Chandra ACIS X-ray Observations of the Cygnus Loop

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Abstract

The Cygnus Loop is one of the nearest supernova remnants (440pc) and has been studied extensively in various wavebands. However with the new capabilities of the Chandra X-ray observatory, studies can be carried to an entirely new level, both in terms of spectral resolution and spatial resolution. The ROSAT PSPC observations of the Cygnus Loop [1] revealed an enigmatic bright V-shaped region on the south-western limb (near RA 20h46m and dec.+30.0deg). The left side of the V is one of the hardest (in the ROSAT band) regions in the Cygnus Loop and the right side is one of the softest. Chandra ACIS observations were obtained covering the region of the V, to obtain a high resolution image of the region and to obtain spatially resolved spectra.

1. Introduction

The Cygnus Loop is a well-studied, nearby [3] large-diameter supernova remnant (SNR) with a clear shell-type morphology in radio, infrared, optical, and x-ray bands. Previous radio observations are summarized by [6] and recent radio observations are presented in [10] (1420 MHz continuum and polarization observations), [11] (408-1420 MHz and 1420-2695 MHz spectral index variations), [12] (21 cm neutral hydrogen observations of the full Cygnus Loop region) and [13] (detection and analysis of an expanding shell of neutral hydrogen along the northeast limb of the Cygnus Loop). The optical nebula is clearly visible on the Palomar sky survey plates. An optical and x-ray study of an optical knot on the SE rim of the Cygnus Loop is given by [5], which also includes references to previous optical studies of the Cygnus Loop.

[8] presented the Einstein IPC x-ray image. Other x-ray observations of the Cygnus Loop are described by [9], [7], [2] and references therein. Studies from the ASCA and ROSAT missions include: an x-ray spectroscopic study of the NE rim of the Cygnus Loop with ASCA by [16]; a ROSAT HRI observation of the western edge of the Cygnus Loop [14]; ROSAT images and spectra of a region in the northern part of the Cygnus Loop [4]; the chemical composition of selected regions using ASCA data [17]; and ROSAT PSPC x-ray images of the

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Fig. 1. ROSAT All-Sky Survey 0.2-2.0 keV map of the Cygnus Loop.

entire Cygnus Loop, in soft and broad bands, including the color map and the "energy image" [1]. Spatially resolved spectra, taken by the Chandra ACIS, of the western edge of the Cygnus Loop are presented by [15].

The southwest "V" region of the Cygnus Loop was first noted as unusual in the observations of [1], which showed the left side of the V to be one of the hardest (in the ROSAT band) regions in the Cygnus Loop and the right side to be one of the softest. Fig. 1 shows the ROSAT 0.2-2.0 keV image of the Cygnus Loop from the ROSAT All-Sky-Survey. The southwest "V" is the bright region inside the western limb about two-fifths of the way up from the bottom of the image. Here are presented Chandra Advanced CCD Imaging Spectrometer (ACIS) observations of the area covering the "V".

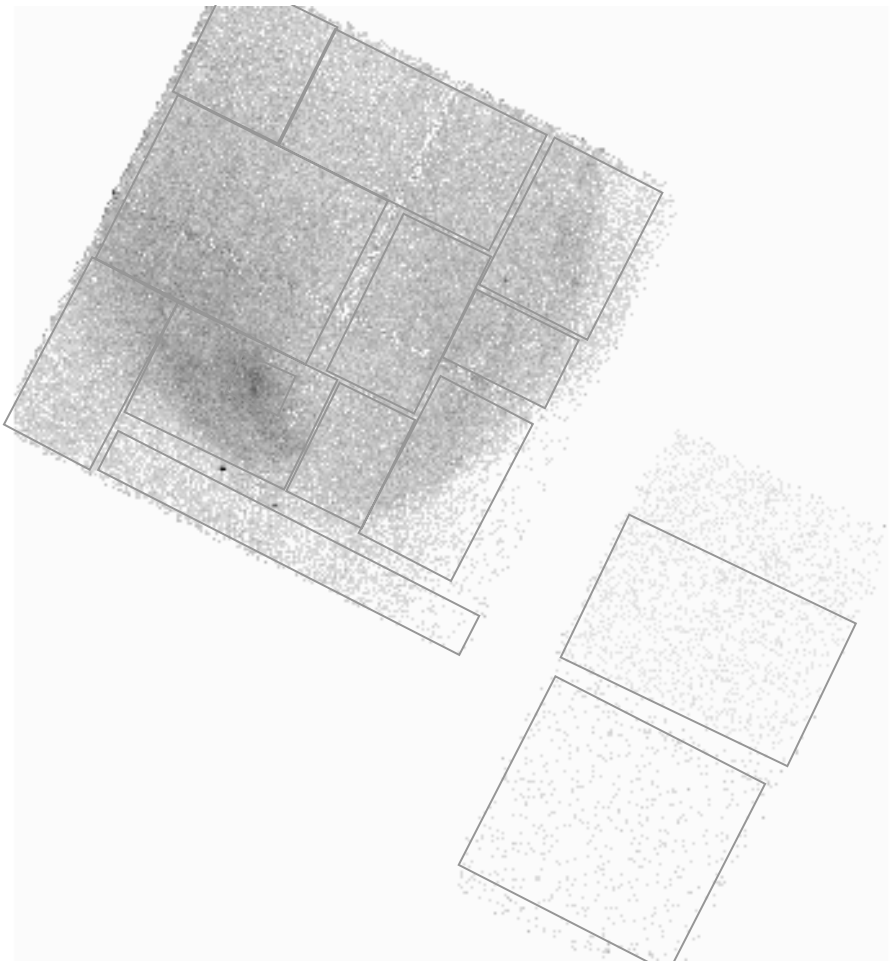

Fig. 2. The Chandra ACIS image of the southwest V region, showing the 14 areas used for spectral analysis.

2. The Observations

A 10 ks exposure of the southwest V region was obtained on 2000 May 21 with the Chandra ACIS. The field of view is roughly 17 arcmin by 25 arcmin, and included the data from the six ACIS CCDs I0, I1, I2, I3, S2 and S3. Fig. 2 shows a processed image from the data from these six CCDs oriented with north up. I0, I1, I2 and I3 form the large square and S2 and S3 are the pair of CCDs with fields-of-view just outside the limb of the Cygnus Loop (see Fig. 1). The processed image in Fig. 2 covers the energy band 0.3 to 1.4 keV and includes destreaking and exposure map corrections. Images were also made in 0.3-0.5 keV, 0.5-0.7 keV and 0.5-2.0 keV bands.

A fairly strong point source ($\sim$ 850 counts) was found just south of the brightest diffuse region in the image. For spectral analysis the point source was

analyzed separately and removed from the diffuse regions being analyzed. The diffuse emission was divided into 14 regions which were chosen to have nearly uniform hardness ratios within each region, using the three energy bands 0.3-0.5 keV, 0.5-0.7 keV and 0.7-2.0 keV. The 14 regions, including 2 regions outside the limb of the Cygnus Loop in CCDs S2 and S3, are shown in Fig. 2. Pulse height spectra were extracted for each region and weighted response matrices and ancilliary response functions were constructed for each region.

3. Results and Summary

The point source and a background annulus around the point source were fit simultaneously to obtain a column density $N_H = 3.4 \times 10^{21} cm^{-2}$, source power law index 0.34, and background Raymond Smith spectrum with temperature 0.20 keV. The 14 diffuse regions are currently under analysis. The left side of the southwest V is clearly hotter than the right side, as suspected from the ROSAT PSPC images. Column densities, temperatures, emission measures and metal abundances for the diffuse emission are being determined. Independent of the spectral analysis, the 0.3-0.5 keV, 0.5-0.7 keV and 0.7-2.0 keV images show clearly that the V has a hot dim interior with a cool narrow rim, and that the bright emission on the left side of the V is hotter than the bright emission on the right side of the V.

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