Progenitors of type Ia supernovae

Rubina Kotak
Queen’s University Belfast
Outline:

• Introduction
  -- Observational facts
  -- Uncertainties + clues + tests

• Current (observational) status on SN Ia progenitors
  -- Surveys and collection of oddballs

• Conclusions / outlook
What do we know?

• Occur in both old and young populations

=> binary

• thermonuclear combustion of a C-O white dwarf

~$1.5 \times 10^{51}$ ergs released

-- produce Fe-group + intermediate mass elements (Si, S, P, Ar, Ca etc.)

• Lightcurve powered by decay of $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$
What do we think we know?

Explosion of a CO white dwarf that has grown to the Chandrasekhar mass by accreting matter from its companion

Thermonuclear explosion is probably some combination of deflagration and detonation and propagates inside-out.

(homogeneity of lightcurves/spectra)
The impressive homogeneity of SNe Ia

e.g. Kotak et al. 2005
What we know we don’t know

Why do we see a variation in type Ia behaviour?
Diversity in SNe Ia light curves

Type Ia SNe are not standard candles.

Large dispersion in peak magnitude

Excellent relative distance indicators

e.g. Kim et al. (2001)
Spectroscopic diversity of nearby SNe Ia
(“all SNe Ia are normal, but some are more normal than others”)

36±9% peculiarity rate for nearby SNe Ia

(Li et al. 2001)
What we know we don’t know?

• **Explosion physics:**
  deflagration/delayed detonation
  location of ignition point(s), turbulent flame speed …
  peak brightness 2.5mag <-> range in 56Ni

• **Nature of progenitor system:**
  single/double degenerate?
  Sub/super or Chandrasekhar mass?
  Role of (differential) rotation + magnetic fields

• **Influence of the environment:**
  metallicity, host galaxy population…

• **How peculiar objects fit into a general framework**

> All of the above as a function of redshift
What we don’t know, we don’t know:
Supernova Taxonomy
(optical spectroscopy)

No Hydrogen
SN I
Strong Si / weak Si
Thermonuclear

Hydrogen
SN II

Explosion of an accreting white dwarf

IIa Narrow emission lines due to interaction with circumstellar medium

Ia
Ic
Ib
IIb
IIP
III

Outer layers lost
Ic: H, He lost
Ib: H lost

Light curve shape

Core-collapse
Recipes for making type Ia SNe:

I The single-degenerate scenario:

One white dwarf + red giant

or main sequence star

or sub-giant/dwarf

or ... 

Veritable zoo of configurations possible:

WD+MS (F,G,K,M), WD+RG (symbiotics), SSXS (U Sco),

CVs (DNe, RNe [U Sco, RS Ophi], VY Scl, V Sge, ...)

~1.37 Msun -- and growing! (next talk)
II Double-degenerate scenario

1 CO white dwarf + 1 CO white dwarf (/ subdwarf) > Mch

Merge within a Hubble time by emitting gravitational radiation

But, outcome of merger uncertain:

Type Ia or

accretion-induced collapse

Systematic search of ~1000 WDs detected = 1 > Mch (Napiwotzki et al. SPY project)

1 (WD + sdB) with \( M_{\text{tot}} = 1.47 \text{ Msun} / P = 2.3 \text{ hrs} \) (Maxted et al. 2000)
Summary of direct observational signatures

Explosions:

- Line profiles and abundances -- esp. at late times
Deflagration

Nomoto et al. (1984)

delayed-detonation

e.g. Hoeflich et al. (2002)
Supernova "tomography"

e.g. Stanishev et al. 2007 / European Supernova Collaboration
Summary of direct observational signatures

Explosions:

- Line profiles and abundances -- esp. at late times

- Near-mid-IR spectroscopy
**SN 2005df:**
the first ever detection of a type Ia in the mid-IR!

Different velocity widths

⇒ layering

See $^{58}\text{Ni}$

⇒ $e^-$ capture

Double-peaked Ar profiles

⇒ asymmetry

Gerardy et al. (2007) + Mid-IR SN Collaboration
Summary of direct observational signatures

Explosions:

- Line profiles and abundances -- esp. at late times
- Near-mid-IR spectroscopy
- Spectropolarimetry
Spectropolarimetry: the shape of SN ejecta

- Outer layers asymmetric →
  Intrinsic magnitude and colour dispersions
- Support for delayed-detonation models

Wang et al. (2007)
Summary of direct observational signatures

Progenitors:

- Xray/radio emission (circumstellar interaction)
- Signature of accreted material (hydrogen / helium)
- Surviving companion (galactic; single degenerate)
SN 2005ke: first detection of a Ia in X-Rays

05ke detected at 3σ level. Mdot ~ $3 \times 10^6$ Msun / yr ($v=10 \text{ km/s}$)

Swift sample: 1 in 8 SNe Ia

Radio emission from SNe Ia

No radio emission has ever been detected from a type Ia SN.

Panagia et al. (2006): over 2 decades of observations

From sample of 27 objects: limits

All: $\dot{M} < 10^6 \text{ Msun/yr}$

$\sim 50\% < 4 \times 10^{-7} \text{ Msun/yr}$

If assume 1 progenitor channel, $2\sigma$ upper limit < $2.6 \times 10^8 \text{ Msun/yr}$

"This severely limits the possibility that the progenitors are symbiotic systems, where the companion is a red giant or supergiant."
The quest for hydrogen

All single-degenerate scenarios predict the presence of hydrogen. Spectroscopic searches at high and low resolution, at early and late times have not revealed the presence of hydrogen in the vast majority of SNe Ia.

Cumming et al. (1996)
The case of SN 2002ic: a type Ia with hydrogen at 280 Mpc!

(Hamuy et al. 2003)
SN 2002ic c.f. ‘normal’ type Ia SN 1999ee

(Hamuy et al. 2003)
The Ha profile -- resolved

P Cygni profile
⇒ not an HII region
⇒ slow-moving outflow (100 km/s)
⇒ wind associated with the progenitor system

Kotak et al. (2004)
What is SN 2002ic?

- **Type 1.5a: single massive AGB star**  (Hamuy et al. 2003)

- **Double degenerate system**  (Livio & Riess 2003)

  Explosion occurs during or just after the CE phase.
  
  Merger of WD + core of AGB star
  
  Neatly explains rarity; timescale problems

- **Post-AGB star 100 km/s wind, dusty CSM**  (Kotak et al. 2004)

- **Nova-like variable**  (Wood-Vasey & Sokoloski 2006)

- **Variant of SSXS**  (Han & Podsiadlowski 2006)

- **Core-collapse supernova**  (Benetti et al. 2006)
SN 2003fg (aka SNLS-03D3bb) at $z=0.2440$:

explosion of a super-Chandrasekhar mass white dwarf?

before

after

$X_2$ brighter than median

$\Rightarrow 1.3$ Msun of $^{56}\text{Ni}$!!

(but see Hillebrandt et al. 2007)

Credit: P. Nugent; Howell et al. (2006)
Conclusions / Outlook

Bad news:

• **From radio limits:** circumstellar medium very tenuous for majority of events.

• **Most single-degenerate systems not ruled out.**

• **Lack of hydrogen (or helium) still a serious problem**

• **Double-degenerate channel not ruled out**

Good news:

• **Exciting prospects at new wavelengths, techniques, and larger sample sizes from new and ongoing surveys.**

• **Models rapidly improving (3D)**

  *(Even 1 galactic SN Ia would be rather useful)._
SN 2002cx: pure deflagration? A new class of SNe Ia?