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Connections between the Radio, Optical and Soft X-ray Luminosities for Flat-Spectrum Radio Quasars

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Abstract. We investigate the connections between radio, optical and soft X-ray luminosities with a sample of 538 FSRQs. We find that the radio luminosity is strongly correlated with the optical luminosity, as well as with the soft X-ray luminosity. We also find that the optical luminosity is strongly correlated with the soft X-ray luminosity.

Key words. Black hole physics—galaxies: active—galaxies: jet.

1. Introduction

Quasars can be divided into radio-loud and radio-quiet classes. Using radio spectral index ($f \propto \nu^{-\alpha}$), radio-loud quasars can be further divided into two subclasses: Flat-Spectrum Radio Quasars (FSRQs, $\alpha < 0.5$) and Steep-Spectrum Radio Quasars (SSRQs, $\alpha > 0.5$). The common features of FSRQs are usually associated with jets and are characterized by the high polarization, violent flux variability, high luminosity, apparent superluminal motion and beaming effect (Urry & Padovani 1995; Wu *et al*. 2004; Chen *et al*. 2011). However, formation of jets remains unknown, being a fundamental problem in astrophysics (Meier *et al*. 2001). In the past several decades, some schemes have been suggested for the origins of jet: (1) from accretion disk (Blandford & Payne 1982; Blandford & Begelman 1999), (2) from energy extraction from the spin of a black hole (Blandford & Znajek 1977). Accretion disk is involved in these above processes, but the underlying mechanisms of accretion process and the jet remain an outstanding problem.

In this work, we employ multi-wavelength observational data of 538 FSRQs to investigate the connection between the jet and accretion disk. Throughout this paper, we adopt the cosmological parameters: $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$.

2. Data and sample

The SDSS DR7 spectroscopic quasar catalogue (Schneider *et al*. 2010) includes 105783 quasars which are brighter than $M_i = -22.0$ mag and have at least one broad emission line (FWHM $>$ 1000 km s^{-1}) or have some complex absorption features. Schneider *et al*. (2010) made a cross-correlation between the SDSS DR7 spectroscopic quasar catalogue with ROSAT All-Sky Survey (RASS) bright and faint source catalogue (Voges *et al*. 1999, 2000) within the position accuracy of 30″, and Shen *et al*. (2011) matched the SDSS DR7 spectroscopic quasar catalogue with faint images of the radio sky at twenty centimeters radio catalogue (FIRST) (White *et al*. 1997) within a radius of 30″. To construct FSRQs sample which were detected by RASS, we cross-correlate Green Bank 6 cm radio source catalogue (GB6) (Gregory *et al*. 1996) with both SDSS DR7 — RASS and SDSS DR7 — FIRST quasar samples within the positional offset of 1′ (Kimball & Ivezić 2008; Chen *et al*. 2009, 2011), which results in 538 FSRQs with the spectral index between 20 and 6 cm radio fluxes $\alpha < 0.5$.

3. Results and conclusion

The jet and accretion disk can emit photons from radio to X-ray bands. It is beleived that the jet formation is linked to the accretion process. The connection of radiation between the jet and the accretion disk in different ways was studied by various authors. Serjeant *et al*. (1998) investigated this relation using the optical and radio emission with a sample of SSRQs, Xie *et al*. (2007) explored the correlation of the radio core luminosity and the luminosity of broad emission line for a large sample of blazars, Brinkmann *et al*. (1997) searched the correlation between 2 keV X-ray and 5 GHz radio luminosities for radio-loud quasars, and Canosa *et al*. (1999) searched for the link between soft X-ray and 5 GHz luminosities for low luminosity radio galaxies. They came to the same conclusion that the formation of jets is linked to the accretion disk. If the formation of jet is really linked to the accretion process, then there should be correlation between the radio, optical and soft X-ray radiations. With this motivation, we searched for the relationship between radio, optical continuum and soft X-ray luminosities for our sample of 538 FSRQs.

In Fig. 1(a), we plotted optical continuum luminosity vs. radio luminosity at 6 cm. It shows a tight correlation between the two quantities (the correlation coefficient is $r = 0.523$ which is at a probability of $P < 10^{-40}$ for rejecting the hypothesis of no correlations). The partial correlation analysis involves investigating the linear relationship between two variables after excluding the dependence on other independent factors. The luminosities are related with redshift. To exclude the dependence on redshift, we performed the partial correlation analysis between the continuum and radio luminosities and found that the partial correlation coefficient r is 0.278 at a probability of $P < 10^{-11}$ which support the strong correlation. Similarily, the soft X-ray luminosity vs. radio luminosity at 6 cm is shown in Fig. 1(b) with correlation coefficient $r = 0.532$ at a probability of $P < 10^{-40}$. Again here to exclude the dependence on redshift, we performed the partial correlation analysis between the soft X-ray and radio luminosities and found that the partial correlation coefficient r is 0.294 at a probability of $P < 10^{-12}$ which also support the strong correlation.

The radio emission comes from the non-thermal synchrotron radiation of the jet (Begelman *et al*. 1984). Several components likely contribute to X-ray flux at some level. They are synchrotron self-Compton radiation of accretion flow, synchrotron

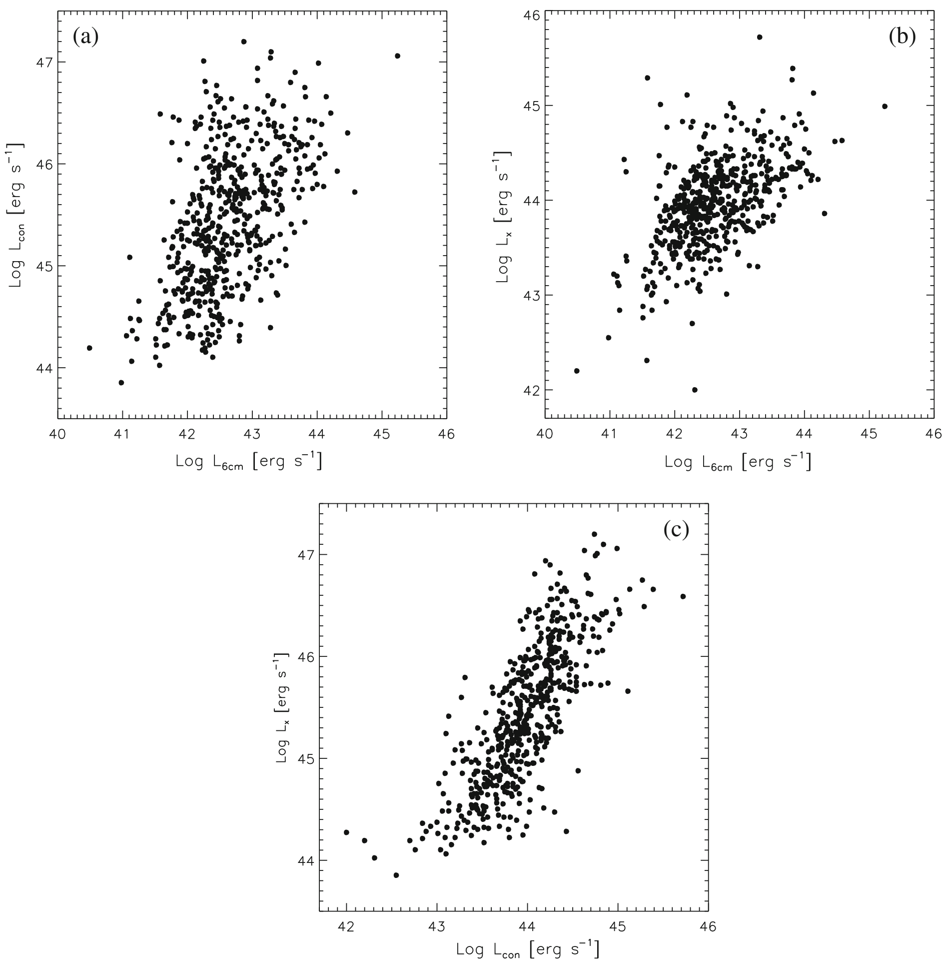

Figure 1. (**a**) The optical continuum luminosity ($L_{\rm con}$) vs. 6 cm radio luminosity ($L_{6\,\rm cm}$) with correlation coefficient $r = 0.523$ at $P < 10^{-40}$. (**b**) The soft X-ray luminosity ($L_{\rm x}$) vs. 6 cm radio luminosity ($L_{6\,\rm cm}$) with correlation coefficient $r = 0.532$ at $P < 10^{-40}$. (**c**) The soft X-ray luminosity ($L_{\rm x}$) vs. optical continuum luminosity ($L_{\rm con}$) with correlation coefficient $r = 0.792$ at $P < 10^{-42}$.

emission from the jet, thermal radiation from accretion disk (Fender & Belloni 2004; Fender *et al.* 2009), and the inverse-Compton scattering from corona. The optical radiation is also due to more than one emission mechanism including non-thermal radiation from the jet, thermal emission from accretion disk (Shakura & Sunyaev 1973), host galaxy, and so on. For FSRQs, the radio, optical and soft X-ray luminosities should be simultaneously enhanced by the relativistic beaming of the synchrotron radiation, which will be dominated by the jet emission. In other words, the optical continuum and soft X-ray luminosities may mainly originate from the Doppler boosted emission of the jet, but may not come from the accretion disk for FSRQs. Therefore, it is natural that the radio luminosity will have a tight correlation with optical continuum and soft X-ray luminosities. These strong correlations weaken the connection between the jet formation and accretion disk for FSRQs.

In Fig. 1(c), we plotted the soft X-ray luminosity vs. optical continuum luminosity and found an obvious correlation with correlation coefficient $r = 0.792$ at a probability of $P < 10^{-42}$. To exclude the dependence on redshift, we performed the partial correlation analysis and found strong correlation with correlation coefficient $r = 0.396$ at a probability of $P < 10^{-21}$. This obvious strong correlation supports the idea that the soft X-ray and optical continuum radiations are from the same emission components. In Fig. 1, the scatters are significant which implies that the total emissions may not be only due to jet emission but also other emission mechanisms which cannot be neglected. They include the emissions from accretion flow, disk corona, and other parameters, e.g., Doppler factor, inclination of the jet, emitting regions, etc.

The effect of the jet is outstanding for FSRQs, suggesting that the luminosities from radio to X-rays are jet dominated. Here we found that radio luminosity tightly correlates with the optical continuum and soft X-ray luminosities, which implies that the optical and soft X-ray emissions are dominated by the radiation from the jet for FSRQs. Therefore, optical and soft X-ray luminosities are not reliable parameters to characterizes the feature of accretion disk in FSRQs.

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