Supernovae Ia: Omens of the past. Today's Auguries.

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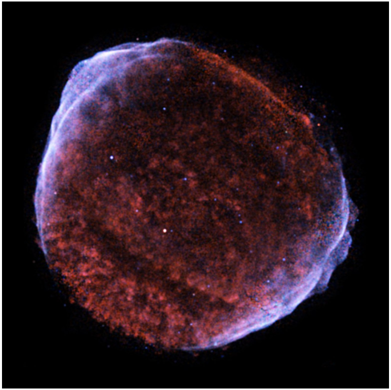
THE UNIVERSITY OF TENNESSEE KNOXVILLE

SN185 & SN1006

SN185 First recorded. Observed for 8 months, even at daytime. Seen by the later Han empire, and Romans under Commodus.

SN1006 Observed from Japan to Egypt, even in Switzerland. Detailed observations in Cairo point to April 30, 1006.

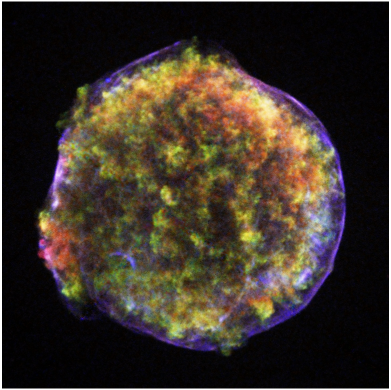



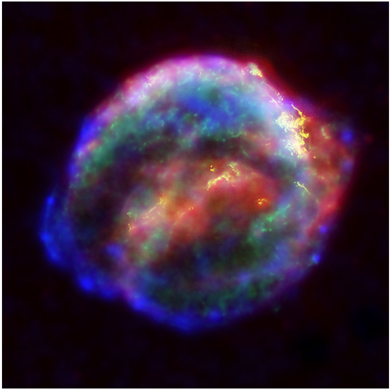
left: SN185 (IR, XRay). right: SN1006 (XRay).

SN1572 & SN1604

`SN1572` Tycho's SN. No parallax during 18 months of observations.

`SN1604` Kepler's SN. Almost an exact repeat merely 32 years afterwards.





left: SN1572 (IR, V, XRay). right: SN1604 (XRay)

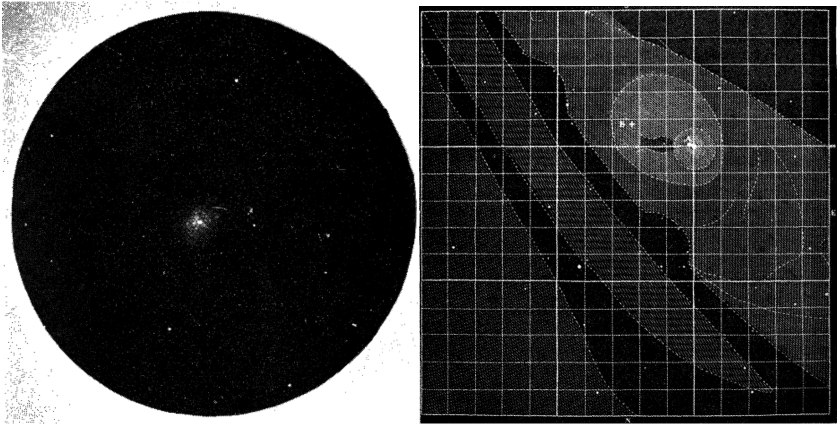
EM silence (1605-1884)

- No visible events between 1604 and 1885!
- Flourishing of science:

  Telescopes improve
  Spectroscopy is invented
  Photography
- Still relying on serendipitous discoveries...

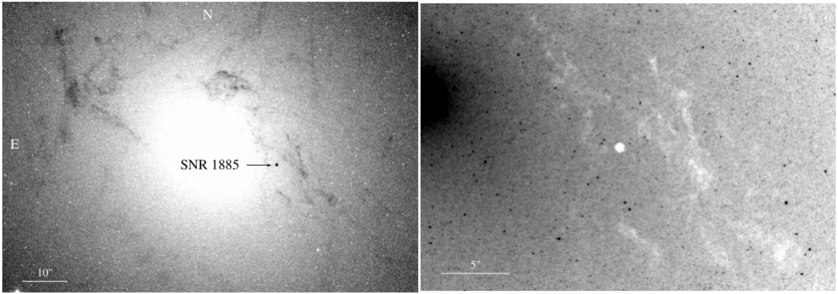
SN1885A

- First extragalactic SN. Found in M31(Andromeda). Thought of as a collapsing nebula.



Jones 1976 (1976JHA.....7...27J)

SN1885A



Fesen et al. 2017 (2017ApJ...848..130F)

SN1885A

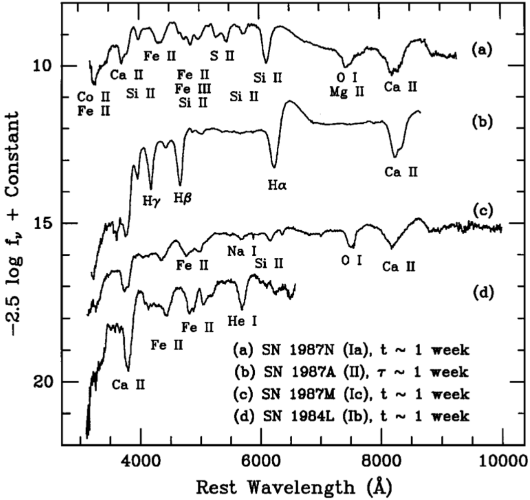
- Sticking point in "Great Debate" about "island universes" (1920):
  - Curtis calculates distance to M31 as 100 times farther than the estimate.
  - This puts SN1885A at a 100 million times brighter than the sun!
  - Shapley finds this unimaginable since the brightest star seen was merely 10000 times brighter.
- In 1923, Hubble observations of Cepheids in M31 certified the huge distance. And the enormous brightness!

"Super-novae"

- 1931: Baade and Zwicky describe main properties
- One per several centuries.
- 20 day transient.
- 100 million times $L_\odot$ at maximum.
- Mass of progenitors up to 10 $M_\odot$
- 1936-9: Zwicky SN search: finds 12 in 3 years, with spectra.
- 1940: Minkowski establishes SN types based on Zwicky's work.

Type	Hydrogen	Silicon	Helium
Ia	No	Yes	No
Ib	No	No	Yes
Ic	No	No	No
II	Yes	No	No

"Super-novae"



Filippenko 1997 (1997ARA&A..35..309F)

Nucleosynthesis

- 1957: B^2FH. Maps all elements to stellar environments. Explosive energy needed past iron.
- 1962: Pankey fits around a solar mass of ^{56}Ni to power the light curves of SN Ia. Which decays into ^{56}Fe seen in spectra.

$$^{56}Ni \xrightarrow{6d} {}^{56}Co \xrightarrow{77d} {}^{56}Fe$$

- Point source. $1M_{\odot}$ of fuel. Explosion. White dwarfs!

Nucleosynthesis

- From obs: $v_{\mathrm{ejecta}} \sim 10^4 \mathrm{km} \cdot \mathrm{s}^{-1}$, $t_{\mathrm{diff}} \sim 10\ d \sim 10^6 \mathrm{s}$.
- Diffusion timescale:

$$t_{\mathrm{diff}} = \tau \frac{R}{c} = \kappa \rho R \frac{R}{c} \sim \frac{\kappa M}{Rc}$$

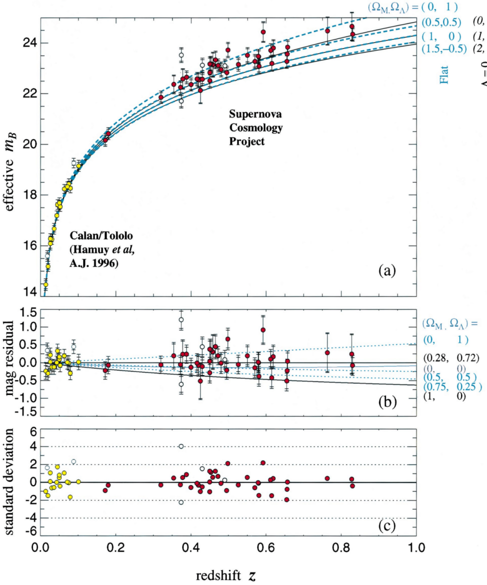
$$R = v t_{\mathrm{diff}}$$

$$t_{\mathrm{diff}} \simeq \sqrt{\frac{M\kappa}{vc}} \implies M_{\mathrm{ejecta}} \simeq 1 M_{\odot}$$

Probing deeper

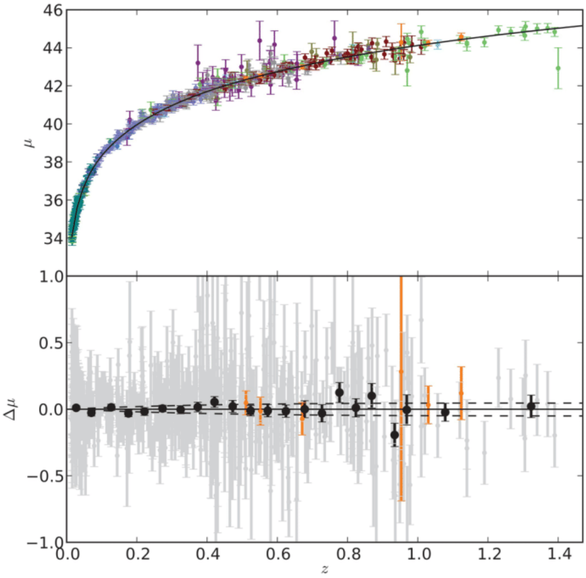
- Space-borne instruments (X-Ray, γ-ray)
- 4m telescope generation (CTIO, Mauna Kea, La Silla, Canarias)
- A couple hundred events up to the 70s.
- 1994: High-Z SN search.

Probing deeper



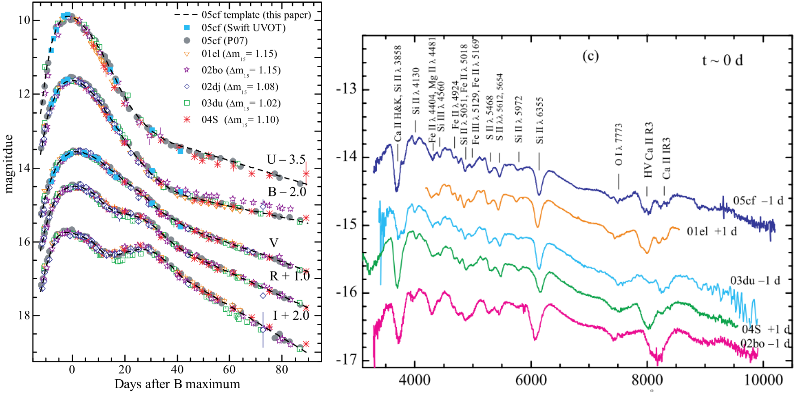
Perlmutter, et al. 1999 (1999ApJ...517..565P)

Probing deeper



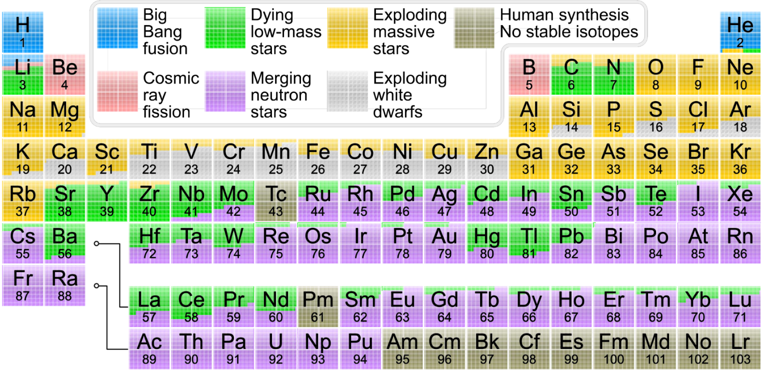
Amanullah, et al. 2010 (2010ApJ...716..712A)

SN2005cf



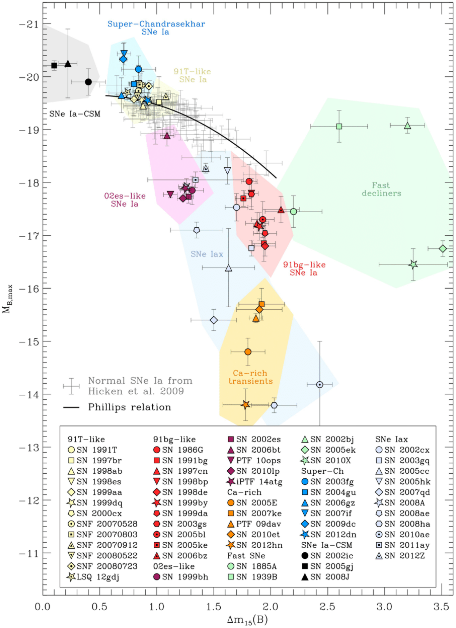
Left: Standardized group of SNIa lightcurves. Right: spectra near peak brightness. Wang, et al. 2009 (2009ApJ...697..380W).

Yields



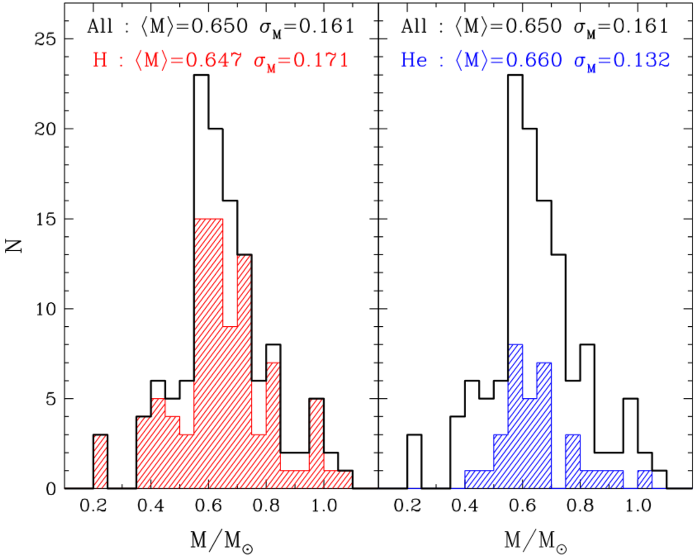
(Jennifer Johnson, Ohio State U).

SN Zoo



Taubenberger, et al. 2017 (2017hsn..book..317T)

WD population

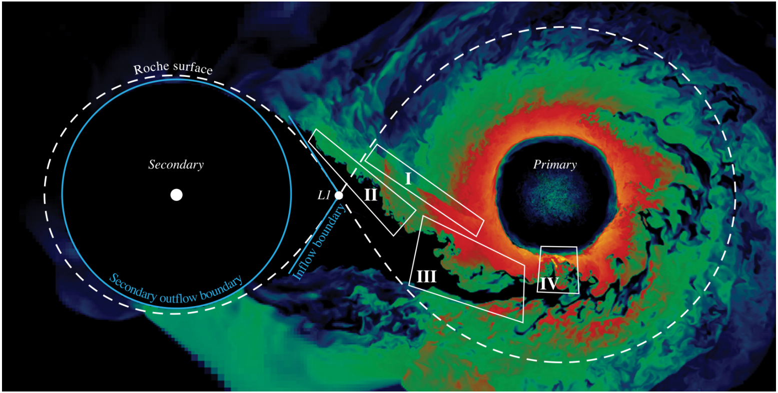


Giammichele, et al. 2012 (2012ApJS..199...29G)

Formation Mechanisms

Name	Companion	Material
Chandrasekhar (M_{Ch})	Deg/Non-Deg	H or He
sub-Chandra (subCh)	Deg	He
Double WD (DWD)	Deg	He, C, O, Ne

sub-Chandra System



Guillochon, et al. 2010 (2010ApJ...709L..64G)

Relevant Scales

Property	Ranges
White dwarf size/mass	$\sim$ 5000km, $\sim 1.0 M_{\odot}$
Envelope size/mass	$\sim$ 2000km, $\sim 0.1 M_{\odot}$
Temperatures	1×10^6 to 1×10^{10} K
Densities	1×10^{-2} to 1×10^6 $\mathrm{g \cdot cm^{-3}}$
Pressures	1×10^{17} to 1×10^{27} $\mathrm{dyne \cdot cm^{-2}}$
Detonation timescale	$\sim$1.0 s
Detonation speeds	1×10^7 to 1×10^9 $\mathrm{cm \cdot s^{-1}}$
Rayleigh Number	$>1 \times 10^{11}$

Table 1. Relevant scales for the problem.

Codebase: FLASH

`Hydro` PPM solver for the compressible Euler equations.

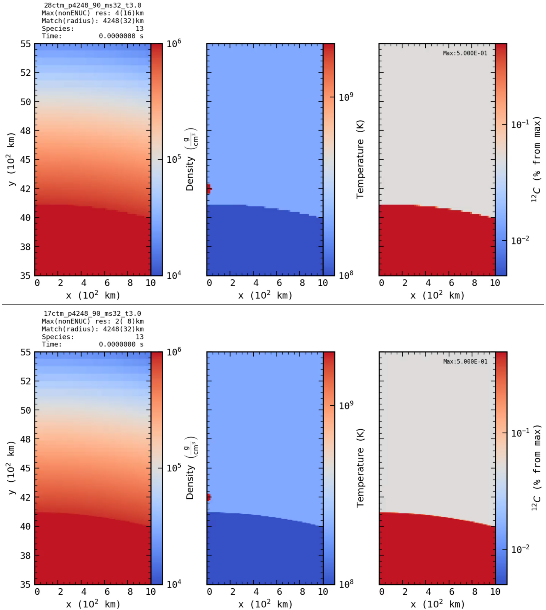
`EoS` applies a set equation of state, updating either hydrodynamic variables or thermodynamic ones as required by `Hydro` and `Burn`, respectively.

`Grid` uses an adaptive mesh refinement (AMR) criteria to increase the resolution of the simulation where needed (`PARAMESH`, Fryxell et al. 2000).

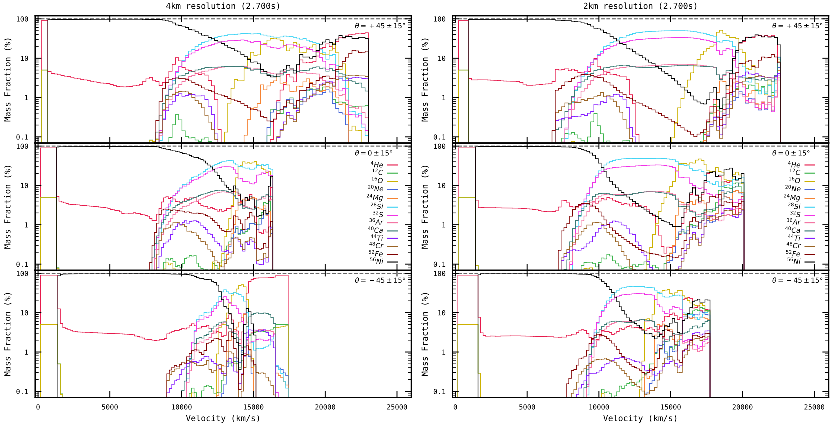
`Burn` calculates burning rates for a given network of species, updating compositions and relevant fluid variables such as temperature (Timmes 1999).

`Gravity` Poisson equation equation solver for the simulation density field via a multipole expansion, yielding an external field for the `Hydro` module.

Double Detonation

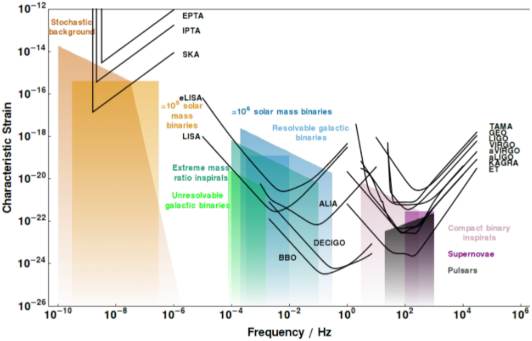


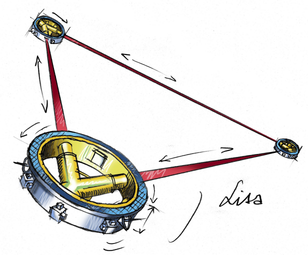
Double Detonation



LISA (2034)

- Space borne interferometer. 1s - 1h periods.

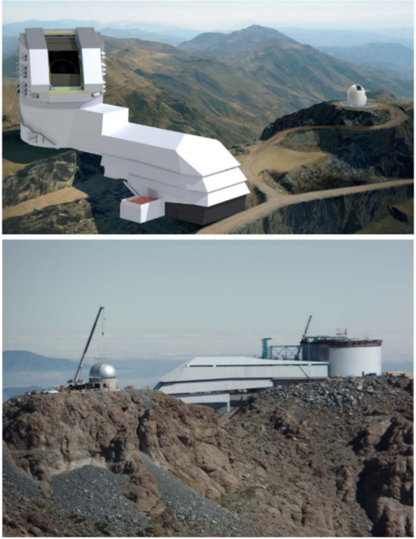




Moore 2014 (2015CQGra..32a5014M). ESA.

Vera C. Rubin (2023)

- 8m class telescope (2x)
  FoV 9.6 $\deg^2$ (10x)
  3200 Mpx (0.2 arsec/px) (=)
- Expected 40 000 SN per year!



Ivezic, et al. 2019 (2019ApJ...873..111I).

Summary

- Supernovae have repeatedly challenged our world view. From immutable skies, to vast distances, to origins of our elements.
- Because of their explosive nature, it is lucky that they're not happening close-by. Yet this is our main challenge to their definitive understanding.
- Given the challenges they've posed and the mysteries they still harbor, they still present a guiding light to future discoveries.