SN 1987A's X-ray Emission: Signatures of Model Components in HETG Data

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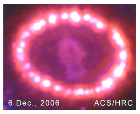
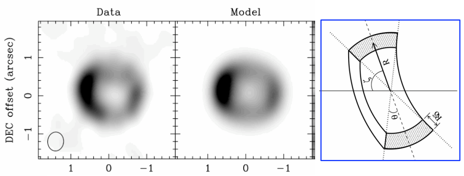


HST optical image



Radio image and best-fit "equatorial belt" model image with model schematic (Ng et al. 2008)

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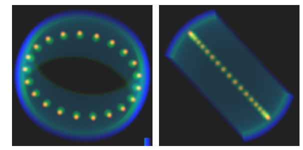


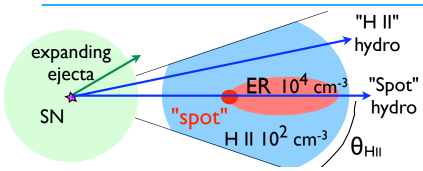
Simulated X-ray images, sky (l) and side (r) views, based on simple 1-D hydro models.

'87A's Emission Components

The iconic HST image of SN 1987A shows emission primarily from the dense equatorial ring (ER) and its shocked protrusions, aka "spots".

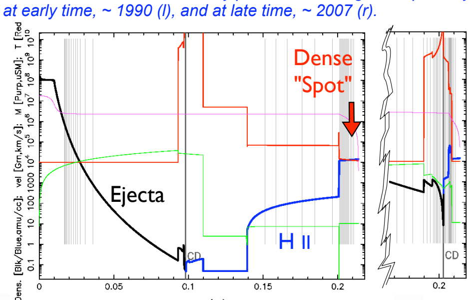
In contrast, the radio image is well modelled by out-of-plane emission, e.g., the "equatorial belt" model of Ng et al (2008). The main parameters are R_ave ~ 0.85", theta_open ~ 40 deg. and a shell thickness < 10% of radius.

In the X-ray, emission is coming from both the shocked ring and the high-lattitude H II region material. Here we look into the spectral signatures of these components.



Above: A simple cross-section of SN 1987A soon after explosion. The two blue lines indicate radial paths of the simple 1-D hydro simulations: in-plane ("Spots") and out-of-plane ("H II").

Below: Radial variation of key parameters along the "Spots" hydro at early time, ~ 1990 (l), and at late time, ~ 2007 (r).



Simple Hydro Model for '87A

Because of the non-power-law nature of the CSM around '87A, the usual analytic self-similar solutions are not applicable.

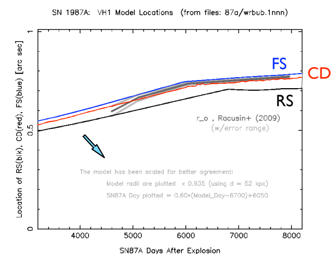
As a first approximation to the hydrodynamics, we can consider to 1-D cases: i) the shock wave encountering the H II region, and ii) a shock wave interacting with the H II followed by a dense spot and equatorial ring - schematic at left.

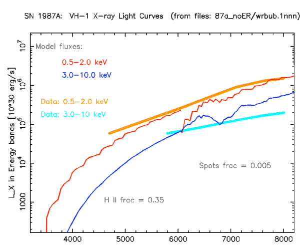
These cases were carried out using the VH-1 code and radial profiles of density, pressure and velocity are created for a set of time snapshots - examples at lower-left.

Althought the model is not yet fine-tuned, a simple scaling gives good agreement between the model locations, the forward shock (FS), contact discontiuity (CD) and reverse shock (RS), and the measured average ring radius from ACIS monitoring (Racusin et al. 2009) - see upper-right plot.

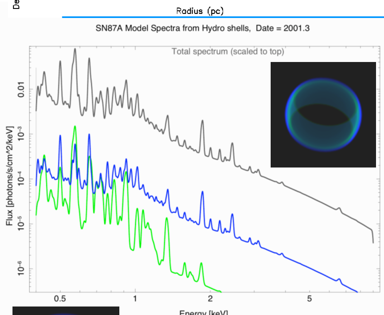
X-ray emission from a simulation is calculated using the simple `vgnei` XSPEC model. Because this requires history information (ionization age and ionization-age-averaged temperature), mass-cuts are identified and followed over time to generate these values. Abundances are set for the CSM (e.g., from the early Chandra results of Michael et al. 2002) and for the ejecta (somewhat more metal rich than the CSM.)

The plot at right shows reasonable agreement between our model calculated soft and hard fluxes and the ACIS-measured fluxes.



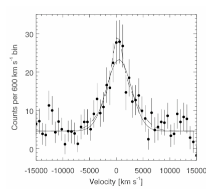


Component Spectra and Doppler Widths



At left: A simulated image of the shocked CSM (blue) and shocked-ejecta (green) emission regions circa 2001.

The H II hydro X-ray lines are broad and shown with the same component color coding.



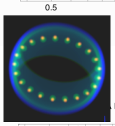
HETG data from 1999 (above) did indeed show broad emission (~ 6800 km/s) dominating the stacked line profile (Michael et al. 2002)

A key output of the hydro simulations is the velocity of each mass-cut's emission which then adds Doppler structure to the modelled spectra.

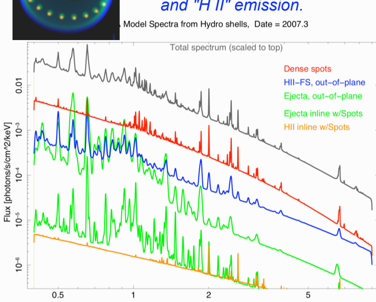
We make a simple composite spectrum at a given epoch by including emission from the high-lattitude H II simulation (times a filling factor for the opening angle) plus the emission from the "spots" hydro simulation (times a spots filling factor.)

Note that the "spots" contain denser regions which do become radiative, hence detailed "shock-cloud" calculations (e.g., Orlando et al. 2008 and earlier papers) would be more appropriate and lead to more low-temperature lines than are shown in the "dense spots" spectrum here (red curve in lower far-left plot.)

Re-analysis of the HETG data from 2007 does show an improved fit when a broad component is included and we are working to achieve better simulation agreement with these and future high-resolution X-ray data.

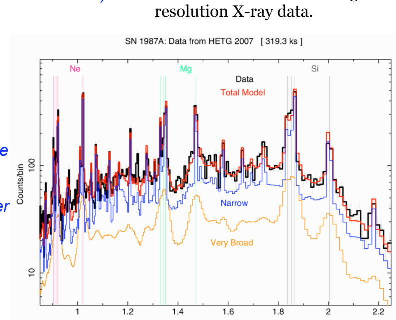


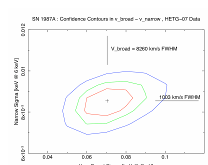
In 2007 the X-ray emission from '87A consists of both ER "spots" and "H II" emission.



The emission from '87A in 2007 is modelled and should include narrow and broad components, shown in the hydro-based spectra at left.

At right the HETG 2007 data have been fit with our nominal 2-shock model (Zhekov et al, 2005, 2006, 2009; Dewey et al. 2008). However here a fraction of the model, 29%, is in a very broad component with FWHM ~ 8200 km/s. The chi-squared went from 650 to 500 (for 320 d.o.f.) by adding this component.





Above: Confidence contours for the very broad and narrow widths in the model fit to the HETG 2007 data. The narrow width, ~ 1000 km/s, is due to the size of '87A. The broad width indicates radial velocities of several thousand km/s.