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Constraints on black hole accretion in V Puppis

Thomas J. Maccarone, Robert P. Fender, Christian Knigge
School of Physics and Astronomy, University of Southampton, Hampshire SO17 1BJ,United Kingdom

A.K. Tzioumis
Australia National Telescope Facility, CSIRO, PO Box 76, Epping, New South Wales 17190, Australia

ABSTRACT

In light of the recent suggestion that the nearby eclipsing binary star system V Puppis has a dark companion on a long orbit, we present the results of radio and X-ray observations of it. We find an upper limit on its radio flux of about 300 μJy and a detection of it in the X-rays with a luminosity of about 3×10^{31} erg/sec, a value much lower than what had been observed in some of the low angular resolution surveys of the past. These data are in good agreement with the idea that the X-ray emission from V Puppis comes from mass transfer between the two B stars in the system, but can still accommodate the idea that the X-ray emission comes from the black hole accreting stellar wind from one or both of the B stars.

Key words: stars:individual:V Puppis – X-rays:stars

1 INTRODUCTION

Nearly every black hole candidate in the Universe is either a supermassive black hole at the center of a galaxy, or a stellar mass black hole in an X-ray binary. Only a few exceptions are known – objects detected through microlensing surveys (Bennett et al 2002; Poindexter et al. 2005). Stellar evolution predictions indicate that there are likely to be about 10^8 black holes in the Galaxy of which only about 10^3-10^4 ever end up as low mass black hole X-ray binaries (Romani 1992; Portegies Zwart et al. 1997). Theoretical modeling also suggests that binary stellar evolution will produce a different distribution of black hole masses than will the evolution of single stars (e.g. Fryer & Kalogera 1998). Thus, our knowledge of black holes is based on a population that is both a small fraction of the total Galactic population, and which is unrepresentative of the larger class.

Microlensing remains one of the few means of detecting isolated black holes (although radio emission may become useful in the LOFAR era – Maccarone 2005). However, black holes in extremely wide binaries may provide a useful set of objects from which we can learn about the properties of isolated black holes. In any event, they are likely to represent a substantial fraction of the black holes in the Galaxy, since nearly all stars massive enough to form black holes are members of multiple star systems. In a sufficiently wide binary star system, the stars evolved essentially independently, so the most serious effects of multiple membership are avoided.

The first serious attempt to find observational evidence for black holes in the Galaxy was an attempt to look for their gravitational signatures on the orbits of other stars, rather than for evidence of accretion (Trimble & Thorne 1969). However, this attempt was unsuccessful, and in the years since, no serious attempts, in the knowledge of the authors, have been made to search for black holes in binary systems, apart from through searches for accretion signatures.

Recently, studies of the close eclipsing binary V Puppis have shown periodic residuals in the eclipse timing suggesting the presence of a $\sim 10\ M_\odot$ companion to the binary, with an orbital period of about 5 years (Qian, Liao & Fernandez-Lujas 2008). If such an object were anything other than a black hole, it would be observable in the optical spectra made of V Puppis, as a third component of brightness similar to the two known components. Qian et al. (2008) pointed out that Uhuru, Copernicus, and ROSAT had all seen X-ray emission from V Puppis, at a level consistent with the level expected from accretion of the stellar winds from V Puppis; V Puppis may represent the first black hole in the Galaxy whose mass can be measured accurately through Keplerian motions, but whose formation is not subject to binary evolutionary considerations (Qian et al. 2008). Triple systems with accreting components have been invoked in the past – to provide an alternative to a black hole in Cygnus X-1 (Bahcall et al. 1975), to explain superorbital periods in systems with accreting neutron stars and black holes (Priedhorsky et al. 1983; Gies & Bolton 1984; Zdziarski et al. 2007), and to explain the presence of an F star counterpart to 4U 2129+47, whose neutron star has an eclipse period of 5.24 hours (Garcia et al. 1989; Nowak, Heinz & Begelman 2002). While the evidence for X-ray triple systems above is, in some cases, strong, in no case is it yet definitive.

Motivated by this possibility, we performed two observations aimed at testing the hypothesis that the X-ray emission from this system is from accretion onto the putative black hole: searching for radio emission from the system, since a high ratio of radio to X-ray flux is a characteristic signature of faint accreting stellar mass black holes; and making an X-ray image of this field with Chandra, to ensure that the X-rays really are coming from V Puppis and not some other nearby object.

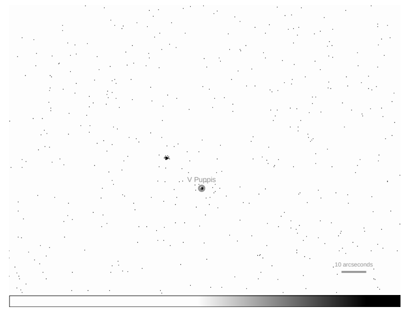

Figure 1. The X-ray image from the Chandra HRC of the region around V Puppis. The circle is about 1 arcsecond in size, centered on the position of V Puppis from SIMBAD. A line segment of 10 arcseconds is shown in the lower left of the figure for scale.

2 DATA USED, ANALYSIS PROCEDURE, AND RESULTS

2.1 Australia Telescope Compact Array data

The Australia Telescope Compact Array observed V Puppis for 2.97 hours on the date of 17 July 2008, simultaneously at 4.80 and 8.64 GHz, using B1934-638 and B0823-500 as flux and phase calibrators, respectively. No emission from V Puppis was detected. The rms noise levels were 0.1 mJy at 4800 MHz, and 0.08 mJy at 8640 MHz.

2.2 Chandra data

We observed V Puppis with the Chandra X-ray Observatory for 1170 seconds on 1 September 2008. The High Resolution Camera (HRC) was used, because its detector is a microchannel plate, rather than a charged coupled device (CCD). Due to optical loading on CCDs, it is not possible to use CCDs to observe an X-ray source which is optically as bright as V Puppis without serious problems with the resultant data quality. We detected 73 photons from within 5 arcseconds on V Puppis. The background level in this area in this exposure with the HRC is about 4 photons. An X-ray image in a region around V Puppis is shown in figure 1. Using HEASARC's WebPIMMS, and assuming a Galactic foreground N_H of 1.5×10^{21} cm^{-2} and a power law spectrum with photon index of 1.7, we make an estimate of the flux of V Puppis, and find an unabsorbed X-ray flux of 2×10^{-12} erg s^{-1} cm^{-2}, giving an X-ray luminosity at 300 pc of 2×10^{31} erg s^{-1}. Unfortunately, it is not possible to obtain reliable spectral information from the Chandra HRC, and no previous observations with reliable spectroscopy had sufficient image quality to resolve apart V Puppis and the other source visible in the figure, which is about 20" away, so the uncertainty in the luminosity is dominated by the uncertainty about which spectral model should be assumed.

3 DISCUSSION

The X-ray luminosity of the V Puppis system, as inferred from these data, is similar to the X-ray luminosities of Algol type systems, and quite a bit fainter than the faintest colliding wind binaries. Following Frank, King & Raine (1995), we can estimate that for a 10 $M_\odot$ black hole in a 5.5 year orbit around a binary of about 25 $M_\odot$ in total mass, the X-ray luminosity should be $\sim 10^{31}$ erg/sec for a mass loss rate of $\sim 10^{-5} M_\odot$ yr^{-1}, albeit with considerable uncertainty in several key parameters making this estimate uncertain by multiple orders of magnitude. Both Uhuru and Copernicus observed much higher X-ray luminosities from V Puppis than what we observe here, while our observations give a similar luminosity to that observed with ROSAT. The Uhuru measurement gives a count rate of 9.4 ± 2.3 counts s^{-1}, equivalent to an X-ray flux of 1.6×10^{-10} erg s^{-1} cm^{-2}, assuming a standard spectral shape (Giacconi et al. 1974), yielding an X-ray luminosity of 2×10^{33} erg s^{-1}, at the distance of V Puppis. Copernicus observed a similar X-ray luminosity from the same region on the sky, but given that one cannot be sure whether the emission came from V Puppis or a nearby object, one cannot make as accurate an estimate of the luminosity from Copernicus, since one needs to know the source position to good accuracy in order to estimate the collimator response (Bahcall et al. 1975). This may be indicative of variability of the X-ray luminosity of either V Puppis or of one of the other sources within the roughly square degree error boxes of V Puppis as seen with Uhuru and Copernicus. If the putative black hole in V Puppis is in a sufficiently eccentric orbit, its Bondi luminosity could change by orders of magnitude over its orbit. The detection in the ROSAT all sky survey (Voges et al. 1999) is at a level which is about twice as bright as what we see with Chandra, under the same assumptions. There is another X-ray source, at the position of the star HJ 4025C (about 20" from V Puppis), which is about 75% as bright in X-rays as is V Puppis and within the ROSAT PSPC error box; there is little evidence for substantial variability between the ROSAT and Chandra observations.

The combination of the X-ray and radio emission argues that not all of the X-ray emission is likely to be coming from a 10 $M_\odot$ black hole. Using the most recent formulation (Köerding, Falcke & Corbel 2005) of the fundamental plane of black hole activity (Merloni, Heinz & Di Matteo 2003; Falcke, Körding & Markoff 2004), we find that a 10 $M_\odot$ black hole with an X-ray flux of 2×10^{-12} erg/sec/cm^2 at a distance of 300 pc should have a radio flux of about 4 mJy. The X-ray/radio correlation of black holes only (Gallo, Fender & Pooley 2003) predicts a flux of about 2 mJy. The rms scatter in Körding et al (2005) of about a factor of 3 is still not large enough to explain the difference between the observed radio flux and the radio flux predicted based on the X-ray luminosity. Therefore, at least a substantial fraction of the X-ray emission we observed was most likely from the mass transfer between the two B star components of V Puppis. However, only deeper radio observations can rule out the possibility that some reasonably large fraction of the emission is from accretion onto the candidate black hole.

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