Progenitors of Type Ia Supernovae in early type galaxies

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Type Ia Supernovae

- standard candles, important for cosmology (dark energy)
- thermonuclear explosion of a C-O white dwarf which mass reached the Chandrasekhar mass limit ($\approx 1.4 \, M_\odot$)
- exact nature of progenitors still unknown
- 2 scenarios:
  - merger of two white dwarfs
  - accretion onto the WD in a close binary system
Type Ia Supernovae

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- 2 scenarios:
  - merger of two white dwarfs
  - accretion onto the WD in a close binary system

<5-10%
Accretion scenario predicts:

• **too large** (soft) X-ray luminosity of E/S0 galaxies, **inconsistent** with Chandra observations

• **too frequent** Classical Novae explosions
Accretion scenario for SNe Ia progenitors

- initial white dwarf mass $\sim 0.7-1.2 \, M_\odot$
- Chandrasekhar mass limit $\approx 1.4 \, M_\odot$
- need to add $\approx 0.2-0.5 \, M_\odot$
- accretion of (hydrogen rich) material onto the WD
Energy release per one SNIa

- gravitational energy of accreted matter
  \[ \Delta E_{\text{grav}} = \int \frac{GM_{WD} \dot{M}(t)}{R_{WD}} \, dt = \int_{M_0}^{M_{\text{Ch}}} \frac{GM}{R(M)} \, dM \sim 4 \cdot 10^{50} \text{ erg} \]

- nuclear energy (hydrogen fusion on the WD surface)
  \[ \Delta E_{\text{nuc}} = \int \dot{M}(t) X_H \varepsilon_H \, dt = \Delta M X_H \varepsilon_H \sim 3 \cdot 10^{51} \text{ erg} \]

prior to the Supernova explosion
Combined luminosity of SNIa prog.

\[ L_{bol} \sim (\Delta E_{grav} + \Delta E_{nuc}) \times \nu_{SNIa} \sim 10^{41-42} \text{ erg/s} \]

To compare with observations:

- absorption
- bolometric corrections
- SED of accreting WDs
Accreting white dwarfs

- magnetized WD - polars etc
- hard optically thin emission with $kT \sim 10$ keV
- powered by gravitational energy of the accreted matter

- unstable nuclear burning
  - Classical Novae

- stable nuclear burning
  - Super-soft X-ray sources
  - powered by hydrogen fusion on the WD surface
  - $kT_{bb} \sim 10$-100 eV

- few $\times 10^{-8}$ $M_\odot$/yr
- accretion rate $\dot{M}_{\text{dot}}$
Accreting white dwarfs

- Magnetized WD - polars etc
- Hard optically thin emission with $kT \sim 10$ keV
- Powered by gravitational energy of the accreted matter

<1–5%

Stable nuclear burning
Super-soft X-ray sources
Powered by hydrogen fusion on the WD surface

$kT_{bb} \sim 10-100$ eV

$10^{-8} M_\odot/yr$ accretion rate $\dot{M}$

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Chandra-10, 23/09/2009
Accreting white dwarfs

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- Stable nuclear burning
  - Super-soft X-ray sources
  - Powered by hydrogen fusion on the WD surface
  - $kT_{bb}\sim 10-100\,\text{eV}$

- Accretion rate $\dot{M}$
  - $\sim 10^{-8}\,M_\odot/\text{yr}$
Accreting white dwarfs

- Classically Novae
  - Unstable nuclear burning
  - Powered by gravitational energy of the accreted matter
  - Hard optically thin emission with $kT \sim 10$ keV

- Super-soft X-ray sources
  - Stable nuclear burning
  - Hydrogen fusion on the WD surface
  - $kT_{bb} \sim 10^{-100}$ eV

Few $\times 10^{-8}$ $M_\odot/yr$

Compilation of super-soft sources from Greiner, 2000

Classical Novae sample of Warner et al.

Chandra-10, 23/09/2009
Super-soft X-ray sources

The combined luminosity of all SN Ia progenitors in the bulge of M31 predicted in the single degenerate scenario is consistent with X-ray observations.
Super-soft X-ray sources

combined luminosity of all SNIa progenitors in the bulge of M31 predicted in the single degenerate scenario consistent with X-ray observations

unstable hydrogen burning

compilation of super-soft sources from Greiner, 2000 and Di Stefano & Kong, 2003
Super-soft X-ray sources

combined luminosity of all SNIa progenitors in the bulge of M31 predicted in the single degenerate scenario

SSS contribution to observed SNIa rate <5–10 %
Classical Novae

• accreted matter is lost in CN events, **WD does not gain mass**
• independent CN frequency argument:

**in the accretion scenario**

CN rate ~ SN rate

\[
\Delta M_{CN} \dot{N}_{CN} \sim \Delta M_{SNIa} \dot{N}_{SNIa}
\]

\[
\Delta M_{CN} \sim 10^{-6} - 10^{-5} M_{\Theta}
\]

\[
\Delta M_{SNIa} \sim 0.3 - 0.5 M_{\Theta}
\]

based on Prialnik, Kovetz et al. observations: Arp; Capaccioli et al.

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Classical Novae

- accreted matter is lost in CN events, **WD does not gain mass**
- independent CN frequency argument:

in the accretion scenario

CN rate $\sim$ SN rate

CN contribution to observed SNIa rate

$<5–7\ %$

based on Prialnik, Kovetz et al.
observations: Arp; Capaccioli et al.
Very high Mdot regime

- common envelope configuration
- optically thick wind (Hachisu et al.)
- low photospheric temperature – optical, UV band

- low mass accumulation efficiency
- may work only with massive donor star i.e. in young galaxies
Contribution of accreting WD to SNIa rate in early type galaxies

- Magnetized WD - polars etc
  - Hard optically thin emission with $kT \sim 10$ keV
  - Powered by gravitational energy of the accreted matter

- Unstable nuclear burning
  - Classical Novae

- Stable nuclear burning
  - Super-soft X-ray sources
  - Powered by hydrogen fusion on the WD surface

- Few $\times 10^{-8} \, M_\odot/yr$

- Accretion rate $\dot{M}$

- $< 1-5\%$

- $< 5-7\%$

- $< 5-10\%$

- Optically thick wind or common envelope configuration
Conclusion

• accreting WDs in binary systems can only account for <5-10 % of SNe Ia in early type galaxies

• accretion scenario predicts too large X-ray luminosity of SNe Ia progenitors and too high frequency of Classical Novae, inconsistent with observations of nearby galaxies

• unless our understanding of accretion and nuclear burning on the WD surface are fundamentally flawed

• this applies to early type galaxies (delayed SNe Ia); SNIa in star-forming galaxies (prompt SNe Ia) may be different
Thank you!
Two populations of SNIa

- **prompt**
  - $t < 100$ Myr
  - young stellar environment
  - disks of spiral galaxies

- **delayed**
  - $t \sim$ few Gyrs
  - old stellar environment
  - elliptical galaxies
  - bulges of spirals
Why elliptical galaxies?

in young galaxies:

• enhanced absorption by gas and dust
• massive donor stars in ellipticals maximal $M_{\text{donor}} \approx 1 \, M_{\odot}$
• configurations with low mass accumulation efficiency are possible:
  – accretion from wind
  – high Mdot regime with optically thick wind
WD color temperature

$$T_{WD} \approx \left( \frac{\varepsilon_H X_H \dot{M}}{4\pi R_{WD}^2 \sigma_{SB}} \right)^{1/4}$$

WD mass-radius relation from Panei et al., 2000
WD color temperature

\[ T_{WD} \approx \left( \frac{\varepsilon_H X_H \dot{M}}{4\pi R_{WD}^2 \sigma_{SB}} \right)^{1/4} \]

compilation of super-soft sources from Greiner, 2000 and Di Stefano & Kong, 2003

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Two populations of SNIa

SNe Ia in star-forming environment tend to be:

• more frequent
• brighter
• more uniform in their parameters (as may be expected in the accretion scenario)
(at least) Two types of SNe Ia

Howell, 2001