Supernova 1998S at 14 years Postmortem:

Continuing Circumstellar Interaction and Dust Formation

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Late-time observations of interacting supernovae (Type IIn/Ibn) provide critical information about the nature and mass-loss history of massive stars immediately before core collapse. The Type IIn/II-L SN 1998S is a relatively nearby SN thought to have had a red supergiant (RSG) progenitor that underwent a phase of very heavy mass loss prior to explosion. Spectroscopic analysis over the first few years of evolution revealed evidence for non-spherical geometry in the envelope of circumstellar material (CSM). We report late-time spectroscopic observations of the Type IIn SN 1998S 14 years post-explosion using the Large Binocular Telescope (LBT) and Multi-Object Double Spectrograph (MODS). The data provide clues about the extent of the CSM, the geometry of the outflow, and the recent formation of obscuring dust.

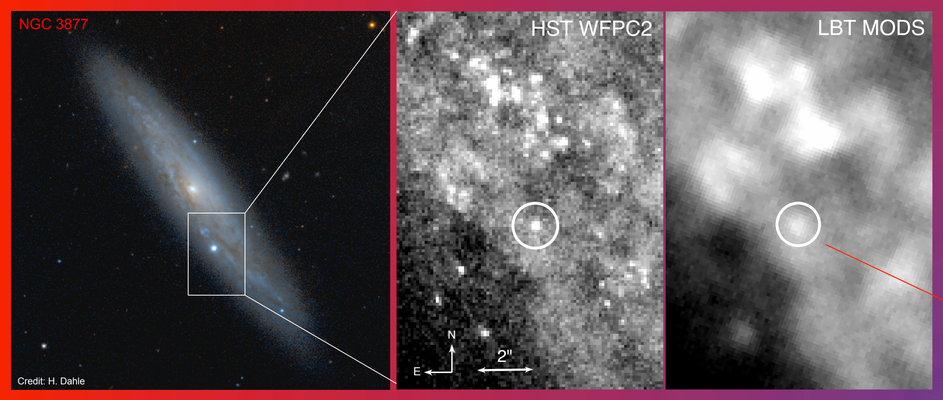

Figure 1: Ground-based (left) and Hubble Space Telescope (center) images of SN 1998S in 1998 and 2000, respectively, and our LBT/MODS image from 2012 Feb 27 (right).

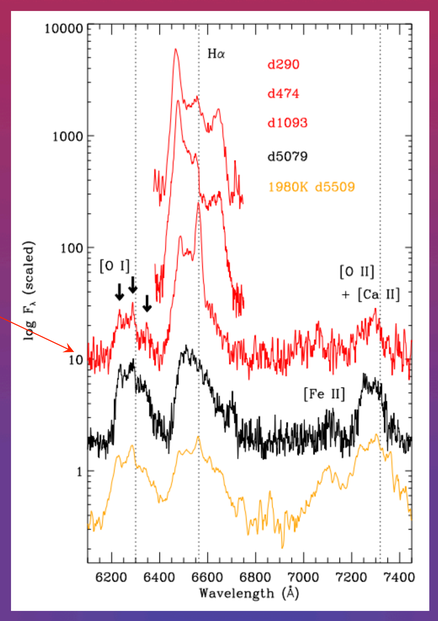

Figure 2: LBT/MODS spectrum of SN 1998S (*black*), compared to earlier spectra from Fassia et al. (2001, *red*). The latest spectrum implies that strong CSM interaction continues. The last decade of spectral evolution has exhibited a strengthening of the oxygen transitions relative to Hα, evidence that the late-time emission is powered by increasingly metal-rich SN ejecta crossing the reverse shock near the SN-CSM interface. The disappearance of the multi-peaked narrow Hα components perhaps indicates that the non-spherical or ring-like component of the CSM, suggested earlier, has since been overtaken by the shock. The latest spectrum of SN 1998S closely resembles that of SN 1980K at a similar late-time epoch (Fesen et al. 1999, *yellow*).

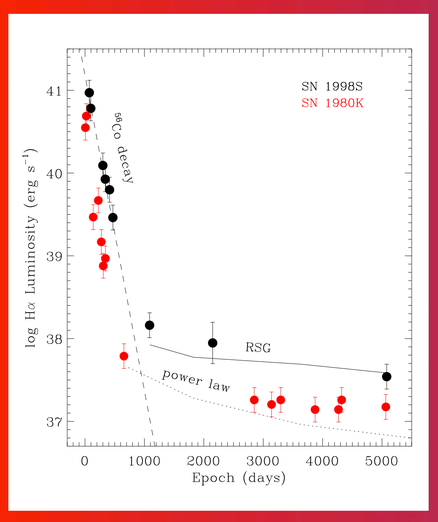

Figure 3: Hα luminosity curves for SN 1998S, and the similar SN 1980K. The luminosity at epochs <1000 days is consistent with the 111.5-day mean lifetime of radioactive ^{56}Co decay (*dashed line*), but later epochs from day 1093 onward fall above this trend by as much as 10 dex, requiring interaction with dense CSM. The late-time Hα luminosity of SN 1998S (currently ~8000 $L_\odot$) and the overall trend appears most consistent with model predictions for an RSG density profile of the envelope (Chevalier & Fransson 1994; *solid line*), more so than a power-law density profile (*dotted line*).

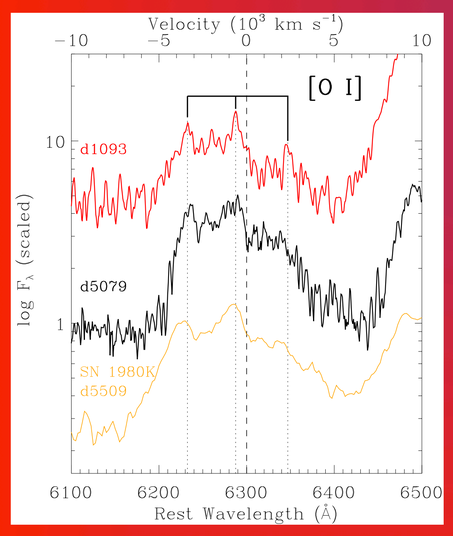

Figure 4: Close-up of the multi-peaked [O I] λ6300 Å profile of SN 1998S on days 1093 and 5079. The dashed line marks the rest wavelength of the of the transition. The dotted lines mark the center wavelengths/velocities of the triple peaks, assuming they all represent λ6300. The multiple peaks could represent individual metal-rich structures from an non-spherically symmetric explosion. The red-shifted portion of the line has become more sharply suppressed over the last decade, and the reddest individual peak has disappeared. We interpret this a the result of dust which has formed in the post-shock medium over the last decade and is obscuring emission from ejecta components on the receding hemisphere of the explosion.

Figure 5: Nebula surrounding the red supergiant VY Canis Majoris, a potential Galactic analog for the progenitor of SN 1998S. The diameter of this nebula, which includes multiple asymmetric arcs, is ~4500 AU, comparable to the estimated CSM dimensions of SN 1998S. The superwind of VY Canis Majoris has been blowing for ~1000 years at a mass-loss rate of 4×10^{-4} $M_\odot$ yr^{-1}; we have derived similar parameters for the SN 1998S progenitor. VY Canis Majoris could likely produce a Type IIn explosion very similar in appearance to SN 1998S.

References: **Mauerhan, J. &Smith N., 2012, MNRAS, 424, 2659**
Chevalier, R.A. & Fransson C., 1994, ApJ, 420, 268
Fassia A. et al. 2001, MNRAS, 525, 907
Fesen, R.A. et al. 1999, AJ, 117, 725