Geometry of the X-ray source 1H0707–495*

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ABSTRACT

We present constraints for the size and location of the X-ray source in 1H0707–495 determined from the shape of the relativistically smeared reflection from the accretion disc, using a new model for an extended X-ray source. We apply it to all archival XMM observations of 1H0707–495. Contrary to Wilkins et al. ([1]) we find that the relativistic reflection in this source is not consistent with an extended uniform corona. Instead, we find that the X-ray source must be very compact, with the size of at most a gravitational radius, and located at most at a few gravitational radii from the black hole horizon. A uniform extended corona does indeed produce an emissivity which is like a twice broken power law, but the inner emissivity is fixed by the source geometry rather than being a free parameter. In 1H0707–495, reflection from the inner disc is much stronger than expected for a uniformly extended source.

I. DATA REDUCTION

We consider 15 XMM-Newton observations of 1H0707–495 between 2000 and 2011 with an exposure time longer than 10 ks. The 15 spectra from the EPIC pn detector were reduced separately using the XMM-Newton Science Analysis Software (SAS). The observation performed in January 2011 (Obs. ID 0554710801) caught the source in an extremely low state and is treated separately here; we refer to it as the very low (VL) state. The remaining fourteen observations are used together to build the spectra of three non-overlapping count rate intervals, with <4, 4–6 and 6–10 cts/s (in the 0.2–10 keV energy range), which we refer to as the low (L), medium (M) and high (H) state, respectively (unfolded data is shown in the upper panel in Figure 1). This selection of flux-resolved spectra is similar to that used in [1] and it is based on the assumption that the state of the X-ray source is determined by the X-ray flux. Following [1] we consider the 1.1–10 keV range.

II. THE MODEL

The model developed here, referred to as `reflkerr_elp` (for 'extended lamp-post') [2], closely follows the lamp-post model `reflkerr_lp` of [3], except for taking into account the spatial extent and rotation of an X-ray source, instead of treating it as point-like and static (lamp-post). We consider a Keplerian disc in the Kerr metric, irradiated by a cylindrical corona with radius r_c, located symmetrically around the black-hole rotation axis between a lower height h_{min} and upper height h_{max} (see Figure 2). The inclination angle of a distant observer is denoted by i. All length scales r, h are in units of the gravitational radius, $R_g=GM/c^2$. All the results presented below are for $a=0.998$. We assume that the corona corotates with the disc, with Keplerian velocity $\Omega_K(\rho)$, where $\rho=r\sin\theta$.

For $\rho<r_{ISCO}$ we assume rigid rotation with $\Omega_K(r_{ISCO})$. To compute the observed reflected component, we apply the procedure used in the `reflkerr_lp` model, with `reflionx` [4] used for the rest-frame reflection. In our fitting procedure we use a free normalization of the reflection component, which allows to compare our results with previous works. We scale the reflection normalization by $\mathcal{R}$, where $\mathcal{R}=1$ corresponds to the actual normalization for a given geometry.

III. SPECTRAL ANALYSIS

PHENOMENOLOGICAL RADIAL EMISSIVITY

Following [1] we fitted the L, M and H spectra assuming a twice-broken power-law radial emissivity. We applied model `reflkerr` [3], which computes the reflection spectrum for an arbitrary twice broken power law radial emissivity. We fixed $\xi=53.4$, $i=53.96°$, $Z_{Fe}=8.88$ and $r_{in}=r_{ISCO}$.

- Our results, see Table 1, are consistent with those of [1]. In particular, we find $r_{br,2}$ between $\simeq 20$ and $\simeq 30$, increasing with the observed flux.
- ✗ We find that the data can only be fit with an *unphysically strong reflection component, with $\mathcal{R}>10$*. This rules out the parameters of [1] for the disc-corona model in 1H0707–495.
- ✗ The empirical twice broken power-law emissivity is *only an approximation* of models with a radially extended X-ray corona over the disc, and is quite a poor approximation for models with very steep inner emissivity as these produce much more inner disc reflection than is expected from an isotropic (in its rest frame) radially extended source.

`REFLKERR_ELP` REFLECTION WITH IONISED ABSORPTION

All four spectra VL, L, M and H were fitted together with `reflkerr_elp` [2] including photoionised absorption calculated with `zxipcf` model. We do not impose any constraints on the model parameters except for linking the reflection 'i' and Z_{Fe} across all four states, and fixing $a=0.998$. We assume $h_{min}=r_{hor}$ for L, M and H and $h_{min}=0$ for VL; allowing h_{min} to vary does not change our results.

- The spectral fitting results are given in Table 2; Figure 1 shows the the spectra and best-fit models to all states.
- Both r_c and h_{max} are small, making the model much more like a lamp-post (but with rotation) than a corona with large scale extent over the disc.
- The best fit corona geometry derived from these fits to the data is a very compact source, with size $<\sim 1R_g$, and located at most $\sim 2R_g$ from the black-hole horizon in all flux states.
- ✓ We allow here the scaling parameter of reflection, $\mathcal{R}$, to vary but:
  All fits, correspond to a physically self-consistent $\mathcal{R}\simeq 1$.

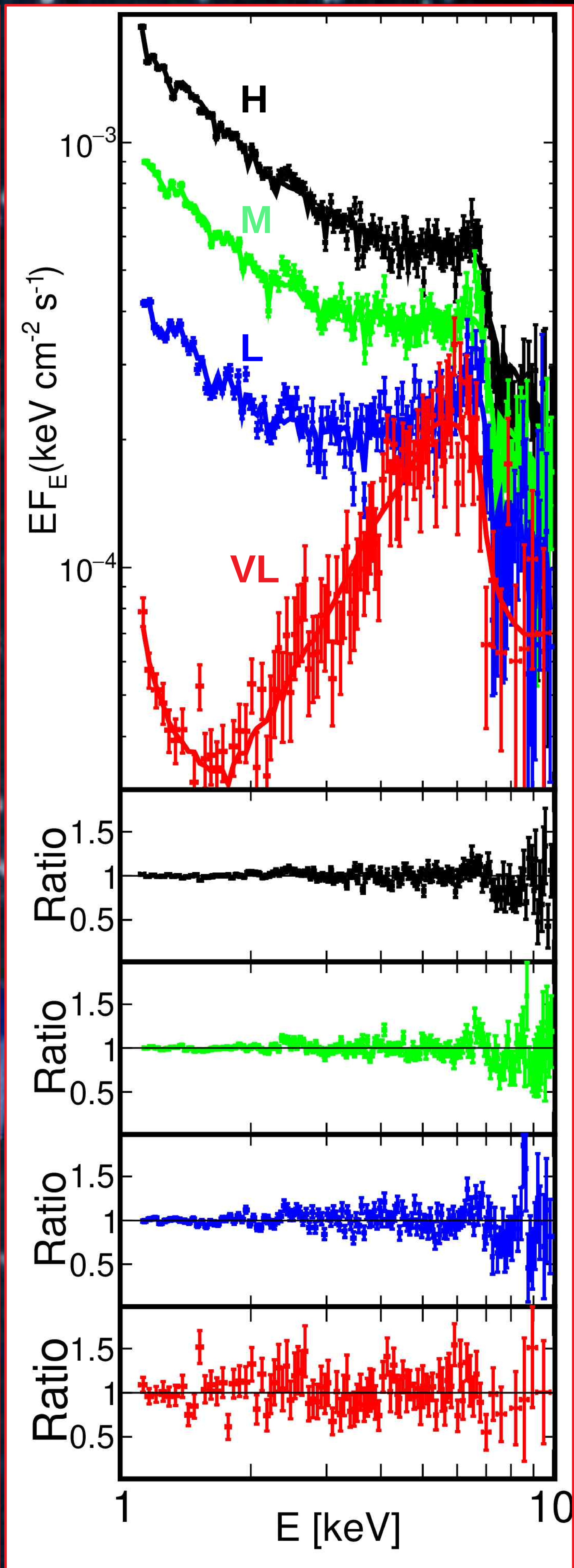

Figure 1: The upper panel shows the unfolded data and model spectra for our best-fitted models for VL (red), L (blue), M (green) and H (black) using `zxipcf*reflkerr_elp`. The model parameters are given in Table 2. The model is shown by the solid curve. The lower panel shows the fit residuals given as the data-to-model ratio for VL, L, M, and H from bottom to top

Model: `reflkerr`

	VL	L	M	H
q_1	$-0.8^{+1.4}_{-\infty}$	$8.9^{+0.5}_{-0.6}$	$8.4^{+0.5}_{-0.4}$	$6.6^{+1.1}_{-0.9}$
q_2	$7.2^{+2.1}_{-1.1}$	$0.0^{+0.9}_{-0}$	$0.1^{+0.7}_{-0.1}$	$1.4^{+0.5}_{-0.8}$
q_3	-	$3.0^{+0.5}_{-0.4}$	$4.0^{+0}_{-0.7}$	$4.0^{+0}_{-0.6}$
$r_{br,1}$	$2.3^{+0.3}_{-0.3}$	$4.5^{+0.5}_{-0.6}$	$5.0^{+0}_{-0.51}$	$4.7^{+0.3}_{-0.7}$
$r_{br,2}$	-	$18.5^{+9.7}_{-5.6}$	$28.2^{+5.7}_{-5.7}$	$32.0^{+3.0}_{-9.1}$
Γ	$2.69^{+0.04}_{-0.16}$	$3.20^{+0.07}_{-0.07}$	$3.10^{+0.06}_{-0.03}$	$3.00^{+0.07}_{-0.03}$
ξ	$10^{+2.0}_{-0}$	$53.44^{(f)}$	$53.44^{(f)}$	$53.44^{(f)}$
$\mathcal{R}$	>750	$88.2^{+20.4}_{-18.3}$	$29.1^{+5.1}_{-3.3}$	$11.4^{+3.1}_{-1.3}$
χ^2/DoF				
	119/86	290/132	293/141	347/140

Table 1: The results of spectral fitting of the coronal model `reflkerr` using empirical radial emissivities. The model fitted to L, M and H assumes a twice-broken power law radial emissivity profile and once-broken power law profile for VL; for VL ξ is free. In all models: $i=53.96°$, $Z_{Fe}=8.88$, $a=0.998$, $r_{in}=r_{ISCO}$ and $r_{out}=1000R_g$

Model: `zxipcf*reflkerr_elp`

	VL	L	M	H
`zxipcf`				
n_H	17^{+2}_{-2}	113^{+69}_{-73}	51^{+42}_{-36}	23^{+31}_{-14}
$\log_{10}(\xi)$	$1.6^{+0.9}_{-0.3}$	$3.9^{+0.2}_{-0.4}$	$4.0^{+0.1}_{-0.2}$	$3.9^{+0.1}_{-0.4}$
f_{cov}	$0.98^{+0.01}_{-0.01}$	$1.0^{+0}_{-0.13}$	$1.0^{+0}_{-0.16}$	$1.0^{+0}_{-0.45}$
z	$0.04^{+0}_{-0.03}$	$-0.09^{+0.01}_{-0.01}$	$-0.10^{+0.01}_{-0.01}$	$-0.12^{+0.01}_{-0.01}$
`reflkerr_elp`				
r_c	$1.7^{+0.5}_{-0.4}$	$1.1^{+0.1}_{-0.1}$	$0.6^{+0.1}_{-0.2}$	$0.7^{+2.2}_{-0.6}$
h_{max}	$1.8^{+1.1}_{-1.2}$	$3.8^{+1.3}_{-0.4}$	$4.0^{+0.5}_{-0.6}$	$4.8^{+1.0}_{-0.9}$
i [°]	$39.7^{+0.9}_{-1.3}$			
Z_{Fe}	$5.0^{+0.4}_{-0.3}$			
Γ	$3.27^{+0.03}_{-0.17}$	$2.38^{+0.02}_{-0.02}$	$2.55^{+0.01}_{-0.01}$	$2.68^{+0.01}_{-0.01}$
ξ	5010^{+2140}_{-2690}	1050^{+110}_{-60}	2120^{+180}_{-300}	3850^{+920}_{-510}
$\mathcal{R}$	>0.6	$1.4^{+1.0}_{-0.3}$	$1.5^{+1.2}_{-0.1}$	$1.0^{+0.1}_{-0.2}$
r_{in}	$2.6^{-0.5}_{-0.5}$	$1.4^{+0.5}_{-0.2}$	$1.4^{+0.2}_{-0.2}$	$1.3^{+0.2}_{-0.1}$
χ^2/DoF	671/484			
	92	202	182	196

Table 2: The results of spectral fitting of the model `reflkerr_elp`, with a partially covering ionised absorption computed with `zxipcf`. In all models: $a=0.998$, $r_{out}=1000R_g$, $h_{min}=0$ (VL) and $h_{min}=r_{hor}$ (L,M,H) The model is fitted jointly with linked 'i' and Z_{Fe}.

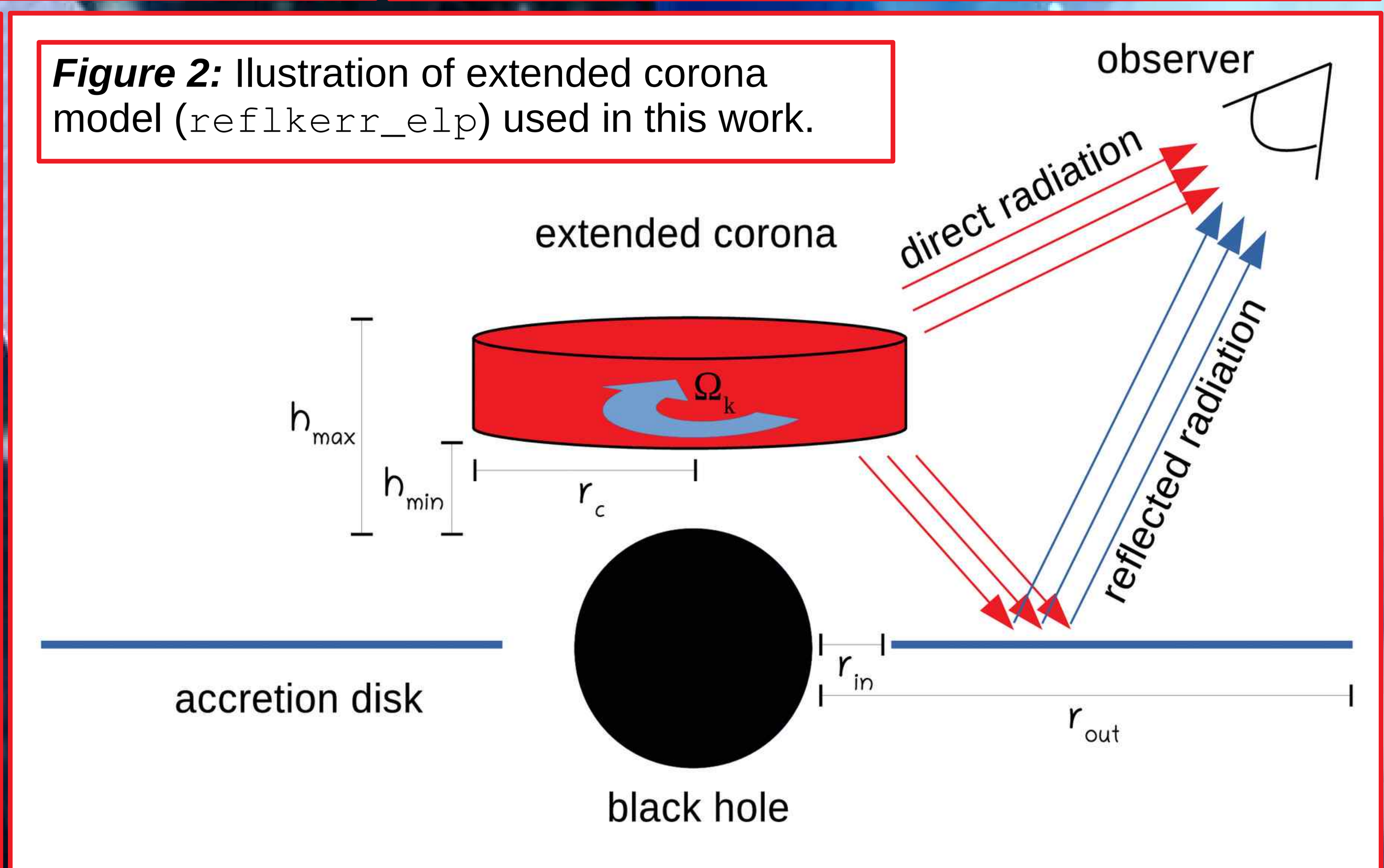

Figure 2: Illustration of extended corona model (`reflkerr_elp`) used in this work.

REFERENCES:

[1] Wilkins, D. R. et al. 2014, MNRAS, 443;
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[4] Ross, R. R. & Fabian, A. C. 2005, MNRAS, 358;