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The variability of BL Lac 3C 66A*

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It is now known that there are supermassive black holes at the centre of a galaxy, surrounded by an accretion disc. The black hole-jet-accretion disc model plays an important role in the explanation of the observational properties of active galactic nuclei. BL Lacertae objects form a subclass of blazars; they are monitored through electromagnetic wave bands. During the OJ-94 project, 3C 66A was observed as a comparison object of OJ287 and found to display a possible 65-day period in the V light curve. In this paper, we show that the instability of an accretion disc surrounding a massive central black hole ($2.5 \times 10^7 M_\odot$) may explain this period in 3C 66A.

Keywords: active galactic nuclei, black hole, accretion disc, variability
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1. Introduction

It is clear that the centre of active galactic nuclei (AGNs) contains supermassive black holes (SMBHs) (see Refs.[1–4] and references therein). The study of AGNs variability can yield more valuable information about their emission mechanism, and the implications for quasars modelling are extremely important.[5–7] BL Lacertae (BL Lac) objects form a special subclass of active galactic nuclei showing some extreme properties: rapid and large variability, high and variable polarization, without or with only weak emission lines in its classical definition. The observed variability has been explained with randomly occurring, radiatively decaying shock in the jet.[8] Other models for the observed variations in the optical bands include flares in the accretion disc around the central black hole,[9] a light-house model,[10] and the microlensing model.[11] 3C 66A is a radio-selected BL Lac object; it has been observed for $\sim$ 25 years in the optical band.[12,13] Lainela *et al*[5] monitored this object during the period 1993 to 1998 and found evidence of a possible 65 day period.[5] This kind of period is probably caused by the instability of a standard disc surrounding the central black hole.[14] The instability depends on the time-dependent accretion ratio and the viscosity. In this paper, we adopt this effect to explain the phenomenon in 3C 66A. In Sec.2, we introduce the method and give our result, and in Sec.3 we give some discussion.

2.Method and result

2.1. Method

The suggested method is based on the paper by Lightman:[14] there are three regions in the accretion disc, i.e. the inner, the middle, and the outer regions, which are described by different equations.[14] Setting the temperatures in both the inner $T_{\rm i5} = (2.5 \times 10^2)\Omega^{1/4}\alpha^{-1/4}$ and the middle $T_{\rm m5} = (8.7 \times 10^2)\Omega^{1/3}\Sigma_4^{2/3}\alpha^{1/3}$ to be equal, one can obtain the critical surface density, i.e. $\Sigma_{4,\rm crit} = 0.15\Omega^{-1/8}\alpha^{-7/8}$, where $\Omega = \Omega_{\rm k}/(2 \times 10^4) = \sqrt{GM/r^3}/(2 \times 10^4)$, $M_* = M/3M_\odot$ is the mass of the central object, $r_6 = r/10^6{\rm cm}$, $\Sigma_4 = \Sigma/10^4$, $T_5 = T/10^5{\rm K}$, and α is the viscous parameter. In the middle region, the ratio of the height to the radius, and the thermal time scale, can be expressed respectively as follows:

$$h/r = (6.0 \times 10^{-3})\Sigma_4^{1/3}\alpha^{1/6}M_*^{-5/12}r_6^{1/4}, \quad (1)$$

$$t_{\rm th} \leq (7.8 \times 10^{-4})\Omega^{-5/6}\Sigma_4^{4/3}\alpha^{1/6}. \quad (2)$$

Let $M_\dagger = M/(2.5 \times 10^7 M_\odot)$, $r = 10N_{10}r_{\rm g}$ ($N_{10} = N/10$, $r_g = GM/c^2$ be the Schwarzschild radius), then

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Eqs.(1) and (2) can be rewritten as

$$h/r = (2.37 \times 10^{-3}) N_{10}^{5/6} \alpha^{-1/8} M_{\dagger}^{-1/8}, \quad (3)$$

$$t_{\rm th} = (4.48 \times 10^{4}) M_{\dagger} N_{10}^{3/2} \alpha^{-1} ({\rm s}). \quad (4)$$

2.2. Result

3C 66A is a radio-selected BL Lac object emitting GeV γ-rays[15] and TeV γ-rays.[16] The optical emissions are polarized at $P_{\rm opt} = 18\%$ and show a variation of 2.0 mag.[13,17] In 1976, Folsom *et al*[18] detected a decline of 1 mag over a time scale 1.0 hour, suggesting a doubling time of $T_{\rm D} = 3.45$ hour; similar results were also obtained by Xie *et al.*[19] If we take the doubling timescale as the orbit period at $3r_{\rm g}$, then the timescale implies a mass of $(2.5 \times 10^{7}) M_{\odot}$. In order to produce the observed recurrence in the light curve of 3C 66A, the Shakura–Sunyaev viscous parameter α must take the form $\alpha = \alpha_0 (h/r)^n$.[20] In this study, we adopt $n = 1$ and ensure α to be less than unity in the limit of large α_0. The recurrence time scale can be expressed in the form

$$t_{\rm D} = t_{\rm th} (h/r)^{-1} \sim 65({\rm days}) N_{10}^{1.06} M_{\dagger}^{1.04} \alpha_{0,125}^{-0.96}, \quad (5)$$

where $\alpha_{0,125} = \alpha_0/125$. Let $M_{\dagger} = N_{10} = \alpha_{0,125} = 1.0$; one obtains a recurrence time scale of 65 days, which is presented in the optical light curve.[5]

3. Discussion

BL Lac objects show variations at all frequencies. The energy output is very enormous so that only the accreting black hole can explain the observed emission. There is no doubt about the existence of SMBH at the centre of AGN. Around the central black hole there is an accretion disc from which materials fall onto the black hole. For an α-disc, the viscous parameter should be less than unity. From the above parameters corresponding to the 65 day period, we can obtain a ratio of $h/r = 1.91 \times 10^{-3}$ and a viscous parameter α=0.238; these results are reasonable. Some models have been also proposed to explain the periodic phenomenon in the light curves.[6,21–25] Since there is a possible instable accretion disc surrounding the massive black hole, the instability of the disc can be thought of as a possible mechanism for the periodicity. For 3C 66A, the instability of accretion disc surrounding a black hole, $M \sim 2.5 \times 10^{7} M_{\odot}$, may cause the period observed in the V light curve.[5] Very recently, a 23 day periodicity has been detected for another BL Lac object, MKn 501.[26] It is expected that this scale of periodicity should be observed in the light curves of other blazars.

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