Subaru Seminar@ Subaru Office, 30/Jan/2015

Supernovae Viewed from Various Angles: A Power of Subaru and 8m-class Telescopes

Keiichi Maeda

Department of Astronomy, Kyoto University

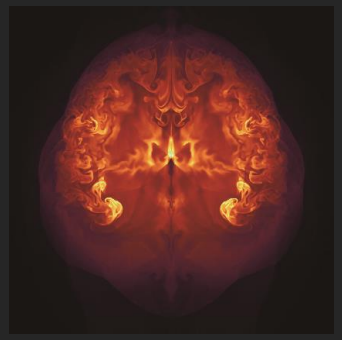
Contents

- **Introduction to supernovae (SNe).**
- **Optical observations in late-phases.**
  - ejecta asymmetry, unburnt materials in SNe Ia, SN Ia outliers and diversities.
  - binary evolution toward core-collapse SNe, nature of a companion star.
- **NIR observations in late-phases.**
  - Dust formation, explosion physics and progenitor, CSM environment.
- **High spectral resolution observations.**
  - CSM around SNe Ia.
  - An origin of Diffuse Interstellar Background.

Type Ia Supernovae (SNe Ia)

- Thermonuclear explosions of a (near Chandrasekhar) white dwarf (WD).
- **But we do not yet know what make them.**

Accreting WD?

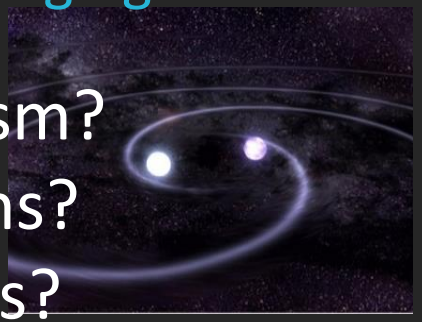


KM+ 2010

?

?

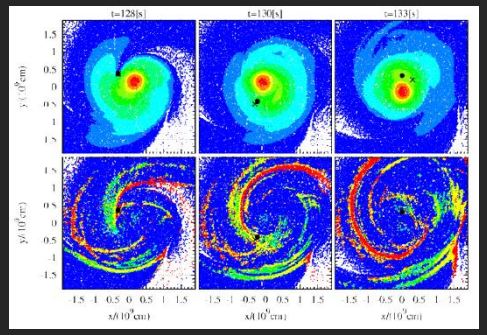
Merging WDs?



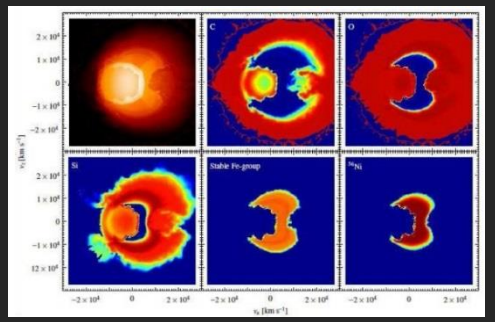
?

Sato+ (w/ KM) submitted

Tanigawa+ (w/ KM) submitted



Roepke+ 2012



Progenitor?

Explosion Mechanism?

Multiple populations?

Diversity and origins?

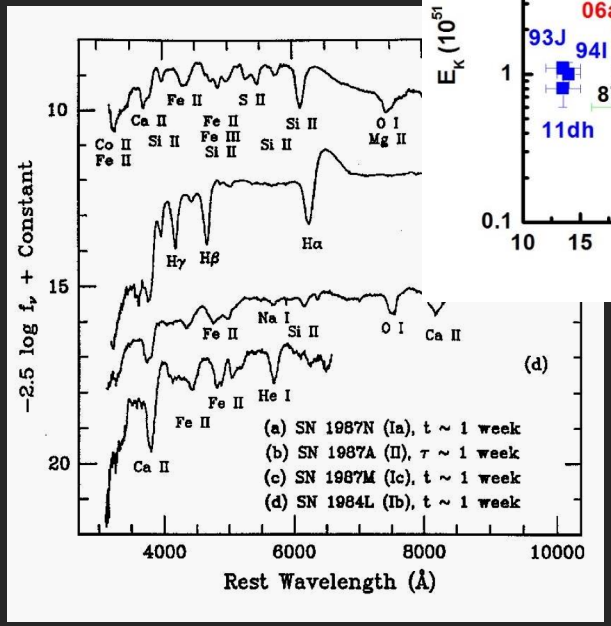
Core-Collapse SNe

- Gravitational collapse of a massive star.
- **But we do not yet know what make them.**

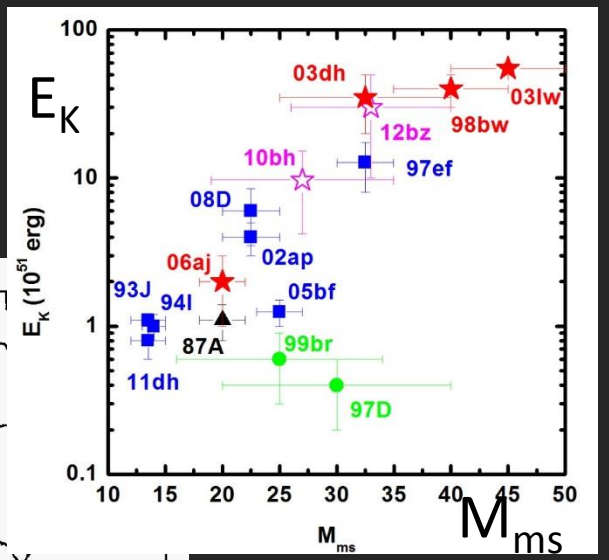
Progenitor mass/rotation/metallicity?
Single/binary evolutions?
Explosion Mechanisms?

Possible Progenitors

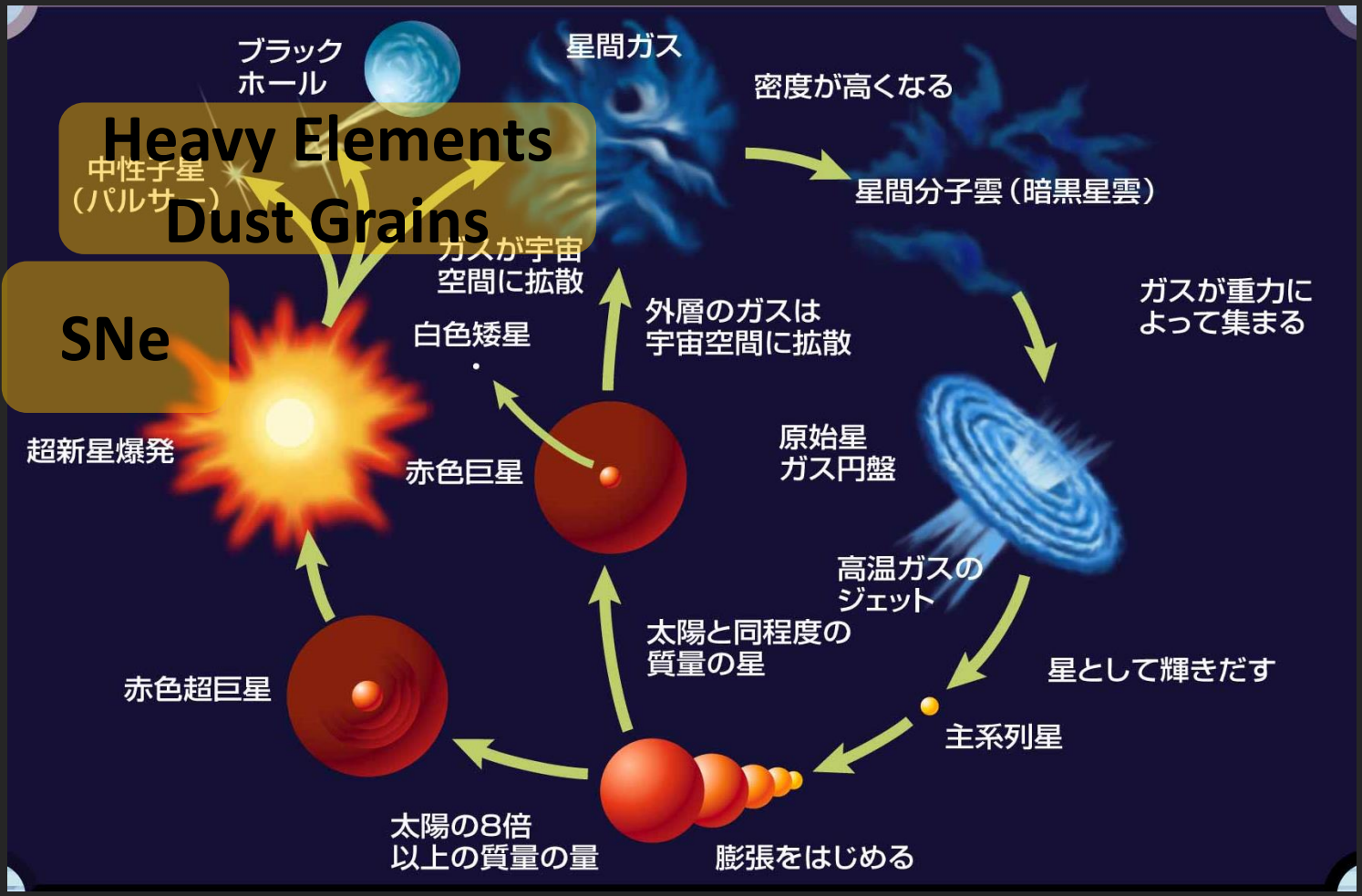
?



Spectral classes



Feedback of SNe into the surroundings



What SNe make what elements?

Do SNe produce dust? And then what kind?

So, we know down to nothing

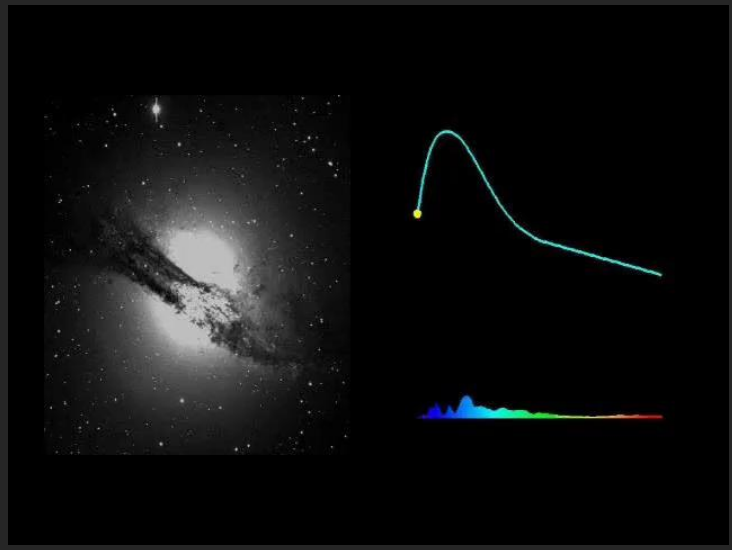
Observational Characteristics of Supernovae

- > 1000 discoveries per year.
  - **Only a part** (nearby) observed in detail.
- Distance > ~ 10 Mpc (extragalactic).

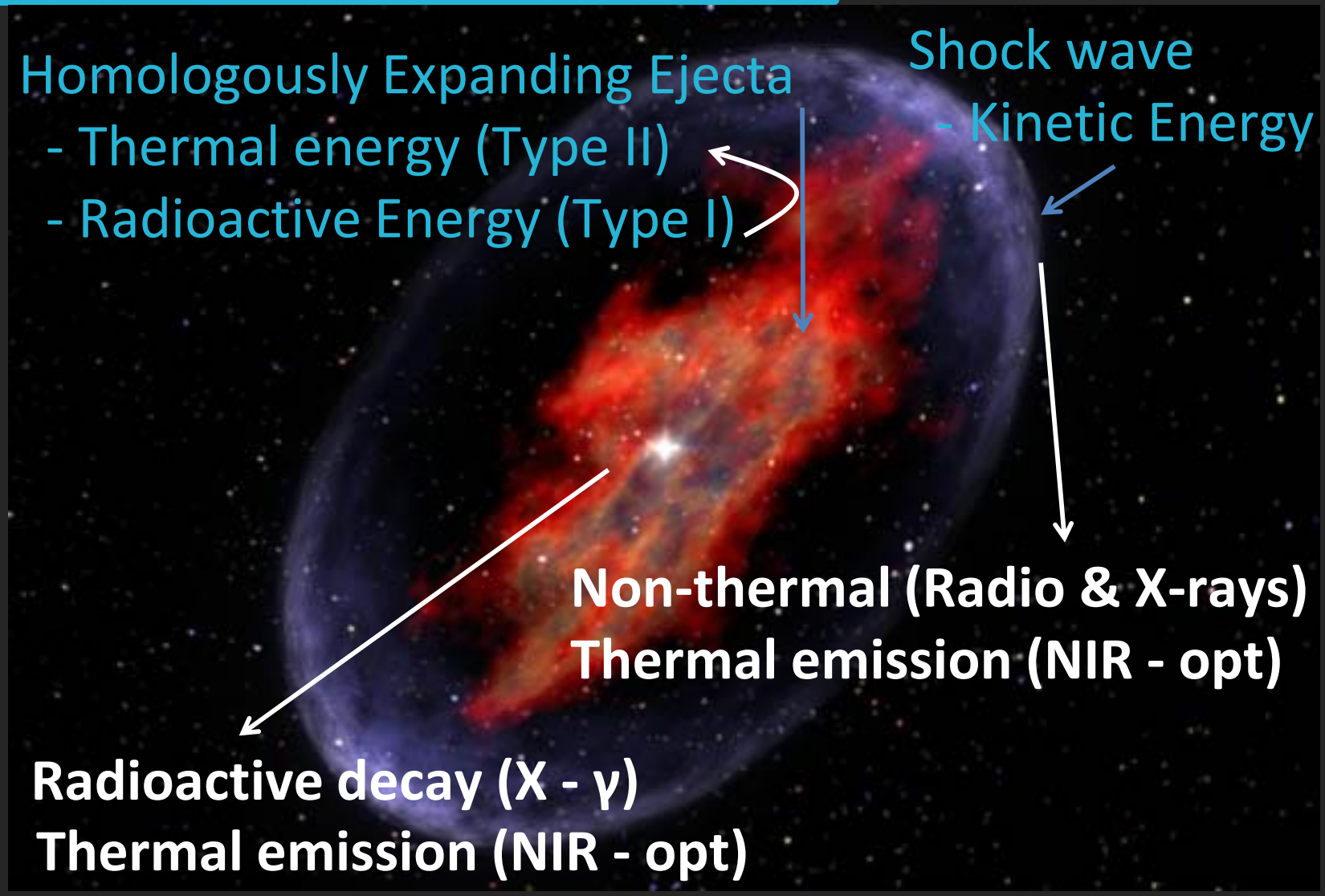
  - **Point sources** (except for a few by HST/AO/VLBI).
  - Typical maximum mag. V > ~ 16 mag（roughly）.
- Most of obs. = Optical.
  - Imaging + spectra (time-dep.)

⬇ Interpretation

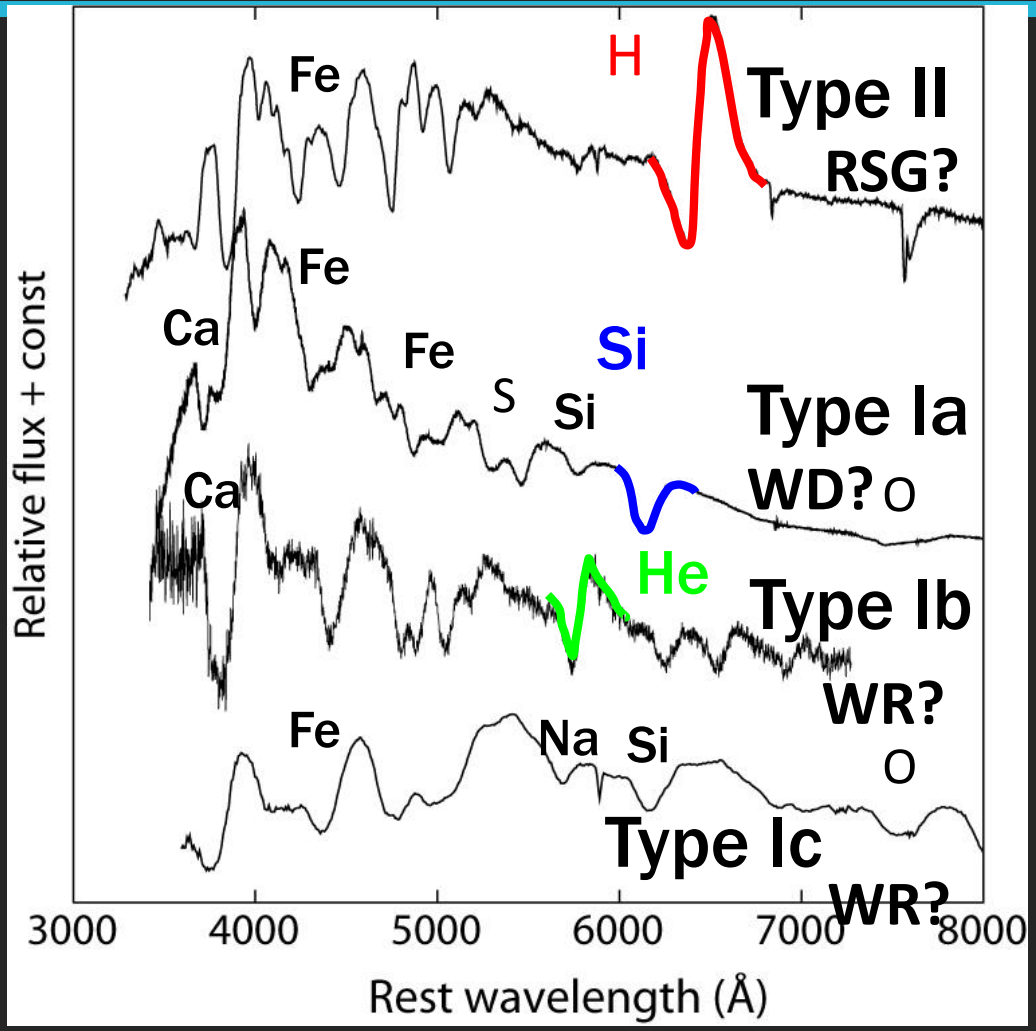
Supernova Physics
（e.g., exp. mech.）



Energy Budget in SNe ⇒ Emission



Supernova Classification

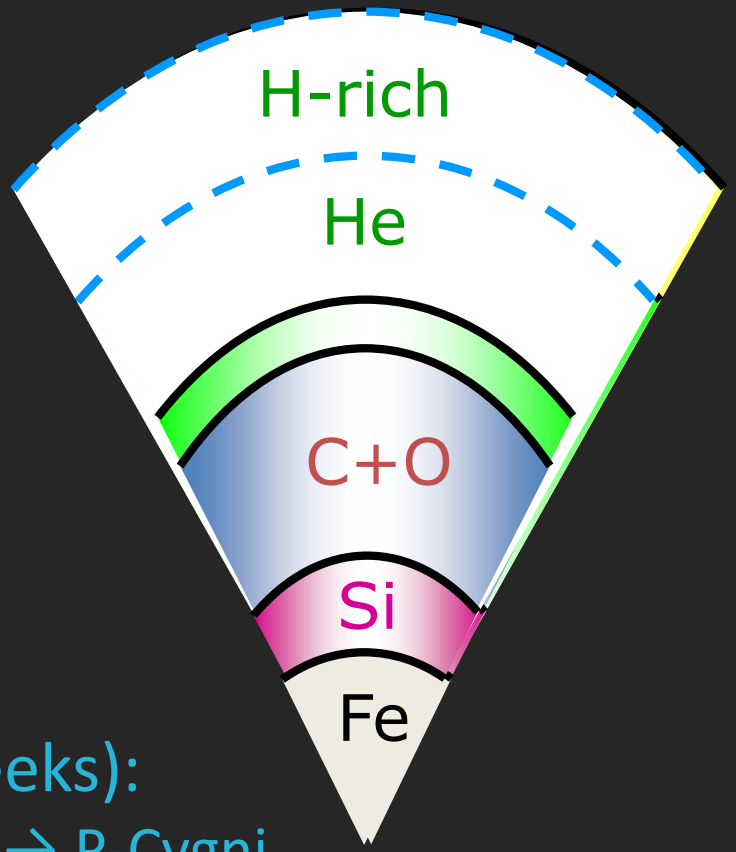


Ia

Thermonuclear exp. of a white dwarf (WD)

II/Ib/Ic

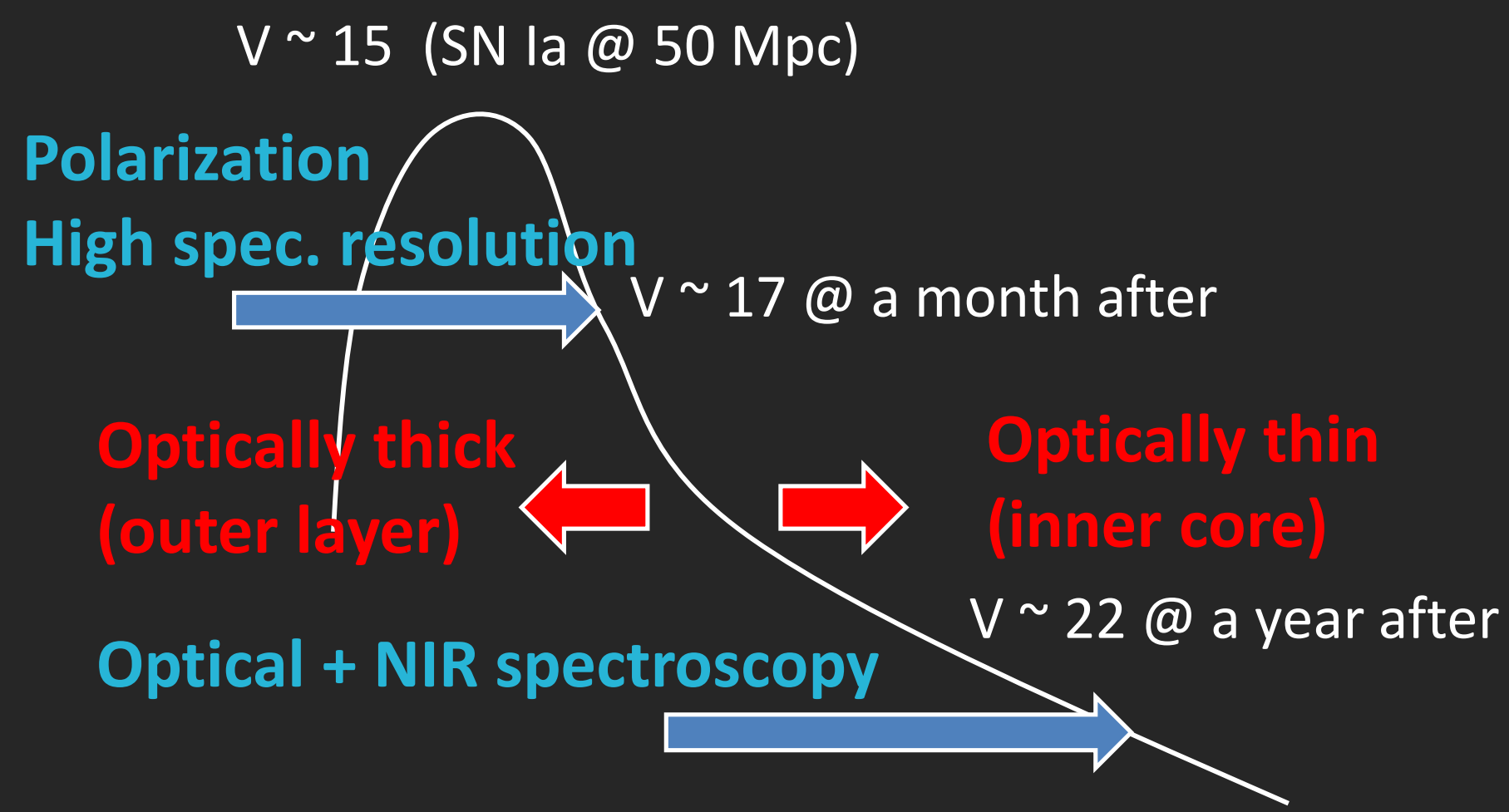
Core-Collapse (CC) of a massive star



@ maximum brightness (~ a few weeks):

– Expanding optically thick medium → P-Cygni.

Nearby SN follow-up with 8m-class telescopes



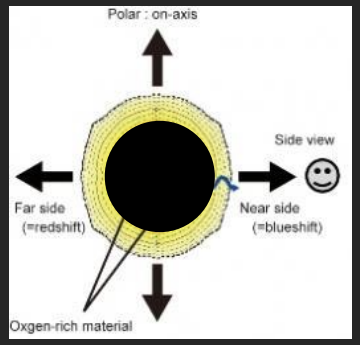
Nearby SN Follow-up

- **Optical observations in late-phases.**
  - ejecta symmetry, unburnt materials in SNe Ia, SN Ia outliers and diversities.
  - binary evolution toward core-collapse SNe, nature of a companion star.

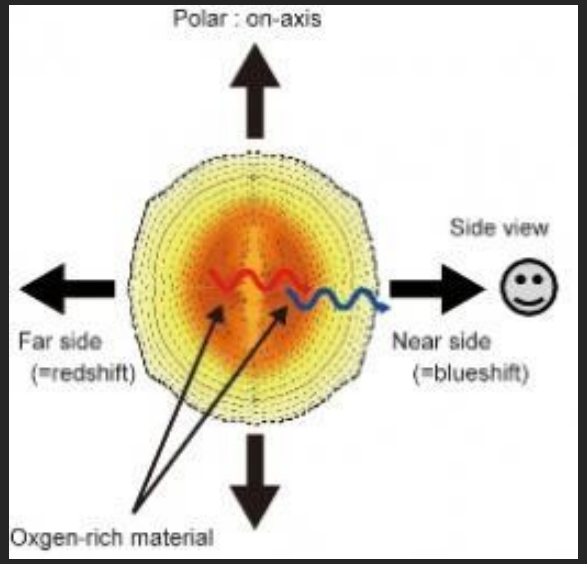
- **NIR observations in late-phases.**
  - Dust formation, explosion physics and progenitor, CSM environment.

- **High spectral resolution observations.**
  - CSM around SNe Ia.
  - An origin of DIB.

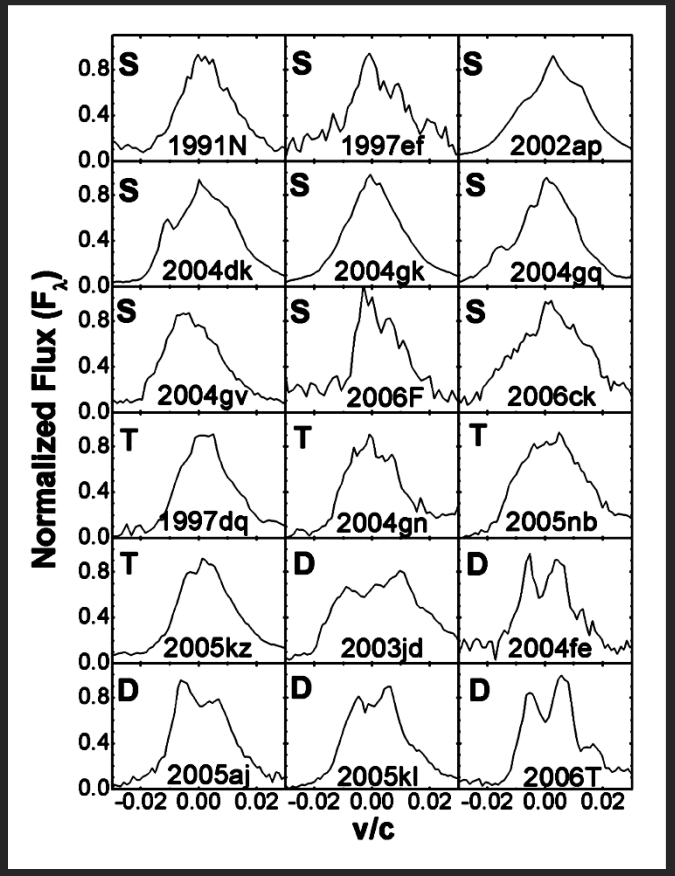
Late-phase spectroscopy

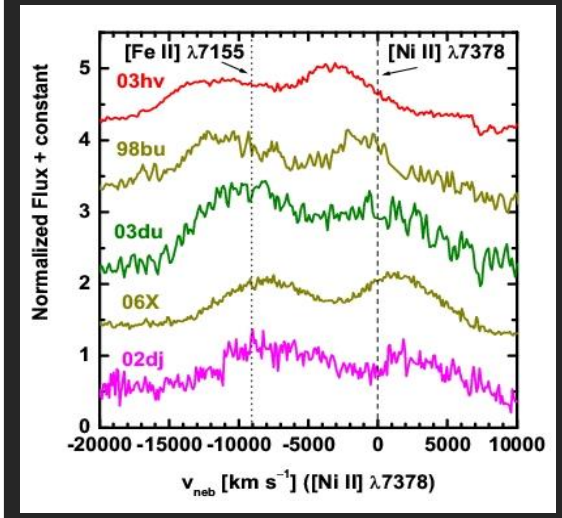


~ year



Abunance+Kinematics→Progenitor+explosion

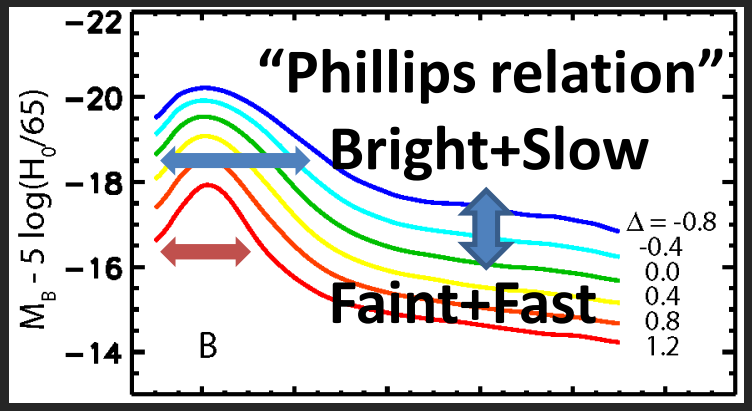




SNe Ia are asymmetric
KM+ 2010
→**Subaru/FOCAS/IRCS**
VLT/FORS2

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

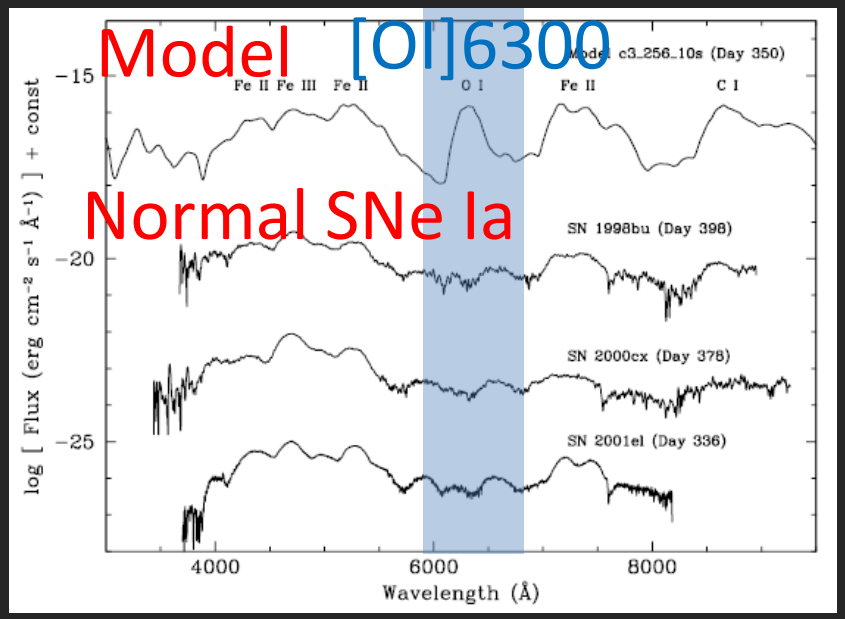
Unburned materials @ inner region of SNe Ia?



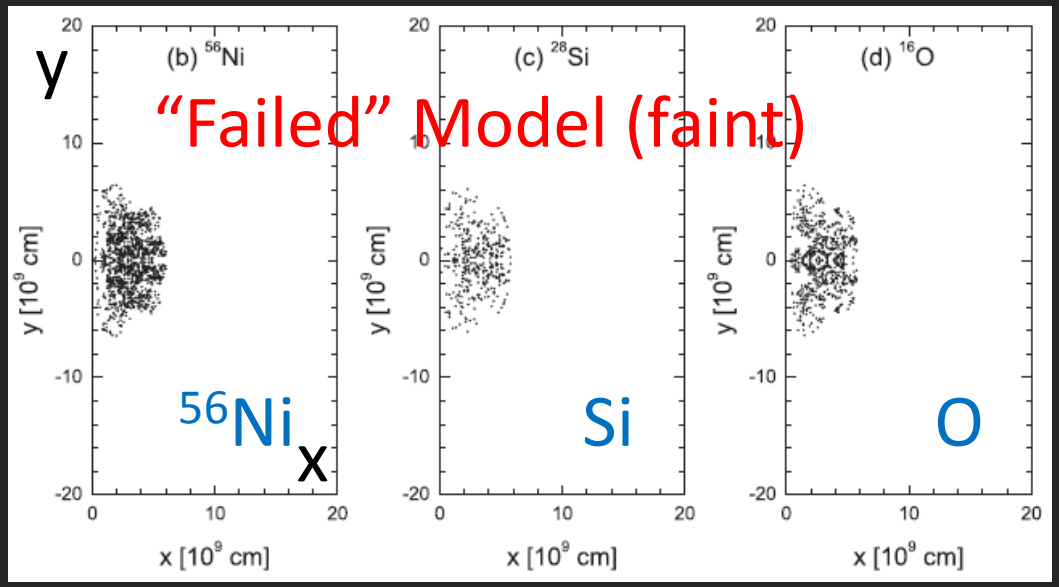
Synthesized + **unburned** ~ $1.4M_\odot$

^{56}Ni (~ $0.6M_\odot$) → Luminosity

Faint → Unburned Oxygen? Where?



Kozma+ 2005



KM, Roepke, Fink+ 2010

Taubenberger+ (w/ KM) 2013, VLT/FORS2

Oxygen in a peculiar faint SN Ia 2010lp

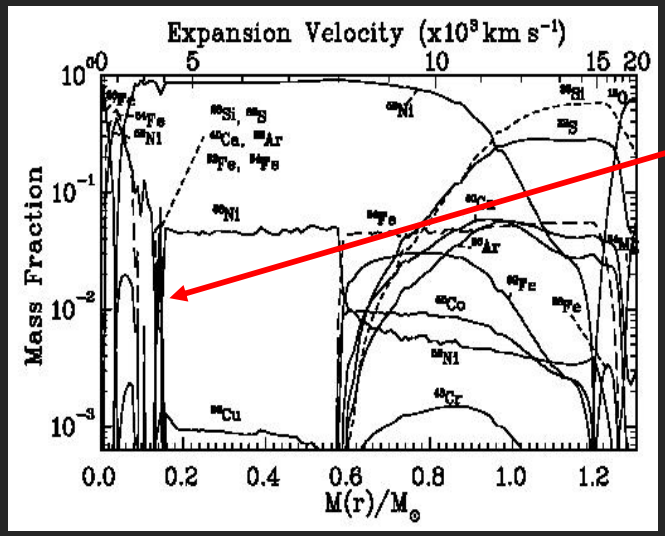
SN 1991bg-like:

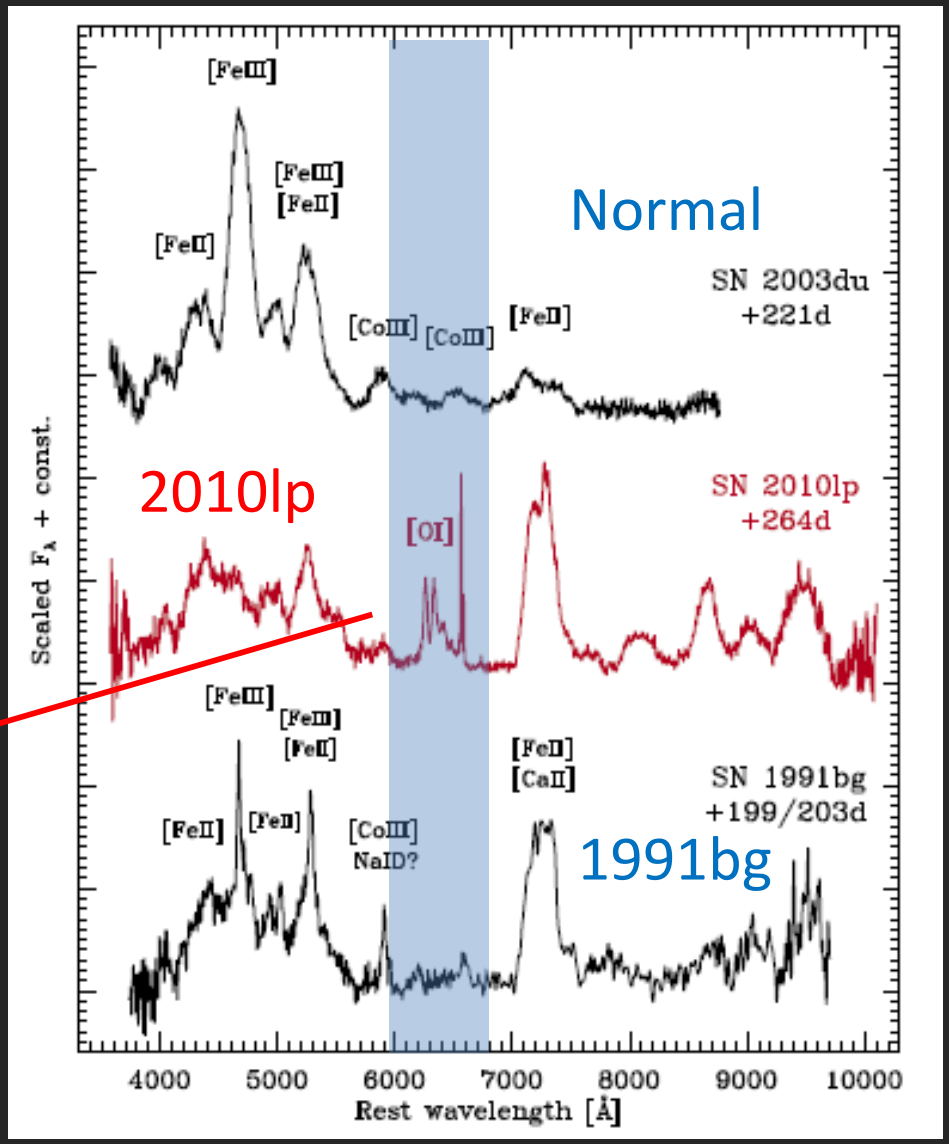
Faint end of SNe Ia

L and ^{56}Ni smaller by ~ 5.

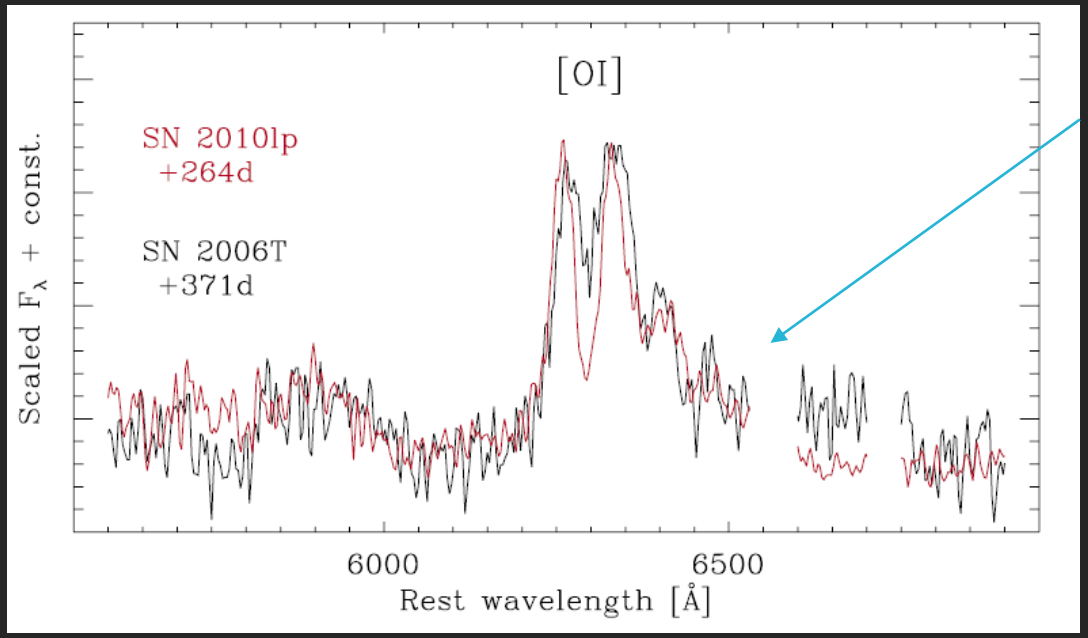
So far no [OI] detected (within a small sample).

→ [OI] detected (first among SNe Ia in the CCD era).





Challenge to Theory… Key to SN Ia diversity?



Core-collapse SN
from a massive star.

The [OI] profile ≠ expected in the faint explosion model.

Narrow, confined
in the center.
Bipolar or disk.

Broad, thoroughly
mixed.

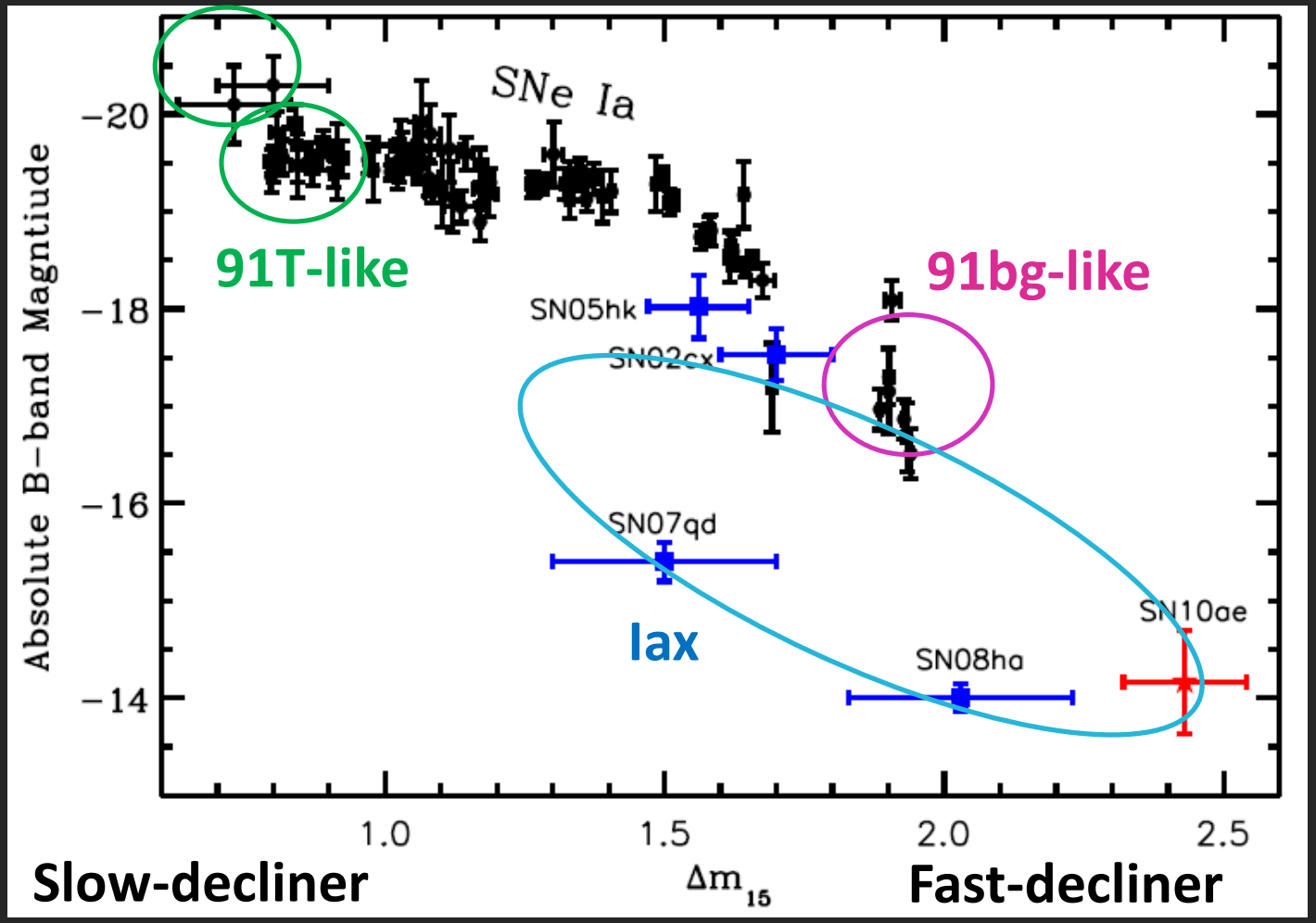
Similar to Core-collapse SN in the O distribution?

Merging two WDs as an alternative scenario?

Normal vs. peculiar SNe Ia

Over-luminous (super-Chandra)?

Bright

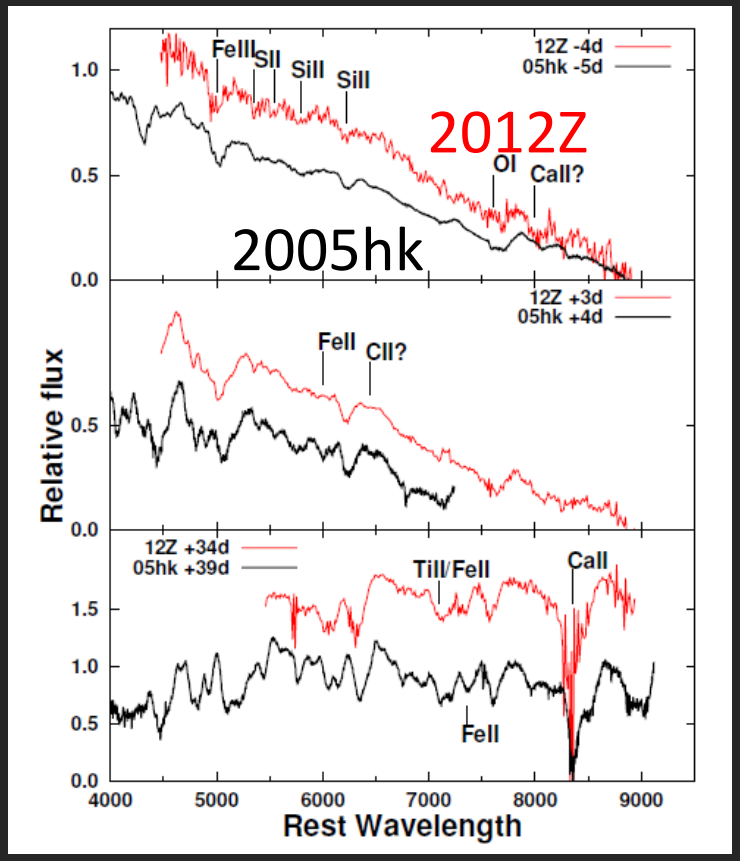


Faint

Stritzinger+ (w/KM) 2014

Yamanaka, KM+, in prep.

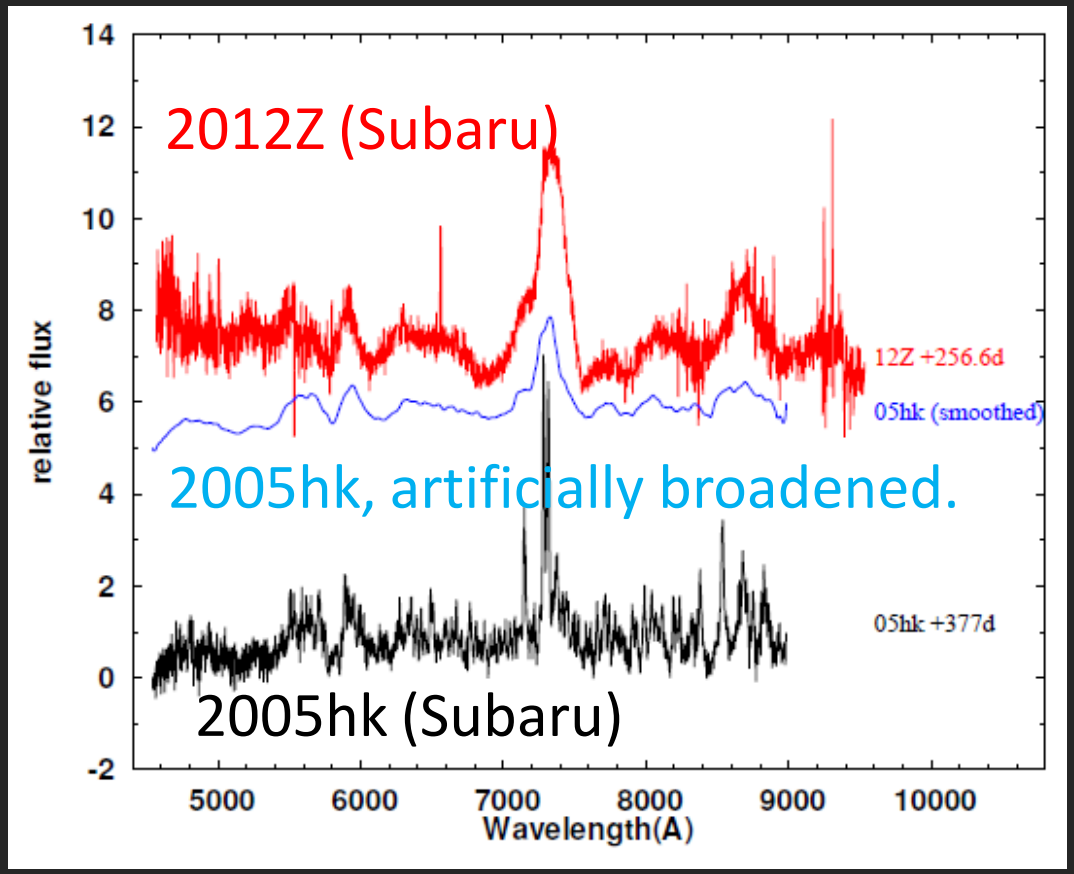
SNe Iax: Uniformity inside, diversity outside



Early phase: Similar to another SN Iax 2005hk

A challenge to models.

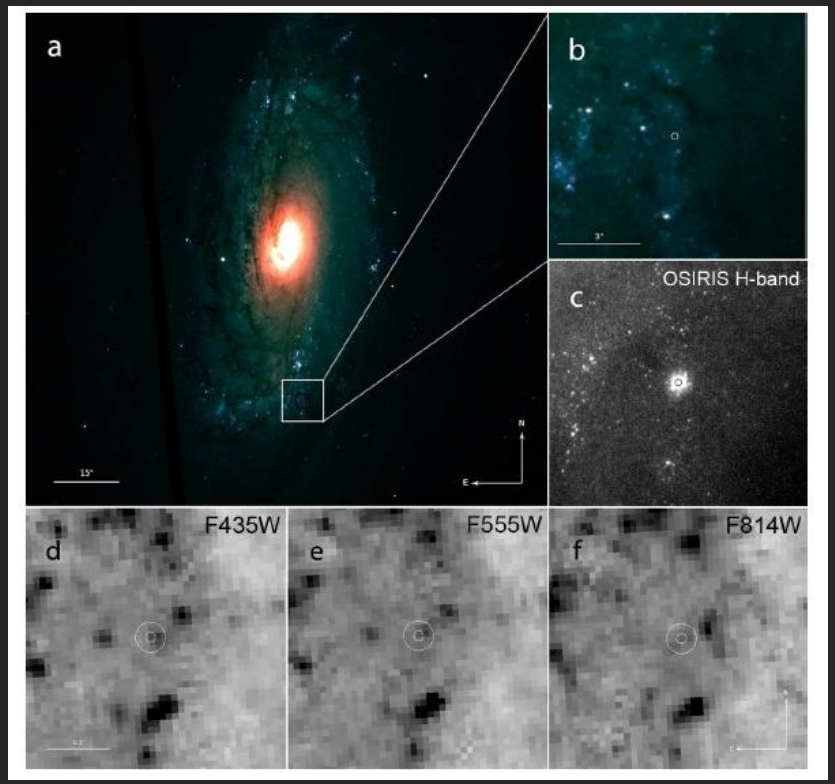
Late phase: Globally similar to another SN Iax 2005hk, but lines much wider **(faster in the core).**



Core-collapse: iPTF13bvn (SN Ib)

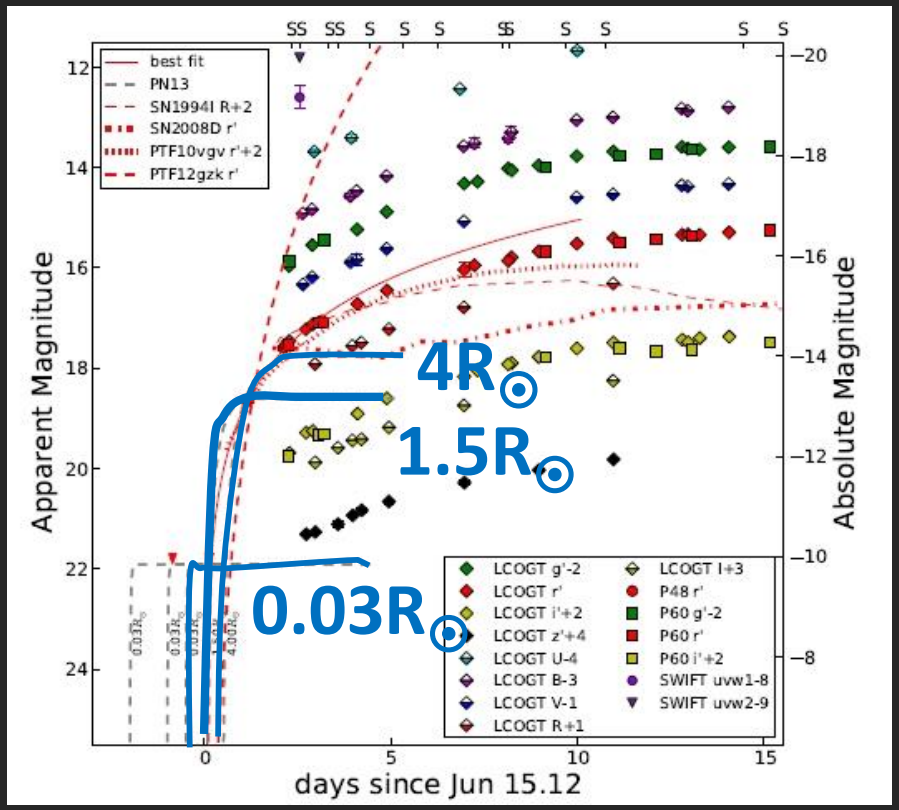
Progenitors have been detected in pre-SN HST images for SNe IIp, being RSGs, but no detection for SNe Ib/c until 2013.

The first detection of a candidate



Cao+ 2013

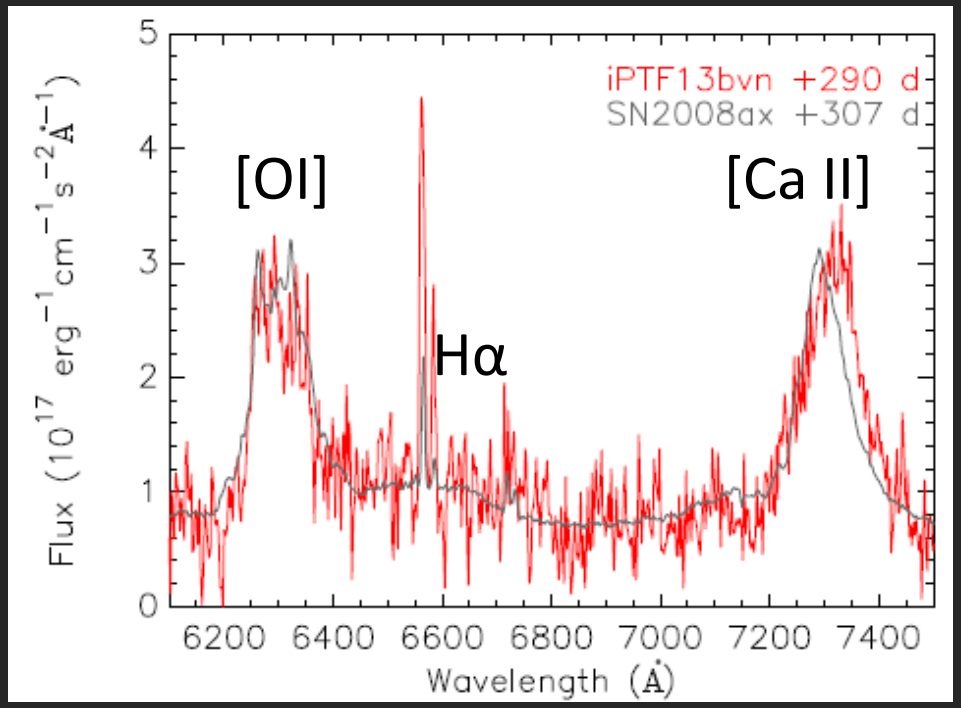
Very early-phase light curve



Massive Wolf-Rayet? (Mms > 20M⊙)

Kuncarayakti, KM+, submitted: SOAR telescope (4.1m)

iPTF13bvn in a late phase: Not that massive

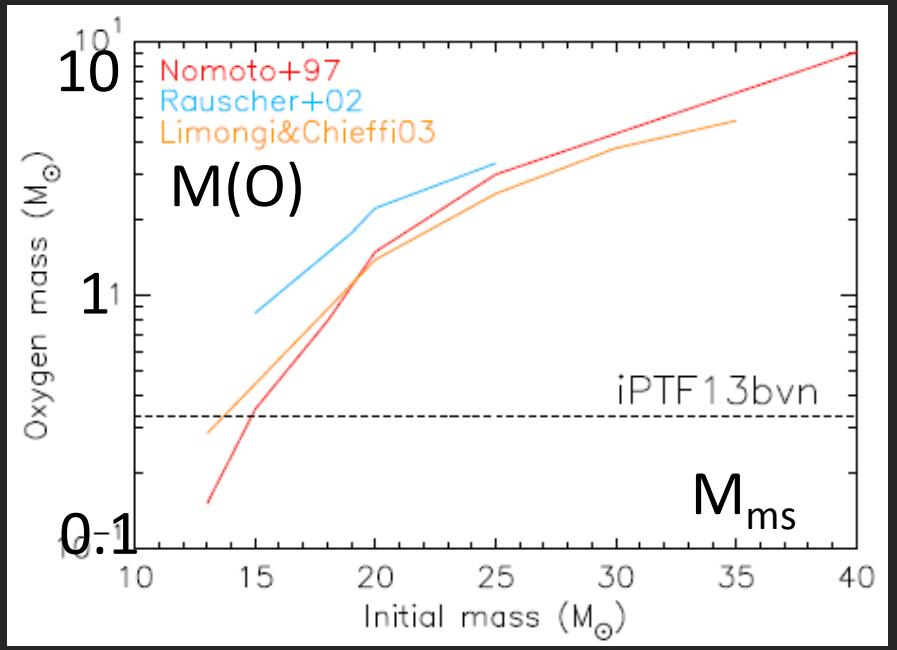


Similar to prototypical "Compact SN IIb" (Very small H-envelope attached to a compact WR-like star).

A link to SN Ib to a part of SNe Ib.

A hint of flat-top/double-peaks in [OI]

→ Asymmetry.

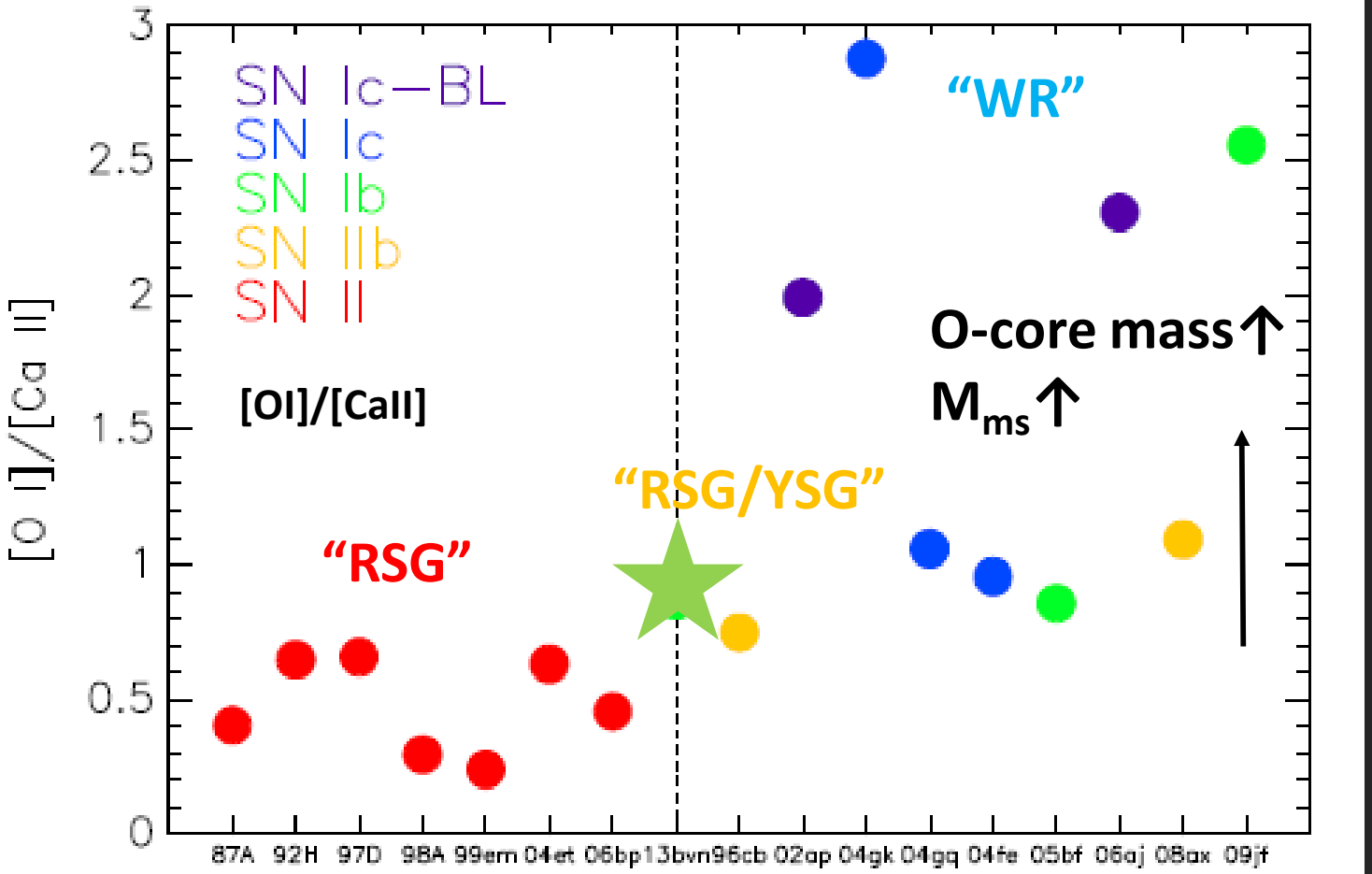


$M(O) \sim 0.3M_\odot \rightarrow M_{ms} < 16M_\odot$

⇒ Binary evolution.

Kuncarayakti, KM+, submitted

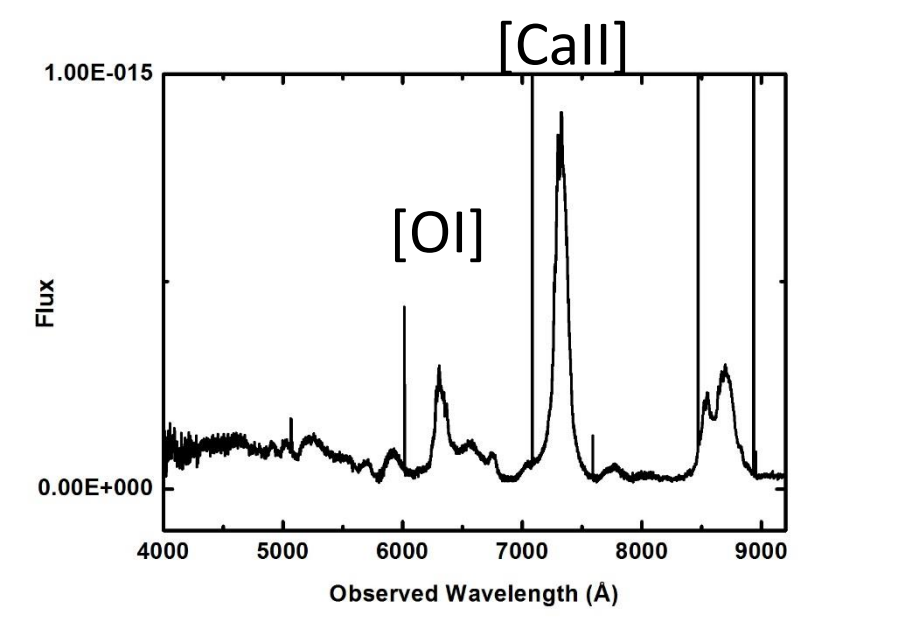
SNe IIb/Ib/Ic coming from two paths?



"Massive"
Single?

"Light"
Binary?

Other examples of SNe w/ Subaru



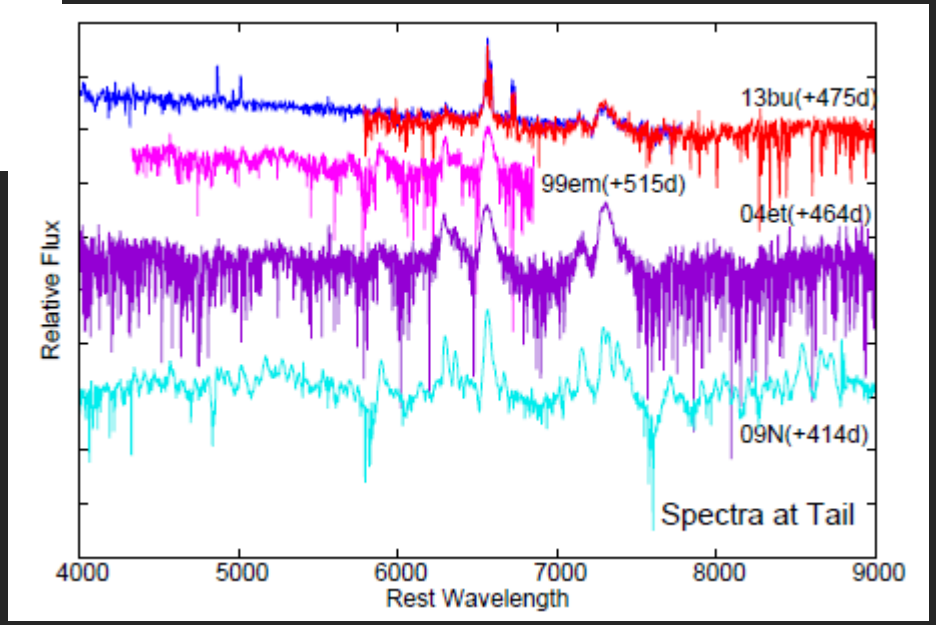
SN IIb 2013df Van Dyk+ 2013

Progenitor: Yellow Super Giant

(2nd exam.: see later)

Large [Ca II]/[OI]: < $16M_{\odot}$

Kawabata+, in prep



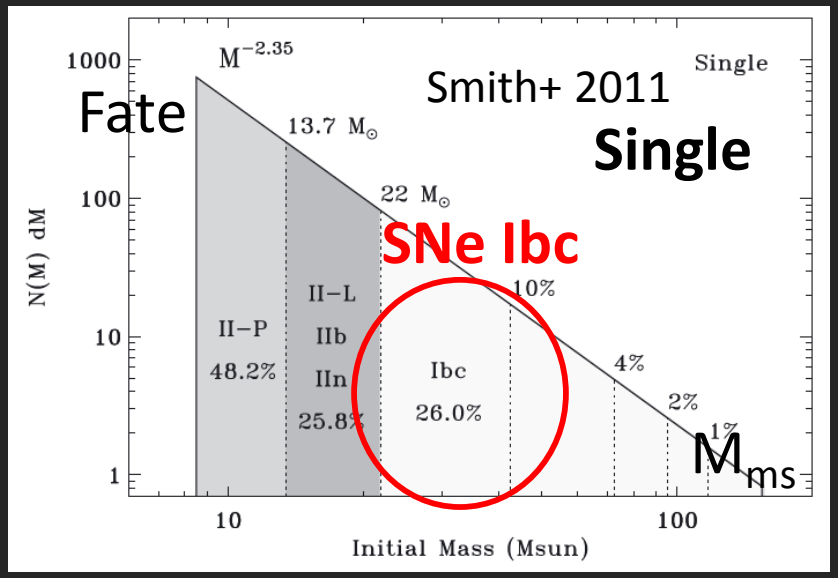
SN IIp 2013bu

Typical in early, but faint in later.

Progenitor M_{ms} ~ $10M_{\odot}$, but w/ normal energy (⇔ faint class w/ low E from M_{ms} ~ 10 $M_{\odot}$)

Masumoto, Yamanaka, KM+, in prep

Studying Companions stars

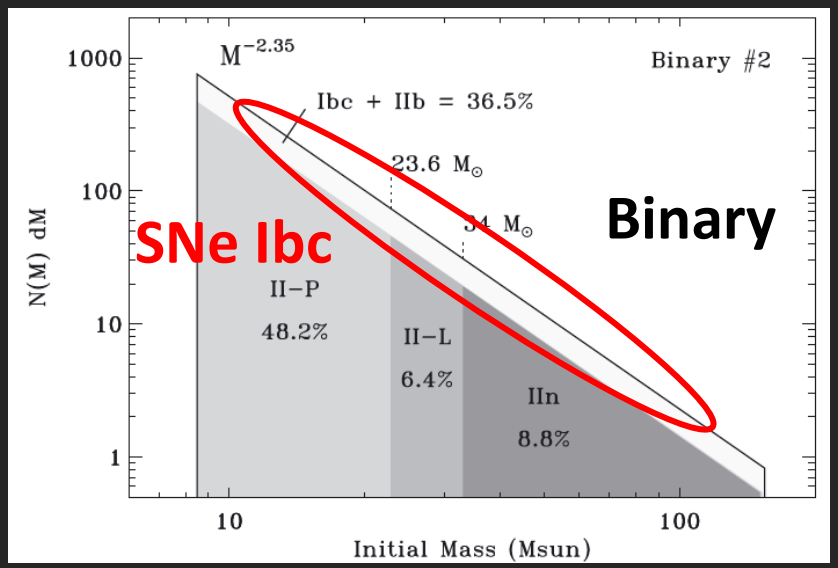


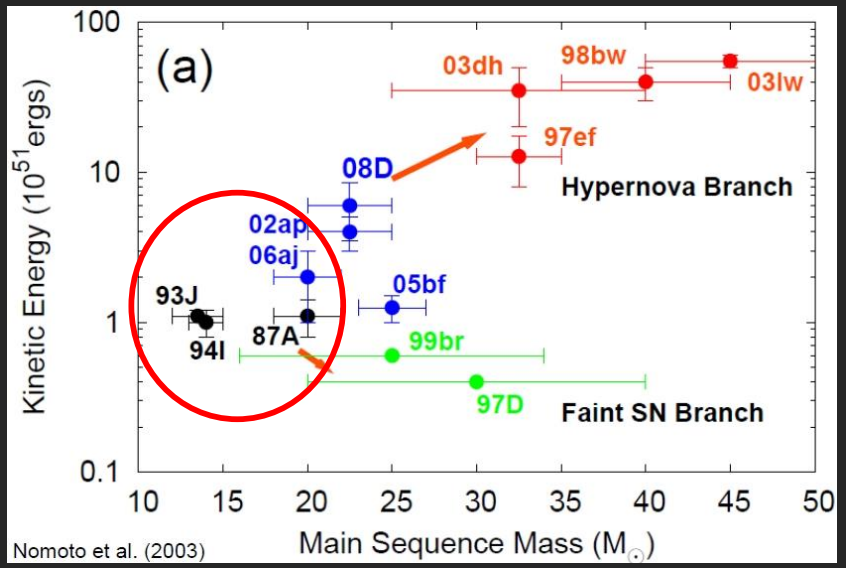
A key unresolved problem in Stellar evolution: Binary

Best lab.: SNe IIb/Ib/Ic (+ Ia)

←H env. lost before the explosion.

Implications from SN properties: Mostly low-mass ejecta, $M_{ZAMS} < 20M_\odot$(?)





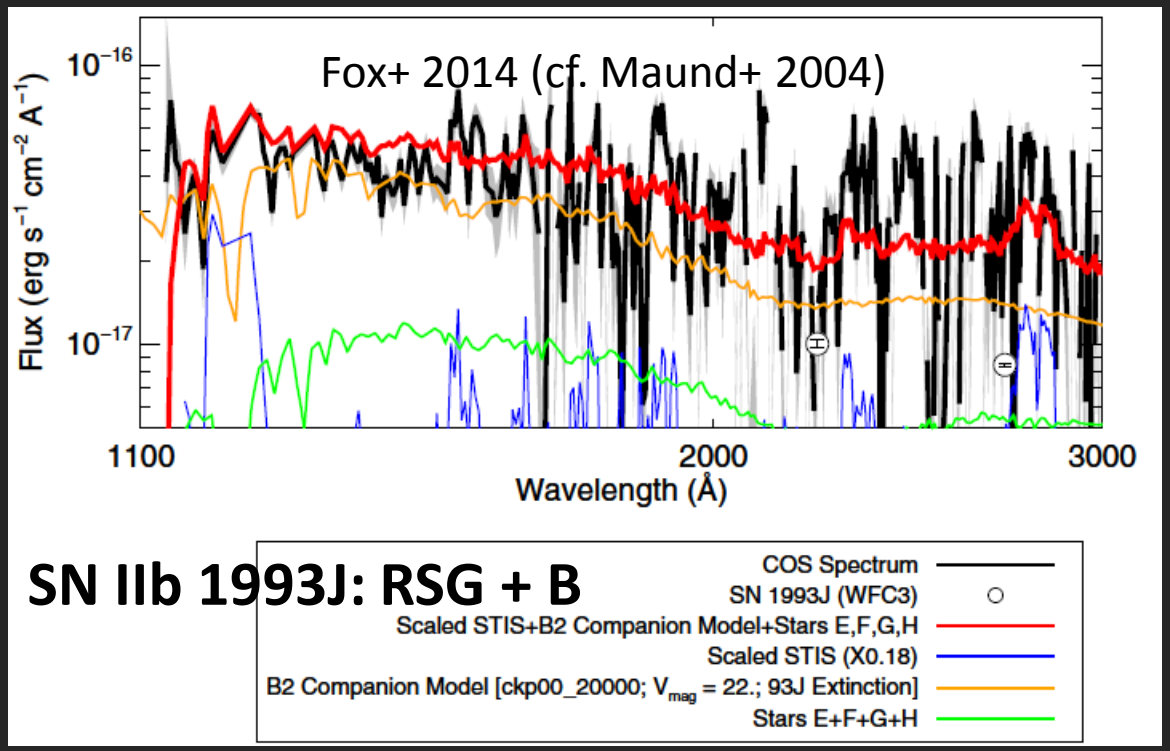
A Major Step: Detecting Companion

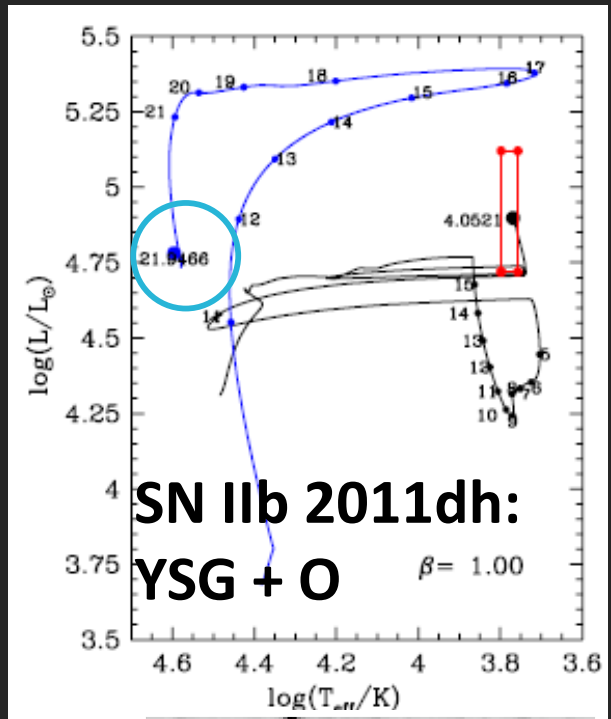
Binary evolution model

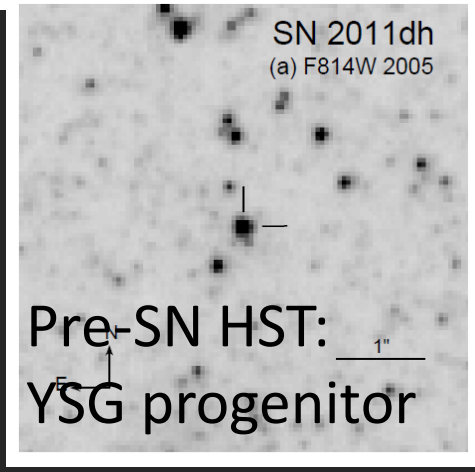
Pre-SN RSG/YSG/WR + **O/B star**

⇒May be visible after a few yrs.

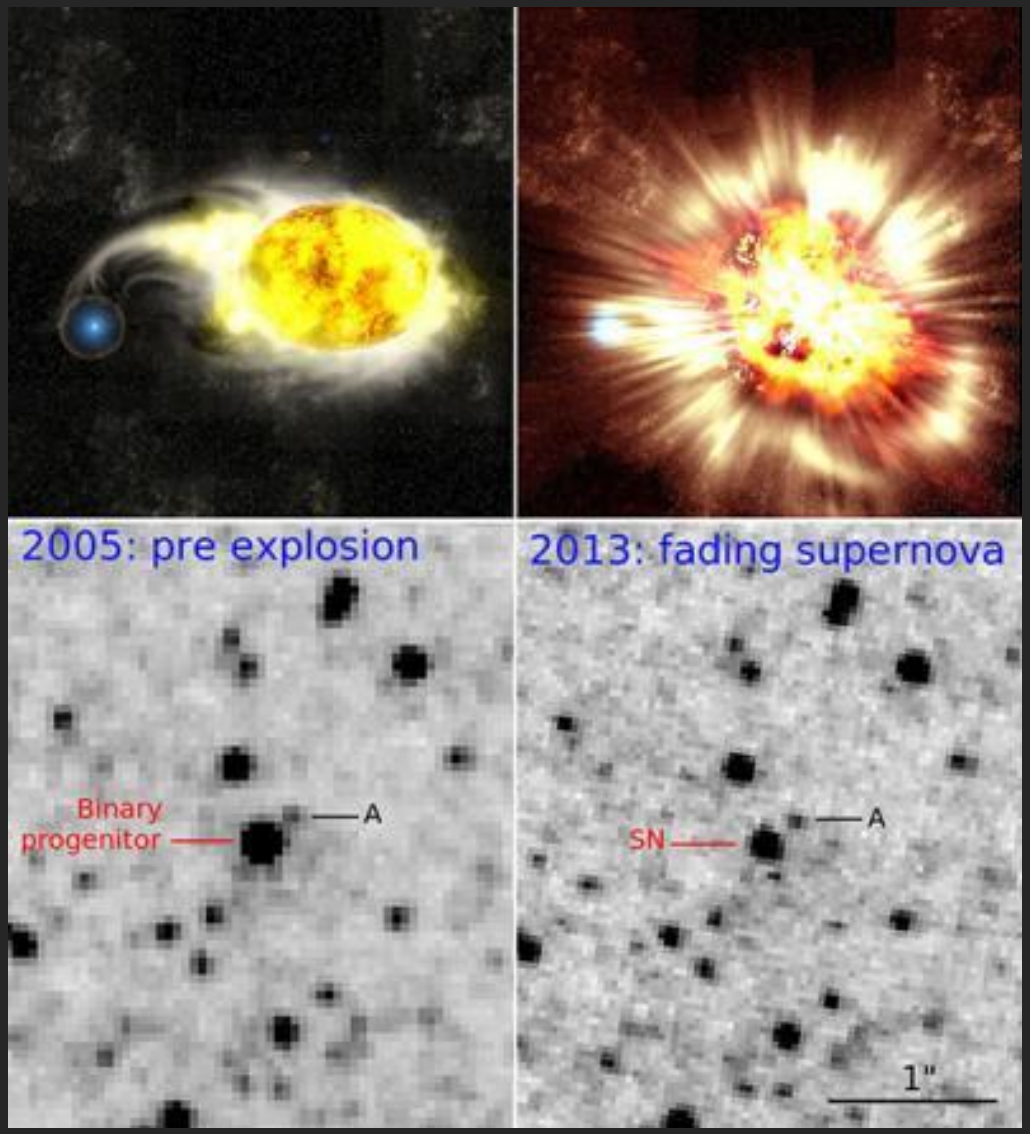
Only example of possible detection







Direct Detection of YSG progenitor (SN IIb)



Van Dyk+ 2011, 2013

First detection of Yellow Supergiant (YSG) progenitor.

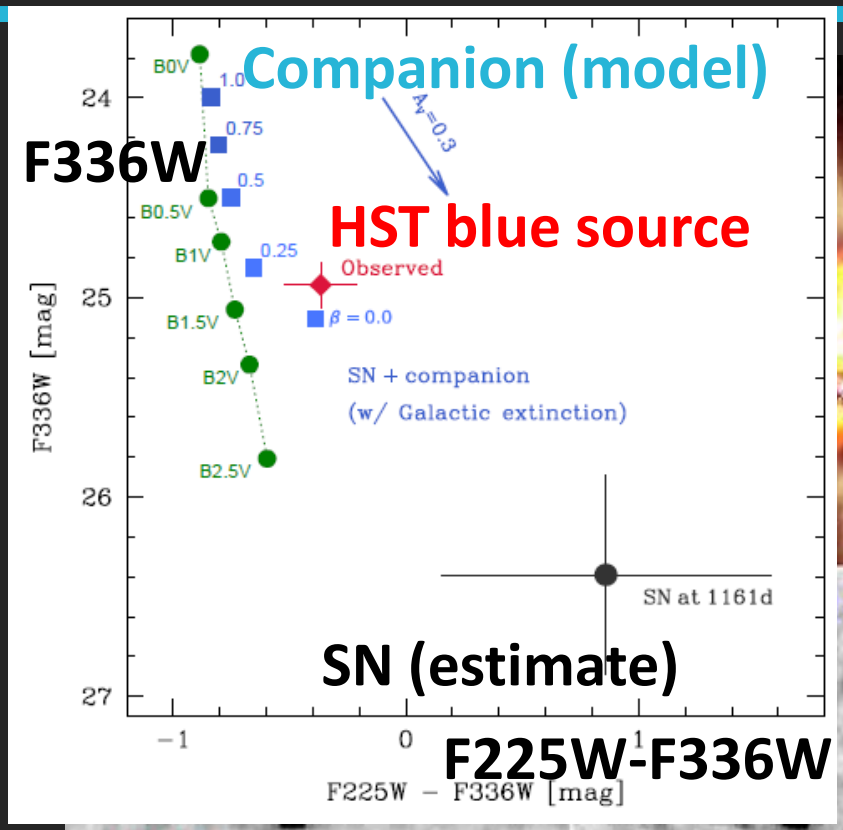
Need binary evolution.

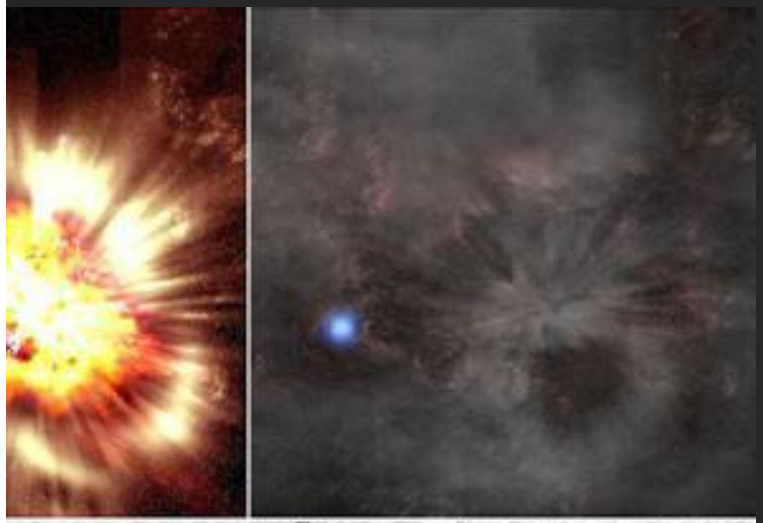
Prediction: Blue MS companion.

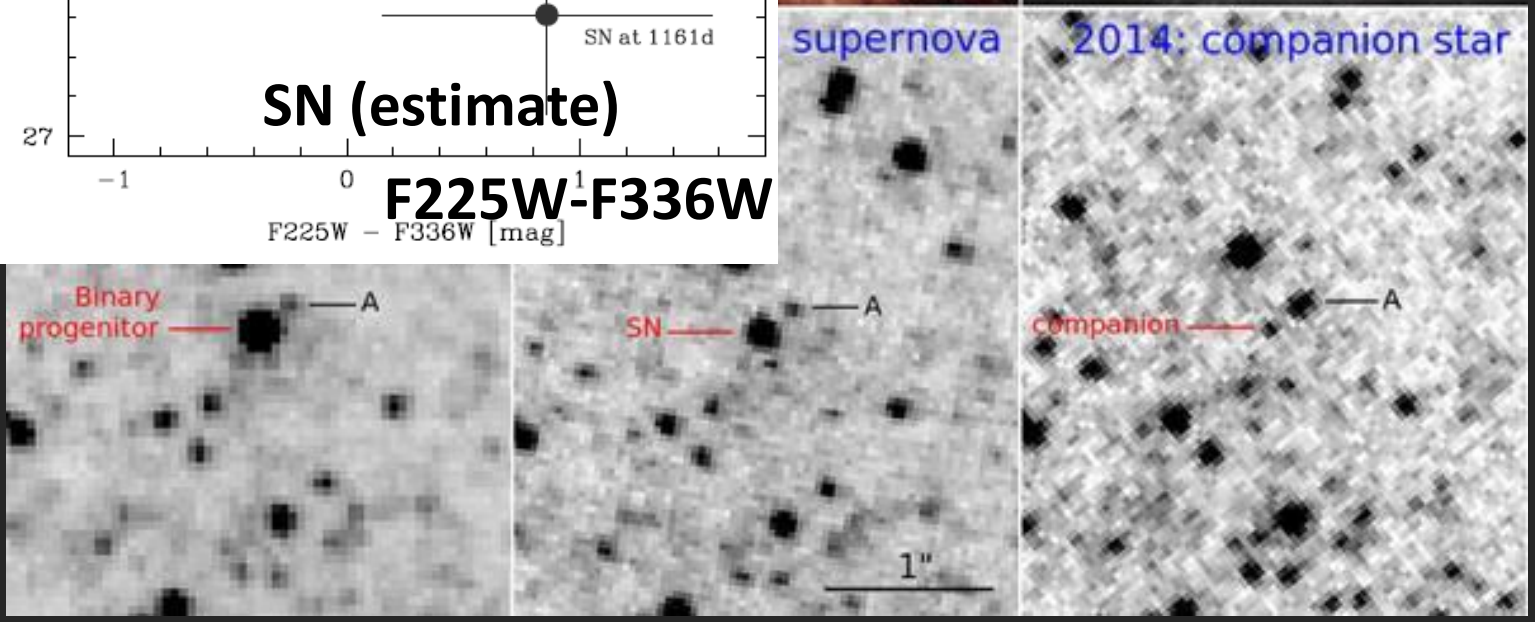
Bersten+ 2012

Folatelli+ 2014, ApJ, 793, L22 (←Folatteli, KM+, HST cycle 21)

Direct Detection of Companion (Candidate)







Summary

- **Optical observations in late-phases.**
  - ejecta symmetry, unburnt materials in SNe Ia, SN Ia outliers and diversities.
  - binary evolution toward core-collapse SNe, nature of a companion star.
- **NIR observations in late-phases.**
  - Dust formation, explosion physics and progenitor, CSM environment.
- **High spectral resolution observations.**
  - CSM around SNe Ia.
  - An origin of DIB.
- Various Observations/analyses ongoing. Stay tuned.