X-Ray Study of the Southern Extent of the SNR Puppis A

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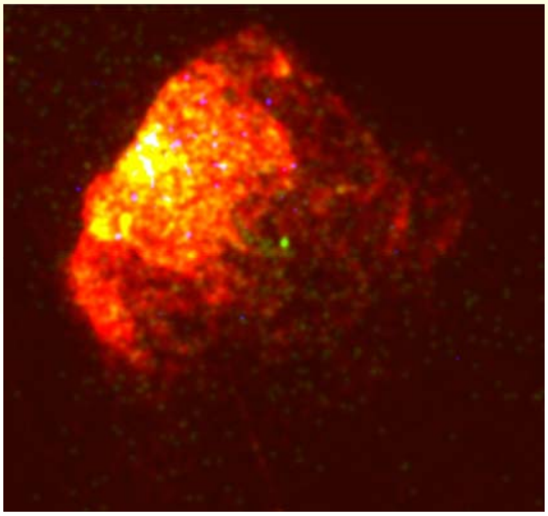
Introduction and Observations

Puppis A is a middle-aged galactic supernova remnant (SNR), approximately 50' in diameter. Its high X-ray surface brightness makes it one of the brightest SNRs in the X-ray sky. Based on optical spectroscopy, Puppis A is categorised as oxygen-rich, a class of SNRs that also includes Cassiopeia A. Spectral imaging studies have shown emission from shock-heated interstellar medium (ISM) as well as signatures of SN ejecta. The composition of ejecta features implies that Puppis A most likely originated from a core-collapse SN. This is consistent with the presence of a central compact object (RX J0822-4300, Petre et al. 1996), a radio quiet neutron star.

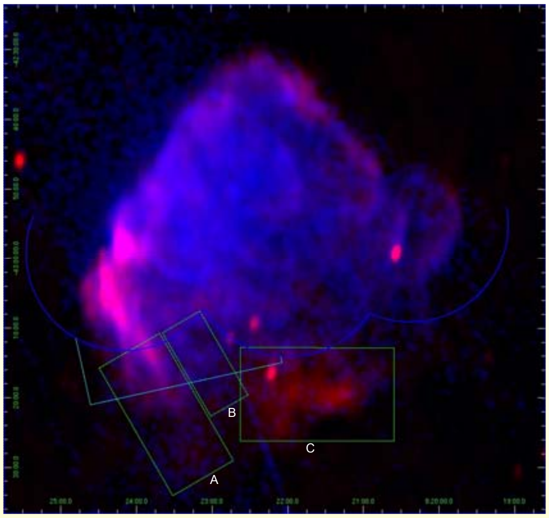
Puppis A has been extensively studied across the whole electromagnetic spectrum. In X-rays, much of the remnant has been observed by the major X-ray missions, such as *ROSAT*, *XMM-Newton*, *Chandra* and *Suzaku*. Recent X-ray observations have shown evidence of Si-rich ejecta in the NE (Hwang et al. 2008), fast moving metal rich ejecta knots and O-Ne-Mg rich ejecta filaments in the NE (Katsuda et al. 2008, Katsuda et al. 2010). However, towards the south and southeast edges, there are regions of X-ray emission which have not been observed by pointed observations. Although the X-ray emission here is faint, these regions are nevertheless of interest, not least as they coincide with features of enhanced radio emission.

In both the S and SE, the shape of the remnant's edge is roughly similar between X-rays and radio, and in the SE there is a large scale correlation in spatial emission. However, the enhanced radio feature in the S is not as apparent in X-rays.

Puppis A in its entirety has however been observed by XMM-Newton through observations performed during slew maneuvers, as part of the XMM-Newton Slew Survey (Saxton et al 2008). Here we present X-ray spectral results of the little studied S and SE regions based on XMM-Newton Slew Survey data.



False-colour X-ray image of Puppis A as observed by the XMM-Newton Slew Survey. Red, green and blue denote the 0.20 - 1.45, 1.45 - 2.45 and 2.45 - 8.00 keV bands respectively. The slew paths cover the entire extent of Puppis A, totalling ~ 1.5 x 10^5 counts (including background) in the 0.2 – 8 keV band.



Two-colour combination of the emission associated with Puppis A with radio emission in red and X-ray emission in blue. The radio data were obtained with the VLA in the CnB configuration at 327 MHz. The final beam size is 90" x 45" and the rms noise level is 10 mJy/beam. (Castelletti et al. 2006). The X-ray emission was obtained from observations of the XMM-Newton Slew Survey.
In this image, the southernmost extension of previous pointed X-ray observations is indicated by the blue and cyan lines (which represent XMM-Newton and Suzaku field-of-view limits respectively).
Beyond this, towards the south, the slew data show a continuation of faint X-ray emission. Here we identify three regions of interest for spectral analysis (green boxes):
• Region "A" contains the continuation of the SE arm, and contains ~ 1600 source counts.
• Region "B" encloses the SE arm adjacent area of lower surface brightness, containing ~ 1200 source counts.
• Region "C" coincides with the area of enhanced radio emission to the southern edge of the remnant, with ~ 570 source counts.

Spectral Analysis

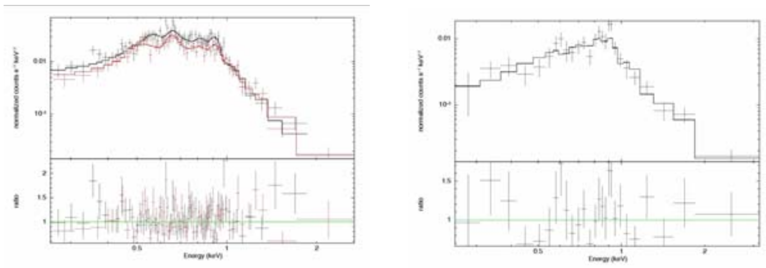
Data were extracted from regions "A", "B" and "C" and were fit in the 0.3 – 5.0 keV band using the constant temperature, plane-parallel shock model `vpshock`, combined with the `Tbabs` absorption component.

Background spectra were obtained from slew data of off-source regions. A comparison was made using background spectra obtained from various locations around the remnant and this yielded no significant differences in spectral results.

The hydrogen column density, N_H, was fixed to 3 x 10^{21} cm^{-2}, a typical value for Puppis A derived from *Suzaku* observations (Hwang et al. 2008).

Plasma temperature, ionisation time scale and normalisation were freely varying parameters.
Elemental abundances were initially fixed to the solar values of Anders & Grevesse (1989), but were then successively left to vary freely if warranted by an F-test (> 99% likelihood criterion).

The spectra, best fit models and resulting parameters are shown below.



X-ray spectra and best-fit models: Left panel: region "A" (black) and "B" (red). Right panel: region "C"

	Region "A" SE arm	Region "B" adj. to SE arm	Region "C" South
kT (keV)	0.38 ± 0.09	0.29 ± 0.07	1.5 (0.9–2.2)
O	0.55 ± 0.1	0.39 ± 0.15	0.24 (0.14–0.44)
Ne		0.46 ± 0.2	
Mg	0.44 ± 0.4	0.1 (0.0–0.5)	
Fe	0.58 ± 0.2	0.19 ± 0.08	
$n_e t$ (10^{11} s cm^{-3})	1.19 (1.00–1.70)	2.3 (1.5–3.0)	0.1 (0.05–0.50)
X^2 / d.o.f.	71.9 / 62	53.0 / 48	27.4 / 23

Best-fit model parameters.
Elemental abundances are relative to their solar values (those not shown in the table are fixed to 1).

Results & Discussion

For the three regions under investigation, the free-parameter abundances result in subsolar values, consistent with those in the interstellar medium (ISM). Relative to O, the measured abundances are consistent with solar ratios to a factor of ~ 2, within statistical errors. This indicates that the X-ray emission in the regions investigated is dominated by swept-up ISM with no significant presence of ejecta.

Our preliminary results indicate an electron temperature in the SE arm ("A") which is slightly higher than that of the adjacent region ("B"). At ~ 0.35 keV, these temperatures are similar to those found towards the W rim, and lower by a factor of ~ 2 than those in the NE rim (Katsuda et al. 2010). Also, these temperatures are slightly lower than those found in towards the brighter northern portions of the respective regions as observed by *Suzaku* (Hwang et al. 2008), pointing to a temperature gradient towards the south.

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