Figure 3. Visualization of the delayed detonation simulation at the onset of the detonation phase: yellow/orange is the density of the exploding WD star. See also the animation available from stackswiopworg/NJP/zyxzfi5yy9xm/media.

Deflagration flame only: the patch where it first enters the distributed burning regime. The subsequent snapshots show how the detonation wave propagates and wraps around the ash structure from the deflagration phase. It burns out the funnels of fuel in between the ash bubbles and therefore leads to a more homogeneous composition of the supernova ejecta than the deflagration model discussed above.

Simulations such as presented here allow us to study whether delayed detonation scenarios are capable of producing models in better agreement with SN Ia observations. In fact, by assuming that the ignition of the initial deflagration is a stochastic process which may sometimes...
Some Questions
Type Ia supernovae

Progenitors
- Accretors
- and/or
- Mergers

Explosions
- Deflagration
- Detonation

White dwarf mass

OMG, if you keep accreting cat biscuits at that rate you’re going to reach the Chandrasekhar limit soon!
Type Ib/c supernovae

Progenitors
loss of envelope
single WR star
and/or binary star

Explosions
Core mass
Jets?

[Image of space galaxy]
[Image of question mark]
[Image of blue and yellow object]
Surviving Companions of Supernovae

Surviving Companion

Supernova

Pakmor et al. 2008

Wolfgang Kerzendorf
(ESO Fellow)
6th of June 2015
Chania - Greece

Surviving Companions of Supernovae
Impact Studies

http://goo.gl/snW5SL
blue = 160 g / cm$^3$
red = $10^{-13}$ g / cm$^3$

Main Sequence Star

t=29s

Marietta et al. 2000
Main Sequence Star

$t=104s$
Fig. 3. from Type Ia Supernova Explosions in Binary Systems: The Impact on the Secondary Star and Its Consequences


http://dx.doi.org/10.1086/313392

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Marietta et al. 2000

Main Sequence Star

Shock in stellar core

Bow Shock

t=329s

Marietta et al. 2000
Figure 4. from Type Ia Supernova Explosions in Binary Systems: The Impact on the Secondary Star and Its Consequences


http://dx.doi.org/10.1086/313392

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Figure 15. from Is There a Hidden Hole in Type Ia Supernova Remnants?


http://dx.doi.org/10.1088/0004-637X/745/1/75

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Fig. 4. from Type Ia Supernova Explosions in Binary Systems: The Impact on the Secondary Star and Its Consequences


http://dx.doi.org/10.1086/313392

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$t=2033\text{s}$
Distinguishing Survivors
Unusual Velocity
3.1 Dependence on kick direction

The plot was calculated for the same initial parameters, in particular the pre-SN orbital separation, the mass of the exploding star, and the kick imparted on the NS. The white area in the figure corresponds to cases where the newborn NS is shot into retrograde directions (companion star and the system is assumed to merge). For highly increasing values of the kick angle, hence the white area at the top of the plot (the shape of which depends on pre-SN parameters, in particular the pre-SN orbital separation, the mass of the exploding star, and the kick imparted on the NS. The white area in the figure corresponds to cases where the newborn NS is shot into retrograde directions (companion star and the system is assumed to merge). For highly increasing values of the kick angle, hence the white area at the top of the plot (the shape of which depends on pre-SN parameters, in particular the pre-SN orbital separation, the mass of the exploding star, and the kick imparted on the NS.

3.2 Dependence on pre-SN parameters

This effect is demonstrated in Fig. 5. The value of the kick angle, \( \theta \), and the mass of the exploding star, \( M_{\text{He}} \), also depends on the explosion energy, \( E \), and the rotational velocity (typically of the order of \( \sim 1000 \) km s\(^{-1}\)). While the kick angle \( \theta \) is quite sensitive to the explosion energy, \( E \), the Galactic rotational velocity \( \omega_{\text{Gal}} \) is less important for the HVSs high in the halo and significantly lower value compared to the late-type B-stars. For example, using a constant value of 550 km s\(^{-1}\), the Galactic rotational velocity would be irrelevant for the HVSs.

Finally, we have investigated disrupted binaries with early-type B-star companions (He cores) and mass of the exploding star, \( M_{\text{He}} \), in order to obtain an isotropic kick vector. While the kick angle \( \theta \) also depends on this parameter, it is possible for a late-type B-star (He core) companions (massive B-star) to obtain an isotropic kick vector. While the kick angle \( \theta \) also depends on this parameter, it is possible for a late-type B-star (He core) companions (massive B-star) to obtain an isotropic kick vector.

The blue and red lines represent the uncertainties \( \sim 1 \) km/s and \( \sim 20 \) km/s, respectively. The uncertainties are due to the measurement errors and the propagation of uncertainties in the kinematical parameters. The uncertainties in the radial velocity are due to the measurement errors, while the uncertainties in the proper motion are due to the propagation of uncertainties in the position and the velocity. The uncertainties in the distance are due to the propagation of uncertainties in the proper motion and the position. The uncertainties in the location are due to the propagation of uncertainties in the radial velocity, the proper motion, and the distance.

Sun like star @ 3kpc with HST \( \sim 10 \) years uncertainties ~ 1 km/s uncertainties ~ 20 km/s uncertainties ~ 1 km/s uncertainties ~ 20 km/s

Taurus 2015

95 %
Unusual Rotation
White Dwarf

Donor Star

spatial velocity

rotational velocity

White Dwarf

Kerzendorf+ 09
Unusual Rotation

Sun

log(g)

4.5

4.0

3.5

vrot [km/s]

60 80 100 120 140 160

68 %

95 %

Han 2008
However ...

\[ y = k \cdot x + b \]
\[ k = 0.52 \]
\[ b = -29.8 \]
Unusual Brightness
Shappee et al. 2013

Luminosity (L\textsubscript{sun})

Time (years)

100 L\textsubscript{sun}

500 years

see also
Marietta et al. 2000
Podsiadlowski 2003
Pan et al.
Liu et al.
and others

Shappee et al. 2013
Searching for survivors
Tycho’s remnant
A good example

Ruiz-Lapuente et al. 2004
Gonzalez-Hernandez et al. 2009
Kerzendorf et al. 2009
Kerzendorf et al. 2014
Bedin et al. 2014
Identify candidates
The Candidates

30 arcsecond roughly 1000 km/s

X-ray-center (Warren+ 05)
~600 km/s
20''

Ruiz-Lapuente+ 2004
see also Bedin et al. 2014
Spectroscopic modeling

Munari Grid

\[ P(T_{\text{eff}}, \log g, [M/H], \nu_{\text{rot}}, \nu_{\text{rad}}, A_V) \]

Photometry

Spectroscopy

StarKit - starkit.readthedocs.org
Tycho B
Tycho B

- A-Star 10,000K
- \([Fe/H]\)~ -1
- \(v_{\text{rot}} = 170\) km/s
- low-res Observations
  - \(\Rightarrow \log(g) = 4.1\)

Kerzendorf+ 2013
Where is it?

Tycho-B

see also
Winkler et al. 2005
Ihara et al. 2007

SNR

HST GO-13432
PI Kerzendorf
preliminary!!!

---

Tycho B spectrum

Model absorption features

- [Fe/H] = 0.0
- [Fe/H] = -1.0
- [Fe/H] = -1.0 with absorption
Conclusion
Tycho’s Six

No unambiguously identifiable companion
Kerzendorf+ 2013

unusual kinematics
no rotation
off-center

unusual star
close to center
high rotation

normal kinematics
probably foreground

G

Kerzendorf+ 2013
Milky Way Remnants
Hunting Grounds

SN1006

Tycho (SN1572)

Don't count on it: Gonzalez-Hernandez+ 2012, Kerzendorf+ 2012

Kepler (SN1604)

Outlook not so good: Kerzendorf+ 2013b priv. comm. Ruiz-Lapuente
Hunting Grounds

•

Sun

Tycho (SN1572)
Magellanic Cloud Remnants
Magellanic clouds are perfect

- little extinction
- large distance
- known velocity & different from Milky Way
  - -> separate interlopers!
talk by L. Hovey later today

Schaefer & Pagnotta 2012
Edwards, Pagnotta & Schaefer 2012
Magellanic Cloud Supernova Remnant Companion Survey

Kerzendorf, van Kerkwijk and Badenes in prep.
The survey

• 22 remnants (regardless of type)

• 153 Companion Candidates of all stars L>100 Lsun!

• 484 Calibration Stars!

• 4 spectra each:
  • GMOS B600 & R400 (3500 - 9000 A)
  • R ~ 1000
The Type Ias
J0509.0-6844
(N103B)

See talk by Williams
See talk by J. Li later today
Summary
A futile search?

- Type Ia
  - don’t seem to have bright survivors (9 remnants)
  - or they hide well
  - double degenerate or alternate scenarios
- some unambiguous candidates
- just at the beginning
Some success
J0459.9-7008 Candidates

100 Lsun @ LMC
Given as a body model, the surface temperature and the emitting radius are famous for being one of the few thermal pulsars. Based on a black-cavity treated as a neutron star, the distance to the source should be consistent with each other. The most precisely measured distance is 1.2 kpc. Kramer et al. (2002) and the dispersion measure (DM) distance is 1.2 kpc (Kramer et al. 2007). Although it presents no evidence of a neutron star, the pulsar is observed to have a high proper motion.

The SNR is expanding in a low density medium, probably in the inter-cloud gas density of 0.03. The explosion energy is between 10^42 erg and the corresponding explosion timescale is 30 kyr (Humphreys & Clark 1986). For a distance of 1.3 kpc, and the central source, PSR J0538+2817, is an extensively studied pulsar with a period of 17 ms (Bell et al. 2000) and the dispersion measure (DM) distance is 1.2 kpc. The parallax distance was measured as 0.026 kpc (Kramer et al. 2002), and the kinematic age of 30 kyr (from the travel time from the GC to the present position) by using the NE2001 model of the Galaxy is 4.22 kyr.

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The fastest star in the Galaxy

Geier et al. 2015

Galactic Center

suggested origin of star
Extragalactic success stories to come

... from Schulyer

... after the break
Thank you