Late time dust emission in the Type IIn supernova SN 1995N

R. Wesson[1], A. Bevan[1], M.J. Barlow[1]

[1]Department of Physics and Astronomy, University College London, United Kingdom

Abstract

The Type IIn supernova 1995N, at a distance of 24Mpc in the galaxy Arp 261, is a bright and long-lived X-ray and radio source, indicating strong interaction between its ejecta and the pre-existing circumstellar medium (CSM).

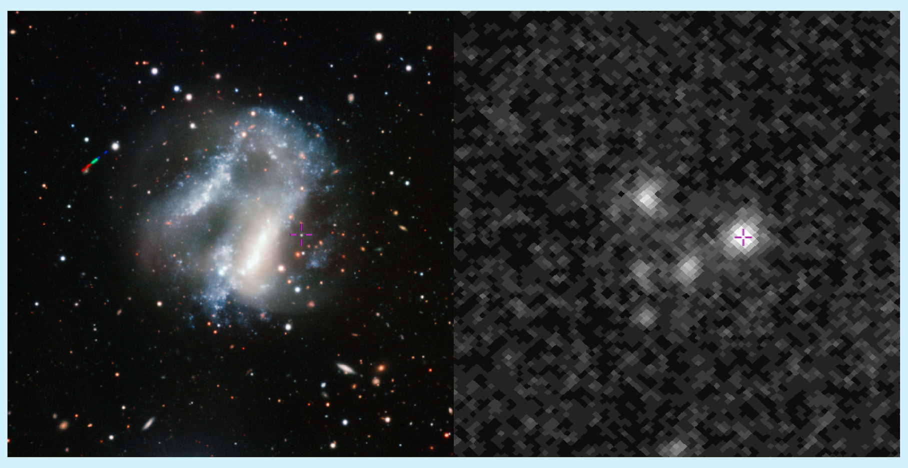

Fig. 1: (l) 2002 optical image of Arp 261 (r) XMM 2003 X-ray image. SN 1995N's position is indicated in both

The supernova was detected as an infrared point source in Spitzer and WISE observations about 15 years after its explosion. This emission has been attributed to $0.12M_\odot$ of CSM dust illuminated by the supernova flash and thermally echoing. We argue, however, that a CSM echo is unlikely given the required geometry of the echoing material. We propose that the emission is due to about $0.2M_\odot$ of newly formed dust in the supernova ejecta, heated externally by the interaction of the ejecta with the CSM. We present radiative transfer models of the spectral energy distribution, and of asymmetric emission lines, which support this scenario.

CSM thermal echo?

Van Dyk (2013) presented *Spitzer* and *WISE* infrared observations of SN 1995N from 2009 and 2010, approximately 5500 days after the explosion. These revealed a point source which Van Dyk attributed to circumstellar dust, thermally echoing having been heated by the supernova flash.

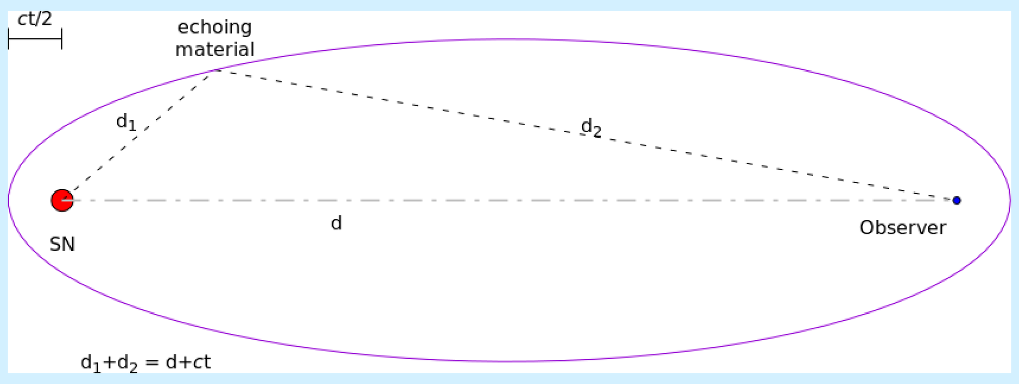

Fig. 2: the geometry of a light echo

We argue that this is not plausible. At a time t after a supernova explosion, thermally echoing material lies on an ellipsoidal surface defined by the additional light travel time ct for the source-dust-observer path. The minimum distance of this ellipsoid from the star is $ct/2$, so that material thermally echoing after 15 years must be at least 2.3 parsec from the supernova. This is too large to be circumstellar material. The dense CSM of VY CMa, considered a likely analogue for the progenitor of SN 1995N, has a radius of only 0.03pc. The tenuous outer rings of SN 1987A, believed to have resulted from an earlier red supergiant phase in the evolution of the progenitor, are about 1 pc from the SN.

Spectral Energy Distribution

We present an alternative model for the late-time infrared emission. In our proposed scenario, it arises from new dust forming in the expanding supernova ejecta. Heating by the decay of radionuclides in the ejecta would be insufficient by many orders of magnitude to illuminate the dust at this epoch, but heating by X-rays emitted by the interaction between the supernova ejecta and pre-existing circumstellar material can provide the required luminosity. We use the 3D radiative transfer code MOCASSIN to calculate the resulting SED, simulating the interaction region as heating sources distributed on the surface of a sphere, with all dust lying interior to the sources.

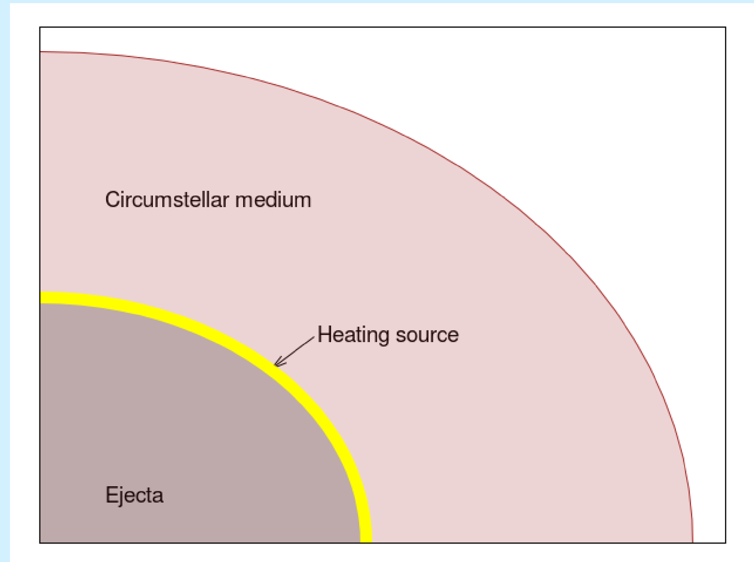

Fig. 3: interaction heating of ejecta dust

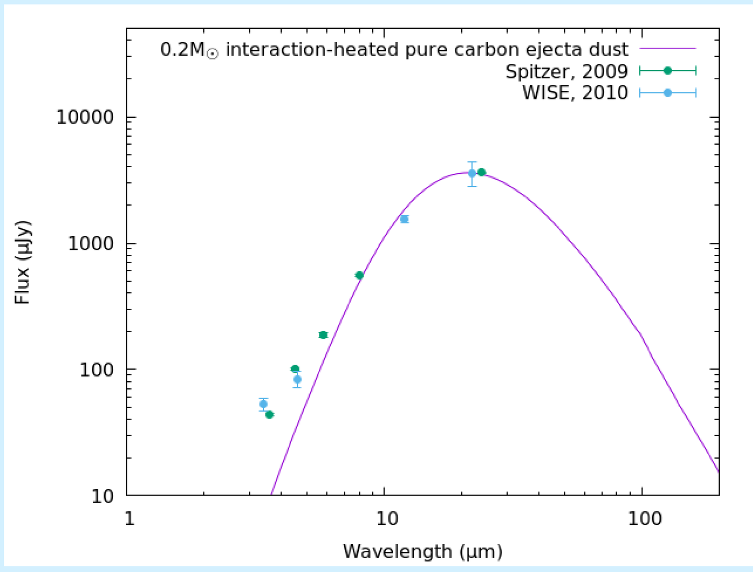

Fig. 4: Predicted SED from $0.2M_\odot$ of interaction-heated ejecta dust, 5500 days after explosion

The observed *Spitzer+WISE* SED in 2009-2010 is well fitted by a model in which the ejecta contains $0.2M_\odot$ of amorphous carbon dust, in clumps with a volume filling factor of 0.1. Pure silicate dust is ruled out as it would result in strong 10 and 18μm emission features which cannot be reconciled with the observed 12μm *WISE* flux, but a silicate fraction of up to 20% results in an SED consistent with the observations. Grain sizes of $\sim 1\mu$m are required to reproduce the observed dust temperature. The total luminosity of the infrared emission is less than the X-ray luminosity at this epoch, indicating that X-ray heating from the ejecta-CSM interaction can easily supply enough energy to heat the dust.

Emission line profiles

Fransson et al. (2002) presented spectra of SN 1995N at 700, 1000 and 1400 days after explosion. At day 700, emission line profiles were symmetric; at the later epochs, the red side of the line profiles diminished relative to the blue side. The observed shift towards the blue indicates the onset of dust formation within the ejecta: red-shifted emission from the far side of the ejecta passes through a column of dust which the blue-shifted emission from the near side does not. Line profiles are sensitive only to ejecta dust; circumstellar dust exterior to the emission region affects both redshifted and blueshifted emission equally.

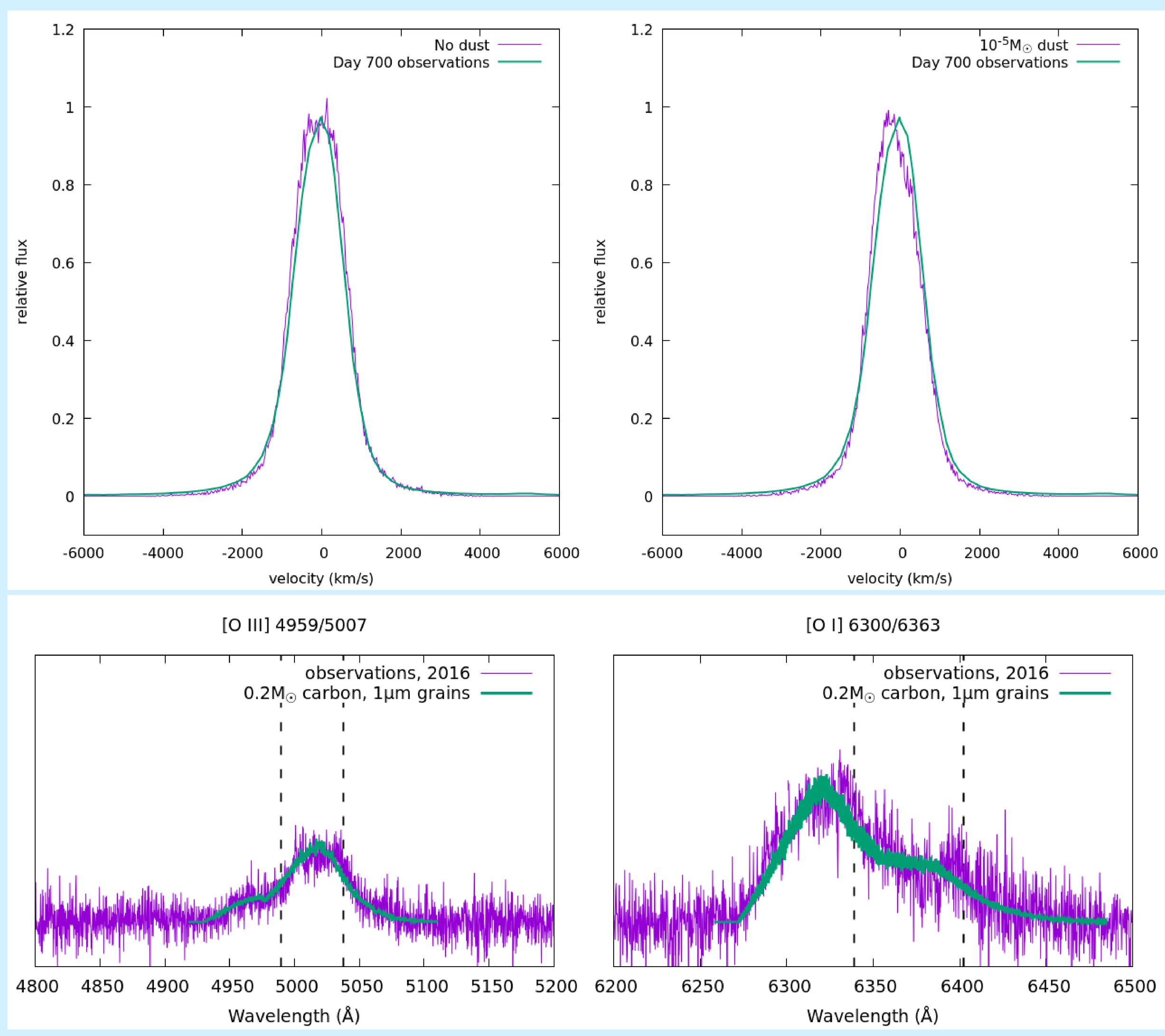

Fig. 5: (top) fits to spectra at day 700, which show that the presence of $10^{-5}M_\odot$ of dust would cause a detectable asymmetry in the line profile at this epoch; (bottom) fits to oxygen emission lines in 2016. Vertical dashed lines indicate the rest wavelengths of the line pair

We obtained spectra of SN 1995N in April 2017, ~7650 days after the explosion, using XSHOOTER at the VLT, and also analysed archival XSHOOTER spectra from July 2010, ~5500 days after outburst. In both, we detected broad and asymmetric emission lines of [O I] (6300, 6363Å) and [O III] (4959, 5007Å), indicating that dust in the ejecta has a high enough optical depth to significantly affect line profiles. We fitted the emission line profiles at all epochs using the radiative transfer code DAMOCLES (Bevan & Barlow, MNRAS, 2016). At day 700, the symmetry of the line profiles allows us to place an upper limit of $10^{-5}M_\odot$ of dust at this epoch. At day 5500, we find that $0.1M_\odot$ of carbon dust within the ejecta can account for the observed profiles. In the latest spectra, $0.1M_\odot$ does not provide sufficient opacity to match the line profile, and $0.2M_\odot$ is required. This evidence for dust formation at very late times is consistent with the evidence from SNe 2010jl (Gall et al. 2014) and 1987A (Wesson et al. 2015, Bevan & Barlow 2016) of gradual dust formation over many years.

References

- Bevan A., Barlow M.J., 2016, MNRAS, 456, 1269
- Ercolano B., et al, 2007, MNRAS, 375, 753
- Fransson C., et al, 2002, ApJ, 572, 350
- Gall C., et al., 2014, *Nature*, 511, 326
- Van Dyk S., 2013, AJ, 145, 118
- Wesson R., et al, 2015, MNRAS, 446, 2089

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