OJ287 impact flare monitoring campaign during November 2015 to February 2016

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ABSTRACT

The blazar OJ287 is the most promising candidate for a supermassive black hole binary inspiralling under the action of gravitational radiation reaction. The central engine of the blazar is a binary supermassive black hole. The model of OJ287 arises from the observations of quasi-periodic optical outbursts at intervals of approximately 12 years dating back to around 1891. Further, the presence of narrow double peaks at maximum brightness along with the timings of these major outbursts are consistent with the scenario where the minor binary component ploughs through the accretion disk of the primary twice every orbit. The binary black hole in OJ287 is modelled to contain a spinning primary black hole with an accretion disk and a non-spinning secondary black hole within the appropriate post-Newtonian approximation to general relativity. A very recent detailed re-modeling of the binary black hole system in OJ287 reveals that the primary black hole should spin approximately at quarter of the maximum spin rate allowed in general relativity. In this scenario, we have a unique solution and also a unique prediction for the next OJ287 impact flare outburst and it is expected to occur on 2015 December 6 $\pm$ 8 weeks. Fortunately, its timing is spin-sensitive. An accurate timing of the impact flare should allow us to constrain the Kerr parameter of the primary black hole with a fraction of percent accuracy. Therefore, the main aim of the present campaign is to constrain the spin of a massive black hole to above accuracy for the first time.

1. Introduction and motivations

OJ287 is a blazar at redshift $z = 0.306$ that exhibits nearly periodic double peaked outbursts at intervals of approximately 12 years in the optical regime (Figures 1-2) (Sillanpää et al. 1988).

The double peak structure in the light curve of OJ287, with the two peaks separated by one to two years, is interpreted as the double impact of the secondary black hole on the accretion disc of the primary supermassive black hole acting as the central engine of the blazar (Figure 3) (Lehto & Valtonen 1996). Further, the orbit of the secondary is sufficiently compact and eccentric ($e \sim 0.7$) to bring it close enough to the primary for strong relativistic precession of the orbit that amounts to $\sim 39^\circ$ per orbit (Valtonen 2007). There does not exist any solution to the timing of the outbursts in OJ287 without this precession, as was most concretely shown in 2005 when the no-precession model predicted the outburst one year too late. The no-precession model predicted the main outburst at 2006.7 when actually the source was at it local minimum brightness (Figure 4). The model is also confirmed by the variation of the jet angle which is seen in radio observations (Figure 5).

The binary black hole acting as the central engine has been fairly successful in predicting these impact outbursts: the predictions for the beginning of 1994, 1995 and 2005 outbursts were correct within one to two weeks (Valtonen 2007; Valtonen et al. 2008a). A crucial element in the predictive capability of the model is the use of general relativistic description for for the temporal evolution of the binary black orbit as demonstrated while observing the 2007 outburst (Figures 5-6)(Valtonen et al. 2008b). A model that neglects the effect orbital period decay due to the emission of gravitational radiation is *not viable* as it predicted the occurance of 2007 impact outburst three weeks later(Valtonen et al. 2008b). The fact that the four major outbursts happening at the predicted times by chance is negligible prompted investigations that incorporated higher order general relativistic effects (Valtonen et al. 2010). The natural extension of the model was to allow the primary black hole to spin and probe the consequences of the dominant general relativistic spin-orbit coupling. The main consequence of including the leading order spin-orbit interactions to the dynamics of a binary black hole is that it forces the orbital plane to precess.

It turns out that the orbital angular momentum vector, characterising the orbital plane, precesses around the spin of the primary in such a way that the angle between the orbital plane and the spin vector remains almost constant for the BBH system in OJ287. Fortunately, (Valtonen et al. 2010) was able to place constrain on the additional parameter, namley the Kerr parameter of the primary BH, by invoking impact flare timing from historical outbursts. It may be noted that the BBH model without the spin effects requires seven well timed outbursts to provide a unique orbit and the usually employed outbursts are those which occurred in the years 1913, 1947, 1973, 1983, 1984, 2005 and 2007. However, a major outburst that occurred in 1957, was identified in the historical record during the last decade. This allowed (Valtonen et al. 2010) to constrain the Kerr parameter of the primary BH to be around 0.28 (the orbit solutions currently involve nine accurately timed outbursts).

Interestingly, recent measurements historical phographic plates of OJ287 in the spring of 1906 provide a new constraint on the spin, though not very accurately (Hudec et al. 2013). The main influence of including the 1906 data while modeling the central engine of the blazar is to make the Kerr parameter of the primary BH to be around 0.23.

One should expect three more impact flare outbursts during the next decade, occuring in 2015/2016, 2019 and 2022. The 2015/2016 outburst should be an easy one to detect, as it comes this (northern) winter. Its timing is expected to be spin-sensitive and it's exact date will give us a good spin value with the help of the following formula:

$$\chi_1 = 0.25 - 0.5 \times (t - 2016.0). \tag{1}$$

where χ_1 is the Kerr Kerr parameter of the primary BH and t is the time of the beginning of the outburst in years. The accuracy is expected to be in fraction of a percent.

Observing strategy: the observations should be nightly in order to catch the beginning of the outburst. It is very sudden, and does not give any warning signs that are known. As illustrated below (Figure 7), weekly observations are not enough to determine the spin value accurately. Even worse, missing the flux maximum can lead to difficulties which may have been the case in the 1972/3 season illustrated here. Getting observers active after the maximum has usually succeeded, but for many purposes it is too late. Campaigns have now been carried out in 1994, 1995, 2005 and 2007; the only truly successful campaign was in 2007 which demonstrates the difficulty of catching the outburst at the very beginning.

This write-up is to motivate the regular monitoring of OJ287 (RA: 08:54:48.87 & DEC:+20:06:30.6) during the nights of November 2015 to February 2016. The plan is to obtain accurately the time of origin of the rapid flux rise.

The expected outburst is thermal radiation at about T=3×10^5 K. Thus the flux peaks a far UV - soft X-rays, and it is most easily recognized above the synchrotron radiation background in this spectral region. The thermal outburst is unpolarized, unlike the background synchrotron flux. In case there are smaller synchrotron flares around the same time, the polarization and UV observations are helpful in discriminating between different sources of origin of the flux (thermal source above the accretion disk vs. jet emission on the disk axis).

A coordinated effort that will allow observations in Japan, then moving to China, India central and western Europe and the united states will be highly recommended.

In summary, the present write-up encourages the daily monitoring of OJ287 during the next three months for the predicted impact flare associated with its binary black hole model.

A link to monitoring at Tuorla observatory is:

$$http://users.utu.fi/kani/1m/OJ287.html \tag{2}$$

REFERENCES

Lehto, H.J., & Valtonen, M.J. 1996, ApJ, 460, 207

Mangalam, A. V., & Wiita, P. J. 1993, ApJ, 406, 420

Sillanpää, A., Haarala, S., Valtonen, M.J., Sundelius, B. & Byrd, G.G. 1988, ApJ, 325, 628

Valtonen, M.J. 2007, ApJ, 659, 1074

Valtonen, M.J., Kidger, M., Lehto, H. & Poyner, G., 2008b, A&A, 477, 407

Valtonen, M.J. et al., 2008c, Nature, 452, 851

Valtonen, M.J. et al. 2010a, ApJ, 709, 725

Hudec, R., Bašta, M., Pihajoki, P., & Valtonen, M. 2013, A&A, 559, A20

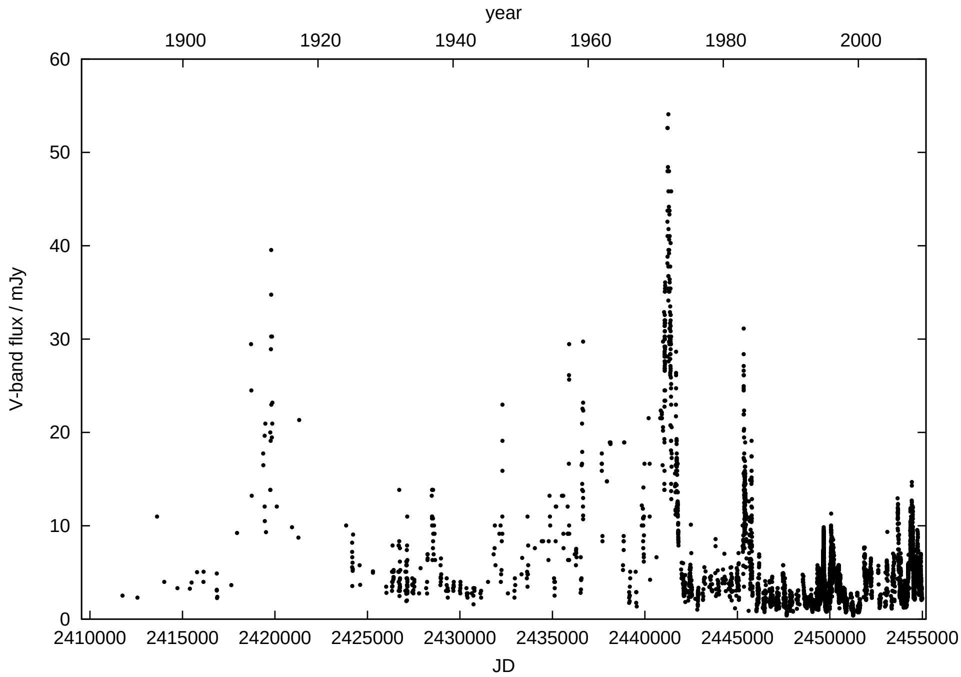

Fig. 1.— One hundred year optical light curve of OJ287 in linear scale.

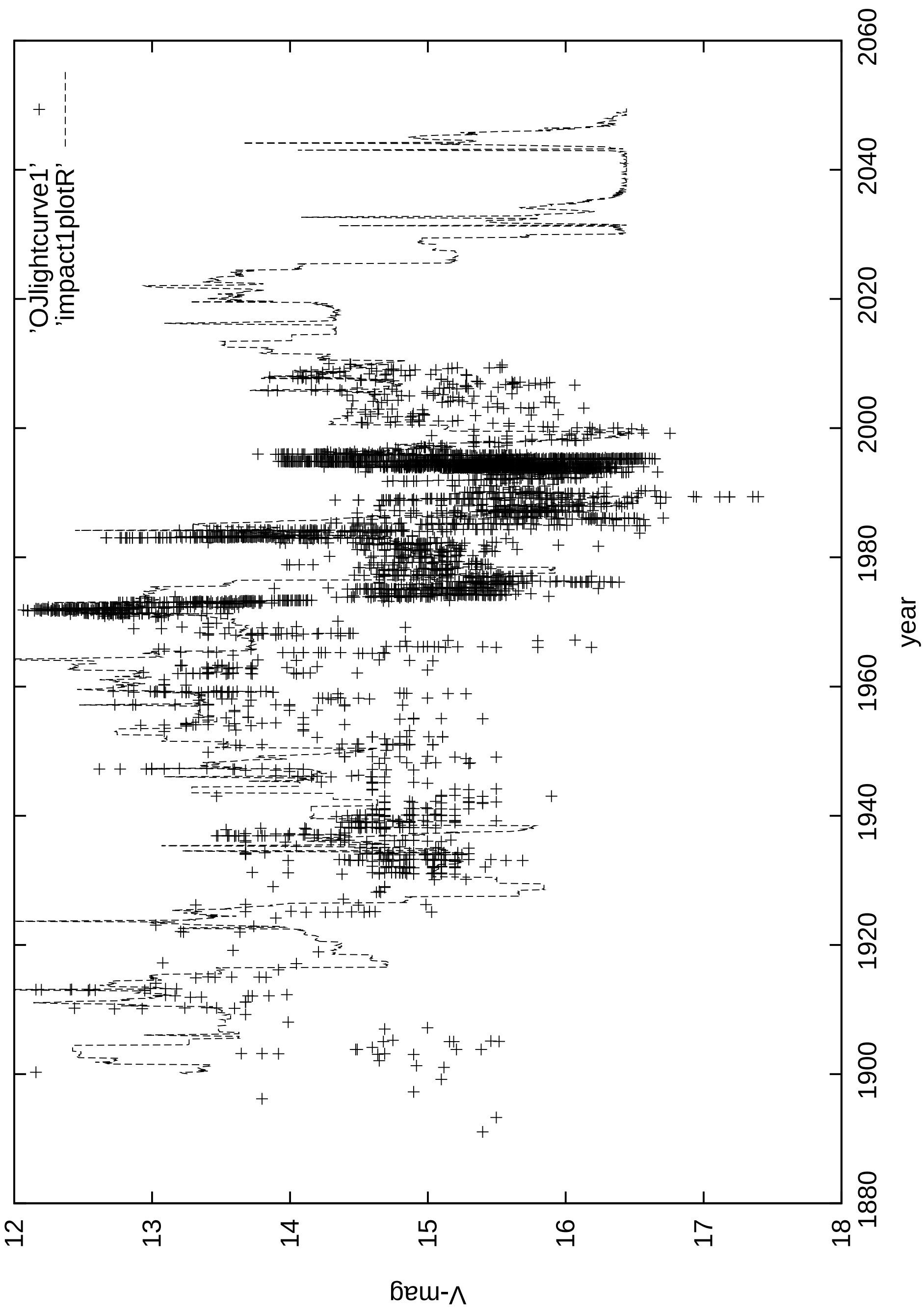

Fig. 2.— One hundred year optical light curve of OJ287 in magnitude scale, and the model fit. The predicted 2015/2016 outburst stands out.

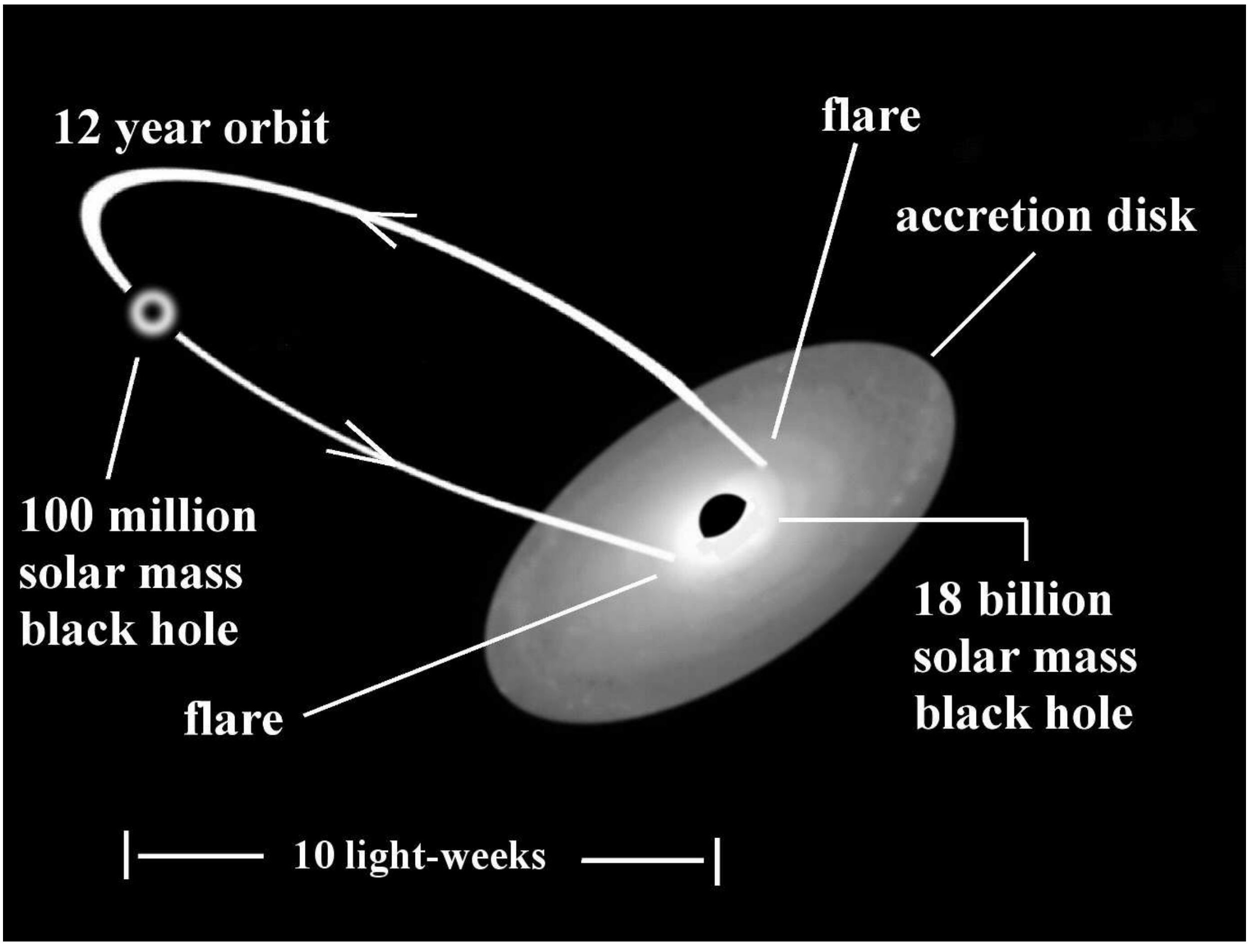

Fig. 3.— An illustration of the OJ287 binary system. The jets are not shown, but they may be taken to lie along the rotation axis of the accretion disk. The two black holes are not resolved in current observations; the required resolution is $\sim 10\mu$arcsec. However, the model explains *all* observations from radio to X-rays and the time variability of these data.

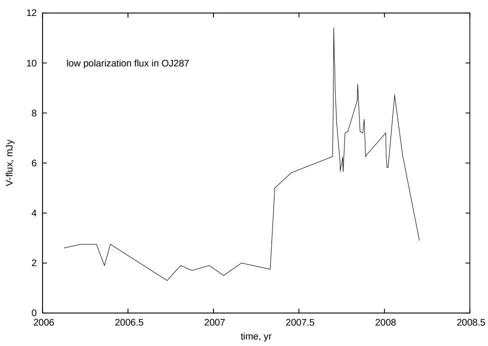

Fig. 4.— The optical light curve of OJ287 during 2006-2008. Only low polarization (less than 10%) data points are shown.

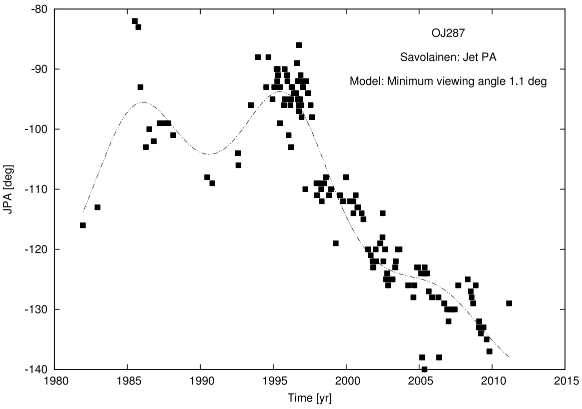

Fig. 5.— Observations of the jet position angle in OJ287 at cm wavelengths. The line represents a model where the orientation change propagates outward in the jet with speed $0.85c$. In observer's time, it takes over 200 years to propagate the change from the optical core to the cm-wave jet. Due to the small viewing angle of $\sim 2^\circ$ of the jet, the small changes in its direction are magnified.

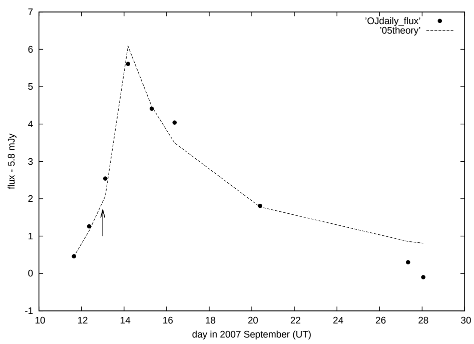

Fig. 6.— The optical light curve of OJ287 during the 2007 September outburst. Only low polarization (less than 10%) data points are shown. The dashed line is the theoretical fit. The arrow points to September 13.0, the predicted time of origin of the rapid flux rise.

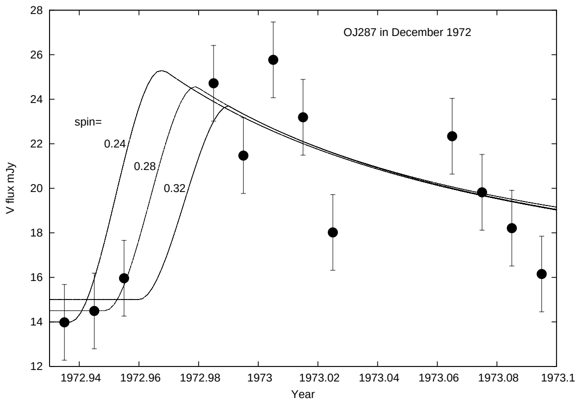

Fig. 7.— Observations of OJ287 in December 1972 - February 1973. Weekly avarages are shown. No points are given when observations were missed during the whole week. The three lines refer to three spin values in the model.