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Recent X-ray Observations of PSR B1957+20

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Abstract. We report on *Chandra* X-ray observations of the eclipsing binary millisecond pulsar B1957+20 in which we detected a narrow X-ray trail. The X-ray nebula lies interior to the known Hα bow-shock nebula and its existence proves the long held assumption that millisecond pulsars have relativistic winds. Unresolved X-ray emission at the location of the pulsar is also detected which we use to show that millisecond pulsar winds are not very dissimilar to those of the normal, higher magnetic field strength, pulsars.

1. Introduction

PSR B1957+20 is a member of the class of neutron stars called millisecond pulsars, that is a neutron star which has been spun up to its present rapid rotation rate by accretion of material from a binary companion. After this accretion phase the pulsar is once again visible as a radio source but has a surface magnetic field strength of $\sim 10^8$ G which is up to four orders of magnitude less than the normal young pulsars. When combined with their older ages and rapid rotation rates, this indicates that the millisecond pulsars form a distinct population compared to young pulsars.

PSR B1957+20 is eclipsed by the wind from its low-mass companion star, which has been almost completely evaporated during the accretion phase, for approximately 10% of every 9.16 hr orbit (Fructher, Stinebring, & Taylor 1988). The companion wind is thought to be driven by x- or γ-rays generated in an intra-binary shock between the pulsar wind and that of the companion star, which also cause substantial heating of the companion star (Fruchter, Bookbinder, & Bailyn 1995). Moreover this pulsar has a large space velocity (> 220 km s^{-1}; Arzoumanian, Fruchter, & Taylor 1994) as it moves through the interstellar medium (ISM) which generates sufficient ram pressure to confine the pulsar wind and results in the formation of a bow shock. Thus this system, where the wind interacts with both the ISM and the companion star wind, provides an excellent opportunity to study the wind of a millisecond pulsar. Along with the pulsar itself, these two interactions are likely to be sources of X-rays. Previous studies did indeed detect X-rays from the system but lacked the spatial and/or timing resolution to distinguish between the three possible origins (Kulkarni et al. 1992).

2. Observations and Results

To search for the origin of the X-rays from PSR B1957+20 and to better understand the properties of a wind of a millisecond pulsar we undertook an observation using the *Chandra* X-ray Observatory. The brightest X-ray source in the field is coincident with the pulsar position and a tail of X-ray emission which is aligned with the pulsar proper motion direction is seen extending to the north-east (Fig. 1). The tail lies inside the Hα bow-shock nebula, which marks the location of the shocked ISM, and is associated with the termination shock where the pulsar wind is thermalised and synchrotron emission is generated. While this structure of bow shocks has been proposed for a long time

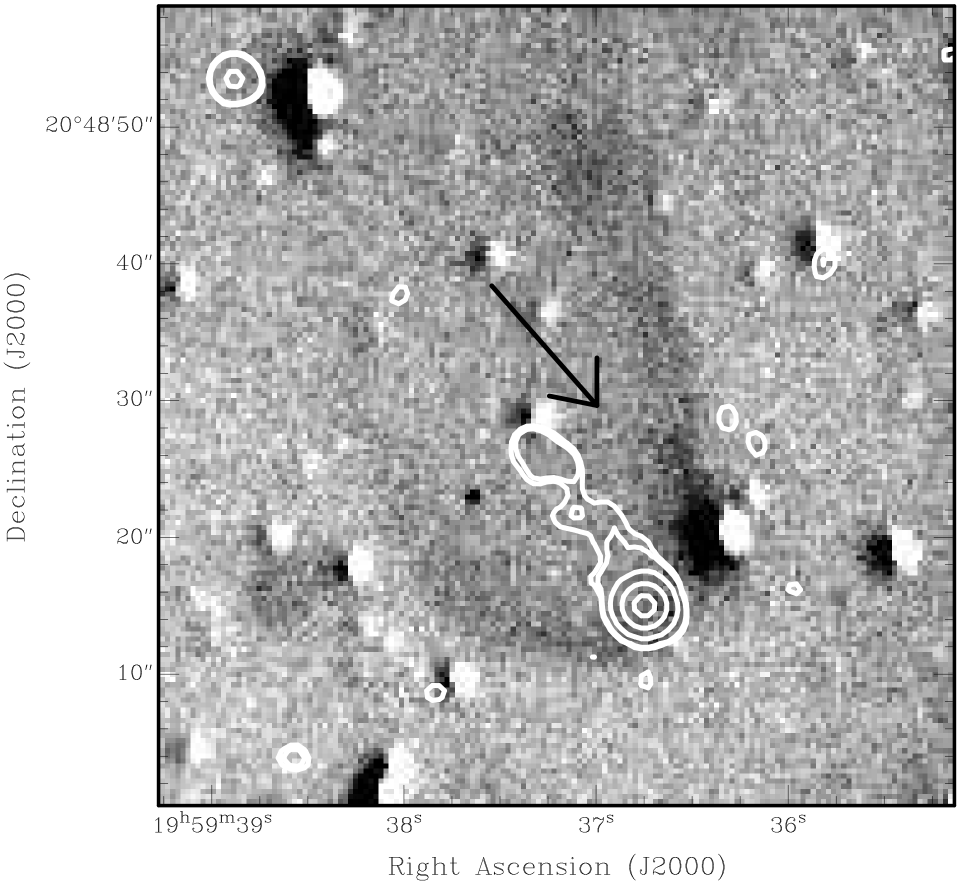

Figure 1. Image of the 43 ksec *Chandra* observation using the ACIS-S3 detector in the energy range 0.3–10.0 keV of the field around PSR B1957+20. The data have been smoothed to a resolution of 5″ (contours) and overlaid on an Hα image obtained using Taurus Tunable Filter service mode observations on the Anglo Australian Telescope. The bright source located near the head of the Hα nebula corresponds to unresolved emission from within the PSR B1957+20 binary system. The X-ray tail extends from the location of the pulsar to approximately half-way to the end of the Hα nebula. The arrow indicates the direction of proper motion of the pulsar and its length corresponds to the distance traversed by the pulsar in approximately 500 years. The nebula is located well inside the boundaries of the Hα emission and also close to its symmetry axis. The X-ray contour levels are shown at 0.9%, 1.2%, 5.3%, 35.0% and 78.8% of the peak X-ray surface brightness. The optical residuals correspond to incompletely subtracted stars.

this is the first time that the double-shock nature has been confirmed. Furthermore, we find that the spectrum of the X-ray emission from the tail is not able to be fit by any shock-heated gas model which could be attributed to a wind carrying away sufficient kinetic energy to be equal to the spin-down luminosity. Thus the tail emission must be due to some non-thermal process and requires that the wind of the millisecond pulsar contains a population of relativistic particles (Stappers et al. 2003).

As the pulsar and the companion are separated by just 1.5×10^{11} cm, the intra-binary shock, formed where the pulsar and companion winds interact, will be located in a strong magnetic field (much stronger than for the Crab nebula). This intra-binary shock is therefore a potential source of unresolved synchrotron emission at the location of the pulsar and can be used to determine the wind characteristics at the shock. The flow just downstream of the intra-binary shock is expected to undergo Doppler boosting as it passes around the companion and so modulation of the X-rays is expected (Arons & Tavani 1993). We find some evidence for modulation and determine that approximately 50% of the point source X-ray emission originates in the shock. Comparing the X-ray luminosity from the shock with the spin-down luminosity of the pulsar we find that a similar fraction of the spin-down luminosity of PSR B1957+20 goes into accelerating electrons with Lorentz factor $\gamma = 10^5$ as is the case for the Crab pulsar and its nebula (Stappers et al. 2003). Thus despite the completely different evolutionary history and differences in age and magnetic field strength the relativistic wind of PSR B1957+20 is not that dissimilar to those of younger pulsars.

For more detailed information on these results we refer the reader to our recent publication (Stappers et al. 2003).

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