The 32nd Texas Symposium on Relativistic Astrophysics

Supernova 2023ixf in Messier 101

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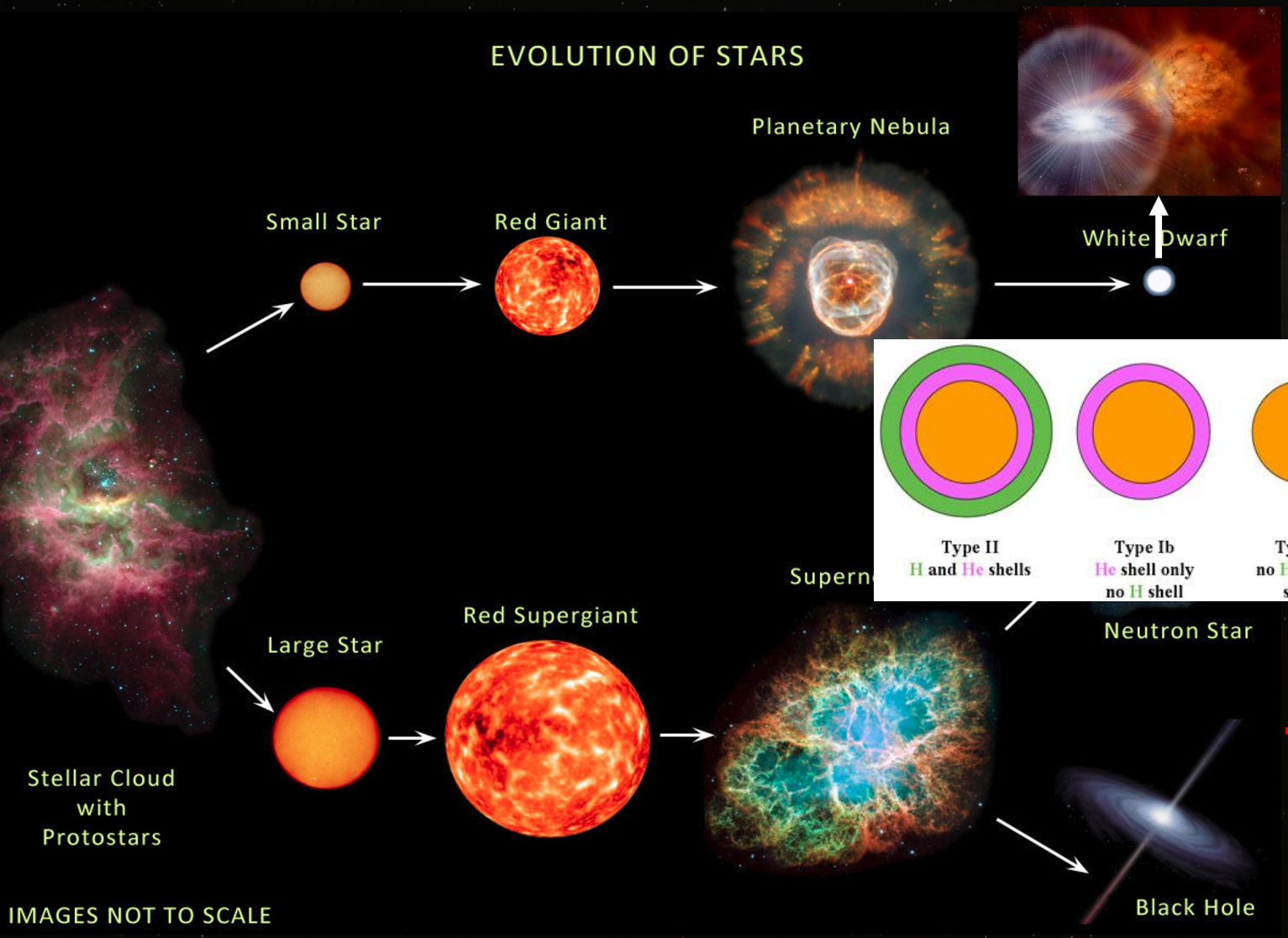
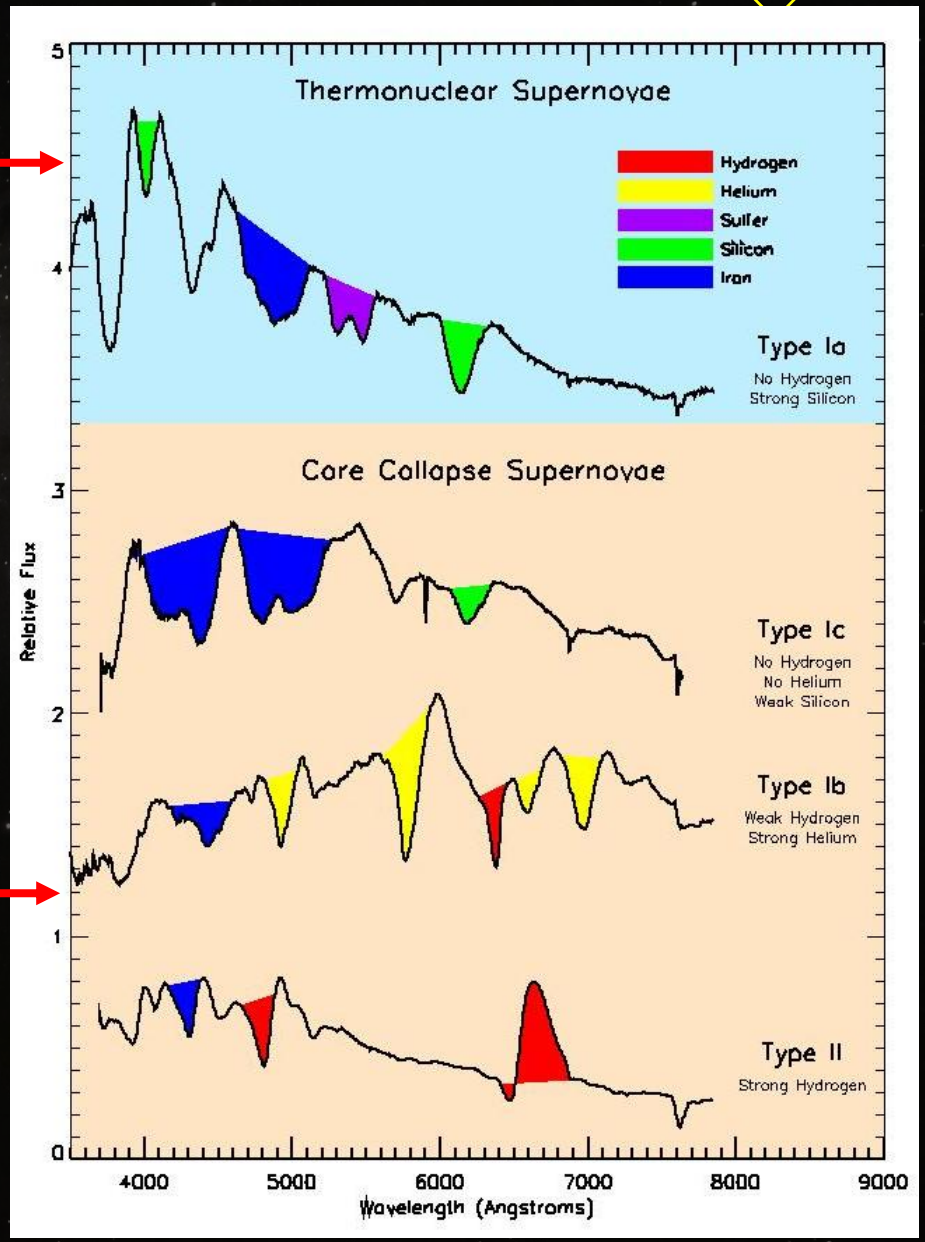
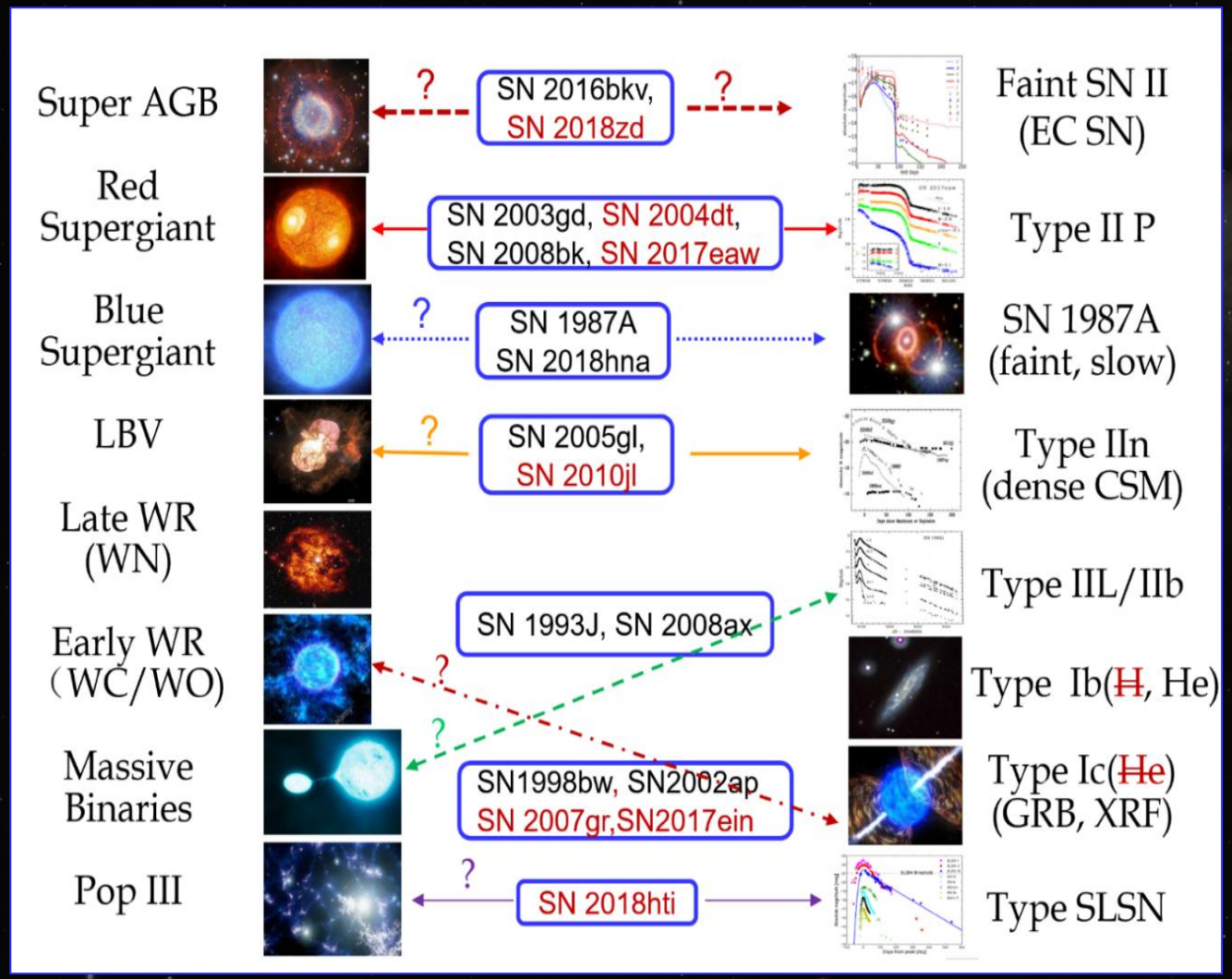
Texas in Shanghai

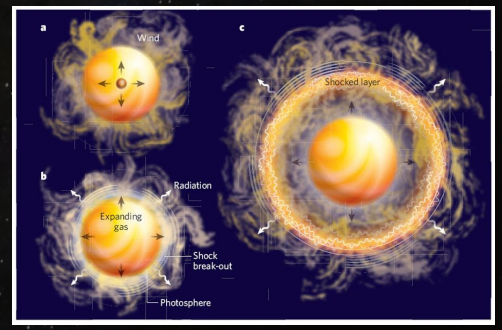
Supernova Spectra

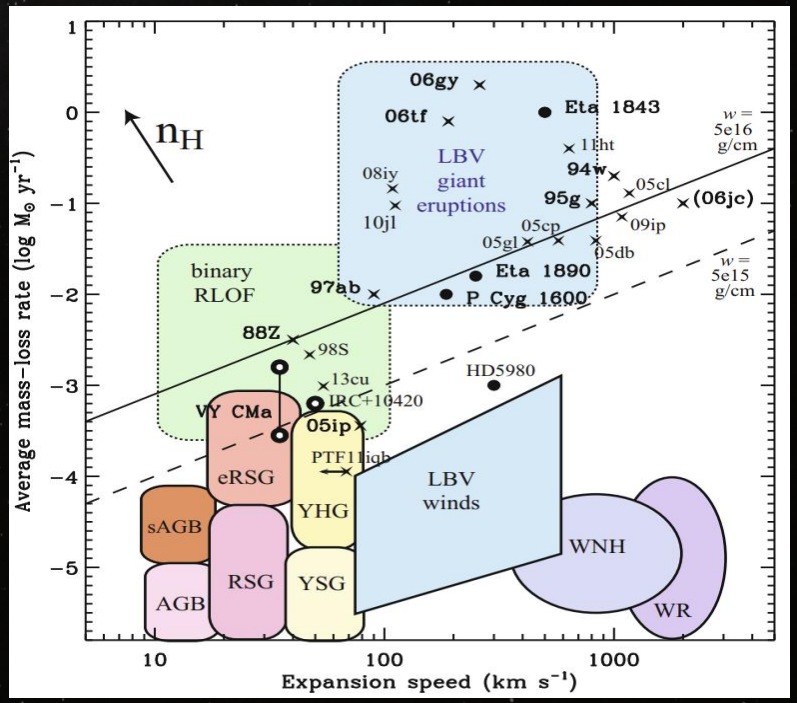


https://en.wikipedia.org/wiki/Stellar_evolution




Super AGB
Red Supergiant
Blue Supergiant
LBV
Late WR (WN)
Early WR (WC/WO)
Massive Binaries
Pop III
SN 2016bkv, SN 2018zd
SN 2003gd, SN 2004dt, SN 2008bk, SN 2017eaw
SN 1987A SN 2018hna
SN 2005gl, SN 2010jl
SN 1993J, SN 2008ax
SN1998bw, SN2002ap SN 2007gr,SN2017ein
SN 2018hti
Faint SN II (EC SN)
Type II P
SN 1987A (faint, slow)
Type IIn (dense CSM)
Type IIL/IIb
Type Ib(H, He)
Type Ic(He) (GRB, XRF)
Type SLSN


Wind
Shocked layer
Radiation
Expanding gas
Shock break-out
Photosphere


n_H
LBV giant eruptions
binary RLOF
LBV winds
sAGB
AGB
RSG
eRSG
YHG
YSG
WNH
WR
06gy
06tf
Eta 1843
08iy
10jl
94w
95g
05cl
(06jc)
05cp
09ip
05gl
05db
Eta 1890
P Cyg 1600
97ab
88Z
98S
13cu
HD5980
VY CMa
IRC+10420
05ip
PTF11iqb
w = 5e16 g/cm
w = 5e15 g/cm
Average mass-loss rate (log $M_\odot$ yr^{-1})
Expansion speed (km s^{-1})

D=6.85 Mpc

SN Ia with Mv (peak) ~ 9.9 mag

SN 2011fe

Discovered at a few hours after explosion

SN 2023ixf

SN II with Mv (peak) ~ 10.9 mag

Discovered at about 1 hour after explosion

Other stellar explosions: AT2015dl, 1970G, 1951H, 1909A

Discovery of SN 2023ixf

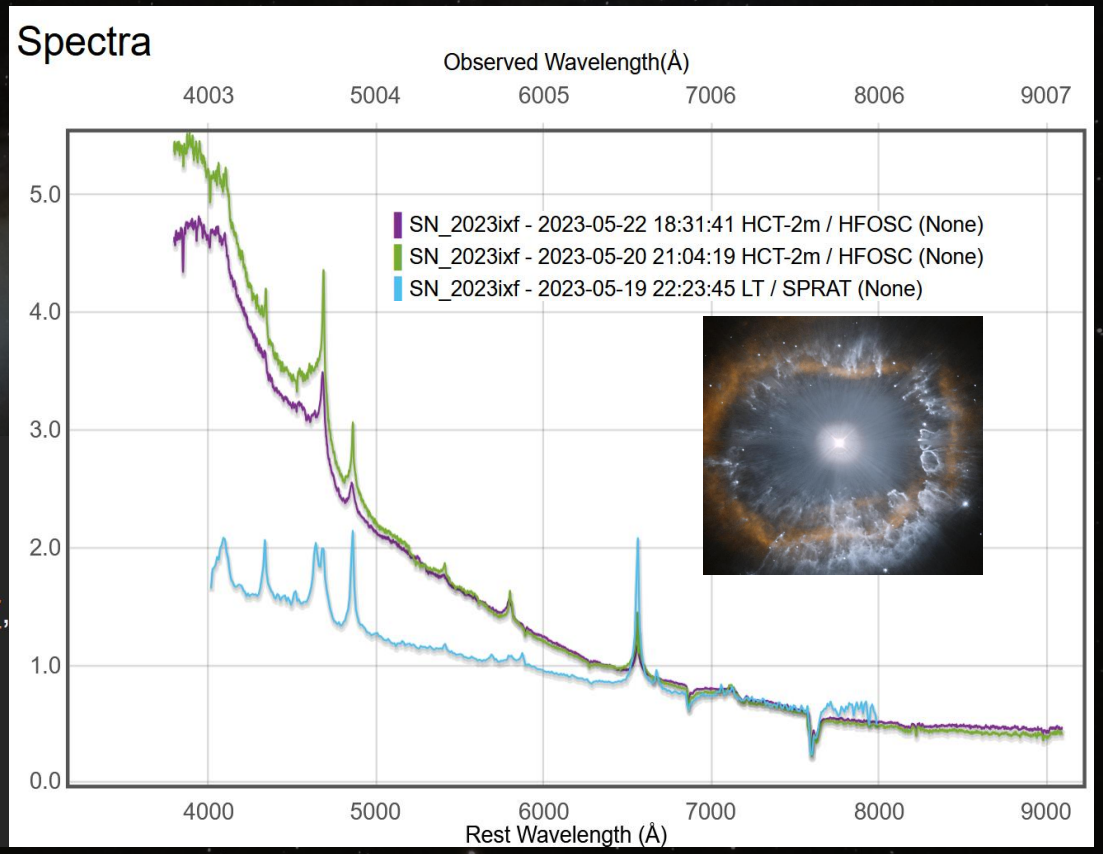
Reporting Group	Discovering Data Source	Discovery Date	TNS AT	Public	Host Name
None	None	2023-05-19 17:27:15.000	Y	Y	M101

Discovery Mag	Filter
14.9	Clear-

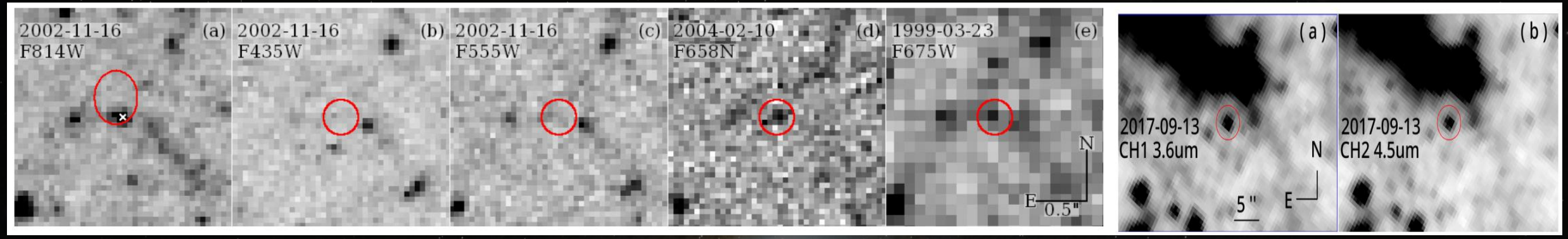
Reporter/s
Koichi Itagaki

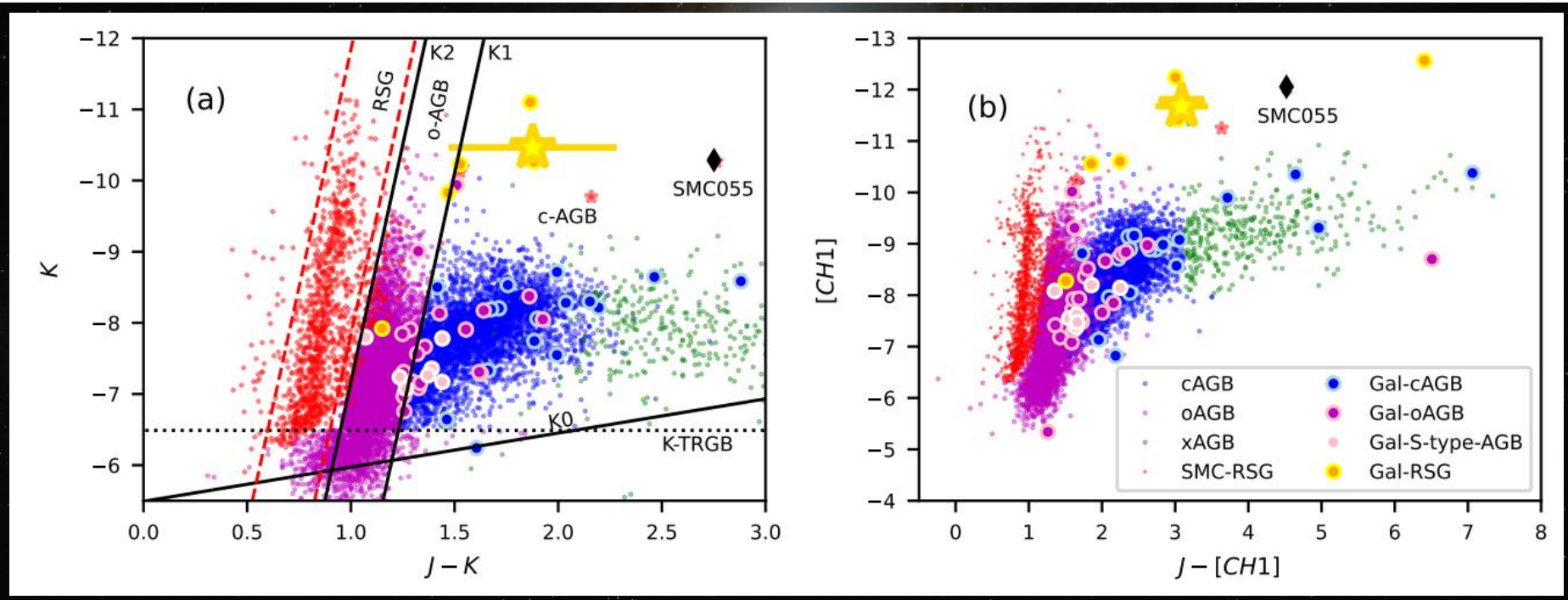
Discovery Report Classification Report

Related AstroNotes: 2023-119, 2023-120, 2023-123, 2023-124, 2023-125, 2023-127, 2023-128, 2023-129, 2023-130, 2023-132, 2023-133, 2023-135, 2023-131, DRAFT-1297, 2023-136, 2023-137, 2023-139, 2023-140, 2023-141, 2023-142, 2023-143, 2023-146, 2023-147, 2023-145, 2023-150, 2023-153, 2023-154, 2023-155, 2023-156, 2023-157, 2023-160, 2023-161, 2023-144, 2023-170, 2023-172, 2023-175, 2023-180, 2023-181, 2023-190, 2023-209, 2023-211, 2023-212, 2023-213



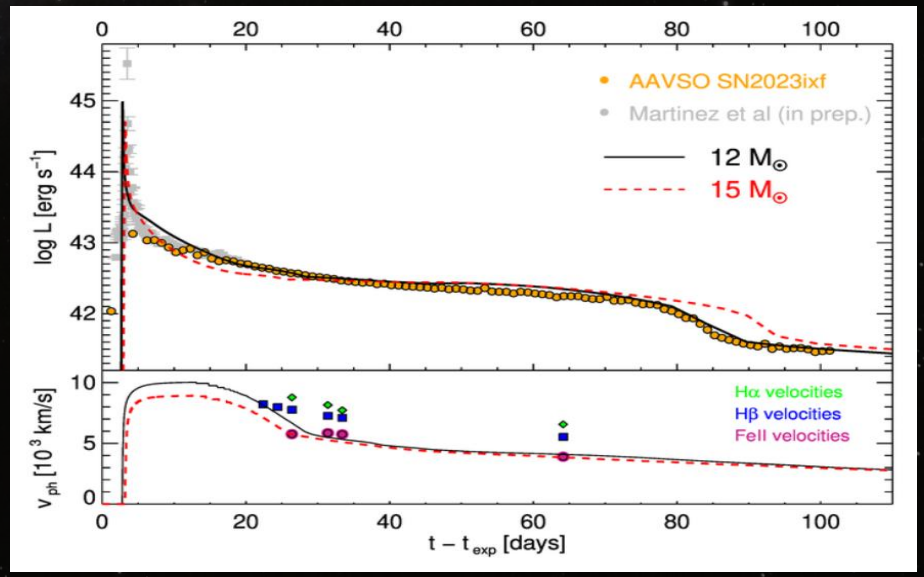
https://www.wis-tns.org/object/2023ixf

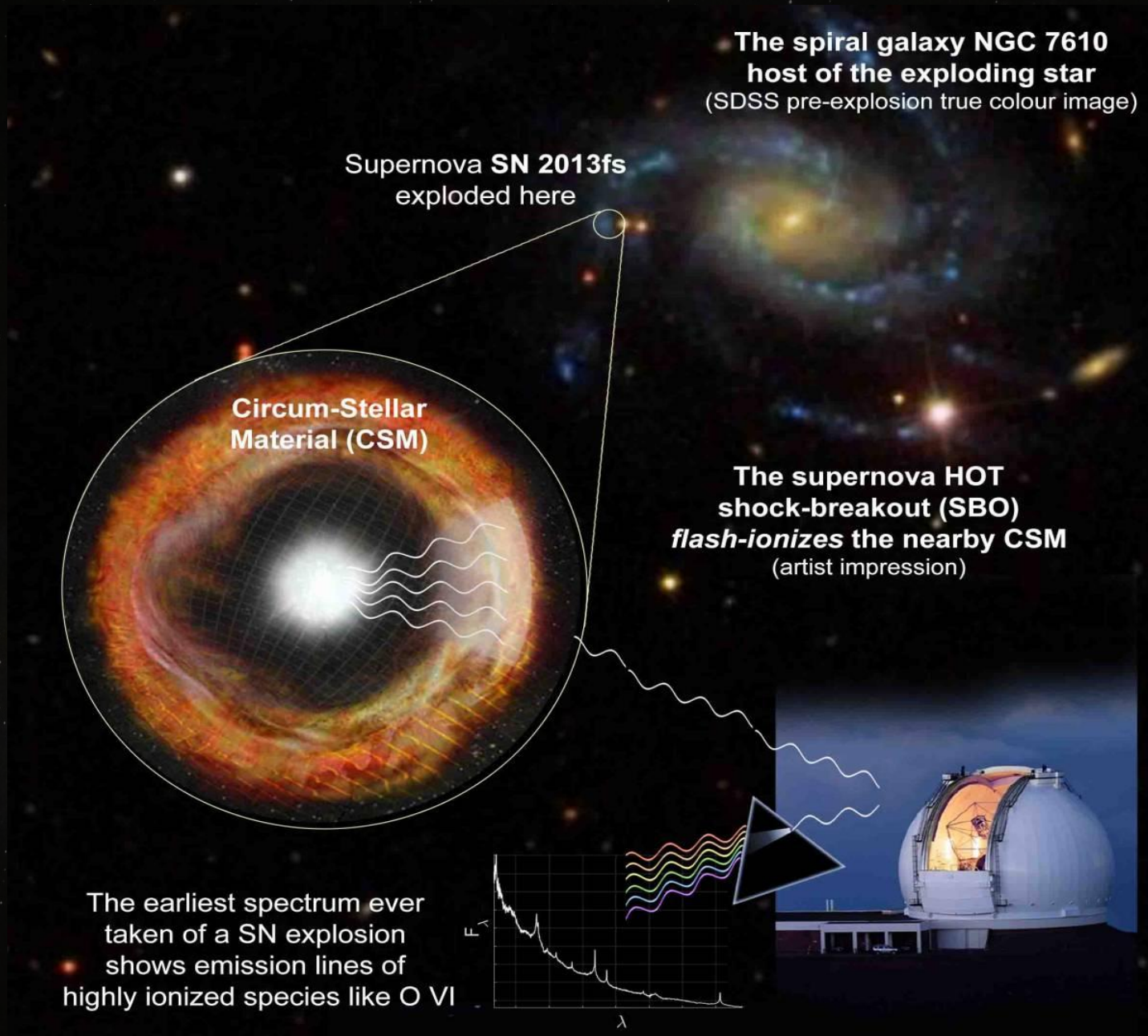

2002-11-16
F814W
(a)
2002-11-16
F435W
(b)
2002-11-16
F555W
(c)
2004-02-10
F658N
(d)
1999-03-23
F675W
(e)
N
E
0.5"
(a)
2017-09-13
CH1 3.6um
N
5"
E
(b)
2017-09-13
CH2 4.5um


(a)
RSG
o-AGB
K2
K1
c-AGB
SMC055
K0
K-TRGB
K
J − K
(b)
SMC055
cAGB
oAGB
xAGB
SMC-RSG
Gal-cAGB
Gal-oAGB
Gal-S-type-AGB
Gal-RSG
[CH1]
J − [CH1]

Initial mass ($M_\odot$)	$T_{\rm eff}$ (K)	log $L/L_\odot$	Mass loss rate $M_\odot$ yr^{-1}	method	Reference
~11	3920^{+200}_{-160}	4.74±0.07	$\sim 5 \times 10^{-5}$	SED(MARCS+DUSTY)	Lilpatric et al 2023
11–14	3091^{+422}_{-258}	$4.83^{+0.13}_{-0.07}$	$\sim 6.97 \times 10^{-6}$	SED(MARCS+DUSTY)	**Xiang et al. 2023**
12–15	3450^{+250}_{-1080}	4.97	$\sim 1.04 \times 10^{-5}$	SED(GRAMS)	Van Dyk et al. 2023
17±4	3500^{+800}_{-1400}	5.1±0.2	$(1.5–15)\times10^{-4}$	SED(GRAMS)	Jencson et al. 2023
16.2–17.4	3700	5.11±0.08	$\sim 2 \times 10^{-4}$	SED(MARCS+DUSTY)	Niu et al. 2023
16.9–18.8	3343±27	5.10±0.02	$(3.58\pm0.15)\times10^{-4}$	SED(MARCS+DUSTY)	Qin et al. 2023
20±4	3200	5.27±0.12	$(2–4)\times10^{-4}$	$P-L$ relation	Soraisom et al. 2023

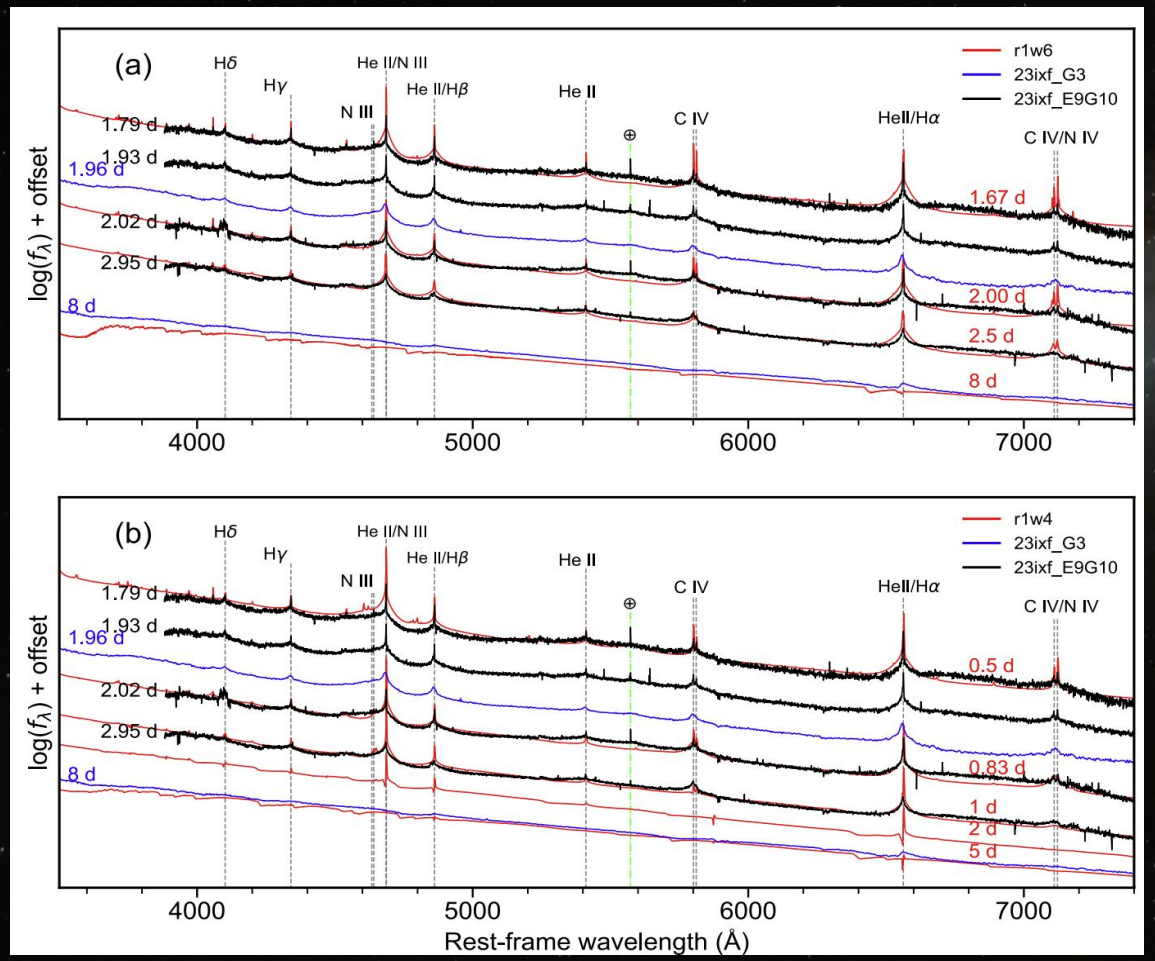
- Low mass (<15M⊙) or high mass (>15M⊙)?
- Late-time observation favors low mass progenitor (Betsten et al. 2023)
- Dusty shell around progenitor

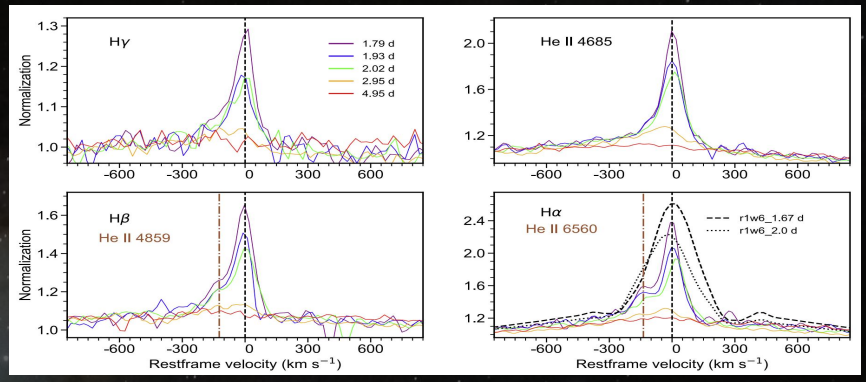


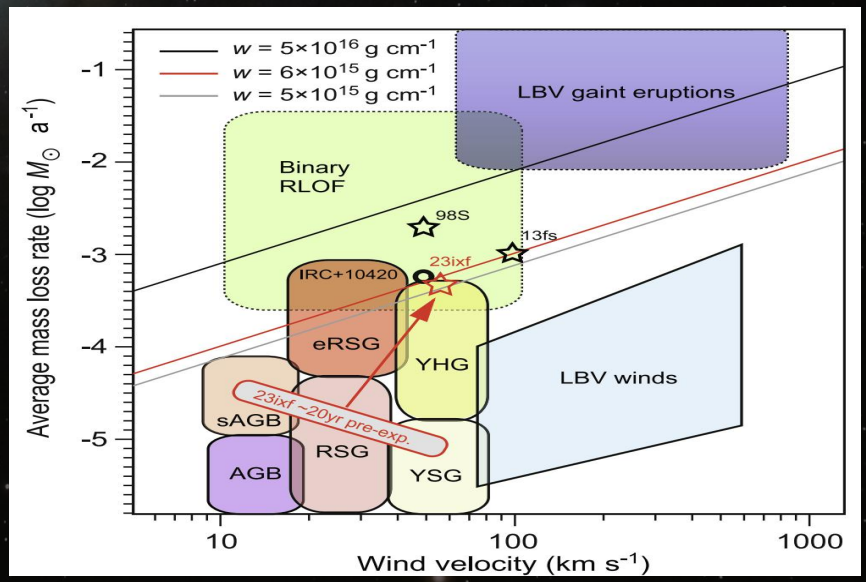

The spiral galaxy NGC 7610
host of the exploding star
(SDSS pre-explosion true colour image)
Supernova SN 2013fs
exploded here
Circum-Stellar
Material (CSM)
The supernova HOT
shock-breakout (SBO)
flash-ionizes the nearby CSM
(artist impression)
The earliest spectrum ever
taken of a SN explosion
shows emission lines of
highly ionized species like O VI
F_λ
λ

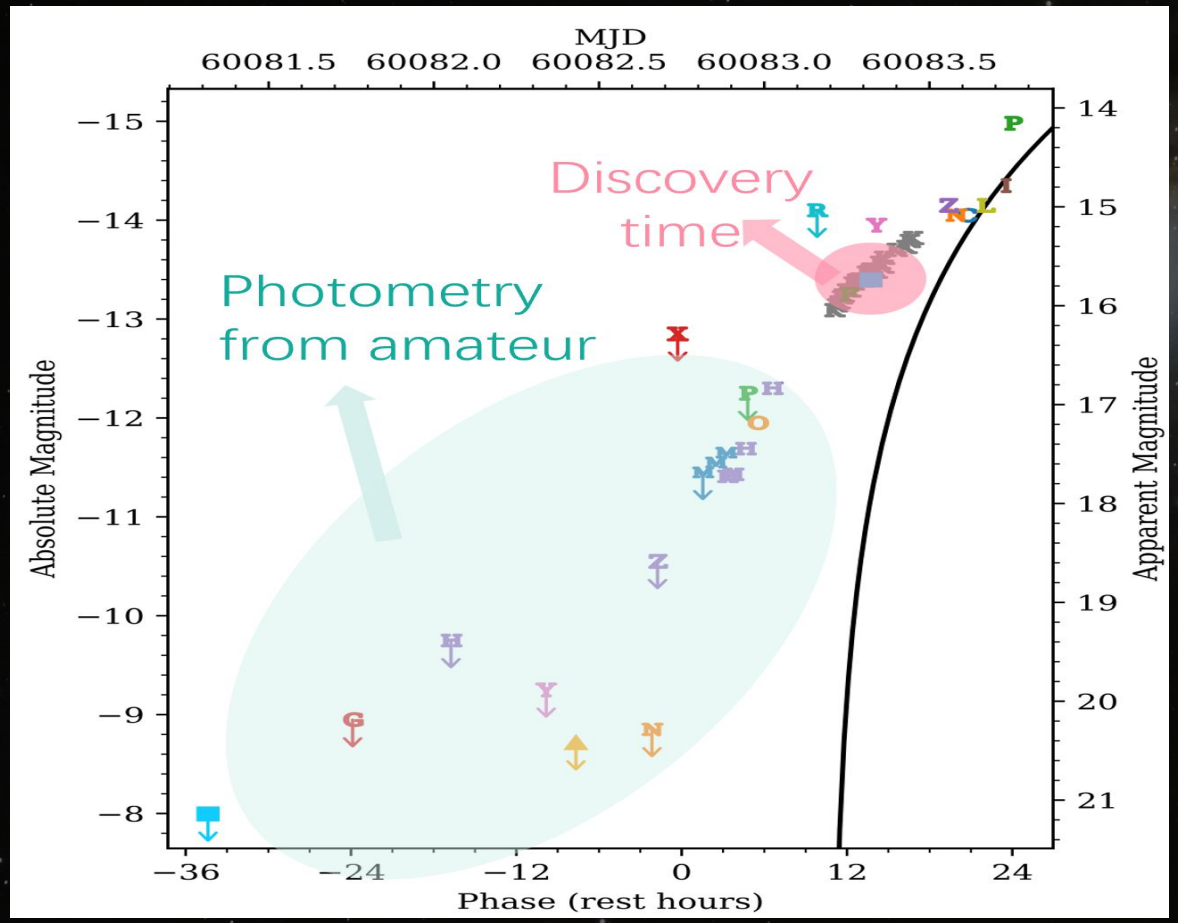
Circumstellar material ejected violently by a massive star immediately before its death

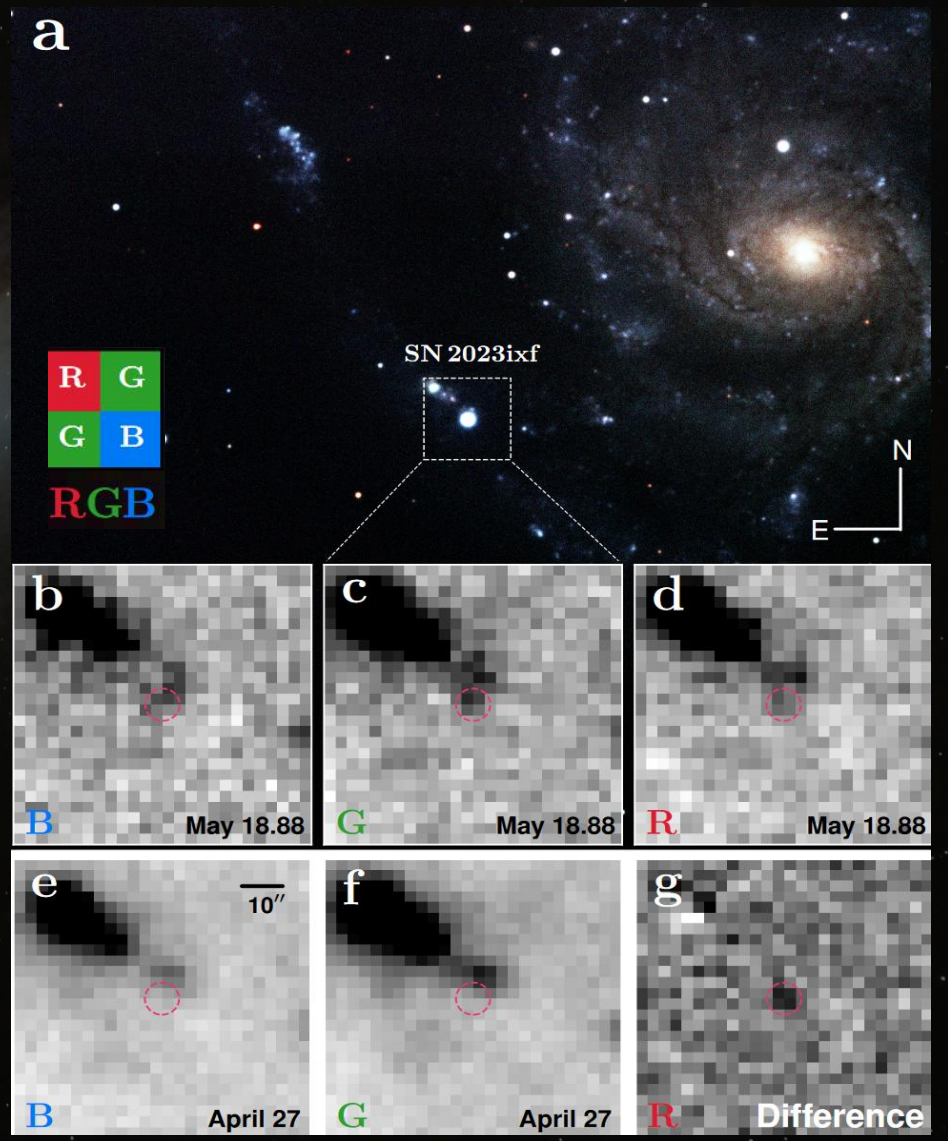
Jujia Zhang [a,b,c,*], Han Lin [a,b,d], Xiaofeng Wang [e,f,*], Zeyi Zhao [a,b,c], Liping Li [a], Jialian Liu [e], Shengyu Yan [e], Danfeng Xiang [e], Huijuan Wang [g,h], Jinming Bai [a,b,c]

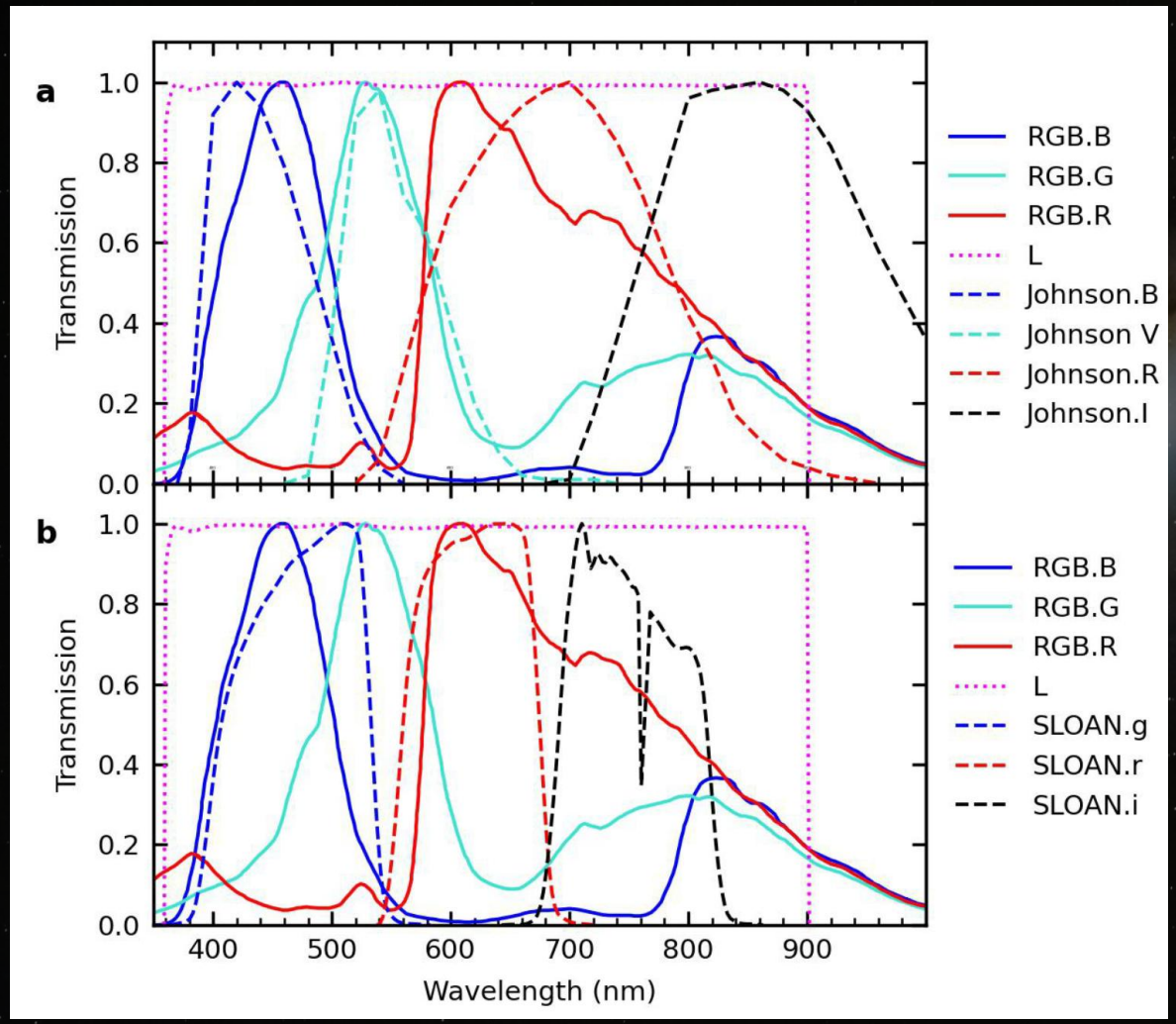


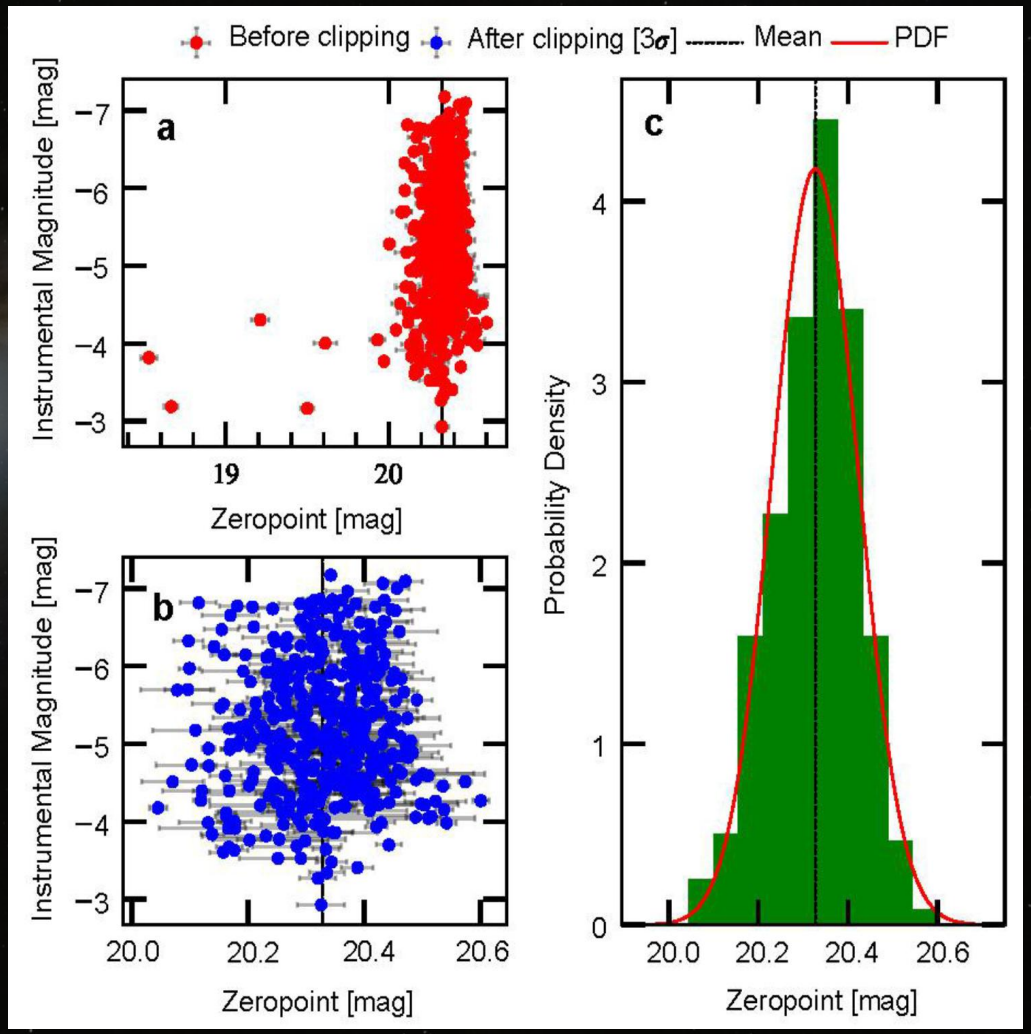




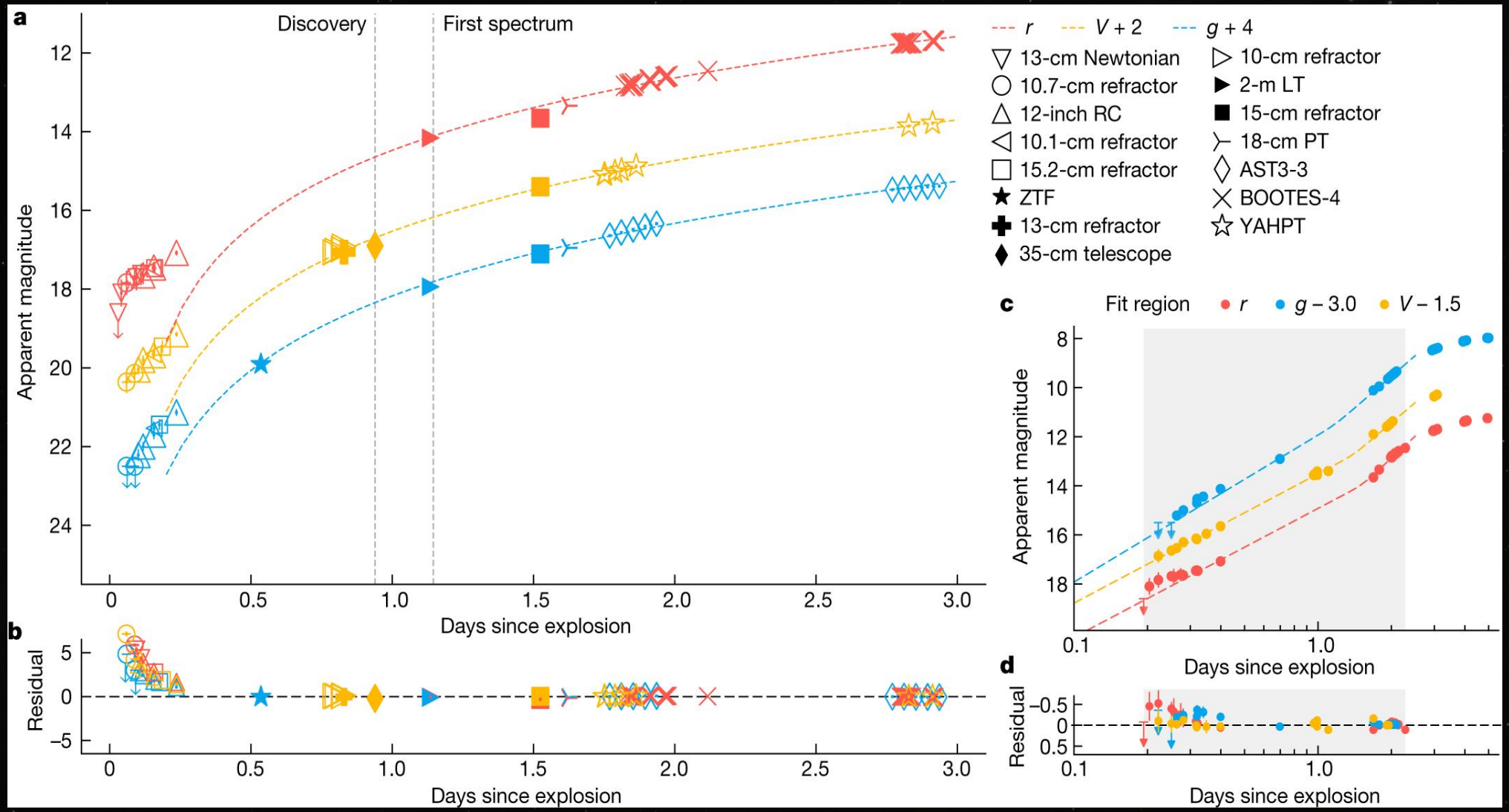

MJD
60081.5
60082.0
60082.5
60083.0
60083.5
Discovery time
Photometry from amateur
Absolute Magnitude
Apparent Magnitude
−15
−14
−13
−12
−11
−10
−9
−8
14
15
16
17
18
19
20
21
−36
−24
−12
0
12
24
Phase (rest hours)


a
SN 2023ixf
R G
G B
RGB
N
E
b
B
May 18.88
c
G
May 18.88
d
R
May 18.88
e
10″
B
April 27
f
G
April 27
g
R
Difference



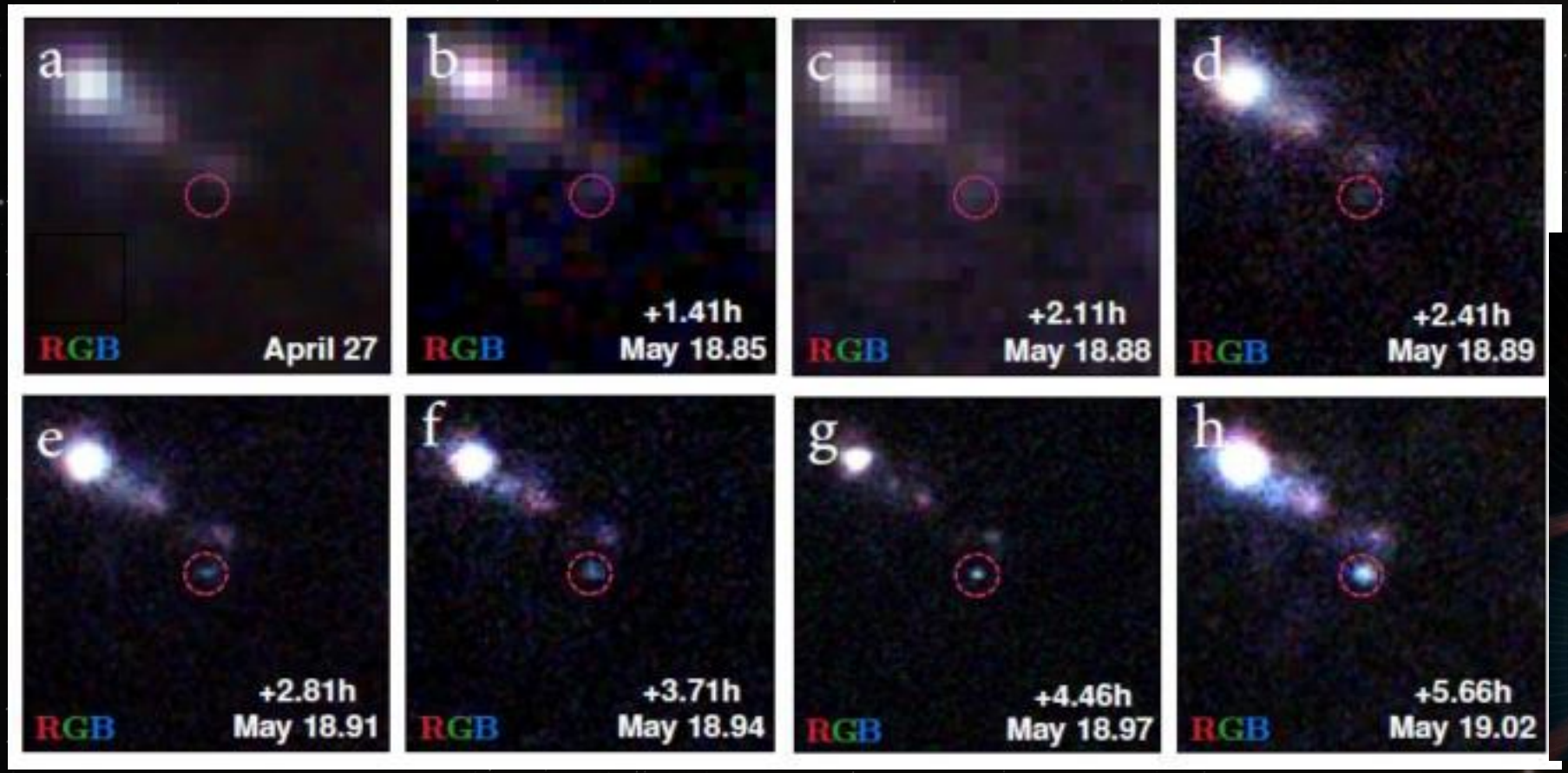


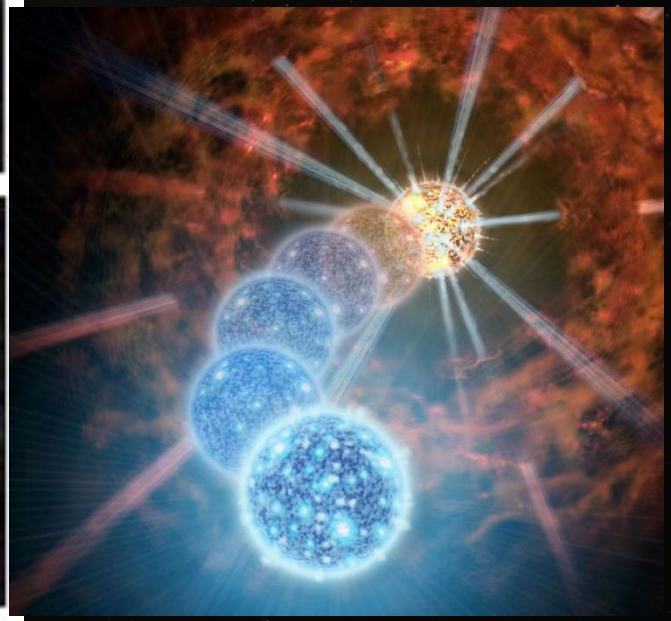
Li, G. C., et al. 2023



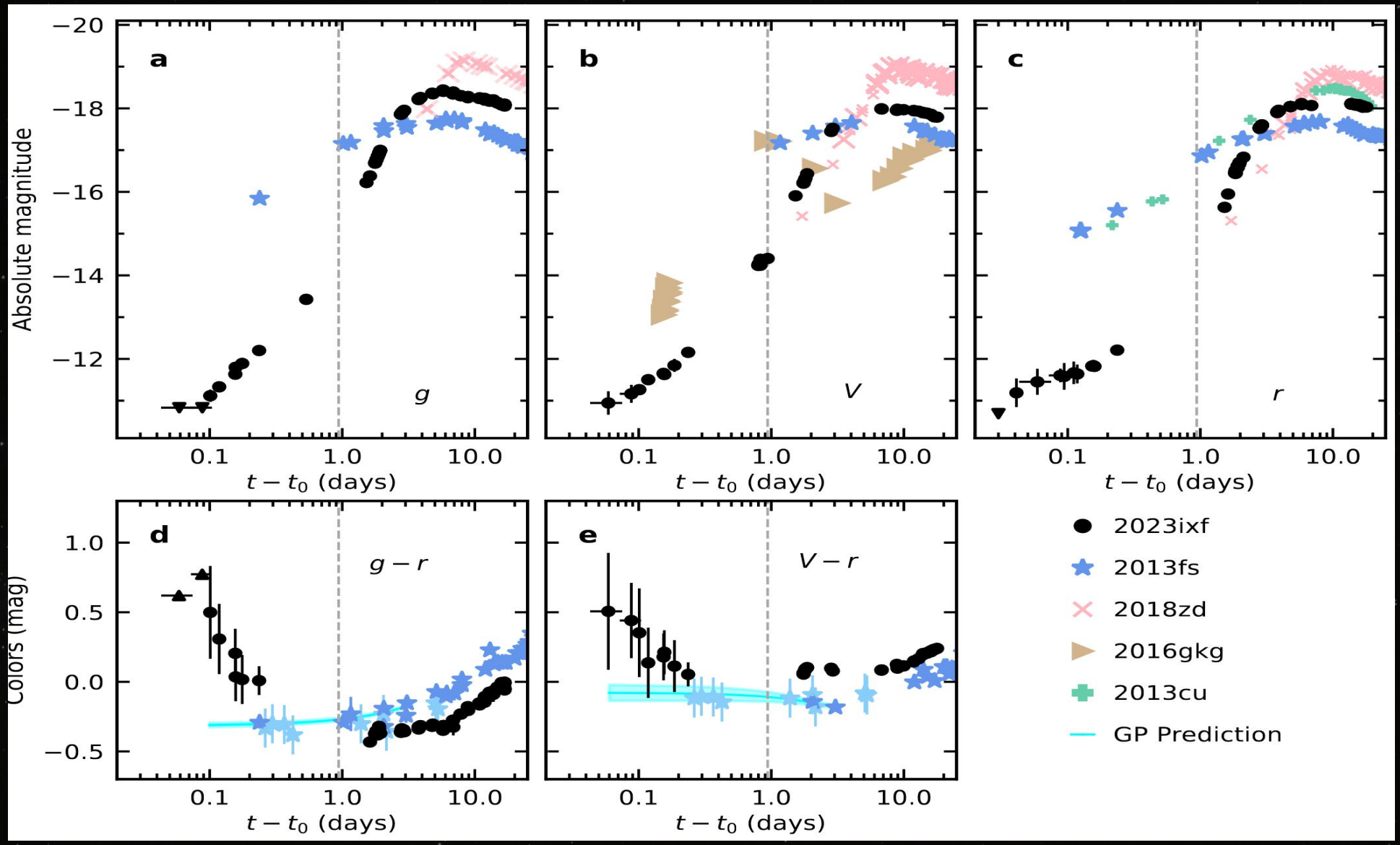
Li, G. C., et al. 2023 (Nature in press)


100KG

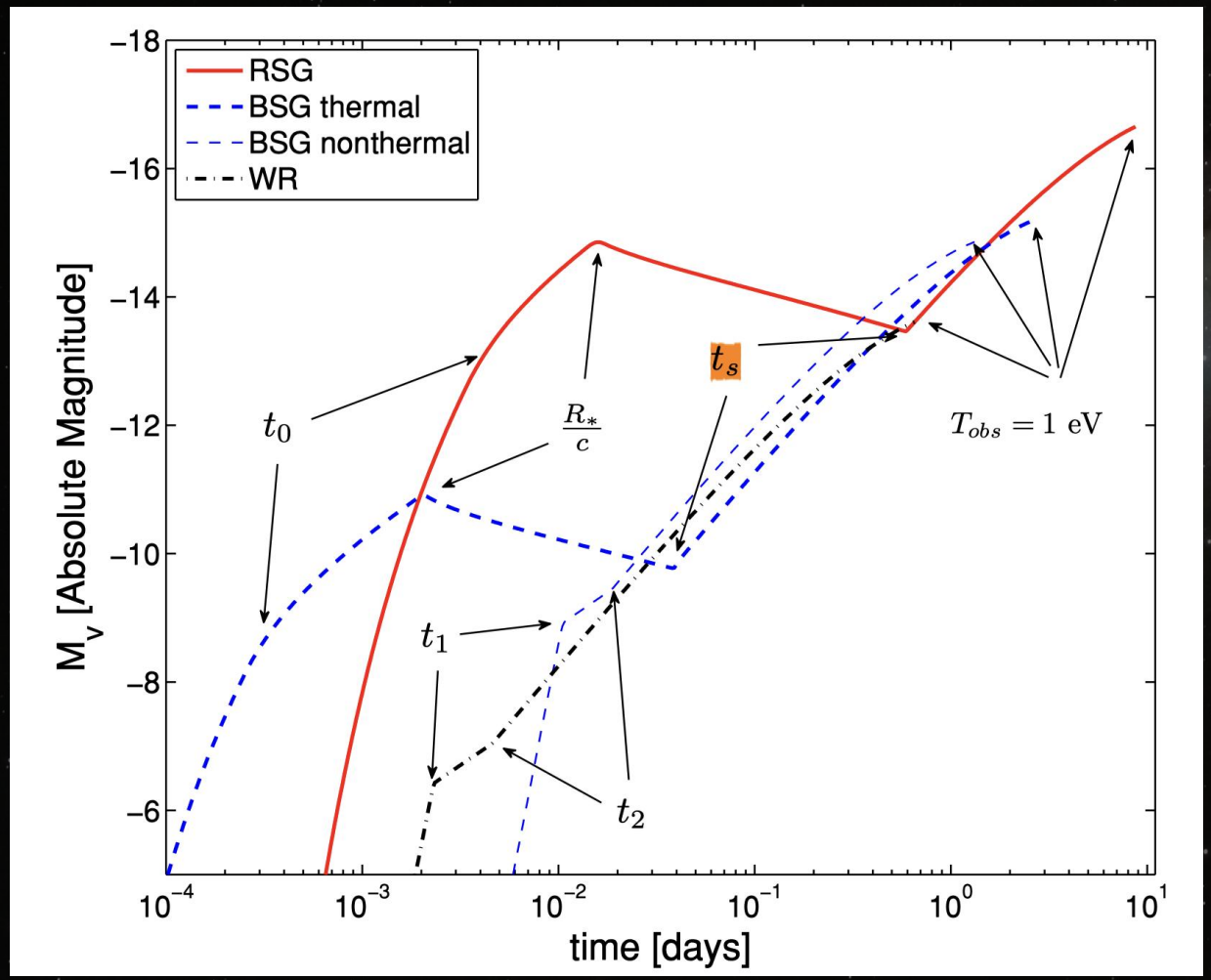


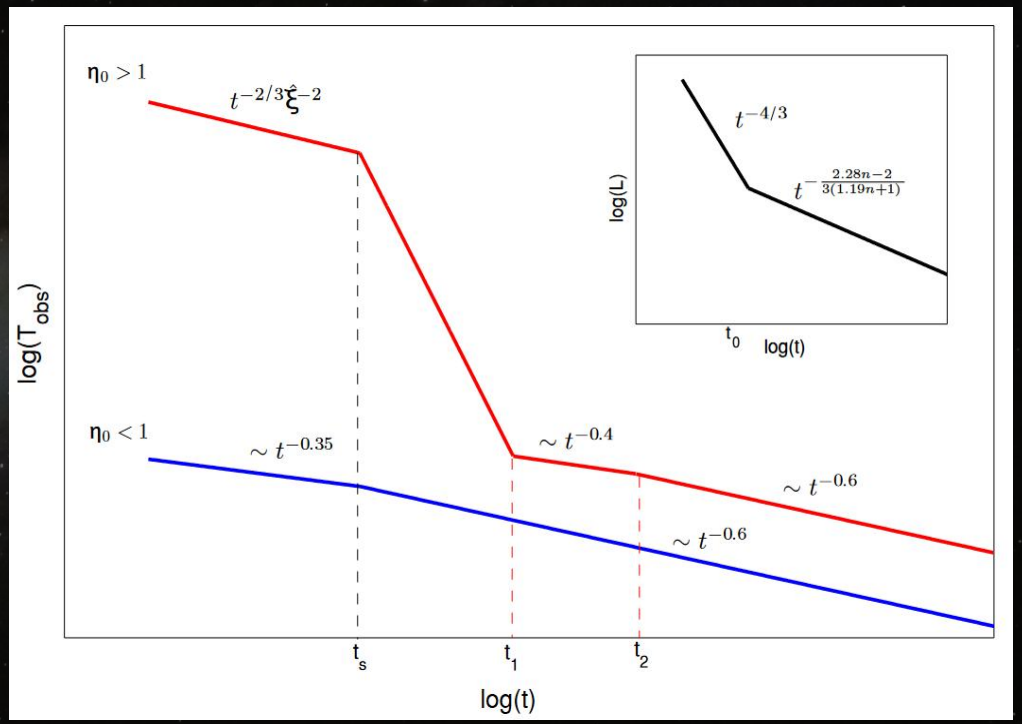


Li, G. C., et al. 2023



Li, G. C., et al. 2023





0.05 d ~ 1.2x10^5 K
0.1 d ~ 9.8x10^4 K
0.5 d ~ 5.3 x10^4 K

$$L = 3 \times 10^{42} \mathrm{erg\ s^{-1}} M_{15}^{-0.87} R_{500} E_{51}^{0.96} t_{\mathrm{day}}^{-0.17}$$

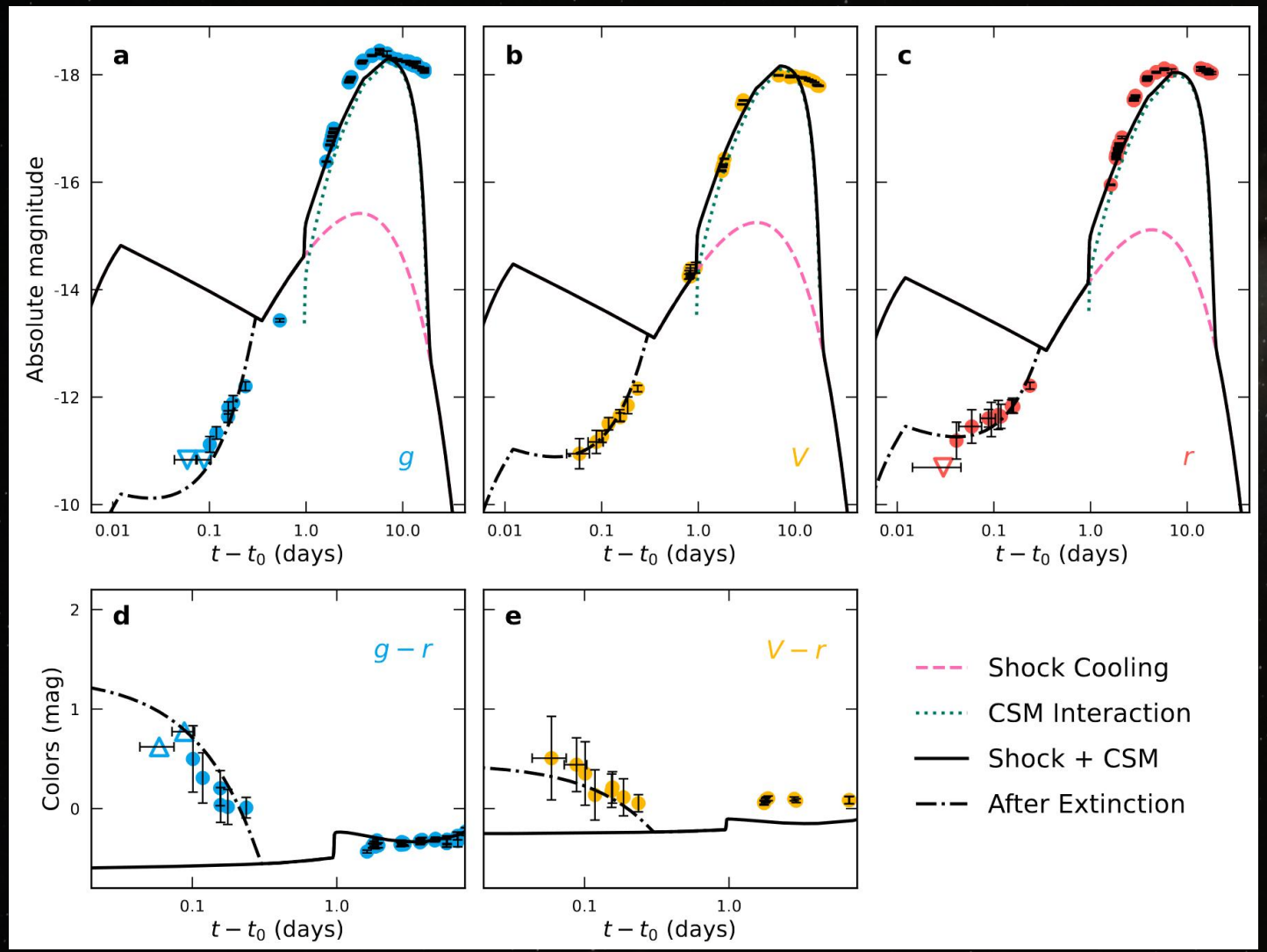
$$T = 3\ \mathrm{eV} M_{15}^{-0.13} R_{500}^{0.38} E_{51}^{0.11} t_{\mathrm{day}}^{-0.56}$$

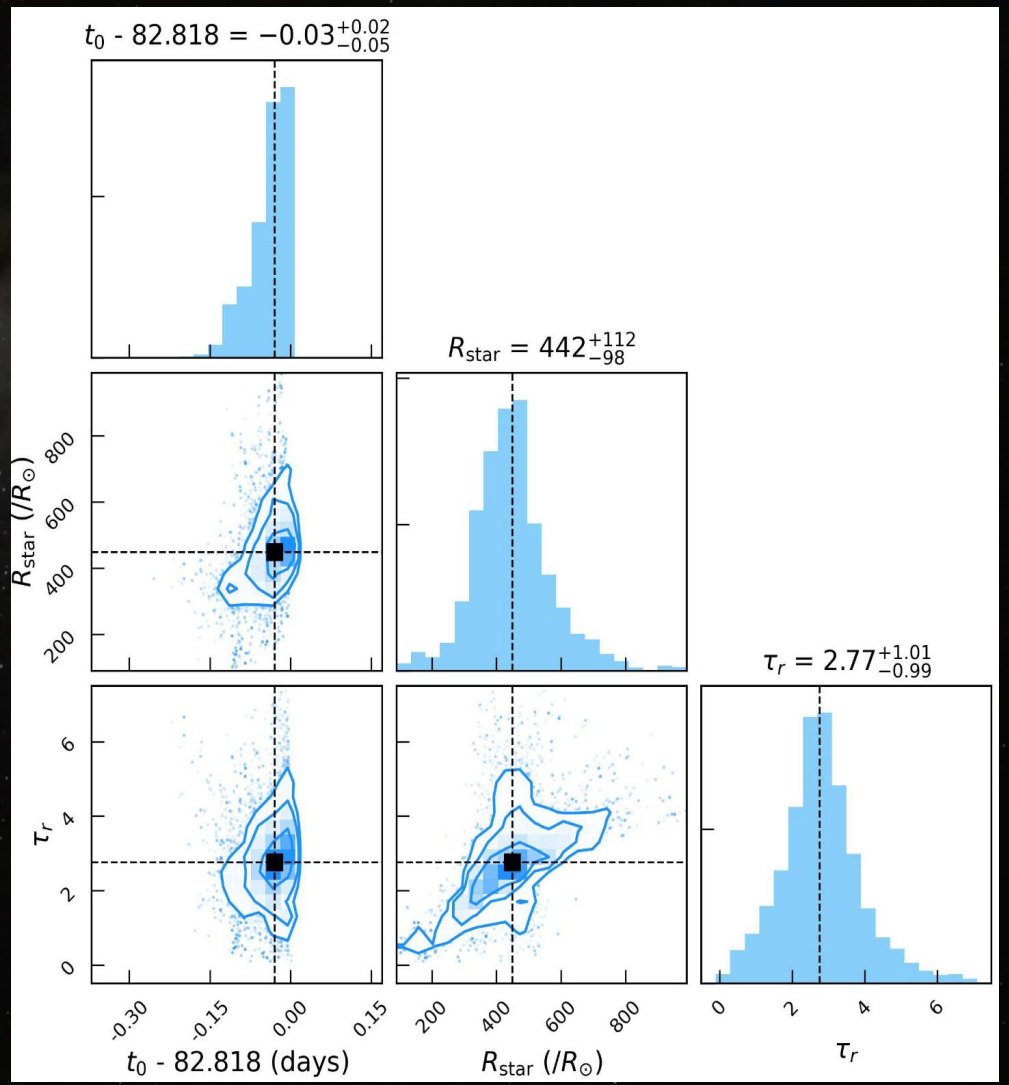
$$L = \frac{\varepsilon}{2} \frac{\dot{M}_{\mathrm{w}}}{v_{\mathrm{w}}} V_{\mathrm{sh}}^{3},$$

$$\dot{M}_{\mathrm{w}}(R) = \begin{cases} 0, & R \le R_0 \\ \dot{M}_{\mathrm{w}}(0)\left(\frac{R-R_0}{R_1-R_0}\right)^{n_1}, & R_0 < R \le R_1 \\ \dot{M}_{\mathrm{w}}(0), & R_1 < R \le R_2 \\ \dot{M}_{\mathrm{w}}(0)\left(\frac{R_3-R}{R_3-R_2}\right)^{n_2}, & R_2 < R \le R_3 \end{cases}$$

$$F(t, d_0) = 2 \int \frac{I(t-\Delta t, \theta) \cdot R(t-\Delta t, \theta)^2}{d(t-\Delta t, \theta)^2} \cos(\alpha)\, \mathrm{d}(\cos(\theta)),$$

Li, G. C., et al. 2023


a
b
c
d
e
Absolute magnitude
$t - t_0$ (days)
Colors (mag)
g
V
r
g − r
V − r
Shock Cooling
CSM Interaction
Shock + CSM
After Extinction


t_0 - 82.818 = $-0.03^{+0.02}_{-0.05}$
$R_{star} = 442^{+112}_{-98}$
$\tau_r = 2.77^{+1.01}_{-0.99}$
R_{star} ($/R_\odot$)
τ_r
t_0 - 82.818 (days)

Parameters	Results
R_0 (10^{14} cm)	2.0
R_1	4.0
R_2	6.0
R_3	16.0
$\dot{M}_{\rm w}(0)$ ($M_\odot$ yr^{-1})	5.0×10^{-2}
n_1	1.5
n_2	3.0

$$\dot{M}_{\rm w}(R)=\begin{cases}0, & R\le R_0\\ \dot{M}_{\rm w}(0)\left(\frac{R-R_0}{R_1-R_0}\right)^{n_1}, & R_0<R\le R_1\\ \dot{M}_{\rm w}(0), & R_1<R\le R_2\\ \dot{M}_{\rm w}(0)\left(\frac{R_3-R}{R_3-R_2}\right)^{n_2}, & R_2<R\le R_3\end{cases}$$

$$\frac{R_{0,3}-R_{\rm star}}{v_{\rm w}}\approx 116\,{\rm day}\left(\frac{R_{0,3}}{10^{14}\,{\rm cm}}-\frac{R_{\rm star}}{450R_\odot}\cdot 0.313\right)/\left(\frac{v_{\rm w}}{100\,{\rm km\,s^{-1}}}\right)$$

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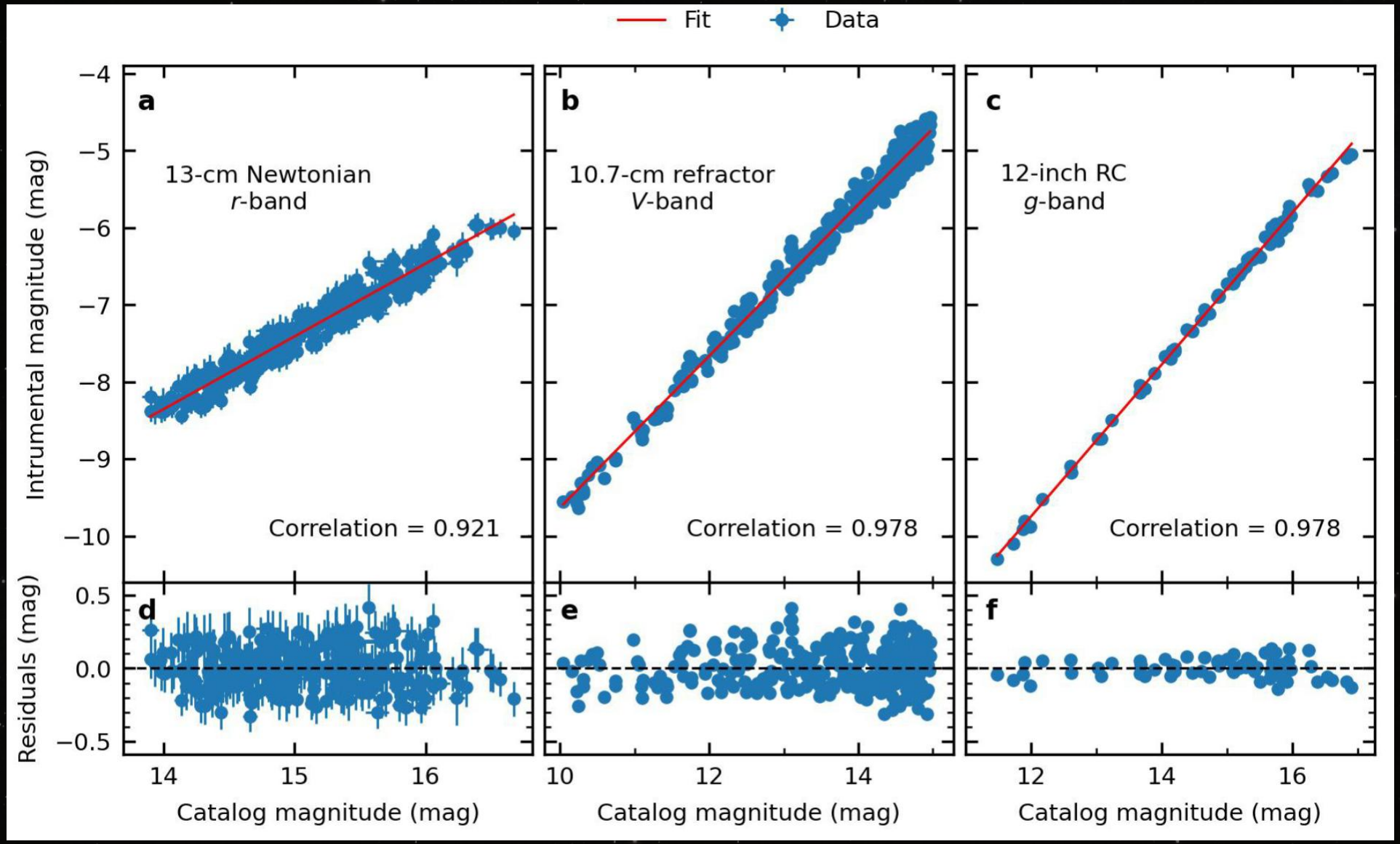
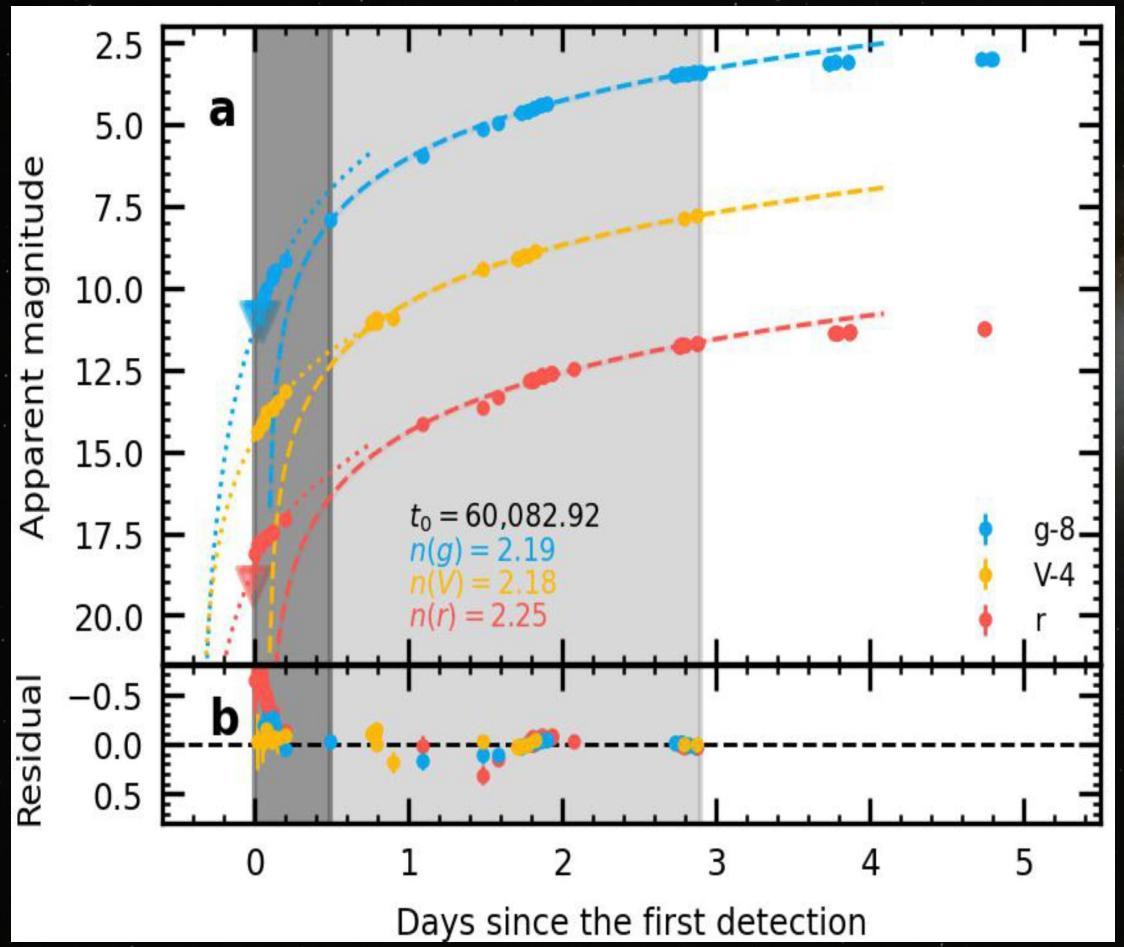

Fit
Data
a
13-cm Newtonian
r-band
Correlation = 0.921
b
10.7-cm refractor
V-band
Correlation = 0.978
c
12-inch RC
g-band
Correlation = 0.978
Intrumental magnitude (mag)
−4
−5
−6
−7
−8
−9
−10
d
e
f
Residuals (mag)
0.5
0.0
−0.5
14
15
16
10
12
14
12
14
16
Catalog magnitude (mag)
Catalog magnitude (mag)
Catalog magnitude (mag)



$$f(t) = A\left(\frac{t-t_0}{t_b}\right)^{\alpha_1}\left[1+\left(\frac{t-t_0}{t_b}\right)^{s(\alpha_1-\alpha_2)}\right]^{-1/s}$$

Band	Data Range[a](days)	t_0(MJD)	t_b[b](days)	α_1[c]	α_2	Reduced χ^2
Broken Power-law						
g	0.0-2.5	$60082.63^{+0.07}_{-0.05}$	$1.18^{+0.15}_{-0.31}$	$2.40^{+0.31}_{-0.44}$	$3.45^{+0.11}_{-0.11}$	4.3
V	0.0-2.5	$60082.63^{+0.07}_{-0.05}$	$1.40^{+0.11}_{-0.15}$	$2.11^{+0.19}_{-0.29}$	$3.38^{+0.19}_{-0.24}$	1.2
r	0.0-2.5	$60082.63^{+0.07}_{-0.05}$	$1.52^{+0.19}_{-0.14}$	$2.10^{+0.29}_{-0.30}$	$3.68^{+0.10}_{-0.15}$	4.6
						Total 3.4
Single Power-law						
g	0.4-3.0	$60082.92^{+0.01}_{-0.01}$	-	$2.18^{+0.02}_{-0.02}$	-	10.1
V	0.4-3.0	$60082.92^{+0.01}_{-0.01}$	-	$2.19^{+0.02}_{-0.02}$	-	4.2
r	0.4-3.0	$60082.92^{+0.01}_{-0.01}$	-	$2.25^{+0.02}_{-0.02}$	-	12.6
						Total 10.2