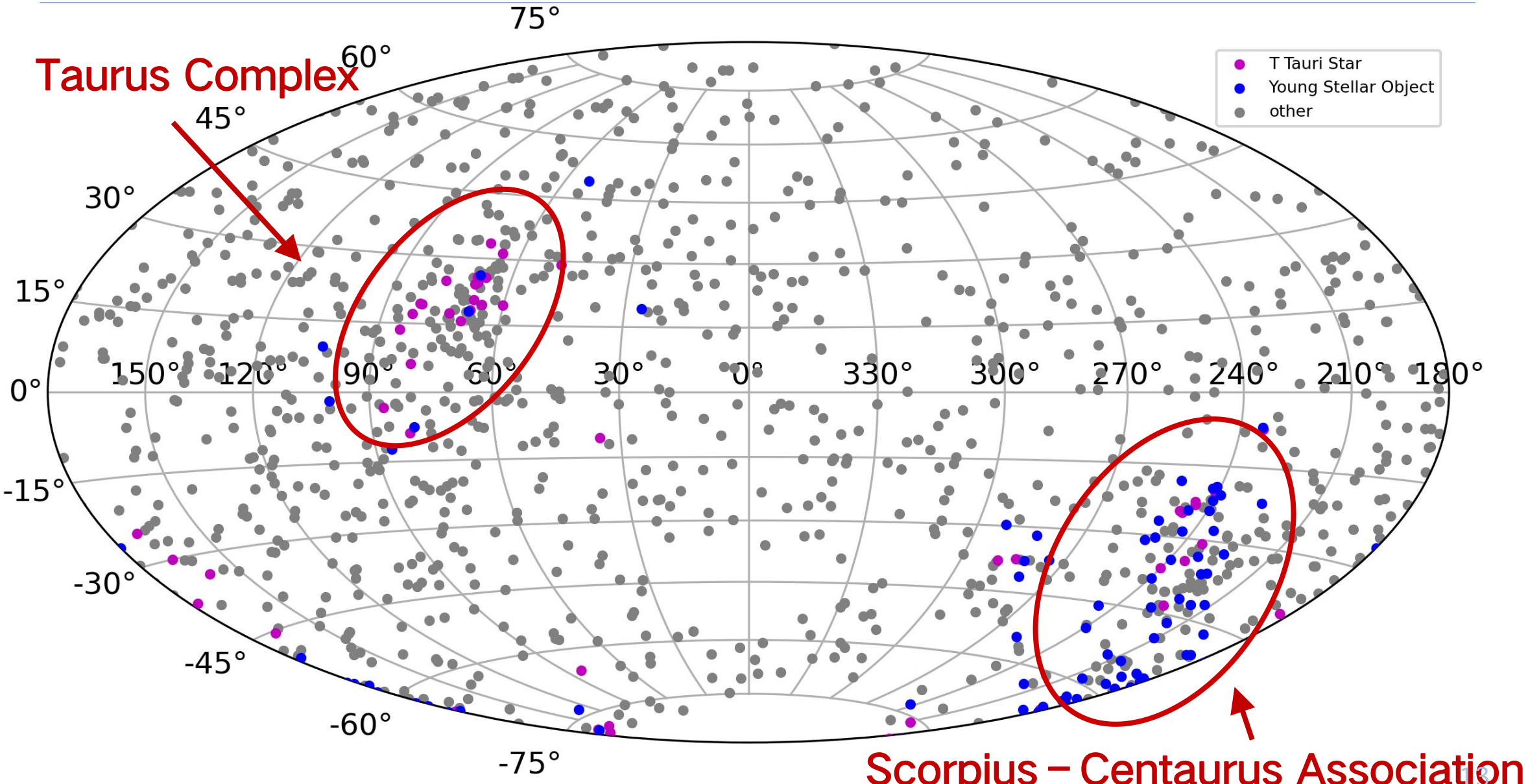
基于Simbad的耀发恒星分类



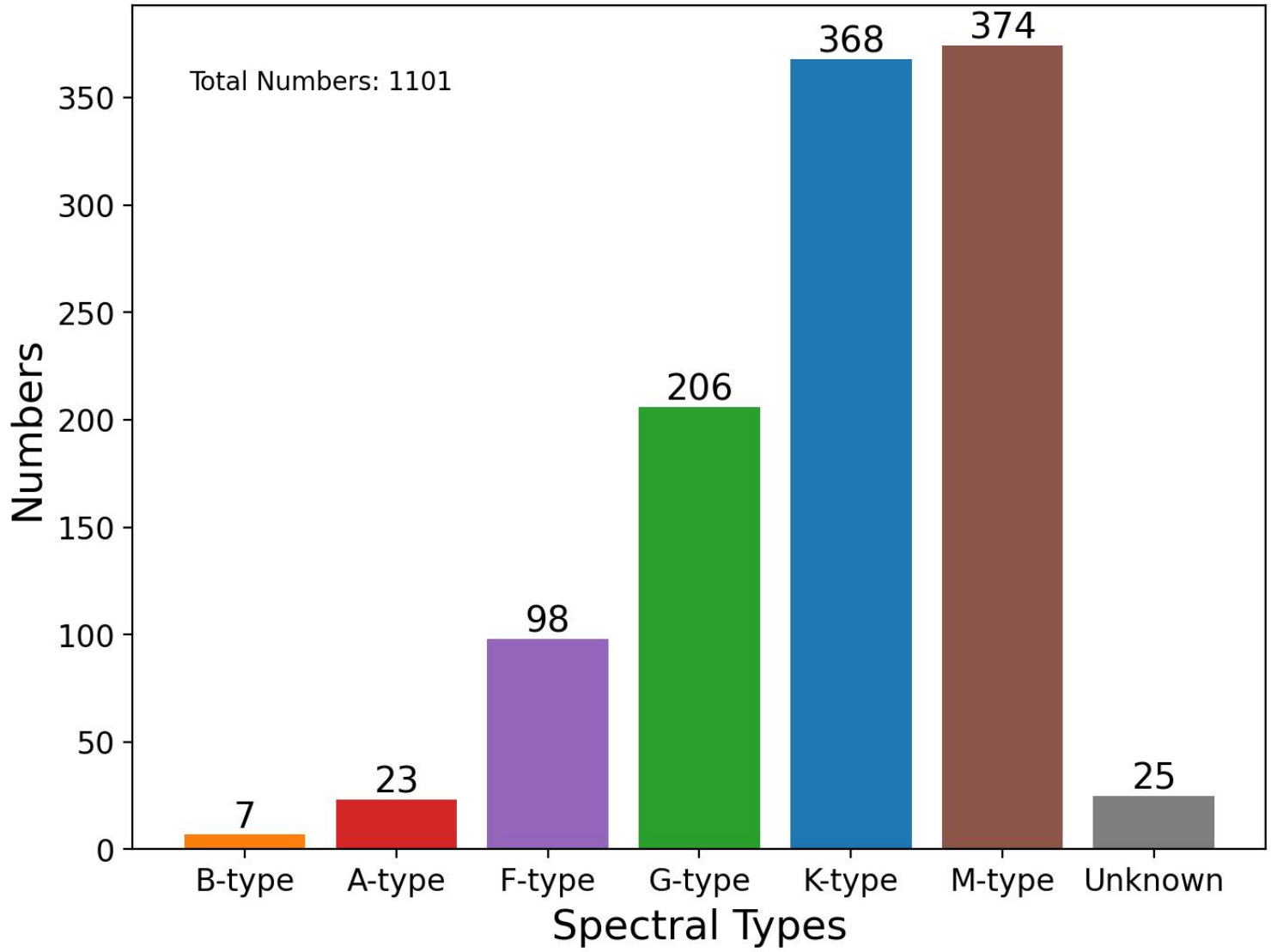
耀发恒星全天分布


75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
150°
120°
90°
60°
30°
0°
330°
300°
270°
240°
210°
180°
B-type
A-type
F-type
G-type
K-type
M-type
Unknown

耀发恒星全天分布

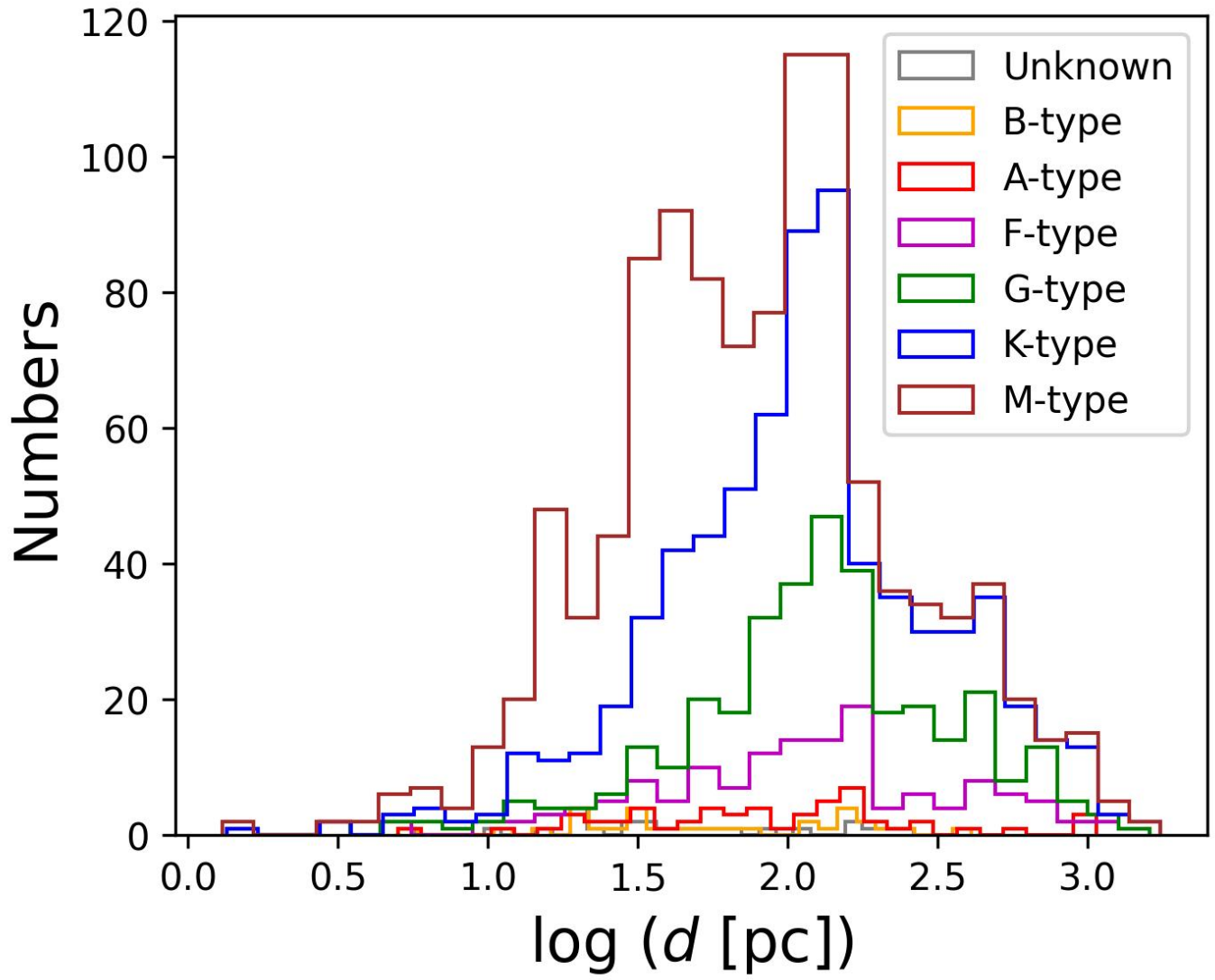

Taurus Complex
T Tauri Star
Young Stellar Object
other
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
150°
120°
90°
60°
30°
0°
330°
300°
270°
240°
210°
180°
Scorpius – Centaurus Association

耀发恒星光谱型分布



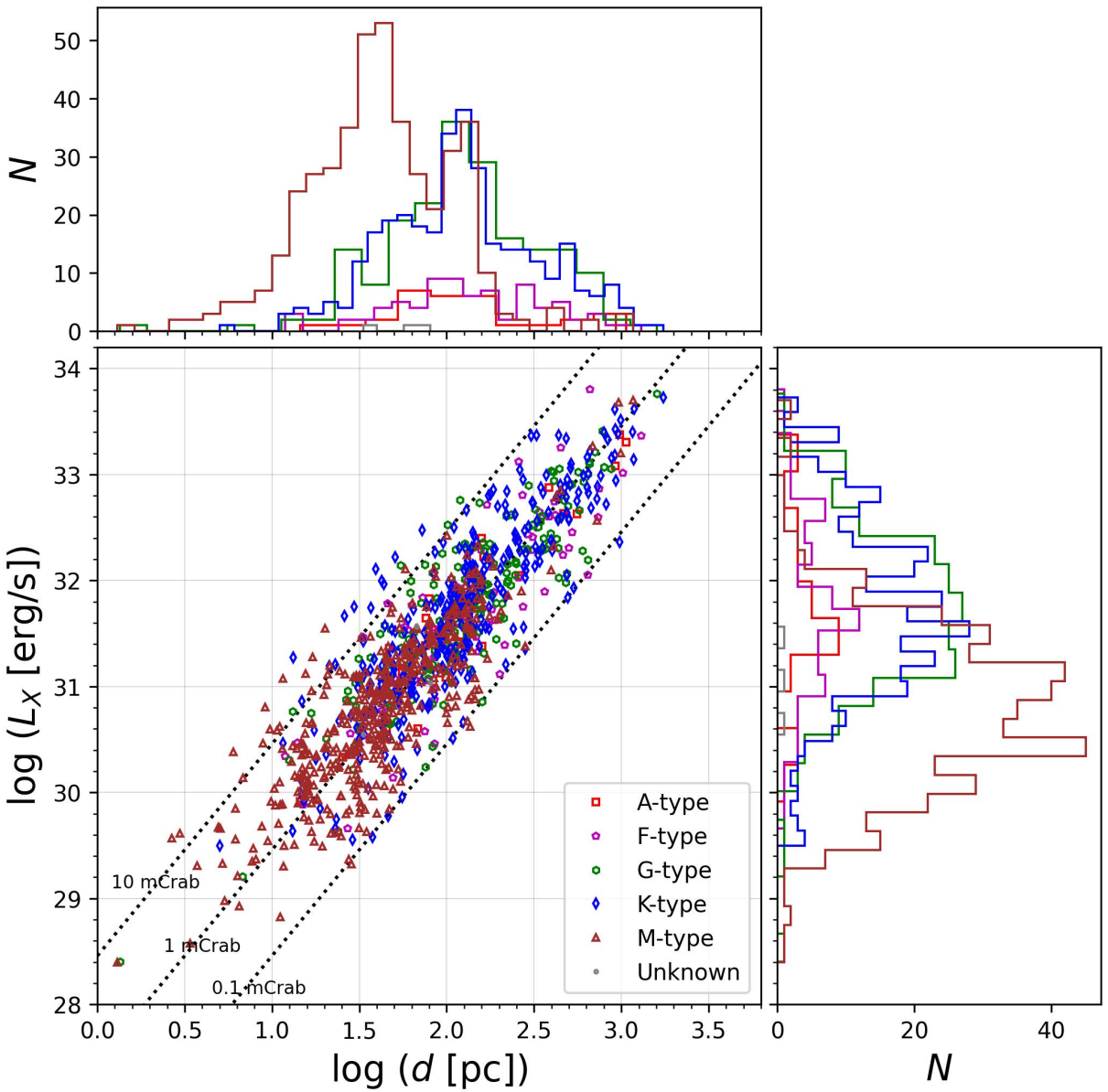
- 按测光数据BP-RP对恒星进行粗略分类
- 光谱型越晚的恒星数量越多

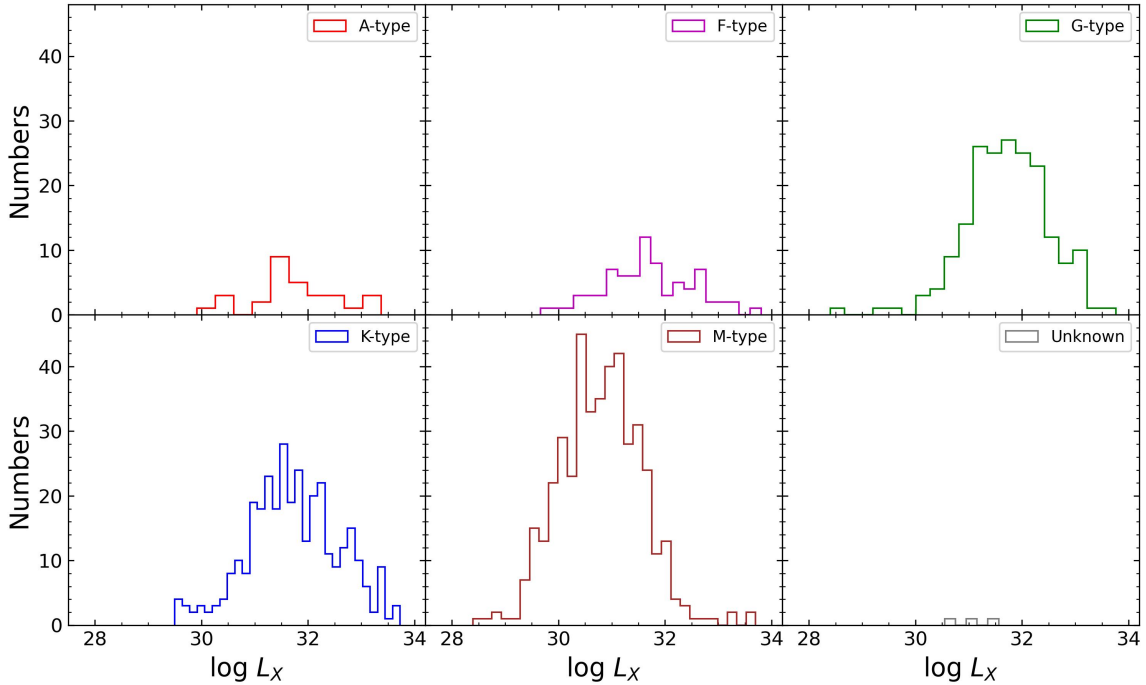
耀发恒星距离分布



- 双峰结构
- M型星与其他光谱型恒星分布存在系统差异

耀发光度分布





光度范围：2e28 – 6e33 erg/s

⩾1e32 erg/s：252 stars

⩾1e33 erg/s：46 stars

1 mCrab = 2.4E−11 erg/cm²/s

有后随观测的恒星耀发

No.	Star	FXT	Swift	NICER	Optical Obs
1	Gaia DR3 5406245351777015040	○			
2	TYC 6079-93-1	○			
3	2MASS J12184187-0609123				○
4	HD 315687	○			
5	UPM J2224-5826	○			
6	Gaia DR3 58995295616014848	○			
7	RX J0106.4-6346	○			
8	ASAS J164602+0718.9		○		
9	LP 924-17		○		
10	LP 820-19	○	○	○	○
11	ASAS J211056+3323.2	○			
12	BPM 46566	○			
13	UCAC4 334-220322	○			
14	TYC 1625-1567-1	○			
15	Gaia DR3 2445442335531658752	○			
16	RX J0123.4+1638	○			
17	TYC 614-313-1	○			
18	UCAC4 216-002052	○			
19	MCC 401		○		
20	CRTS J225211.7+095626	○			
21	Z Ind	○			
22	2MASS J18351416+2435115	○			○
23	PM J23221-0301	○			○
24	Gaia DR3 2636220758434984448	○			

No.	Star	FXT	Swift	Optical Obs
25	2MASS J23301129-0237227	○		○
26	LSPM J0251+4434		○	
27	1RXS J225817.2-110434	○		○
28	LP 402-64	○		
29	Proxima Centauri	○		
30	Gaia DR3 2534635509050352256	○		○
31	BD-19 660		○	
32	V644 Tau	○		
33	HG 7-33	○		
34	BPS CS 31060-0015	○		
35	2MASS J04443916+2224417	○		
36	V410 Tau	○		
37	PM J02146+3121		○	
38	2MASS J04492661+2730388	○		
39	RX J0413.4-0139	○		
40	ATO J079.4052-07.5576	○		
41	UCAC4 797-019583	○		
42	Cl* Melotte 20 DH 189	○		
43	LSPM J0447+1437	○		
44	TYC 5360-423-1	○		
45	V830 Tau	○		
46	ATO J062.5554+20.7139	○		
47	ATO J147.4546+48.1119	○		
48	1RXS J060224.9-163451	○		

有后随观测的恒星耀发

No.	Star	FXT	Swift
49	ATO J042.4338+49.2939		○
50	Gaia DR3 1767184609155208 96	○	
51	RX J0429.3-3124	○	
52	UCAC4 545-027698	○	
53	RX J0534.6-0234	○	
54	LAMOST J05346.93+310945.3	○	
55	LP 844-28/EP J0855.3-2351	○	
56	PM J16196+7655	○	
57	RX J0448.7+1003	○	
58	RX J0916.1+0153	○	
59	UCAC4 185-006985	○	
60	UPM J1217-3644	○	
61	G 118-68	○	
62	EP250204a	○	
63	2MASS J09180165-5452332	○	
64	2MASS J23473680+2702068		○
65	2MASS J01292678+8059457	○	○
66	ATO J076.8002+24.6211		○
67	RX J0523.0-0850	○	
68	Gaia DR3 786082236117965440	○	
69	UCAC4 188-052100	○	
70	V1217 Cen	○	
71	EP J0422.0+2826	○	
72	Gaia DR3 5563280076339409920	○	

No.	Star	FXT	Swift	NICER
73	LP 378-313	○		
74	TYC 4136-261-1	○		
75	ATO J076.8002+24.6211		○	
76	TYC 247397-986-1	○		
77	Gaia DR3 6093234407369953024	○		
78	2MASS J15504650+3054070	○		
79	Gaia DR3 5468643667425957632	○		
80	BD+03 2186	○		
81	LP 368-98	○		
82	ASAS J145837-3915.1	○		
83	CPD-56 965	○		
84	12 Mus	○		
85	TYC 5423-589-1	○		
86	Gaia DR3 4443461705748132608		○	
87	Gaia DR3 4094761312514742656	○		
88	UCAC4 234-081120	○		
89	CRTS J150851.0+032702	○		
90	CF Oct	○	○	○
91	LP 323-169	○		
92	WISEA J122501.45-521614.6	○	○	
93	Gaia DR3 6277472183485764992	○		

有FXT自主后随的耀发：共44例

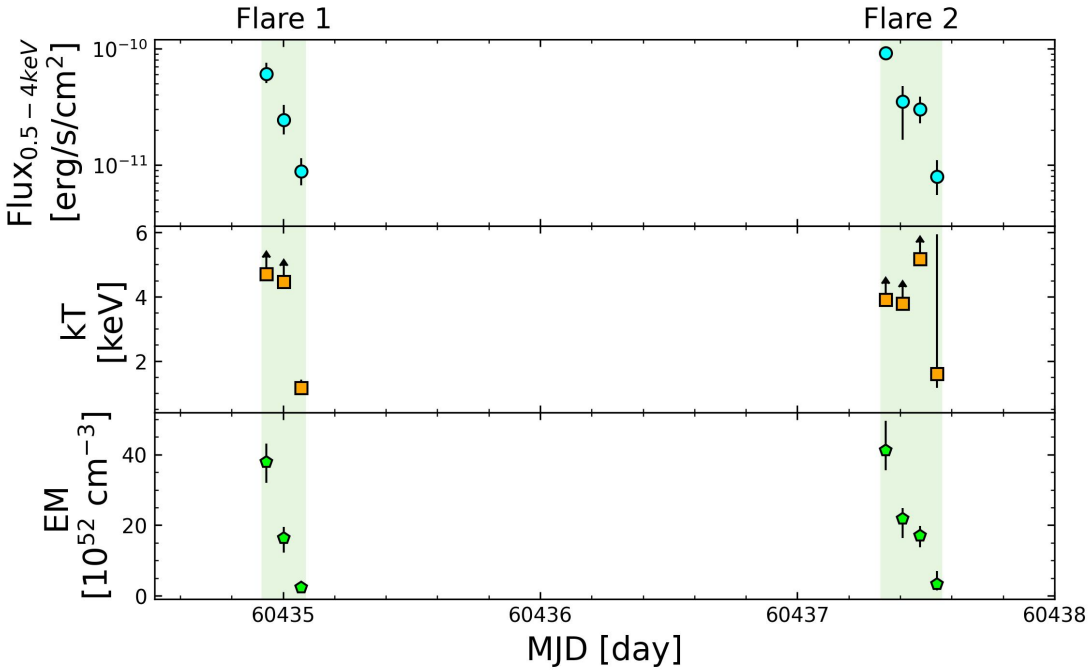
2MASS J12184187-0609123

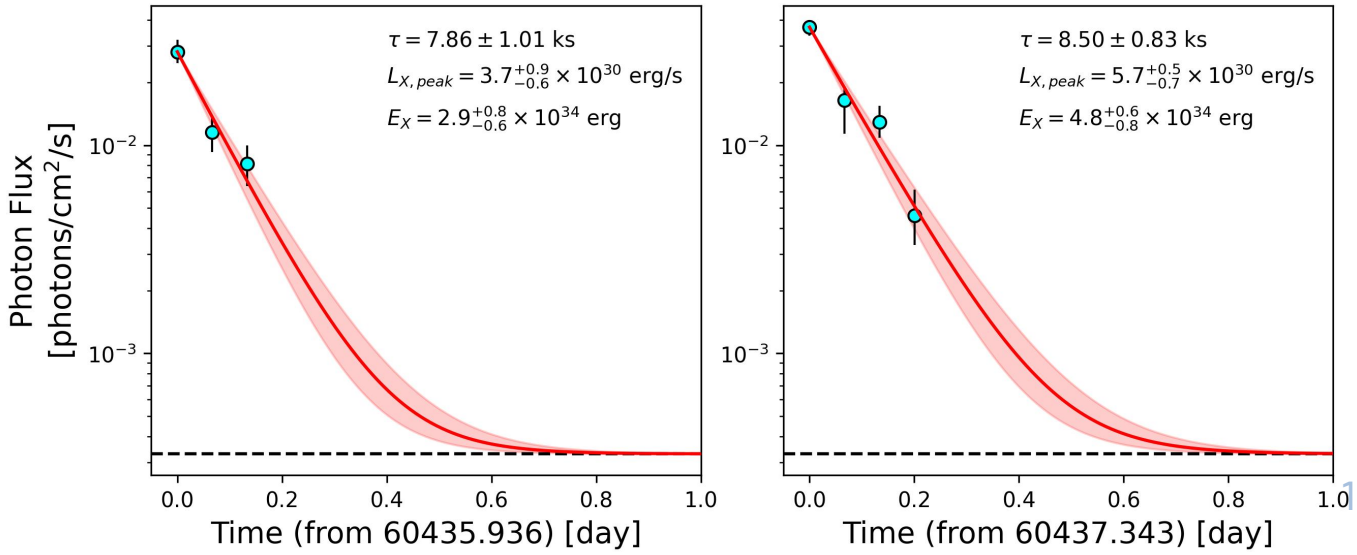
- 3天内探测到2次超级耀发

Table 2. Properties of 2MASS J12184187-0609123

Property	Value
(1)	(2)
Gaia DR2 ID	3584656640992625280
G-band (mag)	13.205 ± 0.003
GBp-GRp (mag)	3.026 ± 0.007
B-band (mag)	16.34
R-band (mag)	13.43
Distance (pc)	22.64 ± 0.05
M_G (mag)	11.43
S.p. Type	M4
$T_{\rm eff}$ (K)	3168.0 ± 157.0
$R_\star$ $(R_\odot)$	0.256 ± 0.008
$M_\star$ $(M_\odot)$	0.227 ± 0.020
$\log(g/\mathrm{cm\ s^{-2}})$	4.98 ± 0.01

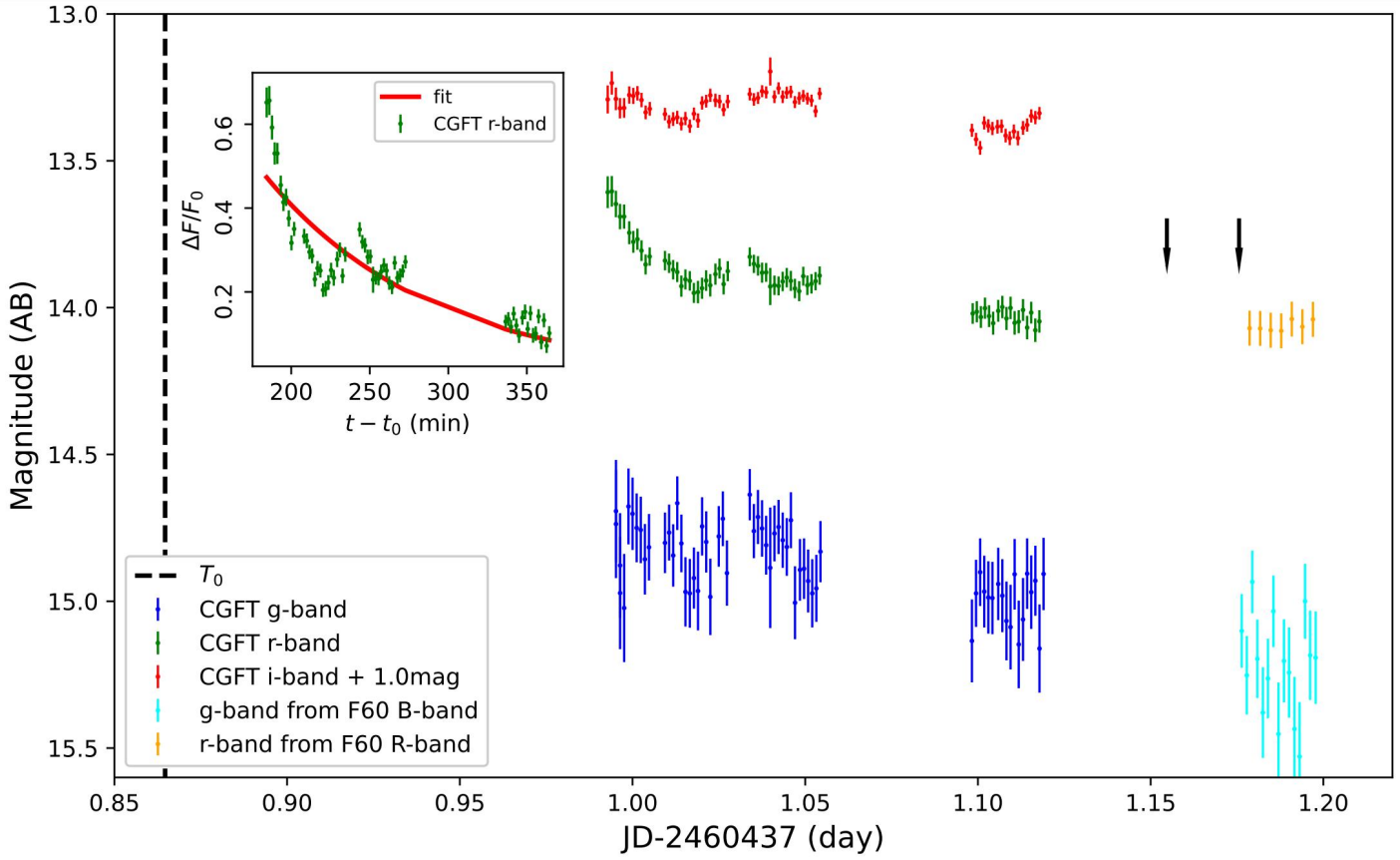
Wang+ 2024





2MASS J12184187-0609123

- 光学快速后随，发现Hα线移动



Hα发射线蓝移的2种解释:

1. 色球蒸发 → $M_{PL} \sim 1.2 \times 10^{18}$ g
2. 日珥爆发 → 7×10^{15} g < M_p < 7×10^{18} g

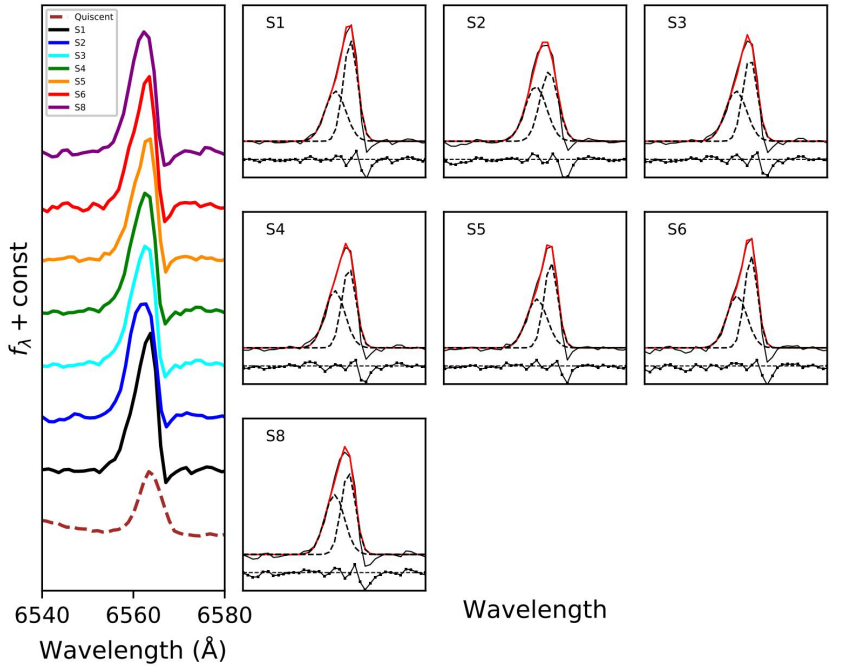


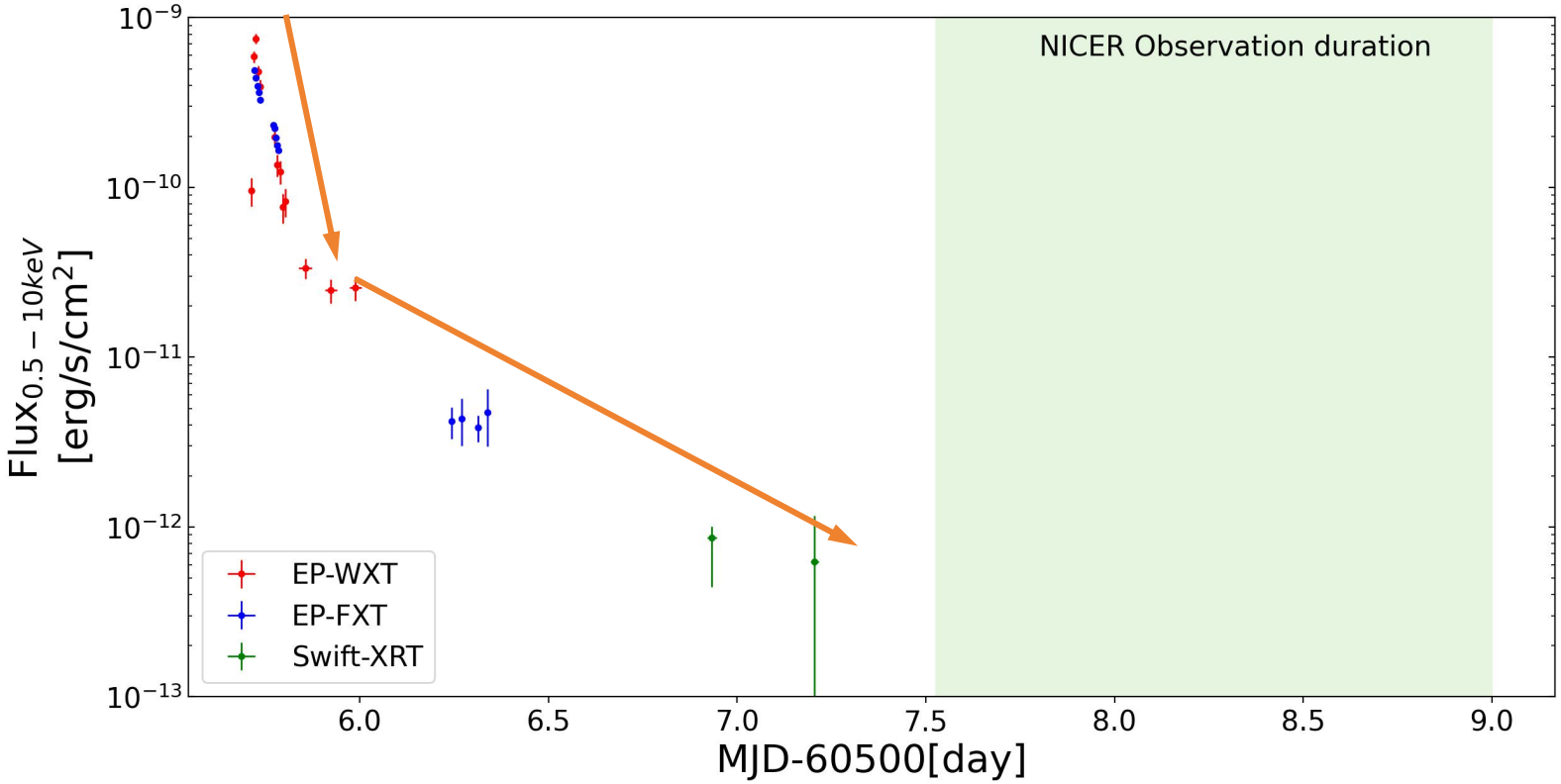
Table 3. Results of Spectral Measurements and Analysis.

ID	$f(\mathrm{H}\alpha_n)$	$f(\mathrm{H}\alpha_b)$	FWHM(Hα)	$\Delta v(\mathrm{H}\alpha_b)$	V_{max}
	(10^{-15}erg s^{-1} cm^{-2})		(km s^{-1})		
(1)	(2)	(3)	(4)	(5)	(6)
1	86.6 ± 1.2	63.5 ± 2.6	200	-150	-240
2	75.6 ± 8.0	71.6 ± 7.0	210	-130	-250
3	74.7 ± 3.7	65.3 ± 4.1	210	-140	-240
4	67.9 ± 2.0	69.8 ± 1.4	190	-140	-230
5	70.4 ± 2.0	61.1 ± 2.8	200	-140	-230
6	72.5 ± 1.6	64.2 ± 3.2	190	-140	-180
8	70.8 ± 2.5	72.0 ± 3.3	190	-140	-210

LP 820-19

- X射线流量下降4个量级

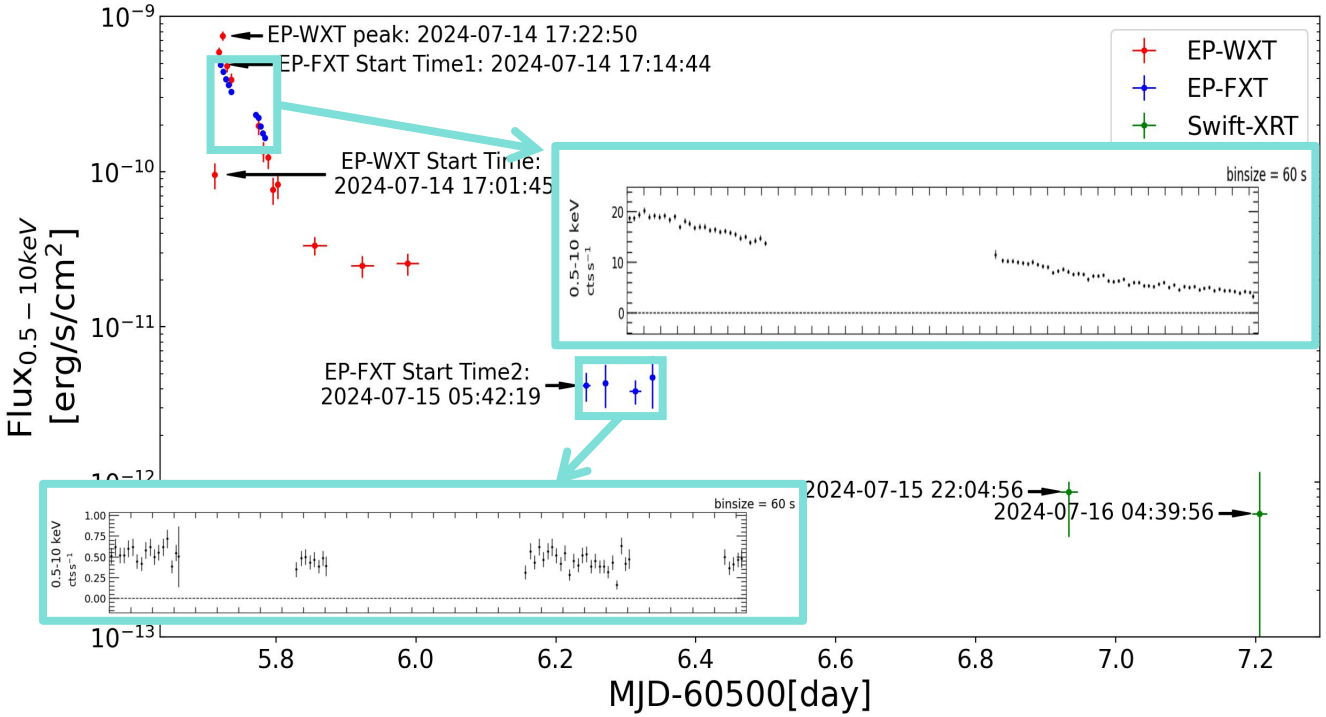
Type	High Proper Motion Star
RA, DEC	336.50 -15.30
Galactic (l, b)	44.72 -54.26
Proper motions	272.423 -53.519
Spectral type	M5.5
Distance	24.4 pc
Mag G	14.96
Teff	2799.2
log g	5.1
L_star/L_sol	1.67e-03
R_star/R_sol	0.166
M_star/M_sol	0.159

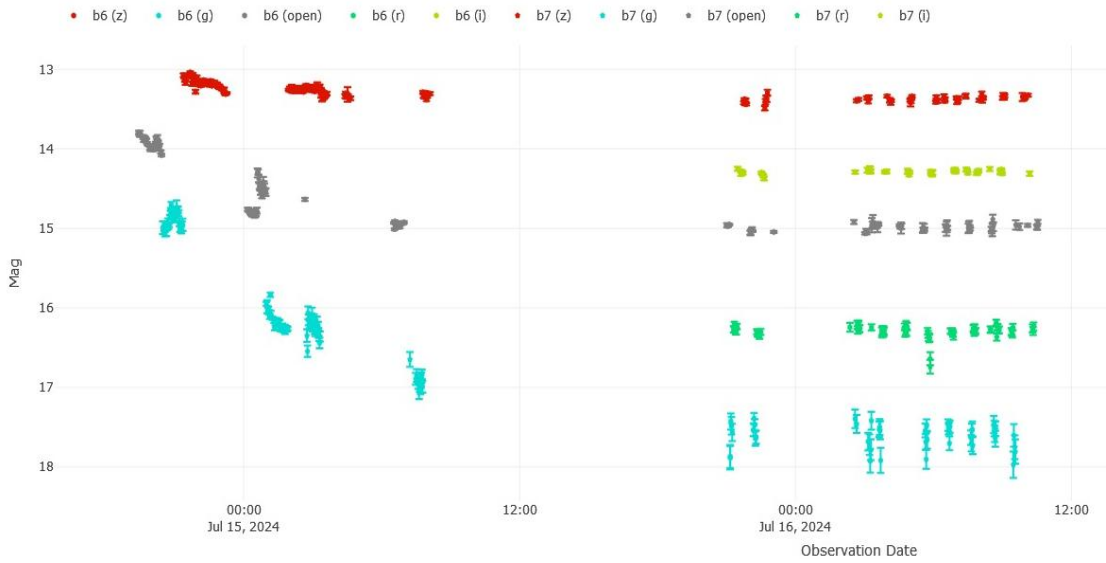


credit: Simbad; GAIA EDR3; Kevin+ 2023

LP 820-19

- 多波段观测及时后随

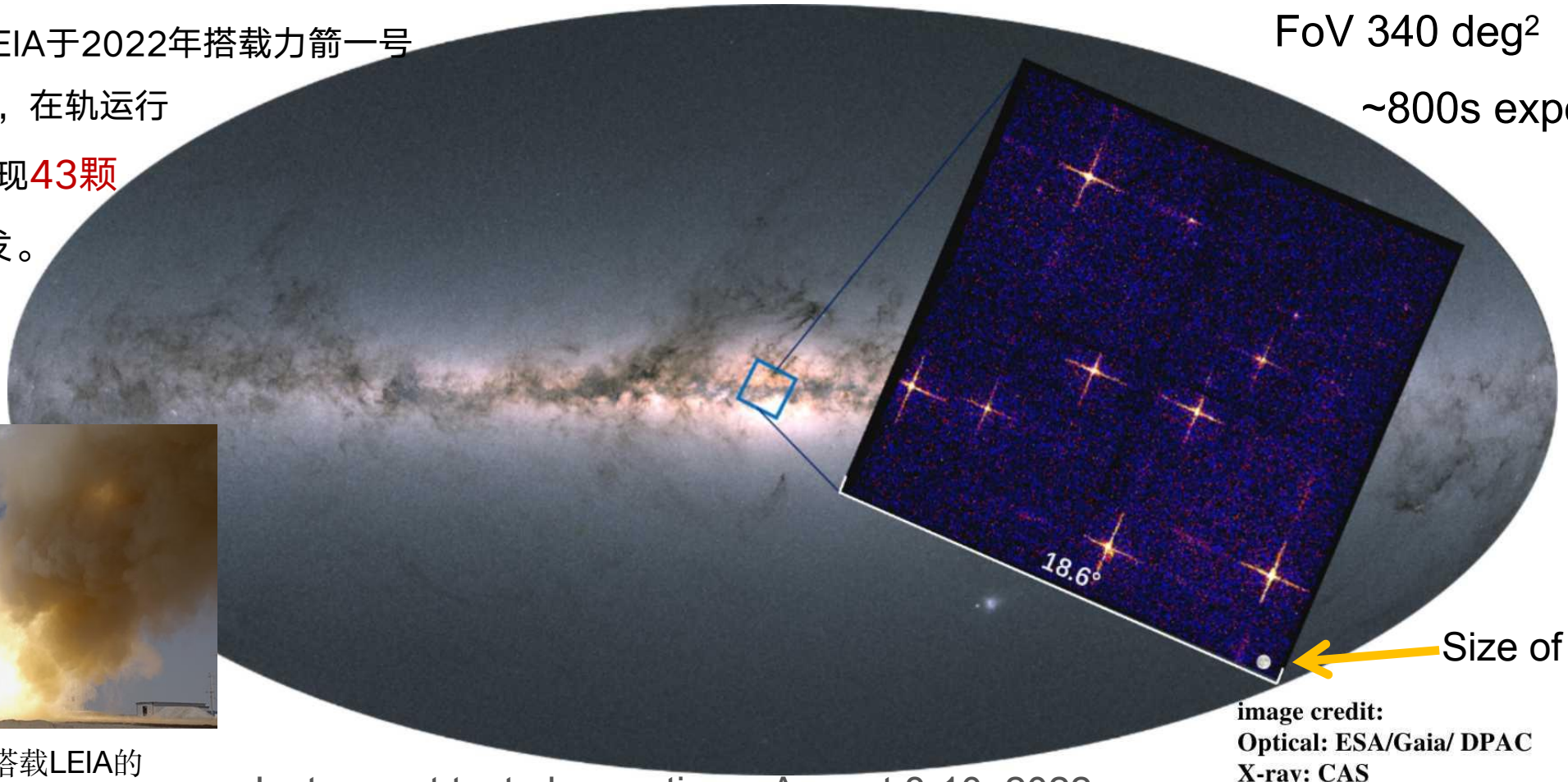




BOOTES-6/DPR & BOOTES-7

LEIA：EP探路者卫星

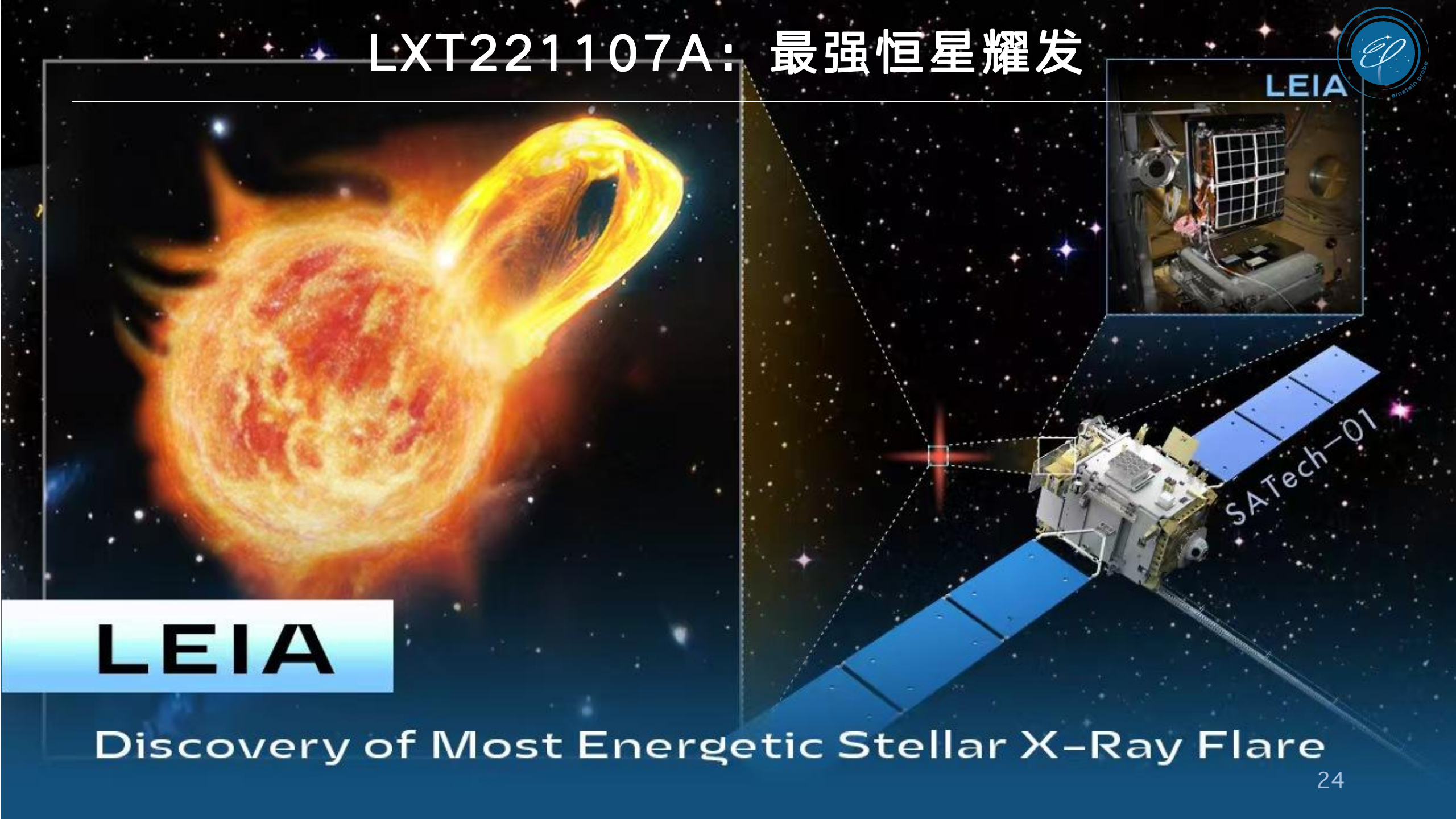
LEIA（Lobster Eye Imager for Astronomy）是EP的探路者卫星，具有340平方度的大视场软X射线探测和成像能力，其科学功能可充分代表EP-WXT的12个模块之一。LEIA于2022年搭载力箭一号运载火箭成功发射，在轨运行两年多以来，已发现43颗恒星共计98次耀发。



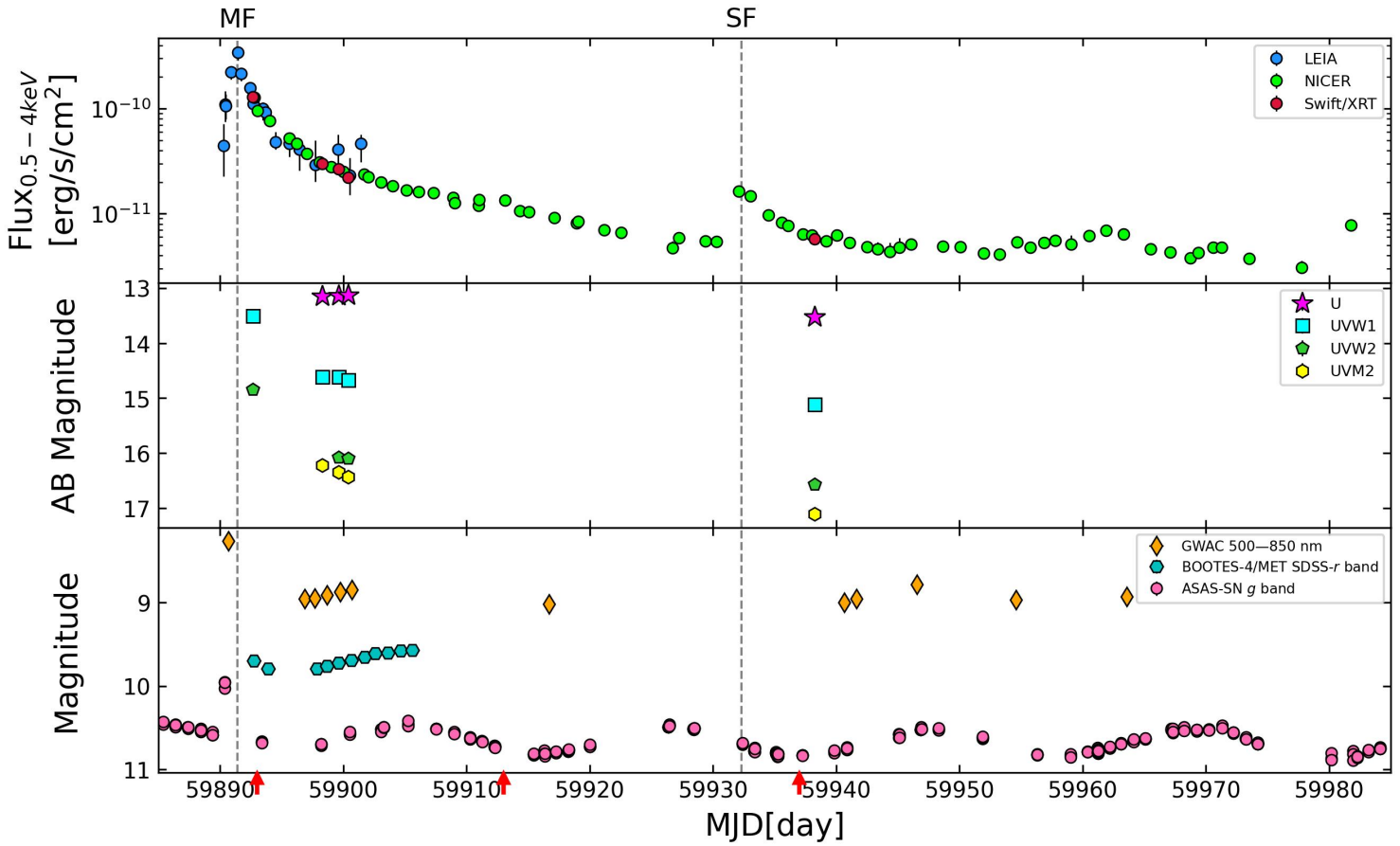
2022年7月27日，搭载LEIA的SATech-01发射升空

Instrument test observations August 8-10, 2022

LXT221107A：最强恒星耀发



LXT221107A：最强恒星耀发



Mao+ 2025

MF: $L_{X,p}$ ~1.1e34 erg/s (0.5-4 keV)
SF: $L_{X,p}$ ~5.8e32 erg/s (0.5-4 keV)

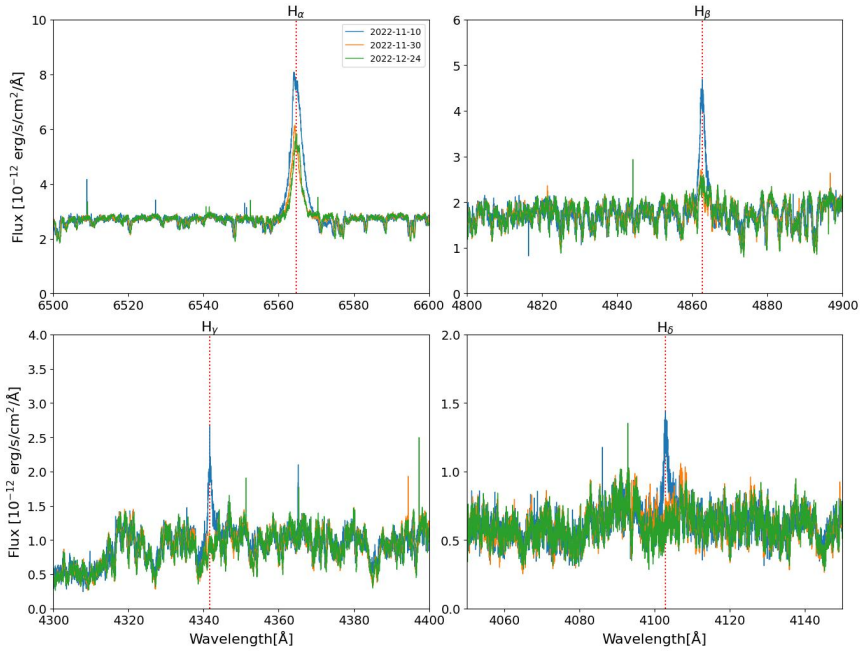


Table 1. Multi-wavelength observations on HD 251108

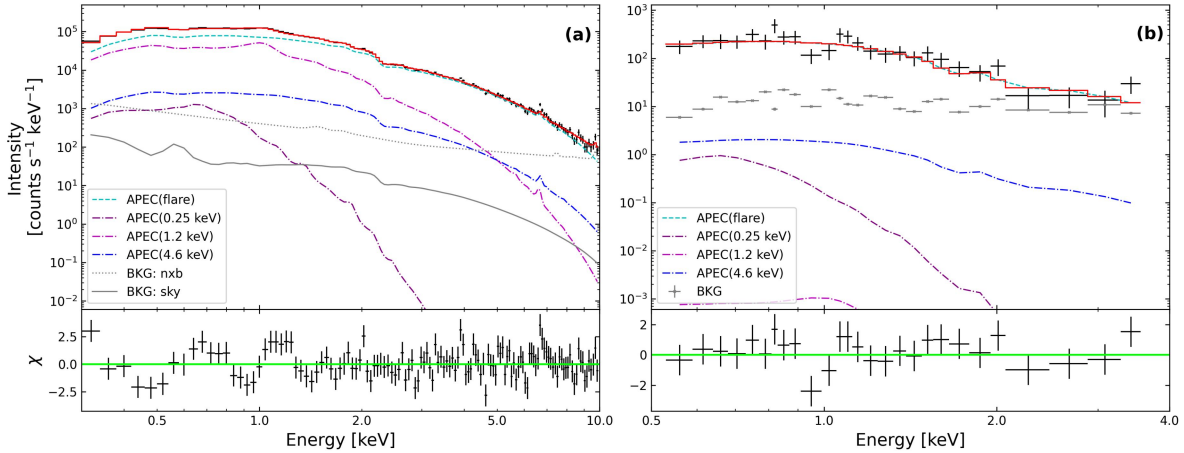
Instrument	Obs-Date	Waveband
LEIA	from 2022-11-07 to 2022-11-18	Soft X-ray
Swift	from 2022-11-09 to 2022-12-25	Soft X-ray/UV
NICER	from 2022-11-09 to 2023-02-06	Soft X-ray
ASAS-SN	from 2022-11-02 to 2023-02-09	optical
GWAC	from 2022-11-07 to 2023-01-19	optical
BOOTES-4/MET	from 2022-11-09 to 2022-11-22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

LXT221107A：最强恒星耀发

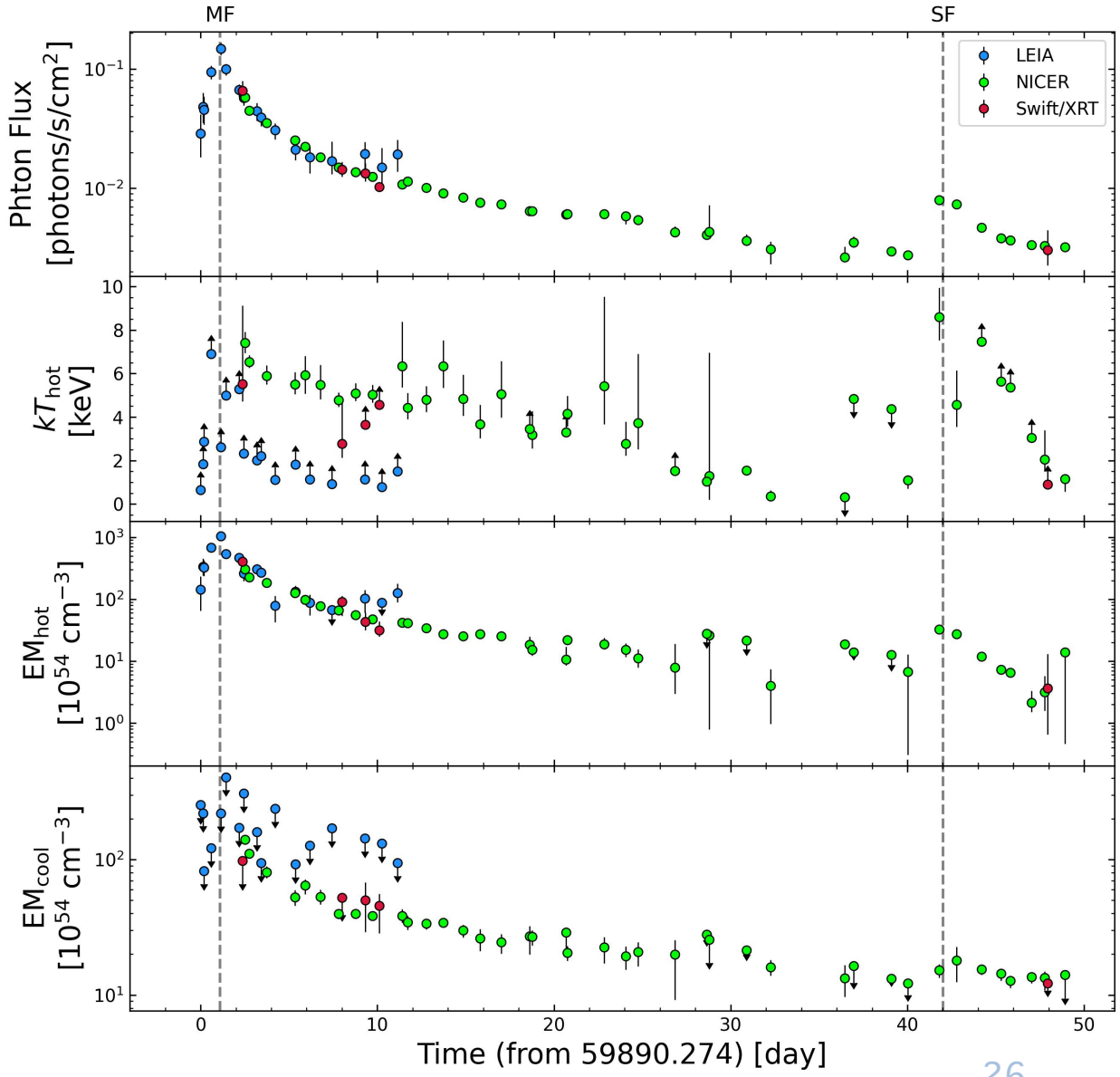
Quiescnet Spectrum (MJD>59940): 3T apec
Flaring Spectra: 3+1T apec

Table 2. Best-fit Spectral parameters for quiescent-state observations.

Parameters	1T apec	2T apec	3T apec
N_H [a] (10^{20} cm^{-2})	6.43	$5.9^{+0.1}_{-0.3}$	$6.7^{+1.0}_{-1.6}$
$kT_{q,1}$ [b] (keV)	1.57	$1.20^{+0.03}_{-0.03}$	$1.20^{+0.03}_{-0.04}$
$EM_{q,1}$ [c] (10^{54} cm^{-3})	25.0	$17.9^{+1.4}_{-1.7}$	$12.3^{+4.3}_{-2.4}$
$kT_{q,2}$ [b] (keV)	-	$8.1^{+3.6}_{-2.1}$	$4.6^{+4.7}_{-0.8}$
$EM_{q,2}$ [c] (10^{54} cm^{-3})	-	$6.9^{+1.0}_{-0.7}$	$9.4^{+1.5}_{-2.4}$
$kT_{q,3}$ [b] (keV)	-	-	$0.25^{+0.04}_{-0.03}$
$EM_{q,3}$ [c] (10^{54} cm^{-3})	-	-	$4.4^{+2.3}_{-1.3}$
Z [d] ($Z_\odot$)	0.04	$0.04^{+0.01}_{-0.01}$	$0.07^{+0.02}_{-0.02}$
χ^2_ν (d.o.f.) [e]	3.18 (128)	1.36 (126)	1.06 (124)



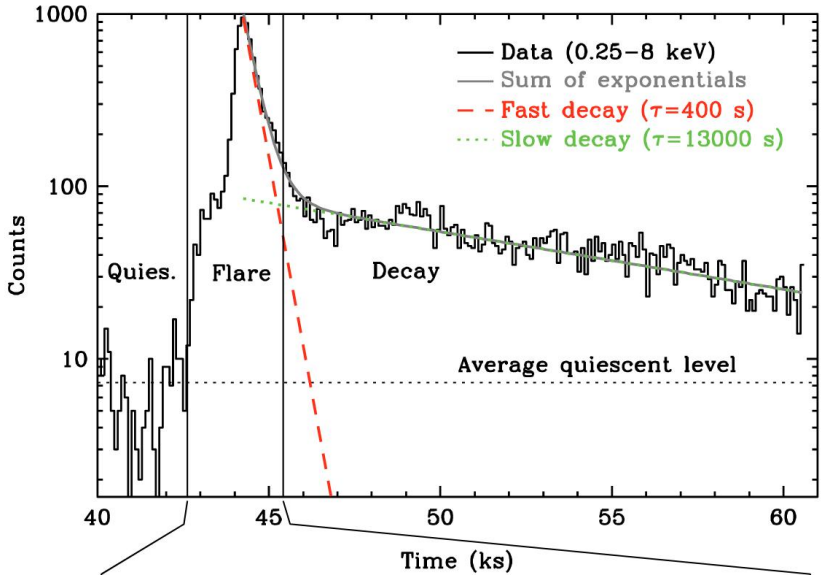
NICER能谱　　LEIA能谱



LXT221107A：最强恒星耀发

Fast Rise and Exponential Decay (FRED) model

$$c(t) = \begin{cases} c_{\rm q} & , \ (t < t_{\rm ST}); \\ (c_{\rm p} - c_{\rm q}) \times \frac{t - t_{\rm ST}}{t_{\rm p} - t_{\rm ST}} + c_{\rm q} & , \ (t_{\rm ST} \leq t < t_{\rm p}); \\ (c_{\rm p} - c_{\rm q}) \times \exp(-\frac{t - t_{\rm p}}{\tau_{\rm d}}) + c_{\rm q} & , \ (t_{\rm p} \leq t). \end{cases}$$



Wargelin+ 2008

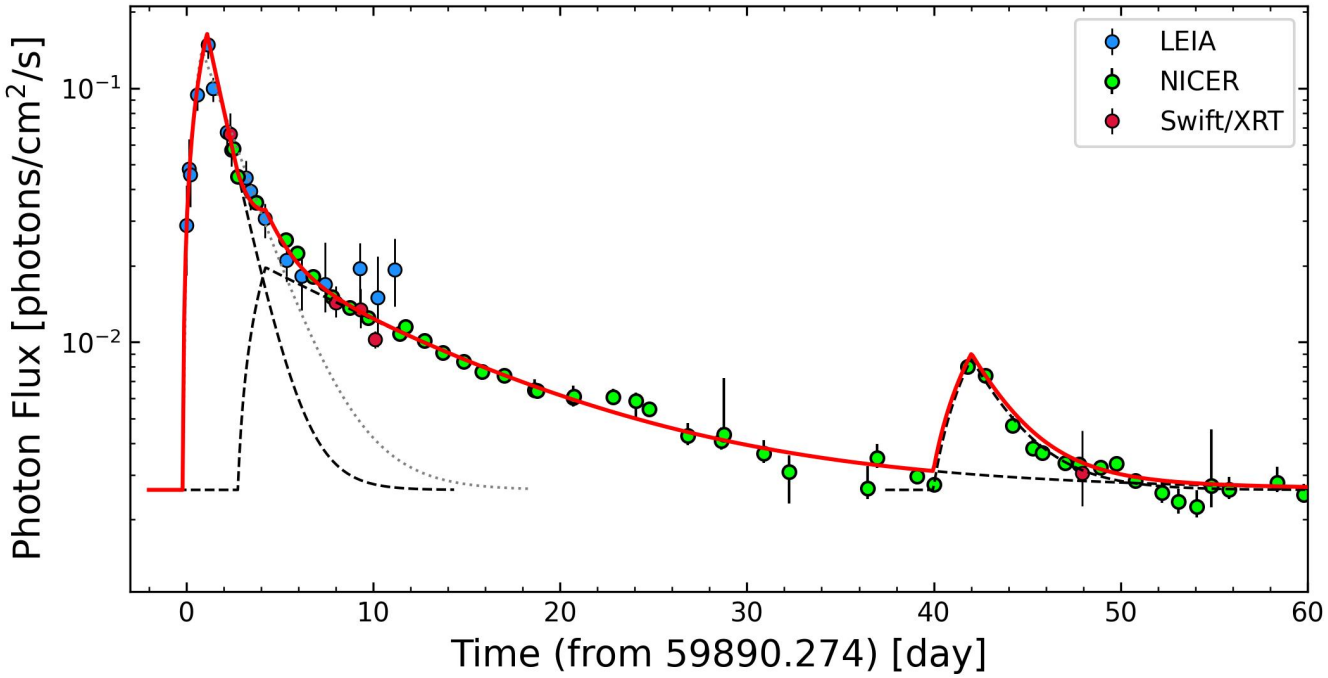
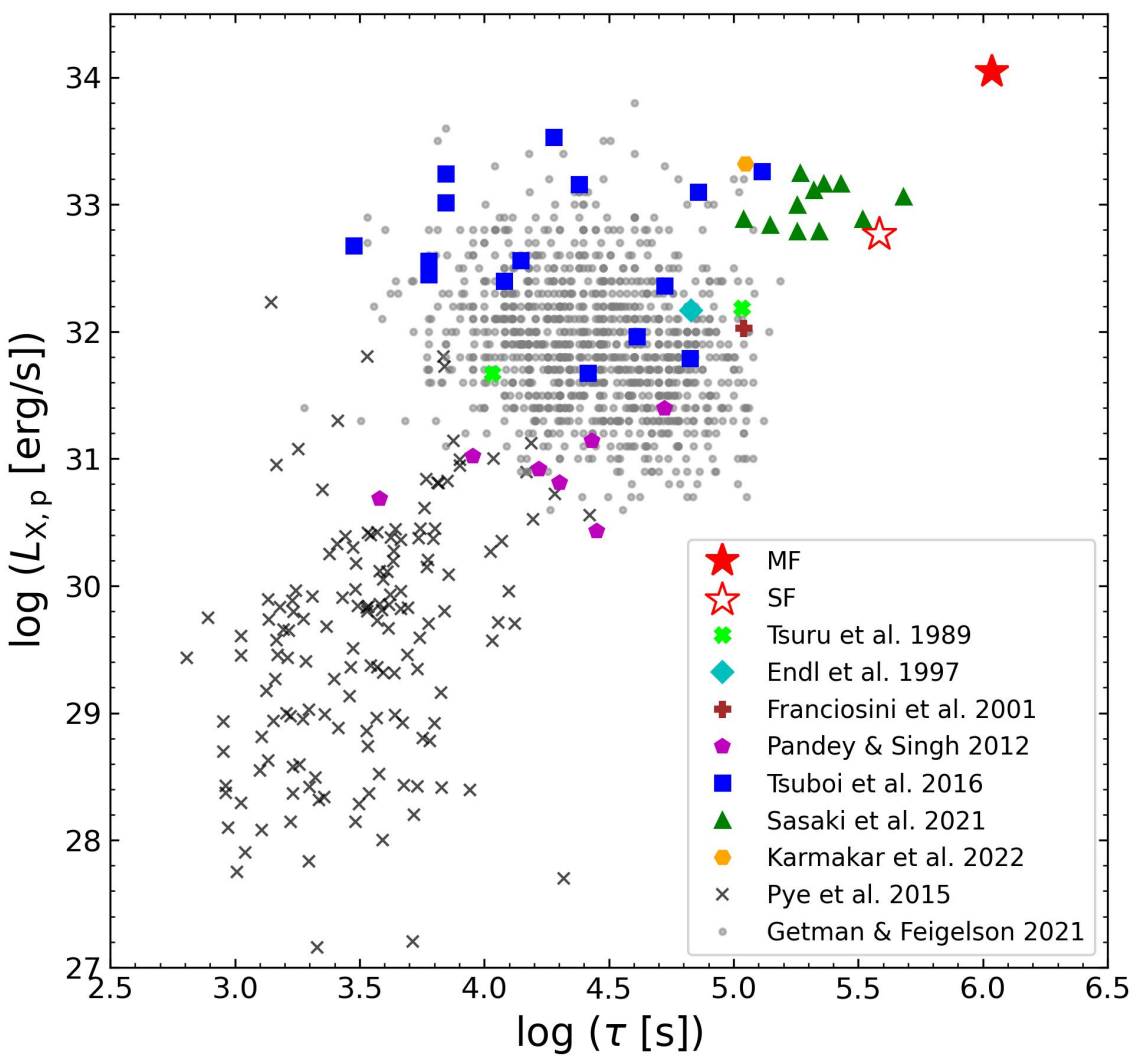


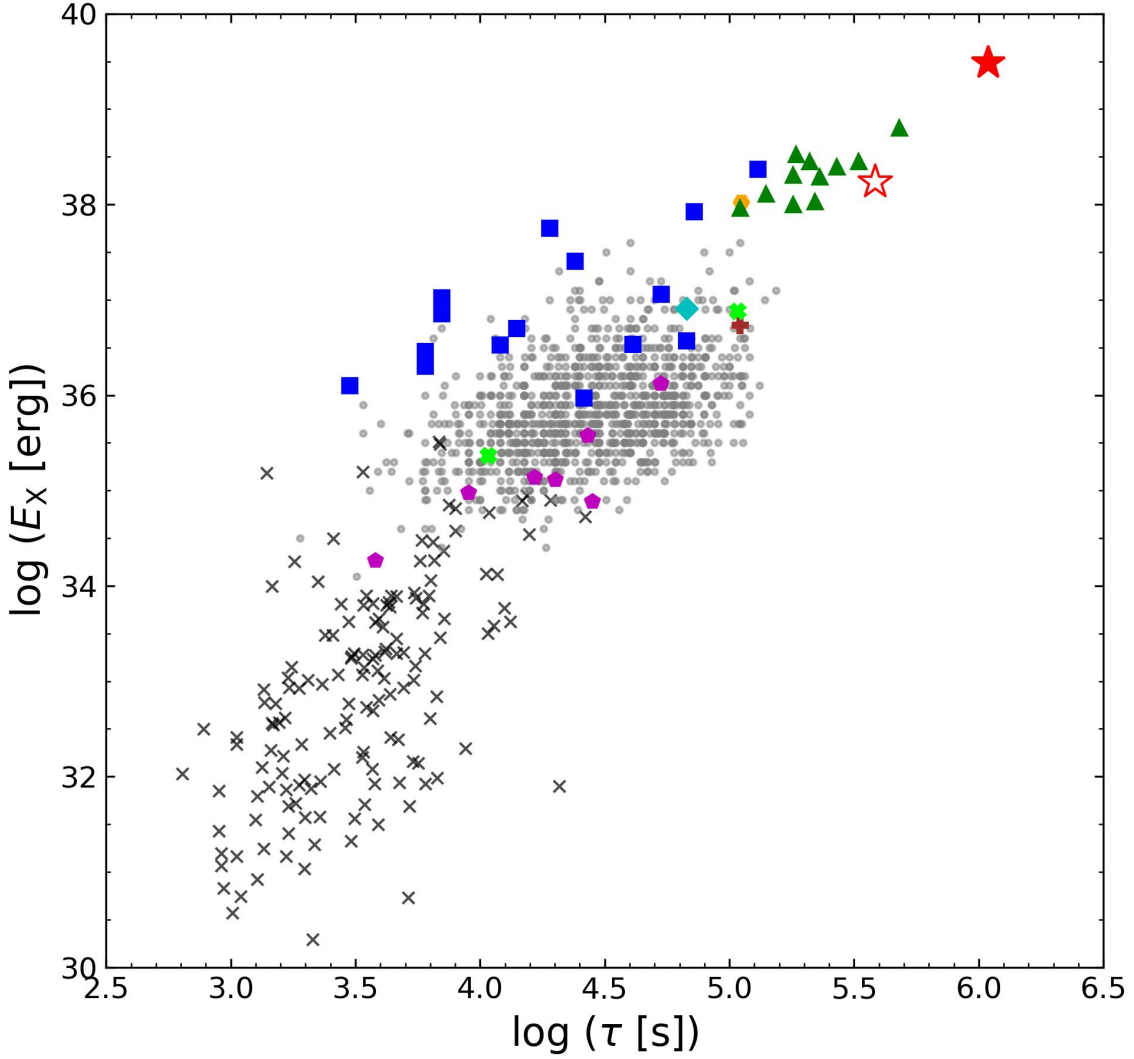
Table 3. Best-fit Parameters of the X-ray light curve

	$t_{\rm p}$ [a]	$c_{\rm p}$ [b]	$\tau_{\rm r}$ [c]	$\tau_{\rm d}$ [d]	$L_{\rm X,p}$ [e]	$f_{\rm X}$ [f]	$E_{\rm X}$ [g]
	(days since MJD=59890.274)	(counts s^{-1} cm^{-2})	(ks)	(ks)	(10^{32} erg s^{-1})	(10^{-5} erg cm^{-2})	(10^{38} erg)
MF1	1.1±0.3	0.16±0.04	112±50	109±9	110.8±29.7	6.0±1.9	18.3±5.7
MF2	4.2±0.2	0.020±0.001	128±12	869±34	13.3±1.7	4.1±1.1	12.4±1.7
SF	42.0±0.2	0.009±0.001	177±18	205±24	5.8±0.8	0.6±0.1	1.7±0.3

MF: τ ~1090 ks, E_X ~ 3.1e39 erg (0.5-4 keV)
SF: τ ~ 382 ks , E_X ~ 1.7e38 erg (0.5-4 keV)

LXT221107A：最强恒星耀发



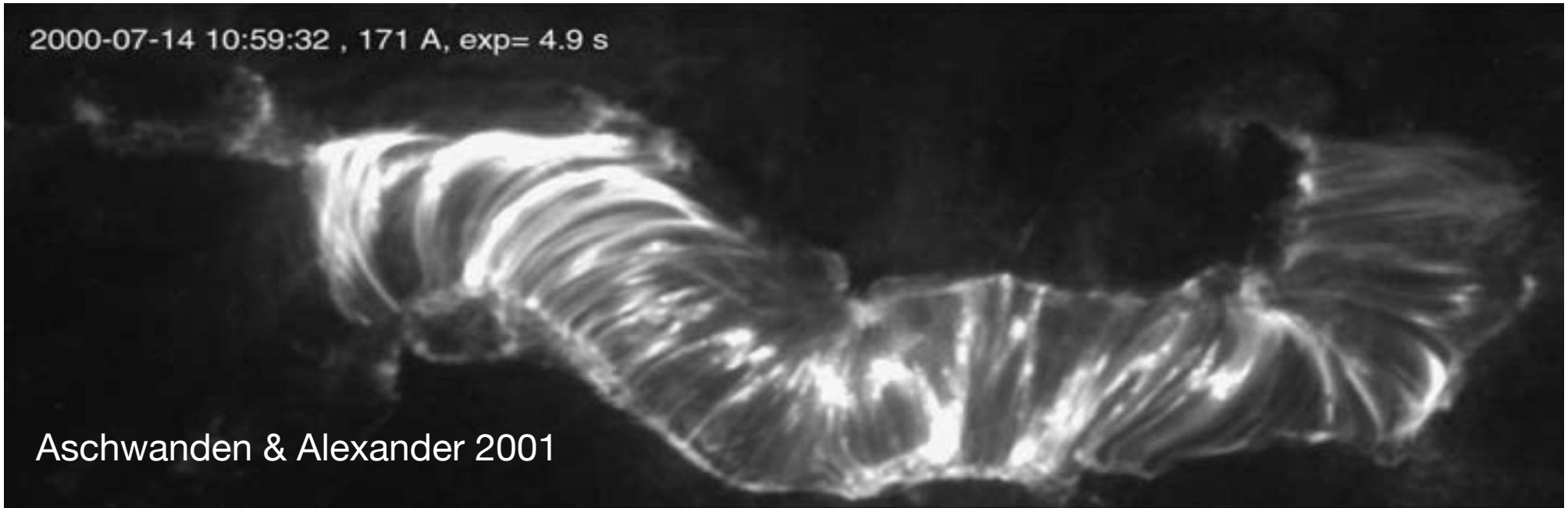


LXT221107A：最强恒星耀发

不管是太阳耀斑(Lin & Forbes 2000; Aschwanden & Alexander 2001; Lin 2002; Kashapova+ 2021)，还是恒星耀发(Reale+ 2004; Getman+ 2008; Wargelin+ 2008)，都不乏呈现出双指数下降的光变曲线。

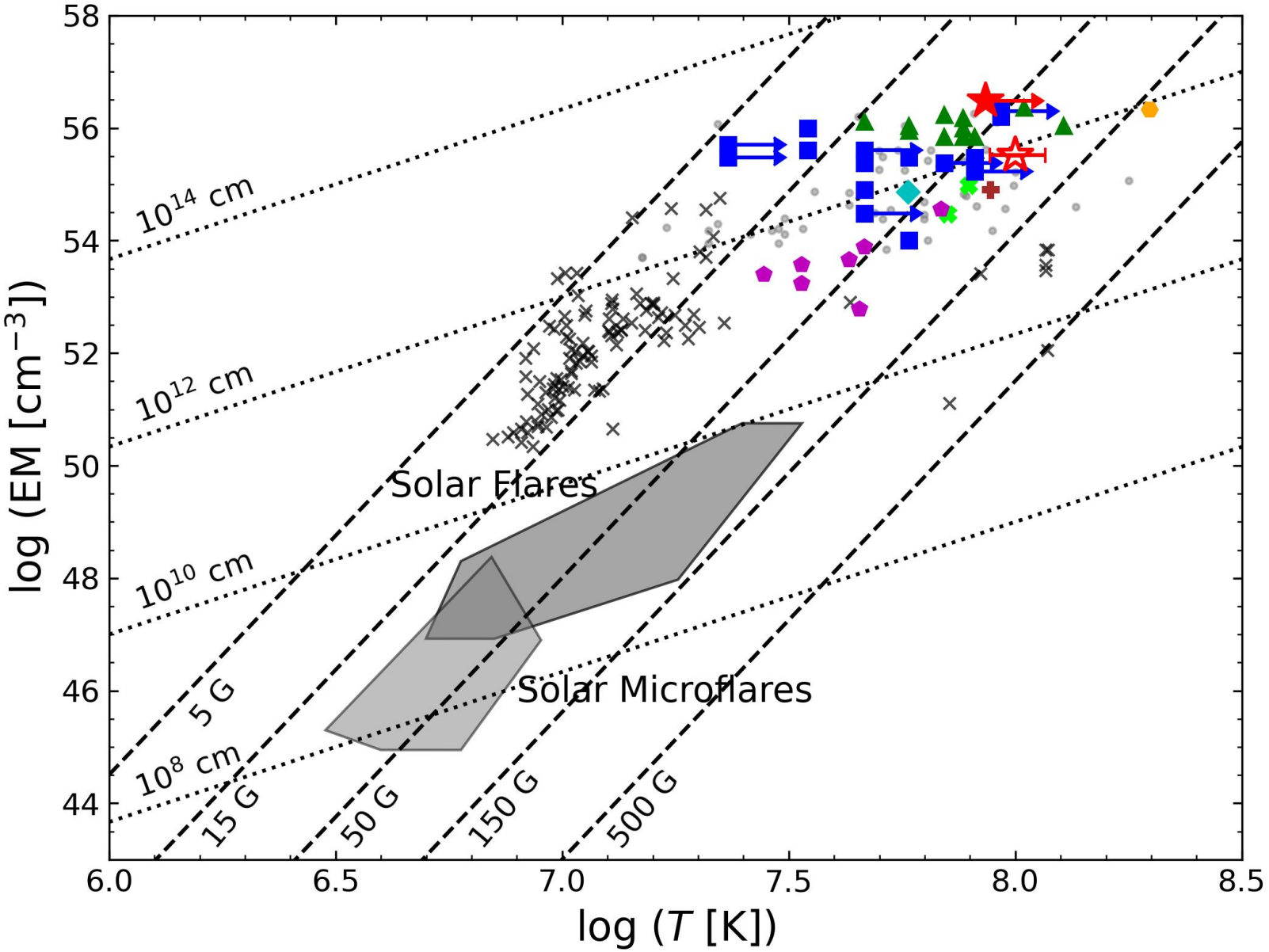
这类耀发过程常被解释为：

- 恒星表面活跃区突然发生磁重联，导致能量的大量释放，最初的单个磁环被“点燃”；
- 这一最初的能量释放逐渐平息，耀发光度迅速衰减，表现为光变曲线中快速下降的部分；
- 残余的能量进而“点燃”了一系列次级磁环，这一结构可能与太阳耀斑中观测到的磁拱廊类似（arcade）；
- 这些次级磁环的冷却相较缓慢，进而贡献了光变曲线中缓慢下降的部分



Aschwanden & Alexander 2001

LXT221107A：最强恒星耀发

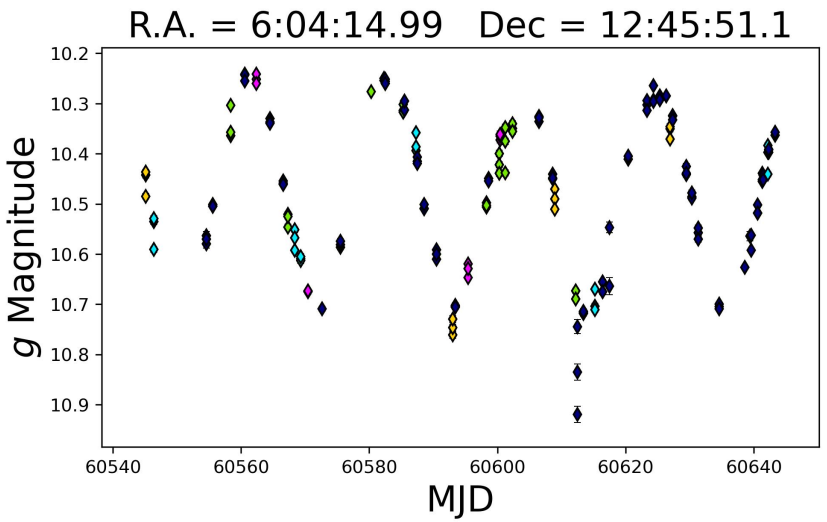


$$EM \propto B^{-5} T^{17/2}$$
$$EM \propto L^{5/3} T^{8/3}$$

Shibata & Yokoyama 1999

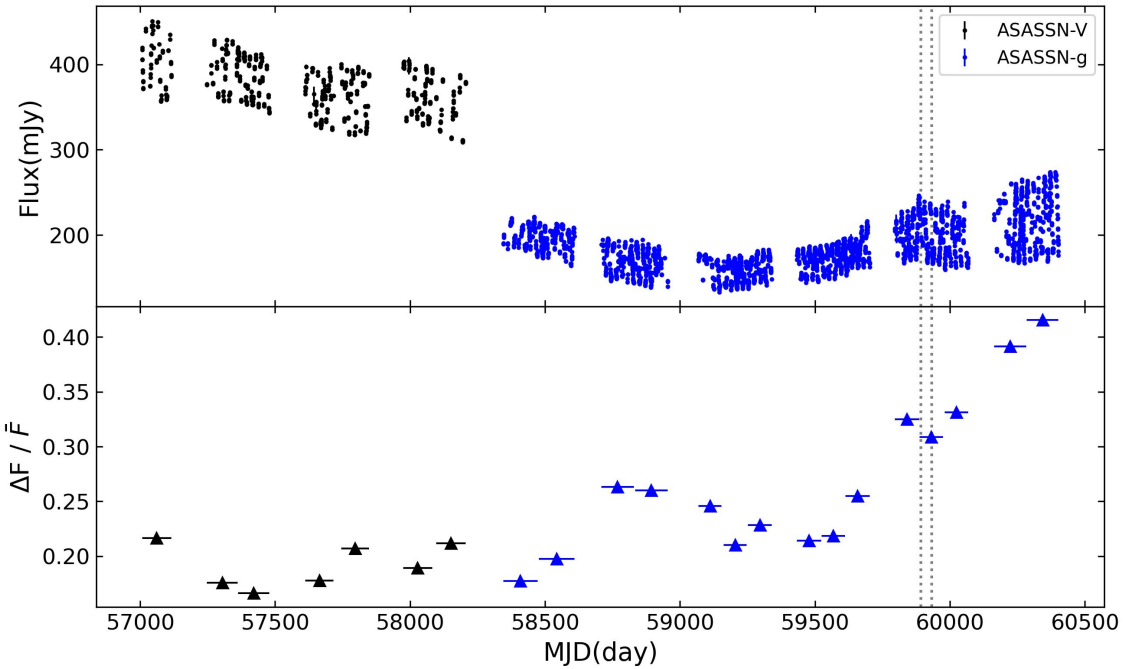
LXT221107A：恒星HD 251108

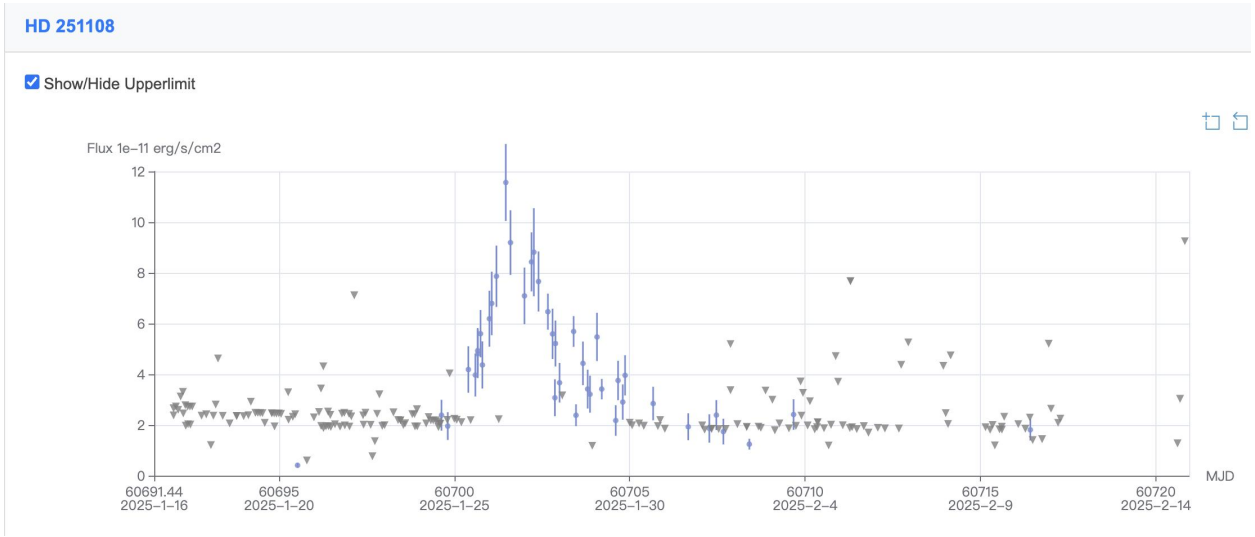
Name	HD 251108
RA, DEC	91.06, +12.76
Galactic (l, b)	196.17, -04.40
Spectral type	K2
Distance	504.7 [+4.8, -4.6] pc
Mag V	9.90 [±0.09]
Teff	4545 [+405, -138] K
log g	2.13 [+0.17, -0.09]
M_star/M_sol	1.14 [+0.48, -0.19]



P ~21.21 d

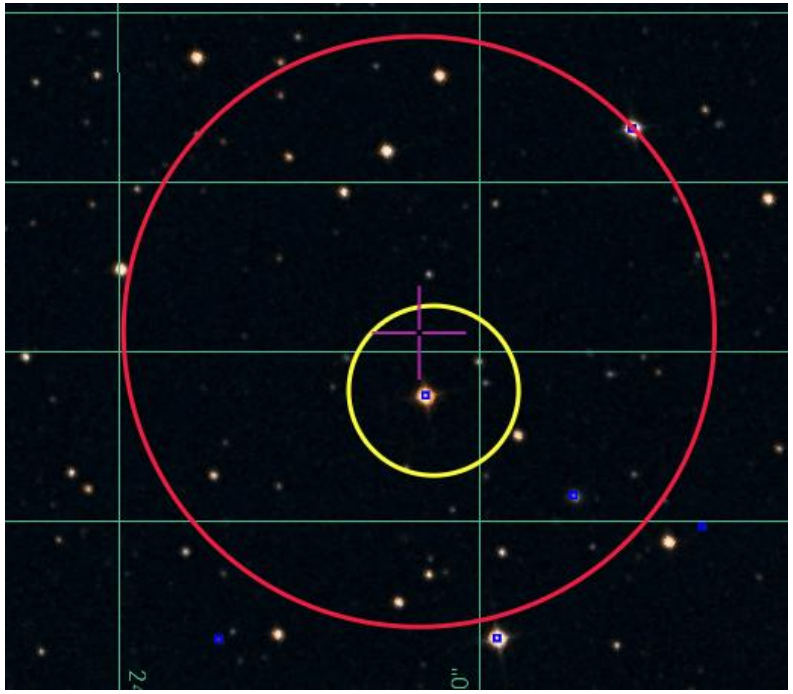
RS CVn? (Kiraga+ 2012)



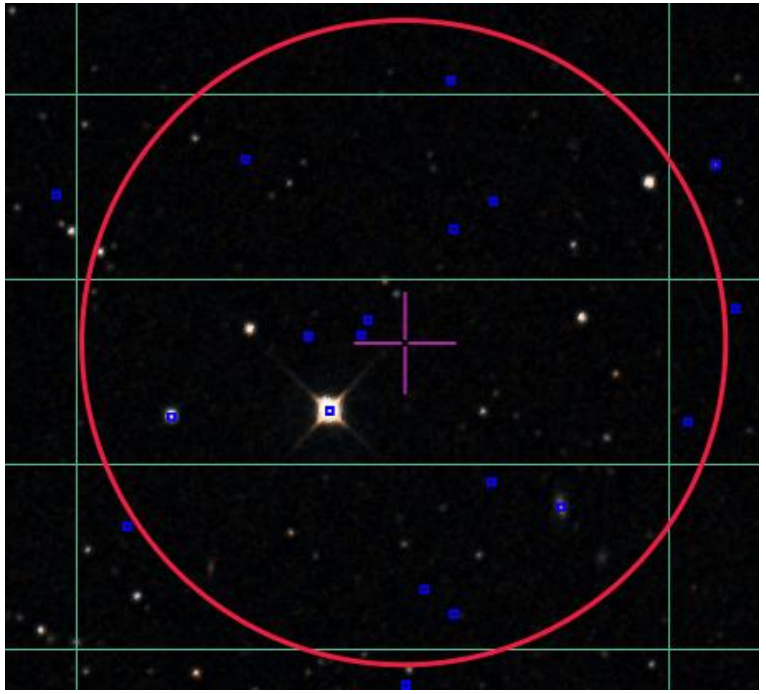


一些困难

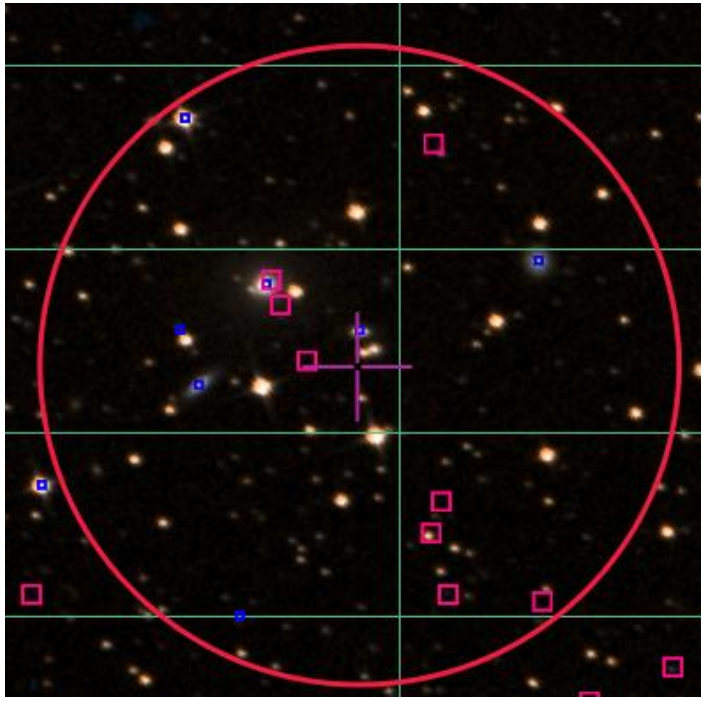
1. 许多疑似恒星耀发的探测，无法确认恒星来源



有X射线探测的恒星存在且唯一



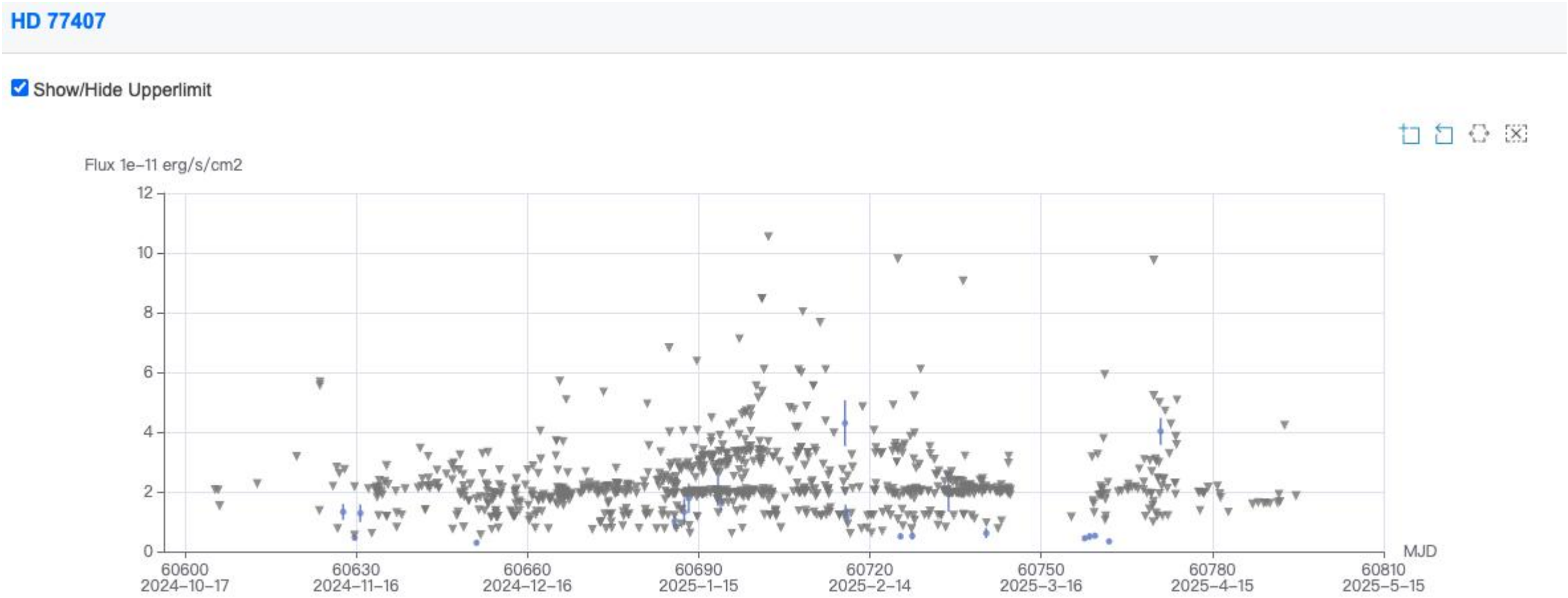
有X射线探测的恒星不存在



有X射线探测的恒星不唯一

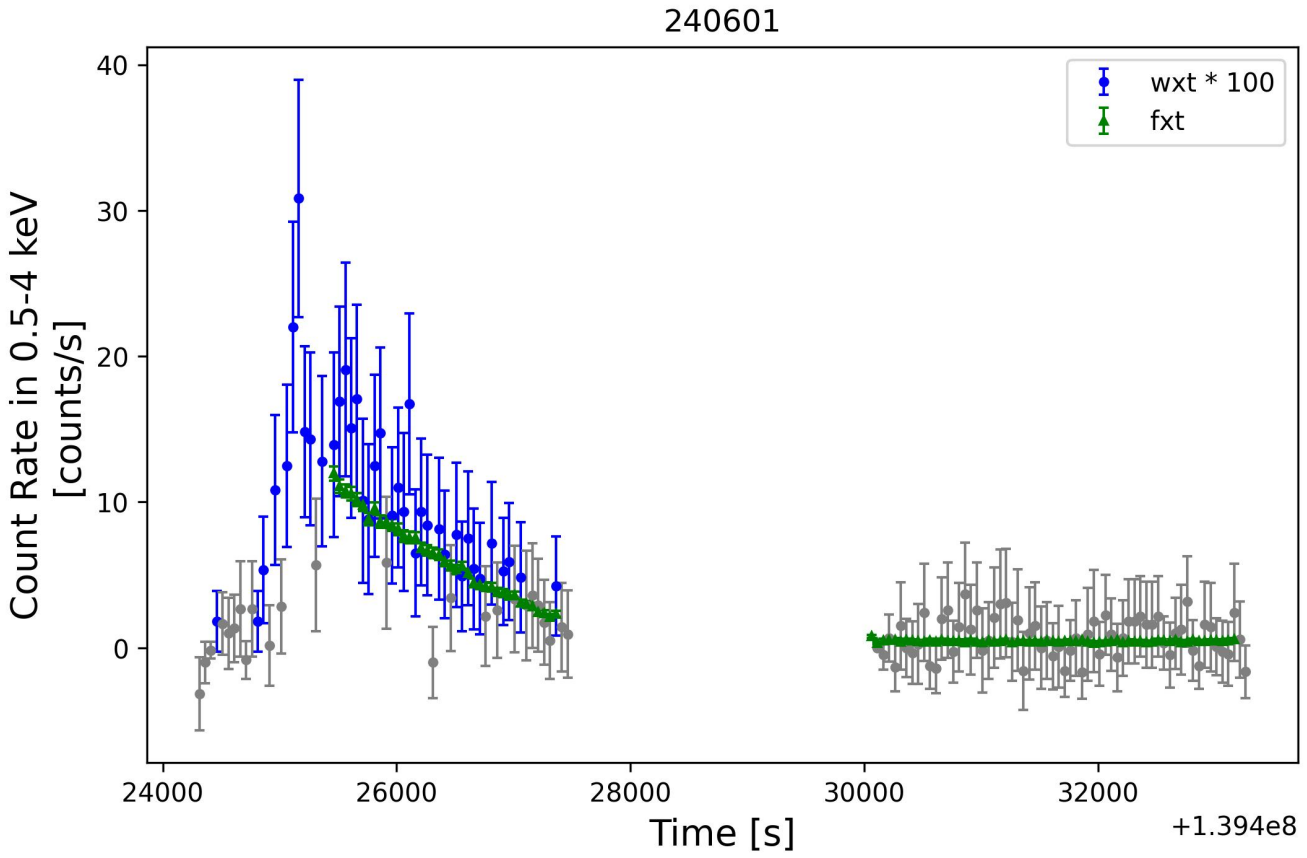
一些困难

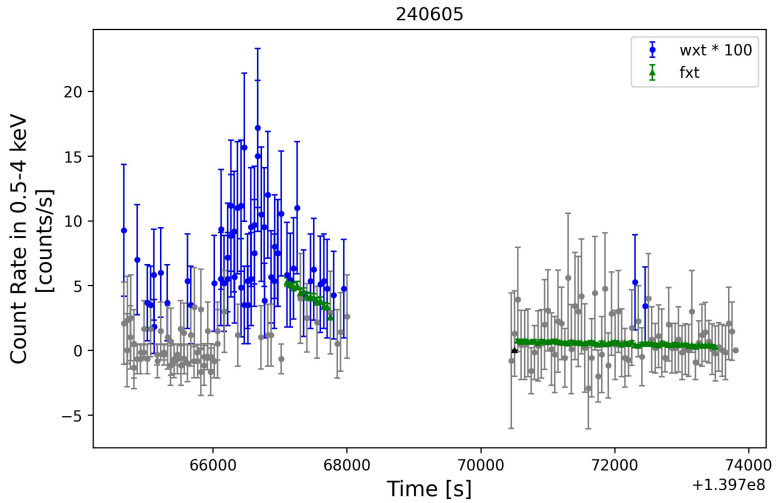
2. 大部分恒星长期持续的监测，没有X射线宁静态信息，难以对单次耀发的数据进行分析

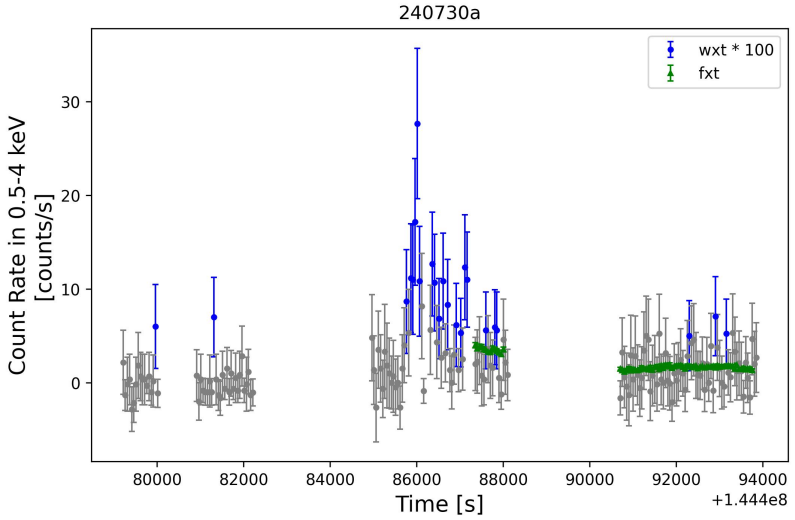


一些困难

3. 大部分触发的FXT后随的恒星耀发，演化较快，FXT只能探测到其下降阶段







总结

1. 由于EP卫星具有大视场、高灵敏度、高探测频次的优势，对恒星耀发的探测十分有利，恒星耀发的数据正快速积累起来
2. EP升空一年多以来，共探测到来自1101颗恒星的耀发，主要来源于晚型星，耀发光度在2e28 - 6e33 erg/s之间
3. 探测到的M型星从统计上来说距离更近，耀发光度更低
4. EP/WXT探测到的恒星耀发中共有93例耀发得到了其他设备的后随，其中44例自动触发了EP/FXT后随
5. LEIA探测到了持续40天左右的“最强”恒星X射线耀发，峰值光度达到1e34 erg/s
6. 目前还存在一些困难，难以识别出所有恒星耀发并进行逐个分析

LXT221107A：根据冷却模型计算磁环参数

传导冷却主导

$$\tau_{\rm C} = \frac{4\times10^{-10} n_{\rm e} L^2}{T^{5/2}}$$

辐射冷却主导

$$\tau_{\rm R} = \frac{3kT}{n_{\rm e}\Lambda(T)}$$

RTV scaling law (Rosner+1978):

$$T_{\rm max}^2 \approx 7.6\times10^{-7} n_{\rm e} L$$

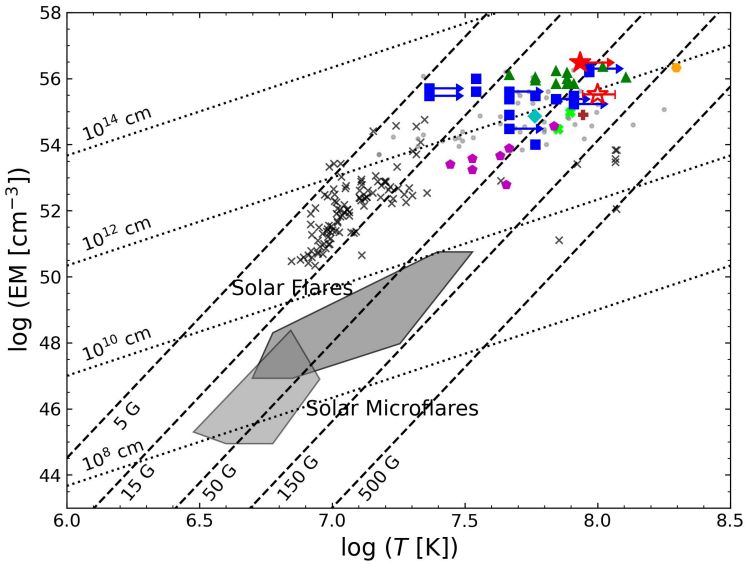


Table B.1. Parameters of loop size and flaring plasma.

	L^a (10^{12} cm)	$n_{\rm e}{}^b$ (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}	$79.8^{+8.8}_{-7.9}$

NOTE—Since the light curve of SF does not deviate from a single exponential decay, the conductive cooling phase is assumed to be skipped (Reale 2007). The cooling process of SF is then solely dominated by radiative loss.