Peering Deeper into the Plerionic Supernova Remnant G21.5-0.9

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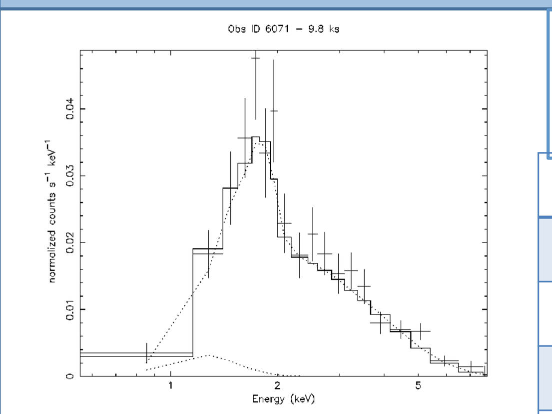
The supernova remnant (SNR) G21.5-0.9 has been observed regularly with the Chandra X-ray observatory since its launch in 1999, and has become a textbook example for a young plerionic SNR. The remnant hosts a bright pulsar wind nebula (PWN), powered by a 61.8 ms pulsar (PSR J1833-1034, $B = 3.6 \times 10^{12}$ G, and spin down luminosity *Edot*=3.3 x 10^{37} erg/s), and a faint limb-brightened shell revealed in X-rays with Chandra. The nature of the X-ray emission from the shell (thermal versus non-thermal) and knots within the nebula (ejecta?) remains a puzzle.
To address this, we present a follow-up X-ray analysis of G21.5-0.9 (study in progress) utilizing the deepest (> 1 Msec total) exposure to date, including ~780 ks with the Advanced CCD Imaging Spectrometer (ACIS) and ~310 ks with the High Resolution Camera (HRC). These observations spanning ~15 years also allow for the study of variability and tracking the motion of small scale structures within the PWN.

Eastern Limb

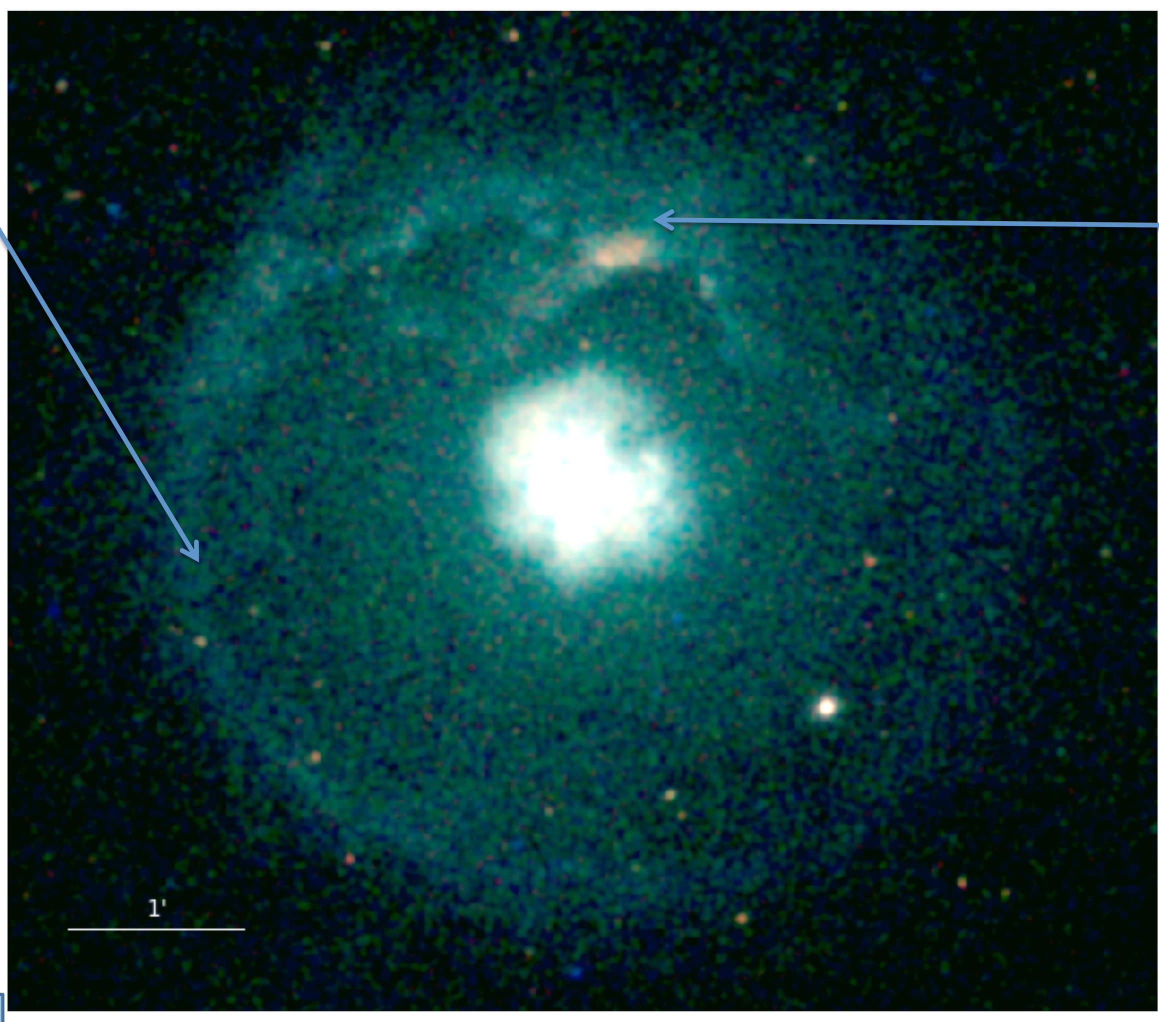


Non-Thermal?

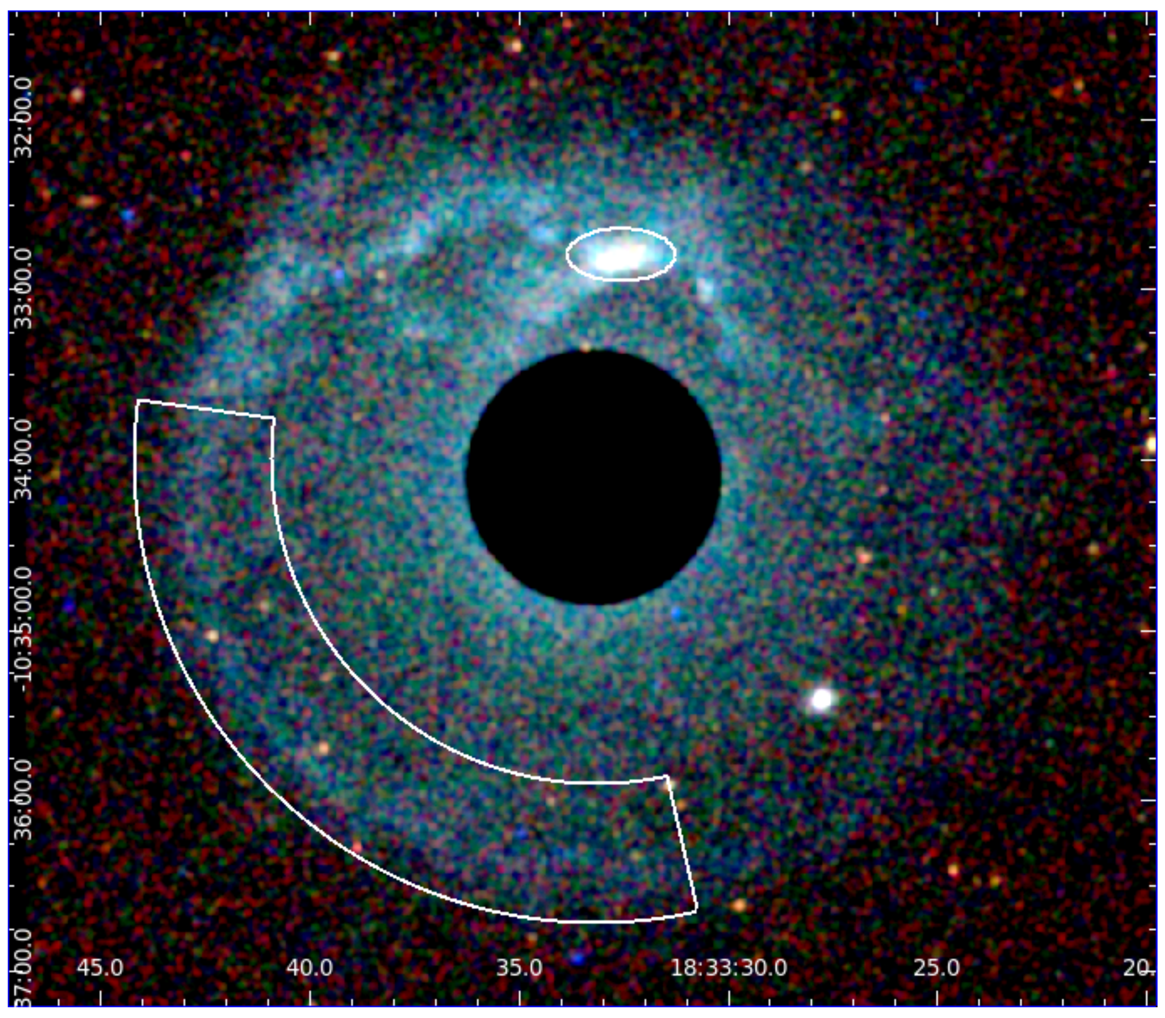
37 Observations	345 ks[1]
	2.37 (2.31 – 2.42)
Norm ()	7.25 (6.74 – 7.73)
kT (keV)	0.18 (0.12 – 0.29)
n_e t (10^9)	1.78 (<5.32)
Norm ()	11.6 (1.2 – 64.4)
Non-Thermal Flux	
Thermal Flux	
X^2	0.95(3157)

[1] Only observations which contained the entire shell region on a single chip were used

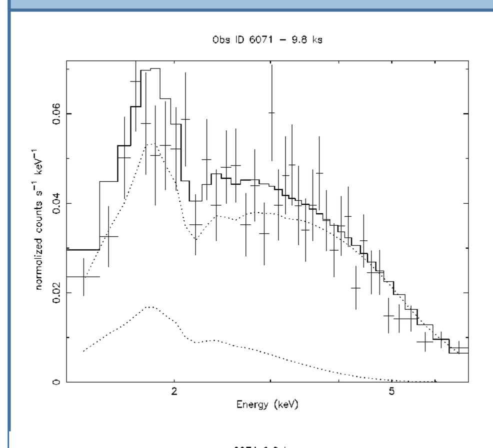
The shell emission is primarily non-thermal. The addition of a thermal component (~few % of non-thermal) improves the fit and is required with an F-Test probability of 6.0E-8

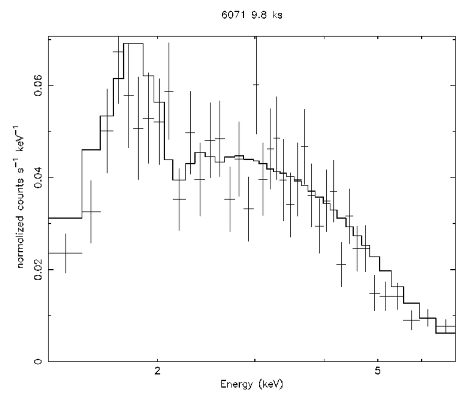


Top: 692 ks RGB Chandra image of G21.5 merging observations with an off-axis angle less than 8' filtered into the bands 0.5-1.2 keV – Red, 1.2-2 keV – Green, 2-8 keV – Blue. Bottom: Image with the bright pulsar wind nebula removed to better show the extended shell emission. The white shapes show the brightest northern knot and the limb brightened eastern shell.



Neutron Star





Including black body Component

	2.15 (Frozen)
	1.25 (1.12 – 1.37)
Norm (10^{-4})	5.3 (4.2 – 6.4)
kT (keV)	0.52 (0.48 – 0.56)
Norm (10^{-6})	7.0 (3.8 – 10.1)
X^2 (v)	1.308 (1421)

Without black body Component

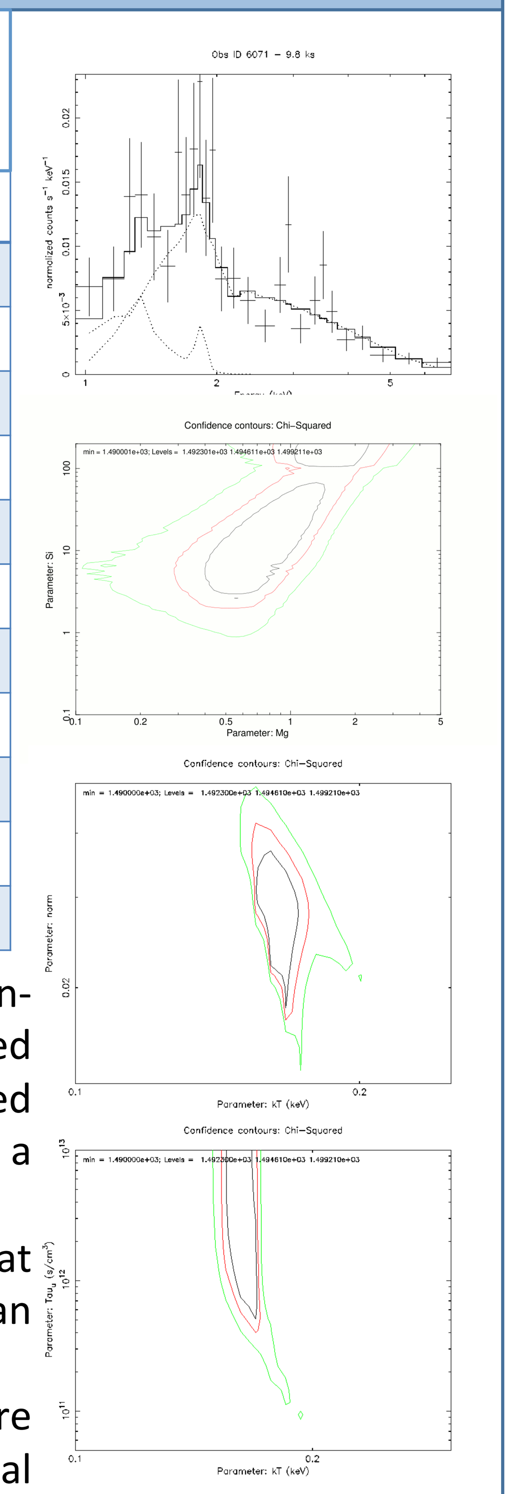
N_H (10^{22} cm^{-2})	2.15 (2.08 – 2.23)
	1.49 (1.44 – 1.53)
Norm (10^{-4})	7.92 (7.39 – 8.48)
X^2 (v)	1.317 (1422)

To confirm thermal emission from the central pulsar, a spectrum was extracted from a circle of radius 2" surrounding the brightest point in the X-ray image including only observations with an off-axis angle less than 3'. The spectrum is well fit by a power-law model and the addition of a black body component does not significantly improve the statistics with an F-Test probability of only 2.6E-3.
The column density found for the single power-law fit is assumed to be constant and is applied to the spectral models in the other regions of interest such as the northern knot and eastern limb.

Northern Knot

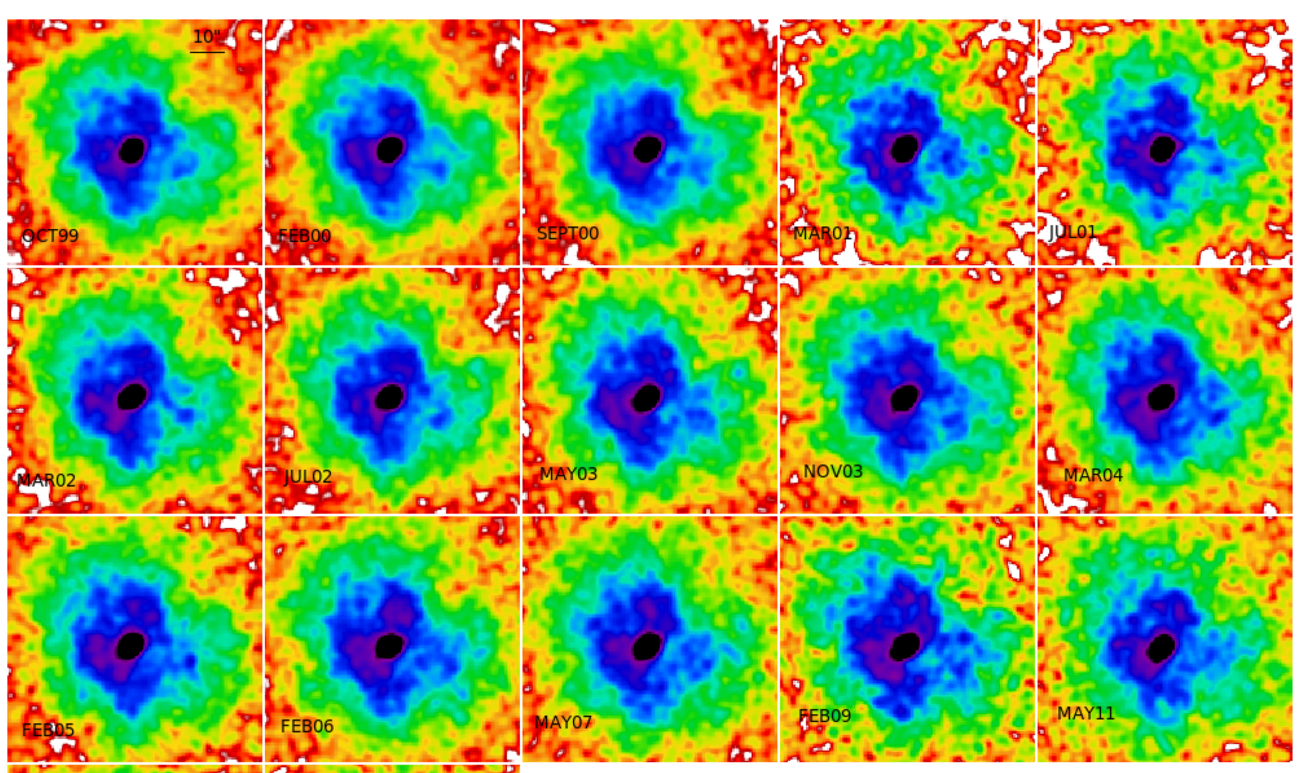
Ejecta?

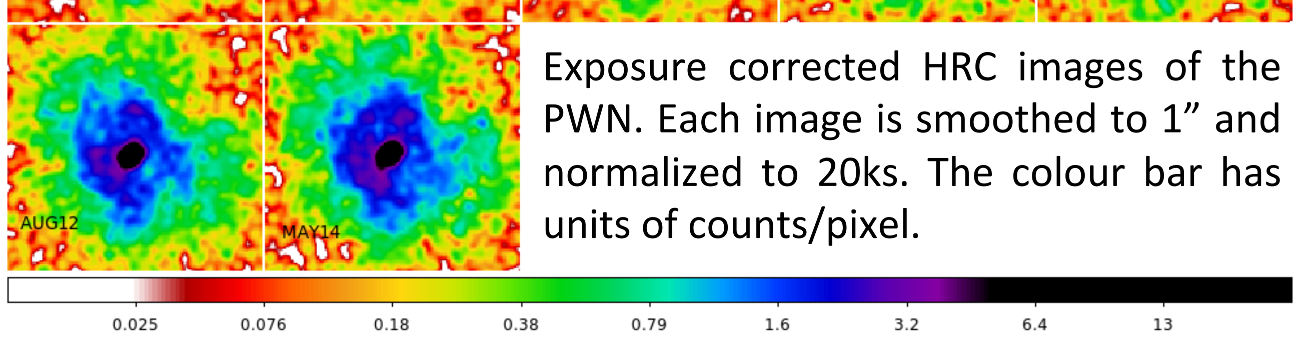
70 Observations	660 ks
	2.23 (2.16 – 2.27)
Norm (10^{-4})	2.15 (2.06 – 2.33)
kT (keV)	0.162 (0.159 – 0.204)
n_e t (10^{12} cm^{-3} s)	2.01 (>0.08)
Norm (10^{-2})	2.74 (1.01 – 6.15)
Non-Thermal Flux	
Thermal Flux	
Mg	0.7 (0.4 – 3.0)
Si	9.8 (5.6 – 362)
S (unconstrained)	0.1 (0 – 184)
X^2 (v)	1.02 (1457)



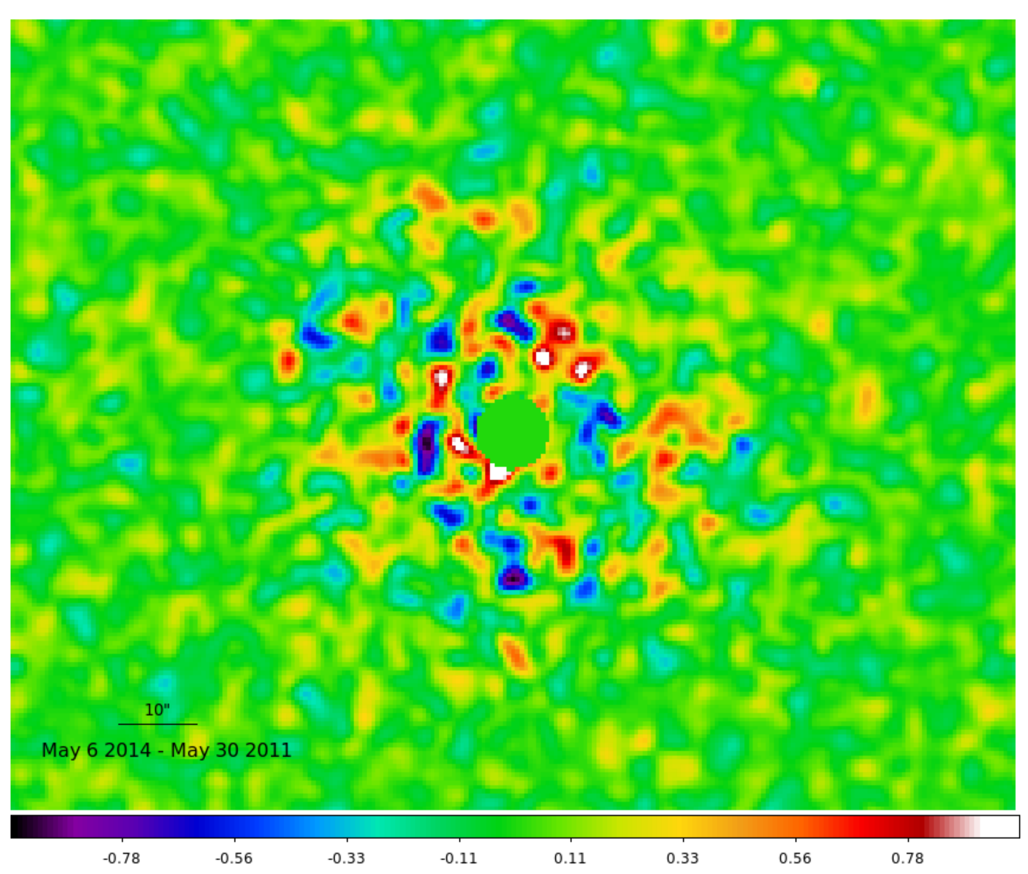
The knot emission is dominated by non-thermal or hard emission, with a shocked plasma thermal component characterised by an enhanced abundance of Silicon and a large ionization timescale.
The overabundance of Silicon suggests that the knot consists of ejecta rather than mass swept-up from the ISM.
A pure thermal model yields a temperature of 5.7 keV, much too high to be physical and points to the need for the two-component model.

Variability in the Pulsar Wind Nebula



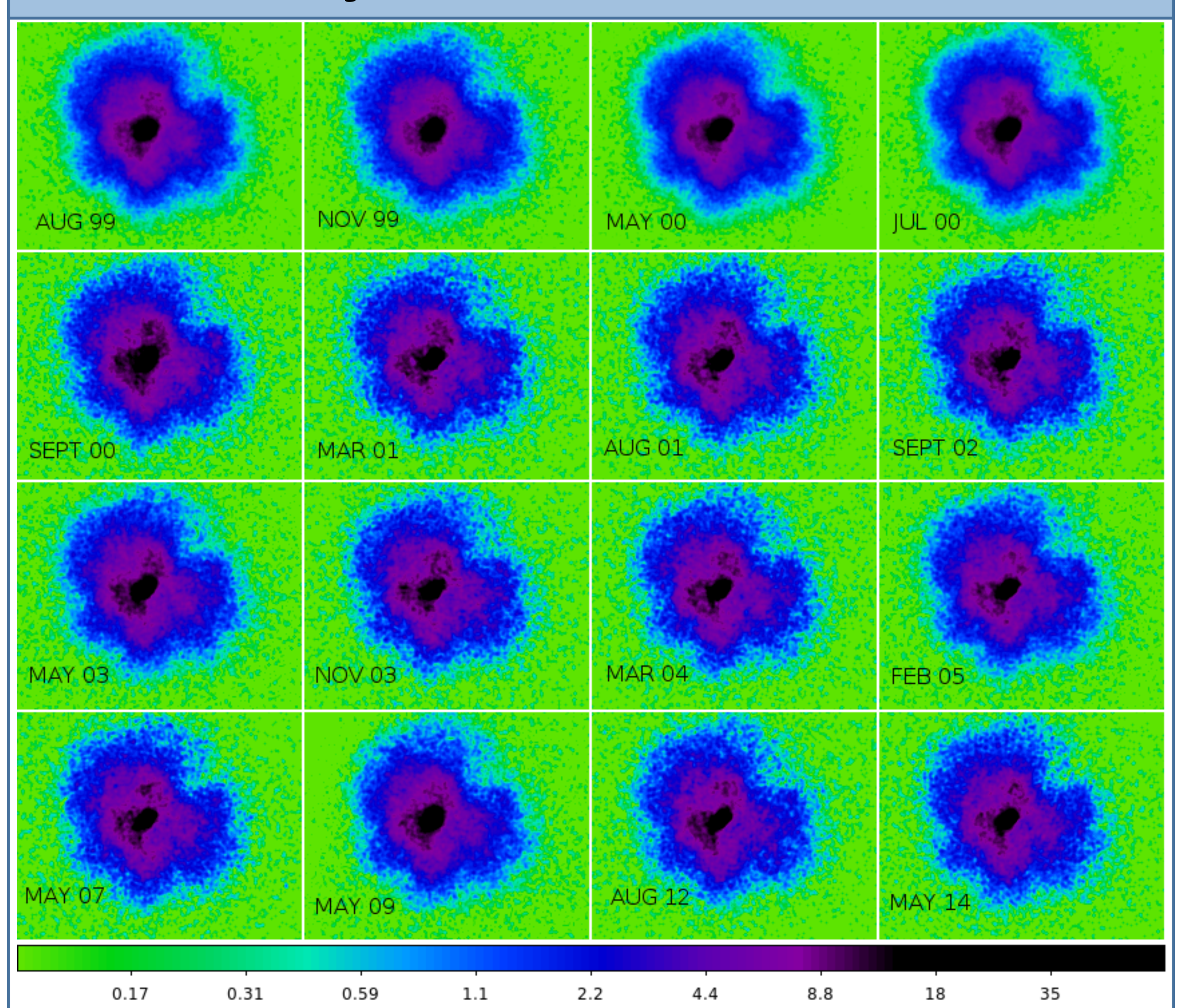


Exposure corrected HRC images of the PWN. Each image is smoothed to 1" and normalized to 20ks. The colour bar has units of counts/pixel.



Example difference image created by subtracting the May 6 2014 observation from the May 30 2011 HRC observation shown in the image on the left. The region close to the pulsar was omitted to highlight the PWN variability.

Variability Observations with ACIS



Exposure corrected ACIS images of the PWN. Each image is smoothed to 1" and normalized to 20 ks.
Transient features are observed near the central pulsar. We cannot be sure that we are seeing the motion of knots rather than the appearance of new knots following the fading of others.

References

1. Bietenholz, Matheson, Safi-Harb et al. 2012, MNRAS, 412, 1221.
2. Matheson, H. & Safi-Harb, S. 2010, ApJ, 724, 572.
3. Camilo et al. 2006, ApJ, 637, 456.
4. Bocchino et al. 2005, A&A, 442, 539.
5. Matheson, H. & Safi-Harb, S. 2005, AdSpR, 35, 1099.
6. Safi-Harb et al. 2001, ApJ, 561, 308.
7. Slane et al, 2000, ApJ, 533, L29.