The connection between the giant optical outbursts of the flat spectrum radio quasars and the black hole precession

Rumen Bachev
Institute of Astronomy and NAO, Bulgarian Academy of Sciences, BG-1784, Sofia, Bulgaria
bachevr@astro.bas.bg

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Abstract. Flat Spectrum Radio Quasars (FSRQ) are a part of the blazar family, which in addition to the dominated nonthermal jet emission shows signatures, normally associated with the presence of a standard thin accretion disk, such like thermal continuum and broad emission lines. Furthermore, there is emerging evidence that the FSRQ are more likely to exhibit giant outbursts in the optical, with amplitudes reaching sometimes up to five magnitudes, compared to their quiescent state. We give examples, compiled from the literature and public archives in support of this statement. The most promising mechanism to account for such outbursts appears to be the changing Doppler factor (orientation with respect to the line of sights) of the jet. We attribute such orientation changes of the jet to the presence of misaligned thin accretion disk, leading to a black hole/accretion disk precession. Such a scheme can explain why FSRQ tend to produce large outbursts while other blazar types do not.

Key words: blazars, black holes, variability

1. Introduction

Depending on their optical spectra, blazars are generally divided into two classes – BL Lac type objects and Flat Spectrum Radio Quasars (FSRQs). While the latter show broad emission lines and thermal hump often associated with the presence of standard thin accretion disk (Shakura & Sunyaev, 1973), the former typically reveal no such features, even often in very deep spectra. This fact implies that the BL Lacs are perhaps powered by optically thin, geometrically thick accretion solution, like ADAF (e.g. Narayan & Yi, 1994). If this interpretation is correct, then the accreting matter will be distributed differently around the central black hole for the two types of blazars; a flattened disk around the FSRQ's black holes and a much more spherical structure around the BL Lac's black holes (Fig. 1).

2. Variability mechanisms

Blazar's low-energy (including optical) emission is primarily generated within a relativistic jet via synchrotron processes and is highly variable on time scales from minutes to years. Different scenarios that might lead to such variability have been discussed throughout the years, but the most promising one appears to be the variable Doppler factor of the emitting blobs, traveling down the jet. The Doppler factor can be defined as $\delta = \Gamma^{-1}(1 - \beta\cos\theta)^{-1}$, where $\Gamma = (1-\beta^2)^{-0.5}$ is the bulk Lorentz factor and θ is the viewing angle (the angle between the jet direction and the line of sight). Since Γ can be as large as $\sim$20, one sees that only a small change of the viewing angle can lead to a significant change in the observed flux, taking

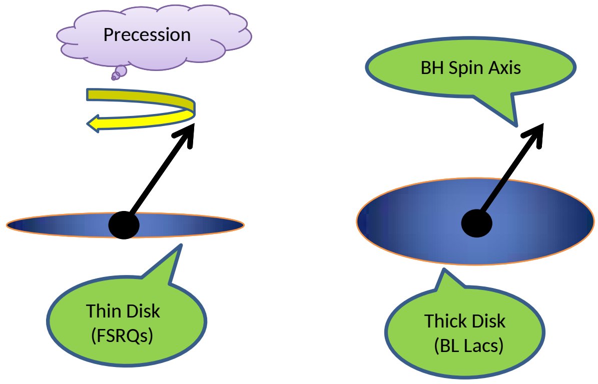

Fig. 1. The black hole is more prone to spin precession if surrounded by a misaligned thin accretion disk (supposedly the FSRQs case) than if surrounded by a quasi-spherical flow (the BL Lacs case), where the matter is more or less symmetrically distributed.

into account that the observed-to-emitted flux ratio is proportional to $\delta^{3+\alpha}$, where $\alpha \sim 1$ is the spectral index. Thus a small jet direction change of a few degrees can lead to a huge, up to several magnitudes change of the observed flux, even without any significant change of the intrinsic emission.

3. Variability statistics

In order to study the connection between the blazar type and the rate of its variability we collected optical light curve data from publicly available sources, such as Tuorla monitoring program (http://users.utu.fi/kani/1m/), St. Petersburg monitoring program (http://vo.astro.spbu.ru/?q=node/10), SMARTS (http://www.astro.yale.edu/smarts/glast/home.php), etc. We used our own data as well. In total, we collected variability data for almost 150 objects, about 44 percent of which were FSRQs. Each object was observed multiple times for a period of non-less than 2 years, but typically 7 – 15 years. We chose the light curve amplitude (in magnitudes) in order to quantify variability. The amplitude is more sensitive to distinguish giant but rare outbursts from intermittent but moderate amplitude variations, than the standard deviation, for instance. Fig. 2 gives variability examples for different blazar types. Fig. 3 gives the magnitude distribution, built separately for BL Lacs and FSRQs. Clearly, FSRQs tend to produce larger amplitude variations than BL Lacs and the difference is statistically significant at >99.9 percent level (see also Hovatta et al., 2014; Zhang et al., 2015).

4. Black hole precession

If the jet direction changes drive the giant outbursts sometimes observed, an interesting possibility is to attribute these changes to a precession of the jet, due presumably to the precession of the black hole spin axis. Although

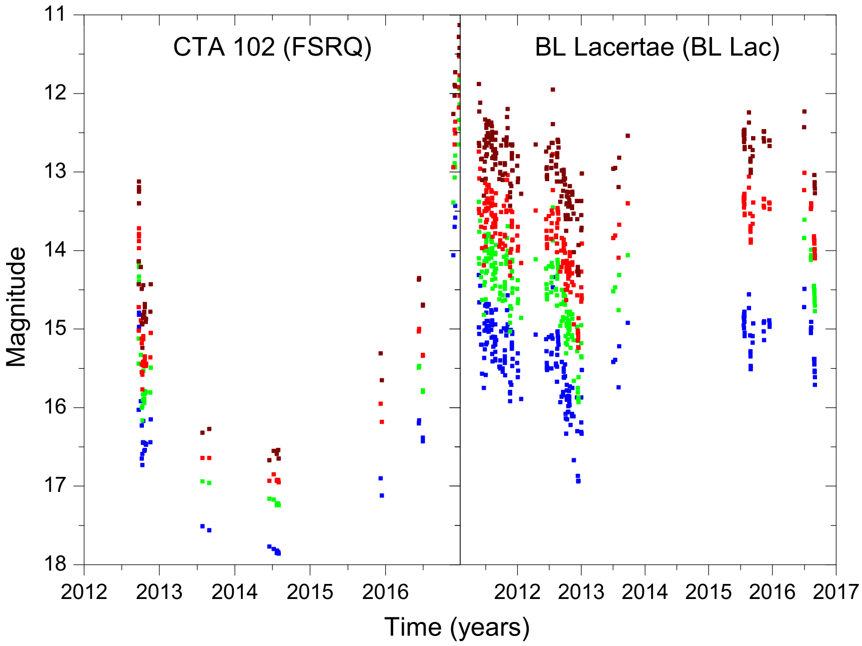

Fig. 2. Typical examples of long-term optical variability of different blazar types. BVRI optical bands are shown as blue, green, red and brown dots, respectively (our observations). Although all blazars appear to be variable, the FSRQs tend to spend more time in a quiescent state, followed by rare but violent outbursts, while BL Lacs show intermittent, but somewhat more restricted in amplitude variations.

there is no firm understanding how exactly the jets are generated, a promising mechanism is the Blandford-Znajek mechanism (Blandford & Znajek, 1977), leading to electromagnetic extraction of the black hole spin energy and producing a relativistic jet along the black hole spin axis. Thus, if precessing itself, the black hole will generate a precessing (or wobbling) jet. The black hole precession can be caused, for instance, by a flattened matter (accretion disk) if the latter is inclined with respect to the hole's equatorial plane (Fig. 4). Then, the black hole precession is a result of a combination of the Lense-Thirring effect and the disk viscosity (Bardeen & Petterson, 1975). Inclined accretion disks will be formed provided the initial angular moment of the accreting matter does not coincide with the black hole spin momentum and there is no a priory reason to expect always the opposite. A detailed analysis by Scheuer & Feiler (1996) shows, that the characteristic precession time is roughly $T_{\rm prec} \simeq 0.15a(M_{\rm BH}/\dot{M})$ [years] (see also Natara-

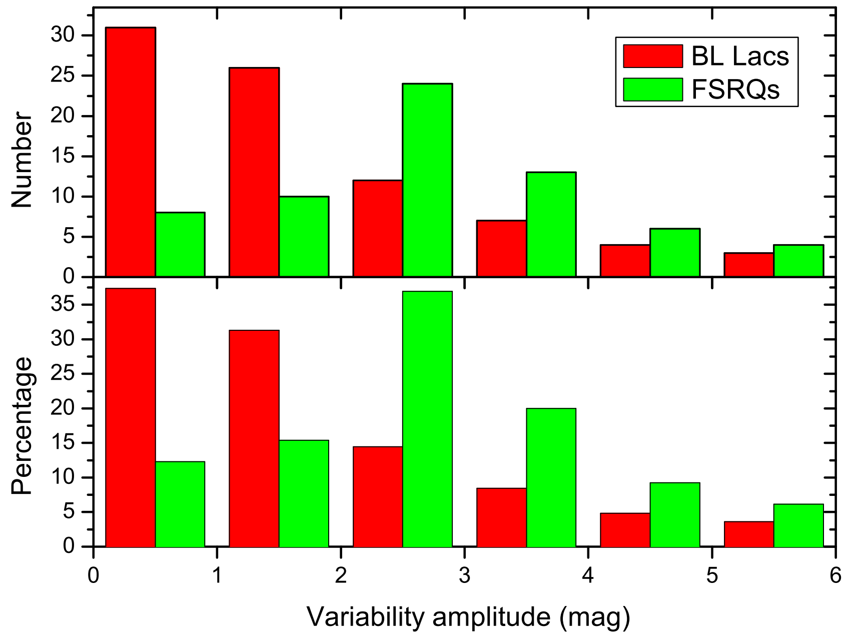

Fig. 3. Distribution of the maximum variability amplitudes registered during long-term monitoring for FSRQs and BL Lacs. The histogram is built for the number of the objects, used for this analysis (upper panel) and for their percentage of the total object number of each blazar type (lower panel). Note the difference in the distributions, showing that FSRQs tend to manifest variability of larger amplitudes.

jan & Armitage, 1999; Lodato & Pringle, 2006), where $M_{\rm BH}$ and a are the black hole mass and spin parameter, and $\dot{M}$ is the accretion rate. Thus, the precession period can be rather long, i.e. thousands of years. In the observer frame, however, the period transfers as $T_{\rm obs} = (1+z)\Gamma^{-1} < \delta^{-1} > T_{\rm true}$, (Caproni et al., 2009) and can be as short as $\sim$10 years, which is rather consistent with the typical cycle of the FSRQ outbursts.

On the other hand, Nixon & King (2013) argued recently that the disk angular momentum might be too small compared to the one of the black hole, leading to a rather stable black hole spin axis. If so, it is possible that the inclined disk itself precesses instead of the black hole. So, if the disk is responsible for the jet generation (so called Blandford-Payne mechanism; Blandford & Payne, 1982), again, a precessing jet will be formed.

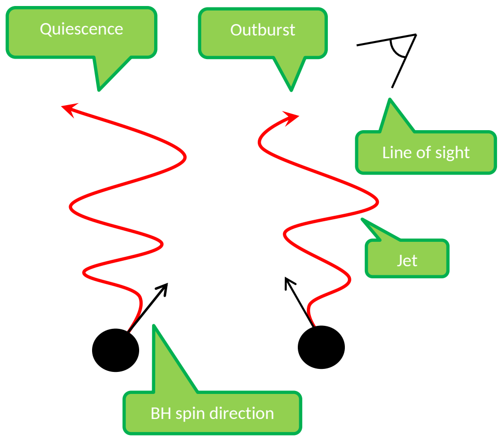

Fig. 4. This picture illustrates why a precessing jet (FSRQs?) is more likely to produce giant outbursts due to the changing Doppler factor, than a relatively stable one.

Conclusions

In this paper we collect and analyze publicly available data and show that the FSRQs tend to manifest larger in magnitude optical variability than the BL Lac type objects. We attribute such a difference to a changing Doppler factor, due perhaps to a precession of the black hole, powered by misaligned thin accretion disk (for the FSRQs). Of course, other possibilities also cannot be ruled out.

Acknowledgements

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