An Analysis of Archival Observations Made of Galactic Supernova Remnants by the *Chandra* X-ray Observatory

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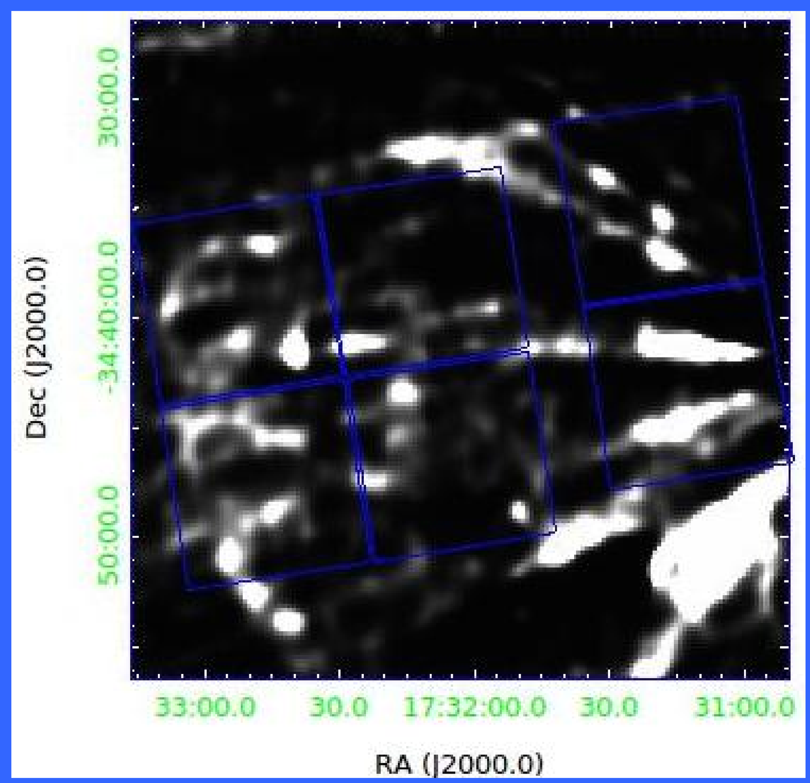
Abstract: Since its launch in 1999, the Chandra X-ray Observatory has spurred explosive growth in the study of Galactic supernova remnants (SNRs) due to its unsurpassed angular resolution (1 arcsecond at 1 keV) and its moderate sensitivity. We are currently analyzing archival observations made by Chandra of two particular classes of SNRs: mixed-morphology SNRs (which feature contrasting center-filled thermal X-ray morphologies with shell-like radio morphologies) and synchrotron X-ray SNRs (which feature X-ray spectra dominated by synchrotron emission). To illustrate some of our initial results, we present spatially resolved spectroscopic analyses of the mixed-morphology SNR 3C 397 and the synchrotron X-ray dominated SNR G353.6-0.7. In the former case, we have fit extracted spectra with a recombination-dominated thermal plasma model to determine the ionization state of the plasma associated with this SNR. In the latter case, we have fit extracted spectra with synchrotron models to determine the maximum energies of cosmic-ray electrons accelerated by the SNR.

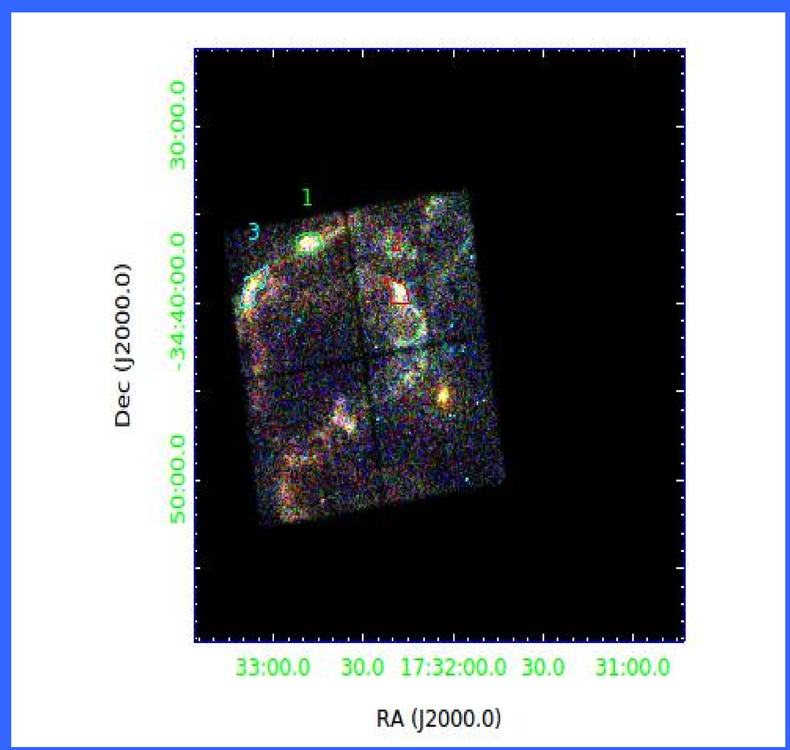
An Analysis of an Archival Chandra Observation of the Galactic Supernova Remnant G353.6-0.7

We present the analysis of an archival Chandra observation of the Galactic Supernova Remnant G353.6-0.7. G353.6-0.7 is an unusual remnant in that its X-ray spectra is dominated by synchrotron radiation. This means that it is accelerating a large number of cosmic ray particles to almost the speed of light. While supernova remnants have been theorized to accelerate particles up to energies of approximately 3000 TeV, no remnants have been discovered that accelerate particles to even within an order of magnitude of this. We analyzed this remnant in an effort to understand why no remnants accelerate particles to this limit.

Twelve spatially resolved regions of the remnant were identified, and spectra was extracted using the specextract tool in CIAO. The spectra was then fit with a powerlaw model and an srcut model using XSPEC. Using the frequency derived from the srcut fit, we calculated the maximum energies of particles being accelerated in certain regions. The highest energy we calculated was 152 TeV, still far short of the 3000 TeV predicted.

The figures on the left side of the middle column (going from top to bottom): a radio map of G353.6-0.7 with the footprint of the *Chandra* observation overlaid (top figure), the *Chandra* observation of G353.6-0.7 shown in three colors (red, green and blue corresponding to low, medium and high energy X-ray photons, respectively – middle figure) with three of the brighter regions indicated, and a table (bottom) that summarizes the parameters of the fits to these three regions. These fits have used the measured flux densities at 1 GHz to constrain the fits: the fitted values for the break frequency at which the synchrotron spectrum deviates significantly from a straight power law are shown. The value of the break frequency is used to calculate the cutoff energy of the electron distribution.

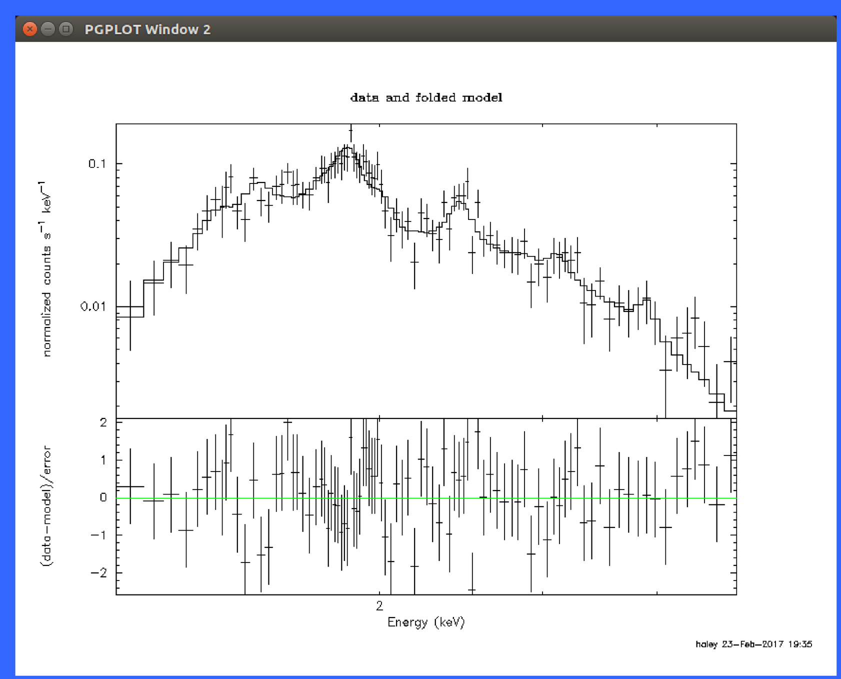


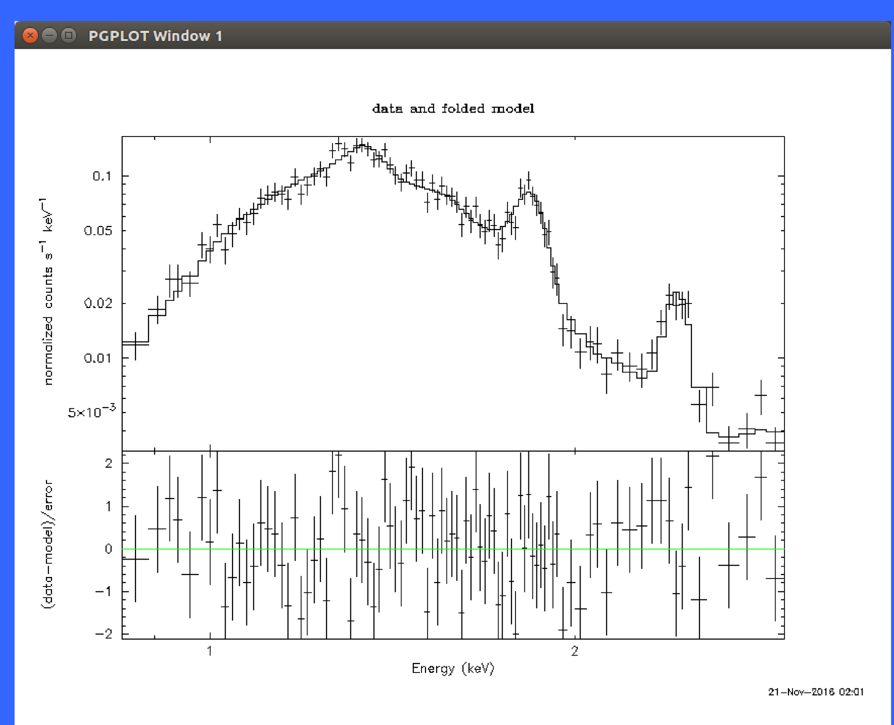


Region	1	2	3
N_h (10^{22})	1.07(1.36, 0.97)	1.51(1.81, 1.25)	0.69(0.80, 0.59)
Radio Spectral Index	0.71(0.75, 0.66)	0.65(0.69, 0.60)	0.73(0.74, 0.71)
Break Frequency	9.43E17	5.47E17	3.73E18
Break Frequency Upper Limit	4.94E18	3.98E18	1.00E25
Flux at 1 GHz	0.41746	0.15828	0.4656
Cutoff Energy (TeV)	76.8	58.5	152.6
Cutoff Energy Upper Limit (TeV)	175.7	157.7	250000


3C397


CTB 37A





A Spatially-Resolved X-ray Spectroscopy of the Galactic Supernova Remnants 3C397 and CTB 37A

We present a comparison of the X-ray properties of the supernova remnants CTB 37A (G348.5+0.1) and 3C 397 (G41.1-0.3). An analysis of archival *Chandra* observations was done for both of these remnants. This study has shown that these supernova remnants are both very different from each other. Because of the models that were used in order to fit the spectra of CTB 37A, it can be said that it is at or is very close to being at ionization equilibrium. However, 3C397 cannot be fit with the same model and because of how its spectra is fit it is shown that it is not at ionization equilibrium. This study also demonstrates that to obtain an adequate fit for the spectra of different regions of 3C 397 a single thermal component model will not work to fit the thermal emission of the remnant, but instead it is necessary to utilize two thermal components.

To analyze the supernova remnant CTB 37A it was first spatially resolved into six different regions. These regions will be referred to as northeast top, northeast bottom, southeast top, southeast bottom, northwest, and southwest. Spectra were then extracted from each of the regions listed. The northeast and southeast regions can be adequately fit with a single thermal model. The northwest region was also fit using the same model. Since the use of a variable recombination non-equilibrium ionization (VRNEI) model provided no improvement in the spectral fitting, it is apparent that the X-ray emitting plasma is not in a state of over ionization. The southwest region was not able to be fit because of the very low amount of photon counts that are present in this area. This result meant that instead of getting a decent spectrum the signal was essentially all background noise.

In contrast, the extracted spectra for 3C397 have not been fit so easily. This supernova remnant was spatially resolved into a multitude of smaller portions and spectra were then extracted from each of them. An attempt was made to fit the results of this process with a single non-equilibrium ionization thermal model. However, this was unsuccessful. Because of this, contrary to what was originally believed, a two thermal component model was required. There has been some success in fitting the spectra of small regions with a two VRNEI component model. The work that is being done is going further than work done on this region before which only utilized a two component constant temperature, plane parallel shock plasma model that is a much simpler thermal component. We have found that on small spatial scales the X-ray emitting plasma of 3C 397 is over-ionized. The use of the VRNEI model in our study helps to identify the presence of over-ionized plasmas in the supernova remnants.