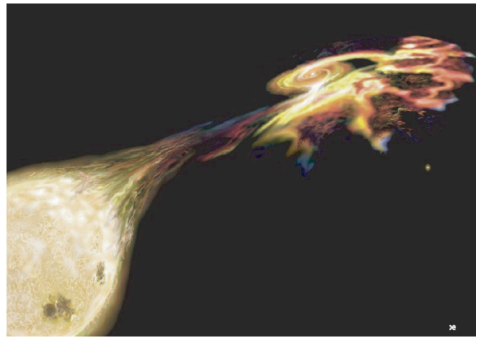
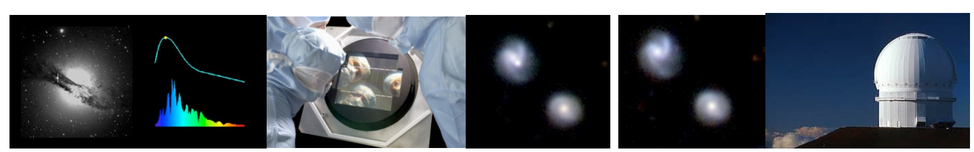
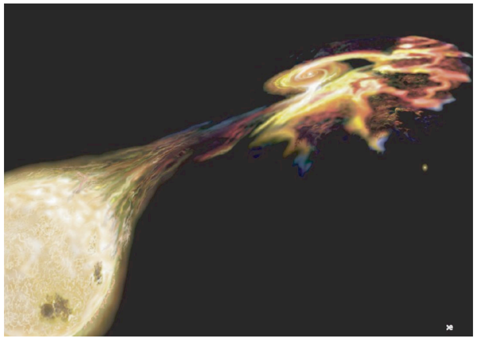


Astr 580 - Part I

Introduction to Supernovae

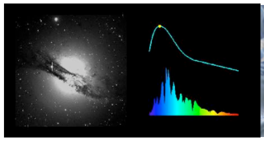
www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf

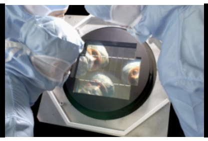




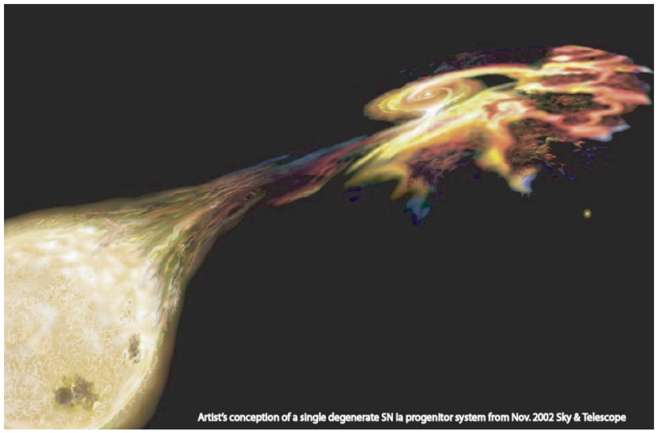
- ***Introduction to the Introduction***
- ***Observational Properties - Spectra & Light Curves***

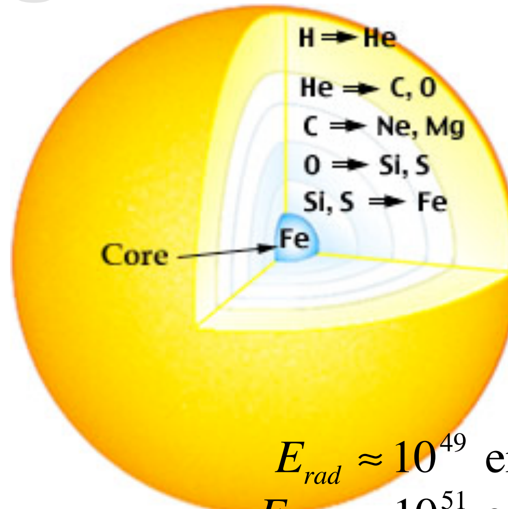
www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf





Why are Supernovae Interesting?





$$E_{rad} \approx 10^{49} \text{ erg}$$
$$E_{mech} \approx 10^{51} \text{ erg}$$
$$E_{\nu} \approx 10^{53} \text{ erg}$$

- ***$L \sim 10^{10} L_{sun} \sim L_{MW}$***
- Source of almost all heavy elements (^{12}C - …)
- Neutrinos, gravitational waves, …
- Great physics!
- Extinction events?
- SN cosmology!

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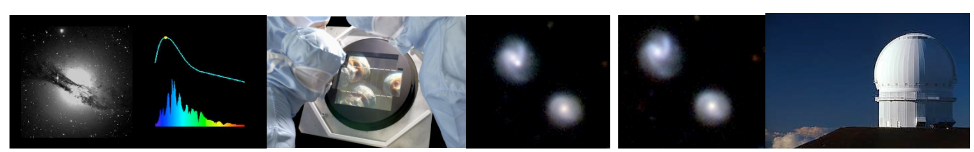
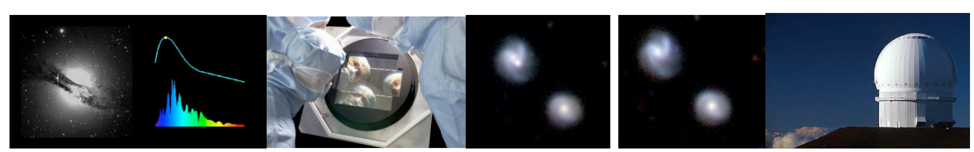


July 5th, 1054AD

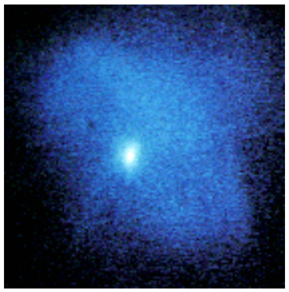
凡十一日沒三年三月乙巳出東南方大中祥符四
年正月丁丑見南斗魁前天禧五年四月丙辰出軒轅
前星西北大如桃速行經軒轅大星入太微垣掩右執
法犯次將歷屏星西北凡七十五日入濁沒明道元
年六月乙巳出東北方近濁有芒彗至丁巳凡十三
日沒至和元年五月己丑出天關東南可數寸歲餘
稍沒熙寧二年六月丙辰出箕度中至七月丁卯犯
箕乃散三年十一月丁未出天囷元祐六年十一月
辛亥出參度中犯掩側星壬子化九游星十二月癸
酉入奎至七年三月辛亥乃散紹興八年五月守婁

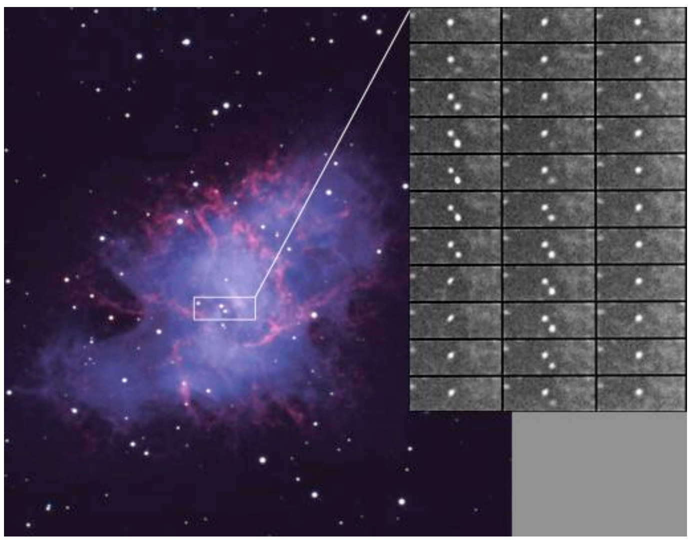
Chaco Canyon, NM

www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf

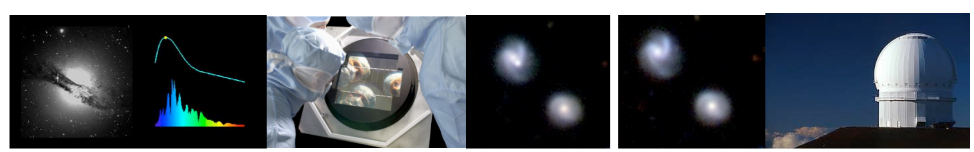


Crab Nebula and Pulsar





www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf

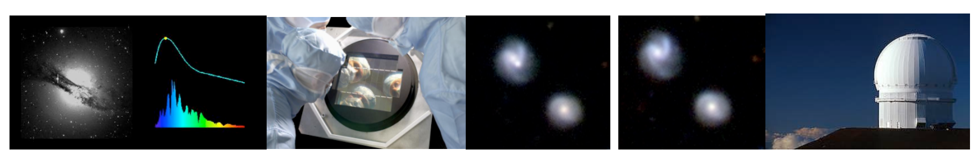


Historical SNe

- Source: Wikipedia …

year (number)	appeared in (constellation)	apparent magnitude	distance (light years)	type	comments
ca. 9000 BC	Vela (Vel)	−13?[citation needed]	815	II	Vela Supernova Remnant[1]
185	Centaurus (Cen)	−8	4000-10,000	I	
386	Sagittarius (Sgr)	+1.5	≥16,000		might have been a nova and not a supernova
393	Scorpius (Sco)	−0	34,000		
SN 1006	Lupus (Lup)	−7.5[2]	7200	I	
1054	Taurus (Tau)	−6	6500	II	remnant is the Crab Nebula with its pulsar (neutron star)
1181	Cassiopeia (Cas)	0	8500		
1572	Cassiopeia (Cas)	−4.0	8000	I	Tycho's Nova
1604	Ophiuchus (Oph)	−3	14,000	I	Kepler's Star
ca. 1680	Cassiopeia (Cas)	+5	9000		has since remained inconspicuous (was too weak); remnant is Cas A, the brightest extrasolar radio source in the sky
1885A	Andromeda (And)	+7	2,400,000	Ipec	first observation of an extragalactic supernova: in the Andromeda Nebula

www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf



(Light Echoes)

- Rest, Welch et al ApJL, 681, L81

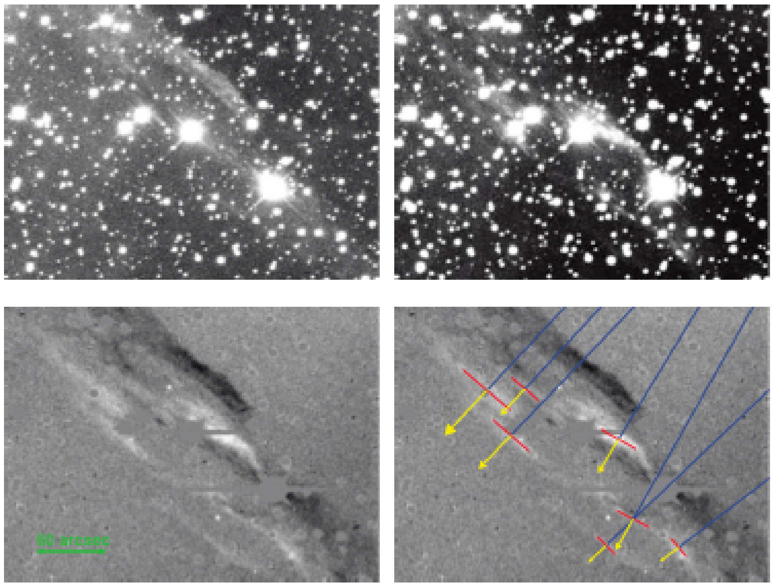


FIG. 1.—Light echo arclets associated with Tycho from field 4821. The orientation is north up and east to the left and the images are 325″ × 250″. The top panels show the first-epoch image from 2006 October 20 (*left*) and the second-epoch image from 2007 December 13 (*right*). The bottom images are the difference images between the two top images where white represents the later (2006 October) image and black the earlier October image. Saturated bright stars are masked gray. In the bottom panels, the left image is repeated in the right panel with the motion vectors plotted. Red represents a straight line fit to the arclet, yellow represents the apparent motion of the arclet, and blue shows the reverse vector direction. The VR surface brightness in the brighter arclets is roughly 24 mag arcsec^{-2}. The widths of the echoes are resolved, and typically 10″ across.

www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf

Rest et al. 2005, Nature, 438, 1132

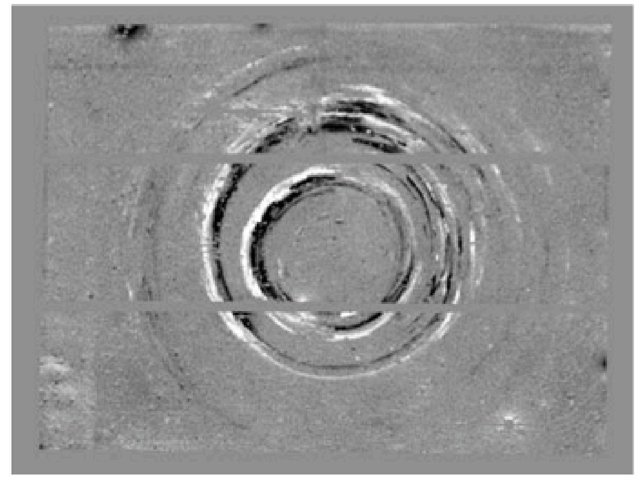
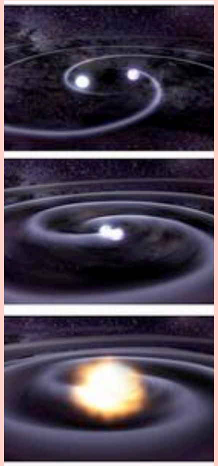
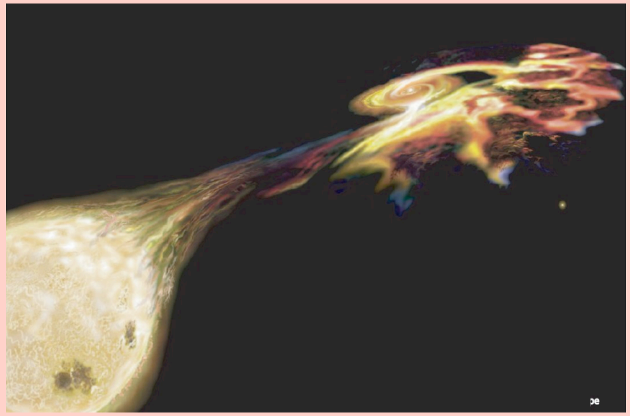


Figure 1 | The light echoes from SN 1987A. Data taken at the CTIO 4-m Blanco telescope with the MOSAIC imager in the *VR* filter were used to make this difference image; it shows epoch 2004.97 data minus epoch 2001.95 data, representing 17.8 and 14.8 yr after the explosion. Our SuperMACHO survey covers 24 degrees^2 in 68 pointings in an approximate rectangle 3.7° by 6.6° aligned with the LMC bar. The images are taken through our custom '*VR*' filter (central wavelength $\lambda_c = 625$ nm, bandpass width $\Delta\lambda = 220$ nm) with exposure times of 60 s to 200 s, depending on the stellar densities. The field is 13.8′ by 18.4′, with north up and east left. Flux enhancements from 2004 are shown white and and those from 2001 are shown black in this difference image. Faint echo arcs can be seen as far out as 6.6′ and 7.3′ from the explosion site, or 0.9 kpc and 1.1 kpc in front of SN 1987A. The *VR* surface brightness varies from 19.8 mag arcsec^{-2} to a limit of ~24 mag arcsec^{-2}, with one knot as bright as 19.3 mag arcsec^{-2}. The widths of the echoes are resolved, and are typically ~2.5″ across.

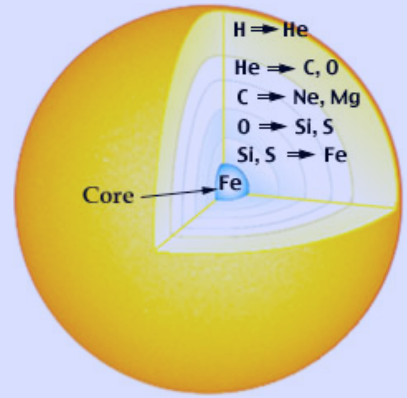
SNe Ia



or



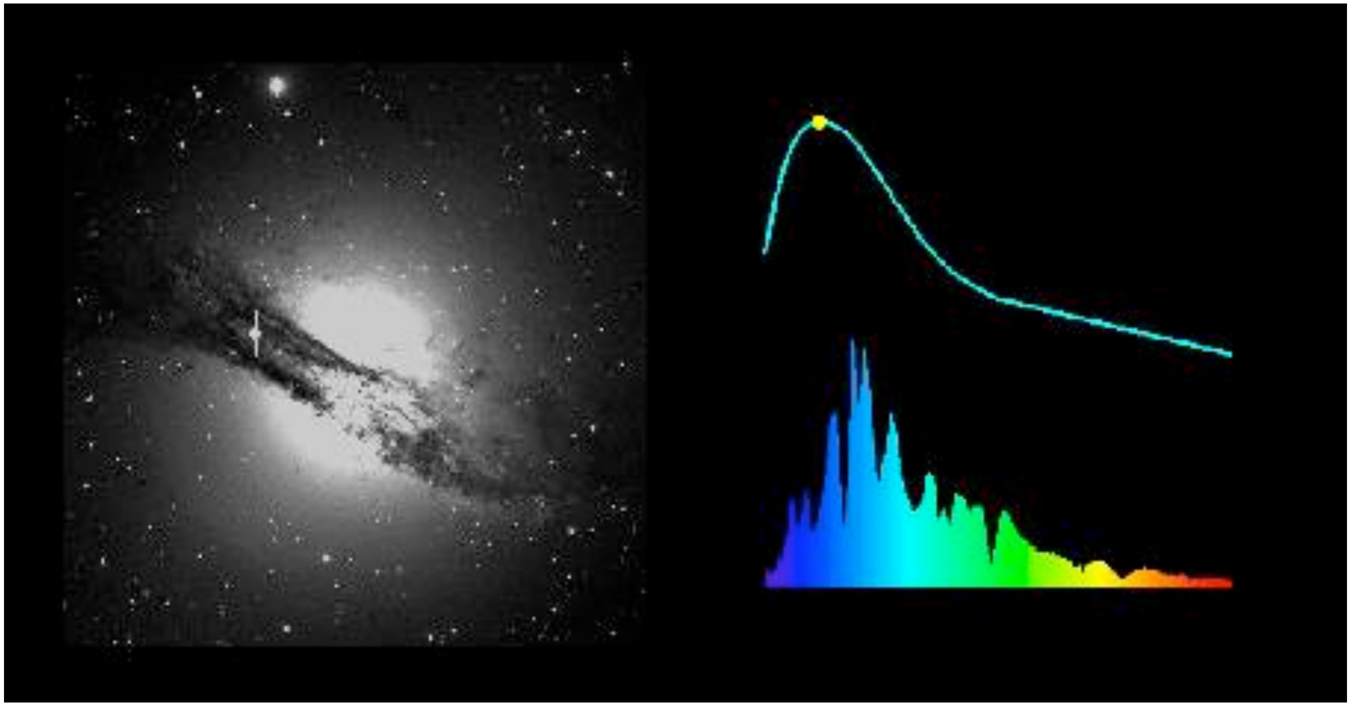
SN II/Ib/Ic (cc)



	SN Ia	*SN II*
brightness	**10^{10} L_{sun}, Std candle**	**10^{9} L_{sun} Not std candle**
progenitor	**1 or 2 white dwarfs:**	massive star
mechanism	**mass transfer or merger**	core collapse:
progenitor age	~~**$\sim 10^{10}$ yr**~~	$\sim 10^{7}$ yr
evolution with z	~~**Little?**~~	$(1+z)^{2\text{-}4}$:
Remnant (ns/bh)	**no**	yes
Metals ejected	**Fe, Ni …**	O, Ne, Si …

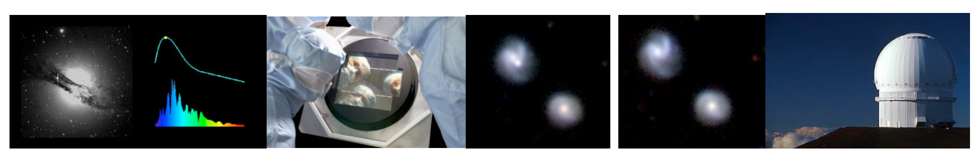
www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf

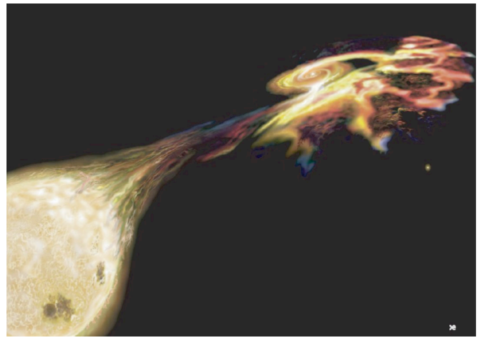
Animations



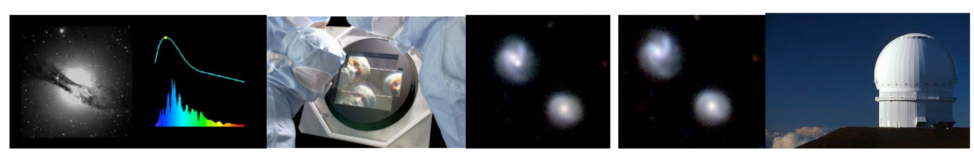
supernova.lbl.gov – SCP web pages

See also *http://jupiter.as.arizona.edu/~burrows/*
(Adam Burrows web page – go to *movies*)



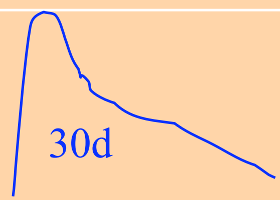
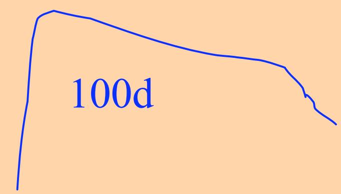


- *Introduction to the Introduction*
- *Observational Properties - Spectra & Light Curves*

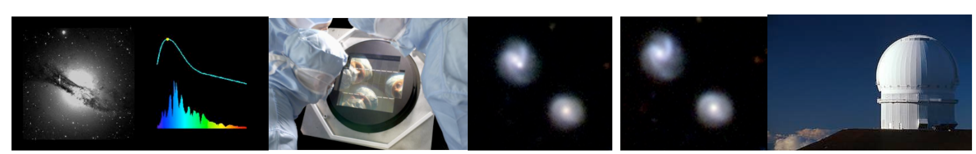


www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf

Observational Properties – Ia vs. II

	Ia	II
Peak M_B	-19.3±0.1(h=0.6) (after stretch/colour corr) - std candle! Distances to ±6%	-17 ±2:
light curve		
local rate	0.15 $h_{50}^2\,(100\,yr)^{-1}\,(10^{10}\,L_{Bsun})^{-1}$	0.50
out to 100Mpc	60/yr	200/yr
spectrum	λ6180 Si II UV	H, no Si II no UV

www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf



SNeIa/II spectral energy distributions

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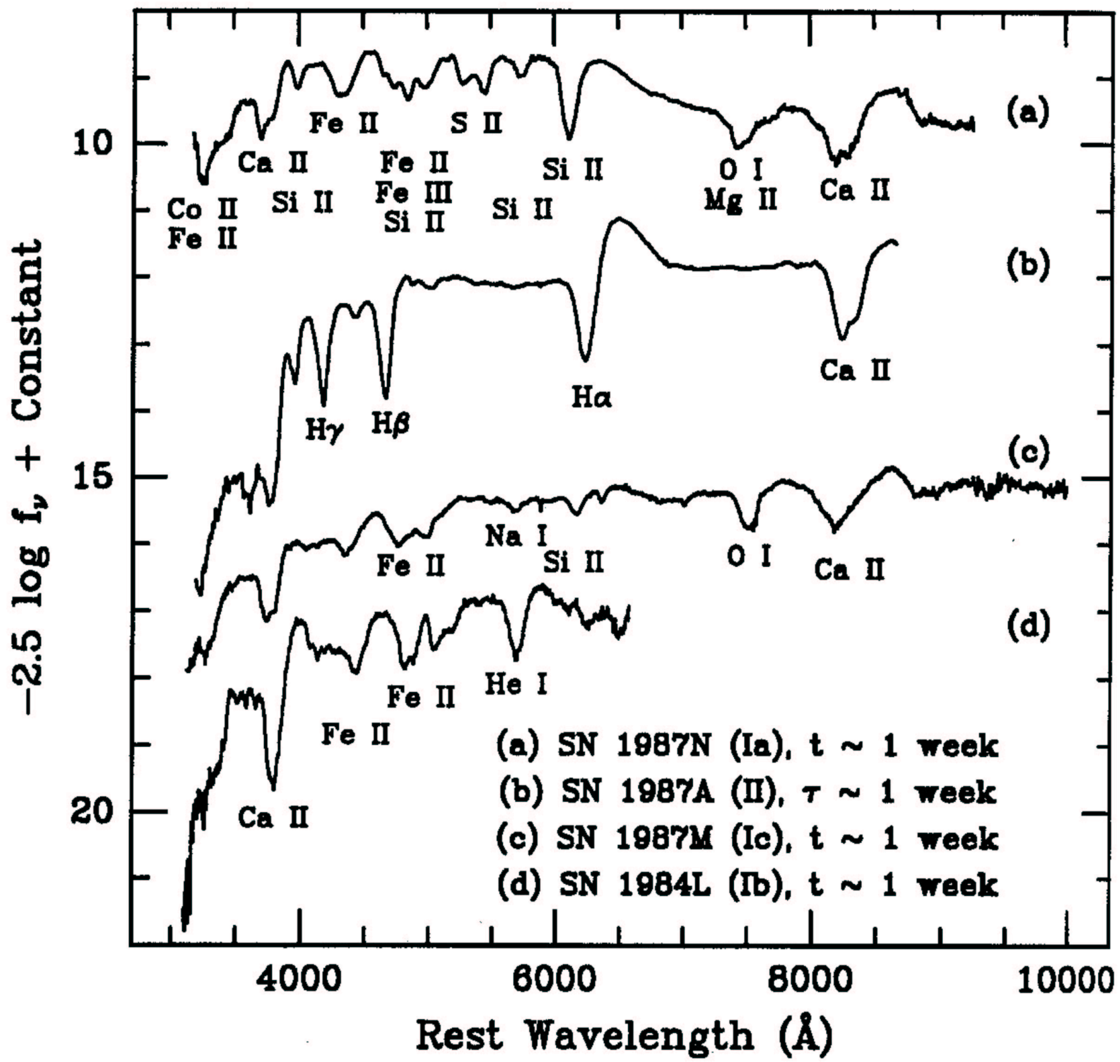
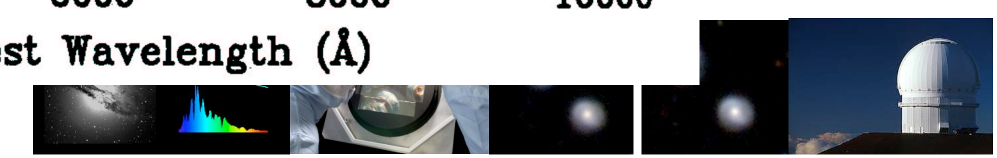


www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf



SN Ia spectra vs time

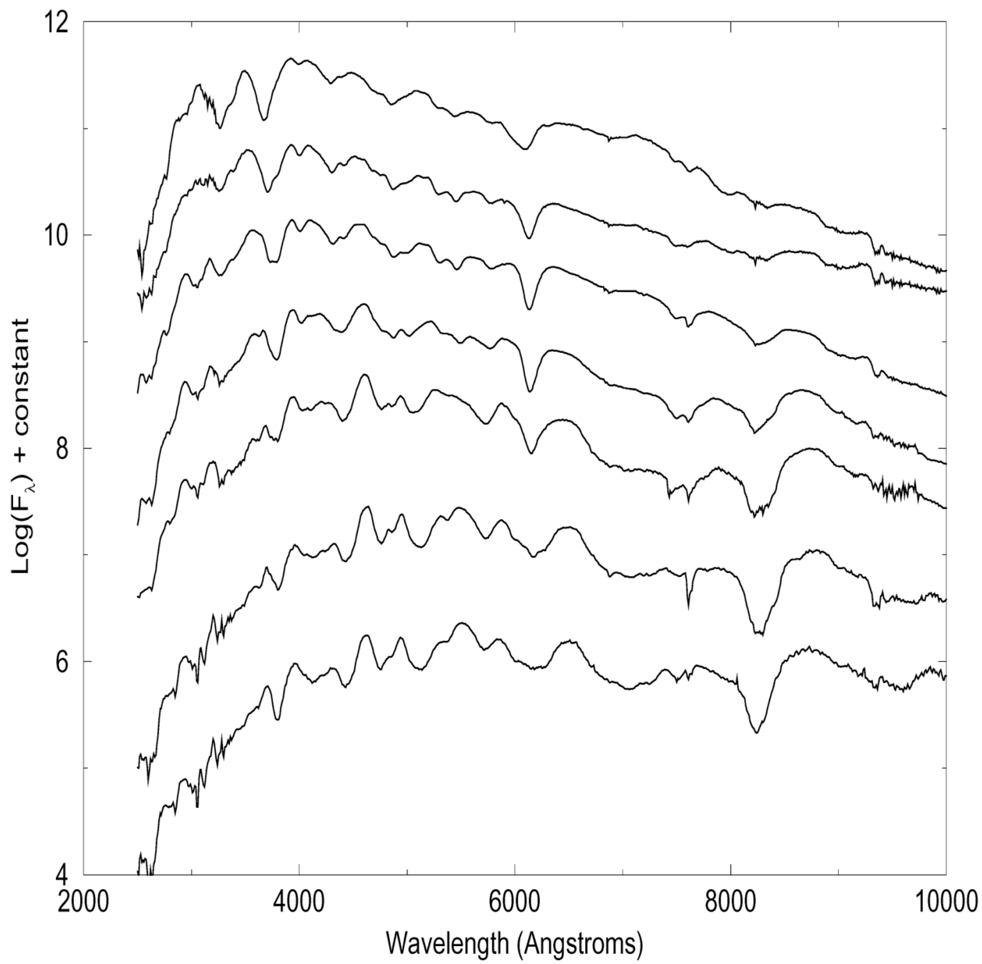
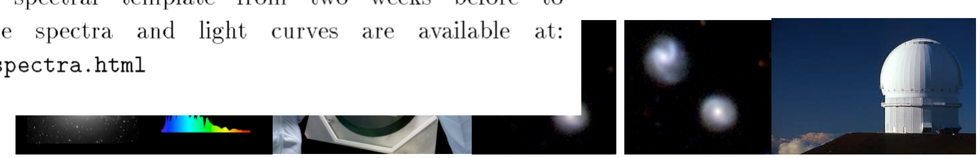


Fig. 6.— A weekly sampling of the spectral template from two weeks before to four weeks after maximum light. The spectra and light curves are available at: http://www.supernova.lbl.gov/~nugent/spectra.html



www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf

Spectral templates

- **k-corrections (Hsiao et al 2007)**

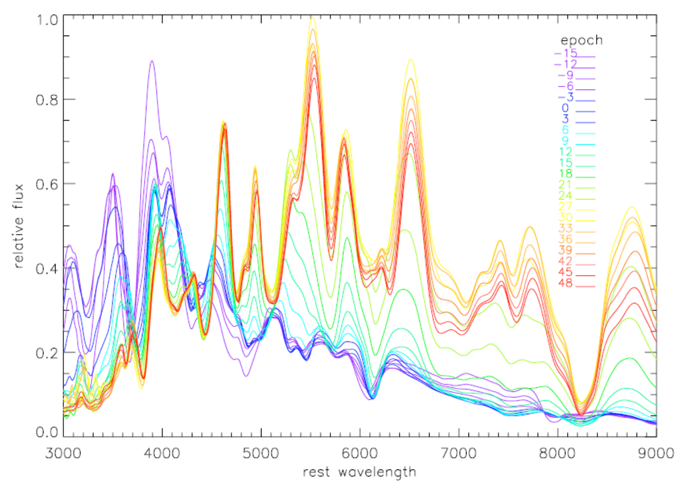


Fig. 5.— An illustration of the time evolution of spectral features of SNe Ia. A spectral template is plotted from $t = -15$ to $t = 48$ relative to maximum B band light. Template spectra at different epochs are normalized to the same B band flux. Spectral features of SNe Ia evolve rapidly around maximum light and slow down pass $t = 20$. This emphasizes the importance of small epoch bins near maximum light.

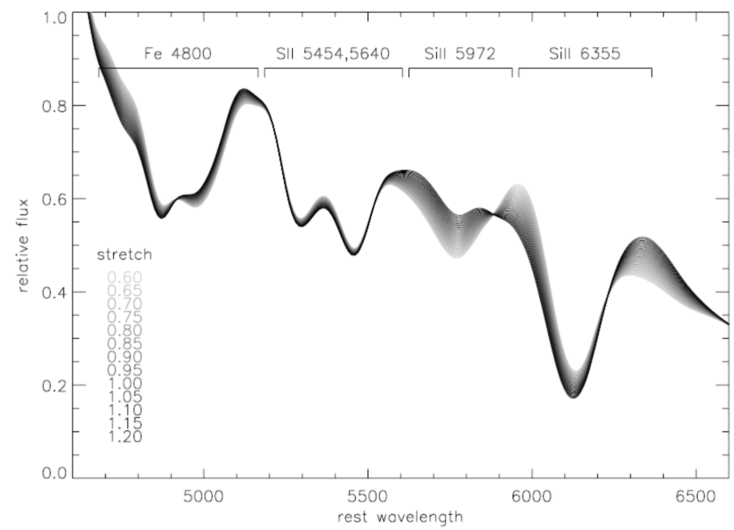


Fig. 14.— The template spectroscopic sequence of Si II $\lambda5972$ and Si II $\lambda6355$. The template is derived from 24 library spectra of 17 SNe Ia with a wide range of stretch factors. The pattern is prescribed by the principal component analysis of the narrow band color measurements described in Section 5.2.

- Based on 800 individual spectra (Suspect, etc)
- Ellis et al 2007 UV

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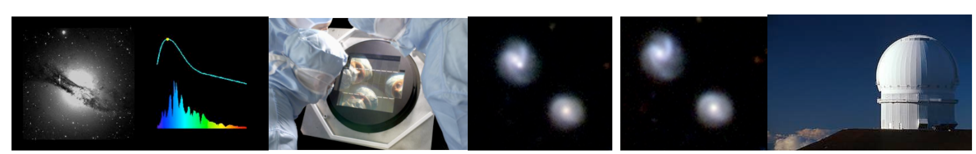
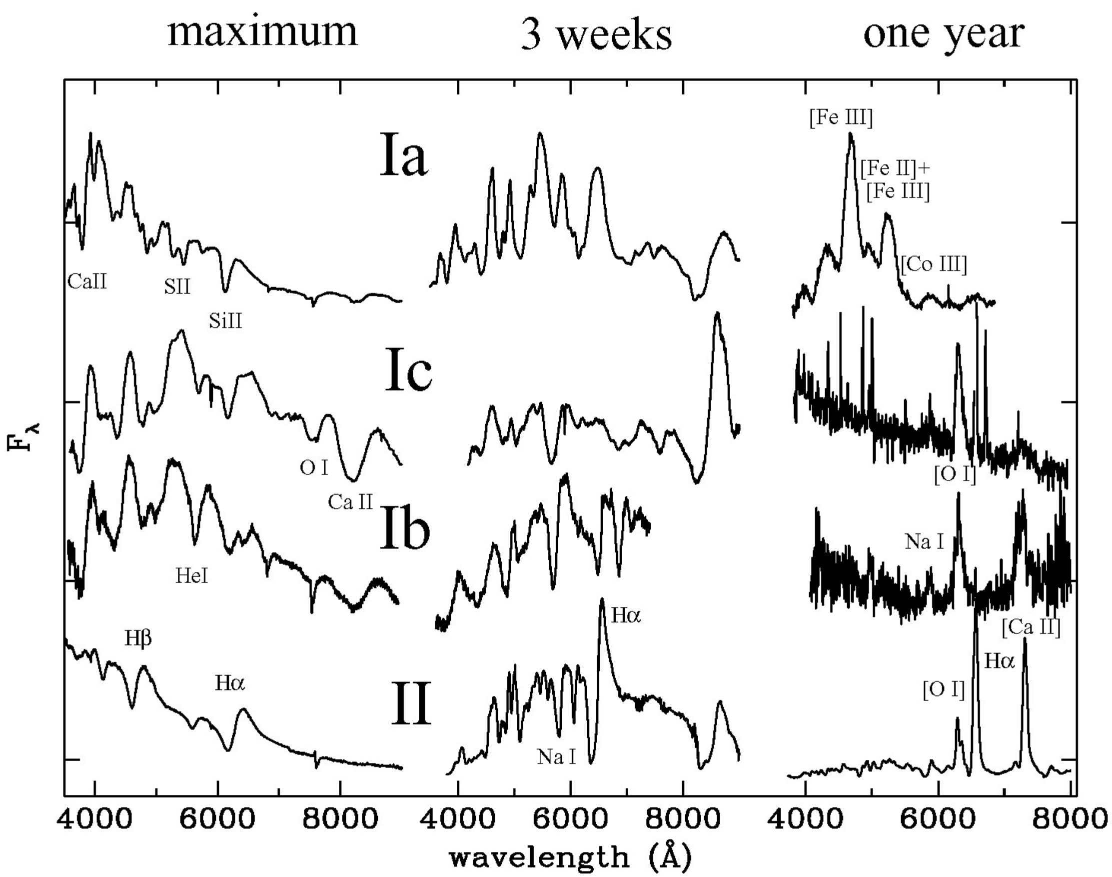
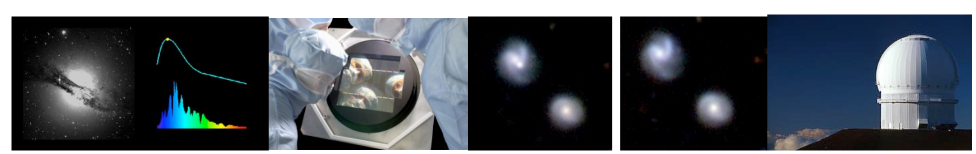


Is it a SNeIa? z?

- Spectra needed for cosmology
- Filippenko ARAA 1997

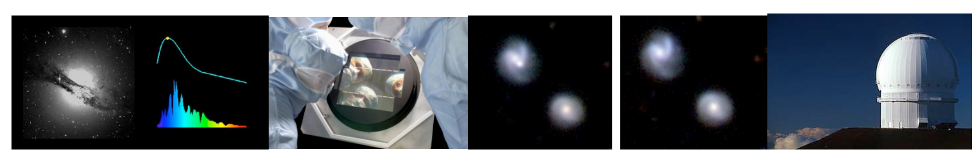


www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf



- “The progressive decrease of the velocities reflects the fact that the SNeIa ejecta are expanding homologously (velocity proportional to the distance to the center of the explosion). Thus, as an ever larger fraction of the ejecta becomes transparent, the photosphere recedes into ever deeper layers which move at lower velocities.”

www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf



Light curves – Filippenko ARAA1997

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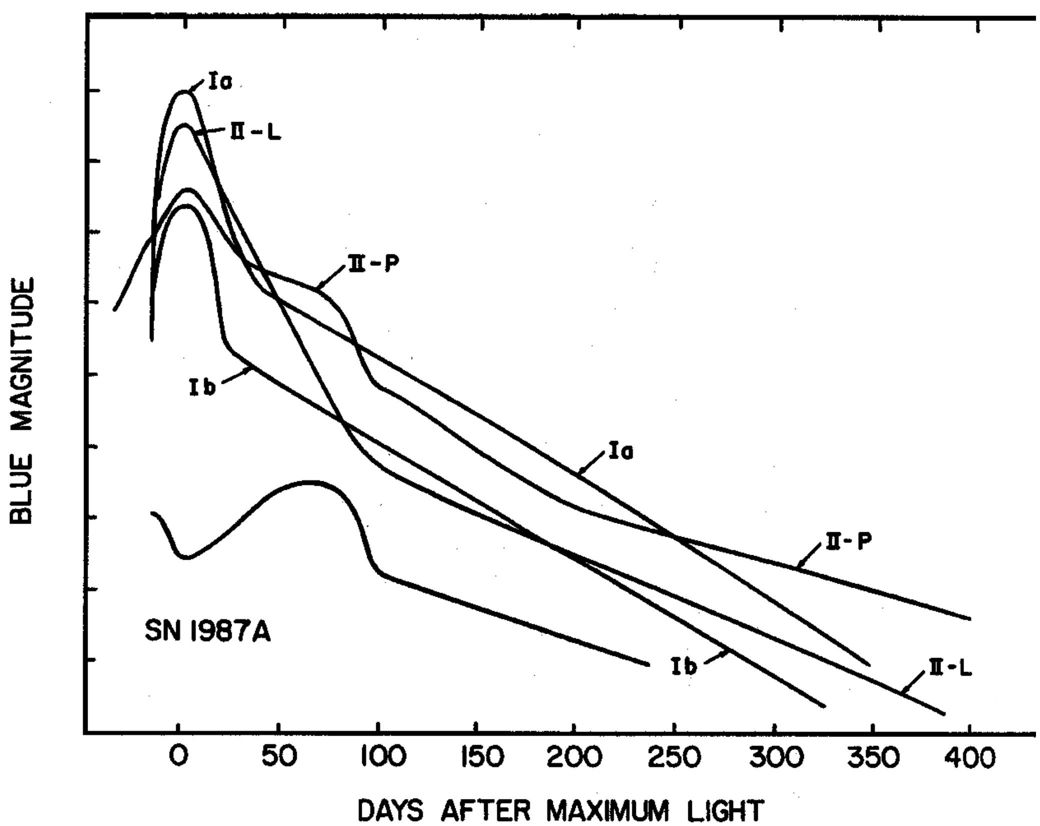
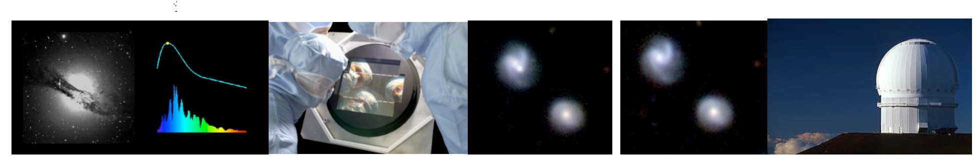


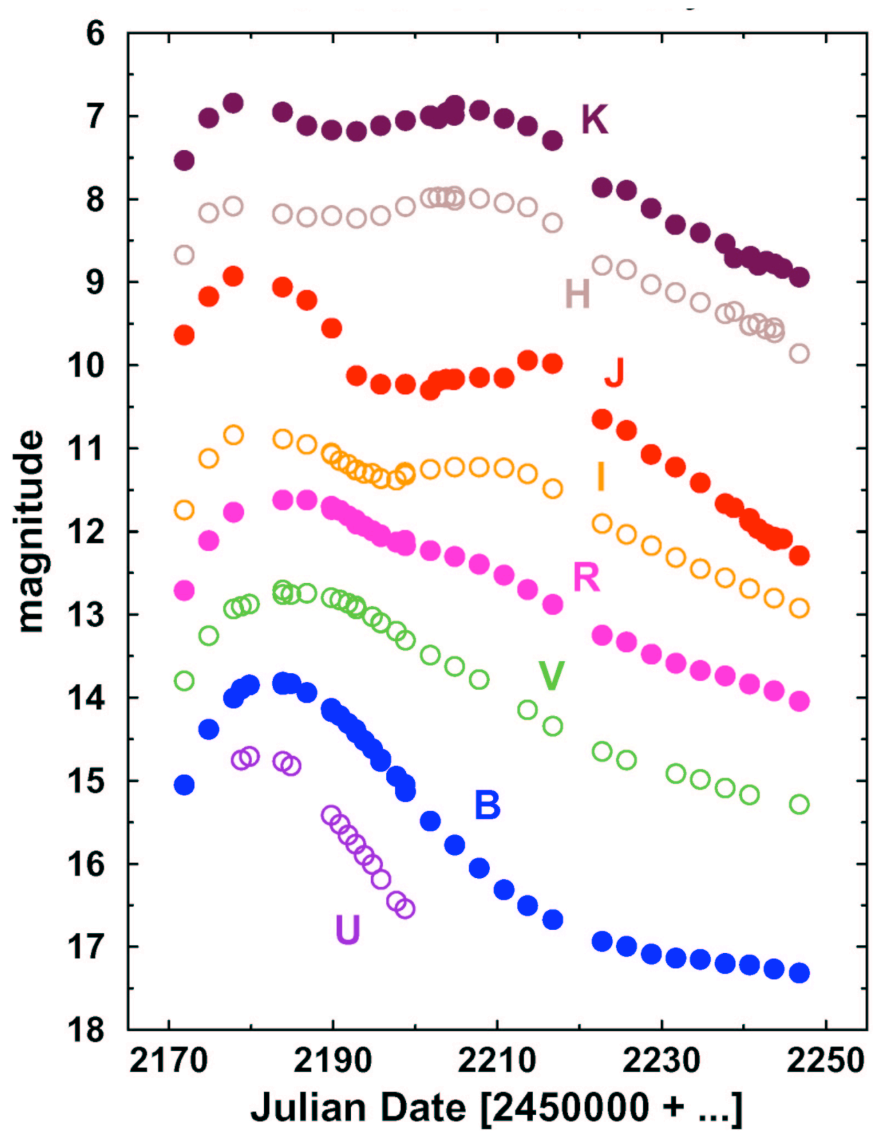
Figure 3 Schematic light curves for SNe of Types Ia, Ib, II-L, II-P, and SN 1987A. The cur for SNe Ib includes SNe Ic as well, and represents an average. For SNe II-L, SNe 1979C a 1980K are used, but these might be unusually luminous. From Wheeler 1990; reproduced wi permission.

- Not much known about:
  - IIP and IIL lightcurves - wide variety
  - Relation between Ia peak vs linear decline

www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf



UVO vs IR - behaviour different in IR



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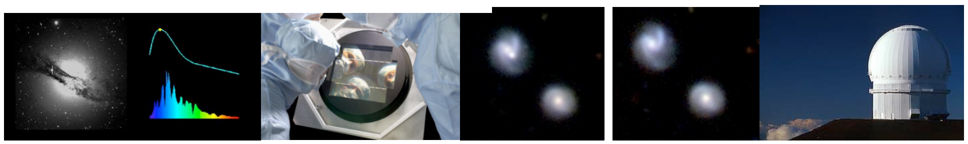


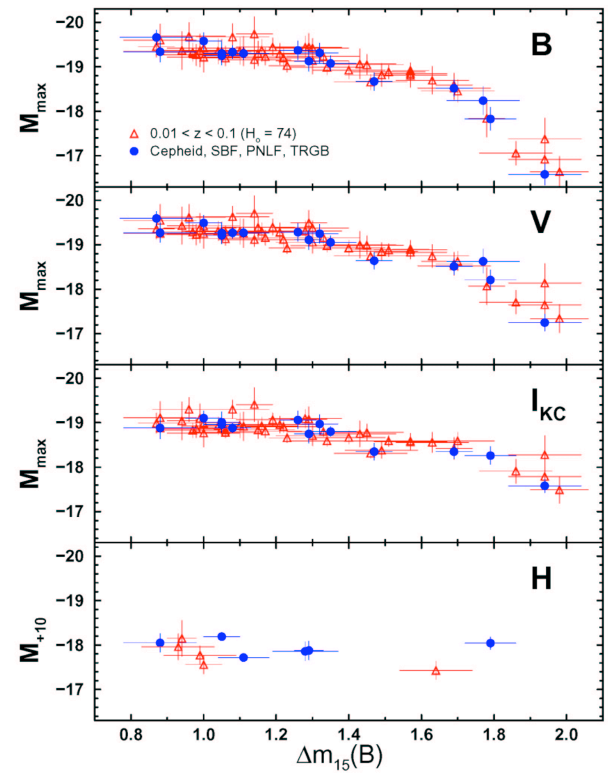
Corrections to max light photometry

- SNeIa are not standard candles
  - cf. Kristian σ~ 0.6 mag
  - Philipps 1993 - m15
  - Perlmutter stretch

Blue magnitude only:

$$m(t) = c + m_0(st)$$

$$s = \text{"stretch"}$$



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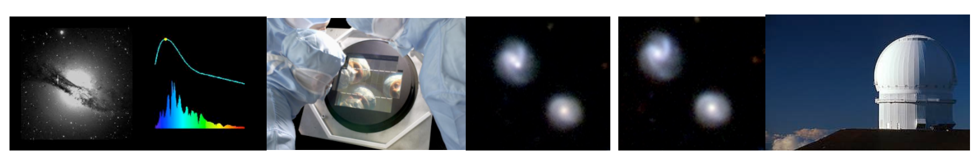
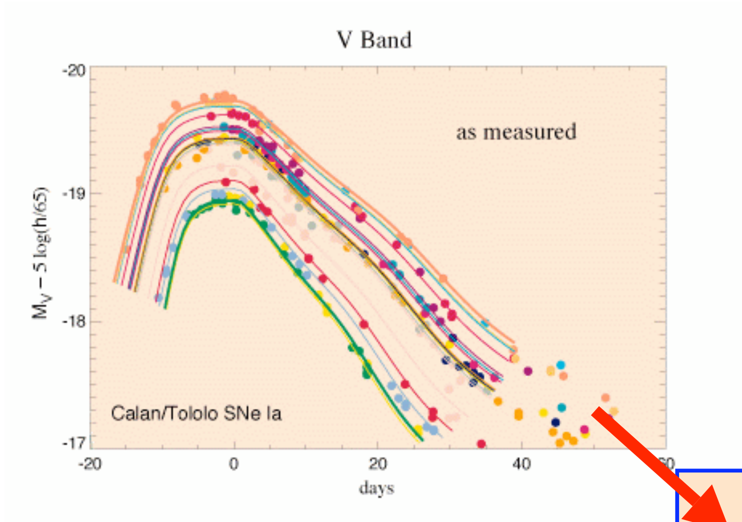
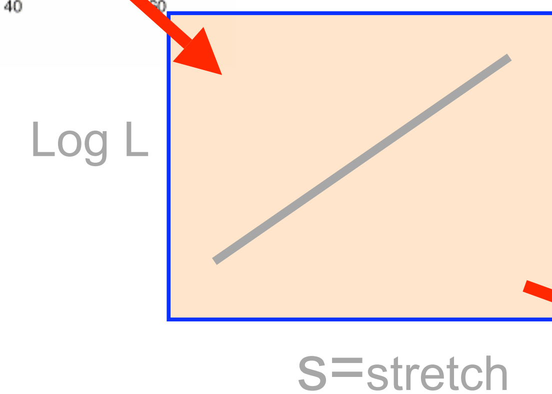
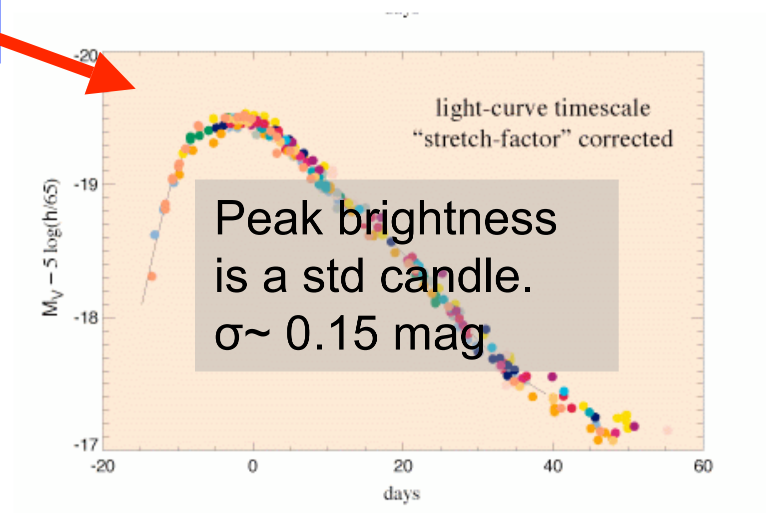


Making a standard candle



$$\log L(t) = \log L_o(st) + \gamma s$$
$$m(t) = M_o(st) + \alpha s + 5\log d - 5$$





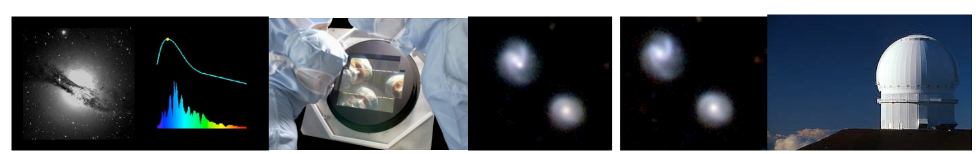
Peak brightness is a std candle.
σ~ 0.15 mag

More ^{56}Ni → Higher Temp → Higher Opacities → *Brighter, Broader SNe Ia*

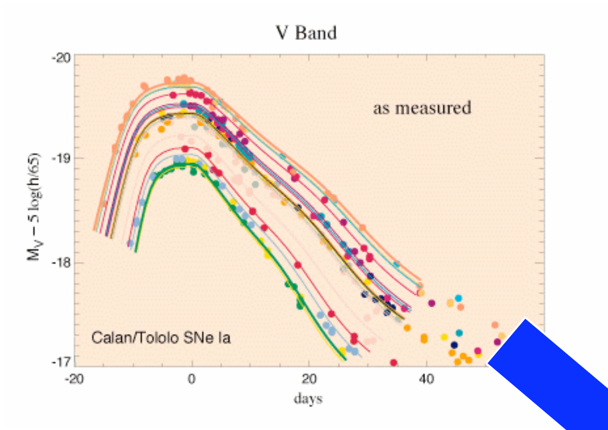
Higher opacities trap the radiation more effectively and release it later, making for broader light curves. (Nugent)

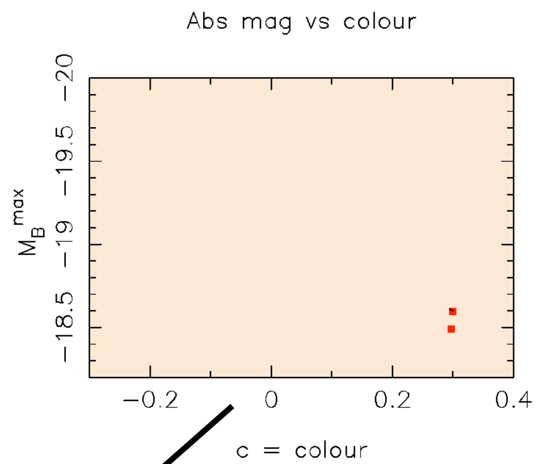
(But Kasen & Woosley astro-ph/ 0609540)

www.astro.uvic.ca/~pritchet/SN/A580-2008-I.pdf

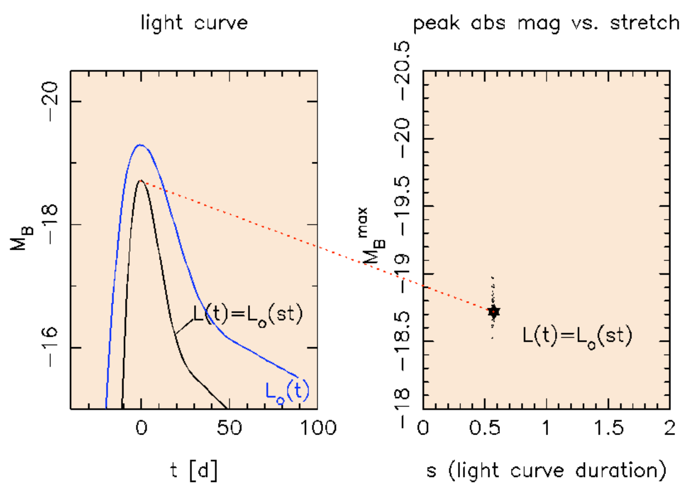


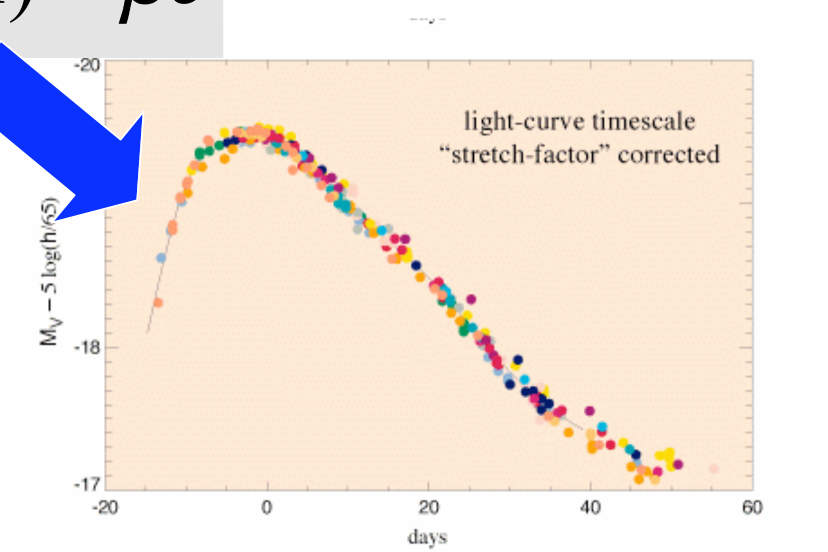
Making a standard candle

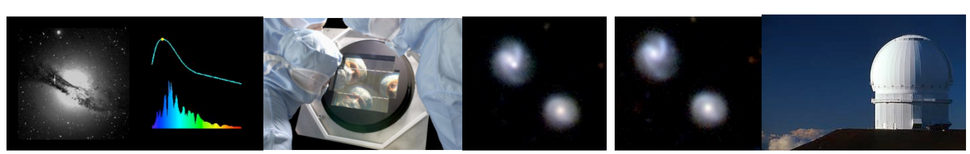




$$M_B = M_{B_O} + \alpha(s-1) - \beta c$$







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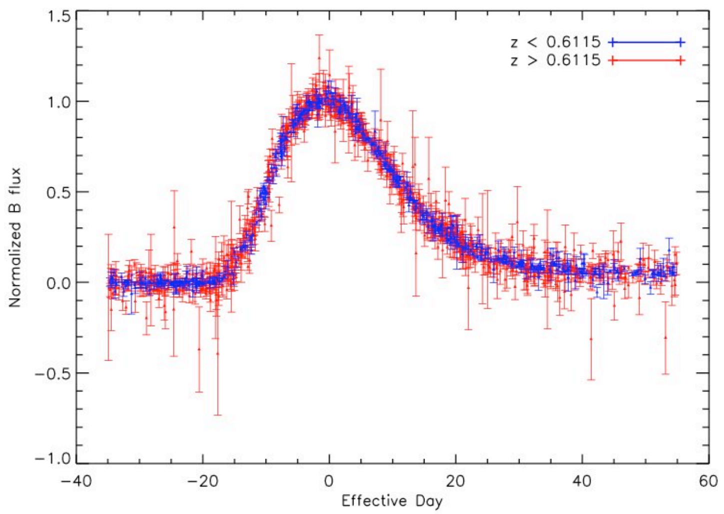
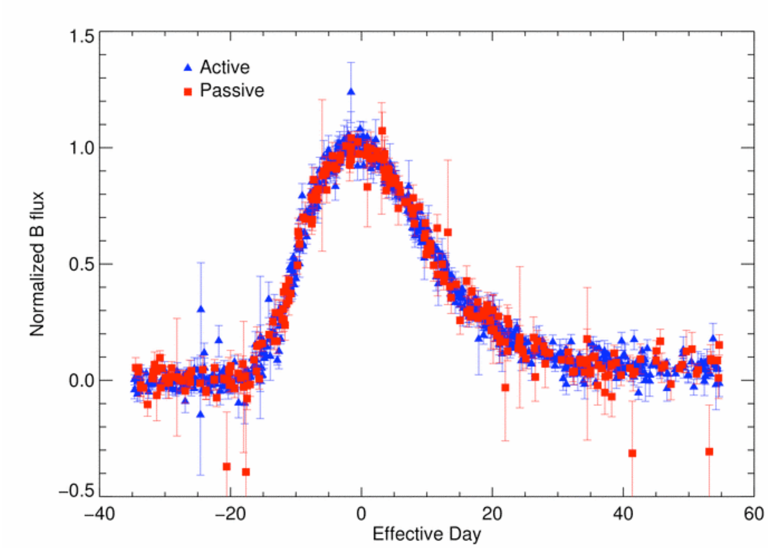
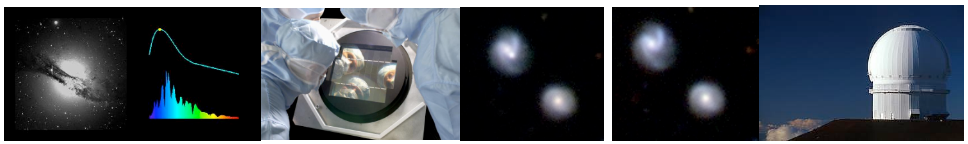
SNLS stretch-corrected (Conley et al 2006)

- s works both pre-max and post-max - remarkable!







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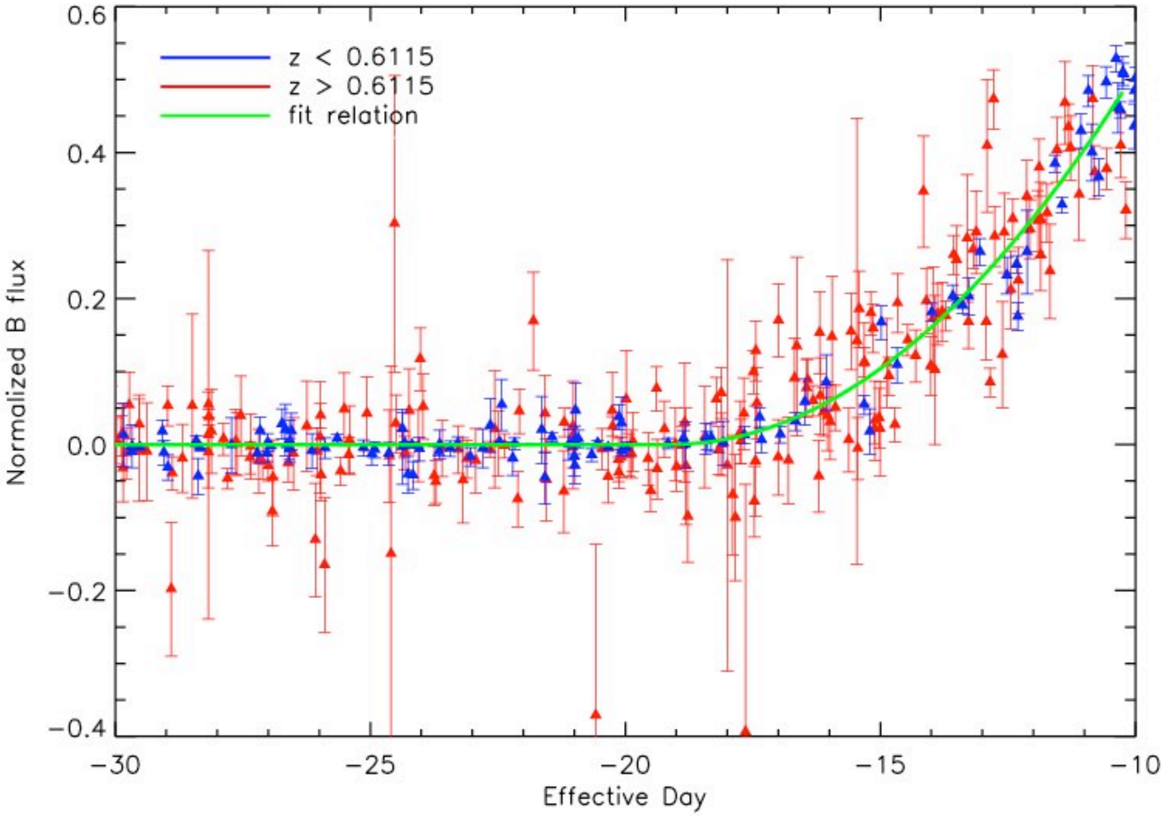
Low z vs High z risetimes

- Low z and high z SNe Ia indistinguishable



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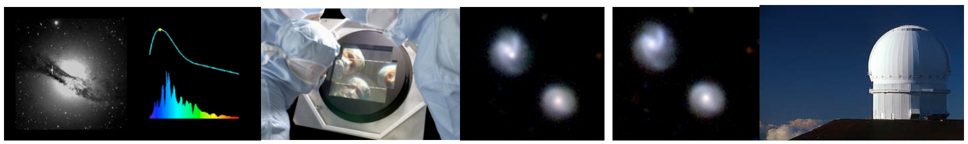

Radioactive decay

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Table 18.6. *Historical supernovae.*

Event	Extended remnant	Compact remnant
185		
1006	Shell, Balmer dominated	
1054 (Crab Nebula)	Filled, helium-rich	33 msec pulsar
1572 (Tycho)	Shell, Balmer dominated	
1604 (Kepler)	Shell, Balmer dominated	
~ 1670 (Cas A)	Oxygen rich knots, He, N-rich, quasistationary flocculi	

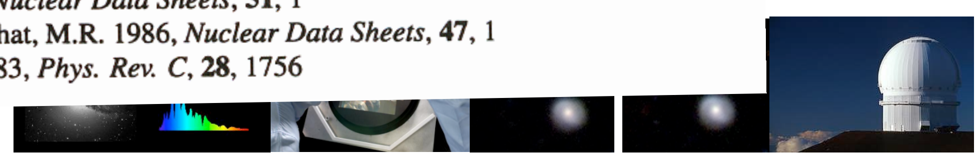
18.10 RADIOACTIVE DECAY

A principal source of power of the light curve peak and especially the late-time tail of many super is the decay of radioactive ^{56}Ni and its daughter ^{56}Co. Other radioactive species that may cont late-time power are ^{57}Co and ^{44}Ti. The decay rates for these species are given in Table 18.7.

Table 18.7. *Radioactive decay time scales in supernovae.*

Element	Half-life	*e*-Fold	Per magnitude
^{56}Ni [1]	6.10 d	8.80 d	8.11 d
^{56}Co [1]	77.12 d	111.3 d	102.3 d
^{57}Co [2]	271.8 d	392.1 d	361.2 d
^{44}Ti [3]	54.2 yr	78.2 yr	72.0 yr

References
1. Huo, J. et al. 1987, *Nuclear Data Sheets*, **51**, 1
2. Burrows, T.W., & Bhat, M.R. 1986, *Nuclear Data Sheets*, **47**, 1
3. Frekers, D. et al. 1983, *Phys. Rev. C*, **28**, 1756



Bolometric light curve and power source

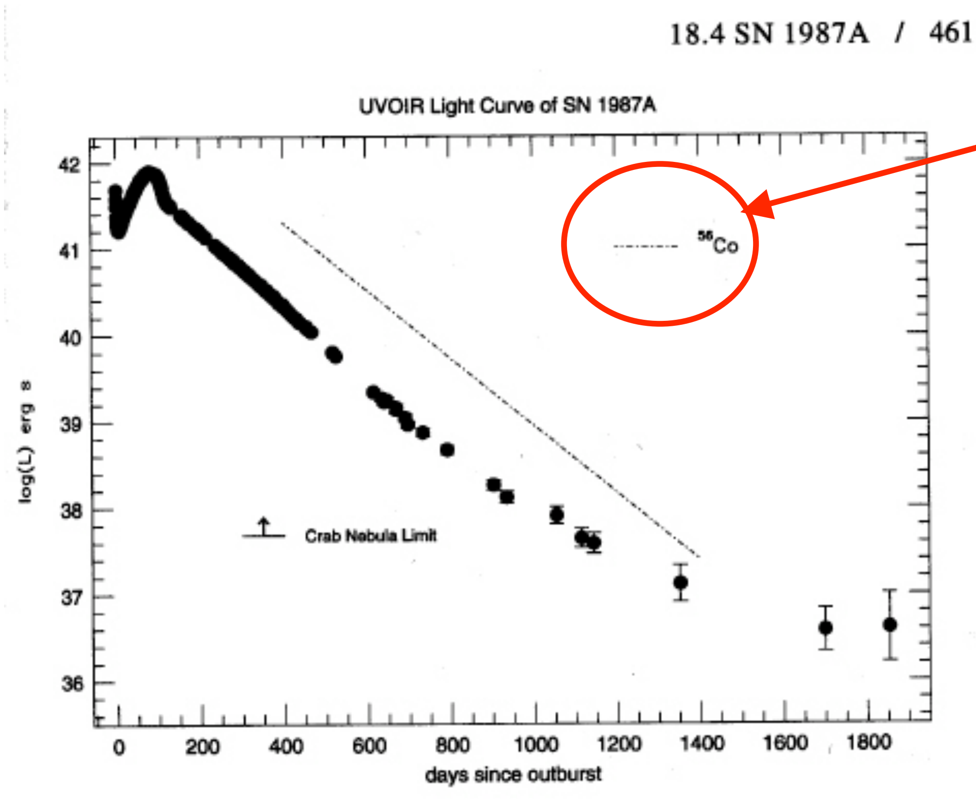


Figure 18.10. Bolometric light curve of SN 1987A. (Courtesy of N. Suntzeff.)

$Co^{56} \rightarrow Fe^{56}$ powers late light curve (both Ia and II)

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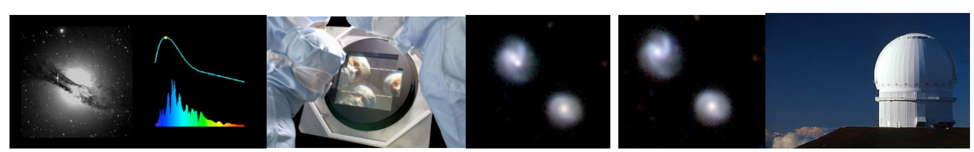
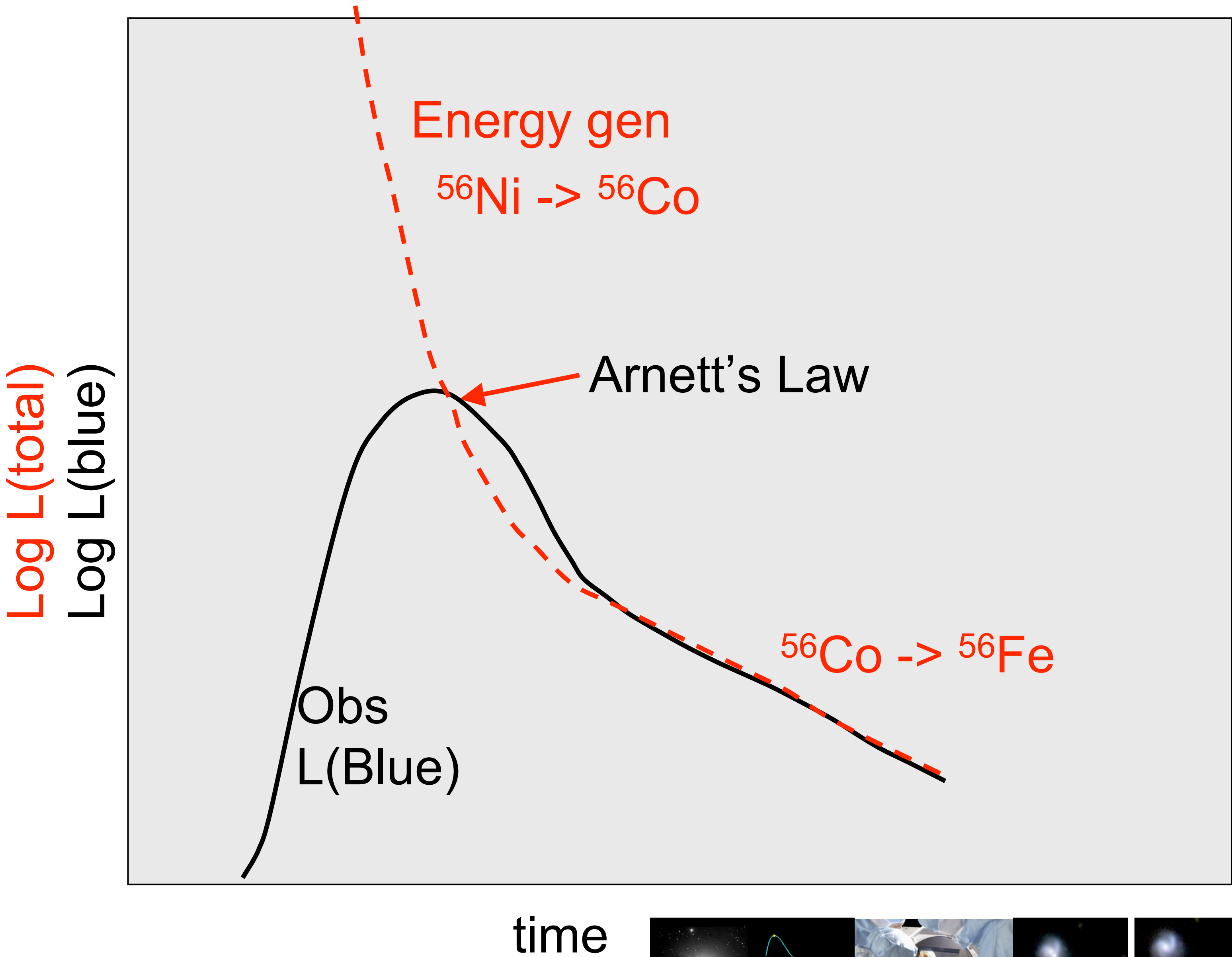
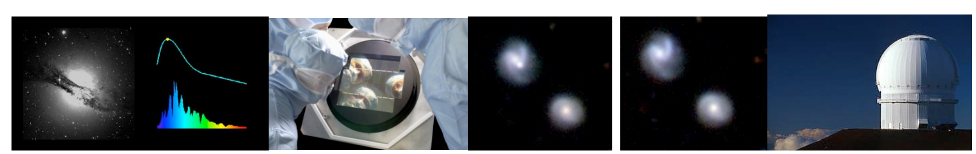


Arnett's Law and radioactive decay - Ia's





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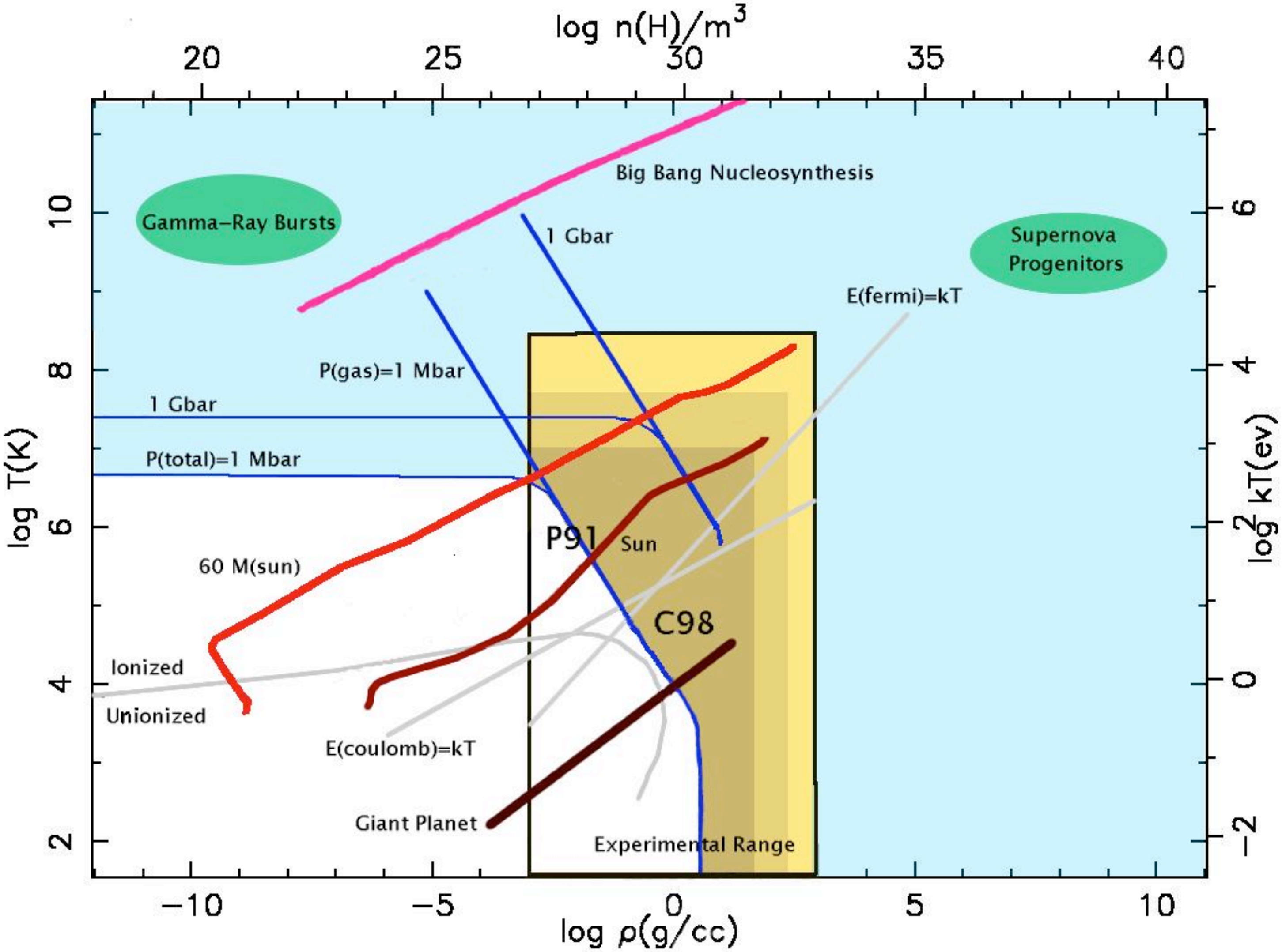
Arnett



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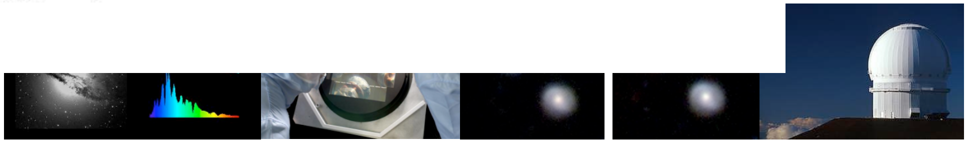

Figure 1.1. Overlap between HED experimental range and astrophysical conditions.

The "High-Energy-Density" conditions lie in the shaded regions, above and to the right of the pressure contour labeled "P(total)=1 Mbar".

The horizontal axis is logarithmic density (lower axis in grams per cubic centimeter; upper in number per cubic meter). The vertical axis is logarithmic temperature (left in degrees Kelvin; right in electron volts). The gray rectangles denote the regions accessible to experiments on NOVA (smallest), OMEGA, and NIF (largest). Z-pinch is roughly comparable with OMEGA. Magnetic fusion experiments probe comparable temperatures, but much lower densities. The rectanges overlap most of the extreme conditions for typical stars (stars of 60 and 1 solar mass are shown; the 60 solar mass star is both burning helium (at the center) and hydrogen (in a shell), while the 1 solar mass star is a model of the present day sun).

Pressure contours for one megabar and one gigabar are shown; the thick blue lines refer to gas pressure only, while the thinner blue lines refer to gas plus radiation pressure. For objects large and dense enough to be opaque, the total pressure is the relevant one. Below the line labeled E(coulomb)=kT, the plasma is strongly coupled. Below the line labeled E(fermi)=kT, the electrons are degenerate. Near a density rho=1, pressure ionization occurs; models of Jupiter and other giant planets probe this region. The symbol P91 is centered on conditions attained in the experiments of Perry, et al., 1991; similarly, C98 refers to Collins, et al., 1998. These experiments have had deep influence on stellar and planetary science. For context, the more extreme regions occupied by models of gamma-ray bursts, supernova progenitors, and the conditions for Big Bang nucleosynthesis are indicated.

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