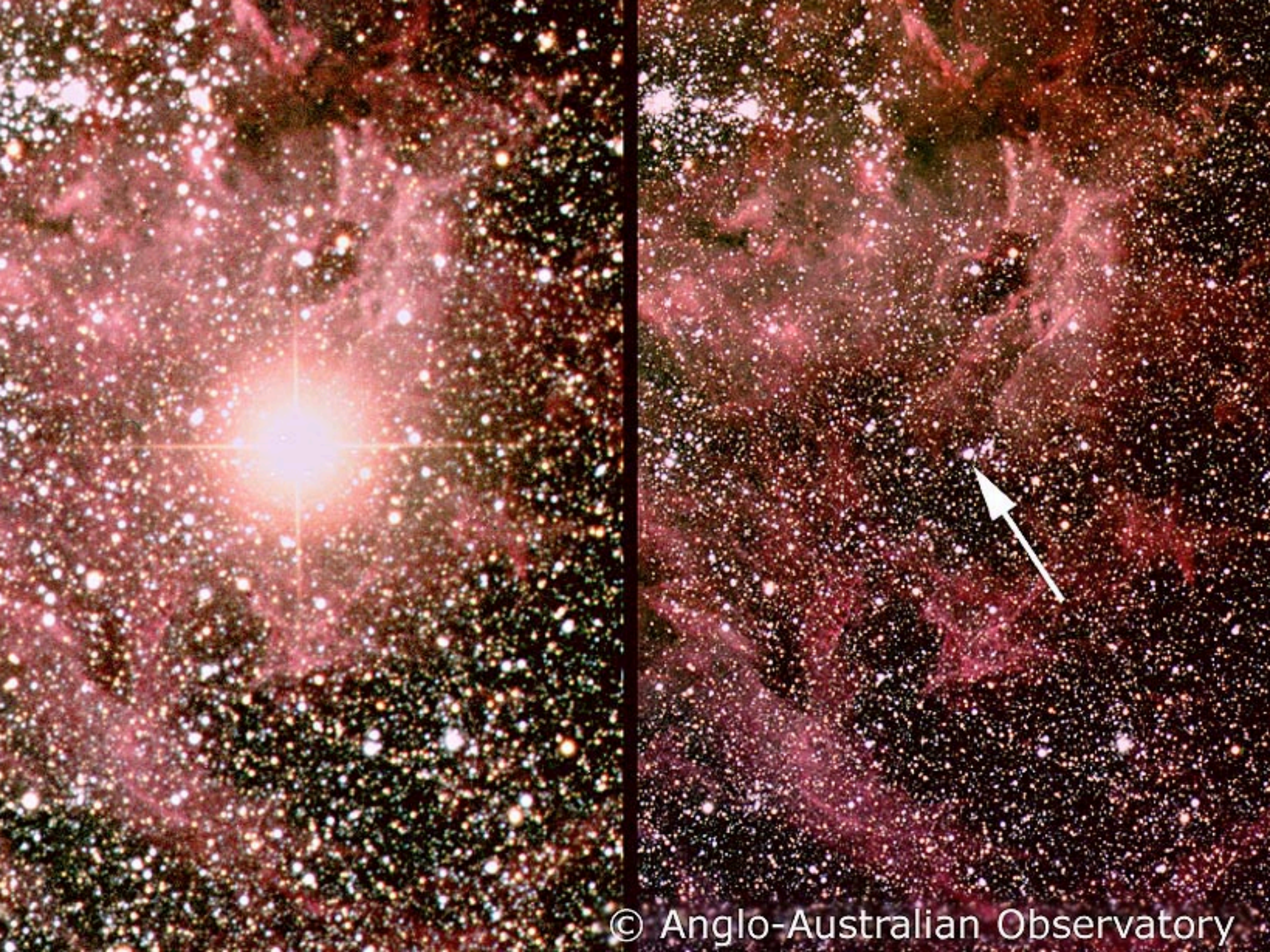
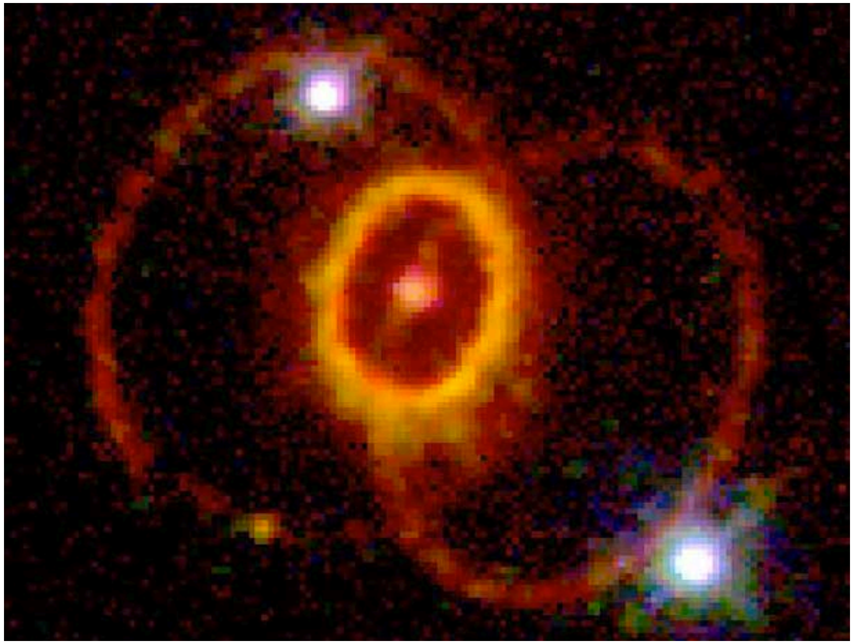

© Anglo-Australian Observatory

Core-collapse Supernovae: Discovery and follow-up observations

Maximilian Stritzinger



AARHUS UNIVERSITY

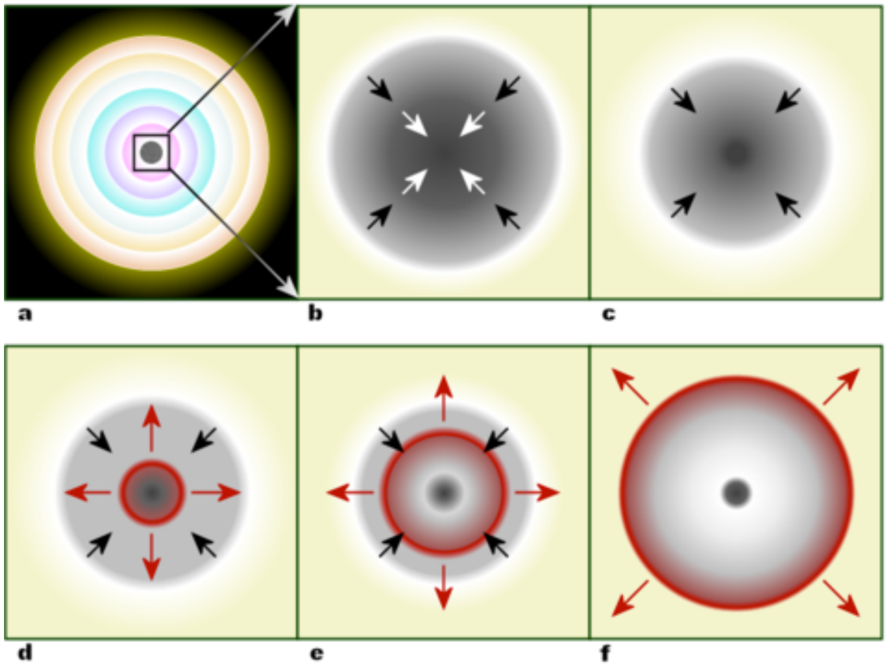

Galaxies and stars evolve on the cosmic time scale…

Massive stars (> 8 $M_\odot$) go out with a stellar:

The evolution of supernovae is on the human time scale

A brief sequential look at the gravitation core-collapse of a massive star

Steps A through F



a) Onion structure with iron-rich core
b) Initial collapse
c) Core bounce → shock wave
d) Shock wave stalls
e) Shock wave is revived?
f) Disruption of star

→ Nucleosynthesis & formation of a neutron star or Black Hole

History in a turtle-shell

Guest stars have been observed and documented since the time of antiquity

- Chinese inscriptions date back to 1500 B.C., with ≈ 75 recorded events cira 530 BC to 1064 AD

- The bright SN 1054 was also recorded by the Anasazi people of the great Sonoran desert

- 1572: Tycho Brahe observed a guest star in the constellation Cassiopeia
  → Heavens were "mutable"

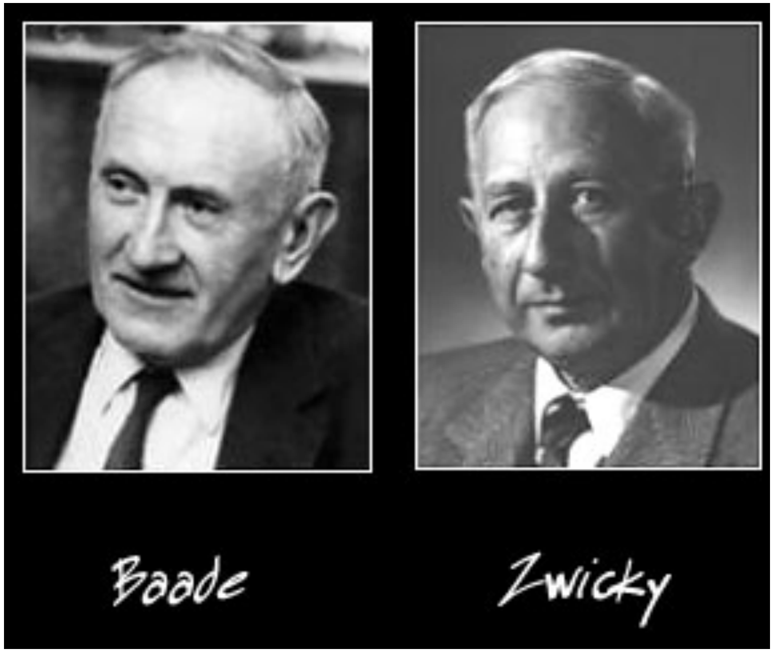
- 1604: Kepler's SN lead Galileo to challenge ideas of Aristotle and Ptolemy

Modern Era

- 1885: Ernst Hartwig discovers first supernova outside the Milky Way, located in Andromeda

Dorpat Observatory

- 1934: Baade & Zwicky connected guest stars to the death of massive stars!

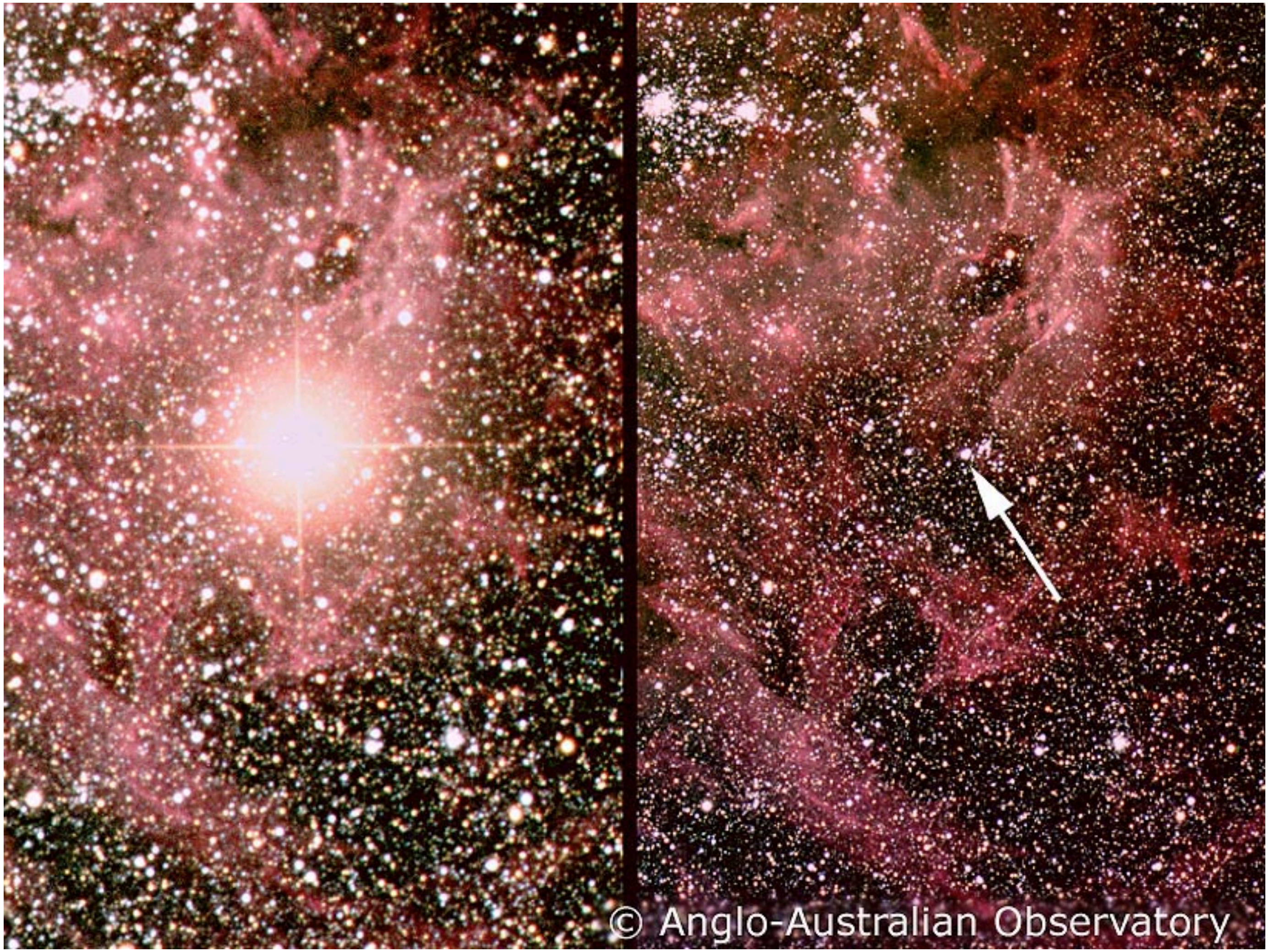


Context of Supernovae in the Cosmos

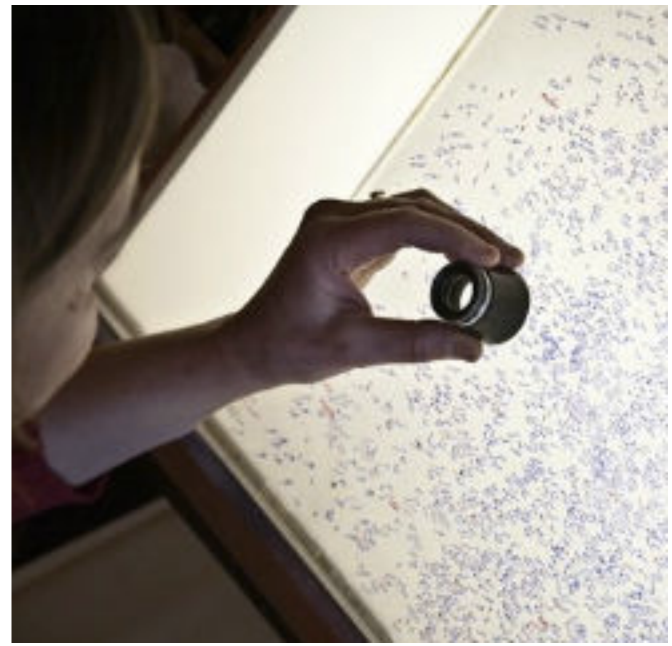
- Provide a direct window to the late stages of stellar evolution
- Responsible for the production of many elements and their enrichment into the Universe (we are star waste!)
- Drive both stellar and galaxy evolution
- Prodigious producers of dust?
- Are used as cosmological probes of the Universe (at peak brightness as bright as several billion Suns!)
- Prodigious producers of cosmic rays

→ perhaps played a role on the evolution of life through genetic mutations

Discovering Supernovae



Once Upon a Time: Photographic plates



Pioneering Work Done Right Here in DK

letters to nature

Nature **339**, 523 - 525 (15 June 1989); doi:10.1038/339523a0

The discovery of a type Ia supernova at a redshift of 0.31

HANS U. NØRGAARD-NIELSEN[*], LEIF HANSEN[†], HENNING E. JØRGENSEN[†], ALFONSO ARAGÓN SALAMANCA[‡], RICHARD S. ELLIS[‡] & WARRICK J. COUCH[§]

[*] Danish Space Research Institute, Lundtoftevej 7, DK-2800 Lyngby, Denmark
[†] Copenhagen University Observatory, Øster Voldgade 3, DK-1350 Copenhagen K, Denmark
[‡] Physics Department, University of Durham, South Road, Durham DH1 3LE, UK
[§] Anglo-Australian Observatory, Epping Laboratory, PO Box 296, Epping, New South Wales 2121, Australia

OBSERVATIONS indicate that nearby supernova of type Ia have similar peak brightnesses, with a spread of less than 0.3 mag (ref. 1), so that they can potentially be used as 'standard candles' to estimate distances on a cosmological scale. As part of a long-term search for distant supernovae, we have identified and studied an event that occurred in a faint member of the distant galaxy cluster AC118, at a redshift of z =0.31. Extensive photometry and some spectroscopy of the event strongly supports the hypothesis that we have detected a type Ia supernova whose time-dilated light curve matches that of present-day supernovae of this class. We discuss the precision to which its maximum brightness can be ascertained, and indicate the implications that such deep supernovae searches may have for observational cosmology.

These efforts were largely hampered due to technology

Today: Amateurs Discovering Supernovae

Georgia, USA

Tim Puckett

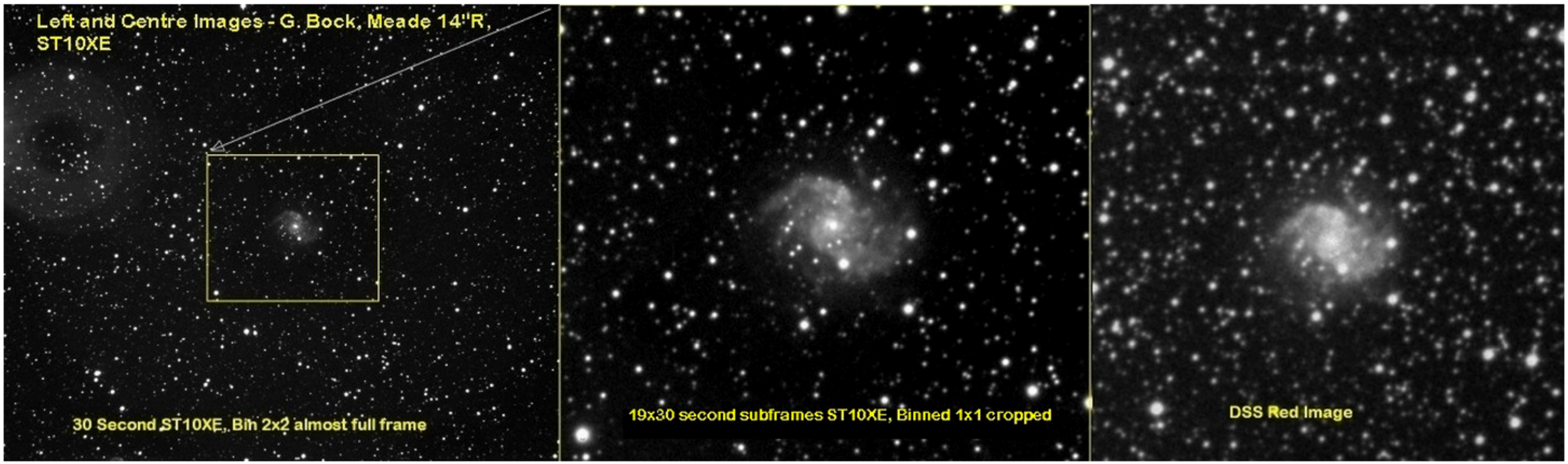
Pretoria, South Africa

Berto Monard

Australia and New Zealand

BOSS: Backyard Observatory Supernova Search

BOSS


Left and Centre Images - G. Bock, Meade 14"R, ST10XE
30 Second ST10XE, Bin 2x2 almost full frame
19x30 second subframes ST10XE, Binned 1x1 cropped
DSS Red Image

Professional Supernova Searches

- Nearby, low redshift supernova
- Intermediate redshift supernova
- Distance, high redshift supernova
- Two methods: targeted & non-targeted

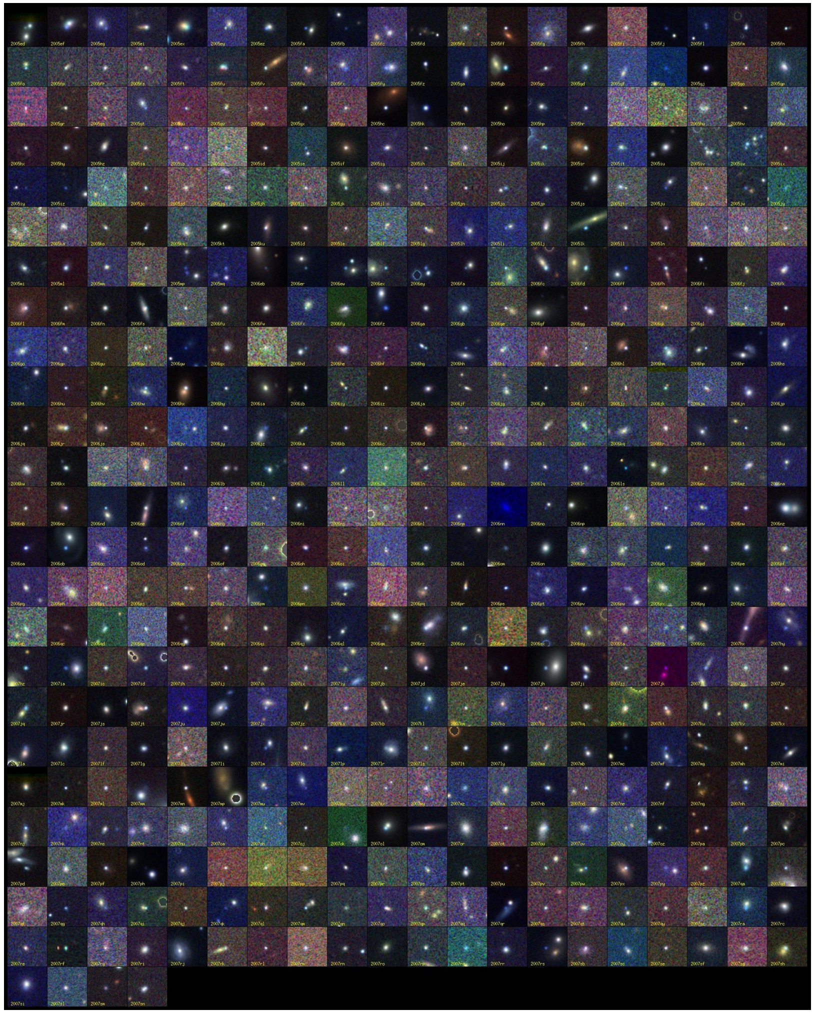
Nearby Supernova Searches Nowadays are Robotic

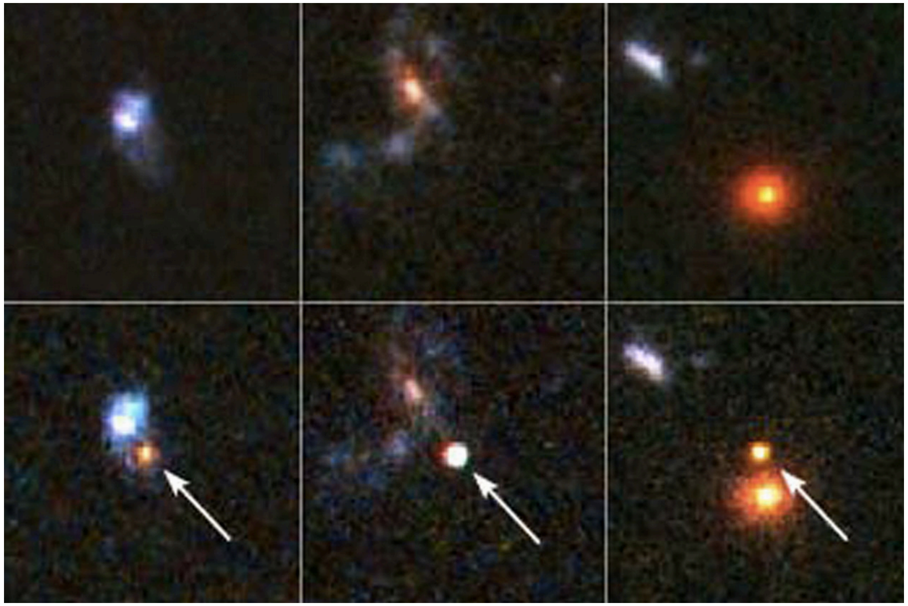
Lick Observatory Supernova Search (LOSS) using the KAIT Telescope

- Difference compared to amateur searches are telescope size, quality of camera and location ← FUNDING!
- Strive to discovery supernovae soon after explosion

Intermediate and Higher Redshift Supernovae

SDSS-II supernova survey



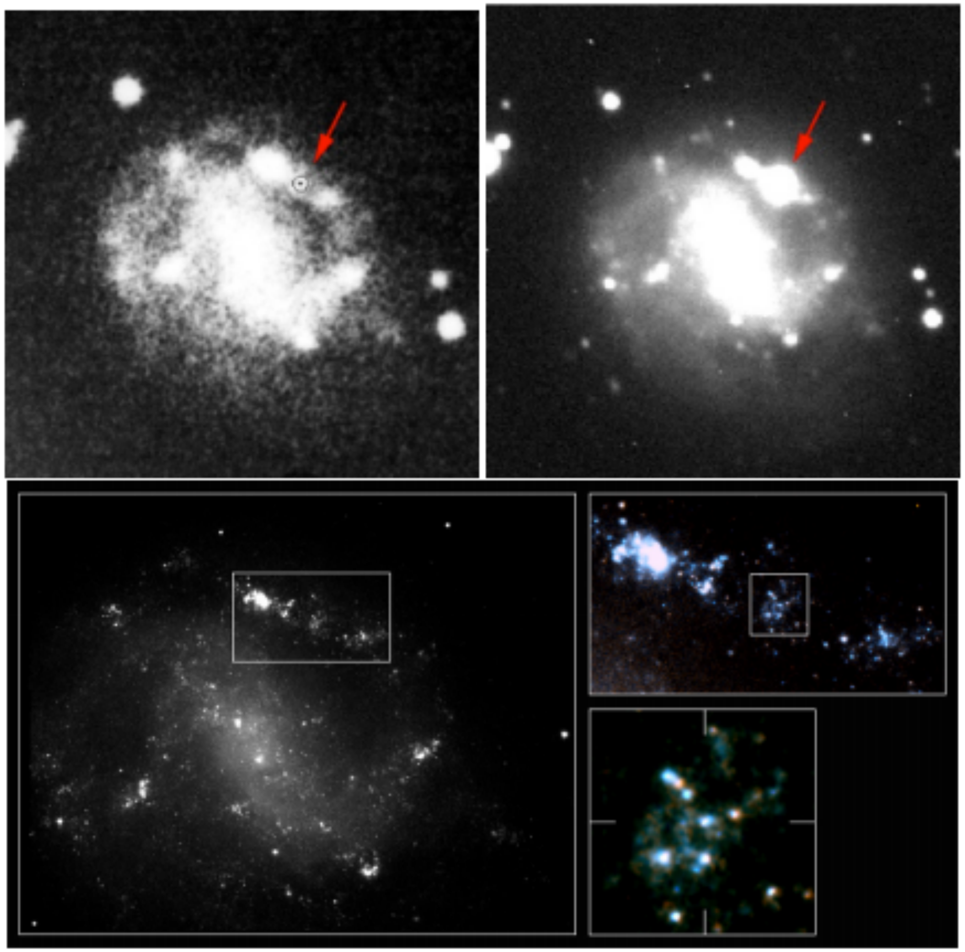


Hubble Space Telescope

Past Supernova Discoveries

http://astro.berkeley.edu/~ishivvers/sne.html

Environments of Core-collapse Supernovae



- Hosts are spiral galaxies and often within spiral arms
  → Star forming regions

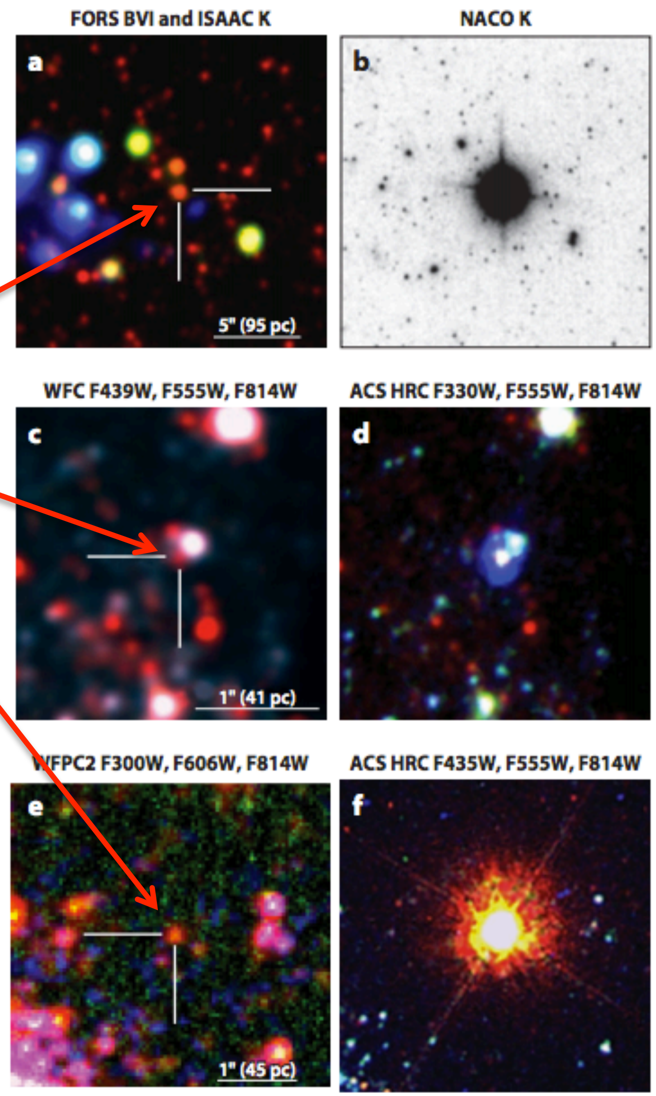
Hjorth & Bloom (2012)

What do pre-explosion images reveal?

Type IIP objects

8±1 $M_\odot$ RSG progenitors!!!

What about more massive progenitors?



SN 2008bk

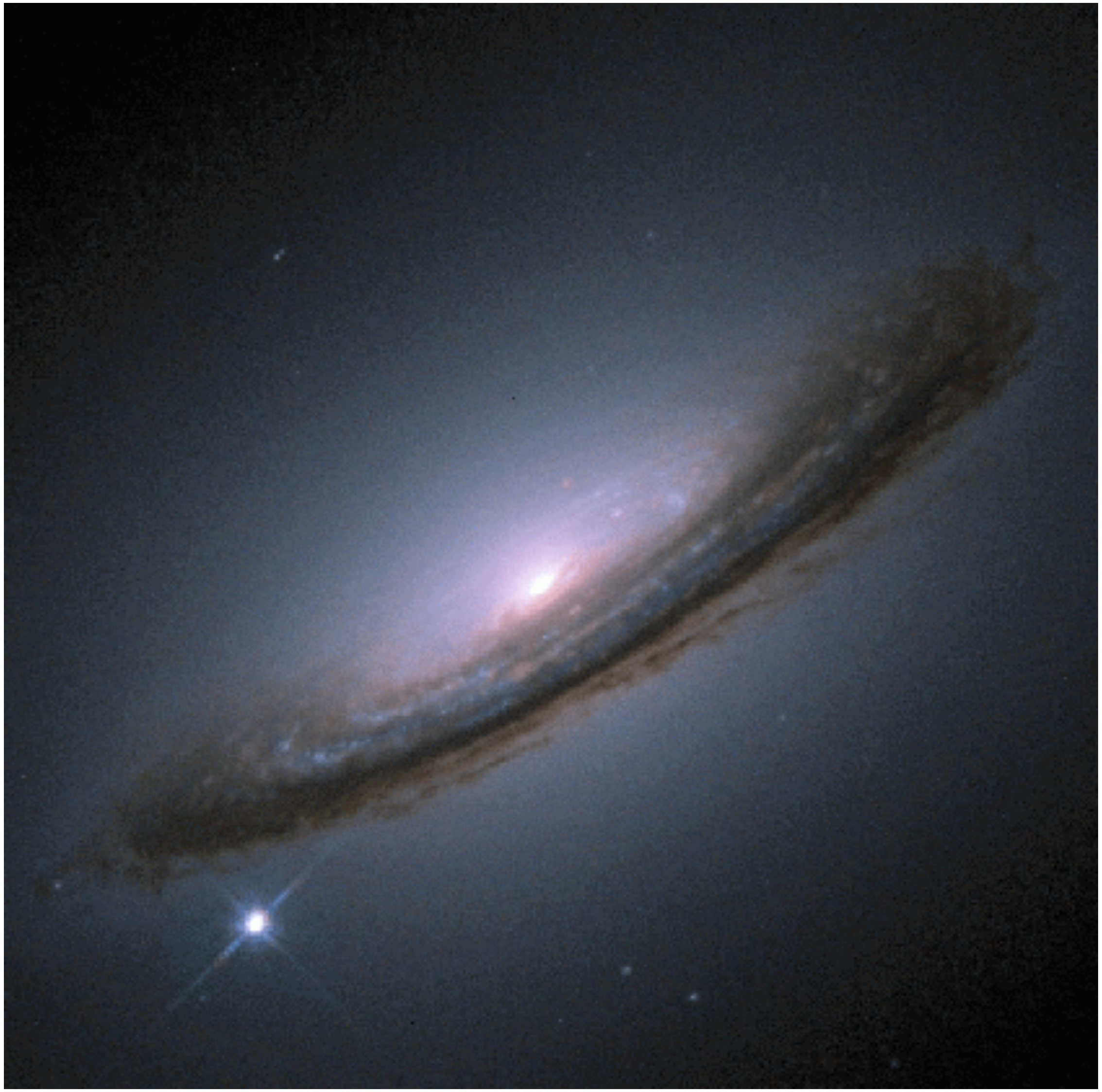
SN 2005cs

SN 2003gd

left: Pre-explosion images

Smartt (2009), ARAA, 47, 63

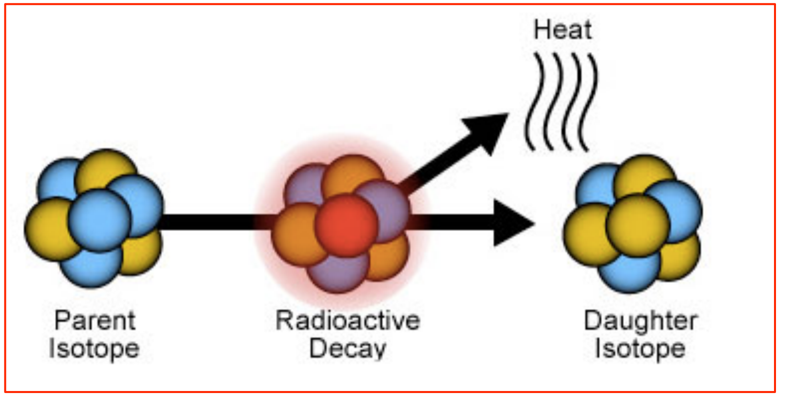
Observations of Core-collapse Supernovae



Supernovae Energetics

We (usually) do not observe the explosion itself, but if discovered soon after explosion: a rise to maximum light.

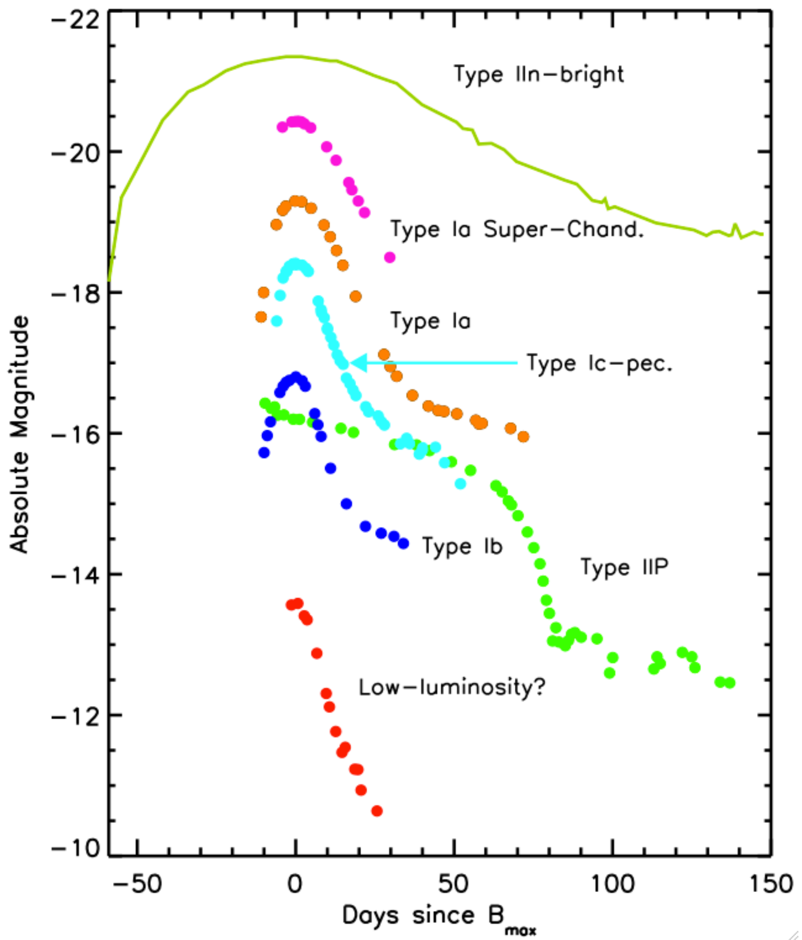
Energy that powers the "light curves" comes from radioactivity (β^+)



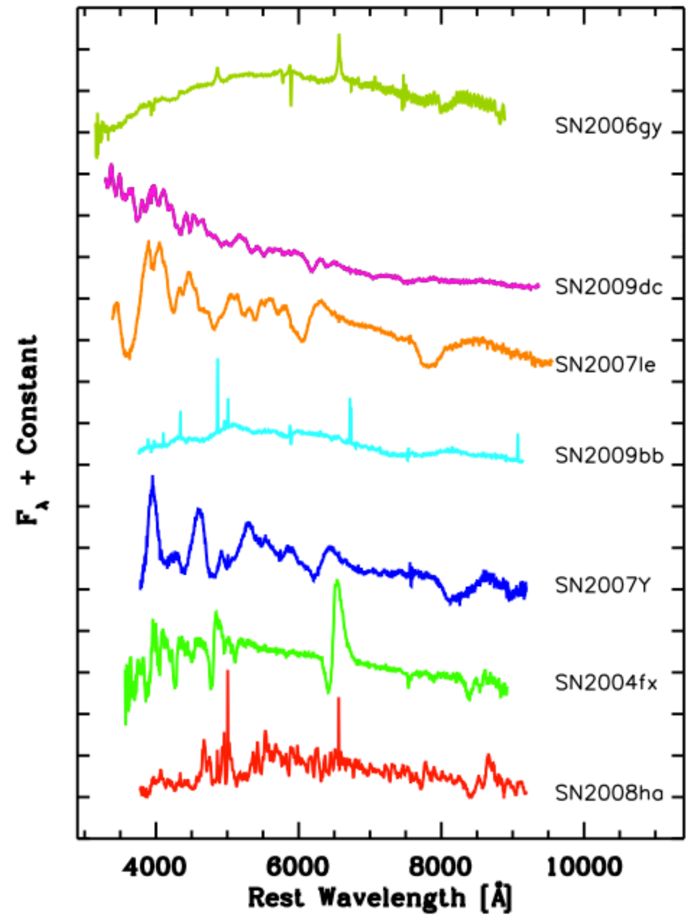
In the case of supernova it's the decay of

$$^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$$

The Supernova Zoo

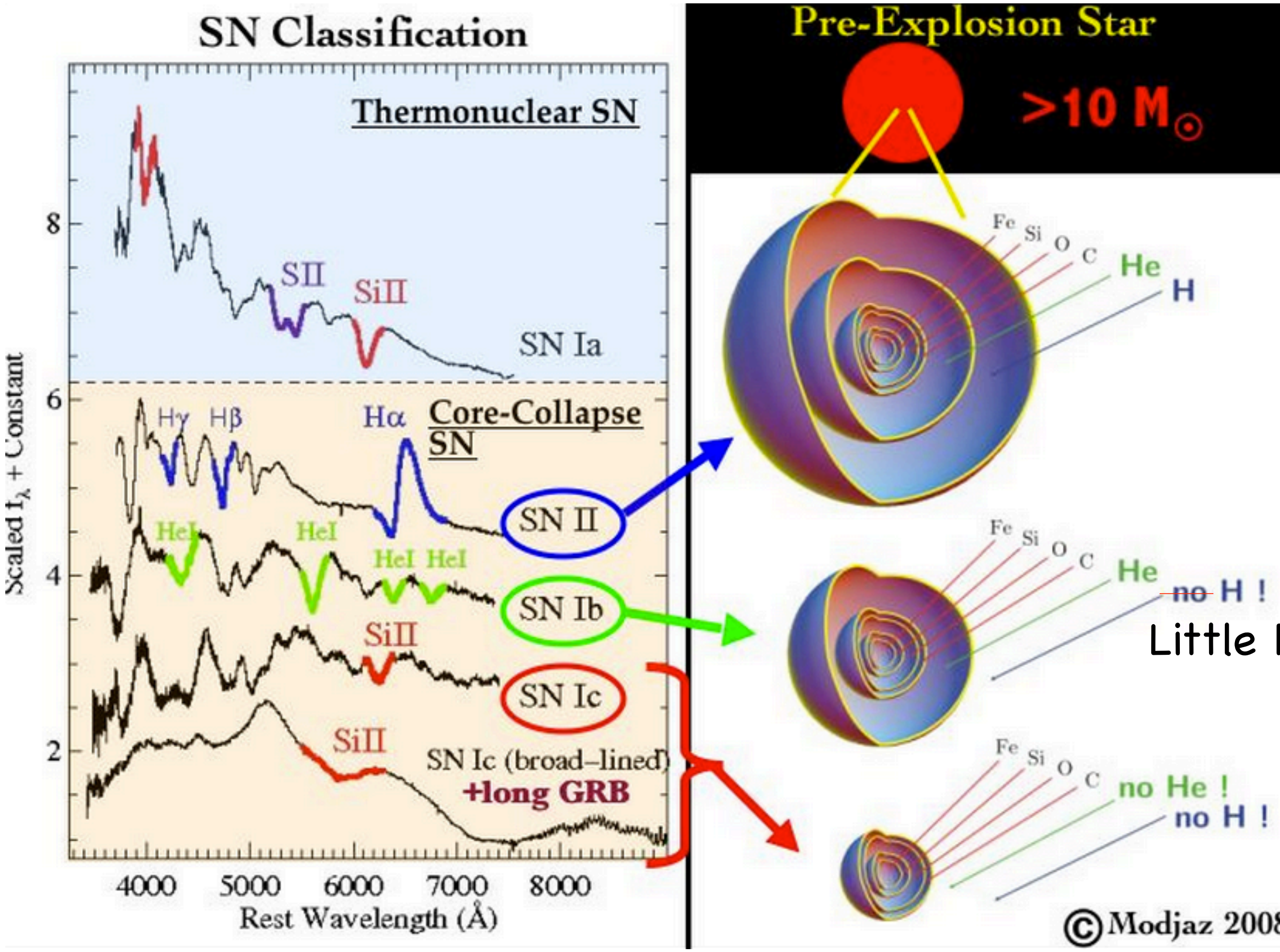


Supernova Forensics



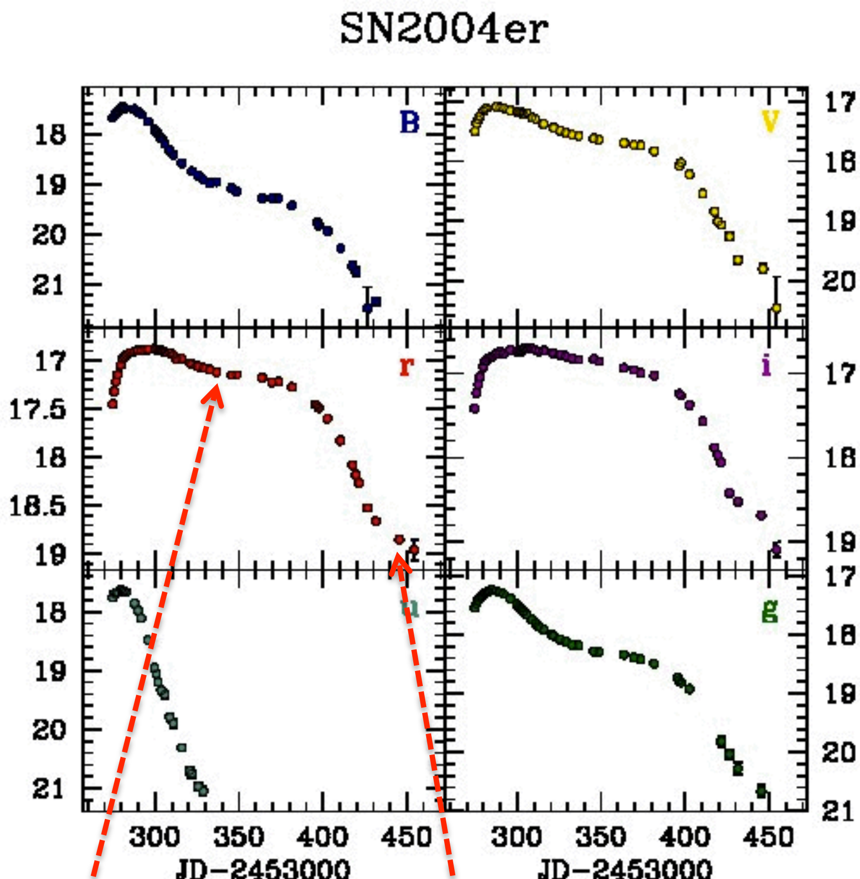
Detailed observations allow us to determine the supernova type, and connect the particular variety to their parent star, and pre-SN evolution

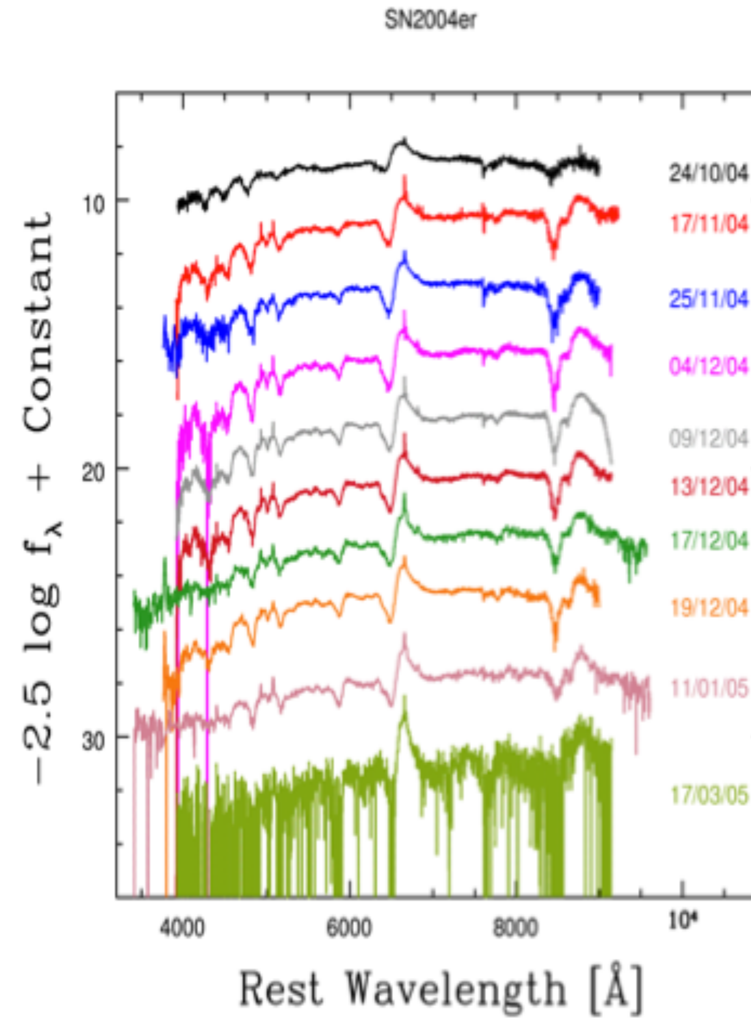
Classical Spectral Classification: Basic sub-types



Little H I

General Observational Properties of the Garden Variety: Type IIP



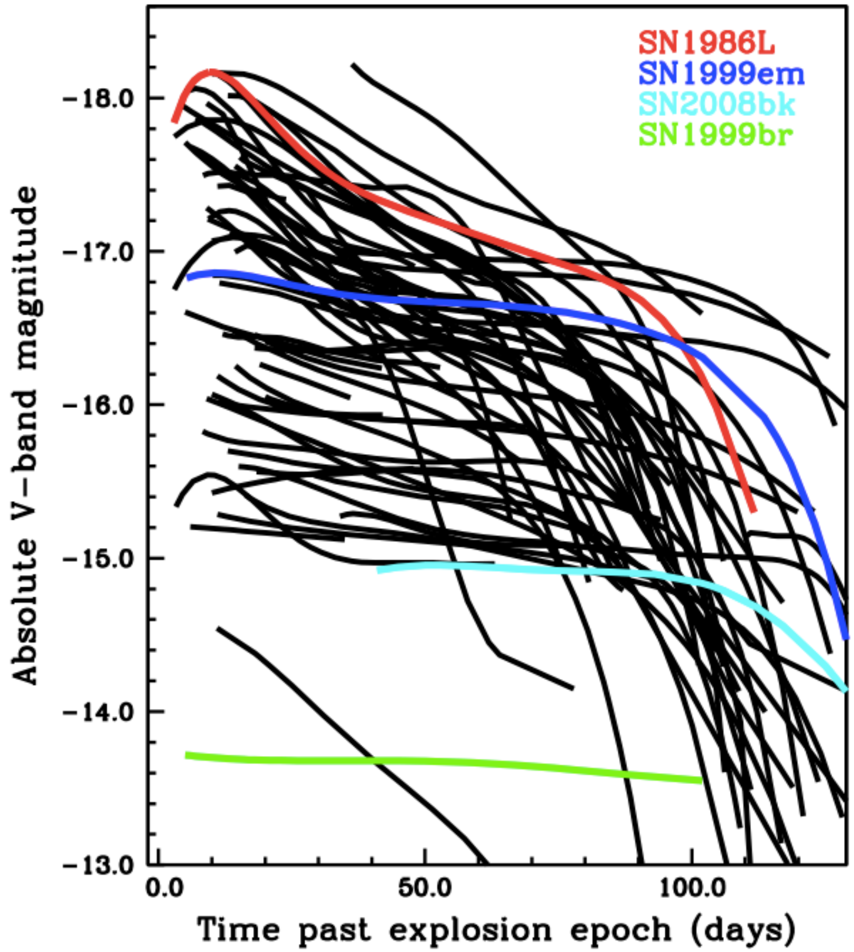


Radioactive decay tail

Recombination wave travelling through the H-rich ejected envelope → drives Hα emission

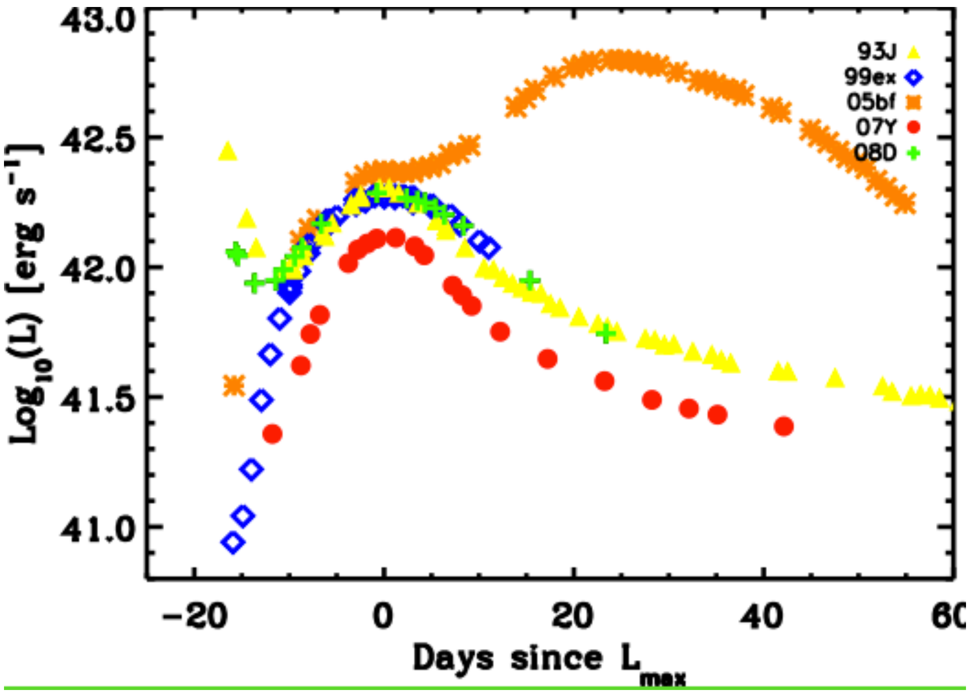
SNe II Plateau Light Curves

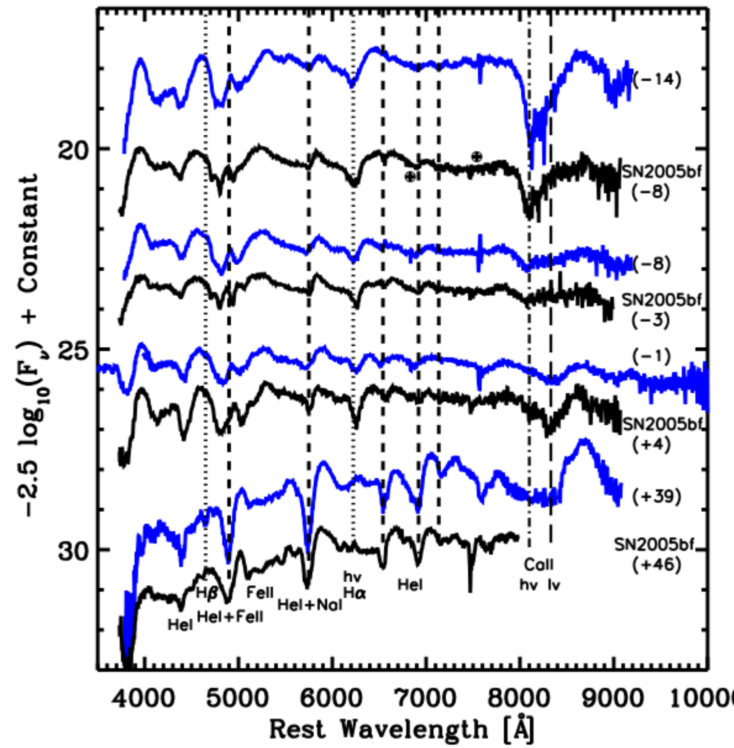
- Range in luminosity of about 5 mag.
- Brighter the SN the faster they evolve of plateau
- Difference traced back to details related to progenitor stars and pre-SN evolution



Anderson et al. (2014)

Stripped-envelope Core-collapse SNe: Type Ib/c, IIb





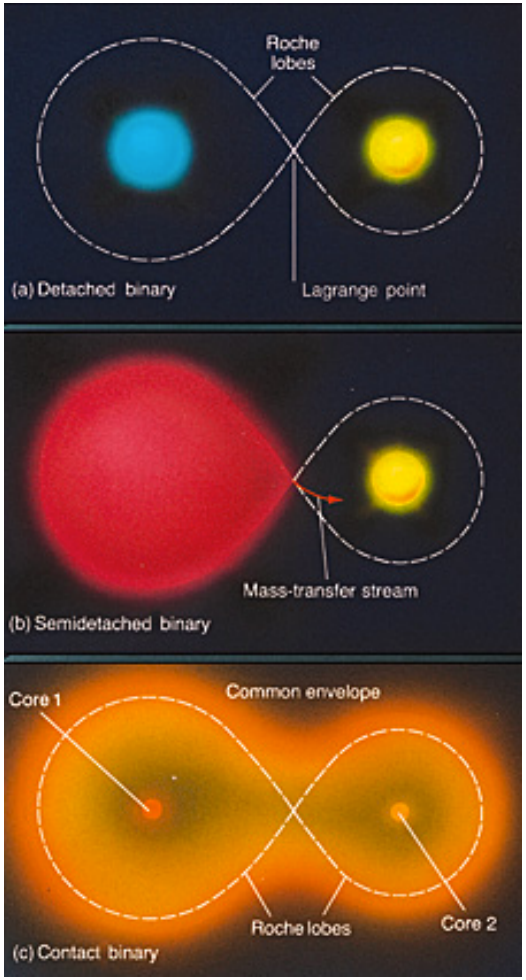
(left) Normally bell-shaped light curves;

(right) Spectra show little to no hydrogen (Type IIb → Type Ib) and/or little to no helium (Type Ib → Type Ic)

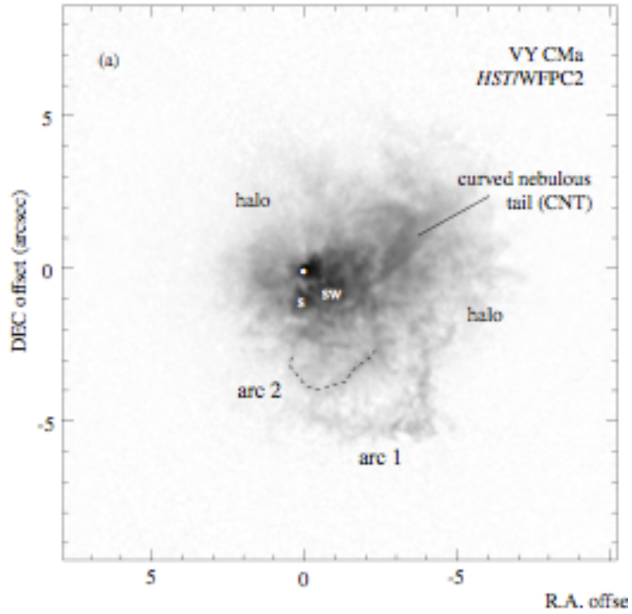
Stritzinger et al. (2009)

Mass-stripping Mechanisms: Single and Binary Progenitors

Binary evolution

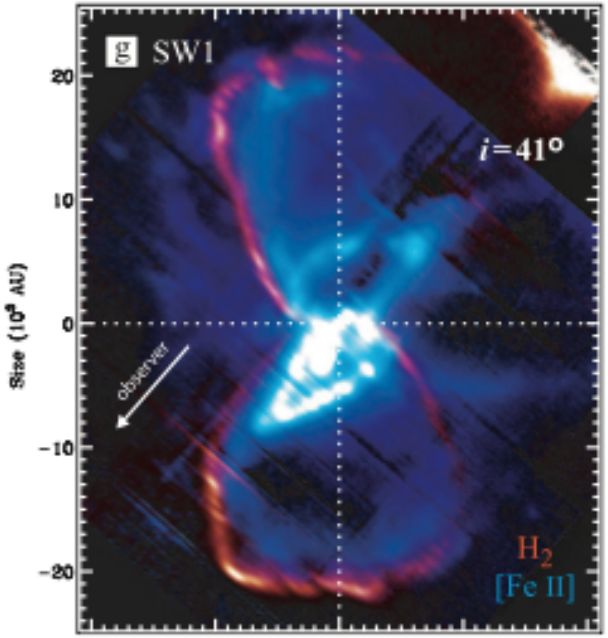


Super-winds



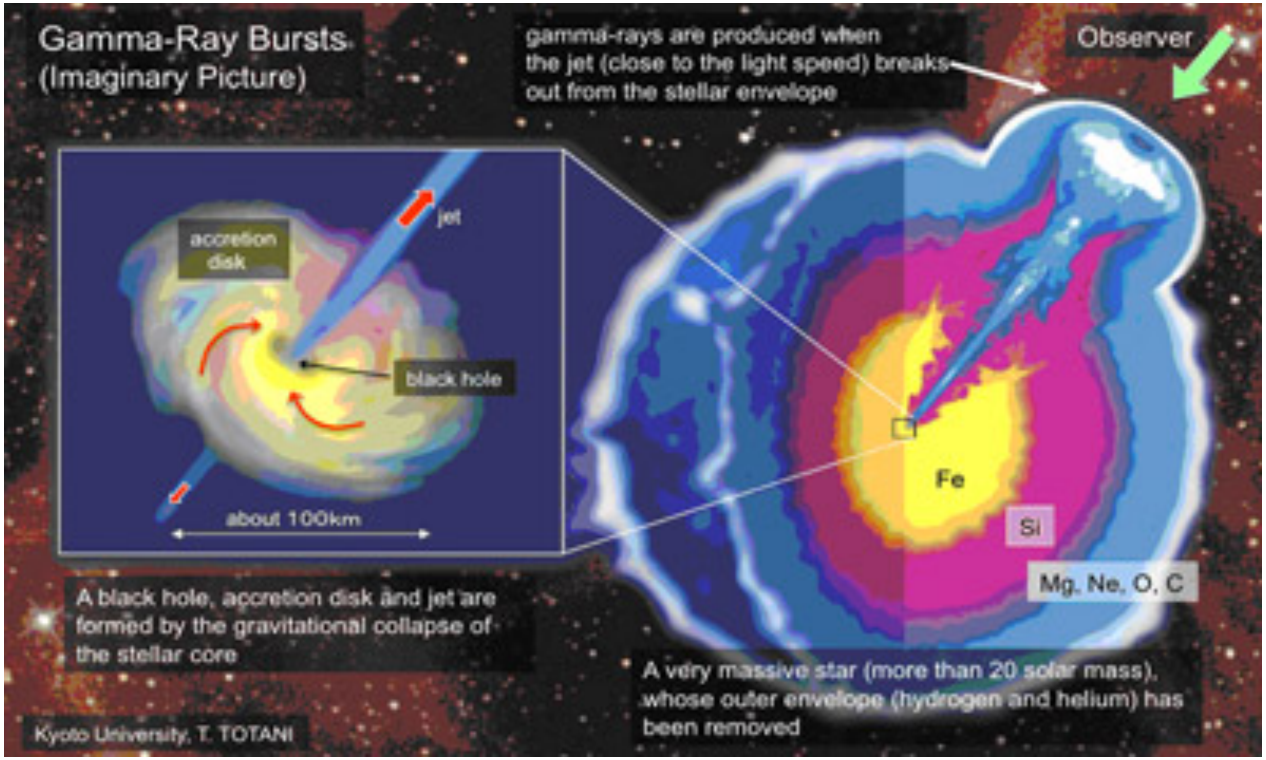
Smith et al. (2009)

η Carinae → LBV

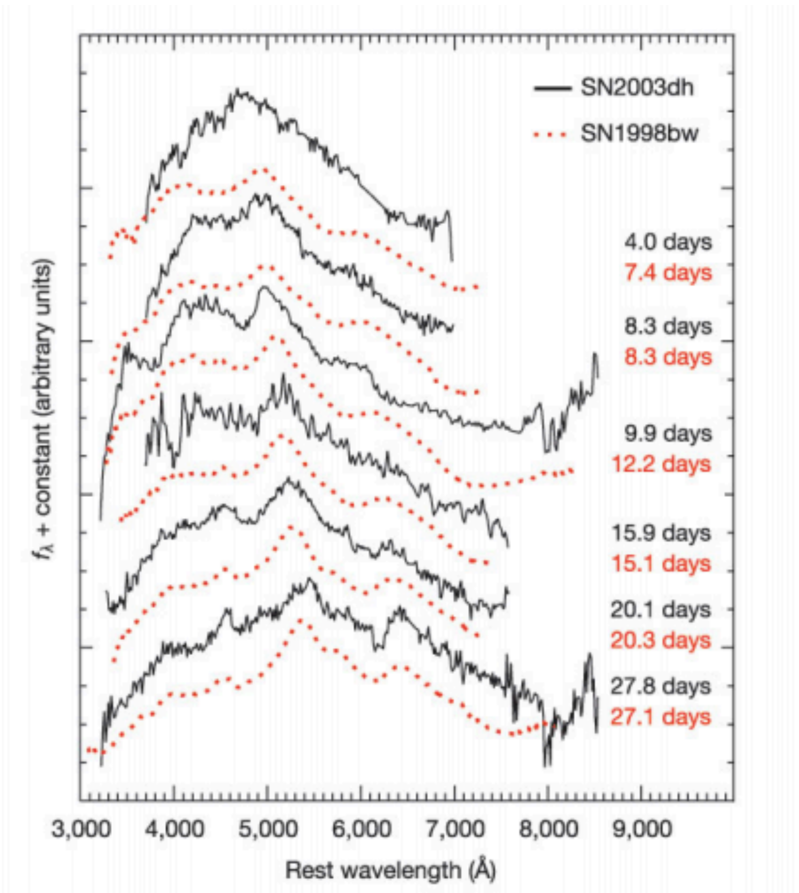


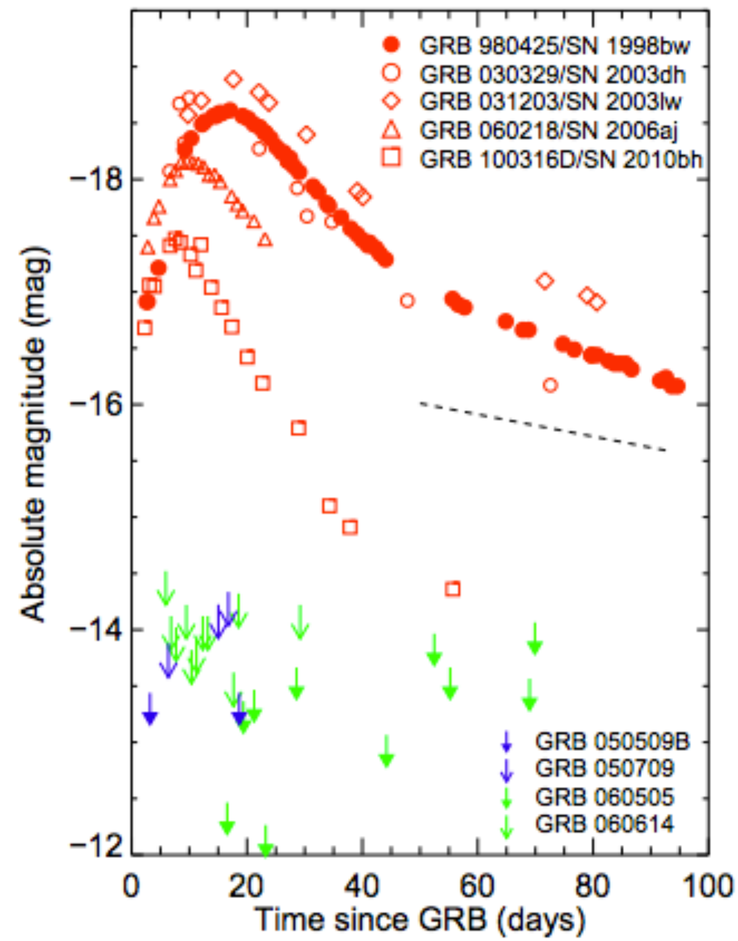
Smith (2006)

Supernova / Gamma Ray Burst Connection



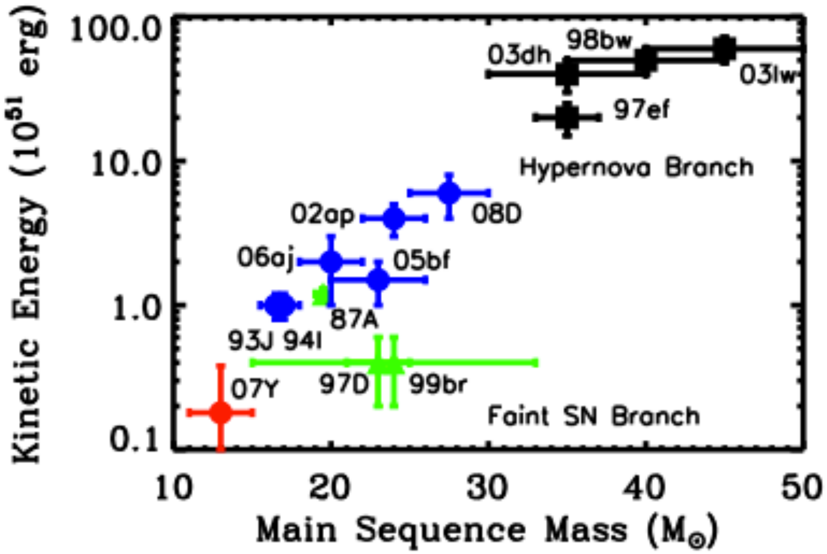
Broad-line stripped core-collapse SNe Ic (hypernovae): the SN/GRB connection

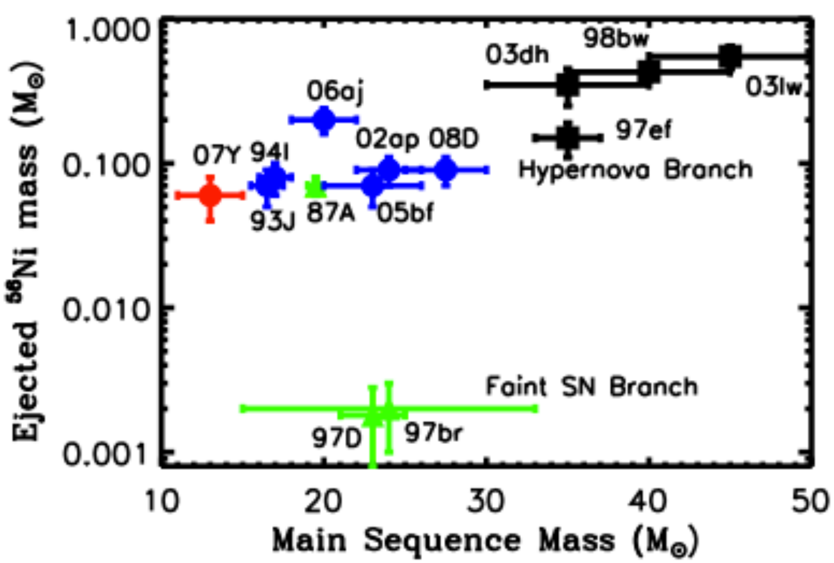




Hjorth & Bloom (2012)

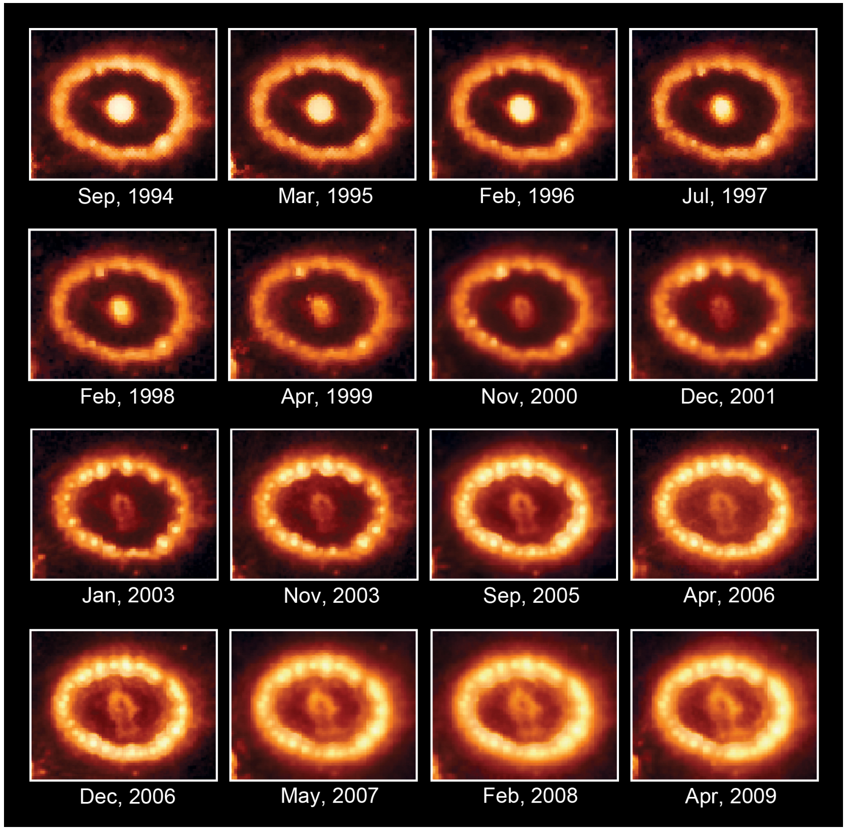
Explosion Parameters of Type II & Ibc SNe

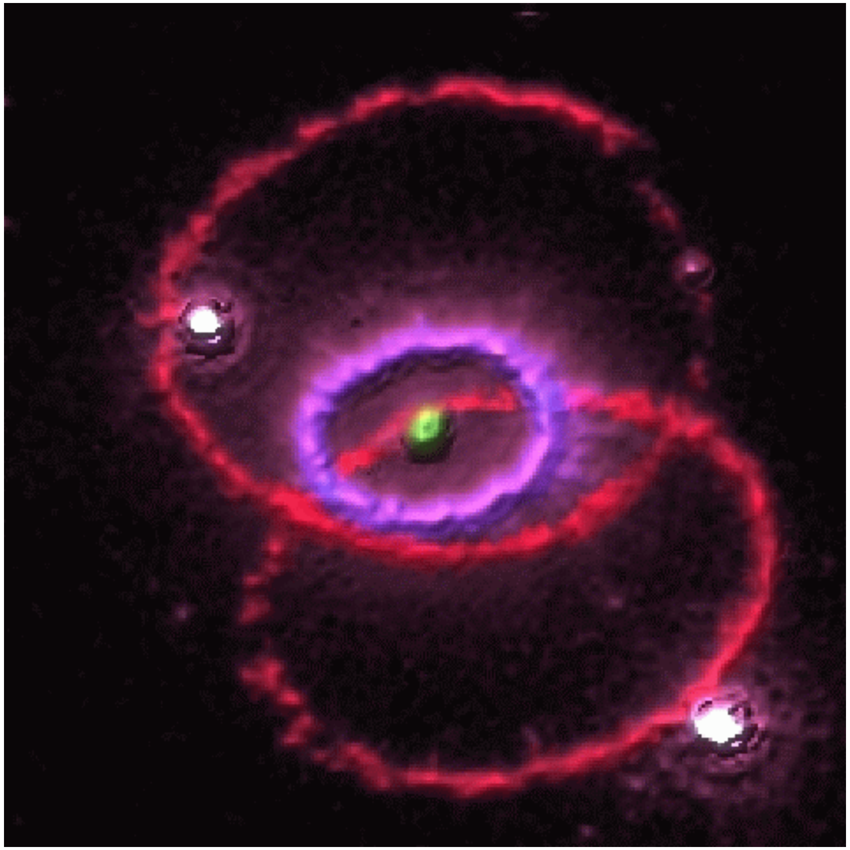




Stritzinger et al. (2009)

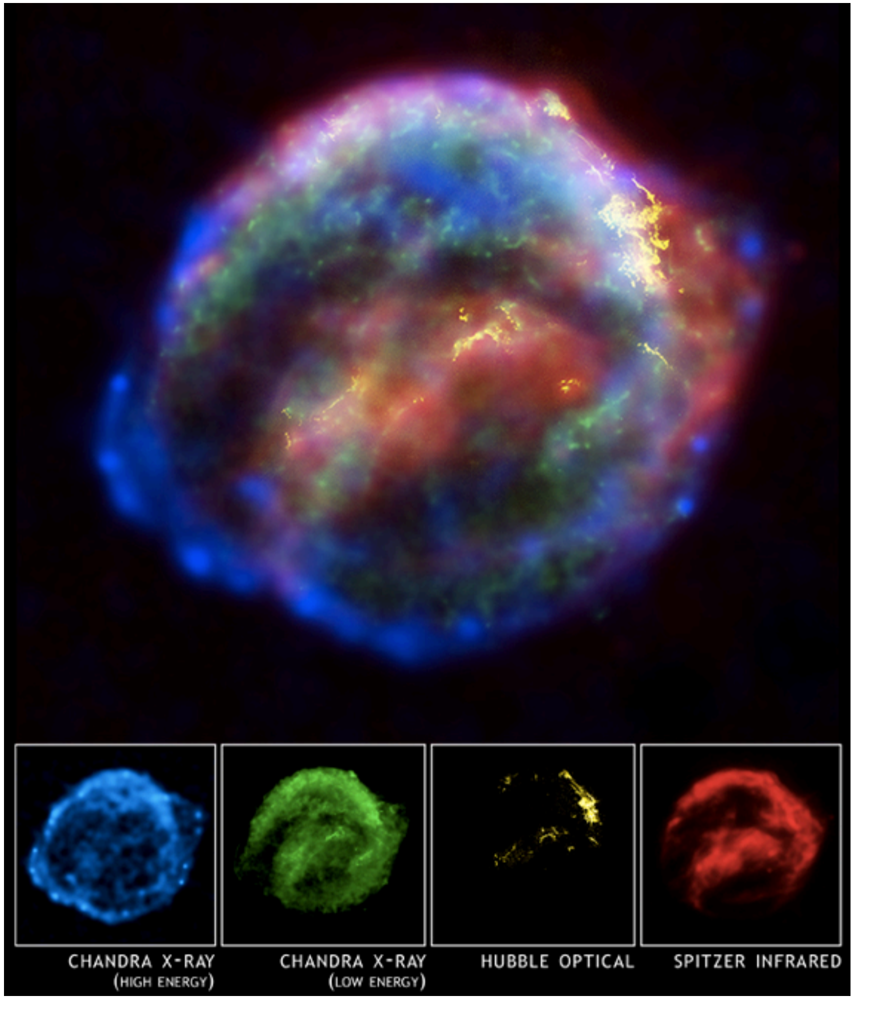
25 years of evolution: SN 1987A





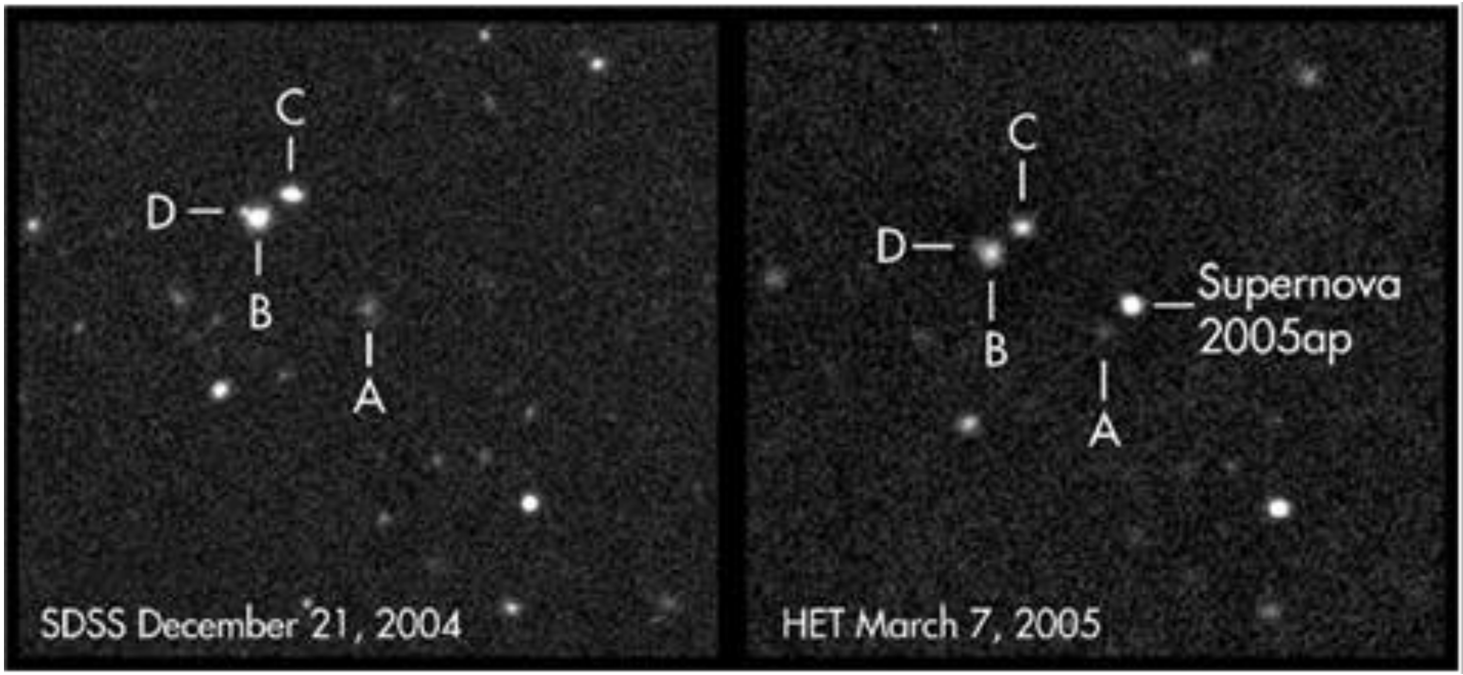
Centuries Later: Supernova Remnant

- Multi-band view
- Bright at X-ray wavelengths
- Multiple shock fronts
- Source of high energy cosmic rays via synchrotron emission



Super-Luminal Supernovae (SLSNe)

The first identified SLSN: SN 2005ap

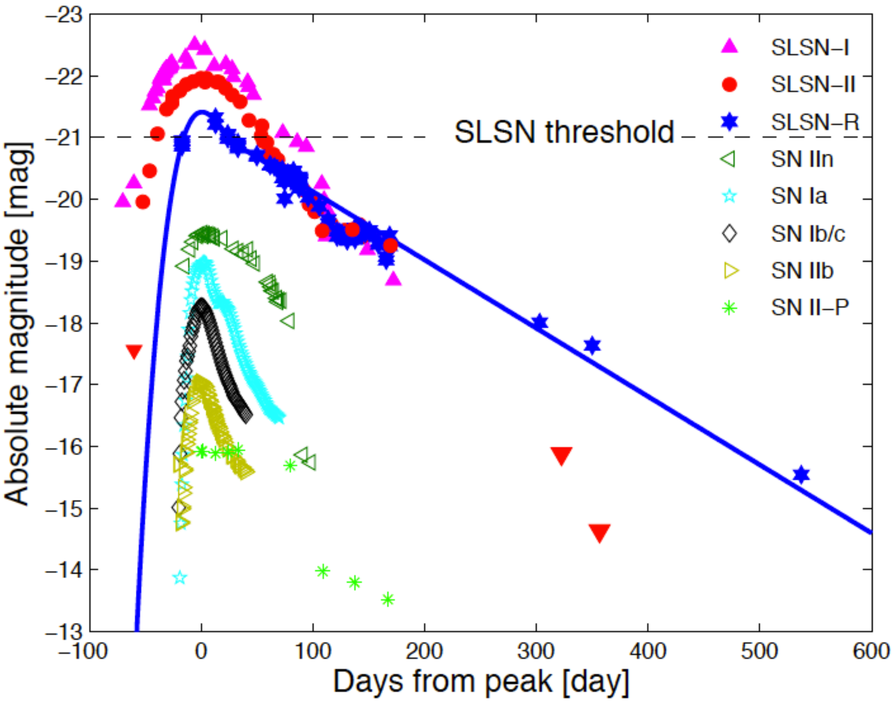


- Peak magnitude of -22.7 mag → 100,000x brighter than normal
- Red-shift z=0.2832

R. Quimby & Texas SN Search

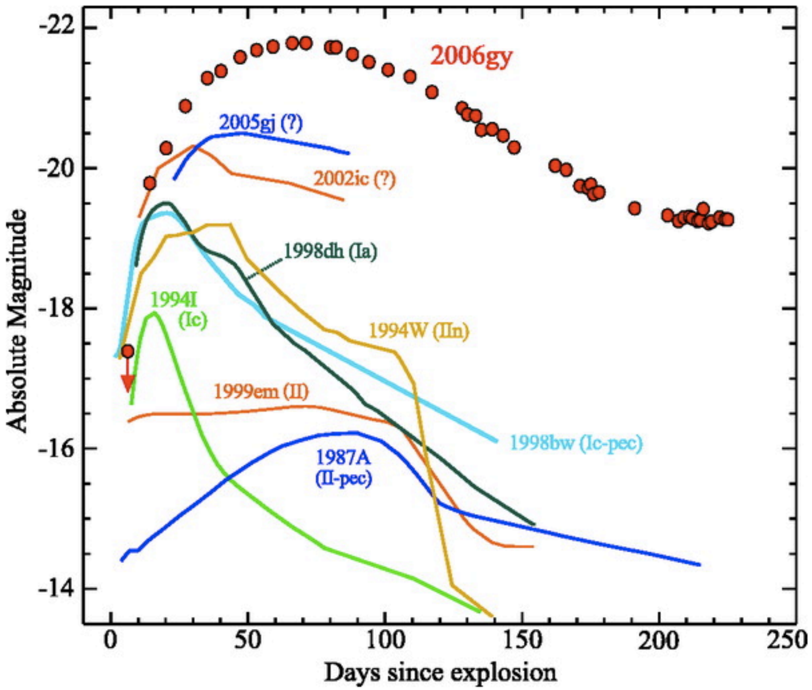
SLSNe: Definition and Diversity

- Extremely high peak luminosity
- Evolution through maximum is on month time-scales as opposed to weeks

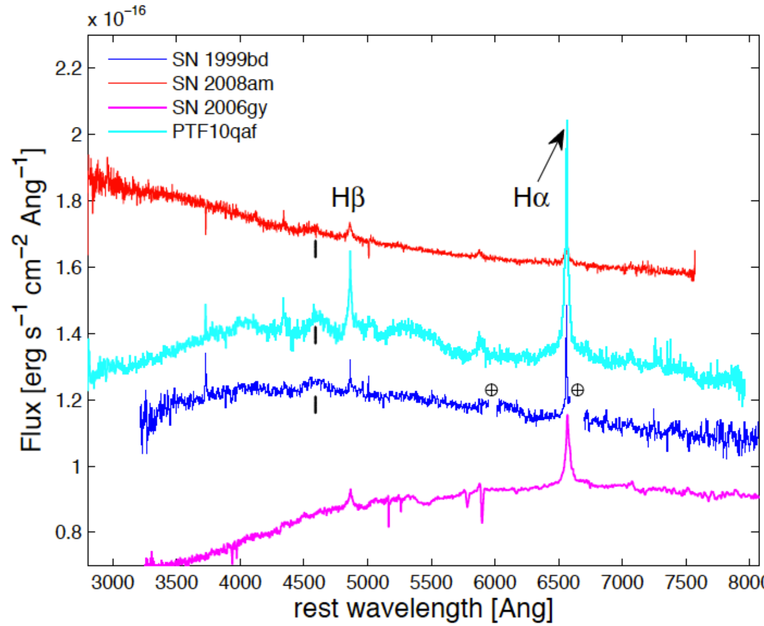


Gal-Yam (2012)

SLSN-II: Hydrogen rich

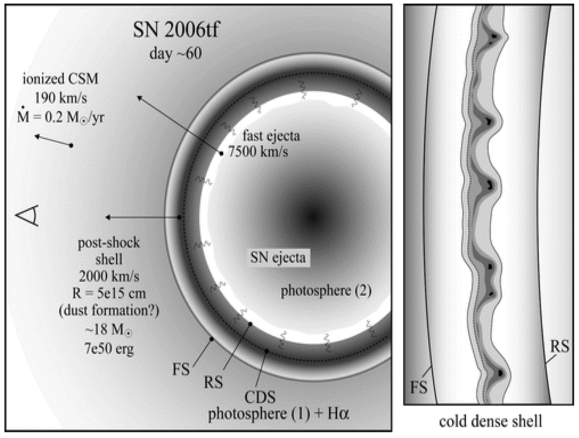


Smith et al. (2007)



Gal-Yam (2012)

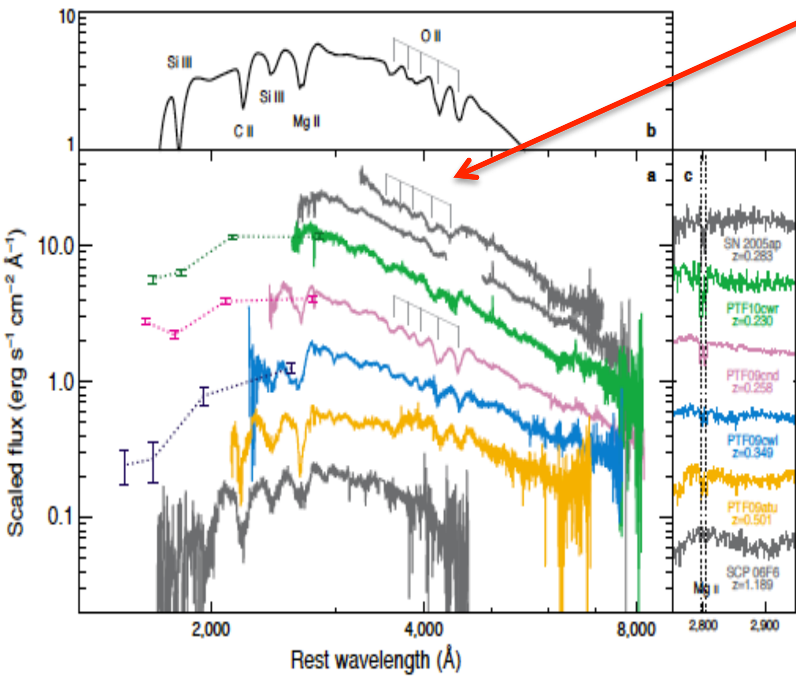
- Perhaps linked to a SN exploding within an extremely dense CSM?
- Explosion occurs in the midst of a robust LBV outburst

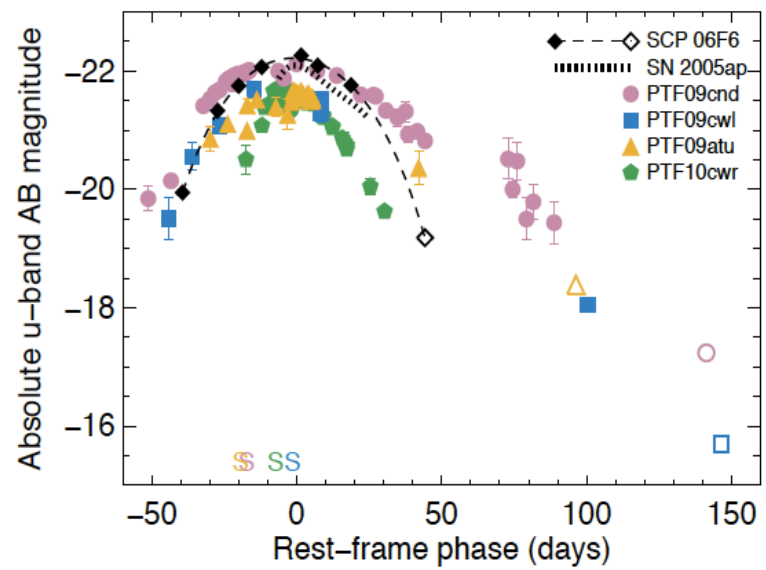


Smith et al. (2008)

SLSN-I: Hydrogen poor

Blue spectra





- Hydrogen poor versions of SLSN-II?
- Collisions of shells of material?
- Light curves evolve faster than expected for ^{56}Ni heating
- Pulsating pair instability SNe? (require 100 $M_\odot$ Oxygen core)
- Origins remain elusive!

Summary

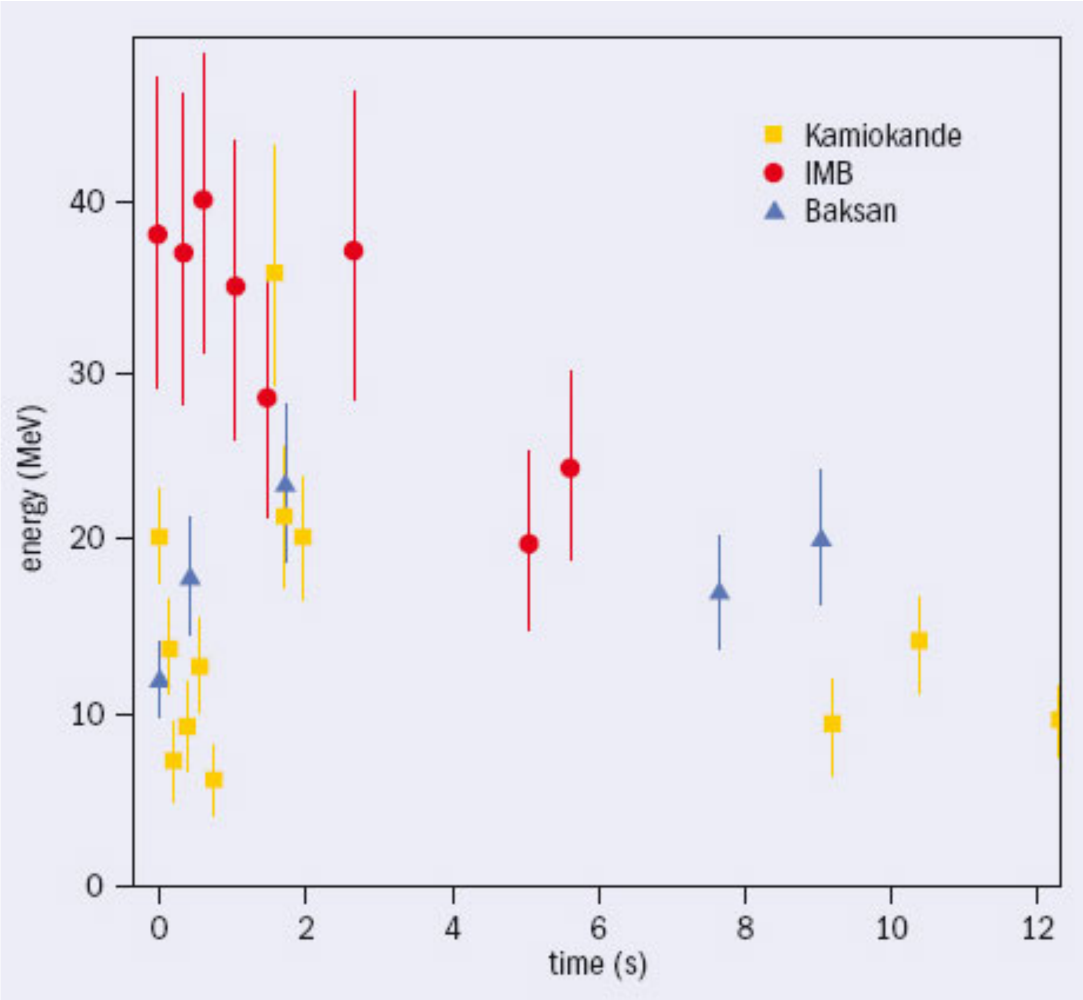
- Core-collapse supernovae exhibit a diverse set of observational properties (luminosity, flux evolution, expansion velocities, spectral features, explosion parameters)
- The observed diversity is related to explosion properties of the SN and its environment
- Beyond the classical SN II → SN Ib → SN Ic sequence modern surveys have discovered a diverse population of superluminal SNe, whose progenitors are a matter of debate and/or unknown
- New, high-cadence transient search programs will discover many supernovae soon after explosion, as well as various flavors of fast and faint transients!


YURI
BELETSKY

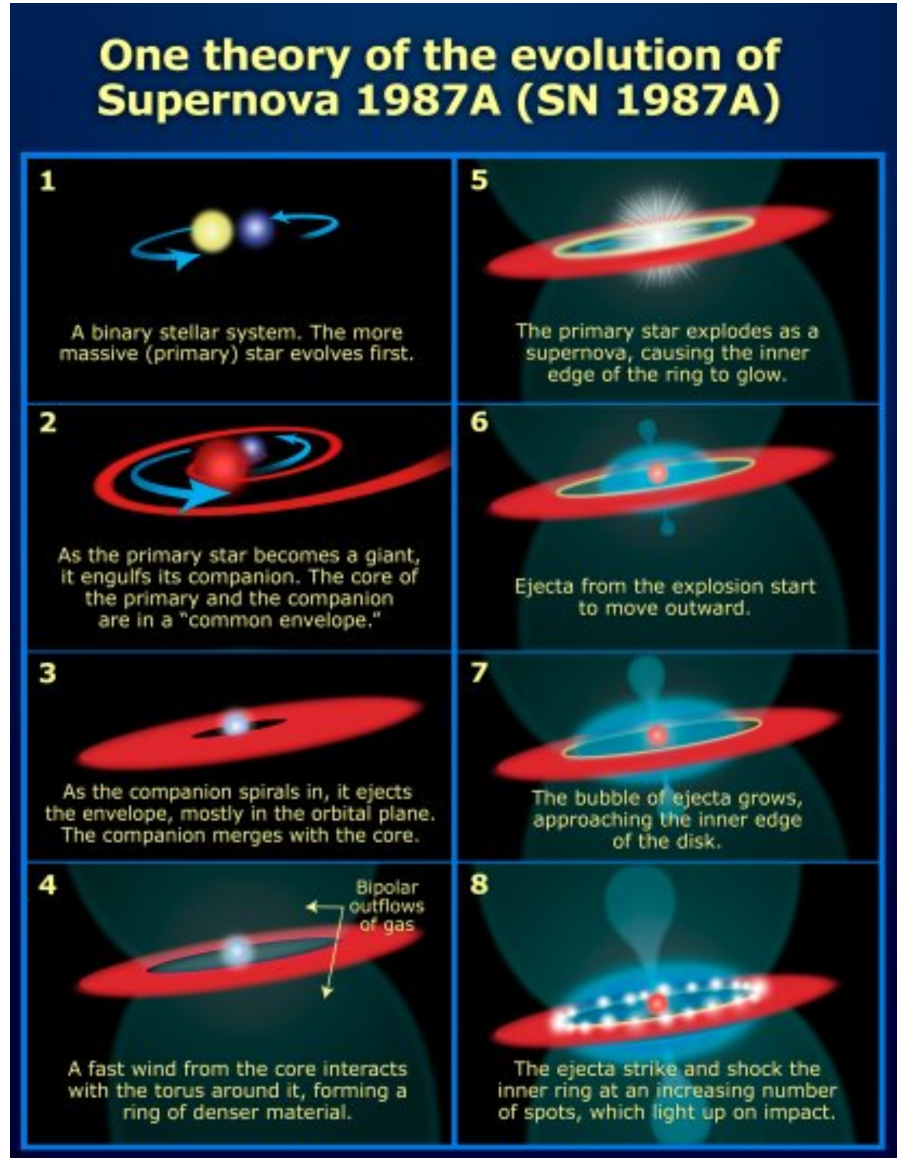
Neutrino Observations of SN 1987A

7 hours prior to optical outbursts a burst of 20 neutrinos was observed with a duration of approximately 1 sec and with observed energy of ≈20 MeV

This corresponds to a total energy of $2x10^{59}$ MeV, which corresponds well with back of the envelope and model predications!



Late, late phase observations (SN 1987A)

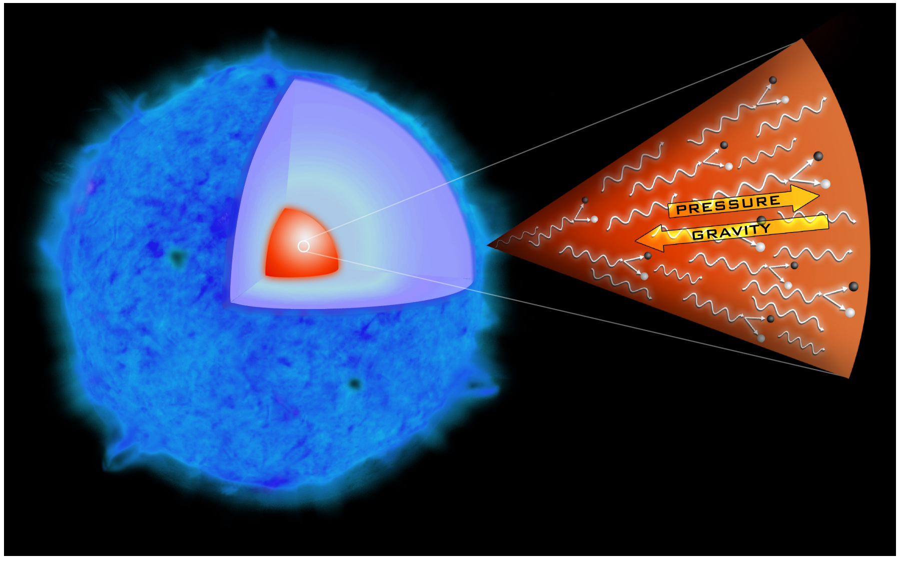


Pair Instability SNe

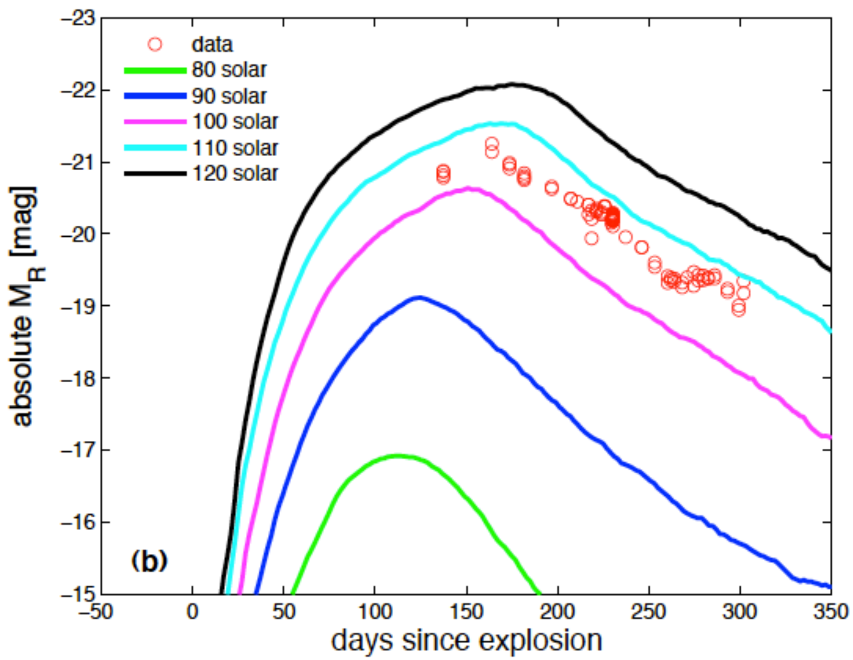
- Collisions of gamma rays and nuclei create e^- / e^+ pairs

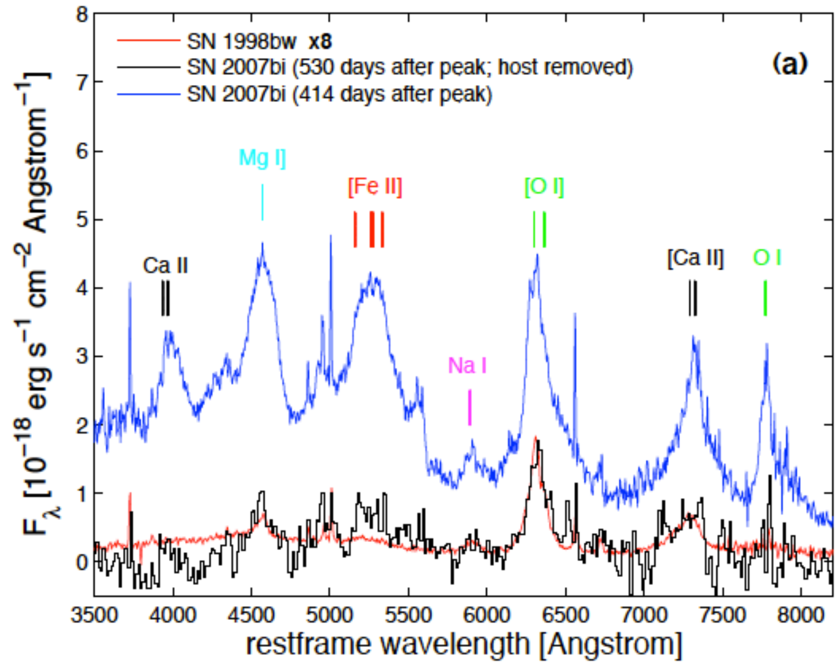
→ reduces pressure
→ partial collapse
→ thermonuclear runaway
→ complete disruption, no BH

- Requires a massive ≈ 100 $M_\odot$ oxygen rich core, i.e. very massive ZAMS star



SLSN-R, where R is for radioactive powered





Gal-Yam et al. 2009, Moriya et al. 2010

- Related to the production of large amount of ^{56}Ni (≈5$M_{\odot}$)

→ Peak brightness, linear decline, and nebular phase spectrum

- Ejected mass of SN 2007bi is estimated to be ≈ 50-100 $M_{\odot}$
- SN 2007bi best candidate for Pair Instability explosion?
- Extremely rare!