Testing the origin of type Ia supernovae through their properties in the first few days

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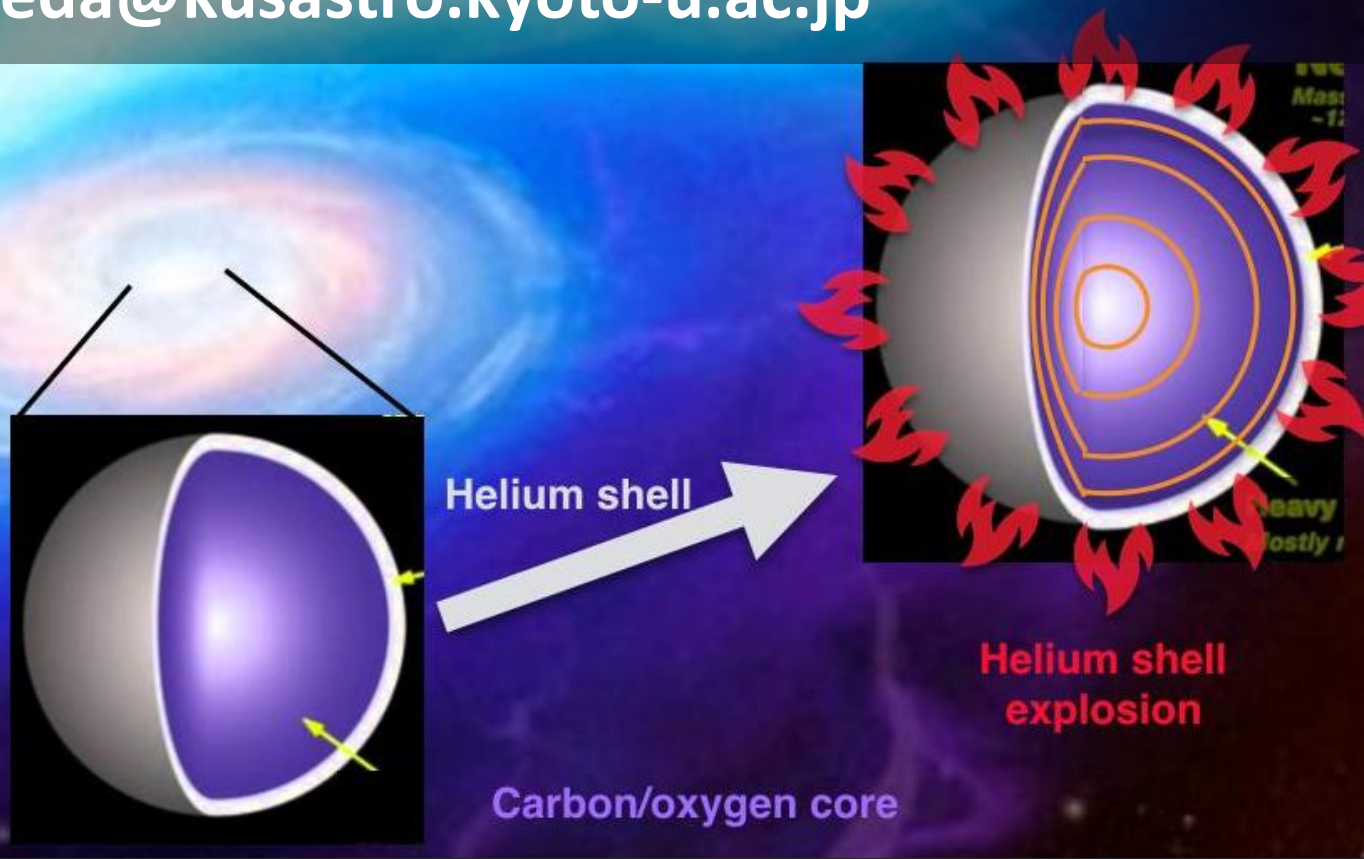


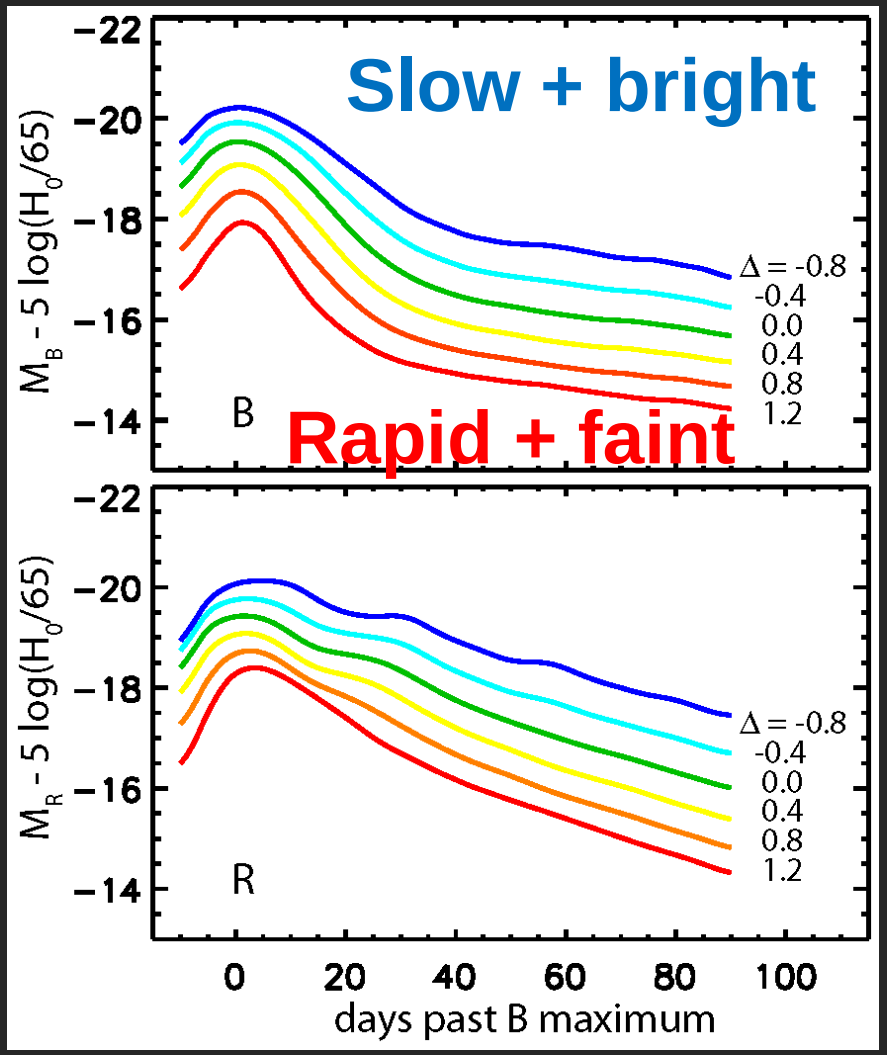
SN Ia: Thermonuclear explosion of a white dwarf

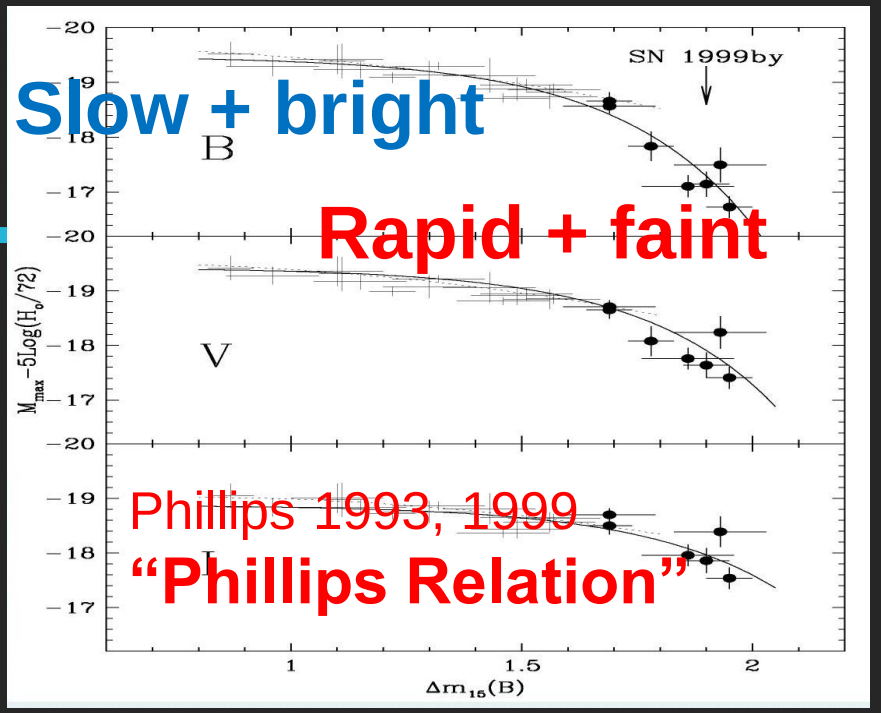
- Supported by degenerate pressure.

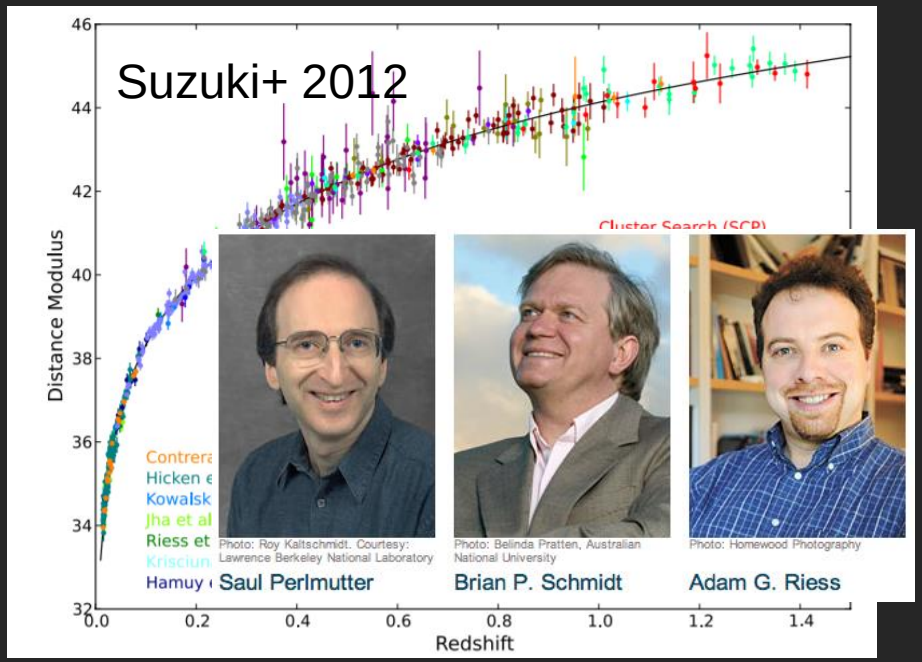
  → Thermonuclear runaway.

- Initiated by $^{12}C+^{12}C \rightarrow ^{24}Mg$ (carbon burning).
  - Gravitational contraction or External compression.
  - **A massive WD (near the Chandrasekhar limit?).**
- Temperature increase by runaway⇒**Fe-peak.**
  - No compact remnant (whole disruption) (in general?).
  - $2 \times ^{12}C + 2 \times ^{16}O \rightarrow ^{56}Ni$.
    - 2×10^{51}erg / Ni $1M_{\odot}$.
  - Nuclear>Gravity **⇒ Explosion energy ~ 10^{51} erg.**

The Standard candles

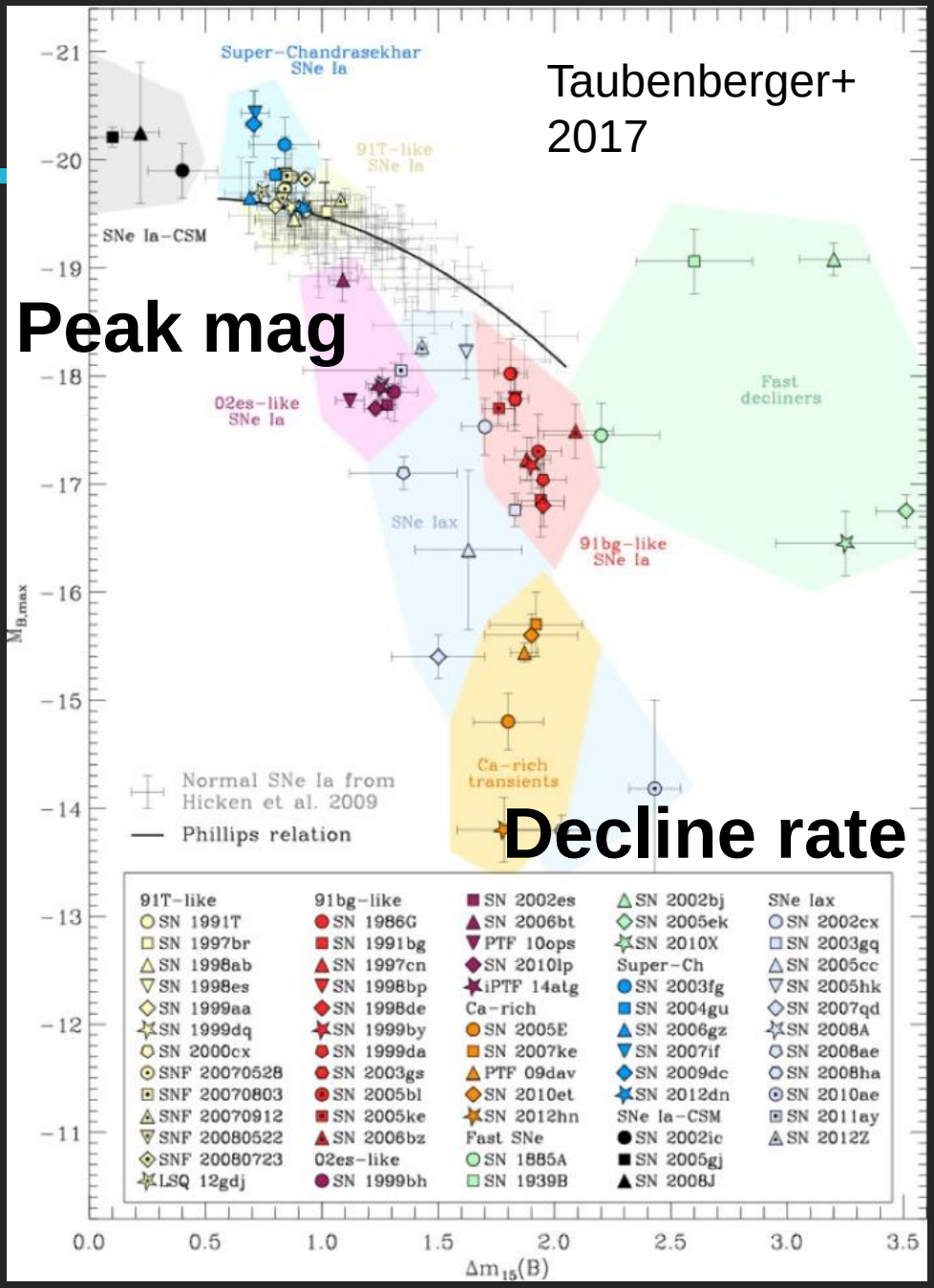






Diversity

- Too much diversity to be a single population.
- Indications for different progenitors/explosions for different classes (e.g., KM+Terada 2012 for a review).
- New paradigm: Multiple progenitors and/or explosion modes.



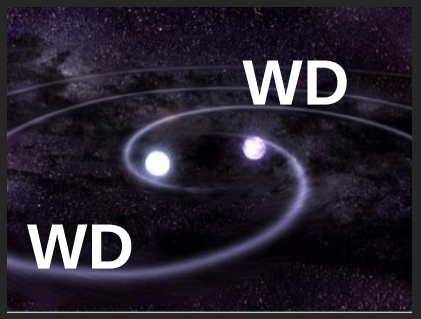
Multiple progenitors/explosions in Theory

Progenitor system(s)

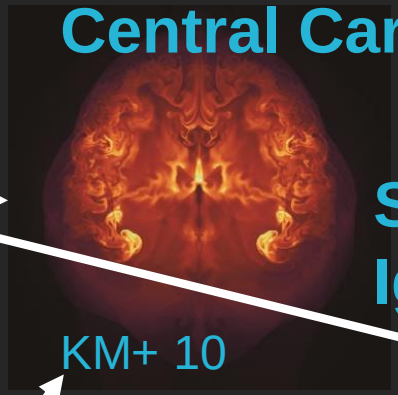
Explosion Mode(s)

Single Degenerate (SD)

Double Degenerate (DD)

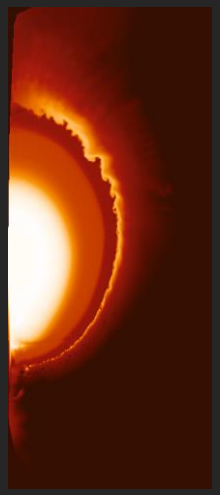


Central Carbon ignition



KM+ 10

Surface Helium Ignition



Fink+ 10

Surface Carbon Ignition

Take Away

SN Ia triggered by Helium detonation on the WD surface does exist.

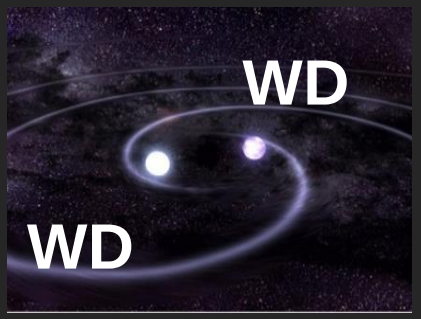
The first robust candidate discovered by Subaru/HSC.

First light (within a few days)⇒Companion?

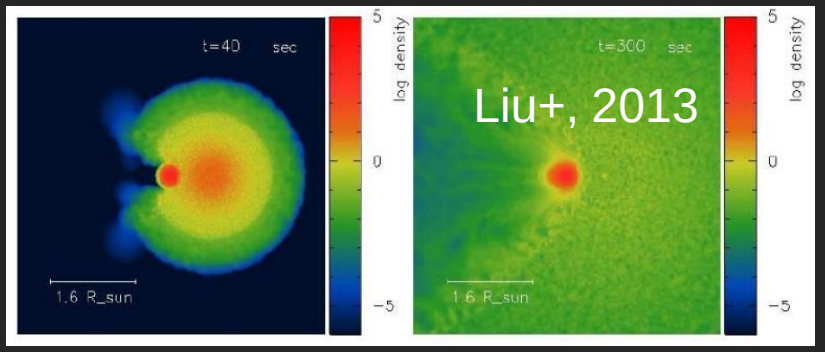
Progenitor system(s)

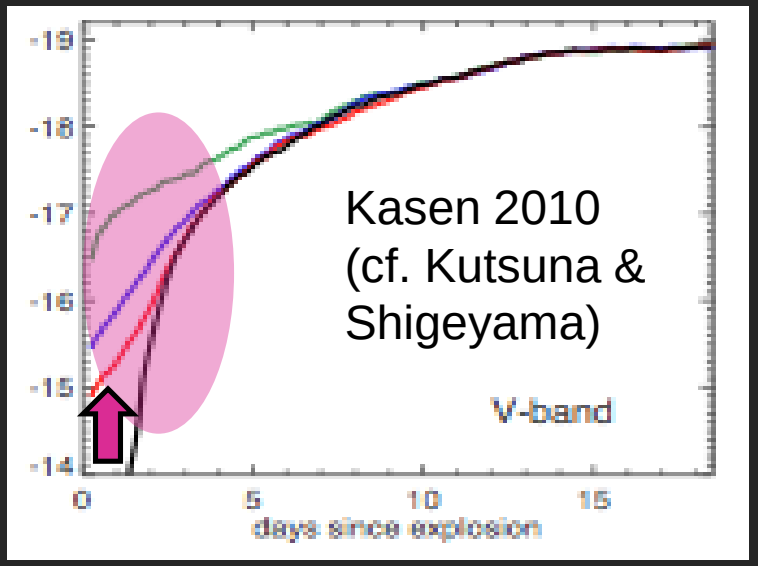
Single Degenerate (SD) →

Double Degenerate (DD)

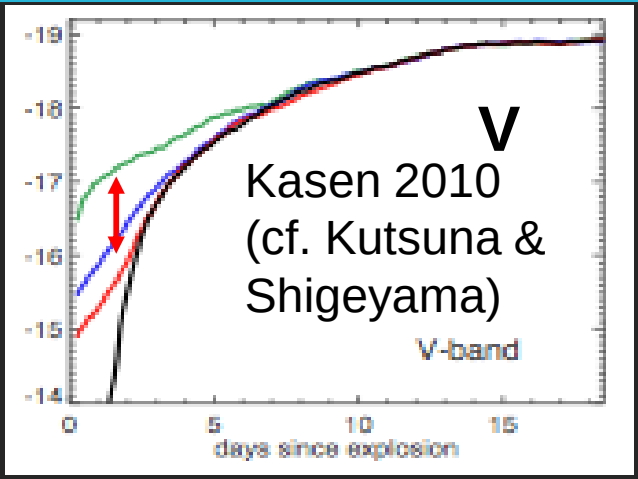


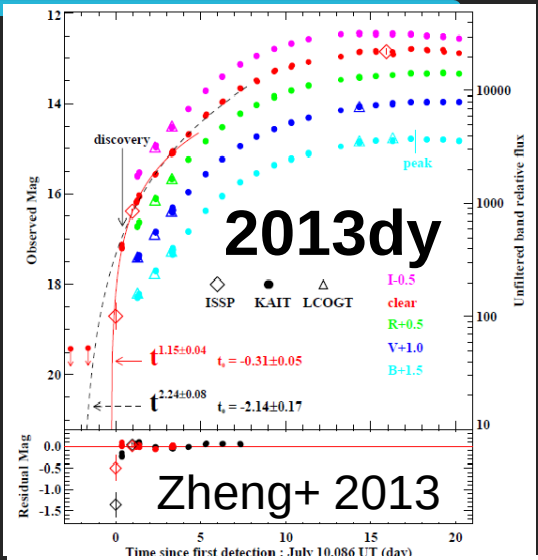
SN ejecta crashing into the companion star

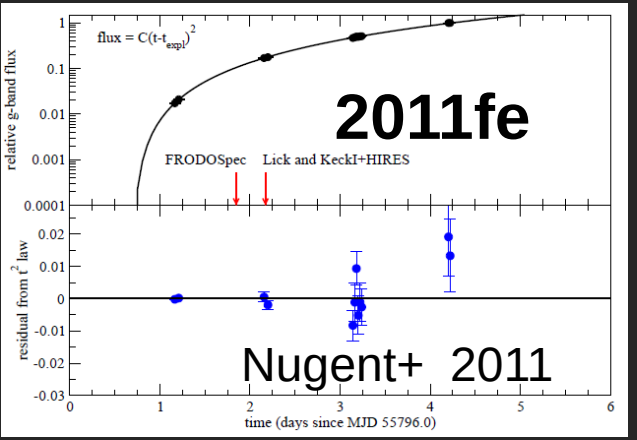


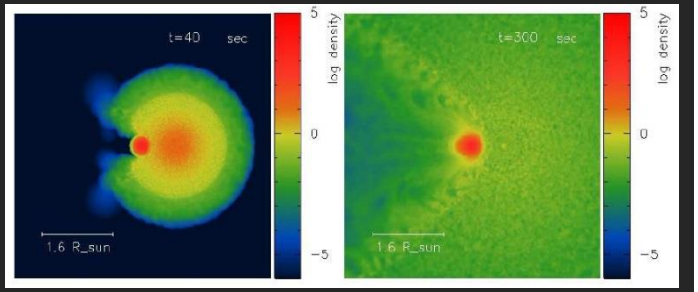


Early emission – No companion crash?

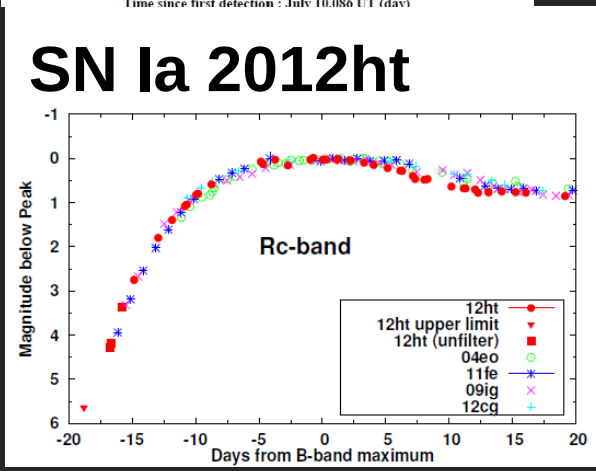


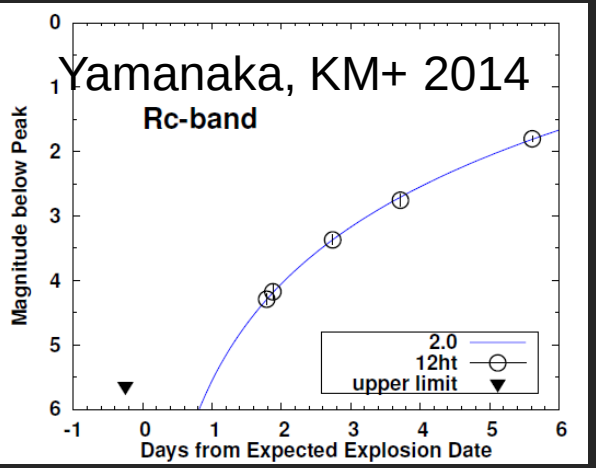






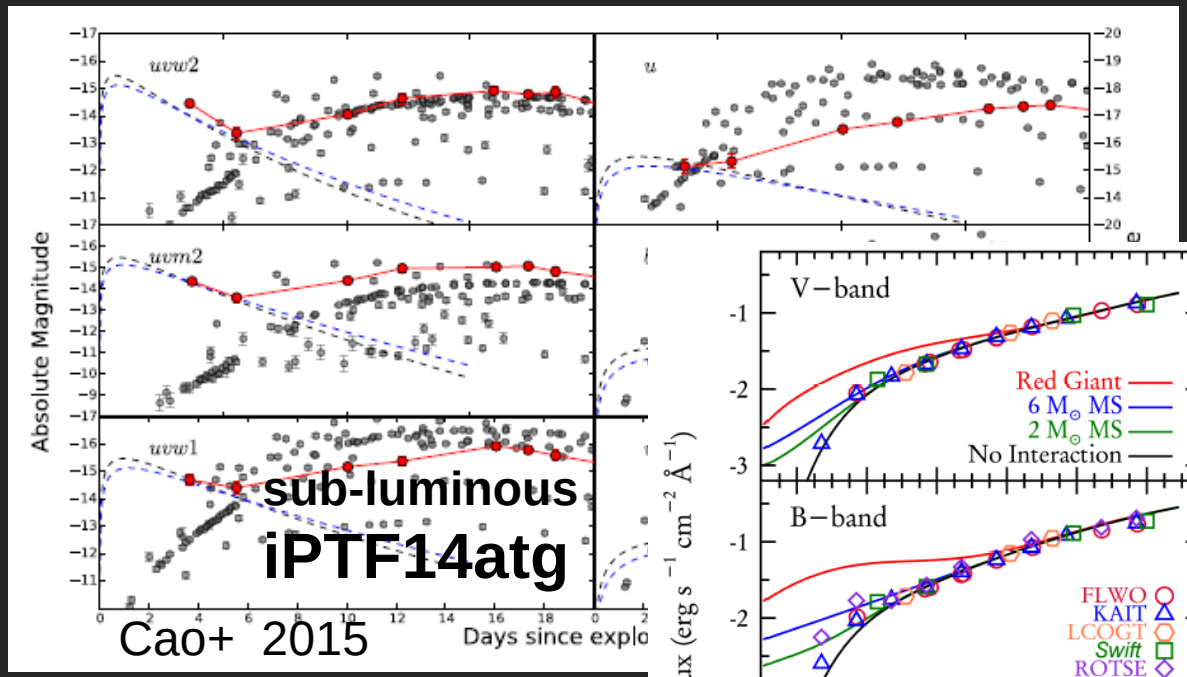
Liu+, 2013

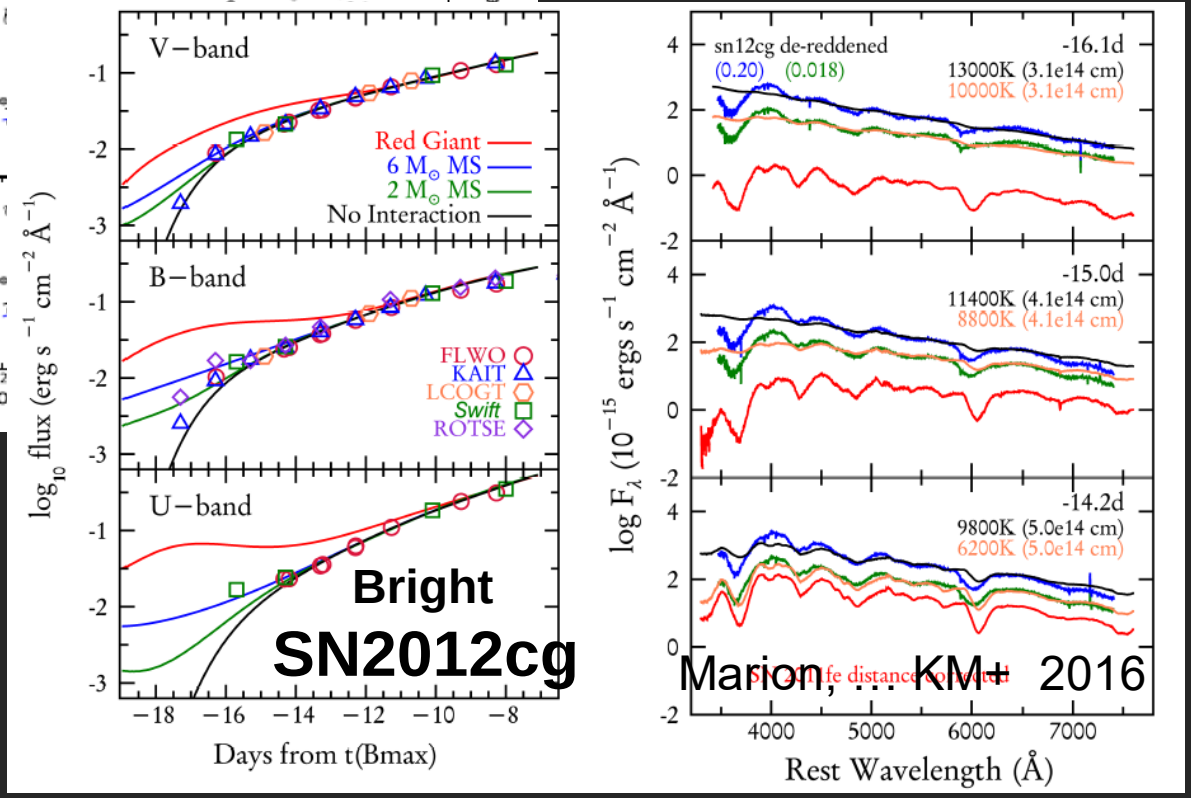




And very good limits by the Kepler (KEGS, red band: Olling+ 15)
Individual SNe and systematics search (e.g., SDSS-II: Hayden+ 10)

Early emission – Companion crash??





First detected for a faint outlier, then for a bright outlier.
Observed only for a specific direction?

Examples with possible signatures

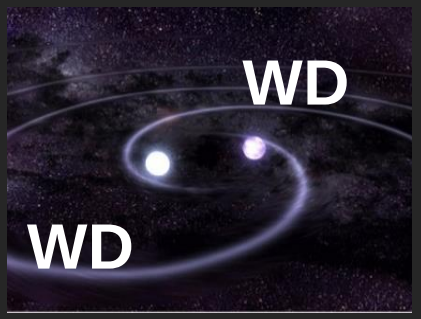
KM+ 2018

Possible mechanisms for the early “flash”

Crash to the companion

Single Degenerate (SD)

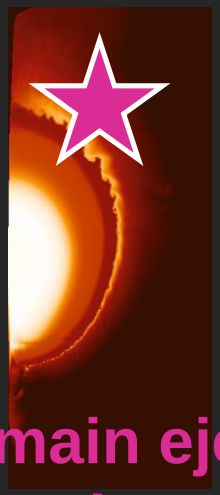
Double Degenerate (DD)



^{56}Ni mixed outward
(carbon burning product)

Central Carbon ignition

Surface Helium
Ignition

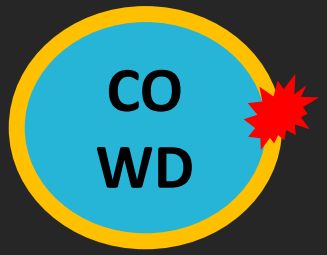


^{52}Fe & ^{48}Cr on the main ejecta
(He burning products)

Note: main source of the SN radiation
= ^{56}Ni (~0.6$M_\odot$ in each SN)

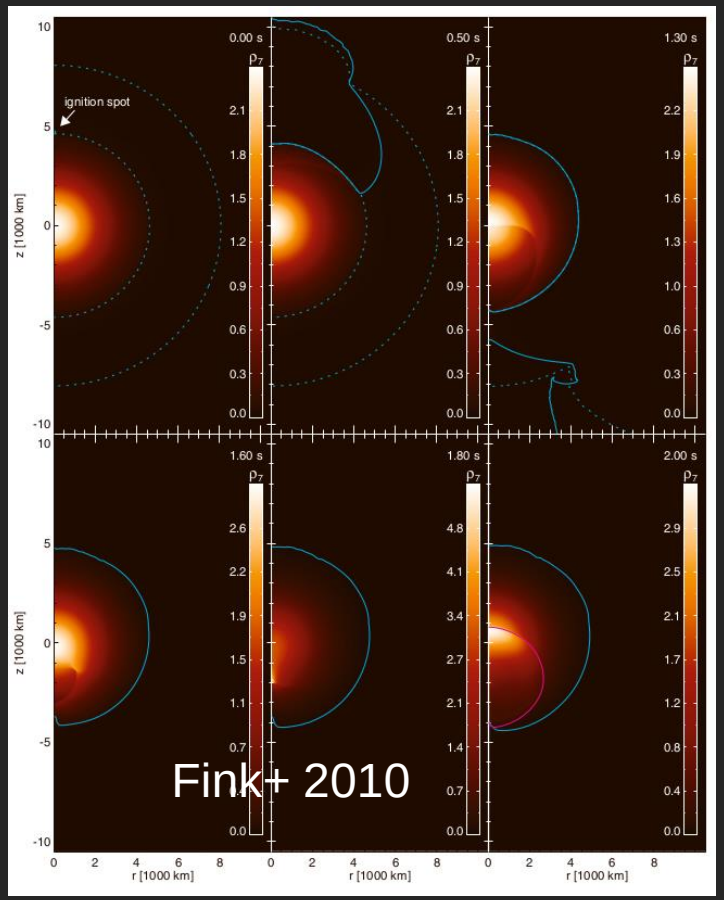
SN Ia triggered by the surface He detonation

He detonation



C detonation

SN



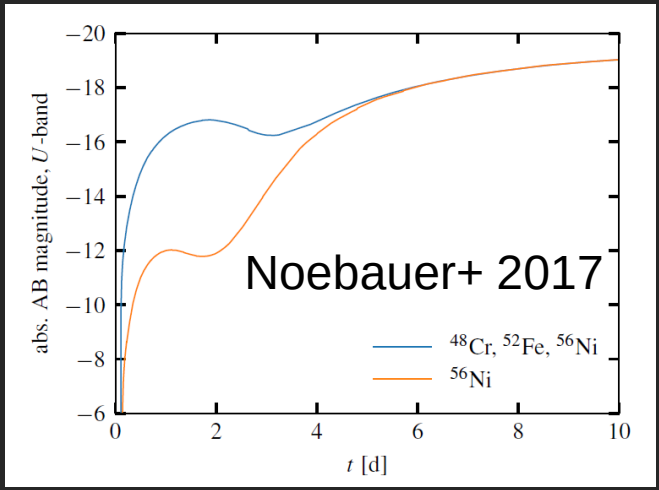
One of the classical models.

Not popular in the last decade (but now ↑).

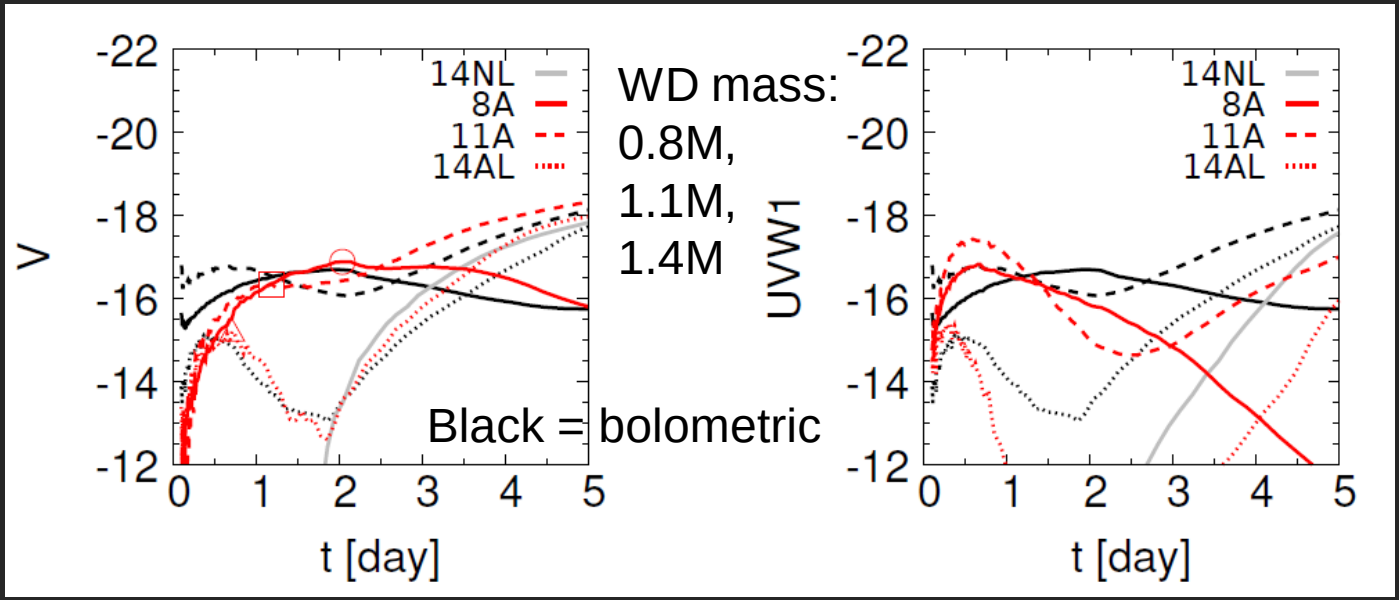
Can happen both in SD & DD.
WD can be < $1M_{\odot}$.
He donor can be both a He star or He WD (or C+O WD w/ He env.).

Jiang, Doi, KM+, 2017, Nature
KM. Jiang, Doi, Shigeyama, 2018, ApJ

New Diagnostics (in the first few days)?

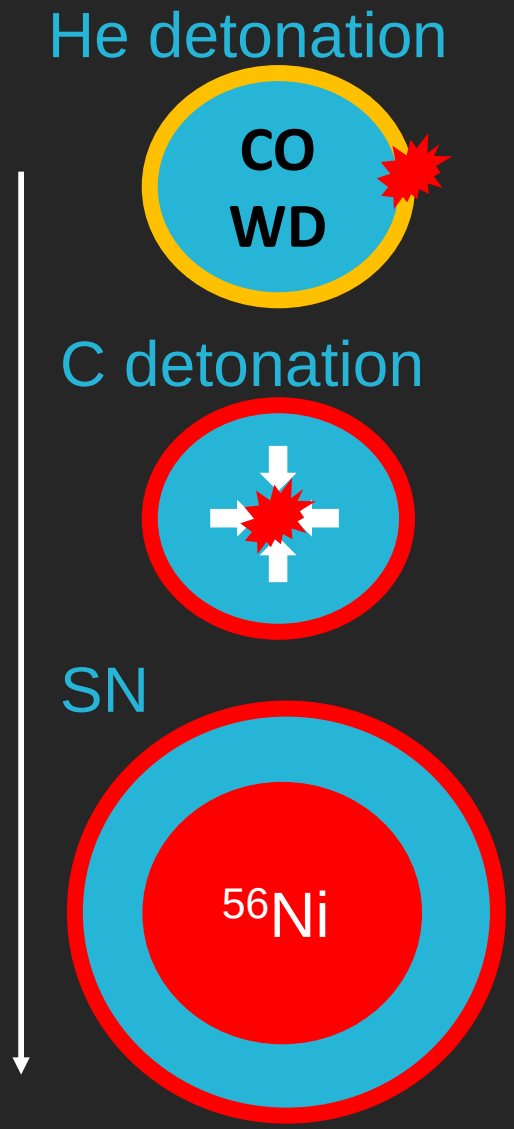


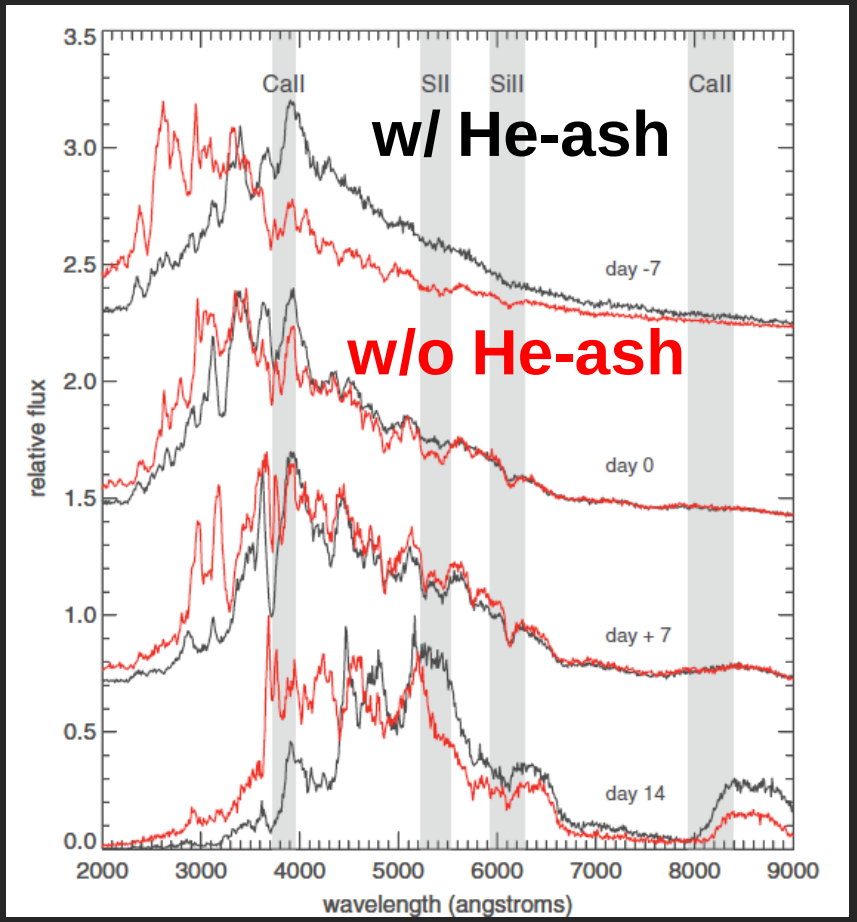
The early "Flash" predicted for the radioactive decay of the He-detonation ash (^{52}Fe & ^{48}Cr).
Not necessarily the companion ("Kasen effect").
Redder than the "companion" interaction.



He detonation for outliers (around maximum)?

Woosley & Kasen 2011

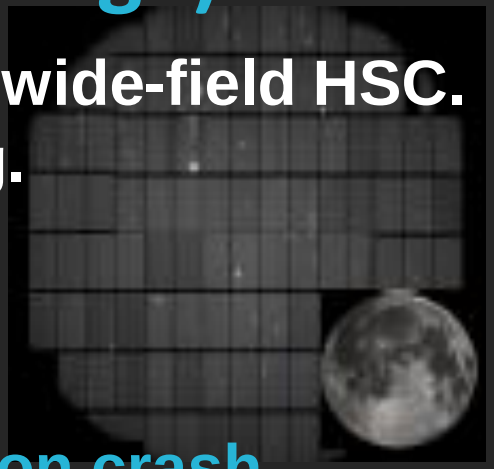


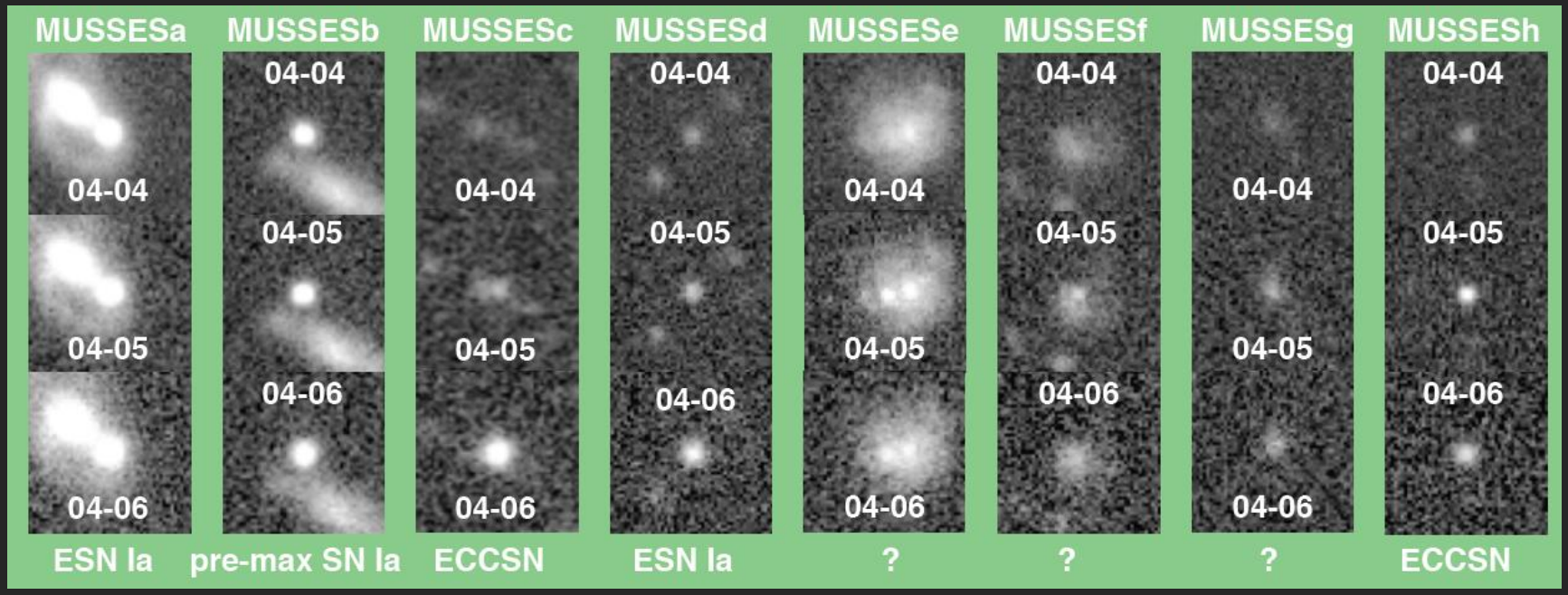


Too red to be normal, absorptions by the He detonation ash (Fe-peaks, Ca, Ti).

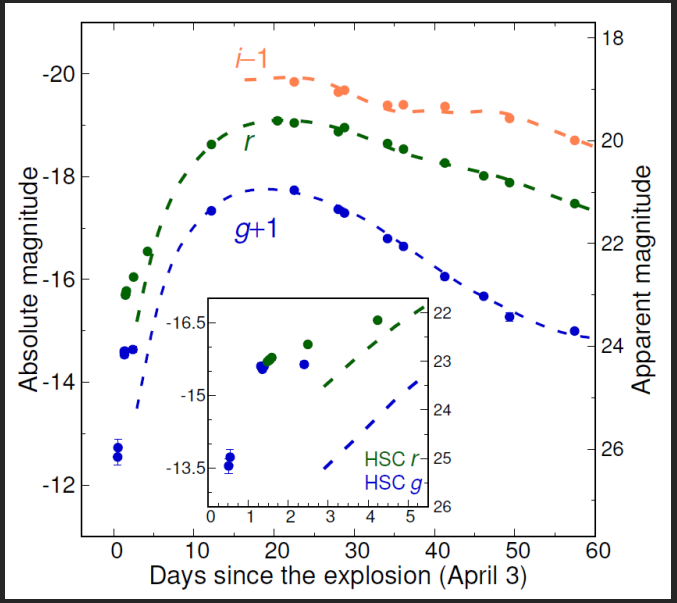
MUlti-band Survey w/ the Subaru telescope for Early phase SNe Ia (MUSSES: Jiang+)

Day cadence survey with Suabru (8.2m) and wide-field HSC.
220 deg^2 covered each night down to 26 mag.
First run in Apr-June 2016.
9 early-phase SN candidates within a few days.
Follow-up coordinated (e.g., Nando involved).
The original idea: Searching for SN-companion crash.





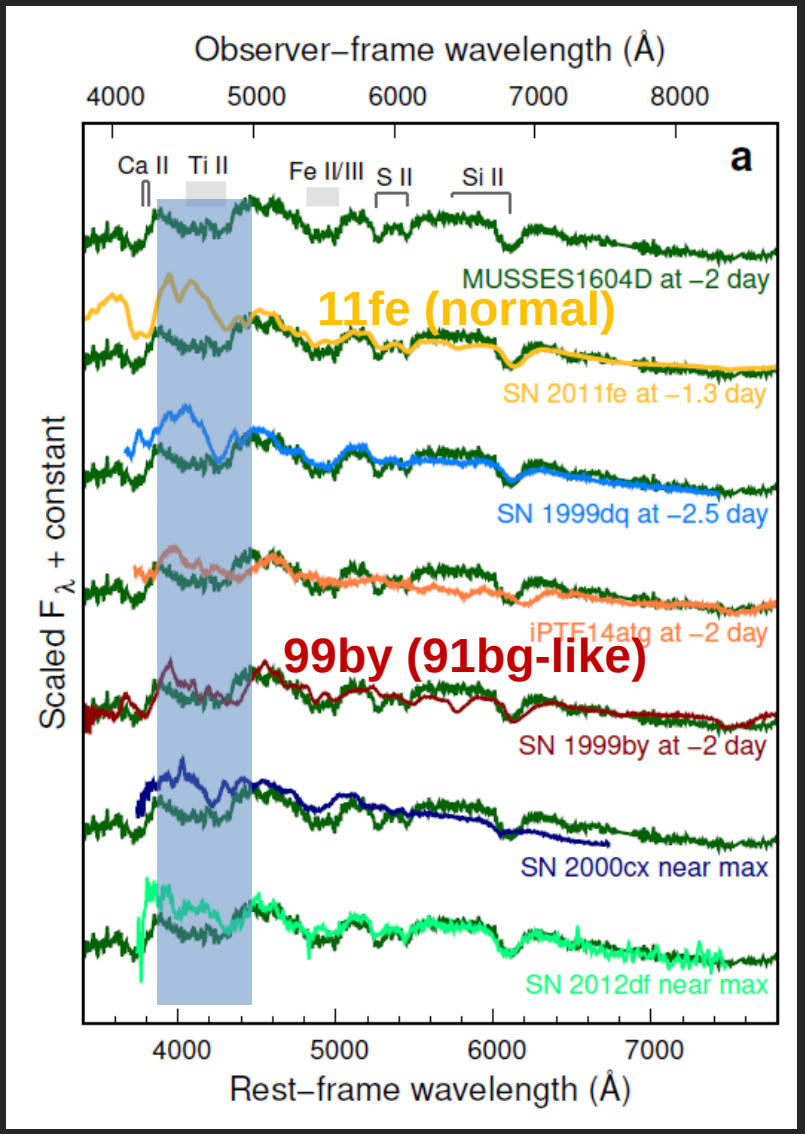
MUSSES1604D: A peculiar SN w/ early flash



"Flash" in the first few days.
Too red for the "interaction".

Spectra of normal SNe but with strong Ti II/Ca II absorptions, while the luminosity is normal.

Should have the same origin.



Jiang, Doi, KM+ 2017, Nature

"He detonation" triggers some SNe Ia

He detonation

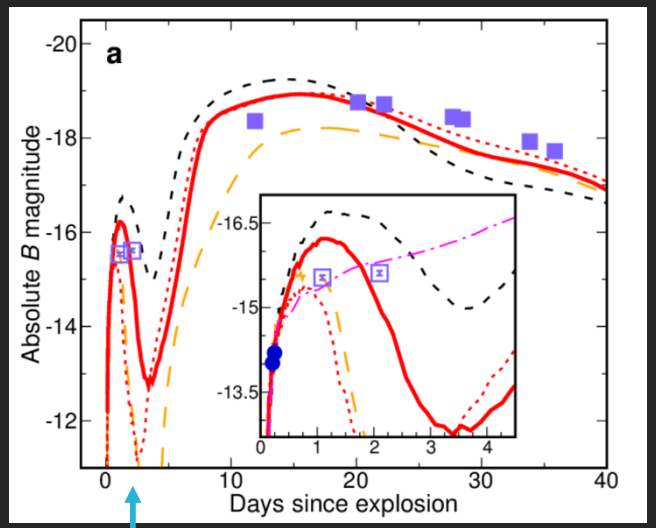
CO WD

C detonation

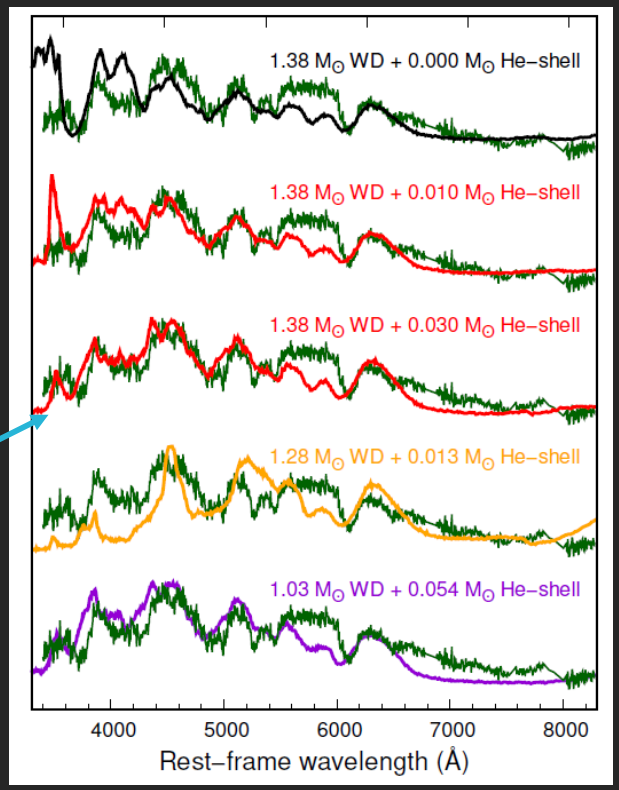
SN

^{56}Ni

He detonation-triggered SN does exist in nature (not only in theory).



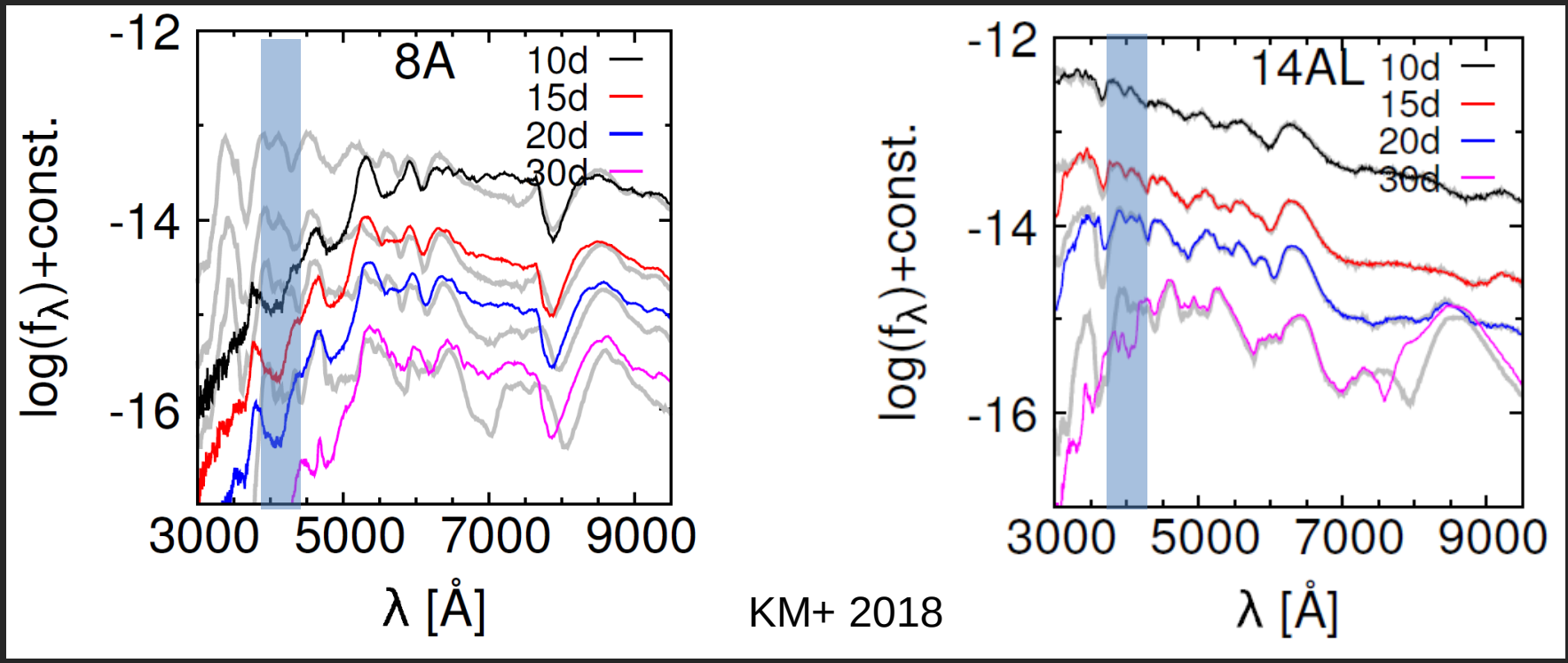
Comparison to radiation transfer models



^{52}Fe/^{48}Cr

⇒Ti, Ca-rich layer

For outliers, or maybe a tip of the iceberg



The "red" spectrum around the maximum light is dependent on two functions: WD mass and the He shell mass.

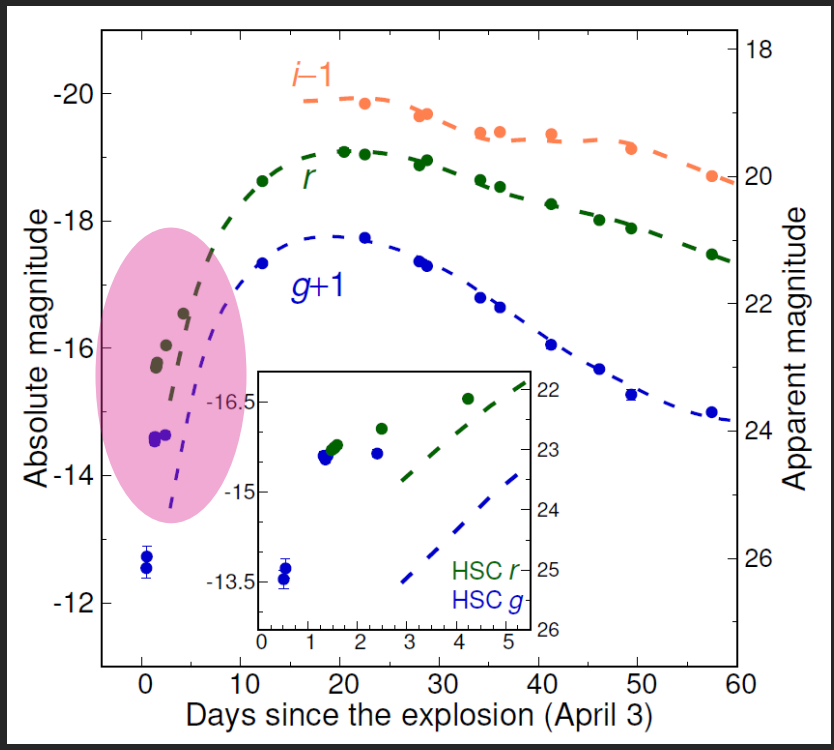
The He-detonation ash may be hidden even for (some) normal SNe Ia.

Perspectives for DEcam and/or LSST

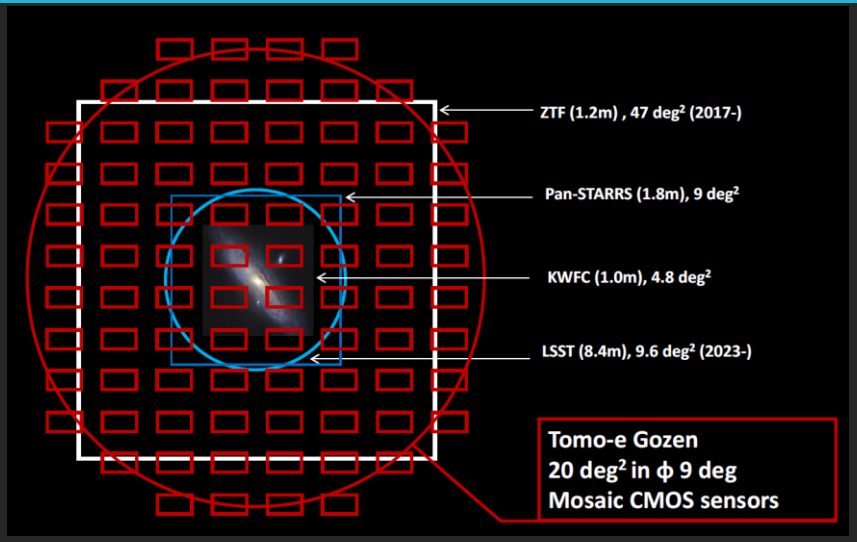
- A case for MUSSEES1604D.
  - **Daily** cadence down to ~23 mag (limiting ~ 25 mag).
  - **Two bands.**
  - Found one in 220 deg^2.

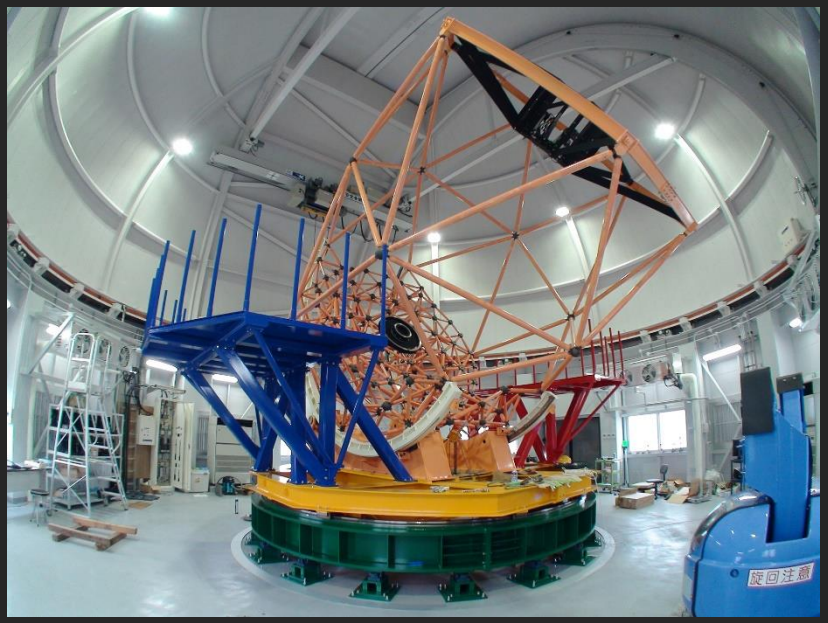
  # ~ 10 "infant" SNe.

- Additional requests:
  - Coordinated follow-up.
    - Light curve coverage (automatically OK for LSST?).
    - Spectra!!!

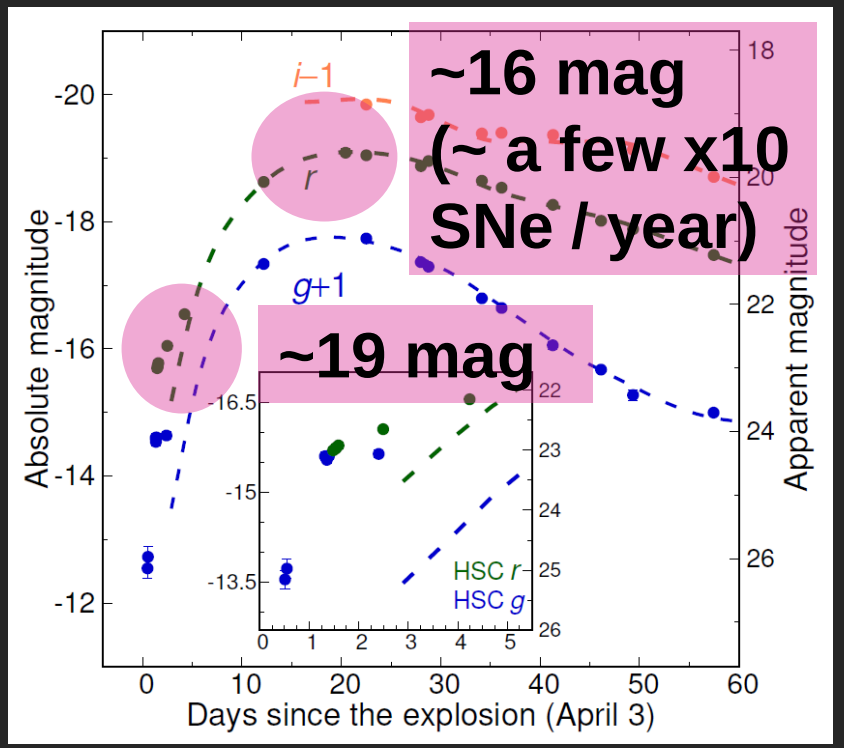


Tomo-e ⇒ Seimei telescope





~10,000 deg² (northern sky), everyday down to 19 mag



New 3.8m telescope at Okayama.
50% for University, 50% for open use.
Quick ToO with IFU.

Conclusions

- SN Ia triggered by Helium detonation on the WD surface does exist. Maybe the tip of the iceberg.
- Multiple populations can be efficiently traced by the very early phase discovery and follow up.
- Bright future with ongoing/future facilities.
  - HSC/DEcam/LSST: > 10 distant SNe Ia in a single campaign ⇒ a potential for large statistics.
  - Tomo-e & Seimei: ~ 20-30 local SNe Ia / year in all-sky survey ⇒ a potential for good follow-up targets.