

Astrophysics I: Stars and Stellar Evolution

AST 4001

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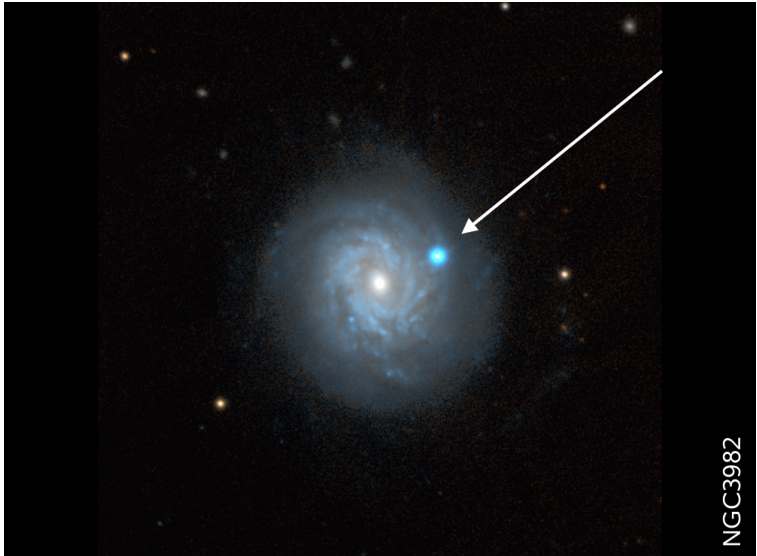
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Stars and Stellar Evolution, Fall 2008

Overview

- 1 Recap
 - Things that blow up
- 2 Supernovae
 - Collapsars
 - Type Ia Supernovae
 - Supernova Types and Light Curves

Supernovae



Supernovae - Overview

Things that blow up

supernovae from massive stars

- CO white dwarf \rightarrow Type Ia SN, $E \approx 1B$ Bethe
- MgNeO WD, accretion \rightarrow AIC, faint SN
- “SAGB” star (AGB, then SN) \rightarrow EC SN
- “normal” SN (Fe core collapse) \rightarrow Type II SN
- WR star (Fe CC) \rightarrow Type Ib/c
- “Collapsar”, GRB \rightarrow broad line Ib/a SN, “hypernova”
- Pulsational pair SN \rightarrow multiple, nested Type I/II SN
- Very massive stars \rightarrow pair SN, $\lesssim 100B$ ($1B=10^{51}$ erg)
- Very massive collapsar \rightarrow IMBH, SN, hard transient
- Supermassive stars \rightarrow $\gtrsim 100000$ B SN or SMBH



$1B=10^{51}$ erg

MASS



Supernovae

Things that blow up

Neutron star-powered supernovae

- CO white dwarf → Type Ia SN, $E \approx 1$ Bethe
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Supernovae

Things that blow up

Thermonuclear supernovae (no r -process)

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Supernovae

Things that blow up

Black hole-powered supernovae (“Collapsars”)

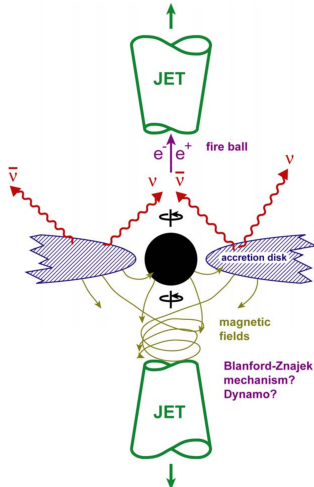
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Supernovae

The Collapsar Engine



Accretion disk around **black hole** may power **jet** by **neutrino annihilation** or by **MHD process**.

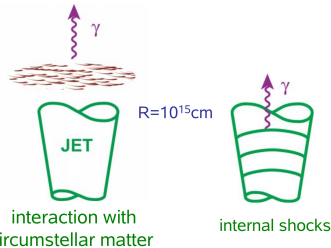
Jet will explode star

("hypernova"; see talk by Andrew MacFadyen)

and may power GRB

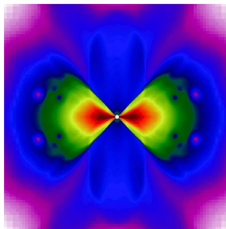
if it can escape from the stellar interior; requires

→ relativistic jet with high $\Gamma > 100$ and low baryon loading

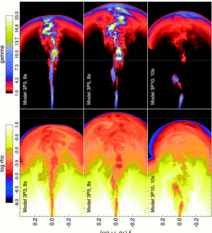


Supernovae

GRBs, Collapsar - Nucleosynthesis



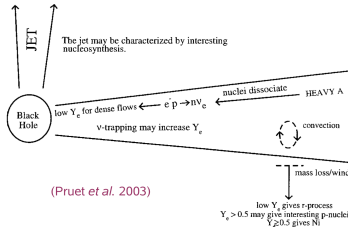
(MacFadyen, Zhang, Woosley 2005)



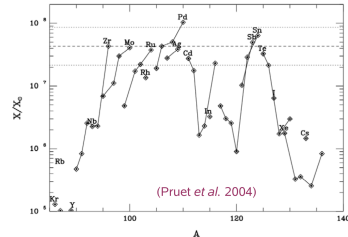
(Zhang, Woosley, Heger 2004)

← Hot accretion disk powers jet that may make GRB and explodes star

Nucleosynthesis in outflow from disk ↓



(Pruet *et al.* 2003)



(Pruet *et al.* 2004)

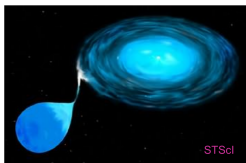
Type Ia Supernovae

Theoretical Model:

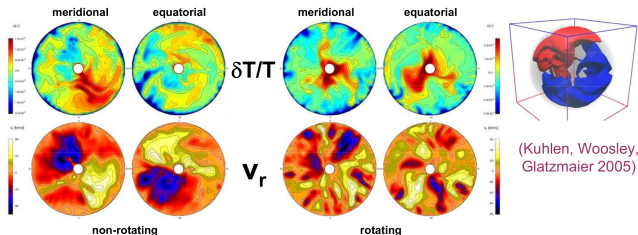
- accretion of material onto a CO white dwarf star in a binary star system
- grow mass to Chandrasekhar mass
- star contacts, stars burning of ^{12}C
- “smoldering” phase for some 1000 yr
- thermonuclear runaway, formation of thin burning flame that incinerates star in ~ 1 s
- explosion, ~ 1 B
- produce $\sim 0.5 M_{\odot}$ of radioactive ^{56}Ni

Type Ia Supernovae

SN Type Ia Ignition

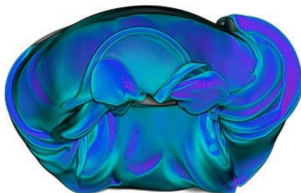


- Accreting CO white dwarf in binary star system
- ~1000 yr of convective “smoldering” carbon burning
- Quick final thermonuclear and ignition
- **How many sparks form? Where? Timescale?**



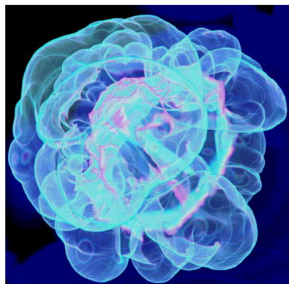
Type Ia Supernovae

SN Type Ia – A single Spark?



(Zingale *et al.* 2005)

Fully resolved single ignition "spark".



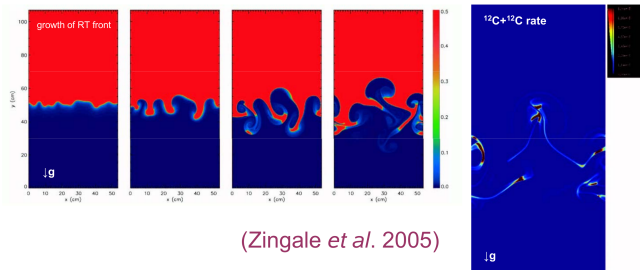
(Calder *et al.* 2004)

Single slightly off-center ignition spot.

Single off-center ignition gives bubble that quickly rises in one direction
→ no successful supernova explosion.

Type Ia Supernovae

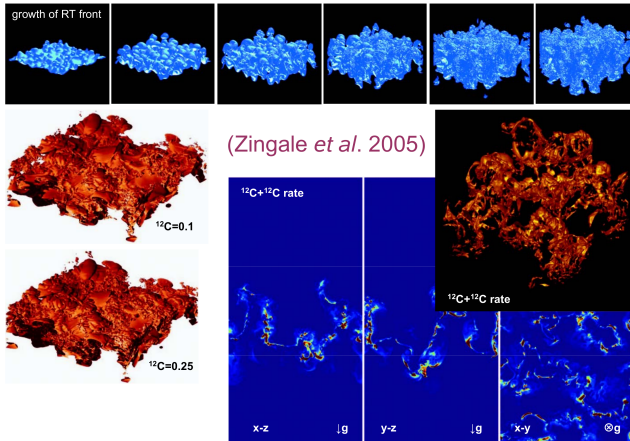
SN Type Ia Flames – 2D



Due to 2D symmetry front has lots of power on large scales

Type Ia Supernovae

SN Type Ia Flames – 3D



Supernovae

Supernova Types

as Function of Mass and Metallicity

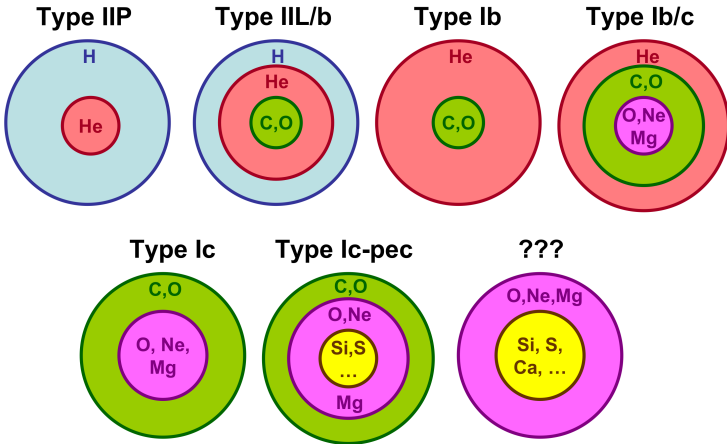
(single stars)

SN Type	pre-SN stellar structure
IIP	$> 2 M_{\odot}$ H envelope
IIL	$< 2 M_{\odot}$ H envelope
Ib/c	no H envelope

Type Ib/c He core mass at explosion	explosion energy	display
$> 15 M_{\odot}$	direct collapse	none
$\sim 15 \dots 8 M_{\odot}$	weak	dim
$\sim 8 \dots 5 M_{\odot}$	strong	dim
$< 5 M_{\odot}$	strong	bright

Supernovae

Sequence of increasingly stripped cc SNe

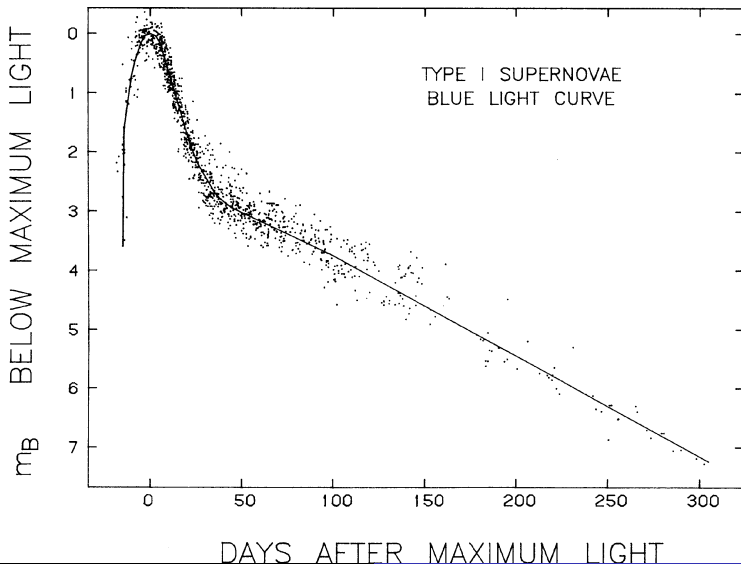


(adopted from Filippenko 2002)

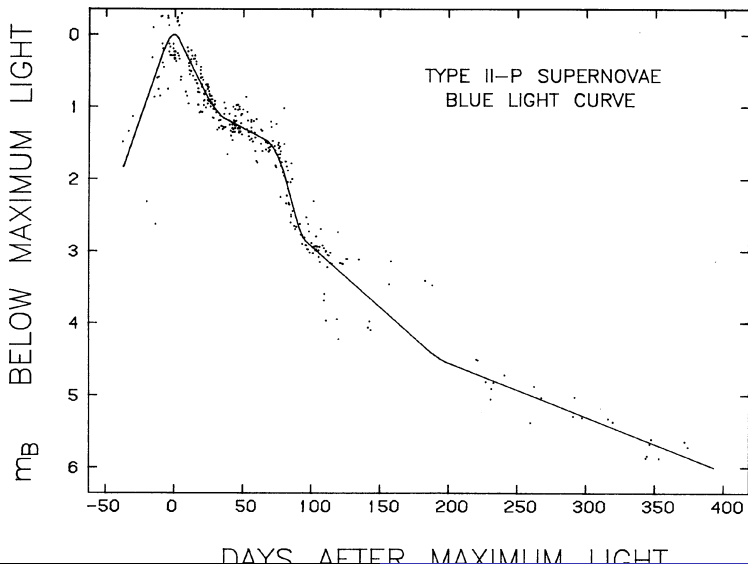
(SN 2002ap?)

(SN 02ap?, 98bw?)

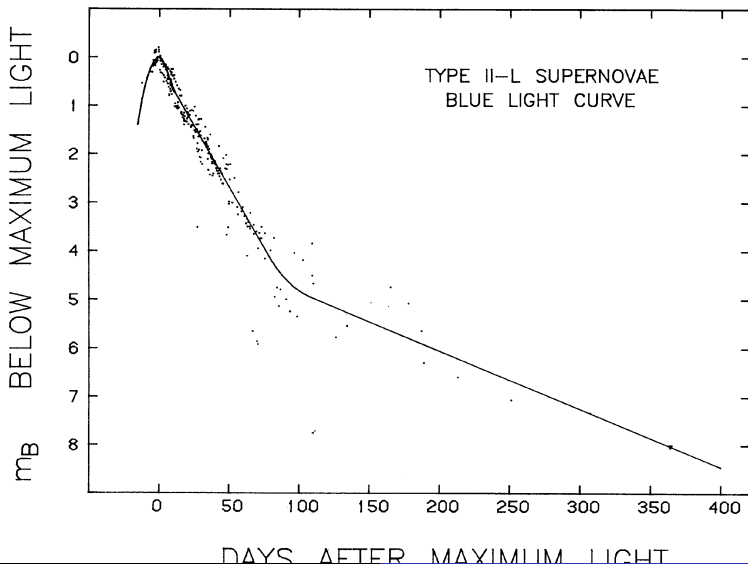
Supernovae Light Curve



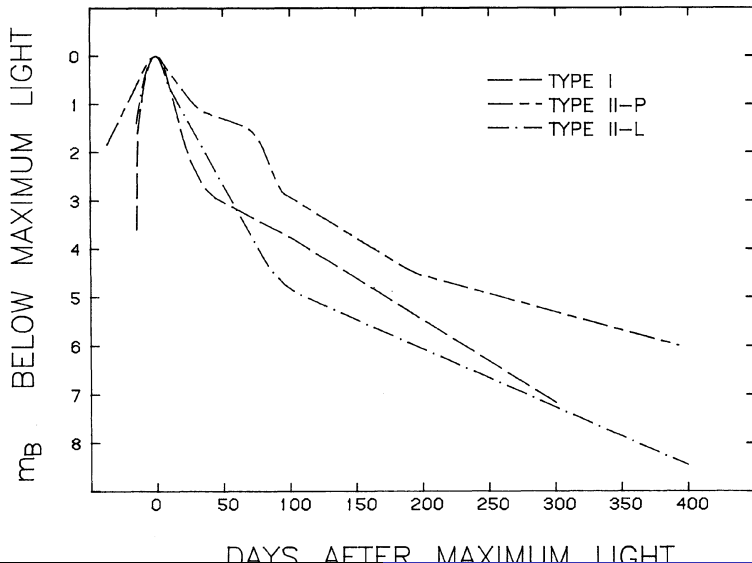
Supernovae Light Curve



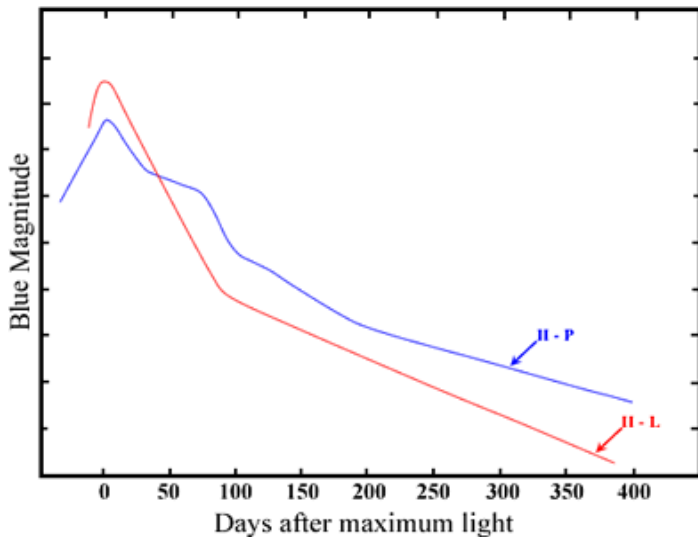
Supernovae Light Curve



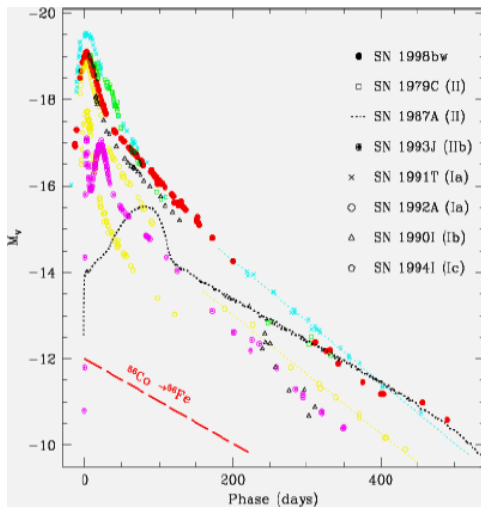
Supernovae Light Curve



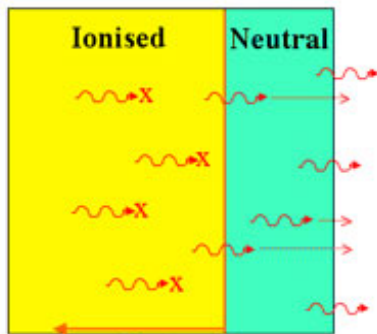
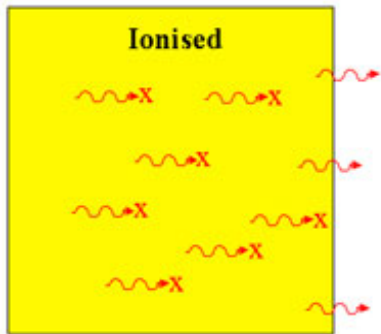
Supernovae Light Curve



Supernovae Light Curve

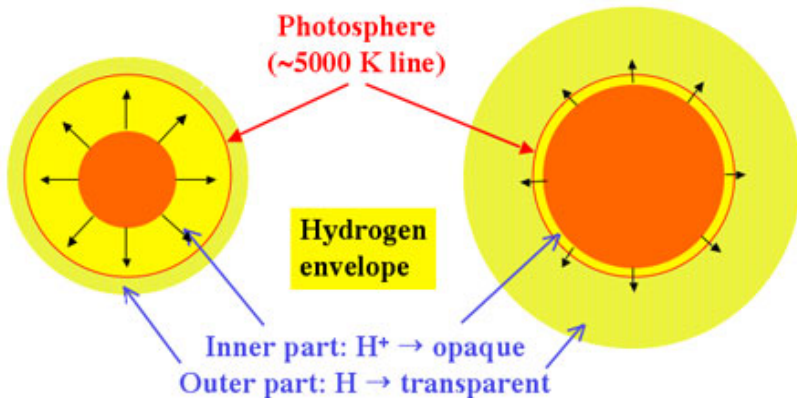


Escape of photons from photosphere

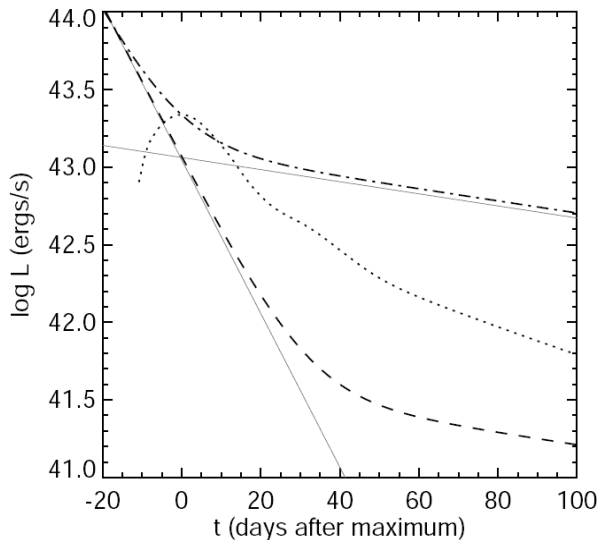


**Photosphere
at ~5000K**

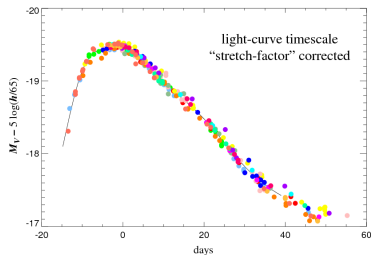
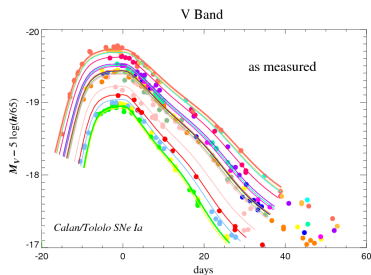
Retreat of Photosphere during SN Expansion



Type Ia Supernovae and Radioactivity



Type Ia Supernovae Lightcurve Fitting



Supernovae Light Curve - SN 1987A

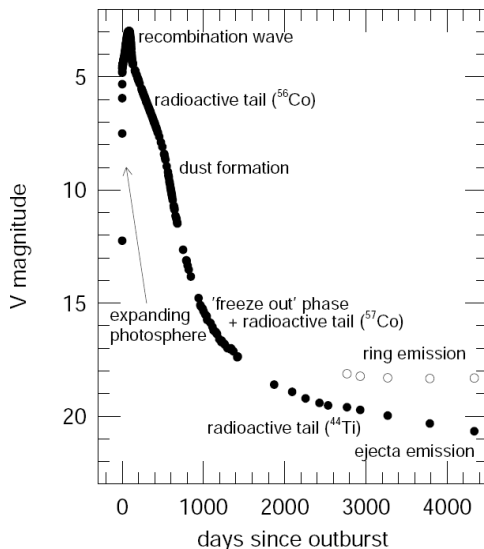
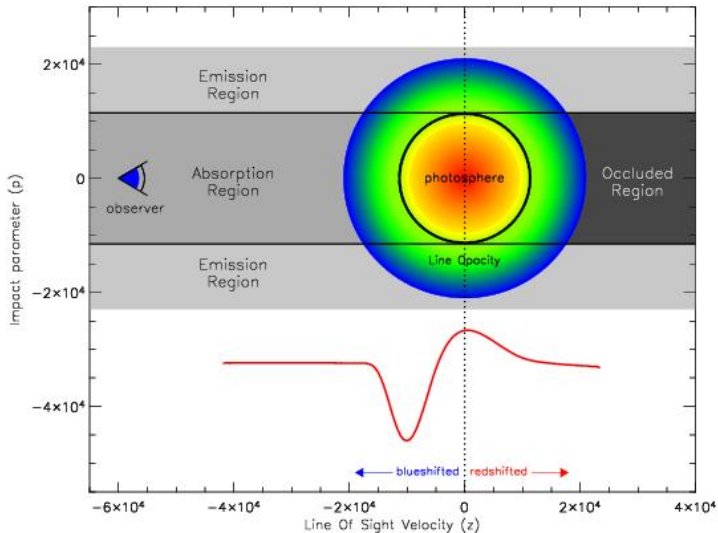


Fig. 1. V light curve of SN1987A. The emission lines are labeled.

Supernovae Light Curve - P-Cygni Profile Formation



Supernovae Light Curve - Composition and Spectra

