HETGS observation of Cas A: Looking at the trees in the forest

J.S. Lazendic, D.Dewey, C.R. Canizares, and N.S. Schulz
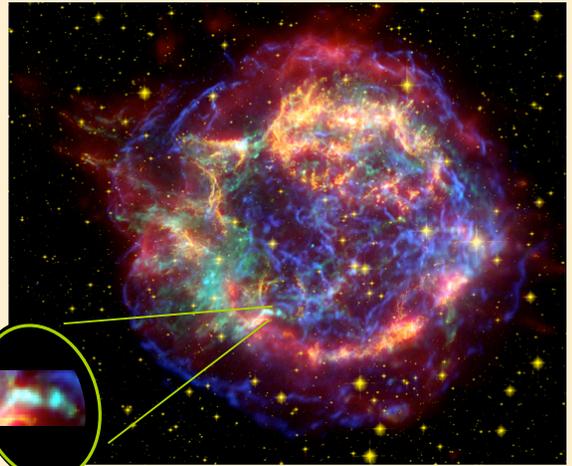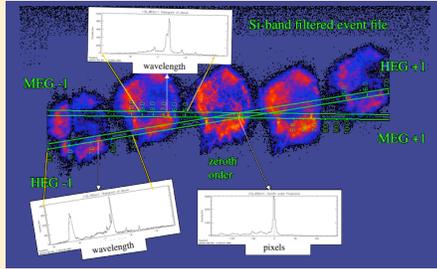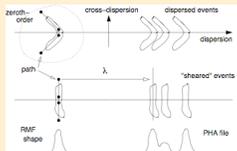MIT Kavli Institute, Cambridge MA, USA

Image of Cassiopeia A combining observations from three of NASA's Great Observatories: The Chandra X-ray data is shown in green and blue (silicon line emission and 4-6 keV continuum, respectively), the Hubble optical image is in yellow, and the Spitzer infrared image is shown in red.
Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Infrared: NASA/JPL-Caltech
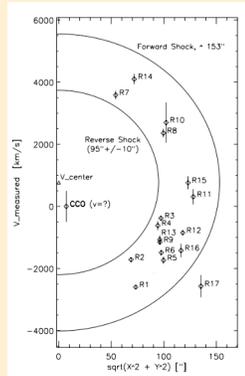
Introduction

We present high-resolution X-ray spectral results from the young supernova remnant Cas A using a 70ks observation taken by the *Chandra* High-Energy Transmission Grating Spectrometer (HETGS). Line emission, dominated by Si and S, from many bright, narrow regions allows us to measure these regions' kinematic and plasma properties. With these high-resolution measurements we hope to advance the 3D modeling of Cas A begun by Markert et al. (1983) using the *Einstein* Focal Plane Crystal Spectrometer.

HETGS image of Cas A filtered on the Si lines. The un-dispersed "zeroth-order" image is seen in the center with an example profile of a narrow, bright feature. To either side along the two grating dispersion axes, MEG and HEG, are seen dispersed images of the remnant in the Si lines. Precise measurement of the location of the dispersed features gives accurate Doppler velocity measurements and line flux information.

Filament Analysis

We used custom software (written in IDL) that basically follows the steps of the CIAO threads for grating spectra, but accounts for an extended, filament-like source when creating spectra (PHA files) and the coresponding instrument response files, RMFs, which relate photon wavelength to dispersion location. The resulting PHA, RMF, and a standard ARF file can then be used in, e.g., ISIS to carry out model fitting.

Simple schematic of the filament analysis. A "path" is defined on the zeroth-order and is used to narrow the projection of lines dispersed from the feature.

*The 17 bright, narrow regions we studied are indicated **at right** on a silicon-line image of Cas A.*

*The plot **at left** has a data point for each of our regions indicating: measured velocity vs. the radial distance of the region from the optical expansion center. These points are seen to lie within a narrow shell in 3D between the reverse and forward shock locations (Gotthelf et al. 2001.) The one exception is R17 - is it part of the NE jet?!*
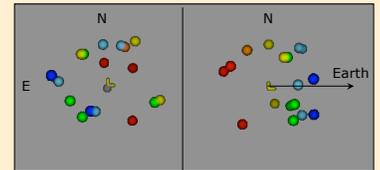
Doppler-shift Results

We derive Doppler shifts for these 17 regions, values range from a blue-shift of 2500 km/s to a red-shift of 4000 km/s. Combined with the spatial sky locations, these velocities are consistent with the Reed et al. (1995) velocity center of +770 km/s and an expansion rate of ~ 0.2 % per year (DeLaney & Rudnick 2003.) This eliminates an apparent "mismatch" of Doppler and transverse velocities (DeLaney et al. 2004) based on earlier X-ray results (Willingale et al. 2002.)

Location of the regions in Si ratio-ratio space, including an NEI kT-tau grid of model values.

Line Diagnostics

We use the high-resolution spectra from the HETGS to investigate the plasma state of the regions using line diagnostics. The forbidden to resonance line ratio, f/r, of the He-like triplet and the Si XIV to Si XIII line ratio are used (**at left**) to determine kT and tau (= n_e t) values for each region under the assumption of a simple NEI plasma model.

Plasma Density

With each regions' kT and tau determined from the line ratios, we can determine the remaining parameters of a single VNEI model (Borkowski et al. 2001) by fitting the regions' non-dispersed zeroth-order spectra (**at left**.) Assuming an oxygen-rich plasma (Laming & Hwang 2003) and setting N_H to 1.5×10^{22} cm^{-2}, we obtain reasonable fits in the Mg through Ca range.

We use the fit "norms" and abundances with the region volumes to determine plasma quantities for the regions: electron density, n_e ~20 to 200 cm^{-3}; the time-since-shocked t_{shock} = tau / n_e ~ 10 to 140 years; and the oxygen mass fraction ranging from 0.83 to 0.97.

The zeroth-order ACIS spectrum from region R9 with prominent Si XIV and Fe-K lines. The VNEI model curve has kT and tau fixed from the line ratio results.

Color = Velocity

Key (km/s):
Red > +2500; Orange +2500 to +1000; Yellow +1000 to -500; Green -500 to -1300; Light-Blue -1300 to -2000; Blue < -2000
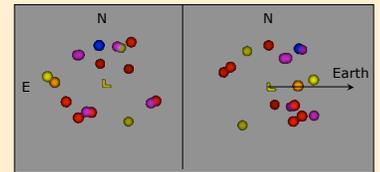
*Using the velocities, the regions can be assigned a location along the line-of-sight adding a third-dimension. The region locations are shown here in "front" (Sky) view (**left**) and a "side" (3rdD) view (**right**.)*

Color = Temperature

Key:
Blue < 0.6 keV; Magenta 0.6-0.8 keV; Red 0.8-1.4 keV; Orange 1.4-3.0 keV; Yellow 3.0-5.0 keV
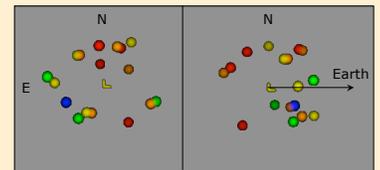
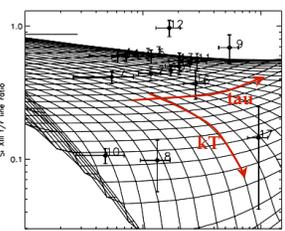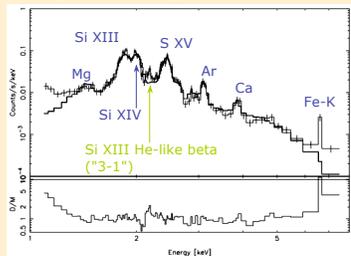### Color = t_shock

The time-since-shock-passage is given by:
t_shock = tau / n_e .
The regions in the "back" of Cas A appear to be just recently shocked compared to most regions in the "front" which have longer t_shock's.
Key:
Red < 30 yr.s; Orange 30-60 yr.s; Yellow 60-90 yr.s; Green 90-125 yr.s; Blue > 125 yr.s

The Regions in 3D

References

Borkowski, K.J. et al. 2001, ApJ, 548, 820.
DeLaney, T. & Rudnick, L. 2003, ApJ, 589, 818.
DeLaney, T., et al. 2004, ApJ, 613, 343.
Gotthelf, E.V., et al. 2001, ApJ, 552, L39.
Laming, J.M., & Hwang, U. 2003, ApJ, 597, 347.
Lazendic, J., et al. 2006, in preparation.
Markert, T.H., et al. 1983, ApJ, 268, 134.
Reed, J.E., et al. 1995, ApJ, 440, 706.
Willingale, R., et al. 2002, A&A, 381, 1039.

Contact: jasmina@space.mit.edu

Acknowledgments