Modelling the relativistic features with the KY models in XSPEC

Michal Dovčiak

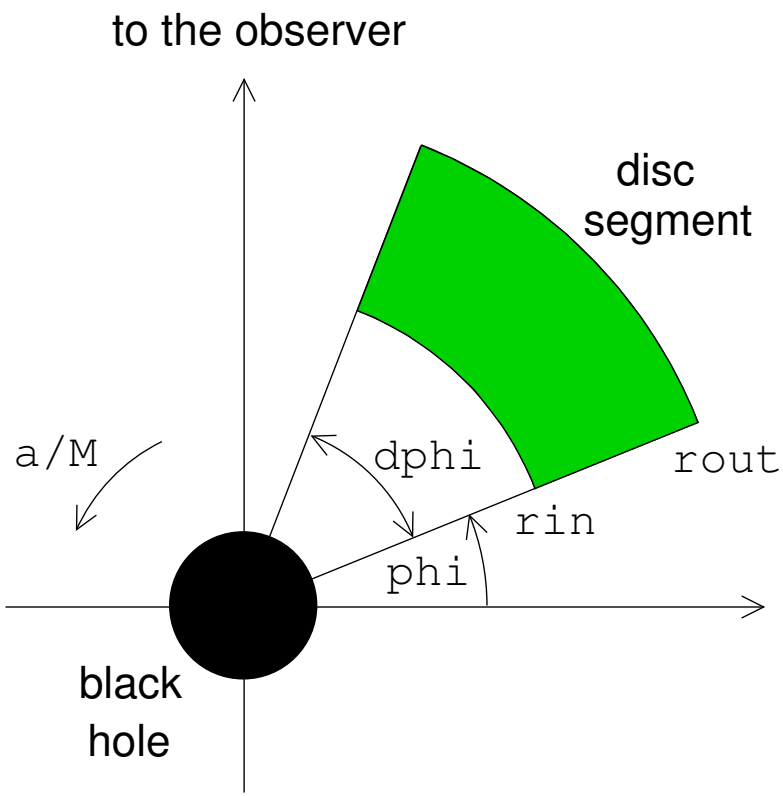
Astronomical Institute
Academy of Sciences of the Czech Republic
Prague

27th – 30th May 2008
The X-ray Universe 2008
Granada, Spain

List of KY models

- additive models
  - line models
    - KYRline and KYR1line
    - KYF1ll
  - continuum models
    - KYPhebb and KYP1hebb
    - KYBb and KYB1b
    - KYL1cr
    - KYH1refl
- convolution models
  - KYConv and KYC1onv
- dynamical model KYSpot

Disc segment



Common parameters

All models:

parameter	unit	default value	minimum value	maximum value
a/M	GM/c	0.9982	0.	1.
theta_o	deg	30.	0.	89.
rin	GM/c^2	1.	1.	1000.
ms	–	1.	0.	1.
rout	GM/c^2	400.	1.	1000.
zshift	–	0.	-0.999.	10.

Non-axisymmetric models:

parameter	unit	default value	minimum value	maximum value
phi	deg	0.	-180.	180.
dphi	deg	360.	0.	360.
ntable	–	0.	0.	99.
nrad	–	200.	1.	10000.
division	–	1.	0.	1.
nphi	–	180.	1.	20000.
smooth	–	1.	0.	1.
Stokes	–	0.	0.	6.

KYRline and KYR1line

$r \leq r_{\rm b}$:

$$f(E_{\rm loc}; r) = \frac{\delta(E_{\rm loc} - \texttt{Erest})}{r^{\texttt{alpha}}} M(\mu_{\rm e})$$

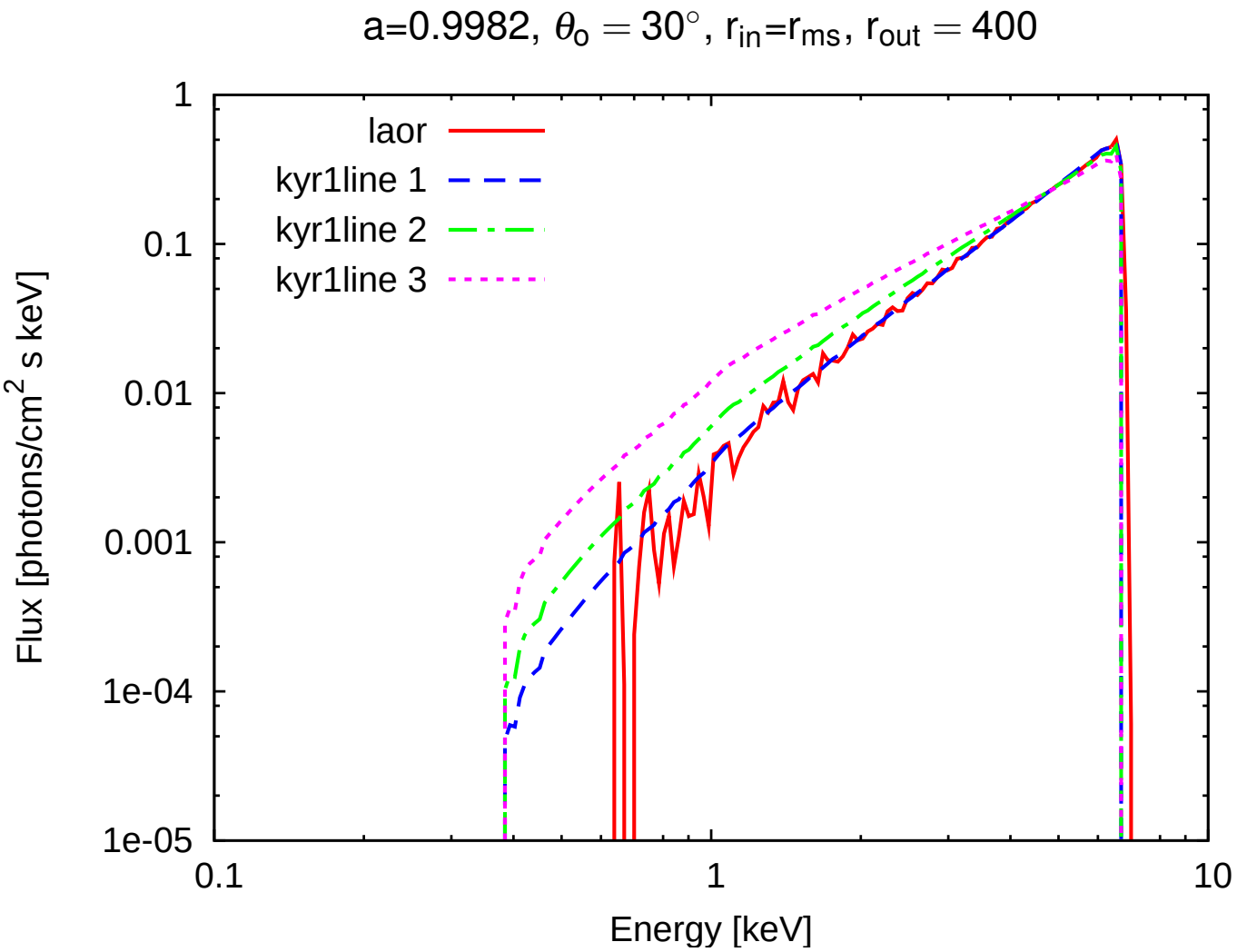
$r > r_{\rm b}$:

$$f(E_{\rm loc}; r) = r_{\rm b}^{\texttt{beta}-\texttt{alpha}} \frac{\delta(E_{\rm loc} - \texttt{Erest})}{r^{\texttt{beta}}} M(\mu_{\rm e})$$

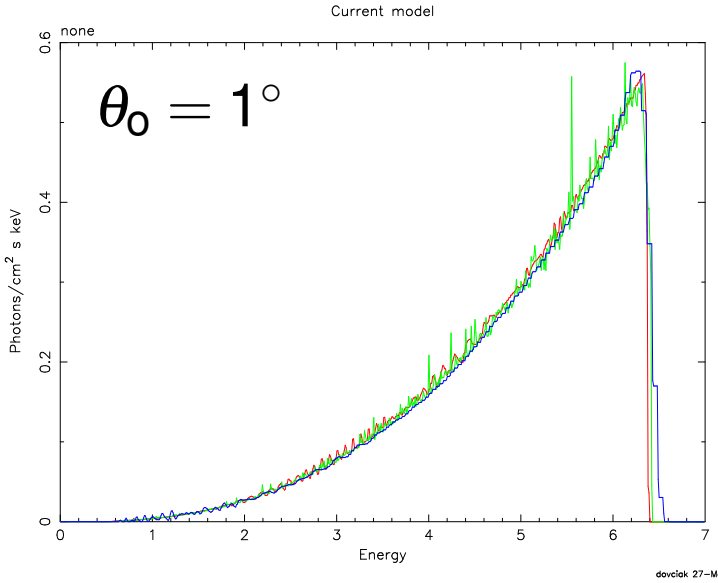
parameter	unit	default value	minimum value	maximum value
`Erest`	keV	6.4	1.	99.
`alpha`	–	3.	-20.	20.
`beta`	–	3.	-20.	20.
`rb`	GM/c^2	400.	1.	1000.
`limb`	–	1.	0.	2.

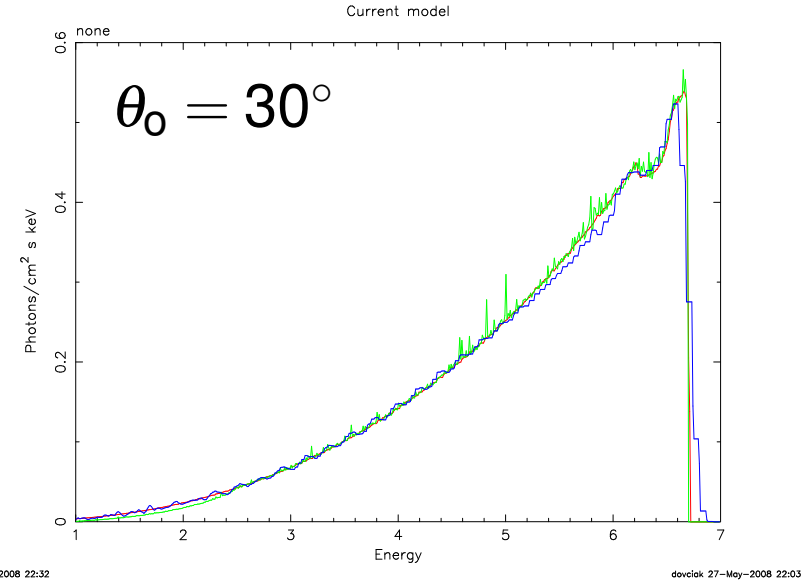
Other models in XSPEC: `laor`, `diskline`, `kerrdisk`

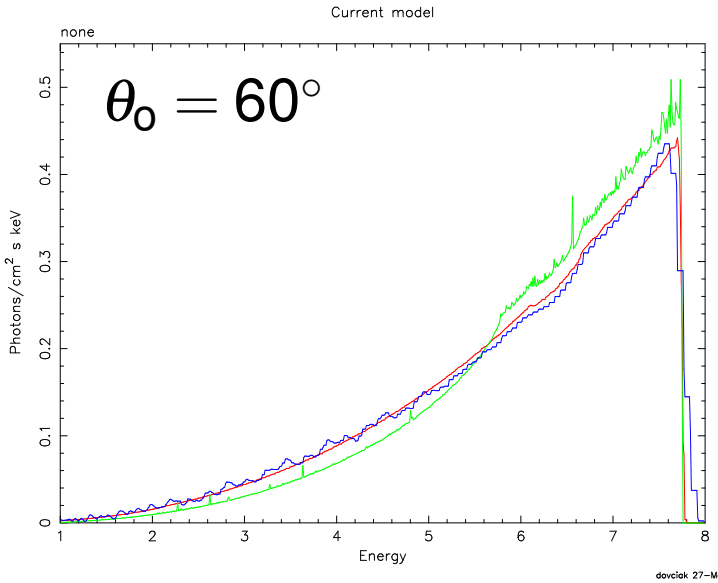
KYRline and KYR1line

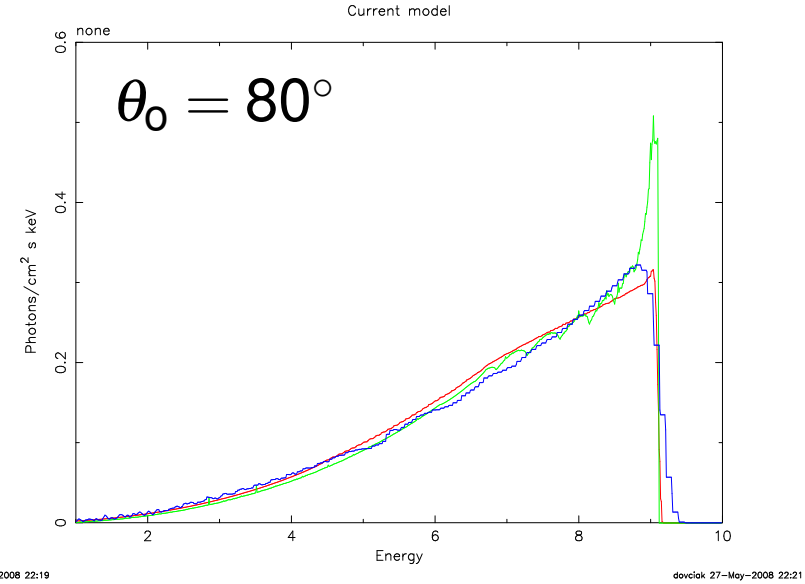


KYRline and KYR1line







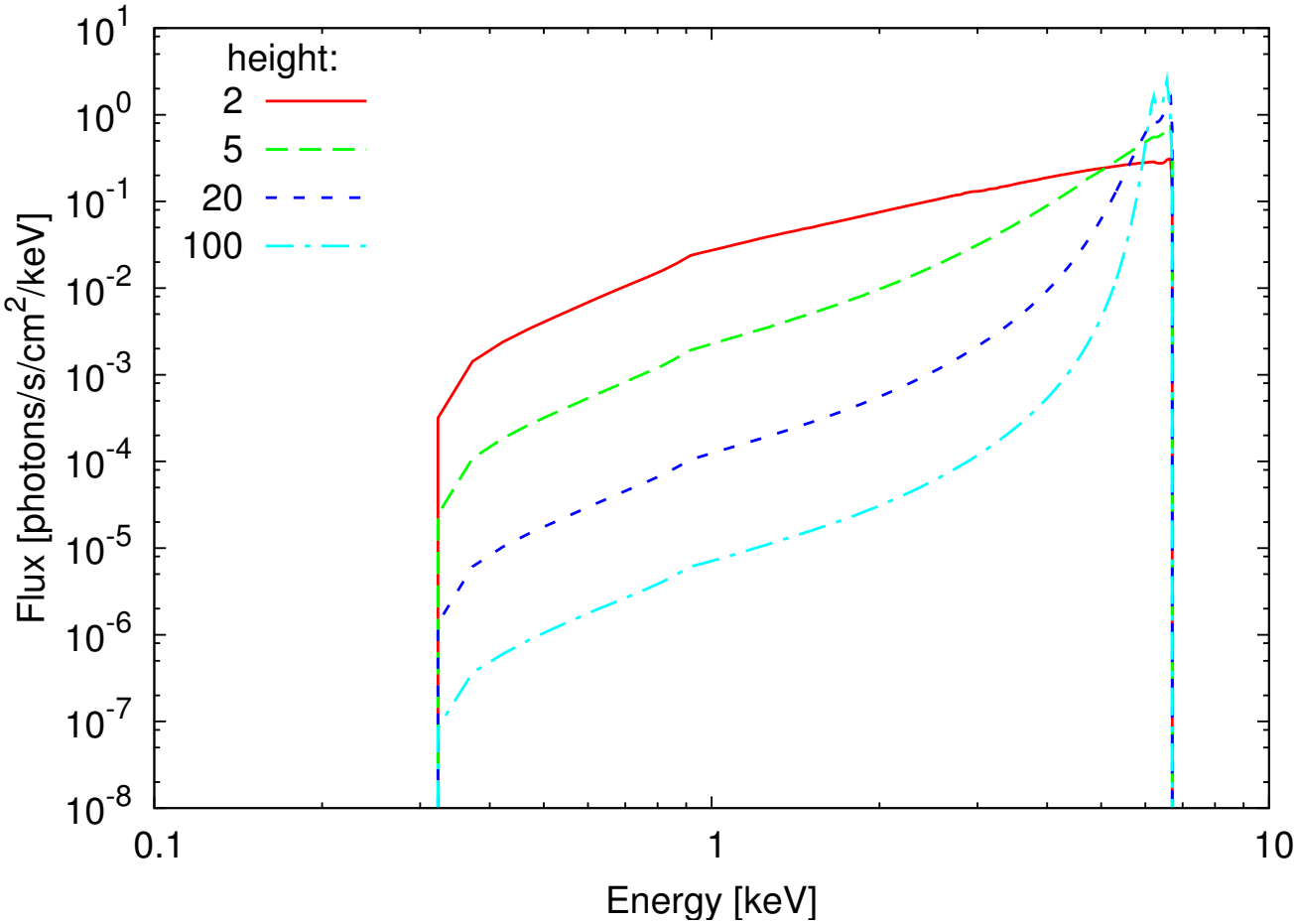


KYF1II

$$f(E_{\rm loc};r;\mu_{\rm e}) = g_{\rm L}^{\tt PhoIndex-1}\frac{\sin\theta_{\rm L}{\rm d}\theta_{\rm L}}{r{\rm d}r}\sqrt{1-\frac{2\,\tt height}{\tt height^2+(a/M)^2}}$$
$$\times M(\mu_{\rm i},\mu_{\rm e})\exp\left[-\left(1000\,\frac{E_{\rm loc}-\tt Erest}{\sqrt{2}\,\tt sigma}\right)^2\right]$$

parameter	unit	default value	minimum value	maximum value
`Erest`	keV	6.4	1.	99.
`sigma`	eV	2.	0.01	1000.
`PhoIndex`	–	2.	0.	10.
`height`	GM/c^2	3.	-20.	100.

KYF1II


height:
2
5
20
100
Flux [photons/s/cm^2/keV]
Energy [keV]
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0.1
1
10

KYPhebb and KYP1hebb

$$R(E_{\rm loc};r) = \frac{E_{\rm loc}^2}{\exp\left(E_{\rm loc}/kT(r)\right)-1}$$

$$T(r) = \texttt{Tin}\left[\frac{r}{\texttt{rin}+r_{\rm h}}\right]^{-\texttt{BBindex}}$$

parameter	unit	default value	minimum value	maximum value
`Tin`	keV	1.	0.	10.
`BBindex`	–	0.75	-20.	20.
`dener`	log(keV)	0.01	0.001 (0.01)	0.1 (1.)

KYBb and KYB1b

$$R(E_{\rm loc};r) = \frac{E_{\rm loc}^2}{\exp\left(E_{\rm loc}/kT(r)\right)-1}$$

- zero torque at the inner edge
- no self-irradiation of the disc
- polarization by Rayleigh scattering

parameter	unit	default value	minimum value	maximum value
`BHmass`	Msun	3.	1.	1e+12
`arate`	Msun/y	1e-9	1e-15	1e+9
`f_col`	–	1.7	1.	2.
`dener`	log(keV)	0.01	0.001 (0.01)	0.1 (1.)

Other models in XSPEC: `kerrbb`

KYL1cr

$\texttt{height} > 0$:

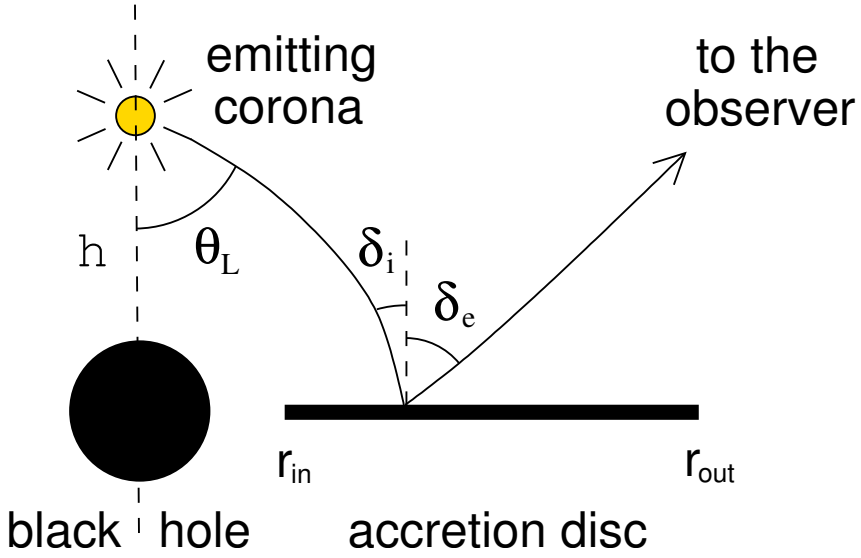
$$f(E_{\rm loc}; r; \mu_{\rm e}) = g_{\rm L}^{\texttt{PhoIndex}-1} \frac{\sin\theta_{\rm L}\,{\rm d}\theta_{\rm L}}{r\,{\rm d}r} \sqrt{1 - \frac{2\,\texttt{height}}{\texttt{height}^2 + (\texttt{a}/\texttt{M})^2}} \times f_{\rm G}(E_{\rm loc}; \mu_{\rm i}, \mu_{\rm e})$$

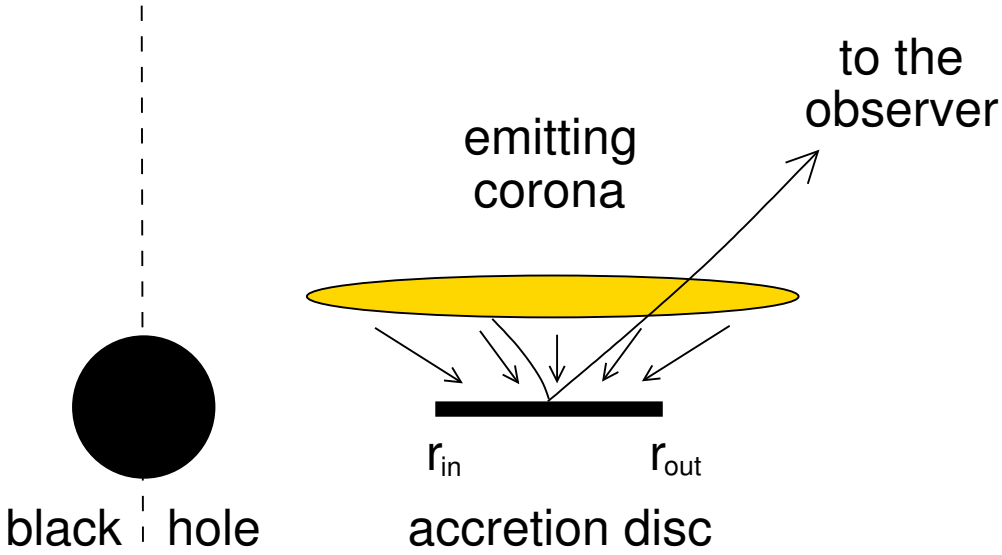
$\texttt{height} \leq 0$:

$$f(E_{\rm loc}; r; \mu_{\rm e}) = r^{\texttt{height}}\, \bar{f}_{\rm G}(E_{\rm loc}; \mu_{\rm e})$$

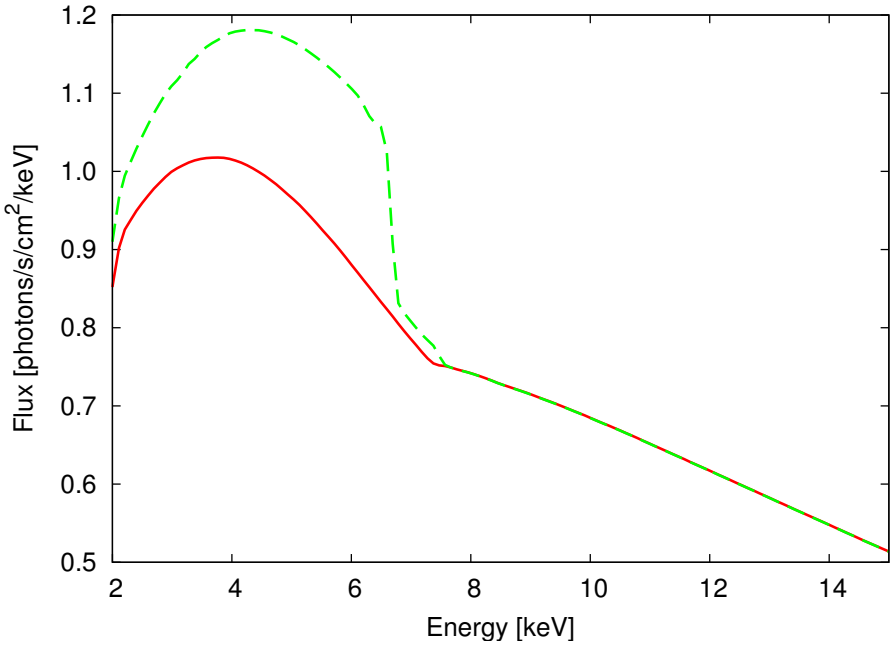
parameter	unit	default value	minimum value	maximum value
PhoIndex	–	2.	1.5	3.
height	GM/c^2	3.	-20.	100.
line	–	0.	0.	1.
E_cut	keV	300.	1.	1000.

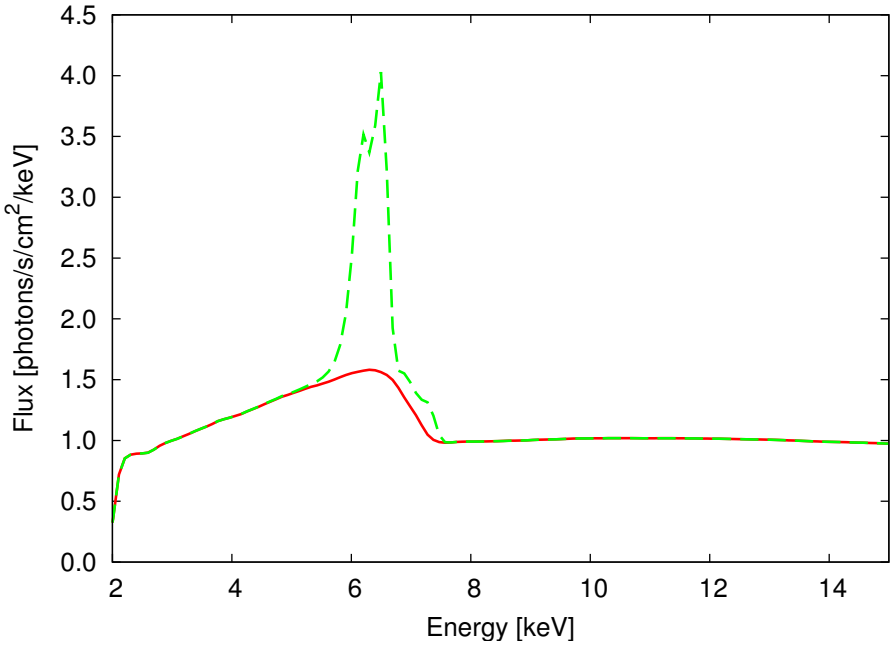
KYL1cr





KYL1cr





KYH1refl

$r \geq r_{\rm b}$:

$$f(E_{\rm loc}; r) = r^{-\texttt{alpha}}\,\texttt{HREFL*POWERLAW}$$

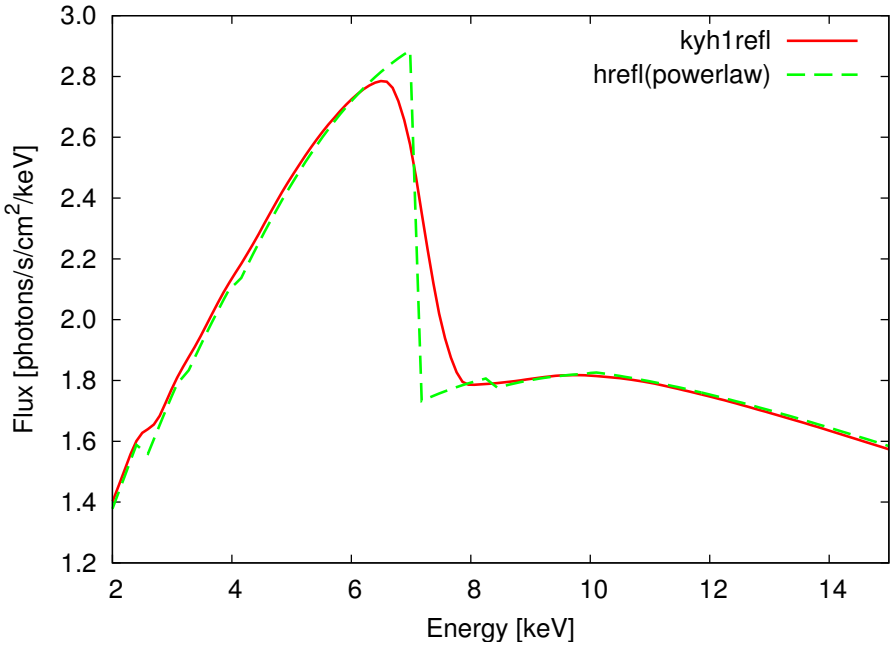
$r < r_{\rm b}$:

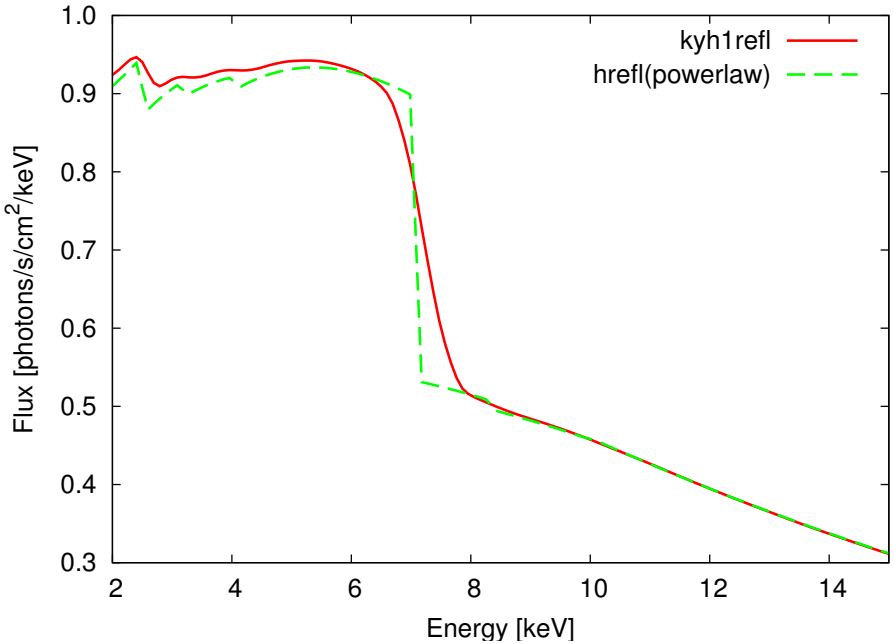
$$f(E_{\rm loc}; r) = \texttt{jump}\; r_{\rm b}^{\texttt{beta}-\texttt{alpha}}\, r^{-\texttt{beta}}\,\texttt{HREFL*POWERLAW}$$

$r_{\rm b} = \texttt{rb} \times r_{\rm ms} \quad (\texttt{rb} > 0)$ or $r_{\rm b} = -\texttt{rb} + r_{\rm h} \quad (\texttt{rb} < 0)$

parameter	unit	default value	minimum value	maximum value
PhoIndex	–	1.	0.	10.
alpha	–	3.	-20.	20.
beta	–	4.	-20.	20.
rb	$r_{\rm ms}$	0.	0.	160.
jump	–	1.	0.	1e6
Feabun	–	1.	0.	200.
FeKedge	keV	7.11	7.0	10.
Escfrac	–	1.	0.	1000.
covfac	–	1.	0.	1000.

KYH1refl


kyh1refl
hrefl(powerlaw)
Flux [photons/s/cm^2/keV]
Energy [keV]
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
2
4
6
8
10
12
14


kyh1refl
hrefl(powerlaw)
Flux [photons/s/cm^2/keV]
Energy [keV]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2
4
6
8
10
12
14

KYConv and KYC1onv

$r \le r_{\rm b}$: $$f(E_{\rm loc}; r) = \frac{\mathrm{MODEL}(E_{\rm loc})}{r^{\mathtt{alpha}}} M(\mu_{\rm e})$$

$r > r_{\rm b}$: $$f(E_{\rm loc}; r) = r_{\rm b}^{\mathtt{beta-alpha}} \frac{\mathrm{MODEL}(E_{\rm loc})}{r^{\mathtt{beta}}} M(\mu_{\rm e})$$

parameter	unit	default value	minimum value	maximum value
`alpha`	–	3.	-20.	20.
`beta`	–	3.	-20.	20.
`rb`	GM/c^2	400.	1.	1000.
`ne_loc`	–	100.	3.	5000.
`normal`	–	1.	-1.	100.
`limb`	–	0.	0.	2.

`normal` $= 0.$ – normalization to unit flux (line)

`normal` $> 0.$ – normalization to unity at `normal` keV (continuum)

`normal` $< 0.$ – resultant spectrum is not renormalized

Tables used in KY

- KBHtables00.fits (290MB)
- KBHline00.fits, KBHline01.fits, KBHline02.fits (83MB)
- refspectra.fits (3MB) — `KYL1cr`
- fluorescent_line.fits — `KYF1ll`
- lamp.fits — `KYF1ll, KYL1cr`

Core integration routine

- more clever integration — better interpolation
  - faster models
  - much smaller tables for axisymmetric models
  - less non-physical parameters

    `nrad, rdivision, nphi, smooth` $\rightarrow$ `dE`

- different type of tables used

  $\delta t,\ g,\ l,\ \mu_{\mathrm{e}},\ \phi_{\mathrm{e}}, \psi\ \rightarrow \delta t,\ \alpha,\ \beta,\ p^r,\ l$
  - better interpolation for spin and observers inclination (critical point)
  - easy to implement non-Keplerian motion
  - slightly smaller tables for non-axisymmetric models

- better timing computations

  numerical computation $\rightarrow\ k_{\mathrm{t}} = \left[1 + \Omega \frac{\partial(\delta t)}{\partial \varphi}\right]^{-1}$
  - faster “spot” computation

Models

- lamp-post models — primary radiation will be included
- new tables for reflection spectra (azimuthal emission dependence included)
- better polarization modelling

Conclusions

- advantages of KY
  - lamp-post line model (KYF1ll)
  - continuum models (KYBb, KYH1refl, KYL1CR)
  - non-axisymmetric models (segment of the disc)
  - emission from below ISCO (free fall)
  - suitable for polarization computations
  - suitable for timing analysis
  - KYRline — smoother than other models (narrow rings close to the black hole)
- disadvantages of KY
  - non-axisymmetric models are slow (but we are working on a new much improved and faster version)

The last version of KYRline and KYConv models available at:

`http://astro.cas.cz/dovciak/pub/KY`