The environment of SN 2004dj in NGC 2403 as seen by the *Hubble* and *Spitzer Space Telescopes*

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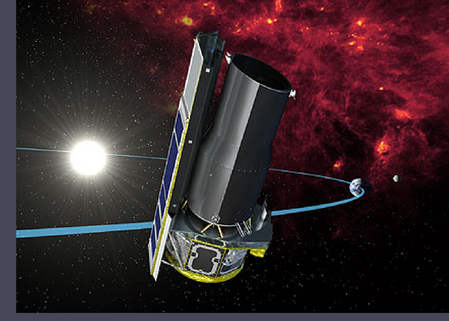


Introduction

SN 2004dj, discovered by K. Itagaki on July 31, 2004, is the one of the closest and brightest supernovae observed in the era of space astronomy. It occured in a spiral arm of a star-forming galaxy, NGC 2403. The SN was a core-collapse event of a massive star (a Type II-P SN) as characterized by the ~100 day-long plateau in the light curve and strong Balmer-lines in the spectrum (e.g. Vinkó et al. 2006).

The birthplace of SN 2004dj was a young, very massive stellar cluster, Sandage-96. This provided a unique opportunity to place strong constraints on the mass of its progenitor star via the empirical determination of the cluster age. In this work we present the results of this analysis based on archival data obtained with the *Hubble* and *Spitzer Space Telescopes*. Details can be found in Vinkó et al. (2009) and Szalai et al. (in preparation).

Dust formation during the nebular phase

The evolution of SN 2004dj in the nebular phase was followed by the *Spitzer Space Telescope*. Our study is based on public archival data. Mid-IR photometry was performed using the 4 *IRAC* channels (3.6, 4.5, 5.8 and 8.0 μm) and the *MIPS* 24 μm frames. We have applied *IRACproc* (developed by the SAO) for mosaicing and aperture photometry. The *MIPS* frames were reduced by the DAT program, and PSF-photometry was done by *IDP3* and *DAOPHOT* using a self-developed PSF. Spectra were obtained with *IRS* and were extracted with the *Spice* software. The data reveal the brightening of the source in the mid-IR at ~600 days after explosion. The excess emission is probably due to freshly synthesized dust (T_{dust} ~ 800 K) in the ejecta at v ~ 1000 km s^{-1}.

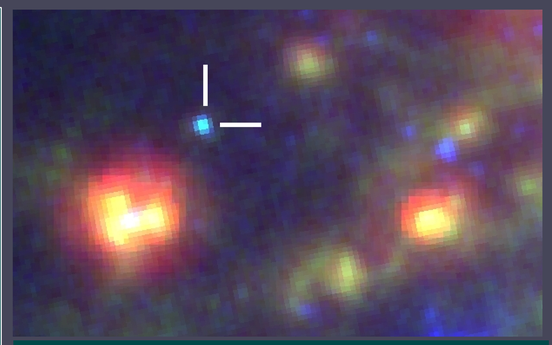
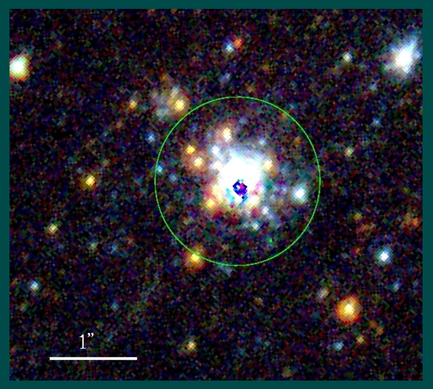


Fig.3: color-combined mid-IR image of the region around SN 2004dj/Sandage-96 (red:24 μm, green: 8.0 μm, blue: 3.6 μm).

The mass of the progenitor star



Sandage-96 consists of at least two populations: a younger one with ages of 10-16 Myr and an older one with ages higher than 32 Myr. If the progenitor of SN 2004dj was the member of the younger population, then its mass was 12 - 15 $M_{\odot}$.

Fig.1: color-combined image of the cluster Sandage-96 observed by *HST Advanced Camera for Surveys* (*ACS*) on Aug. 28, 2005, 425 days after the SN explosion (GO-10607, P.I. B.E.K. Sugerman). The PSF of SN 2004dj has been removed from all frames. The error of the PSF-subtraction is represented by the residual close to the cluster center.

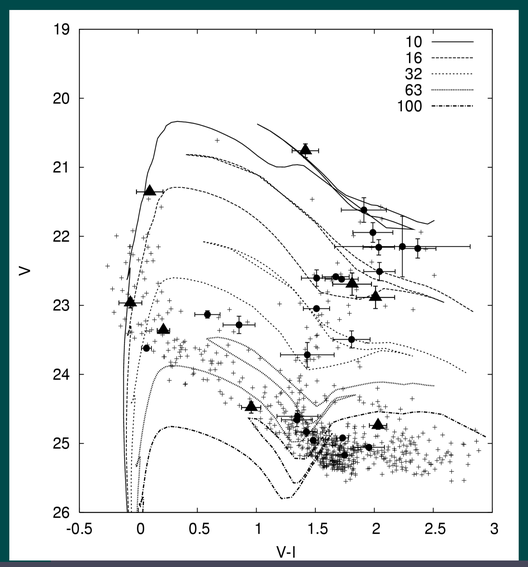


Fig.2: color-magnitude diagram of the resolved stars within Sandage-96 (filled symbols) and other sources in the field covered by *ACS* (plus signs). The photometry was computed with the *DOLPHOT* code. The instrumental magnitudes in the *ACS* filters *F606W* and *F814W* were transformed into Johnson-Cousins *V* and *I* magnitudes, respectively.

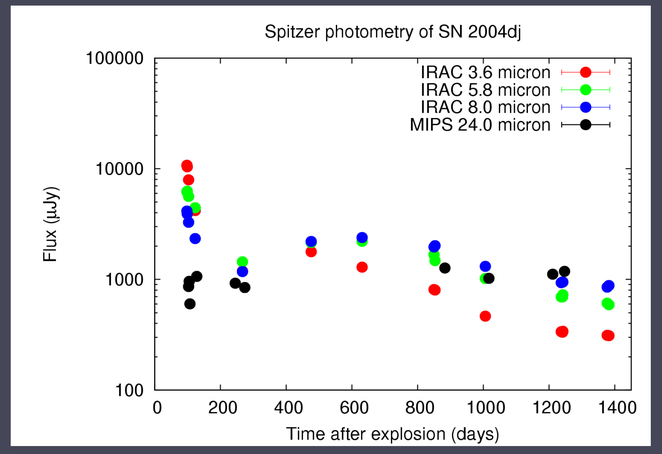


Fig.4: mid-IR light curves of SN 2004dj. The excess emission peaks later at longer wavelengths, which is indicative of a warm, constantly cooling dust formed roughly after one year of the core collapse event.

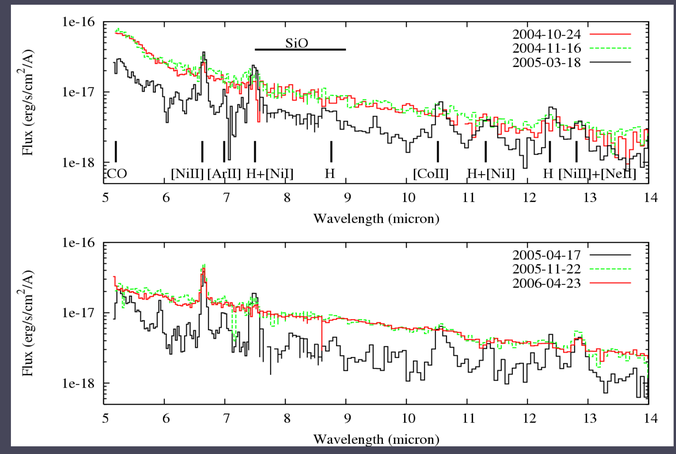


Fig.5: IRS spectra of SN 2004dj in the nebular phase (top panel: before +300 days; bottom panel: after +300 days). The nebular lines disappeared during the "bump" phase in 2006 (bottom panel), due to the developing pseudo-photosphere caused by the newly formed dust layer. Line identifications are based on Kotak et al. (2005, 2006).

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References

Kotak, R. et al. 2005, ApJ 628, L123
Kotak, R. et al. 2006, ApJ 651, L117
Vinkó, J. et al. 2006, MNRAS 369, 1780
Vinkó, J. et al. 2009, ApJ 695, 619