Simulations of Type Ia Supernova Explosions

Rüdiger Pakmor
Heidelberg Institute for Theoretical Studies

October 25th, 2012
In collaboration with

× M. Kromer, S. Taubenberger, A. Ruiter, W. Hillebrandt (MPA Garching)
× F. Röpke, M. Fink, I. Seitenzahl, S. Hachinger (Würzburg)
× S. Sim (ANU Canberra)
Outline

✓ Observational constraints on SNe Ia
✓ First principle explosion models
✓ Violent mergers in detail
Supernova spectra

Fillipenko 1997
Type Ia Supernovae

✗ No Hydrogen/Helium
✗ Produce C/O/Si/Ni...
✗ About 0.1-1.0 $M_\odot$ $^{56}\text{Ni} > (6\text{d}) \ ^{56}\text{Co} > (77\text{d}) \ ^{56}\text{Fe}$
✗ No compact remnant
✗ About a solar mass of ejecta
✗ Also old stellar systems

=> Thermonuclear explosion of CO-WD in binary system
The Problem

✗ What is the nature of the companion star?

✗ What causes the explosion?
Progenitor systems

Main sequence, red giant or He WD companion

stable accretion of H or He

CO WD or He WD Companion

Disruptive merger
Modelling a SN Ia

- Progenitor system
- 3D Hydrodynamics explosion model including nuclear burning
- Detailed nucleosynthesis
- Radiative transfer
- Comparison with observations
Explosions I: Chandrasekhar-mass

- H-rich accretion
- WD grows to $M_{Ch}$
- Ignition of deflagration
- Delayed detonation

Roepke et al. 2011
Delayed detonations

✗ Good agreement for spectra and lightcurves
✗ Details of ignition unknown
✗ Rates: possibly not enough systems
✗ No pre-explosion detections
✗ No sign (of interaction with) companion star
✗ No first parameter for brightness variations
✗ But: CSM interactions for some SNe Ia
Explosions II: $M_{Ch}$ pure deflagrations

- Pure deflagration
- Bound WD remnant
- $0.4M_\odot$ mixed ejecta

Kromer et al. 2012
Explosions II: $\text{M}_{\text{Ch}}$ pure deflagrations

× Good agreement for spectra and lightcurves with subclass of 02cx-like objects
× Relative rates of model viable

05hk (black) vs. model (red)
Explosions III: Double detonations

- He accretion on sub-Chandra CO WD
- He-shell accumulates and detonates
- CO-detonation follows
- Natural explanation of brightness range
- Problems with ashes of He-shell

Fink et al. 2008, 2010
Explosions IV: Violent WD mergers

Pakmor et al. 2012
Explosions IV: Violent WD mergers

Pakmor et al. 2012
Explosions IV: Violent WD mergers
Explosions IV: Violent WD mergers

SN 2003du, model

Pakmor et al. 2012
Explosions IV: Violent WD mergers

✗ Good agreement for spectra and lightcurves
✗ Details of ignition unknown
✗ Brightness given by mass of primary WD
✗ Rates?
✗ Ages?
White Dwarf mergers: Rates

Ruiter et al. 2012
White Dwarf mergers: Brightnesses

Ruiter et al. 2012
Summary

✗ We can now simulate SNe Ia in 3D from progenitors to observables!
✗ Probably different explosion scenarios realised in nature
✗ Mergers of two white dwarfs are a good candidate for bulk of normal SNe Ias
✗ Merger scenario still rather unexplored