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Deceleration in the Expansion of SN 1993J

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Abstract. With new 6 cm observations we confirm the self-similar expansion of SN 1993J previously discovered at 3.6 cm and estimate the expansion deceleration parameter. The results are inconsistent with the existence of a constant pre-explosion stellar wind but otherwise confirm the standard radio supernova model. The first map at 13 cm showing shell structure is also presented.

The radio structure of SN 1993J in M81 is shell-like and its expansion self-similar (Marcaide et al. 1995a, 1995b). The standard circumstellar interaction model for radio supernovae (Chevalier 1996 and references therein) suggests that the radio emission arises from a shocked region between the supernova ejecta and the circumstellar material (CSM) resulting from the wind of the SN's progenitor star. This model considers supernova ejecta with steep density profiles ($\rho_{ej} \propto r^{-n}$) shocked by a reverse shock moving inwards from the contact surface and a CSM with density profile $\rho_{csm} \propto r^{-s}$ shocked by a forward shock moving outwards from the contact surface. For $n>5$, self-similar solutions are possible and the supernova size grows with the power law t^m (t, time after explosion, and $m=(n-3)/(n-s)$).

We present in Figure 1.a a preliminary map at 13cm from 1 October 1995 which shows, for the first time at this wavelength, the shell structure of SN 1993J. In Figure 1.b we plot the results of the expansion at 6 cm through October 1996 (42 months after explosion); the corresponding 6 cm maps are presented by Marcaide et al. (1997). The result at 13 cm has been included in Figure 1.b. A fit of a function of the form R $\propto t^m$ to the data gives an m=0.89±0.04. (Marcaide et al. (1997) obtain m=0.86±0.02 with 3.6 and 6 cm data.) Within the framework of self-similar models, the opacity follows $\tau \propto t^{2m(-s+0.5)}$. Combining the result by Van Dyk et al. (1994) with our estimate of m=0.89±0.04 we obtain $s=1.62^{+0.14}_{-0.25}$. This value is lower than the usually assumed s=2 in the standard model for a constant stellar wind but very close to the value s=1.7 given by Fransson et al. (1996) to explain X-ray emission. Suzuki & Nomoto (1995) suggest s=3 for the region swept by the supernova between months 24 and 42 after explosion. Our results argue against their model.

The self-similar case with m=0.89 and s=1.62 gives an ejecta density profile of $n=14.2^{+10.5}_{-4.2}$. In the standard model, for values n=14.2 and s=1.62, the forward shock radius is ~20% larger than the radius of the contact surface

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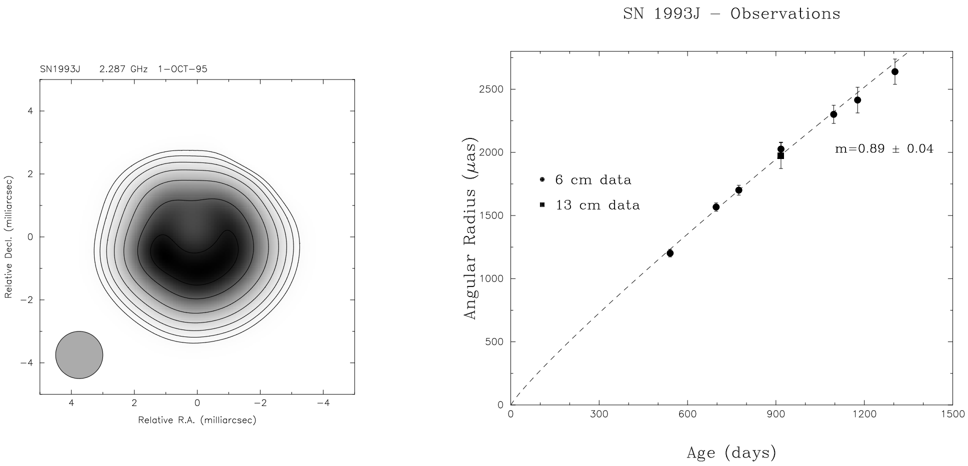

Figure 1. a) Map at 13 cm of SN 1993J from 1 October 1995, 907 days after explosion, showing the shell structure for the first time at that wavelength. The maximum brightness is 12.7 mJy/beam. The circular gaussian beam used in the convolution to obtain this CLEAN map is shown in the lower left and has FWHM of 1.5 *mas*; b) Angular radius of SN 1993J vs. days after explosion. The line is a fit of a function of the type R $\propto t^m$ (t, time after explosion) to 6 cm data. The value of m which corresponds to such a fit is 0.89±0.04. Combining these data (not including the 13 cm result) with the 3.6 cm data, Marcaide et al. (1997) obtain m=0.86±0.02.

between shocked supernova ejecta and shocked CSM. In contrast, Marcaide et al. (1995b) estimate that the width of the radio shell is about 40% the size of the inner radius; the present results confirm those findings. Perhaps clumpy ejecta and/or CSM can broaden the shell (Houck & Fransson 1996), thus enabling the standard model and the observational results to be reconciled. If the physical picture of the radio and Hα emission in the standard model were correct, there should also be a correlation between the slowdown in the growth rate we measure and a decrease of the maximum speed measurable in the Hα emission which originates in the neighborhood of the inner radius. Between months 12 and 42 the expansion speed as measured by VLBI has decreased by ~15%. This decrease should also be observable in the Hα emission.

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