超新星・突発現象研究の現状と今後:
High-z and low-z

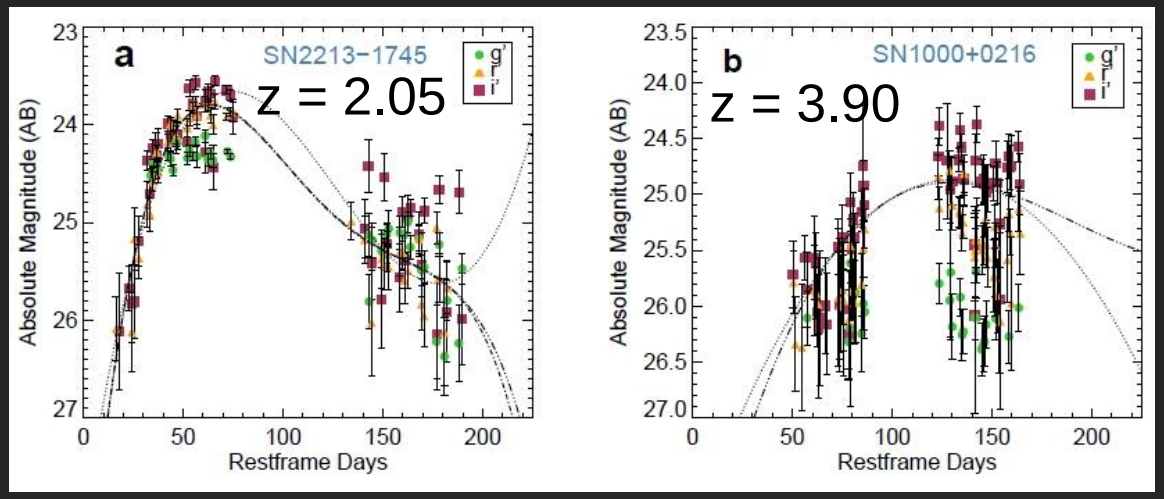
Cosmology
Star Formation History

Stellar Evolution
Explosion Physics

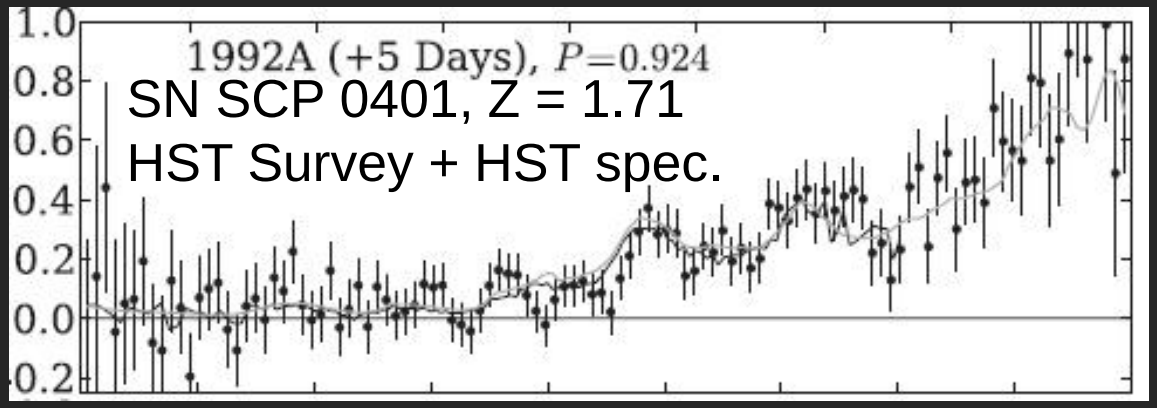
SN Feedback
Metal, Dust, Cosmic Ray, …

Keiichi Maeda (Kavli IPMU, U. Tokyo）

Exploring high-z and z-evolution



Cooke+ 2012, CFHT Legacy Deep (stacking)

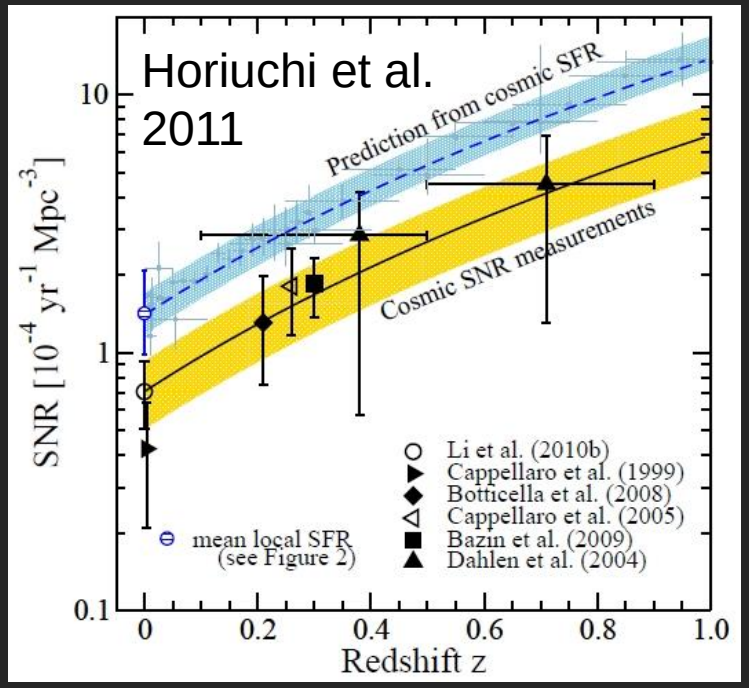


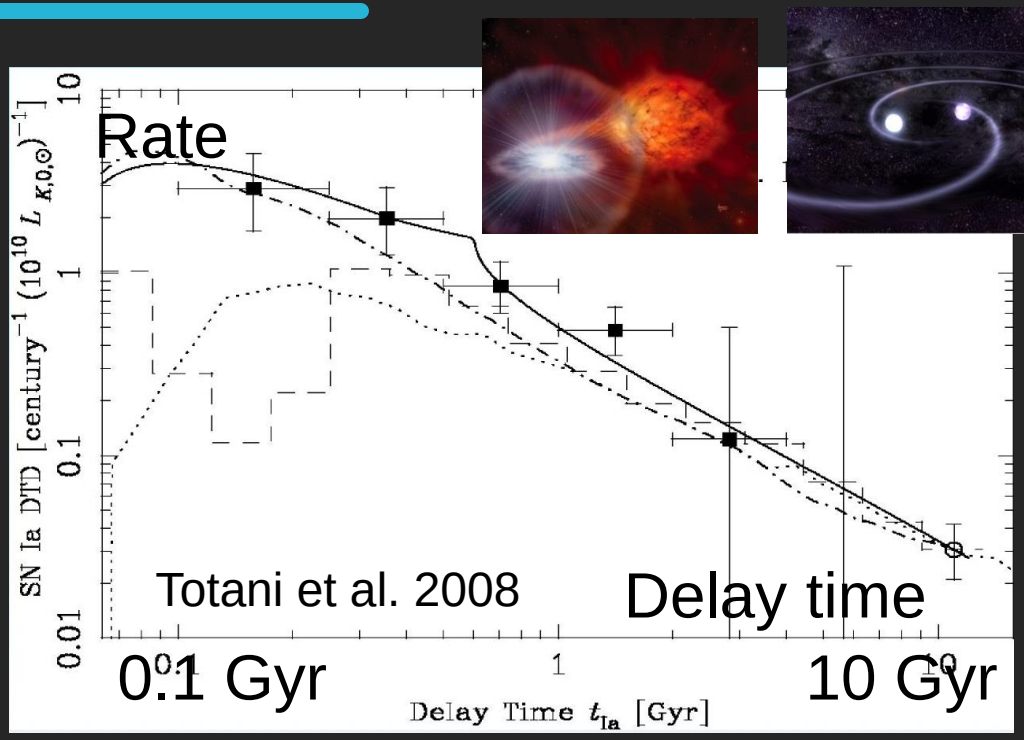
Rubin+ 2013, HST survey + spec. (8 orbits)

Super-Luminous SNe (SLSNe):
Massive star(?)
< - 21 mag,
long lasting (~ year)

SN Ia:
White Dwarf
~ - 19 - 20 mag,
~ month

Exploring high-z and z-evolution





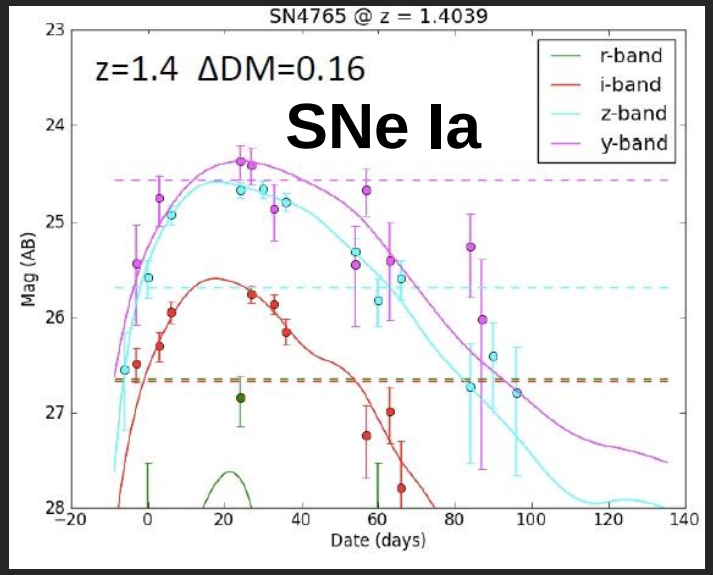
SN rate - SFR

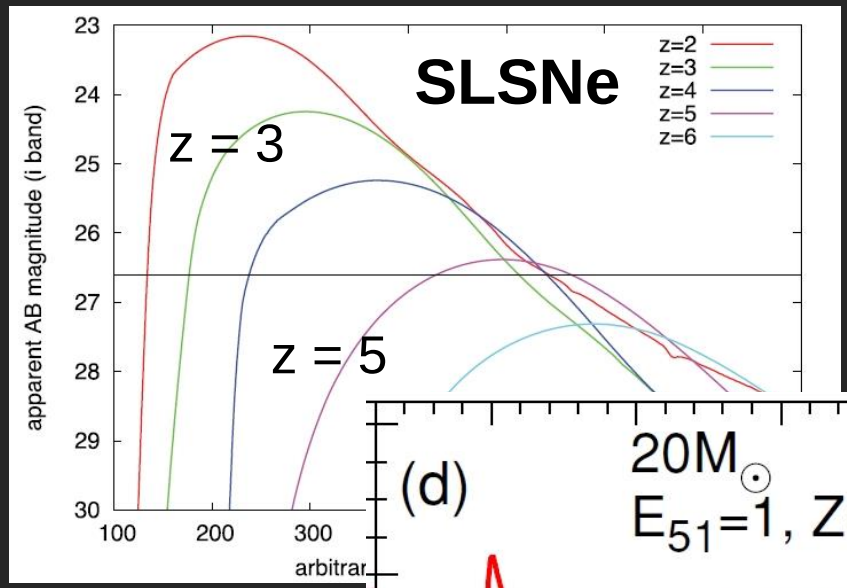
Delay time (progenitors' life time)

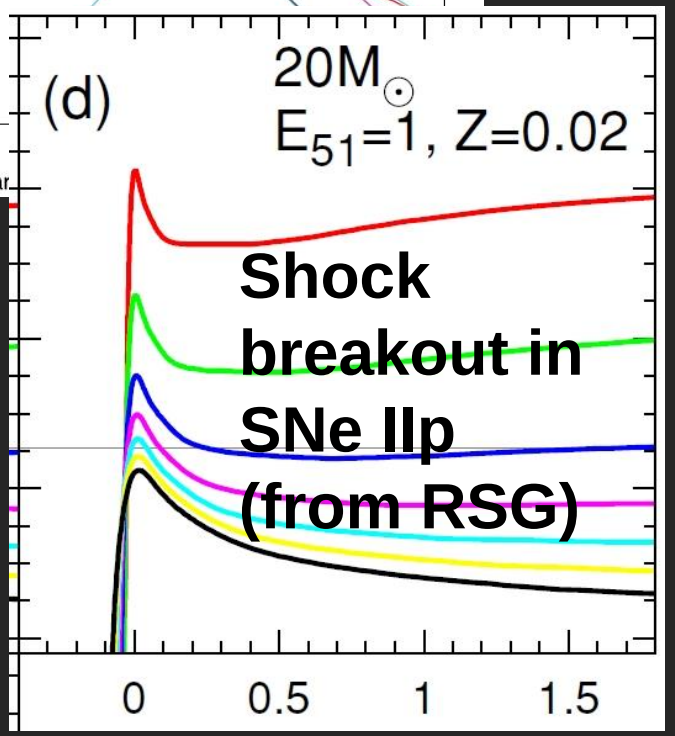
SFR tracer? (⇒ Star formation, Galaxy evolution)
Different SN populations? (⇒ Stellar evolution)
Change in SN properties? (⇒ Cosmology)

High-z SNe @ optical (future)

Moriya+ 2012; Tanaka+ 2012





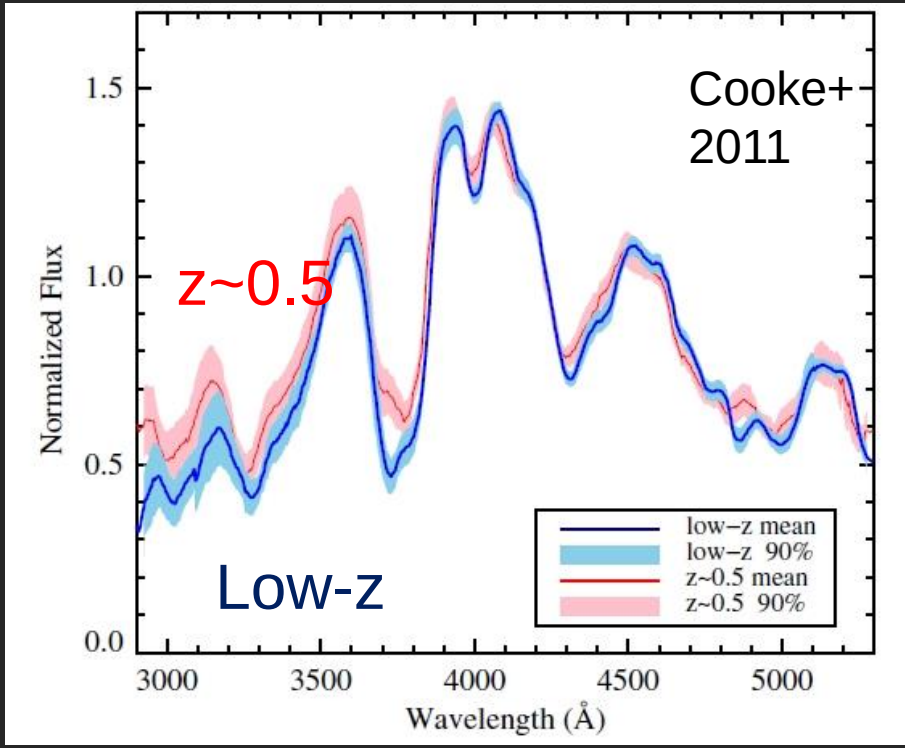


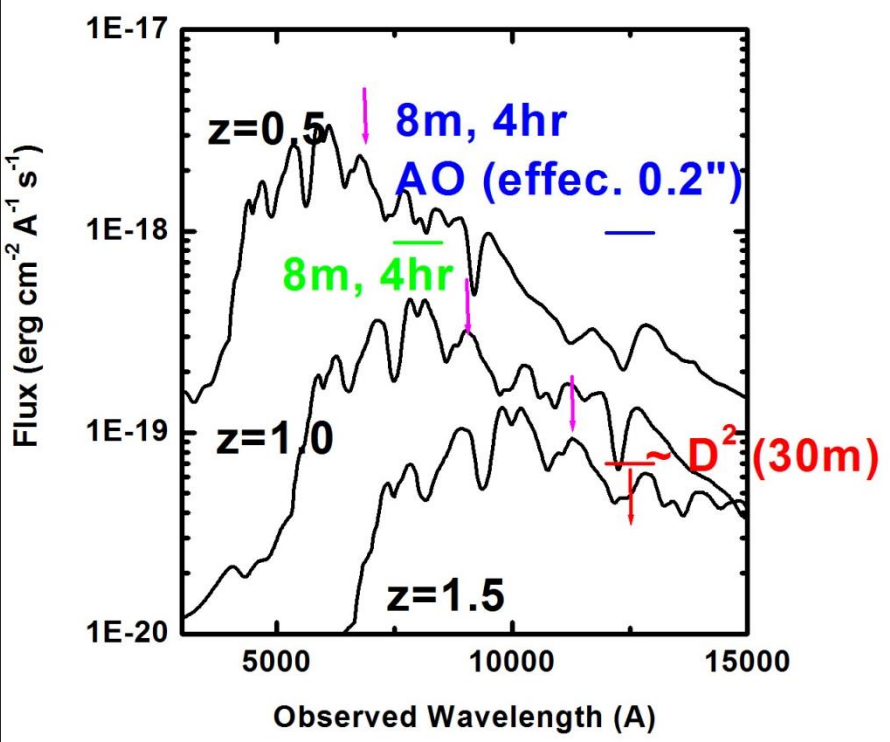
HSC survey expectation (Yasuda+)

8m-survey ⇒ spec. requires 30-m class.
TMT in the future (or JWST).

Tominaga+ 2011

Evolution w/ redshift?

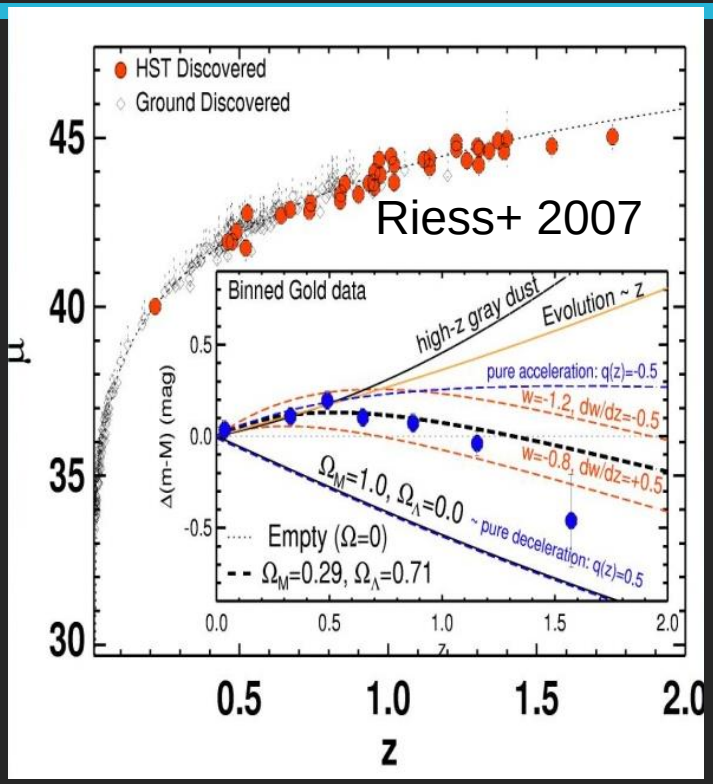


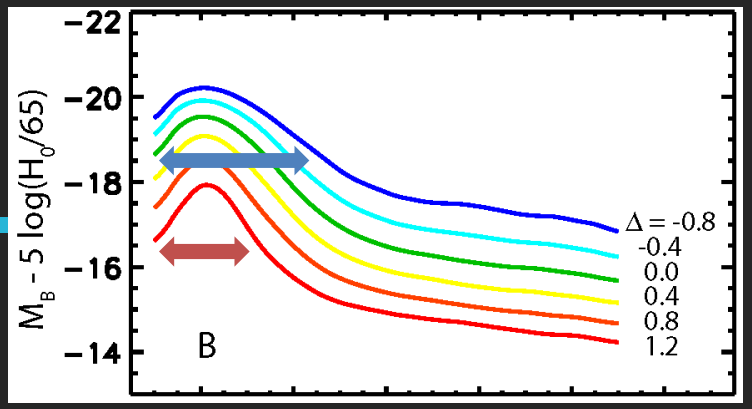


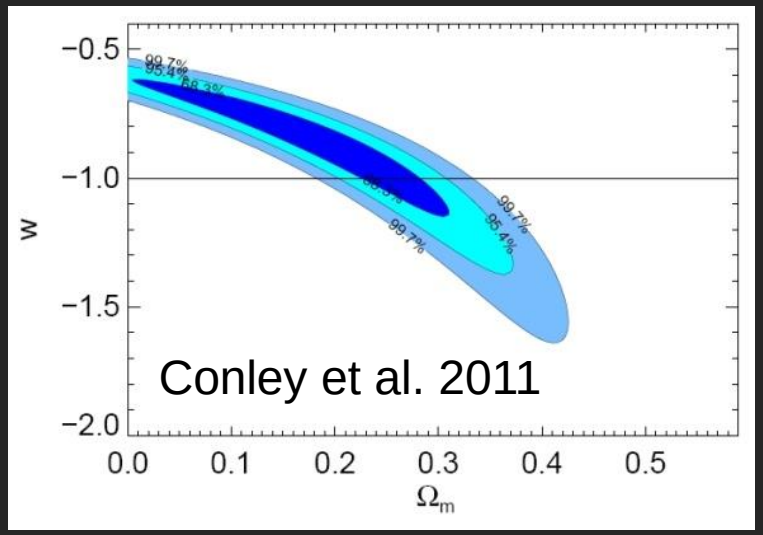
Evolution in rest “UV”? Local sample limited.

⇒ Rest flame “optical” (used for cosmology), need 30m (or NIR space).

SN Ia Cosmology







Future: w… cosmological constant or not?

Ground, optical: DES, HSC, LSST (+ spec., TMT in the future?)

Space, NIR: WFIRST, WISH

(Ground, NIR at z < 0.2?: TAO… calibration sample, K-cor. etc.)

Causes of systematics?

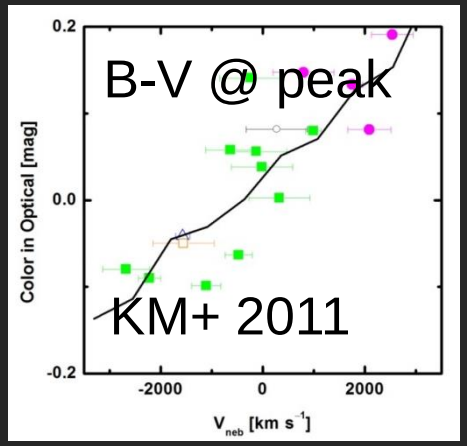
Table 7: Identified systematic uncertainties

Description	Ω_m	w
Stat only	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$
All systematics	0.18 ± 0.10	$-0.91^{+0.17}_{-0.24}$
Calibration	$0.191^{+0.095}_{-0.104}$	$-0.92^{+0.17}_{-0.23}$
SN model	$0.195^{+0.086}_{-0.101}$	$-0.90^{+0.16}_{-0.20}$
Peculiar velocities	$0.197^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$
Malmquist bias	$0.198^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$
non-Ia contamination	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$
MW extinction correction	$0.196^{+0.084}_{-0.100}$	$-0.90^{+0.16}_{-0.20}$
SN evolution	$0.185^{+0.088}_{-0.099}$	$-0.88^{+0.15}_{-0.20}$
Host relation	$0.198^{+0.085}_{-0.102}$	$-0.91^{+0.16}_{-0.21}$

- Studying local samples will be kept important.
  - **Systematics.**
  - How and where ?
    - Extinction?
    - Different Populations?
  - z-evolution, host-depend.?

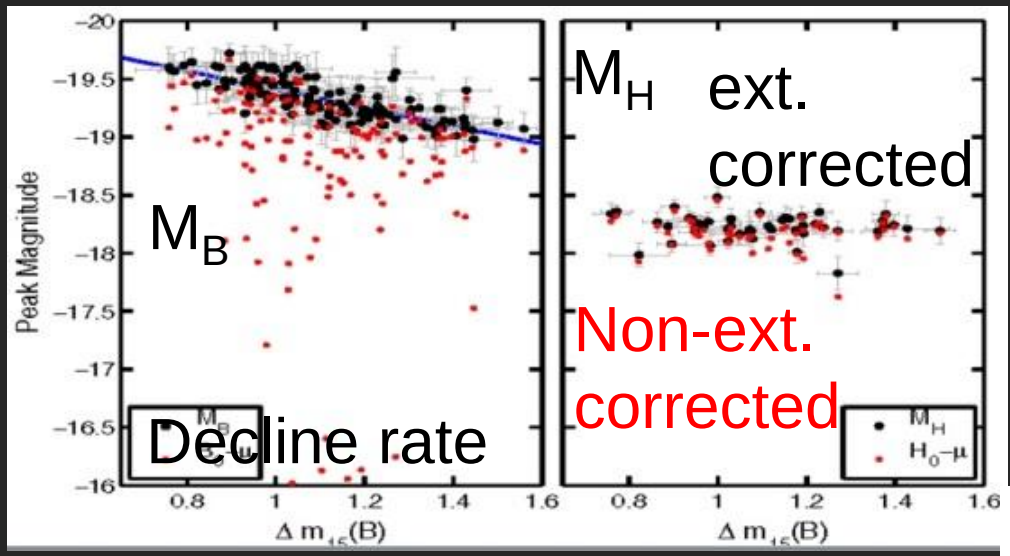
HSC, PFS

Intrinsic variation in explosion mech. can mimic extinction.



Line shift in late-phase (intrinsic)

Rest-frame NIR SN Ia Cosmology



As distance indicators,
Rest optical: "standardized"
Rest J, H: "standard"

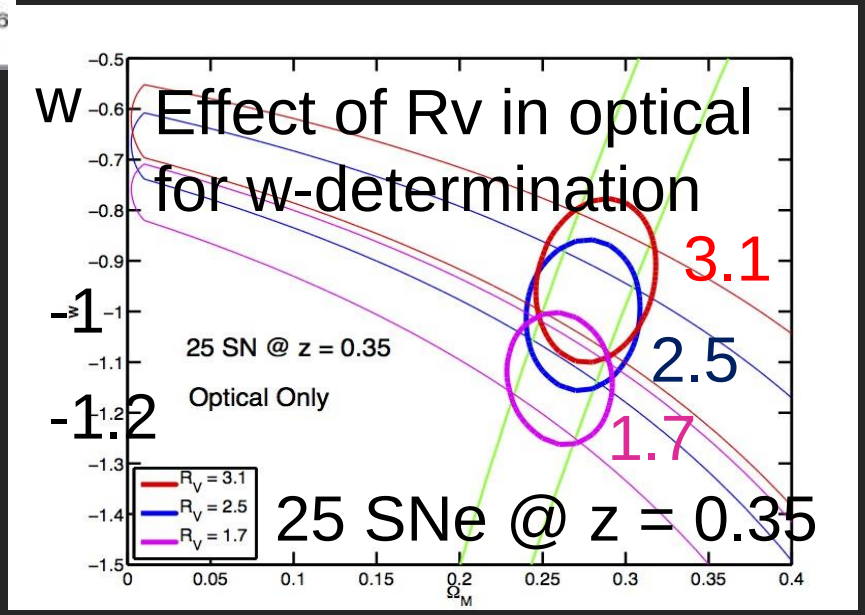
Extinction unimportant

By B. Kirshner

Currently: Pan Starrs (opt)+ HST (NIR), up to z ~ 0.5

Future: NIR survey (WFIRST, WISH) also low redshift?

Local samples for K-cor. (TAO?)

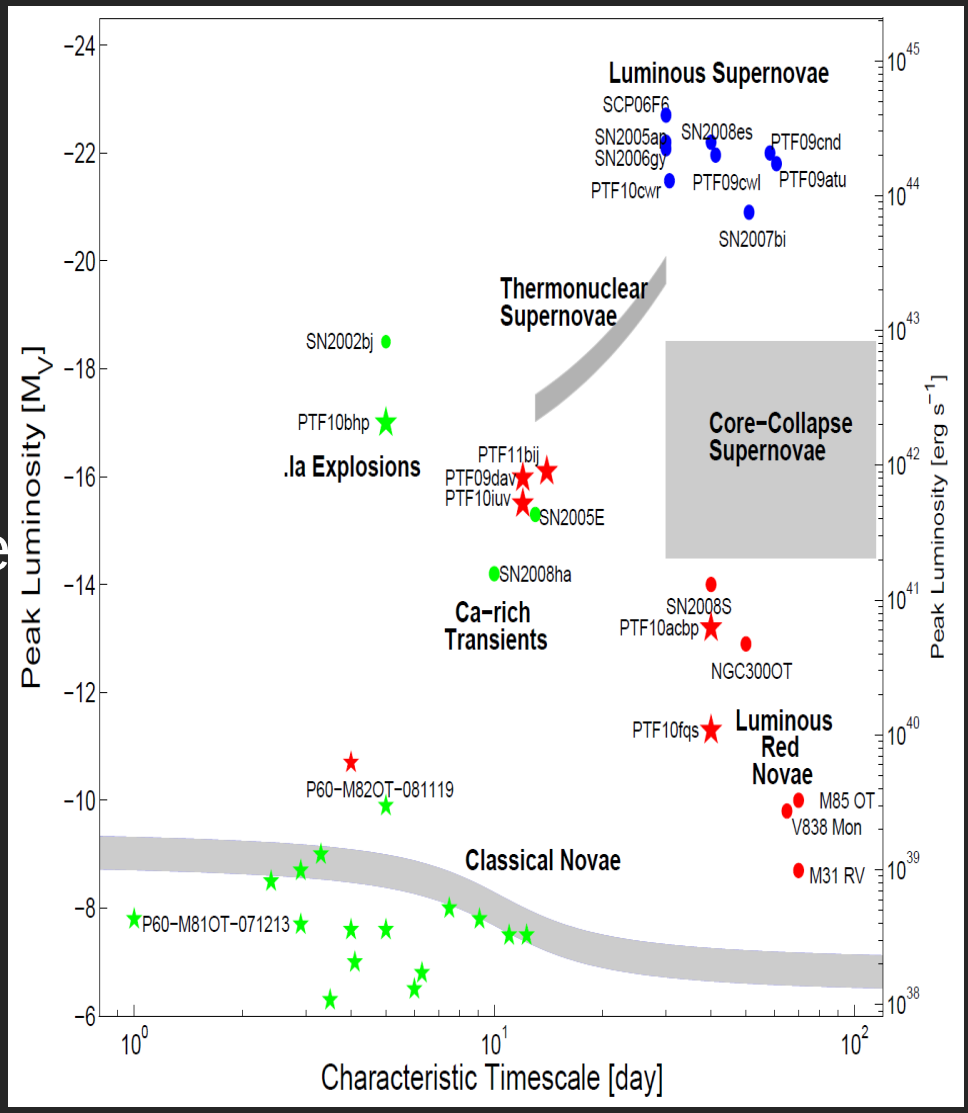


Clarifying natures @ low-z

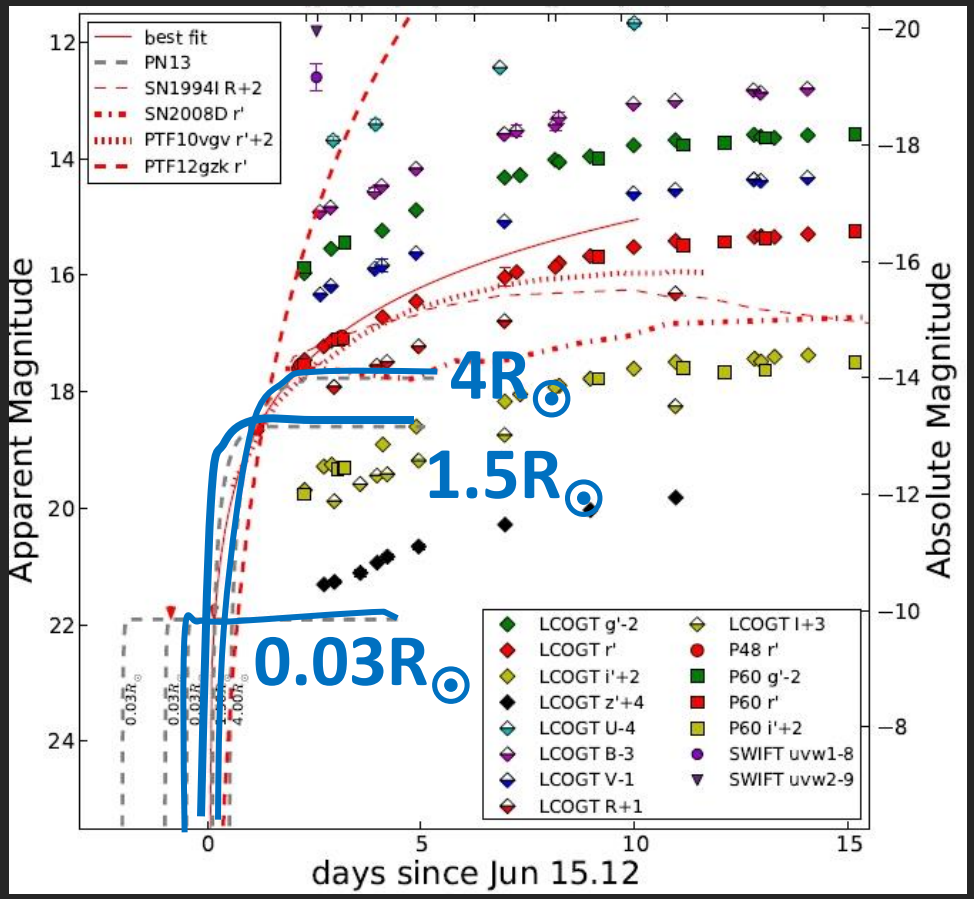
Wide-field Untargeted

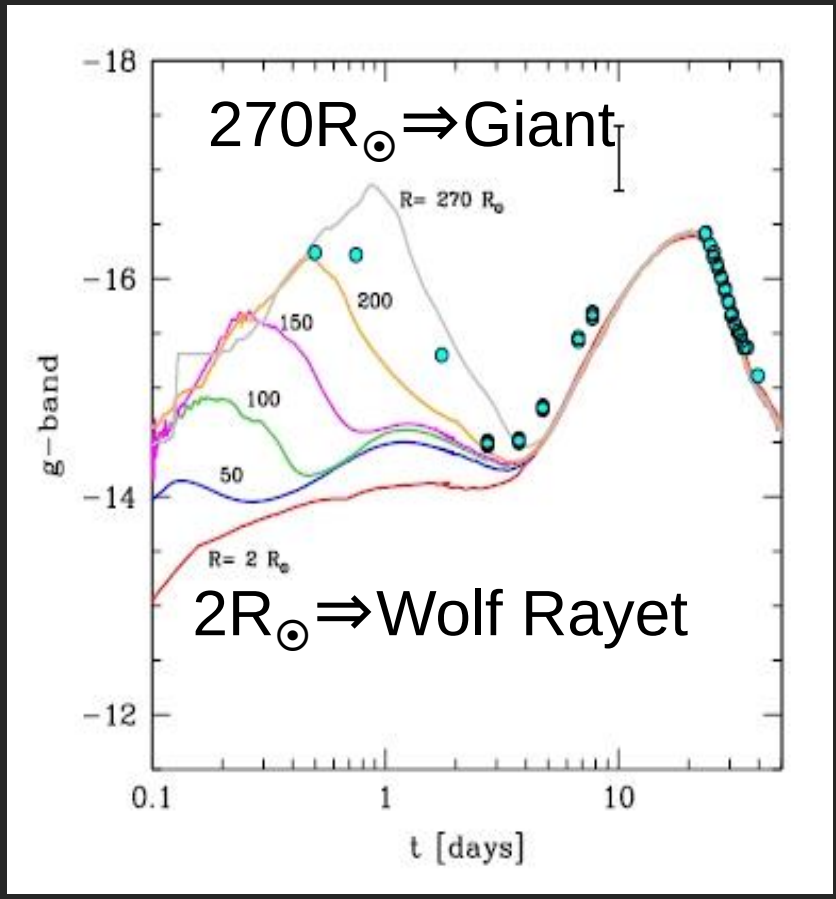
Example: PTF
Survey: 1.2m, 7 deg^2 (~ KISS)
Identification: 1.5m, low-R IFU
Follow-up: Keck etc.
Filling up time-luminosity space

Expected future upgrade:
Survey 7 deg^2⇒40 deg^2
… will fully "kill" the local Universe transient space?
(both in time and luminosity)



Just after the explosion





Cao+ 2013, SN Ibc iPTF13bvn
Progenitor < a few $R_\odot$ ⇒ WR

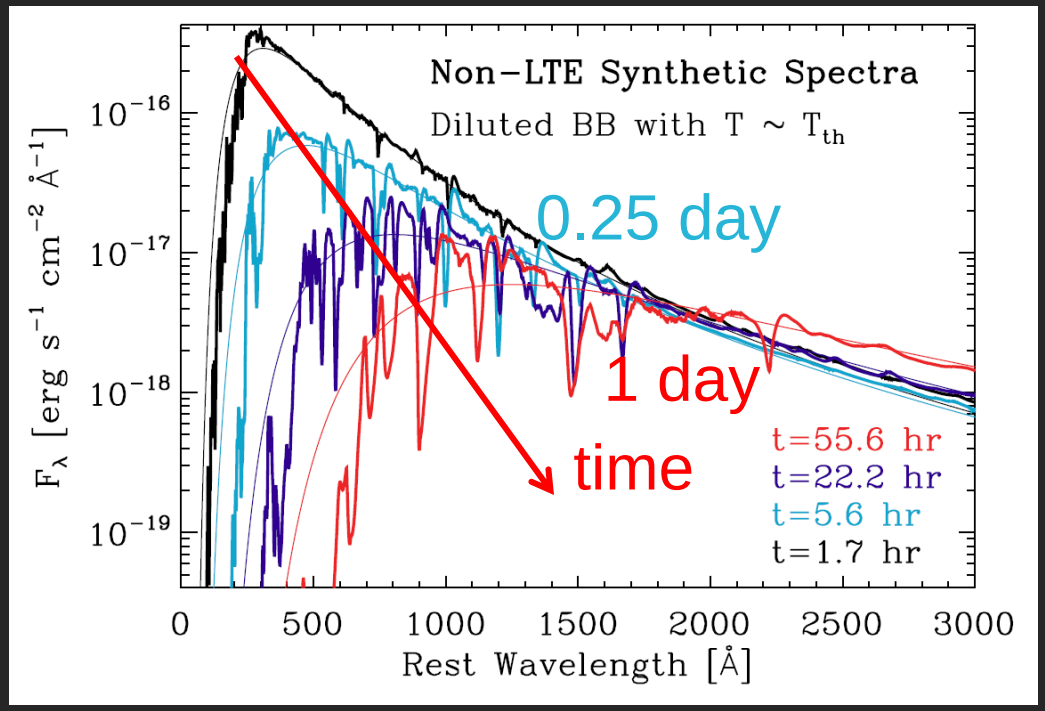
Bersten+ 2012, SN IIb 2011dh
~ 250$R_\odot$ ⇒ Yellow supergiant

Quick follow-up by 1m: e.g., OISTER

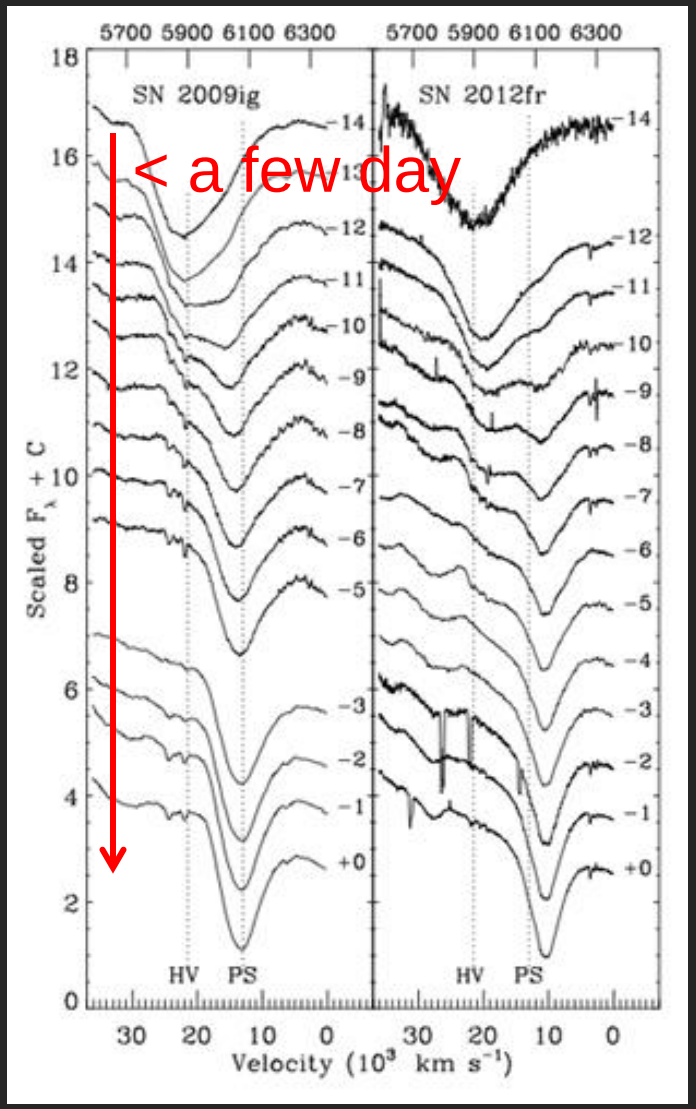
Just after the explosion

Quick ToO by 2 - 4m.
Kyoto 3.8m

SNe IIp (RSG progenitor)

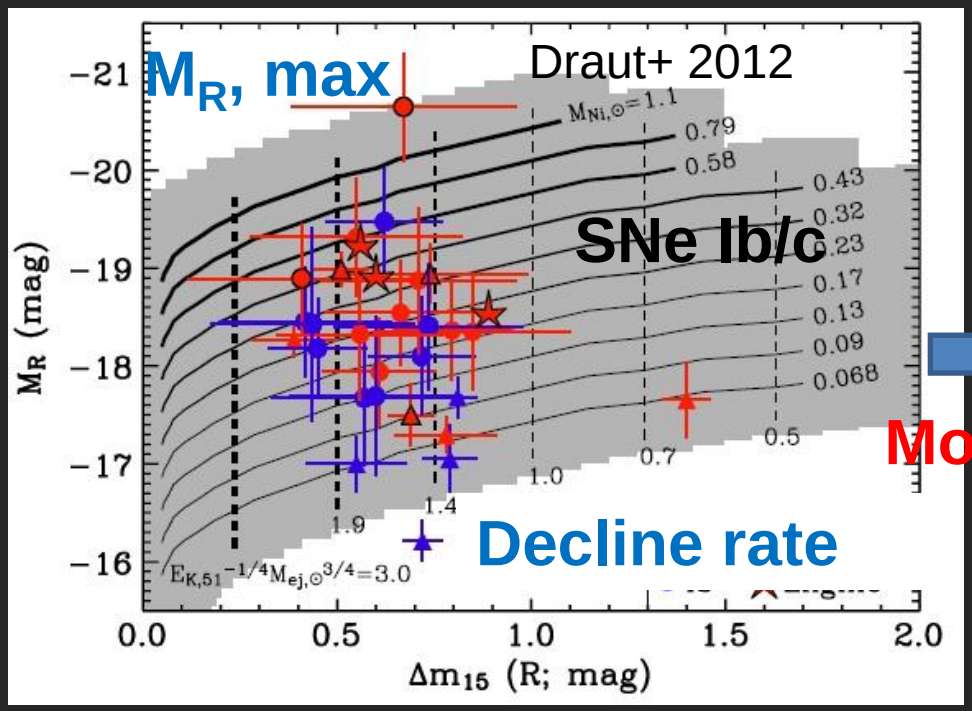


SNe Ia

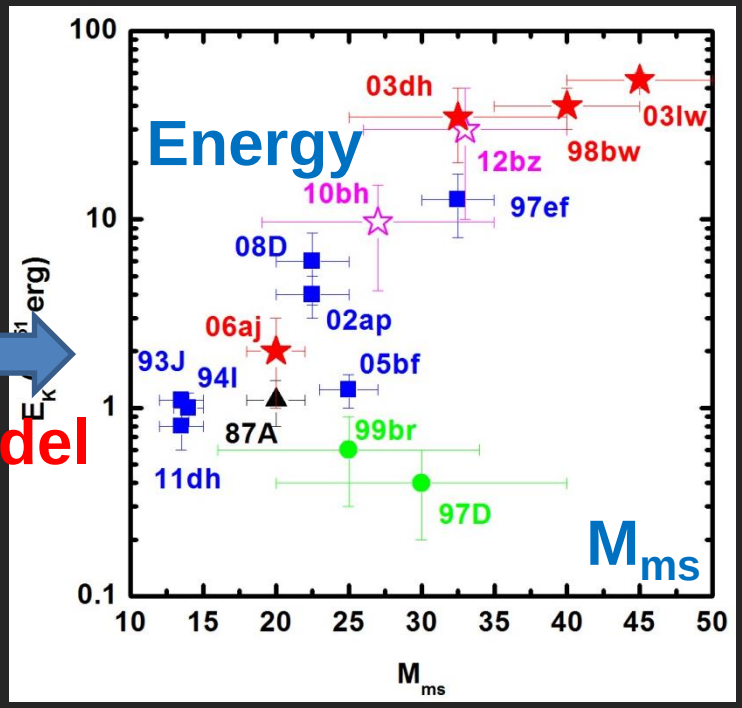


Shock breakout
Surface composition
Unexplained features
⇒ Important for theory

How progenitor-SN properties related?



Model

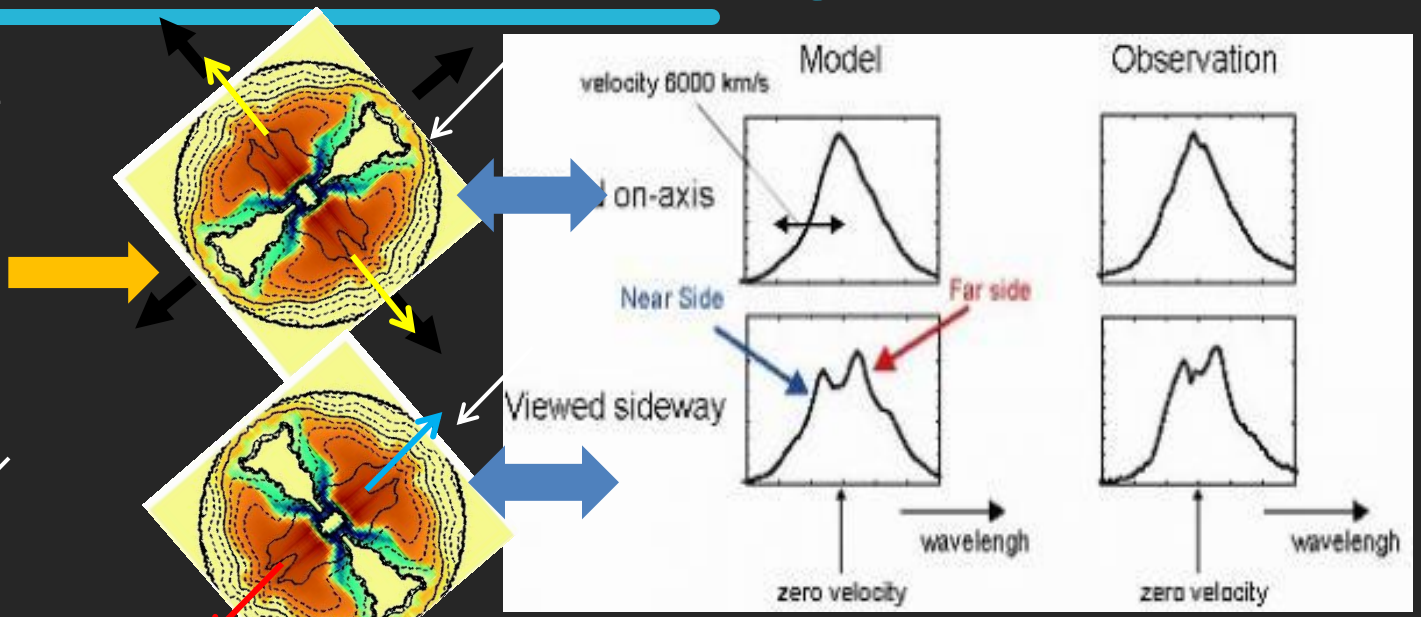


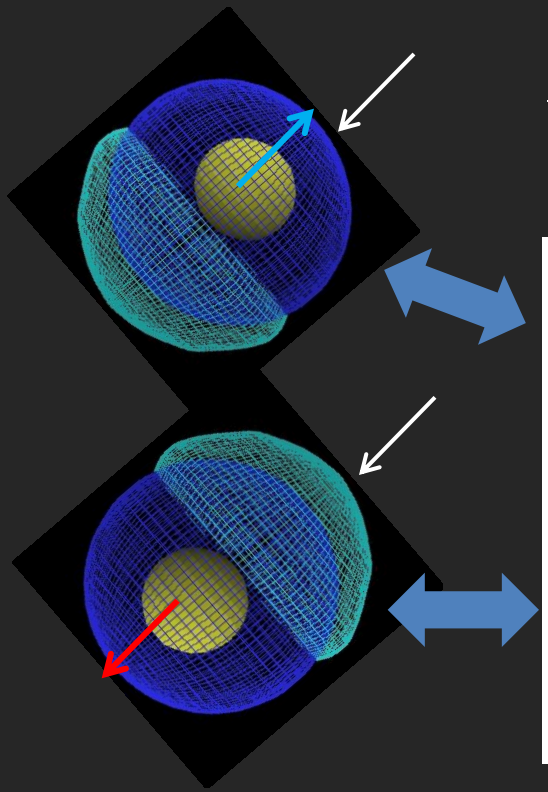
Future (on-going): Unbiased + large sample
⇒ IMF, single/binary evolution, etc.

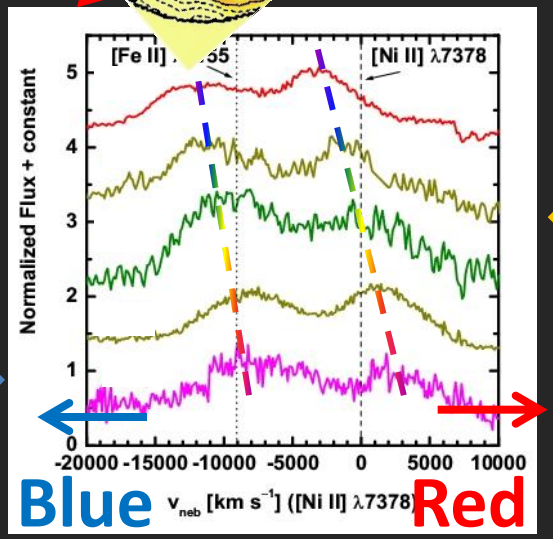
Intensive follow-up required. Resource will be on-line (Kyoto, TAO). Strategy? (for competition)

Explosion Mechanism (~ 1 year)

Core-collapse
KM+ 2008
Subaru







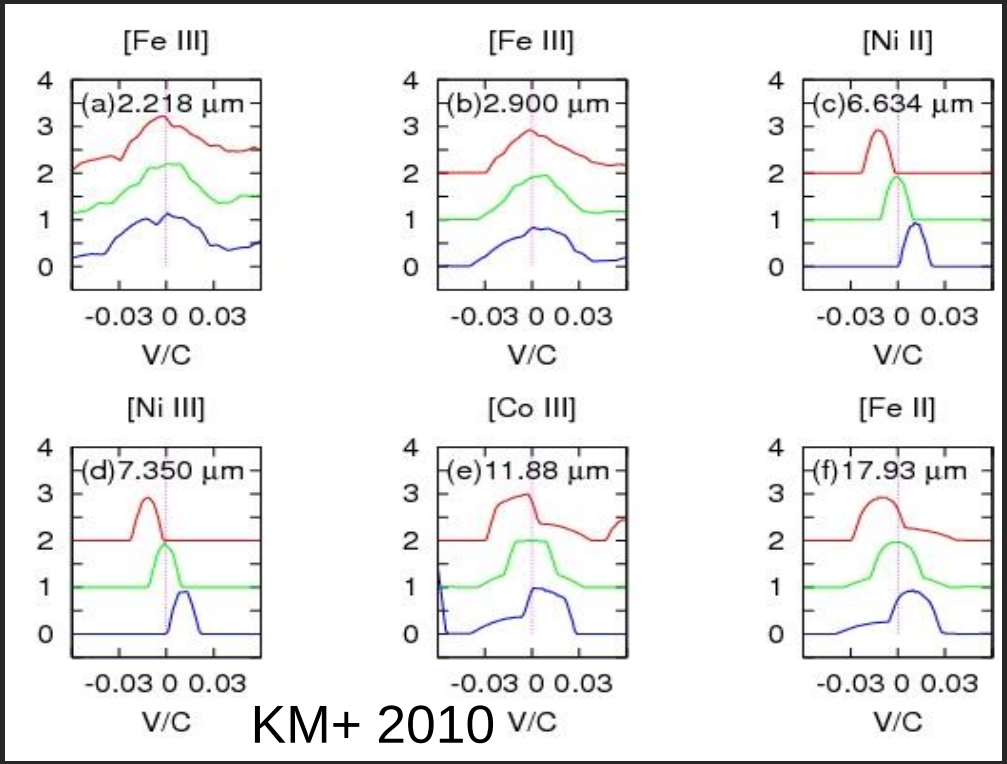
Type Ia SNe
KM+ 2010
Gemini+

Different type of explosion geometry

Explosion Mechanism (~ 1 year in IR)

NIR is better (e.g., less blending than opt)

⇒ IRCS+AO188 for 8 nights in 2011-2012 (KM+, to come), but limited to a few very nearby SNe ⇒ TMT?

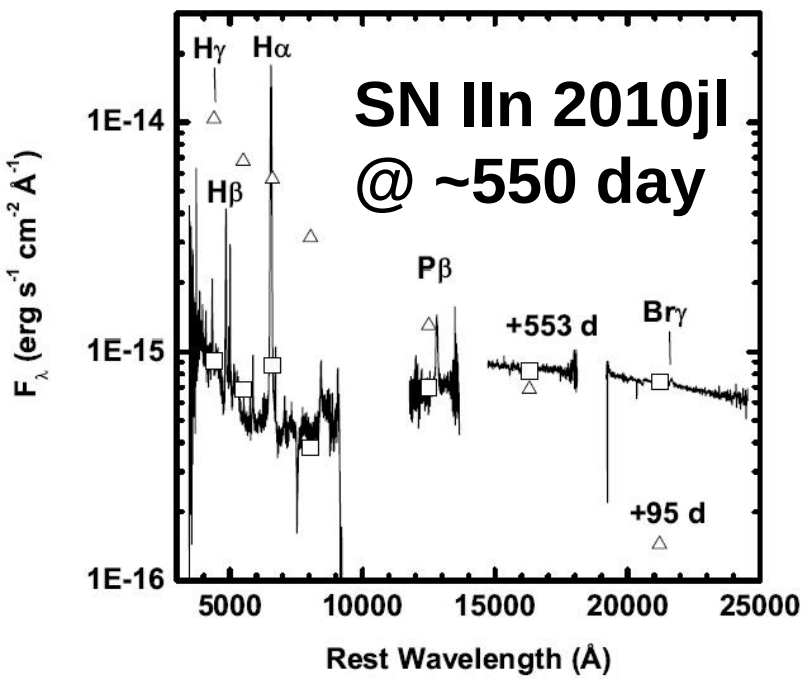


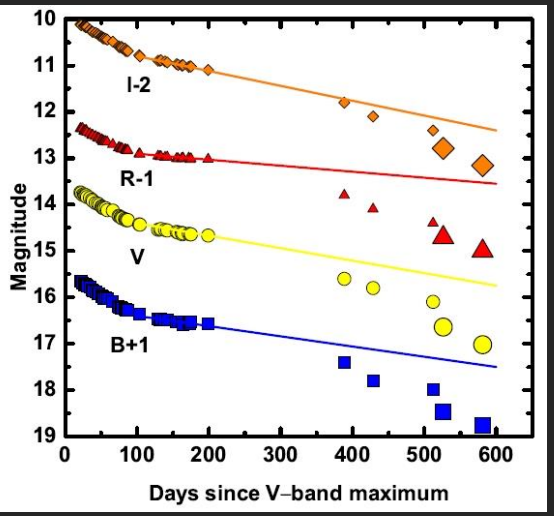
KM+ 2010

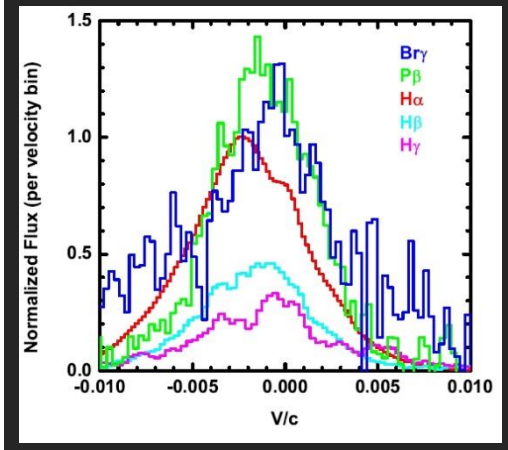
Can also be done in mid-IR. (almost no blending, very low temperature regions).

SPICA
(also strong for dust: Tanaka+ 2012)

Dust Formation… Origin of dust in Universe







KM+ 2013 **Subaru IRCS+LGSAO**

A minute of dust formation… NIR (~1000 – 2000K)

Photometry is OK, but spectra provide complete view. (e.g., dust size + optical depth require spectra).

Optical also necessary.

TAO, kyoto 3.8m (but south and north)

Synergy w/ High Energy Astrophysics

- SN-GRB relation ($z < 0.2$ w/ 8m, $z > 1$ w/ 30m).
- Hard X, soft-γ
  - Radioactive decay emission (only SN 1987A so far).
    - Nearby SNe Ia possible w/ Astro-H (2015-) (KM+ 2012)

SN Ia standard candle

- Radio, soft X

Progenitor

  - Mass loss + particle acceleration (KM 2012, 2013).
  - Speed of breakout shock wave (KM 2013)

Shock breakout

  - A few program running.
    - KM+, Alma cycle 1; Alak+, Chandra + VLA cycle 15.
  - ALMA, SKA, …

Summary

- High redshift.
  - SN populations and evolution. SFR.
  - SN Ia Cosmology. Rest-NIR. Systematics (low-z).
    - Main drivers – HSC + upcoming (in relatively long term).
- Low redshift.
  - Basis for high-z study.
  - Surveys begin filling up “t-L” space.
  - Intensive follow-up required ⇒ unbiased picture.
  - Lots of question… progenitor, explosion.
    - Main drivers – existing and near future.