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Letter to the Editor

The massive black hole in the center of the active galaxy Mrk 421

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Abstract. We report the observation of a dramatic outburst in the optical band from the active galaxy Markarian 421 (Mrk 421). During this outburst, the brightness of Mrk 421 increased rapidly by 1.34mag from B=15.67 to B=14.32 in 26 minutes. Another interesting fact is that this extremely rapid burst in the optical band is similar to the dramatic outburst of TeV photons which was obtained by Gaidos et al. (1996) in every essential respect, for example, the time scales on which they vary, and the shapes of the light curves. These data in the optical band and TeV γ-ray suggest that they are both produced in the same emission region, and that the emission region is extremely small, $R \approx 1.23 \times 10^{14}$cm. With these results, we prove that there is a massive black hole with $M = 2 \times 10^6 M_\odot$ in the centre of Mrk 421. We obtained also a important result R=205R$_g$ $> 200R_g$ (Sunyaev 1975). This could provide a new challenge for current theoretical model of such emissions. We prove that the origin of TeV γ-ray is by Synchrotron self-Compton.

Key words: BL Lacertae objects: individual: Mrk 421 – γ-rays: theory – galaxy: photometry

1. Introduction

What observations can provide crucial checks or determine important parameters of the source? Perhaps the best tool we have is the variability observed in different wave bands, because the variability on short time scales can give strong constraints to the emission models and the nature of the central nucleus (Xie et al. 1989), can also be applied to learn about the efficiency of conversion of matter into radiation energy, $\eta \geq 5.0 \times 10^{-43} \triangle L/\triangle t_{min}$ (Frank et al. 1985), and sometimes can lead to the development of theory (Zamorani 1984). The nearby BL Lac object, Mrk 421, provides particularly fertile ground for such studies. Previous campaigns emphasizing radio through X-ray observations have generally found that the extremely rapid bursts (in one hour) are very rare. But TeV Gamma-ray observations are proved to be a very valuable addition to this field. An extremely rapid burst of TeV photons from Mrk 421 has been obtained (Gaidos et al. 1996). In this outburst, the time scale of the burst is about 50$\pm$5 minutes, and the flux increased by a factor of 20–25. This is the shortest time scale of variability for Mrk 421. With this result, Gaidos et al. propose that there is a massive black hole in the center of Mkn 421. Obviously, it is very important to search similar rapid variability in other wavelengths and study the relations between them.

Observations in the radio, IR, mm, UV and X-ray bands have not recorded such variability, but in optical bands we have recorded in 1986 an extremely rapid burst at Yunnan observatory with the one meter telescope (Xie et al. 1988a), which is similar in essential respects to the extremely rapid burst of TeV photons observed by Gaidos et al. (1996). Two outburst are compared in Fig. 1. The origin of the time axis is at the peak of the light curve in each case. The optical data in Fig. 1 (open circles) is from Table 1 of paper 12 (Xie et al. 1988). The TeV γ-ray data in Fig. 1 (solid circle) is from paper 5 (Gaidos et al. 1996). From Fig. 1, we have following results:

(i) The time scale of the extremely optical rapid burst (from the lowest point to the highest point of the light curve) is about 45 minutes. The time scale of the extremely γ-ray burst is 50 minutes. However, the observational interval in optical wave band is 8–10 minutes, so we can say that the two time scales are the same.

(ii) The shape and amplitude of the light curve of the two bursts are similar.

Our observations in the optical band provide important new data for testing emission models. The rapid variability and high energy (TeV) of the γ-ray imply compact emission regions and require significant Doppler boosting. It is well known that the beaming effect may smear out a possible correlation. The above-mentioned two relations between optical and γ-ray bands for Mrk 421 imply that optical emission is produced in the same emission region as the TeV γ-ray radiation. γ-ray emission mechanism is an open question. Many models have been proposed to explain the origin of the γ-ray emission, including

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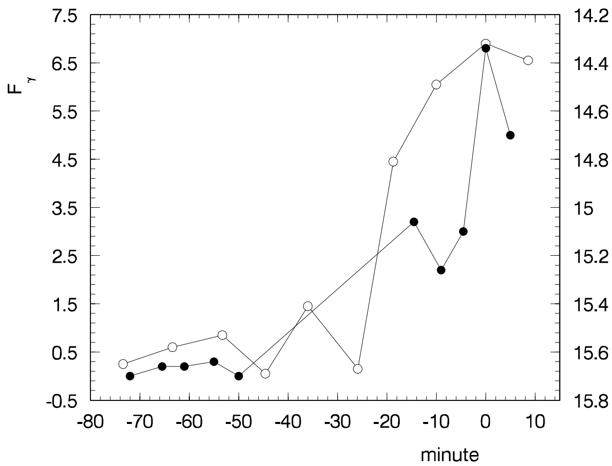

Fig. 1. The optical and TeV Gamma-ray light curves for Mrk 421, the open circles for the optical data and the solid circles for the TeV γ-ray data. The scale on the left is for F_γ, and on the right is for B magnitude. The origin of the time axis is at the peak of the light curve in each case.

synchrotron self-Compton (e.g. Maraschi, et al. 1992), inverse Compton on photons produced by the accretion disk (Dember, et al. 1992), or Scattered by ambient material or by the broad-line clouds (Sikora et al. 1994; Blandford & Levinson 1995; Wagner et al. 1995, Xie et al. 1997), and Synchrotron emission by ultrarelativistic electrons and positrons (e.g. Mannheim 1993; Ghisellini 1993). As the large number of proposed models indicators, there is no consensus yet on the dominant emission process. In order to discriminate between those models for the emission mechanisms of the high-energy TeV γ-ray photons, it is important to investigate whether the variability at the high energy is associated with variability at lower energy.

In this paper, we will discuss the emission mechanism of the TeV γ-ray photons. The variability time scale of both optical and TeV γ-ray emissions shows that there is a massive black hole in the centre of Mark 421, but the mass of the central black hole have not obtained up to now. We will estimate the mass of the central black hole in this paper.

2. The massive black hole in the centre of Mrk 421

For emission from a spherical blob with an observed time variability T, relativistic causality requires the size of the emission region R in the jet to satisfy the inequality, $R \leq c\triangle T\delta/(1+Z)$, where Z is the cosmological redshift; Z=0.03 for Mark 421. From the light curves of both optical and TeV γ-ray bursts, we have, $\triangle T \approx 50$ minutes (see Fig. 1) The Doppler factor of Mark 421 is given by Xie et al. (1995), it is $\delta = 1.4$. The spatial extent is

$$R \leq 1.23 \times 10^{14} cm, \quad (1)$$

a remarkably small region. Using the historical light curve of Mark 421 and the theory of the slim accretion disk in AGN, we have obtained that the mass of the central black hole of Mark 421 is (Liu, and Xie, 1997),

$$M \approx 2 \times 10^6 M_\odot. \quad (2)$$

On the basis of the accretion disk theory, We have also obtained similar result for the mass of the central black hole of Mark 421 (Xie et al. 1986),

$$M \approx 3 \times 10^6 M_\odot. \quad (3)$$

Obviously, results (2) and (3) are very interest. For a black hole with $M = 2 \times 10^6 M_\odot$, the Schwarzschild radius is $R_g = \frac{2GM}{c^2} = 0.6 \times 10^{12}$cm. Form (1) and (2), we can obtain the relation between the size of the emission region R and the schwarzschild radius of the central black hole, $R \approx 205 R_g$. Obviously, this is a very important result. It is well known that according to the theory of accretion (Sunyaev, 1975). R is a very important parameter. Because, when $R < 200 R_g$, the electrons in the accretion flow became ultrarelativistic. On the other hand, the mixture of relativistic electrons and nonrelativistic protons has an adiabatic index $\gamma < \frac{5}{3}$, with such an adiabatic index the transition to supersonic accretion regime is possible in the region where $R < 200 R_g$ (Sunyaev, 1975). Our results show that the extremely rapid bursts of both optical and TeV photons from Mark 421 occur at just outer side of $R=200R_g$.

3. The main origin of TeV photons of Mrk 421

Direct variability studies of the optical and TeV γ-ray emissions in this paper (see Fig. 1) indicate that the TeV γ-ray and optical emission region are the same. As a consequence, it is possible to interpret the TeV γ-ray emission as being directly related to the optical radiation, as in a simple homogeneous synchrotron self-compton model. This suggestion is consistent with the propose of high energy γ-ray emission of Lin (Lin, et al. 1995) and Dondi et al. (1995). On the other hand, the observations show the γ-ray radiations have been detected during their optical bursts for Mark 421, OJ 287 and 0836+716 (Hurst 1992; Schramm et al. 1992; Toone & Worraker 1992; Fiorucci & Tosti 1992; Sillanp$\ddot{a}\ddot{a}$ et al. 1996). It is also suggested that the γ-ray emission is associated with the optical emission. It is well known that production of TeV γ-rays in active galactic nuclei is poorly understood. It is generally assumed that most of the non-thermal emission derives from relativistic jets of material beamed towards the observer. One class of popular models assumes that low-energy are boosted to high energies by inverse Compton scattering (IC model). The observations in the optical and TeV γ-rays studied in this paper provide a new clue and place new severe constraints on model of the production mechanism and site of high-energy γ-rays in AGNs. They show that the site of both target photons and boosted TeV γ-rays are the same which is located within the relativistic jet. So that both target photons and boosted TeV γ-rays are moving in the same direction. These observational facts obviously support the inverse Compton scattering model. If the inverse Compton scattering model is truly responsible for TeV γ-rays emission, both the observations for optical burst and TeV γ-rays burst are of the same kind of typical event.

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