On the spectra and variability of luminous inhomogeneous accretion flows

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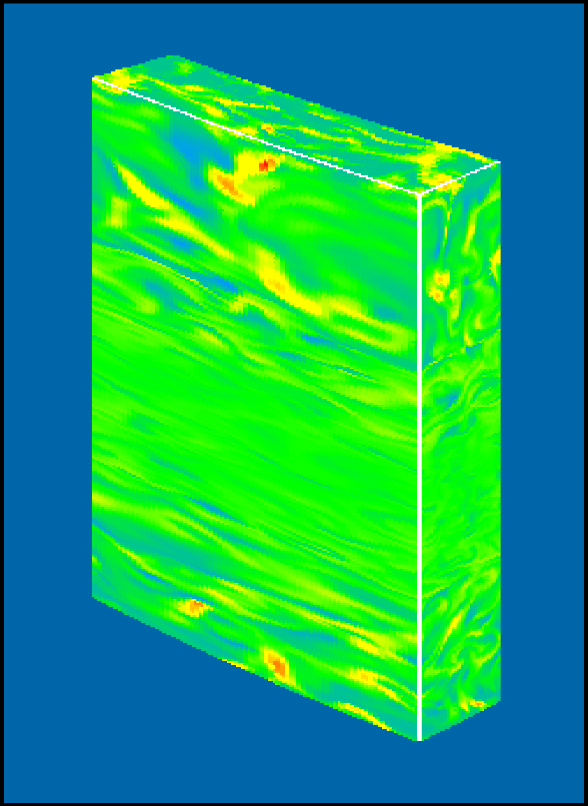
Accretion at the limit

- BH binaries in the Very High state, Quasars, NLS1 etc.
- Spectra dominated by (quasi-)thermal component
- Main mode of growth by accretion of SMBH in the Universe (Soltan argument)
- **However**, they are radiation pressure dominated, thus thermally and viscously unstable, whenever stress scales proportionally to total pressure
  - Powerful coronae (**Svensson and Zdziarski 1994**)
  - Limit cycle instabilities (slim discs; **Abramowicz et al. 1988**)
  - Clumpy two phases equilibrium (**Krolik 1998**)
  - Dissipation proportional to gas pressure only (**Coroniti, Sakimoto, Stella, Rosner in the 80s**)

Inhomogeneous discs, simulations

- First 3-D MHD simulation of radiation dominated discs (see N.Turner's talk) 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
- **Ballantyne et al. (2004;2005)** have instead studied the spectra of inhomogeneous discs (from radiative MHD simulations) illuminated from outside



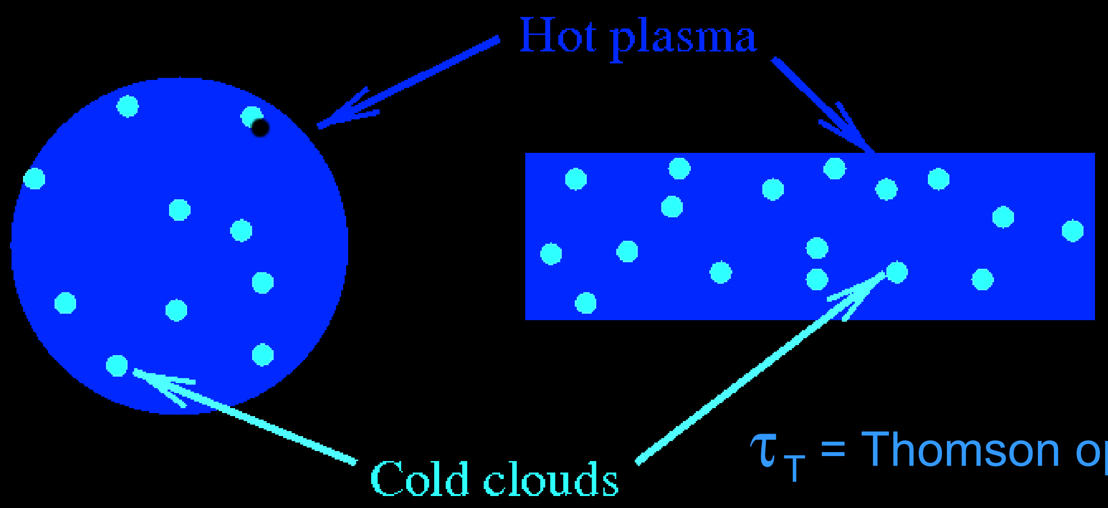
From Neal Turner's homepage

Inhomogeneous discs, spectra

- Spectral properties of inhomogeneous two-phase discs were studied early on (**Guilbert and Rees 1988**, **Celotti et al. 1992**)
- **Collin-Souffrin et al. (1996)** concluded that the cold phase was consistent only with irradiated clouds optically thick to Thomson scattering with large covering fraction (weak or absent absorption features; see also **Kuncic et al. 1997**)
- **Ballantyne et al. (2004;2005)** have instead studied the spectra of inhomogeneous discs (from radiative MHD simulations) illuminated from outside

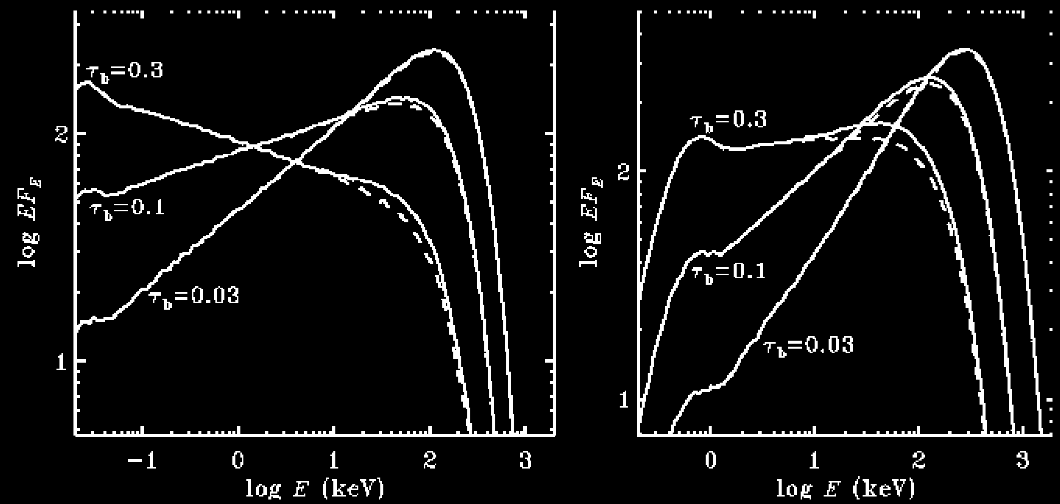
Inhomogeneous discs, spectra

Malzac and Celotti 2002

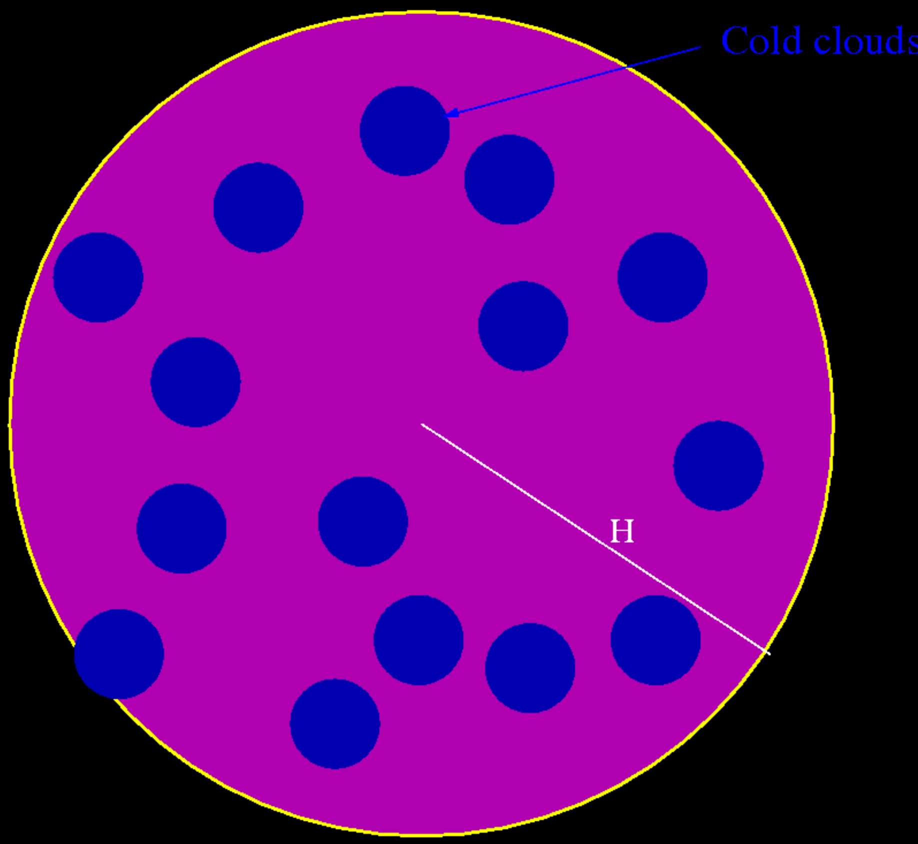


τ_T = Thomson optical depth of hot phase

τ_b = effective optical depth of cold clumps

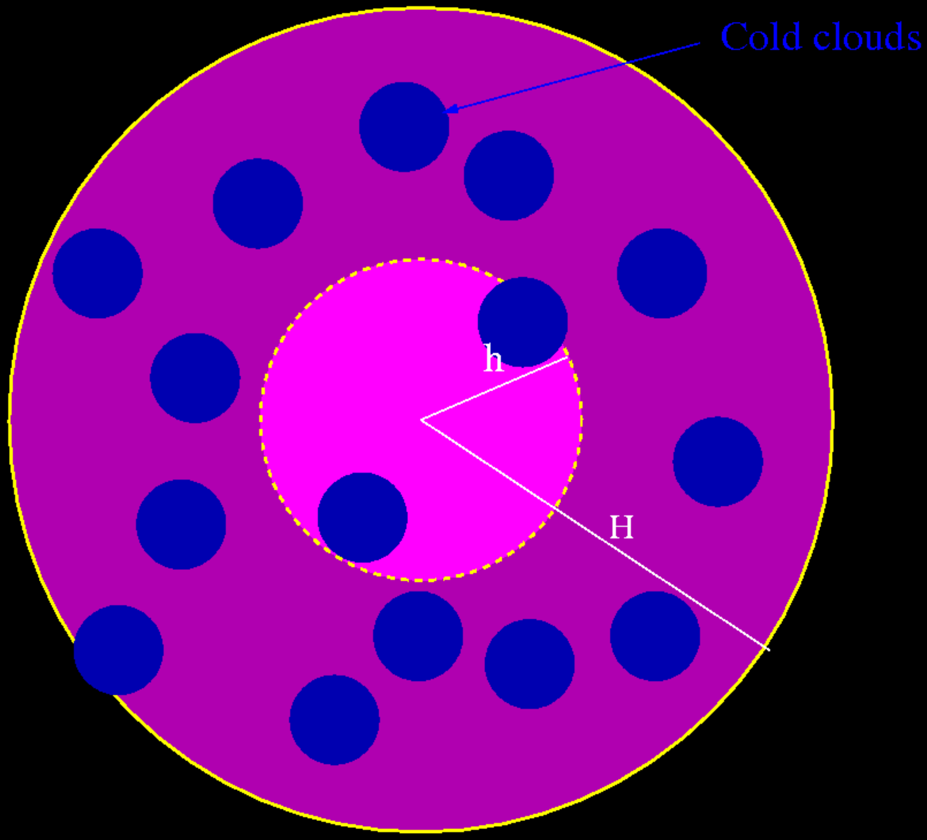


A new, two zones toy model



A new, two zones toy model

Dissipation concentrated in the inner sphere

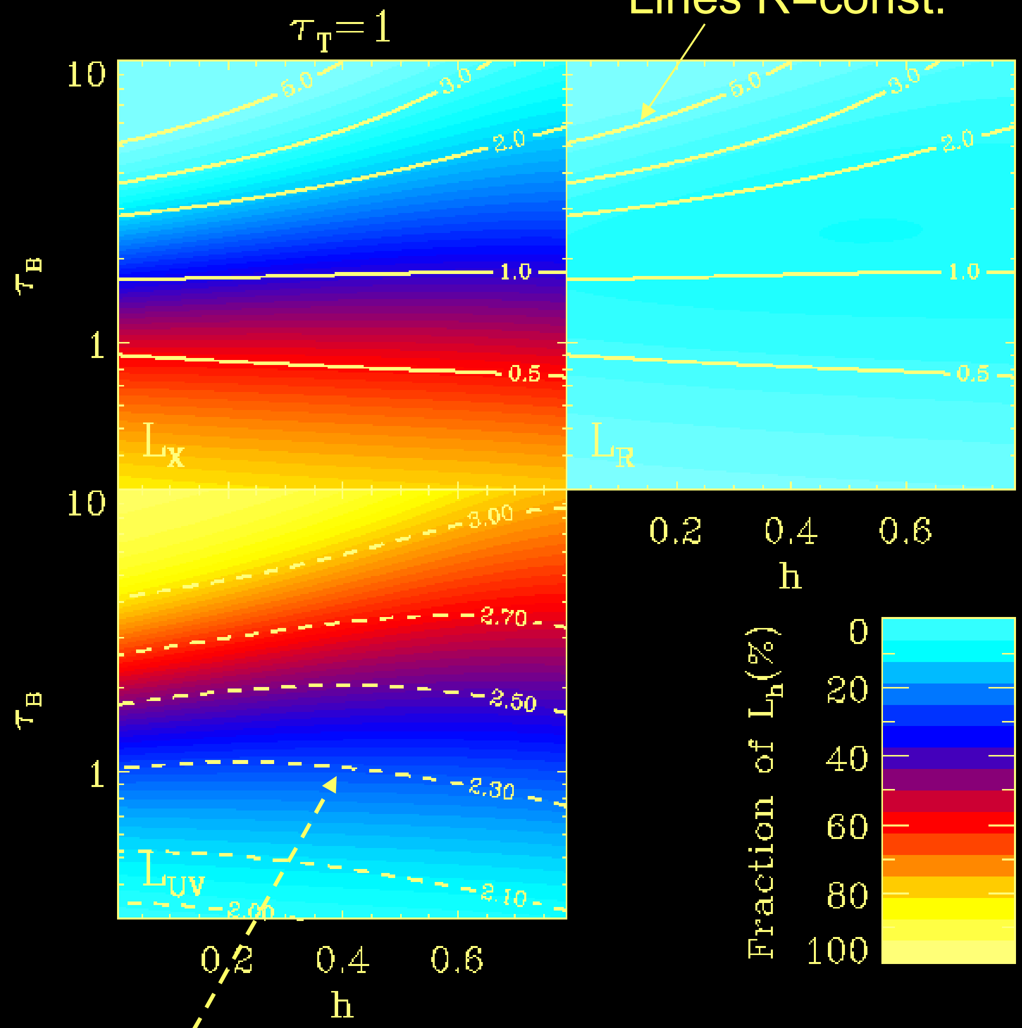


A new, two zones toy model

- 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
- Three spectral components: L_{UV}, L_X, L_R
- Within each zone
  - L_{UV} in: absorption and reprocessing of Comptonized and reflected radiation in the cold clumps
  - L_{UV} out: Compton scattering on the hot phase electrons
  - L_X in: localized heating, Compton scattering of soft and reflected radiation
  - L_X out: absorption and reflection on the cold clumps
  - L_R in: reflection of Comptonized and reflected (multiple refl.) component
  - L_R out: scattering on hot electrons and absorption by cold clumps
- Parameters are τ_T, τ_B , and albedos

Analytic model, spectra

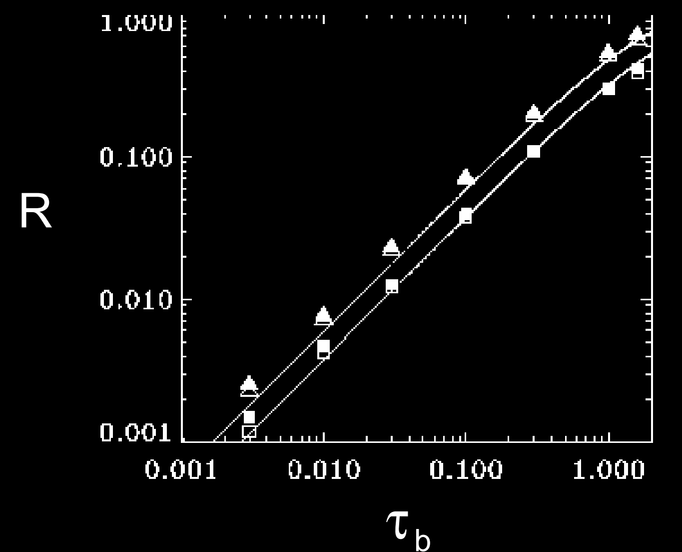
Lines R=const.



Lines Γ=const.

- Reflection fraction **R** increases with τ_b and, for large τ_b, decreases with h

Homogeneous case (h=1)

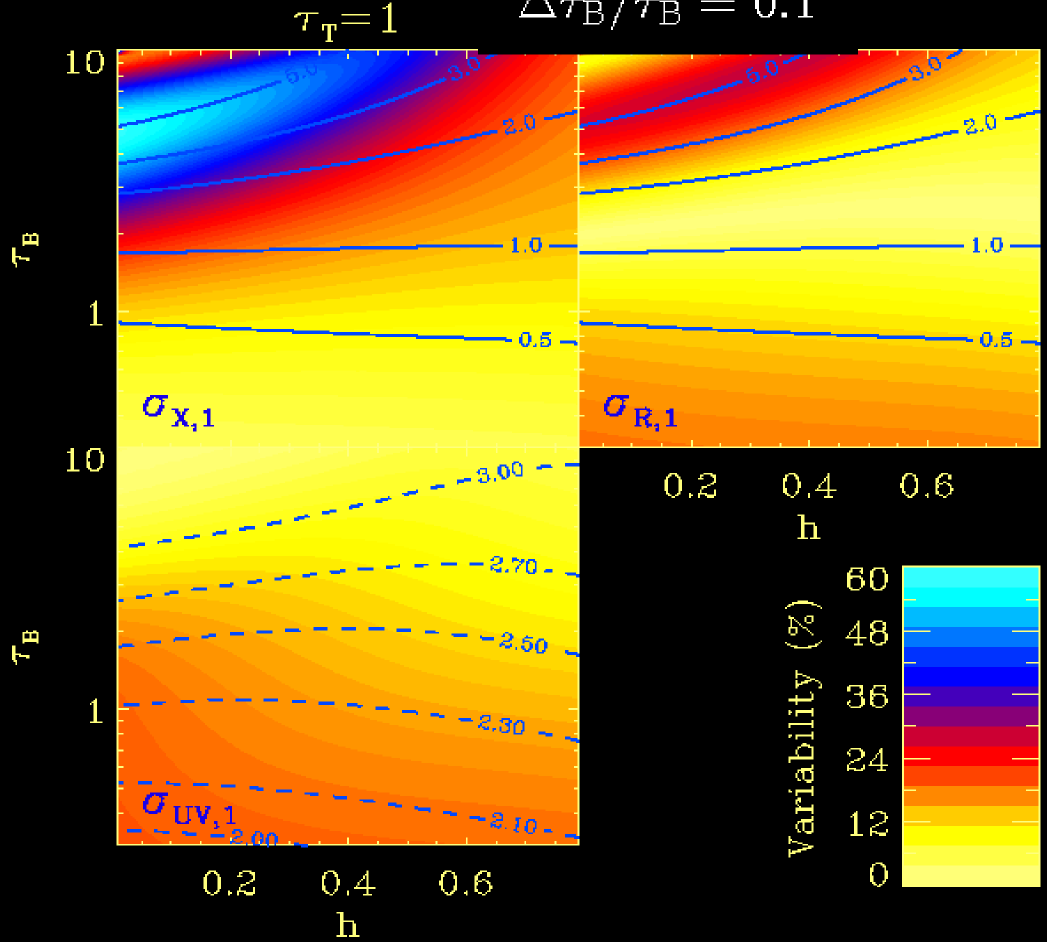


Malzac and Celotti 2002

Analytic model, variability

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

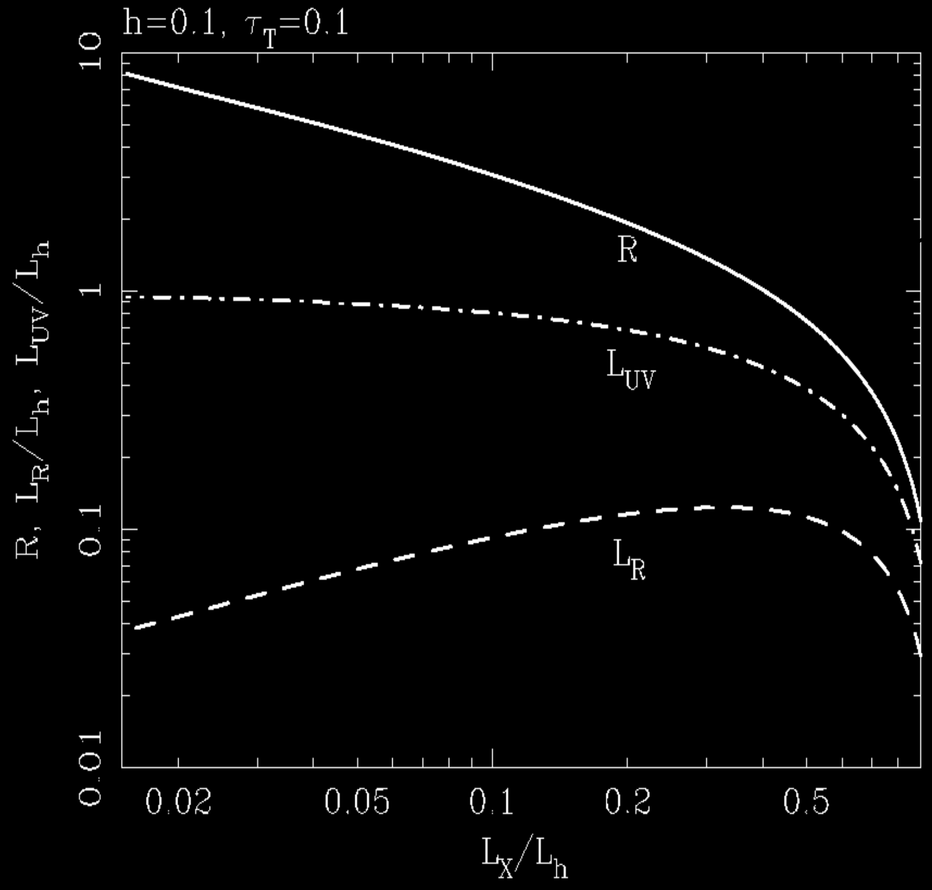
$$\Delta\tau_{\rm B}/\tau_{\rm B} = 0.1$$

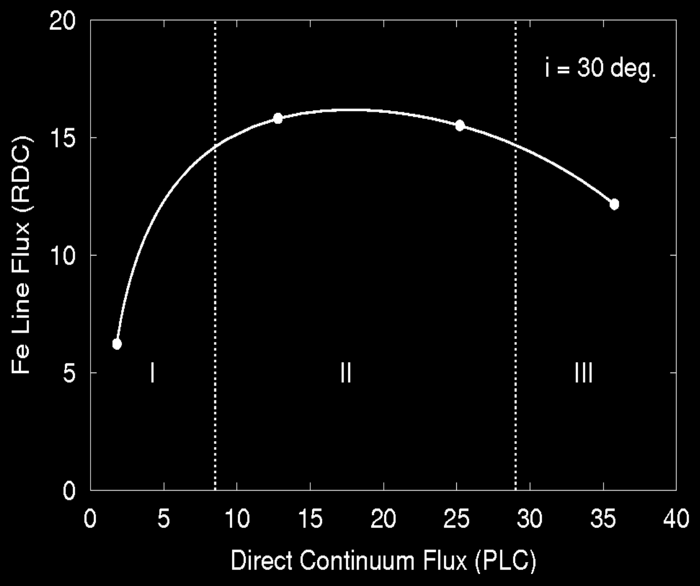


- Reflection fraction almost constant for 1<R<2
- More complex variability patterns should be expected: varying heating rate

Analytic model, variability

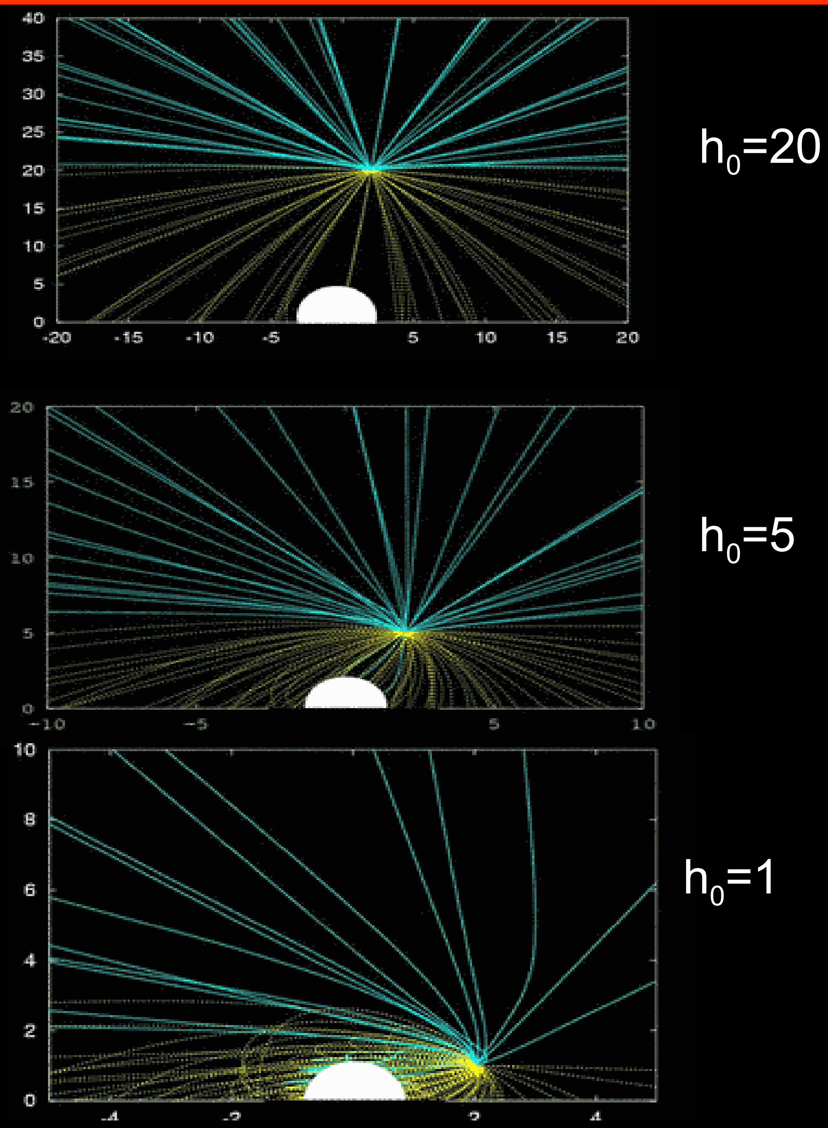
Reflection component (and Iron line) almost constant for large variations of the continuum flux (as observed e.g. in MCG-6-30-15)



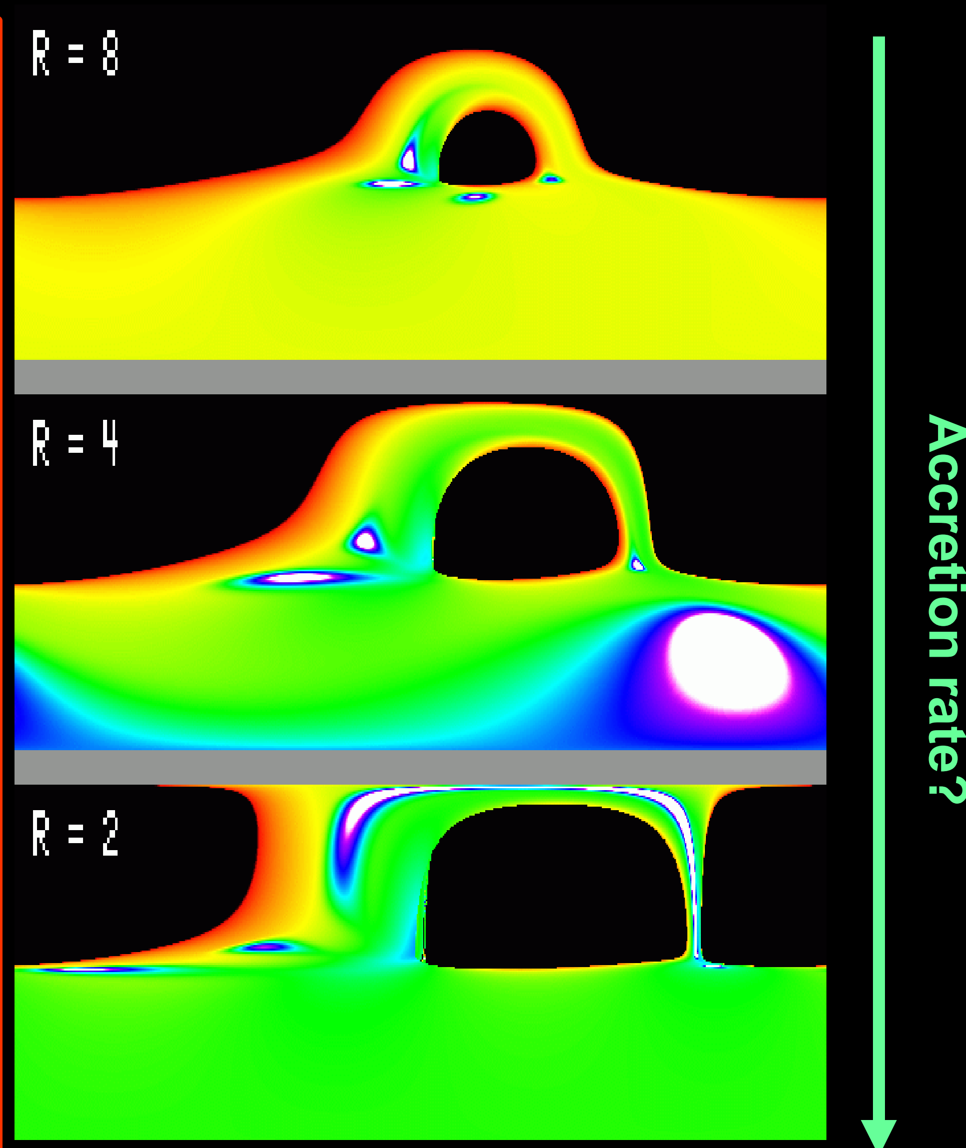


Miniutti and Fabian 2004

Analogies with the light bending model



Courtesy of G. Miniutti



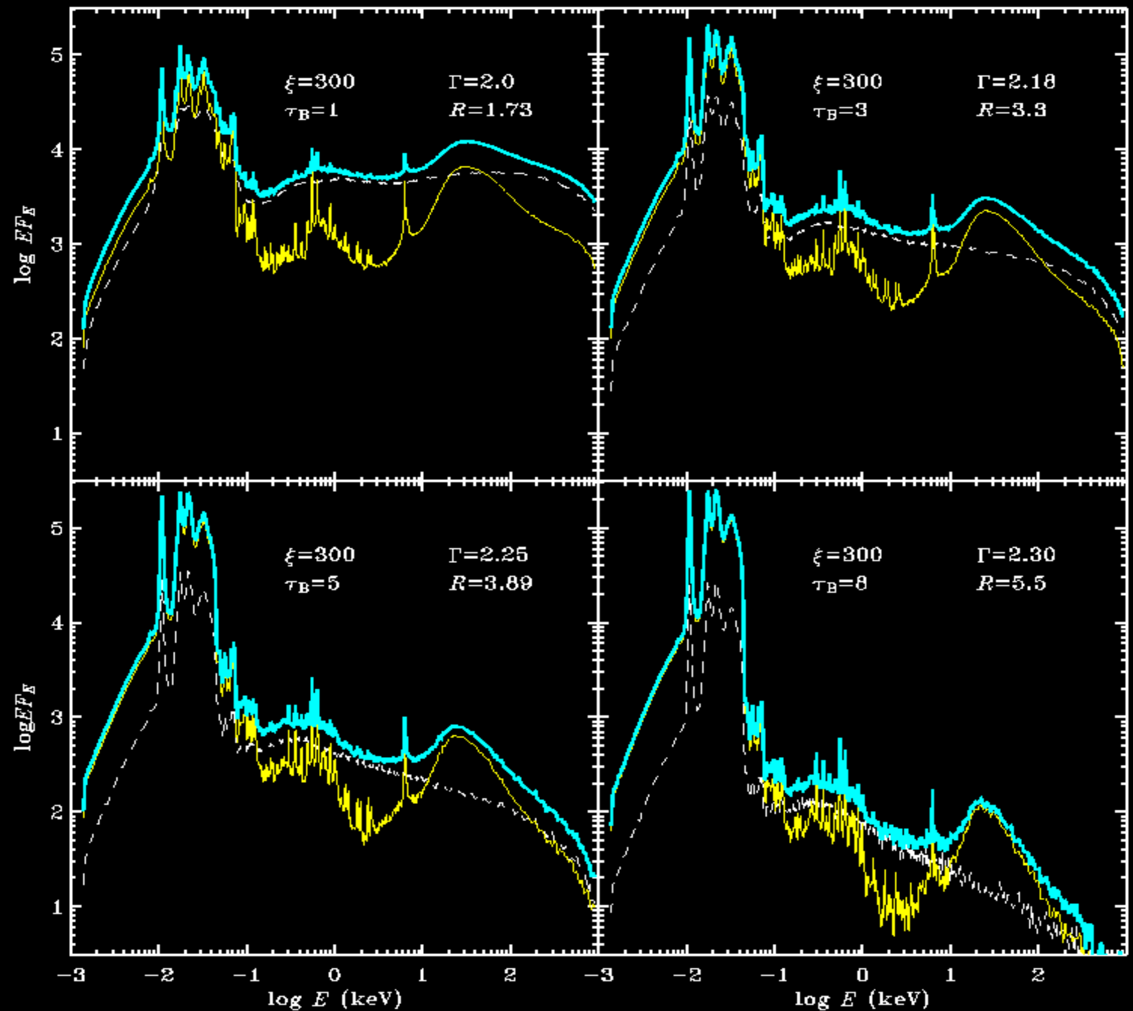
From K.P. Rauch’s homepage

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)**
- Multiple reflections taken into account

Simulations

$\tau_T = 1$

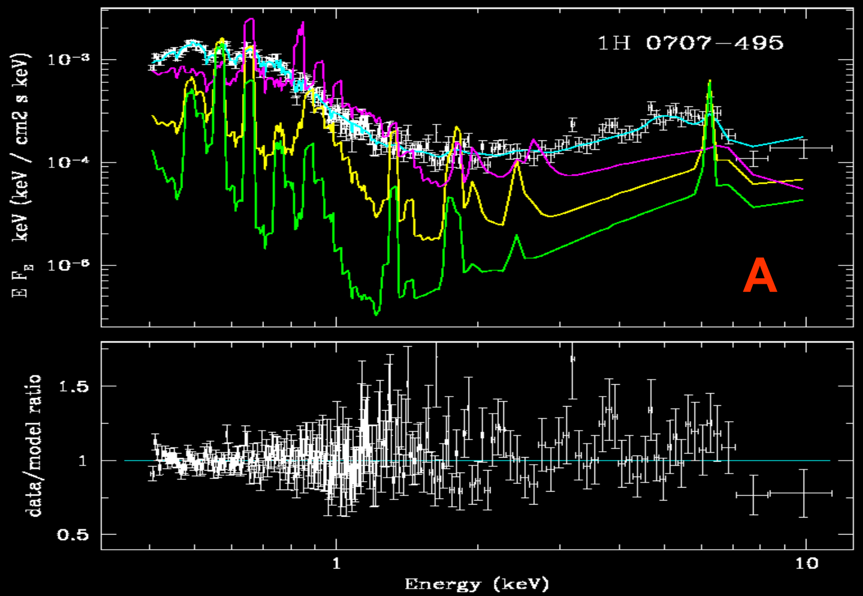


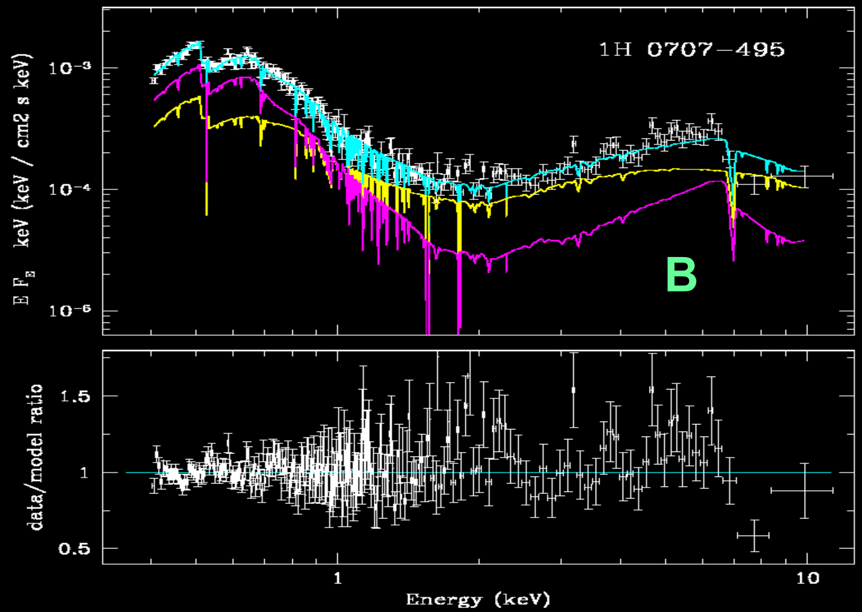
Parameters show results from PEXRAV fits in the 3-20 keV band

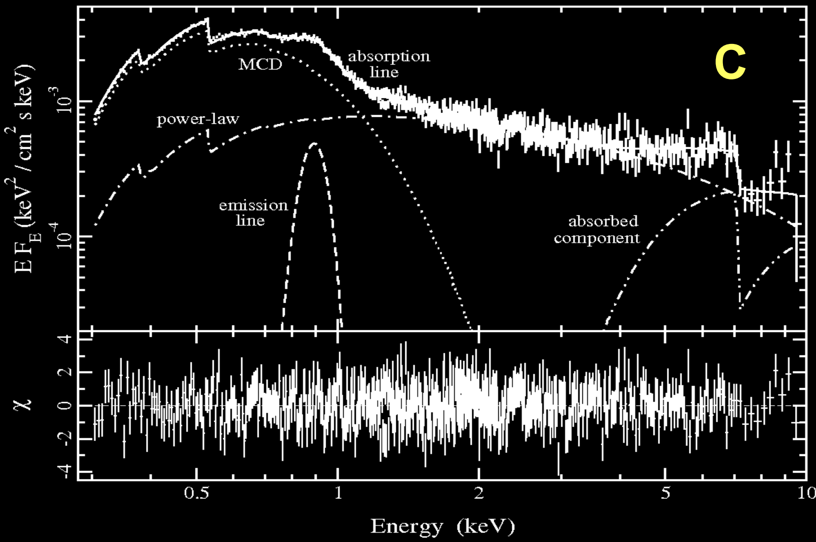
Inhomogeneous discs and NLS1s

- Strong Soft Excesses Steep X-ray spectra, Extreme variability
- XMM high quality spectra of NLS1 have revealed more features, most notably, a sharp, time variable drop above 7 keV (1H0707-495: **Boller et al. 2002**)
- Proposed models include:
  - (multiple) Ionized reflection + strong relativistic smearing (**Fabian et al. 2002; 2004**)
  - Partial covering (**Boller et al. 2002; Gallo et al. 2004**)
  - Comptonization continuum + Warm absorbers (**Gierlinski and Done 2005; Sobolewska and Done 2005**)

Inhomogeneous discs and NLS1







A: Three ionized reflectors

B: Comptonization, reflection and warm absorber

C: Partial covering

Inhomogeneous discs and NLS1s

- Inhomogeneous model has similar behavior to the ionized reflection with light bending
  - 0.2-2 keV emission is due to a collection of lines and bremsstrahlung in the hot surface layers of the cold medium (soft excess IS NOT a black body)
- Comprehensive analysis of many XMM observations of NLS1 (**Tanaka et al. 2004**) indeed shows that:
  - Temperature of soft excess (when fitted with BBody) is almost constant across more than 4 orders of amgnitude in source luminosity (but: warm absorbers? **Gierlinski and Done 2005**)
  - Stronger soft excesses tend to be associated with deeper 7keV drop
- Additional constraints on the partial covering model come from the rapid spectral variability (coverer has to be very close to the continuum source)

Conclusions

- Accretion flows close to the Eddington limit may develop strong inhomogeneities
- Not only the density, but also the dissipation may be inhomogeneous
- The observed spectral and variability properties of highly accreting BH are consistent with the characteristics of clumpy discs
- In general, with increase of luminosity, sources show a trend from "open" (illuminating source outside the cold reprocessor) to "closed" (illuminating source within the cold reprocessor) geometry
- Detailed spectral fitting of NLS1 has so far been unable to distinguish between ionized reflection, warm absorber and partial covering models
  - Are inhomogeneous discs the "truth in the middle"?
- More simulations to study the effects of varying ionization parameter and degree of heating inhomogeneity are underway!