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Radio Variability Properties of a Sample of 168 Radio Sources: Periodicity Analysis

J. H. Fan[1,2 ⋆], Y. Liu[1], Y. H. Yuan[1], H. G. Wang[1], Y. X. Wang[3], A. C. Gupta[4,5], J. H. Yang[6], J. Li[1], J. L. Zhou[1], S. X. Xu[1], J. L. Chen[1], F. Liu[1] and Y. Z. Li[1]

[1] Center for Astrophysics, Guangzhou University, Guangzhou 510400, China
[2] Physics Institute, Hunan Normal University, Changsha, China
[3] College of Science and Trade, Guangzhou University, Guangzhou 511442, China
[4] Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai - 400 005, India
[5] Harish-Chandra Research Institute, Chhatnag Road, Jhunsi, Allahabad - 211 019, India
[6] Department of Physics and Electronics Science, Hunan University of Arts and Science, Changde 415000, China

Abstract In this work, using the data base at the University of Michigan Radio Astronomy Observatory (UMRAO) at 8 GHz, we investigated the possible periodicity in the radio light curves using Jurkevich analysis method. The results show that the radio sources display a possibly physically significant periodicity in a range of 0.08 to 14.5 years. Besides, the radio spectral indexes are also calculated, the results show that the averaged radio spectral index is $\alpha_{4.8}^{14.5} = -0.15$ ($f_\nu \propto \nu^\alpha$) for flat spectrum radio quasars (FSRQs) and $\alpha_{4.8}^{14.5}$=0.01 for BL Lacertae objects. Some discussions are included.

Key words: galaxies: blazars — radio continuum: general — methods: data analysis

1 INTRODUCTION

The nature of the central regions of blazars and other AGNs is still an open problem. Monitoring programmes for blazars are important tools for constructing their light curves which can yield with valuable information about the mechanisms operating in these sources, with important implications for quasar modeling (see Fan et al. 1998). Optical monitoring programmes display that the sources are variable on the time scales of from minutes to even a few years (Fan 2005 for review), the variability on years can give the long term flux variation behavior and will be helpful to predict for further outburst time.

Radio monitoring programmes are carried out in Bologna at 408 MHz, in Michigan University at 4.8 GHz, 8 GHz, and 14.5 GHz, and the Metsähovi at 22 GHz, 37 GHz, and 87 GHz , in ESO site on Cerro La Silla, Chile at 90 GHz and 230 GHz (see Terësranta et al. 2005 for detail). Based on the UMRAO data base, Ciaramella et al. (2004) investigated the quasi-periodicity for several selected objects while Aller et al. (2003) investigated other variability properties.

In the paper, making use of the UMRAO data base, we investigated the possible periodicity in the radio light curves.

2 PERIODICITY ANALYSIS METHOD AND RESULTS

There are many methods for the time series analysis, but for the sake of the characteristic of astronomical observations, namely the data based are not evenly sampled, which constrains the analysis methods. In this paper, we used the Jurkevich method for the periodicity searching (Jurkevich 1971; Fan et al. 1998, 2002). This method is based on the expected mean square deviation. It tests a run of trial periods around which the data are folded. All data are assigned to m groups according to their phases around each trial period. The variance $V_{\rm i}^2$ for each group and the sum $V_{\rm Sm}^2$ of all groups are computed. For the whole data, one can

⋆ E-mail: fjh@gzhu.edu.cn

calculate the variance $V_{\rm h}^2$. By virtue of the well known theorem on the addition variance, Jurkevich (1971) obtained that $V_{\rm h}^2 > V_{\rm Sm}^2$. We can then get the normalization $V_{\rm m}^2 = \frac{V_{\rm Sm}^2}{V_{\rm h}^2}$. If a trial period equals the true one, then $V_{\rm m}^2$ reaches its minimum. So, a "good" period will give a much reduced variance relative to those given by other false trial periods and with almost constant values. The computation of the variances has been described in the paper of Jurkevich (1971). Kidger et al. (1992) introduced a fraction of the variance $f = \frac{1-V_{\rm m}^2}{V_{\rm m}^2}$ where $V_{\rm m}^2$ is the normalized value. In the normalized plot, a value of $V_{\rm m}^2 = 1$ means f =0 and hence there is no periodicity at all. The best periods can be identified from the plot: a value of $f \geq 0.5$ suggests that there is a very strong periodicity and a value of $f < 0.25$ suggests that the periodicity, if genuine, is a weak one.

From the UMRAO data base, we got light curves for 168 radio sources including BL Lacertae objects (BLs) and flat spectrum radio quasars (FSRQs). Since the data at the three frequencies, 4.8 GHz, 8 GHz, and 14.5 GHz cover almost the same observing period, we used the 8 GHz light curve for the periodicity searching in the present paper. When the Jurkevich method was adopted to the 8 GHz light curves for those 168 sources, possible periodicity was only determined for 113 sources as listed in Table 1, which shows that the periodicity is in a range of 0.08 to 14.5 years. The rest sources did not show periodicity signs. The less than 1.0 year period sources found in the present paper are 0059+581, 0917+458, 1222+216, 1817–162. The second part in Table 1 shows the possible periodicity that displays a less than 0.25 f factor.

Table 1 Periodicity Analysis Results for 113 Radio Sources at 8 GHz

Name	P_1	P_2	P_3	Name	P_1	P_2	P_3
0003–066	9.82 ± 1.41	3.43 ± 0.21	2.70 ± 0.1	1226+023	8.30 ± 0.9		
0007+106	5.40 ± 0.49			1253–055	10.13 ± 0.97		
0016+731	6.83 ± 1.43	4.28 ± 0.48	3.15 ± 0.2	1335–127	7.75 ± 1.7		
0040+517	1.75 ± 0.2	5.11 ± 0.83		1354–152	3.75 ± 0.35	6.02 ± 0.7	
0059+581	0.40 ± 0.02	2.37 ± 0.2		1413+135	8.33 ± 1.3	4.63 ± 0.3	
0109+224	4.40 ± 0.41			1418+546	10.58 ± 1.55		
0133+476	11.25± 1.3			1510–089	11.28 ± 1.63		
0134+329	5.62 ± 0.59	2.89 ± 0.08		1538+149	9.28 ± 1.45		
0153+744	5.00 ± 0.85	1.23 ± 0.11		1609+660	2.95 ± 0.37		
0215+015	3.35 ± 0.24			1624+416	3.65 ± 0.45		
0218+357	1.55 ± 0.09	2.98 ± 0.51		1634+628	2.22 ± 0.27		
0219+428	3.04 ± 0.23	2.13 ± 0.1		1637+574	3.82 ± 0.4		
0234+285	5.45 ± 0.72			1641+399	11.85 ± 2.05		
0235+164	5.80 ± 0.49			1642+690	6.80 ± 1.13		
0306+102	6.87 ± 0.85			1652+398	12.07 ± 1.83	7.20 ± 0.47	
0315+416	4.07 ± 0.42	7.02 ± 0.99		1717+178	6.65 ± 0.9		
0336–019	11.03± 1.95	5.83 ± 0.54		1721+343	3.41 ± 0.35		
0440–003	8.81 ± 1.15	5.54 ± 0.5		1730–130	6.30 ± 0.43		
0454–234	9.23 ± 1.14	5.53 ± 0.34	4.00 ± 0.23	1741–038	5.17 ± 0.37	3.47 ± 0.27	
0458–020	5.43 ± 0.83			1749+096	6.37 ± 0.57		
0518+165	5.43 ± 0.83			1803+784	6.38 ± 1.18		
0528–250	1.16 ± 0.04			1823+568	8.40 ± 1.03		
0538+498	14.54± 2.47	8.57 ± 0.41		1828+487	11.03 ± 1.47	5.30 ± 0.2	
0605+480	8.14 ± 1.46			1845+797	9.65 ± 1.48	4.58 ± 0.53	
0605–085	7.13 ± 0.94			1901+319	7.47 ± 1.47	3.53 ± 0.33	
0607–157	11.01 ± 1.32			1928+738	8.13 ± 1.47		
0804+499	6.00 ± 0.83			1951+498	5.19 ± 0.52		
0818–128	9.73 ± 2.03	4.53 ± 0.35		2021+614	6.83 ± 0.57		
0831+557	13.28 ± 1.78			2121+053	7.20 ± 0.83	5.00 ± 0.4	
0838+133	7.83 ± 0.97			2131–021	9.40 ± 1.53	6.23 ± 0.98	
0850+581	8.50 ± 1.67			2155–152	5.63 ± 0.53	8.83 ± 0.88	
0851+202	9.53 ± 0.97			2155–304	3.40 ± 0.25		
0954+658	6.35 ± 1.08			2201+315	6.12 ± 1.23		
1031+567	2.68 ± 0.32			2223–052	7.30 ± 0.5		
1034–293	9.30 ± 1.28			2230+114	8.15 ± 1.25		
1038+528	1.89 ± 0.39			2243+394	5.93 ± 0.8		
1100+772	2.00 ± 0.28	1.25 ± 0.1		2251+158	6.77 ± 0.53		
1101+384	7.63 ± 0.72			2335+031	2.33 ± 0.18		
1156+295	3.33 ± 0.13			2345–167	6.80 ± 0.83	3.53 ± 0.15	
1219+285	10.03 ± 1.5			2351+456	6.93 ± 0.73	3.90 ± 0.38	
1222+216	0.66 ± 0.09			2356+196	6.43 ± 0.78	10.78± 1.6	4.65 ± 0.28

Table 1 – Continued.

Name	P_1	P_2	P_3	Name	P_1	P_2	P_3
0106+013	4.10 ± 0.31	2.93 ± 0.31		0917+458	2.25 ± 0.22		
0133+476	5.75 ± 0.86			0951+699	4.13 ± 0.43		
0153+744	3.71 ± 0.46			1034–293	4.60 ± 0.45	2.83 ± 0.18	
0215+015	2.62 ± 0.11			1055+018	4.07 ± 0.37	2.55 ± 0.42	
0202+149	5.44 ± 1.02			1101+384	3.90 ± 0.25	5.17 ± 0.32	
0220+427	9.88 ± 0.81			1127–145	10.27 ± 0.90		
0234+285	3.54 ± 0.31			1137+660	1.50 ± 0.10		
0235+164	3.72 ± 0.31			1215+303	8.25 ± 1.37		
0300+470	3.30 ± 0.26			1253–055	7.27 ± 0.43		
0336–019	5.83 ± 0.54	4.05 ± 0.28		1358+624	5.70 ± 0.58		
0333+321	6.55 ± 0.55			1611+343	9.90 ± 0.98	6.50 ± 0.60	
0420–014	3.29 ± 0.22			1633+382	3.07 ± 0.13		
0422+004	6.93 ± 0.59	4.96 ± 0.39		1749+096	4.42 ± 0.35		
0458–020	3.33 ± 0.37			1807+698	3.35 ± 0.17		
0521–365	4.31 ± 0.33	3.24 ± 0.20		1921–293	3.33 ± 0.07		
0552+398	7.18 ± 0.89			1939+605	5.63 ± 0.70		
0716+714	4.00 ± 0.29	3.14 ± 0.16		2005+403	8.28 ± 0.83	5.85 ± 0.43	
0735+178	5.10 ± 0.54			2032+107	6.95 ± 0.92		
0754+100	4.01 ± 0.39			2134+004	9.00 ± 1.03		
0831+557	6.00 ± 0.38	3.93 ± 0.15		2145+067	9.70 ± 1.23		
0838+133	4.33 ± 0.40			2153+377	2.68 ± 0.20		
0836+710	3.02 ± 0.54			2200+420	3.85 ± 0.22		
0906+430	4.12 ± 0.32						

3 SPECTRAL INDEX CALCULATION RESULT

From this database, we also calculated the averaged flux density, $\langle F_{4.8}\rangle$,$\langle F_8\rangle$ and $\langle F_{14.5}\rangle$, for the three bands (4.8 GHz, 8 GHz and 14.5 GHz), then we performed the linear regression to the three bands for each source and get a statistical result

$$\log F = \ (\alpha \pm \Delta\alpha) \log \nu + c,$$

where α and $\Delta\alpha$ are the spectral index and its uncertainty ($F_\nu \propto \nu^\alpha$).

The results are listed in Table 2, in which column (1) gives IAU Name; column (2) shows the spectral index and the uncertainty. For the two subclasses of blazar, we have that the averaged radio spectral index is $\alpha_{4.8}^{14.5} = -0.15$ ($f_\nu \propto \nu^\alpha$) for flat spectrum radio quasars (FSRQs) and $\alpha_{4.8}^{14.5}$=0.01 for BL Lacertae objects.

4 DISCUSSION

Blazars are variable over the whole electromagnetic wavelengths. Optical photometry has been done for about one hundred years for some BL Lacertae objects (Fan 2005 for review). Radio monitoring programme started about 40 year ago, the monitoring coverage is also long enough for the periodicity analysis in the radio bands and the radio variability properties investigation.

Our periodicity analysis shows that the possibly physically significant periodicity is in the range of 0.08 to 14.5 years, which is consistent with the results obtained based on the optical data (Fan et al. 2002). Our results are also consistent with the results obtained by Ciaramella et al. (2004), who analyzed the periodicity from the high frequency radio data. It is interesting that less than one year periods are found in the radio bands. This kind of periods are found in the optical and the high energetic bands.

Some models have been proposed to explain the long-term periodic variations in AGNs: binary black hole model, the thermal instability model, and the perturbation model (see Fan 2005 for review). The promising models are the binary black hole model and the perturbation model. The helical jet related with the binary black holes have been used to explain the optical behavior and the objects (3C 345, OJ 287, BL Lacertae, and PKS 0735+178) being claimed to show periodicity in the historic light curves also show helical trajectories of their VLBI radio components. In this sense, one would expect the similar periodicity behavior in the radio bands. Our analysis results confirmed this expectation.

In the present paper, made used of the data of UMRAO, possibly physically significant periodicity ranging from 0.08 to 14.5 year and the spectral indexes are obtained for a sample of radio sources.

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Table 2 The Radio Spectral Index between 4.8 and 14.5 GHz for the Radio Sources

Name	$\alpha \pm \Delta\alpha$	Name	$\alpha \pm \Delta\alpha$	Name	$\alpha \pm \Delta\alpha$	Name	$\alpha \pm \Delta\alpha$
0003–066	–0.09 ± 0.00	0605+480	–1.09 ± 0.03	1157+732	–0.83 ± 0.01	1749+701	–0.04 ± 0.04
0007+106	0.94 ± 0.09	0605–085	0.04 ± 0.01	1215+303	0.01 ± 0.01	1803+784	0.11 ± 0.02
0016+731	–0.02 ± 0.00	0607–157	0.32 ± 0.00	1217+023	–0.15 ± 0.02	1807+698	–0.04 ± 0.01
0022+638	–1.98 ± 0.21	0710+439	–0.63 ± 0.03	1219+285	0.07 ± 0.02	1817–162	–0.92 ± 0.16
0040+517	–1.00 ± 0.02	0711+356	–0.63 ± 0.02	1222+216	0.01 ± 0.02	1823+568	0.10 ± 0.00
0048–097	0.25 ± 0.02	0716+714	0.28 ± 0.04	1225+206	–1.04 ± 0.01	1828+487	–0.48 ± 0.00
0059+581	0.18 ± 0.02	0723+679	–0.36 ± 0.00	1226+023	–0.03 ± 0.01	1842+455	–0.98 ± 0.01
0106+013	–0.14 ± 0.06	0735+178	–0.06 ± 0.00	1253–055	0.22 ± 0.00	1845+797	–0.83 ± 0.01
0108+388	–0.84 ± 0.08	0754+100	0.09 ± 0.00	1254+476	–1.00 ± 0.03	1901+319	–0.29 ± 0.00
0109+224	0.19 ± 0.01	0804+499	0.19 ± 0.01	1307+121	0.01 ± 0.02	1921–293	0.24 ± 0.00
0127+233	–0.83 ± 0.01	0808+019	0.14 ± 0.03	1308+326	0.21 ± 0.01	1928+738	–0.04 ± 0.00
0133+476	0.30 ± 0.02	0809+483	–1.15 ± 0.02	1328+307	–0.67 ± 0.01	1939+605	–1.07 ± 0.01
0134+329	–0.96 ± 0.02	0814+425	0.05 ± 0.05	1335–127	0.39 ± 0.00	1951+498	–0.30 ± 0.08
0153+744	–0.89 ± 0.02	0818–128	0.06 ± 0.00	1354–152	0.42 ± 0.38	1954+513	–0.04 ± 0.00
0202+149	–0.08 ± 0.02	0829+046	0.24 ± 0.01	1358+624	–0.80 ± 0.01	2005+403	–0.05 ± 0.05
0212+735	0.09 ± 0.00	0831+557	–1.05 ± 0.03	1400+162	–0.48 ± 0.00	2007+777	0.09 ± 0.00
0215+015	0.35 ± 0.04	0836+710	–0.19 ± 0.00	1409+524	–1.20 ± 0.02	2014+370	–1.39 ± 0.16
0218+357	–0.08 ± 0.00	0838+133	0.00 ± 0.00	1413+135	0.61 ± 0.02	2020+614	–0.01 ± 0.03
0219+428	–0.77 ± 0.07	0850+581	–0.38 ± 0.02	1418+546	0.13 ± 0.02	2032+107	–0.11 ± 0.01
0220+427	–1.21 ± 0.01	0851+202	0.39 ± 0.01	1458+718	–0.52 ± 0.00	2037+421	–0.21 ± 0.00
0234+285	–0.02 ± 0.02	0859+470	–0.28 ± 0.01	1504–166	–0.06 ± 0.02	2121+053	0.05 ± 0.01
0235+164	0.20 ± 0.01	0906+430	–0.29 ± 0.00	1510–089	0.14 ± 0.00	2131–021	–0.06 ± 0.03
0300+470	0.07 ± 0.02	0912+297	–0.32 ± 0.00	1514+197	0.06 ± 0.00	2134+004	–0.29 ± 0.05
0306+102	0.32 ± 0.01	0917+458	–1.17 ± 0.03	1538+149	0.16 ± 0.02	2136+141	0.12 ± 0.01
0315+416	–1.08 ± 0.00	0923+392	–0.04 ± 0.02	1543+005	–0.52 ± 0.00	2145+067	0.53 ± 0.00
0316+413	–0.13 ± 0.03	0951+699	–0.58 ± 0.00	1606+106	–0.10 ± 0.03	2153+377	–1.26 ± 0.02
0323+022	–0.25 ± 0.00	0954+556	–0.35 ± 0.01	1609+660	–1.12 ± 0.01	2155–152	–0.09 ± 0.00
0333+321	–0.27 ± 0.02	0954+658	0.04 ± 0.08	1611+343	0.03 ± 0.00	2155-304	–0.09 ± 0.01
0336–019	0.00 ± 0.01	0957+227	–0.76 ± 0.00	1624+416	–0.34 ± 0.01	2200+420	0.03 ± 0.03
0355+508	0.19 ± 0.06	1003+351	–0.56 ± 0.00	1633+382	–0.07 ± 0.00	2202+315	0.20 ± 0.00
0404+768	–0.59 ± 0.00	1031+567	–0.89 ± 0.01	1634+628	–1.17 ± 0.01	2223–052	0.14 ± 0.00
0420–014	0.15 ± 0.01	1034–293	0.22 ± 0.00	1637+574	0.19 ± 0.00	2229+391	–1.21 ± 0.03
0422+004	0.20 ± 0.02	1038+528	0.20 ± 0.00	1641+399	0.12 ± 0.01	2230+114	–0.26 ± 0.00
0430+052	–0.05 ± 0.07	1040+123	–0.45 ± 0.01	1642+690	0.10 ± 0.01	2243+394	–1.44 ± 0.06
0440–003	–0.06 ± 0.01	1055+018	0.25 ± 0.00	1652+398	–0.21 ± 0.00	2251+158	–0.18 ± 0.03
0454–234	–0.08 ± 0.00	1100+772	–0.63 ± 0.00	1717+178	0.13 ± 0.00	2254+074	0.01 ± 0.02
0456–020	0.05 ± 0.00	1101+384	–0.18 ± 0.00	1721+343	–0.94 ± 0.04	2335+031	–0.63 ± 0.02
0518+165	0.05 ± 0.00	1127–145f	–0.39 ± 0.02	1727+502	–0.40 ± 0.02	2345–167	–0.08 ± 0.01
0521–365	–0.48 ± 0.01	1133+704	–0.18 ± 0.02	1730–130	0.10 ± 0.00	2351+456	–0.13 ± 0.00
0528+134	0.22 ± 0.00	1137+660	–0.71 ± 0.02	1741–038	0.33 ± 0.00	2352+495	–0.71 ± 0.01
0528–250	–0.51 ± 0.06	1147+245	–0.02 ± 0.00	1749+096	0.48 ± 0.00	2356+196	–0.54 ± 0.00
0538+498	–0.95 ± 0.01	1148–001f	–0.43 ± 0.04				
0552+398	–0.12 ± 0.01	1156+295	0.18 ± 0.00				

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