Constraints on the Progenitor System of a Type Ia SN 2019ein from the Early Light Curve

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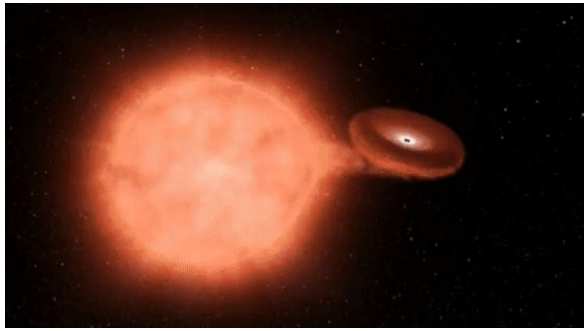
Type Ia Supernovae

- **Thermonuclear runaway of carbon-oxygen white dwarf (CO WD)**
  - A lack of H & He in their spectra
  - Occurrence of some SNe Ia in elliptical galaxies

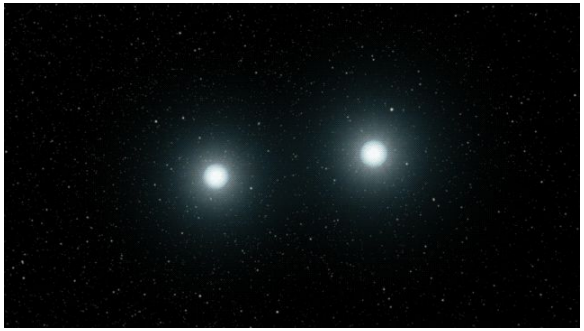
- **Standard rising of SNe Ia light curve**
  - Powered by radioactive decay of iron group elements (^{56}Ni, ^{56}Co, ^{56}Fe)
  - Power-law (flux $\propto$ time$^{\alpha}$, α ~2)

- **Cosmological distance indicator**
  - The empirical relation btw the peak luminosity & the width of LC

Progenitor scenarios of SNe Ia



WD - MS or Red (Sub)giant
(Single degenerate)
Whenlan & Iben 1973, Hachisu+96

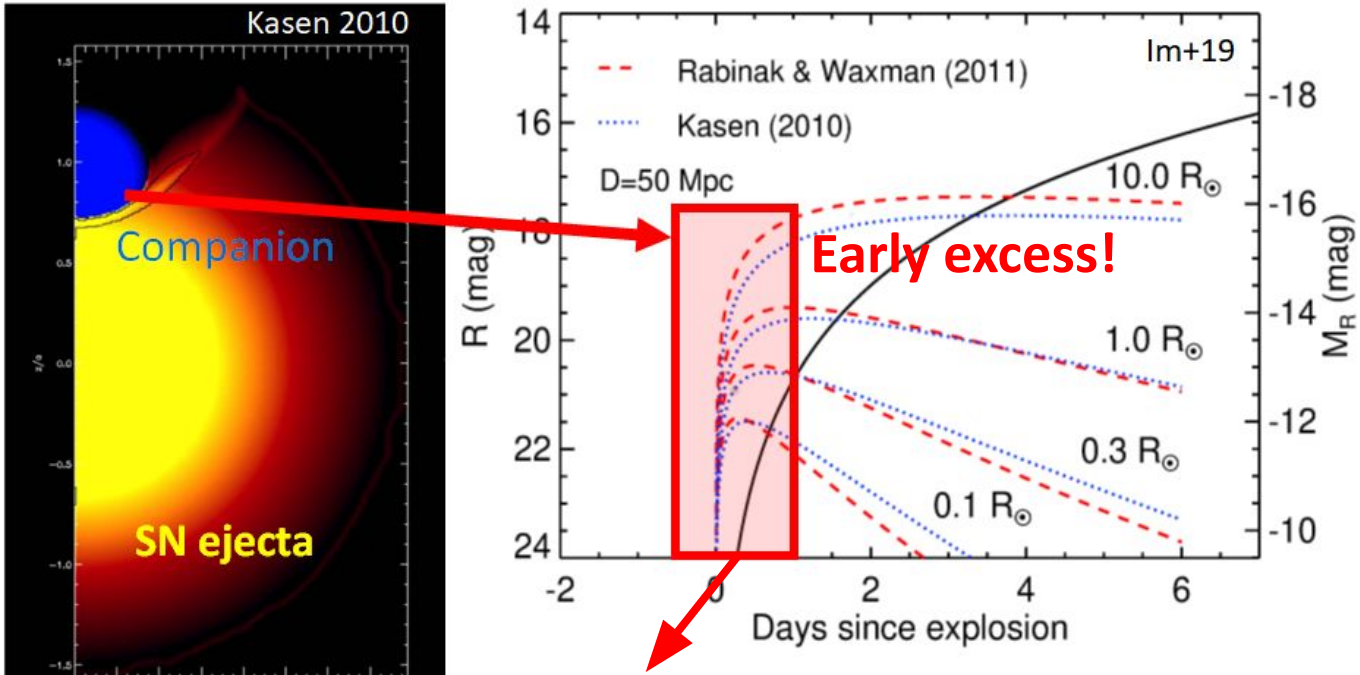


WD - WD
(Double degenerate)
Iben & Tutukov 1984

What is prevalent progenitor scenario for Type Ia SNe?

Not enough observational evidence

Shock-heated cooling emission (Companion model)



L(t) ∝ Companion Radius

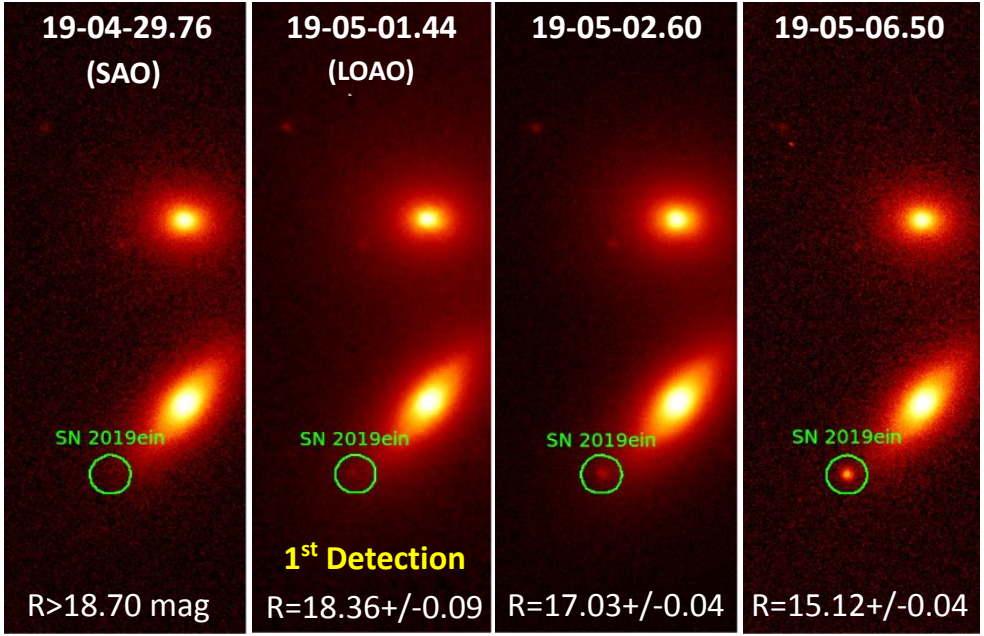
High-cadence monitoring < 1d is important

Intensive Monitoring Survey of Nearby Galaxies (IMSNG)

- High cadence (≲1day) monitoring of 60 nearby UV bright galaxies (Im et al. 2019)

Follow-up data from 7 facilities (including MAO, June 19~)

Early detection of SN 2019ein in NGC 5353

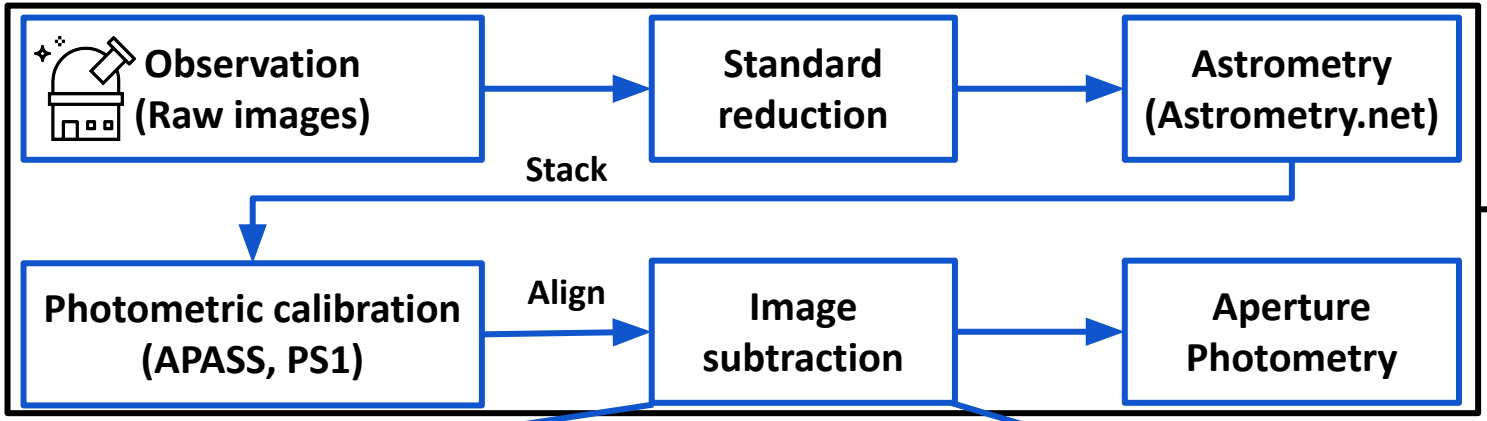


50 min earlier than the discovery report (Tonry et al. 2019, TNS)

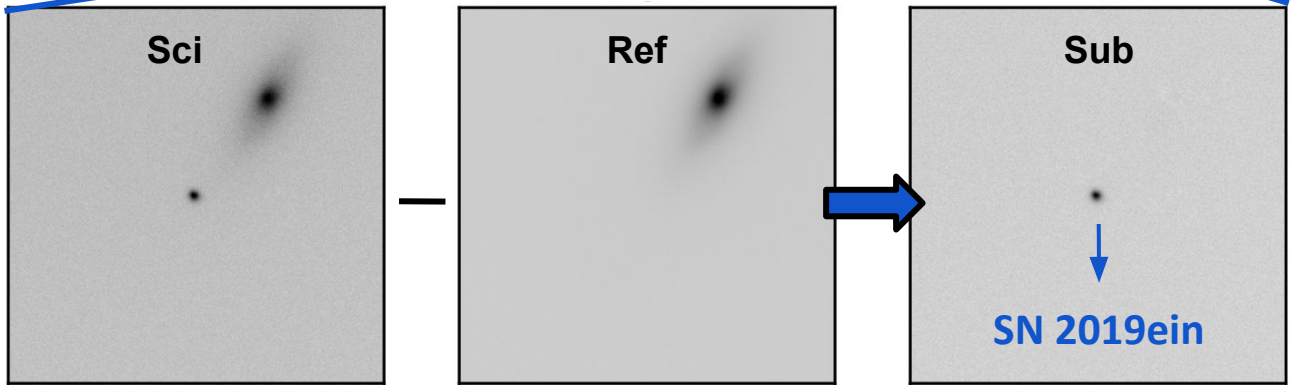
9 hours earlier than Kawabata et al. 2020

Follow-up with BVRI+JHK > 4 months

Data reduction



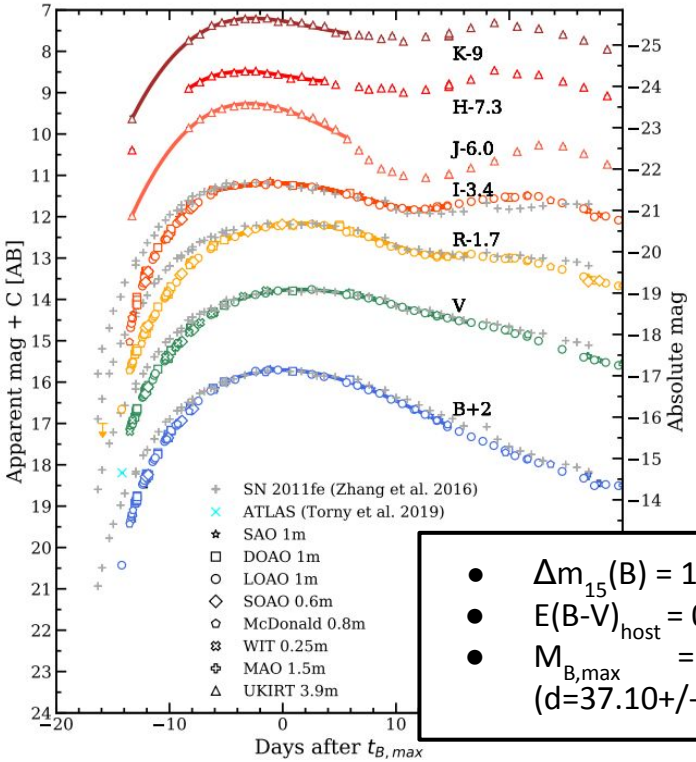
"gppy"
(Gregory Paek et al.
in prep)



Light curve

Basic characteristics of SN 2019ein

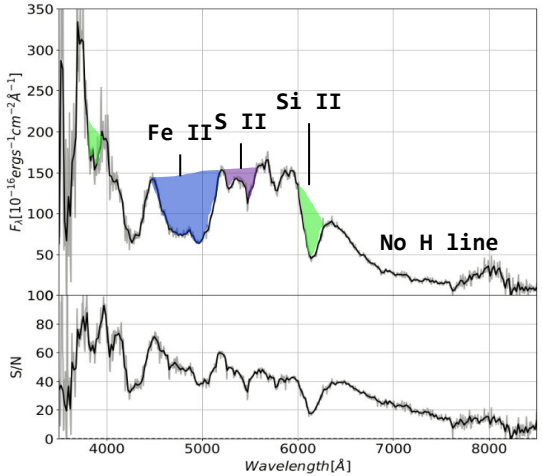
Long-term light curve



- $\Delta m_{15}(B)$ = 1.39+/-0.03 mag
- $E(B-V)_{host}$ = 0.09+/-0.04 mag
- $M_{B,max}$ = -19.14+/-0.03 mag (d=37.10+/-0.49Mpc)

Long slit spectroscopy at SAO

- R = 600, grating=25 μm
- Rmag = 14.3 on 2019-05-22 (20min exp)



A normal type Ia SN
but early excess was not found!

Early light curve

- **Companion model + Power-law**
  - **χ^2 minimization fitting on the early data**
    - **Power-law → (^{56}Ni decay)** $M(t) = M_0 - 2.5\alpha \log_{10}(t - t_{\rm fl})$
    - **Early excess → (SHCE)** $L(t) = 2.0 \times 10^{40} \frac{R_{10} M_c^{1/4} v_9^{7/4}}{\kappa_{0.2}^{3/4}} t_{\rm day}^{-0.5}\ {\rm erg\ s^{-1}}$

Kasen (2010)

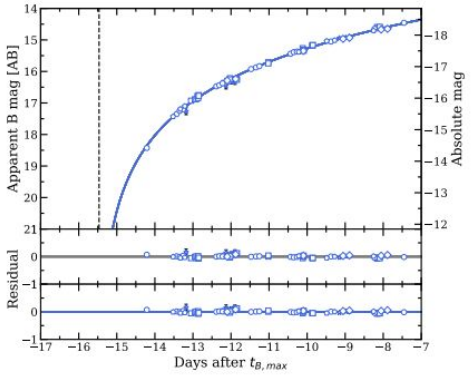
(Opacity $\kappa_{0.2}$ = 1.0 cm^2 g^{-1}, Ejecta mass Mc = 1.0/1.4 , Ejecta velocity v_9)

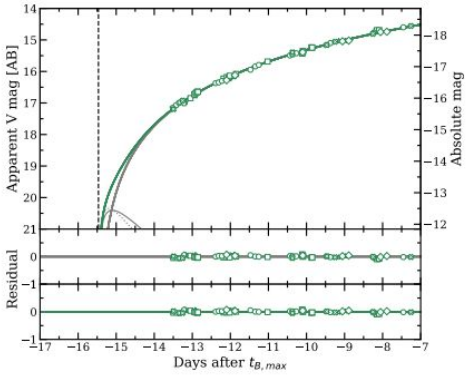
✓ **10 Free parameters : α, M_0 (for BVRI), t_{fl} , R_***

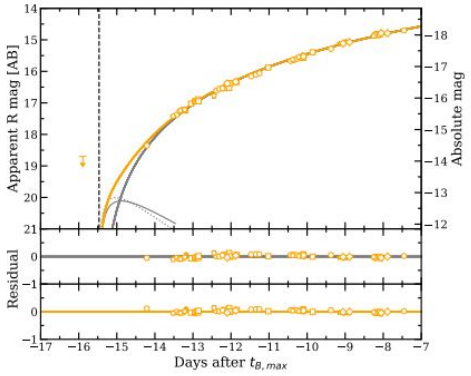
- **First light time?**

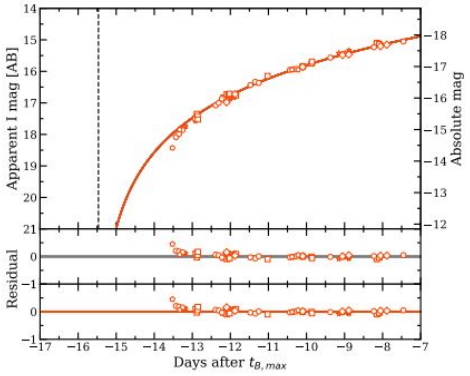
(1) One t_{fl} Same for BVRI bands?
(2) Use mean value of $t_{fl,B}$, $t_{fl,V}$, $t_{fl,R}$, and $t_{fl,I}$?
(3) Use $t_{fl,I}$ as t_{fl} (SCHE is little)?

Early light curve fitting (1)







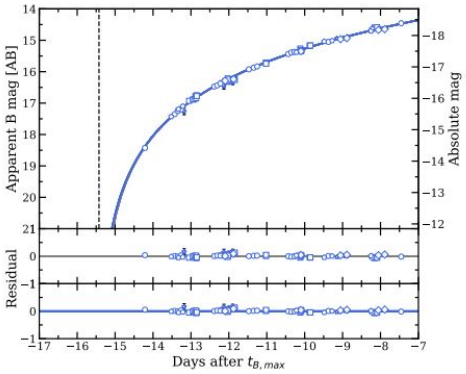


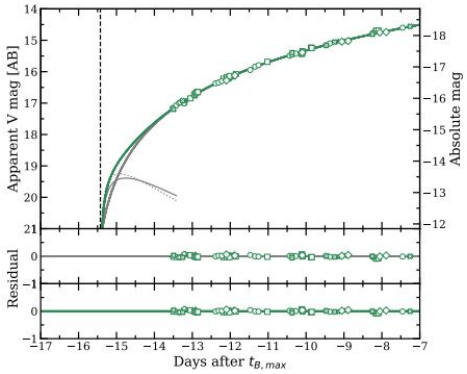
(1) Determine one t_{fl}

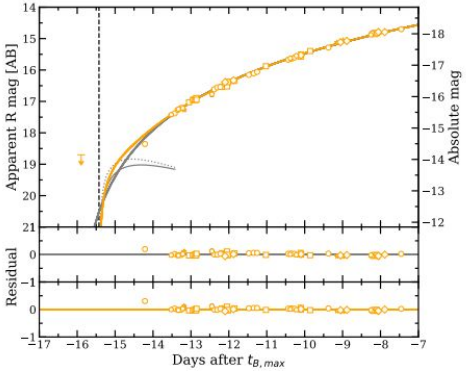
Band	α	m_0	t_{fl}	χ^2_ν	$R_*[R_\odot]$
			(1)		
B	1.929±0.039	18.829±0.110	58603.185±0.087	3.398	-
V	1.690±0.035	18.433±0.096			0.168±0.094
R	1.851±0.040	18.862±0.107			0.244±0.045
I	1.934±0.040	19.373±0.109			-

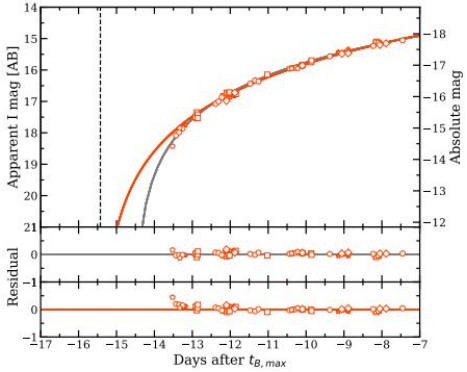
- Very weak SHCE ⟶ $R_*=0.24R_\odot$

Early light curve fitting (2)









(2) Use mean t_{fl} from the separate BVRI fitting

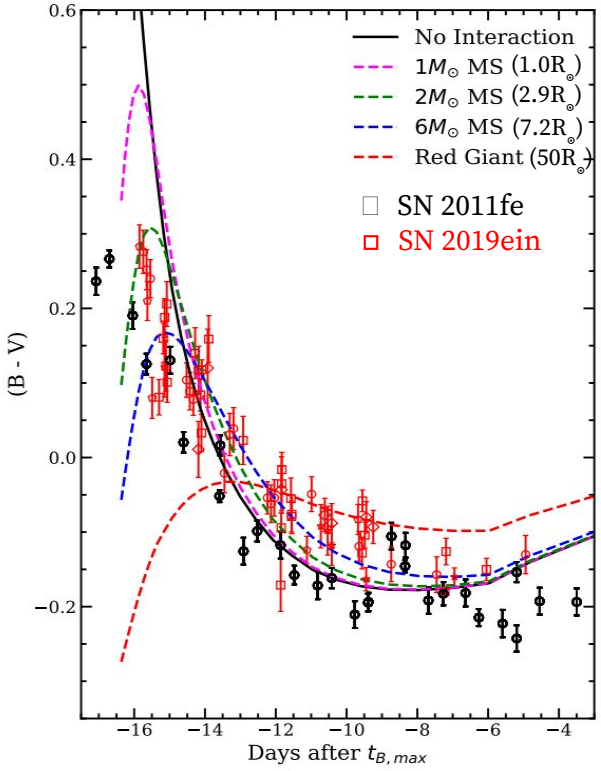
Band	α	m_0	t_{fl}	χ^2_ν	$R_*[R_\odot]$
B	1.909±0.006	18.774±0.013	58603.226±0.575	-	-
V	1.713±0.013	18.470±0.027			0.577±0.142
R	1.927±0.019	19.023±0.042			0.921±0.144
I	1.915±0.010	19.322±0.020			-

- Very weak SHCE ⟶ R_*=0.92$R_\odot$

(3) Assuming I band LC has no SCHE (The latest $t_{fl,I}$ = 58603.23) ⟶ R_*~1.2$R_\odot$

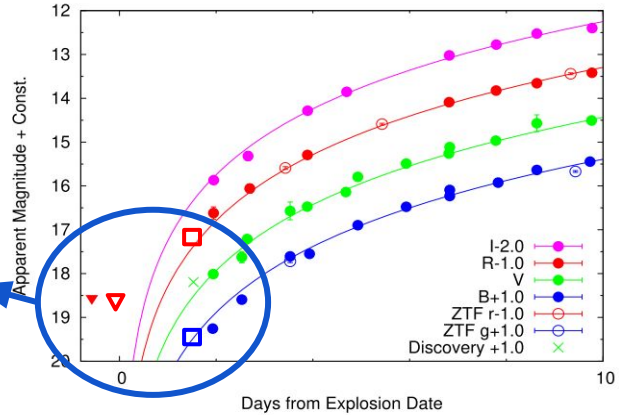
The companion model constrain the companion size to ~1.2$R_\odot$ at maximum

Color & Previous study



- **Early color evolution**
  - Bright SHCE ⟶ Blue at the early phase (Dashed line)
  - Similar with SN 2011fe no SHCE
  - <2M$_\odot$ MS (<2.9 R$_\odot$)?
- **This result is agreed with Kawabata+20, giving a tight constraint on the companion size**
  - R$_*$ ~ 4.3-7.6 R$_\odot$ (Kawabata et al. 2020)

IMSNG limit & detection



Possible progenitors of SN 2019ein

- **No early blue excess :**
  - Early light curve fitting using the companion model $\rightarrow R_* < \sim 1.2R_\odot$

- **Possible progenitor systems**
  - Low mass MS ~ $1R_\odot$ (Kasen 2010)
  - Recurrent nova with a rapid mass accretion ~$0.2R_\odot$ (Hachisu & Kato 2003)
  - CO WD binary with the long delayed time ~$0.01R_\odot$ (Yoon et al. 2007)

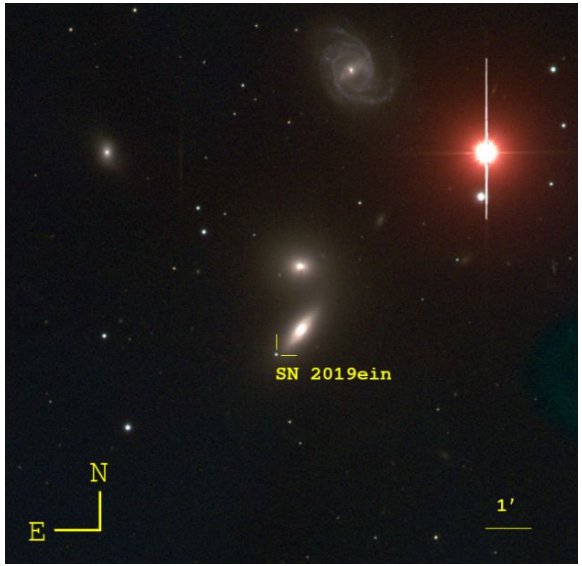
Large companion can be ruled out via the companion model

Summary

1. **Early detection of SN 2019ein (IMSNG)**
   - 50 min/9hours earlier (1st report/Kawabata et al. 2020)

2. **SN 2019ein : normal SN Ia + no early excess**
   - Long-term LC : Similar with the LC of SN 2011fe
     - ➢ *Maidanak supports when SN is faint!*
   - Spectroscopy : No H, He + Strong Si, S, Fe spectral features

3. **Early light curve fitting using companion model**
   - ~1.2$R_{\odot}$ sized companion star at maximum
   - Large giant stars can be ruled out.



Maidanak BVR color (Lim in prep.)

Thank you very much