Chandra HETG Spectra of SN 1987A at 20 Years

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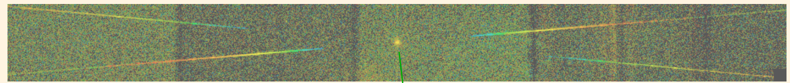
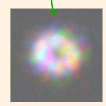
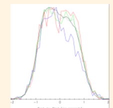
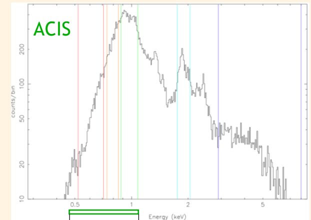
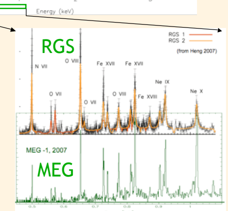








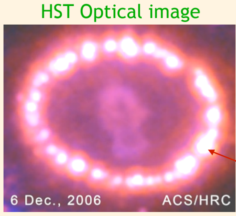
The HETG observation (**top**) provides dispersed spectra (the four arms of the "X" pattern) as well as a direct image, the "zeroth-order". SN 1987A is resolved in the image which gives information on the coarse spatial-spectral properties of the source, e.g., the E-W projections in ACIS energy bands shown **above**.



The high resolution of the gratings is clearly seen in the comparison with the ACIS spectrum, **above**.

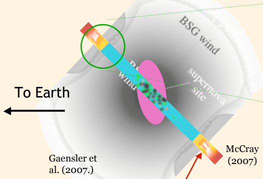
" What's happening ? "

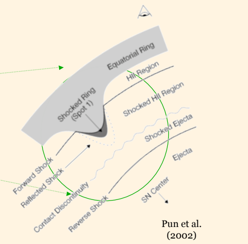
HST Optical image



"inner ring" with shocked protrusions

Side View Cross-section

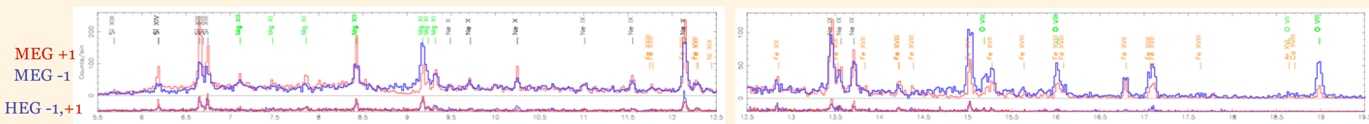




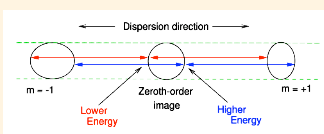
20 years after explosion, SN 1987A's blastwave and debris are interacting with a pre-existing dense "inner ring". The initial interactions are at discrete "spots": the inward protrusions of dense ring material.

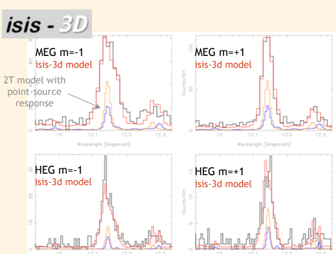
A schematic of the interaction includes many regions and components with a variety of densities. X-ray emission is now primarily from the (reflected) shocked H II region.

HETG Observation, Spring 2007, 360 ks



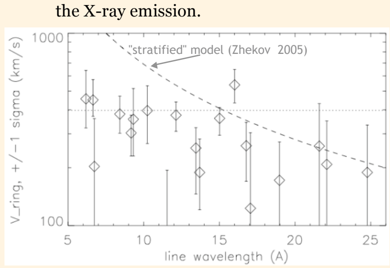
Line Profile Modeling: Bulk Velocities





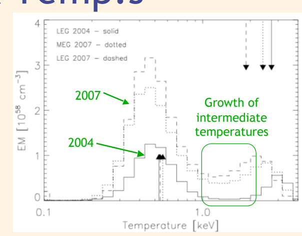
Following the scheme of Zhekov et al. (2005) we use a model which includes spatial-spectral Doppler effects **(left)**. Assuming a tilted non-uniform ring emission, the bulk in-plane velocity can be fit for each bright observed line (e.g., Ne X, **lower left**), giving the "v_{ring}" results plotted **below**.

The measured velocities for Si and Mg lines are significantly lower than expected in a simple shock scenario -- confirming that **reflected shocks** play a large role in the X-ray emission.



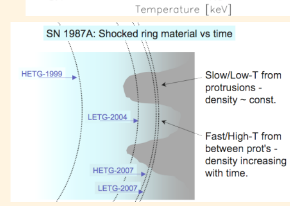
Global Spectral Modeling: Evolving Shock Temp.s

We fit the global MEG'07 spectra jointly with the previous LETG'04 data and new LETG'07 data, using common abundances and N_H but allowing each data set it's own distribution of shock temperatures (Zhekov et al. 2006). The resulting distributions (**right**) show a clear evolution of the emission from 2004 to 2007: more intermediate temperature components are present.



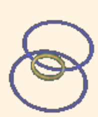
Note: In this work "APEC_nei" files provided by K. Borkowski were used with the vpshock model in XSPEC.

This evolution is as might be expected: the inter-protrusion density is likely increasing as the full inner ring is approached, cartoon at **right**.



More Questions...

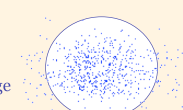
- Can we fully explain the kinematics seen in the X-ray emission ?
  (low v_{ring} , a range of broadening velocities)
- Is evaporation of the protrusion material important ? At the sides in oblique shocks ?
- Does the X-ray plasma significantly cool over years time scale,
  or are we seeing new cooler plasma emission added ?
- What is a self consistant model for Radio, Optical, and X-ray emission ? Vs time ?
- When will shock SN debris (as opposed to shocked H II) emission become visible ?
- Is there indication of X-ray emission other than in the inner ring per se ?
- Will we see emission when the blastwave impacts the "outer rings" ? When ?
- When will we see the compact object ? With ALMA ? JWST ?

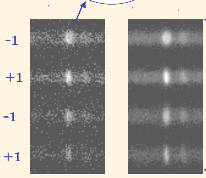


More Data Analysis...

The HETG data provides "spectral images" of SN 1987A, especially useful in the "stretched"-order data (-1), **right**. Comparison of the data and models in 2D may help separate the emission components.

~ 600 events in the MEG -1 Ne X line-image





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