Reverse Engineering Supernovae

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The SN-SNR Connection

Supernovae (t < 14 months)

Intermediate-Aged Supernovae (2 < t < 100 yr)

Young Supernova Remnants (100 < t < 1000 yr)
The SN-SNR Connection

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Outer knots

NE Jet

Main Shell

SW Jet

~ 10,000 km/s
Movie available upon request
Ejecta Rings!

The main shell of Cas A’s optically-emitting ejecta as represented in a Mercator projection.

Rings → Bubbles? Blondin, Borkowski, Reynolds (2001)
Emission interior to Cas A’s main shell has been found.
Movie available upon request
Clues to the Explosion Mechanism

$^{56}$Ni Outflows → Bubbles → Rings

Carbon  Nickel  Oxygen

Cassiopeia A

Hammer, Janka, Müller (2010)

Optical X-ray Fe-rich (DeLaney et al. 2010)

Movie available upon request
Cas A has exceptionally high-velocity S-rich outflows
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Movie available upon request

2010
Cas A’s high velocity outflows are opposing

The NE and SW jets show a broad spattering of ejecta suggesting opposing flow in three dimensions with comparable conical opening angles approximately between 35 – 40 degrees.

Fesen et al. (2006)

Movie available upon request
Cas A has an older brother

Cassiopeia A

E0102

\(~330\) yr

\(~1000\) yr
The SN-SNR Connection

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(100 < t < 1000 yr)
Intermediate-Aged Supernovae
$(2 < t < 100 \text{ yr})$

Young Supernova Remnants
$(100 < t < 1000 \text{ yr})$

The SN-SNR Connection
Above we show an integrated spectrum of the young (330 yr), nearby (3.4 kpc) Galactic supernova remnant Cassiopeia A. The data are from an investigation of the remnant's three-dimensional kinematic structure (Milisavljevic & Fesen 2011, in prep). The spectrum mimics what the remnant would appear as as a distant unresolved point source like the supernovae studied here. Preferentially blueshifted emission with many minor emission peaks is observed.
SN 1980K
HST/WFPC2
F606W
2008 Jan 19

NGC 6946
D = 6.5 Mpc

SN 1980K
2010 Oct 09
t ~ 31 yr

Relative Flux
5000 5500 6000 6500 7000 7500
Ha
[O III] [O I] [Fe II] [Ar III] [O II]

Relative Flux + Constant
5000 5500 6000 6500 7000 7500
1995-11-28 2010-10-09

Wavelength [Angstroms]

Comparing the [O III] 4959, 5007 emission line profile of the integrated Cas A spectrum to supernovae aged +10 yr shows that preferentially blueshifted emission with multiple minor emission peaks are common. The origin of the emission peaks in Cassiopeia A is known to be due to its numerous rings/tori of emitting ejecta. This suggests that ring-structured ejecta may be common in a number of core-collapse supernovae.

Recent optical spectra of SN 1970G, SN 1980K, and SN 1993J obtained with the 2.4m Hiltner telescope at MDM Observatory and 6.5m MMT telescope are presented below. Also shown are archival Digitized Sky Survey and Hubble Space Telescope images covering the regions around the supernovae.

SN 1970G
HST/WFPC2
F606W
1998 Apr 21

SN 1970G
HST/WFPC2
F606W
1998 Apr 21

M 101
D = 7 Mpc

SN 1970G
2010 Mar 12
t ~ 40 yr

Relative Flux + Constant
Wavelength [Angstroms]

4500 5000 5500 6000 6500 7000 7500 8000

SN 1970G
(Enlarged and H II region lines removed)

Relative Flux
Wavelength [Angstroms]

5000 5500 6000 6500 7000 7500

Ha [O II] [O III] [O I]
Ultra-luminous SNR in NGC 4449

Bietenholz et al. (2010)

Milisavljevic & Fesen (2008)
The SN – SNR Connection

Large rings of ejecta like those observed in Cas A may be a common phenomenon of CCSNe.

Movie available upon request
The SN – SNR Connection

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The SN-SNR Connection

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(100 < t < 1000 yr)
SN 2012au – A “Golden” Link Super-luminous SN and Lower Luminosity Counterparts

Milisavljevic et al. (2013)

Au → Gold!
Type Ib

Type Ic

???
Two distinct regions, unusually dense oxygen
Conclusion:

The SN-SNR Connection is Important!
Thank You