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Article

Search for QPOs in the Light Curve of the Blazar OJ287: Preliminary Results from 2015/16 Observing Campaign

S. Zola [1,2], M. Valtonen [3,4], G. Bhatta[1], A. Goyal[1], B. Debski[1], A. Baran[2], J. Krzesinki[2], M. Siwak[2], S. Ciprini[5,6], A. Gopakumar[7], H. Jermak[8], K. Nilsson[4], D. Reichart[9], K. Matsumoto[10], K. Sadakane[10], K. Gazeas[11], M. Kidger[12], V. Piirola[3,4], F. Alicavus[13,14], K.S. Baliyan[15], A. Berdyugin[4], D. Boyd[16], M. Campas Torrent[17], F. Campos[18], J. Carrillo Gómez[19], D. B. Caton[20], V. Chavushyan[21], J. Dalessio[22], D. Dimitrov[23], M. Drozdz[2], H. Er[24], A. Erdem[13,14], A. Escartin Pérez[25], V. Fallah Ramazani[4], A. V. Filippenko[26], F. Garcia[27], F. Gómez Pinilla[28], M. Gopinathan[29], J. B. Haislip[30], J. Harmanen[4], R. Hudec[31,32], G. Hurst[33], K. M. Ivarsen[30], M. Jelinek[31], A. Joshi[34], M. Kagitani[35], N. Kaur[15], N. Karaman[51], W. C. Keel[36], A. P. LaCluyze[30], B. C. Lee[37], E. Lindfors[4], J. Lozano de Haro[38], J. P. Moore[30], M. Mugrauer[39], R. Naves Nogues[18], A. W. Neely[40], R. H. Nelson[41], W. Ogloza[2], S. Okano[35], J. C. Pandey[34], M. Perri[5,42], P. Pihajoki[43], G. Poyner[44], J. Provencal[22], T. Pursimo[45], A. Raj[46], R. Reinthal[4], S. Sadegi[4], T. Sakanoi[35], J.-L. Salto González[47], Sameer[15], T. Schweyer[48,49], F. C. Soldán Alfaro[50], E. Sonbas[51], I. Steele[8], J. T. Stocke[52], J. Strobl[31], L. O. Takalo[4], T. Tomov[53], L. Tremosa Espasa[54], J. R. Valdes[21], J. Valero Pérez[55], F. Verrecchia[5,43], J. R. Webb[56], M. Yoneda[57], M. Zejmo[58], W. Zheng[26], J. Telting[45], J. Saario[45], T. Reynolds[45], A. Kvammen[45], E. Gafton[45], R. Karjalainen[59] and P. Blay[60]

1 Astronomical Observatory, Jagiellonian Unviersity, ul. Orla 171, 30-244 Krakow, Poland; szola@oa.uj.edu.pl
2 Mt. Suhora Observatory, Pedagogical University, ul. Podchorazych 2, 30-084 Krakow, Poland
3 Finnish Centre for Astronomy with ESO, University of Turku, Turku, Finland
4 Tuorla Observatory, Department of Physics and Astronomy, University of Turku, Turku, Finland
5 Agenzia Spaziale Italiana (ASI) Science Data Center, I-00133 Roma, Italy
6 Istituto Nazionale di Fisica Nucleare, Sezione di Perugia, I-06123 Perugia, Italy
7 Department of Astronomy and Astrophysics, Tata Institute of Fundamental Research, Mumbai 400005, India
8 Astrophysics Research Institute, Liverpool John Moores University, IC2, Liverpool Science Park, Brownlow Hill L3 5RF, UK
9 University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA
10 Astronomical Institute, Osaka Kyoiku University, 4-698 Asahigaoka, Kashiwara, Osaka 582-8582, Japan
11 Department of Astrophysics, Astronomy and Mechanics, National & Kapodistrian University of Athens, Zografos GR-15784, Athens, Greece
12 Herschel Science Centre, ESAC, European Space Agency, 28691 Villanueva de la Cañada, Madrid, Spain
13 Department of Physics, Faculty of Arts and Sciences, Canakkale Onsekiz Mart University, TR-17100 Canakkale, Turkey
14 Astrophysics Research Center and Ulupinar Observatory, Canakkale Onsekiz Mart University, TR-17100, Canakkale, Turkey
15 Physical Research Laboratory, Ahmedabad 380009, India
16 5, Silver Lane, West Challow, Wantage, Oxon, OX12 9TX, UK
17 C/ Jaume Balmes No 24, E-08348 Cabrils, Barcelona, Spain
18 C/.Riera, 1, 1^o 3^a B, Spain
19 Carretera de Martos 28 primero Fuensanta, Jaen, Spain
20 Dark Sky Observatory, Dept. of Physics and Astronomy, Appalachian State University, Boone, NC 28608, USA
21 Instituto Nacional de Astrofisica, Óptica y Electrónica, Apartado Postal 51-216, 72000 Puebla, México
22 University of Delaware, Department of Physics and Astronomy, Newark, DE 19716, USA
23 Institute of Astronomy and NAO, Bulg. Acad. Sc., 72 Tsarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria
24 Department of Physics, Faculty of Science, Atatürk University, Erzurum 25240, Turkey
25 Aritz Bidea No 8 4 B (48100) Mungia Bizkaia, Spain
26 Department of Astronomy, University of California, Berkeley, CA 94720-3411, USA
27 Muñas de Arriba La Vara, Valdés (MPC J38) 33780 Valdés, Asturias – Spain
28 C/ Concejo de Teverga 9, 1 C, E-28053 Madrid, Spain
29 Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, 263002 India
30 University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA

[31] Astronomical Institute, The Czech Academy of Sciences, 25165 Ondřejov, Czech Republic
[32] Czech Technical University in Prague, Faculty of Electrical Engineering, Prague, Czech Republic
[33] 16 Westminster Close, Basingstoke, Hampshire RG22 4PP, UK
[34] Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, 263002 India
[35] Planetary Plasma and Atmospheric Research Center, Tohoku University, Sendai, Japan
[36] Department of Physics and Astronomy and SARA Observatory, University of Alabama, Box 870324, Tuscaloosa, AL 35487, USA
[37] Korea Astronomy and Space Science Institute, 776, Daedeokdae-Ro, Youseong-Gu, 305-348 Daejeon, Korea
[38] Partida de Maitino, pol. 2 num. 163 (03206) Elche, Alicante, Spain
[39] Astrophysikalisches Institut und Universitäts-Sternwarte, Schillergächen 2-3, D-07745 Jena, Germany
[40] NF/Observatory, Silver City, NM 88041, USA
[41] 1393 Garvin Street, Prince George, BC V2M 3Z1, Canada
[42] INAF–Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy
[43] Department of Physics, University of Helsinki, P.O. Box 64, FI-00014 Helsinki, Finland
[44] BAA Variable Star Section, 67 Ellerton Road, Kingstanding, Birmingham B44 0QE, UK
[45] Nordic Optical Telescope, Apartado 474, E-38700 Santa Cruz de La Palma, Spain
[46] Indian Institute of Astrophysics, II Block Koramangala, Bangalore 560 034, India
[47] Observatori Cal Maciarol módul 8. Masia Cal Maciarol, camí de l'Observatori s/n 25691 Ager, Spain
[48] Max Planck Institute for Extraterrestrial Physics, Giessenbachstrasse, D-85748 Garching, Germany
[49] Technische Universität München, Physik Department, James-Franck-Str., D-85748 Garching, Germany
[50] C/Petrarca 6 1[a] 41006 Sevilla, Spain
[51] University of Adiyaman, Department of Physics, 02040 Adiyaman, Turkey
[52] Center for Astrophysics and Space Astronomy, Department of Astrophysical and Planetary Sciences, Box 389, University of Colorado, Boulder, CO 80309, USA
[53] Centre for Astronomy, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, ul. Grudziadzka 5, 87-100 Torun, Poland
[54] C/Cardenal Vidal i Barraquee No 3, E-43850 Cambrils, Tarragona, Spain
[55] C/Matarrasa, 16 24411 Ponferrada, León, Spain
[56] Florida International University and SARA Observatory, University Park Campus, Miami, FL 33199, USA
[57] Kiepenheuer-Institut fur Sonnenphysic, D-79104 Freiburg, Germany
[58] Janusz Gil Institute of Astronomy, University of Zielona Góra, Szafrana 2, PL-65-516 Zielona Góra, Poland
[59] Isaac Newton Group of Telescopes, Apartado 321, E-38700 Santa Cruz de La Palma, Spain
[60] IAC-NOT, C/Via Lactea, S/N, E-38205, La Laguna, Spain
* Correspondence: szola@oa.uj.edu.pl; Tel.: +48-12-6238-624

Abstract: We analyse the light curve in the R-band gathered during the 2015/16 observing season of OJ287. We did a search for QPOs using several methods in wide time domain. No statistically significant periods were found in the high frequency domain both in the ground data and also in K2 observations. In the longer periods domain the Lomb-Scargle periodogram revealed several peaks above the 99% significance level. The longest one, about 95-day, corresponds to the ISCO period of the more massive SMBH. The 43-day period could be an alias or can be attributed to accretion in the form of two armed spiral wave.

Keywords: galaxies: active; BL Lacertae objects: individual (OJ 287); super massive black holes

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1. Introduction

OJ287 is the only blazar known to exhibit certain quasi-periodic variability in its light curve with a rough period of 12 years. A model that successfully explains this observational feature requires the blazar central engine to contain a binary, consisting of two SMBHs (Valtonen et al. 2008 [6] and references therein). The less massive BH (150 million solar mass) orbits the more massive one (18 billion solar mass) and pierces the accretion disk surrounding the latter BH twice per orbit. The

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general relativistic orbital precession naturally explains the quasi-periodic light curve variability of OJ287.

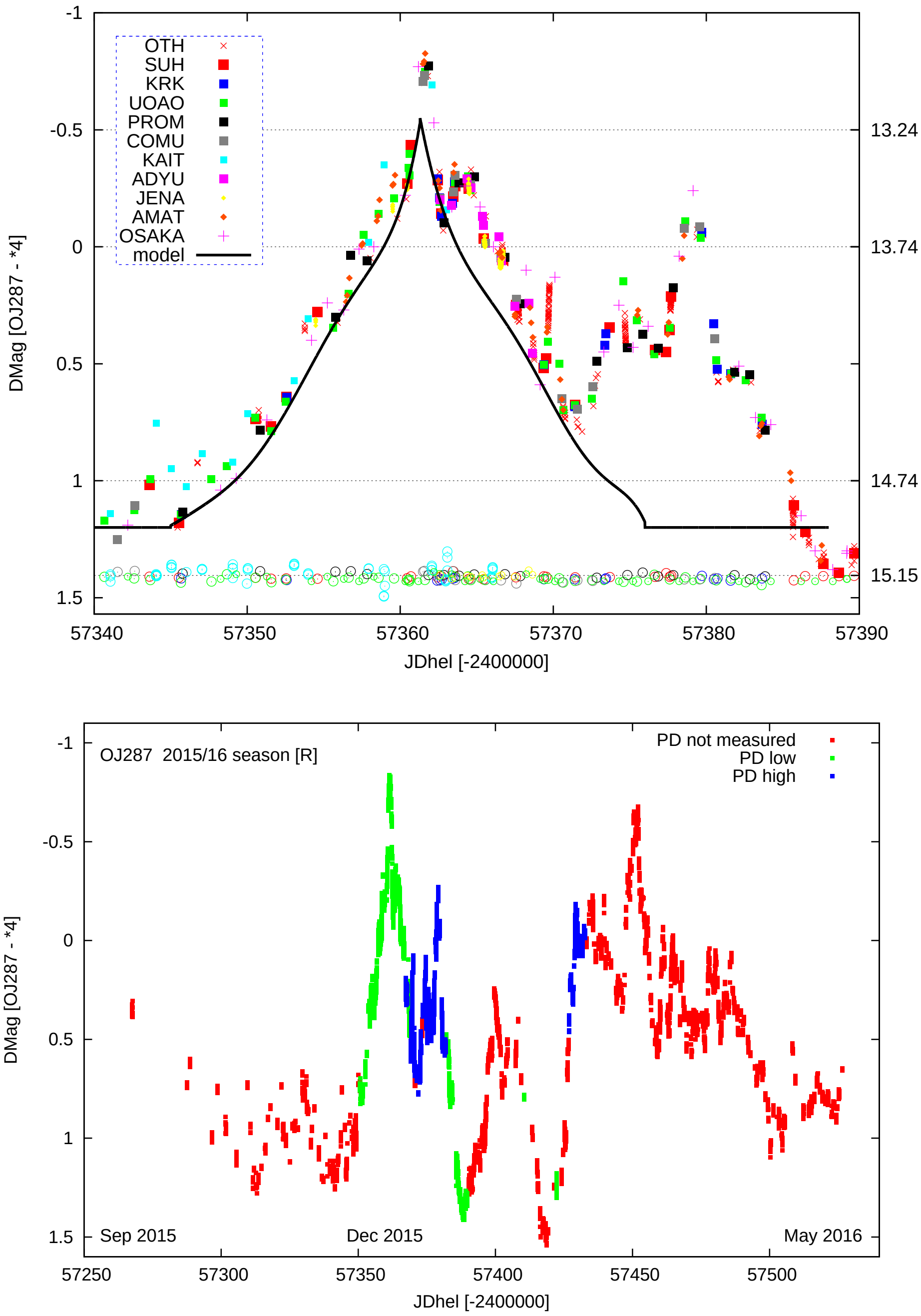

Figure 1. R filter light curve of OJ287 gathered during the 2015/2016 season. (**a**) The light curve of the December 2015 outburst is shown in the top panel. (**b**) The 2015/16 season light curve is presented in the bottom panel. The December 2015 high amplitude flare turned out to be unpolarized.

Since 2006, OJ287 has been regularly monitored in optical at the Mt. Suhora observatory with supporting observations at Krakow and Athens. In the 2015/16 season, we started observations in September, soon after the blazar became visible after the summer conjunction with the Sun. In anticipation of the outburst predicted for this season by the binary model, a multi-site campaign was organized. Polarimetric observations were also scheduled to reveal the nature of the expected brightening. The predicted outburst started at the end of November 2015 with an initial slow rise

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in brightness followed by a very rapid brightening. On our alert, almost two dozen telescopes in 4 continents joined photometric observations providing a very good coverage of the event shown in upper panel of Fig. 1. Polarimetric observations were taken at Canary Islands, Hawaii, Mt. Suhora and in India. The season LC of OJ287 taken until mid May 2016 is presented in bottom panel of Fig. 1, symbols in green denote dates when low polarisation (PD lower than 11%) was measured. UV and X-ray data were also obtained with the SWIFT satellite. Timing of this and previous outbursts allowed to revise masses of the SMBHs and to measure the spin of the more massive BH to be 0.31 ± 0.01 (Valtonen et al. 2016 [8]).

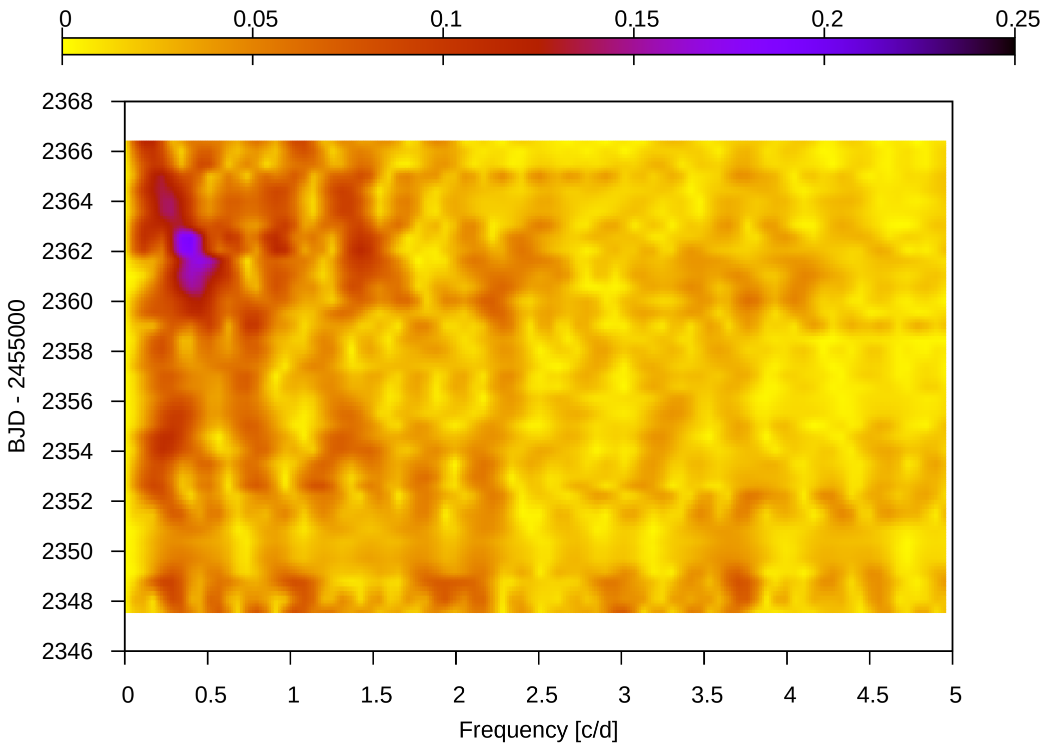

Figure 2. Running FT of the OJ287 data gathered during the 2015/2016 outburst.

2. Search for QPOs

2.1. Ground-based data

Variability at all wavelengths is commonly observed in blazars. Amplitude of flux change in optical band can reach a few magnitudes. These variations can be fast, often the intra day varability can be seen. There are physical processes in blazars that could lead to periodic or quasi-periodic behaviour (eg. these arising at the innermost stable circular orbit). Detection of such QPO variations could give a better understanding of the underlying physical processes in blazars. There were numerous periodicity analyses and discussions of the physical significance of the various frequencies in OJ287. Results covering the previous outburst in 2005 were published in Valtonen et al. (2012) [7] and in Pihajoki et al. (2013) [3].

The intensive multi-site monitoring of OJ287 in the 2015/16 season resulted in best coverage ever obtained from ground: between mid November 2015 and mid May 2016 OJ287 was observed a few times per day. Our first goal was to search for any periodic signal present in the data around the December flare. We analyzed the residuals left after the trend plotted as the model line (Fig. 1 top panel) have been subtracted. Three methods were applied: regular Fourier Transform (FT), wavelet and the running FT (rFT). We found no significant (above 4 σ level) peaks with FT. A period of about 3 hours can be recognized, however, at about 2 σ level only. Both wavelet and rFT techniques revealed

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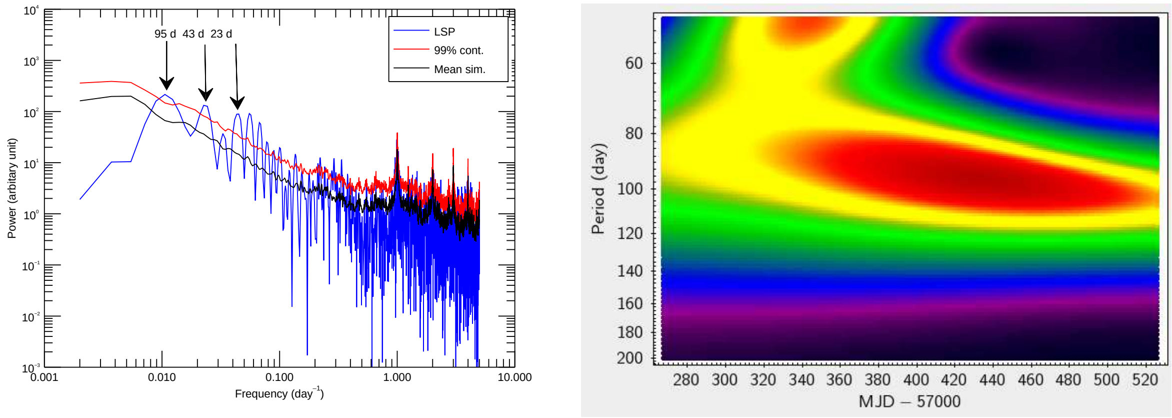

Figure 3. (**a**) left panel: Lomb-Scargle periodogram of 2015/16 data (blue line). The 99% confidence level is shown as the red contour. (**b**) right panel: the resulting graph from the wavelet Z-transform analysis.

a presence of a statistically significant, short living period of about 3 days at the outburst maximum. The period of its visibility was centered at the maximum of brightness (Fig. 2) - it showed up near JD 2457360 and disappeared after about 4 days.

We also performed a thorough search using the entire season dataset covering the period from mid September 2015 to mid May 2016. Several statistical tools have been used and we show the Lomb-Scargle periodogram (LSP; Lomb 1976 [2], Scargle 1982 [4]) in the left panel of Fig. 3. The red-noise (β=1.5) light curves were simulated by the randomization of both phase and amplitude as described in Timmer & Koenig 1995 [5]. The light curves were then re-sampled according to the sampling of the real light curve, and their LSP was computed. The mean LSP of 1000 simulated light curves is shown in green in Figure 3a. No significant peaks corresponding to short periods were found. In the longer periods domain there seems to be statistically significant peaks in the range between 0.01 and 0.1 c/d. However, the WWZ analysis (Foster 1996 [1]) indicate they are not stable. As seen in Fig. 3 (right panel), the length of the longest, about 95 days period, has been increasing since it started to be visible at about JD 2457330.

2.2. K2 observations

OJ287 had been observed by the Kepler spacecraft during K2 Campaign 5. This run resulted in almost continuous 75 days coverage (2015, April 27 to July 10) with about 1 minute cadence. We used both short and long cadences target pixel files. We employed our custom IRAF tasks to pull out fluxes, applying three-pixel circular apertures. We computed PSD functions for the resulting light curve and also 2015/16 ground based data. Neither show any statistically significant periodicities that could be attributed to QPOs.

3. Conclusions

We found no stable periods in the OJ287 photometric data over the entire 2015/16 season. However, the 95-day peak in the power spectrum is close to the period for the more massive BH ISCO while the 43-day peak half to it. Accretion in the form of one armed stationary spiral density wave should show up as the full ISCO period, while two armed stationary wave will feed the central black hole at one-half of the ISCO period. Both types of density waves are observed e.g. in galactic disks under perturbation. These phenomena are not expected to produce stable periodicities as interactions between the exact ISCO period and wave frequencies may occur. The 95-day period started to be visible somewhat before the December outburst and its best visibility continued after the outburst.

With time the period length was increasing, simultaneously, high variability of OJ287 in optical was observed.

We found no firm evidence of any short period variability that could be attributed to the secondary black hole (at ISCO or the event horizon). The peaks that different techniques revealed are either transient, like the 3-day period found in the maximum of the December 2015 flare, or, the periods and the variability amplitudes of these in the higher frequency domain change with time. Such flux changes at shorter time scales most likely originate in the jet. The 3-day quasiperiodicity is the expected jet counterpart of the half-ISCO, with the Lorentz compression factor of 14.
The PSD analysis for both ground and K2 data shows no statistically significant peaks. However, if they do exist they could be hidden due to high amplitude variability of the flaring component present after the unprecedented December 2015 outburst.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:
BH: black hole
SMBH: super massive black hole
ISCO: innermost stable circular orbit
PD: degree of polarisation
QPO: quasi-periodic oscillation
WWZ: weighted wavelet Z-transform

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