Numerical Models of the Cygnus Loop Shock-Shell Interaction

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ABSTRACT

A variety of observations indicate that the explosion that formed the Cygnus Loop SNR went off inside a pre-existing cavity carved out of the ISM by the SN progenitor's stellar wind. We have created numerical hydrodynamical models for the evolution of the SNR and the resulting X-ray emission observed by Chandra.

GOALS

- understand Cygnus Loop X-ray emission spectra and distribution from observations in NE region (see Fig. 1)
- constrain shell and shock properties
- explore effects of the non-steady, non-planar shock propagation on the spectra
- investigate coupling of SN energy to the ISM for a cavity remnant

METHODS

- hydrodynamics using the VH-1 code (Piecewise Parabolic Method, multi-dimensional hydrocode) enhanced to include cooling and non-equilibrium ionization – 1-D models for now
- emission spectrum calculated from ionization, density, temperature using Raymond & Smith code (updated)
- integrals along sightlines through the remnant (assume $D = 500$ pc)

DATA

- 60 ks Chandra observation; with flares removed ~ 42 ks
- reprocessed using latest CIAO tools and CALDB including time-dependent gain correction & spatially varying contamination model
- spatial extraction regions were chosen to follow post-shock structure as revealed by Hα with size large enough to contain 10^4 counts each.

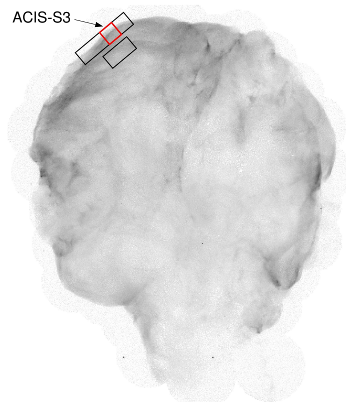

Fig 1.: ROSAT HRI image of the Cygnus Loop (N. Levenson) with position of the observation and ACIS field of view shown in NE

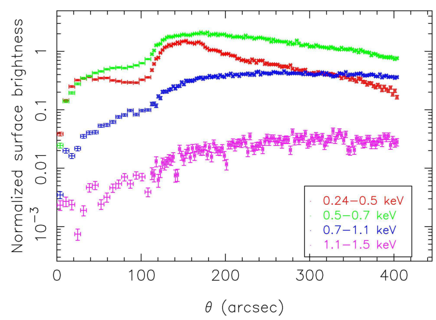

Fig 2.: Background subtracted surface brightness in different energy bands as a function of distance from the shock front. Note that ramp on left is believed to be a geometrical effect of the wavy shock front viewed almost edge on.

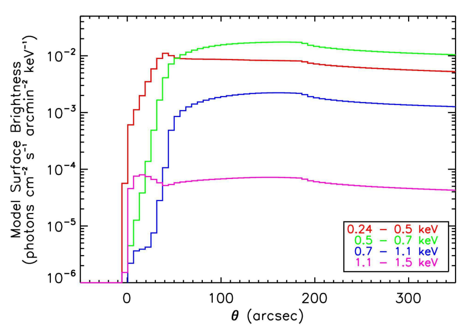

Fig 4.: Surface brightness distribution calculated for hydrodynamical model as a function of angular distance from the shock front. The bands are the same as for the data plotted in Fig 2. This emission distribution is for the last time plotted in Fig 3. ($t = 1.63 \times 10^4$ yr).

Model Parameters

We model the remnant as an explosion in cavity with uniform interior density. Results shown here assume:

- explosion energy, $E_0 = 0.22 \times 10^{51}$ ergs
- ambient density (inside the shell), $n_a = 0.5$ cm^{-3}
- shell density, $n_{sh} = 5$ cm^{-3}
- shell radius, $R_{sh} = 12.2$ pc
- shell transition zone thickness, $\Delta = 0.5$ pc

We assume a linear density ramp from the bubble interior to the shell.

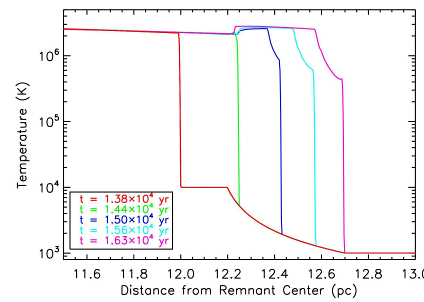

Fig 3.: Temperature evolution in the model calculations. The shock runs into the shell at $t \sim 1.4 \times 10^4$ yr. After impact there is a slower (colder) forward shock and a reverse shock.

RESULTS

- hydro models can replicate the peak in the soft bands – but spatial distribution is not matched – geometrical effects?
- speeds inferred from UV/optical emission (~350 – 400 km/s) lead to emission that is softer than seen in X-ray data. Are we seeing the hot, reflected shock or a part of the forward shock that has not yet run into the shell?
- translating the observational constraints into limits on the model parameters is difficult and will be the focus of ongoing work.

This is work in progress!

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