Relativistic reflection from accretion disk with warm absorption and photoionized emission in Seyfert galaxy 1H0707-495

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Introduction

NLSy1s are often found to accrete at super-Eddington accretion rates. Such luminous disks should launch strong winds due to continuum radiation pressure. Indeed, a variety of NLSy1s, exhibit blueshifted absorption features above 7 keV, interpreted as an ultrafast outflow (v>10000km/s) of highly ionized material. Therefore, spectral properties of these sources may be affected by absorption, emission and scattering in a wind. Absorption has been considered as an alternative to reflection explanation for the observed features, but proposed models are complex and often give a poor fits, even for restricted bands or have inconsistent spectral setups. However, no self-consistent model for the full energy range was presented so far.

We performed a spectral analysis of the X-ray source in the soft state of NLSy1 galaxy 1H0707-495, with the attempt to use the most self-consistent model possible (building it on the previous results [6]), on all archival XMM data in its full energy range (0.3-10 keV). The model consists of six components: the neutral absorber `tbabs`, black-body emission `bbody`, two ionized absorbers `warm26`, photoionized emission `photem26` and the intristic power-law emission and its reflection `reflkerr_elp` in two versions denoted as an `[r]` and `[x]`, respectively, with rest-frame reflection described by either `reflionx` (with fixed low-density disk) or `xillverD` (with higher disk density fitted as a free parameter).

Observations

We use all XMM-Newton observations of 1H 0707-495 with exposure time >10 ks. 14 observations, between 2000-2010, used to build spectra corresponding to three non-overlapping count rate intervals: <4, 4-6, and 6-10 counts/s (in the full energy range: 0.3-10 keV), referred to as the low (L), medium (M) and high (H) state, respectively. The remaining observation, from 2011, treated separately, as a very low (VL) state. The spectra of these four states are shown in Figure 1 below.

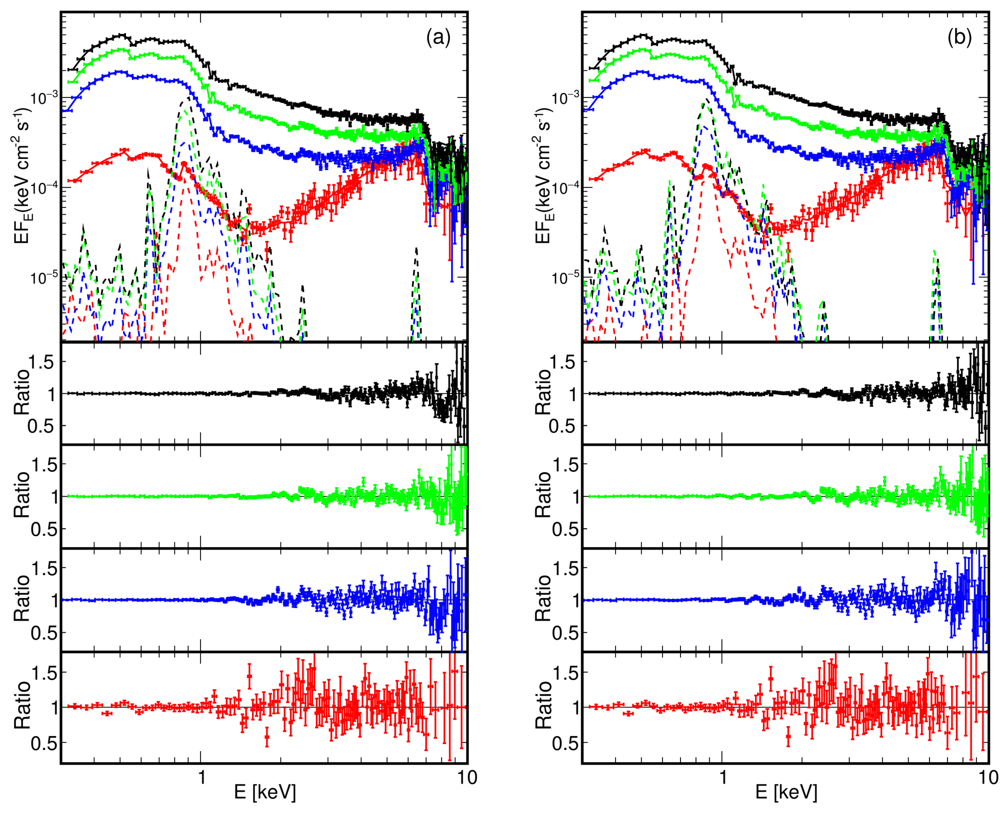

Figure 1: The upper panels show the unfolded data and model spectra for our best-fitted model (a) `[r]` and (b) `[x]`, using self-consistent photoionized absorption and emission, for VL (red), L (blue), M (green), H (black). The short dashed lines show contributions of `photem26`. The lower panel shows the fit residuals given as the data-to-model ratio.

Reflection model

The model applied here extends the `reflkerr` model [1]. We consider a Keplerian disk in the Kerr metric, irradiated by a cylindrical corona with the radius r_c, located symmetrically around the black hole rotation axis, between the lower height $h_{\min}$ and the upper height $h_{\max}$. All the geometrical parameters of the corona, are in units of the gravitational radius, $R_g = GM/c^2$. We assume that the corona is uniform. The rest-frame reflection is computed with `reflionx` [2] and with `xillverD` [3].

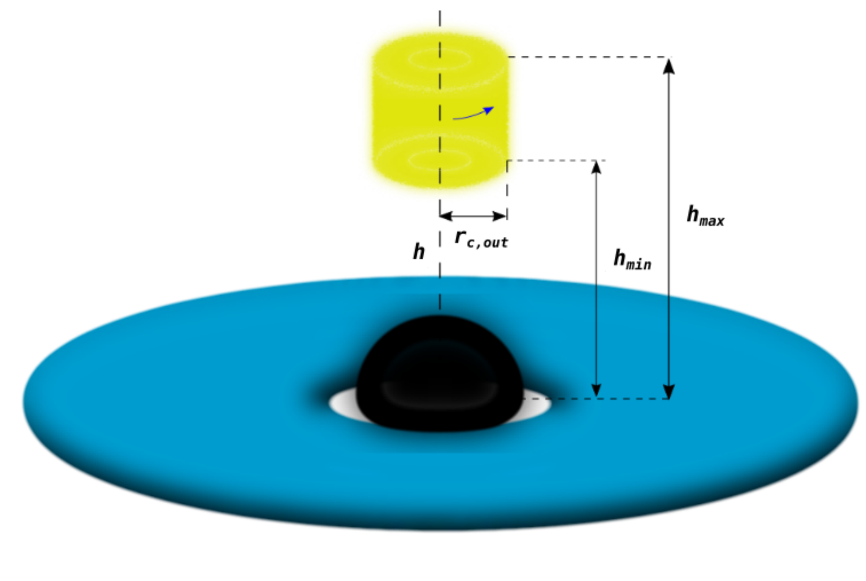

Figure 2: Geometrical setup in the `reflkerr_elp` model.

Spectral Components

To model warm absorbers, we used the absorption tables calculated with `XSTAR` [4]. We first tried `zxipcf` (with photon index Γ = 2.2, and solar abundance of iron A_{Fe}= 1) versus the intrinsic spectrum of 1H0707-495 (Γ ∼ 2.6) and $A_{Fe} \gg 1$ values found in all spectral models of this object. Our new model `warm26` assumes Γ = 2.6 and uses Fe abundance, ionization and column density as a free parameters. Both models assume partial covering f_{cov} of the source. Our spectral setup uses two `warm26` components, the one with lower column density N_H represents highly ionized absorber outflowing at 30000-50000 km s^{-1}. The higher N_H absorber allows the model spectra to have a sufficient curvature.

Our analysis indicated additional emission components of photoionized wind, which we described, at first, by two `gaussian` components (at 0.9 keV and 6.5 keV), and then by the physical `photem26` component, which has calculated emission tables (by `XSTAR`) for Γ = 2.6 and variable Fe abundance with the turbulent velocity set to 6000 km s^{-1} as the only difference to `warm26`, which has v_{turb} = 200 km s^{-1}.

Spectral setup

Previous models in literature used inconsistent setups relating to iron abundance, leading to super-solar values in reflection components and solar values in absorbers. Here we link the Fe abundance across the four states for all relevant components i.e. `warm26`, `photem26`, `reflkerr_elp`. In `reflkerr_elp` we now use the physical normalization of the reflected component ($\mathcal{R}$ = 1), however the angular velocity of the corona is a free parameter.

Final remarks

1) Our final fitted models have systematic residuals, around 2-3 keV. Can be improved by including the variable abundance of Si or S.

2) Adding variable Γ into emission/absorption model likely improve the description at 6.5 keV.

Results

We have obtained best-fit $\chi^2/DoF \simeq 1.4$ (model `[r]`), and fit $\chi^2/DoF \simeq 1.45$ for model `[x]`.

Corona

1) Very compact, (size ∼1 R_g), located a few R_g from black hole horizon.
2) The corona in `[r]` $h_{\max} \simeq (3-4)$, consistent with [7].
3) The corona in `[x]` at lower $h_{\max}$ < 2, i.e. almost on the event horizon, implies fully dominated spectrum by reflection (due to light bending, increasing the disk irradiation), contradicts variability studies.
4) No systematic changes in the geometrical parameters of the corona with change of the X-ray flux.

Ionized Wind

1) In the VL state the absorber, has different properties than during other observations, is weakly ionized and strongly absorbs the continuum emission.
2) The `photem26` emitter was fitted in all cases with outflow velocity (in the host galaxy frame) ≃ 7000 km $^{-1}$, consistent with [5].
3) The velocity of absorbers in the model `[r]`, i.e. ∼ 48000 km s^{-1} for the less ionized **warm26**$_1$ and ∼ 36000 km s^{-1} for the more ionized **warm26**$_2$ are also in agreement with estimates of [8] and [5].
4) The velocity of absorbers in model `[x]` (∼ 8000 km s^{-1} and ∼ 65000 km s^{-1}) do not agree with any previously reported value.
5) The ionization parameters of ionized absorbers in our models are larger than those estimated by [8] and [5], however, this property is strongly model dependent.
6) We find a systematic decrease in the strength of absorption line with increasing X-ray flux (at least in model `[r]`). Decrease may be due to increase of the ionization of the absorber and/or the decrease of the column density. In our model, we find the latter.

Disk and black hole spin

1) The model `[r]`, has properties consistent with earlier estimates of the wind parameters and variability of this source.
2) The disk extends down to the ISCO (or very close to it) in all our models and an almost maximal rotation of the central black hole is strongly preferred.

References

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