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Interpretation of the development of flare phenomena 2004-2007 in the blazar 3C454.3

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Abstract. Radio and optical data are used to analyze the development of the flare in the blazar 3C454.3 observed in 2004-2007. A detailed correspondance between the optical and radio flares is established, with a time delay that depends on the observing frequency. Small–scale flux variations on time intervals of 5-10 days in the millimeter and optical are also correlated, with a time delay of about ten months. This may provide evidence for a single source generating the radiation at all wavelengths. The presence of a tight correlation between the features and shapes of flux–variation curves during the development of a flare in the optical and radio enables us to specify in somewhat more detail the physics of phenomena occurring in the accretion disk and jet outflows.

Key words. AGN: observations, flare, black-hole

1. Introduction

The long-term monitoring of non-stationary sources provides opportunities for establishing relationships between the radio structure of a source derived from interferometric observations and variability of its integrated flux. The aim of the current paper is to analyze the development of the flare that occurred in 3C454.3 in 2004-2007, appearing first in the optical and then, after a delay of about 10 months, in the radio. We especially pay attention to details of the flare development in the radio and optical. We also consider a possible emission mechanism in AGN associated with the loss of angularmomentumin a binary blackhole system.

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2. Observations and results

Observations were carried out at 22.2 and 36.8 GHz with the 22-m radio telescope of the Crimean Astrophysical Observatory (Ukraine). Observations were carried out at 4.8, 8, and 14.5 GHz using the 26-m radio telescope of the University of Michigan Radio Astronomy Observatory (USA) (Volvach et al. 2007). The optical data were obtained as part of the coordinated international program Whole Earth Blazar Telescope (WEBT), and were stored in the WEBT archive at the Turin Astronomical Observatory of the National Astrophysics Institute of Italy (Villata et al. 2006, 2007). Radio and optical data are used to analyze the development of the flare in the blazar 3C454.3 observed in 2004-2007. A detailed correspondance between the optical and

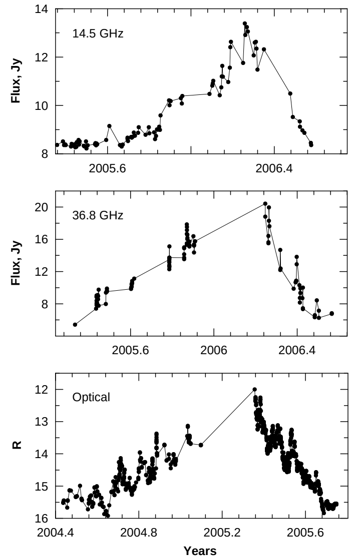

Fig. 1. Development of the flare in 3C454.3 in the optical and radio.

radio flares is established, with a time delay that depends on the observing frequency (fig.1). Small–scale flux variations on time intervals of 5-10 days in the millimeter and optical are also correlated, with a time delay of about ten months. This may provide evidence for a single source generating the radiation at all wavelengths.

The presence of a tight correlation between the features and shapes of flux–variation curves during the development of a flare in the optical and radio enables us to specify in somewhat more detail the physics of phenomena occurring in the accretion disk and jet outflows. The processes in the development of a flare at each frequency occupy a time interval of about one year (fig.2). Against the background of slow flux variations, we observe fast variations with time scales of five to ten days, determined by the observing interval, whose amplitude comprises an appreciable fraction of the maximum flare flux.

These two types of flux variations may correspond to different radiating regions, but they are undoubtedly interconnected by some common physical processes giving rise to the observed radiation. In connection with the proposed physical additions to our picture of the phenomena occurring in supermassive black–hole binaries that are actively interacting and in a phase close (in cosmological terms) to coalescence, we suggest the following. The companion of the central supermassive black hole has a mass about an order of magnitude smaller than that of the central black hole (Volvach et al. 2007), and moves with supersonic speed ($v \approx 7 \cdot 10^8$ cm/s) through a fairly dense medium ($n \approx 3 \cdot 10^9$ cm^{-3}). The radii of the orbits of the two black holes in the system, which are both bright sources of emission, are contained in the narrow interval from $3 \cdot 10^{16}$ cm to 10^{17} cm. This is due to the fact that losses to gravitational radiation grow sharply when the orbital radius of the companion is less than $3 \cdot 10^{16}$ cm, making the orbit extremely unstable. Orbital radii greater than 10^{17} cm require black–hole masses exceeding $10^{10} M_o$, which are not observed (Volvach et al. 2008). The gravitational radius of a central black hole with mass ($M \approx 3 \cdot 10^9 M_o$) is $R_g \approx 3 \cdot 10^{15}$ cm. Shocks created by the moving companion propagate in the ambient medium, and some penetrate into the accretion disk. Having an elliptical orbit with a mean radius of $R \approx 3 \cdot 10^{16}$ cm, the companion moves essentially in the peripheral regions of the disk surrounding the central black hole, plunging into the disk at pericenter. The fragmentary disruption of the disk due to the moving companion, in particular at pericenter, can be accompanied by an enhanced release of energy, which is transferred to the outflowing jets by shocks propagating in the disk. The partial sweeping out of the matter by the companion creates a temporary decrease in the density in the region where it is moving. However, the appreciable speed associated with the chaotic motions of the heated gas (thousands of km/s) and the excess pressure of the ambient medium can lead over some time (of the order of several years) to a re–establishment of the gas density along the path of the companion black hole. These time estimates were obtained based on the dimensions of the companion and the speeds of the chaotic motions in the gas. It is also necessary to take into account relativistic effects due to the mo-

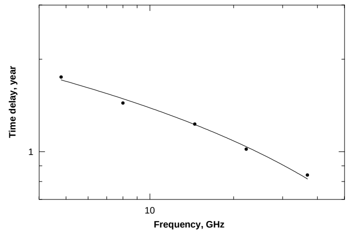

Fig. 2. Dependence of the time delays for flare in 2005-2006 in 3C454.3 at various radio frequencies relative to the optical flare.

tion of the pericenter of the binary system, due to which the companions orbit will encompass new regions following each pericenter passage.

3. Conclusions

The shape of the light curve for the development of the flare is also noteworthy. It is plays a gradual rise in intensity followed by amore rapid decay. This shape can be explained in various ways in the following scenarios.

1. We observe an increase in intensity because the companion moves in a denser medium at pericenter, and the volume luminosity I begins to increase due to the growth in the temperature and density. The companion then emerges from these denser regions of the accretion disk, and the radiative efficiency beings to drop. Rapid variations in the intensity could be due to inhomogeneities in the density in the accretion disk. Over about ten days, the companion has moved a distance of R$\approx 10^{15}$ cm, possibly reflecting the characteristic sizes of inhomogeneities in the disk surrounding the central black hole. If this is correct, observations of rapid flux variations can be used to study the structure of the accretion disk. The appreciable rise in the flux during the flare is due to the directed action of the collimation mechanism during the transformation of the system of shocks in the jet outflows into the relativistic motion of plasma along these outflows.

2. In an alternative scenario, we are dealing with a more complex structure for the accretion disk. It is known that the accretion disks in Galactic close binary systems can be warped at their edges, causing the disk to precess in a non–rigid–body fashion. In this case, the companion can cross the disk at pericenter twice-first through the warped periphery of the disk, and then through the denser central part (when the orbital plane of the companion is inclined to the plane of the disk). The resulting light curve will be a superposition of two curves corresponding to the passage of the companion through regions of enhanced density. The first will have a lower amplitude, while the second (main) component will have higher amplitude. This is surprisingly similar to the observed flare flux variations in 3C345 (Lobanov 2004), where the overall duration of a flare is about one year, and a double-peaked shape is clearly visible in the light curve. It becomes clear in this picture for the emission of AGN why only a small fraction of the total emission is transformed into the narrowly directed jet emission. First, the solid angle occupied by the shocks from the point of view of the accretion disk is much less than 4π. Second, the shocks in the disk propagating toward the jet outflows have a large scattering coefficient. As a result, only about 1–2% of the total energy released during the orbital motion of the companion goes into the jets. This is the energy fraction that is transformed into the observed flare.

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