A NEW PULSAR/SNR PAIR: AX J1845–0258 IN G29.6+0.1

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ABSTRACT

We present a follow-up X-ray and radio study of the field containing the 7-s X-ray pulsar AX J1845−0258, the serendipitous *ASCA* source whose characteristics are found to be similar to those of the anomalous X-ray pulsars (AXPs). Newly acquired *ASCA* data confirms a dramatic reduction in flux from the pulsar and reveals instead a faint X-ray point source, AX J184453.3−025642, within the pulsar's error circle. This X-ray source is surrounded by a partial shell of emission coincident with a newly discovered young shell-type radio supernova remnant, G29.6+0.1. The central X-ray source is too faint to provide a detection of the expected pulsations which might confirm AX J184453.3−025642 as the pulsar. We argue that this system is similar to that of RCW 103, another AXP-like object whose central source displays low/high flux states (but no pulsations). The alternative interpretation of a binary system, perhaps associated with a supernova remnant, is still possible. In either case, this result may have profound implication on the evolution of young neutron stars.

KEYWORDS: pulsars: individual (AX J1845−0258); supernova remnants: individual(G29.6+0.1); star: individual (AX J184453.3−025642); stars: neutron.

1. INTRODUCTION

The 7-s pulsar, AX J1845−0258, was discovered during an automatic search of the *ASCA* archival data (Gotthelf & Vasisht 1998; Torii *et al.* 1998). Based on its spectral and timing properties, AX J1845−0258 is likely the latest addition to the class of anomalous x-ray pulsars (AXPs) (Duncan & Thomson 1996; Mereghetti & Stella 1995; van Paradijs *et al.* 1995). Evidence included a long rotation period, large modulation ($\sim 30\%$), steady short-term X-ray flux during the original *ASCA* observation, steep characteristic spectrum (power-law photon index $\Gamma \sim 5$), location at low Galactic latitude, and the lack of known counterpart. A rough distance estimate derived from the X-ray absorption places the pulsar at distance of $5 - 15$ kpc giving an inferred X-ray luminosity of order $\sim 10^{35}$ erg s^{-1}.

Herein we report on new *ASCA* X-ray and VLA radio observations directed at the pulsar's location. Our goal was to identify the pulsar and confirm or repudiate the AXP hypothesis by measuring the spin-down rate of the pulsar and searching for an associated radio supernova remnant (SNR). We succeeded in finding a young radio SNR within the pulsar's error circle, however the pulsator was not seen again. Instead, we find a faint ASCA point source (Vasisht *et al.* 2000) at the center of the newly discovered radio SNR G29.6+0.1 (Gaensler *et al.* 1999). We argue that this faint source is the pulsar AX J1845−0258 in a low state; we consider the pulsar's location at the center of a young SNR and the lack of a radio counterpart as evidence for the AXP interpretation, but with a twist.

2. THE X-RAY OBSERVATIONS

We revisited the field containing the pulsar AX J1845−0258 with the *ASCA* observatory on March 28-29, 1999 UT. Figure 1 reproduced the smoothed and exposure corrected image taken with the gas imaging spectrometers (GISs) aboard *ASCA*. The GIS is sensitive to photon in the $\sim 1-10$ keV energy range and has a spatial resolution $\sim 1-2'$. All data were edited following the standard *ASCA* reduction procedures resulting in an effective observation time is 49 ks.

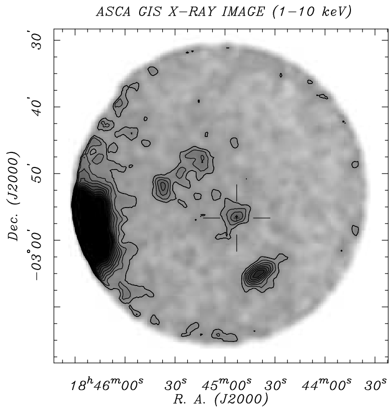

FIGURE 1. The follow-up *ASCA* observation of AX J1845−0258. The full GIS image showing the new X-ray source AX J184453.3−025642 marked by the cross, and several serendipitous sources to the northeast and southwest. The bright emission near the east edge is the SNR Kes 75.

Near the center of the field-of-view we find a faint unresolved point source within the large $\sim 3'$ radius error circle for AX J1845−0258. The pulsar's poor astrometry is due to the extreme off-axis detector location of the discovery observation. The faint source is also detected by *ASCA*'s solid-state imaging spectrometers (SISs) (see Fig 2) with a similar significance of $\sim 5\sigma$. The spatial resolution of the SIS is $\sim 1'$, but the derived coordinates of $18^h45^m53.3^s$, $-02°56'42''$ (J2000) have an uncertainty of only $20''$ after correcting for the temperature dependent coordinate offsets (Gotthelf *et al.* 2000). We refer to this source as AX J184453.3−025642, and consider whether this is indeed the expected pulsar, but at a flux level an order of magnitude less than expected; the dearth of source photon prohibits a proper spectral analysis or search for pulsations, which might allow identification with AX J1845−0258.

3. THE VLA RADIO IMAGES

Radio observations of the field of AX J1845−0258 were made with the D-configuration of the Very Large Array (VLA) on 1999 March 26. The total observing time was 6 hr, of which 4.5 hr was spent observing in the 5 GHz band, and the remainder in the 8 GHz band. At both 5 and 8 GHz a distinct shell of emission is seen, which is designated G29.6+0.1 (see Fig. 2). The shell is clumpy, with a particularly bright clump on its eastern edge. In the east the shell is quite thick (up to 50% of the radius), while the north-western rim is brighter and narrower. Two point sources can be seen within the shell interior.

The shell-like radio emission ($\sim 5'\!.0$ in diameter) is found to be linearly polarized and non-thermal, which, along with the lack of significant counterpart in 60 μm *IRAS* data, are characteristic properties of supernova remnants (e.g. Whiteoak & Green 1996). G29.6+0.1 is thus classified as a previously unidentified SNR. Its inferred age suggests a young remnant, with an upper limit of 8000 yr. The location of the X-ray source AX J184453.3−025642 at the center of the SNR is highly unlikely to be due to a chance superposition, suggestion that the two are related.

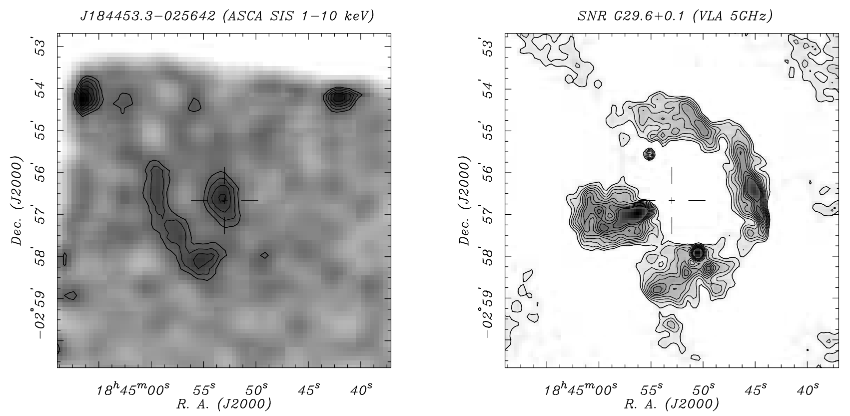

FIGURE 2. Discovery of a new supernova remnant, G29.6+0.1, containing a central X-ray source, AX J184453.3−025642, within the error box of the X-ray pulsar AX J1845−0258. **(LEFT)** The *ASCA* SIS X-ray image centered on the AX J184453.3−025642, marked by the cross. An arc of emission is evident surrounding the point source overlapping the radio shell shown in the next panel. **(RIGHT)** The 5 GHz VLA radio map of the same region, which reveals a clumpy shell, whose spectral index is consistent with a SNR hypothesis.

4. THE NATURE OF AX J1845−0258: A VARIABLE AXP?

The lack of a bright pulsator in the new *ASCA* observation of AX J1845−0258 is quite surprising. The spectral and temporal properties of this pulsar had strongly implied an AXP interpretation. Indeed the discovery of a young radio remnant coincident with the pulsar is consistent with the AXP hypothesis. Conversely, the detection of an X-ray point source in the center of the SNR is in itself indicative of a neutron star candidate associated with the remnant. This new source is exactly where we would expect the AXP to be, to within errors, consistent with this interpretation. We therefore suggest that AX J184453.3−025642 is indeed the pulsar, but at a much reduced ($\sim$ order of magnitude) X-ray flux.

We now consider the interesting possibility that AXP can exhibit extreme, factor of ten, variability. There is some evidence for this already from two well studied AXPs which show large $\gtrsim 4$ variations in flux on year timescales (e.g. 1E 1048.1-593, Oosterbroek *et al.* 1998). Most intriguing, the properties of the central, unpulsed, neutron star candidate in SNR RCW 103 are otherwise typical of the AXPs, but its flux has also been found to vary by an order of magnitude at energies > 3 keV (Gotthelf, Petre, & Vasisht 1999), just what is observed for AX J1845−0258. Conversely, this provides further evidence that RCW 103 is an AXP with unseen pulsations, perhaps due to unfavorable beaming geometry.

The identification of another AXP at the center of a young SNR have important implications on the birth properties of pulsars. This result is certainly consistent with AXPs being young, isolated neutron stars, as argued by the magnetar hypothesis. There is the possibility then that AXPs might exhibit periods of enhanced emission. In this case, the population of AXPs might be much greater than previously thought, and we are only detecting a fraction of AXP, those currently in their bright "on" state. Perhaps a duty-cycle (fraction of time the AXP is "on") of only $\lesssim 5\%$ would be required to square the known Galactic SNRs population with the detected AXPs, if most young neutron stars manifest themselves as AXPs as some authors suggest (see Gotthelf 1998). Although the magnetar hypothesis is attractive, we cannot reject a a binary system origin, perhaps embedded and associated with a young SNR. Further monitoring of this region is planned.

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