

The blazar S5 0014+813: a real or apparent monster?

G. Ghisellini,^{1*} L. Foschini,¹ M. Volonteri,² G. Ghirlanda,¹ F. Haardt,³ D. Burlon⁴
and F. Tavecchio¹

¹INAF – Osservatorio Astronomico di Brera, Via Bianchi 46, I–23807 Merate, Italy

²Astronomy Department, University of Michigan, Ann Arbor, MI 48109, USA

³Università dell’Insubria, Dipartimento di Scienze Chimiche, Fisiche e Matematiche, Via Valleggio 11, 22100 Como, Italy

⁴Max Planck Institut für extraterrestrische Physik, Giessenbachstrasse 1, 85748 Garching, Germany

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ABSTRACT

A strong hard X-ray luminosity from a blazar flags the presence of a very powerful jet. If the jet power is in turn related to the mass accretion rate, the most luminous, hard X-ray blazars should pinpoint the largest accretion rates, and thus the largest black hole masses. These ideas are confirmed by the *Swift* satellite observations of the blazar S5 0014+813, at the redshift $z = 3.366$. *Swift* detected this source with all its three instruments, from the optical to the hard X-rays. Through the construction of its spectral energy distribution, we are confident that its optical-ultraviolet (UV) emission is thermal in origin. Associating it with the emission of a standard optically thick geometrically thin accretion disc, we find a black hole mass, $M \sim 4 \times 10^{10} M_{\odot}$, radiating at 40 per cent the Eddington value. The derived mass is among the largest ever found. Super-Eddington slim discs or thick discs with the presence of a collimating funnel can in principle reduce the black hole mass estimate, but tend to produce spectra bluer than observed.

Key words: radiation mechanisms: non-thermal – quasars: general – gamma-rays: theory – X-rays: general.

1 INTRODUCTION

Most of the estimates of the black hole mass in quasars make use of the width of broad emission lines in their spectra and an empirical relation between the luminosity of the ionizing continuum and the size of the broad-line region (BLR; Bentz et al. 2006, 2009; Kaspi et al. 2007). This, plus the assumption of virial velocities, allows us to estimate the black hole mass (albeit with some uncertainties). In recent years, the Sloan Digital Sky Survey (SDSS) of galaxies and quasars is providing the largest quasar samples suitable to study both the black hole mass of quasars and how their corresponding mass function evolves with redshift. We use here a different (and ‘more ancient’) method to estimate the black hole mass, by directly interpreting the optical-ultraviolet (UV) flux of a source as the emission produced by a standard accretion disc, namely Shakura-Sunyaev (1973) multi-colour disc, emitting as a blackbody at each annulus.

We do this exercise for carefully selected sources: blazars that are very luminous in hard X-rays, above 10 keV. The rationale for this choice is as follows. We know that the spectral energy distribution (SED) of blazars is characterized by two broad humps, whose peak frequencies (in νF_{ν}) are a function of the observed bolometric

luminosity of the blazars (the so-called ‘blazar sequence’; Fossati et al. 1998; Ghisellini et al. 1998). Larger powers correspond to smaller peak frequencies and more dominance of the high-energy peak to the low-energy one. According to this scenario, the most powerful blazars should have their peaks in the far-infrared (FIR) and in the ~ 1 MeV bands. The latter peak should also carry the bulk of the electromagnetic output. This has two important consequences: (i) the hard X-ray luminosity, being close to the peak, is large, and (ii) the non-thermal (synchrotron) radiation of the first peak (being in the FIR) does not hide the accretion disc radiation peaking at optical-UV frequencies. Therefore, in these kinds of blazars, we can study the radiation from the accretion disc directly (see e.g. Sambruna et al. 2007; Landt et al. 2008; Maraschi et al. 2008). The last and important steps link the observed luminosity to the power carried by the jet (in bulk motion of particles and fields) and the jet power to the mass accretion rate. The latter point, investigated by Rawlings & Saunders (1991), has been since then confirmed by other groups and using different methods (e.g. Celotti, Padovani & Ghisellini 1997; Cavaliere & D’Elia 2002; Maraschi & Tavecchio 2003; Sambruna et al. 2006; Allen et al. 2006; Celotti & Ghisellini 2008; Kataoka et al. 2008; Ghisellini & Tavecchio 2008, 2009).

From the above, it is clear that having a sample of distant flat spectrum radio quasars (FSRQs) detected in hard X-rays allows us to pinpoint the most accreting systems, and thus large black

*E-mail: gabriele.ghisellini@brera.inaf.it

hole masses and large accretion rates. The recently published list of blazars detected by the Burst Alert Telescope (BAT) onboard the *Swift* satellite (Ajello et al. 2009, hereafter A09) has provided the first well-constructed sample suitable for our aim. It contains 26 FSRQs and 12 BL Lacs detected during 3 yr of survey in the 15–55 keV range. One of those, S5 0014+813 ($z = 3.366$), is exceptionally bright in the optical band. Adopting a cosmology with $\Omega_M = 0.3$ and $\Omega_\Lambda = h_0 = 0.7$ we have, in the optical, $\nu L_\nu \sim 10^{48} \text{ erg s}^{-1}$. This is the source discussed in this Letter, with the aim to find the mass of its black hole and the corresponding accretion rate.

2 THE BLAZAR S5 0014+813

This FSRQ was discovered in the radio band by Kuhr et al. (1981), and it was soon noted as exceptionally luminous in the optical (Kuhr et al. 1983). The spectrum taken by Sargent, Steidel & Boksemberg (1989) had a (extinction corrected) slope of $\alpha = 0.8$ [$F(\nu) \propto \nu^{-\alpha}$] longward of the Ly α line of equivalent width of 158 Å. Fried (1992) find no excess of foreground galaxies in the direction of the blazar, so disfavours the hypothesis of gravitational lensing. It is not polarized in the optical (Kuhr et al. 1983), and showed very mild optical variability (max $\Delta m \sim 0.15$ in 9 yr; Kaspi et al. 2007). At a Galactic latitude of 18°8, it suffers from a non-negligible optical extinction. Schlegel, Finkbeiner & Davis (1998) list $E(B - V) = 0.19$, corresponding to $A_V = 0.62$.

This blazar was discussed in detail by Bechtold et al. (1994), who also analysed *ROSAT* data and showed the overall SED. These authors estimated the black hole mass on the basis of the optical-UV luminosity, that was, however, severely underestimated.

The results of the *XMM-Newton* observations on 2001 August 23 are presented by Page et al. (2005). An absorbed power law of photon index $\Gamma = 1.61 \pm 0.02$ best-fitted the data, with a column $N_H^{\text{host}} = (1.8 \pm 0.19) \times 10^{22} \text{ cm}^{-2}$ located at the redshift of the source, in addition to the Galactic one. The [0.3–10 keV] flux was $F_X = 5.6 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$, corresponding to $L_X \sim 6 \times 10^{47} \text{ erg s}^{-1}$. Observed with very long baseline interferometry (VLBI), it showed no superluminal motion (Piner et al. 2007).

3 SWIFT OBSERVATIONS AND ANALYSIS

Swift observed S5 0014+813 in 2007 January. We analysed these data with the most recent software *SWIFT_REL3.2* released as part of the *HEASOFT* v. 6.6.2. The calibration data base used was that updated on 2009 April 10.

The X-Ray Telescope (XRT) data were processed with the standard procedures (*XRTPIPELINE* v.0.12.2). Source events were extracted in a circular region of aperture ~ 47 arcsec, and background was estimated in a same-sized circular region far from the source. Response matrices were created through the *XRTMKARF* task. We analysed the single observations separately and also summed them together. Each spectrum was analysed through *XSPEC* with an absorbed power law with a fixed Galactic column density ($N_H^{\text{Gal}} = 1.32 \times 10^{21} \text{ cm}^{-2}$ from Kalberla et al. 2005). The computed errors represent the 90 per cent confidence interval on the spectral parameters. The best-fitting photon index of the summed spectrum was $\Gamma = 1.36 \pm 0.11$ with a $\chi^2 = 16$ for 19 degrees of freedom and an observed (de-absorbed) flux $F_X = 5.3 \times 10^{-12}$ ($F_X = 6.1 \times 10^{-12}$) $\text{erg cm}^{-2} \text{ s}^{-1}$. All quantities are calculated in the [0.2–10 keV] band.

We have also re-analysed the *XMM-Newton* observation by using the *SAS* software (v. 9.0.0). After screening the data for high-background phases, we have a net exposure of 11 ks. Fitting the

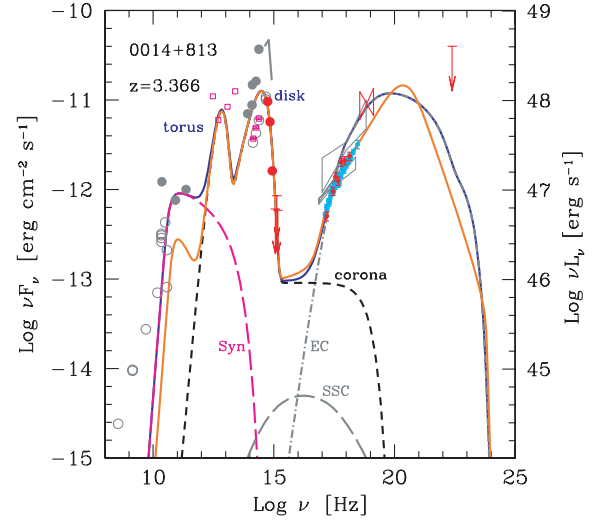


Figure 1. SED of S5 0014+813 together with the fitting models, with parameters listed in Table 1. UVOT, XRT and BAT data are indicated by red symbols, while archival data (from NED) are in light grey. The magenta square symbols are IRAS and 2MASS data points. The dotted line is the emission from the IR torus, the accretion disc and its X-ray corona. The blue and orange lines are the sum of all components. The two models differ mainly for the location of the dissipation region of the jet: outside (blue) or inside (orange) the BLR.

0.2–10 keV energy range with a power law, we obtain $\Gamma = 1.44 \pm 0.05$, with $N_H^{\text{host}} = 6 \times 10^{21} \text{ cm}^{-2}$ (in addition to N_H^{Gal}), harder than obtained by Page et al. (2005). This is likely due to our better screening and the improved calibrations. A broken power law (with N_H fixed to N_H^{Gal}) better fits the data (at the 99.99 per cent level), with a break at $E_b = 1.0 \pm 0.2 \text{ keV}$ and slopes $\Gamma_1 = 1.1 \pm 0.2$ and $\Gamma_2 = 1.43 \pm 0.04$ below and above E_b , respectively (see Fig. 1).

UVOT (Roming et al. 2005) source counts were extracted from a circular region 5 arcsec sized centred on the source position, while the background was extracted from a larger circular nearby source-free region. Data were integrated with the *UVOTSUM* task and then analysed by using the *UVOTSOURCE* task.

The observed magnitudes have been dereddened according to the formulae proposed by Cardelli, Clayton & Mathis (1989) and converted into fluxes by using standard formulae and zero-points from Poole et al. (2008). The source was detected in *V*, *B* and *U* (observed magnitudes $V = 16.43 \pm 0.05$, $B = 17.57 \pm 0.06$ and $U = 18.2 \pm 0.1$, not corrected by extinction), while only upper limits were obtained in the remaining three filters ($UVW1 > 19.4$, $UVM2 > 19.6$ and $UVW2 > 20.0$, 3σ limits).

4 THE SPECTRAL ENERGY DISTRIBUTION

Fig. 1 shows the SED of S5 0014+813. The BAT data correspond to the average flux of the 3 yr survey, while the UVOT and XRT data are the sum of three-pointed observations. The grey empty symbols are archival data, while filled grey symbols and thick (optical) segments are from Bechtold et al. (1994). The magenta points are from IRAS (Moshir et al. 1990) and Two-Micron All-Sky Survey (2MASS) (Cutri et al. 2003). The solid lines correspond to our modelling (see below). This source is not in the list of blazars detected in the first three months of *Fermi* (Abdo et al. 2009). We have estimated the corresponding upper limit shown by the arrow. There must be a peak between the BAT and the *Fermi* energy range. There

is a slight mismatch between the level of the BAT flux and the extrapolation from the XRT spectrum, while the *XMM-Newton* data agree well with the XRT ones. The BAT/XRT mismatch can be easily accounted for by considering that all blazars are very variable sources (despite the XRT/*XMM-Newton* coincidental resemblance) and the BAT flux is a 3-yr average, while the shown XRT spectrum is the sum of three observations within 3 days.

The optical-UV spectrum is dominated by a narrow bump that we interpret as the emission produced by the accretion disc. This is substantiated by three facts: (i) the broad emission lines of the source are well visible (e.g. Sargent et al. 1989; Bechtold et al. 1994; Osmer, Porter & Green 1994), and are therefore not swamped by the non-thermal continuum; (ii) there is a general consensus to interpret the overall non-thermal SED of blazars, from the FIR to γ -rays, as due to a single population of electrons. If so, the relatively steep emission above the high-energy peak is made by electrons that emit, by synchrotron, a correspondingly steep spectrum in the IR-optical-UV band. This leaves the accretion disc component unhidden; and (iii) a synchrotron and inverse Compton model that reproduces the observed fluxes in the UVOT optical-UV and \sim MeV bands fails to reproduce the very hard optical spectrum [that has a slope $F(\nu) \propto \nu^0$] (although the non-simultaneity of the IR-optical data leaves some uncertainties).

Then we model the optical-UV flux by a standard multi-colour accretion disc, with a temperature profile given by (see e.g. Frank, King & Raine 2002)

$$T^4 = \frac{3R_S L_d}{16\pi\eta\sigma_{\text{MB}} R^3} \left[1 - \left(\frac{3R_S}{R} \right)^{1/2} \right], \quad (1)$$

where $L_d = \eta \dot{M} c^2$ is the bolometric disc luminosity, R_S is the Schwarzschild radius and σ_{MB} is the Maxwell-Boltzmann constant. The maximum temperature (and hence the peak of the disc νF_ν spectrum) occurs at $R \sim 5R_S$ and scales as $T_{\text{max}} \propto (L_d/L_{\text{Edd}})^{1/4} M^{-1/4}$. The total optical-UV flux gives L_d [that of course scales as $(L_d/L_{\text{Edd}}) M$]. Therefore, we can derive both the black hole mass and the accretion rate.

The results of changing both are shown in Fig. 2, where we show the accretion disc luminosity for a black hole of 10, 20 and 40 billion solar masses accreting at the Eddington or at 40 per cent of the Eddington rate. With $M = 4 \times 10^{10} M_\odot$, we can reasonably well reproduce both the current state observed by UVOT and the old data discussed by Bechtold et al. (1994).¹ The two states would then differ because of the different accretion rate.

In Fig. 1, we show two theoretical models, one accounting for the BAT data, but overproducing the ~ 10 keV flux, the other accounting for the entire XRT and *XMM-Newton* data range but underproducing the BAT flux. The two models, bracketing the XRT and the BAT states, are obtained with a minimal change in the values of the input parameters (listed in Table 1). The little differences have no impact on our conclusions. We used the model discussed in detail in Ghisellini & Tavecchio (2009), accounting for the presence of many sources of photons located externally to the jet. We would like to stress that the use of a particular jet model is not crucial for our discussion. What is important is that the optical-UV emission is dominated by the accretion disc emission. Indeed, as Fig. 1 shows, the non-thermal emission from the jet contributes only for a few per cent of the total flux.

¹ Note that Bechtold et al. (1994) used a cosmology with $H_0 = 100$ and $q_0 = 0.5$, giving a smaller distance than used here.

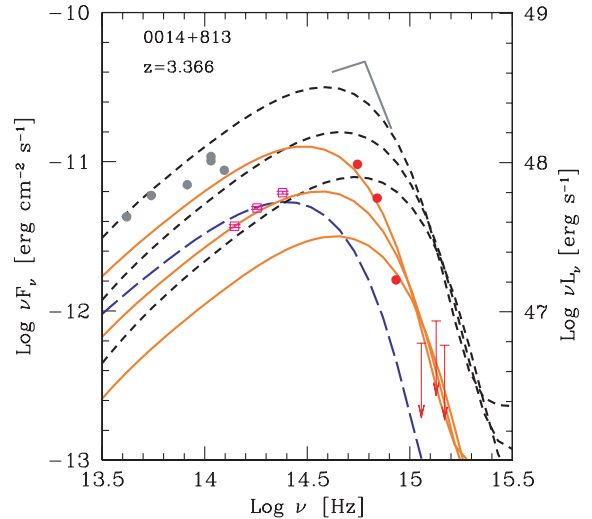


Figure 2. Zoom of the SED of S5 0014+813. The three dashed lines correspond to $L_d = L_{\text{Edd}}$ for three black hole masses (40, 20 and 10 billion solar masses, from top to bottom). The three solid lines correspond to $L_d = 0.4L_{\text{Edd}}$ for the same three black hole masses. The blue line corresponds to $M = 4 \times 10^{10}$ and $L_d = 0.17L_{\text{Edd}}$. Note that $M = 4 \times 10^{10} M_\odot$ can reasonably account for the two states of S5 0014+813 observed in 1993 (Bechtold et al. 1994; grey symbols and line) and in 2007 January (red symbols). A still smaller accretion rate can (approximately) account for the 2MASS data.

5 DISCUSSION

5.1 Comparisons with other black hole mass estimates

The value of $4 \times 10^{10} M_\odot$ for the black hole of S5 0014+813 is unprecedented for a radio-loud source. Among quasars studied with the velocity width and continuum luminosity method, there seems to be a saturation value around 5×10^9 to $5 \times 10^{10} M_\odot$ (Shen et al. 2008), with very few black hole masses above $10^{10} M_\odot$ (see also Vestergaard et al. 2008; Kelly, Vestergaard & Fan 2008; Vestergaard & Osmer 2009; Natarajan & Treister 2009).

For one specific quasar, Q0105–2634, Dietrich & Hamann (2004) estimated a black hole mass of $(41.4 \pm 12.2) \times 10^{10} M_\odot$ by using the H β linewidth and the luminosity/BLR size as discussed in Kaspi et al. (2000), but for the same object the estimate decreases to $(5.2 \pm 1) \times 10^9 M_\odot$ by using the Mg II line and the McLure & Jarvis (2002) BLR size/luminosity relation. This testifies the large uncertainties related to this method of estimating the black hole masses.

Our method is free from this kind of uncertainties, but relies mainly on three assumptions: (i) the emission of the disc, apart from a $\cos \theta$ term, is isotropic; (ii) a standard (optically thick, geometrically thin) disc; and (iii) a blackbody emission at each radius. While the latter assumption is conservative (since the blackbody is the best radiator, it is bound to give a lower limit to the derived masses and accretion rates), the first two hypotheses can seriously affect our mass determination. We will first discuss the implications of having found such a large mass, assuming that 40 billion solar masses is the real value, and then we will discuss how a non-standard disc can impact our mass estimate.

5.2 Consequences of the huge black hole mass estimate

The fact of having found such a huge black hole mass in a blazar has a simple and profound implication: since we selected it on the

Table 1. Parameters used to model the SED.

R_{diss} [1]	M [2]	R_{BLR} [3]	P'_i [4]	L_d [5]	B [6]	Γ [7]	θ_v [8]	γ_b [9]	γ_{max} [10]	s_1 [11]	s_2 [12]	$\log P_r$ [13]	$\log P_B$ [14]	$\log P_e$ [15]	$\log P_p$ [16]
9.6e3 (800)	4e10	4.9e3	0.1	2.4e3 (0.4)	0.22	16	3	70	3e3	−1	2.3	46.3	46.6	45.7	47.4
4.8e3 (400)	4e10	4.9e3	0.1	2.4e3 (0.4)	1.54	11	3	60	3e3	−1	3.6	46.1	47.4	44.5	47.1

Column [1]: dissipation distance in units of 10^{15} cm and (in parenthesis) in units of R_S ; Column [2]: black hole mass in solar masses; Column [3]: size of the BLR in units of 10^{15} cm; Column [4]: power injected in the blob (in the comoving frame), in units of 10^{45} erg s $^{-1}$; Column [5]: accretion disc luminosity in units of 10^{45} erg s $^{-1}$ and (in parenthesis) in units of L_{Edd} ; Column [6]: magnetic field in gauss; Column [7]: bulk Lorentz factor at R_{diss} ; Column [8]: viewing angle in degrees; Columns [9] and [10]: break and maximum random Lorentz factors of the injected electrons; Columns [11] and [12]: slopes of the injected electron distribution [$Q(\gamma)$] below and above γ_b ; Columns [13]–[16]: jet power in the form of radiation, Poynting flux, bulk motion of electrons and protons (assuming one proton per emitting electron). These powers are derived quantities, not input parameters. For a detailed description of the parameters and the model, see Ghisellini & Tavecchio (2009).

basis of the beamed non-thermal hard X-ray continuum, there must be many other sources like S5 0014+813 that are pointing in other directions, with a much fainter (de-beamed) non-thermal emission. The relative number scales as $\Gamma^2 \gtrsim 100$, where Γ is the bulk Lorentz factor of the jet. These misaligned sources are unnoticeable in the X-ray and γ -ray bands, but since the accretion disc is unbeamed (and if its emission is isotropic), they should be detectable in optical all sky surveys, like the SDSS. Assuming that there are 100 sources as optically bright as S5 0014+813 in the 30000 deg $^{-2}$ of the sky excluding the Galactic plane with $|b| < 15^\circ$, the surface density of these objects is of the order of $\Sigma \sim 3.3 \times 10^{-3}$ ($\Gamma/10$) 2 deg $^{-2}$. We can estimate how many of these sources the SDSS can detect. For the part of the sky already monitored and covered by spectroscopy by the SDSS (i.e. 5700 deg 2 for quasars), we expect ~ 19 sources like S5 0014+813. Having a few objects that are indeed that luminous, the SDSS results are in this respect borderline (e.g. Vestergaard 2009).

We can also compare these estimates with the expectations of different models/correlations relating the black hole mass (M_{BH}) with the velocity dispersion, σ , the mass of the host galaxy bulge and its dark mass halo.

Assume first that the relations among these quantities are redshift-independent. Then, from Tremaine et al. (2002), an M_{BH} of 40 billion M_\odot should correspond to $\sigma = 824$ km s $^{-1}$, and according to Ferrarese (2002) this yields $M_{\text{halo}} = 6.7 \times 10^{13} M_\odot$. Adopting a Press & Schechter law we derive $\Sigma \sim 0.07$ deg $^{-2}$.

Alternatively, we can derive the mass of the host bulge by applying the relation $M_{\text{BH},8} \sim 1.68 M_{\text{bulge},11}^{1.12}$ proposed by Haring & Rix (2004), finding $M_{\text{bulge}} = 1.4 \times 10^{13} M_\odot$. This M_{bulge} can be related to σ by assuming the ‘fundamental plane of black holes’ proposed by Hopkins et al. (2007), finding $\sigma \sim 10^3$ km s $^{-1}$, and so $M_{\text{halo}} = 1.3 \times 10^{14} M_\odot$, corresponding to $\Sigma \sim 7 \times 10^{-4}$ deg $^{-2}$.

The above estimates assumed that the correlations between black holes and their host are redshift-independent. However, the $M_{\text{BH}}-M_{\text{bulge}}$ and the $M_{\text{BH}}-\sigma$ correlations might evolve with the cosmic time, as suggested by McLure et al. (2006), Peng et al. (2006), Treu, Malkan & Blandford (2004), Woo et al. (2006). McLure et al. (2006) suggested that the ratio $M_{\text{BH}}/M_{\text{bulge}}$ can evolve as $(1+z)^2$. In this case, $M_{\text{bulge}} \sim 2.3 \times 10^{12} M_\odot$. Through the fundamental plane, we find $\sigma \sim 1800$ km s $^{-1}$ and $M_{\text{halo}} = 5.1 \times 10^{14} M_\odot$. This large halo mass makes the surface density to drop to $\Sigma \sim 2 \times 10^{-9}$ deg $^{-2}$. Note, however, that such a high-velocity dispersion is rather extreme, implying a very dense bulge, with a size of ~ 3 kpc, within a very large halo.

Finally, Woo et al. (2008) proposed that, at a fixed velocity dispersion, the M_{BH} scales with redshift as $(1+z)^3$. This means that, at large redshifts, we can find larger M_{BH} within hosts with smaller

bulge and halo masses. We then use the Tremaine et al. (2002) relation to find $\sigma = 257$ km s $^{-1}$, corresponding to $M_{\text{halo}} = 3.5 \times 10^{12} M_\odot$. This relatively small halo mass corresponds to a very large surface density: $\Sigma \sim 6000$ deg $^{-2}$.

We can conclude that the current predictions for the number density of the largest M_{BH} are far from conclusive, essentially because we are far in the exponential tail of the distributions, and small changes of the host properties can dramatically change the predicted numbers: while the first two estimates of Σ are not far from the limits derived from our (single) object, the last two are either too small or too large.

5.3 Super-Eddington discs

The observed large optical luminosity is at the base of our black hole mass estimate. While we can exclude that it is dominated by beamed jet emission, we discuss here the possibility that the underlying accretion disc producing it might be non-standard. In the literature, two main alternatives have already been proposed: geometrically thick and radiation supported disc, for super-Eddington accretion rates (Jaroszynski, Abramowicz & Paczynski 1980) and the so-called slim disc, with accretion rates close to the Eddington one (Abramowicz et al. 1988). The latter can emit a super-Eddington luminosity because the advection of the flow helps gravity to sustain the radiation force, but are characterized by a relatively small height-to-radial distance ratio (H/R) that does not allow a strong collimation of the produced radiation. The foreseen emission is not a pure blackbody, but a modified one, since electron scattering is very important. This implies larger temperatures than in the standard case (Szuszkiewicz, Malkan & Abramowicz 1996), that might be a problem in our case, due to the relatively severe upper limits in the UV.

In the thick disc case, instead, the emission is locally close to Eddington, but the presence of a narrow funnel can collimate (via electron scattering) the radiation produced deep in the inner funnel into a narrow cone. Observing at small angles from the axis of the funnel, we can then have the impression of a super-Eddington luminosity (up to a factor of 10–20). However, as detailed in Madau (1988), it is the high-frequency radiation that is boosted the most (being the one produced mostly in the inner funnel), and this can be a problem in our case.

6 CONCLUSIONS

The optical-UV luminosity of the blazar S5 0014+813 exceeds 10^{48} erg s $^{-1}$, and through the construction of the overall SED it can be convincingly associated with the radiation produced by an

accretion disc. The found black hole mass is 40 billion of solar masses accreting at 40 per cent of the Eddington rate, and in the past it might have reached the full-Eddington rate. Since this source was found because of its relativistically beamed hard X-ray emission, there should be many other sources of the same mass and accretion rate, but whose jet is pointing in other directions. Current theoretical estimates do not exclude this, but are very uncertain.

There are ways to reduce the estimated black hole mass, invoking non-standard accretion discs that, however, tend to emit a spectrum bluer than observed. On the other hand, the real physical properties of these slim or thick discs may be somewhat different from the assumed ones, and we cannot rule them out. A more definite mass estimate would also greatly benefit by simultaneous data, from the FIR to the UV.

The fact that this very large black hole mass has been found in a radio-loud source may not be a coincidence, if the presence of a jet is a crucial ingredient for the transfer of the angular momentum of the accreting matter, allowing the black hole to grow faster, as pointed out by Jolley & Kuncic (2008). In this case the found black hole mass can be real, or else the presence of the jet induces a super-Eddington accretion rate, making the disc slim or helping the formation of a funnel. Either way, S5 0014+813 is an exceptional source, worth investigating further.

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