Supernova Science in NIR

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Will move to Kyoto from this fall.

Summary

- SN follow-up.
- Progenitor (pre-SN and post-SN).
- NIR Transient Survey (esp., dusty environment).
- Lensed high-z SNe survey.

  - Intensive time + flexible coordinate are required.
  - Some need AO, and the IFU preferred (over 2d-MOS).

Current Status of NIR SN follow-up w/ > 6m

Example: SNe Ia by CSP II (Carnegie SN Project II).

- **6.5-m Baade + FIRE**
  3+ nights/month
  CSP, CfA(Kirshner, Marion), Australia (Lidman), Chile (Förster)
- **8.1-m Gem-N + GNIRS**
  3 hours/month
  GNIRS is kaput...
- **8.1-m Gem-S + FLAMINGOS-2**
  FLAMINGOS-2 is kaput...
- **8.2-m VLT + ISAAC**
  3 hours/month
  through Stritzinger, not continued
- **3.6-m NTT + SofI**
  through PESSTO
- **3.0-m IRTF + SpeX**
  through Marion et al., 2013A?
- **8.2-m Subaru + IRCS**
  nebular phase, through Maeda et al.

Main driver: 6.5m, 3+ nights/month

8m, ~ 1 night/month in total

3-4m, photo. + very nearby / bright phase SN spec.

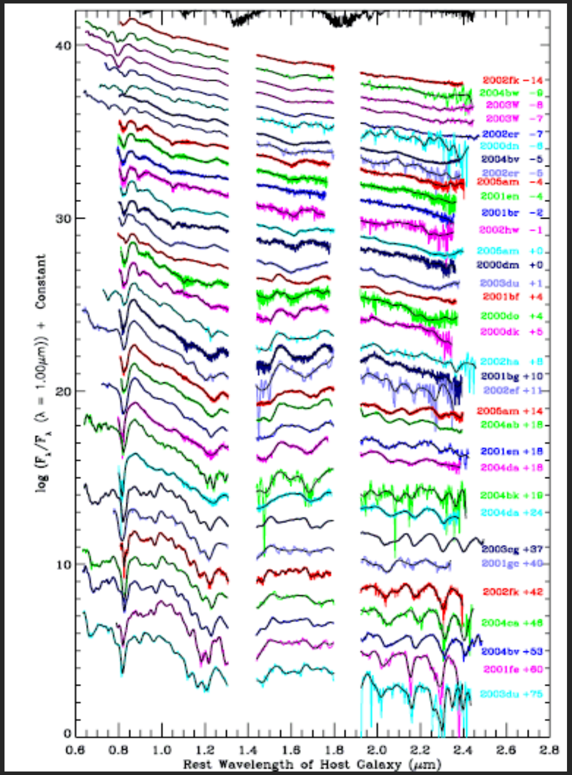
Subaru (IRCS). Loosely collaborating (KM+, 8 nights in 2011-2012)

Why NIR?

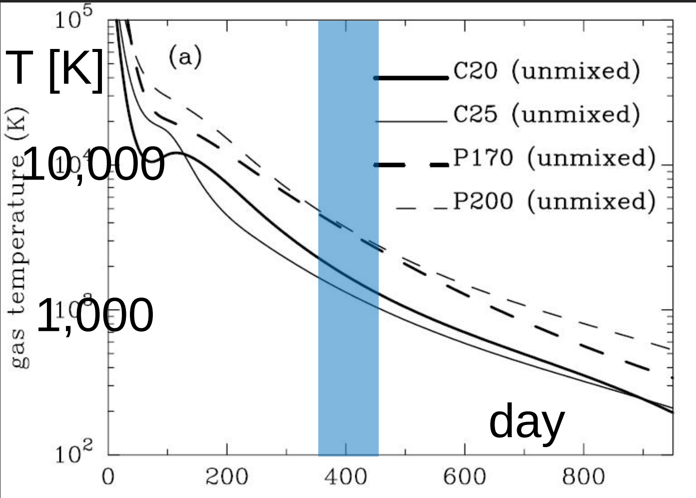
- SNe Ia are better standard candles in NIR than opt.
- Diagnostics different from optical.
  - Ionization, excitation temperature.
    - e.g., Mg, C in SNe Ia, He in SNe Ic.
- Extinction measurement (w/ opt).
- Dust detection ability.

- But still rare.
  - Especially, spec. and/or non SNe Ia.

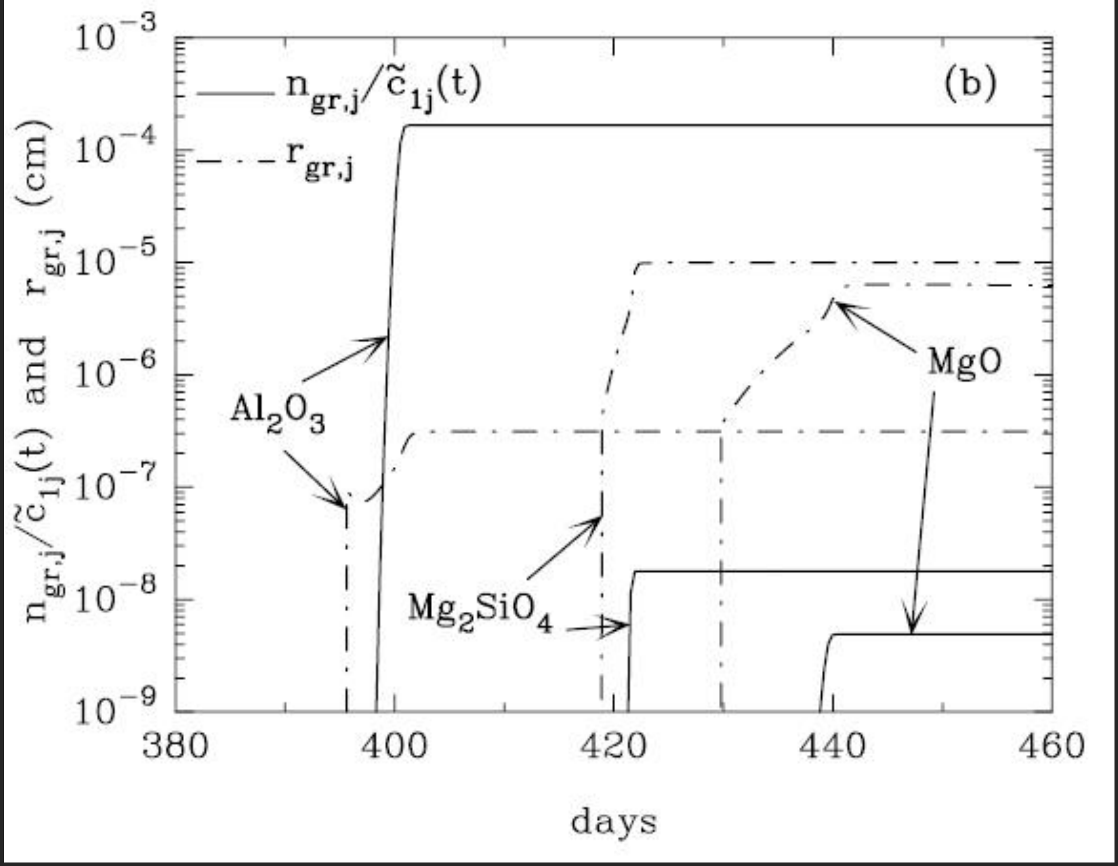
Marion + 2009



Dust (and Molecular) Formation in SNe



Nozawa+ 2003

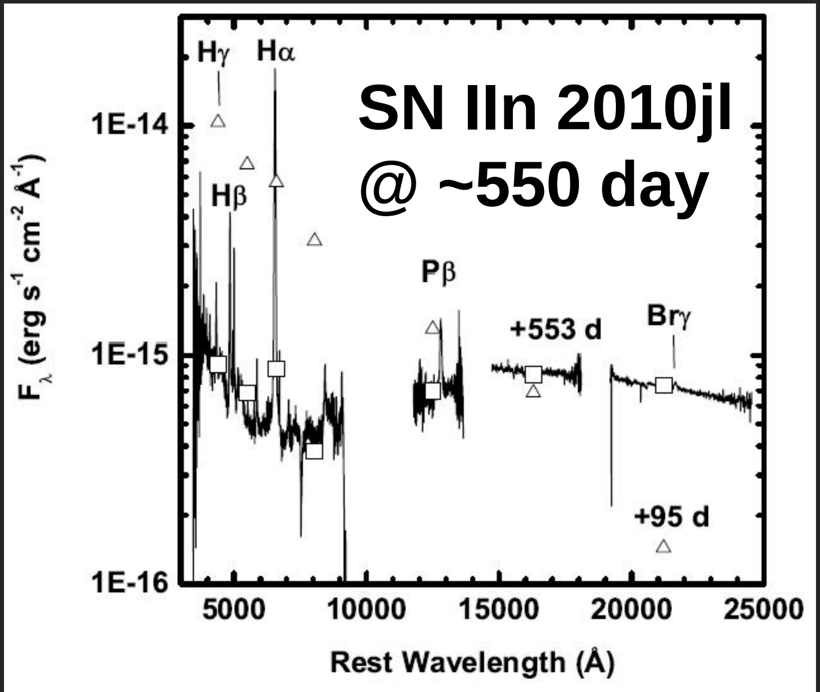


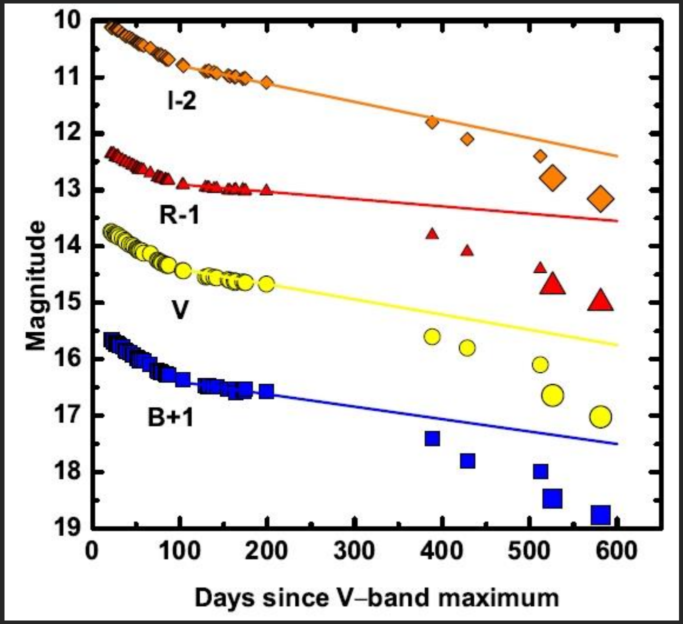
Condensation Temp.
~1,000 – 2,000 K

Dust "Formation" seen @ NIR

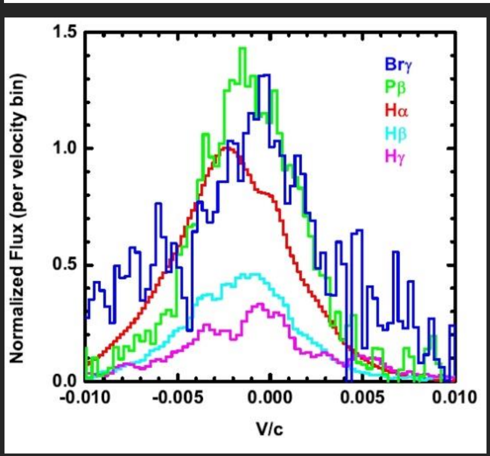
species, mass, temperature, size, distribution?

Dust Formation seen @ NIR



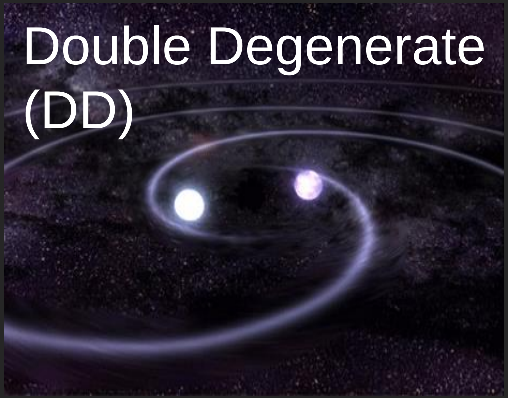


KM+ 2013, ApJ, accepted



Species ← NIR SED.
Mass ← NIR SED.
Temp. ← NIR SED.
Size ← Opt – NIR Line profile.
Distrib. (clumpiness) ← Opt – NIR LC.

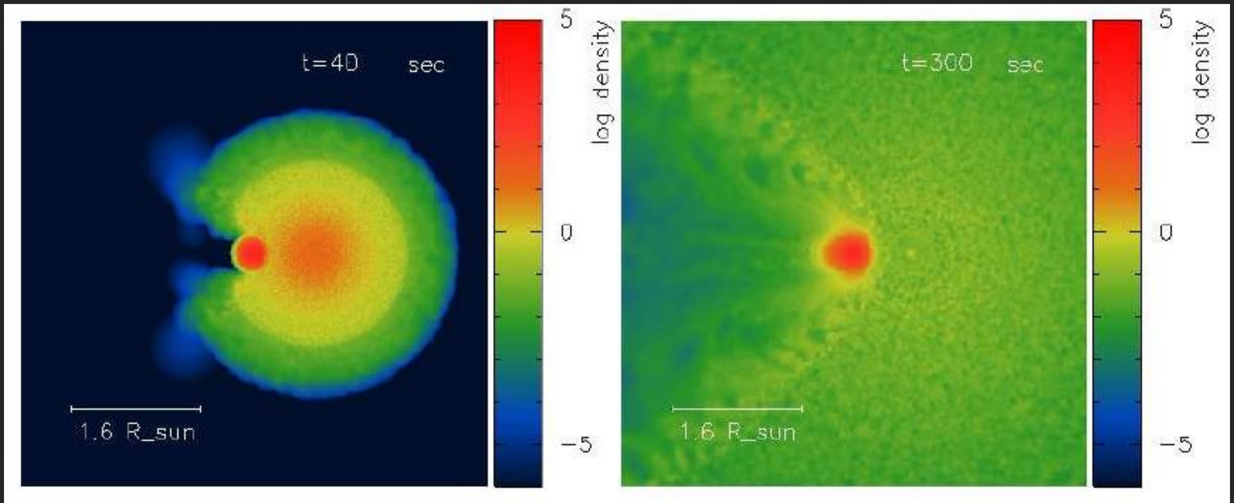
SN Ia Progenitor



- Delay time (←SN rate evolution).
- Progenitor companion search (RSG/MS vs. WD).
- Interaction signal from CSM (optical, radio+X).
- Early UV/blue emission due to the collision w/ a companion.
- Hα in late-time (collision w/ a companion).

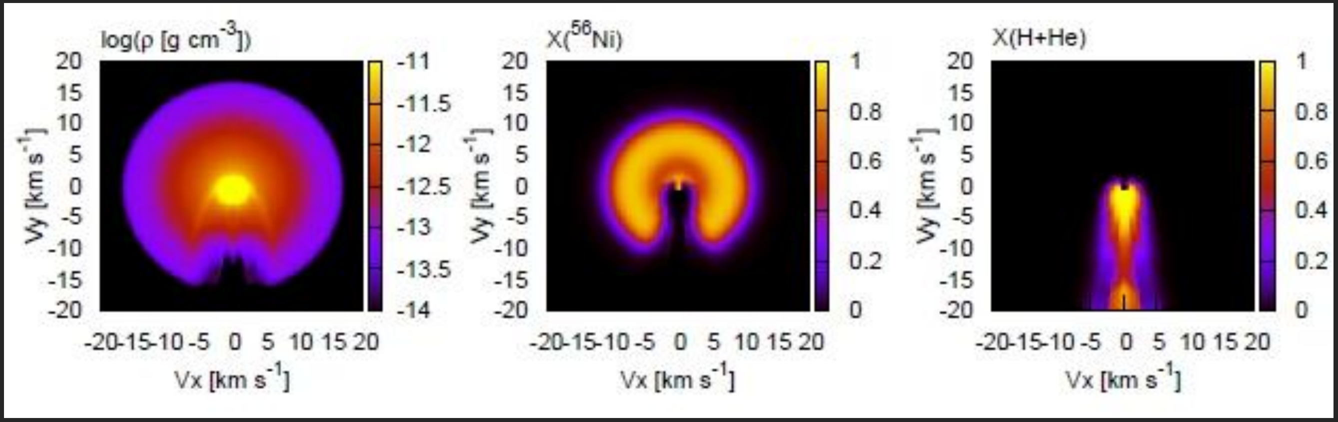
- Some prefer DD, others SD.
- Can be dependent on model assumptions (in some cases).
- Combination of Independent methods encouraged.

SN Ia Progenitor: Is Hydrogen there?



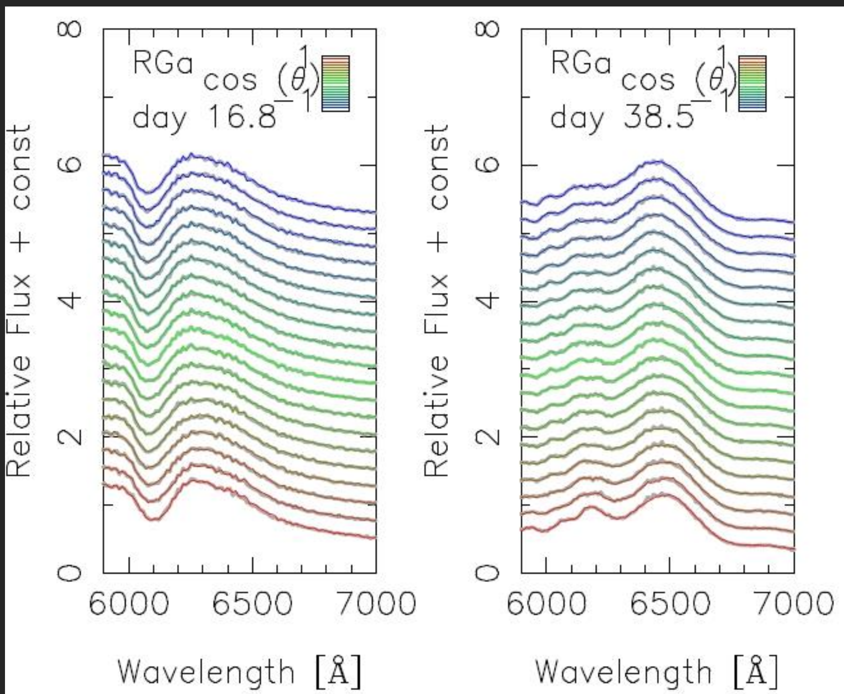
Liu+ 2013, ApJ, accepted

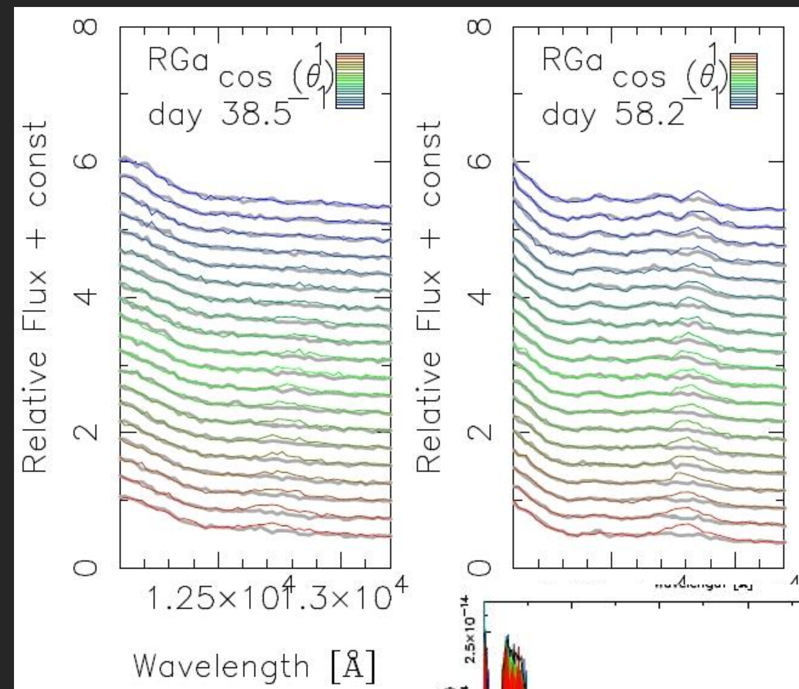
Kutsuna, Shigeyama, 2013, submitted
KM, Kutsuna, Shigeyama, in prep.



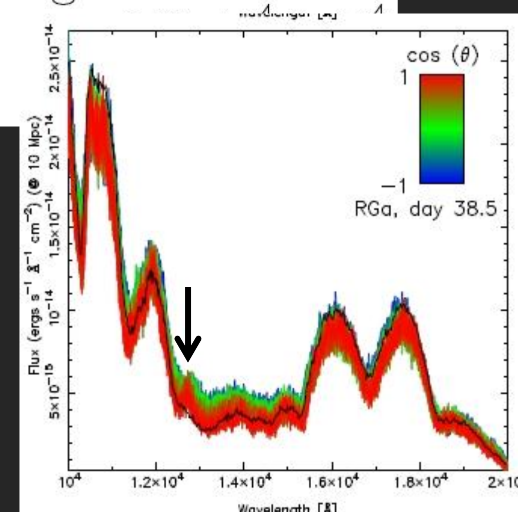
SN Ia Progenitor: Is Hydrogen there?

Hα peak +20day Pβ +20day +40day





KM, Kutsuna, Shigeyama, in prep.



Could be observationally manageable.

@ 40 – 60day (NIR peak), J ~ 17 - 18 for z ~ 0.02.

Need: low atmospheric absorption @ Pβ.

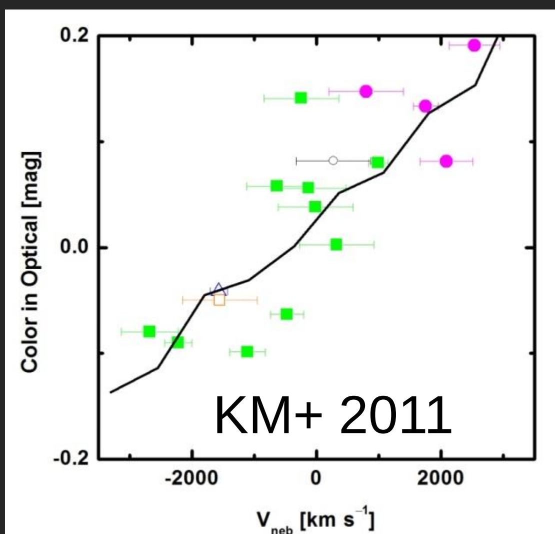
Spectra also useful for "NIR standard candle" calibration.

Extinction

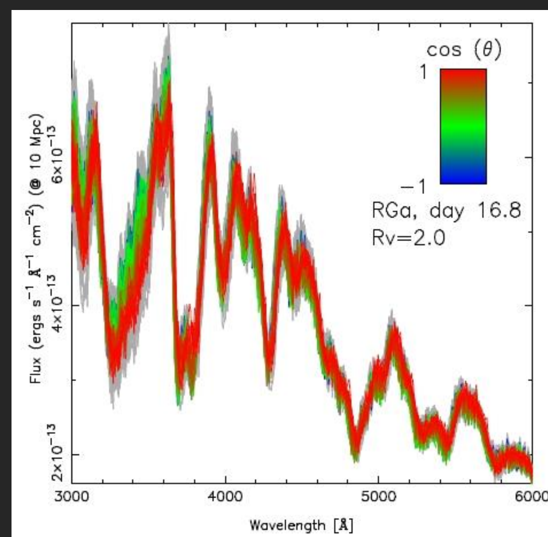
- Intrinsic color vs. extinction (e.g., Ia cosmology!).
  - Low Rv (~ 2) found for SNe Ia. Core-collapse not clarified.

B-V @ peak

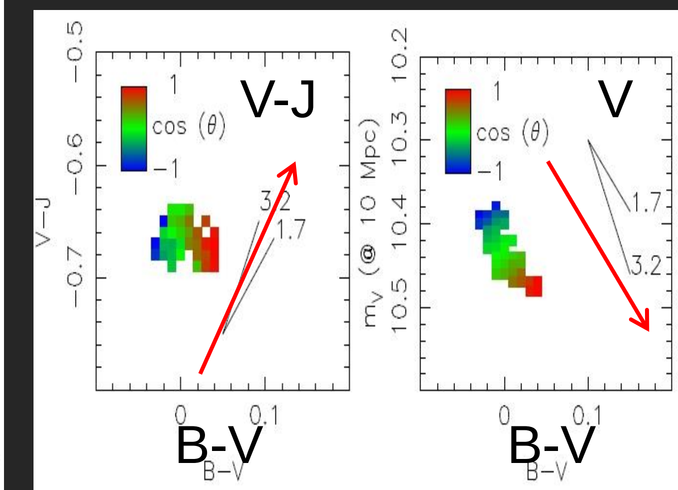
Intrinsic color can mimic extinction.



Line shift in late-phase (intrinsic)



Ex. Companion impact
Red = decrease dispersion
w/ **false** extinction

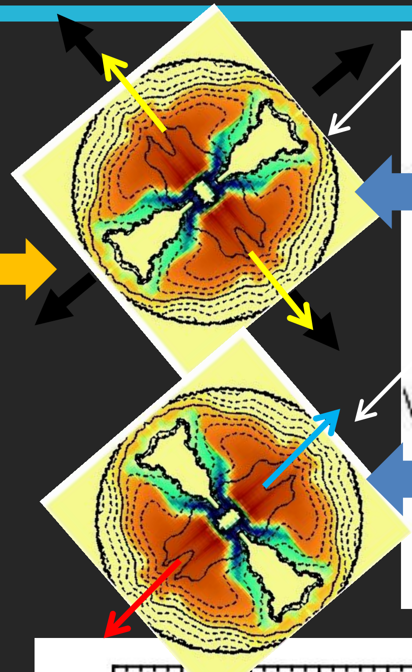


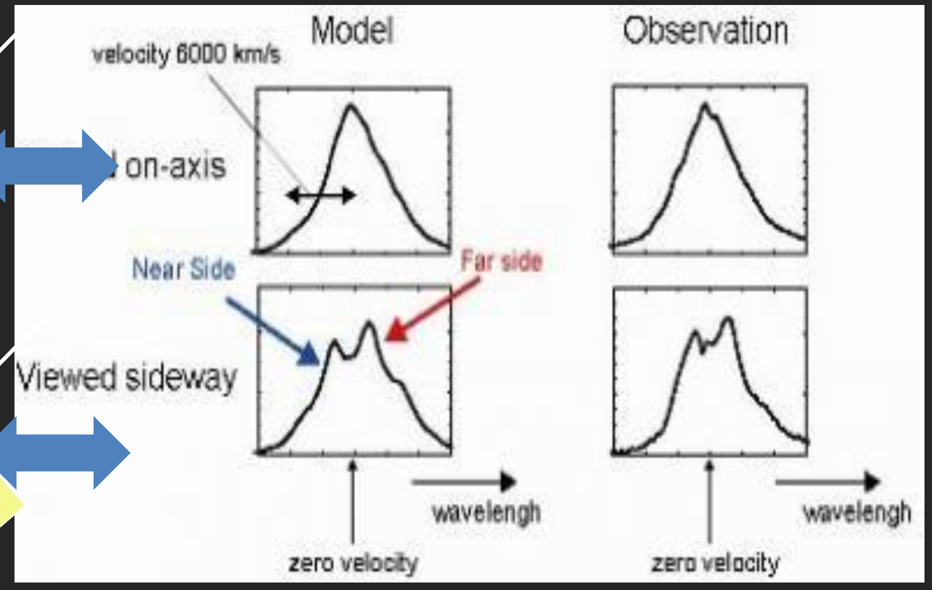
NIR helps

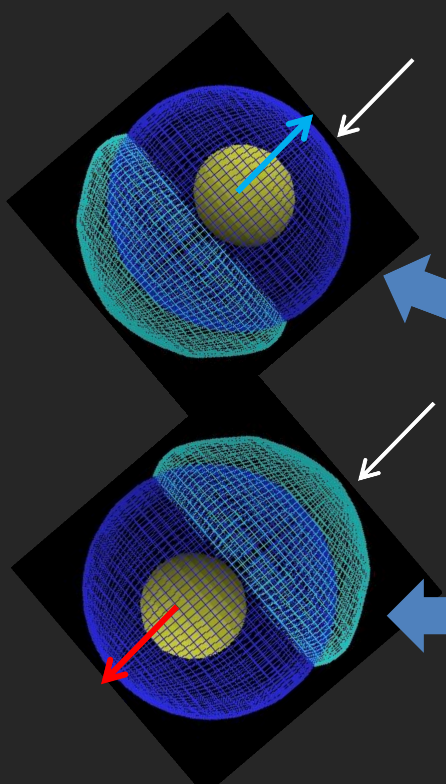
KM+, in prep.

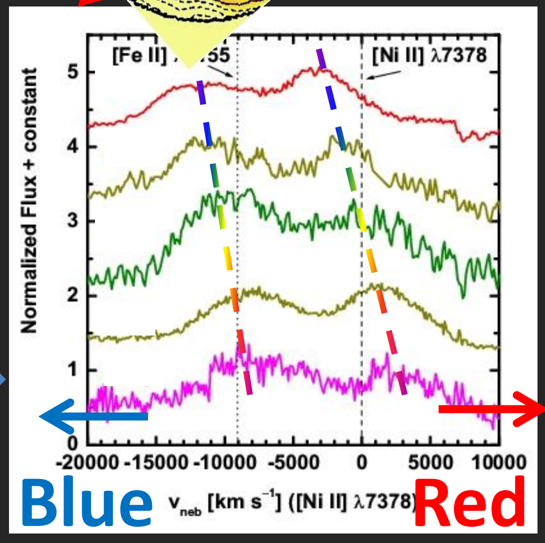
Explosion Mechanism (~ 1 year in optical)

Core-collapse
KM+ 2008
Subaru (8m)







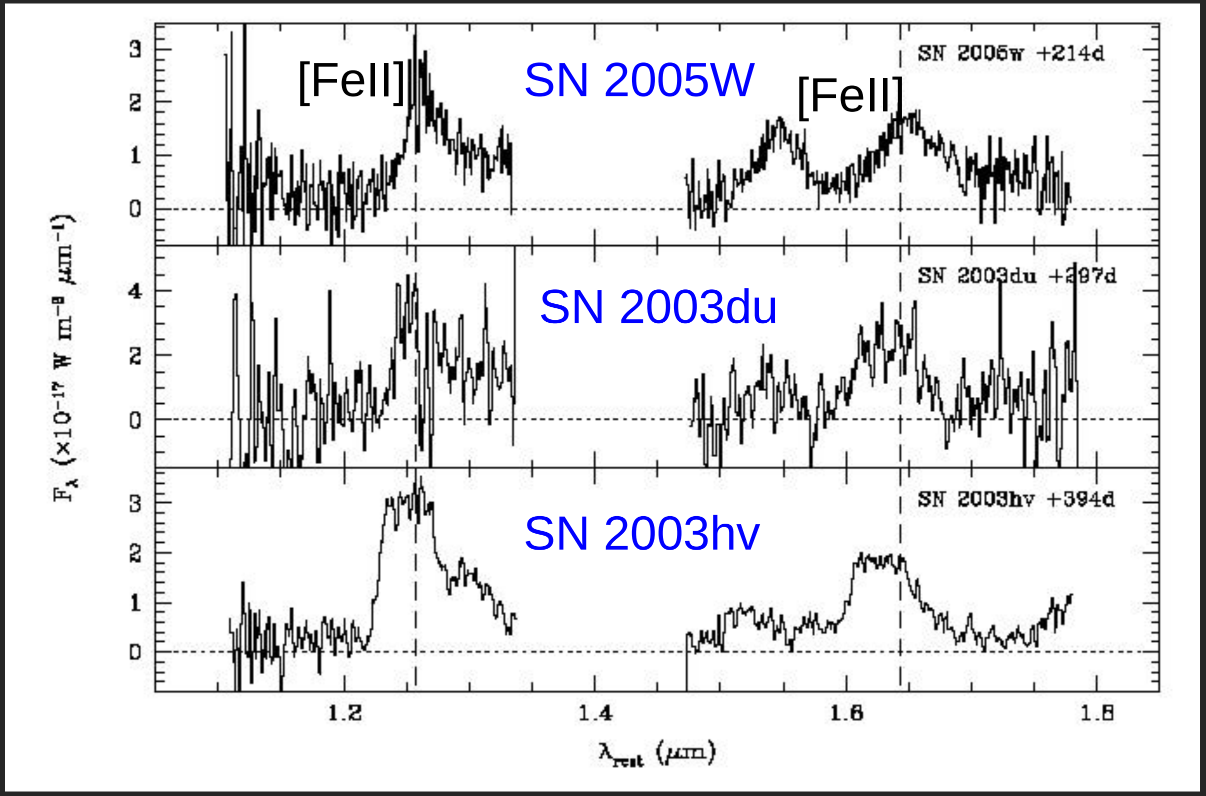


Type Ia SNe
KM+ 2010
Gemini (8m) etc.

Different type of explosion geometry

Explosion Mechanism (~ 1 year in NIR)

- Only ~ 5 SNe with published NIR late-time spectra.
  - 3 by Subaru/CISCO/OHS.



Motohara, KM+ 2006

Variations in
Line Wavelengths
Line Profiles

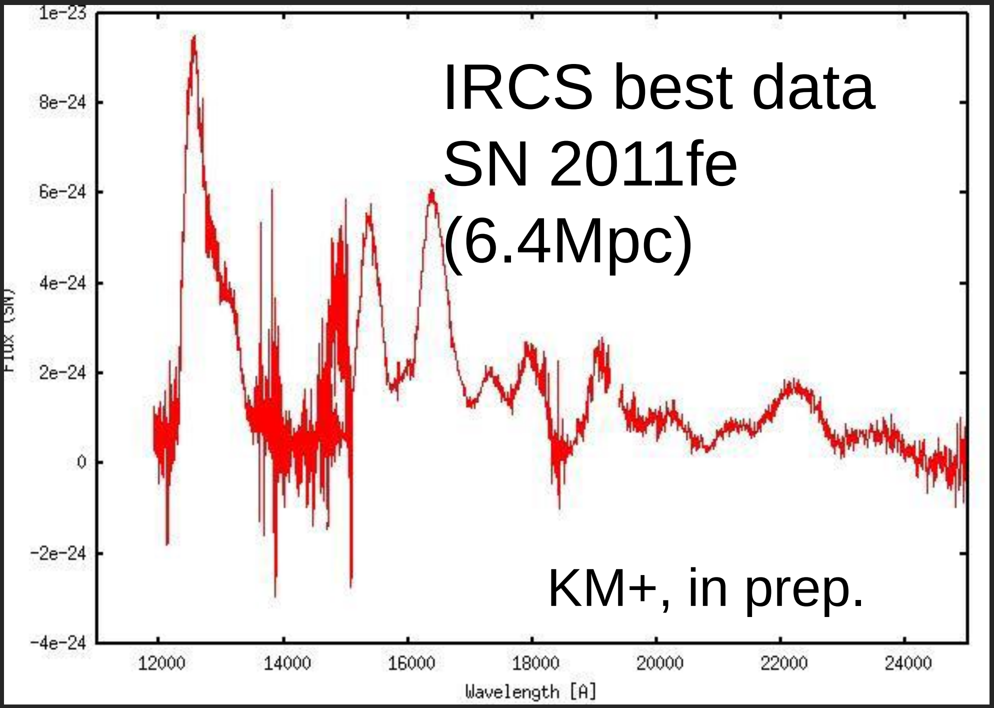
Wavelength = Global
Profile = rel. local

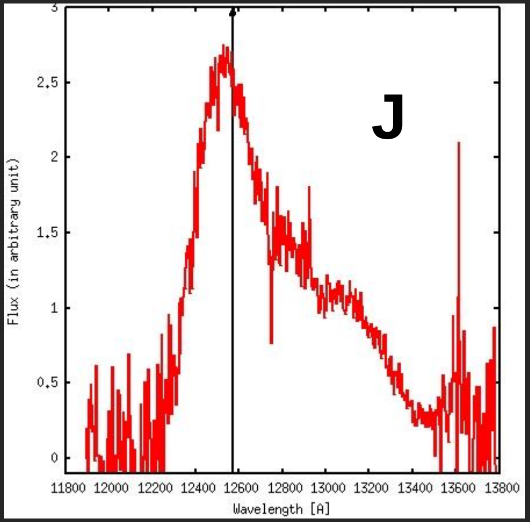
- Line profile is difficult to see in optical (blending).
- NIR line flux quite uniform→extinction?

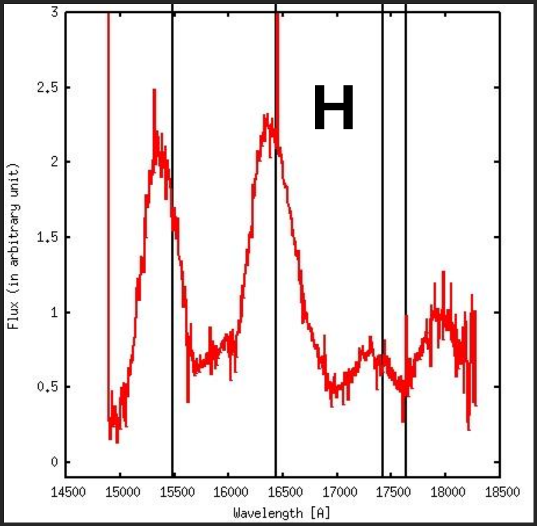
Also a few core-collapse (KM+ 2013, ApJ; Kitagawa+, in prep.)

Subaru IRCS data to come (w/ Motohara-san)

8 nights in 2011-2012, but bad weather…
Even @ 20Mpc, J ~ 19 @ 200 days.
Open use not optimized (need ToO!).
4hr, S/N =10 … J ~ 19 mag w/o AO
~ 20.5 w/ AO





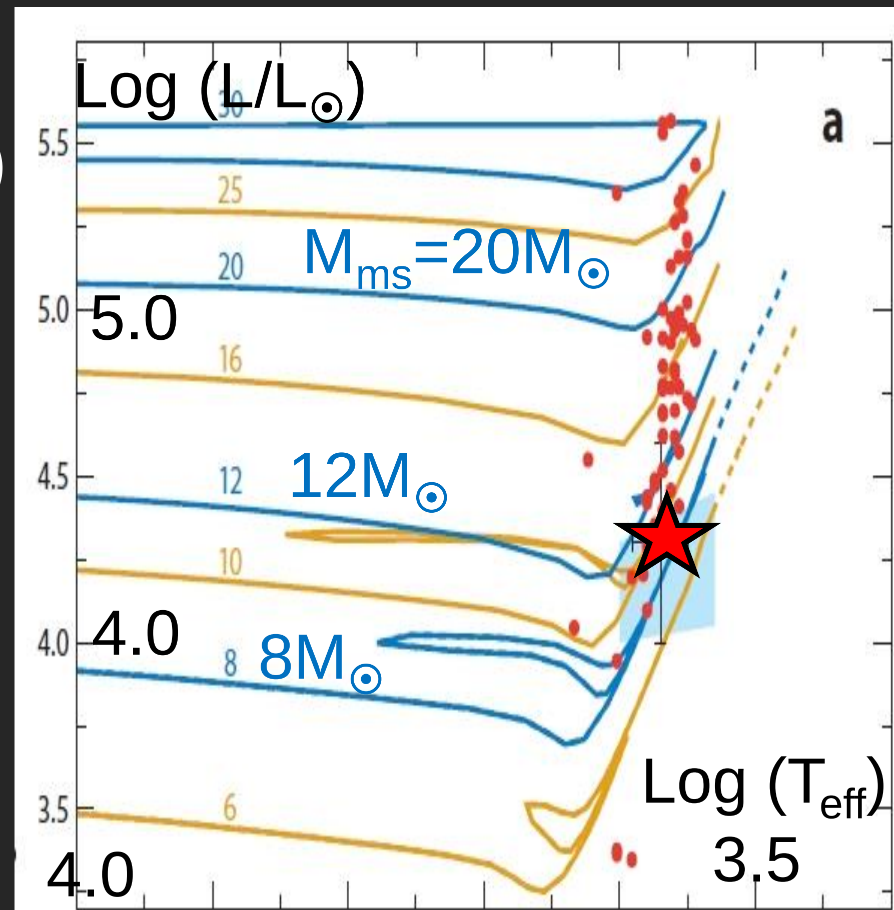


Comment… IFU favored w/ AO

- Single object, point-source spectroscopy.
  - MOS does not help much .
- An issue… AO-induced spectral warping.
  - Critical for SN study… **Temperature** is one of the most important function.
  - **IFU really wanted.**
    - according to own past experience w/ IRCS.

Smartt 2009 (Review)

Progenitor search in past images



Progenitor Detection

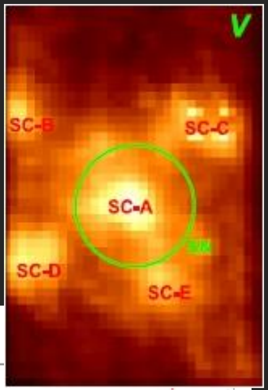
< ~ 10 Mpc with HST.

Good for SNe IIp (Giant, bright in optical)

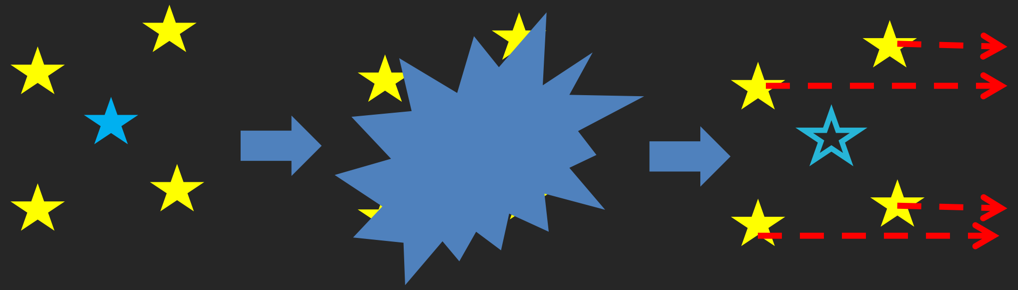
Bad for SNe Ib/Ic (Wolf –Rayet, bright in UV, not in opt.)

Progenitor system search after SN

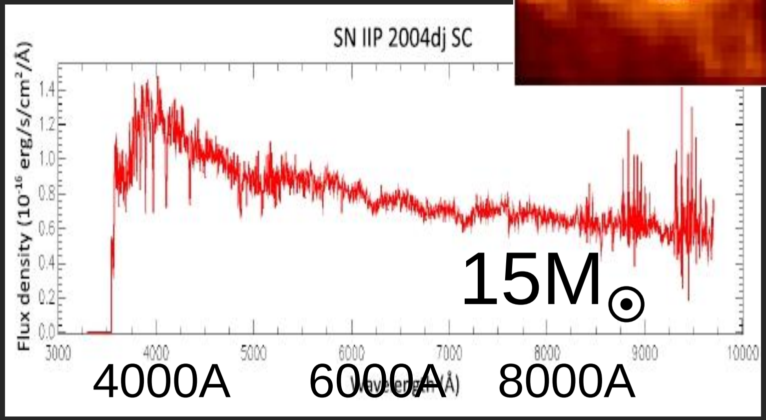
Kuncarayakti+ 2013ab



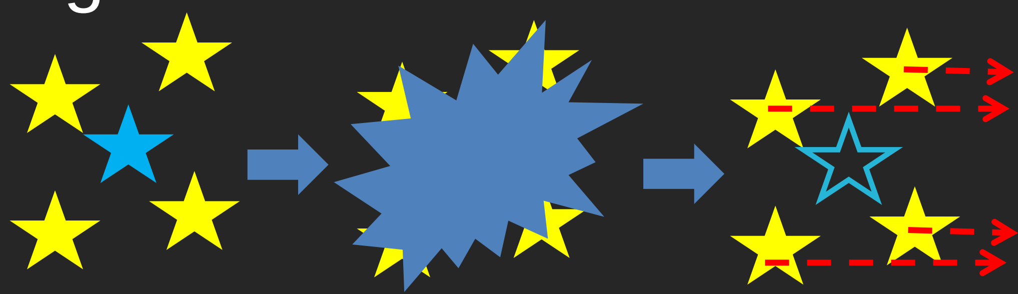
Low mass

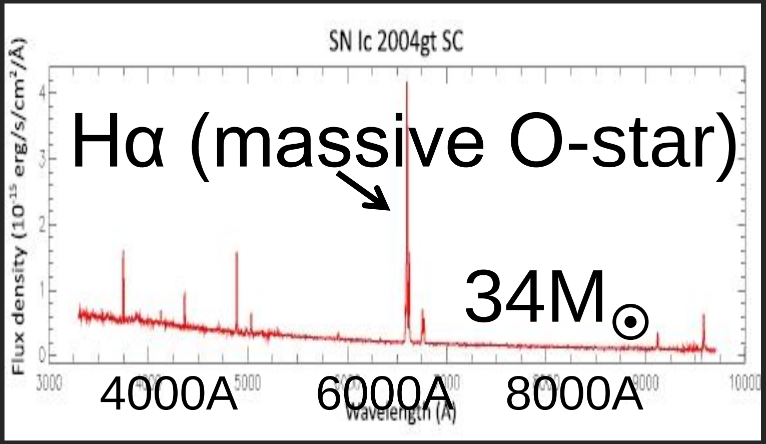


SN > A few yrs



High mass



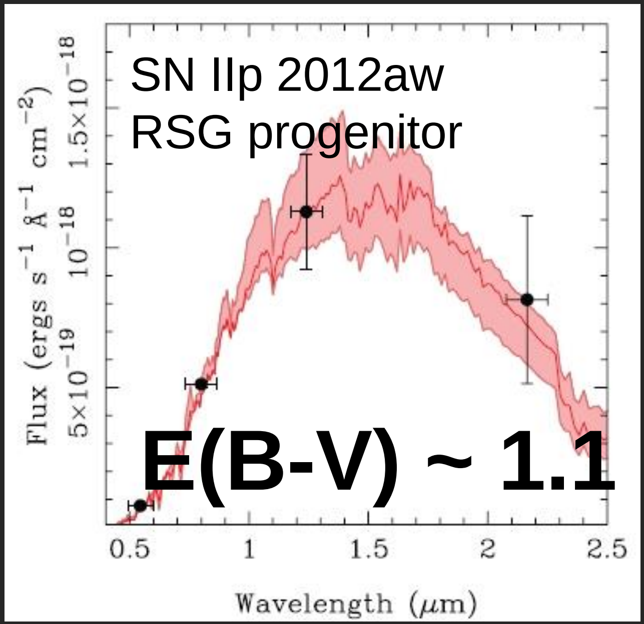


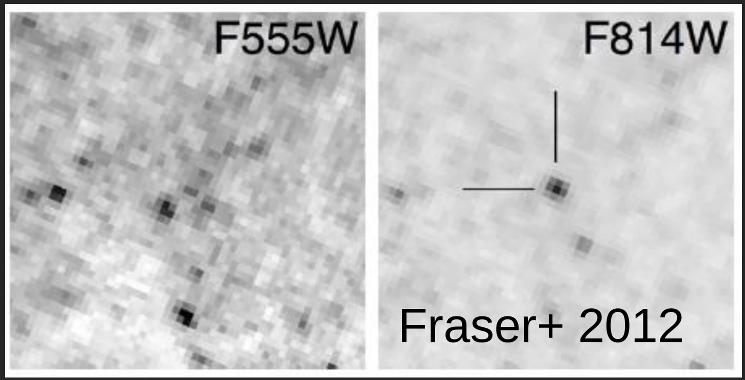
Type of SNe does not matter

Deeper than direct search (w/ 8m-Subaru, VLT)

Pre-SN Progenitor/environment @ NIR

- SN emission may destroy the surrounding dust.
- Need to have **both pre and post SN** progenitor/environment properties.
  - "True" nature of the progenitor (e.g., mass, mass loss).
  - Feedback of SNe on the surroundings.

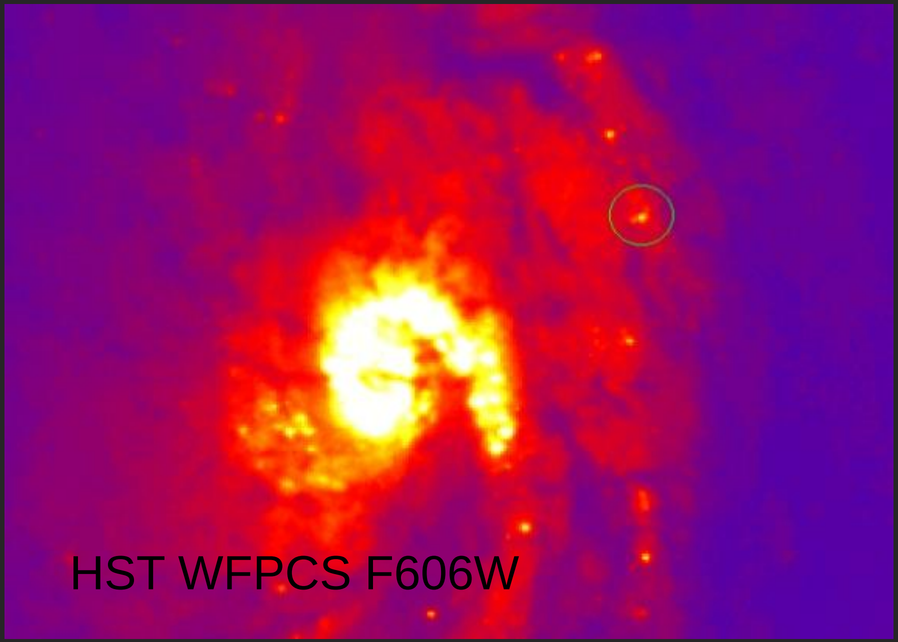


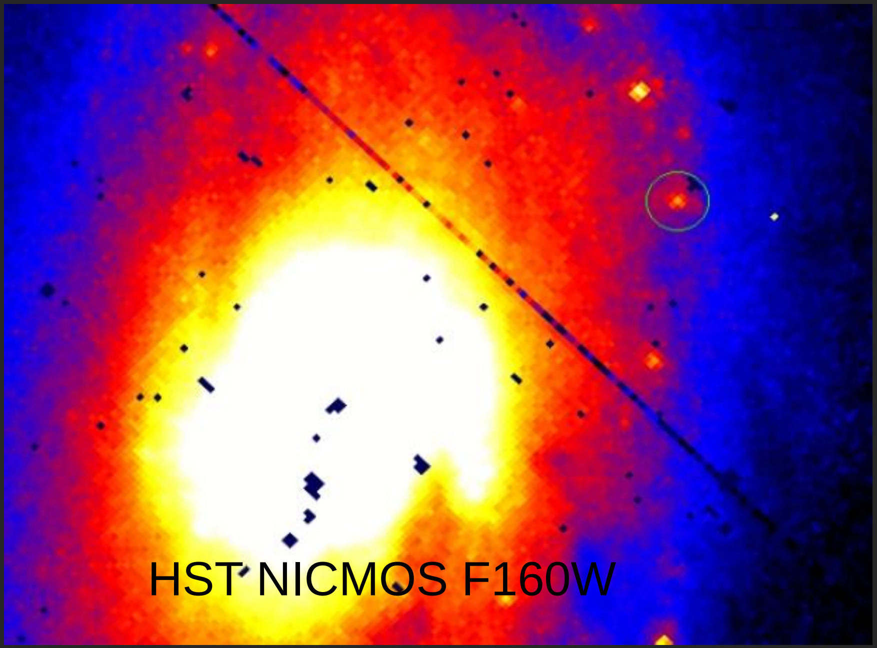


⇔ SN properties indicate E(B-V) ~ 0.1

Pre-SN Progenitor system @ NIR

Work in progress.



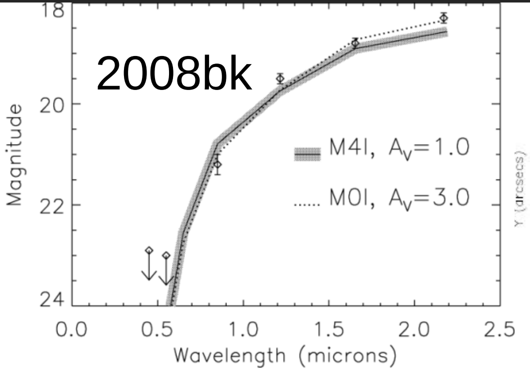


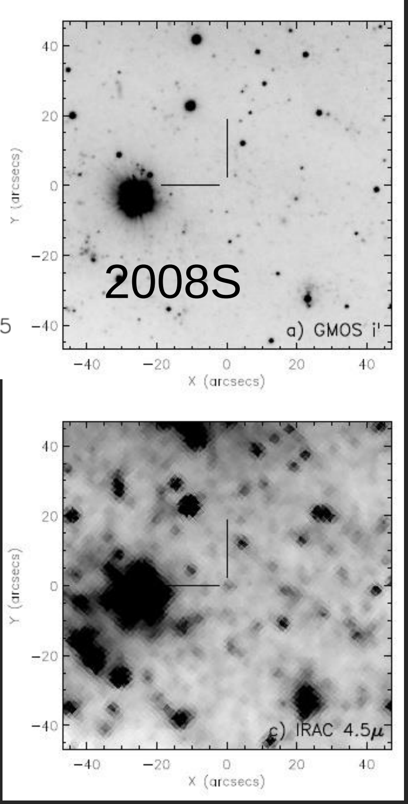
Follateli+ in prep (progenitor analysis by Hanin-san)

NIR progenitor search in pre-SN images

- **A new window for a class of SNe.**
  - E.g., dusty, obscured system (e.g., SN 2008S, 2008bk).
  - Extinction measurement.
- 2008bk progenitor
  - J ~ 19 @ 4 Mpc

  → up to ~ 20 Mpc (J_{lim} ~ 23).





Survey of Star forming galaxies within 20 Mpc for pre-SN template?

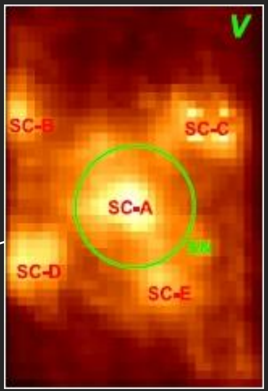
- 0.2" resolution (w/ AO) → 20pc resolution.
- 8' FOW → 50 kpc (single shot for each gal.).

\+ SN AO image (astrometry)

\+ post-SN image (single prog. Will disappear)

NIR… Test systematics in optical progenitor search

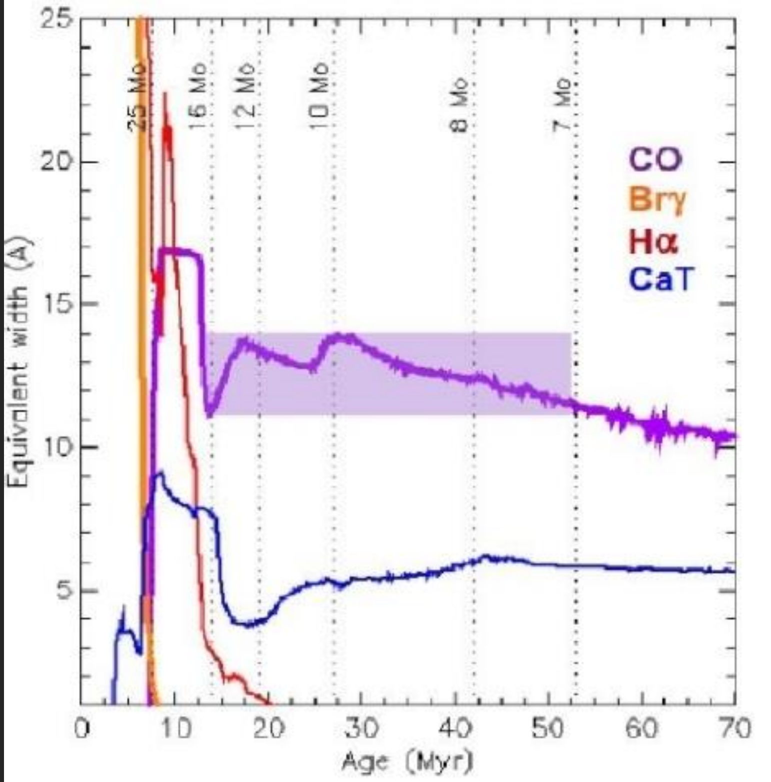
Post-SN Progenitor system @ NIR



Independent estimate on progenitor properties (e.g., mass).
- NIR sensitive to old pop.
- Better resolution than opt.
- IFU or MOS favored.

Progenitor disappeared?
- single vs. cluster.

Extinction.
- pre-SN vs. SN. vs. post-SN.
- SN intrinsic color.



Kunkarayakti+, VLT/SINFONI observations (to come).

NIR Survey – normal environments

- NIR Transient sky has not been explored.
  - A few ongoing, e.g., w/ ULTRA-VISTA.
- May pick up not-yet-known populations.
  - Intrinsically red.
  - Heavily obscured (even in normal galaxies).
- Can be arranged w/ NIR SN Ia cosmology survey.

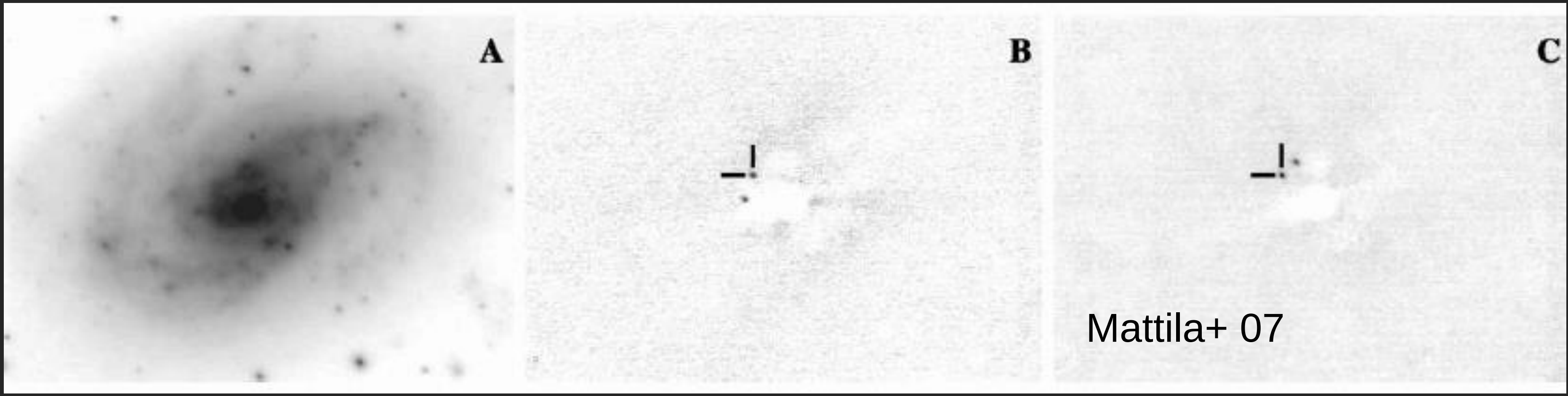
NIR Survey – Dusty environments

- **SN search has been conducted in optical.**
  - SNuB = SNe / 100yr / 10^{10} (L_B/Lsun).
- **A large fraction of SF = dusty starburst galaxies.**
  - SNe in LIRGs (+ULIRGs) are HIDDEN.
  - L_B in these galaxies is NOT a good measure.
- **Cosmic SN rate is then highly model dependent.**

- Importance of **DIRECT SN detections** in dusty galaxies.
  - Go to NIR. SNuJ, SNuH, SNuK.
  - Core-Collapse SNe.
- Morokuma-san?

Obscured SNe Search

- **A lesson from the past study** (Grossan+ 99).
  - Even in NIR, a large fraction of SNe are likely missed.
  - Why? Host galaxy nucleous (so, →AO).



- VLT program, but not much progress (seems time and follow-up difficulty).

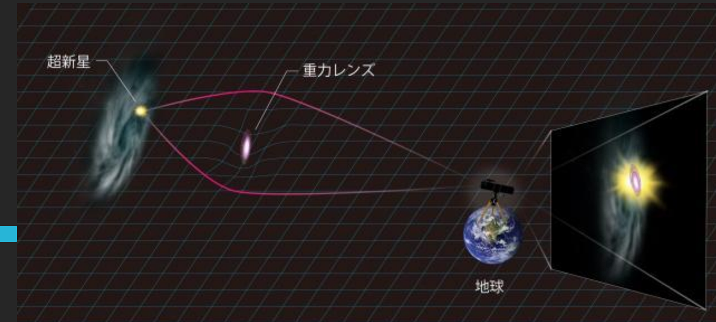
Obscured SNe Search

- M_J ~ -18, A_J ~ 3→ J = 20 - 21 @ z = 0.03. → 10 min?

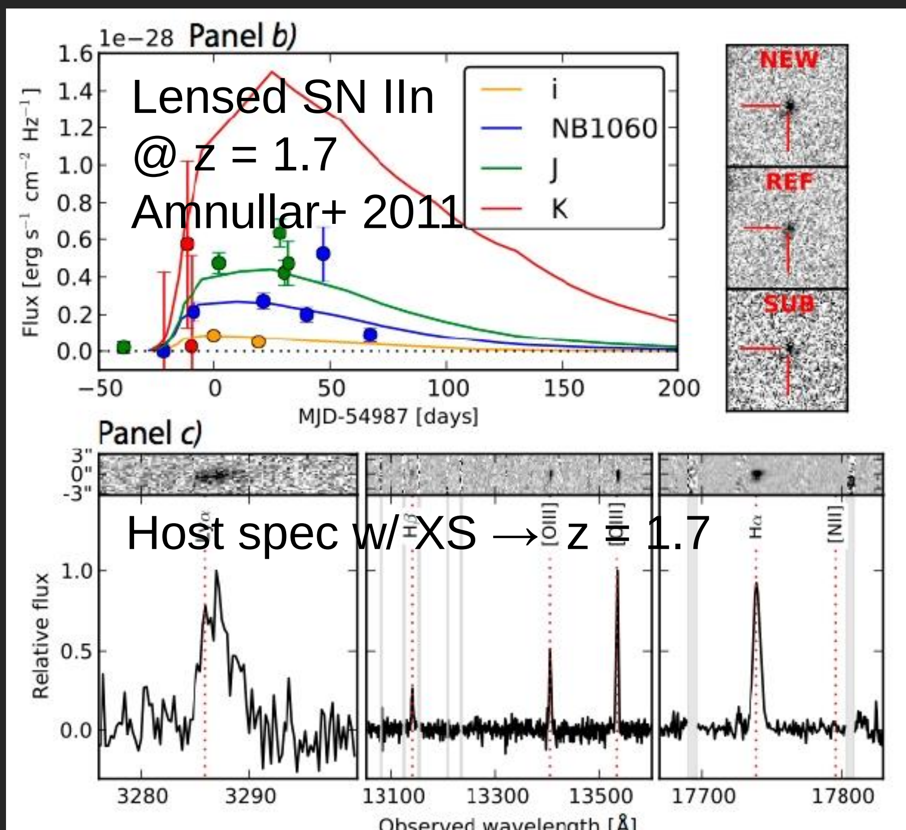
- **LIRGs AO patrol** at z < 0.03.
  - L_{FIR} ~ 10^{10-11}Lsun, 10 (?) SNuFIR => ~ 0.1 – 1 SN /yr/gal.
  - **30 galaxies x 10 min/month => ~ 3 - 30 SNe II/1 year survey.**
- Exposure time should be optimized.

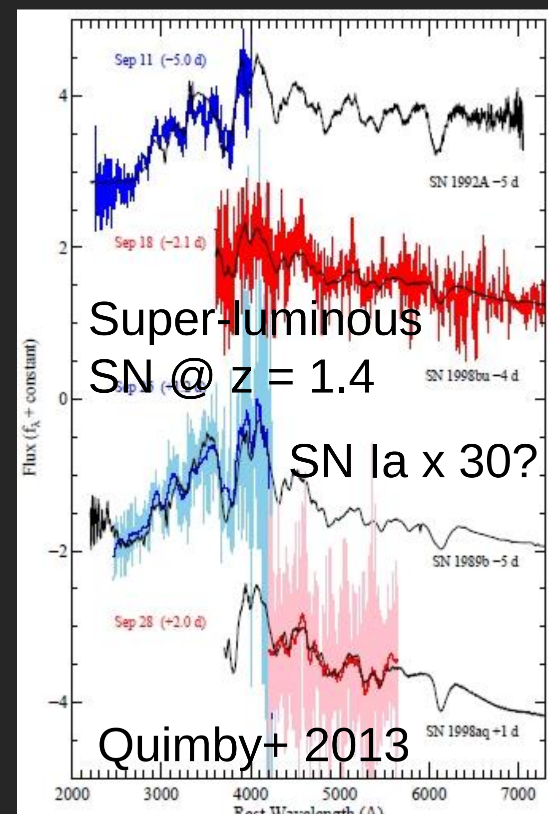
- **Why TAO?**
  - NIR AO. Patrol observations (hard w/ 8m at least now).
  - Flexibility for follow-up.

Lensed SNe

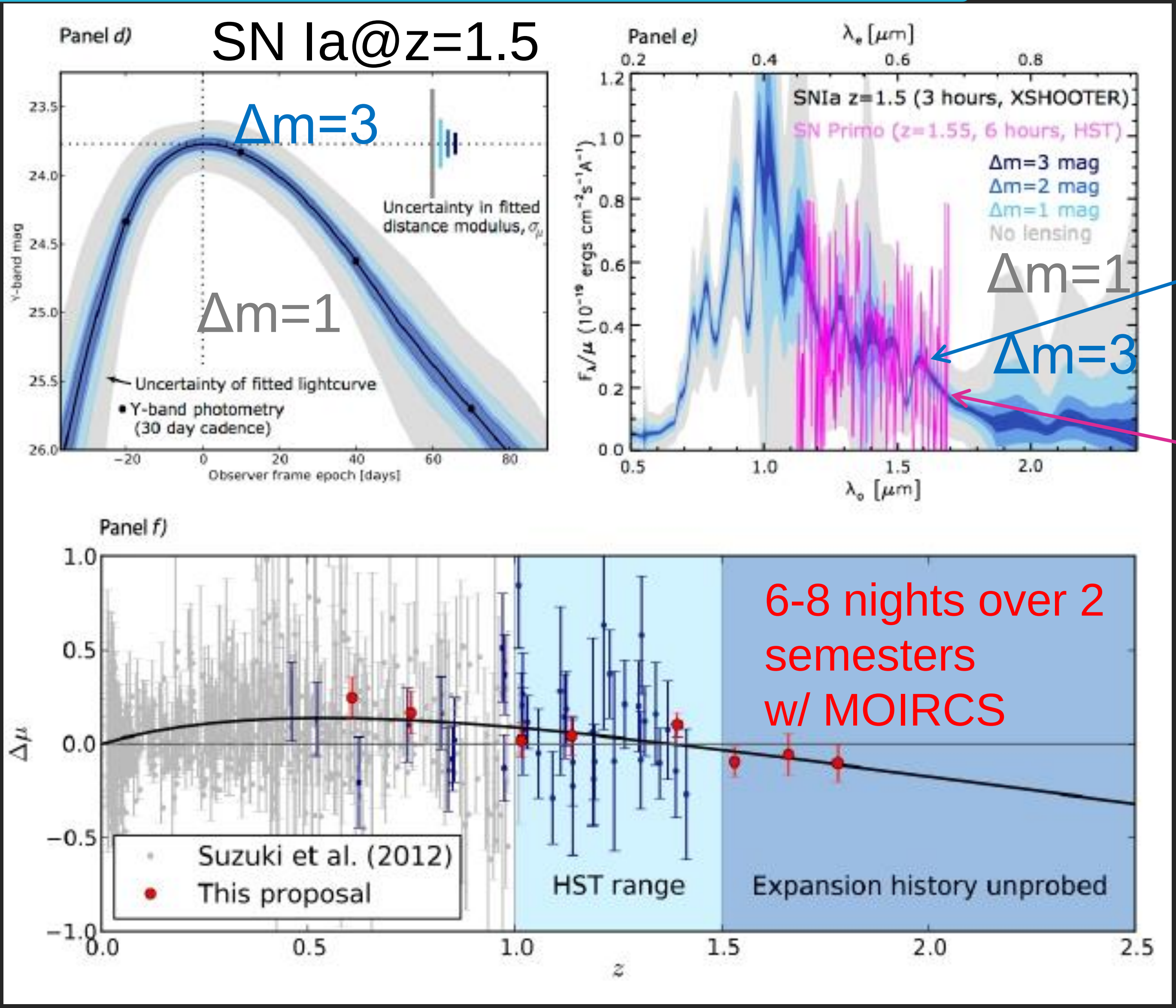


- High-z SNe can be detectable behind a cluster (or something else), thanks to lensing magnification.





Lensed SNe – cluster survey



Lensed, XSHOOTER, 3hr

No-lense, HST, 6 hrs

Lensed SNe – cluster Survey

- Follatteli+ (Amanullah, Doi, Goobar, Konishi, KM), prop. for MOIRCS.
  - Y = 23.5 at S/N > 5 → 0.5hr in each exposure. 10 clusters/night.
  - 1 month cadence.
    - ~ 10 Lensed SNe in 2 semesters.
  - Spec. follow-up. 3 – 4 hrs by XS etc.
  - Search for second magnified image.
- SN Ia rate and properties @ high z (systematics).
- Cosmology from high-z HD + time-delay.
- 8m open use not optimized → TAO/SWIMS promising.
  - Survey.
  - Spec. followup. AO to increase S/N?
  - higher cadence follow-up (for the discovered SNe + 2nd image).

Summary

- SN follow-up.
- Progenitor (pre-SN and post-SN).
- NIR Transient Survey (esp., dusty environment).
- Lensed high-z SNe survey.

  – Intensive time + flexible coordinate are required.
  – Some need AO, and the IFU preferred (over 2d-MOS).