2.8 Science—Mapping Elemental and Velocity Structures in Cas A with Micro-X – Figueroa-Feliciano PI, MIT

Figure 1: (Left) Chandra image. (Middle) Micro-X image of Cas A with its 256-pixel array. (Right) Simulation of a Micro-X 30 ks global Cas A spectrum containing 1.3x10^6 counts.

Supernova remnants (SNRs) are an integral part of the cycle of matter from which stars, planets, and life itself are formed. This investigation addresses the following fundamental NASA Science Questions: How do planets, stars, galaxies, and cosmic structure come into being? When and how did the elements of life and the universe arise?

Cassiopeia A is the 2nd youngest known SNR in the Galaxy (340 yrs old), and has been studied extensively across the electromagnetic spectrum from radio to gamma-rays. Because it is bright, and its X-ray and optical emissions are dominated by the supernova ejecta formed during the explosion, it is a premier testbed for studying the physical processes that occur in core-collapse supernovae. We now know that it was the product of a Type IIb supernova of a massive star that retained a thin H envelope. Detailed studies of Cas A will thus shed light on the physics of both Type IIb supernovae and their progenitors. Micro-X combines a 2 eV energy resolution transition-edge sensor (TES) X-ray micro-calorimeter with a 30'' resolution mirror to offer unique capabilities to address the following questions:

Question 1: What are the physical properties of the shocked ejecta and CSM, and what do they tell us about the cycles of matter in the Universe?

Question 2: What was Cas A’s progenitor, how did it explode, and how does that fit into the range of core-collapse explosion scenarios?

A non-dispersive high-energy-resolution imaging spectrometer can map the distribution, velocity structure, and thermal state of the ejecta and shocked circumstellar material (CSM) in Cas A. The physical conditions of the emitting gas are encoded in the ionization state of the plasma primarily via the line fluxes of the H- and He-like emission from abundant elements, e.g., Mg, Si, and the range of Fe ions, Fe XVII to Fe XXVI (Figure 1). This detailed mapping of the shocked ejecta and CSM will enable understanding of the mechanism of the explosion.

The Fe-rich and Si-rich ejecta that are of primary interest in Cas A are distributed on different dynamical structures, but are often superposed against each other. With several high-resolution spectral lines, we can test if the plasma states are the same for the Fe- and Si-rich ejecta. In the southeast, the ejecta are especially Fe-rich, and in that region we will also identify diffuse Ni-L emission that is not detectable with Chandra and XMM observations. Fe and Ni are particularly important because they are formed during the explosion itself.
The Micro-X observation will map the X-ray emitting O in Cas A. The total oxygen content constrains the properties of the supernova progenitor, but is difficult to measure in Cas A due to strong absorption towards the SNR ($N_{\text{H}} \sim 10^{22}$) and the low resolution of CCD spectrometers.

High energy resolution will also provide high-quality dynamical maps through Doppler shifts, which trace the dynamical evolution of ejecta and encode information about the explosion. Since Cas A has complex small-scale structure on the order of 1'', each of our pixels will contain emission from multiple components, each having their own Doppler velocity. With line brightnesses of \(~1000\) counts at 2 eV resolution, we will attain a velocity resolution of \(~20\) km/s. Our Micro-X spectra will be used in conjunction with the Chandra ACIS and HETG spectra to model different abundance, ionization, and Doppler structures at our 30'' spatial sampling. In addition to measuring individual ejecta knot Doppler velocities, we will also measure the “dynamical width” of the shocked ejecta, which is determined by the myriad of low-level emission that contributes to the broadening of spectral lines.

**Technical Approach—Spectroscopy with a TES Microcalorimeter Instrument**

![Figure 2: The current suborbital Micro-X science instrument.](image)

Micro-X offers a unique combination of bandpass, collecting area, and spectral and angular resolution. The spectral resolution across the 0.2-3.0 keV band is 2 eV. The angular resolution is 30'' with an effective area of 300 cm$^2$ at 1.5 keV. An 16x16 array of 256 pixels, at a 20'' pitch, gives a field of view of 5.3' that is very well matched to Cas A (Figure 1). Figure 2 shows the current suborbital science instrument. The TES array requires a cryogenic system with a base temperature of 50 mK which uses a liquid He bath as its heat sink. Due to this consumable, our current system has a stand-alone operational time of \(~30\) hours. Assuming 30% on-target science efficiency in orbit, this would give us \(~30\) ks of observing time, equivalent to \(100\) rocket flights.

Micro-X will resolve the confusion that the Japanese led Astro-H mission (set for launch in 2013 with a silicon thermistor microcalorimeter on board) will have when it looks at Cas A with a 1.2' resolution mirror, 6x6 array of 32 pixels at a 30'' pitch, and \(~5\) eV resolution. Micro-X will have \(~3\)x the imaging resolution, \(~3\)x the energy resolution, and 8x more pixels than Astro-H. A Micro-X 30 ks observation will have an integrated total of \(1.3\times10^6\) counts in the spectrum, which will enable separate high-resolution spectral analysis on each of its smaller 256 pixels. The combination of better imaging and higher energy resolution enables Micro-X to study the substructure in Cas A to a level not possible with Astro-H. For \(~$1M\), a modified cryogenic tank would give the mission a 30-day lifetime and open up the possibility of a multi-target observing program with a broader range of science objectives.