



# Observational studies of SN 2017ein and a peculiar transient AT2018cow

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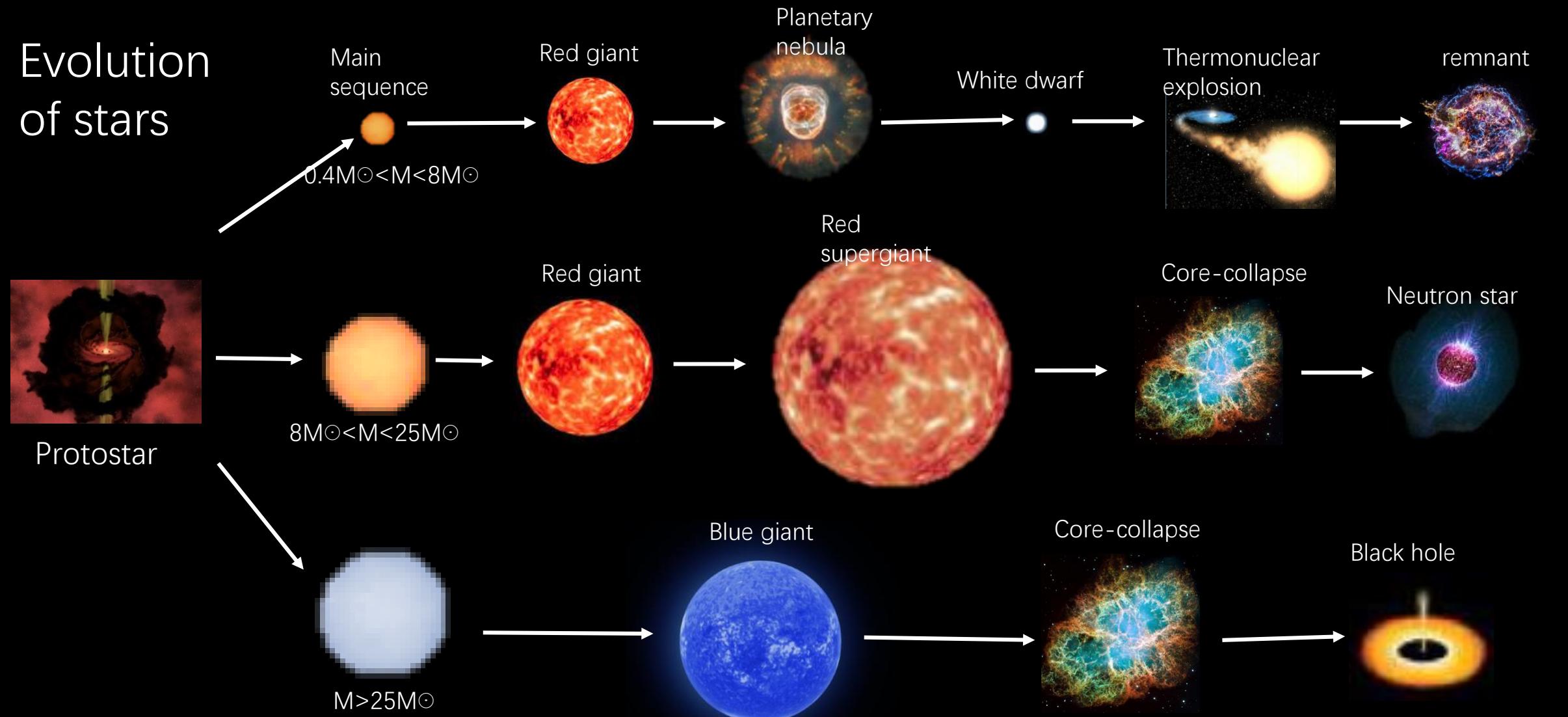


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Tsinghua





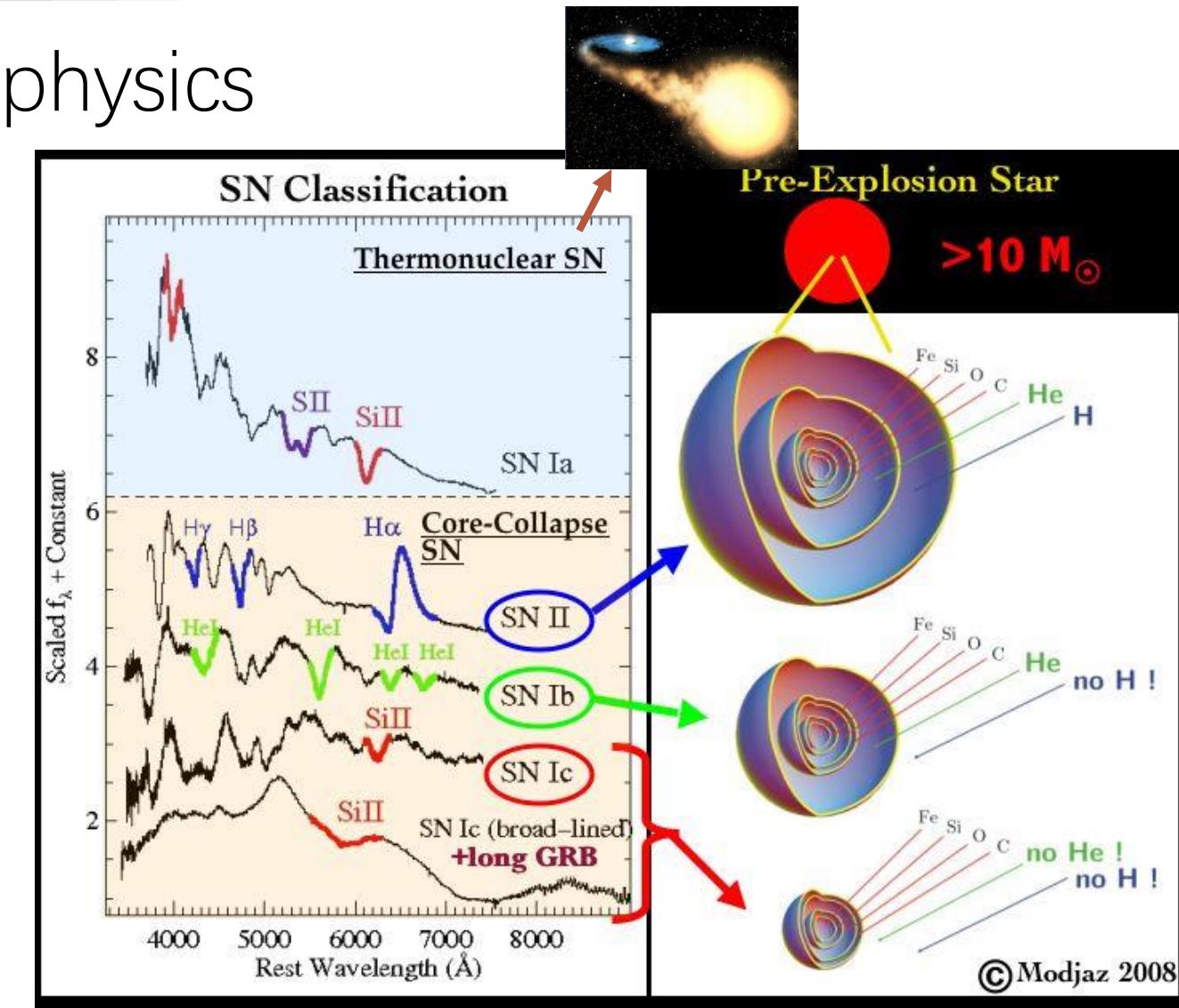
## Evolution of stars

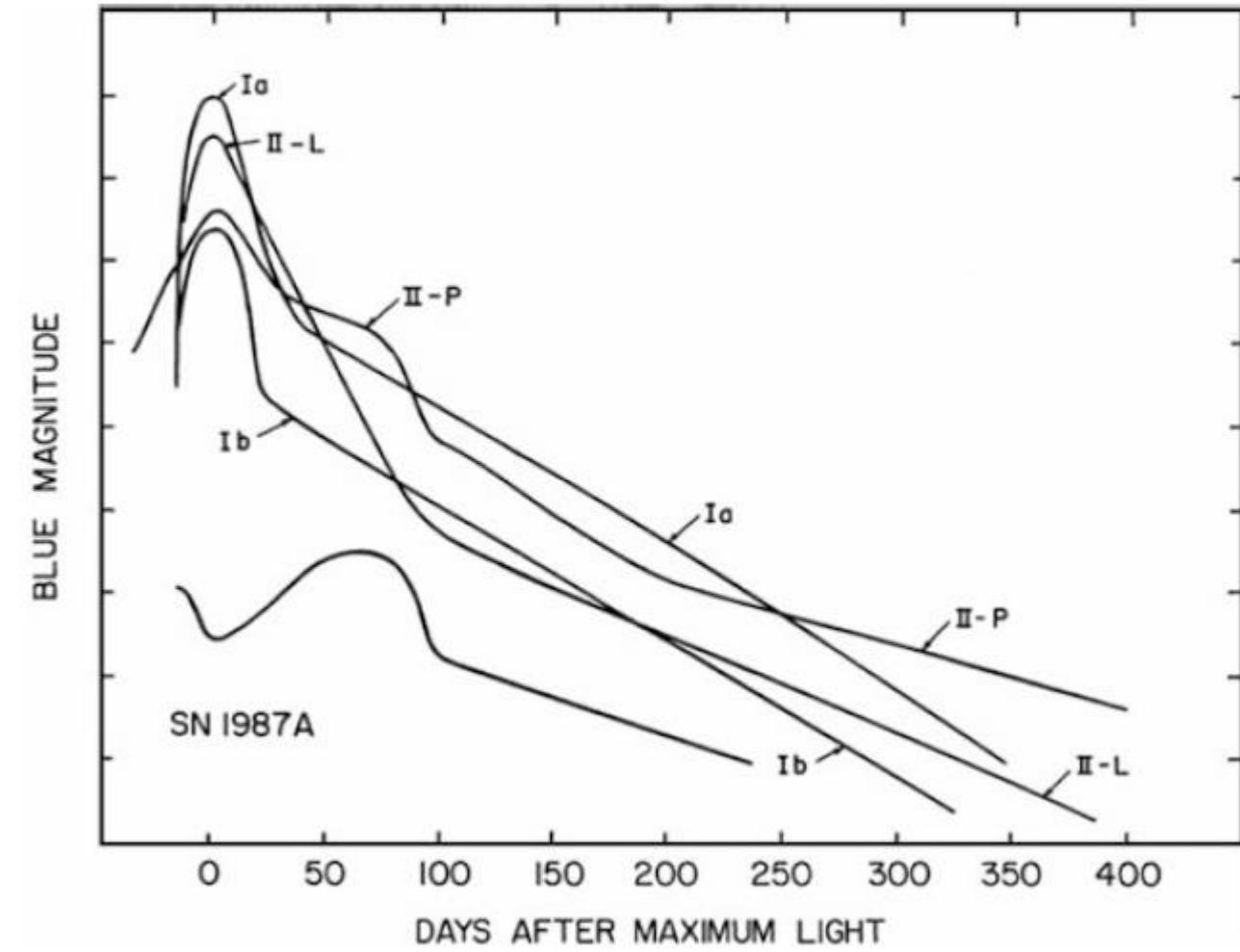
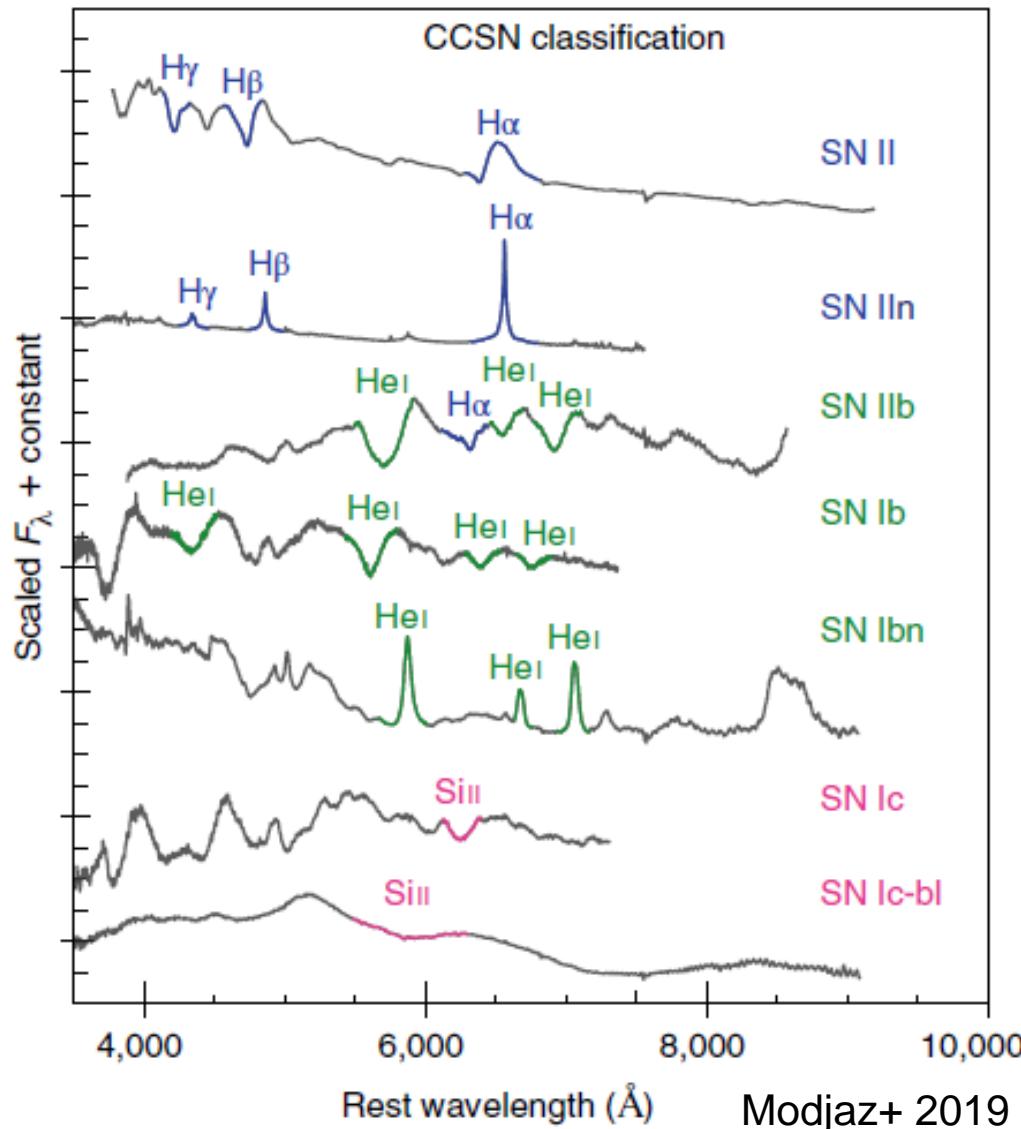




# SNe Zoo: observation and physics

- Thermonuclear supernovae: Explosion of white dwarfs
  - Ia: Strong Si II lines
- Core-collapse supernovae: death of massive stars ( $M_{\text{ZAMS}} > 8M_{\odot}$ )
  - IIP/IIL/I Ib: P Cygni H lines
  - Ib: Hel absorption lines
  - Interacting SNe: Narrow emission lines
- Stripped-envelope Supernovae (SE-SNe)
  - Stars who has lost their H/He envelopes
  - Ib Ic IIb IIn
- Superluminous supernovae
  - $M_{\text{peak}} < -21 \text{ mag}$
- Peculiar SNe: 02cx-like, Ic-BL, Ca-rich, ...





Wheeler&Harkness 1990



# Energy sources of SN light curves (type I)

- Shock breakout / shock cooling       $\tau \sim c/v_{\text{sh}}$

$$L_{\text{sh}} \propto R^2(v/\rho)^{1/3} \quad L_{\text{sc}} \propto R^x M^y$$

- Radioactive decay       $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$

$$L(t) = \frac{M_{\text{Ni}}}{t_0} e^{-t/t_0} \int_0^t e^{t'/t_0} [(\epsilon_{\text{Ni}} - \epsilon_{\text{Co}}) e^{-t'/t_{\text{Ni}}} + \epsilon_{\text{Co}} e^{-t'/t_{\text{Co}}}] dt' (1 - e^{-At^{-2}}) \quad \tau_m = \left( \frac{2\kappa_{\text{opt}} M_{\text{ej}}}{\beta c v_{\text{ph}}} \right)^{\frac{1}{2}}$$

- Magnetar

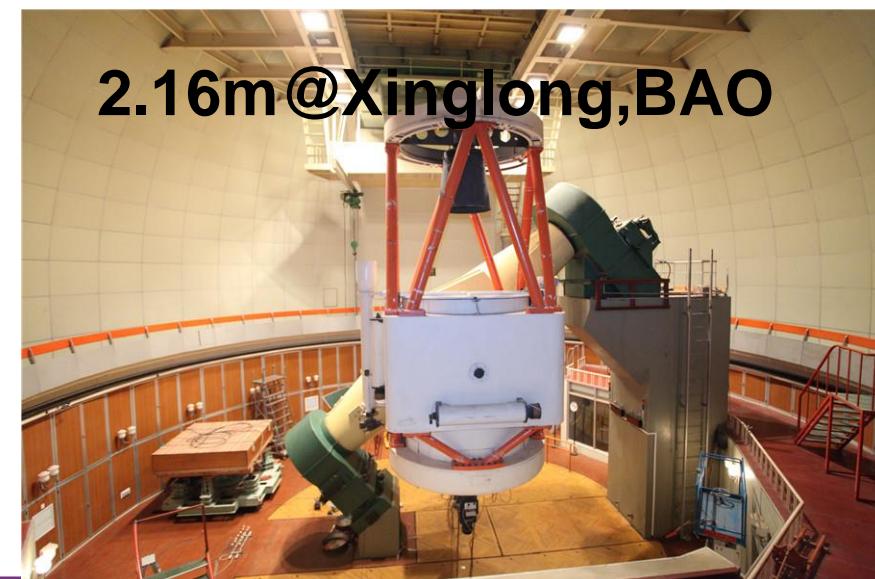
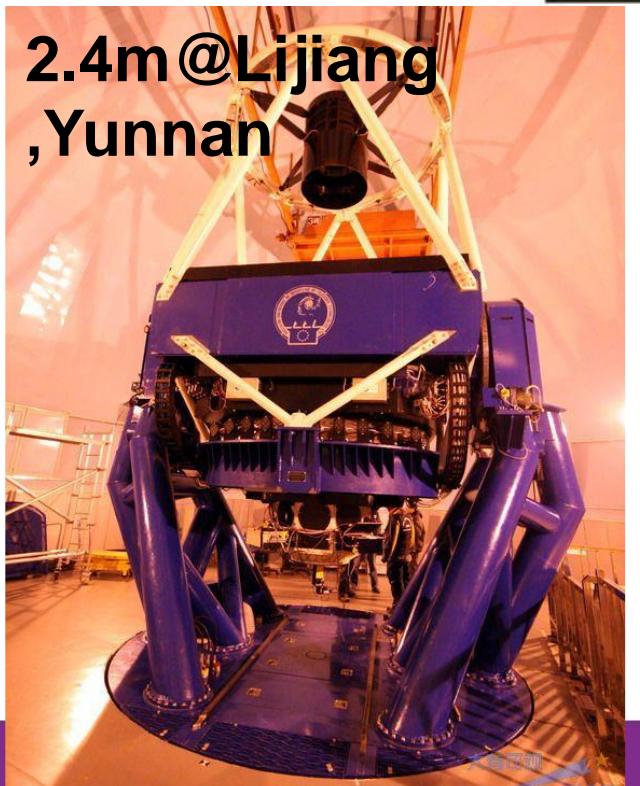
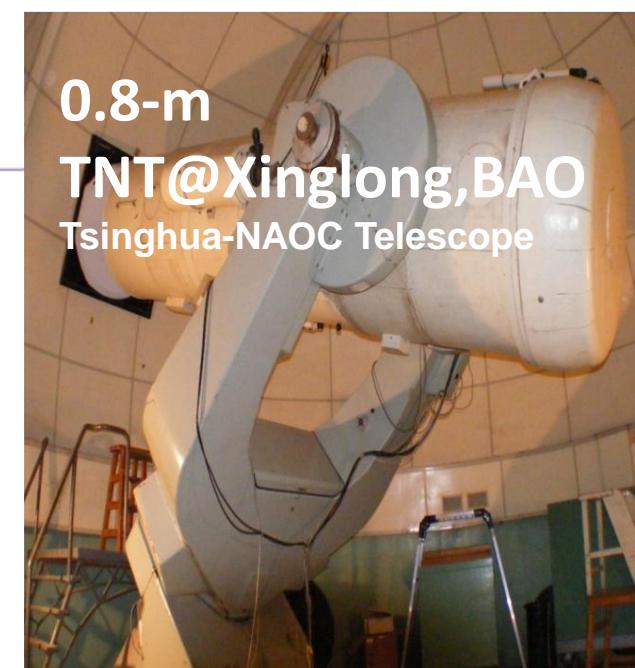
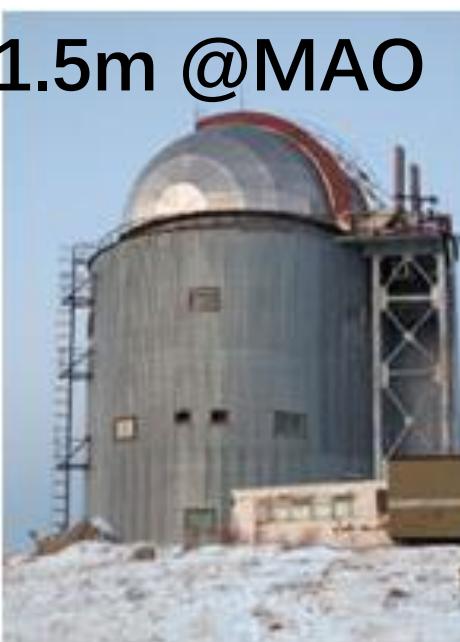
$$F_{\text{mag}}(t) = \frac{E_{\text{mag}}}{t_{\text{mag}}} \frac{1}{(1 + t_{\text{mag}}^2)} \quad E_{\text{mag}} = E_{\text{mag}}(M_{\text{NS}}, P), \\ t_{\text{mag}} = t_{\text{mag}}(M_{\text{NS}}, P, B)$$

- Circumstellar interaction

$$\rho_{\text{CSM}} = qr^{-s}$$



# Telescopes





# Objects observed by MAO

1	SN 2017egm	SLSN	R.A.=10:19:05.62, Decl.=46:27:14.08	Lin et al, in prep.
2	SN 2017faf	SN II	R.A.=17:34:39.98, Decl.=26:18:22.00	
3	SN 2017eaw	SN IIP	R.A.=20:34:44.24, Decl.=60:11:35.90	Rui et al, 2019
4	SN 2017ein	SN Ic	R.A.=11:52:53.25, Decl.=44:07:26.20	Xiang et al, 2019
5	SN 2017erp	SN Ia	R.A.=15:09:14.81, Decl.=-11:20:03.20	Brown et al, 2019
6	AT2018cow	FBOT	R.A.=16:16:00.22 , Decl.=22:16:04.83	Xiang et al, 2021
7	SN 2018bek	SN IIn	R.A.=15:32:01.55, Decl.=68:14:31.00	
8	SN 2018hti	SLSN	R.A.=03:40:53.75, Decl.=11:46:37.29	Lin et al, 2020
9	ASASN18ey	BBH	R.A.=18:20:21.9 , Decl.=07:11:07.3	Sai et al. 2021
10	SN 2019ein	SN Ia	R.A.=13:53:29.11, Decl.=40:16:31.33	Xi et al, in prep.



# Science on optical transients

- SN 2017ein
- AT2018cow

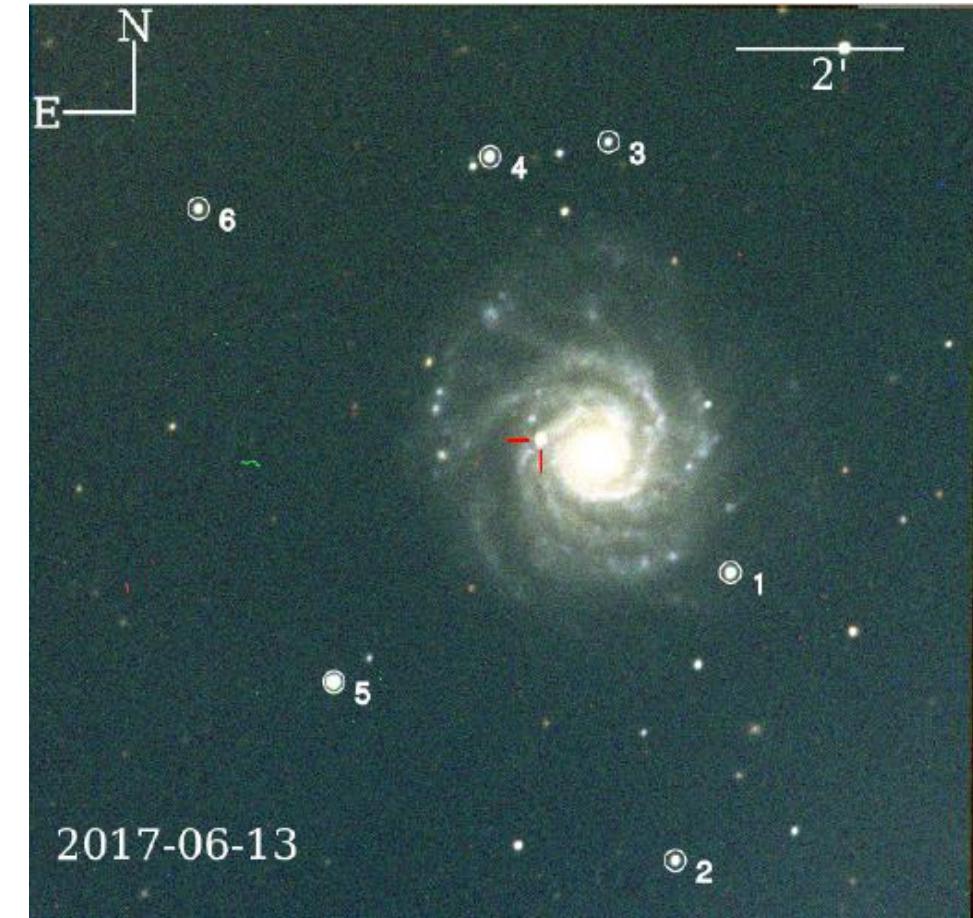


# SN 2017ein

## Overview

- A normal SN Ic
- $z = 0.0027$ ,  $D_L \sim 18.9\text{Mpc}$
- $E(B - V) = 0.412 \pm 0.06 \text{ mag}$

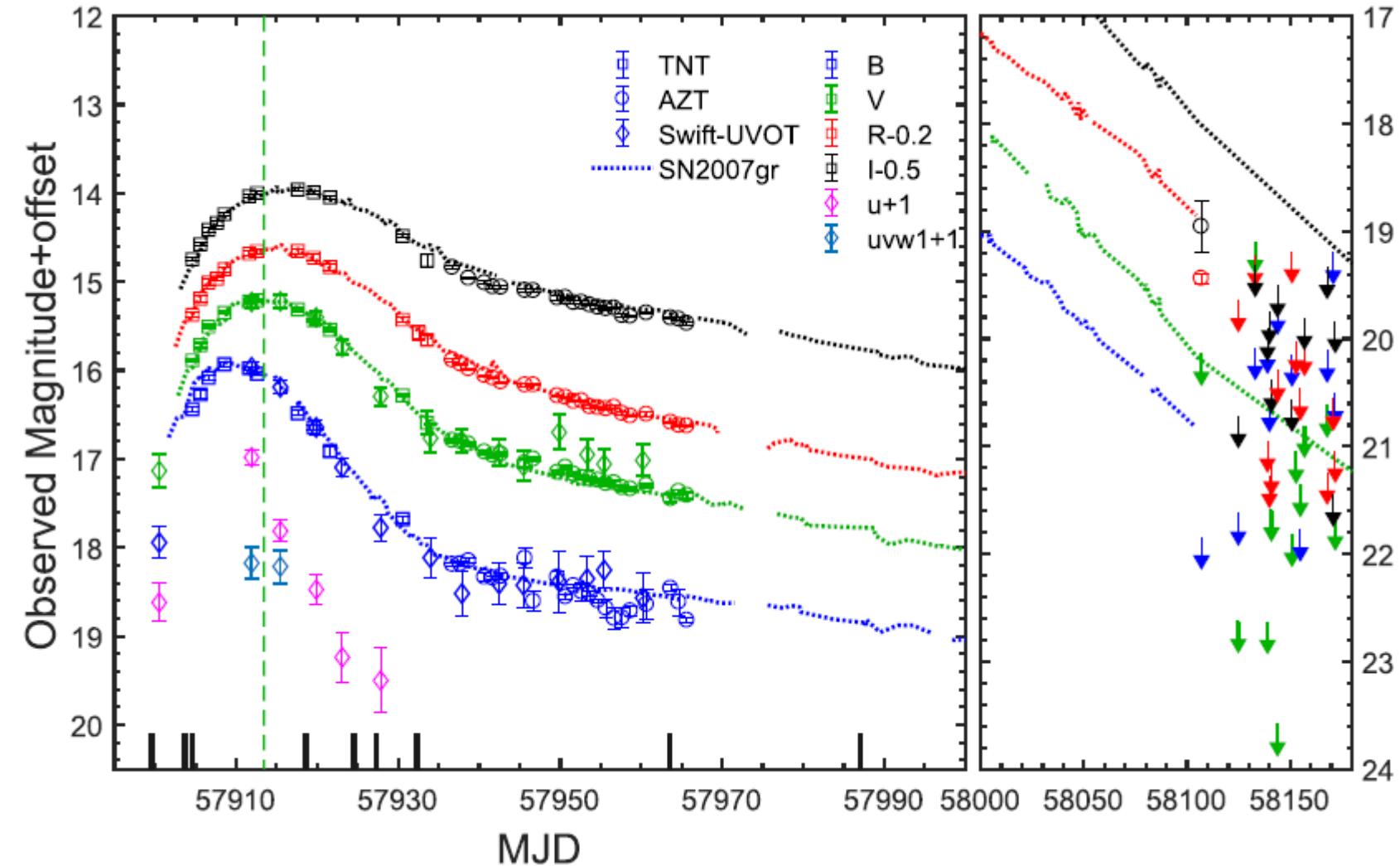
Band	Peak Date (MJD)	Peak Obs. Mag.	Peak Abs. Mag.	$\Delta m_{15}$
<i>B</i>	57909.86 $\pm$ 0.24	15.91 $\pm$ 0.04	-17.20 $\pm$ 0.38	1.33 $\pm$ 0.07
<i>V</i>	57913.49 $\pm$ 0.20	15.20 $\pm$ 0.02	-17.47 $\pm$ 0.35	0.93 $\pm$ 0.04
<i>R</i>	57914.67 $\pm$ 0.28	14.81 $\pm$ 0.05	-17.54 $\pm$ 0.33	0.75 $\pm$ 0.09
<i>I</i>	57916.32 $\pm$ 0.30	14.43 $\pm$ 0.04	-16.93 $\pm$ 0.32	0.61 $\pm$ 0.09

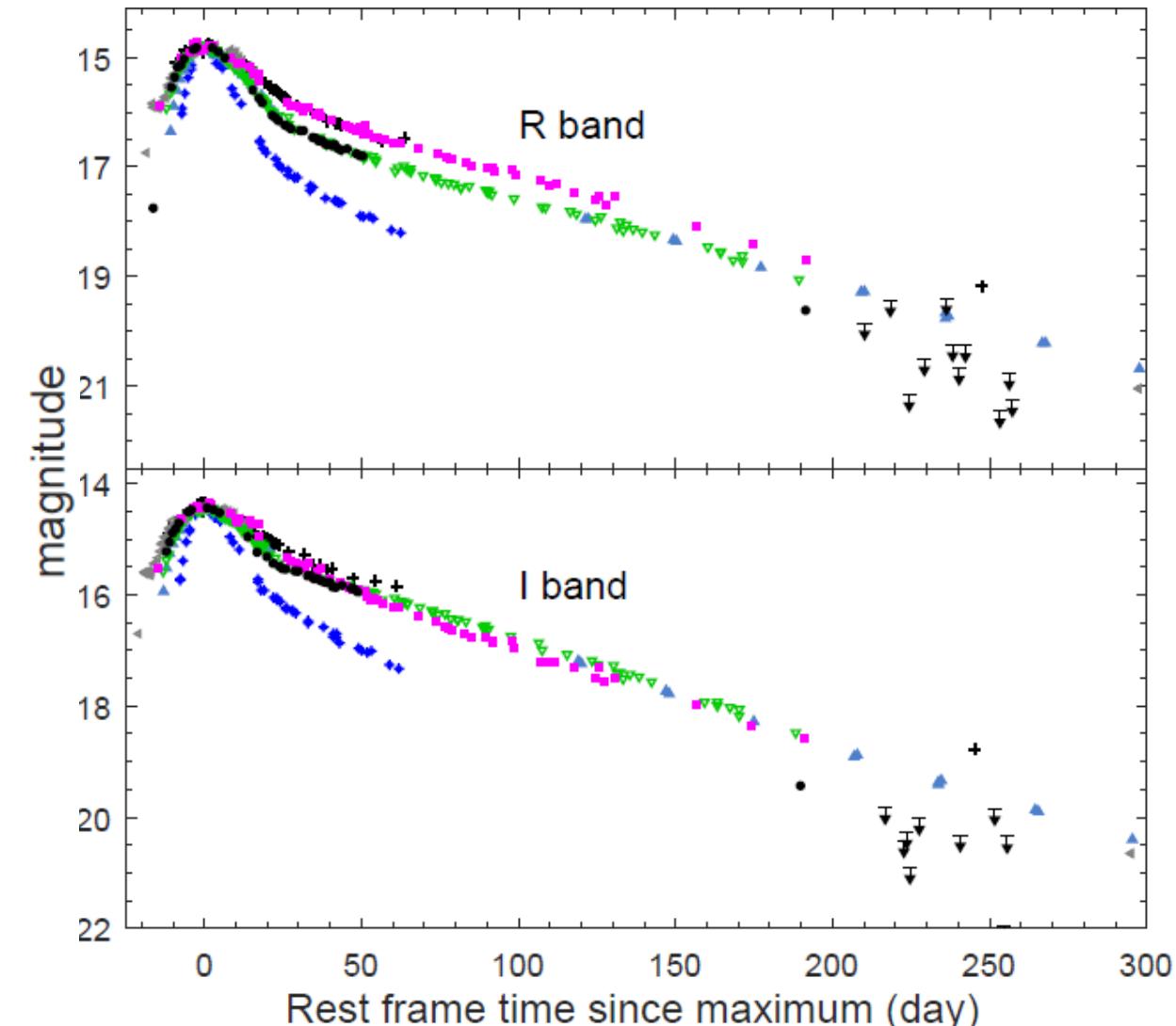
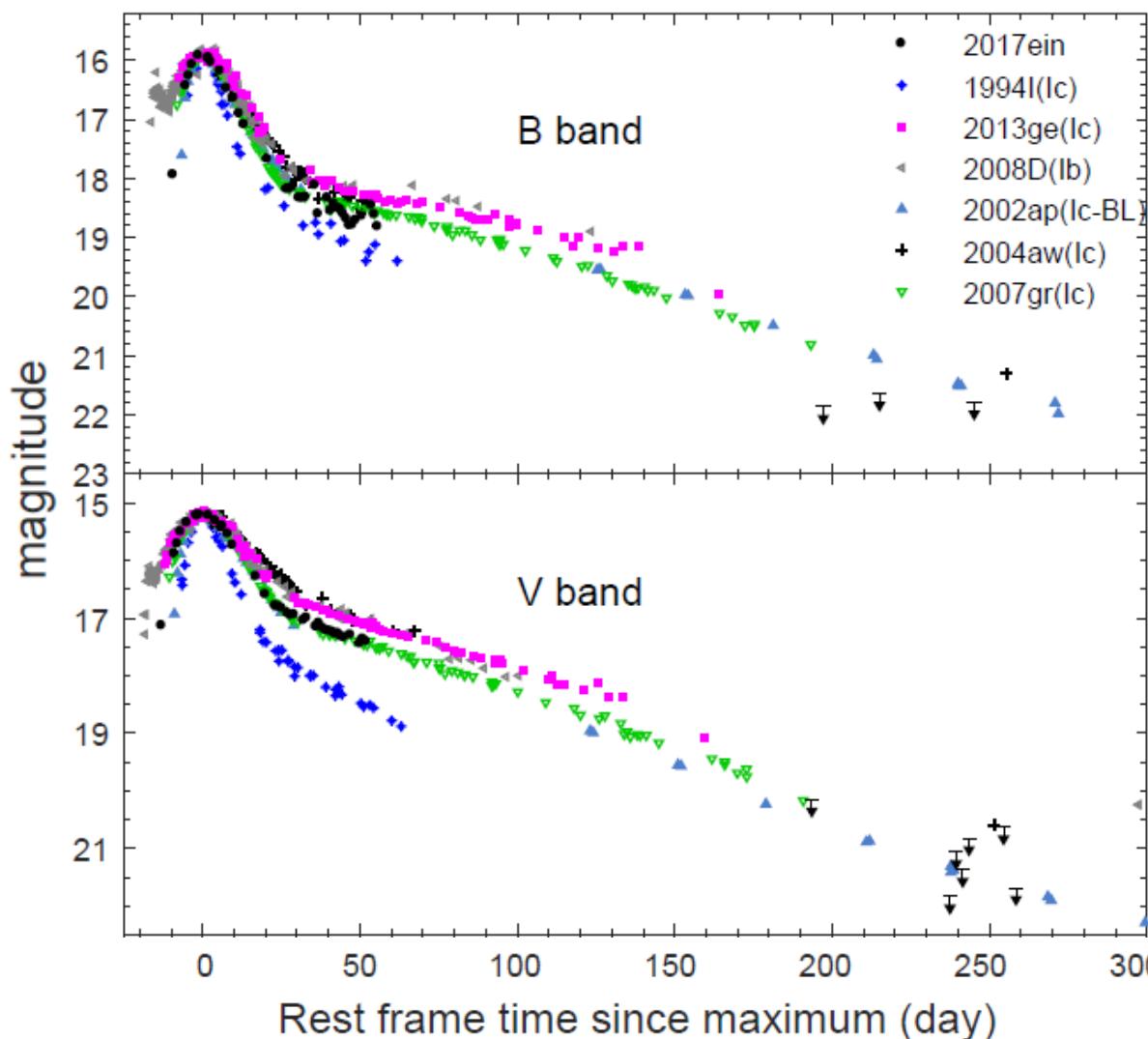




BVRI light  
curves of SN  
2017ein

AZT 1.5m: post  
peak + late  
phase







# HST progenitor observation

HST-WFPC2 pre-explosion observations

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F555W  $24.46 \pm 0.11$  mag

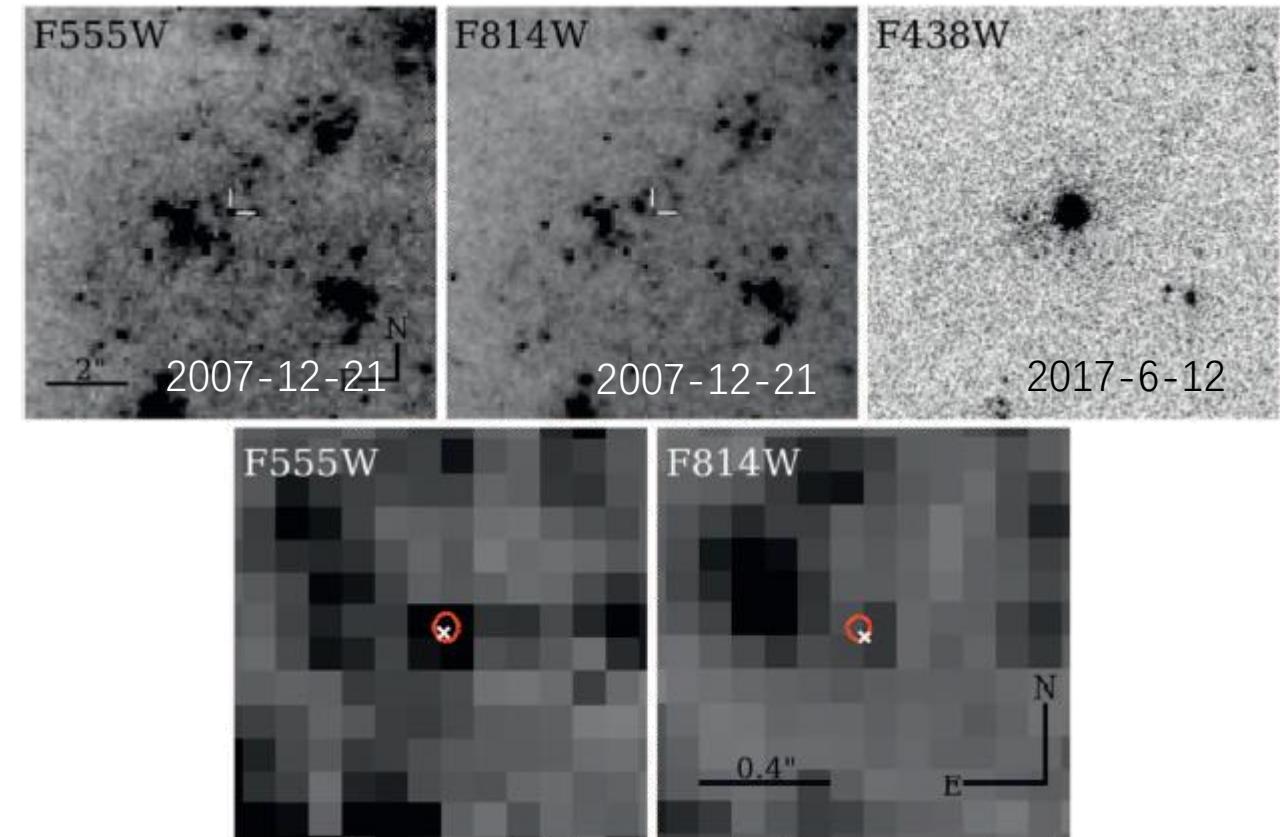
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F814W  $24.39 \pm 0.17$  mag

$$M_{F555W} = -8.17 \pm 0.37 \text{ mag}$$

$$M_{F555W} - M_{F814W} = -0.47 \pm 0.27 \text{ mag}$$

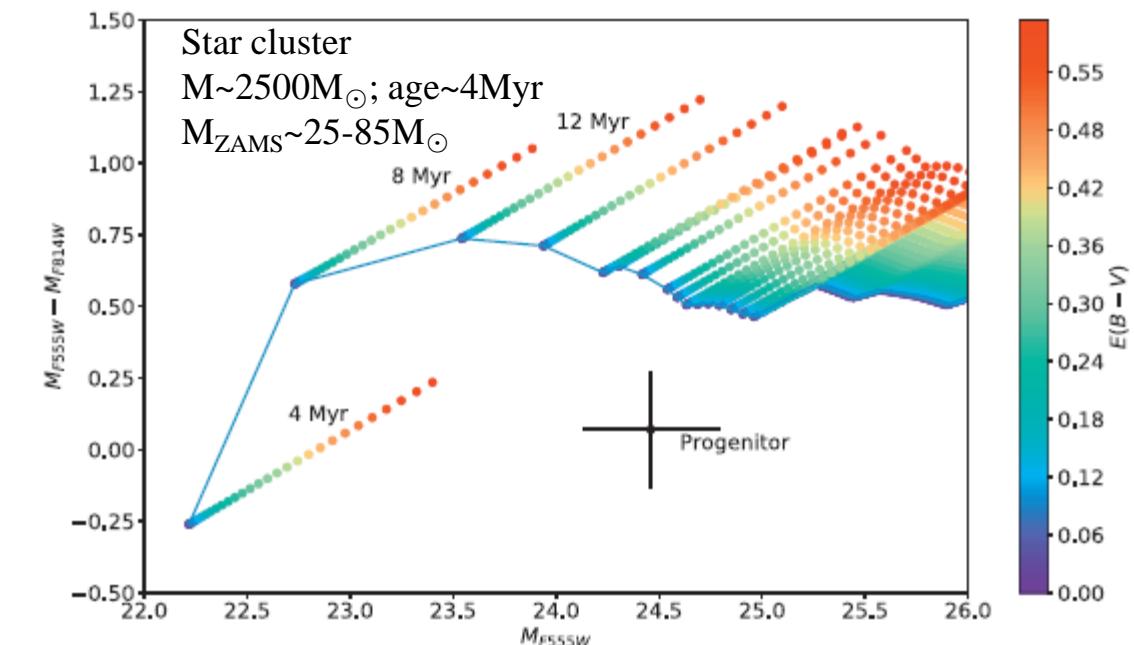
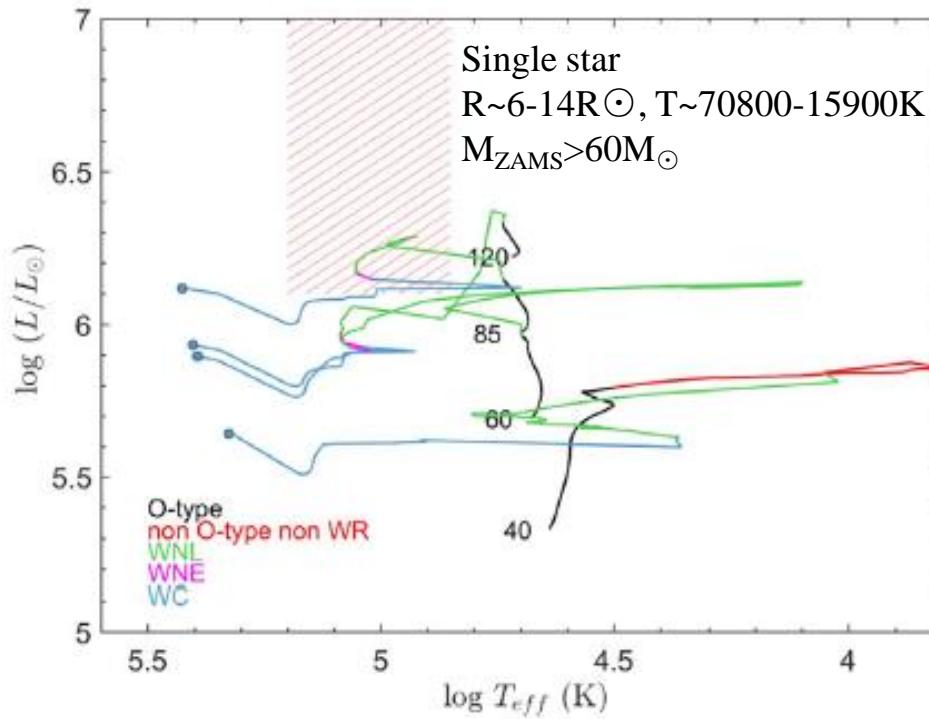
A blue and luminous object!





# Properties of the progenitor candidate

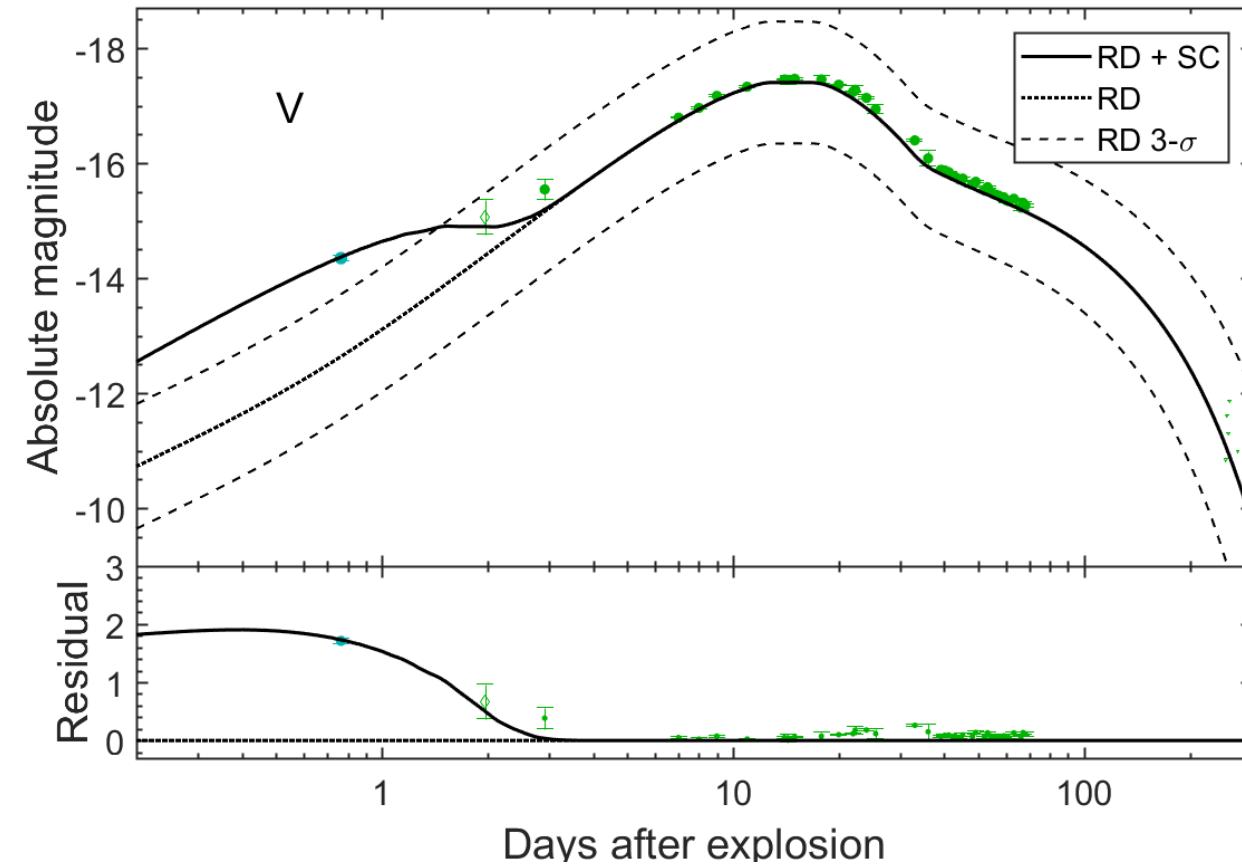
## Single star? Binary? Star cluster?





Shock cooling from the  
stellar envelope  
Timescale~1 day

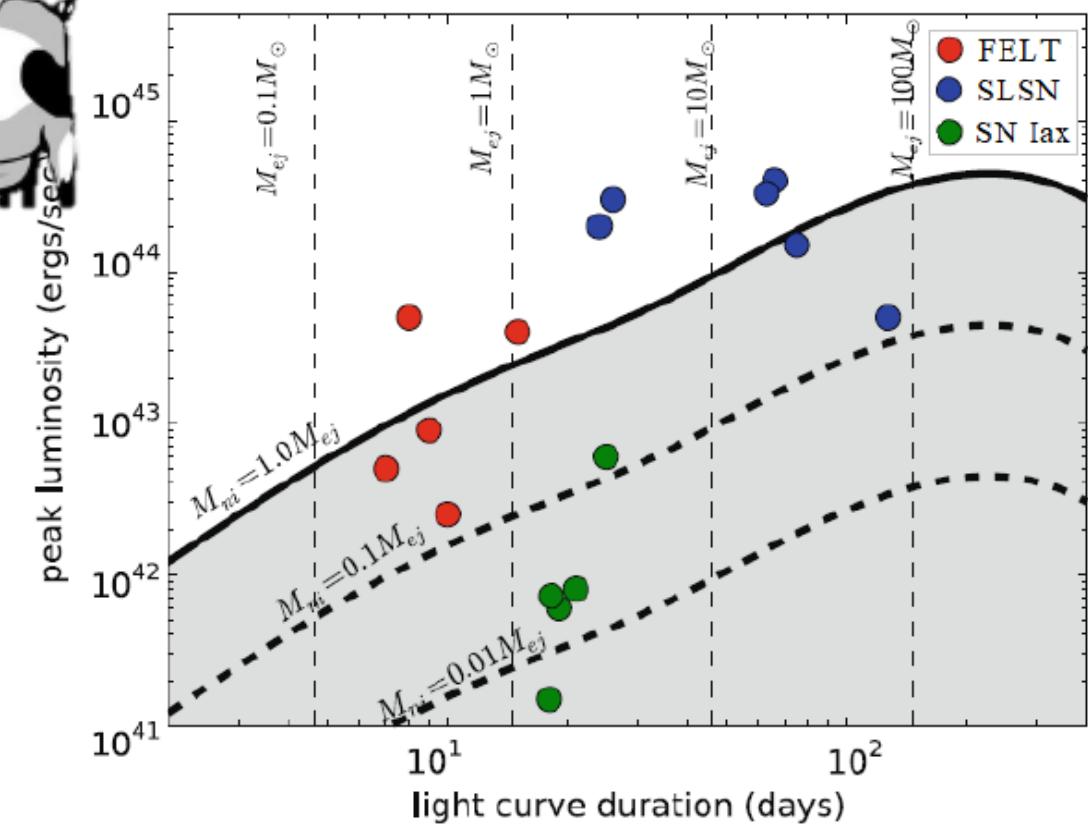
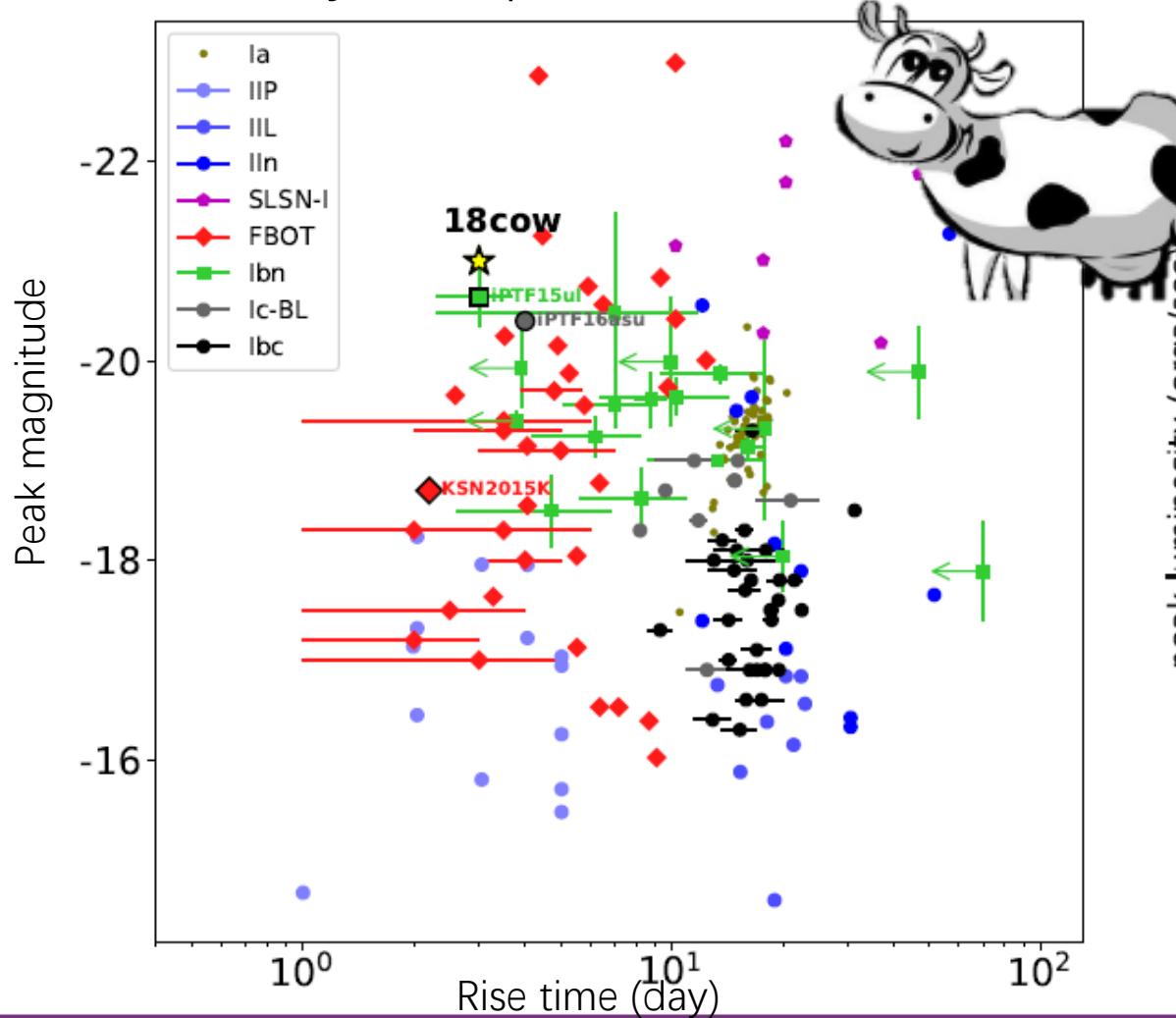
$M_{\text{ej}}(M_{\odot})$	$0.9 \pm 0.1$
$v_{\text{ph}}(\text{km/s})$	9300
$E_{\text{k}}(10^{51}\text{erg})$	0.5
$M_{\text{Ni}}(M_{\odot})$	0.13
$t_0(\text{MJD})$	57897.6
$R_{\text{env}}(R_{\odot})$	$8 \pm 4$
$M_{\text{env}}(M_{\odot})$	0.02





## The COW

Diversity of optical transients



Kasen 2017



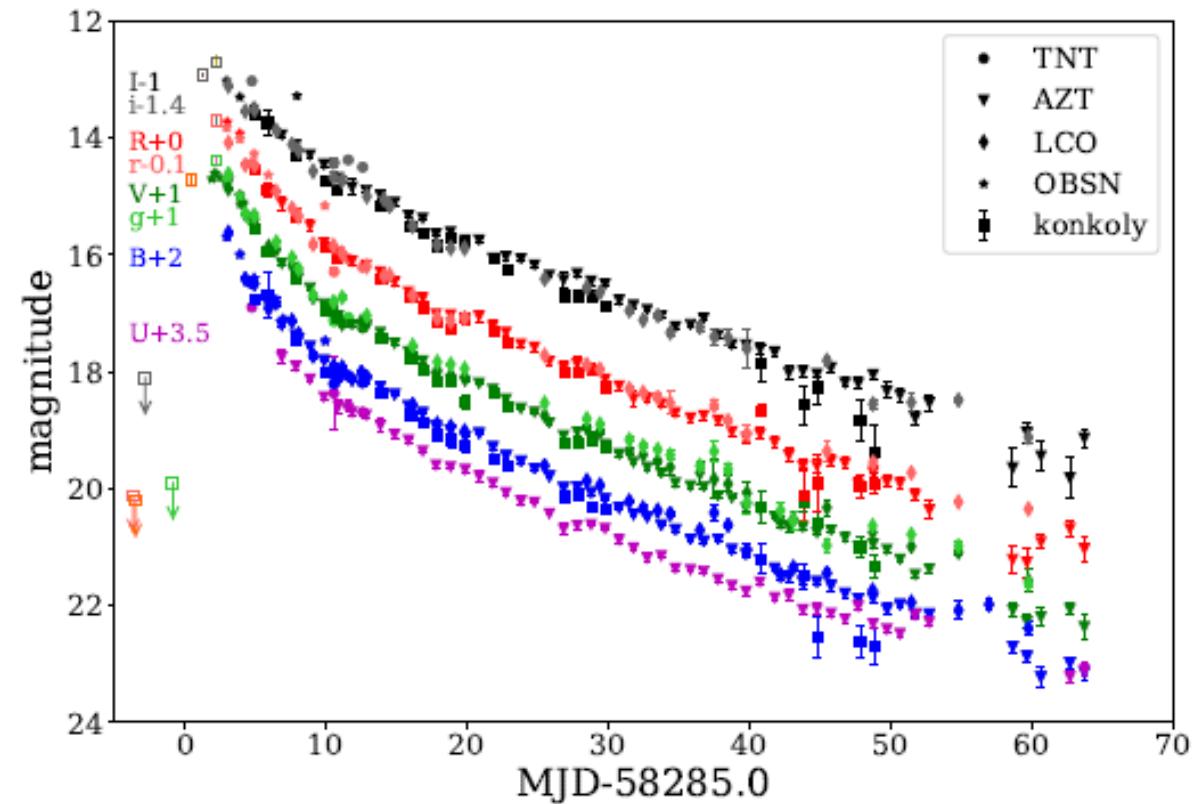
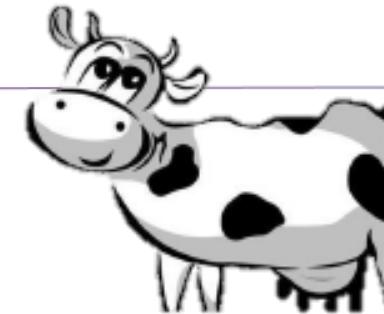
# A special FBOT: AT2018cow

$m_{\text{dic}} \approx 14.76 \text{mag}$  ( $M \approx -19.24 \text{ mag}$ )

$z=0.014$

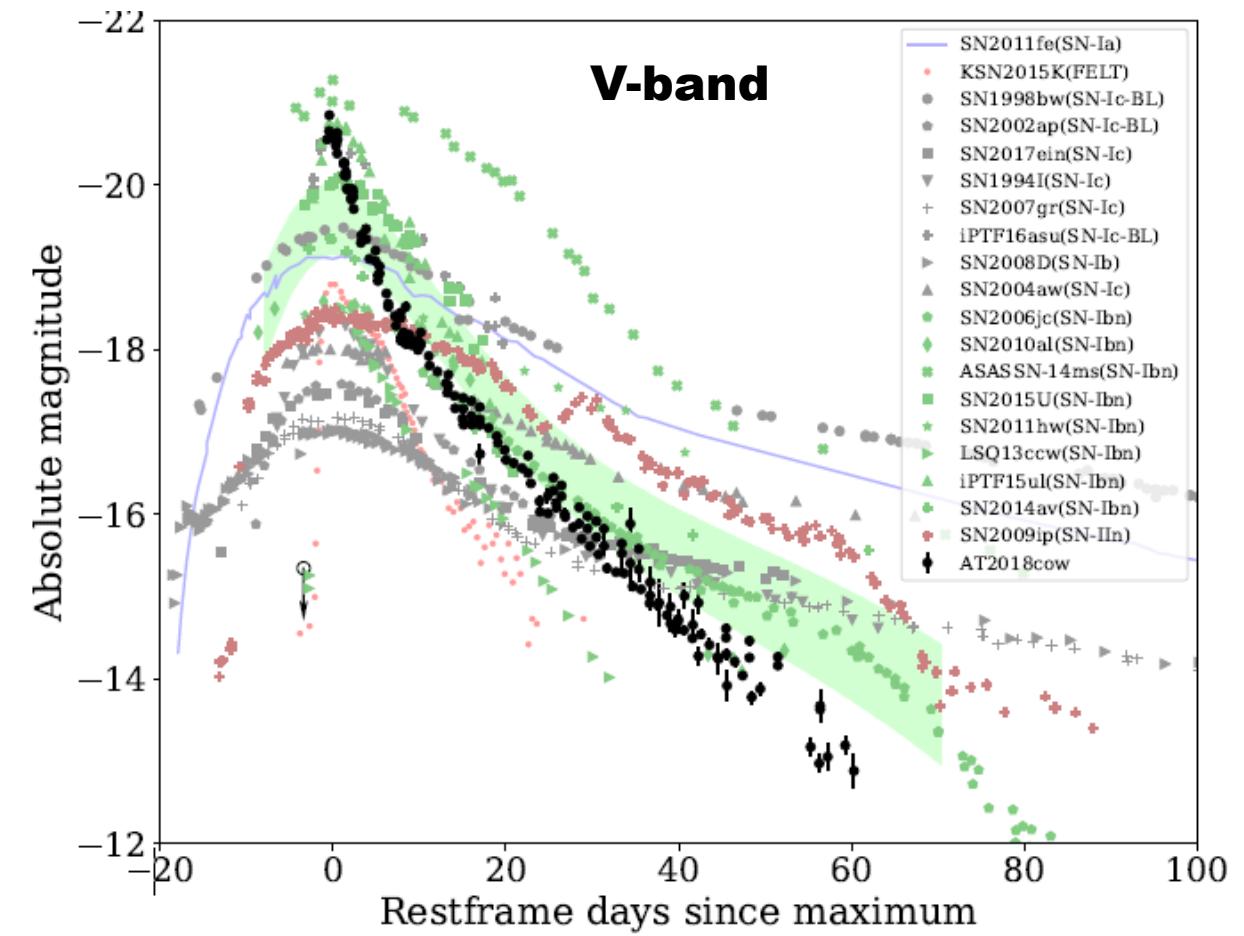
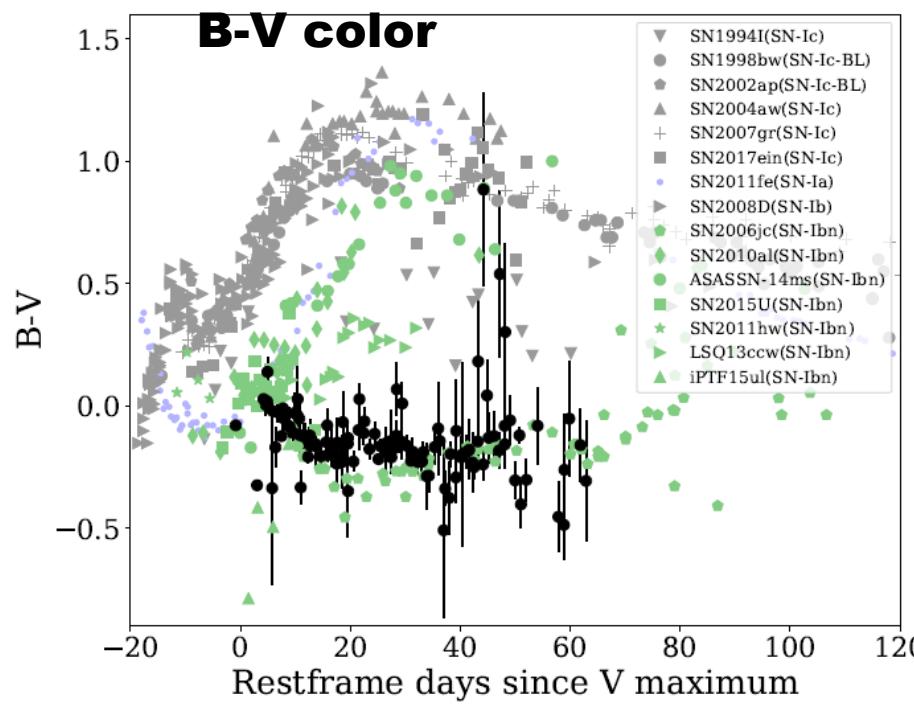
$D_L \sim 63 \text{Mpc}$

Short cadenced UBVRI photometry  
by AZT 1.5m, till  $>60$  days after  
discovery



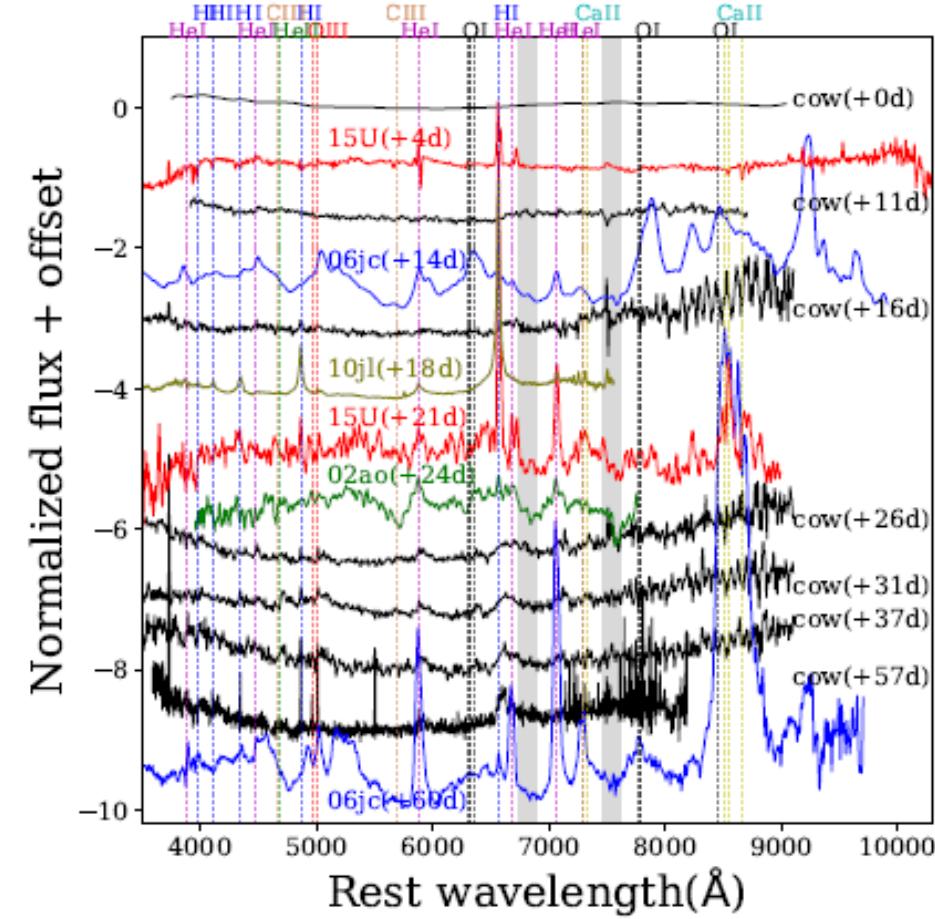
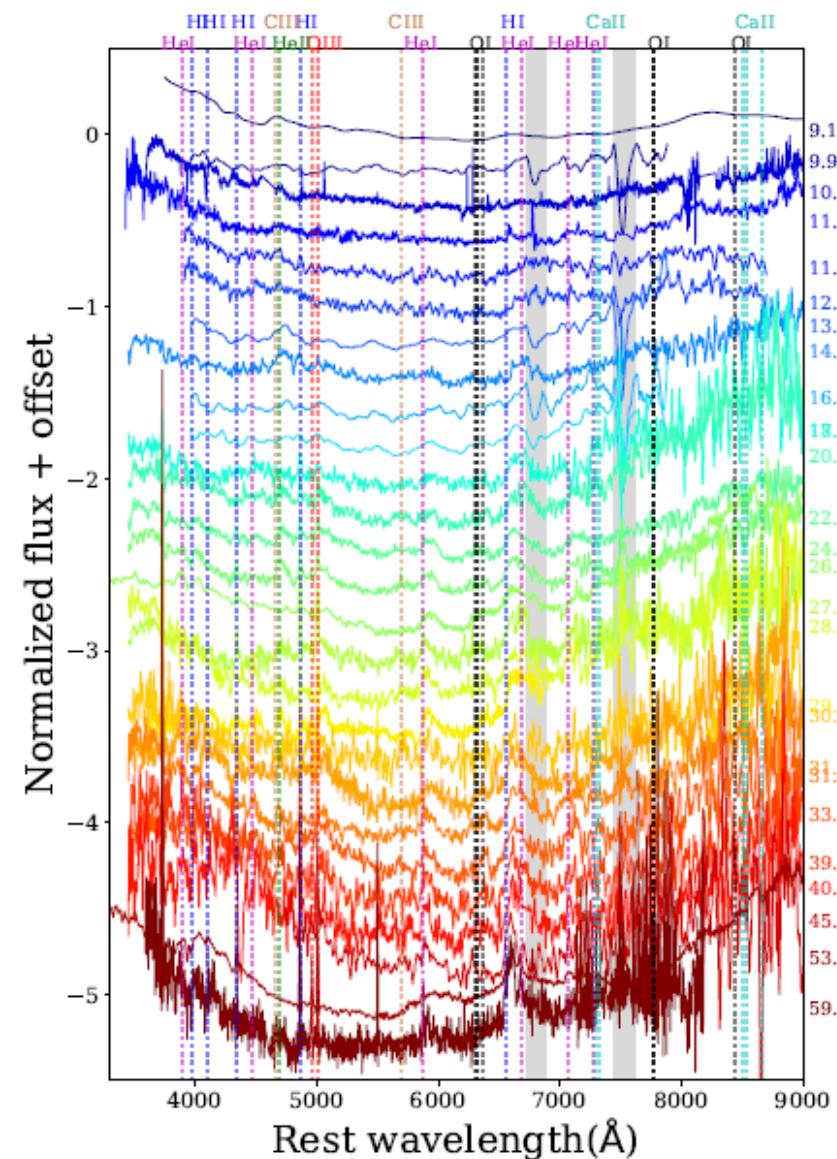


## Possible correlation of FBOTs and SNe Ibn





- Circumstellar interaction(CSI) features in spectra
- Emission lines of CIII, HeI, OI, OIII





## Possible sources powering the light curves of AT2018cow

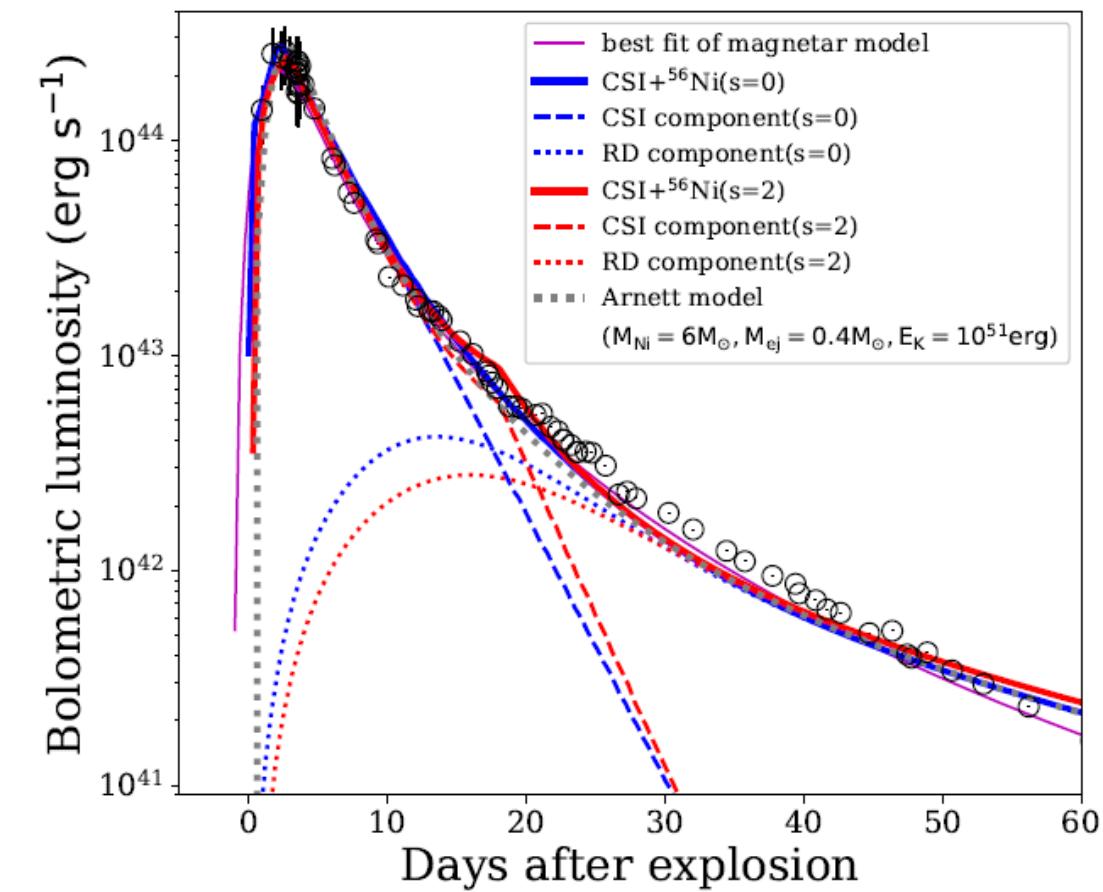
1. TDE:  $M_{\text{BH}} \sim 10^4 M_{\odot}$ ,  $M_* \sim 1 M_{\odot}$
2. Shock cooling: timescale is too short
3. Pure RD:  $M_{\text{Ni}} > M_{\text{ej}}$
- 4. Magnetar**
- 5. CSI**

Magnetar

RD+CSI:

RD+CSI( $s=0$ )

RD+CSI( $s=1$ )





## Light curve modeling-3 models

### Magnetar

$M_{ej} \sim 0.1 M_{\odot}$   
 $v_{ej} = 2.72 \times 10^4 \text{ km s}^{-1}$   
 $P = 4.5 \text{ ms}$   
 $B = 1.11 \times 10^{14} \text{ G}$

Not possible for a massive star  
Or an ECSN?

### CSI+RD(s=0)

$\rho_{csm} = \text{constant}$   
A CSM shell with uniform density  
 $M_{ej} \sim 3.16 M_{\odot}$ ,  $M_{Ni} = 0.23 M_{\odot}$   
 $v_{ej} = 2.60 \times 10^4 \text{ km s}^{-1}$   
 $M_{CSM} = 0.04 M_{\odot}$   
 $r_{CSM,in} \sim 3 R_{\odot}$   
 $r_{CSM,out} \sim 1200 R_{\odot}$   
 $\rho_{CSM,0} \sim 2.9 \times 10^{-11} \text{ g cm}^{-3}$   
 $\dot{M} \sim 0.15 M_{\odot} \text{ yr}^{-1}$



### CSI+RD(s=2)

$\rho_{csm} \sim r^{-2}$   
A steady wind  
 $M_{ej} \sim 1.69 M_{\odot}$ ,  $M_{Ni} = 0.14 M_{\odot}$   
 $v_{ej} = 1.36 \times 10^4 \text{ km s}^{-1}$   
 $M_{CSM} = 0.12 M_{\odot}$   
 $r_{CSM,in} \sim 150 R_{\odot}$   
 $r_{CSM,out} \sim 4500 R_{\odot}$   
 $\rho_{CSM,0} \sim 5.6 \times 10^{-10} \text{ g cm}^{-3}$   
 $\dot{M} \sim 1 M_{\odot} \text{ yr}^{-1}$



$\dot{M}$  much higher than that derived from radio observation ( $10^{-4}$ - $10^{-3} M_{\odot} \text{ yr}^{-1}$ )



Thank you for your attention!