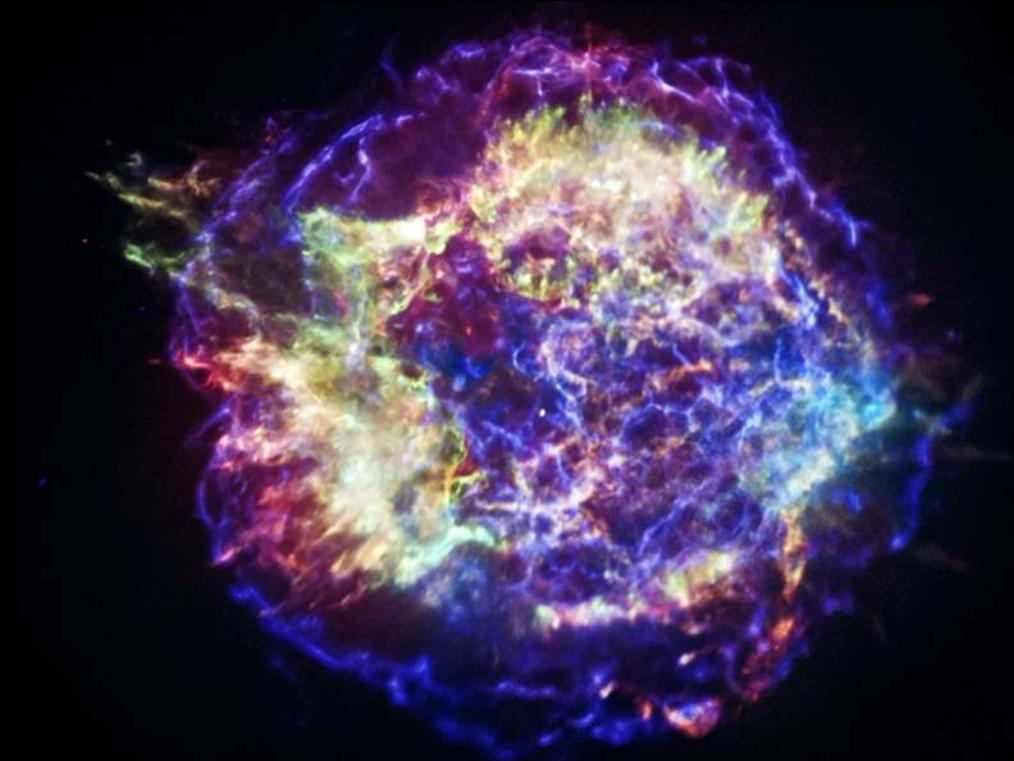


Time-Domain Astronomy: Type 1a Supernovae



Ryan Hazlett

Quick Outline

- Early time-domain astronomy with supernovae.
- Time evolution of a Type 1a supernova.
- I'm bored, why should I care about this?

**Are supernovae the first examples
of time-domain astronomy?**

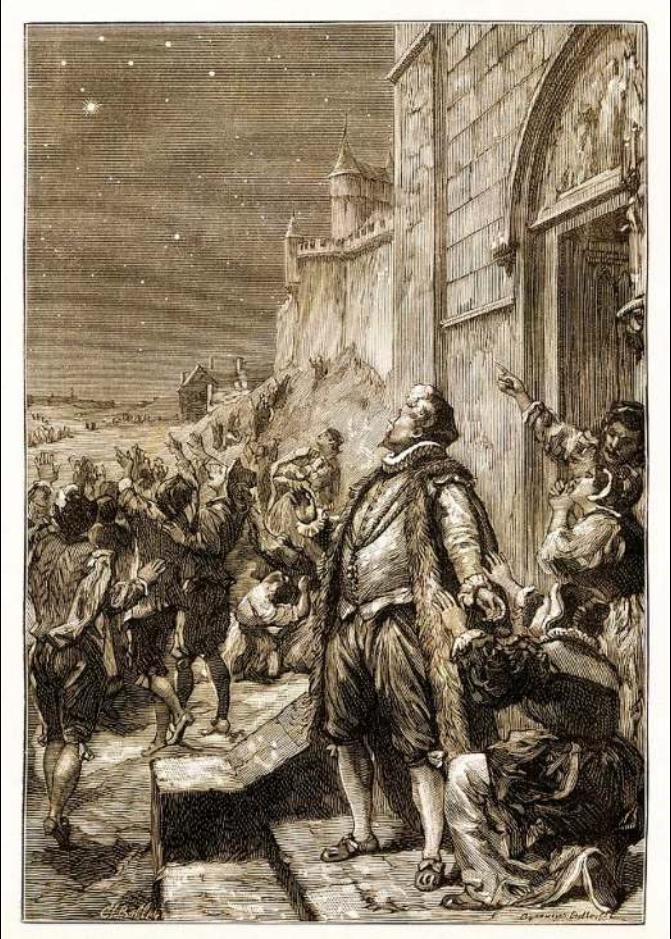
What Does “Nova” Mean?

- a) Explosion
- b) New
- c) Expansion
- d) Bright

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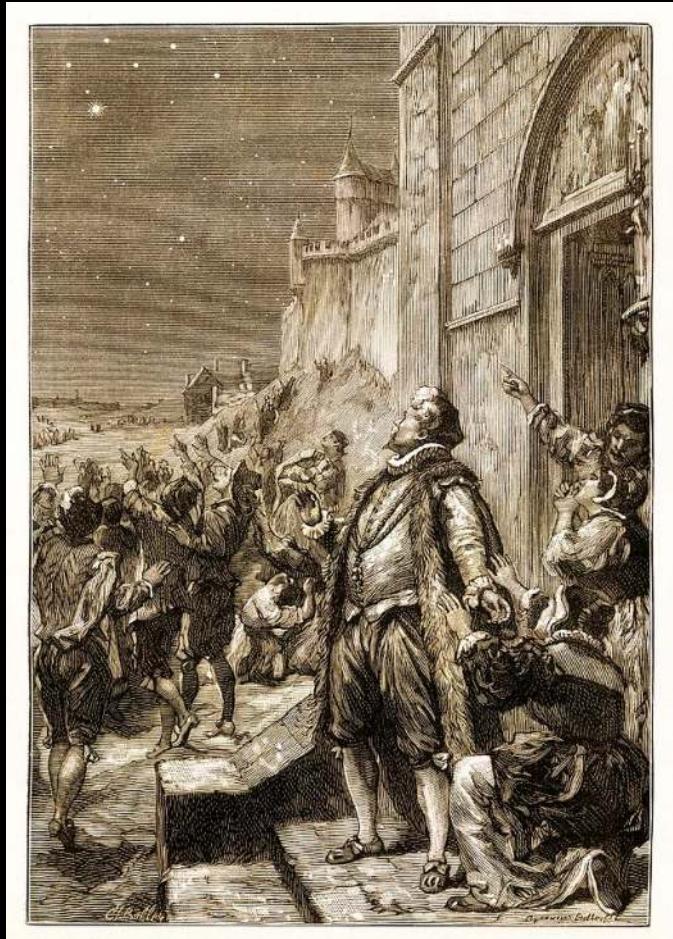
Observing a New Star?



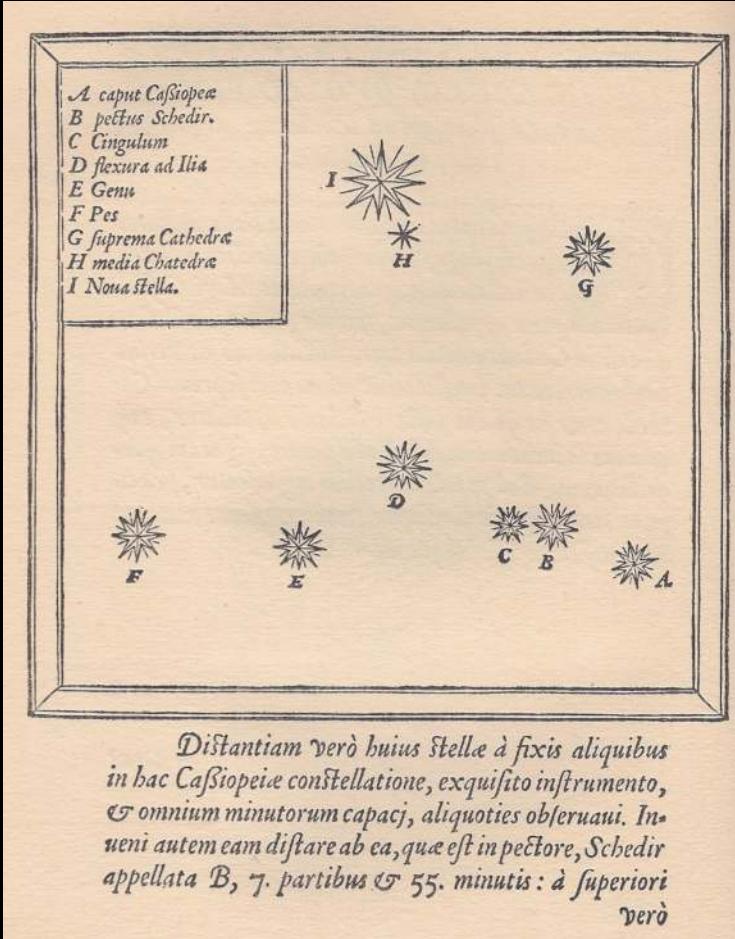
Engraving from Camille Flammarion's
Astronomie Populaire (1880).

- Tycho Brahe observes a “nova” in Cassiopeia in 1572.

Observing a New Star?



Engraving from Camille Flammarion's *Astronomie Populaire* (1880).



SN 1572 seen as Object I
in *De nova stella* (1573).

- Tycho Brahe observes a “nova” in Cassiopeia in 1572.
- Parallax measurements show “new star” is beyond the moon.
- Stars can change!

What are Super-Novae?



NGC 4157 with Arrow Pointing to
Zwicky's 1937 Supernova

- Fritz Zwicky and Walter Baade 1934
- Two classes, common and super-novae.

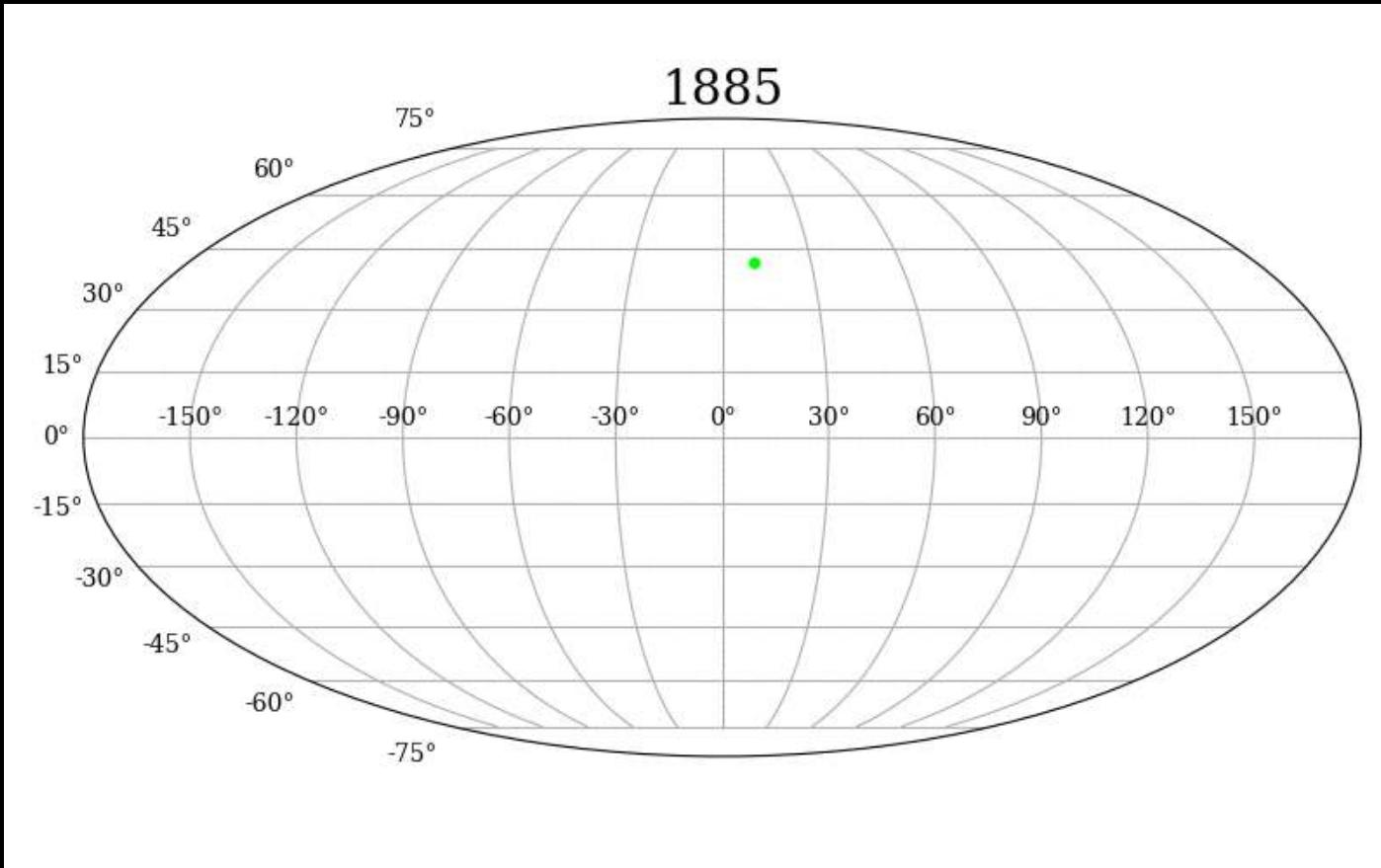
What are Super-Novae?



NCG 4157 with Arrow Pointing to
Zwicky's 1937 Supernova

- Fritz Zwicky and Walter Baade 1934
- Two classes, common and super-novae.
- Gravitational collapse of core into small object.
- Sphere of neutrons at nuclear density, a neutron star.

Searching for Elusive Supernovae



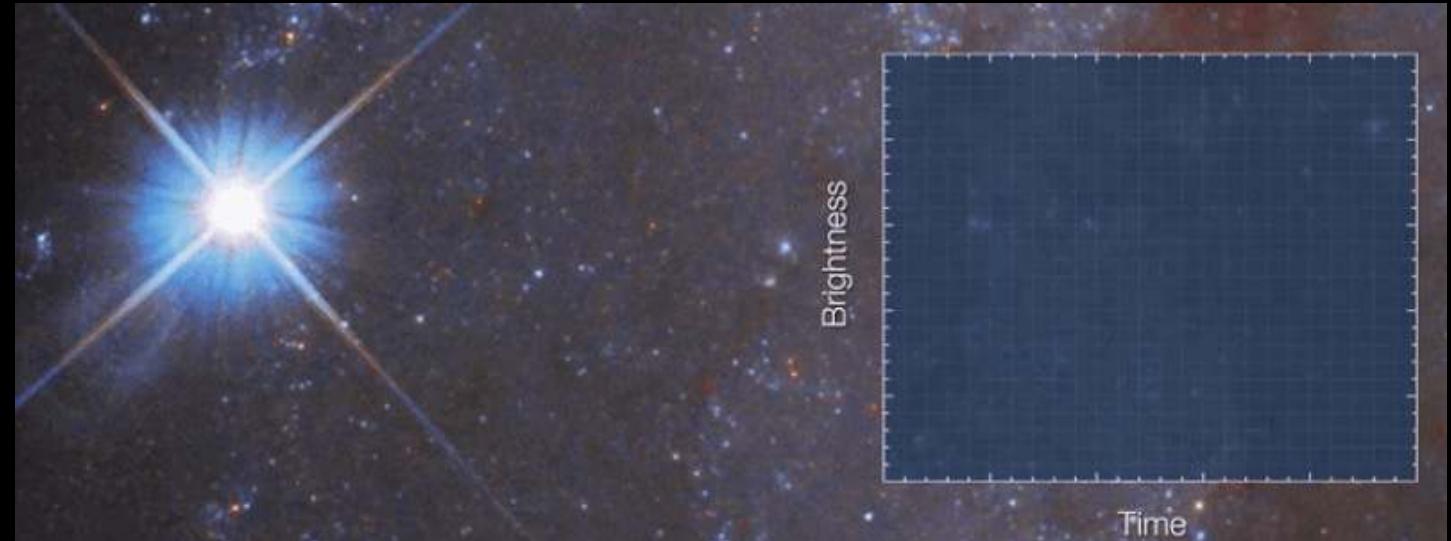
Timelapse of SN Discoveries

Modern Observations of Supernovae



SN 1994D within NGC 4526

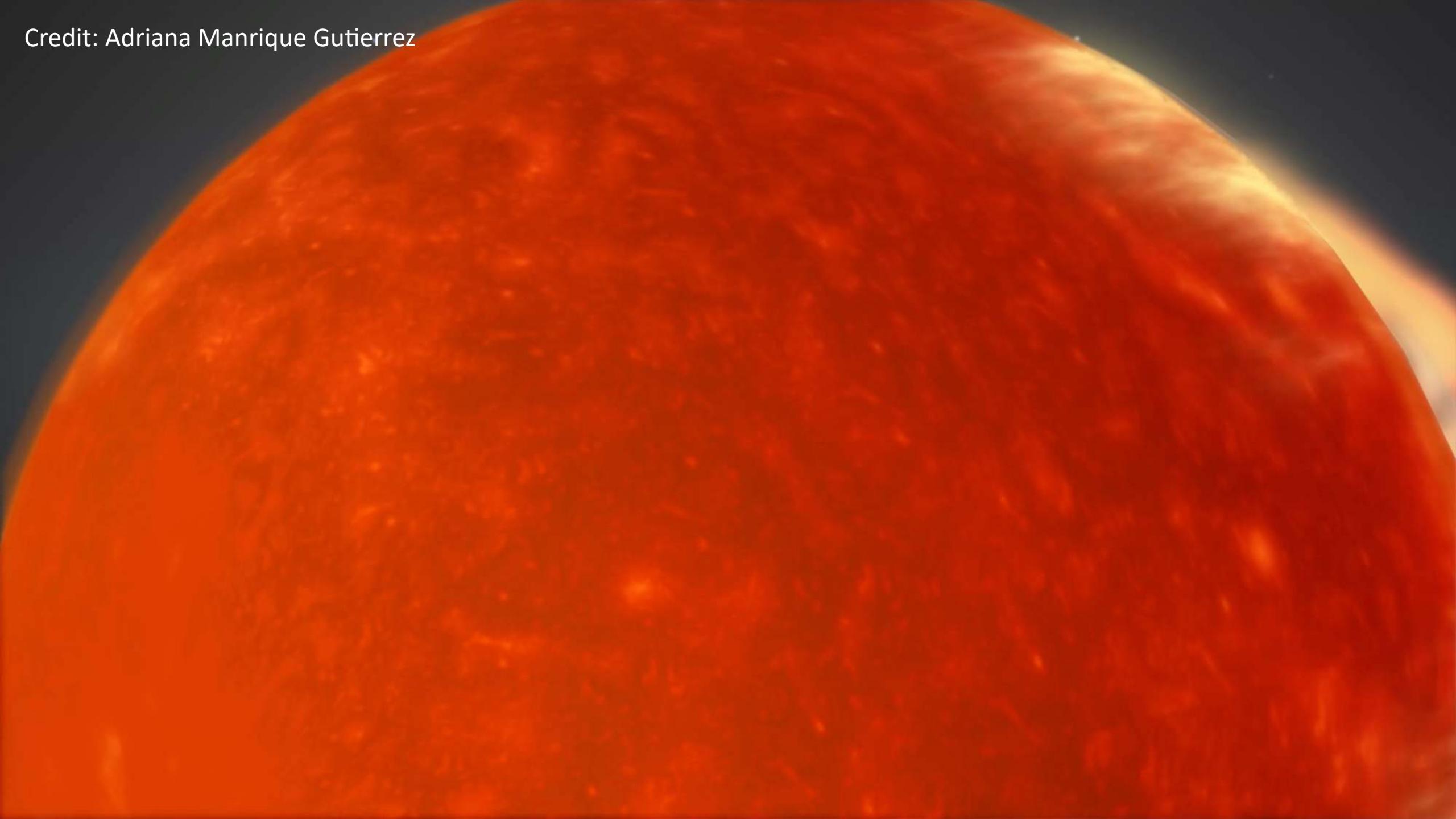
Credit: NASA/ESA



Credit: ESA

What is a Type 1a Supernova?

Credit: Adriana Manrique Gutierrez



Sequence of Supernova Explosion

- White Dwarf accretes mass from companion star.
- Reaches a critical mass of $\sim 1.4M_{\odot}$
- Electron degeneracy pressure unable to resist collapse.
- Runaway carbon fusion leads to supernova explosion.

What do we observe?

1. Changes in Luminosity

- How are photons escaping (or not) from the remnant?

What do we observe?

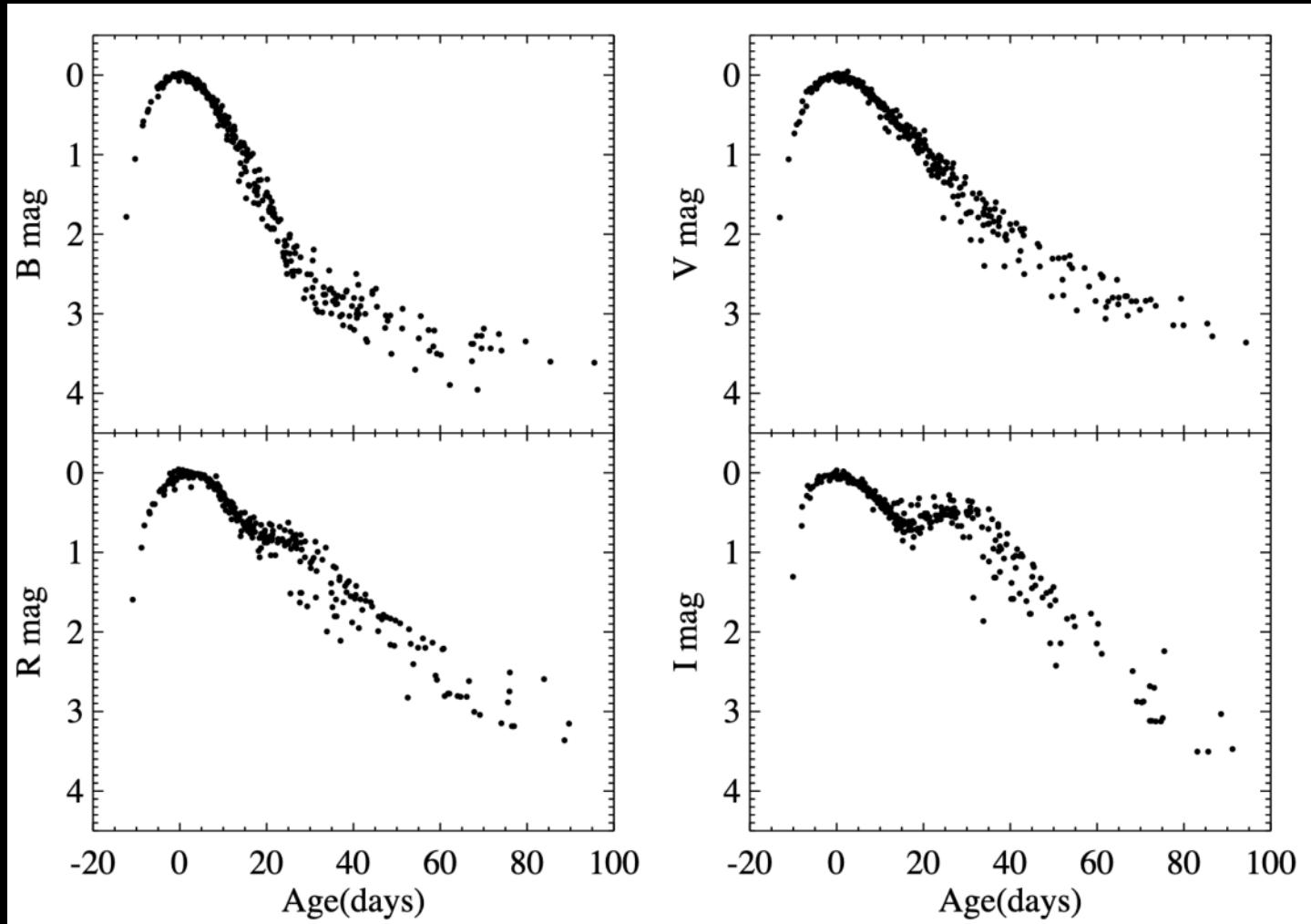
1. Changes in Luminosity

- How are photons escaping (or not) from the remnant?

2. Time evolution of Spectra

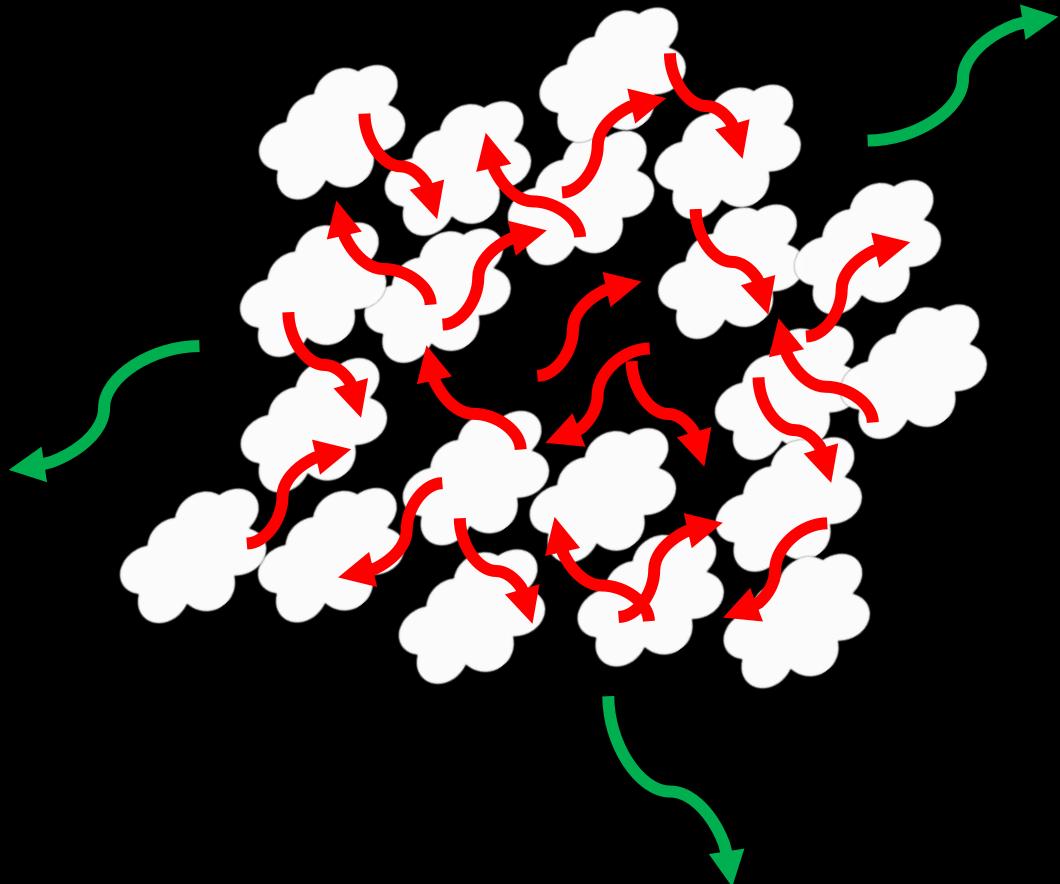
- Probe composition of ejecta.

What Determines the Light Curve Shape?



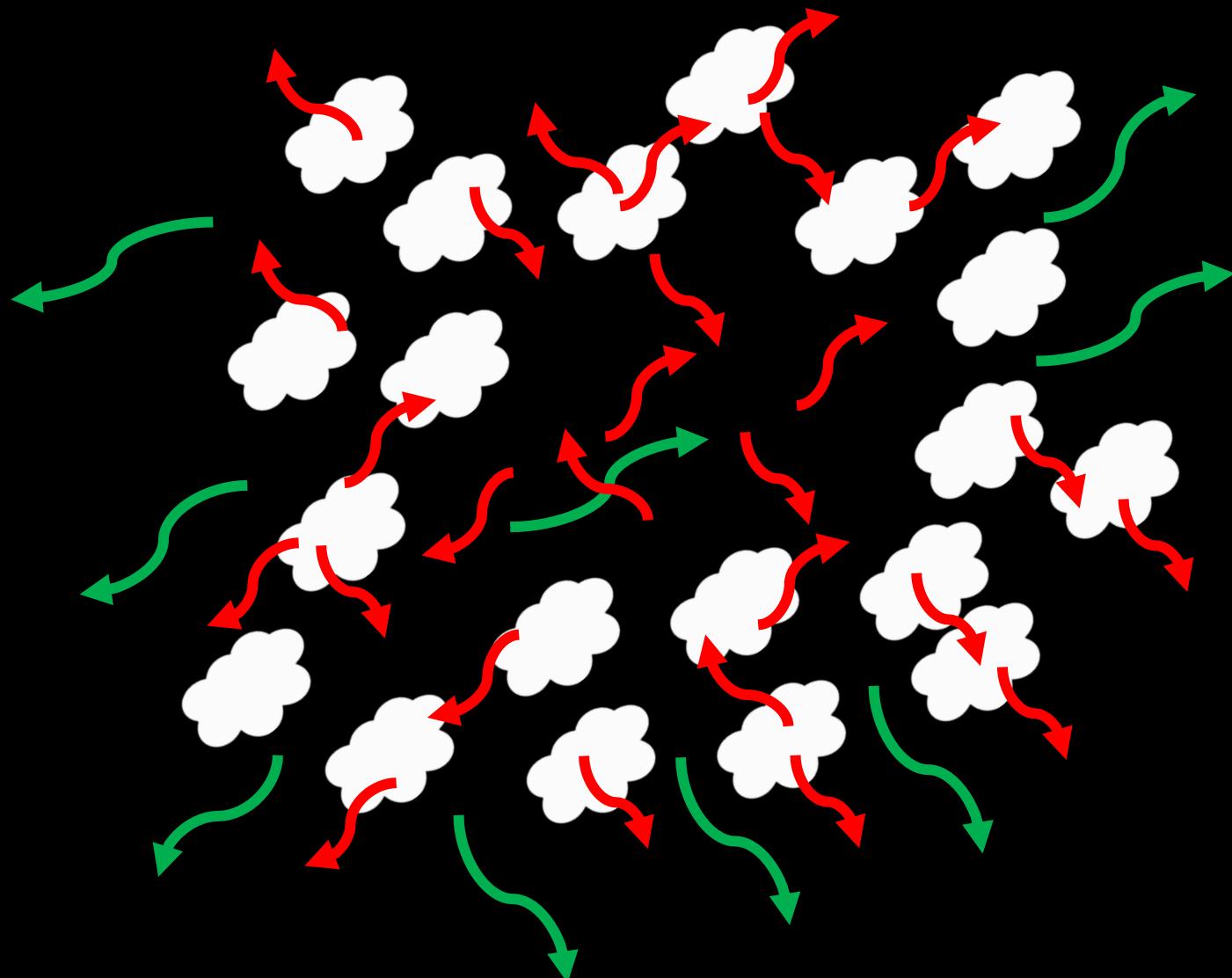
Composite of 22
SN Ia light curves

Why is it dimmer at the beginning?



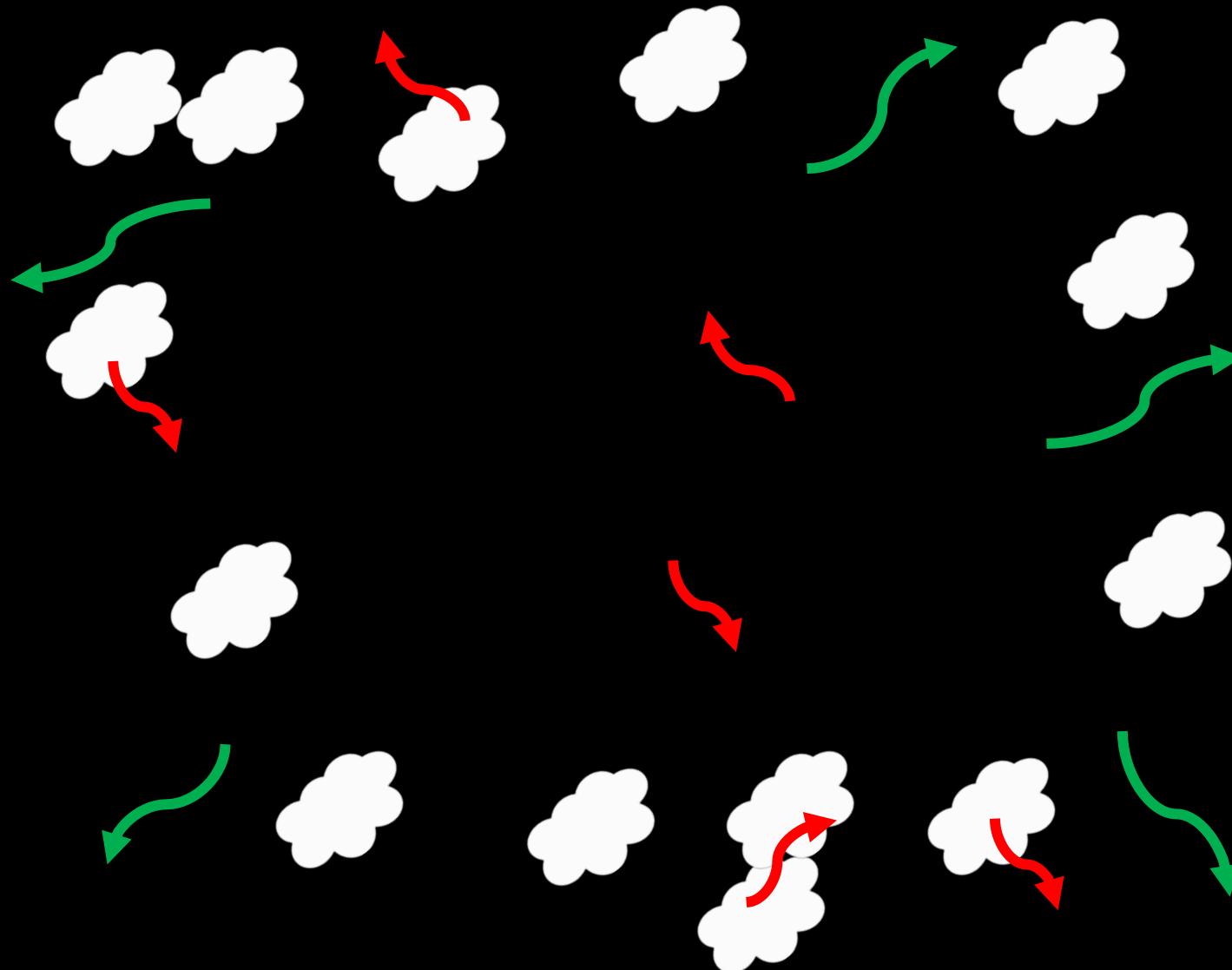
- Very optically thick at beginning.
- High energy photons absorbed and reemitted.
- Photons take a long time to escape.

Why does the Luminosity Increase?



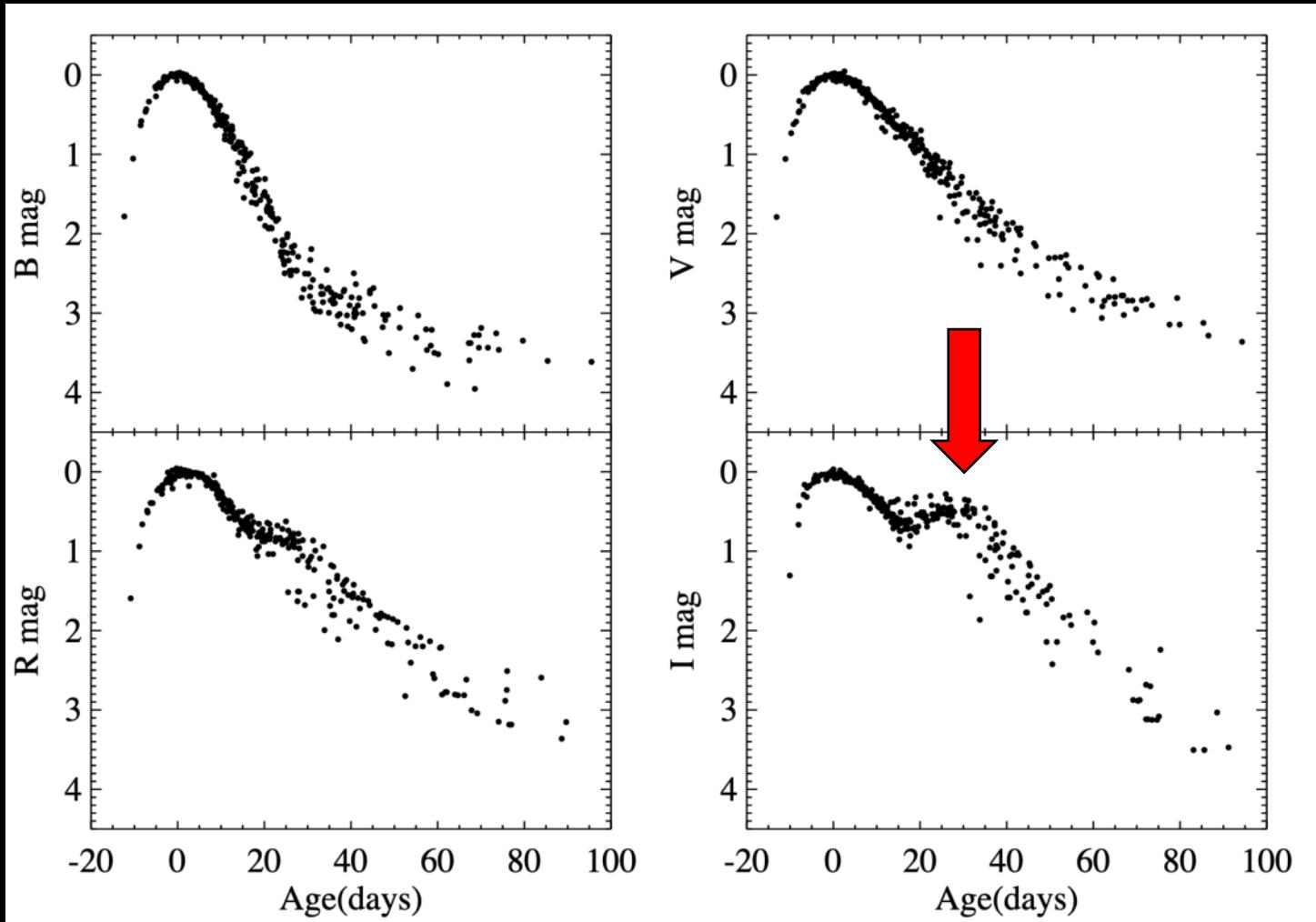
- Opacity decreases, more emission visible.
- High energy photons are reprocessed to lower energies.

Why does the Light Curve Fade?



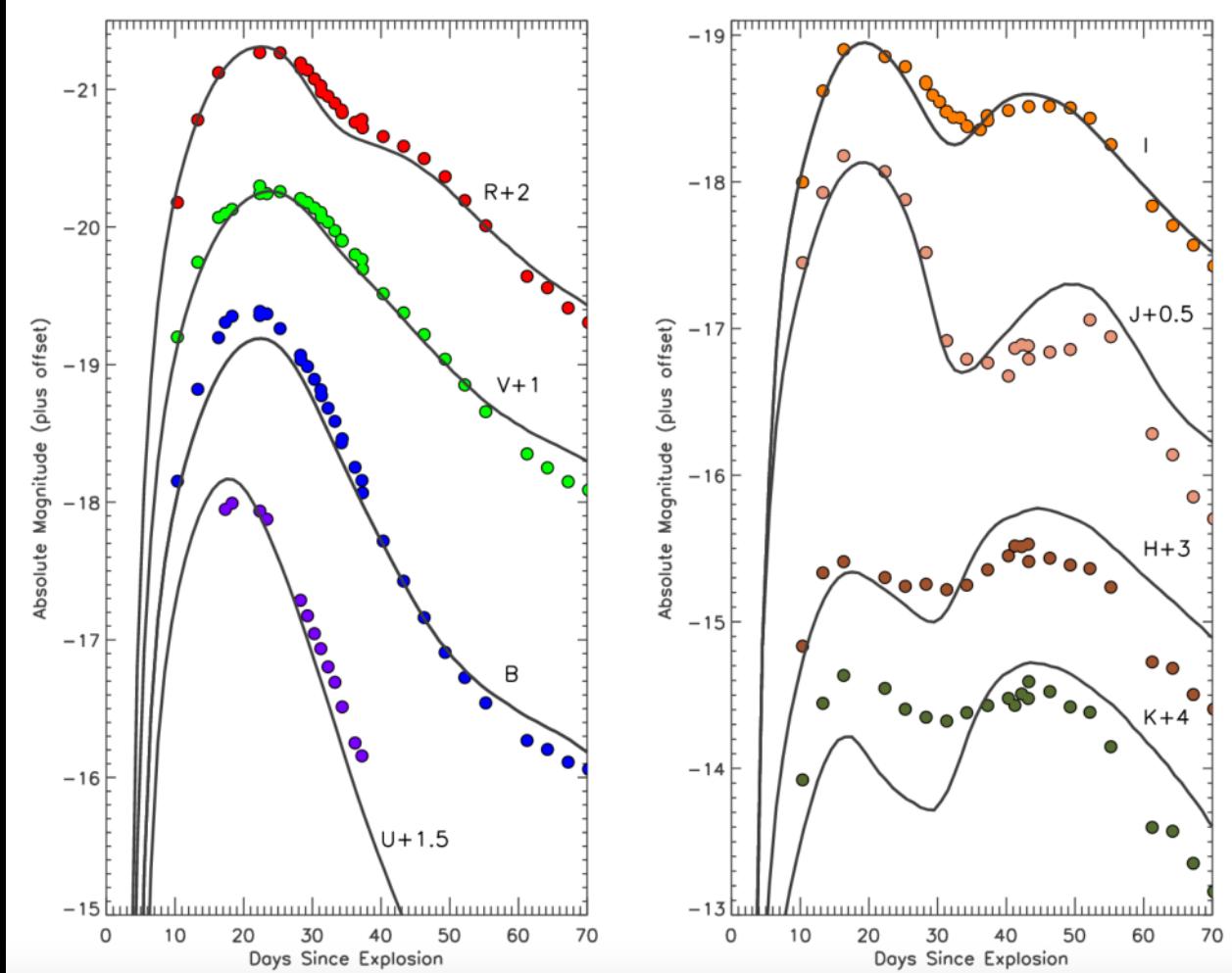
- Opacity is low
- Most photons escape
- Emission decreases

Bump in Light Curve in I-Band?



Reiss et al. (1999)

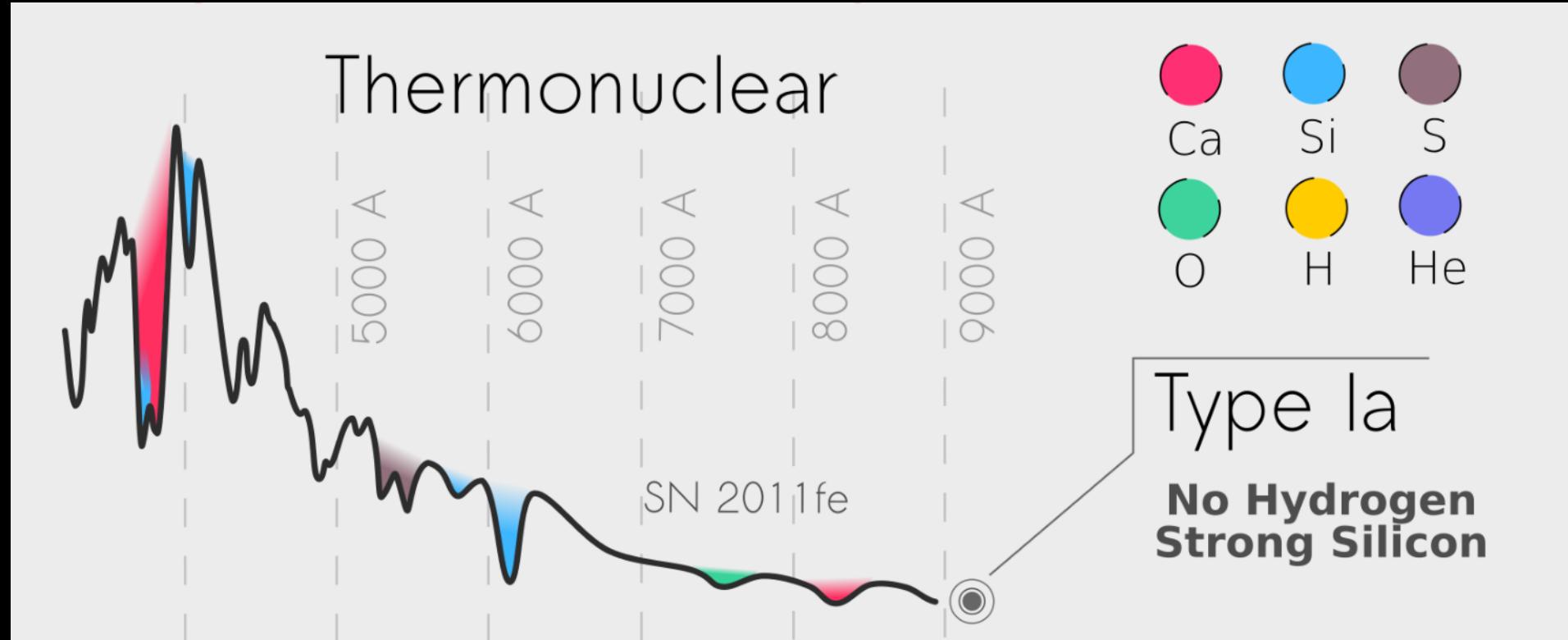
What Transitions are we seeing?



Light curves of SN Ia SN2001el from Kasen (2006)

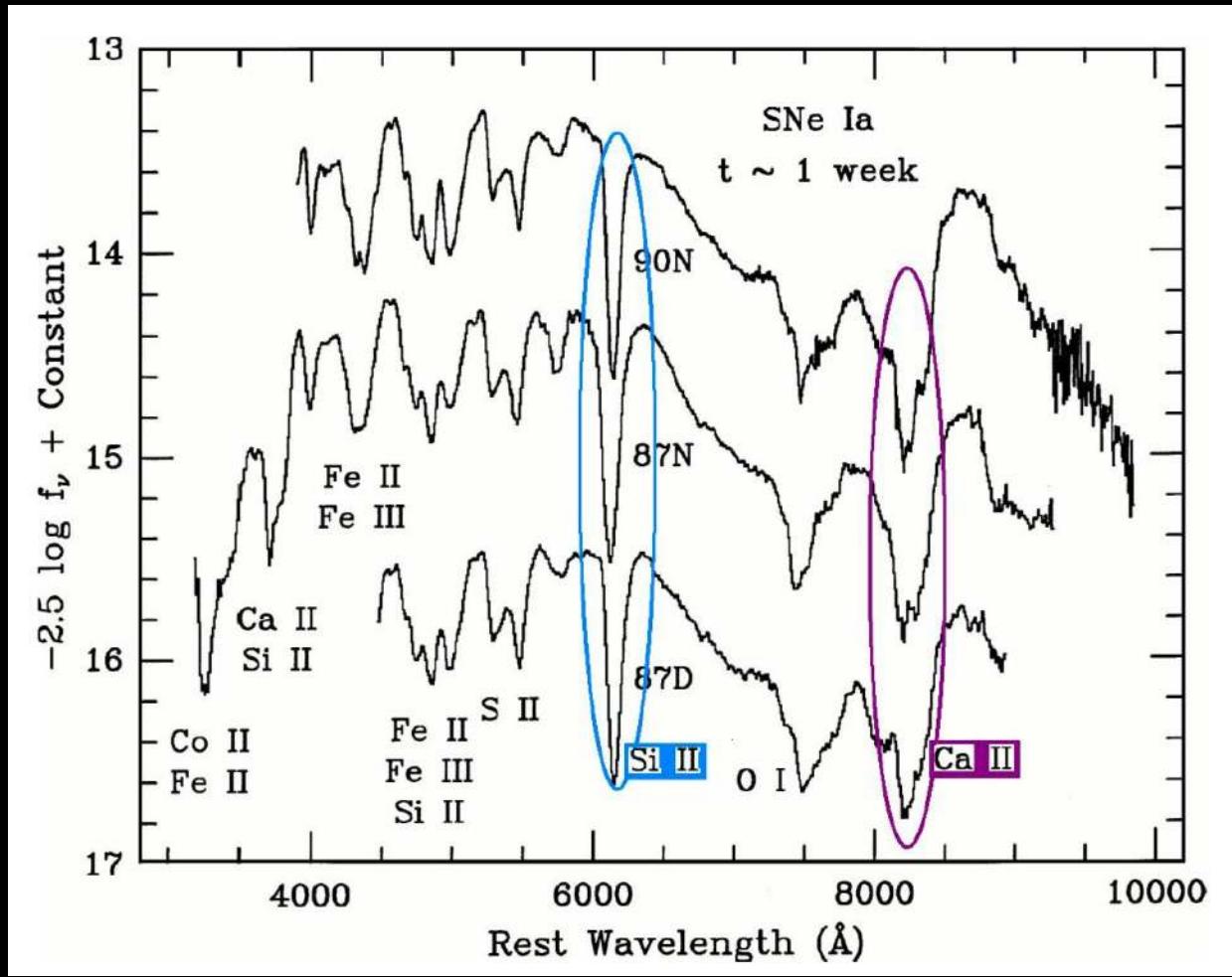
- High energy photons absorbed.
- Can be reemitted as lower energy photons.
- What is reprocessing the light?

Composition of the Ejecta?



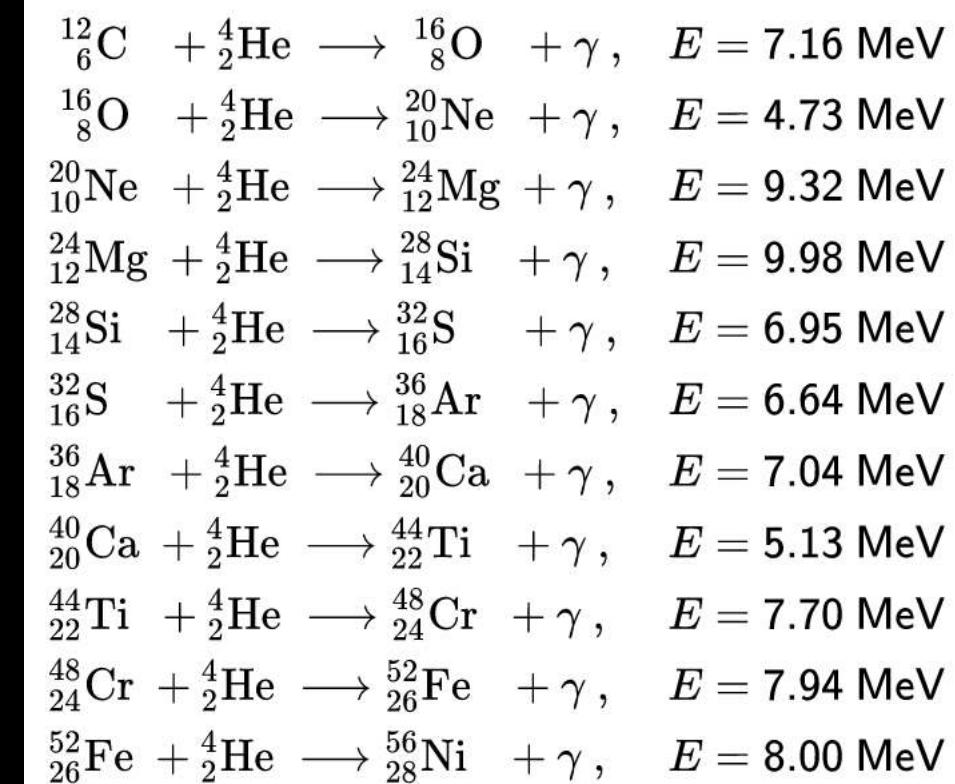
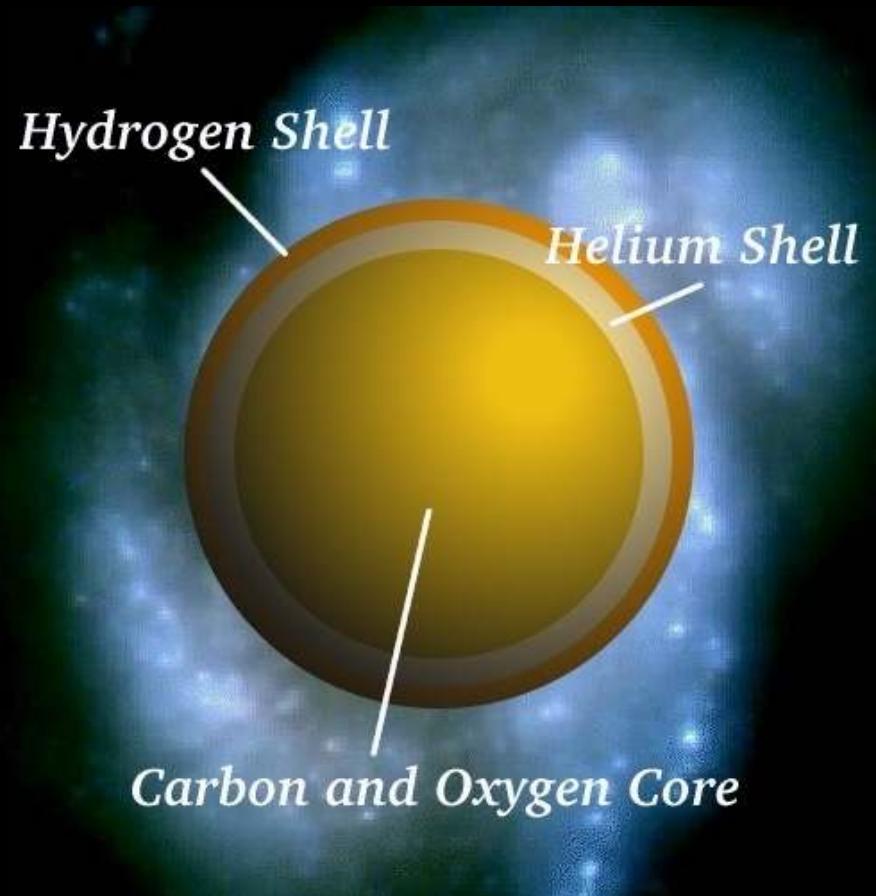
Credit: Heloise Stevance

Absorption from Metals right after SN

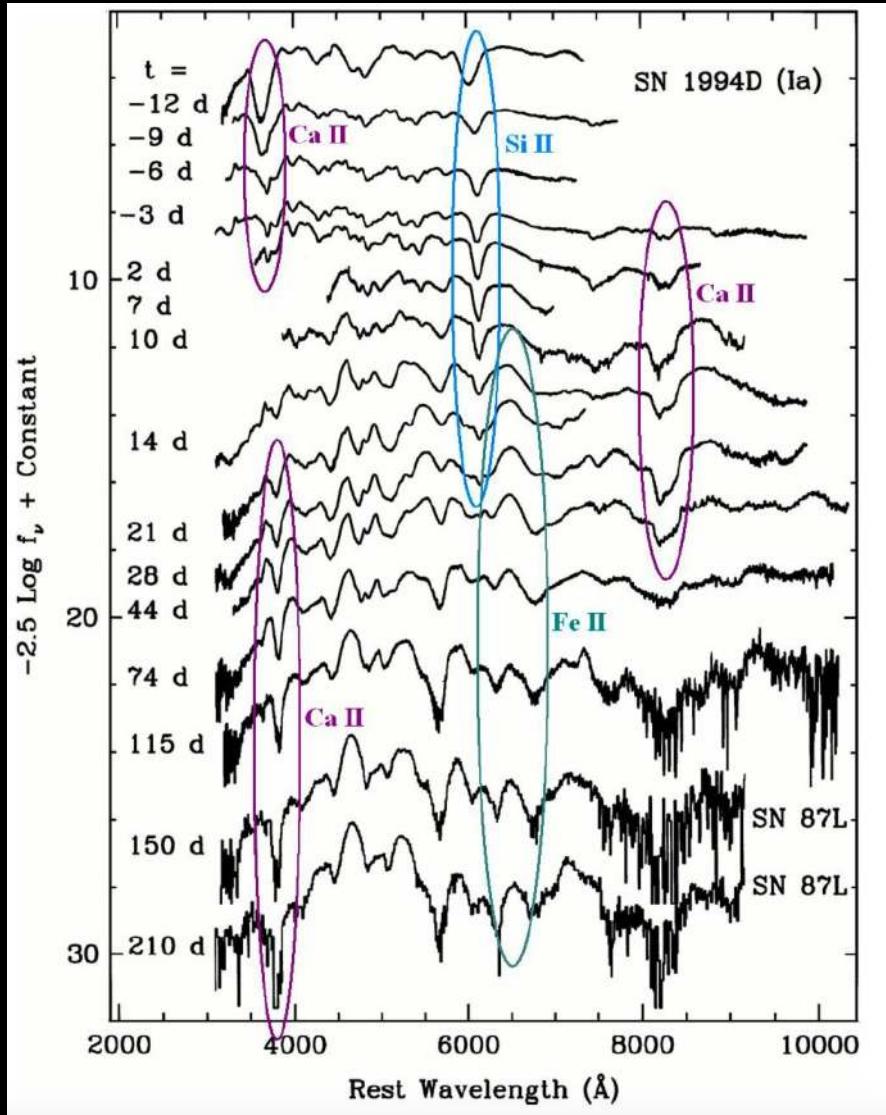


Filippenko (1997)

Alpha Process Elements from Runaway Fusion



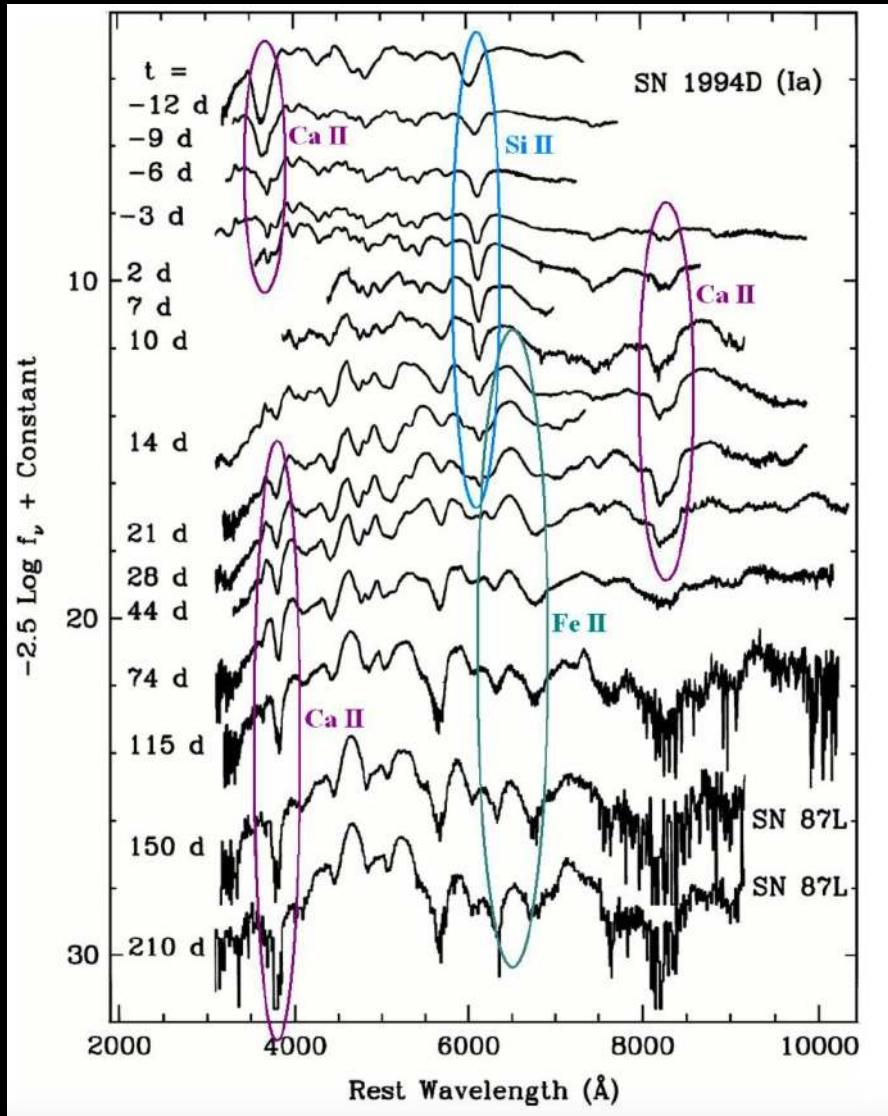
Lower Mass Element Lines Stronger First



- Si II absorption begins to weaken after 21 days.
- See lines in outer layers of ejecta first
- Runaway fusion in outer layers didn't reach iron.

Filippenko (1997)

Iron-Group Lines Stronger Later

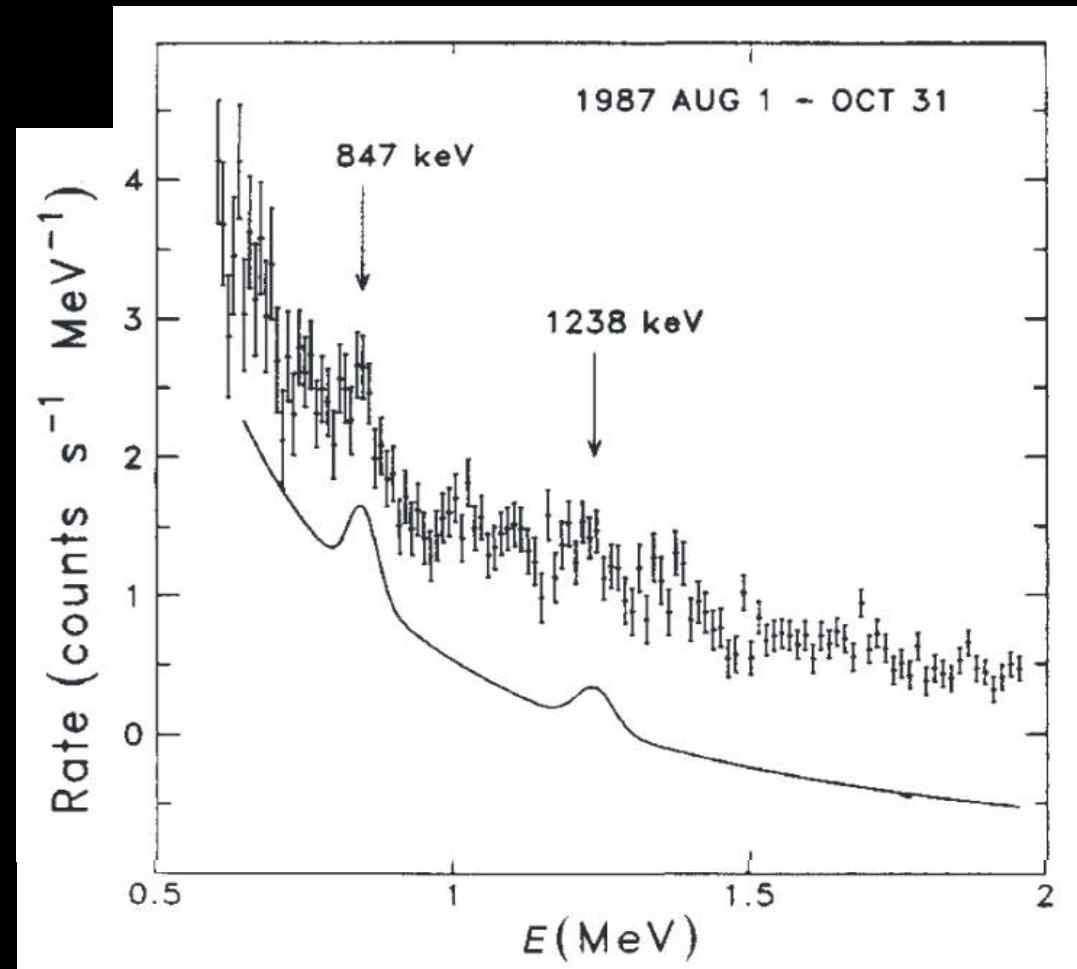
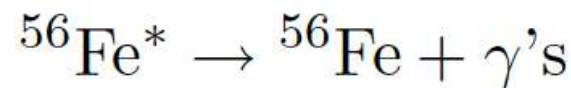
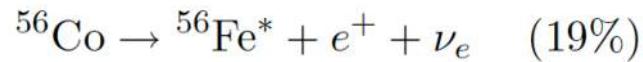
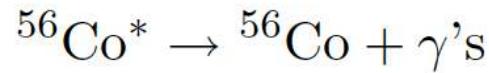
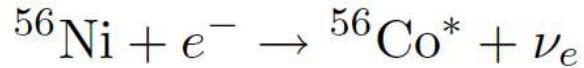


- See strong Fe II lines after 14 days.
- Runaway fusion more complete in interior of white dwarf.
- Beginning to see inner parts of the SN ejecta.

Filippenko (1997)

**What is illuminating the supernova
ejecta after 100+ days?**

Radioactive Decay of Heavy Elements



Nadyozhin (1994)

Matez et al. (1988)

Best Time-Domain Astronomy Topic?

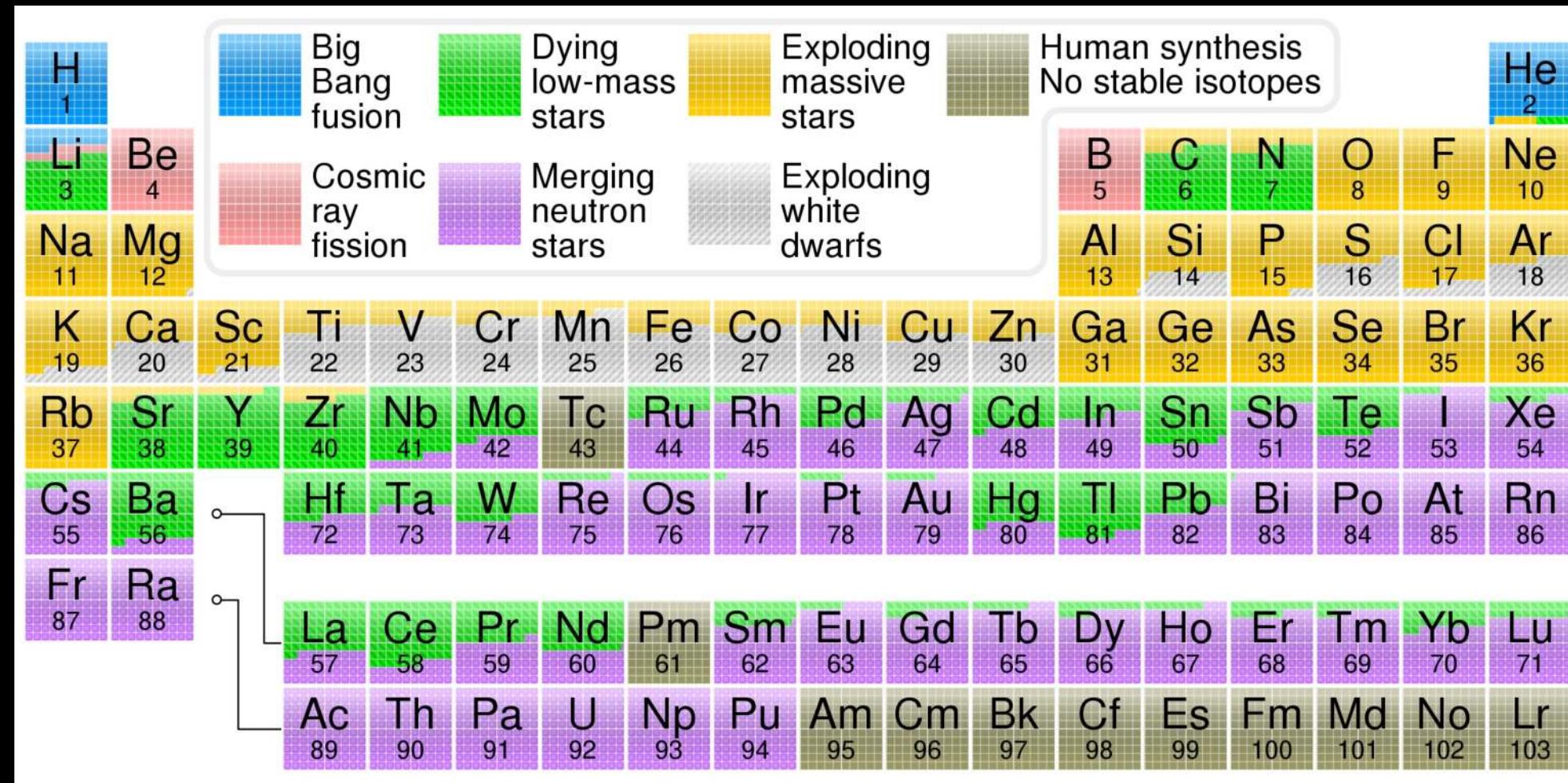
- a) Supernovae
- b) Core-Collapse Supernovae
- c) Pair-Instability Supernovae
- d) Type 1a Supernovae

Best Time-Domain Astronomy Topic?

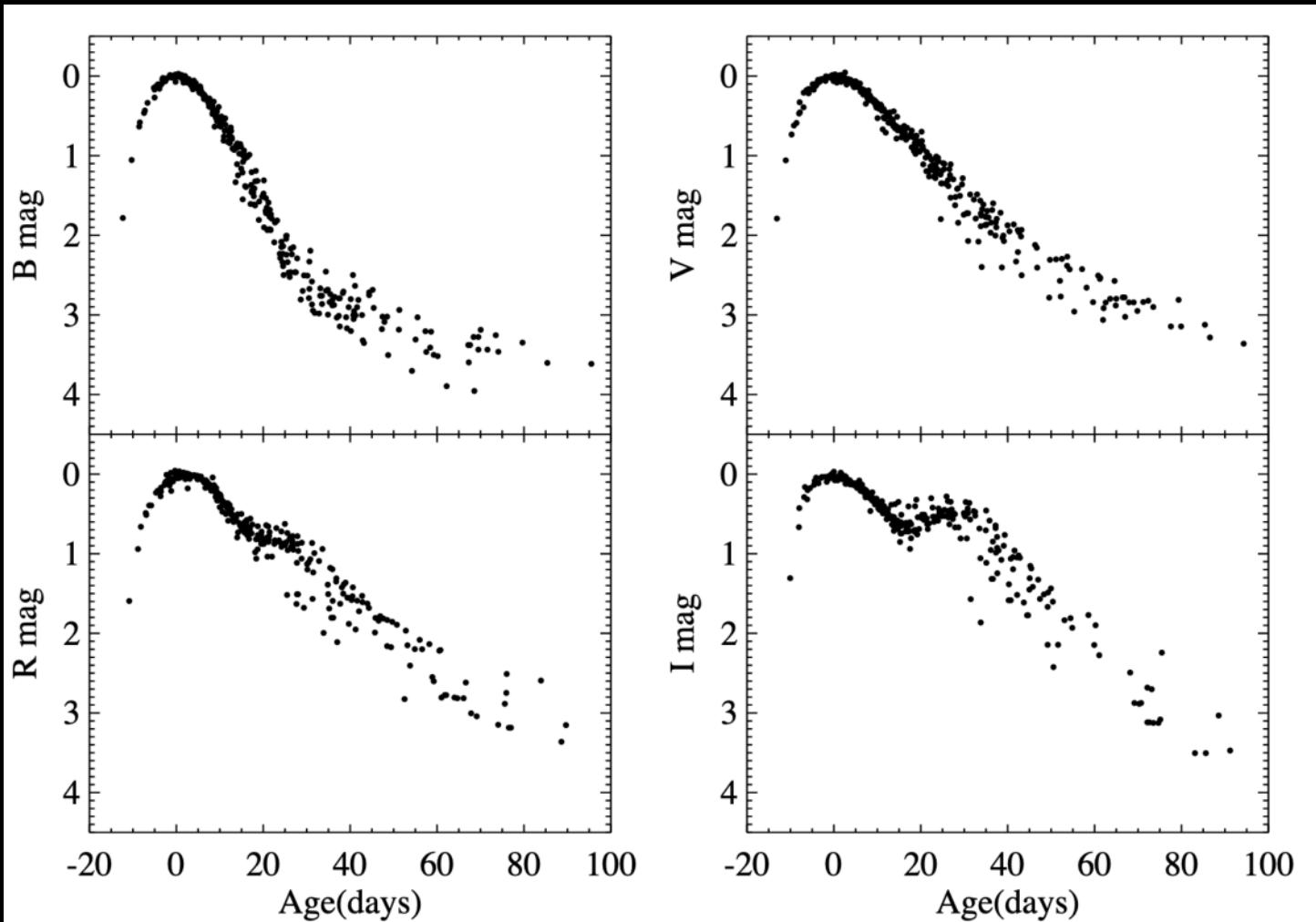
- a) Supernovae
- b) Core-Collapse Supernovae
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- d) Type 1a Supernovae

Why do we care about this?

Enrichment of the Interstellar Medium

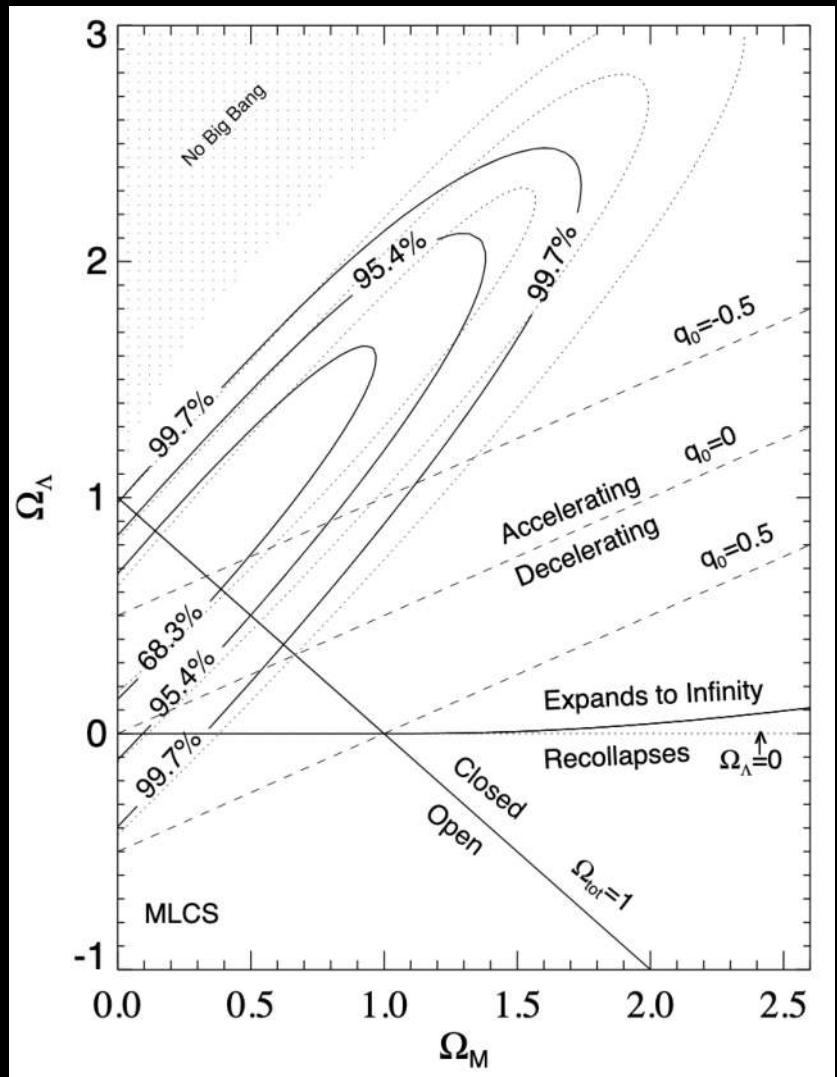


Supernova 1a as “Standard Candles”

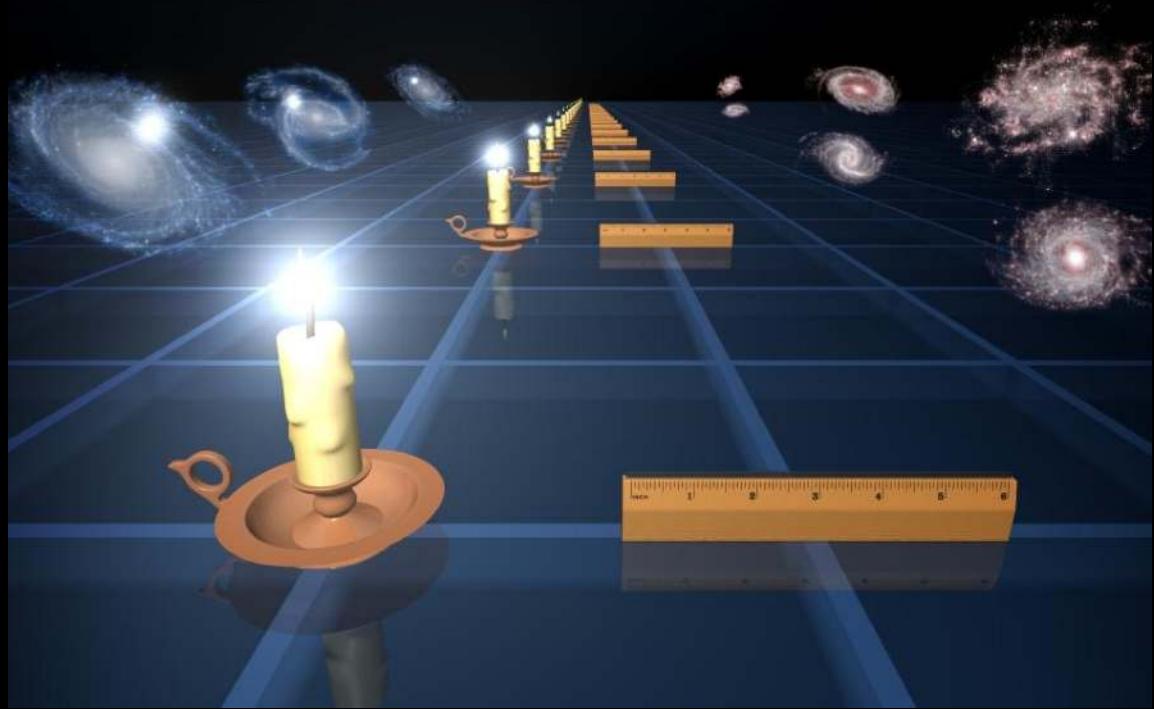


Reiss et al. (1999)

Supernova 1a as “Standard Candles”



Reiss et al. (1998)



Credit: NASA

Accelerating Expansion of the Universe

<https://ui.adsabs.harvard.edu> › abs › abstract ::

Observational Evidence from Supernovae for an ... - NASA/ADS

by AG Riess · 1998 **Cited by 22983** — We present spectral and photometric observations of 10 Type Ia supernovae (SNe Ia) in the redshift range $0.16 \leq z \leq 0.62$. The luminosity distance...

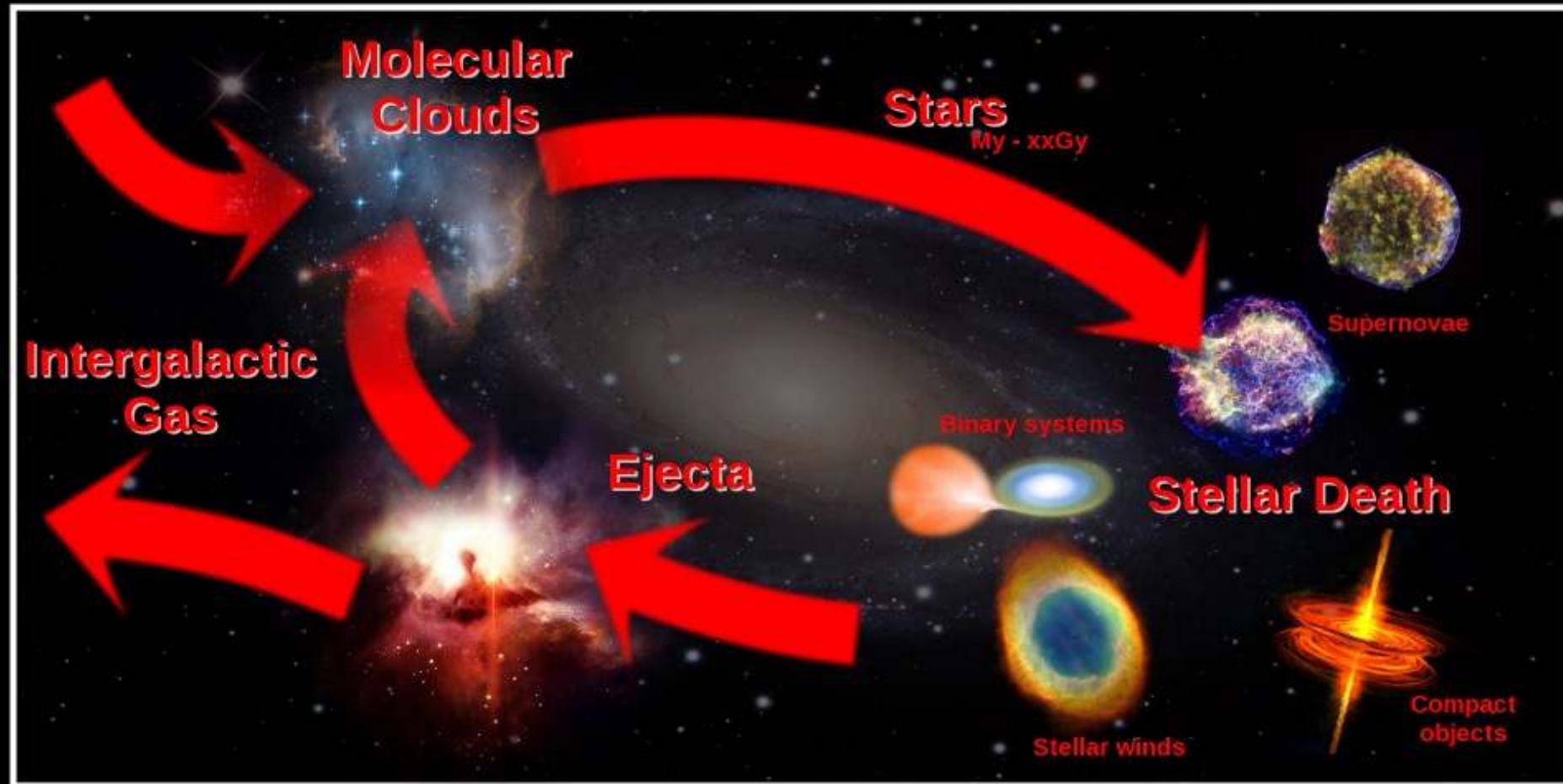
Take away

- Light curves and spectra offer key insights into the evolution of a supernova and its ejecta.
- Supernovae can be used to understand enrichment of the ISM and predict the fate of the Universe.

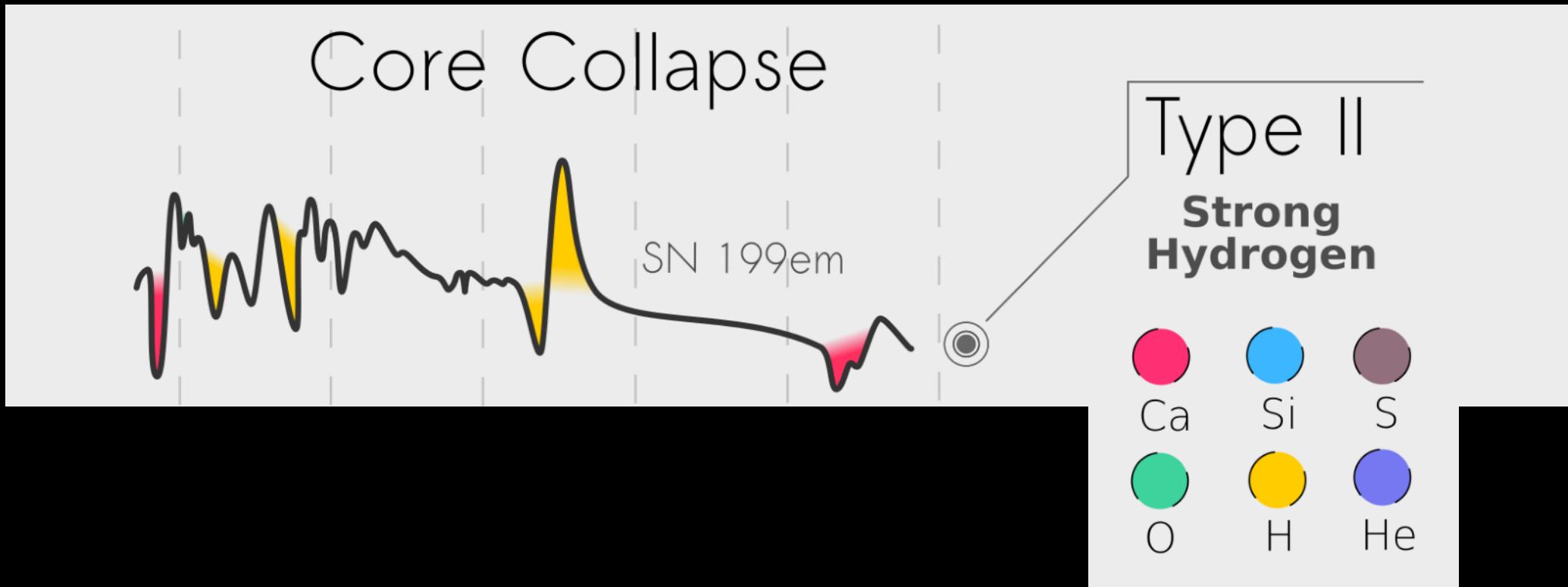
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Impact of Supernova Feedback

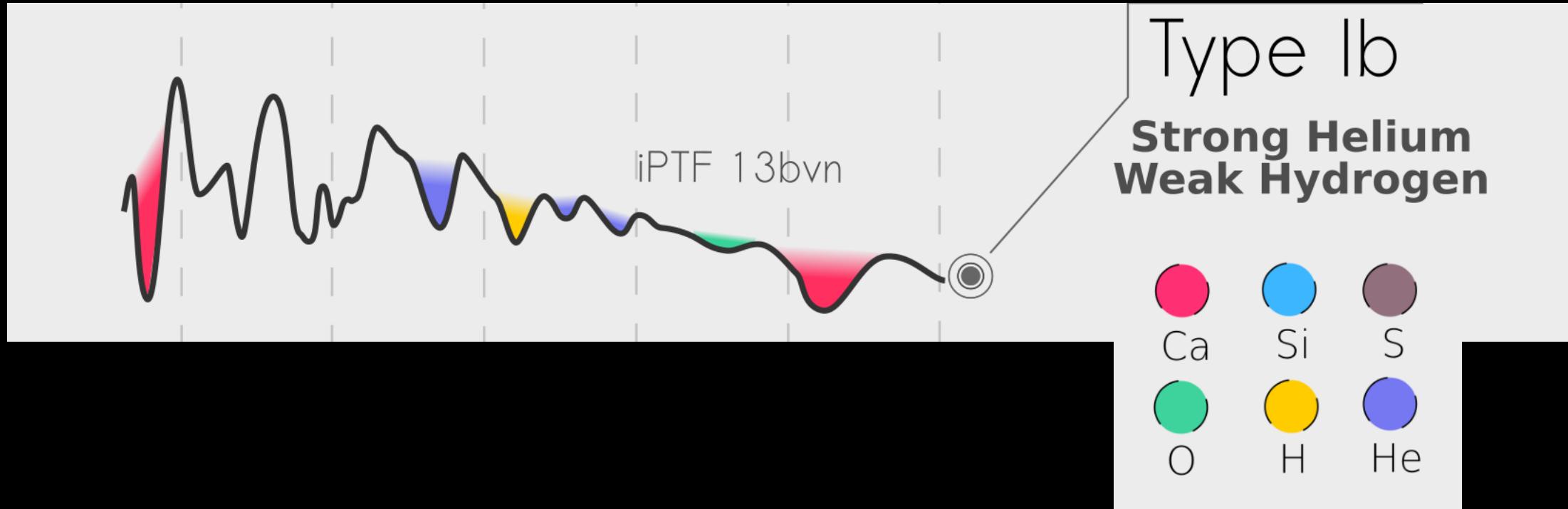


Supernovae Spectra Differences



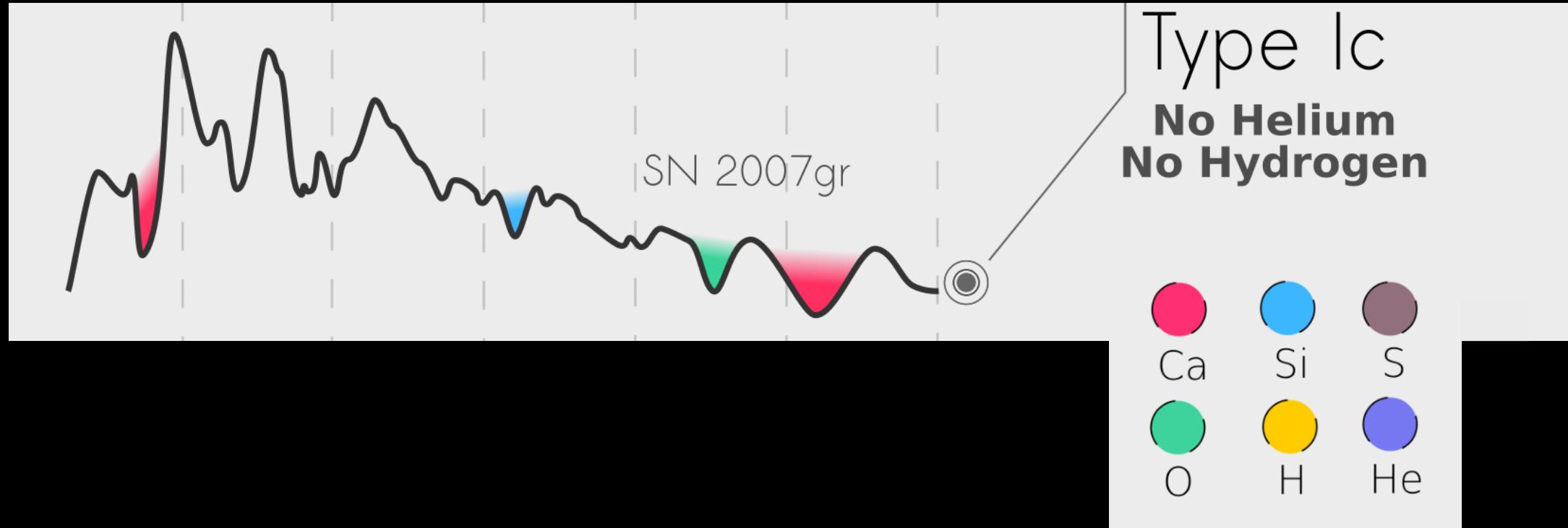
Credit: Heloise Stevance

Supernovae Spectra Differences



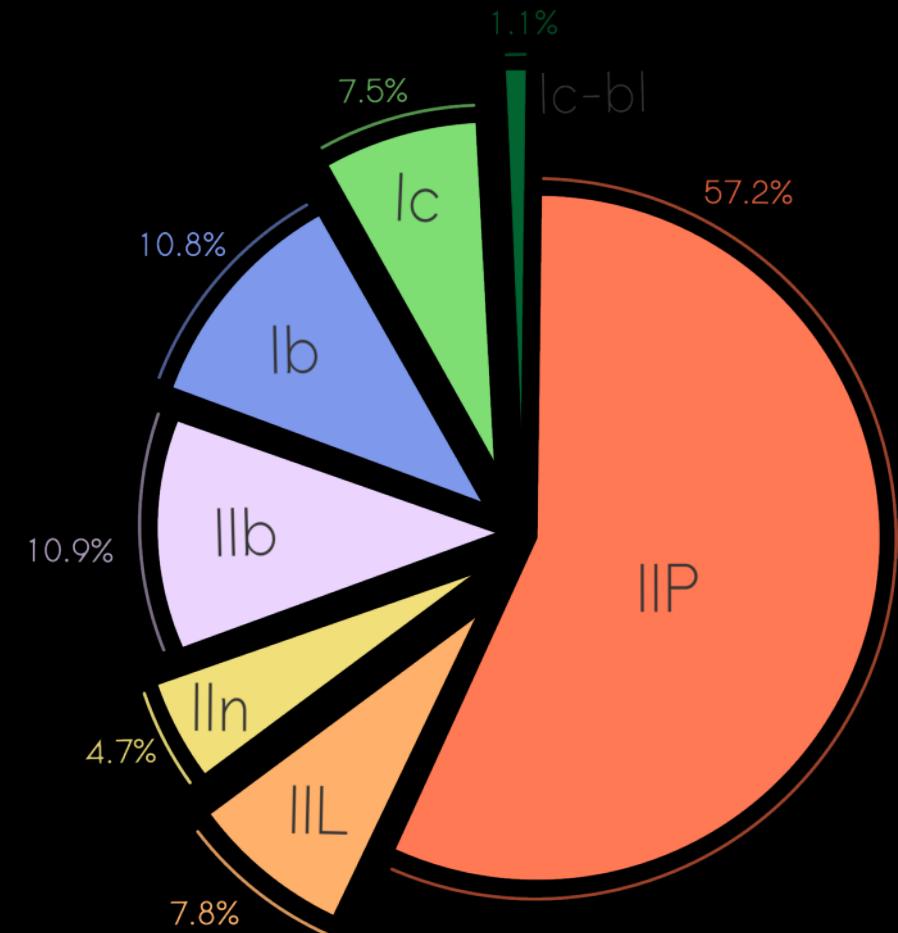
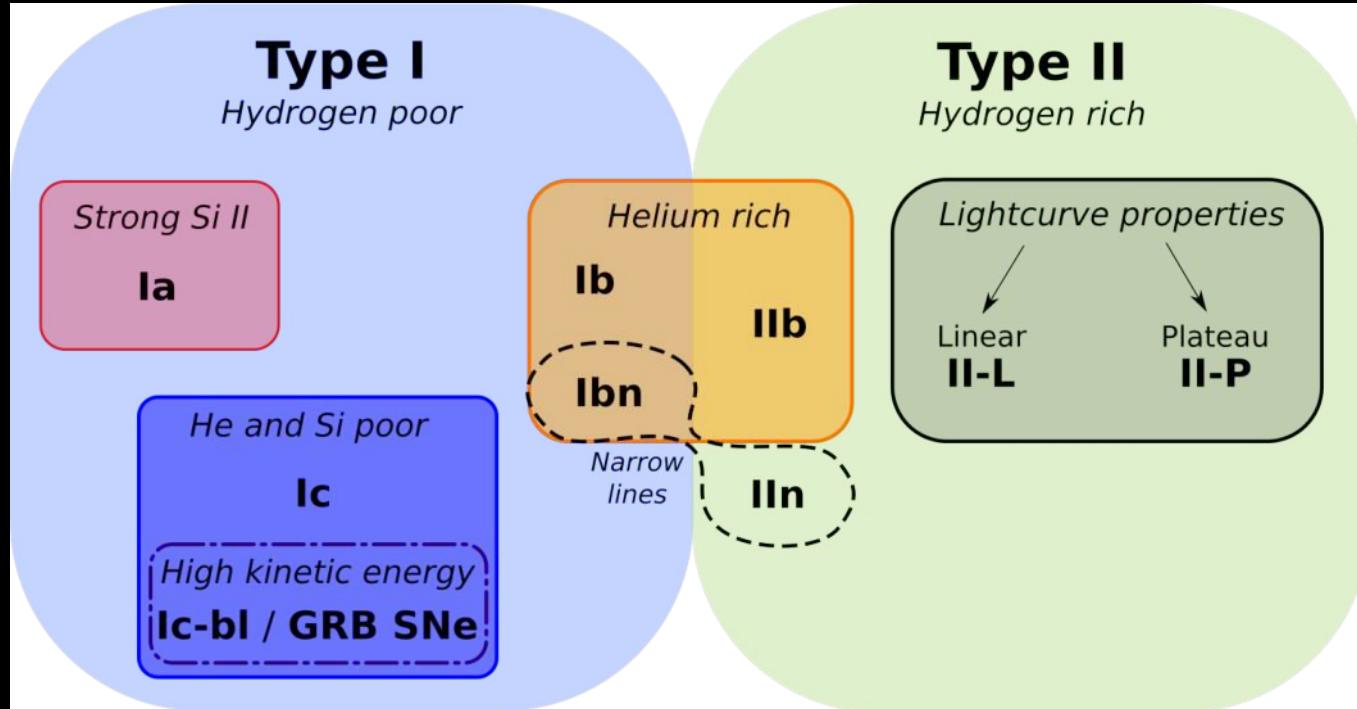
Credit: Heloise Stevance

Supernovae Spectra Differences



Credit: Heloise Stevance

Observed Supernova Summary



Light Curves Evolve Differently

