

Predicted General Relativity centenary flare from OJ287 & its implications

Achamveedu Gopakumar

Tata Institute of Fundamental Research, Mumbai

January 11, 2017



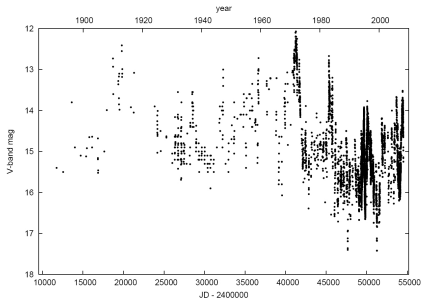
- ▶ *This is a brief update on our efforts to confirm the presence of **a spinning supermassive black hole binary** in blazar OJ287*

Valtonen, Zola, Ciprini, Gopakumar, et al. 2016, ApJL , 819, L37

An observational campaign involving roughly two dozen optical observatories & *Swift/XRT*

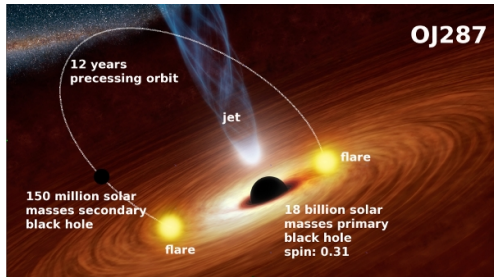
OJ287: Facts

- ▶ It is a quasar at $\sim 1\text{Gpc}$ away
- ▶ Its optical light curve exists from 1891 !
And shows variations in brightness by orders of magnitude
- ▶ Long term variations having ~ 60 yr time scale
Shorter variations with peaks in \sim every 12 yrs
- ▶ Recent data points to double peak structure



OJ287 & its central engine: I

- ▶ Valtonen & his co-workers proposed a SMBH binary model for OJ287
- ▶ OJ287 contains a SMBH with an accretion disk
The slow accretion of gas on to the BH makes it **VISIBLE !**
- ▶ SMBH is orbited by another massive BH that plunges through the accretion disk regularly
- ▶ This causes the gas in the disk to heat up dramatically, radiating strongly for weeks
This explains why peaks occur

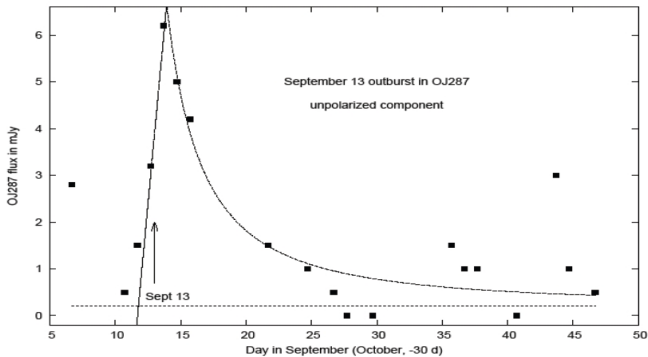


OJ287 & its central engine: II

- ▶ Accurate timings of six peaks is required to provide a unique solution for the simplest binary BH model
- ▶ The 2005 outburst allowed us to close the orbit
- ▶ $M_p \sim 18 \times 10^9 M_\odot$ $M_s \sim 10^8 M_\odot$, $e \sim 0.66$, $T_{\text{orb}} \sim 12$ years,
The observations were consistent with a massive BH binary having $\Delta\omega \sim 40$ deg/orbit !!!
(v/c) > 0.1!!
- ▶ Valtonen et al. in 2006 predicted that the next outburst is due in 13/09/2007 (± 2 days)
General relativistic equations of motion for BH binaries with non-spinning components

Validating massive BBH scenario for OJ287: I

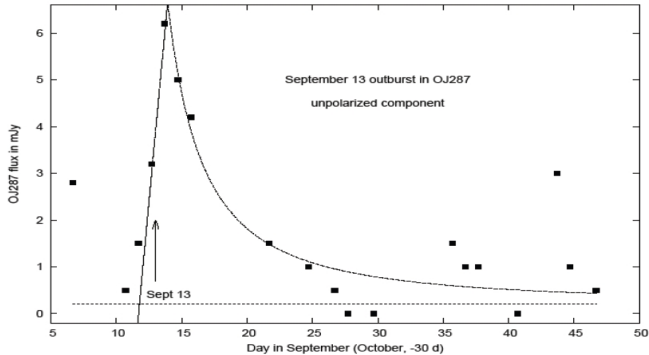
Valtonen et.al ..Nature 2008



The black squares are the data & the dashed line is the theoretical prediction !!

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This is truly amazing as the scenario involved plasma physics and turbulences

Validating massive BBH scenario for OJ287: II

- ▶ If the reactive 2.5PN terms in the BBH dynamics (this term causes binary pulsars to have \dot{P}_b) is neglected, the outburst should occur around 01/10/2007 !
- ▶ Post-Newtonian corrections to the orbital dynamics are crucial !!

$$\ddot{\mathbf{x}} = \boxed{\text{N}} \boxed{\text{1PN}} \boxed{\text{2PN}} \boxed{\text{2.5PN}}$$

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- ▶ If one allows the primary black to spin, the spin-orbit coupling enter the dynamics at 2PN order (if the BH is not spinning with $\chi \sim 1$ [$S = Gm^2 \chi/c$])
- ▶ It may be possible to constrain the spin of the massive BH !

Validating massive BBH scenario for OJ287: III

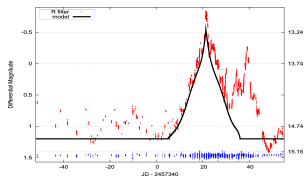
- ▶ Using post-Newtonian accurate BBH dynamics that included the leading order spin-orbit coupling, the spin of the primary BH was constrained to be $\chi \sim 0.27$
Mining of historic photographic plates provided accurate timings of more outbursts ([Valtonen et.al ..2010](#))
- ▶ The impact flare after 2007 outburst was predicted to occur during the fall 2015 !!
- ▶ It was predicted that the exact date of the flare rise should lead to a very accurate determination of the spin of the primary BH

$$\chi_1 = 0.25 - 0.5 \times (t - 2016.0)$$

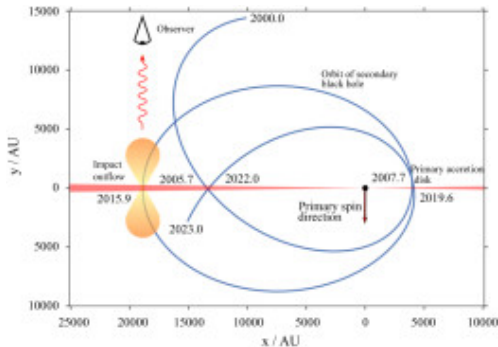
- ▶ The accuracy is expected to be in fraction of a percent.

Confirming the massive BBH scenario for OJ287: I

- ▶ The model of OJ 287 predicted another disk crossing in December 2015,
- ▶ Professional & amateur astronomers around the world readied more than two dozen ground-based optical telescopes and the Swift/XRT satellite to observe OJ 287 during November-December 2015
- ▶ The outburst began during GR centenary & peaked on 5/12/2015



Confirming massive BBH scenario for OJ287: II



One observes outbursts (the yellow bubbles) every time the secondary black hole crosses the accretion disk (shown in red, in a side view) surrounding the primary (the black circle)

Valtonen et al. 2016

Confirming massive BBH scenario for OJ287: III

- ▶ The peak magnitude of our targeted optical outburst was ~ 12.9 in the optical R-band
- ▶ With the help of Swift/XRT measurements and ground-based optical polarization data, it was demonstrated that the optical flare did contain a major thermal component

Confirming massive BBH scenario for OJ287: III

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- ▶ With the help of Swift/XRT measurements and ground-based optical polarization data, it was demonstrated that the optical flare did contain a major thermal component
- ▶ Timing of the rising flare provides an accurate estimate for the spin of the primary black hole

$$\chi_{\text{primary}} = 0.313 \pm 0.01$$

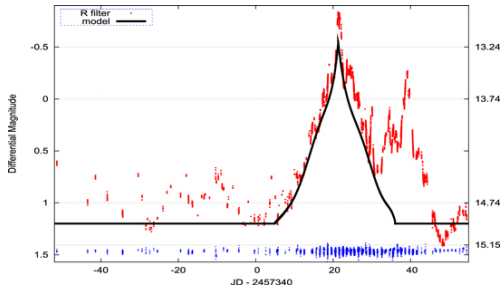
Confirming massive BBH scenario for OJ287: IV

- ▶ **First accurate measurement for the spin of a massive BH !!!**
- ▶ General Relativity centenary flare did confirm earlier established properties of the binary BH at 2% level

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- ▶ At present, we are exploring the influence of higher order PN contributions

Optical Photometry

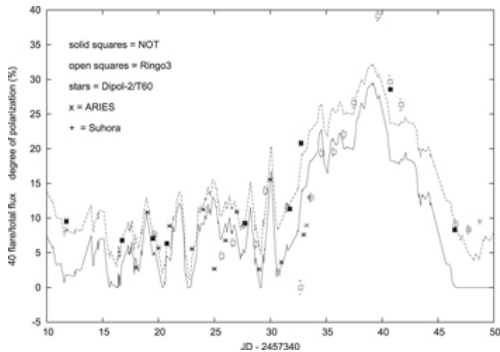


Nature of the CENTENARY FLARE is similar to earlier major outbursts

Theoretical line arises from a uniformly expanding plasma sphere

Like in previous instances, major component of the outburst was unpolarized, accompanied by polarized synchrotron flares

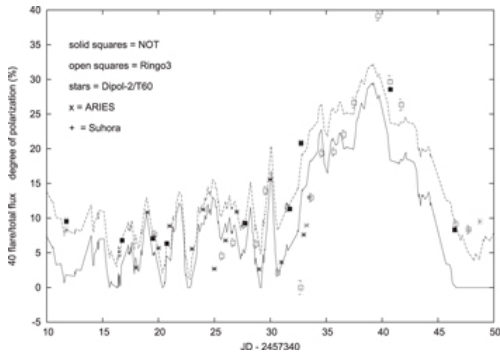
Degree of polarization in the optical R-band



Models involve synchrotron flares with 40 % polarization superposed on thermal bremsstrahlung components

Jet based X-ray emission should follow the optical excess emission

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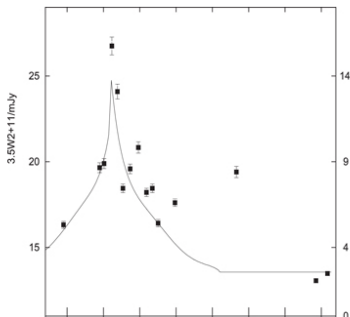


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Jet based X-ray emission should follow the optical excess emission

The optical excess emission: the total optical flux minus theoretically estimated bremsstrahlung flux.

X-ray observations by *Swift*/XRT



The X-ray flare is rather modest, much smaller than the optical outburst overall

However, it correlates very well with the excess flare emissions.

The flares arising at this time are not different from flares observed during various stages of our observational campaign

Conclusion

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- ▶ Possible to test *BH no-hair theorem* in 2019 ?
- ▶ OJ287 is a marginal case for **Event Horizon telescope**