RevMexAA (Serie de Conferencias), **32**, 22–24 (2008)

OJ287: A BINARY BLACK HOLE SYSTEM

M. J. Valtonen[1]

RESUMEN

Usando el destello de noviembre de 2005 como un punto fijo, derivamos nuevas soluciones para el modelo de agujero negro binario de OJ287. Modelos anteriores habían usado el destello de septiembre de 1994, y dado que su determinación no es muy precisa, había incertidumbres importantes en la órbita. Los parámetros del sistema que se han encontrado son el periodo orbital, determinado por el tiempo transcurrido entre los destellos de 1947.30 y 1983.00, la orientación del eje mayor orbital en un momento dado, determinado por el destello de 1972.97, el factor de retraso temporal, que es una función del ancho del disco y determinado por el destello de 2005.76 y la tasa de precesión determinada por el destello de 1913.00. Se encuentra una única solución tanto para un modelo en el que se considera radiación gravitacional como para uno en el que ésta no es considerada. El destello de septiembre de 2007 se espera para 2007.70 (septiembre 13 + o − unos días) en el primer modelo y a principios de octubre en el segundo. Las tres semanas de diferencia entre los dos modelos serán fácilmente resueltas temporalmente en las observaciones por lo que la emisión de radiación gravitacional podrá ser medida de manera indirecta. Observaciones de rayos-X soportan la idea de que el destello de 2005 está relacionado con el impacto del agujero negro secundario sobre el disco de acreción del agujero negro primario.

ABSTRACT

We derive new solutions for the binary black hole model of OJ287, using the November 2005 outburst as one of the fixed points. Previous models have used the September 1994 outburst which is in many ways ill-defined, and leads to considerable uncertainty in the orbit. The parameters of the system to be determined are the orbital period, fixed by the separation of the 1947.30 and 1983.00 outbursts, the orientation of the major axis of the orbit at a given time, fixed by the 1972.97 outburst, the time delay factor which is a function of the disk thickness, fixed by the 2005.76 outburst, and the precession rate of the binary, fixed by the 1913.00 outburst. A unique solution is found for the case of gravitational radiation and of no gravitational radiation. The 2007 September outburst begins 2007.70 (September 13, + or − a few days) in the former model, and at the beginning of October in the latter model. The three weeks difference will be easily resolved in observations, and thus the emission of gravitational radiation can be indirectly measured. X-ray observations support the idea that the 2005 outburst is related to an impact of a secondary black hole on the accretion disk of a massive primary.

Key Words: quasars: general — quasars: individual (OJ287)

1. INTRODUCTION

The quasar OJ287 shows interesting quasi-periodic behavior: There are two clear cycles of 12 yr and 60 yr in its light curve which extends more than 100 yr in the past (Valtonen et al. 2006b). In addition, there are brief intense outbursts which occur in pairs during the 12 yr cycle, separated by 1–3 yr. This double peak structure is a puzzle since the peaks do not follow a 12 yr or any other easily recognizable cycle. If we measure the time intervals between the peaks, and divide by the number of cycles, we obtain intervals like 11.18 yr (1984.15–1972.97), 11.35 yr (2005.76–1983.00), 11.90 yr (1983.00–1947.30), 11.99 yr (1972.97–1913.00), etc. No single interval repeats itself, and therefore it is clear that the sharp outburst peaks are not periodic.

However, in spite of the apparent irregularity, there is a simple mathematical rule which gives the times of all known outbursts from 1913 up to today. This rule is obtained if we take a binary orbit of about 12 yr cycle and suitable eccentricity, and require that an outburst happens every time when the binary goes through a constant phase angle or the angle 180 degrees on opposite side. The known outburst times are generated by this rule quite accurately (Lehto & Valtonen 1996, model 1). The mathematical solution requires that the binary orbit precesses. Since the precession is a feature of

[1]Tuorla Observatory and Department of Physics, University of Turku, Finland (mvaltonen2001@yahoo.com).

General Relativity, we arrive quite naturally at the binary black hole model.

The next step is to ask what process might generate the outbursts at the constant phase angle. Lehto & Valtonen (1996, model 2) show that a suitable outburst arises when a black hole of 10^8 solar mass impacts on the accretion disk of a bigger black hole. The two opposite phase angles then represent impacts on opposite sides of the disk, once on the way in, the second impact on the way out. The mass of the primary is determined in two ways: (1) from relativistic precession which gives an accurate value of 1.7 10^{10} solar mass, and (2) from the requirement that the disk is stable in spite of repeated impacts which gives a lower limit of about 10^{10} solar mass. A variant of the model, proposed by Valtaoja et al. (2000) is violently unstable, since in this model the primary black hole is assumed to be so small that precession is negligible. Then the gravitational confinement of the disk fails by orders of magnitude.

Here we report the latest solution to the problem of unevenly spaced outburst peaks.

2. ORBIT SOLUTIONS

The complete solution of the orbit requires the timing of at least 6 outbursts. Lehto & Valtonen (1996) used the 1947.30, 1972.97, 1983.00 and 1984.15 outbursts as fixed points. The missing data was filled in by a guess of the timing of the ill-defined 1994 outburst as well as by an estimate of the disk thickness. Consequently the predictions of this model were not very precise. For example, the prediction for the 2005 outburst was uncertain by 0.5 yr either way (Pietilä 1998). Fortunately, the observing campaign for the current outburst season had already started, and by good luck, there was intense monitoring just when the outburst came. The best timing for the event is 2005.76 even though the data has not yet been fully analyzed.

Using this outburst as a new fixed point, Valtonen (2007) calculated a new orbit model. However, in this work the timing of 2005.82 was used. Correcting to 2005.76 leads to somewhat different predictions which will be reported here. The models include astrophysical effects such as bending of the accretion disk which means that the solutions are not purely mathematical, even though they are unique within the framework of the given astrophysical model.

The most immediate prediction concerns the next disk crossing at 2007. The timing of the outburst is now September 13, plus or minus a few days. The orbit model includes a shortening of the orbital period based on emission of gravitational waves from the system. Without such emission, the outburst would come three weeks later.

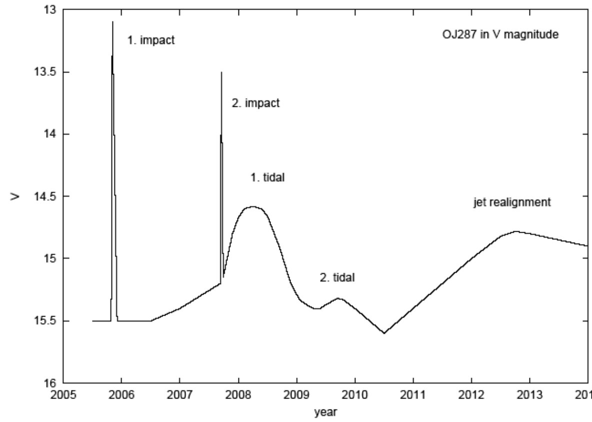

Fig. 1. The predicted optical light curve of OJ287 until 2014. The three types of brightness features are indicated; the rapid events arising from disk impacts, slow events arising from accretion flow variations caused by tides, and very slow flux changes arising from jet realignment and the consequent change in Doppler boosting. The calculations are based on the exact orbit solution, but the general features and in particular time scales are valid for any other binary model of OJ287.

3. OTHER PROPERTIES OF THE MODEL

The precession of the orbit is 39 degrees per period. It means that the major axis rotates through 180 degrees in less than 5 periods, i.e., 60 yr. This is a straightforward explanation of the longer brightness cycle. The details of the model are related to the wobble of the inner accretion disk, and the resulting variations of jet orientation. These lead to brightness variations via varying Doppler boosting.

The observed twelve year cycle comes from tidal force variations during the orbital period. They affect accretion flow, and thus jet brightness (Sundelius et al. 1997). Taken all together, the predicted brightness behavior of OJ287 is as shown in Figure 1. The impact peaks are sharp, while the tidal peaks are broad, and the jet realignment is very slow. These are fundamental time scales which come from the sound crossing time across the region which is causing the brightness variations. The tidal and jet realignment peaks can never be as sharp as the observed sharp peaks, quite independent of the details of the model.

Thus, models where the sharp brightness variations are thought to arise from jet wobble or from tides fail, by at least an order of magnitude. Moreover, such models do not explain the uneven spacing of the sharp peaks.

One of the definite predictions of the disk impact model is that hot gas close to a million degrees temperature is pulled out of the accretion disk. The gas should radiate in UV and in soft x-rays, causing a soft x-ray excess bump. RXTE x-ray telescope observed a 4 sigma event at 2005.76 and an unusual number (11) of 3 sigma detections followed during the 0.3 yr optical outburst. For comparison, in 2007.04–2007.34 only two 3 sigma detections of OJ287 were recorded. XMM-Newton spectral observations during the outburst and six months prior to it confirm that the increased x-ray emission at the outburst comes in soft x-rays, not in hard x-rays (S. Ciprini, private communication). These detections are most easily interpreted as Bremsstrahlung from the hot gas.

4. CONCLUSIONS

The binary orbit model will soon be definitely determined, using 6 fixed points, if the 2007 September event comes as scheduled. After that, predictions both as regard to the past light curve, which is now intensively studied, and as regard to future outbursts will be quite definite. This will be the most precise test of the binary black hole model of OJ287.

The x-ray timing results are provided by the ASM/RXTE teams at MIT and at the RXTE SOF and GOF at NASAs GSFC.

REFERENCES

Lehto, H. J., & Valtonen, M. J. 1996, ApJ, 460, 207
Pietilä, H. 1998, ApJ, 508, 669
Sundelius, B., Wahde, M., Lehto, H. J., & Valtonen, M. J. 1997, ApJ, 484, 180
Valtaoja, E., et al. 2000, ApJ, 531, 744
Valtonen, M. J., et al. 2006a, ApJ, 643, L9
_________. 2006b, ApJ, 646, 36
Valtonen, M. J. 2007, ApJ, 569, 1074