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A close look at the γ-ray emitting Narrow-Line Seyfert 1 FBQS J1644+2619

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FBQS J1644+2619 is one of the most recently discovered γ-ray emitting Narrow-Line Seyfert 1s (NLSy1s). Here we present a multiwavelength analysis of this source, focussing on a recent 80 ks X-ray observation with *XMM-Newton*. The spectral energy distribution of the source is similar to the other γ-ray NLSy1s, confirming its blazar-like nature. The X-ray spectrum is characterised by a hard photon index ($\Gamma = 1.66$) above 2 keV and a soft excess at lower energies. The hard photon index provides clear evidence that inverse Compton emission from the jet dominates the spectrum, while the soft excess can be explained by a contribution from the underlying Seyfert emission. This contribution can be fitted by reflection of emission from the base of the jet, as well as by Comptonisation in a warm, optically thick corona. We also compare these results with X-ray observations of other γ-ray NLSy1s. The majority of the sources have similar X-ray spectra, with properties intermediate between blazars and radio-quiet NLSy1s.

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1. Introduction

Observations with the *Fermi Gamma-ray Space Telescope* have revealed NLSy1s as a new class of γ-ray emitting AGN with blazar-like properties [1]. It is a very small class, consisting of only about a dozen sources to date [2]. Compared to the population of blazars, the NLSy1s are similar to the Flat Spectrum Radio Quasars (FSRQ), but with typically lower γ-ray luminosities. Given that NLSy1s are normally associated with spiral galaxies, low-mass black holes and high accretion rates, they do not fit in with the typical paradigm of systems that host powerful relativistic jets. This makes the γ-ray NLSy1s very interesting in terms of understanding the conditions required for jet formation.

Here, we present a multiwavelength analysis of the γ-ray NLSy1 FBQS J1644+2619, focussing on the X-ray properties. Full details of the analysis are presented in [3]. FBQS J1644+2619 is located at $z = 0.145$ in a host galaxy without any clear signature of disc-related structures [4]. It has an average γ-ray luminosity of 1.6×10^{44} erg s^{-1} [5], a high radio loudness (log R $= 2.39$) and a two-sided radio structure on kpc scales [6]. Estimates of the black hole mass are in the range $8 \times 10^6 - 2 \times 10^8$ M$_\odot$ and the related estimates of the Eddington ratio are in the range $0.007 - 0.2$ (see [3] for further discussion of these estimates).

2. Observations

The main focus of this work is an *XMM-Newton* observation carried out on 2017 Mar 3-4 with a total exposure time of 82 ks. After removing time periods affected by flaring background, ~ 50 ks of good exposure time was left for the spectral analysis. The unabsorbed $0.3 - 10$ keV flux is $(3.34 \pm 0.04) \times 10^{-12}$ erg cm^{-2} s^{-1}, which is the highest X-ray flux recorded in this source. In addition, we also present multiwavelength observations from radio to γ rays in order to investigate the spectral energy distribution (SED) and multiwavelength variability. These observations include (i) an observation at 24.1 GHz with the Medicina radio telescope on 2017 Mar 4 ; (ii) Monitoring in the V, R and I filters by the Rapid Eye Mount (REM) telescope during 2017 March 3-30; (iii) Monitoring in X-ray, UV and optical by *Swift* between 2015 April 9 - Sept 5 and 2017 Feb 27 - March 7; (iv) γ-ray observations by the *Fermi* Large Area Telescope (LAT) in a one-month interval around the time of the *XMM-Newton* observation. Full details of all observations are given in [3].

3. SED and multiwavelength variability

The SED of FBQS J1644+2619 is shown in Fig. 1, including the new data from our monitoring campaign as well as archival observations [7, 5]. The source was not detected in γ rays by *Fermi* LAT in the one-month interval around the *XMM-Newton* observation. The 2σ upper limit of 1.44×10^{-8} photons cm^{-2} s^{-1} is well below the highest γ-ray flux observed in this source (5.2×10^{-8} photons cm^{-2} s^{-1}), but about a factor 2.5 higher than the average γ-ray flux [5]. For comparison, the SED of the well-studied NLSy1 PMN J0948+0022 [8] is also included in Fig. 1. The SEDs of the two sources are similar in the radio – X-ray range, but PMN J0948+0022 is much brighter in γ rays. In fact, FBQS J1644+2619 is among the least luminous NLSy1s in γ rays and is only occasionally detected by the LAT, indicating a lower Compton dominance and less active jet

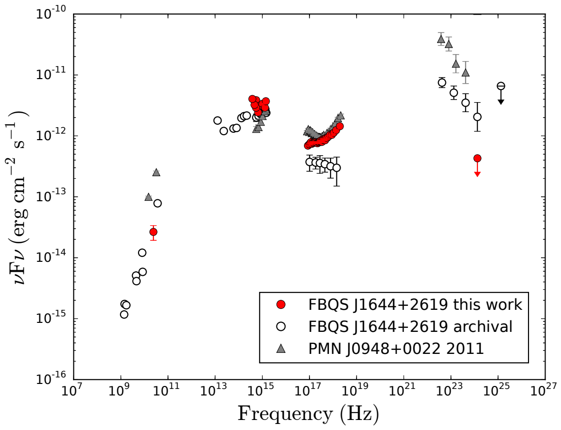

Figure 1: SED of FBQS J1644+2619. Quasi-simultaneous data from 2017 are shown in red, while archival observations are shown with open symbols. The grey triangles show the SED of the NLSy1 PMN J0948+0022 during an intermediate flux state in 2011 [8].

in this source. Apart from the low γ-ray luminosity, the SED of FBQS J1644+2619 is similar to the other NLSy1s, confirming its blazar-like nature.

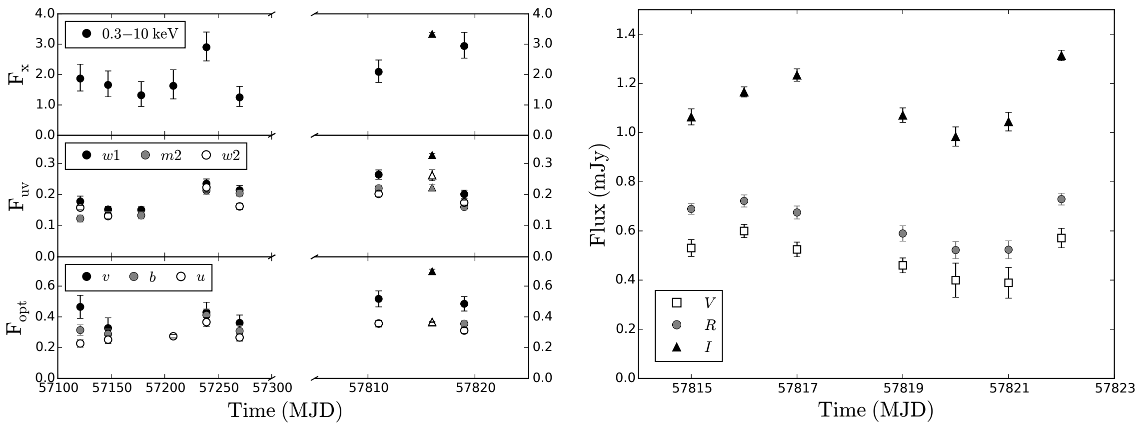

Figure 2: Multiwavelength light curves of FBQS J1644+2619. *Left:* X-ray, UV and optical fluxes observed by *Swift* (circles) and *XMM-Newton* (triangles). The X-ray flux is in units of 10^{-12} erg cm^{-2} s^{-1}, while the UV and optical fluxes are in units of mJy. *Right:* Optical fluxes observed by REM. All fluxes have been corrected for extinction.

Fig. 2 shows light curves of FBQS J1644+2619 from the monitoring in X-rays, UV and optical. The monitoring with *Swift* (left panel) is probing the variability on a time-scale of months, as well as the few days around the time of the *XMM-Newton* observation, while the REM observations (right panel) are probing one-day times-scale. The source is clearly variable on all time-scales, with maximal variability amplitudes of ~ 2.7 in X-rays and $\sim 1.4-1.8$ in UV/optical. The V and R bands are correlated at $> 3\sigma$, while all the other UV/optical filters show weaker $(1-2\sigma)$ evidence of correlated variability. The larger variability amplitude in X-rays is consistent with our

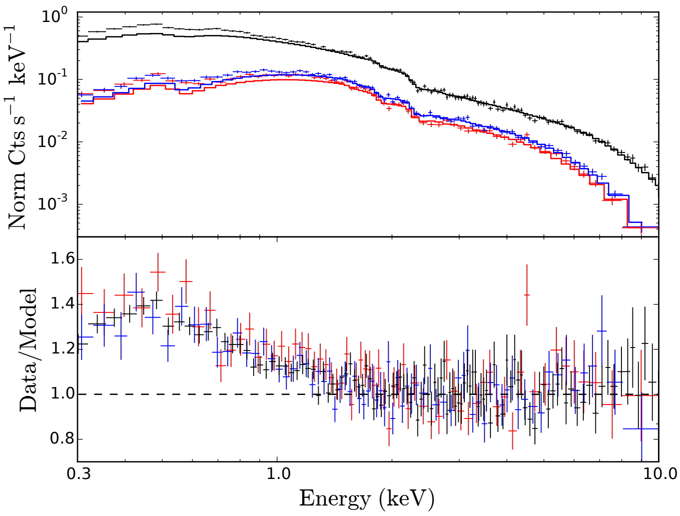

Figure 3: *XMM-Newton* spectrum of FBQS J1644+2619 together with the power-law model fitted in the $2-10$ keV range. The ratio between the data and the model is shown in the bottom panel. The black, red and blue data points are from pn, MOS1 and MOS2, respectively.

spectral analysis, which shows that the jet dominates the X-ray flux (cf. Section 4), while the disc dominates the UV/optical [9].

4. X-ray spectra

The spectral fitting was performed using all three EPIC detectors (pn, MOS1 and MOS2) with all parameters tied, expect for a cross-normalisation constant. Absorption fixed at the Galactic value was also included in all fits. The 2–10 keV spectrum is well described by a hard power law with $\Gamma = 1.66 \pm 0.04$ (χ^2/d.o.f. $= 244/235$). However, the model clearly underpredicts the data when extrapolated to lower energies, revealing a soft excess (see Fig. 3). The full 0.3–10 keV spectrum is well fitted by a broken power law with $\Gamma_1 = 1.90 \pm 0.02$, $\Gamma_2 = 1.66^{+0.03}_{-0.04}$ and $E_{\rm break} = 1.9^{+0.3}_{-0.2}$ keV (χ^2/d.o.f. $= 349/353$). There is no detection of an Fe line at 6.4 keV and no evidence for intrinsic absorption. The photon index above the break is significantly harder than in radio-quiet NLSy1s and instead similar to FSRQs, showing that Inverse Compton emission from the jet is dominating the spectrum. At the same time, the break to a softer slope at low energies suggests that an additional emission component is present. A plausible candidate for this is the underlying 'Seyfert' emission, i.e. the emission from the corona and/or accretion disc. We explored three different possibilities for this emission, briefly summarised below. They all provide statistically acceptable fits to the spectra. All best-fitting parameters and plots with fit residuals can be found in [3].

Two power laws. These represent emission from a corona and a jet, respectively. The best-fitting photon indices are $\Gamma_1 = 2.01^{+0.14}_{-0.07}$ and $\Gamma_2 = 1.0^{+0.3}_{-0.4}$. Although the former value is typical for AGN coronae, the photon index associated with the jet is extremely hard. This, together with the fact

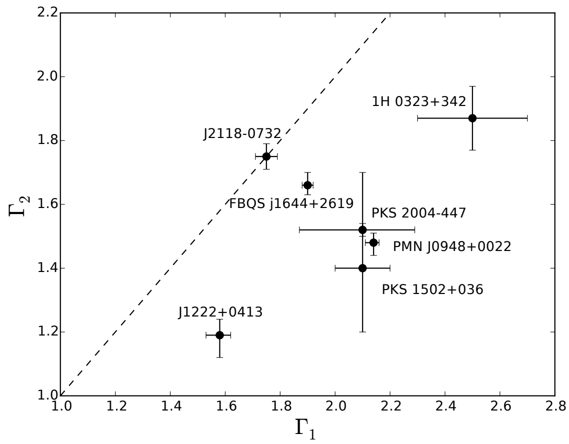

Figure 4: Photon indices obtained from broken power-law fits to X-ray spectra of γ-ray NLSy1s. Γ_1 and Γ_2 are the photon indices below and above the break (typically at ~ 2 keV), respectively. Only sources with high-quality *XMM-Newton* observations are included in the plot. Note that the spectrum of 1H 0323+342 is more complex than a broken power law and that in the case of PKS 2004-447 there is a tentative detection of a soft excess in only one of three observations.

that the hard X-ray flux predicted from this model is in contention with the non-detection by *Swift* BAT, makes this explanation less likely.

Power law + COMPTT. In this case the power law represents the jet, while COMPTT models Comptonisation of disc photons by a warm, optically thick corona. The best-fitting parameters of the COMPTT component ($\tau = 16^{+11}_{-4}$ and $kT_e = 0.30^{+0.21}_{-0.11}$ keV) are similar to those found in cases when Comptonisation by such a corona is used to fit the soft excess in radio-quiet NLSy1s.

RELXILLP. We use this model to test the scenario where we see direct emission from the jet together with reflection of the emission from the base of the jet by the disc. The best-fitting parameters of this model imply a large height for the base of the jet ($h > 11\ r_g$) and no significant emission from the innermost part of the accretion disc ($R_{in} < 42\ r_g$). The black hole spin could not be constrained.

From these fits we conclude that the X-ray spectrum of FBQS J1644+2619 can plausibly be explained by a contribution from the disc/corona in addition to the emission from the jet. The jet clearly dominates and provides ~ 90 % of the total flux in the different models. Combinations of the above models are of course also possible, but the poor constraints on the fit parameters in this case prevents us from investigating such combinations in detail. Finally, we note that the spectrum is also well fitted by a blackbody together with a hard power law. We do not explore this scenario in detail since it suffers from well-known problems with fine tuning and does not agree with standard accretion disc theory [10].

5. The X-ray properties of the population of γ-ray NLSy1s

When considering the X-ray spectra of the population of γ-ray NLSy1s, some common properties clearly emerge. The majority of sources for which high-quality X-ray observations are available have hard spectra above ~ 2 keV and a soft excess at low energies. These spectra are usually well modelled by a broken power law. Additional spectral features, in the form of an Fe line and intrinsic absorption, have been reported only in the case of 1H 0323+342 [11]. Fig. 4 show the photon indices of broken power-law fits for the seven γ-ray NLSy1s with *XMM-Newton* observations [12, 13, 14, 7, 15]. Out of these, the only sources that do not have a significant soft excess are J2118-0732 [15] and PKS 2004-447. However, in the latter source there is a tentative soft excess reported in one of three *XMM-Newton* observations [16]. As in FBQS J1644+2619, the spectra can be interpreted in terms of the jet dominating the hard spectra above the break (or the whole spectrum when there is no break) and the underlying Seyfert emission having a noticeable contribution at low energies. The source 1H 0323+342, which has the softest spectrum as well as a weak Fe line, seems to have the strongest contribution from the Seyfert component. In addition, the two sources for which RMS spectra have been studied (PMN J0948+0022 and 1H 0323+342; [13, 11]) show breaks in the RMS-variability around the spectral breaks, lending further support to a scenario where different components dominate at low and high energies.

Another possibility is that the soft excess originates from the jet itself. While this could be the case if the tail of the synchrotron emission extends to the X-ray range, we note that the SED modelling of these sources do not favour this scenario. It has also been suggested that bulk Comptonisation by a blob of plasma travelling along the jet could produce an excess at soft X-rays [17]. However, this feature should be transient, which makes it unlikely that we should observe it in the majority of sources. Further X-ray spectral analyses of γ-ray NLSy1s with the jet in different flux states should allow us to better discriminate between the different models for the soft excess and also probe the disc-jet connection.

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