SNR E0102:  
Building a Supernova Remnant

A SNORE talk by Dan Dewey  
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"SNR-3D" Collegues at MIT:  
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Talk Overview

• Introduction to E0102 Spectra Images
• Getting 3D Information
  In general
  For E0102
• 3D Visualization
  3D scalar: thin/thick Examples
• 3D Model Construction
  Model Parameters
  E0102 beginnings
HETGS
Spatially broadened
Flanagan et al. 2004

XMM/RGS
Velocity broadened
Global Model Abundances

<table>
<thead>
<tr>
<th>Element</th>
<th>Sasaki... A&amp;A '01</th>
<th>V. d. Heyden... a-ph/0309030</th>
<th>Previous plot, vnpshock</th>
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</thead>
<tbody>
<tr>
<td>O</td>
<td>1.1</td>
<td>0.87</td>
<td>~0.7</td>
</tr>
<tr>
<td>Ne</td>
<td>2.6</td>
<td>1.99</td>
<td>~1.0</td>
</tr>
<tr>
<td>Mg</td>
<td>1.5</td>
<td>1.32</td>
<td>~0.7</td>
</tr>
<tr>
<td>Si</td>
<td>0.4</td>
<td>0.21</td>
<td>~0.15</td>
</tr>
<tr>
<td>Fe</td>
<td>0.3</td>
<td>0.29</td>
<td>~0.075</td>
</tr>
</tbody>
</table>

Converting Abundances and EM to Masses, etc. :
- Volume, geometry, filling factor
- Blast wave vs Ejecta
- Assumptions on \( n_e / n_{ion} \) in regions

Use spatial information too!
X-ray Images...

- Bright thin ring of reverse-shocked ejecta, primarily O and Ne.
- An outer blast wave shell.
- Radial "spokes" of material.
- *Unresolved structure?*

Color-intensity images of E0102 (right) and Cas A (left). The Cas A image has been degraded as if it were observed at the distance of E0102.
Chandra Imaging


O VIII - O VII image
At right the dispersed images of various He-like ions (left column) and H-like ions (right column) are shown from the MEG spectrum.

Measuring the location of the SE arc and N shelf shows a clear trend with the tau of maximum emissivity which can be interpreted as resulting from the passage of the reverse shock through the ejecta.
Spatially-resolved spectra

- NE - Region 01
- SE - Region 02
- Fredericks (AAS Poster)
- N shelf
- SE arc
- Blastwave spectrum
- Ejecta spectrum

How to model / understand the data ?
Can we get 3D information too ?
Getting 3D Information

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  Spectra
  Images

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Clues to the Third Dimension

• Assume it, e.g. Neutron Star as a sphere
• Viewing angle
  o Rotating systems, e.g., binary systems
  o Multiple instances of same system, e.g., Seyfert 1 and 2
  • Velocity, e.g., v proportional to radius
Ne X line images

- Usefulness of plus, minus, and zeroth order data
- Asymmetry in Ne X image: simple explanation:
Adjust zeroth-order "planes" to model data

Modelled zeroth-order Velocity-planes

Dan Dewey
SNORE talk, Dec.1, 2003
Ne X dispersed order modelling

MEG minus 1st order

MEG plus 1st order
Ne X zeroth-order Velocity Planes

E0102_NaX Model, 12.096 Å

E0102_NaX Model, 12.132 Å

E0102_NaX Model, 12.169 Å

E0102_NaX Model, 12.050 Å

E0102_NaX Model, 12.205 Å

MAX Contour = 13.3

MAX Contour = 18.7

MAX Contour = 16.8

MAX Contour = 4.7

MAX Contour = 17.4

0 km/s

-900 km/s +900 km/s

-1800 km/s +1800 km/s
Ne X Spatial-Velocity Map

- Analysis of the Ne X dispersed images suggests regions of red and blue shift appearing on the sky as displaced rings.
  - Red: 900 and 1800 km/s
  - Green: -900 km/s
  - Blue: -1800 km/s

Interpret this as cylinder viewed almost end-on:

Constrain: length x off-axis-angle
Contrast the E0102 velocities distribution with Cas A velocities (Willingale 2002, Figure 7)

Cas A is an inclined ring with red and blue shifted emission generally segregated.

**Same system at different viewing angles?**
3D Visualization ...

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3-D Data Structure and Uses

• Purposes for modeling:
  – Visualization ("pretty")
  – Modeling ("quantitative")

• Building model data structures, "voxels" for optically thin volumes

• 3-D arrays of scalar (plasma) parameters…

Pretty pic.s

Creation

Data structures

Ray-trace
Input events
Optically "thick" and "thin" views

• IDL project_vol.pro used here, wrapped into "v3d_project.pro"
• Optically thick and thin views of a cylinder intensity array.

Optically thick view
• Maximum value along a ray is used.
• The material has an opacity.
• Depth cuing darkens distant points.

Optically thin (i.e. X-ray) view
• Sum of values along a ray is used.
• The material has NO opacity.
• No change in intensity with distance.
Example: cone + sphere

Side view

"Optically thin" color-intensity projection:
Example: SNR 0103-72.6

Park et al., astro-ph/0309271
"more evolved version of 0102"

What 3D model agrees with observed blast wave morphology?

Spherical shells of uniform intensity:

Ro = 85
Ri = 80

Ro = 85
Ri = 65
Example: Three E0102 models

- Three geometric models for E0102 emission have been used in preliminary modeling work:
  - Hughes 1994 model: an inner ring formed from a partial sphere is embedded in a larger outer spherical shell. The model is viewed on-axis. Hughes also added discrete points which are not included here.
  - Our internal "Gaussian-tire" model: a Gaussian variation in intensity with latitude and a power-law variation with radius is viewed 34 degrees off axis. This model does well in fitting the cross-dispersion edge profile.
  - The Ne X spatial-velocity map suggests a cylinder embedded in an outer spherical shell and view about 17 degrees off axis.
"Thick" views of the three models

- Blastwave sphere
- Side view
- Cylinder in blastwave sphere

Hughes 1994

One half of "Gaussian tire"
Comparing the visualizations…

Above are sky color-intensity images produced by the three models considered (left to right): spherical ring plus shell (Hughes 1994), "Gaussian-tire" model, and the Ne X cylinder plus spherical shell.

At right is the E0102 zeroth-order image to the same spatial and intensity scale as the models. There is much structure left to model!
Example: Visualizing the Ne X Model Planes
3D Model Construction

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Model Parameters…

- What parameters to define the 3D model?
  - EM, T, tau, abunds in regions
  - Basic: n_ion, (n_e), T_e, T_ion

- Hydro models as examples of data structures…

- Goal of model is to generate "photons" from the sky: X, Y, Energy.

Generating "photons"/"events"

3D Scalar Line Intensity

Randomly generate photons from the object.

Modify the observed energy by a radial velocity field.
Cylindrical emission. Radial velocity field. Generate photons. Select +/-900 km/s. Create color composite. Similar to E0102 map.
Summary and Next Steps

3D Information useful/necessary for SNR modeling.

Can be obtained from velocity, absorption, etc.

E0102 is a good test object for 3D modeling.

Create spatial counterparts of our models, e.g., sedov and Type Ia (Badenes et al.) models have explicit spatial variations and make imaging predictions.

3D in modeling and analysis is a many headed Hydra - many fronts to make progress on!
The End

Thanks to Manami Sasaki for invitation and logistics.