High-resolution radio imaging of young supernovae

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SN1979C

- SN1979C in M100 (D= 16.1 Mpc)
- $t_{\text{explosion}} = \text{April 4, 1979}$
- $V_{\text{expansion}} = 9200$ km/s at around $t = 45$ days
- Type II SN-L
- Progenitor: binary system
- $M_{\text{progen}} \sim 17-18 \ M_{\text{sun}}$ (Van Dyk et al. 1999)
- Radio emission interpreted within the minishell model (Chevalier 1982)
Previous VLBI observations

- VLBI observations 5 years after the explosion (Bartel et al. 1985)
- Source structure was not resolved by VLBI
- Observations consistent with undecelerated expansion ($m = 1.0; R \sim t^m$) for the first 5 years!!
VLA radio measurements

(From Montes et al. 2000)

$\frac{dM}{dt} \sim 10^{-4} M_{\text{sun}}/\text{yr}$

Is flux increasing?
VLBI observations at 18 cm, ~20 yr after explosion

4 June 1999

(Marcaide et al. 2002)
Angular size of SN1979C

- Optically thick disk:
  4.57 +/- 0.25 mas

- Optically thin shell of width 0.3*R_out:
  3.60 +/- 0.17 mas

- Optically thin ring:
  3.10 +/- 0.14 mas

- Best model: Thin shell

1 mas @ 16.1 Mpc ~ 0.08 pc
Strong deceleration of SN1979C

\[ R \propto t^m; \quad m = 0.62^{+0.22}_{-0.17} \]

(from Marcaide et al. 2002)
\( t_{\text{break}} = 6 \pm 2 \text{ yr} \)

- Strong deceleration \( \rightarrow M_{\text{swept}} \geq M_{\text{env}} \)
- \( v_{\text{wind}} = 10 \text{ km/s} \)
- \( \frac{dM}{dt} = 1.2 \times 10^{-4} M_{\odot}/\text{yr} \)
- \( \rho_{\text{csm}} \sim r^{-s} ; s = 2 \)

- \( M_{\text{swept}} = 1.6 M_{\odot} \geq M_{\text{env}} \)
- \( M_{\text{env}} \leq 0.9 M_{\odot} \)
- Binary star scenario favoured

From VLBI observations taken 20 yrs after the explosion:

**SNI979C in a strong decelerated phase**
- \( m = 0.62 \) (strong interaction with CSM)
- \( t_{\text{break}} = 6 \pm 2 \text{ yr} \)
- \( M_{\text{swept}} = 1.6 M_{\odot} \)
- \( M_{\text{env}} = 0.9 M_{\odot} \)
- Binary star scenario favoured
SN1986J

- SN1986J in NGC891 (D \(\sim 9.6\) Mpc)
- Lumin @ 6 cm \(\sim 8^{*}\)SN1979C, \(~13^{*}\)SN1993J
- It probably exploded at the end of 1982
- MSM of progenitor \(\sim 20 - 30\) M\(_{\text{sun}}\)
- Type II supernova
- Strong mass loss: \(dM/dt \geq 2 \times 10^{-4}\) M\(_{\text{sun}}\)/yr
Previous VLBI observations of SN1986J

VLBI @ 3.6 cm in 1988.74
($t_{\text{exp}} \sim 5.7$ yr)

(Bartel et al. 1991)
NGC891 @ 6cm (VLA, Feb. 1999)

Nucleus

SN1986J with VLBI
Protrusions?

Explosion Center?

Beam = 1.3 x 0.9 mas

1 mas @ 9.6 Mpc ~ 0.05 pc
VLBI on SN1986J

- Mean angular size of ~ 4.7 mas ~ 0.22 pc => v ~ 6300 km/s between 1988.74 and 1999.14
- R ~t^m, m = 0.90 +/- 0.06 (very close to free expansion)
- Anisotropic brightness distribution: shell structure likely due to a collision with a clumpy, or filamentary, wind

- For a standard v_w= 10 km/s, SN1986J is sampling the CSM at time ~ 11000 yr; dM/dt ~ 2 x 10^{-4} M_{Sun}/yr => M_{swept} ~ 2.2 M_{Sun}
- Momentum conservation implies that M_{env} >= 12 M_{Sun}
- Single star scenario is favoured

If equipartition betw/ fields and particles, then B_{min} ~ 2-90 mG compression of B_{wind} not enough => turbulent amplification of B?
SN2001gd

NGC 5033

Prediscovery image

Image taken on 13 Jan 2002
SN2001gd: a SN1993J-like event

SN2001gd spectrum on 4 Dec 2001 (Matheson et al. 2001)

Comparison spectra SN2001gd/SN1993J (from Matheson et al. 2001)
First radio detection of SN2001gd

8 Feb 2002
\( t_{\text{exp}} \sim 150 \text{ days} \)

(from Stockdale et al. 2002)

\( L_{6 \text{ cm peak}} \sim 3 \times 10^{27} \text{ erg/s/Hz} \)
First VLBI detection of SN2001gd

VLBI @ 3.6 cm

26 June 2002
t_{\text{exp}} \sim 300 \text{ days}

Source structure unresolved

(Pérez-Torres et al., in preparation)
Angular estimates for SN2001gd

Optically thick source:
\[ a = 0.37 \pm 0.02 \text{ mas} \]
\[ b/a = 0.45 \pm 0.22 \]

Optically thin sphere:
\[ 0.39 \pm 0.01 \text{ mas} \]

Optically thin ellipsoid:
\[ a = 0.41 \pm 0.02 \text{ mas} \]
\[ b/a = 0.45 \pm 0.21 \]

Distance

<table>
<thead>
<tr>
<th>(Mpc)</th>
<th>Inferred velocities (1000 km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.5</td>
<td>14.4 -- 16.3</td>
</tr>
<tr>
<td>21.6</td>
<td>23 -- 26</td>
</tr>
</tbody>
</table>

Beam = 1.23 \times 0.51 \text{ mas}

1 \text{ mas} @ 21.6 \text{ Mpc} \sim 0.11 \text{ pc}
## Summary

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Distance (Mpc)</td>
<td>16.1</td>
<td>9.6</td>
<td>21.6</td>
<td>3.63</td>
</tr>
<tr>
<td>Time since explosion (yr)</td>
<td>20.1</td>
<td>~16</td>
<td>&lt;1</td>
<td>8.6</td>
</tr>
<tr>
<td>(\frac{L_{\text{6cm}}}{L_{\text{6cm SN1993J}}^{\text{peak}}})</td>
<td>~1.6</td>
<td>~13</td>
<td>~2</td>
<td>1</td>
</tr>
<tr>
<td>Resolved by VLBI?</td>
<td>Not yet</td>
<td>Yes</td>
<td>Not yet</td>
<td>Yes</td>
</tr>
<tr>
<td>Optically thin phase?</td>
<td>Yes</td>
<td>Yes</td>
<td>Likely yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Radio brightness structure</td>
<td>shell</td>
<td>distorted shell</td>
<td>---</td>
<td>~smooth shell</td>
</tr>
<tr>
<td>(\frac{dM}{dt}) / ((M_{\odot})/yr)</td>
<td>~10^{-4}</td>
<td>~2 x 10^{-4}</td>
<td>?</td>
<td>~5 x 10^{-5}</td>
</tr>
<tr>
<td>Deceleration parameter (m)</td>
<td>0.62</td>
<td>0.90</td>
<td>1.0?</td>
<td>~0.83</td>
</tr>
<tr>
<td>Asymmetric expansion?</td>
<td>No</td>
<td>Yes</td>
<td>?</td>
<td>No (&lt;5%)</td>
</tr>
<tr>
<td>Circumstellar medium</td>
<td>---</td>
<td>clumpy</td>
<td>?</td>
<td>~smooth</td>
</tr>
<tr>
<td>(M_{\text{swept}} / M_{\odot})</td>
<td>1.6</td>
<td>2.2</td>
<td>?</td>
<td>~0.4</td>
</tr>
<tr>
<td>(M_{\text{env}} / M_{\odot})</td>
<td>0.9</td>
<td>12</td>
<td>?</td>
<td>~0.2-0.4</td>
</tr>
<tr>
<td>Explosion scenario</td>
<td>Binary</td>
<td>Single</td>
<td>?</td>
<td>Binary</td>
</tr>
<tr>
<td>Magnetic field amplification</td>
<td>Turbulent</td>
<td>Turbulent</td>
<td>?</td>
<td>Turbulent</td>
</tr>
<tr>
<td>(t_{\text{break}}) (years)</td>
<td>6 +/- 2</td>
<td>----</td>
<td>----</td>
<td>~1</td>
</tr>
</tbody>
</table>
VLBI data and superimposed model of an optically thin shell of angular diameter 4.7 mas
Magnetic Field in SN1986J

- If equipartition between fields and particles
- \( E_{\text{min}} \sim (2-90) \times 10^{48} \text{ erg} \)
- \( B_{\text{min}} \sim 13-93 \text{ mG}; \ B_{\text{wind}} \sim 0.32 \text{ mG at } R=3.4 \times 10^{17} \text{ cm} \)
- Compression of \( B_{\text{wind}} \) not enough => turbulent amplification of \( B \)?
SN2001gd @ 3.6 cm

VLBI data and superimposed model