Relativistic Reflection with the RELXILL model version 2.0

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The RELXILL model calculates relativistic reflection from the innermost regions of the accretion disk around black hole binaries (BHB), neutron stars (NS), and active galactic nuclei (AGN). The reflection is caused by a primary source irradiating the accretion disk atmosphere. Due to relativistic effects close to the compact object, the reflected spectrum is strongly distorted on its way to the observer. With the RELXILL model, the irradiation of the disk, the intrinsic reflection, and the relativistic broadening are modeled. Depending on the flavor of the RELXILL model, different assumptions are used, which allows you to flexibly choose the flavor most appropriate for your analysis. These range from simple empirical models to a fully self-consistent calculation of the ionization gradient in the accretion disk illuminated by the primary source. To successfully fit relativistic reflection models to observational data, you need to understand the assumptions and implications of each model. The following document will provide you with all required information to fit the RELXILL model to data and correctly interpret the obtained parameters. The model can be downloaded at the RELXILL homepage at `https://www.sternwarte.uni-erlangen.de/research/relxill/`, which also includes detailed installation instructions.

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1 Introduction

The RELXILL model calculates the relativistic reflection spectrum from an illuminated accretion disk around a compact object (a black hole or neutron star). This is done through the combination of the ionized reflection model XILLVER and the relativistic blurring kernel RELLINE.

The implementation of the RELXILL model is described in several publications which are listed throughout the document. The basic ray-tracing calculations are described in Dauser et al. (2010) which are extended to the lamp post geometry in Dauser et al. (2013). Basic information on the intrinsic XILLVER reflection model can be found in a separate series of detailed publications (García & Kallman, 2010; García et al., 2011, 2013). The combined RELXILL model is described in García et al. (2014) and the subsequent inclusion of the reflection fraction in Dauser et al. (2014) and Dauser et al. (2016). Reflection models for the high-density regime are described in García et al. (2016). A model flavor designed to fit reflection from neutron star systems in which the illumination is a black body spectrum is described in García et al. (2022). Finally, returning radiation and its implementation in the model can be found in Dauser et al. (2022).

In the following, we present a detailed *documentation* of the RELXILL model. Firstly, we will briefly summarize the evolution of the models in recent decades from pure line models to all-inclusive relativistic reflection models like RELXILL (Sect. 2). In Sect. 3 we then explain the existing model flavors, and their usage, in detail. Lastly, a full list of all models (Sect. 4) and all parameters (Sect. 5) is given. The environment variables that allow default settings to change or provide additional output are described in Sect. 6.

2 Relativistic Reflection Models

The strongest feature of the intrinsic reflection in the frame of the disk (often also called non-relativistic reflection), is the fluorescent Fe Kα emission line at 6.4 keV. Therefore, historically, the relativistic reflection was first seen, and modeled, only by calculating the line shape of this one feature that is broadened by relativistic effects. The two most famous models from the early 90s are the DISKLINE model (Fabian et al., 1989) for a non-rotating black hole, and the LAOR model (Laor, 1991) for a maximally rotating black hole. The RELXILL model also has this type of "line model" included, called RELLINE. Its implementation is described in Dauser et al. (2010) and constitutes the basis of the relativistic blurring kernel of RELXILL. However, as relativistic broadening affects not only the strongest emission line, but also the full reflection spectrum emitted from the accretion disk, using a single line to model relativistic reflection is not advisable with the currently available models and high quality observational data.

A simple extension of the pure line models predicting relativistic broadening for any input spectrum, are "convolution models", `relconv` in the case of the RELXILL model. They are typically applied to detailed reflection spectra calculated by the REFLION model (Ross et al., 1999) and, later, the XILLVER model (García & Kallman, 2010; García et al., 2011, 2013). The combination of such a reflection model with `relconv` was used to predict the full relativistic reflection over the full accretion disk. The convolution model, however, has one major limitation: only one average intrinsic reflection spectrum of the disk can be used as input for the relativistic convolution. Even for constant physical parameters of the accretion disk (density, ionization, ...), the intrinsic reflection spectrum strongly depends on the emission angle with respect to the disk surface. Due to strong relativistic effects, the photon trajectories are bent, and therefore a single observer sees a mixture of reflection spectra emitted at a wide range of different emission angles (see García et al., 2014).

The RELXILL model was created to correctly implement this angular dependency of the intrinsic reflection spectra in the relativistic reflection model. This is done by calculating the reflected spectrum with XILLVER for each radius separately as a flux weighted average, taking into account the emission angle for each azimuthal bin. These spectra are then convolved with the respective blurring kernel for this radius and are only afterwards integrated to yield the full reflection spectrum of the complete accretion disk. The approach and results are discussed in detail in García et al. (2014). Overall, deviations of up to 20% are expected compared to using a convolution model as an approximation. With the quality of data currently available, it is best to use a combined model such as RELXILL.

Additionally, the RELXILL model is able to predict the full reflection spectrum as well as the primary spectrum. Besides being easier to handle when model fitting, this approach has other fundamental advantages. Most importantly, the "reflection fraction" parameter can be used to directly measure the fraction of photons which are reflected by the disk, which allows us to draw conclusions about the accretion geometry. When choosing the "lamp post geometry", this reflection fraction can be predicted by the model and used as an additional constraint when model fitting (see Dauser et al., 2014, 2016, for more information). While the lamp post geometry is a simplified model for a point source, its physical interpretation is that of an slightly extended source approximated by the point-like lamp post.

As of v2.0, returning radiation is implemented in the RELXILL model. This additional component is radiation that is returning to the accretion disk after the initial reflection to produce additional reflection. A detailed description is given in Dauser et al. (2022), including simulations showing the expected difference to models without returning radiation.

In summary, we therefore recommend, as a standard approach, using the RELXILL flavor models for analyzing relativistic reflection. The different flavors of the RELXILL model will be explained in the following.

3 Overview of the relxill family

If you have not yet extensively used relativistic reflection models, then the following section should give you a guideline on where to start. Moreover we give a detailed explanation of the more complex type of RELXILL models. This section is divided into several subsections to address different aspects of the model and fitting it to data. Table 1 lists all available RELXILL type models and the main differences between them.

Table 1: *List of all* RELXILL *type models and their major distinguishing factors. First, the emissivity can be either modeled by an empirical broken power law, or by assuming a lamp post source on the rotational axis of the black hole. The primary spectrum of the source also changes between the model flavors; for all models with an* **`nthcomp`** *primary spectrum, the density is a free parameter in the model.*

Model Name	Emissivity	Primary Spectrum	Disk Density [cm^{-3}]	Ionization Gradient
`relxill`	empirical powerlaw	`cutoffpl`	10^{15}	no
`relxillCp`	empirical powerlaw	`nthcomp`	$10^{15} \ldots 10^{20}$	no
`relxillNS`	empirical powerlaw	`black body`	10^{15}	no
`relxilllp`	lamp post	`cutoffpl`	10^{15}	no
`relxilllpCp`	lamp post	`nthcomp`	$10^{15} \ldots 10^{20}$	yes

3.1 The primary source

First and foremost, the RELXILL models are distinguished by the assumptions about the primary source. First, there are different ways to implement the irradiation of the accretion disk by the primary source. It is specified by the *emissivity*, which is the radially dependent flux irradiating the disk by the source. Then also the spectrum of the primary source can be different, which directly influences the intrinsic reflection calculations by XILLVER.

3.1.1 Emissivity: lamp post geometry or empirical power law

For the emissivity the standard approach, until recently, was to use an empirical implementation without assuming a geometry or physical location of the primary source. This is done by simply assuming that the emissivity depends on the radius as a broken power law, which changes at the break radius `Rbr` from $r^{-\mathtt{Index1}}$ to $r^{-\mathtt{Index2}}$. As of several years now, there are models using the lamp post geometry. In this case there is an actual, simple, geometry assumed, where the primary source is point-like and on the rotational axis of the black hole. The source is specified by its `height` above the center of black hole and, potentially, by its velocity `beta` along this axis. The emissivity then depends on these parameters. The lamp post geometry and its implementation in RELXILL is explained in detail in (Dauser et al., 2013).

3.1.2 Primary source spectrum

Apart from the emissivity, the second distinguishing factor is the spectral shape of the primary continuum. The previous standard used to be a simple power law with an exponential cutoff. More commonly used in recent years are the `Cp`-type models, which use the `nthcomp` model (Zdziarski et al., 1996; Życki et al., 1999) as a simple Comptonization model to calculate the primary source spectrum. The major difference is that instead of an empirical cutoff, the temperature of the emitting source is given. Hidden parameters for the calculation of the continuum for every Cp-type model are that $kT_{\mathrm{bb}} = 0.01\,\mathrm{keV}$ and inp_type = 1.

Additionally, a completely different input spectrum in form of a black body with temperature kT_{bb} is also available. Those models are meant to model the reflection of thermal radiation from a neutron star (NS) irradiating the accretion disk and are therefore called the NS-type models. This model implementation is described in detail in García et al. (2022).

3.2 The accretion disk

As described in Dauser et al. (2010), the accretion disk is assumed to be optically thick and geometrically thin. The reflection on the disk is calculated by the XILLVER model. Besides the input spectrum (see previous section), the model depends on the intrinsic parameters of the accretion disk such as the ionization, ξ, density, n, and the iron abundance, A_{Fe}. The detailed dependencies of the intrinsic reflection on the accretion disk parameters can be found in García et al. (2013).

The Cp-type models have another practical difference compared to the model with a cutoffpl continuum in terms of how the accretion disk is modeled. Besides the difference in spectral shape, the Cp-type[1] models have a variable density, allowing to directly fit the density of the accretion disk. While for all other models it is currently fixed at $n = 10^{15}\mathrm{cm}^{-3}$, the Cp-type models allow a range of $n = 10^{15} - 10^{20}\mathrm{cm}^{-3}$.

3.3 Reflection fraction and reflection strength

A major advantage of using the RELXILL model is that the *reflection fraction* is included as an intrinsic parameter. It is a measure of what fraction of the emitted flux is reflected versus directly emitted towards the observer. In contrast to this, the *reflection strength* is a measure of the *observed strength* of the reflection compared to the direct emission. Unfortunately, these two quantities are sometimes used mistakenly with different definition in publications, therefore great care has to be taken when using those and also when reading literature using these quantities. In the following we give a brief summary of both definitions. More details can be found in Dauser et al. (2016).

Reflection fraction The definition of the reflection fraction R_{f} is related to the non-relativistic reflection fraction as defined in the pexrav model and the XILLVER model included in the RELXILL model package. There, the reflection fraction is defined as the ratio of the intensity of the primary source irradiating the disk and the intensity directly going to infinity. This means that an isotropically emitting source above an infinitely extended disk has $R_{\mathrm{f}} = 1$, which means that the intensity irradiating the disk is the same as that seen by the observer.

In the case of a relativistic reflection model, the definition of the reflection fraction is, in principle, identical. The important difference is, due to the relativistic light-bending, the location of the primary source influences the value. This has the important implication that the intensities used to calculate the reflection fraction have to be given in the rest-frame of the primary source. In other words, this means that the reflection fraction is defined in the frame of the source as the ratio of emitted photons that will hit the accretion disk to the ones that will directly go to infinity.

Therefore, to calculate if such a photon ends up hitting the disk or the observer by ray-tracing, we need to make an assumption about the location of the primary source. Only then can we properly define the reflection fraction. In the RELXILL model we therefore choose the lamp post geometry to define the primary source in the simplest way[2]. Because of the strong gravitational effects, photons are preferentially bent towards the disk and away from the observer, and values of $R_{\mathrm{f}} > 1$ are expected. As shown in Dauser et al. (2014), a low source height typically leads to large reflection fraction values, while for a primary source far above the black hole its value converges towards 1 and is identical to the non-relativistic definition. Additionally, the source can have a velocity away from the black hole, which reduces the reflection fraction.

For completeness, the RELXILL-type models with the empirical emissivity and without a geometric assumption of the primary source also have a reflection fraction parameter. It is defined identically to the non-relativistic case meaning no light-bending effects are taken into account, as without geometrical assumptions this cannot be calculated. It can be interpreted as a corona directly on top of the disk as, in this case, light-bending does not play a role. However, this assumption has several problems. Firstly, it would require the emissivity to follow the standard

[1] The reason that only the Cp-type models have a variable density is that the intrinsic XILLVER reflection for different densities of the disk has only been calculated for a nthcomp input spectrum, as its calculation is very time consuming.

[2] in case of the relxilllpCp model the lamp post can also have an out-flowing velocity.

α-disk emissivity of r^{-3}, which is typically not found in observations. And secondly, as primary source and reflector are at the same location, a reflection fraction of $R_\mathrm{f} = 1$ would be expected. Values deviating from 1 are not very meaningful to interpret in geometrical terms. We note that for a large covering fraction of the disk, which is inherent to this type of sandwich corona, Comptonization of the reflected radiation can play an important role (see, e.g., the `simpl` model Steiner et al., 2009).

Boost parameter A practical problem of the reflection fraction parameter in the RELXILL model is that its predicted value from the lamp post geometry changes depending on height, spin, and velocity (Dauser et al., 2014). When model fitting, however, it is not possible to judge from the obtained reflection fraction value whether it is in agreement with the expected value. Therefore we included the `boost` parameter in the RELXILL model (in analogy to RELTRANS; Ingram et al., 2019). It is simply the reflection fraction normalized by the predicted reflection fraction for the current parameters of the model. Therefore setting `boost` $= 1$ means that the model output is the combined reflected and direct source spectrum for the lamp post geometry. Values > 1 can be interpreted as the fitted model showing stronger reflection than predicted by the given lamp post parameters in the model.

To activate the `boost` parameter, the `lp`-type models include the parameter `switch_reflfrac_boost`. Setting it to $= 1$ changes the interpretation of the `refl_frac` parameter to act as the `boost` parameter. The value of the actual reflection fraction can be printed on the screen by setting the environment variable for additional output (see Sect. 6).

Reflection strength The reflection strength on the other hand is a measure of the observed reflected photon flux in comparison to flux directly reaching the observer from the primary source. It is a quantitative characterization if a spectrum is observed to have strong reflection. In order to be as independent as possible from the parameters of the accretion disk such as iron abundance or ionization, the RELXILL model uses the energy band from 20-40 keV to calculate the reflection strength. It is not an intrinsic parameter of the model, but for each lamp post model configuration, this quantity can be printed by setting the environment variable for additional output (see Sect. 6). See Dauser et al. (2016) for more details on the reflection strength.

3.4 Ionization and density gradients: The `relxillpCp` model

The most powerful model is the `relxillpCp` model flavor. With its default settings it is very similar to `relxillp`, except that it has an `nthcomp` primary spectrum. The two main differences between it and `relxillp` are that with `relxillpCp` it is also possible to model the velocity of the primary source (`beta`), and the radial ionization and density gradient in the accretion disk.

For example it allows the modeling of an out-flowing corona and the determination of its velocity, including a self-consistent calculation of the reflection fraction. Additionally, the model can be set to self-consistently calculate the ionization gradient when assuming that the density follows the α-disk model (Shakura & Sunyaev, 1973). We assume a constant α-parameter, which leads to a density gradient of

$$n(r) = r^{3/2}\left[1-\left(\frac{R_\mathrm{in}}{r}\right)^{1/2}\right]^{-2} \quad . \tag{1}$$

Then the ionization gradient $\xi(r)$ can be self-consistently predicted from the lamp post irradiation F_X of the accretion disk, as the ionization is defined as

$$\xi = 4\pi F_\mathrm{X}/n \tag{2}$$

(García et al., 2013). This approach connects the primary source directly with the accretion disk parameters, ensuring that the parameters are in agreement with the assumptions of the α disk as well as the lamp post corona. Overall, this leads to a more flexible and self-consistent model.

3.4.1 Velocity of the primary source

A non-zero velocity of the primary source changes the emissivity profile and the angle δ_i at which photons are incident on the accretion disk (Dauser et al., 2013). It is defined as moving away from the black hole. The velocity also changes the reflection fraction in such a way that radiation is boosted away from the black hole and therefore fewer photons hit the disk (Dauser et al., 2014). Taken together, this means that allowing a non-zero velocity can influence parameters such as the reflection fraction or the height of the source. More details on the relativistic reflection by a moving primary source can be found in (Dauser et al., 2013).

3.4.2 Ionization and density gradient

There are two types of ionization and density gradients currently implemented in the model, which can be selected by setting the parameter `iongrad_type`.

- Setting it to = 1 implements a simple and empirical version of the ionization gradient, where it is assumed to be a power law described by $\xi \propto r^{-\mathtt{iongrad\_index}}$. The parameter `iongrad_index` is a fit parameter of the model. The density is constant throughout the disk, described by the parameter `logN`.
- Setting it to = 2 switches to the α-disk model. Now the density is calculated from the α-disk model (Shakura & Sunyaev, 1973). The parameter `logN` then specifies the density at the inner edge of the disk. Using the emissivity profile calculated from the lamp post for a given height, spin, and velocity, the ionization gradient is then calculated following Eq. 2. The parameter `logxi` in the model sets the maximal ionization. We use as maximal ionization the value of the ionization at $r = (11/9)^2$, which is only exact for an emissivity following r^{-3}. A more detailed numerical calculation would cost additional computational resources for no real gain (see discussion in Ingram et al., 2019). This ionization gradient is then internally converted into an effective ionization. This step allows us to take the approximate incident angle of the photon into account, while the intrinsic XILLVER reflection is only calculated for 45°. As the ionization depends on the incident intensity at the surface of the disk, the projection adds a $cos(\delta_{\mathrm{i}})$ (see Eq. 21 in Dauser et al., 2013, and the discussion in Ingram et al., 2019). We note that if the calculation of the ionization gradient yields values outside the tabulated range ($\log\xi = 0 - 4.7$), the reflection spectrum of the lower or upper limit is used, respectively.

For completeness, setting `iongrad_type` = 0 models a disk with constant ionization and constant density.

3.5 Returning radiation

All lamp post-type models[3] allow for the inclusion of returning radiation in the reflected spectrum. The details of the implementation are described in Dauser et al. (2022). It only affects reflection for larger values of spin ($a > 0.9$) and low source heights ($h < 10\,r_{\mathrm{g}}$). Due to the additional necessary extensive calculations, adding returning radiation will increase the evaluation time of the RELXILL model[4]. However, as shown in Dauser et al. (2022), especially for extreme values of high spin and compact corona, returning radiation has a significant impact on the reflection spectrum. Most importantly, the height, and therefore the reflection fraction, is affected and not using returning radiation might lead to a bias in these parameters.

[3] since RELXILL v.2.0

[4] It is automatically switched off for lower values of spin to speed up the computation in cases where the returning radiation is negligible.

4 Full list of models

The meaning of the different model parameters for all RELXILL model flavors can be found in Sect. 5. The code of all the models described in the following can be downloaded at http://www.sternwarte.uni-erlangen.de/research/relxill/.

4.1 relxill: relativistic reflection models

`relxill` The previous standard model for relativistic reflection uses an empirical broken power law emissivity and a `cutoffpl` spectral shape for the primary source. The emission angle-dependent spectrum for each emitting point on the accretion disk is properly taken into account, which makes any empirical limb-darkening/-brightening obsolete.

`relxillCp` Identical to `relxill`, but with the `nthcomp` model as the primary source spectrum. Note that the temperature of the corona (kT_e) is given in the frame of the source (see Sect. 3.1.2).

`relxilllp` Similar to `relxill`, but now the emissivity is predicted from the lamp post geometry (Dauser et al., 2013). A major difference is that now the reflection fraction has a physical meaning and can be compared to the prediction for the lamp post geometry, activating the `boost` interpretation of the reflection fraction (see Dauser et al., 2014 and Sect. 3.3).

`relxilllpCp` Similar to `relxilllp`, but with the spectrum of the primary continuum modelled by `nthcomp`. Furthermore, this models allows for an ionization and density gradient in the disk, which is explained in detail in Sect. 3.4.

`relxillNS` The distinguishing feature of this model is that instead of a power law-like input spectrum, a black body with temperature kT_{bb} is used. It should model the thermal radiation of a neutron star incident on the accretion disk and is described in García et al. (2022). This model uses an empirical power law emissivity.

4.2 xillver: non-relativistic reflection

In order to allow for non-relativistic reflection and provide an identical interface, the XILLVER table model (see https://sites.srl.caltech.edu/~javier/xillver) is included in the RELXILL modeling package. It is commonly used to model distant reflection further away from the compact object, where relativity does not play role anymore. Besides the normal parameters of the table, the reflection fraction is also included as a fitting parameter (similar to the `pexrav` reflection model). Similar to the `relxill`-type models, different input spectra are possible for the XILLVER model.

`xillver` using a cutoff power law incident spectrum and density $10^{15}\,\mathrm{cm}^{-3}$. The corresponding XILLVER table is `xillver-a-Ec5.fits`.

`xillverCp` `nthcomp` incident spectrum (see Sect. 3.1.2) and variable density from 10^{15}–$10^{20}\,\mathrm{cm}^{-3}$. It uses the XILLVER table `xillver_v3.4.fits`.

`xillverNS` uses a black body spectrum as input. In the current version the table `xillverNS-2.fits` is implemented.

4.3 Line and convolution models

For completeness, the RELXILL model package also includes line models and standard convolution models. While the major advantages of the `relxill`-type models are lost (see Sect. 3), the convolution models have the advantage that they can be applied to any intrinsic reflection model. Two types of model exist: one for the empirical power-law emissivity and one for the lamp post geometry.

`relline` Line model using an empirical power law emissivity.

`relline_lp` Line model for the lamp post geometry

`relconv` Convolution Model for `relline`.

`relconv_lp` Convolution Model for `relline_lp`.

5 Model Parameters

In the following, a table of all parameters for the `relxill` model flavors used in the different implementations is given. Some parameters have a special meaning if their value is negative, as also indicated in the list below.

`a`	spin of the black hole in dimensionless units, negative values mean the accretion disk is counter-rotating with respect to the black hole
`Incl`	inclination angle in degrees measured with respect to the normal of the disk
`Rin`, `Rout`	inner and outer radius of the accretion disk in gravitational radii. Can also be given in units of the ISCO, when it is set to negative values.
`Index1`, `Index2`, `Rbr`	the emissivity for the coronal flavor models is given as $r^{-\texttt{Index1}}$ between `Rin` and `Rbr` and $r^{-\texttt{Index2}}$ between `Rbr` and `Rout`. `Rbr` is measured in gravitational radii, but can also be given in units of the ISCO if given as negative value.
`z`	redshift to the source
`lineE`	line energy in the rest frame of the disk
`limb`	limb-darkening/-brightening law for $\mu = \cos(\delta_\mathrm{e})$: 0 = isotropic, 1 = darkening $(1 + 2.06\mu)$, 2 = brightening $(\ln(1 + 1/\mu))$
`gamma`	Power Law Index of the primary source spectrum ($E^{-\texttt{gamma}}$)
`kTbb`	Black body temperature (in keV) of the primary source spectrum for the `NS`-type models
`h`	Height of the primary source above the black hole in gravitational radii. Can be given in units of the event horizon if set to negative values.
`beta`	velocity of the primary source (in units of c)
`logN`	logarithmic value of the density (in cm^{-3}); given at `Rin` in case of a gradient
`Afe`	Iron Abundance in Solar Units
`Ecut`, `kTe`	Parameter describing the observed high energy cutoff `Ecut` of the primary spectrum. In case of the `Cp`-type models it is given as the electron temperature in the corona (`kTe`). *Important*: For all `lp`-type models, `Ecut` is given in the frame of the observer and therefore the value at the primary source has to be calculated by multiplying with the redshift factor (see Sect. 6 on how to get this value printed on the screen for the current model). `kTe` is given in the frame of the primary source, as the temperature of the plasma. In the case of the empircal power law emissivity model, no energy shift is applied.
`logxi`	Ionization of the accretion disk, ranging from 0 (neutral) to 4.7 (heavily ionized). In the case of an ionization gradient, it specifies either the ionization at the inner edge (`ion_grad_type` =1) or the maximal ionization at $(11/9)^2$ Rin for the α-disk model (`ion_grad_type` =2).
`iongrad_index`	ionization gradient index of the accretion disk ($\log\xi \propto r^{-\texttt{ion\_index}}$)
`ion_grad_type`	specifies the radial behavior of the ionization on the accretion disk 0: constant ionization and constant density 1: power law ionization gradient ($\log\xi \propto r^{-\texttt{ion\_index}}$) and constant density 2: alpha-disk density (Shakura & Sunyaev, 1973) and ion grad from irradiation
`refl_frac`	reflection fraction parameter, see Sect. 3.3 and Dauser et al. (2016) for a detailed definition. Its interpretation of either reflection fraction or boost depends on the `switch_reflfrac_boost` value. Important: a positive value means the direct continuum is included, while a negative value returns only the reflection (as also defined in `pexrav`).
`switch_reflfrac_boost`	switches how the parameter `refl_frac` is interpreted 0 : means `refl_frac` behaves as the reflection fraction, defined in Dauser et al. (2016) 1 : means `refl_frac` is interpreted as `boost` parameter, which is the reflection fraction normalized by the expected reflection fraction of the lamp post geometry (i.e., `boost` = 1 returns the complete reflection plus continuum for a lamp post).
`switch_returnrad`	switches the returning radiation on (=1) or off (=0)

6 Environment variables

Environment variables are defined to allow default settings to change or to get more output information.

`RELXILL_PRINT_DETAILS`	setting it to = 1 prints additional information such as the reflection fraction and reflection strength for the current model parameters when the model is evaluated
`RELXILL_TABLE_PATH`	path to where the tables are stored (see installation instructions)
`RELLINE_PHYSICAL_NORM`	if set, the relline and relconv models return are not re-normalized, but return the normalization following the irradiation of the accretion disk and transfer function. The integrated emissivity for the empirical power law is chosen to be unity, and therefore this normalization is not very useful. The physical normalization makes most sense for the `lp`-type models, where the integrated emissivity strongly depends on the height. However, as this also implies that the normalization also depends strongly on the height, it is not recommended to use this setting for model fitting.
`RELXILL_NUM_RZONES`	set the number of radial zones for which a different xillver spectrum is used (ionization gradient, change of `Ecut` due to energy shift from the primary source to the disk). Its default value of 25 in case of an ionization gradient ensures the correct computation of the output spectrum at a reasonable speed.
`RELXILL_WRITE_FILES`	write a few auxiliary output files, such as the emissivity profile, the ionization gradient, or the intrinsic line profile. Files follow the naming convention `__relxillOutput_*.dat`.
`DEBUG_RELXILL`	(development) additional debug information is printed on the screen

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