

Subaru UM 2013@ NAOJ, 23/Jan/2014

# Supernova Follow-up with Subaru and other 8m-class telescopes

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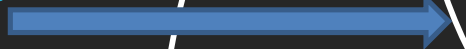
# Nearby SN follow-up with 8m-class telescopes

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$V \sim 15$  (SN Ia @ 50 Mpc)

**Polarization**

**High spec. resolution**

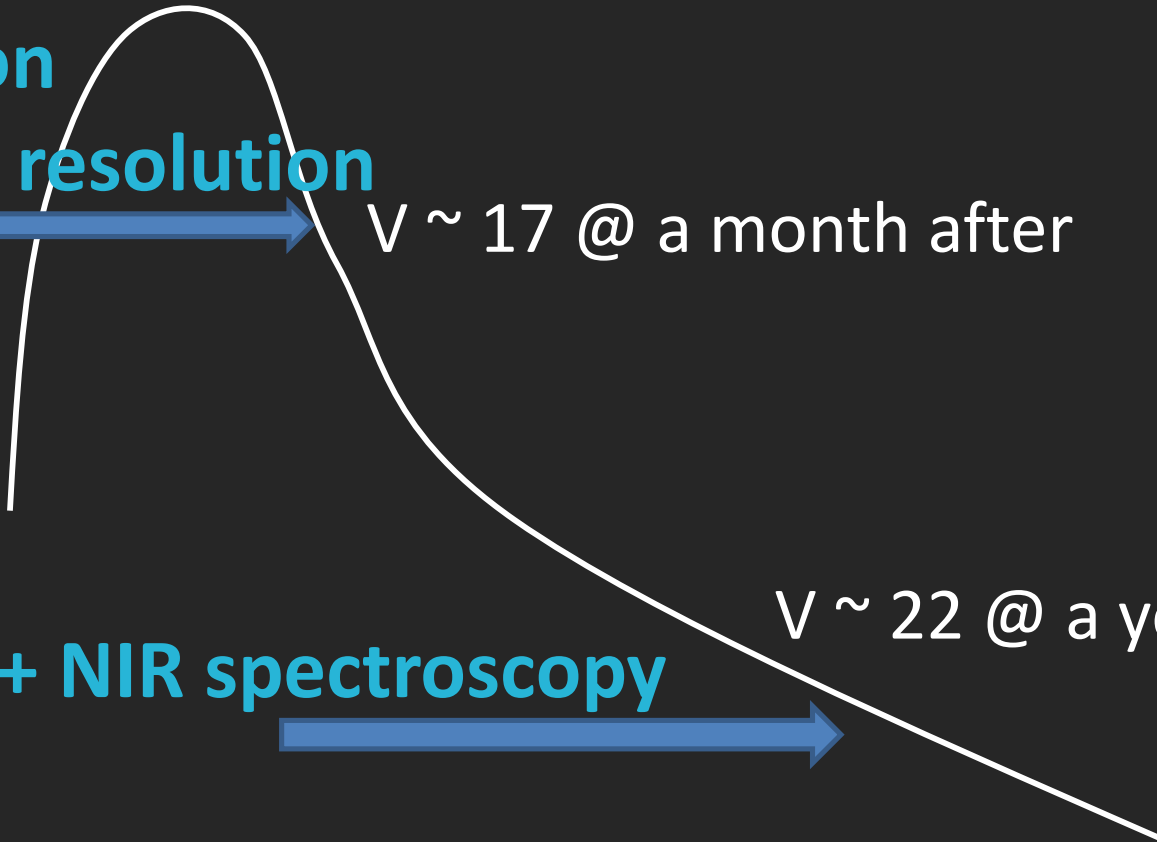


$V \sim 17$  @ a month after

**Optical + NIR spectroscopy**

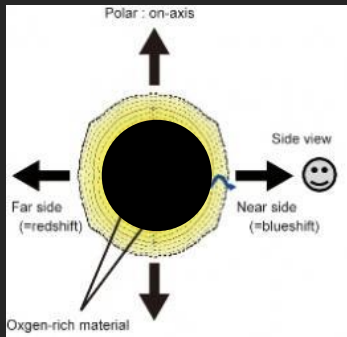


$V \sim 22$  @ a year after

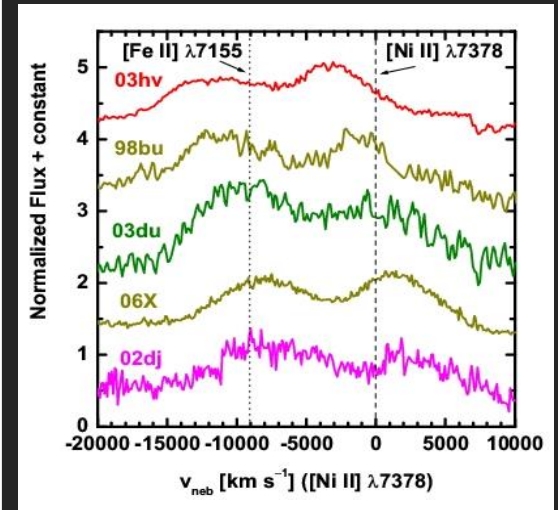
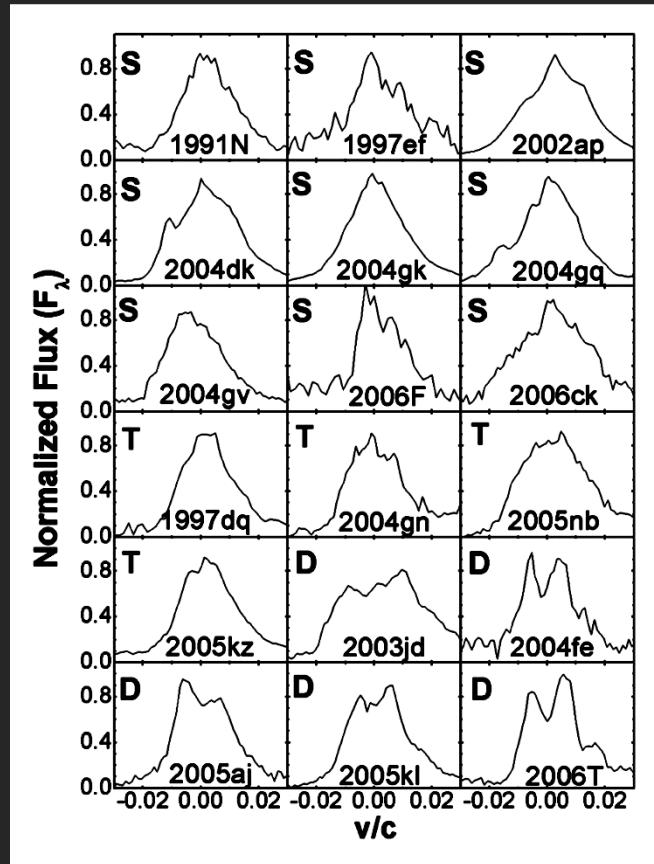
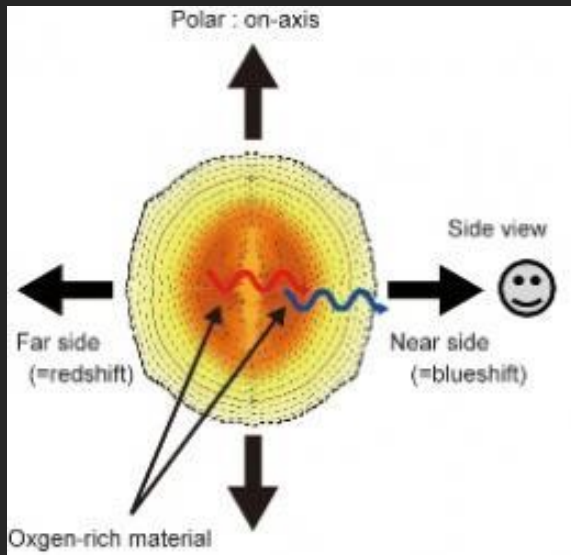


# An example: Late-phase spectroscopy

Abundance+Kinematics → Progenitor+explosion



~ year



SNe Ia are asymmetric  
 KM+ 2010  
 → Subaru/FOCAS/IRCS  
 VLT/FORS2

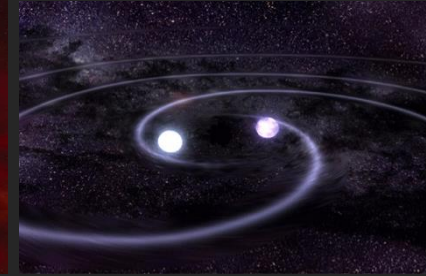
Core-collapse SNe are aspherical  
 KM, Kawabata+ 2008 ← Subaru/FOCAS

# Topics in 2013 (among others)

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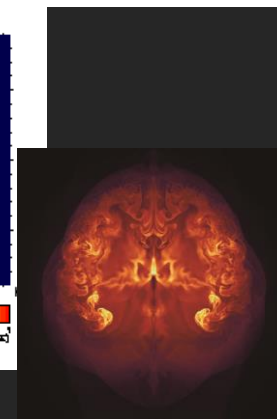
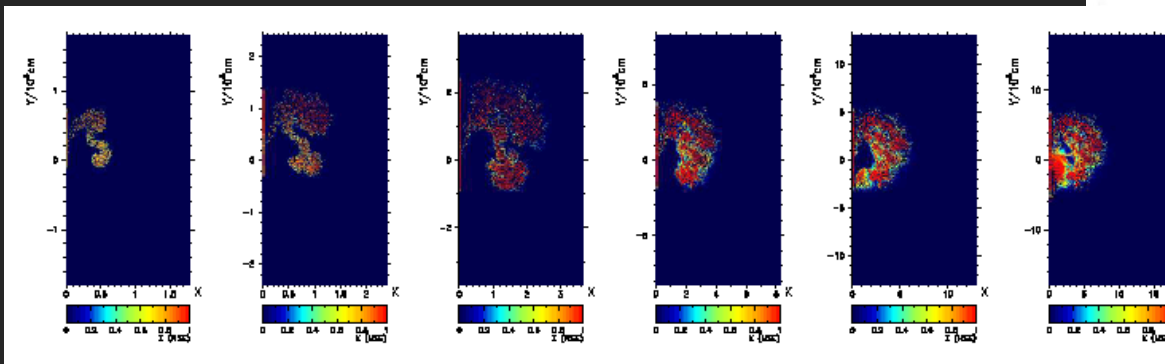
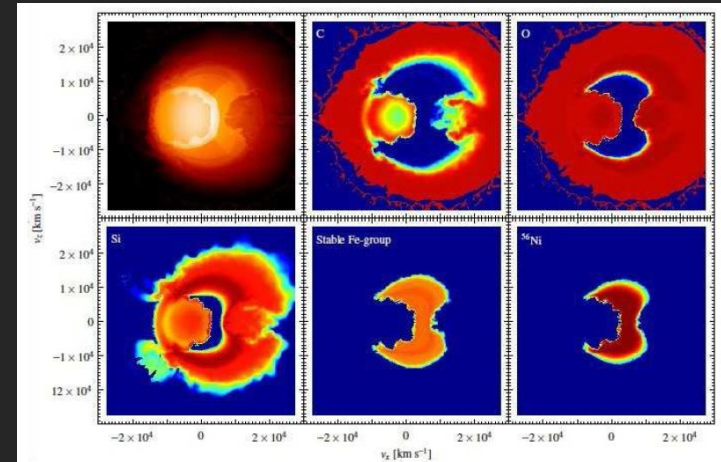
- Unburned material in SN Ia.
  - ←Late-phase.
- Dust formation in SN within dense CSM.
  - ←Late-phase NIR.
- Local environment at SN site.
  - ←S/N (now), and High-spec. resolution (in the future).

# Type Ia Supernovae

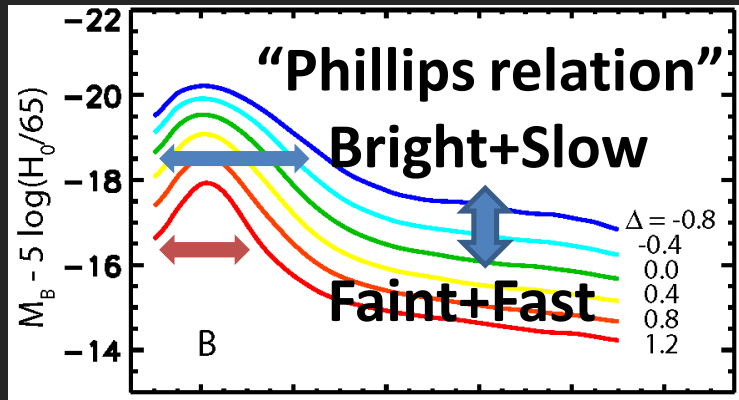


- Thermonuclear explosion of (nearly Chandrasekhar-mass) C+O WD(s). WD Merger: Roepke+ 2012
- **Diversity** exists, reflecting various evolution paths and/or explosion modes?

Off-center: KM, Roepke+ 2010



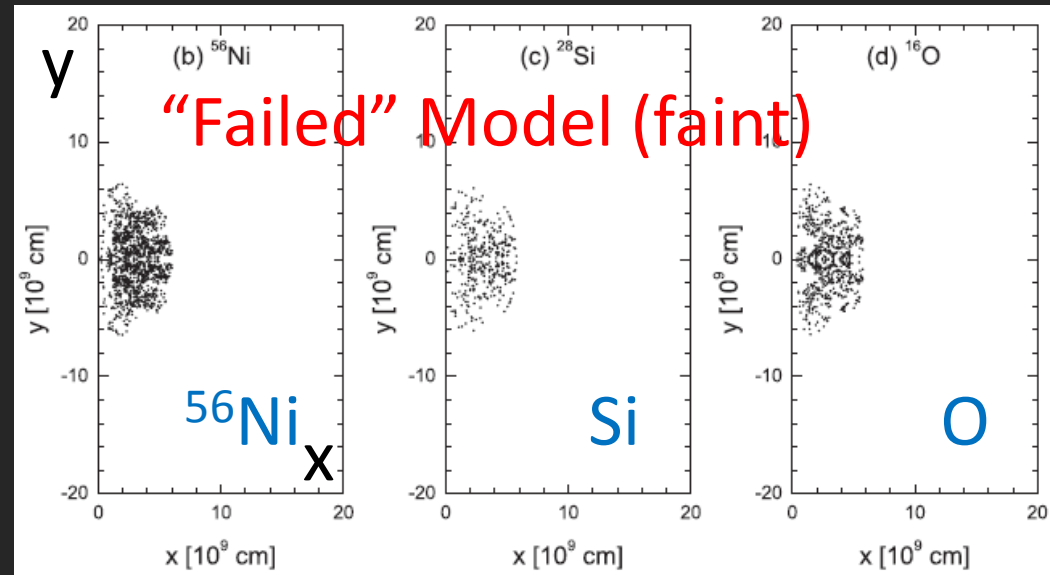
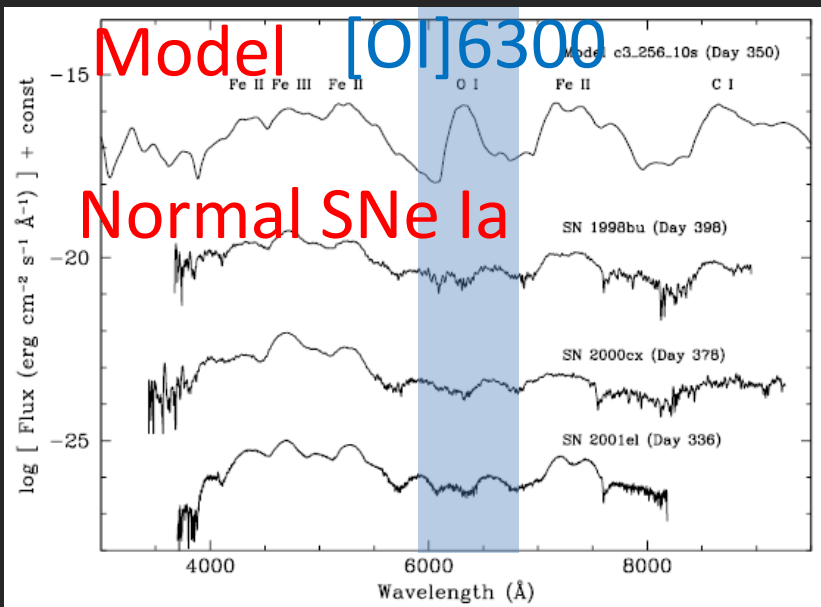
# Unburned materials @ inner region of SNe Ia?



Synthesized + unburned  $\sim 1.4M_\odot$

$^{56}\text{Ni}$  ( $\sim 0.6M_\odot$ )  
 $\rightarrow$  Luminosity

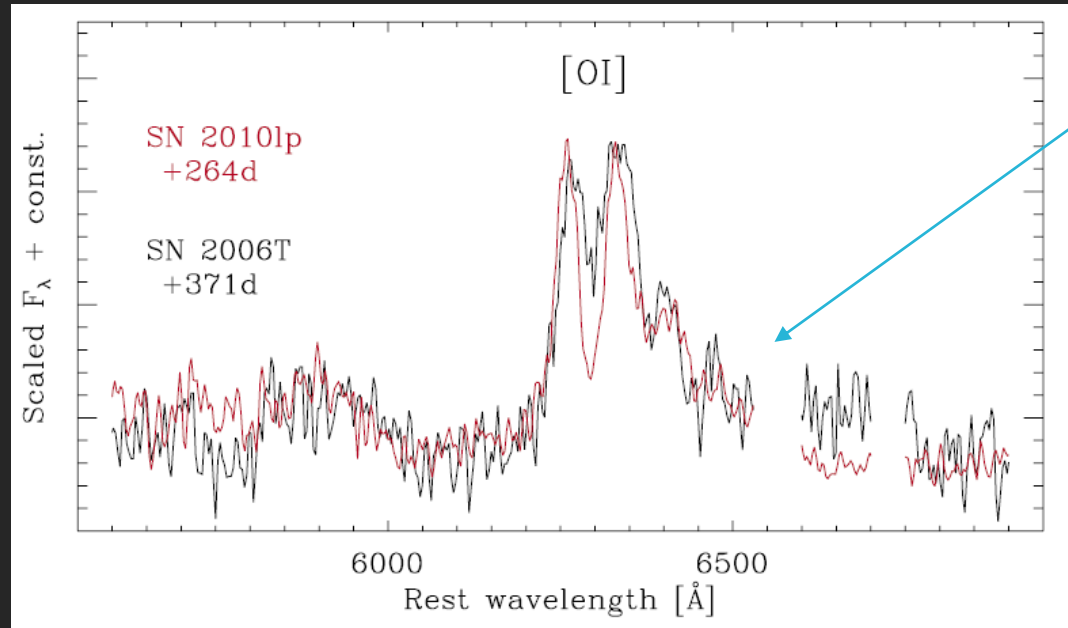
Faint  
 $\rightarrow$  Unburned Oxygen?  
 Where?







# Challenge to Theory... Key to SN Ia diversity?



Core-collapse SN  
from a massive star.

The [OI] profile  $\neq$  expected in the faint explosion model.

Narrow, confined  
in the center.

Broad, thoroughly  
mixed.

Bipolar or disk.

**Similar to Core-collapse SN in the O distribution?**

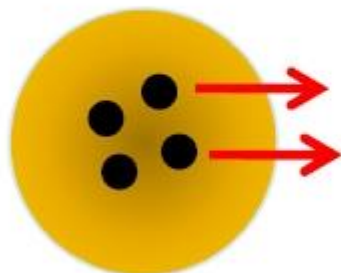
**Merging two WDs as an alternative scenario?**



# Late-Phase NIR: Dust Formation in SNe

- SNe = origins of dust (?), especially at high-z.
  - Yes or no? What kind of dust? **Yet to be clarified.**

Dust formation in the ejecta



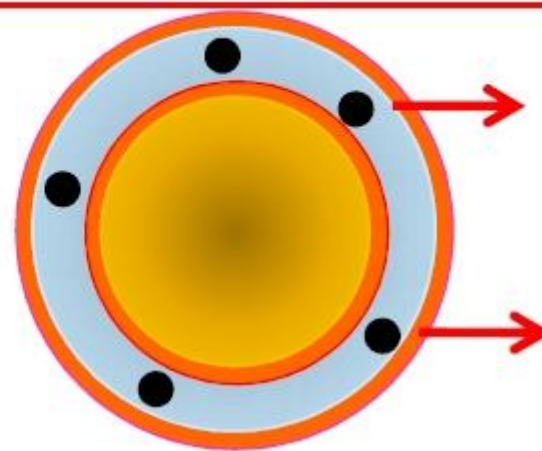
By T. Nozawa

Massive star ( $> 10M_{\odot}$ )

Type IIp Supernovae (?)

→ SN 1987A

Dust formation in dense shell



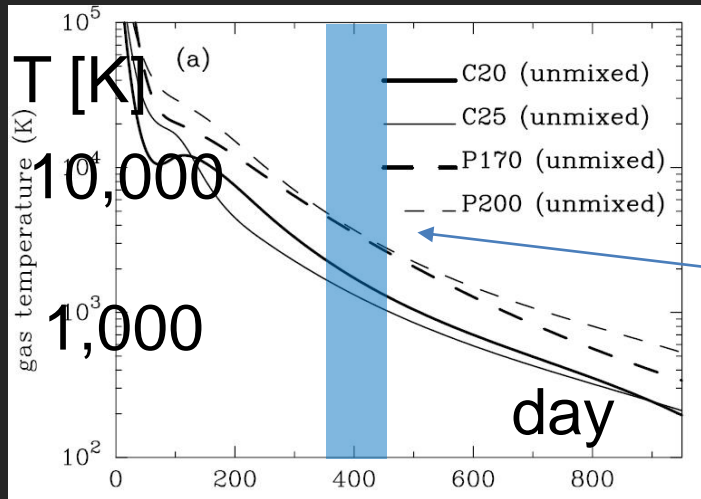
Very massive ( $> 50M_{\odot}$ )?

Very dense CSM → SN-CSM interaction.

Type IIIn Supernovae (?)

→ SN 2010jl (This study)

# Why NIR?

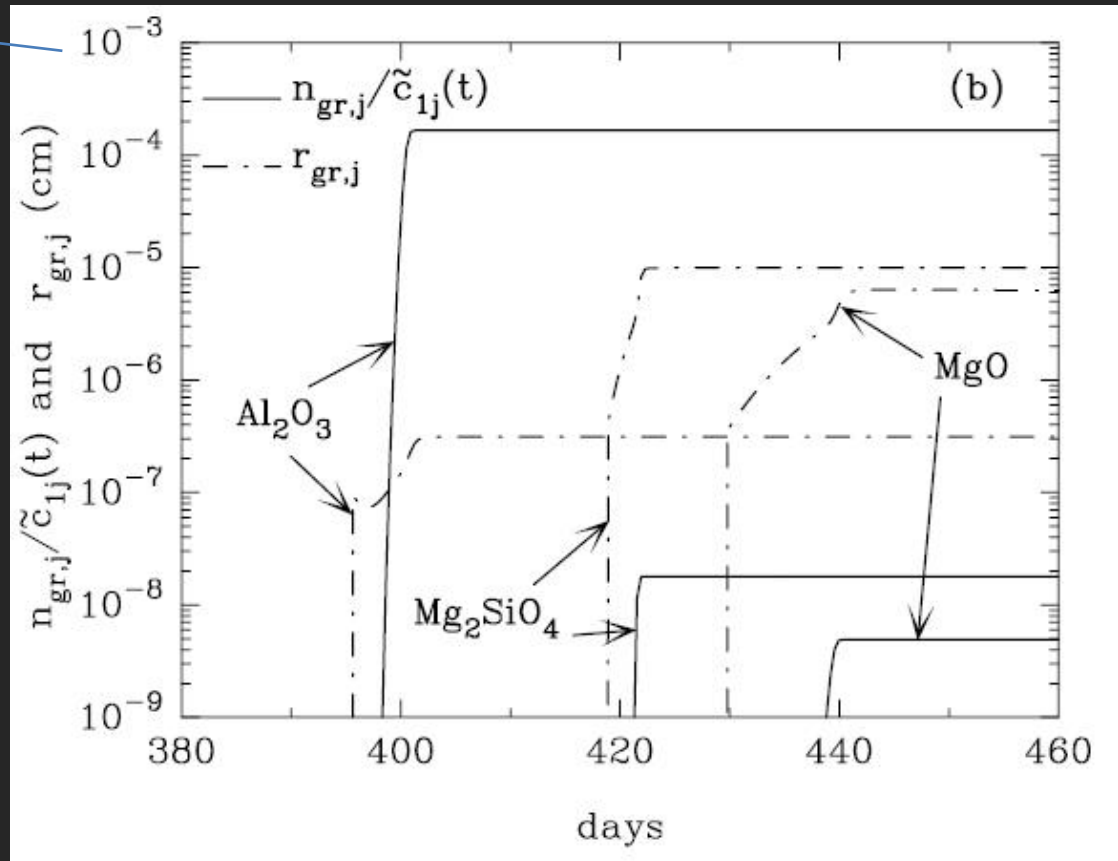


Nozawa+ 2003

Condensation Temp.  
 ~1,000 – 2,000 K

**Dust “Formation”**  
 seen @ NIR

species, mass,  
 temperature, size?



# Luminous SN IIn 2010jl

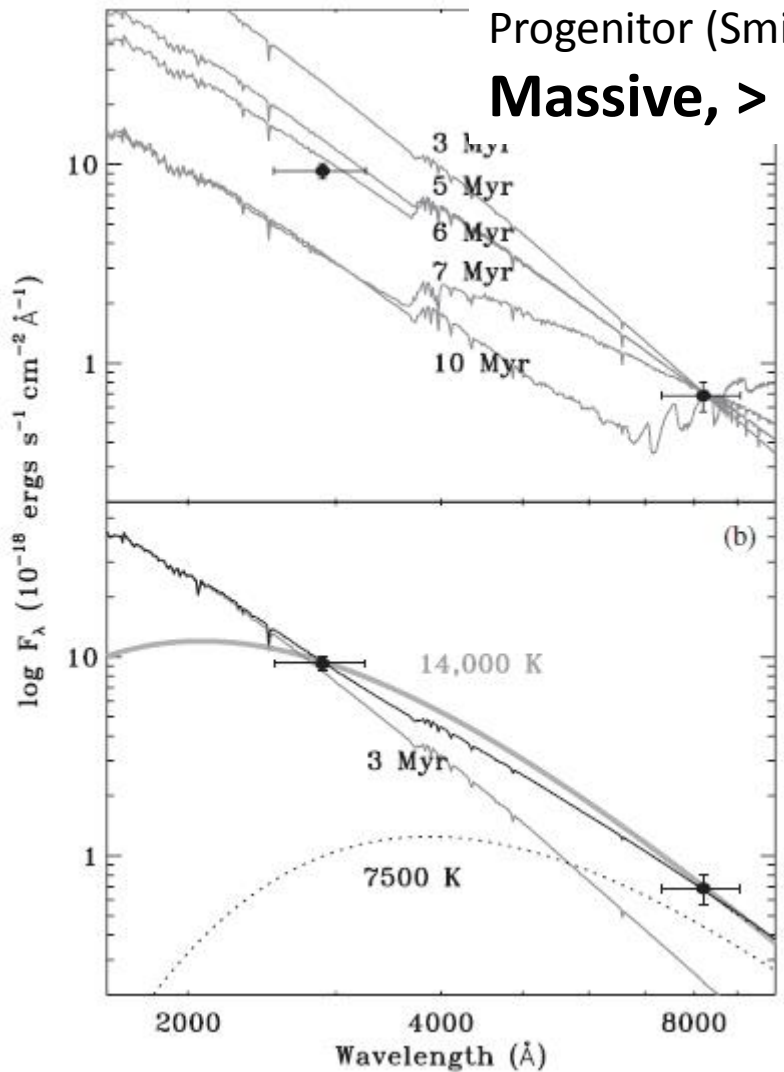


Progenitor (Smith+ 2011)

**Massive,  $> 30M_{\odot}$**

Host (NGC5189A)

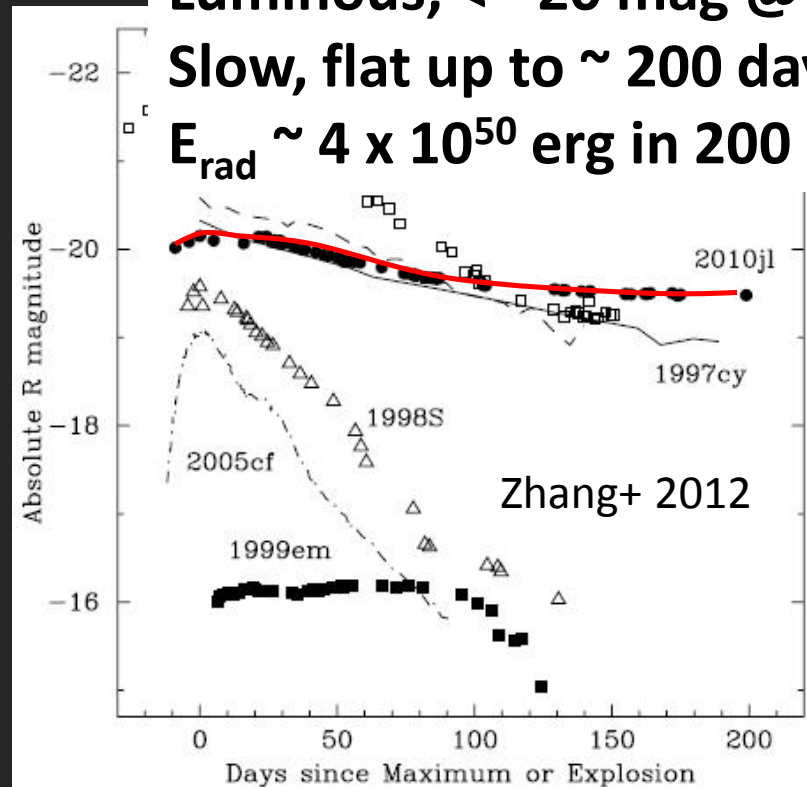
**Nearby,  $\sim 50$  Mpc**



**Luminous,  $< -20$  mag @ peak**

**Slow, flat up to  $\sim 200$  days**

**$E_{\text{rad}} \sim 4 \times 10^{50}$  erg in 200 days**

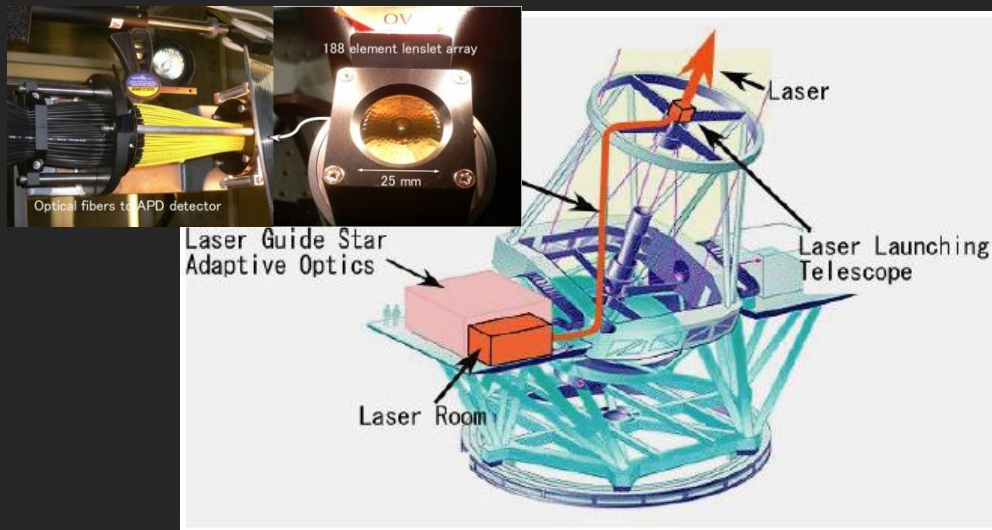


KM+ 2013, Subaru/IRCS/AO188 (ApJ, 2013, 776, 5)

# SN IIIn 2010jl: Subaru + HCT @ ~ + 550 days

**Subaru, IRCS + AO188 (NIR)**  
KM, Motohara, Minowa, Pyo,  
Kawabata, ...

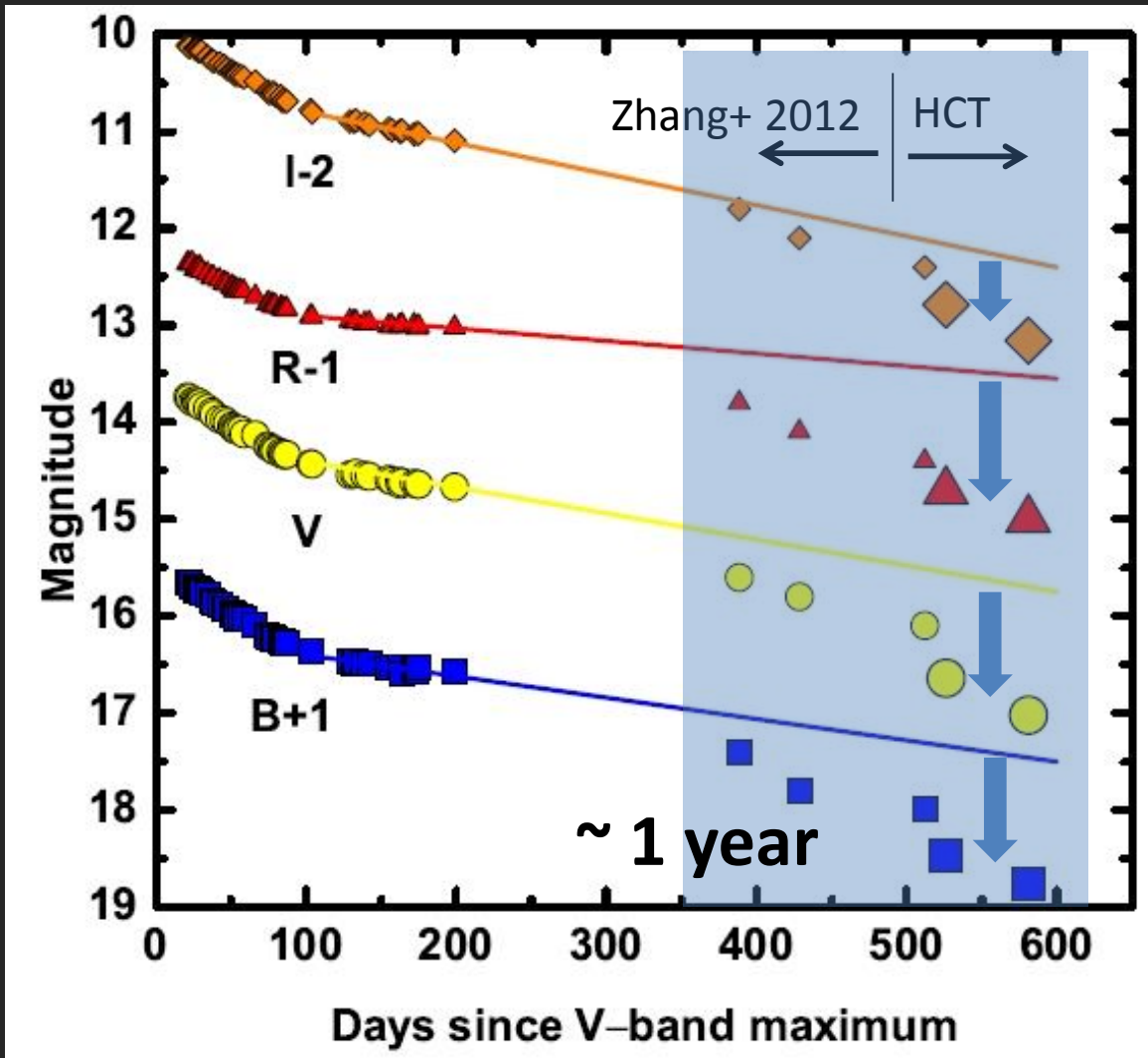
**HCT (2m), HFOSC (optical)**  
Sahu & Anupama



**24 Apr 2012 (+ 553 days from V-max)**  
J, H, K spectroscopy + imaging

**15 Mar + 20 May 2012**  
3,500 – 9,200Å spec.  
B, V, R, I imaging

# Drop in optical (absorption)



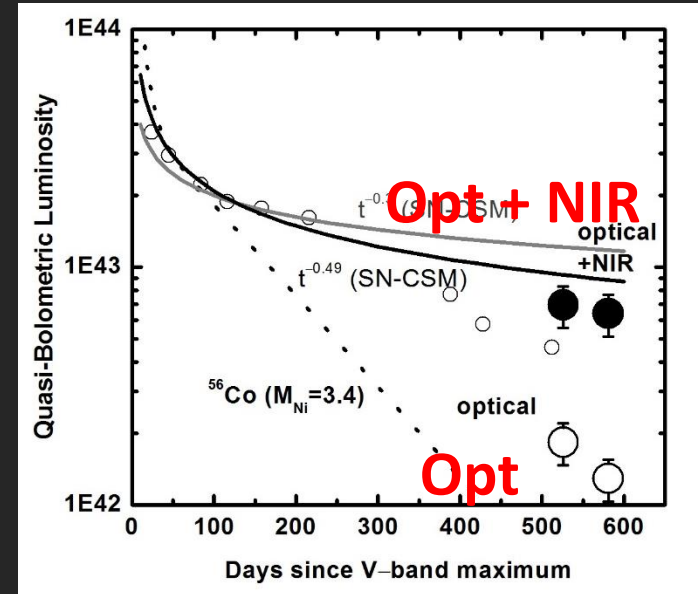
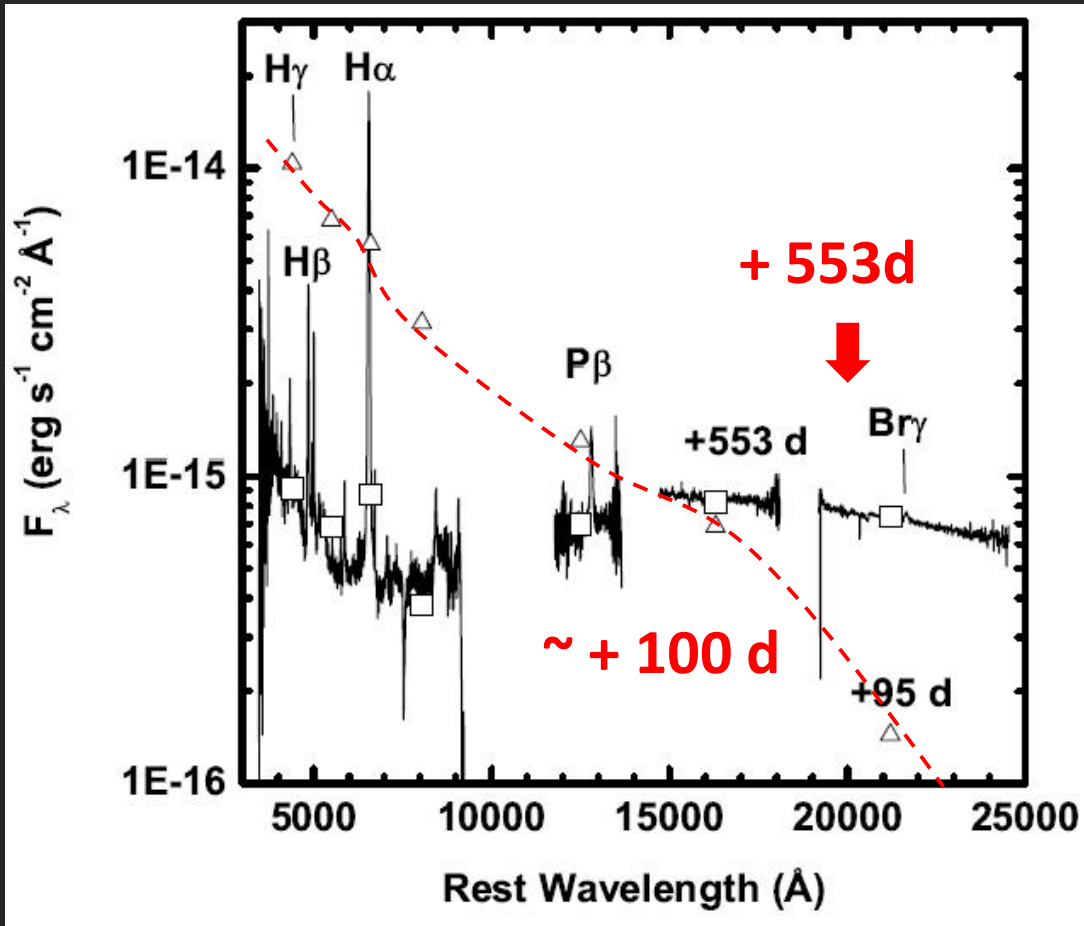
$\Delta I \sim 0.8$  mag

$\Delta R \sim 1.4$  mag

$\Delta V \sim 1.2$  mag

$\Delta B \sim 1.3$  mag

# NIR thermal continuum (re-emission)

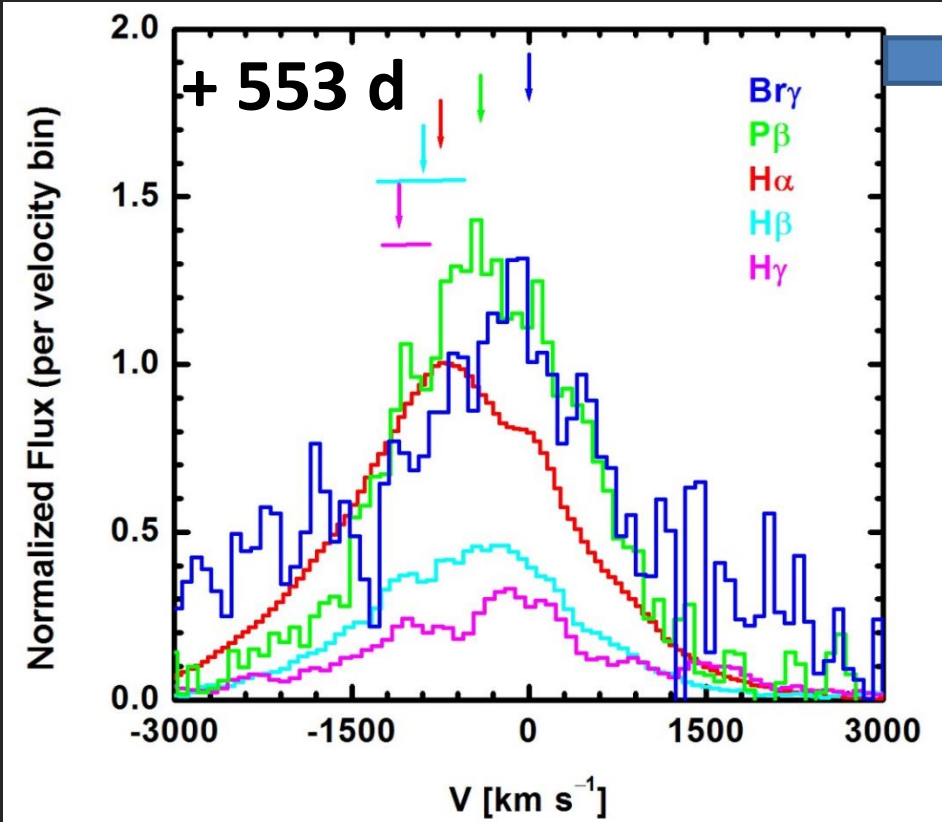


**Carbon**  
**1350 – 1450 K**  
 **$(7.5 - 8.5) \times 10^{-4} M_\odot$**

**First** clear spectroscopic detection of SN dust formation in NIR.

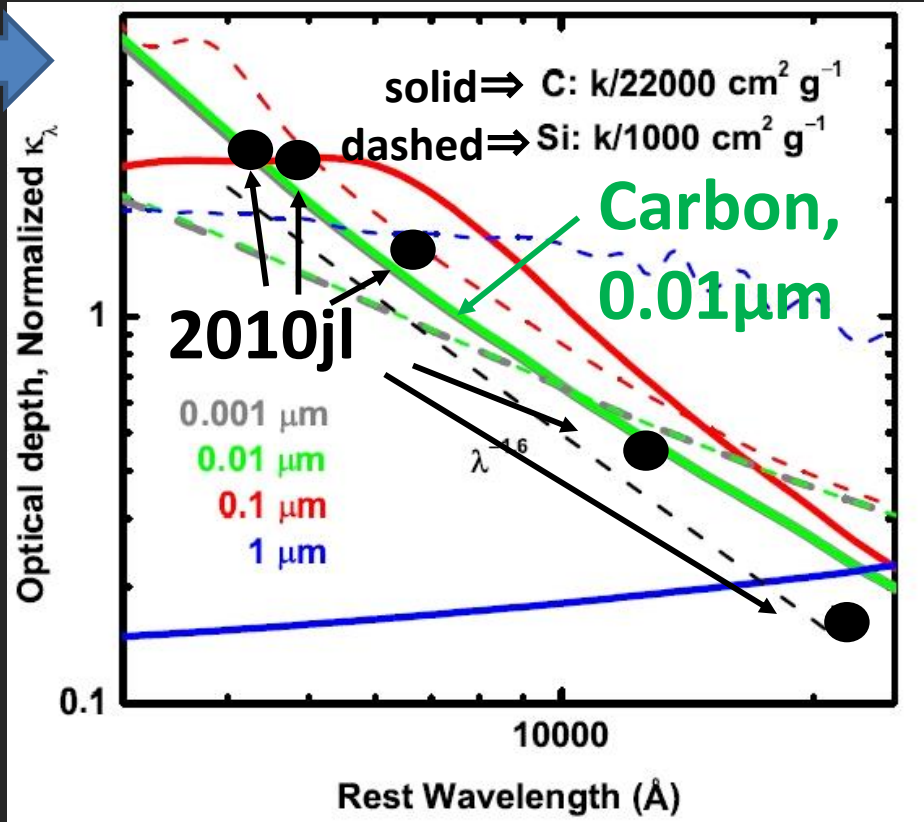


# Line profiles



Blueshift in the broad component.  
Bluer for shorter  $\lambda$ .

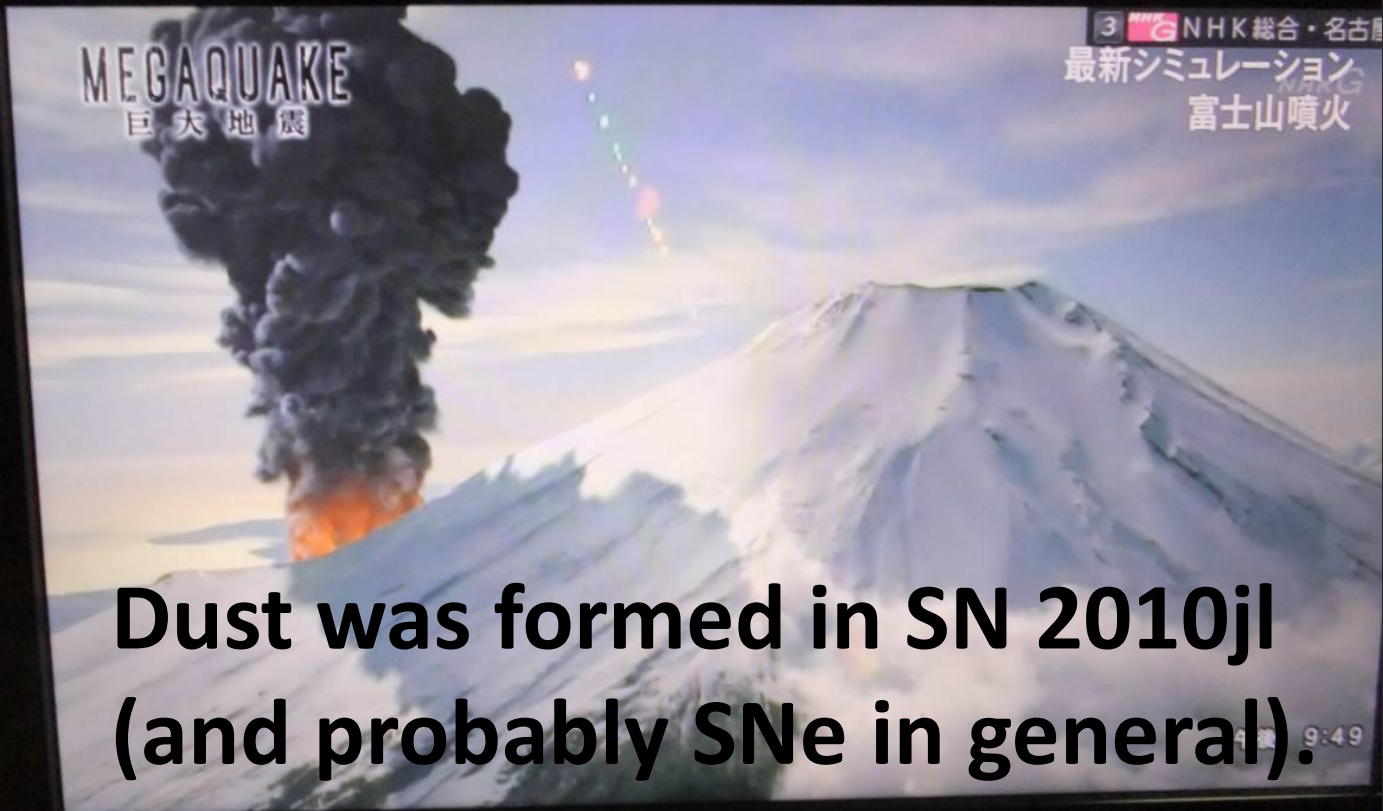
# Dust opacity



Carbon (indep. From SED)  
Dust size  $< 0.1 \mu\text{m}$ .  
 $\tau \sim 1$  @ H $\alpha$ .



# Short summary on SN 2010jl



**Dust was formed in SN 2010jl  
(and probably SNe in general).**

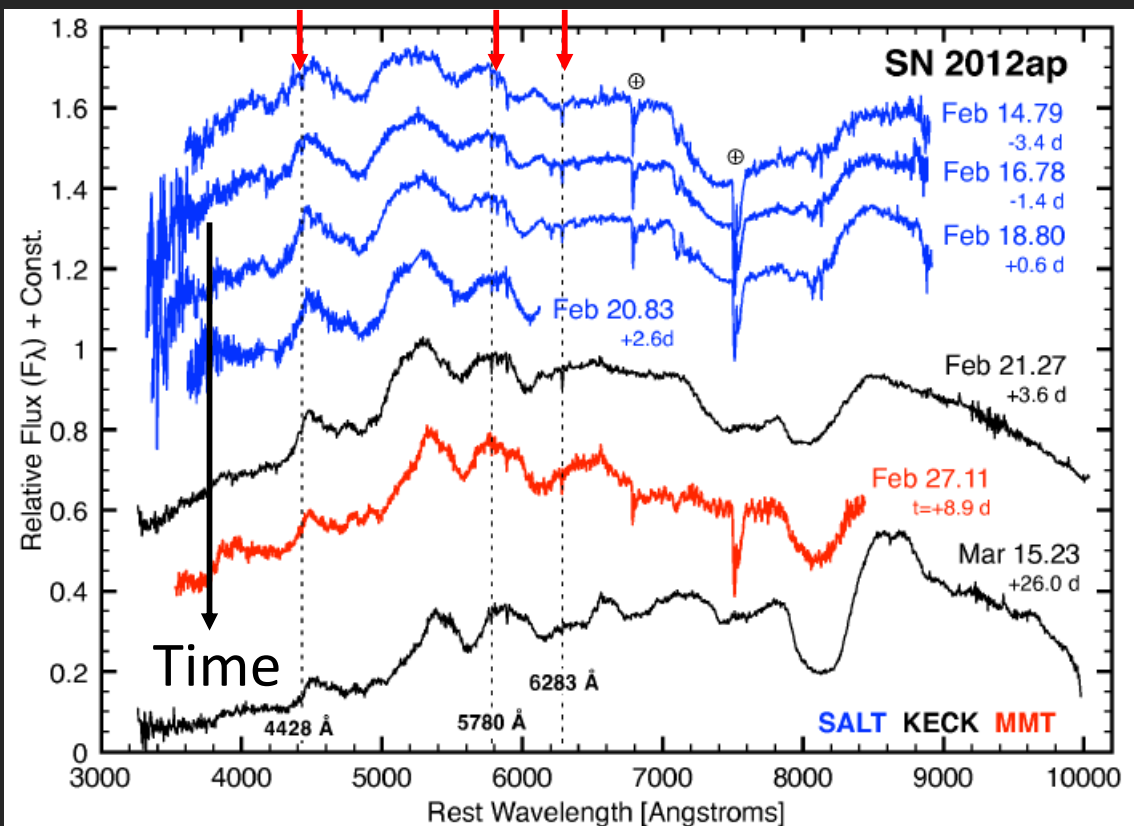
# Implications

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- **Nature of dust** formed in an SN.
  - **First in SN IIn**, only rivaled by study on SN 1987A.
  - Carbon,  $\sim 10^{-3}M_{\odot}$ ,  $< 0.1\mu\text{m}$ .
    - Input for dust/star formation at high-z?
- SN 2010jl is surrounded by **dense CSM**.
  - Independent from the argument on the energy budget (light curve – e.g., Moriya, KM+ 2013, 2014).
  - $0.02 - 0.2 M_{\odot} \text{ yr}^{-1}$  fully consistent with the optical output.
    - Independent calibration for the light curve models, which apply to bright (super-luminous) SNe (targets for high-z).

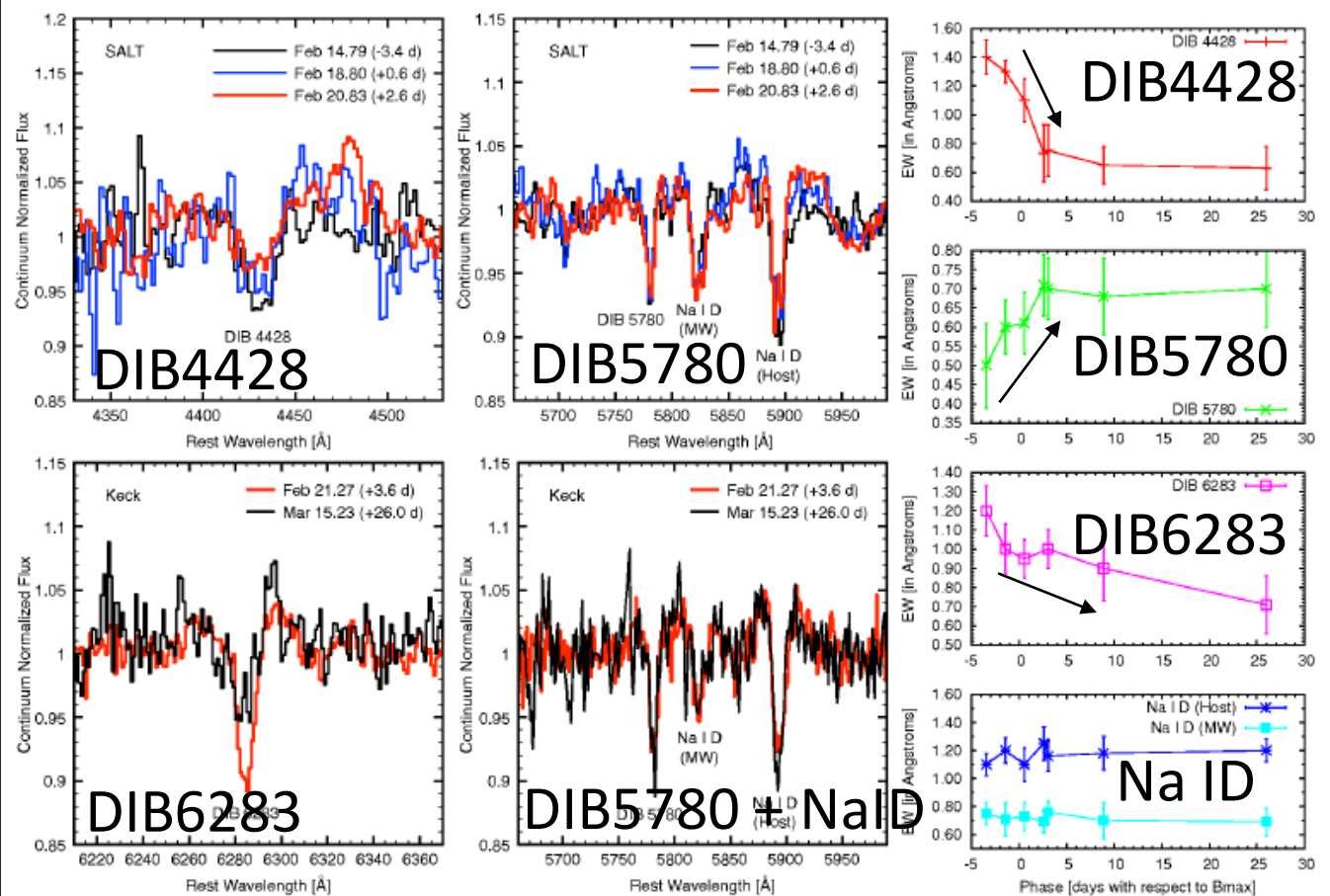
# SN as a backlight (now absorption within CSM)

- SN light as a **backlight** to study materials along the line-of-sight.
- Time **variability** → **local** CSM (or at least related).



- Detection of DIBs (Diffuse Interstellar Bands) beyond the local group.
- Good S/N + time sequence.
- Any hint for the origin/site of DIBs?
  - Mystery for ~ century.

# (Some) DIBs local to massive star environment



Variability.  
 ↓  
 local to the progenitor (massive star).

DIBs + other CSM features → Progenitor environment/evolution.

Future (hope): Rapid + high-cadence and/or High resolution.

Subaru HDS (ToO or non-ToO)?

# Summary

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- Late-time, optical + NIR.
  - Discovery of [OI] in an SN Ia.
  - First solid case of dust formation in an SN IIn.
    - Subaru/FOCAS+IRCS, VLT/FORSI2 analyses ongoing.
- Good S/N and/or High-spec. resolution.
  - Some DIBs related to massive stars (probably CSM).
    - High spec. resolution SN follow-up in need.