Search for Quasi-periodic Oscillations of Spectral Variability with Jurkevich Technique

XIAOPAN LI, HAIYAN YANG, CHENG YANG and GUANGYANG XU

ABSTRACT

We have analyzed the multi-wavelength observations taken from the database of Quasar 3C 273 hosted by ISDC (INTEGRAL Science Data Centre) with the Jurkevich technique, and presented the multi-wavelength spectral indices variability behaviors. The quasi-periodic oscillations of multi-wavelength spectral indices are in agreement with the flux variability period of about 2.5 years, 5.0 years and 8.0 years in the radio band. Furthermore, a tendency that spectral indices to become bluer as the brightness increase can be confirmed.

KEYWORDS

Quasi-periodic oscillations, spectral variability, Jurkevich method, 3C 273.

INTRODUCTION

The radio loud quasar 3C 273 is one of the best monitored active galactic nuclei (AGNs). It is variable at all wavelengths and has been extensively studied at all frequencies in the past 50 years. In retrospect, Courvoisier’s review shows that 3C 273 has most of the properties characteristic of blazars, such as a jet with apparent superluminous motion, large flux variations and strong radio emission and so on [1]. As for the long-term multi-wavelength flux variability, 3C 273 has also exhibited different periodicities of 9 years[2], of 2.0 years, 13.65 years and 22.5 years[3], and of about 16 years in the radio band[4].

In recent years, many researchers have investigated this source and found a significant variation in the spectral indices and paid attention to the spectral indices and variability of 3C 273. In other objects’ study, like AGN OJ 287, It is seems to be a controversy over the bluer-when-brighter and redder-when-brighter arguments [5].

Generally, for this source, it is worth to analyze its spectra variability. Based on the available data, we analyze the multi-wavelength spectra variability properties of 3C 273, studying both the flux and the spectra variations and trying to understand the connections between them. The 3C 273’s database we used is hosted by ISDC (INTEGRAL Science Data Centre) and available on line [6].
We give a general description of analytical methods in Section 2 and Section 3, and present our results in Section 4. Our summary is given in Section 5.

**BROAD BAND SPECTRAL INDICES**

Daily-averaged flux curve and spectral indices curve of the quasar 3C 273 in the radio 15 and 37 GHz bands are presented in Figure 1. The top panel shows the light curve at 37GHz, and the bottom panel shows the spectral indices curve, connecting the radio observations in 15 GHz and 37 GHz. Here, we define the broad band spectral indices between frequencies $v_i$ and $v_j$ as follow:

$$\alpha_{ij} = -\log(F_i/F_j)/\log(v_i/v_j)$$

Where $F_i$ and $F_j$, respectively, is the intrinsic flux density corresponding to the frequency $v_i$ and $v_j$. According to the above definition and the observations in 15 and 37 GHz, we can calculate the broad band spectral indices connecting the flux in the radio 15 with 37 GHz. As shown in Figure 1, in the radio band, 3C 273 has extreme flux and spectral variability. It can be seen that when the flux density increase, the spectra decrease. It seems that there are some significant peaks in the flux curve in 1983, 1992 and 1999. But in 1994, 2002 and 2006, we can also find some weaker peaks. The spectral indices curve (Figure 1 bottom panel) shows a large scatter of the spectral indices, from -0.16 (JD 2450151) to 0.70 (JD 2451671) between 1981 and 2006. From the spectral curve, we can find that the spectral indices variability seems having quasi-periodic oscillations. For the purpose of looking for the possible period of the spectral indices variability, we use the Jurkevich technique.
JURKEVICH TECHNIQUE

The Jurkevich technique [7] is based on the expected mean square deviation. It tests a run of test periods around which the observations are folded. All observations are assigned to m groups according to their phases around each group (bin), and the sums Vm2 of all groups are computed. For a test period equal to a true one, if any, Vm2 reached its minimum. A “good” period will give a much reduced variance relative to those given by “false” test periods with almost constant values. No firm rule exists for assessing the significance of a minimum in the Vm2 plot. More details about the Jurkevich technique refer to [7] and references therein.

After analyzing the results of the statistical F-test, we have a good guide to the fractional reduction of the variance, as in Kidger et al. [8].

\[ f = \frac{(1 - V_m^2)}{V_m^2} \quad (2) \]

Where Vm2 is the normalized value. In the normalized plot, a value of Vm2 = 1.0 implies that f = 0 and hence there is no periodicity. The best period can be identified from the Vm2 plot. In general, a value of f > 0.5 implies that there is a very strong periodicity in the observations, while a value of f < 0.25 usually indicates a weak periodicity exists in the observations.

When using the Jurkevich technique, we can modify the parameter artificially. If we select more groups, i.e., bigger group number m, Jurkevich technique can provide higher sensitivity. However, fewer data points per group introduce a large noise in the plot, which could affect the minimum value of Vm2. The error of the candidate period can be estimated by calculating the half width at half maximum (HWHM) of the corresponding valley in the Vm2 plot.

ANALYSIS AND RESULTS

Quasi-Periodic Oscillations

We analyzed the data from Figure 1 using group number of m = 12. The results obtained with Jurkevich technique are shown in Figure 2. The left panel shows the Jurkevich technique result for the flux quasi-periodic oscillations in the quasar 3C 273 at 37 GHz, the right panel shows the spectral indices quasi-periodic oscillations using the data shown in Figure 1 bottom panel. From the left panel of Figure 2, a significant period can be find, which is 8.03 years with a big error of 1.11 years. We also can find that there are other three obvious minimum values in the Vm2 plots, indicating three possible quasi-periodic oscillations exist in the observations. These candidate periods are 2.76±0.12 years, 3.76±0.11 years and 5.01±0.21 years, and the value of the F-test are all larger than 0.25. In the right panel of Figure 2, there are four similar quasi-periodic oscillations can be found, i.e., 2.50±0.22 years, 3.76±0.11 years, 5.01±0.15 years, 7.60±0.15 years. The values of the F-test of these quasi-periodic oscillations are larger than 0.5 accept the period of 2.50±0.22 years. We can find a minimum value of 10.02±0.24 years in this panel too.
Fig. 2 Search for the quasi-periodic oscillations of flux variability (left panel) and spectral variability (right panel) with the Jurkevich technique.

Figure 3. Log FR versus spectral indices $\alpha$ at 15 and 37GHz in the quasar 3C 273, the solid line is the regression line.

In the radio band, researchers had found a weak evidence of a quasi-periodic oscillation of 16 years [4]. After performing the Jurkevich technique to the daily-averaged flux curve and spectral indices curve, we found that there is a minimum value around about 16 years. However, considering the time interval we analyzed is about 25 years, we conclude that this quasi-periodic oscillation is not credible enough. Moreover, it is worth mentioning that the periodicity of about 8 years which is half of the period of 16 years mentioned above. Thus, this periodicity maybe a real component. In the right panel of Figure 2, compared with the possible period of 5.01 ± 0.15 years, the significance of 2.76 years (2.5 years in left panel) and 3.76 years are a little weaker. Lin and Fan et al. [3, 4] analyzed the optical variability periodicity of the quasar 3C 273 and reported the period of 2 years, 9 years and 13.65 years. We also determined there are week periodicities exit in 2.5 years, 5.0 years and 7.5 years in their Jurkevich periodgrams.
Spectral Variability

From Figure 1, there is another result can be obtained, that is a tendency for spectral indices to become bluer as the brightness increase. Actually, many researchers have paid attention to the spectral indices and flux variability of 3C 273 in recent years [9, 10]. In other objects, like AGN OJ 287, it is seems to be a controversy over the bluer-when-brighter and redder-when-brighter arguments [5]. For the quasar 3C 273, based on the data shown in Figure 1, we have also analyzed the correlation between spectral indices and flux densities at 15 and 37GHz. The relationship between Log FR and α is shown in Figure 3, where Log FR corresponds to the mean value at 15 and 37GHz respectively. With linear regression, we obtain the correlation:

$$\alpha = (1.74 \pm 0.17) - (1.06 \pm 0.12)\text{Log}F_R$$

With a correlation coefficient γ=−0.61, a chance probability less than 0.0001, and standard deviation S=0.17. Therefore, we can conclude that there is a significant negative correlation between the spectral Indices and the flux variability.

SUMMARY

We calculated the spectral indices based on the observations in the radio 15 and 37 GHz bands taken from the database of Quasar 3C 273 hosted by ISDC. After performing the Jurkevich technique to the flux curve and spectral indices curve, we found that the quasi-periodic oscillations of spectral indices are in agreement with the flux variability period of about 2.5 years, 5.0 years and 8.0 years, and a negative correlation between the spectral Indices and the flux variability.

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REFERENCES

6. Information on: http://isdc.unige.ch/3c273

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