THE MOST COMPLETE AND DETAILED X-RAY VIEW OF THE SNR PUPPIS A

G. Dubner (1), N. Loiseau (2,3), P. Rodríguez-Pascual (2), M. J. S. Smith (2,4), E. Giacani (1), and G. Castelletti (1)

(1) IAFE, Buenos Aires, Argentina; (2) ESAC, Villafranca del Castillo, Spain; (3) ISDEFE, Madrid, Spain and (4) Telespazio Vega U.K. S.L.

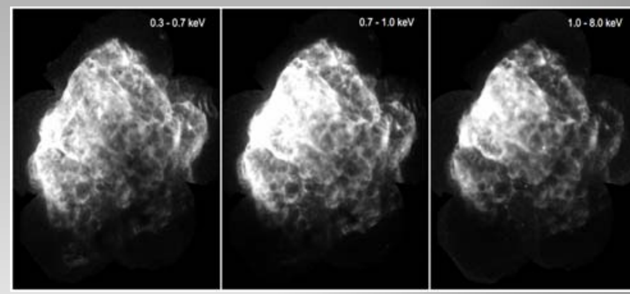
Puppis A is an extended, nearby Galactic supernova remnant (SNR), ~50′ in diameter, located at ~2.2 kpc, about 4000 yr old. It is one of the brightest SNRs in X-rays.

In optical wavelengths, the brightest filaments agree reasonably well on a large scale with the location of radio and X-ray emission.

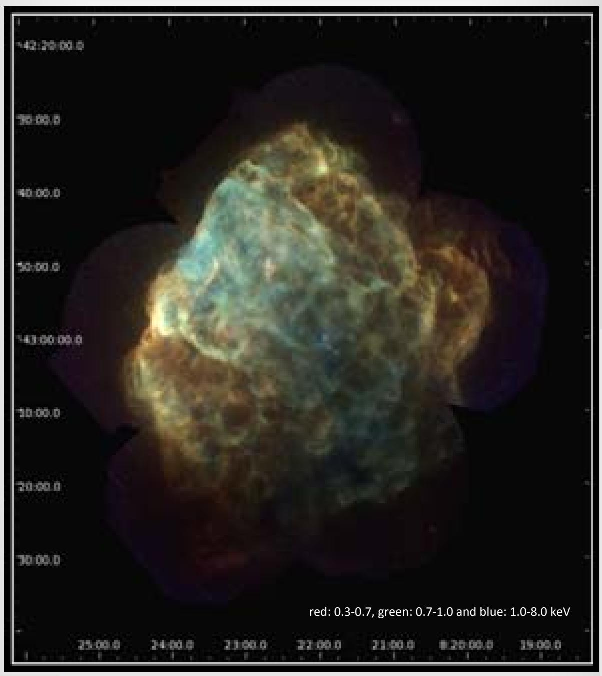
The IR radiation is dominated by the thermal emission of swept-up interstellar dust collisionally heated by the hot shocked gas (Arendt 2010).

Despite the rich nature of this remnant that includes a central compact object (CCO RX J0822-4300), relics of the presupernova and traces of the interaction between the SN shock and the surrounding gas, the known X-ray images surprisingly lack a considerable portion of this source.

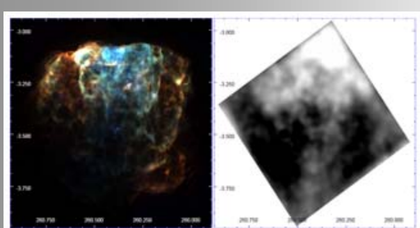
We report the first detailed full view of the supernova remnant (SNR) Puppis A in the 0.3-0.7, 0.7-1.0 and 1.0-8.0 keV energy bands. The images were produced from the combination of two new pointings observed with *XMM-Newton* towards the missing regions in the southern half with 51 *XMM-Newton* EPIC and 8 *Chandra* ACIS images.



The combined images were corrected for vignetting, weighted according to their respective energy-dependent effective areas, subsequently merged with a 2 arcsec spatial binning and smoothed with a 10 arcsec Gaussian kernel.

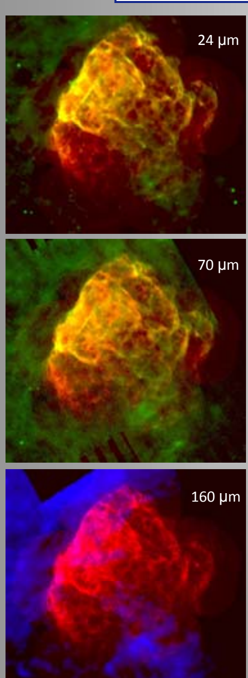


X-ray and NH



Comparison of the three-band X-ray emission (left) with the distribution of NH integrated between 0 and the systemic velocity of Puppis A (right) (in Galactic coordinates). The central higher column density band absorbing soft X-rays, provides a natural explanation for the blue fringe observed in the X-ray image.

X-ray and IR

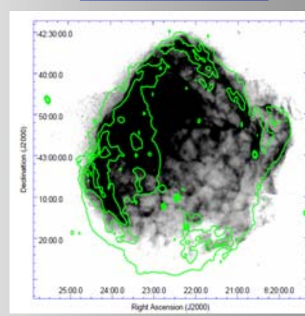


Two-color images comparing X-rays (0.7 - 1 keV in red) with *Spitzer* IR images (Arendt et al. 2010) at (top) 24 μm (green), (middle) 70 μm (green), and (bottom) 160 μm (blue).

Excellent agreement between X-ray and 24 and 70 μm IR emission is observed in the northern half of the remnant. To the SW the new X-ray data revealed a complex network of filaments that in general agree with the location of the 24 μm emission, although some X-ray features lack an infrared counterpart and viceversa.

The correlation with 160 μm emission is very useful as a proxy to trace the spatial distribution of the foreground and co-spatial interstellar gas. It corresponds to the larger size dust grains that are not destroyed by the passage of the shock front. The emission along the eastern flank seems to be associated with an external cloud that is being shocked by Puppis A and partially covers its eastern border in the line of sight.

X-ray and radio



X-ray emission between 0.7 and 1.0 keV in gray with radio contours at 1425 MHz

All along the NE limb, it is remarkable how the sharp edge of the bright X-ray emission runs farther inside than the radio emission. The diffuse radio emission ahead the X-rays limb might represent precursor synchrotron radiation from relativistic electrons that have diffused upstream from the shock. The observed scale-length of this emission agrees well with the typical upstream scale-length expected for the diffusive shock acceleration of cosmic rays by supernova remnants. On the N and W boundaries radio and X-ray emissions coincide in extension and in shape. The difference between NE and NW sides can be explained by a change in the orientation of the magnetic field lines from almost perpendicular to the shock front on the NE side to almost parallel on the NW. Toward the S and SE, the radio emission extends considerably farther than the X-ray emission, while to the SW the new image underscores X-ray emission that exactly correlates with a bright radio feature that was suggested by Castelletti et al. (2006) as a possible site of interaction with dense ISM.

Physical properties

Based on the new X-ray image, we determined the observed X-ray flux density over the complete extent of Puppis A in soft, medium, and hard bands to within 5%.
The total X-ray flux measured between 0.3 and 8.0 keV is : $21.6^{+14}_{-10} \times 10^{-9}$ erg cm^{-2} s^{-1}, is consistent within errors with previous estimates.

At the assumed distance of 2.2 kpc the total luminosity in X-rays is

$$L_X = 1.2\times10^{37} \text{ erg s}^{-1}$$

which is 800 times higher than the radio luminosity and only a quarter of the infrared luminosity, confirming the significance of the IR emission in the energetics of Puppis A.

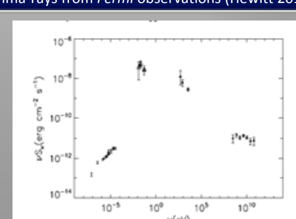
We also re-analyzed radio data to estimate the minimum energy content stored in relativistic particles, as well as the magnetic field strength assuming equipartition. From these calculations we derived

$$U_{min} = 4.8 \times 10^{49} \text{ erg} \quad \text{and} \quad B = 26\ \mu\text{G}$$

Energy (keV)	Photon energy (eV)	Energy density νS_ν (erg cm^{-2} s^{-1})
[0.3-0.7]	0.50×10^3	$12.6^{+13.2}_{-7.8} \times 10^{-9}$
[0.7-1.0]	0.85×10^3	$6.2^{+2.2}_{-2.3} \times 10^{-9}$
[1.0-8.0]	3.50×10^3	$2.8^{+0.5}_{-0.5} \times 10^{-9}$

Spectral energy distribution

Spectral energy distribution of Puppis A from radio to GeV energies, including data in IR (Arendt et al. 2010) and gamma-rays from *Fermi* observations (Hewitt 2012).



Arendt, R. G., Dwek, E., Blair, W. P., et al. 2010, ApJ, 725, 585
Castelletti, G., Dubner, G., Golap, K., & Goss, W. M. 2006, A&A, 459, 535
Hewitt, J. W., Grondin, M.-H., Lemoine-Goumard, M., et al. 2012, ApJ, 759, 89

gdubner@iafe.uba.ar