A&A 447, L1–L4 (2006)
DOI: 10.1051/0004-6361:200500227

Astronomy & Astrophysics

Assisted stellar suicide in V617 Sagittarii[⋆]

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Received 7 December 2005 / Accepted 18 December 2005

ABSTRACT

Context. V617 Sgr is a V Sagittae star – a group of binaries thought to be the galactic counterparts of the Compact Binary Supersoft X-ray Sources – CBSS.

Aims. To check this hypothesis, we measured the time derivative of its orbital period.

Methods. Observed timings of eclipse minima spanning over 30 000 orbital cycles are presented.

Results. We found that the orbital period evolves quite rapidly: $P/\dot{P} = 1.1 \times 10^6$ years. This is consistent with the idea that V617 Sgr is a wind driven accretion supersoft source. As the binary system evolves with a time-scale of about one million years, which is extremely short for a low mass evolved binary, it is likely that the system will soon end either by having its secondary completely evaporated or by the primary exploding as a supernova of type Ia.

Key words. binaries: close – stars: winds, outflows – stars: individual: V617 Sgr – supernovae: general

1. Introduction

Compact Binary Supersoft X-ray Sources (CBSS) are a class of objects that share in common a set of properties. They are luminous (~Eddington luminosity) sources of soft (15–70 eV) X-ray photons and were initially discovered in the Magellanic Clouds by the Einstein observatory and ROSAT. The CBSS are thought to be cataclysmic binaries in which the secondary is more massive than the primary star. In this situation, when the secondary fills its Roche lobe a dynamical instability occurs and the mass transfer takes place on the thermal time-scale, which is about 10 million years for donor stars of 1–1.5 $M_{\odot}$. This produces accretion rates 100 times larger than in normal cataclysmic variables and causes hydrostatic nuclear burning on the surface of the white dwarf (see Kahabka & van den Heuvel 1997 for a review).

Only two CBSS (MR Vel and QR And) are found in the Galaxy, where one should find about a thousand. This is presumably due to the absorption of their soft X-ray emission by the interstellar gas in the Galactic plane. V Sagittae stars (Steiner & Diaz 1998) were proposed as a new class of binaries that display properties quite similar to those of CBSS, but are not detected as supersoft sources. They may be the galactic counterpart of the CBSS. The soft photons are either absorbed by the stellar wind or by the interstellar medium (or both). In case this hypothesis is correct, these two classes should share a number of properties in common. For example, the time variation of the orbital period should be high and similar in the two situations – and this could be a critical test for the hypothesis of the CBSS – V Sge connection.

What do we expect in terms of the orbital period time derivative? In the scenario of dynamical instability, we expect that the orbital period decreases with time. There is only one such object for which the period derivative has been measured: V Sge. Its period, in fact, decreases with a time-scale of 5 million years (Patterson et al. 1998). However, this scenario only predicts the existence of orbital periods longer than 6 h (Deutschmann 1998; King et al. 2001). For periods smaller than this limit, the mass transfer is too small for nuclear burning to occur. This limitation on the orbital period imposes a problem to the interpretation of the short orbital period systems among CBSS (SMC 13 and RX J0537.7-7034) and among V Sge stars (V617 Sgr), which have orbital periods shorter than 5 h.

[⋆] Based on observations made at Laboratório Nacional de Astrofísica/CNPq, Brazil.

It has been proposed that in such objects the mass transfer occurs because of radiation induced wind from the secondary (van Teeseling & King 1998). If a low mass secondary star ($M_2 \leq 0.6\,M_\odot$) looses mass adiabatically, that is, on a time-scale short compared to the thermal time-scale, it expands as

$$\frac{\dot{R}_2}{R_2} = \zeta \frac{\dot{M}_2}{M_2} \tag{1}$$

where $\zeta = -1/3$ is the effective mass-radius index of the secondary star. In this case, the expansion forces mass transfer through the internal Lagrangean point at a high rate, producing a CBSS. In this situation, the orbital period increases with time (van Teeseling & King 1998).

We have, thus, two distinct scenarios for CBSS as well as for V Sge stars: systems with initial orbital periods longer than 6 h evolve with negative derivative while systems with shorter periods should evolve with positive derivatives, both with high absolute values. For wind driven supersoft binaries, the orbital period increases with time and may become longer than 6 h. The total possible orbital period range is 2–30 h (van Teeseling & King 1998). So, for a given object, how to decide to which of the two above paradigms the object belongs? In principle one could determine the mass ratio or the secondary's spectral type. But no secondary star has been detected so far in any of the CBSS or V Sge stars. Emission lines are strongly contaminated by the wind and are not reliable dynamical indicators.

For eclipsing systems there is an alternative way of finding whether a given star belongs to one class or to the other: by measuring its orbital period time derivative. A critical test could be provided by V617 Sgr. A positive period derivative with time-scale of about a million years is predicted. This should be measurable, given the time base of our eclipse timings. A similar study was proposed for T Pyx, a recurrent nova with an orbital period of 1.8 hour (Knigge et al. 2000).

V617 Sgr (Steiner et al. 1999; Cieslinski et al. 1999) was identified as a V Sge star (Steiner & Diaz 1998) with an orbital period of 4.98 h. It presents a light curve with two maxima and two minima (see Fig. 3 in Steiner et al. 1999) of unequal depths. The system presents high and low photometric states, like V Sge itself and most CBSS. Timings of the main (deepest) minima provide an opportunity to measure the orbital period with accuracy as well as its time derivative.

2. Observations and data analysis

V617 Sgr was initially classified as a Wolf-Rayet star and received the designation of WR 109 (van der Hucht et al. 1981). It was also classified as an irregular variable of type I in the General Catalogue of Variable Stars (Kholopov et al. 1987) and, for that reason, included in a program to search for new close binary systems (Steiner et al. 1988) when its orbital period was discovered. Since then, timings for the light curve minima of V617 Sgr were measured with distinct telescopes, photometers and CCDs at the Observatório Pico dos Dias – LNA/MCT – in southeast Brazil, spanning an interval of more than 32 000 orbital cycles.

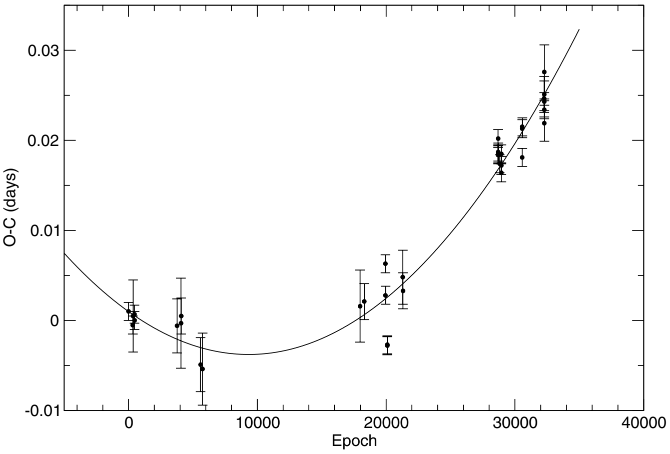

Fig. 1. O−C diagram of the timings of minima observed from 1987 to 2005, relative to the constant period of 0.2071667 days from the ephemeris given by Steiner et al. (1999). The fitted parabola indicates a period that increases with $\dot{P} = 1.1 \times 10^{-10}$ day/cycle.

We obtained new observations of V617 Sgr with the Zeiss 60 cm telescope of OPD in 2003, 2004 and 2005. We employed a thin, back-illuminated EEV CCD 002-06 chip and a Wright Instruments thermoelectrically cooled camera. The images were obtained through the Johnson V filter and were corrected for bias and flat-field, using the standard IRAF [1] routines. The differential aperture photometry was performed with the aid of the DAOPHOT II package. In Table 1 we list the timings of minimum light of V617 Sgr. This list includes the photometric minima already presented in Steiner et al. (1999) along with 17 new timings determined in this work.

An O−C diagram constructed for all timings relative to the linear ephemeris given by Steiner et al. (1999) is shown in Fig. 1. A quadratic function fits the data and yields the ephemeris

$$\begin{aligned} \text{Minimum light} &= \text{HJD}\ \ 2,446,878.7730(\pm 7) \\ &\quad +0.20716568(\pm 4) \times E + 5.5(\pm 1) \times 10^{-11} \times E^2. \end{aligned} \tag{2}$$

This implies $\dot{P} = 1.1 \times 10^{-10}$ day/cycle, so the observed time-scale of period change is 1.1×10^6 year. A first point to notice is that the time derivative is positive, as expected in a system that follows the paradigm of a wind driven accretion supersoft X-ray source. Second, this time-scale is much shorter than the one of V Sge, which has a negative $\dot{P}$ and has a time-scale of 5×10^6 year (Patterson et al. 1998), almost 5 times longer than that of V617 Sgr.

3. Discussion and conclusions

An important system parameter is the mass of the white dwarf. This is usually derived from dynamical measurements. In the case of this system, however, the observed strong wind complicates this kind of determination (Cieslinski et al. 1999).

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[1] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Table 1. Times of minima.

Obs. minimum (HJD)	E (cycle)
2446878.773(1)	0
2446947.758(1)	333
2446952.731(4)	357
2446973.655(1)	458
2446974.483(1)	462
2447658.754(3)	3765
2447721.733(5)	4069
2447725.670(2)	4088
2448036.829(3)	5590
2448069.768(4)	5749
2450246.685(6)	16 257
2450602.595(4)	17 975
2450671.582(2)	18 308
2451011.754(1)	19 950
2451013.615(1)	19 959
2451040.541(1)	20 089
2451041.577(1)	20 094
2451290.806(3)	21 297
2451292.669(2)	21 306
2452822.612(1)	28 691
2452823.646(1)	28 696
2452824.682(1)	28 701
2452825.718(1)	28 706
2452849.748(1)	28 822
2452873.572(1)	28 937
2452874.607(1)	28 942
2452875.645(1)	28 947
2453211.669(1)	30 569
2453212.708(1)	30 574
2453213.744(1)	30 579
2453564.688(2)	32 273
2453565.723(1)	32 278
2453566.552(2)	32 282
2453566.758(1)	32 283
2453567.798(3)	32 288
2453568.621(2)	32 292

Steiner et al. (1999) considered that the mass of the white dwarf must be quite low. This, however, was based on the erroneous assumption that the system is a CBSS with a secondary more massive than the primary and that accretion is driven by the thermal expansion of the donor star.

One alternative way of estimating this mass is by measuring the time-scale of decline from outburst maxima (Southwell et al. 1996). V617 Sgr displays such outbursts as most of other well observed V Sge and CBSS systems do. One such event can be seen in Fig. 4 of Steiner et al. (1999). Eclipse cycle 4069 was observed when the system was at high state. Four days later cycle 4088 was observed at about one magnitude fainter. The decay timescale is, therefore, 4 days or shorter.

From the outburst decline we derive a high mass for the white dwarf: $M_1 = 1.2\,M_\odot$ or higher. If one assumes that the secondary is in the main sequence (this is not obvious, as it is not necessarily in equilibrium), $M_2 = 0.48\,M_\odot$ and the mass ratio is $q = 0.40$.

In the wind driven supersoft X-ray binary scenario, the orbital period time derivative is given by the formula (Knigge et al. 2000)

$$\frac{P}{\dot{P}} = \frac{2M_2}{(3\zeta - 1)(1+g)\dot{M}_{\rm w2}} \tag{3}$$

where

$$\dot{M}_{\rm acc} = -g\dot{M}_{\rm w2} \simeq 1.2\times10^{-6} g^2\phi^2\eta_{\rm a}\eta_{\rm s}\left(\frac{q^{5/2}}{1+q}\right)^{2/3} m_1\ M_\odot{\rm yr}^{-1} \tag{4}$$

and

$$g = \frac{(6\beta_2 + 2q) - (5+3\zeta)(1+q)}{(1+q)(5+3\zeta-6q)} \tag{5}$$

here $q = M_2/M_1$ is the mass ratio, $\dot{M}_{\rm w2}$ is the wind mass loss rate from the irradiated secondary star, $\dot{M}_{\rm acc}$ is the accretion rate, $m_1 = M_1/M_\odot$, $\eta_{\rm a}$ measures the luminosity per gram of matter accreted relative to the value for nuclear shell burning, $\eta_{\rm s} \sim 1$ for CBSS (the efficiency of the primary's spectrum in producing ionizing photons and driving a wind), β_2 is the specific angular momentum loss of the secondary star, and ϕ is an efficiency factor parameterizing the fraction of the companion's face which is irradiated.

In the present case the period derivative and the mass ratio are self-consistent if $\beta_2 = 1.2$. That is the ratio of the specific momentum of the wind relative to that of the secondary star. The observed period variation suggests that V617 Sgr is, indeed, a wind-driven supersoft X-ray source. This adds more evidence to the hypothesis that V Sge stars are the galactic counterparts of the CBSS objects.

This binary system evolves with a time-scale of about one million years, which is extremely short for this kind of low-mass evolved binary. As the white dwarf is quite massive and if it accretes half of the mass of the secondary star it may soon reach the Chandrasekhar limit and, eventually, explode as a Supernovae type Ia. Such binary systems may occur in old populations as demanded by SN Ia statistics, contrary to thermal time-scale mass transfer systems that require relatively young populations. The other possibility is that the secondary will evaporate completely. In this situation one would expect the orbital periods to increase up to 30 h (van Teeseling & King 1998).

V617 Sgr is a system that has left completely the standard CV evolutionary track and will probably destroy itself. This is a channel that may remove this kind of system from the general CV population.

V617 Sgr is a member of a group of 3 known stars that are wind driven supersoft X-ray binaries; the other members of the group are SMC 13 and T Pyx (van Teeseling & King 1998; Knigge et al. 2000). It is the first system in which the predicted evolutionary trend has been clearly observed, thanks to the existence of a relatively deep eclipse in the orbital light curve.

Acknowledgements. We acknowledge Barbara Kato for help in observations and data reduction. A. S. Oliveira and T. V. Ricci thank FAPESP for financial support.

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