# 超新星の未解決問題と早期発見・分光の重要性


前田　啓一

京都大学　宇宙物理学教室

Tomoe-Kyoto 3.8m SN WG (?)

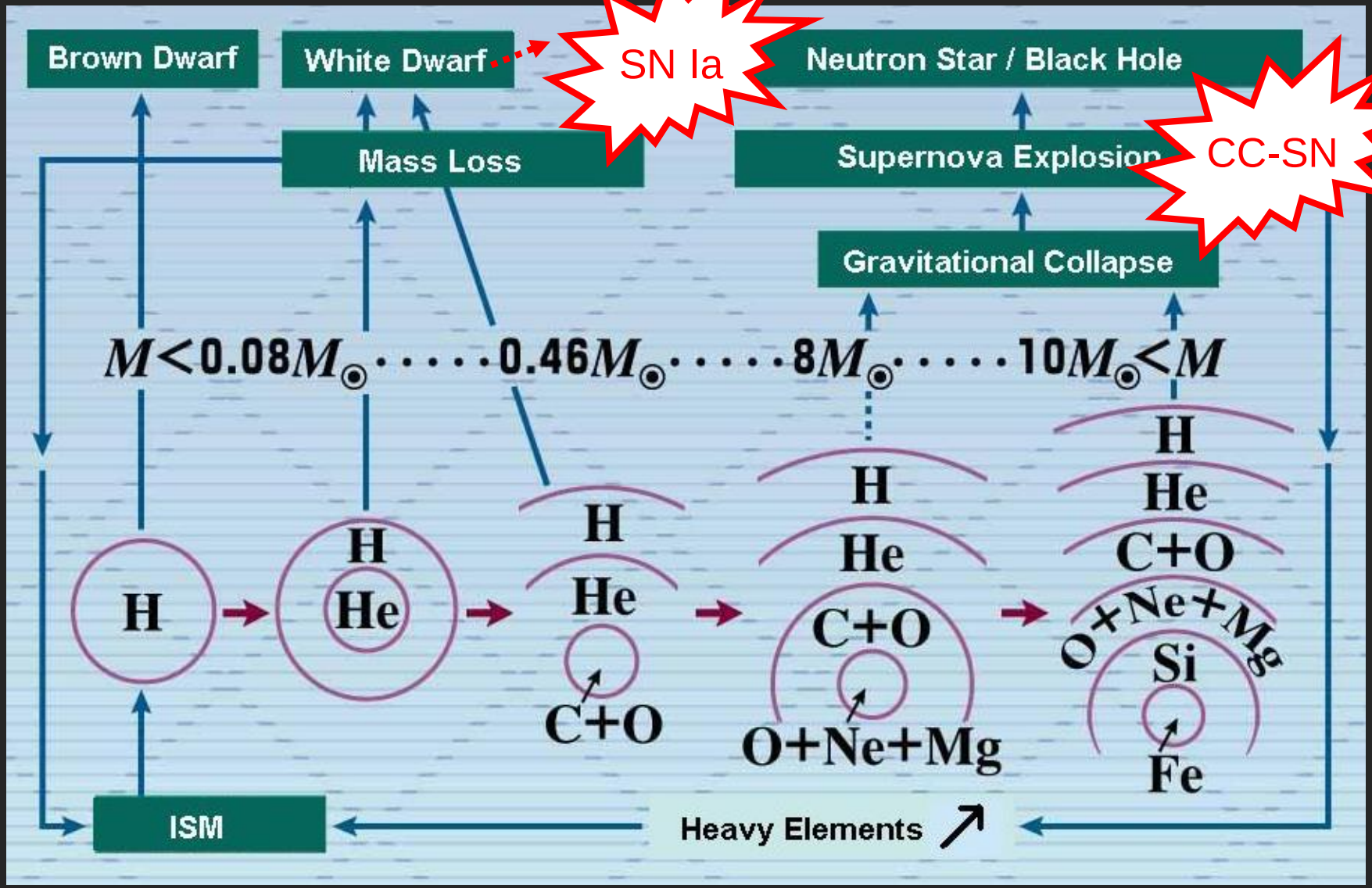
（大澤、太田、酒向、田中、富永、松林、諸隈）


Tomoe – 京都3.8m Time Domain研究会

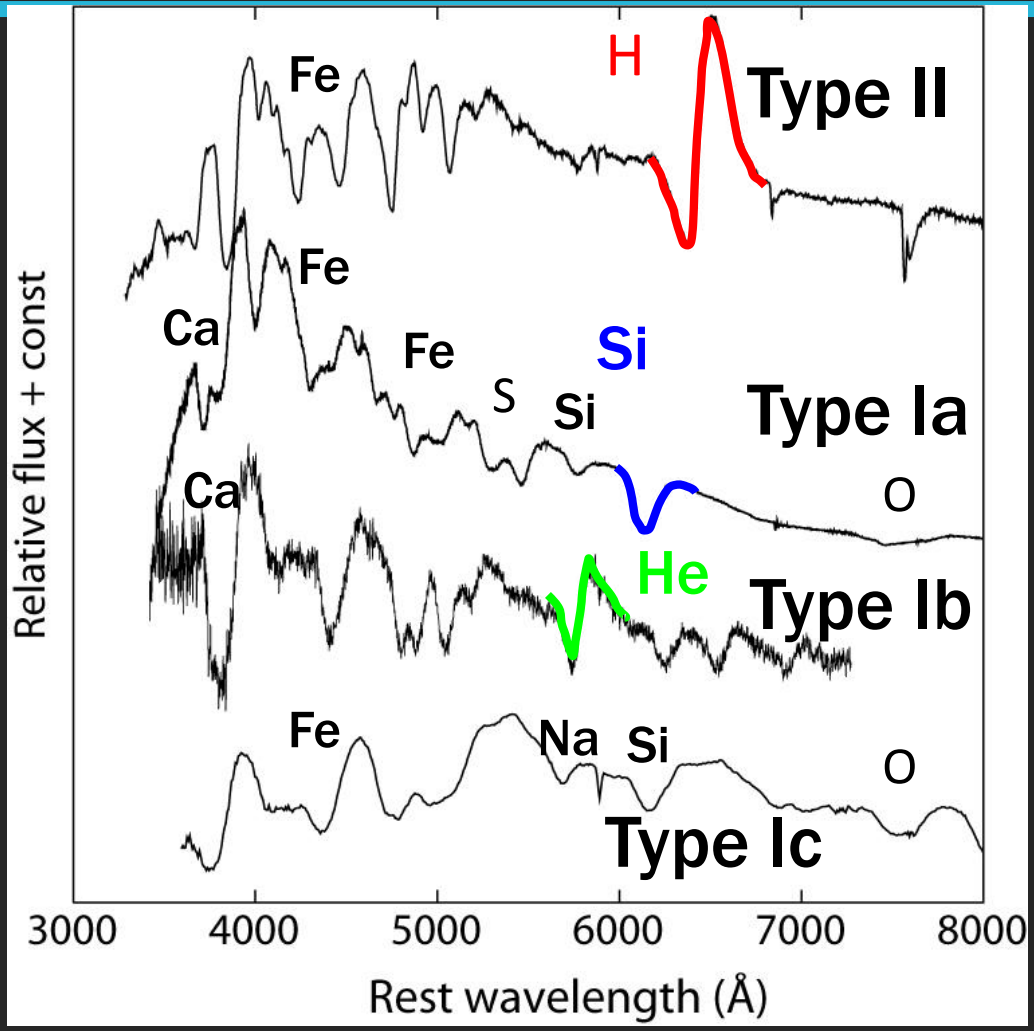
＠京都、2017.02.20


Supernova 2014J in Galaxy M82
*Hubble Space Telescope* ▪ WFC3/UVIS ▪ ACS/WFC

# Stellar Evolution and Supernovae (SNe)



# Supernova Classification

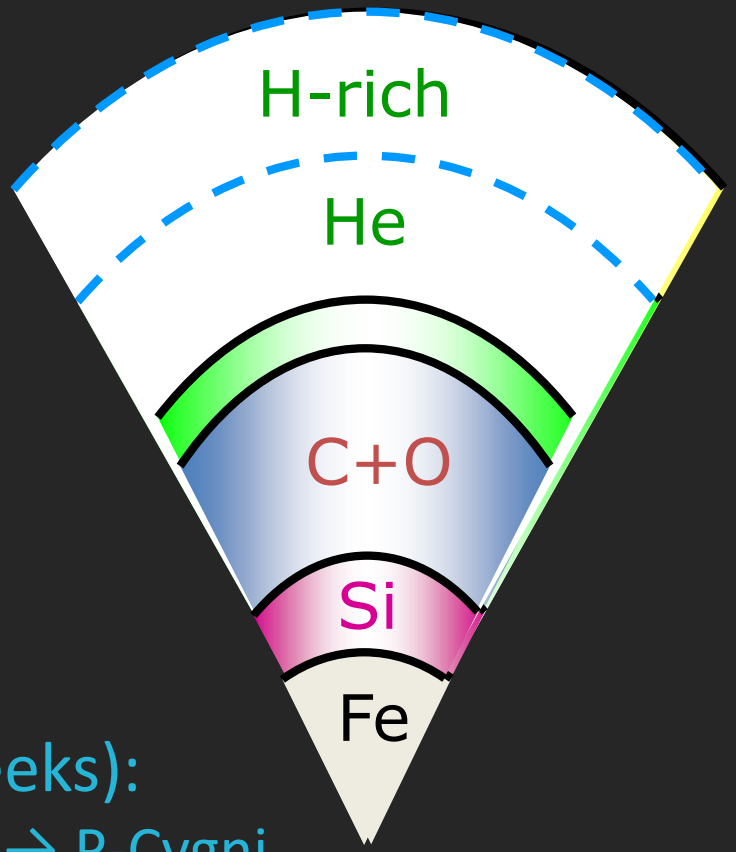



**Ia**

Thermonuclear exp. of a white dwarf (WD)

**II/Ib/Ic**

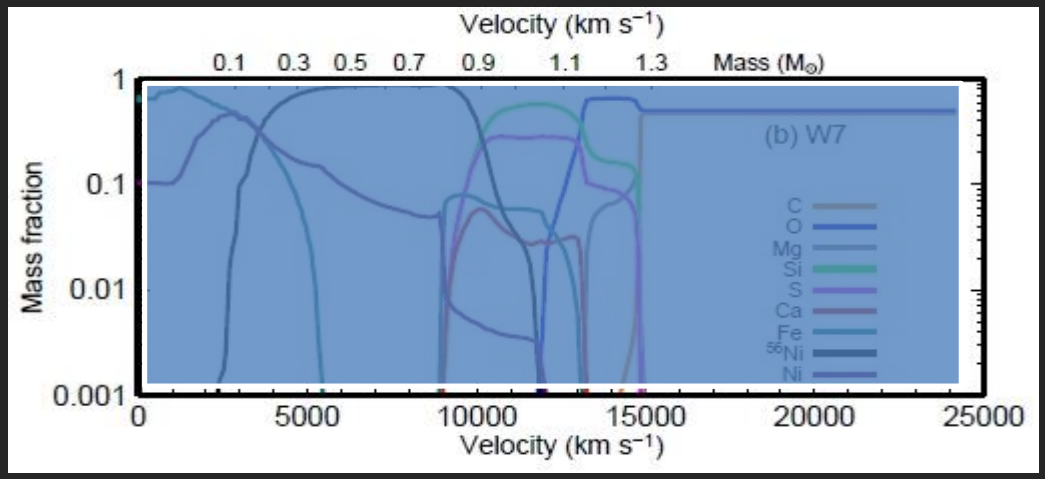
Core-Collapse (CC) of a massive star




@ maximum brightness (~ a few weeks):

– Expanding optically thick medium → P-Cygni.

# SN emission: first few days




**Progenitor**
**Companion**
**CSM**

$R \sim Vt$

$\rho \propto t^{-3}$

Thermal
$E, M_{ej}, R$

$^{56}Ni \rightarrow Co \rightarrow Fe$
$E, M_{ej}, M(^{56}Ni)$

CSM-int.
$E, M_{ej}, CSM$

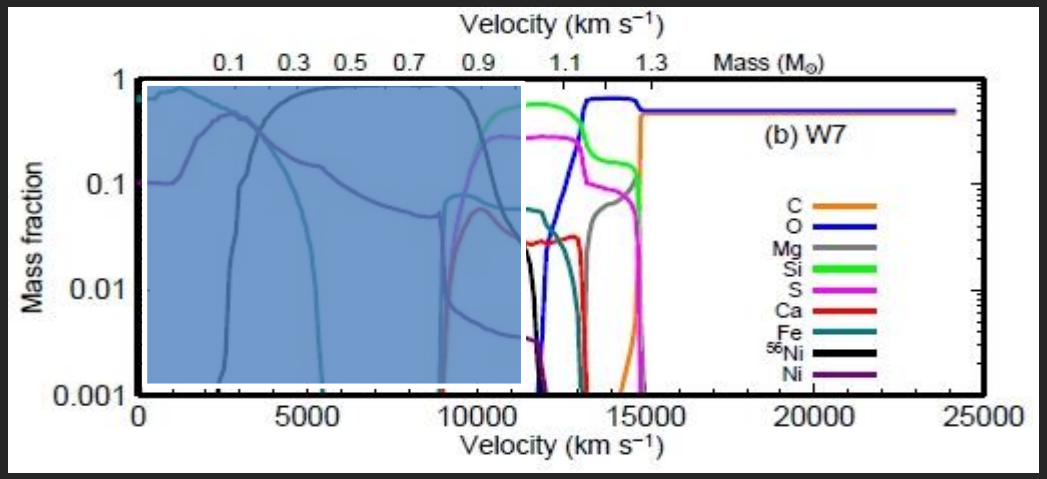
Very Early… Outermost

UV/Opt

Opt/IR

X/Radio/Opt

# SN emission: weeks to months




## Global properties

R~Vt

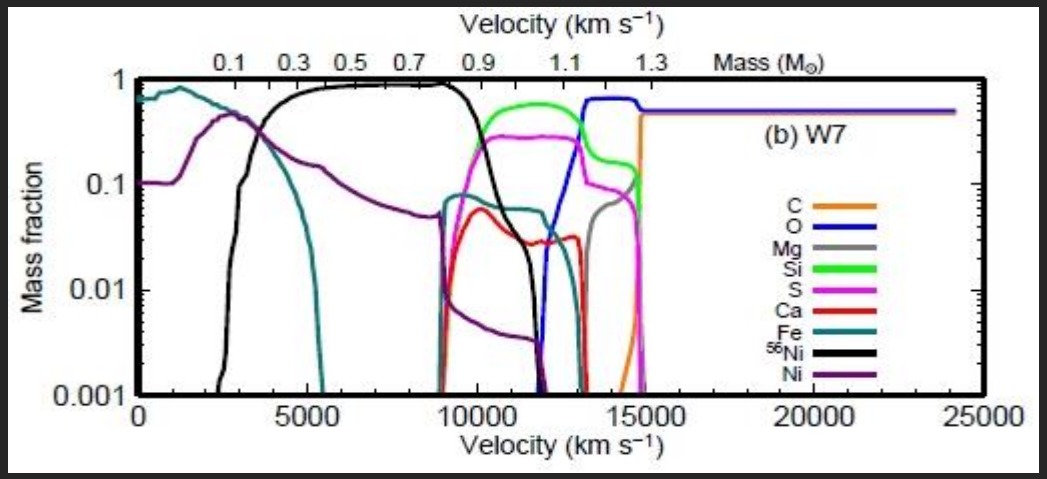
$\rho \propto t^{-3}$

| Thermal | $^{56}$Ni→Co→Fe | CSM-int. |
|---|---|---|
| E, $M_{ej}$, R | E, $M_{ej}$, M($^{56}$Ni) | E, $M_{ej}$, CSM |
| UV/Opt | Opt/IR | X/Radio/Opt |

Very Early… Outermost

@Max… Outer

# SN emission: months to years




**Explosion**
**Companion**
**CSM**

R~Vt
$\rho \propto t^{-3}$

Thermal — E, $M_{ej}$, R → UV/Opt

$^{56}$Ni→Co→Fe — E, $M_{ej}$, M($^{56}$Ni) → Opt/IR

CSM-int. — E, $M_{ej}$, CSM → X/Radio/Opt

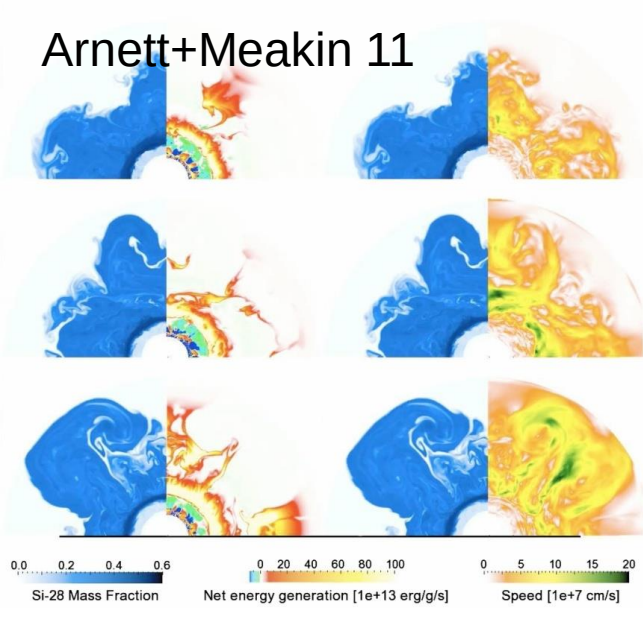
Very Early… Outermost

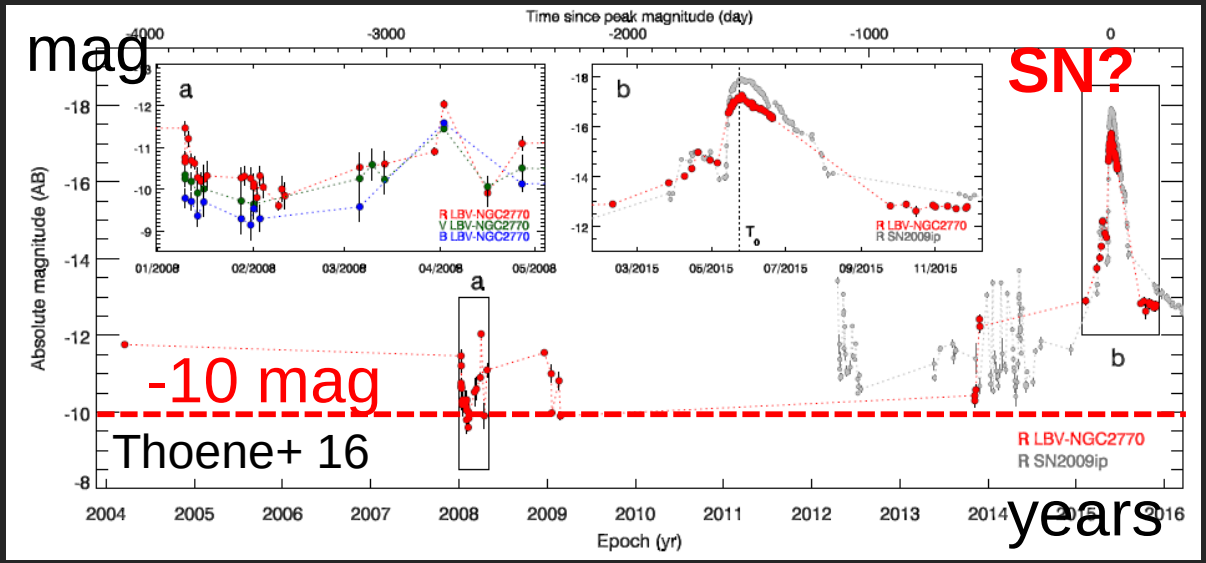
@Max… Outer

Late… Innermost

# Unresolved problems for CC-SNe

- Explosion mechanism.
- **Final evolution of massive stars (single & binary).**
  - **Progenitor at the time of the explosion.**
  - **Mass loss in the final decades.**



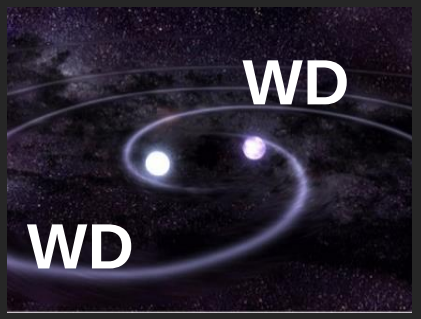



# Unresolved problems for SNe Ia

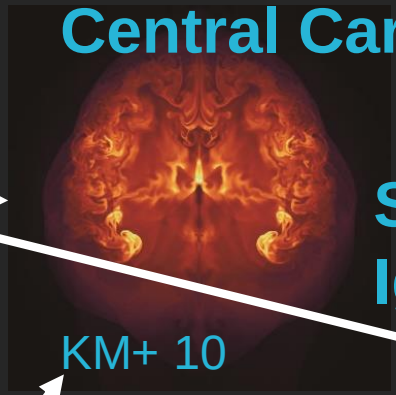
- Explosion mechanism (multiple paths?).
- **Progenitor systems.**

**Single Degenerate (SD)**


**Double Degenerate (DD)**

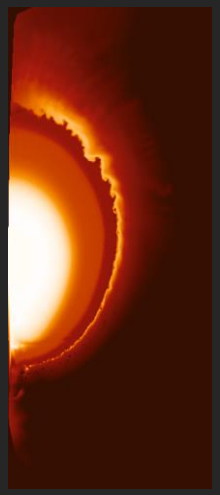



**Central Carbon ignition**



KM+ 10

**Surface Helium Ignition**



Fink+ 10

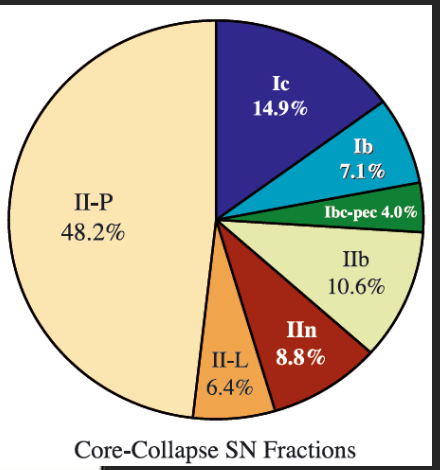
Roepke+ 12

**Surface Carbon Ignition**

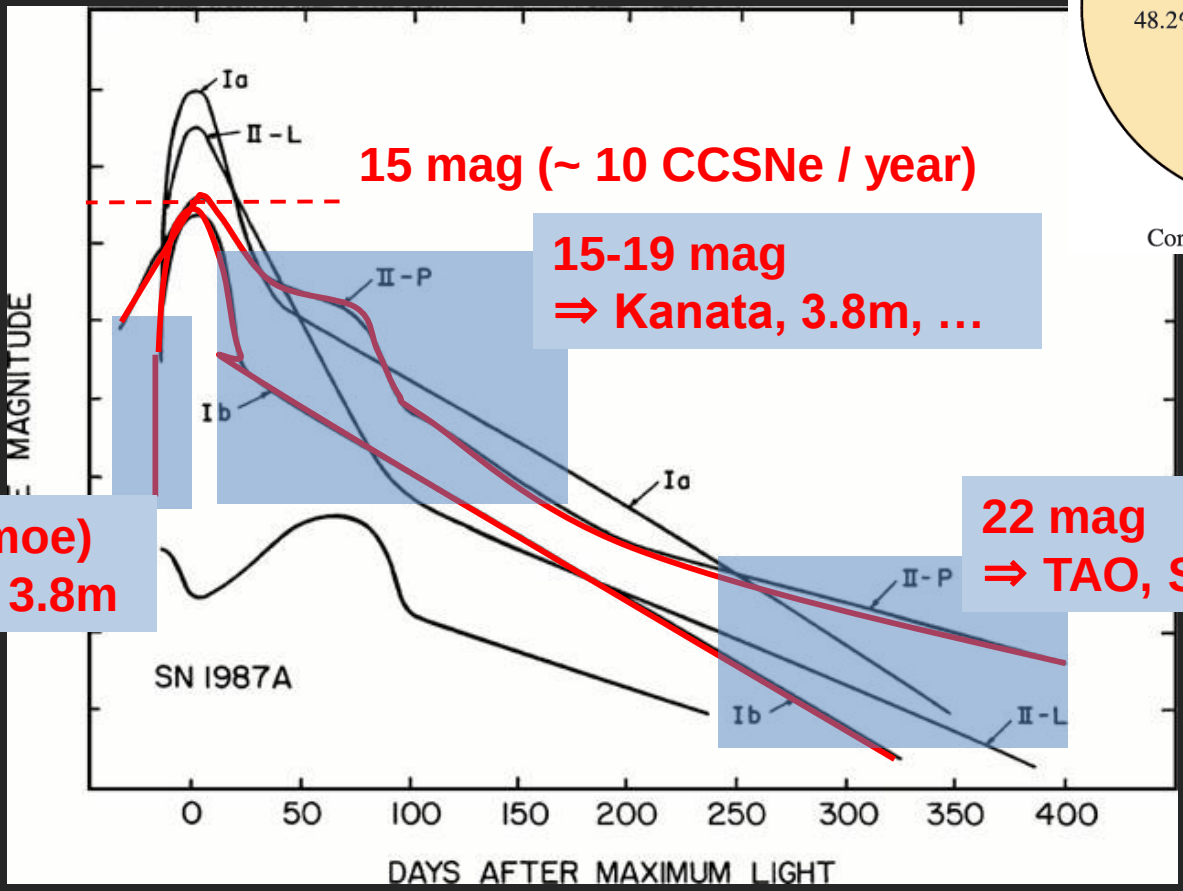
# Main topics addressed by the early emissions

- CC-SNe Ia:
  - Shock Breakout [Morokuma, Suzuki].
  - Progenitor radius and composition.
  - CSM at < ~ a few 0.01pc scale (final mas loss).
- SNe Ia:
  - Outermost layer (progenitor and/or explosion).
  - Companion or not [Jiang].
  - Explosion mechanism.
  - CSM and extinction [Nagao].
- Connection to the other properties [Yamanaka].

# CC SN statistics




Li+ 2011




15 mag (~ 10 CCSNe / year)

15-19 mag
⇒ Kanata, 3.8m, …

19 mag (Tomoe)
⇒ Kools on 3.8m

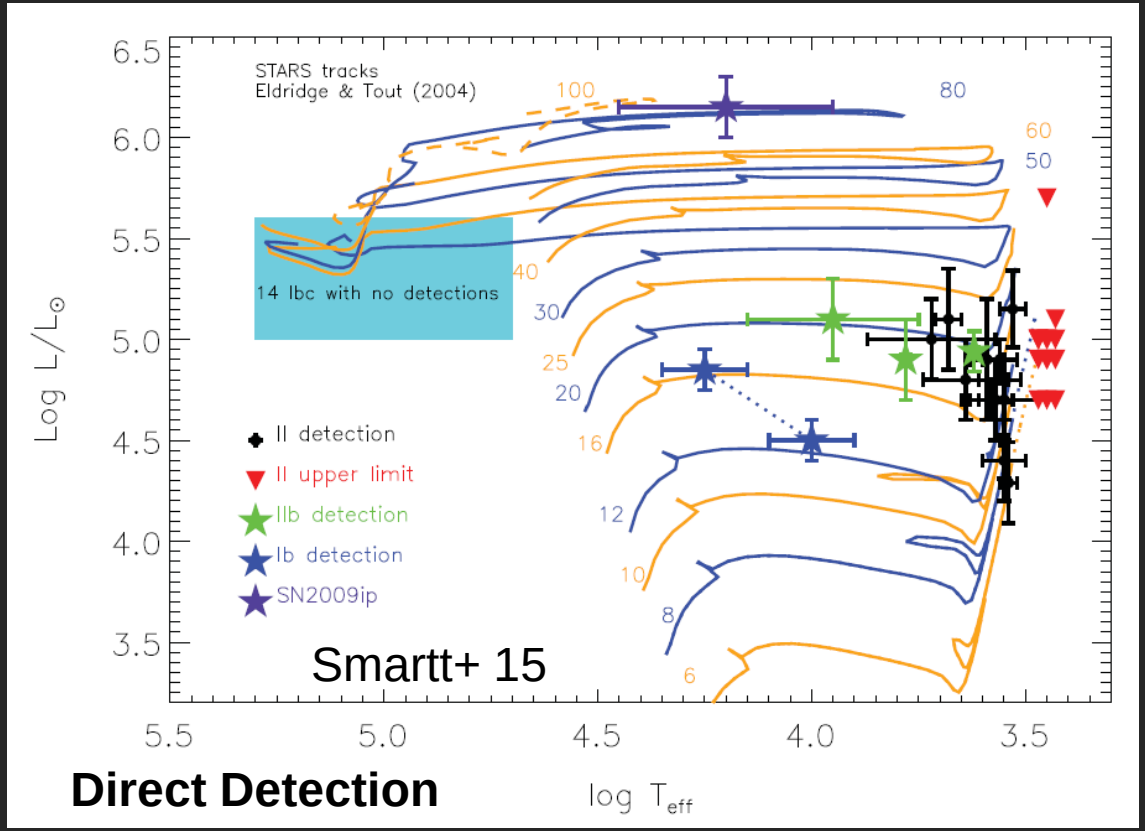
22 mag
⇒ TAO, Subaru/Gemini

Extensive data set: ~ 10 SNe? (peak ~ 15 mag)
Focusing on early to max: ~ 100 SNe ? (peak ~ 17 mag)

# CC SNe: Progenitor Radius and properties

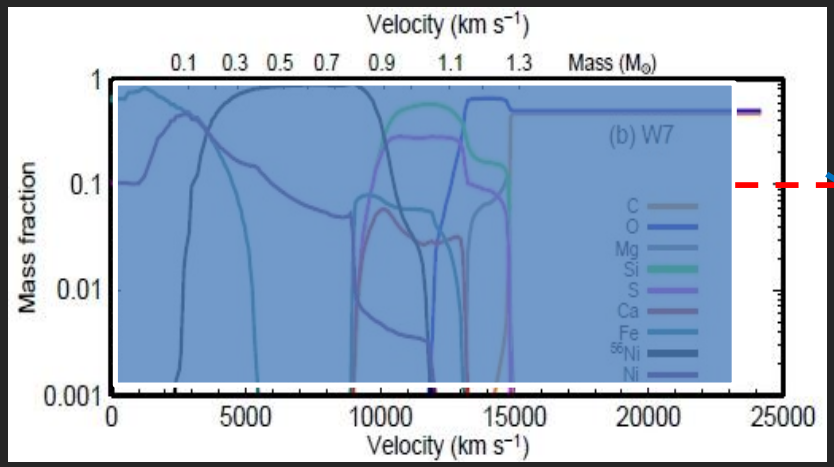
- Direct detection (pre-SN HST) limited.
- A tension between the progenitor and SN emission?
- Diversity not fully understood.

- A need for
  - A large sample.
  - Independent method.
  - **Comprehensive data for SN itself (w/ progenitor information).**

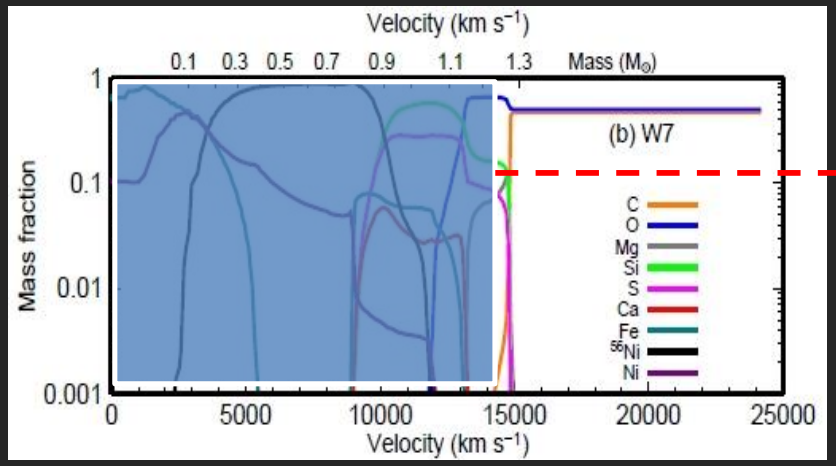


# CC SNe: Progenitor radius and properties

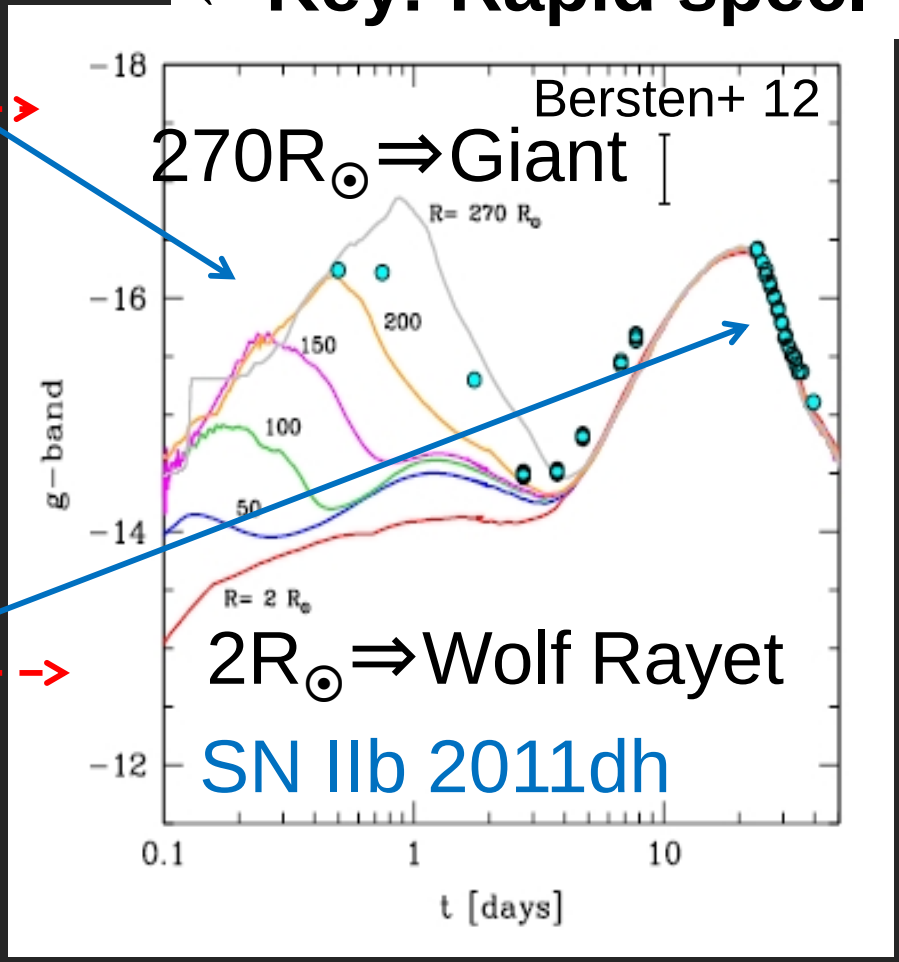
days Surface→Radius, Composition→**Progenitor**




weeks ⇓ $\rho \propto t^{-3}$

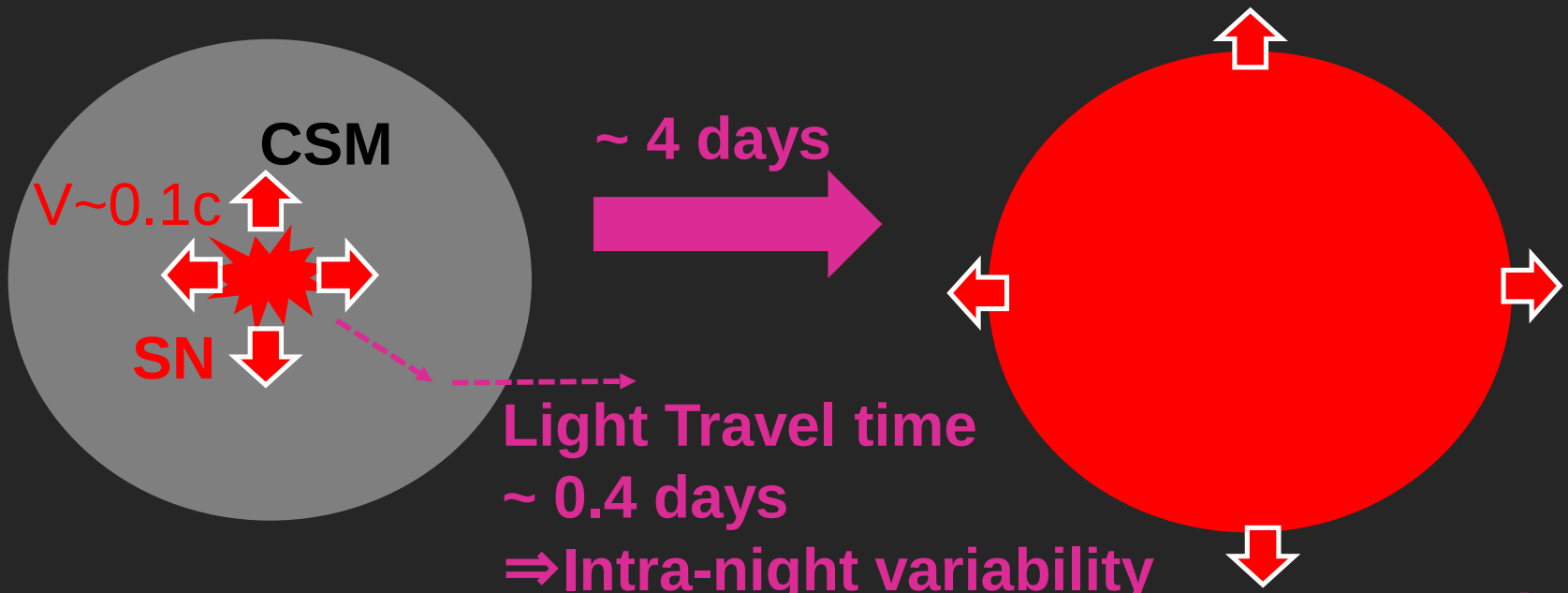



←**Key: Rapid spec.**



# CC SNe: CSM – mass loss in the final decades

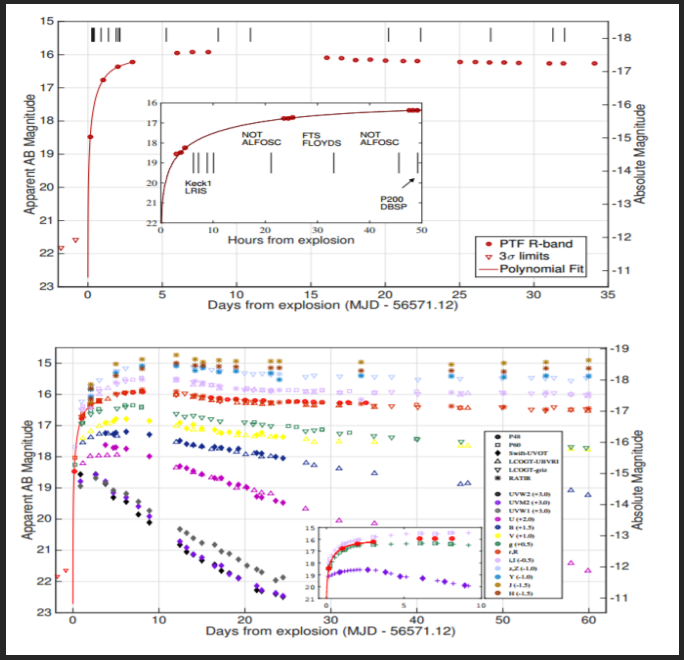
- **Final evolution of massive stars may be dynamical w/ non-stationary mass loss in days – years.**



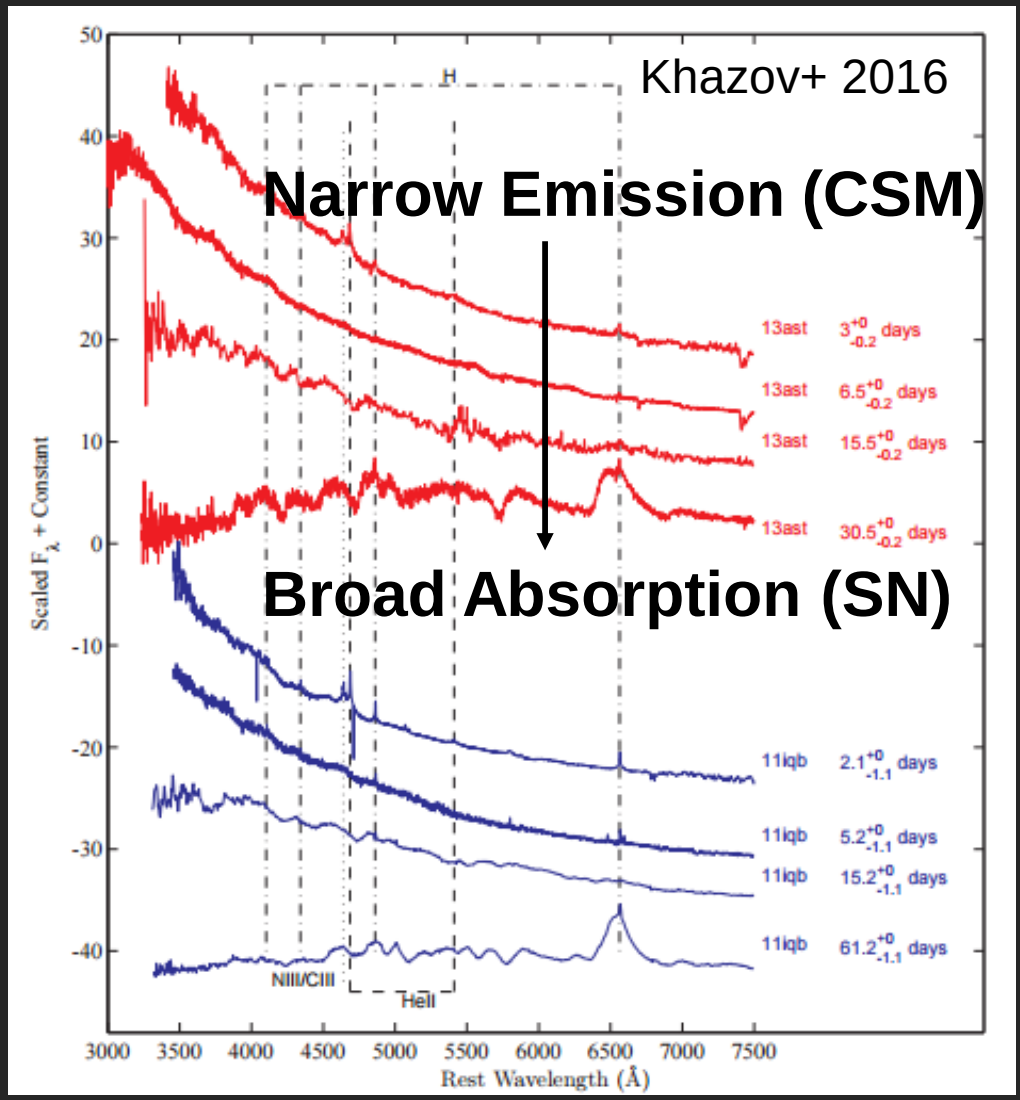

eg. ~$10^{15}$ cm
⇒Mass loss in the final
**~100 days** (w/ 1,000 km/s: WR)
**~30 years** (w/ 10 km/s: RSG)

# “Flash” spectroscopy

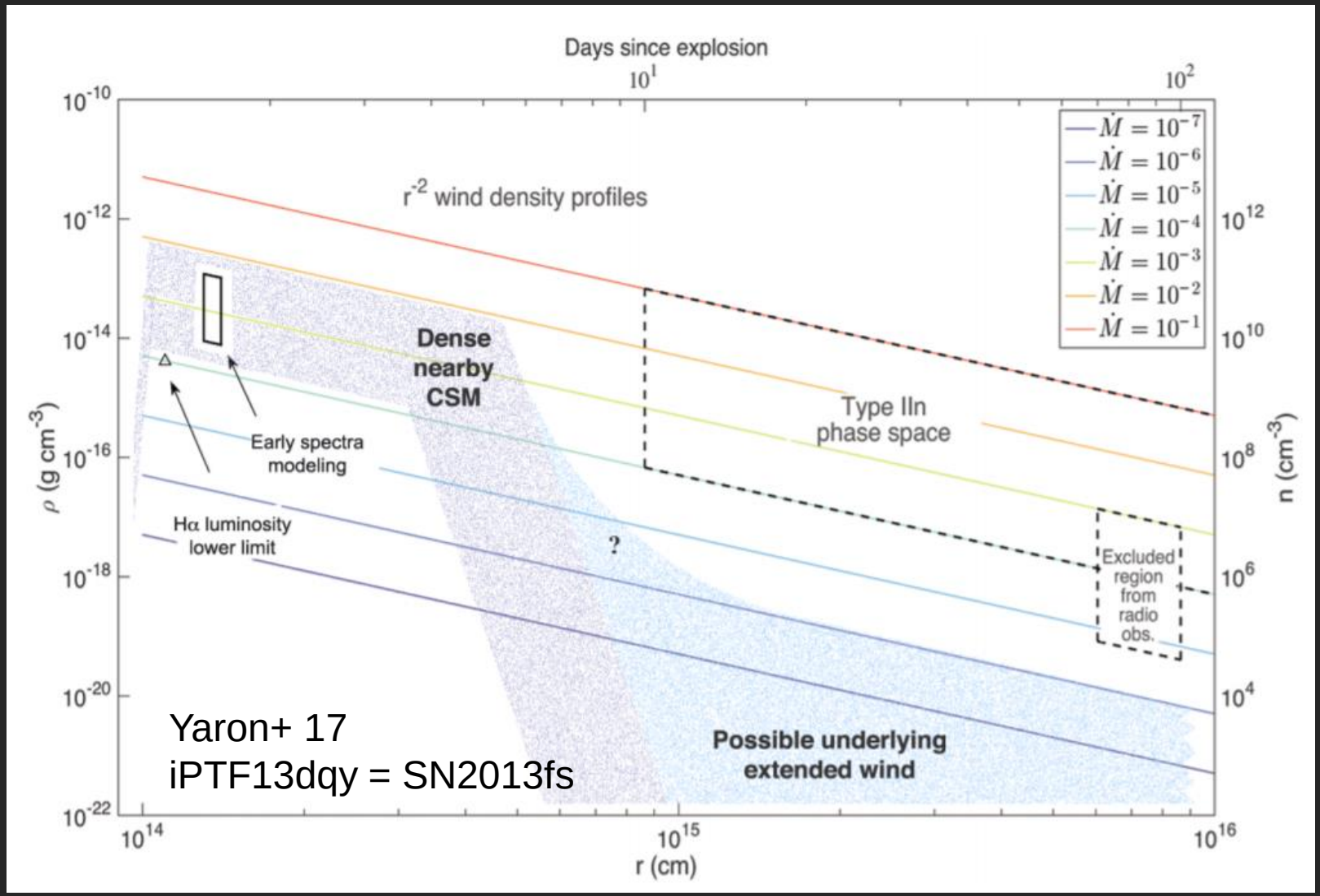
Recombination from the massive CSM near the SN???
（so far detected in one SN Ib and some SNe II）
→ **New probe of CSM.**




Yaron+ 17
iPTF13dqy = SN2013fs



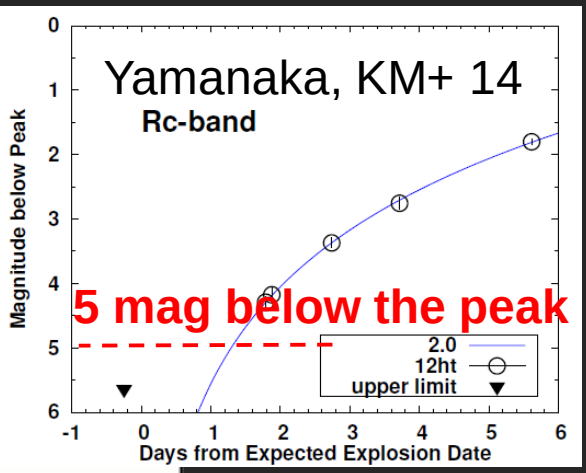
# Mass loss in the final days to decades (< $10^{15}$cm)

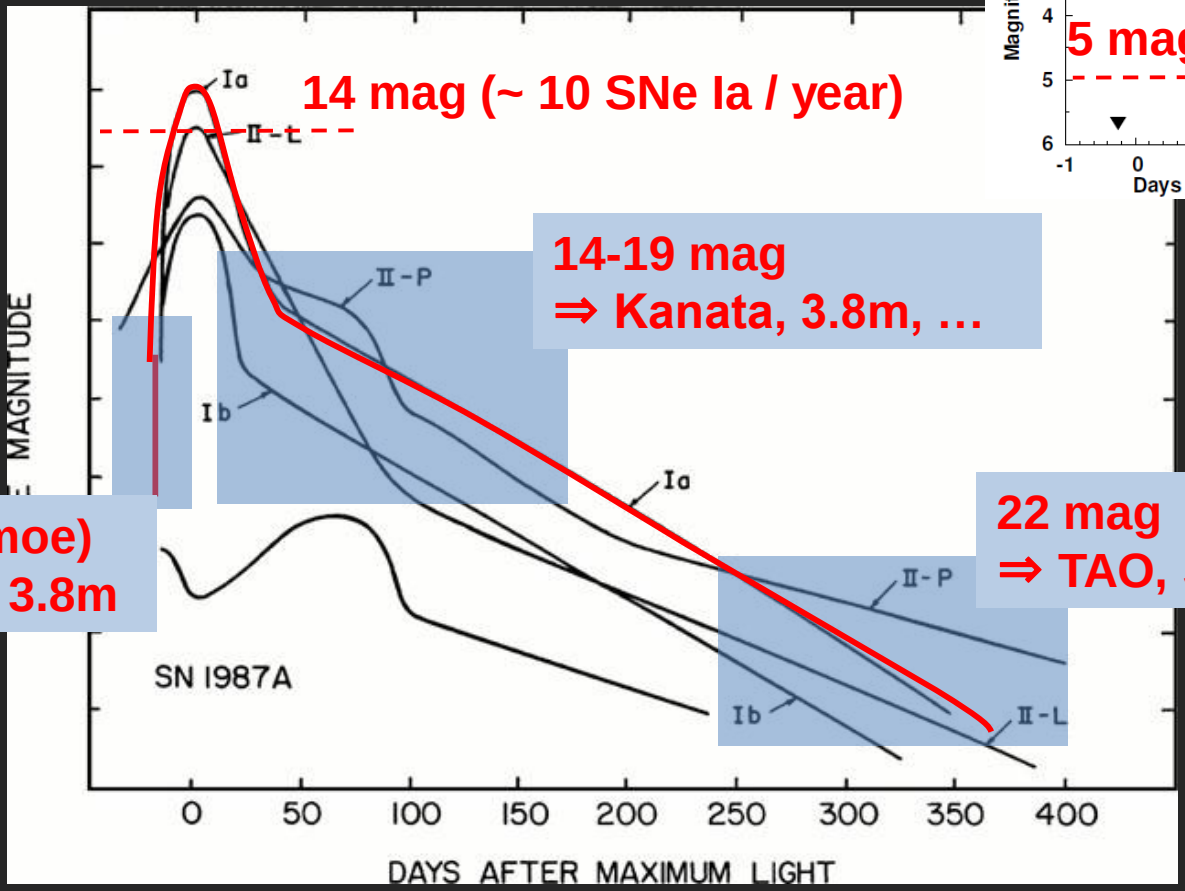



Yaron+ 17

iPTF13dqy = SN2013fs

# SN Ia statistics



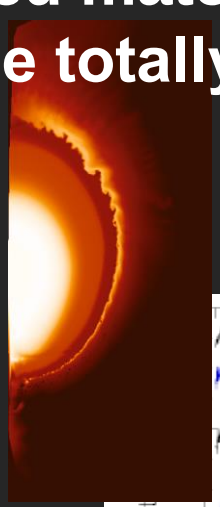

Extensive data set (w/i 1 day): ~ 10 SNe? (peak ~ 14 mag)
Moderate data set (w/i 3 days): ~ 100 SNe ? (peak ~ 16 mag)

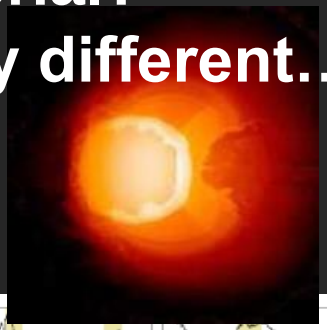
# SNe Ia: Properties of the outermost layer

Oxygen (~week)

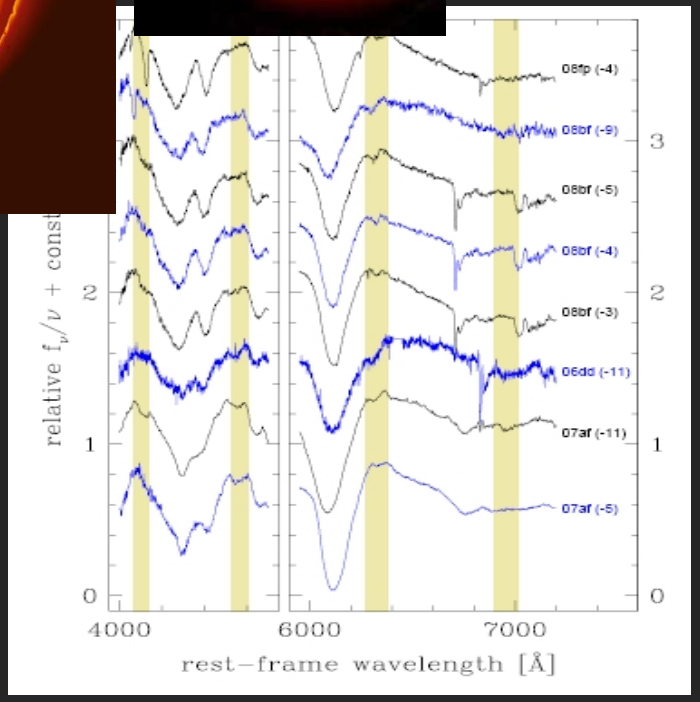
Unburned material?

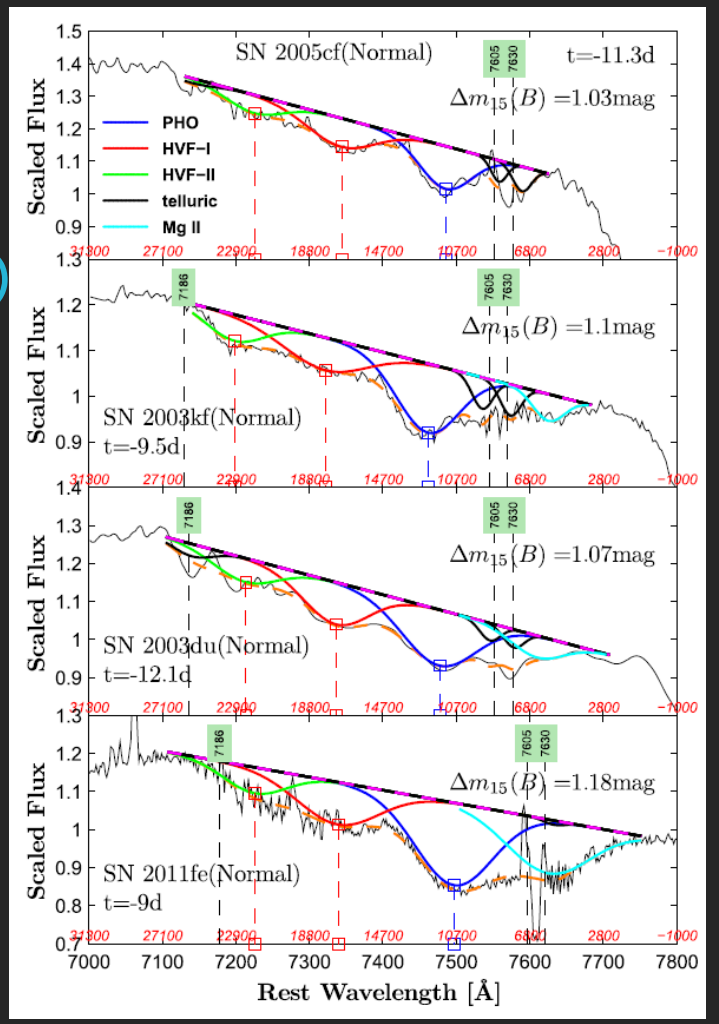
… will be totally different…





Carbon (~ week)




**Key:**
**Need to go for even earlier.**

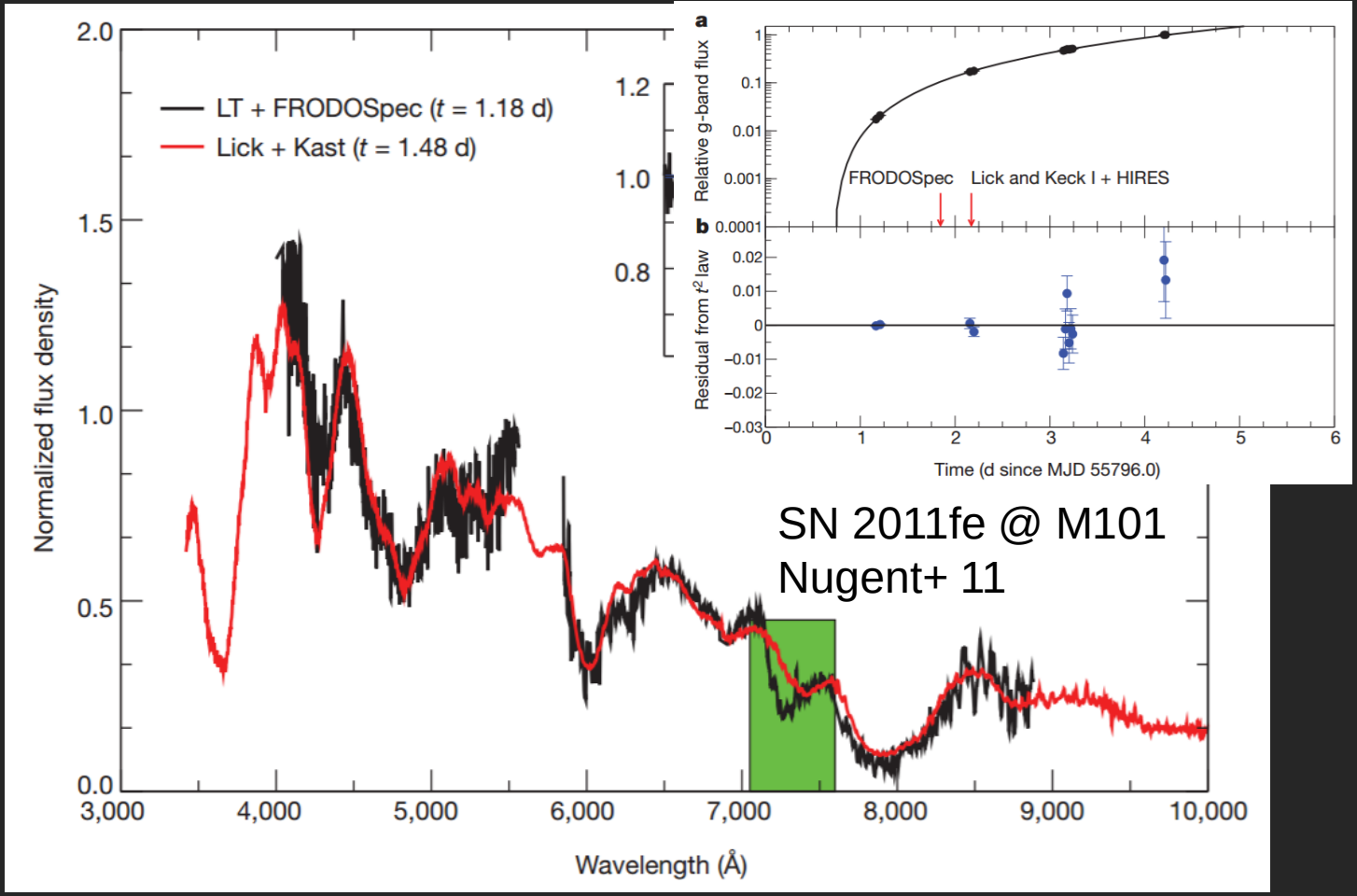
Folatelli+ 2011

Zhao, KM+ 2016, Sai, KM+, in prep.

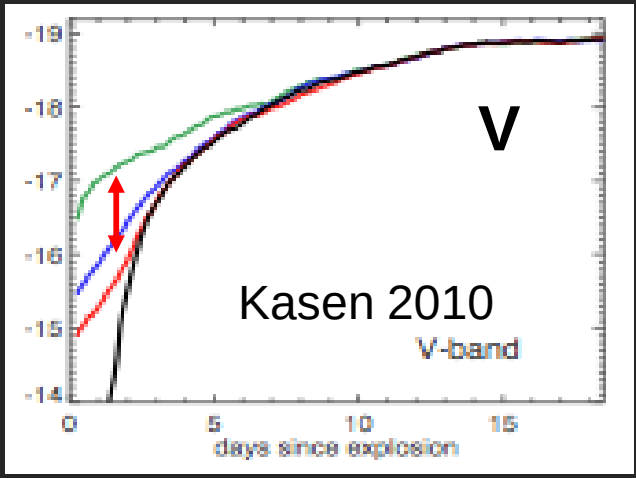
# SNe Ia: Properties of the outermost layer

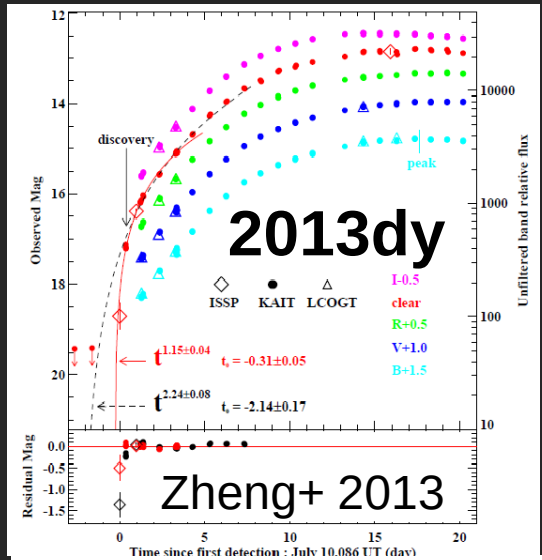
An **only** example of SN Ia spectrum in the 1st day.

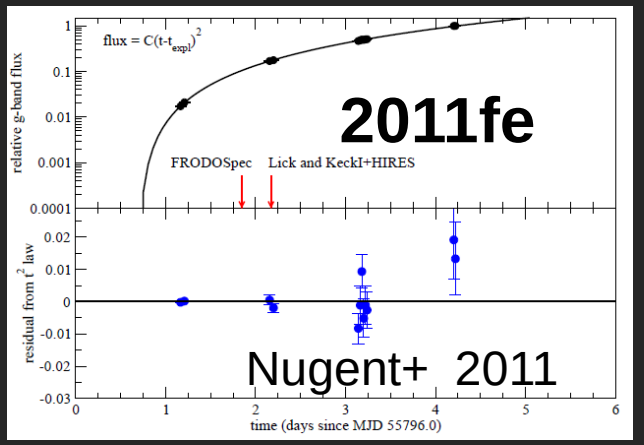
**Rapid change in the oxygen feature… origin not clear yet.**

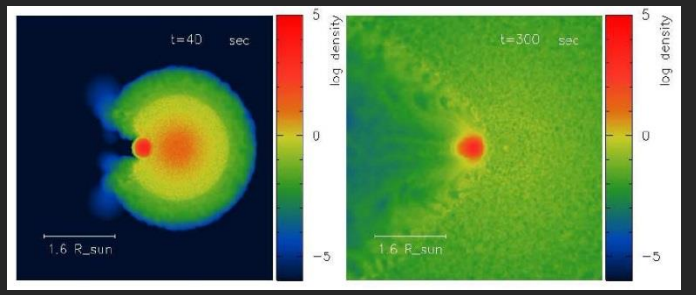


# No SN-companion crush (against SD?)



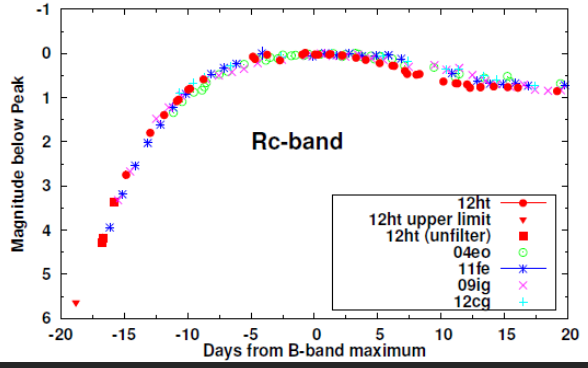



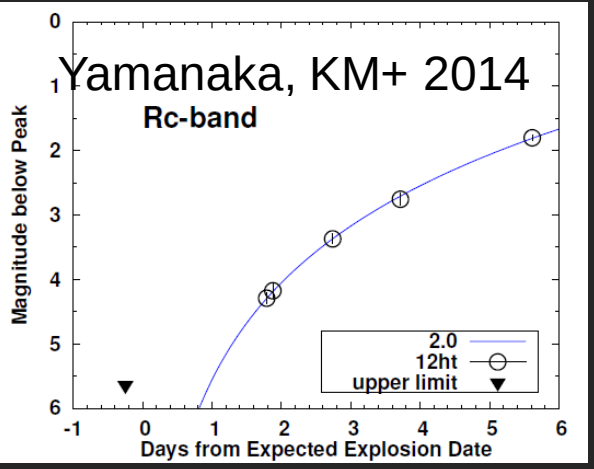




Liu, …, KM+, 2013

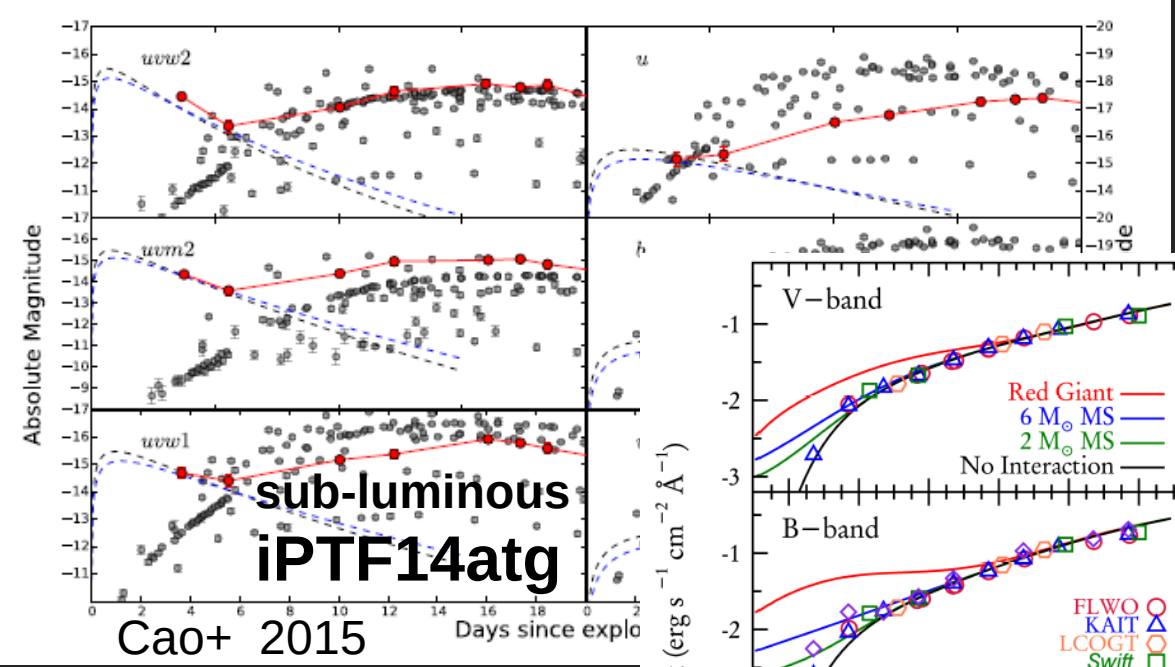
## SN Ia 2012ht




Examples with no signatures

# SN-companion crush? (SD?)



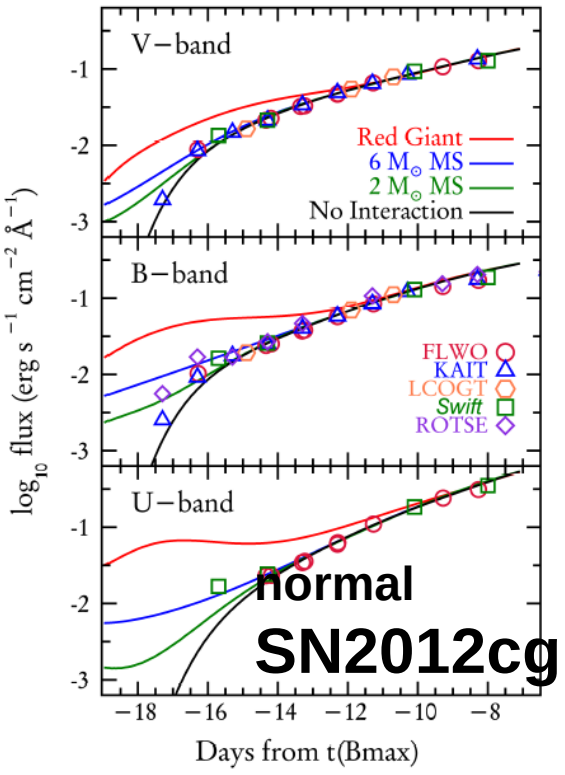

Cao+ 2015

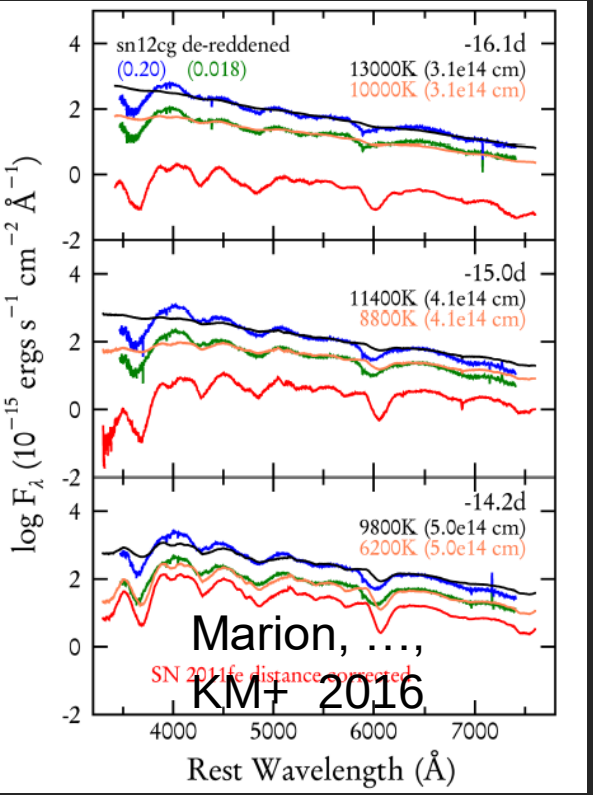
w/ a blue spectrum
@ -16 day

Maybe something totally different.

**Key:**

**Spectra in the first few days**



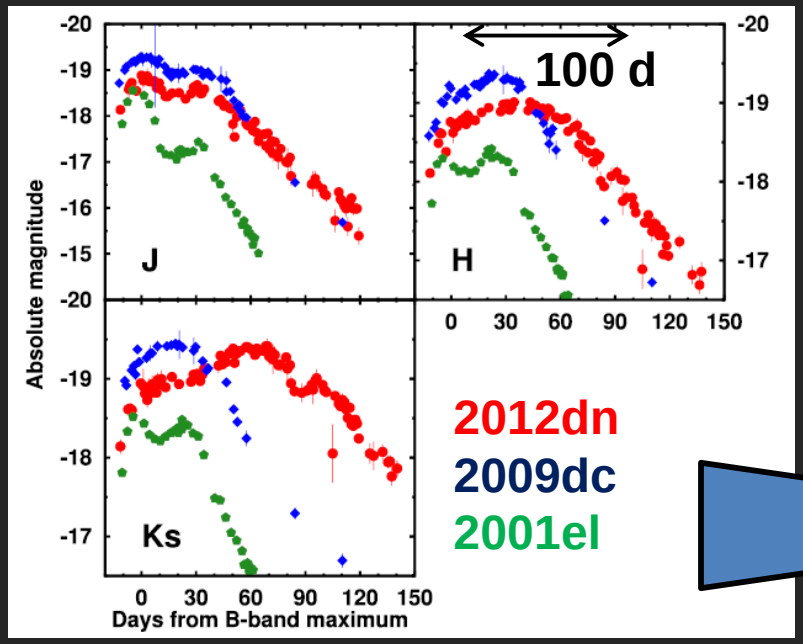




Marion, …, KM+ 2016

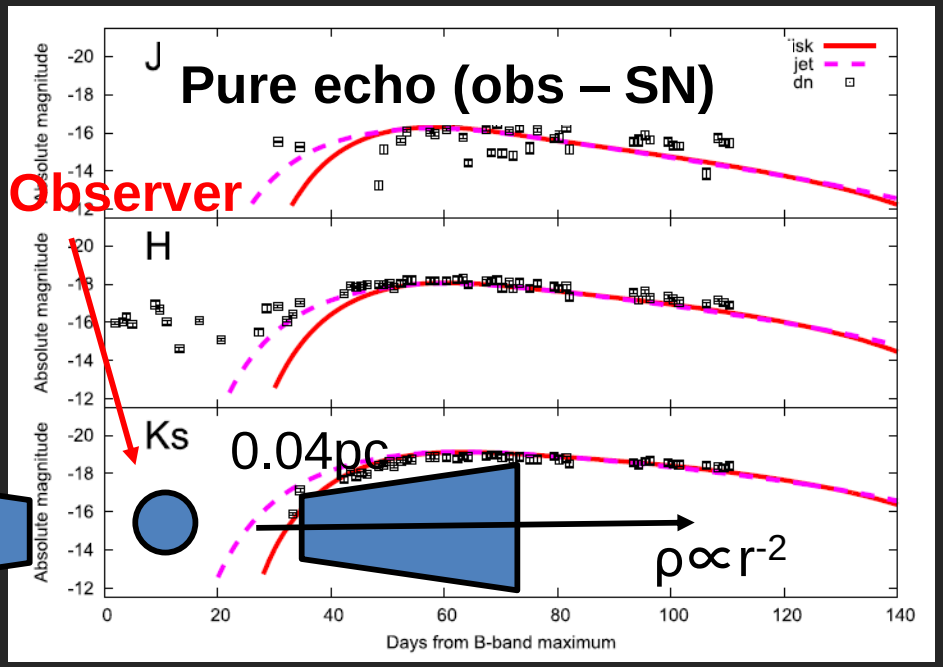
Examples with possible signatures

# CSM around SNe Ia

Yamanaka, KM+ 2016




Nagao, KM, Yamanaka 2017



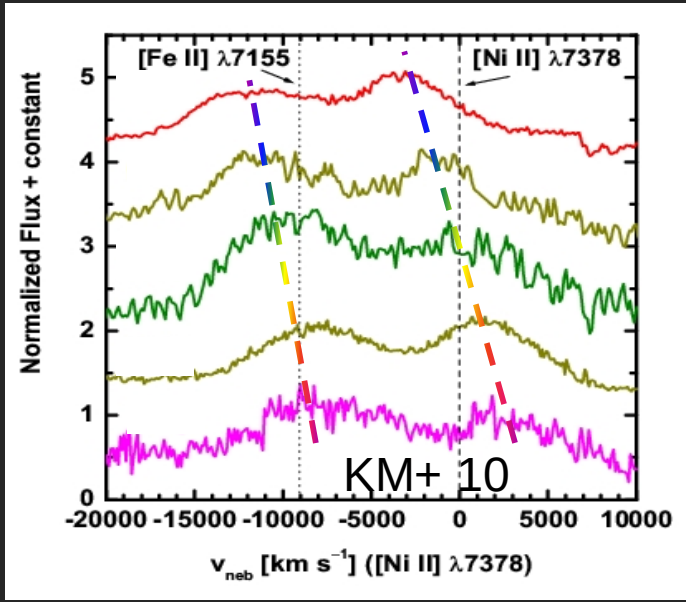

Discovery of "CSM NIR echo" from a peculiar SN Ia 2012dn.

1. Long-term NIR follow-up. See Nagao's talk.
2. Color evolution **before** the peak (~ 100 SNe per year?).
3. A high-res. spec. **before** the peak (for ~ 10 / year w/ 8m's?)

# A need for follow-up (examples for 8m)

Late-phase spec. (~year)

⇒ Explosion and progenitor.

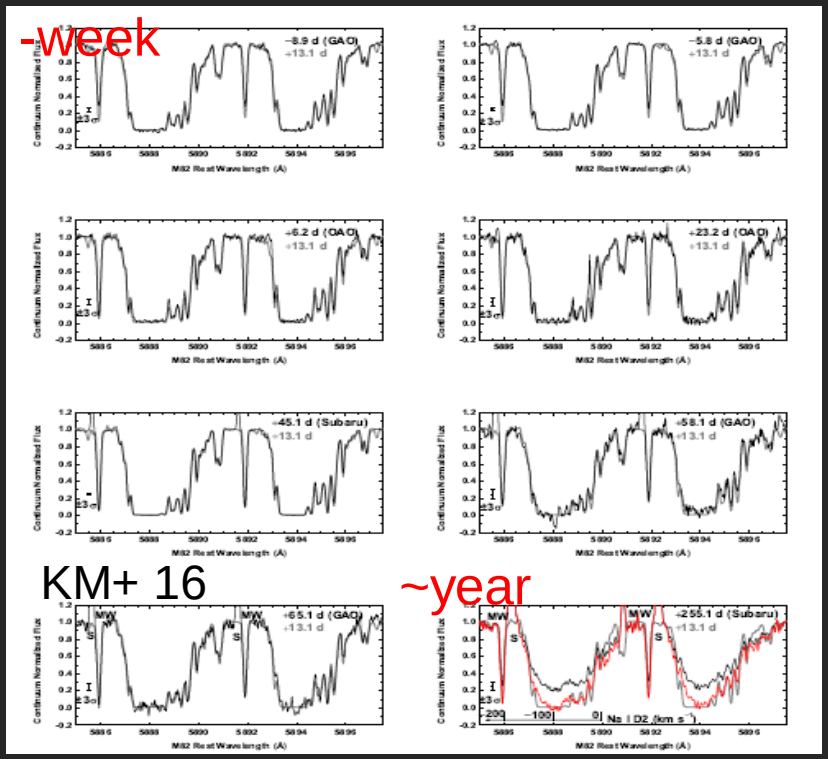



**Emission lines from the region where the explosion started.**

**My Homework: finalize the Subaru sample before the tomoe-3.8m.**

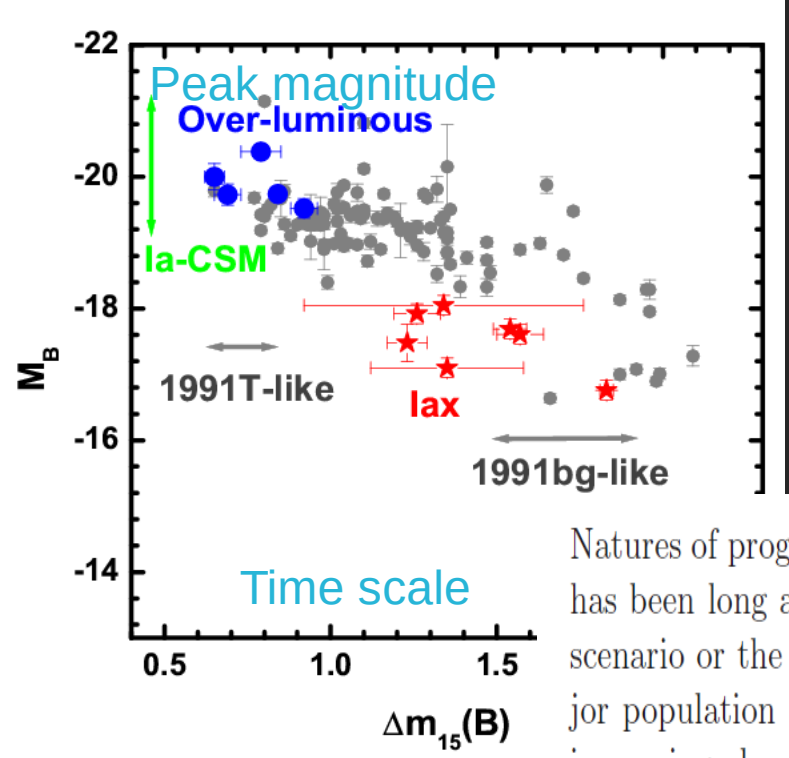
High-res. spec

⇒ CSM and progenitor.




**Probing the absorption through CSM (or no CSM).**

# Understanding the origin of diversity




KM, Terada 2016

SNe Ia may likely come from multiple progenitor paths / explosion modes.

**⇒ Rapid discovery and follow-up not only for normal, but for outliers.**

Natures of progenitors of type Ia Supernovae (SNe Ia) have not yet been clarified. There has been long and intensive discussion on whether the so-called single degenerate (SD) scenario or the double degenerate (DD) scenario, or anything else, could explain a major population of SNe Ia, but the conclusion has not yet been reached. With rapidly increasing observational data and new theoretical ideas, the field of studying the SN Ia progenitors has been quickly developing, and various new insights have been obtained in recent years. This article aims at providing a summary of the current situation regarding the SN Ia progenitors, both in theory and observations. It seems difficult to explain the emerging diversity seen in observations of SNe Ia by a single population, and we emphasize that it is important to clarify links between different progenitor scenarios and different sub-classes of SNe Ia.

# Summary and opinions for Tomoe-3.8m

- Many exciting scientific outcomes for SNe expected.
- Early discovery + quick follow-up (esp. spec) is key.
  - Stellar evolution in the **final months – decades.**
- Long-term follow-up important as well.
  - We need a comprehensive view for **real science**.
- Do our own science.
  - We need young generation (attract/educate(?)).
  - Keep time to think about new ideas.
    - Simple organization, systematic observations/reduction.
    - Finish the pilot studies in one year. Be ready.