Seimei User's Meeting 2023 (Sep. 12-13)

SN2020uem: A Possible Thermonuclear Explosion within A Dense Circumstellar Medium

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KU, Keiichi Maeda, Takashi Nagao et al. 2023a (https://ui.adsabs.harvard.edu/abs/2023ApJ...944..203U/abstract)

KU, Takashi Nagao, Keiichi Maeda et al. 2023b (https://ui.adsabs.harvard.edu/abs/2023ApJ...944..204U/abstract)

Diversity of Type Ia Supernovae

Type Ia Supernova: Standard Candles, but…

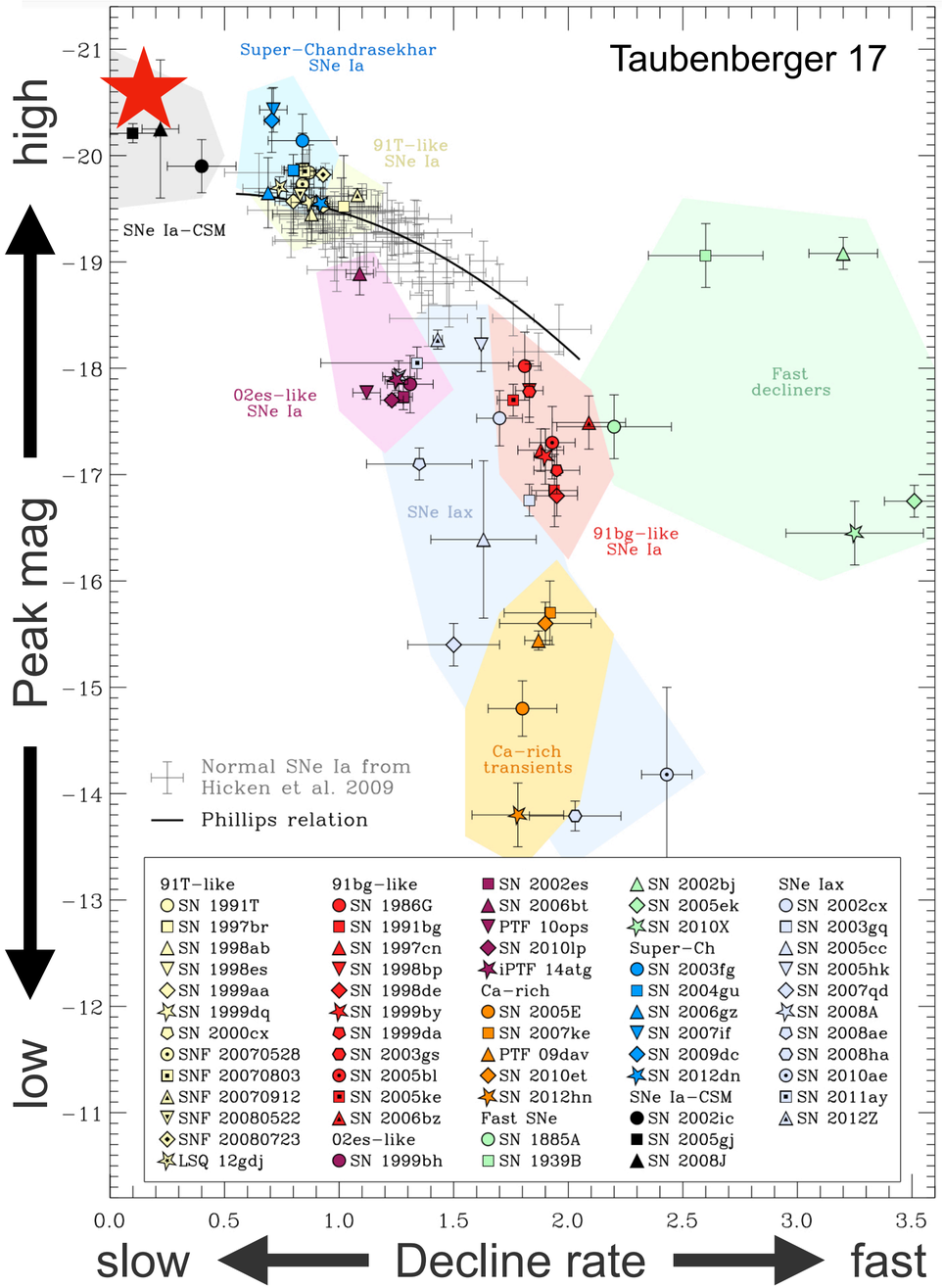
New Generation Surveys

ASAS-SN · Pan-STARRS · Tomo-e Gozen · atlas · ZTF · Vera C. Rubin Observatory

Much more diversity than expected !

- different progenitor & explosion Mechanisms
- new insights for Stellar Evolution
- more robust cosmology

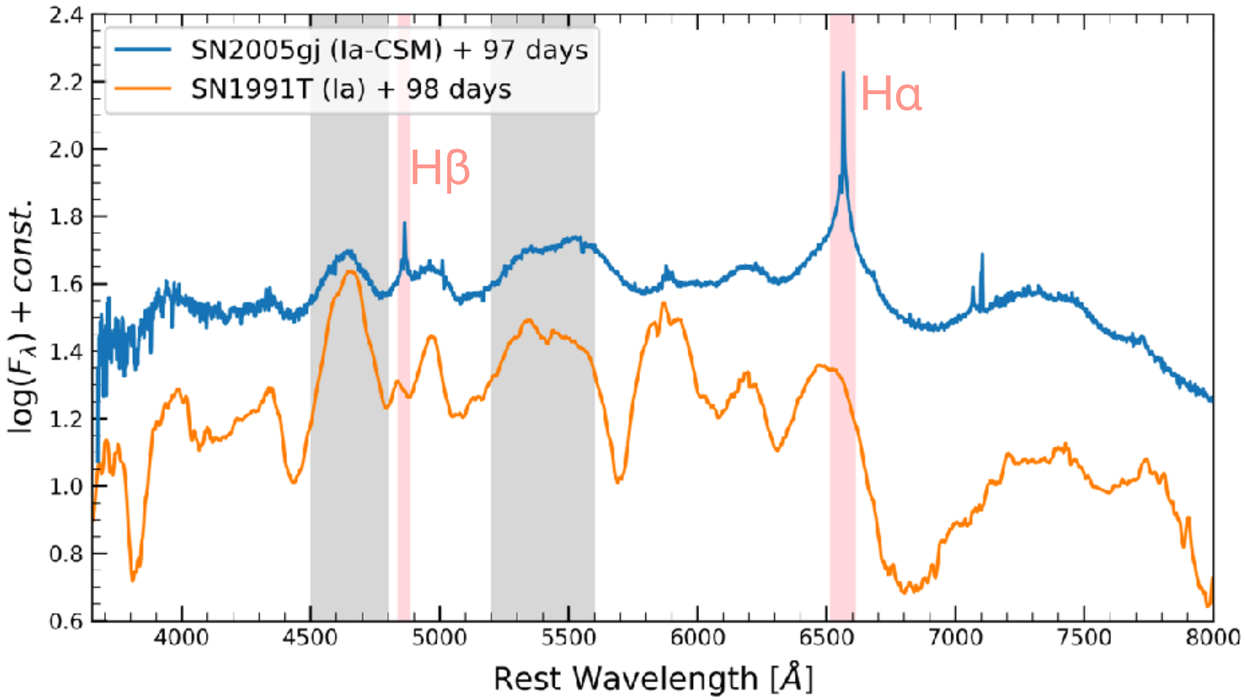
SN 2020uem is one of the peculiar SN Ia.

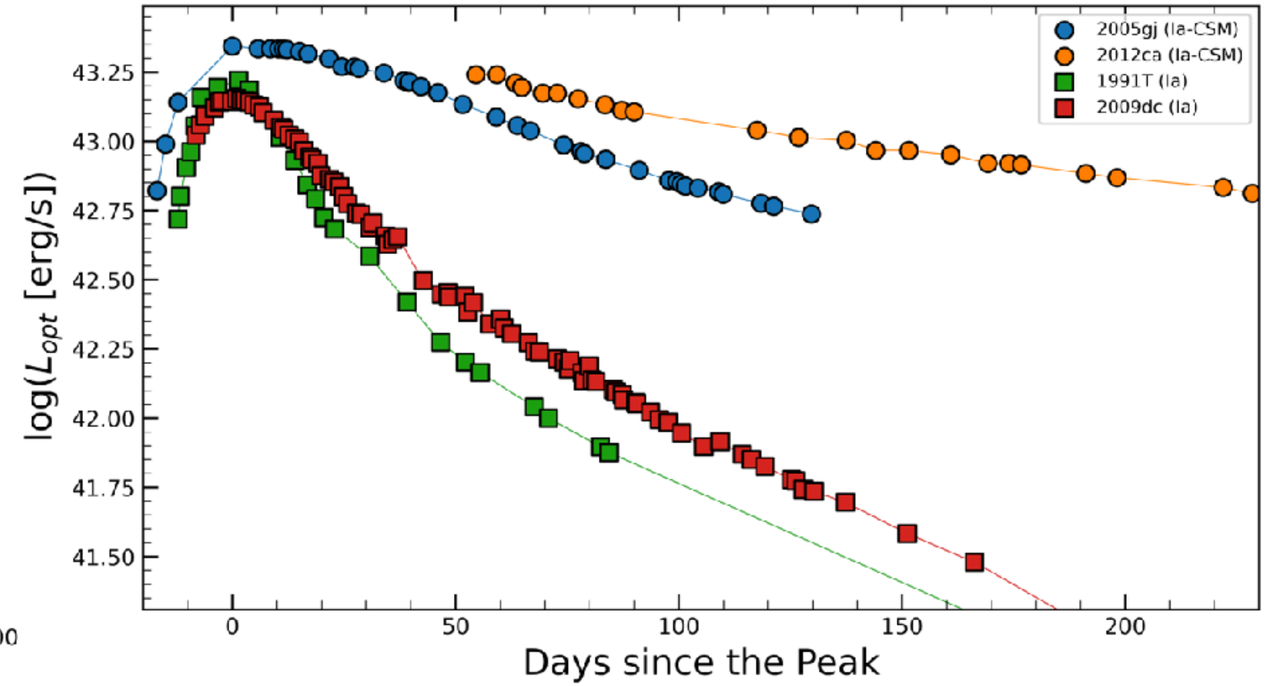


Type Ia-CSM Supernovae

Type Ia-CSM Supernovae

- Spectrum: high temperature Ia + **narrow H emission lines**
- Light cueve: high and long-lasting luminosity



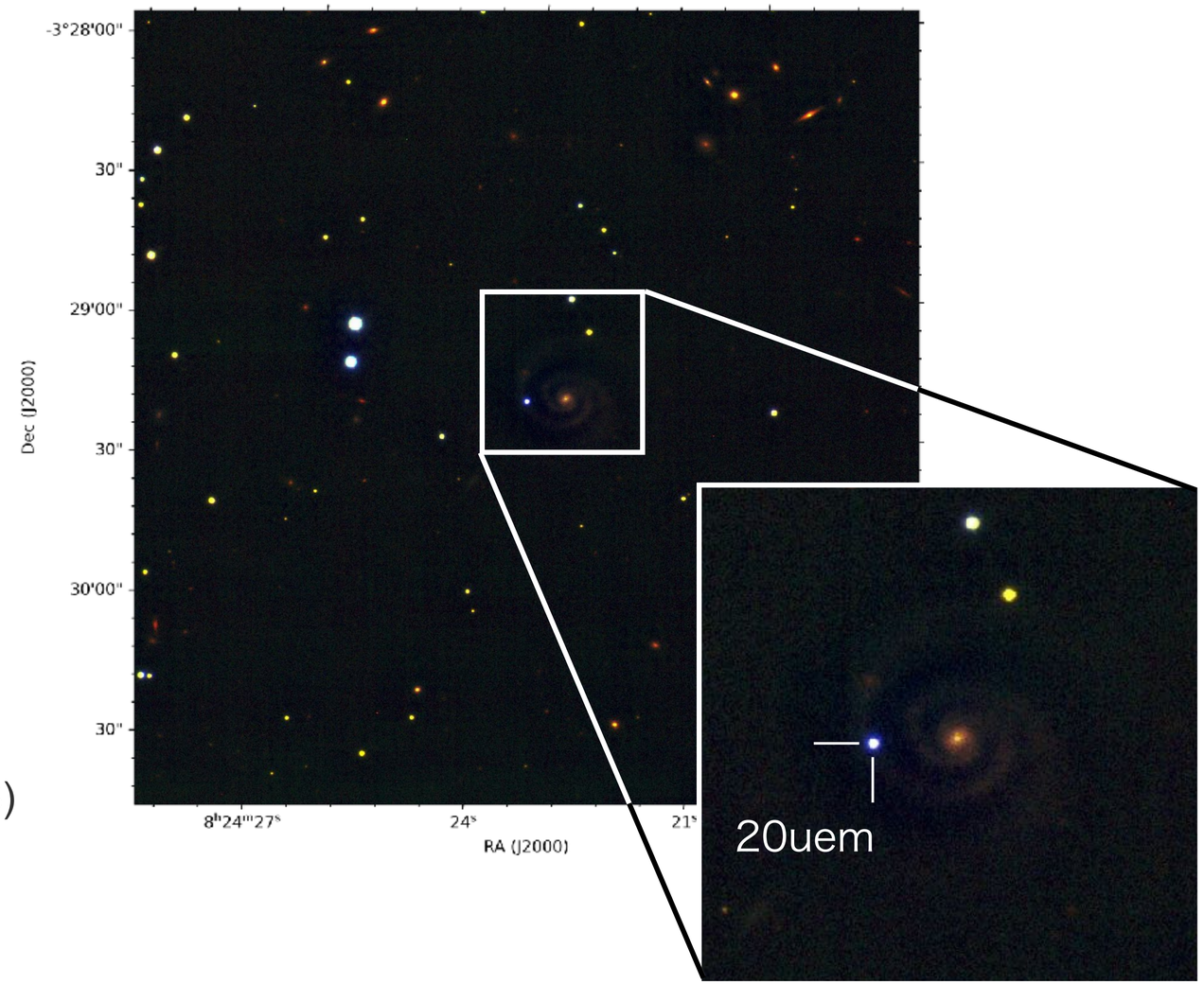


Type Ia-CSM SNe = Interaction between energetic Ia and dense circumstellar matter (CSM)

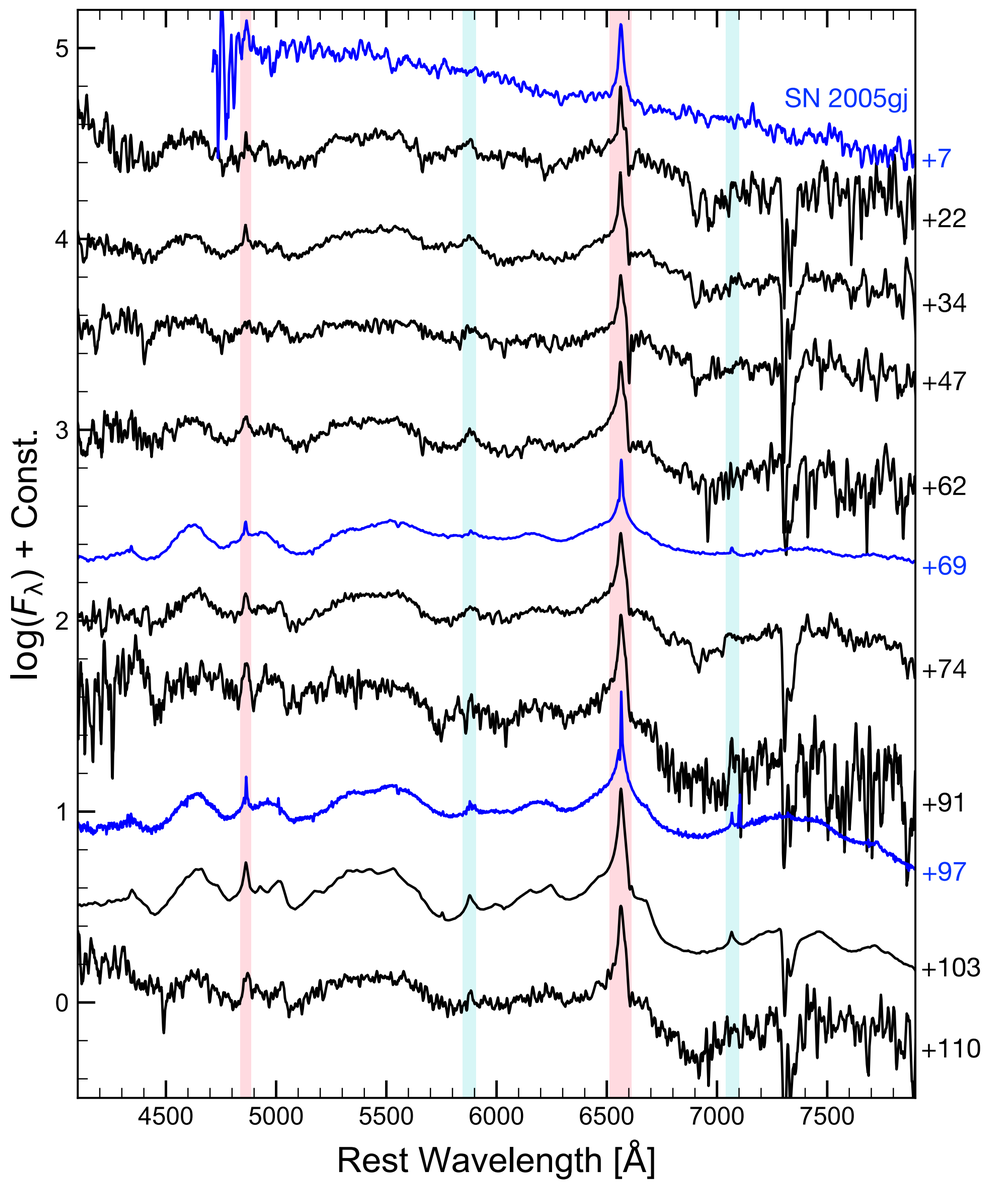
What is the origin of the dense CSM？

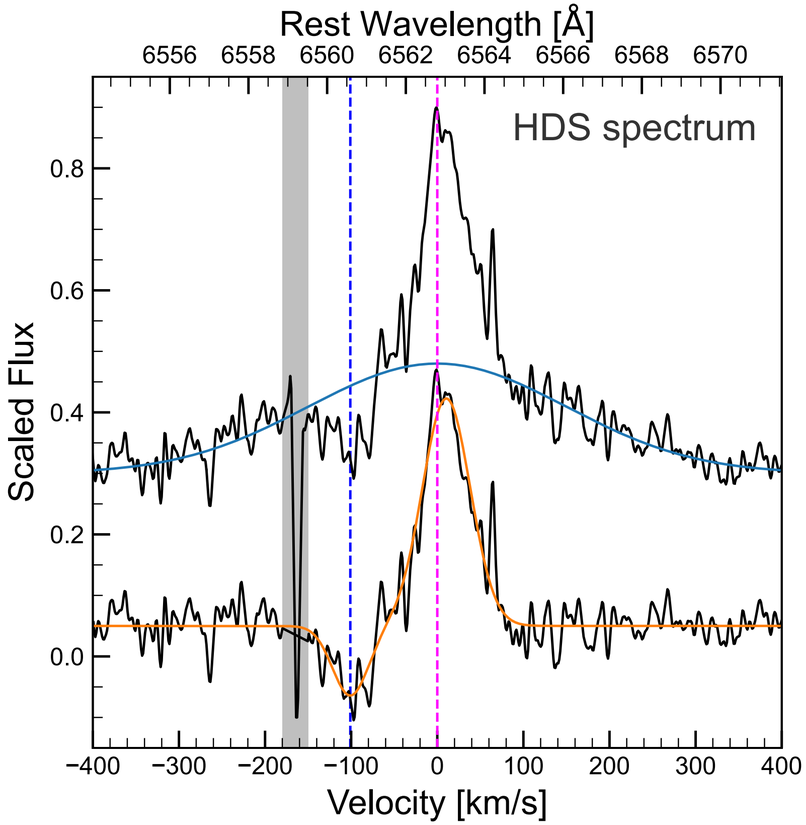
Type Ia-CSM SN 2020uem

- Discovery: 16.5 mag on 2020-09-22 by ATLAS
- Coordinate: RA = $08^h24^m23.85^s$, Dec=-3°29′19.1″
- Distance: d_L = 173.3 Mpc (z = 0.041)
- Follow-up observation
  - **Photometry**: Kanata 19/21 nignts (HOWpol/HONIR)
    Subaru 1 nights (SWIMS)
    Seimei 3 nights (TriCCS)
  - **Spectroscopy**: Seimei 8 nights (VPH-blue & VPH-683)
    Subaru 3 nights (FOCAS, HDS & SWIMS)
  - **Polarimetry**: Subaru 1 nights (FOCAS)
    Tohoku T60 1 nights (Dipol-2)



Spectral Evolution

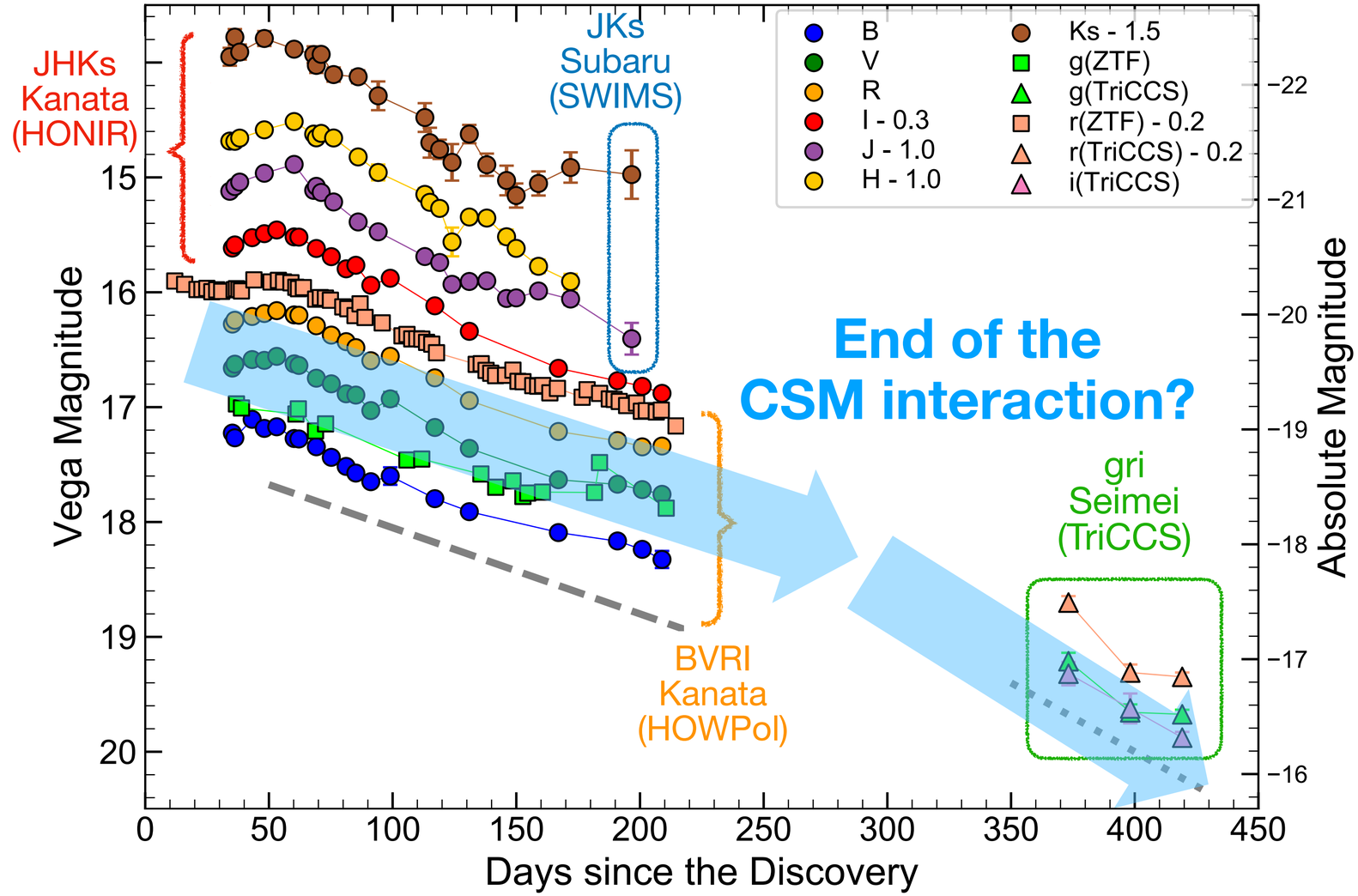




- Prominent narrow H lines
- Narrow P-Cygni Profile with 100 km/s
- intermediate mass elements (Fe)

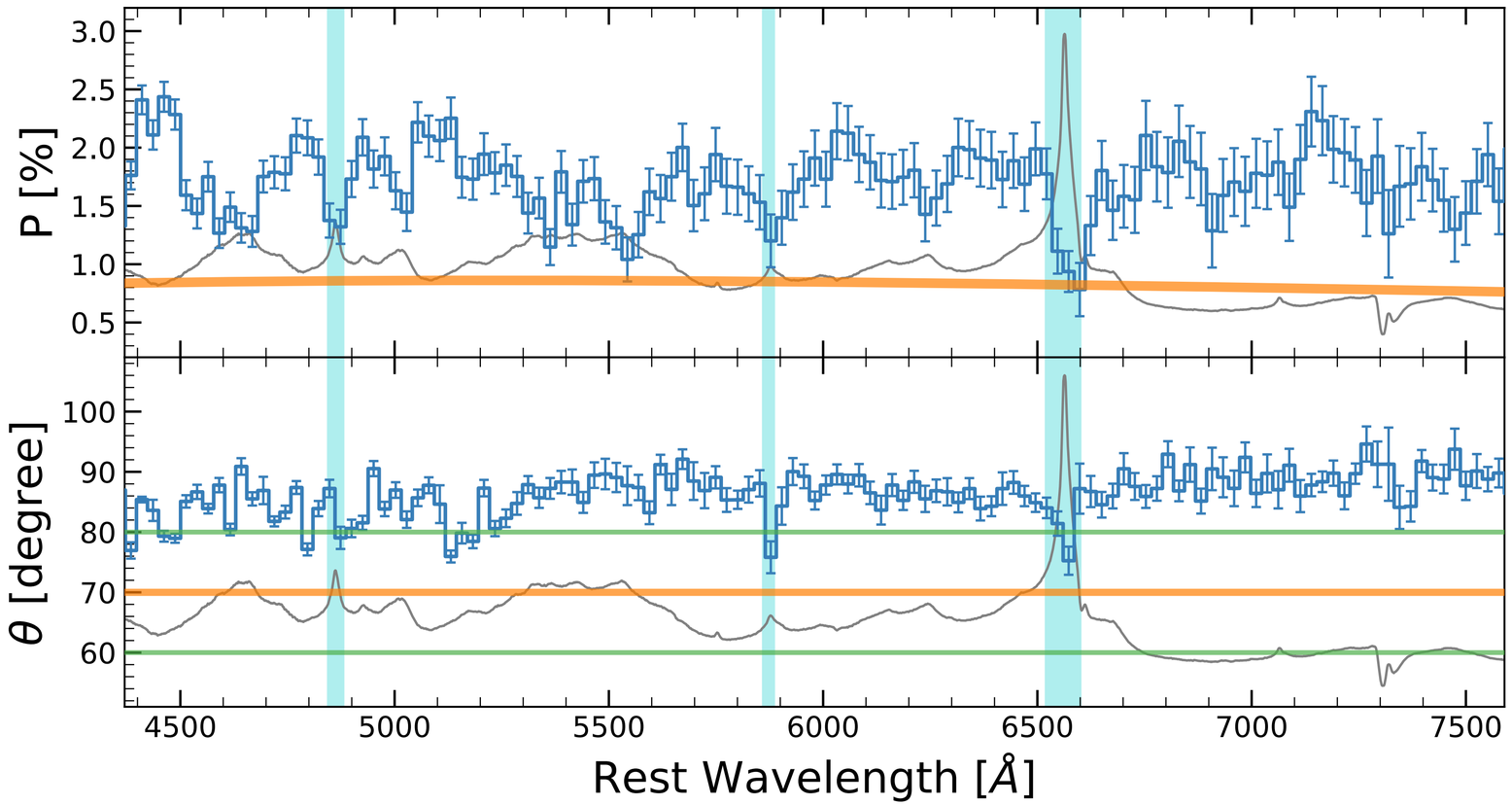
→ Typecal spectral features of SNe Ia-CSM

Multi-band Light Curves



Constraint on the CSM mass ?? (later slides)

Polarimetry: Polarization Degree & Angle



Interstellar Polarization (ISP)

$$P_{\mathrm{ISP}}(\lambda) = P_{\mathrm{max}} \exp\left[-K \ln^2\left(\lambda_{\mathrm{max}}/\lambda\right)\right]$$

$$\rightarrow \quad P_{\mathrm{ISP}} \sim 0.8\,\%$$

SN Polarization:

- $P_{\mathrm{SN}} \sim 1.0 - 1.5\,\%$
- constant angle of ~85 degree
- without wavelength dependence

geometry: **aspherical CSM**

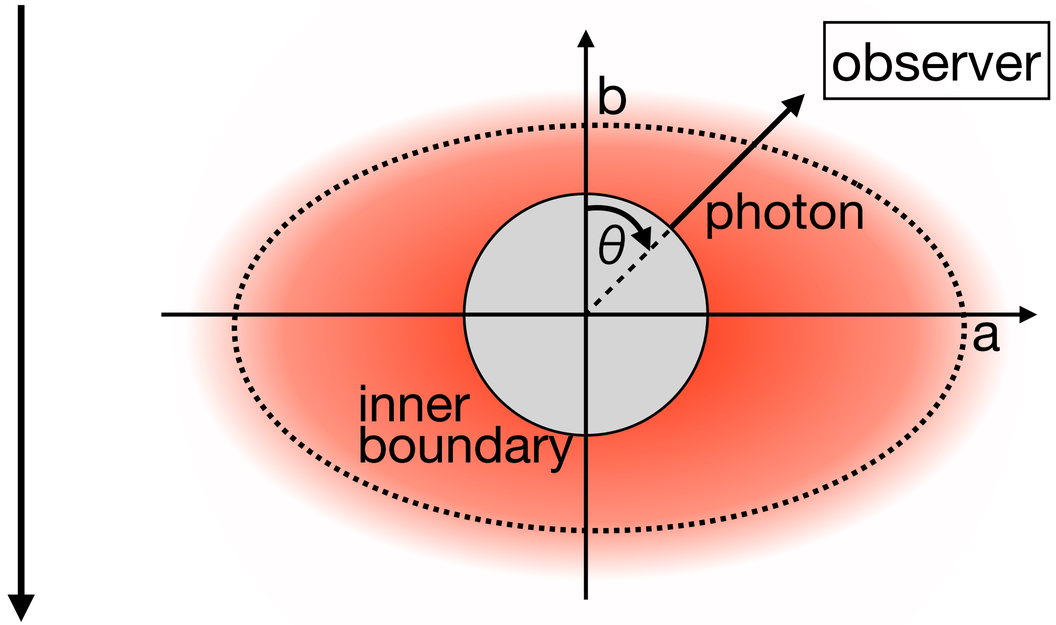
polarization source: **electron scattering**

CSM Geometry

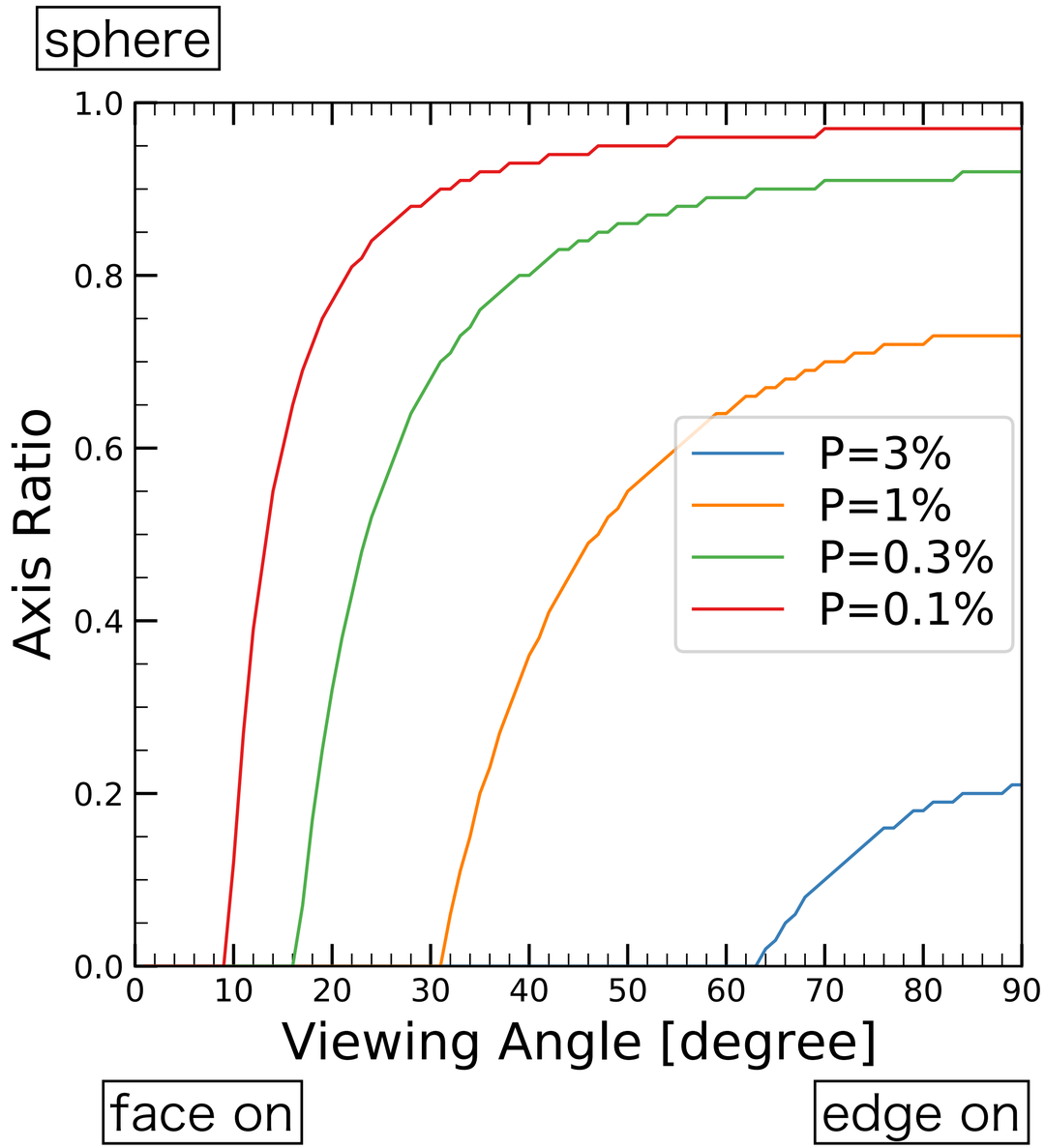
$P_{\rm SN} \sim 1.0 - 1.5\,\%$ → asymmetric CSM geometry

- **'Elliptical' CSM** (c.f., Hoflich 91)

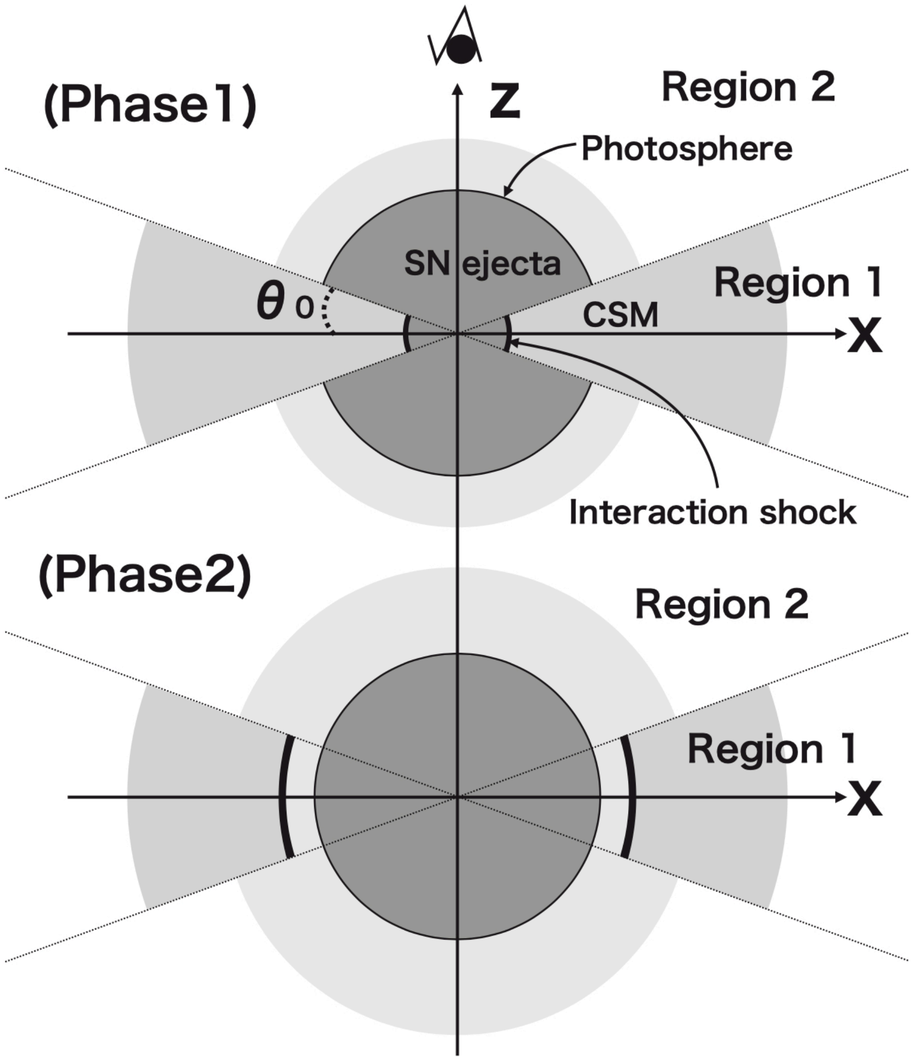
  requires extremely-flat CSM



- **'Disk/Torus' CSM ?**



Lighr Curve Modeling



CSM interaction model (modified Nagao+ 20)

- disk-like CSM
- $\rho \propto r^{-2}$
- CSM velocity: 100 km/s ← constrained by Subaru/HDS
- kinetic energy: 1×10^{51} erg
- ejecta mass: 1.4 $M_\odot$

} assuming Ia explosion

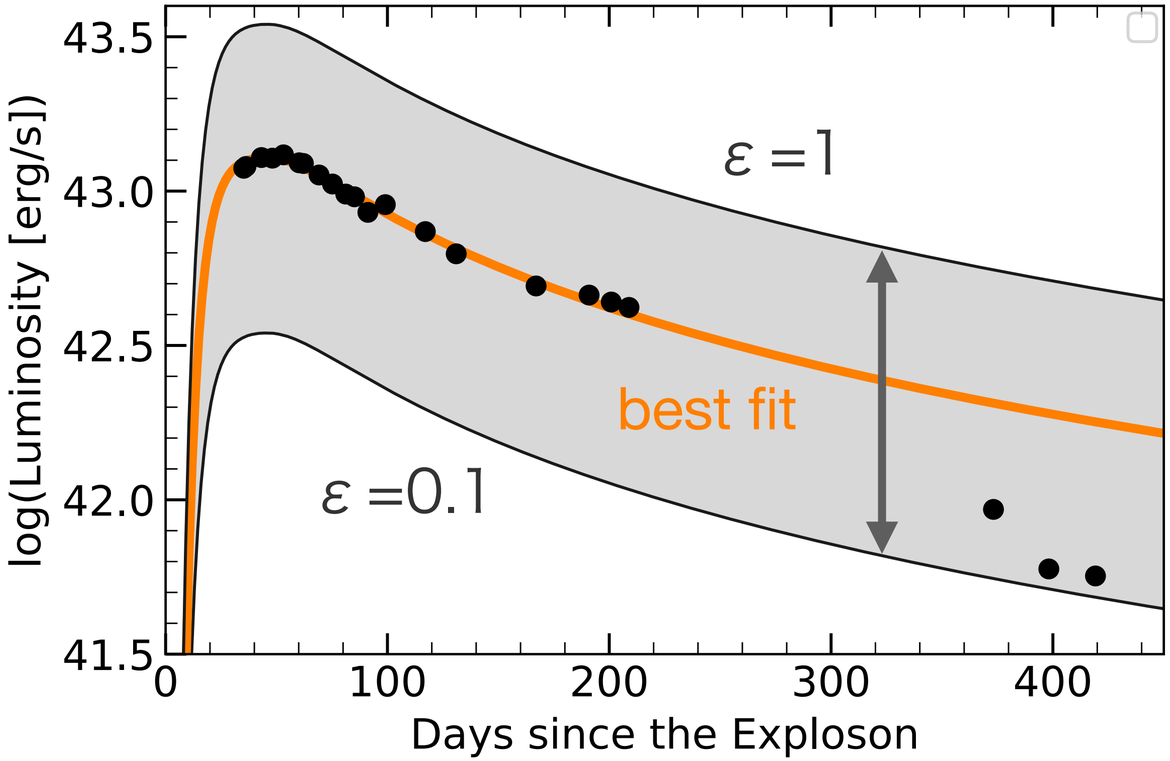
$$L_{\rm sh}(t) = \varepsilon \frac{{\rm d}E_{\rm kin}(t)}{{\rm d}t} = 2\pi\epsilon\rho_{\rm CSM}(r_{\rm sh}(t))r_{\rm sh}^2(t)v_{\rm sh}^3(t)$$

$$L_{\rm sphere}(t) = \int_0^t \frac{L_{\rm sh}(t')}{t_{\rm diff}(t')} \exp\left(\frac{t-t'}{t_{\rm diff}(t')}\right) dt'$$

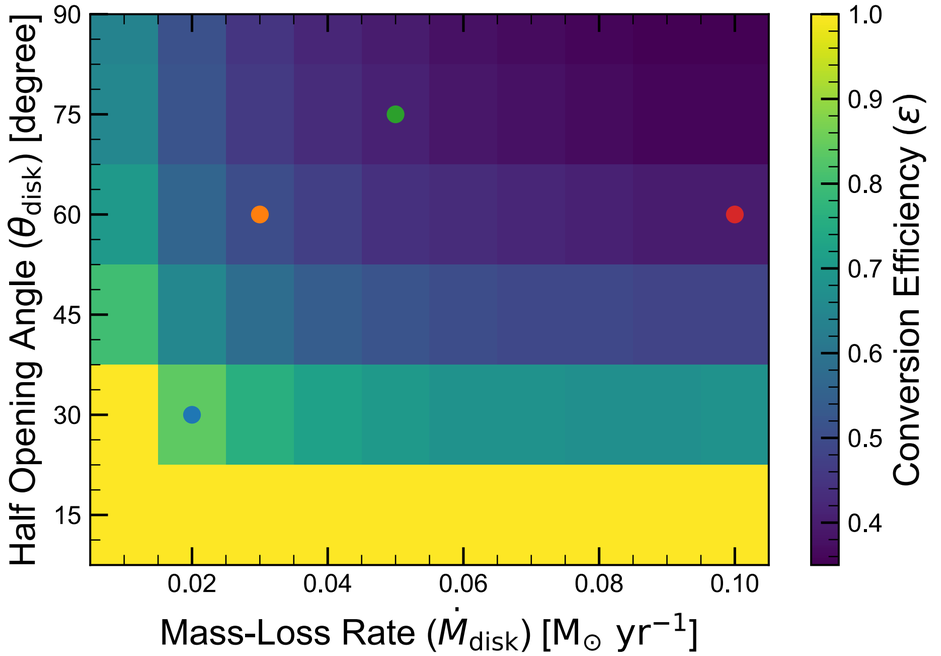
$$L_{\rm disk}(t, \dot{M}_{\rm disk}) = \omega_{\rm disk} L_{\rm sphere}(t, \widetilde{\dot{M}}_{\rm sphere}) \qquad \omega_{\rm disk} = \frac{\Omega_{\rm disk}}{4\pi} = \sin\theta_{\rm disk}$$

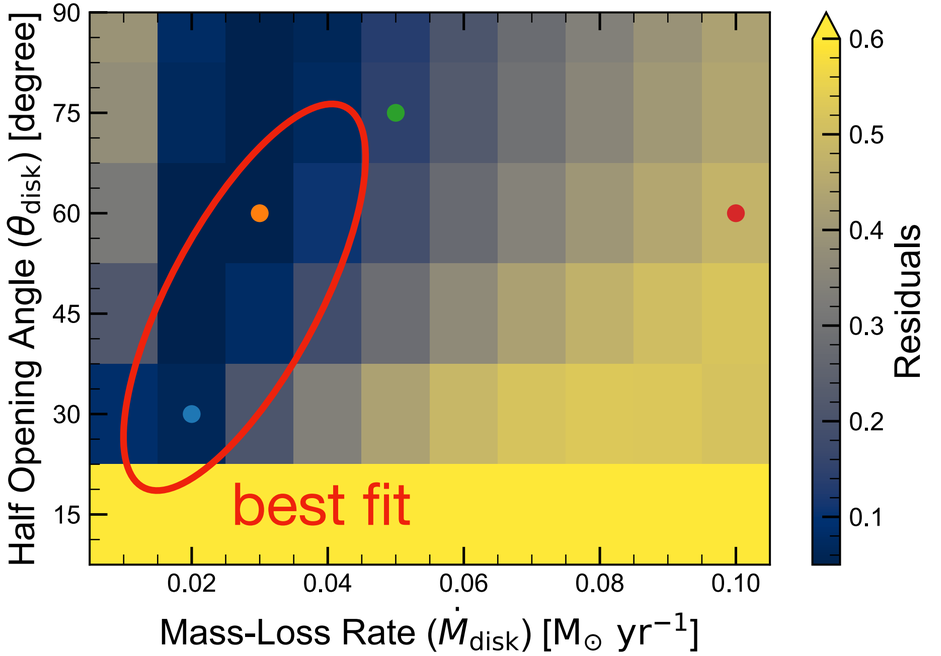
Fitting Free Parameter: ε

$$L(t) = \epsilon \frac{\mathrm{dE_{kin}(t)}}{\mathrm{dt}}$$ (ε: radiation-kinetic conversion efficiency)



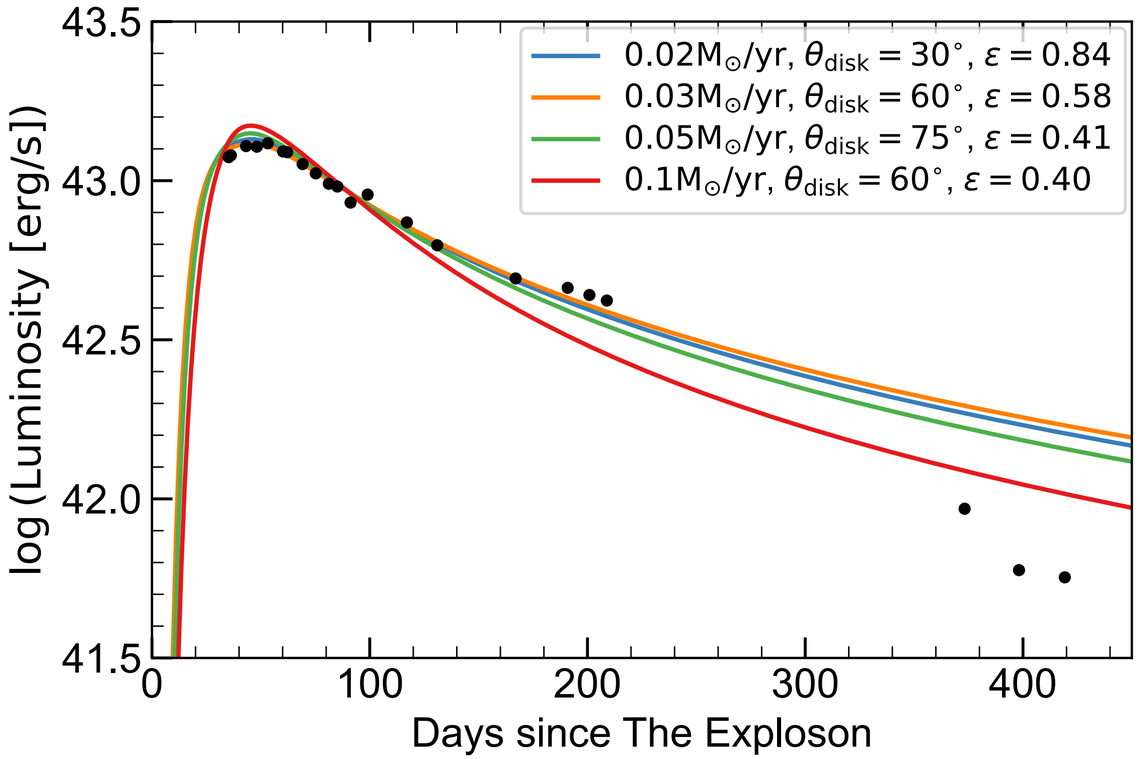
best-fit ε

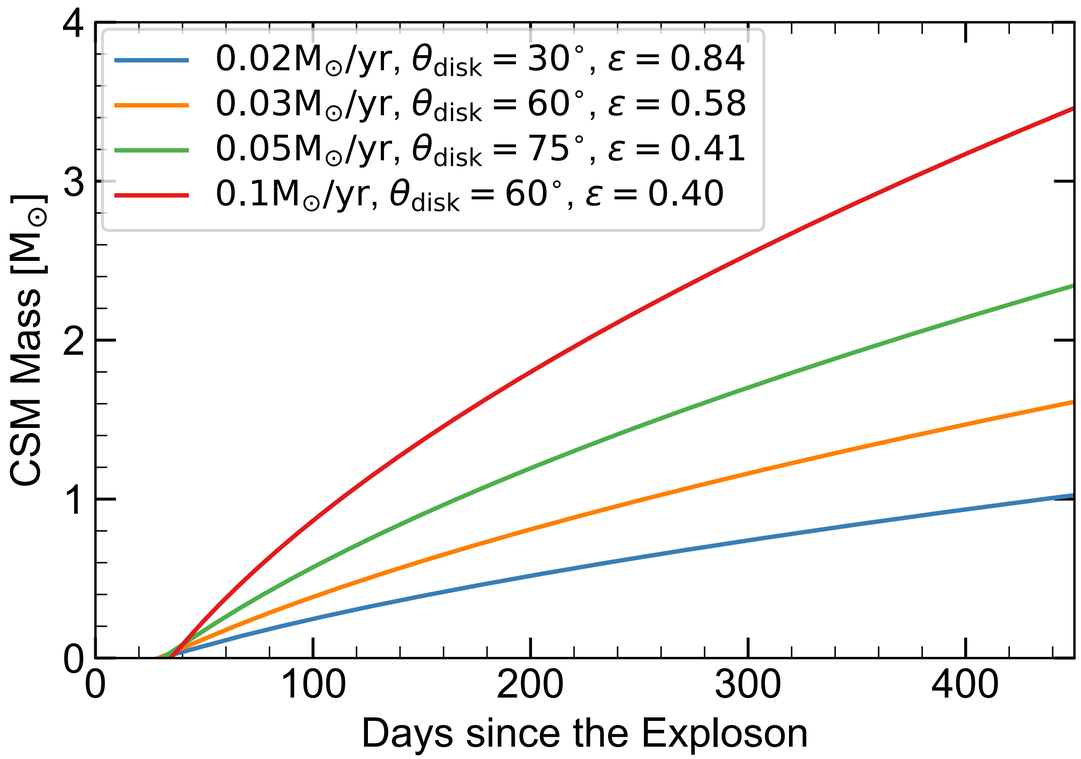




$$\mathrm{RMS} \equiv \sum \left(\frac{\mathrm{fit} - \mathrm{data}}{\mathrm{data}} \right)^2$$

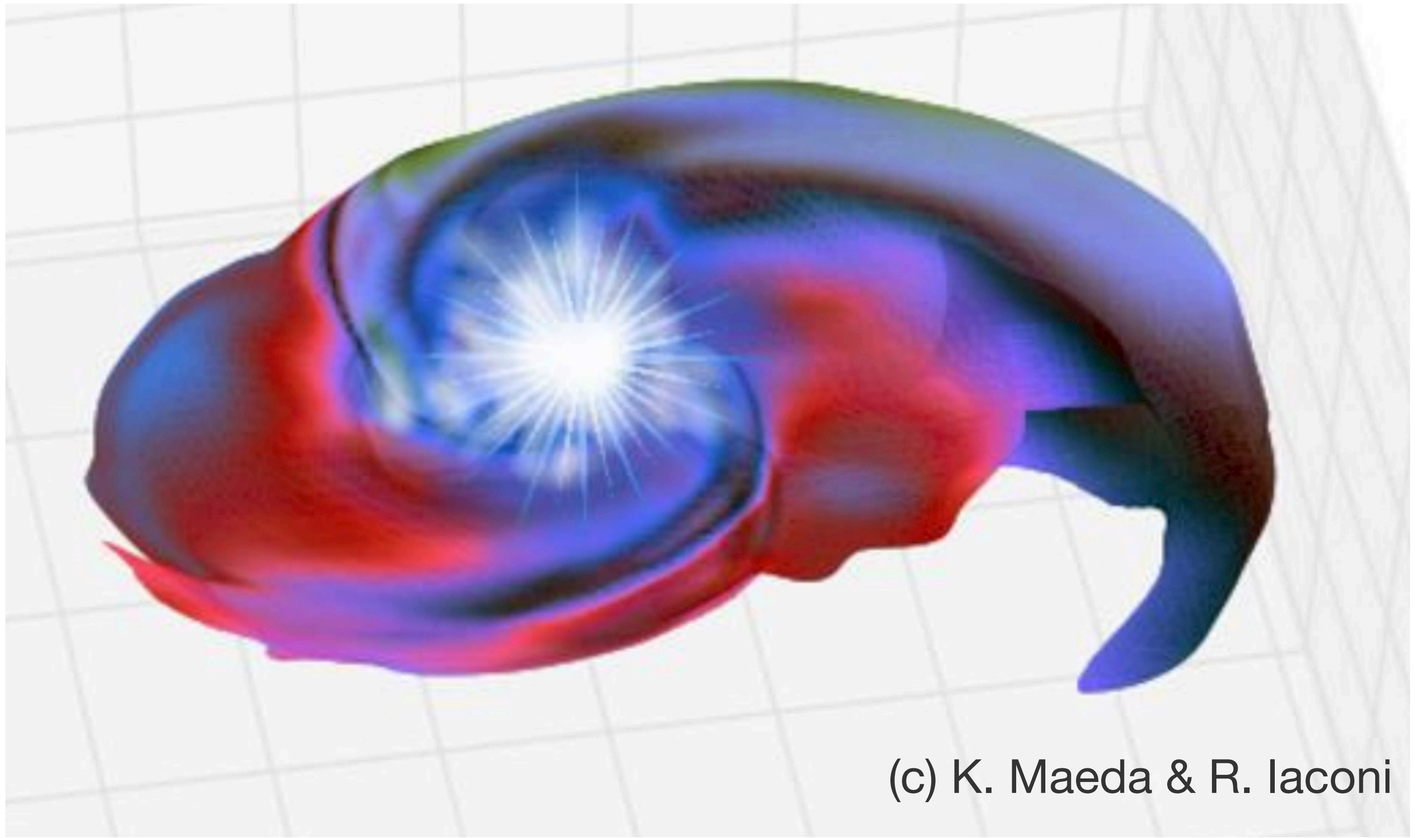
Light Curve & CSM Mass





- Mass-loss rate: 0.02-0.03 $\mathrm{M}_\odot$/yr with $v = 100$ km/s
- Opening angle: 30-60 degree
- CSM mass: 0.5-3 $\mathrm{M}_\odot$

Possible Progenitor System of SN 2020uem



- Mass-loss rate: 0.02-0.03 $\mathrm{M}_{\odot}$/yr w/ 100 km/s
- Opening angle: 30-60 degree
- CSM mass: 0.5-3 $\mathrm{M}_{\odot}$

Progenitor: WD + AGB/RG common envelope ?

Scenario: Core-Degenerate scenario ?

Take Away

- We performed follow-up observation for 2020uem with Seimei/Subaru.
- Photometric & Spectroscopic properties suggest that 2020uem is an SN Ia-CSM.
- 2020uem shows polarization of ~1% without wavelength dependence.
  - geometry: **disk-like CSM**
  - polarization source: electron scattering
- We compute light curves and constrain the CSM mass.
  - CSM mass: **0.5 - 4** $\mathrm{M}_{\odot}$
- We propose the following scenario for 2020uem.
  - progenitor: **common envelope of WD + AGB/RG star**
  - explosion scenario: **core-degenerate scenario**