Modeling the deep HETG observation of SN 1996cr

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Above. SN 1996cr is seen in the lower-right corner of this Chandra press release image of the Circinus Galaxy. SN 1996cr is about 25" south of the galaxy center (the orientation is not the usual N-up-E-left.)

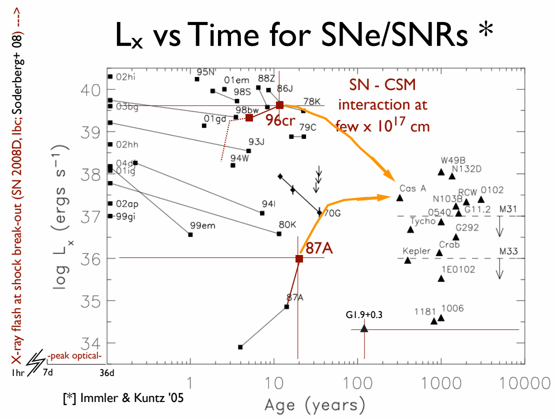
SN 1996cr is located near the Circinus Galaxy at a distance of 3.7 Mpc; it was discovered in the X-ray and has been studied with archival and targeted data (Bauer et al. 2008.)

SN 1996cr and SN 1987A are currently the only SNe known to have an *increasing* X-ray luminosity at a few years after the explosion.

The likely scenario is that the progenitor created a wind-blown bubble in its vicinity, sweeping material into a dense shell outside the bubble, which is then shocked once the ejecta--forward-shock expands sufficiently.

A very deep, 485 ks, Chandra GO observation was taken of SN 1996cr using the HETG; this observation shows the velocity structure of the X-ray emission lines with reasonable statistics.

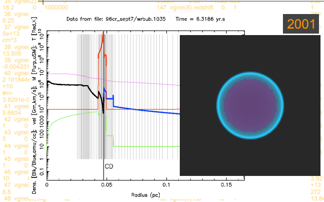
Here we compare the synthetic flux and spectra of a 1-D hydro model of SN 1996cr with the multi-epoch data sets that are available.

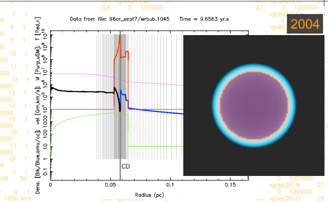


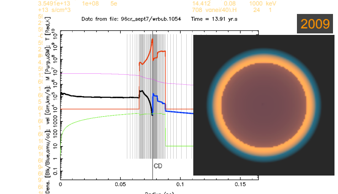
Above. The X-ray luminosities of SNe and SNRs are plotted vs. their age. Most SNe show a steadily declining flux years after the explosion; with the exceptions of SN 1996cr and SN 1987A. Presumably the SN progenitors of current SNRs followed some path to get where they are. With '96cr and '87A we will get to follow their progress in the coming decades *!*

Below. Three epochs of SN 1996cr 1-D models and spectral data are shown. The **lower panels** show the measured data (black) with the synthetic X-ray spectrum of the hydro model overplotted (red).

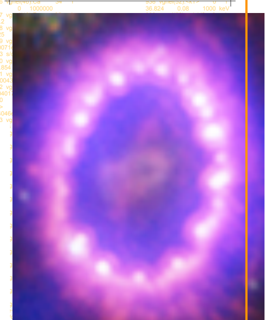
The **upper-left panels** show radial profiles of the 1-D hydro model values of density (black-ejecta, blue-CSM), velocity (green), and temperature (red). The **upper-right images** show a schematic of the X-ray emission with shocked CSM in blue and shocked ejecta in orange. The SN core is in purple.

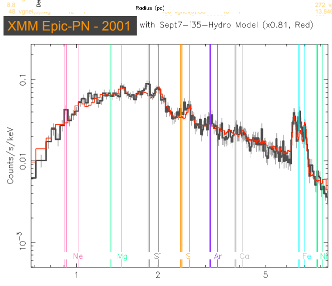


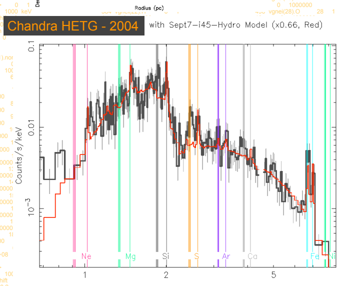


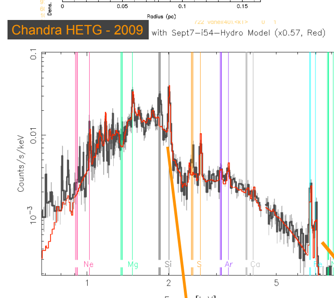


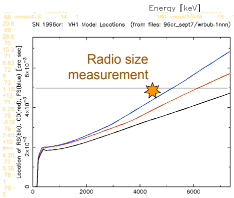
Below. SN 1987A optical/X-ray composite is shown here on the same distance scale as the schematic images of '96cr to emphasize how compact '96cr is especially given its high flux.



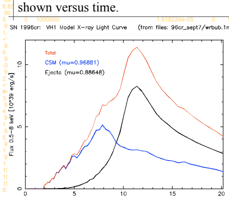




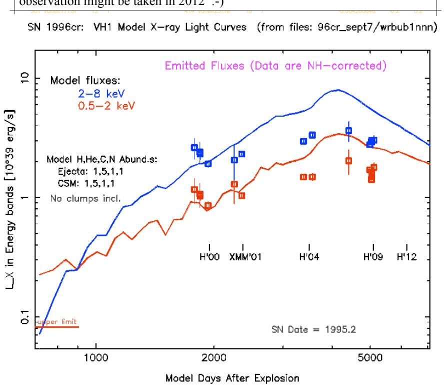


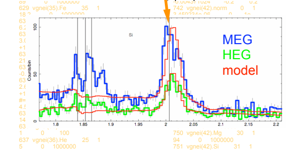


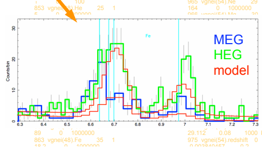
Above. The location of the forward shock (blue), contact discontinuity (red), and reverse shock (black) are plotted for the model; the model agrees reasonably with the VLBI radio measurement indicated. **Below.** The flux from the shocked CSM (blue) and the shocked ejecta (black) is shown versus time.



Below. The fluxes calculated from the 1-D hydro model are shown by the curves for two energy bands. Measured points are plotted as well. We are in the process of "fitting" the model to the data and here fluxes are within a factor of 2. We expect further tweaking of the 1-D model (e.g. reducing the shell outer radius to reduce the late-time flux) will give agreement at the 30% level across the epochs. Note that we indicate when a further deep HETG observation might be taken in 2012 :-)





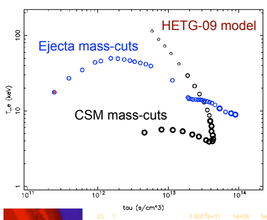


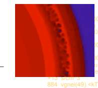
Above. Close-ups of the Si and Fe line regions are shown along with the 1-D hydro-based model for 2009. The general size of the velocity effects are similar in model and data although the data hint at further structure.

The X-ray emission model includes emission from 55 shells, each with their own values of T and tau, shown in the **plot at right** (and listed in the poster background.)

As the Si comparison shows we are missing significant He-like Si emission in the current model. We suspect this is likely due to lower temperature "clumps" in the system. Source include a clumpy CSM, ejecta, and/or from R-T instabilities at the contact discontinuity (**2D image at right**.)

To be continued ....





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