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The transient OT J213806.6+261957 in Pegasus - Possible emitter of gravitational waves

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The transient OT J213806.6+261957 in Pegasus showed an outburst in 2010 and an unexpected new outburst in 2014. The system has been classified as a SU UMa system and as a possible member of the WZ Sge subclass. The present paper reports about the spectroscopic monitoring of OT J213806.6+261957 (secured at Loiano Observatory, Italy) during the 2014 outburst and the potential of the system as a gravitational wave emitter. Since the system has an orbital period of 82 minutes and is at a distance of 70 pc only, it could be a strong gravitational source for the forthcoming space based interferometers.

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1. Introduction

Dwarf novae are cataclysmic variables showing outbursts due to thermal and tidal instabilities in the accretion disk [1]. The members of the SU UMa subclass have orbital periods shorter than three hours and show also rarer and brighter superoutbursts [2]. Among SU UMa objects, WZ Sge systems have orbital periods of about 80 minutes and show bright superoutbursts, with an amplitude of several magnitudes, and long recurrence times, a few years at least [3], [4]. Superoutbursts are accompanied by periodic variations of brightness, the superhumps, with an amplitude in the range of tenths of magnitude and a periodicity very close to the orbital period. To date, about one hundred WZ Sge systems are known [4]. The physical conditions of the accretion disk during superoutbursts can be investigated by optical spectroscopy, since the accretion disk is providing the bulk of the optical radiation.

The object OT J213806.6+261957 (J2138+26) was detected in outburst on 2010 May 6, achieving a maximum magnitude of 8.7 on May 8 [5]. The object was classified as a dwarf nova [6], [7]. Spectra secured during the plateau stage [8] were similar to the spectra of GW Lib at the same stage during the 2007 superoutburst [9], [10], as the spectra measured during the decline from the plateau and the fading tail [11]. The observations of J2138+26 during the plateau, the decay from the plateau and the fading towards quiescence showed that the optical thickness of the accretion disk of J2138+26 was progressively decreasing [12], [11], [13].

It has been suggested that J2138+26 is a candidate strong gravitational wave emitter [11], due to the short orbital period and its close proximity, less than 100 pc. The emission is expected in the sub-Hz region, the domain of space based interferometers.

A single previous outburst of J2128+26, dating back to 1942, was reported by [14], who suggested a possible classification as a WZ Sge system. The position of J2138+26 coincides with an X-ray source and a double star [15], whose south-east component has a significant proper motion [16]. The photometric evolution and the superhump history of J2138+26 during the 2010 outburst have been discussed by [17], [18]. The orbital period of J2138+26, 82 minutes, is compatible with the WZ Sge class [7]. The estimated distance, about 70 pc [19], makes J2138+26 one of the closest cataclysmic binaries. An unexpected outburst of J2138+26 occurred on 2014 October 22, when the system achieved a magnitude of 9.7 [20]. The rapid dissemination of events by the AAVSO triggered immediate observations. The role of AAVSO in the astrophysics of cataclysmic variables and related objects is described elsewhere in these proceedings [21]. The outburst recurrence time, below 5 years, is very short for WZ Sge systems [4]. Ordinary (stage A) superhumps were detected on October 24 [22], lasting less then one day before the appearance of stage B superhumps [22]; stage C superhumps started on November 3, just before the rapid drop from the plateau starting on November 6 [22]. Triggered by the unexpected outburst, I have secured spectroscopic observations of J2138+26 during the plateau and the final decline to quiescence, to investigate the physical conditions of the accretion disk and to assess possible differences with the 2010 outburst. The photometric evolution of J2138+26 is presented in Section 2. The spectroscopic observations are reported in Section 3. I will show that the spectroscopic evolution of the 2014 outburst of J2138+26 was similar to the evolution of 2010 outburst. The disk of J2138+26 evolved from being optical thick during the plateau stage to becoming optically thin, starting from the drop from the plateau stage down to the final decline to quiescence. Then I will discuss the possible emission of gravitational waves by J2138+26, comparing it with the sensitivity of the future space based interferometers.

2. Photometric evolution

The V band light curves of J2138+26 shown in Fig. 1 have been built with the data of IAUC circulars [1] and of VSNET database [2] for the 2014 (left) and 2010 (right) outbursts.

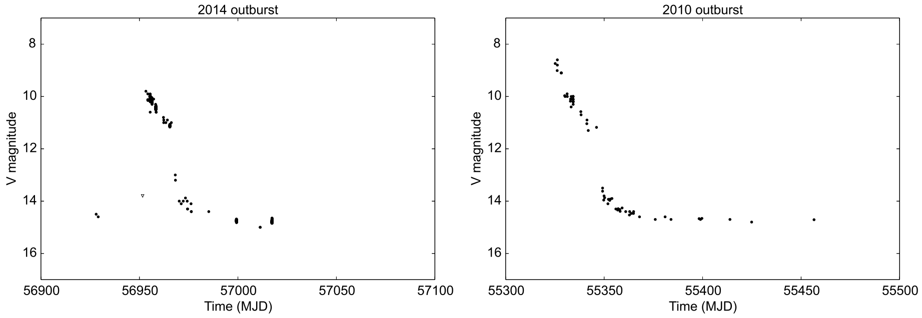

Figure 1: Photometric evolution of J2138+26 during the 2014 (left) and 2010 (right) outbursts

The rise to the maximum was very fast for both superoutbursts. The plateau stage is remarkably different: despite the shape of the light curve of the two outbursts is similar, the 2014 outburst was fainter and shorter that the 2010 outburst [4]. The plateau stages of 2010 and 2014 superoutbursts were followed by similar steep drops in magnitude leading to the fading towards quiescence. The recurrence time between the superoutbursts, 4.5 years, is short for a WZ Sge system, but is of the order of the recurrence time observed for EZ Lyn [4]. However, R. Hudec pointed out at the conference that the results of his analysis of some thousands photographic plates distributed over some tens years with high temporal cadence are not consistent with the short recurrence time.

The 2010 and 2014 superouburst of J2138+26 did not show any echo outburst [4], as the ones occurring in other WZ Sge systems, such as EZ Lyn.

3. Spectroscopic evolution

The differences of the photometric evolution during the 2010 and 2014 superoutbursts could be accompanied by differences in the spectroscopic evolution. I am performing a spectroscopic follow-up of J2138+26, that started a few days after the outburst. The spectroscopic observations are secured at the Cassini 1.52 m telescope, Loiano Observatory, Italy, equipped with the BFOSC imager and spectrograph. Some spectra are presented here to compare the 2010 and 2014 outbursts. The spectra have been secured using grism 4, with a spectral coverage of 3800-8700 Å and a resolution of 3.97 Å/pixel. The spectra frames have been reduced, then each spectrum has been extracted and wavelength calibrated with HeAr lamps. The spectra have been normalized to continuum using a low order polynomial.

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[1] http://cfa-www.harvard.edu/iau/services/IAUC.html

[2] http://ooruri.kusastro.kyoto-u.ac.jp/mailman/listinfo/vsnet-alert

The spectrum secured on 2014 October 25, during the plateau stage, is reported in Fig. 2. The spectrum shows the Balmer transitions Hα, Hβ, Hγ as absorption troughs with narrow central emissions. The narrow peak is very intense for Hα. The transitions of helium have different profiles: He I 4471, 5015 are observed in absorption, while He I 5876, 6678 appear in emission. The complex C III/N III is in emission. The spectrum is very similar to the spectra secured during the plateau of the 2010 outburst [12], [13].

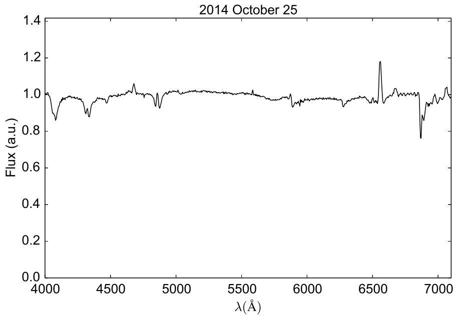

Figure 2: Spectrum if J2138+26 secured on 2014 October 25

The second spectrum has been secured on 2015 August 22 during the fading tail (Fig. 3). The spectrum shows strong emission lines: Hα, Hβ, Hγ, Hδ, He I 4471, 4921, 5015, 5876, 6678, 7065. The spectrum is similar to the spectra measured during the previous outbursts, on 2010 August [11], [12], [13].

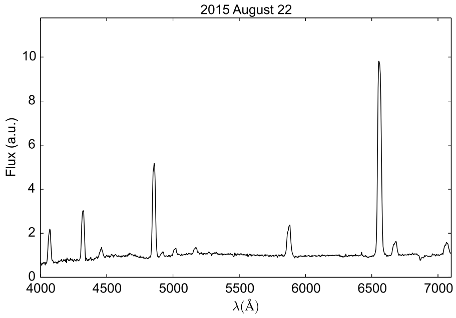

Figure 3: Spectrum if J2138+26 secured on 2015 August 22

Despite the different photometric behavior during the 2010 and 2014 superoutbursts, the spectroscopic evolution of J2138+26 during the two events was quite similar. The two spectra are typical of WZ Sge systems and provide two snapshots of the accretion disk evolution [9]. The accretion disk was optically thick at the epoch of the first spectrum, during the plateau of the light curve. The outer part of the disk was irradiated by the UV photons of the white dwarf and its own inner part. The observed lines were produced by photoionization. The accretion disk was optically thin and no more irradiated at the epoch of the second spectrum. The observed lines, all in emission, were produced by collisional excitation.

4. J2138+26: a gravitational wave emitter?

The search for the direct detection of gravitational waves is being pursued by ground based laser interferometers: no direct detection has been made, but several upper limits have been put on a large variety of astrophysical sources. Since cataclysmic variables are binary systems, they are natural candidates for gravitational wave emission that is related to the quadrupole moment of the mass distribution. The estimated galactic population is of the order of 10^6 [23]. Due to the close distance, J2138+26 could be a potentially strong source. In the following, I will present the estimation of the gravitational wave emission of J2138+26 and will compare it to the sensitivity of planned detectors [11]. As we will show below, the gravitational wave emission of cataclysmic variables is in the sub-Hz region, that is not accessible to ground based interferometers, because of the seismic noise. The sub-Hz range is expected to contain a large variety of detectable sources: cataclysmic variables, compact binaries, massive black hole binaries, stellar mass black holes inspiraling into supermassive ones [24]. The sub-Hz region can be accessed by operating laser interferometers in space [25], where there is no seismic noise and there are no specific limits to the arm length.

The first conceptual study of LISA, a space based interferometer for gravitational wave detection has been performed by NASA and ESA [26]. The gravitational waves produce a tidal acceleration of test masses pairs, that is sensed via the modulation of the frequency of a laser beam travelling from one test mass to the other. The LISA interferometer concept was based on three spacecrafts in heliocentric orbit at 1 astronomical unit, forming an equilateral triangle with 5 Million kilometers arm length. The spacecraft constellation was behind the Earth by 20 degrees. Each spacecraft contained free falling test masses and the laser systems to operate the interferometer. The budget crisis forced NASA to abandon the support to the mission in 2011 and LISA was redesigned as an ESA only mission. The design was rescaled to a shorter arm length for the interferometer and to the choice of different orbits, with cheaper access, for the spacecrafts, leading to the new concept of eLISA, evolving LISA. The eLISA mission has been selected by ESA as the subject of a L3 Science Theme and is scheduled for launch in 2034 [27]. eLISA is made of three spacecrafts (the mother and two daughters) that orbit the Sun in nearly circular orbits and form an interferometer with arm lengths of one million kilometers. The constellation is arranged to form an equilateral triangle and to retain that shape and will have access to the whole sky. Each arm is made of two spacecrafts that exchange laser beams, providing two laser links. The spacecrafts contain free falling test masses shielded from external disturbances. A system of thrusters maintains the spacecrafts centered on the test masses. The passage of a gravitational wave produces a modulation of the laser frequency, sensed by the link. The contribution of the acceleration of the spacecraft relative to the test mass is locally measured and subtracted.

The LISA Pathfinder is an ESA mission that is the precursor to the eLISA mission, with the aim to demonstrate the measurement strategy and test the technology that will be used by eLISA [28]. The Pathfinder contains a small scale version of the eLISA arm. The payload includes two test masses (2 kg Au-Pt cubes) at a distance of 0.38 m, two interferometers to measure the displacement of the test masses from each other and relative to the spacecraft, a Nd:YAG laser and μN thrusters. The Pathfinder is scheduled for launch in December 2015. It will follow a Lissajous orbit around Lagrange point L1.

The sensitivity curve of space based interferometer discussed above is U-shaped. The low frequency part, below a few mHz, is dominated by the acceleration noise, caused by residual spurious forces acting on the test masses. The sensitivity in the high frequency region, above some tens mHz, is dominated by the shot noise of the laser. The high frequency sensitivity decreases since the wavelength of the gravitational wave becomes smaller than the double of the interferometer arm length and radiation is not able to complete the back and forth trip in the arm.

In addition to the instrumental noise, space based interferometers are limited by an astrophysical background, the confusion noise caused by the unresolved population of galactic close binaries [23], [29].

The cataclysmic variables we are interested in emit gravitational waves at twice the orbital frequency and at the relative harmonics. Since the orbit of cataclysmic variables becomes circularized during evolution, it is safe to assume a zero eccentricity and consider only the double of orbital frequency frequency. The gravitational wave strain is [30]:

$$h = 8.7 \times 10^{-21} \left(\frac{\mu}{M_\odot}\right) \left(\frac{M}{M_\odot}\right)^{\frac{2}{3}} \left(\frac{100pc}{r}\right) \left(\frac{f}{10^{-3}Hz}\right)^{\frac{2}{3}} \tag{4.1}$$

where $M = M_1 + M_2$, $\mu = \frac{M_1 M_2}{M_1 + M_2}$, M_1, M_2 are the masses of the primary and secondary star, r the cataclysmic distance and f the frequency. The distance has been estimated by [19] as 70 pc, making J2138+26 one of the closest cataclysmic variables. The orbital period of J2138+26 is 82 minutes [7]. The estimation of masses [11] has been performed using the catalog by Ritter and Kolb [31] [3]. The mass of the primary star has been estimated by the average of the masses of the white dwarfs below the period gap, M_1=0.74 $M_\odot$. The mass of the secondary star has been estimated by fitting the secondary mass M_2 against the orbital period P, for the systems with orbital periods below nine hours. The result of the fit is $M_2(M_\odot) = (0.106 \pm 0.006)P(hr) - (0.026 \pm 0.022)$, thus the mass of the secondary of J2138+26 is M_2=0.12 $M_\odot$. The value of the primary and secondary masses are in agreement with the values of the members of WZ Sge class [13]. The estimated value of the strain h for J2138+26 is 6.3×10^{-22} at a frequency of 3.9×10^{-4} Hz. The strain h is reported in Fig. 4; the gravitational wave emission of 156 cataclysmic variables estimated by [32] is reported for comparison. The three solid curves are, from top to bottom, the instrumental thresholds of the eLISA interferometer with 1 Million km arm length, with 2 Million km arm length and of LISA interferometer [33]. The sensitivities have been estimated for 1 year of integration time and unit signal to noise ratio. The dashed curve is the contribution of confusion noise [4], the astrophysical background produced by unresolved binary systems [23], [29]. The gravitational strain of the system J2138+26 is above the threshold of confusion noise. It is above the instrumental threshold of the LISA interferometer, but not of the eLISA interferometerm unless the arm length is doubled.

A focus quantity for estimating the gravitational wave emission of cataclysmic variables is the great uncertainty of distance values. The system WZ Sge has been considered the prototype of the gravitational wave emission of cataclysmic variables for initial LISA studies. However, its distance ranges from 43 pc [34] to 194 pc [32]. Using the last value, as in [32], the estimated strain is 8×10^{-23}, smaller than the strain of J2138+26.

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[3] http://physics.open.ac.uk/RKcat/

[4] http://www.srl.caltech.edu/ shane/sensitivity/

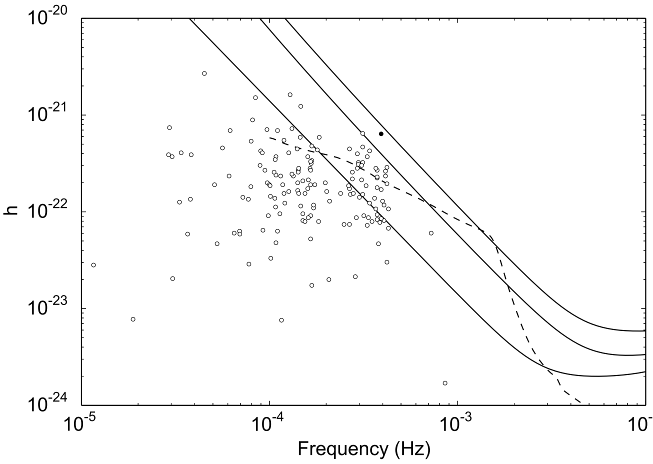

Figure 4: Gravitational wave emission of J2138+26 (full circle) and of the cataclysmic variables reported by [32] (empty circles); the solid curves are, from top to bottom, the instrumental thresholds of eLISA with 1 Million km arm length, with 2 Million km arm length, of LISA, while the dashed line is the binary confusion noise; the noise curves have been computed for 1 year of integration time and unit signal to noise ratio

5. Conclusions

The system J2138+26 is a peculiar system that belongs to the SU UMa class of cataclysmic variables. It showed three recorded outbursts in 1942, 2010, 2014. Despite the 2014 outburst was shorter and fainter than the 2010 outburst, the spectroscopic evolution was very similar. The short orbital period and the close distance make J2138+26 a gravitational wave emitter for space based interferometers.

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