3D Maps of the Supernova Remnant Cassiopeia A

Greg Olmschenk, Karl Isensee, Lawrence Rudnick and the Cas A Group*

Introduction

Cassiopeia A (Cas A) is a very young supernova remnant (pictured in Fig. 1) in the constellation Cassiopeia.

Supernova Remnant – Supernovae are the explosive deaths of stars at least 8 times as massive as the Sun. A *supernova remnant* is the remains of a supernova observed up to ~100,000 of years after the initial explosion. Individual clumps of material from the supernova are made up of plasma and are called “ejecta”.

Shock Waves – A “forward shock” wave forms in the ejecta during the supernova explosion itself and moves outward at over 5000 km/sec. The forward shock eventually reflects off of surrounding material about a hundred years later. This results in a “reverse shock” wave which moves back toward the center of the remnant.

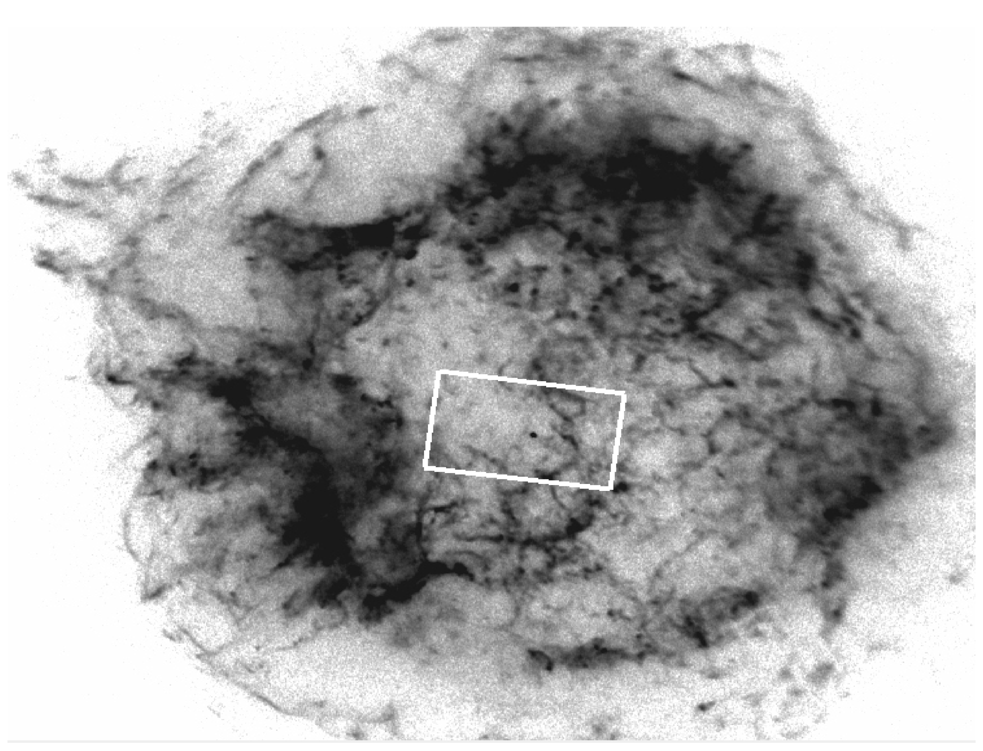

Fig 1: Cassiopeia A as seen in X-rays. The box indicates the region from which we have data and corresponds to the x and y axes of the 3D images in Fig 3.

Goals of Project

Our goals are to determine the density and temperature of recently produced supernova ejecta and to determine how plasma is affected by encounters with strong shock waves. We accomplish these goals by observing infrared light from ejecta which have not yet encountered Cas A's reverse shock with NASA's *Spitzer Space Telescope*. These ejecta, whose location is indicated in Fig. 1, are currently being observed only 330 years after the initial explosion (Thorstensen et al. 2001).

Methods and Results

We plot the light from two different electron transitions of a Sulfur ion in Fig. 3. We determined the location of the ejecta along the z axis (the axis parallel to our line of sight) by measuring the velocity of the ejecta with the Doppler effect. Since we know that all of the ejecta originated at the same point at the same time, we can turn this velocity into a spatial coordinate.

We observe that the 3D structures formed by the ejecta are very similar for all the observed electron transitions of the same atom (illustrated for two transitions in Fig. 2). This similarity allows us to obtain intensity ratios of the light for each region in Cas A.

We use recent theoretical models (Eriksen et al. 2009) to determine the temperature and density of the ejecta. Eventually we will make 3D maps of these properties. Our preliminary results indicate that typical densities are around 50-100 particles per cubic centimeter at a temperature of ~500 K. We compare these densities to other well known environments in Fig. 4.

We will also eventually compare our results for ejecta that has yet to encounter the reverse shock to similar results for recently shocked ejecta in order to determine how a strong shock modifies plasma.

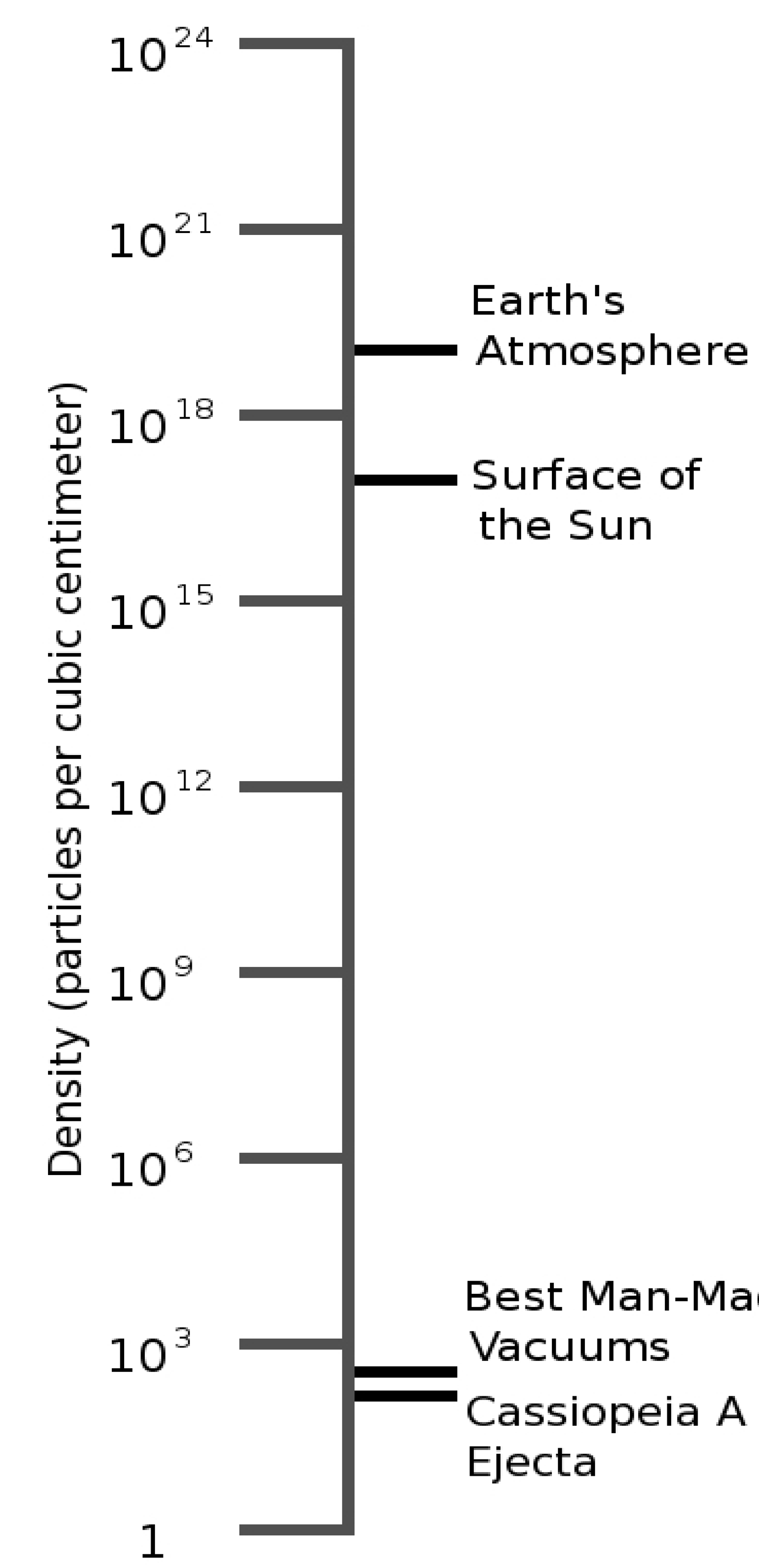

Fig 4: Particle density of Cas A ejecta compared to other environments.

Density and Temperature

Electrons in an atom can move between discrete energy levels. However, they must either absorb or emit specific amounts of energy in order to make such a transition. This energy is observed as light at specific wavelengths.

The likelihood of any specific transition occurring (and therefore being observed) is a sensitive function of the density and temperature of the plasma. We know what this dependence on density and temperature is from theoretical and laboratory work, and can therefore use observations to determine the density and temperature of the plasma.

For example, we show the ratio of intensity of light from two different electron transitions in Sulfur ions as a function of density in Fig. 2. Strictly speaking this test only applies to recently shocked plasma, but we include it here as a simple illustration of the slightly more complicated procedure that we used with our plasma. If we measure the ratio of the intensity of light at a specific location from these two transitions, we can determine the local density of the plasma. We use similar tests to determine the temperature of the ejecta.

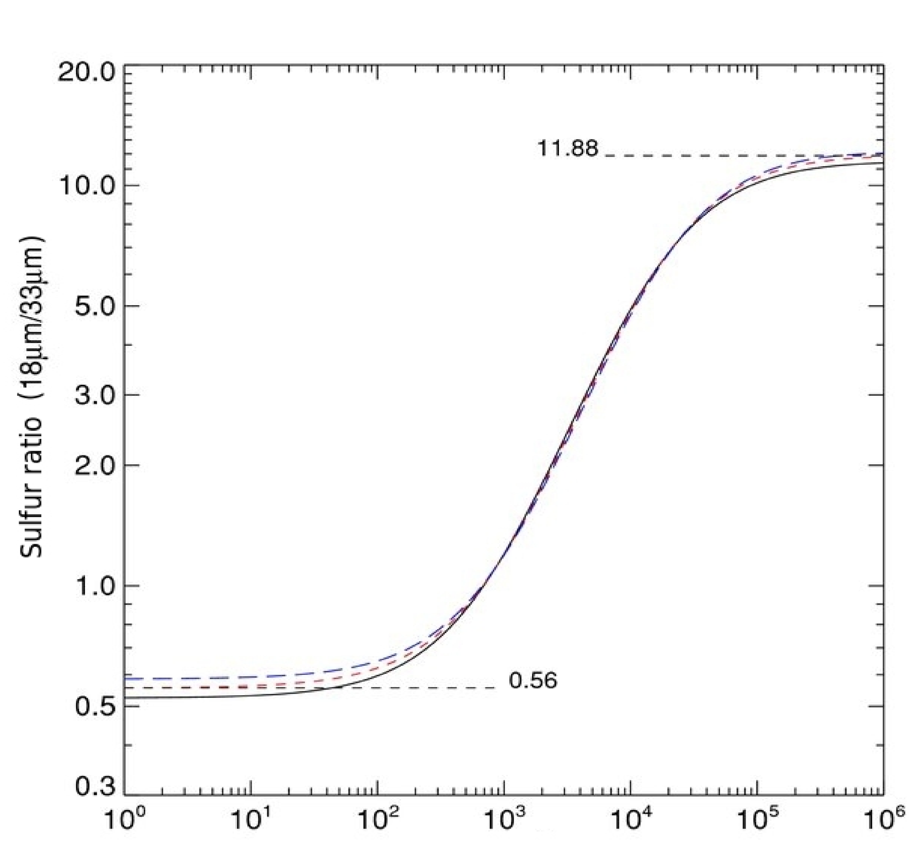

Fig 2: The ratio of the amount of light from two Sulfur ion transitions as a function of density

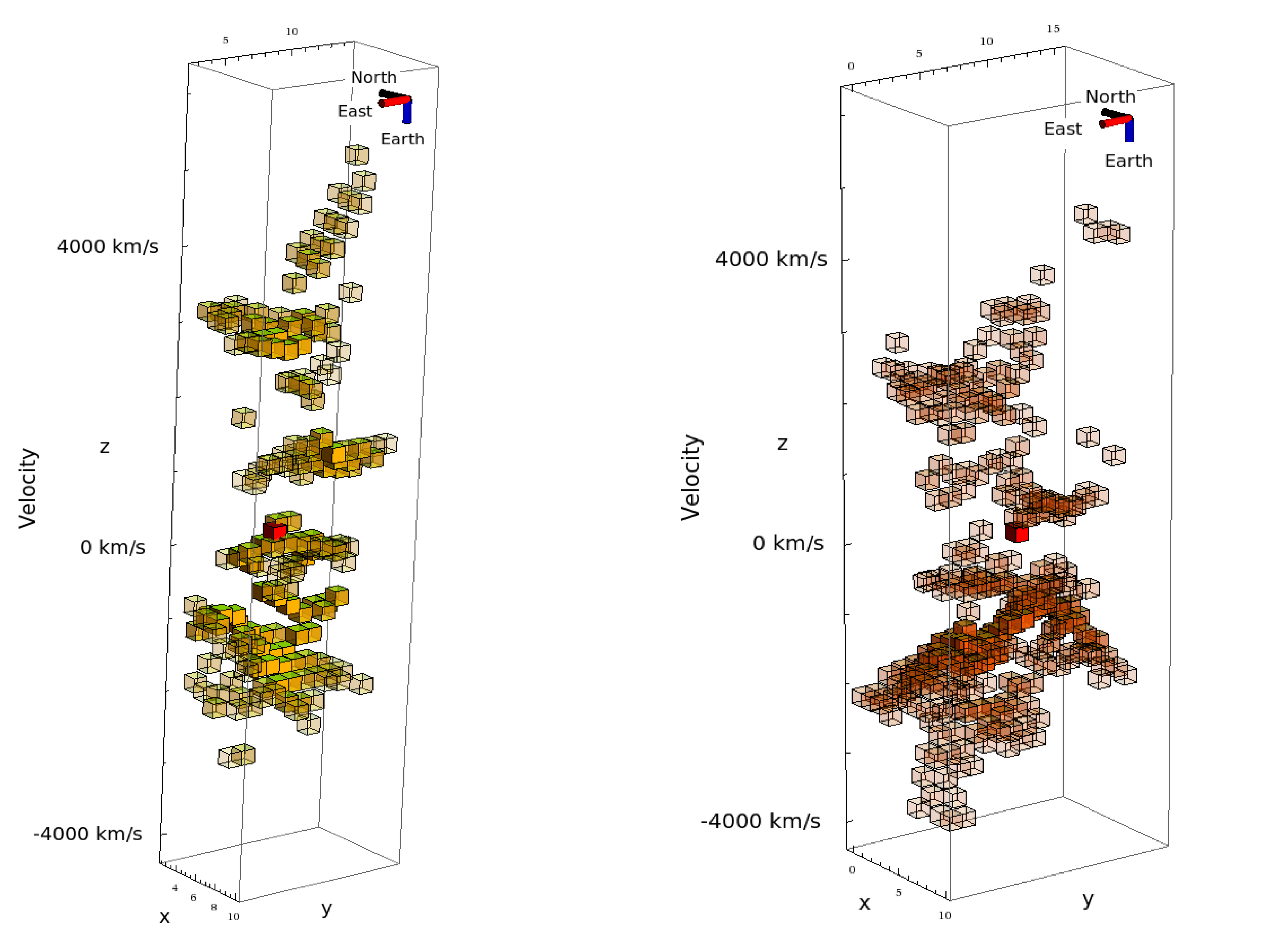

Fig 2: 3D map of energy from two different electron transitions in Sulfur ions. The z axis has been stretched by a factor of 1.8 for clarity.

References

Eriksen, K.E. 2009, ``New Observational and Theoretical Insights on Cassiopeia A”, Ph.D. thesis, Arizona University

Thorstensen, J. R., Fesen, R. A., & van den Bergh, S. 2001, AJ, 122, 297

* Tracey DeLaney (MKI), J.D. Smith (Toledo), M.D. Stage (UMass), Jeonghee Rho (SSC), William T. Reach (SSC), Takashi Kozasa (Hokkaido), Haley Gomez (Wales), Glenn E. Allen (MKI), J.E. Davis (MKI), and J.C. Houck (MKI)

Funding

This work was supported in part by NASA/SAO Award No. AR5-6008X and NASA/JPL through award 1265552 to the University of Minnesota.