

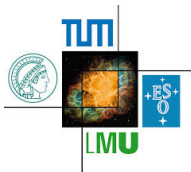
Type Ia Supernova Progenitors and Models

(and a Bit On How Models Compare With Nature)

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Research Area G Science Day
Thursday, July 9th, 2015



SN Ia
Progenitors

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What are Type Ia
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Progenitor Models

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Explosion
Mechanism
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- Progenitor Models

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What are Type Ia Supernovae?

- Transient events. Occur both in young and in old stellar environments.
- Light-curve is powered by radioactive decay

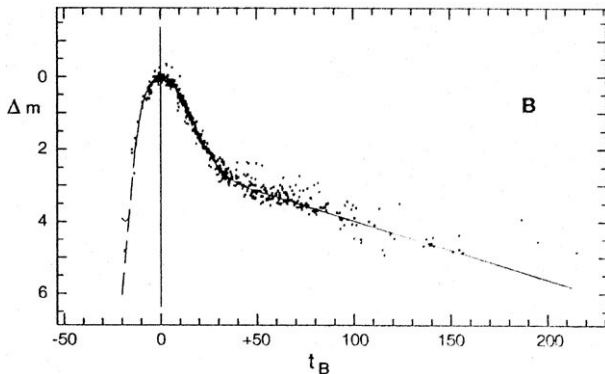


Figure : The standard B light curve (adapted from Cadonau 1987), based on observations of 22 SNe Ia (Branch & Tamman 1992 ARAA, 30, 359).



Type Ia Supernova Spectra

- A large fraction of SNe Ia follow a stretch-luminosity relationship (Phillips 1993).
- These events can be standardized and used as standard candles for measurements on cosmic distance scales.

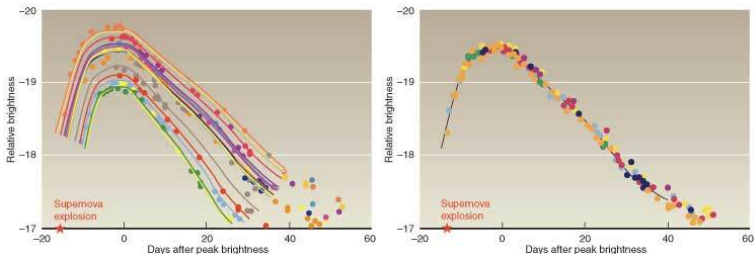
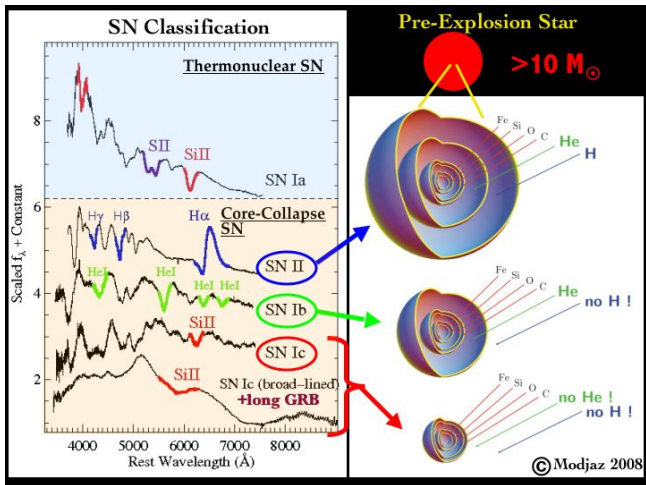


Figure : SNe Ia from the Calan/Tololo sample seen both as observed (left) and as corrected according to the stretch-luminosity relation.

Type Ia Supernova Spectral Classification

- Spectroscopically classified based on the lack of H and the presence of strong Si II lines.



What are Type Ia Supernovae?



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- Based on the light curve behavior and the elements present in their spectra, conventional wisdom is that SNe Ia are thermonuclear explosions of carbon-oxygen (CO) white dwarfs (WDs).
- SN 2011fe: The radius of the exploding star was consistent with that of a CO WD (Nugent et al. 2011, Nature, 480 344; Bloom et al. 2012, ApJ, 744, L17).

What are Type Ia Supernovae?



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- But theory predicts that a WDs are stable, so why should a CO WD explode as a SN Ia?
- A number of models have been proposed in an attempt to explain how to make a CO WD explode.

The Single-Degenerate (SD) Model

- A WD in a close binary system with a non-degenerate star. Accretion of material via Roche-lobe overflow, stellar wind accretion, etc.
- Pycnonuclear reactions close to the Chandrasekhar mass (M_{ch}).



Figure : An artist impression of a SD model (Credit: David A. Hardy/AstroArt.org)

The Double-Degenerate (SD) Model

- A close binary system of two WDs. Mass transfer via a merger event (angular momentum lost via gravitational wave emission).

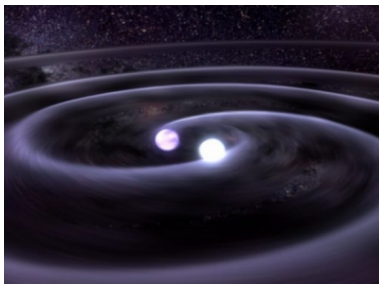


Figure : An artist impression of a DD model (Credit: GSFC/D. Berry)

- Mass transfer via Roche-lobe overflow is possible if the companion is a He WD.



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The Core-Degenerate (CD) Model

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- Merger of a CO WD and the core of an AGB star.
- Either prompt or delayed explosion.
- Are the rates high enough?

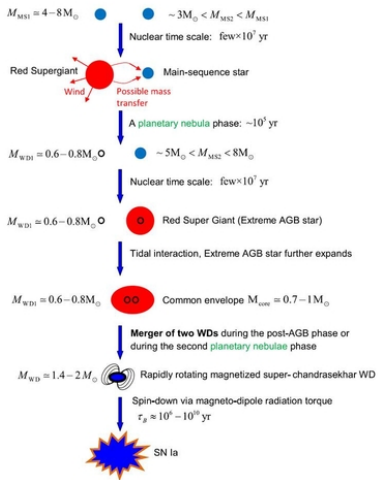


Figure : Taken from Ilkov & Soker 2011.

Head-on Collisions



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- Kozai Mechanism: A head-on collision of two WDs in a triple system (Kushnir et al. 2013 ApJ, 778L, 37).
- Collision releases enough energy to induce an explosion.
- **Are the rates high enough?**

Why is it Important to Know?



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- **Cosmology**: SNe Ia are used as standard candles to measure distances on a cosmic scale. A standardizing process is needed. Different progenitors might need a slightly different treatment.
- **Astrophysics**: Better understanding of the end-point of certain binary/multiple systems' evolution.

Telling the Models Apart



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- Models can differ by,
 - Explosion mechanism.
 - Circumstellar environment at time of explosion.
- Different progenitor models predict different observables. Comparing predicted observables with observations can allow us to constrain or even invalidate models.

Constraining the Explosion Mechanism



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- The prompt detonation model - A centered ignition of an outgoing detonation wave. Produces enough energy to unbind the WD, but presence of intermediate-mass elements in SN Ia spectra rules out this scenario as a way to produce normal SNe Ia.
- The deflagration model - A subsonic burning. Possible to produce enough energy to unbind the WD but hard to produce enough ^{56}Ni . Maybe explains lower luminosity events?
- The detonation-deflagration model - Seem to work. Produce the required intermediate-mass elements. Produces enough ^{56}Ni

Constraining the Explosion Mechanism

- Double Detonation - Sub-Chandrasekhar explosions.

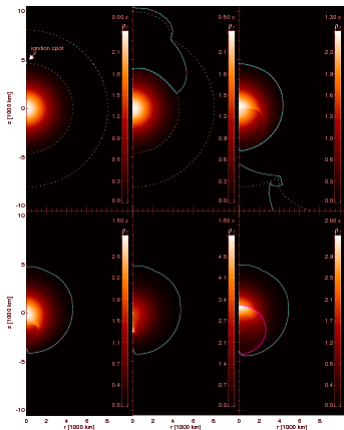


Figure : A double detonation of a sub-Chandrasekhar WD using a helium shell of $0.084M_{\odot}$ on top of a $0.92M_{\odot}$ CO WD (Fink et al. 2010).

Constraining the Explosion Mechanism

- Head-on Collision - Seems to work, but due to the high asymmetry there are viewing angle effects. **Question of rates.**

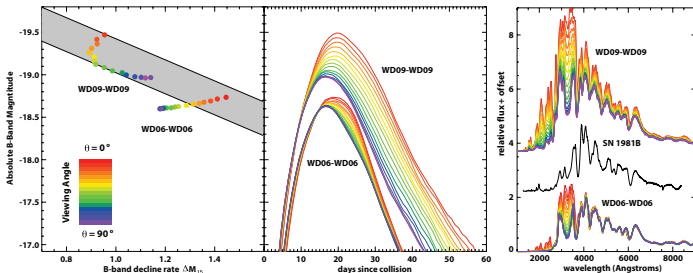


Figure : Spectra, light curves, and B-band maximum magnitude vs. B-band decline rate for tow head-on collisions taking viewing angle into account. Taken from Rosswog et al. 2009.

High-Velocity Features

TUM
LMU

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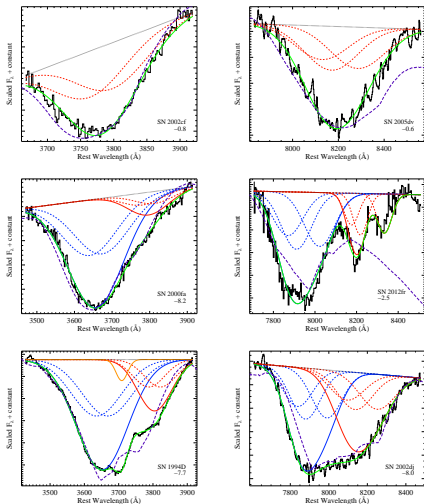


Figure : Gaussian fits of HVF (blue), PVF (red) and Si II $\lambda 3858$ (orange).
taken from Silverman et al. arXiv:1502.07278v2.

Strong Interaction with CSM



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- Silverman et al. (2013) claim to find a rare sub-class of SNe Ia that exhibit strong H features. Some events were initially classified as SN IIn.
- H-rich CSM around at least a small sub-set of SNe Ia.
- **Not representative of normal SNe Ia.**

Single-Epoch High-Resolution Spectra

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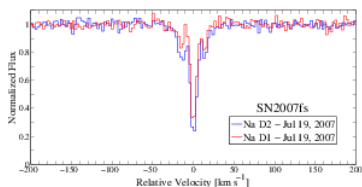
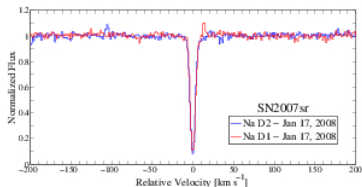
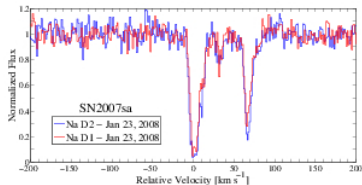
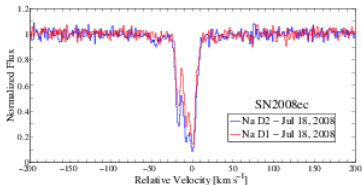
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(Sternberg et al. 2011 Science 333, 856)

Single-Epoch High-Resolution Spectra



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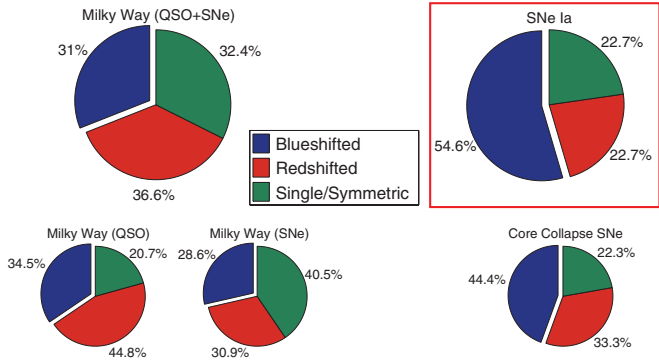
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Sample	Blueshifted	Redshifted	Single/Symmetric	Total
SNe Ia	12 [16]	5 [6]	5 [6]	22 [28]
CC SNe	4 [8]	3 [5]	2 [3]	9 [16]
MW (SNe)	12 [13]	13 [16]	17 [22]	42 [51]
MW (QSO)	10	13	6	29
MW (QSO+SNe)	22 [23]	26 [29]	23 [28]	71 [80]



(Sternberg et al. 2011 Science 333, 856)

CSM or ISM?

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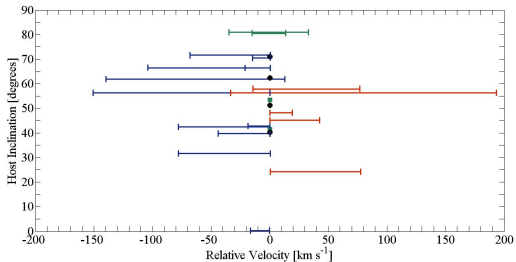
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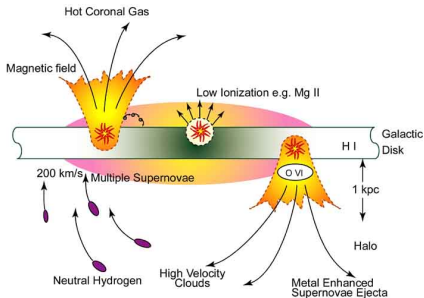
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(Sternberg et al. 2011 Science 333, 856)



Circumstellar Material (CSM) Signature

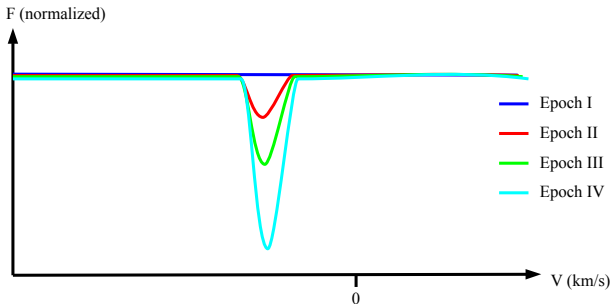
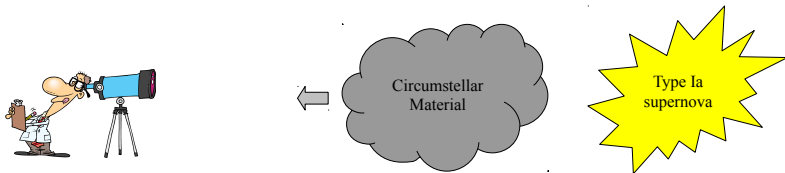
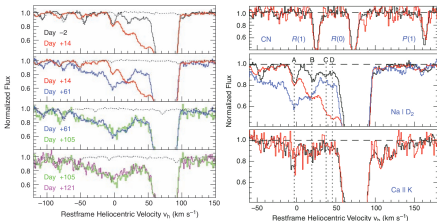


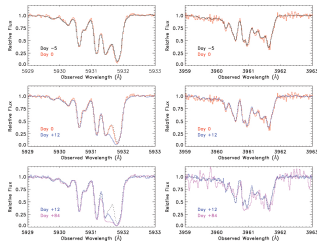
Figure : Time-variable absorption features due to ionization-recombination of CSM by the SN Ia UV radiation.

SN 2006X



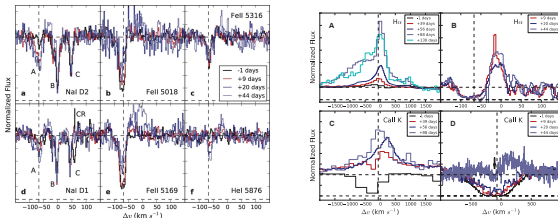
(Patat et al. 2007 Science 317, 924)

SN 2007le



(Simon et al. 2009 ApJ 702, 1157)

PTF 11kx



(Dilday et al. 2009 Science 337, 942)

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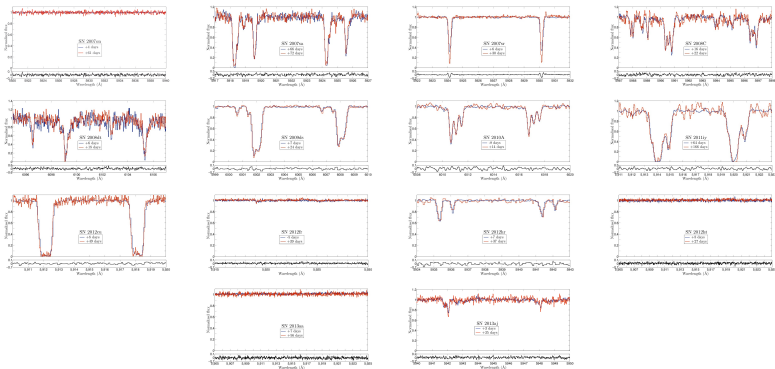
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(Sternberg et al. 2014, MNRAS, 443, 1849)

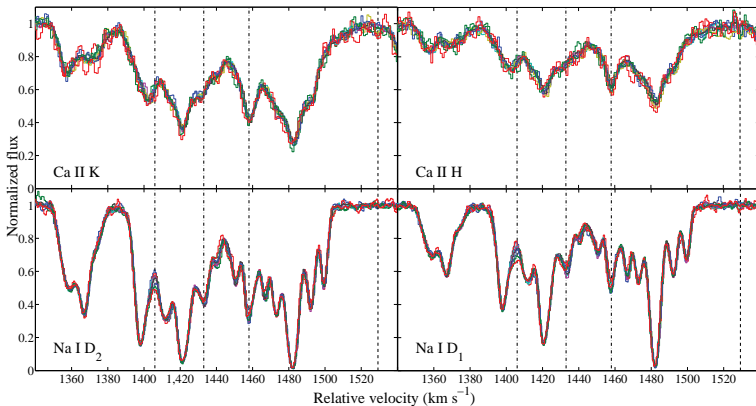


Figure : ASASSN-14lp Multi-epoch high-resolution spectra showing the Ca II H & K and Na I D_{1,2} regions (Sternberg et al., in preparation).

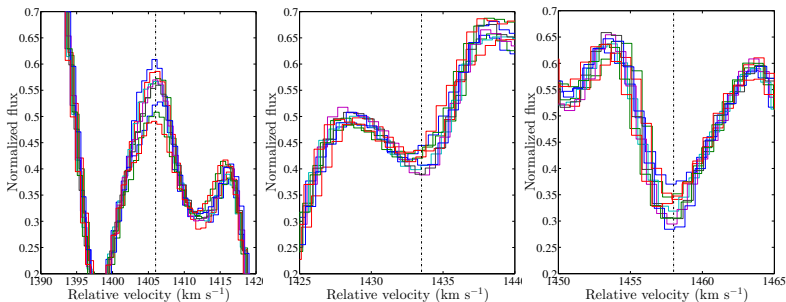


Figure : A zoom-in of the time variable features observed in ASASSN-14lp (Sternberg et al., in preparation).

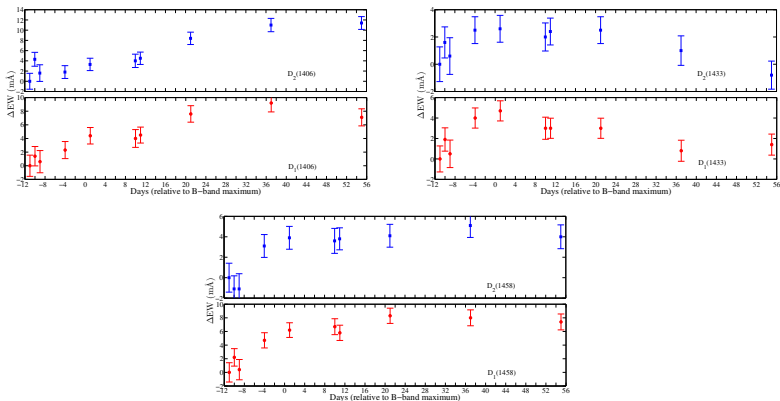


Figure : ΔEW , in mÅ, as a function of days relative to B-band maximum. Blue squares represent values for the D_2 features and red circles for the D_1 (Sternberg et al., in preparation).

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- Spectra + light curves = CO WD.
- Four main progenitor types (SD, DD, CD, and HoC)
- IME + IGE = constraints on explosion mechanism.
- High-Velocity features → H-rich CSM? He detonations?
- Time-variable CSM signatures → SD? DD? Something else?



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*Thank you for your
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