Models for the X-ray spectra and variability of luminous accreting black holes

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- X-ray spectra of bright seyferts and NLS1 very well fitted by relativistically blurred reflection models (Crummy et al. 2005). Some appear to be reflection dominated.
- In some cases variable continuum but no variability of iron line/reflection

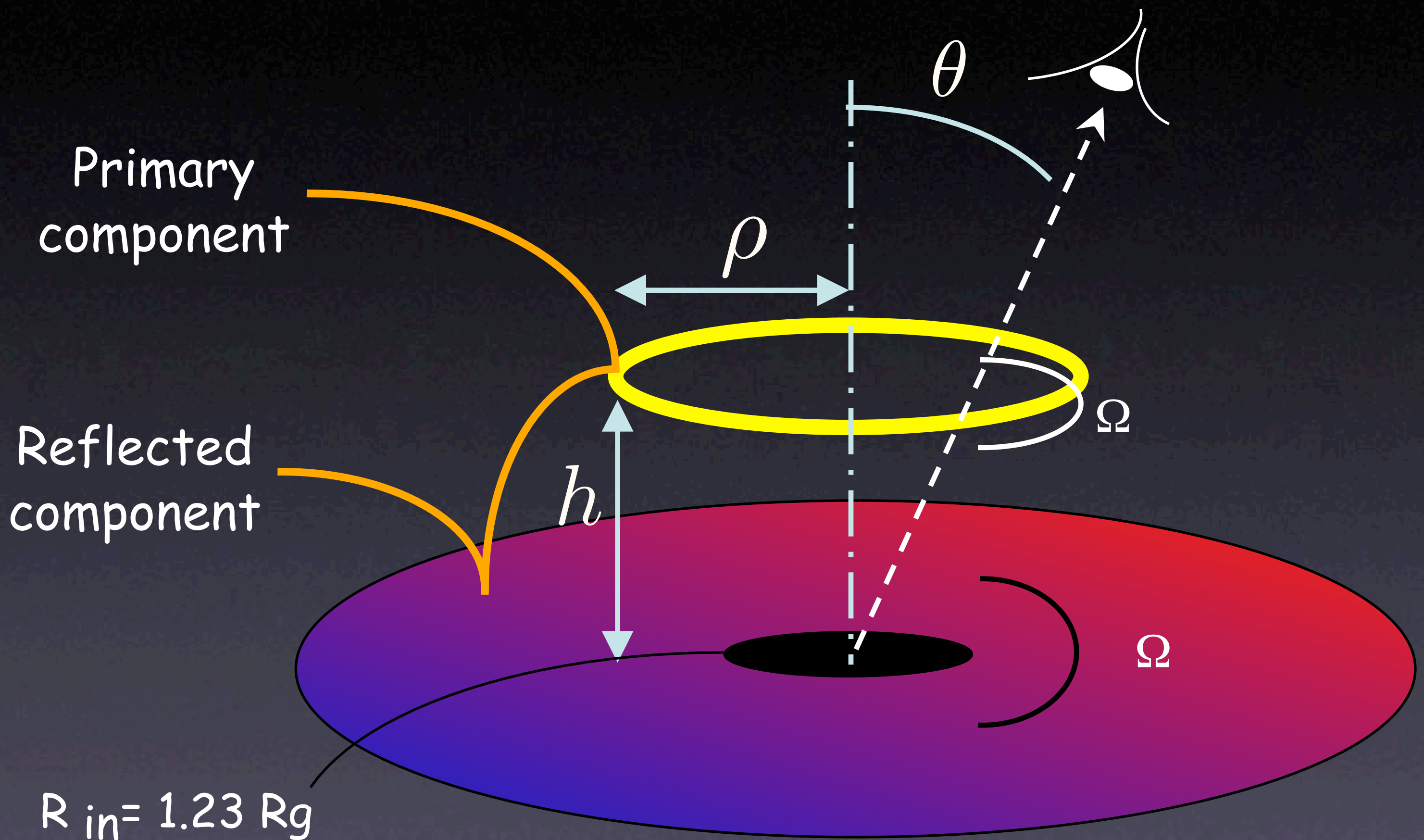
⇨ light bending ? (see talk by Miniutti)

Suebsuwong, Malzac, Jourdain and Marcowith, 2006, astro-ph/0603767

⇨ inhomogeneous (clumpy) accretion flow ?

Merloni, Malzac, Fabian and Ross, 2006, astro-ph/0606262

Monte-Carlo simulations of light bending model spectra

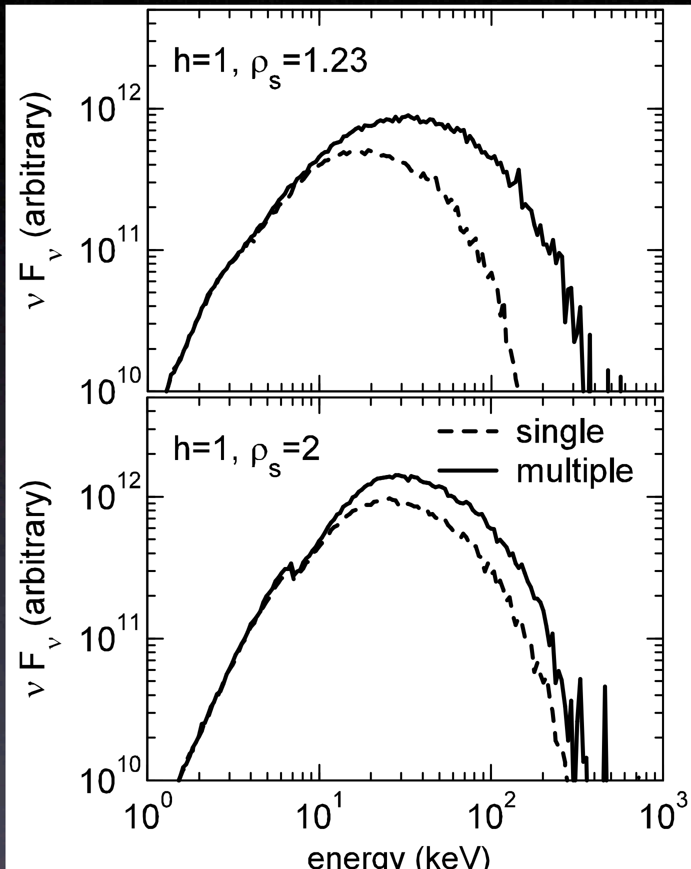


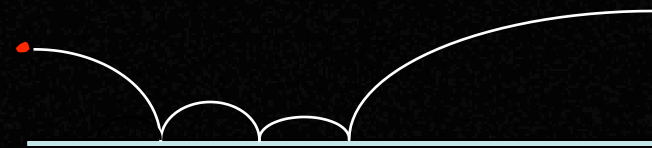
Maximally rotating Kerr black hole

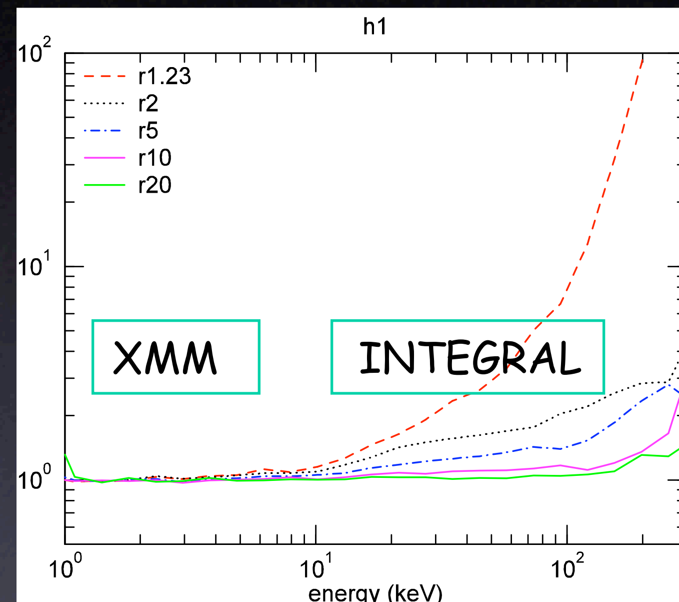
Primary component: power-law + cut-off (Γ=2, Ec=200 keV)

Reflection continuum and iron line: neutral cold material

Effects of multiple reflections





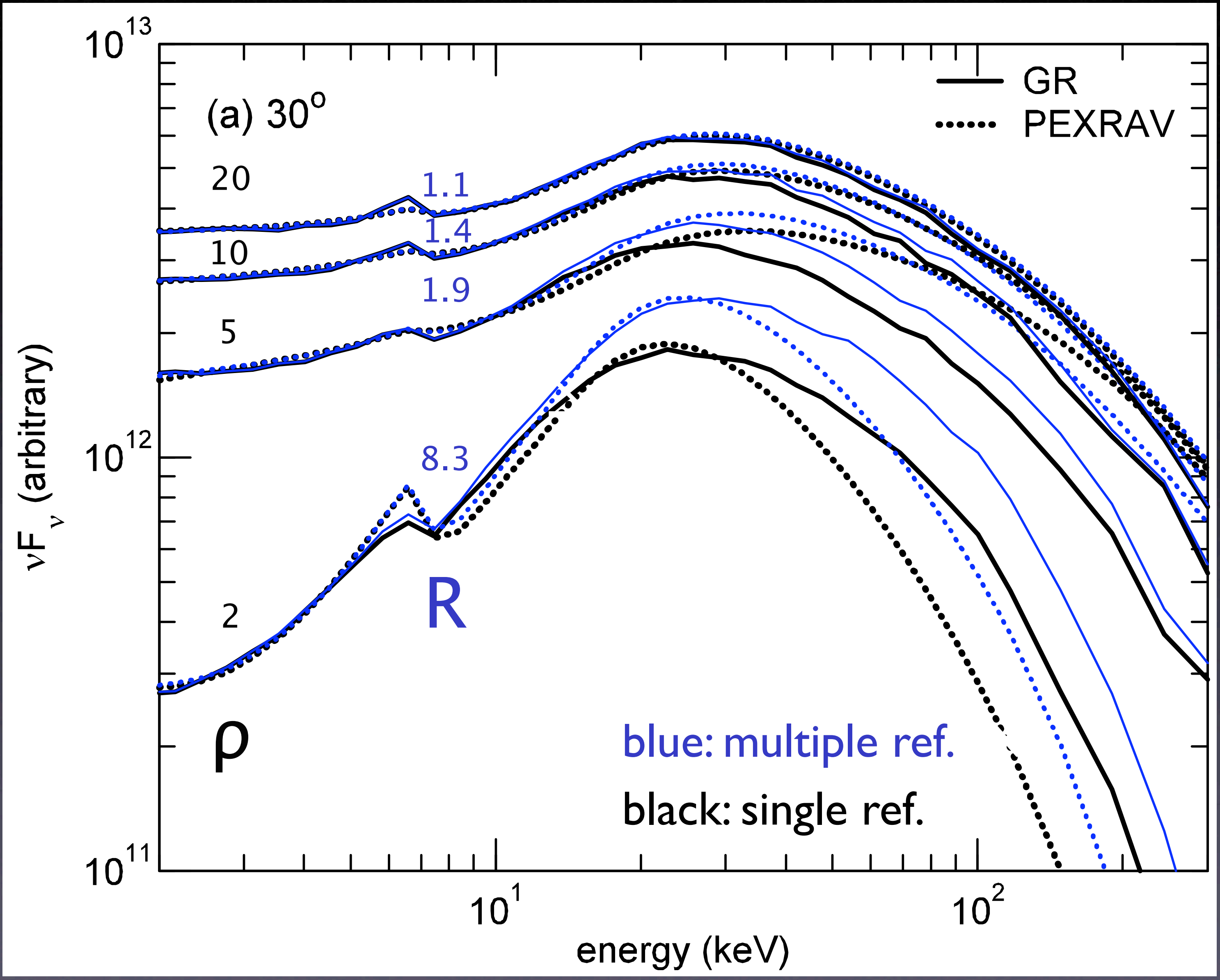


- Multiply reflected photons have a harder spectrum
=> hardening of the reflected spectrum above 10 keV

- stronger effects when reflection takes place closer to the black hole

Light bending model spectra

h=2



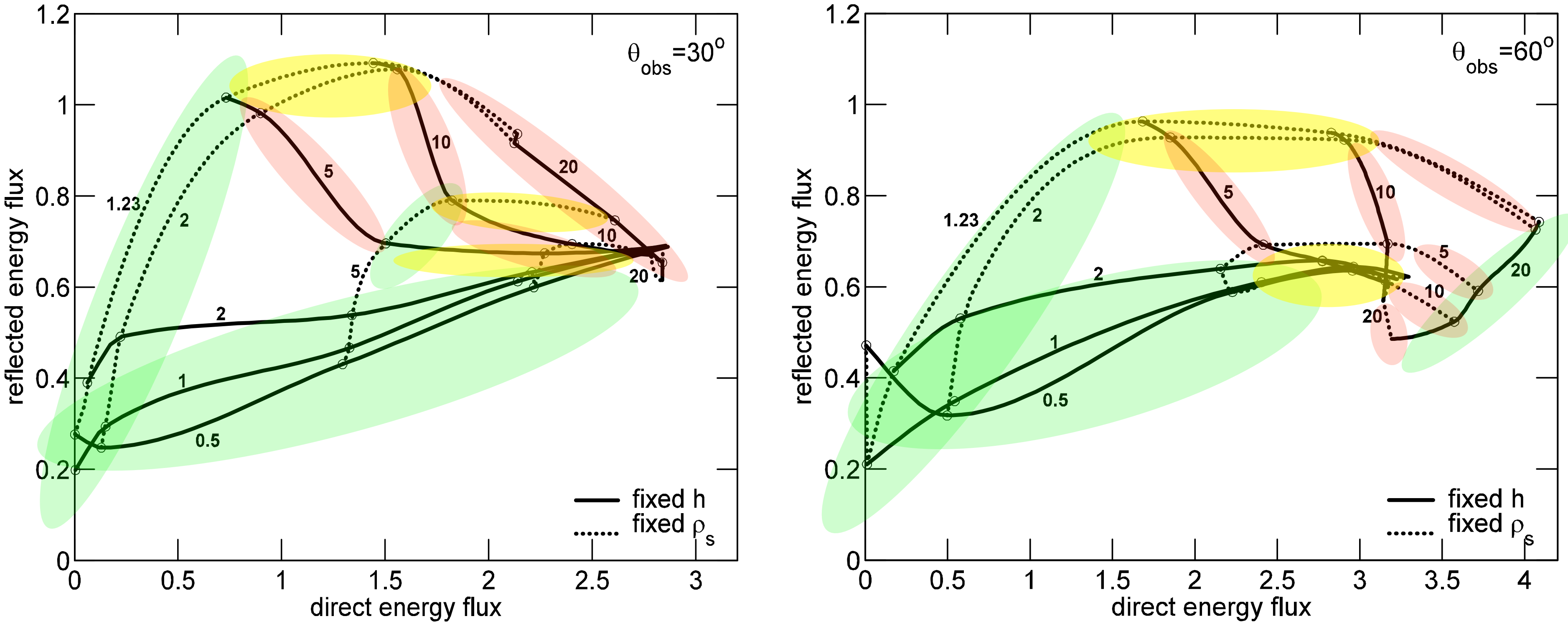
Reflected vs Primary component diagrams

PC and RC correlated

nearly constant RC, varying PC

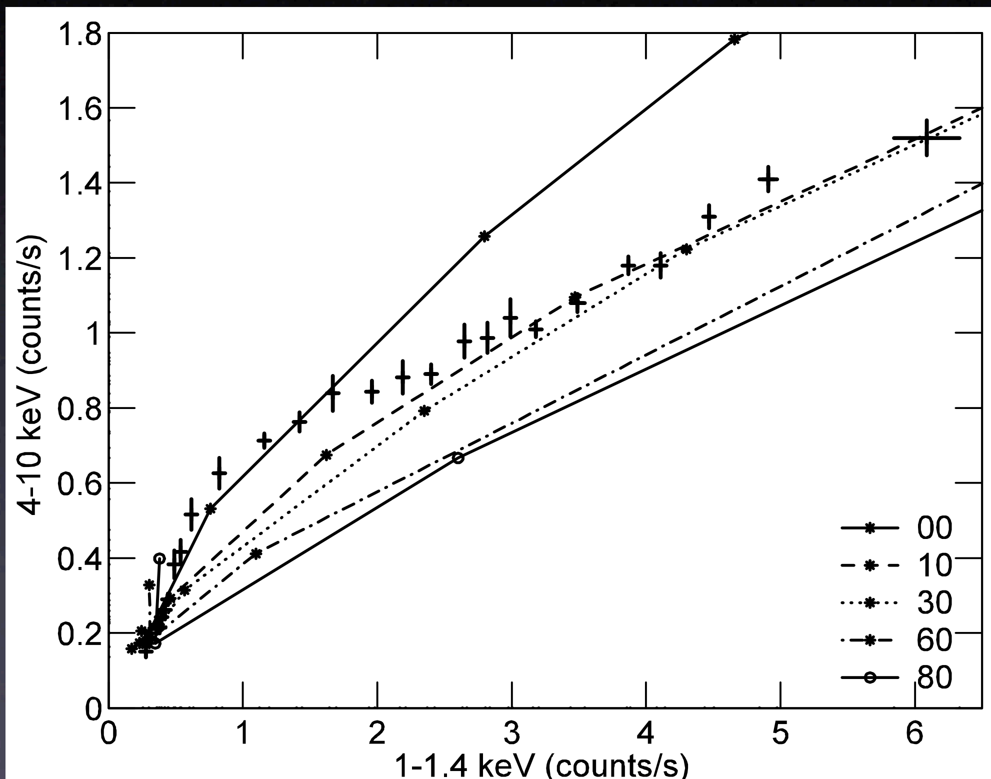
PC and RC anti-correlated   <- not observed

the observed variability is driven by h (rather than rho)



Flux-flux diagrams

XMM-Newton data of NGC4051 (Ponti et al 2006.)



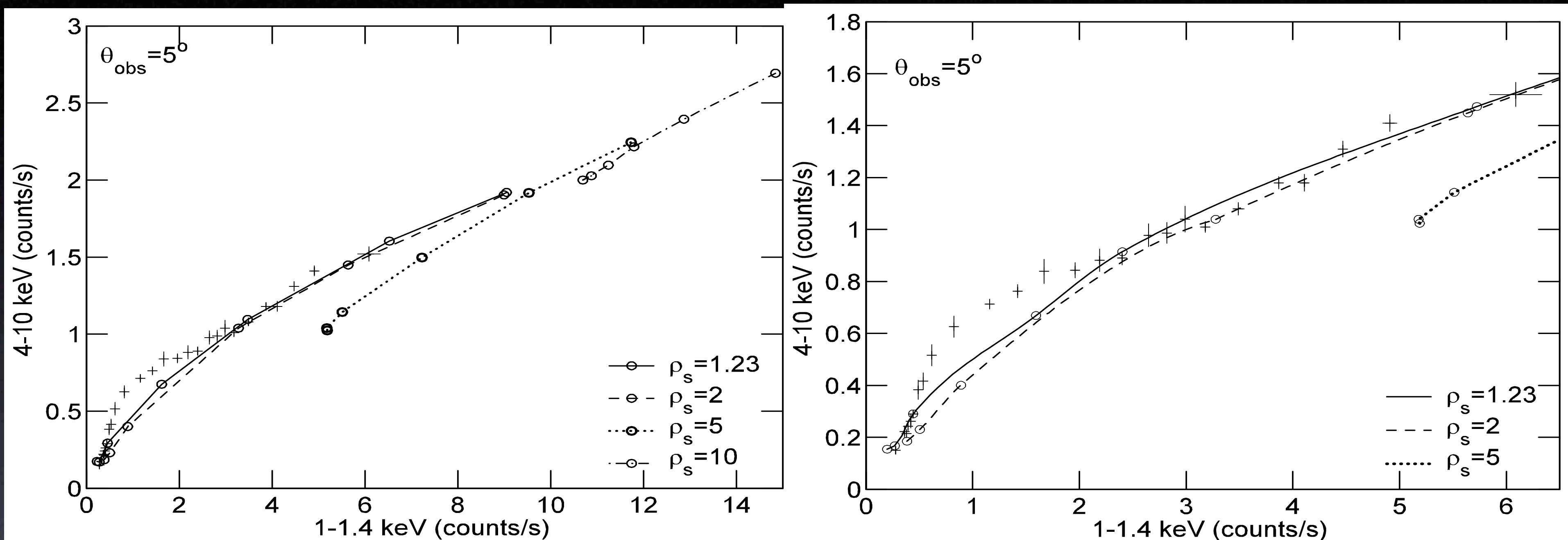
Γ=2.3

Model parameters : h, ρ and inclination angle

Best results:
inclination 0-10 deg.

ρ = 1.23 (fixed), h increases from 0.5 to 20 along the curves.

Flux-flux diagrams

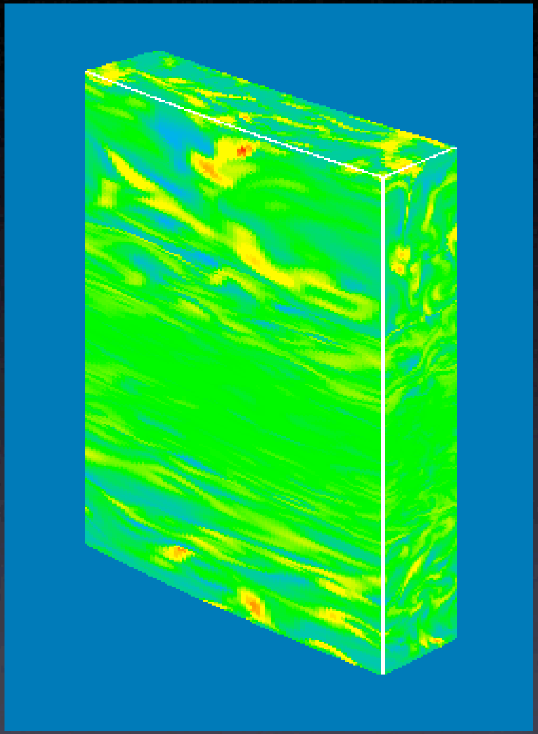


Non-linear flux-flux relation at low luminosity obtained for emitting region very close to the BH:

ρ constant = 1.23 Rg
inclination 5 deg
h spanning 0.5-10 Rg

An alternative: inhomogeneous accretion flows

At L~Ledd accretion discs are unstable and could become strongly inhomogeneous



- First 3-D MHD simulation of radiation dominated discs have shown discs prone to violent clumping instabilities
- Density variations in the upper disc layers may be up to a factor of 100, much of the dissipation occurs at low column depth

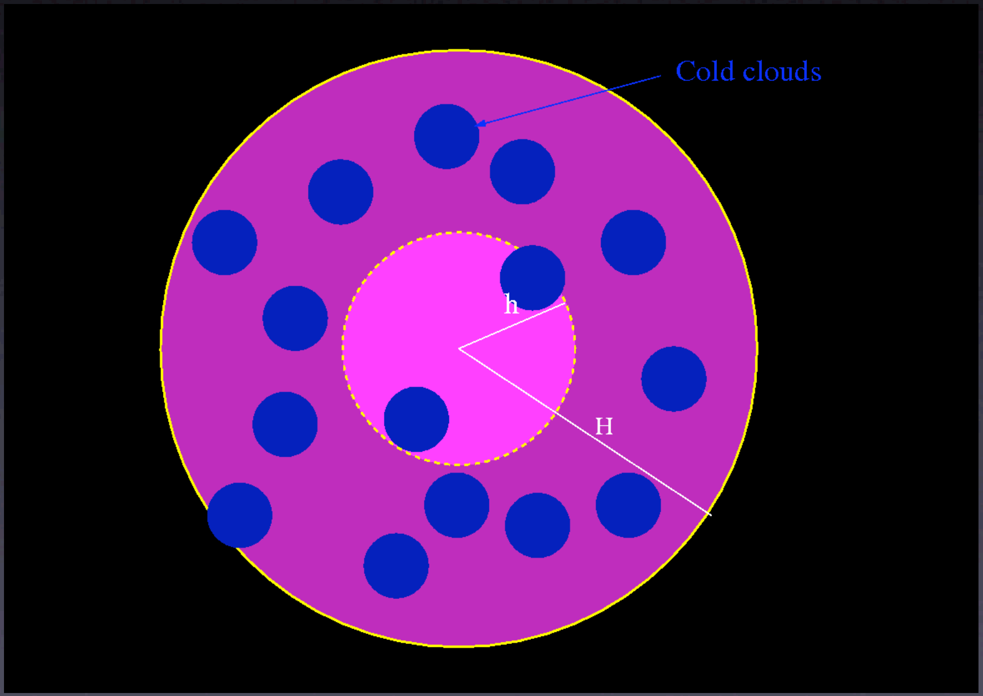
Turner et al. 2002, 2003, 2004

see also: Guilbert and Rees 1988; Celotti et al. 1992; Krolik 1988; Collin-Souffrin et al 1996; Kuncic et al. 1997; Gammie 1998; Blaes and Socrates 2002, 2003; Begelman 2002; Fabian et al. 2002; Malzac and Celotti 2002; Balantyne et al. 2004, 2005 etc..

→ relevant to BHB in Very High State, Quasars, NLS1...

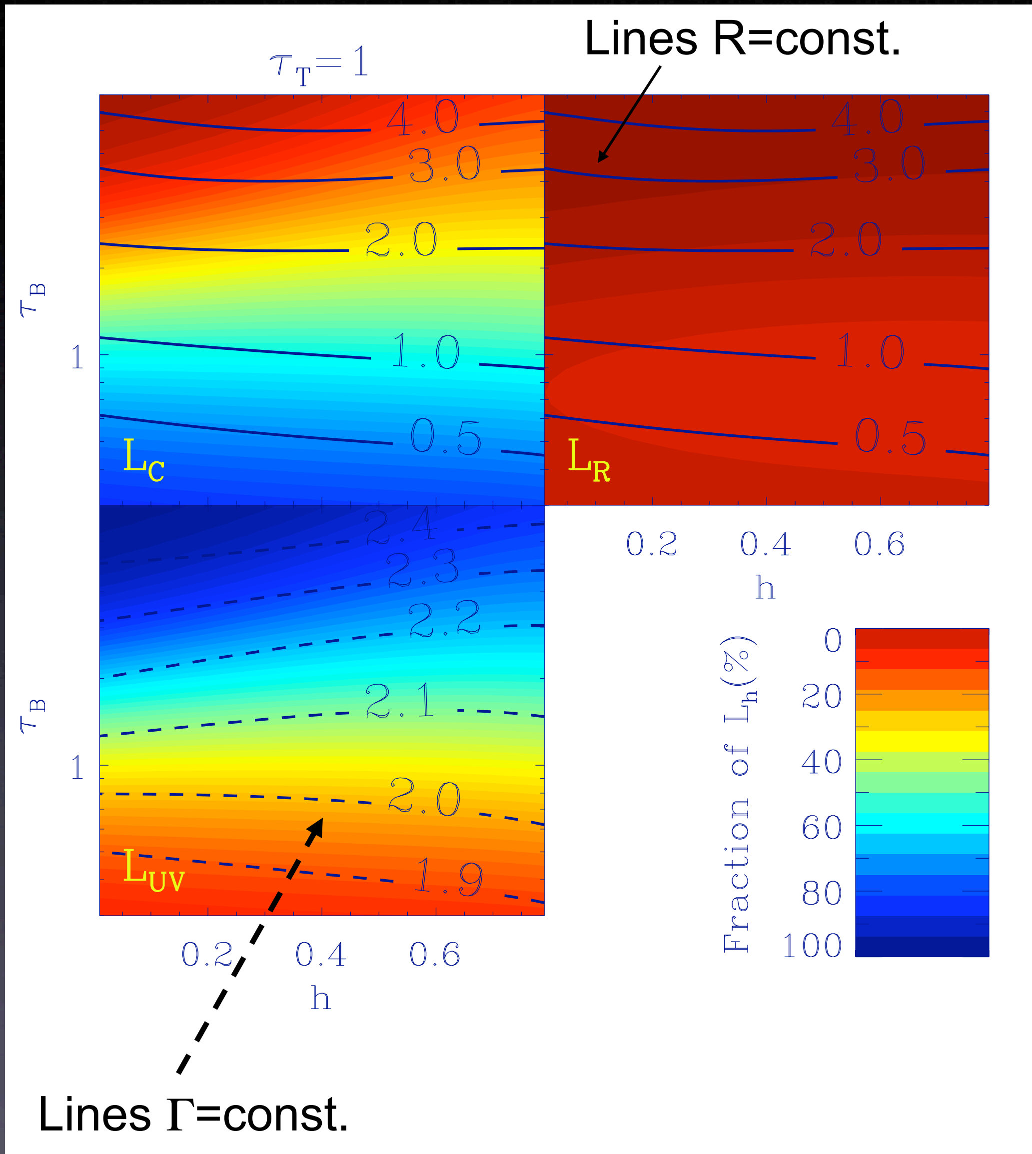
A two zones toy model

Dissipation concentrated in the inner sphere



- Three spectral components: L_{UV}, L_X, L_R
- We can calculate analytically the different emission components of the radiation emerging from our two zones model
  - Radiative equilibrium between the hot and cold phase
  - Radiative exchange between the zones
- Main parameters:
  - τ_T: Thomson depth
  - τ_B: effective optical depth of cold clumps (~covering fraction)
  - h/H

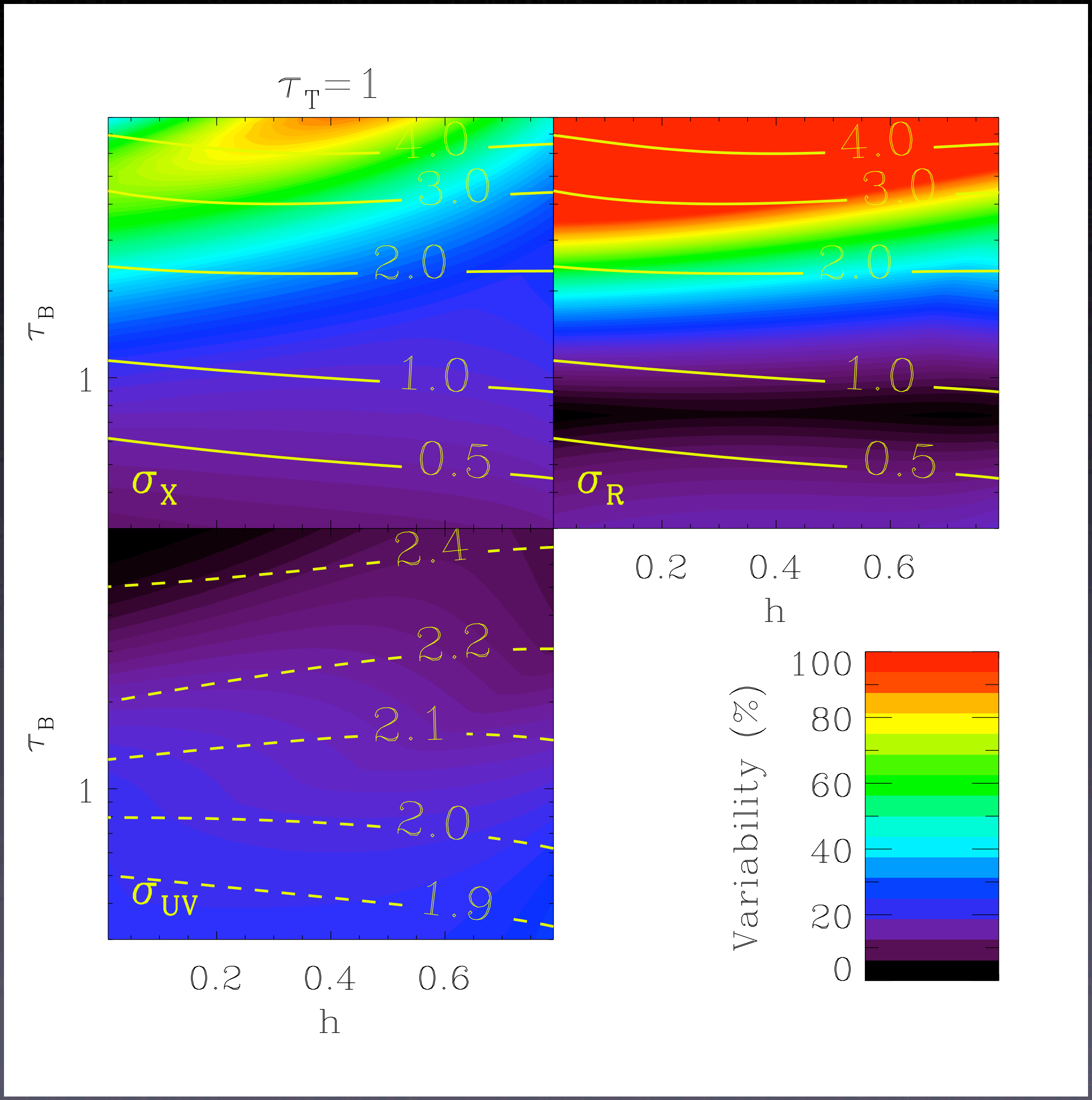
Analytic model, spectra



Reflection fraction **R** increases with τ_b, and for large τ_b, the spectra are reflection dominated.

Analytic model, variability

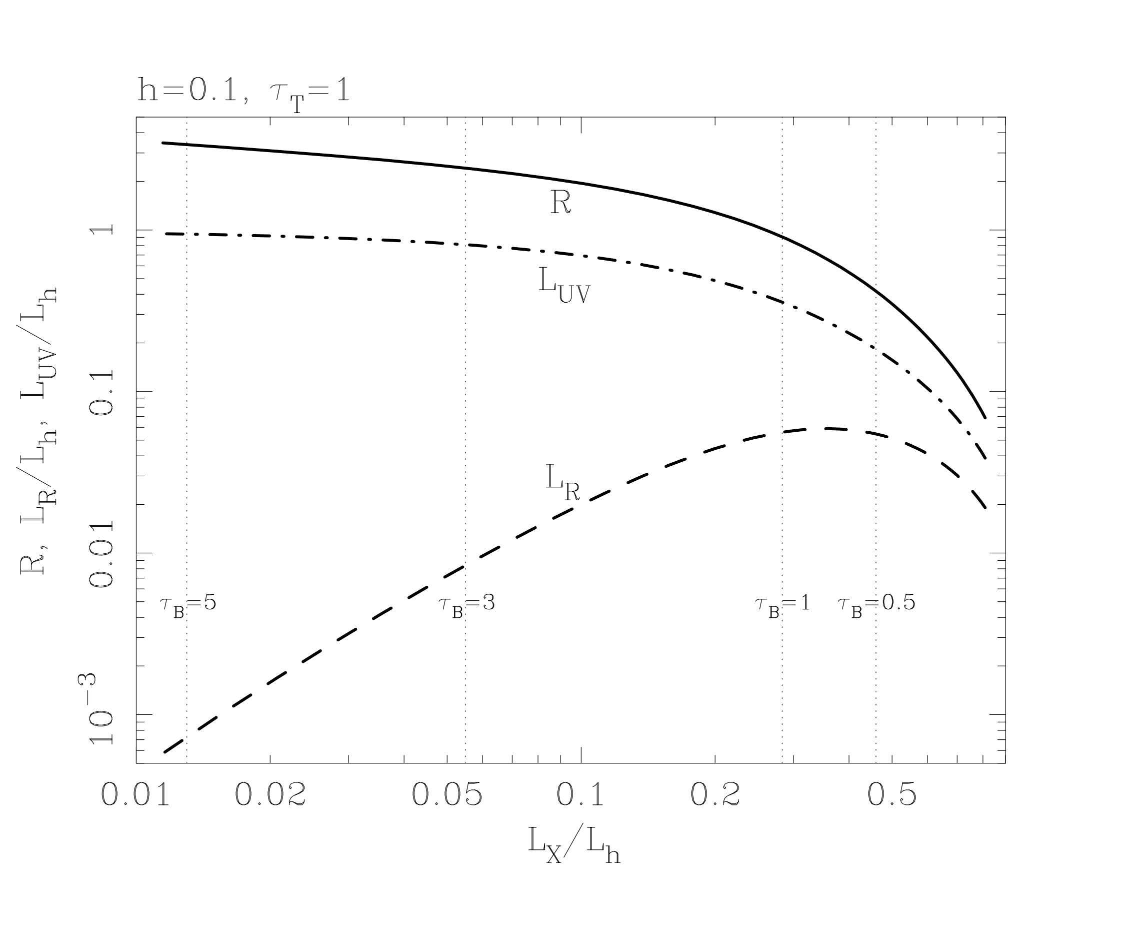
$$\sigma_i(\Delta \log \tau_B, \Delta \log h) \equiv \left|\frac{\partial \log L_i}{\partial \log \tau_B}\right| \Delta \log \tau_B + \left|\frac{\partial \log L_i}{\partial \log h}\right| \Delta \log h$$

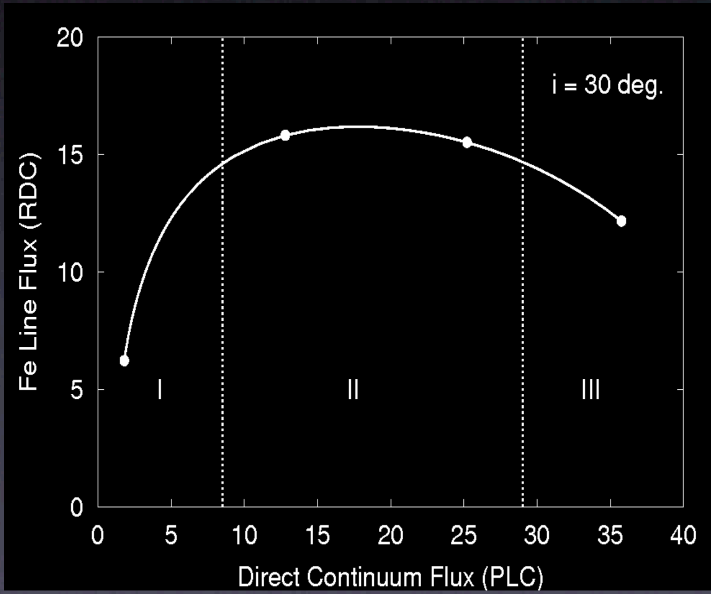


- Reflection fraction almost constant for R~1
- More complex variability patterns should be expected: varying heating rate

Analytic model, variability

Reflection component (and Iron line) almost constant for large variations of the continuum flux (as observed e.g. in MCG-6-30-15)





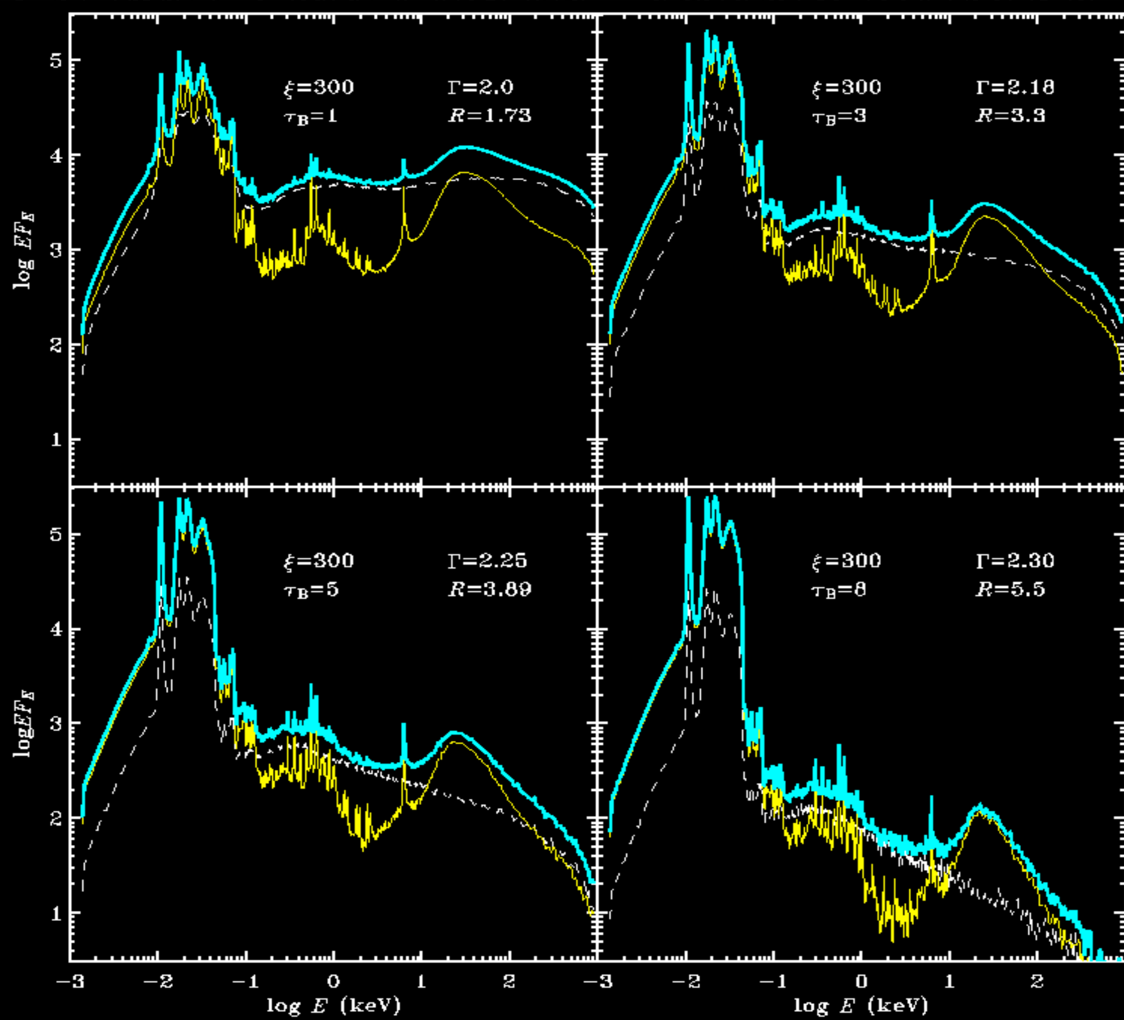
Miniutti and Fabian 2004

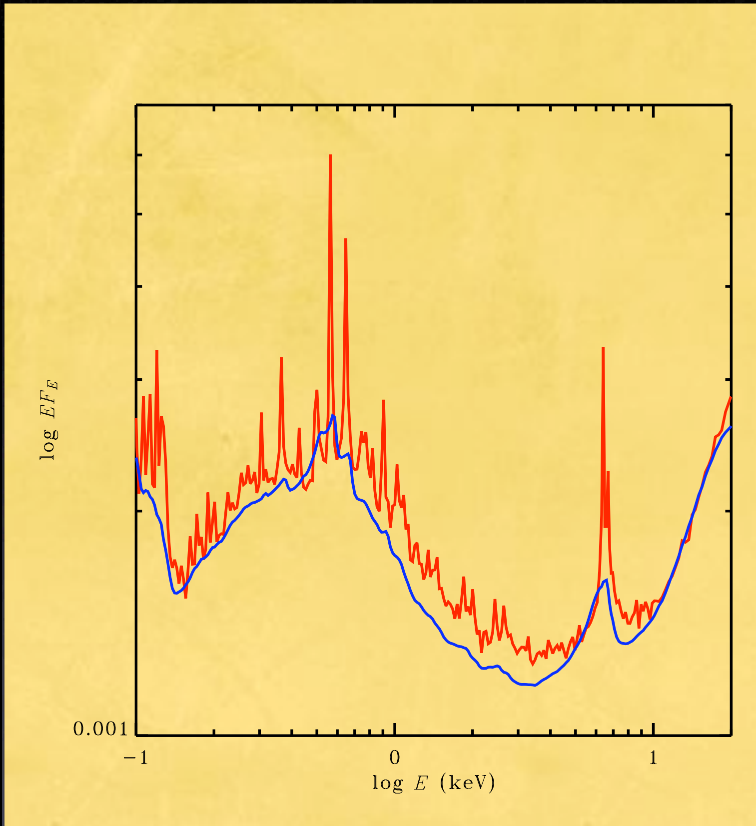
Numerical Simulations

- We simulate such a system with a multizone numerical code
- We assume the accretion disc is tiled with equal size cubes: heating localized in the inner zone only (with size~0.1 of the cube size)
- Full radiative coupling between the two phases (see also **Malzac, Dumont & Mouchet 2005**)
  - Energy balance in the hot phase: Comptonization with a Non Linear Monte Carlo code (**Malzac and Jourdain 2000**)
  - Reflection, reprocessing, ionization and thermal balance in the cold phase with the code of **Ross and Fabian (1993, 2005)**
- Optically thick clouds, multiple reflections taken into account

Simulations

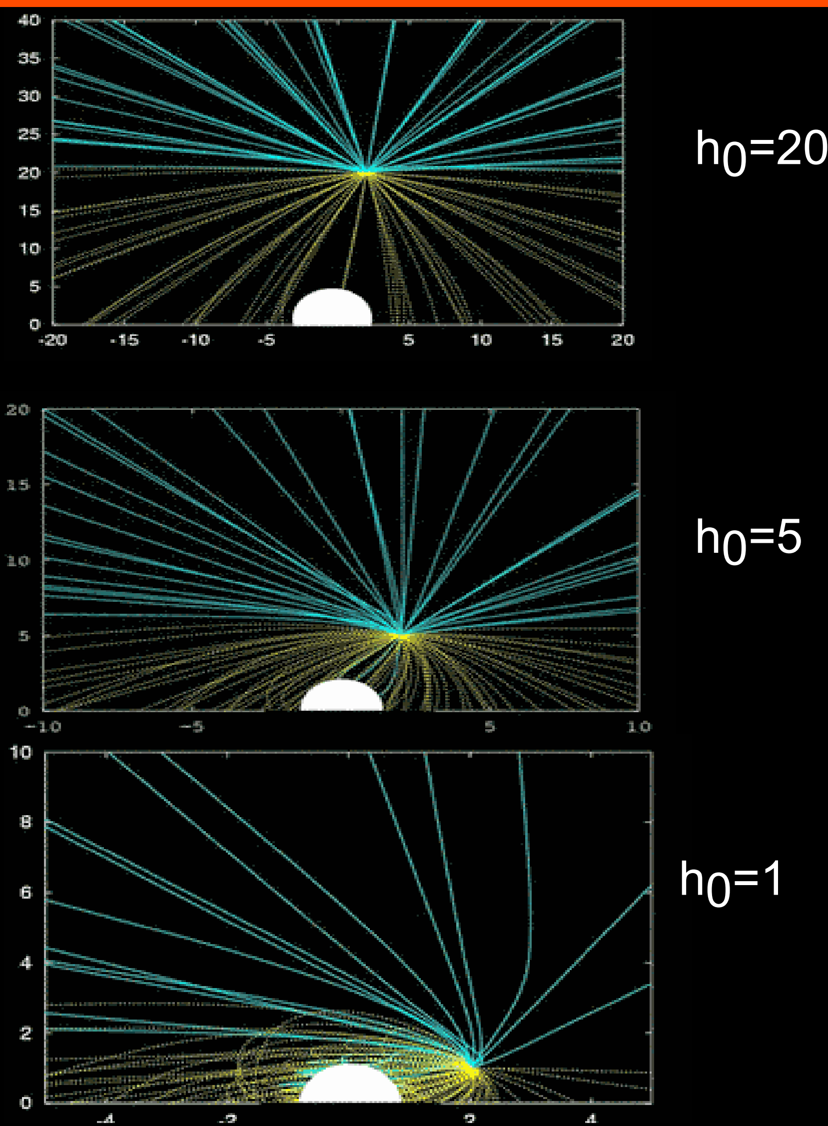
$\tau_T = 1$



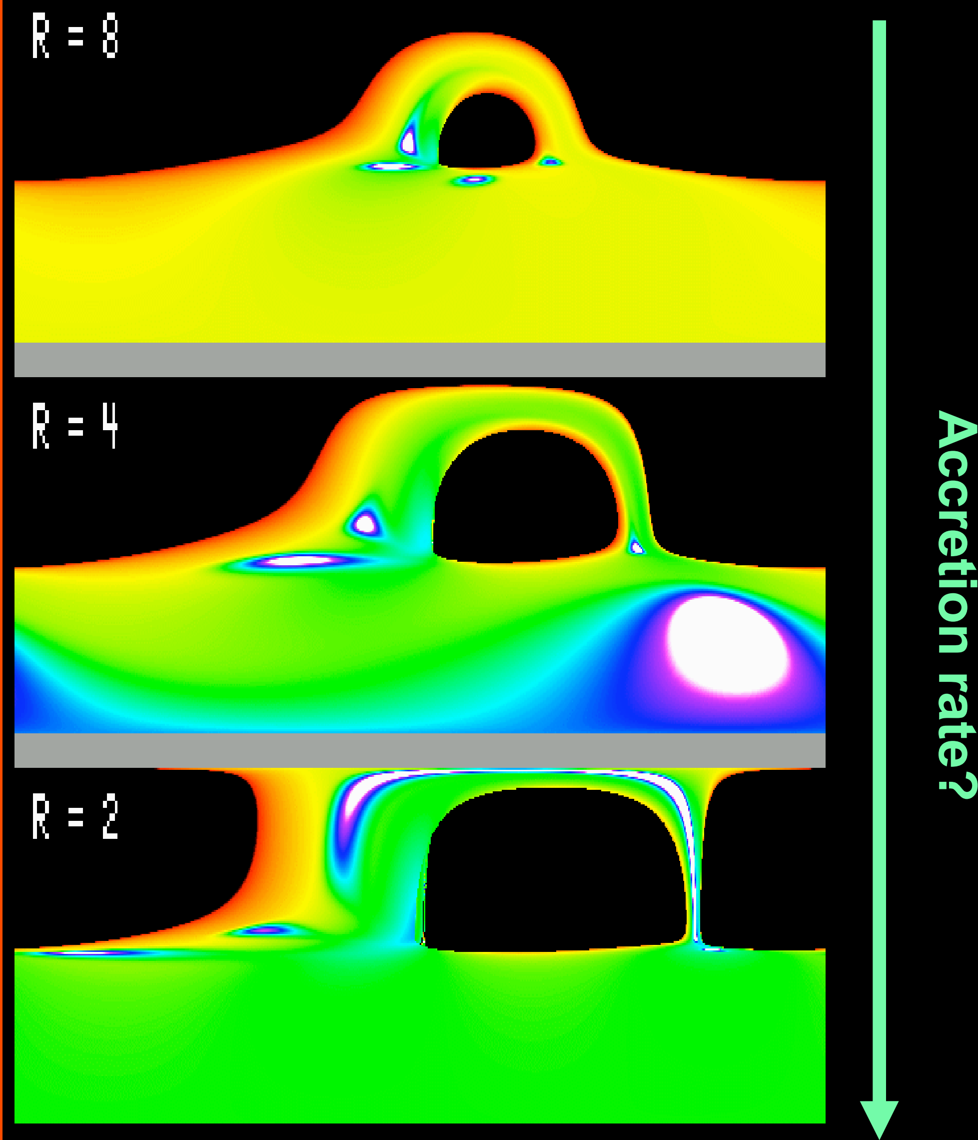


Parameters show results from PEXRAV fits in the 3-20 keV band

Analogies with the light bending model



Courtesy of G. Miniutti



From K.P. Rauch's homepage

Conclusions

- Detailed Monte-Carlo calculations confirm that the spectra and variability properties of highly accreting black holes are consistent with the light bending model.
- The clumpy disc model represents a very promising alternative, requiring further investigation (effects of absorption, bulk motion, coupling MHD models with radiative transfer calculations...)