Modeling the X-ray variability of active galactic nuclei with multiple flares

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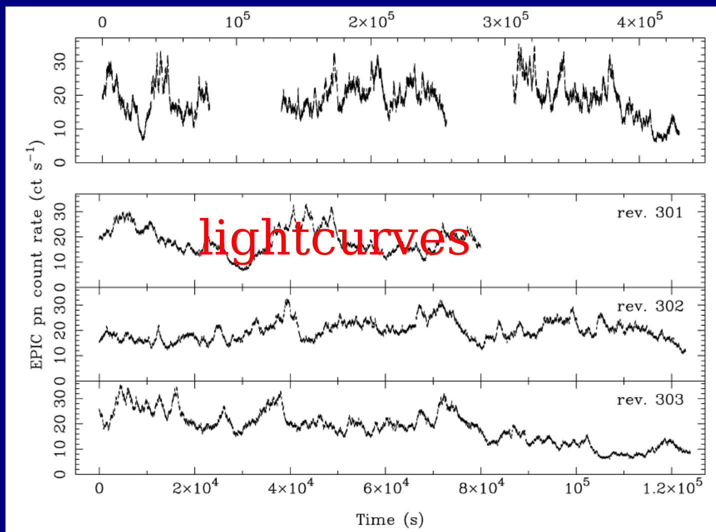
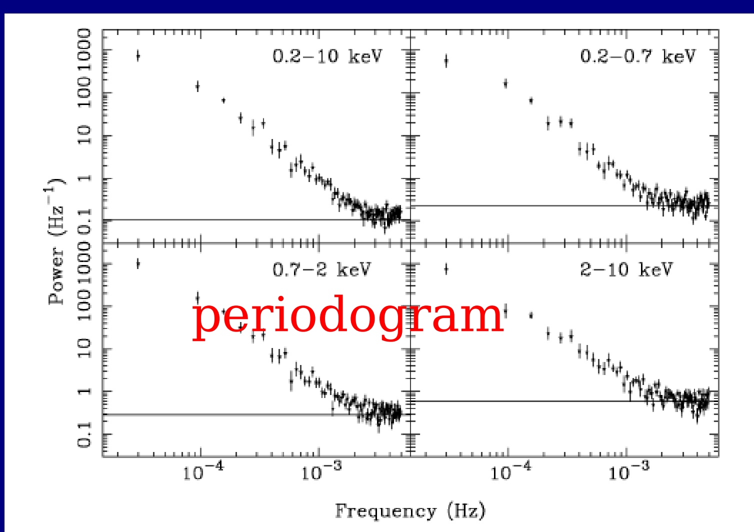
The 300 ksec XMM-observation of MCG-6-30-15

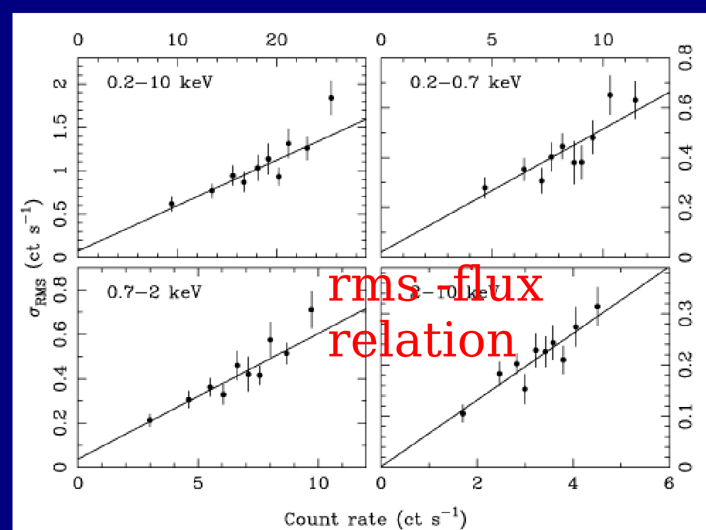


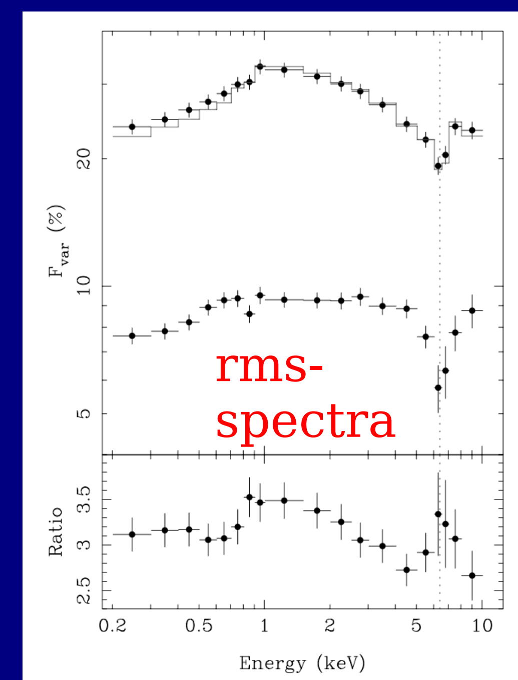
Several timing results to explain simultaneously…

Vaughan & Fabian (2004)

Vaughan et al. (2003)



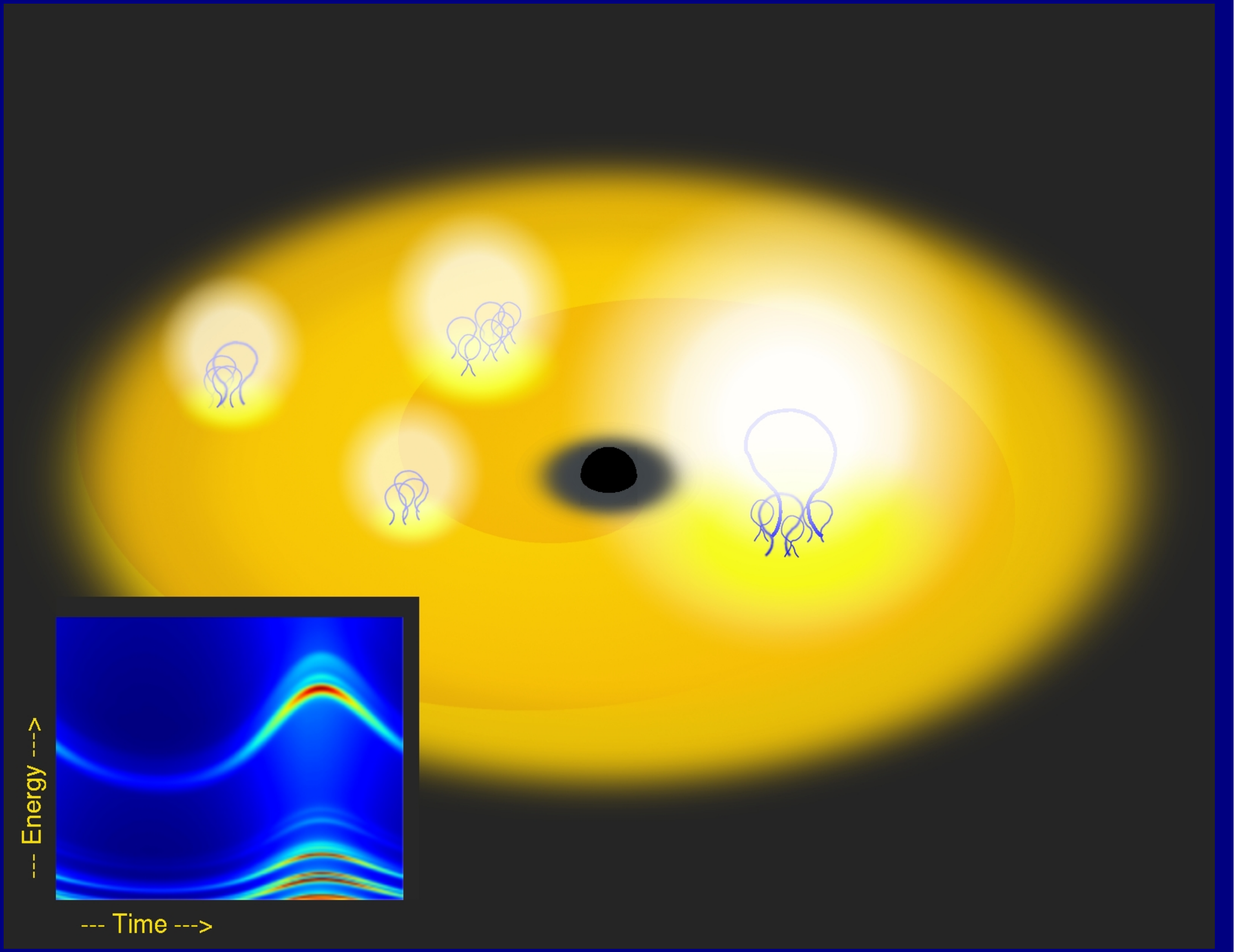




X-ray variability and multiple flares

Motivating the magnetic flare model

- Galeev et al. (1979)
- Haardt et al. (1994)
- Beloborodov (1999)
- Poutanen & Fabian (1999)
- ...



Spectral modeling

- Ross et al. (1999)
- Merloni & Fabian (2001a,b)
- Nayakshin & Kazanas (2002)
- Collin et al. (2003)
- Goosmann et al. (2007)

...

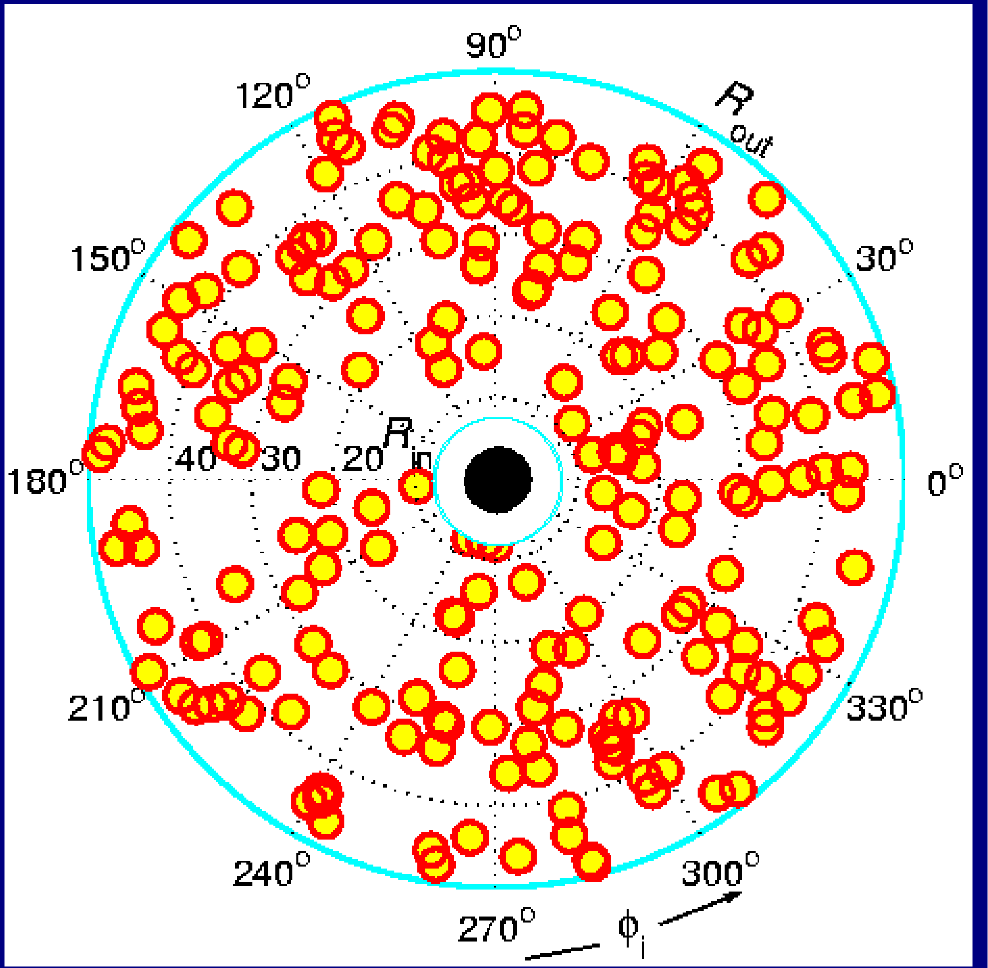
Monte-Carlo spot distributions

Parameterization of the radial probability density

$$f(r)=f_0\left(\frac{r}{r_0}\right)^{-beta}$$

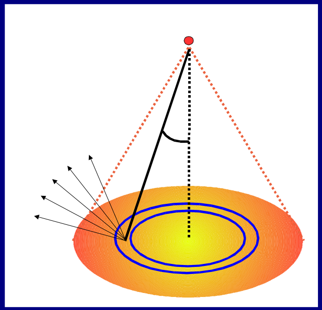
$$n(r)=n_0\left(\frac{r}{r_0}\right)^{2-gamma}$$

$$t(r)=t_0\left(\frac{r}{r_0}\right)^{delta}$$



Randomly distributed flares above an accretion disk (Czerny et al. 2004)

Considering a single flare



Computing the local reprocessed spectra

- Schwarzschild black hole with

  $M = 10^8\ M_{sun}$

  $dm/dt = 0.001$ Eddington units

  $r_{disk} = 7\ R_g$

- hydrostatic equilibrium

  Różańska (2002)

  +

  relativistic corrections

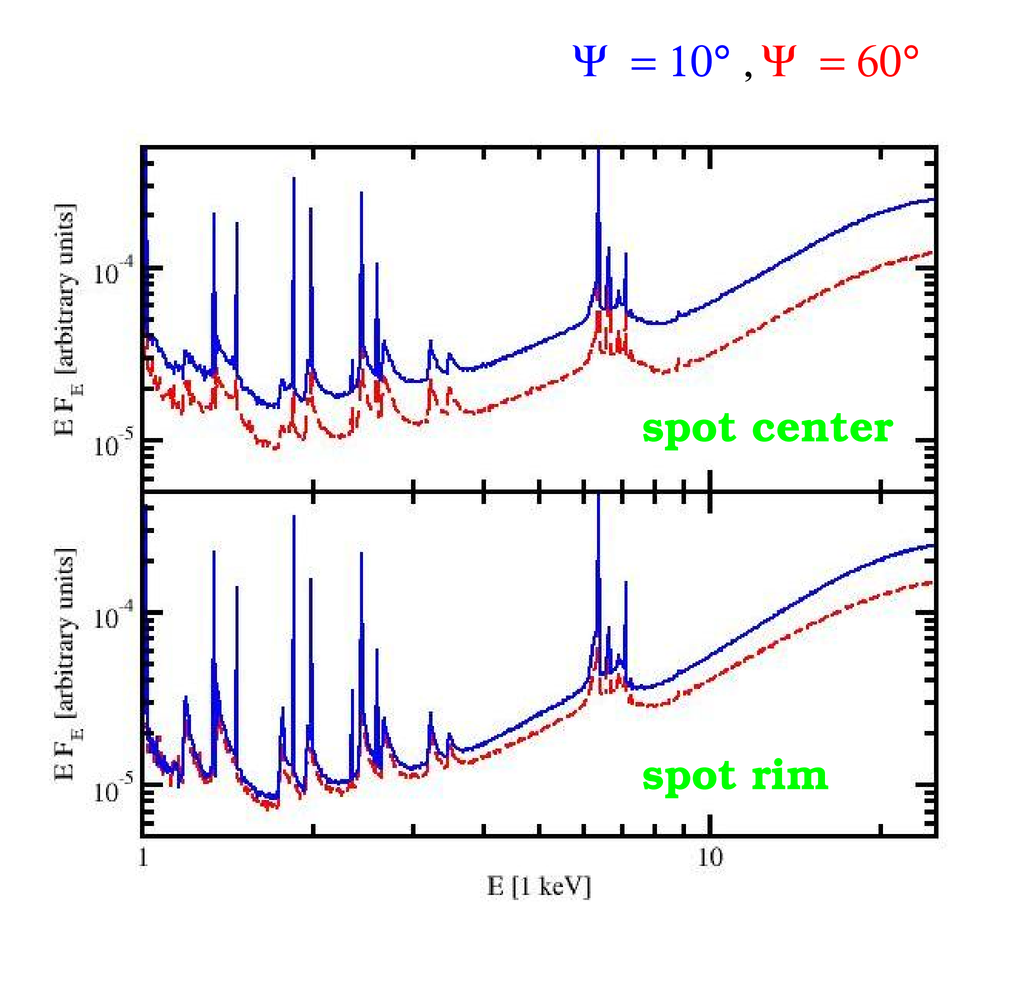
- local radiative transfer

  TITAN (Ali method)

  | |

  NOAR (Monte-Carlo)

  Dumont et al. (2000, 2003)



Goosmann et al., 2007, A&A, 475, 155

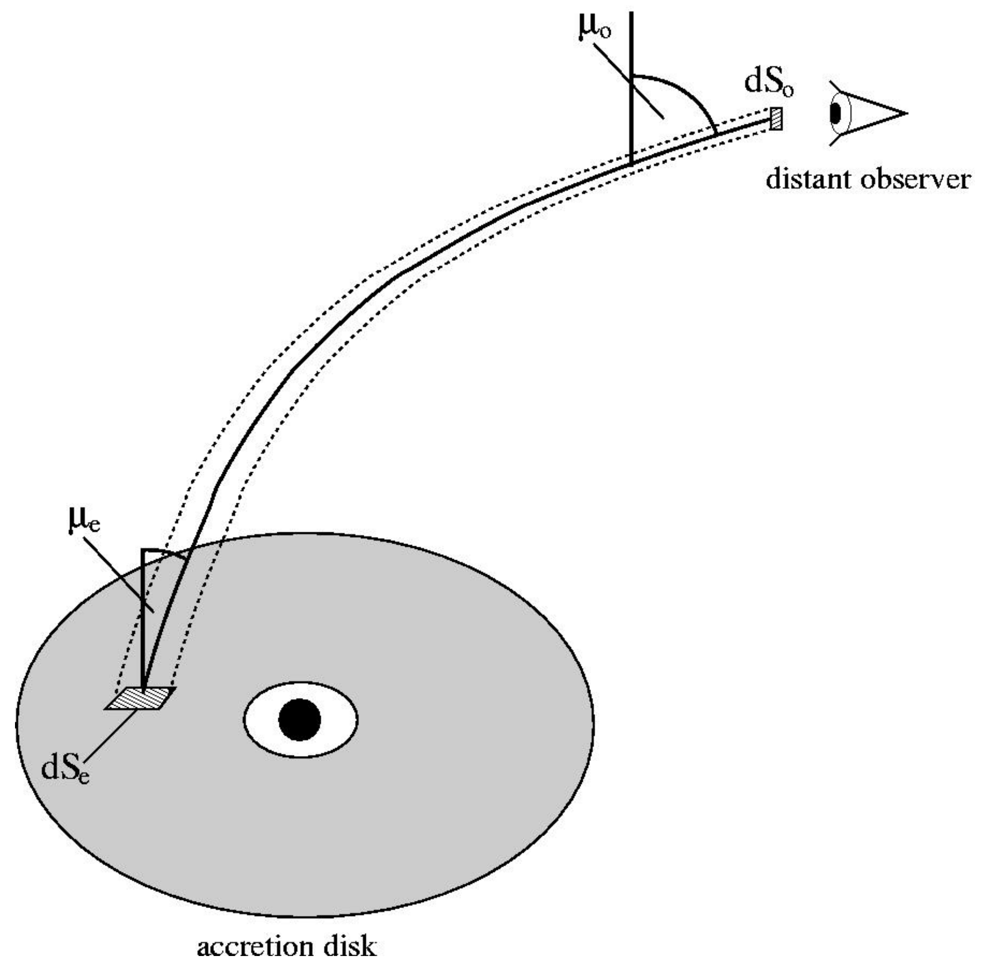
Including relativistic corrections...

... by applying a relativistic ray-tracing method:

KY code

(Dovčiak et al. 2004)

available for XSPEC with several emission models



$$\Delta N_o^{\Omega_o}(E, \Delta E, t) = \int_{r_i}^{r_o} dr \int_{\phi}^{\phi+\Delta\phi} d\phi \int_{E/g}^{(E+\Delta E)/g} dE_l \, N_l(E_l, r, \phi, \mu_e, t-\Delta t) \, g^2 l \, \mu_e r \, .$$

observed photon flux | **disk integration** | **ener-gy** | **local photon flux** | **trans-fer**

Variability offers a better access!

Modeling large spot distributions

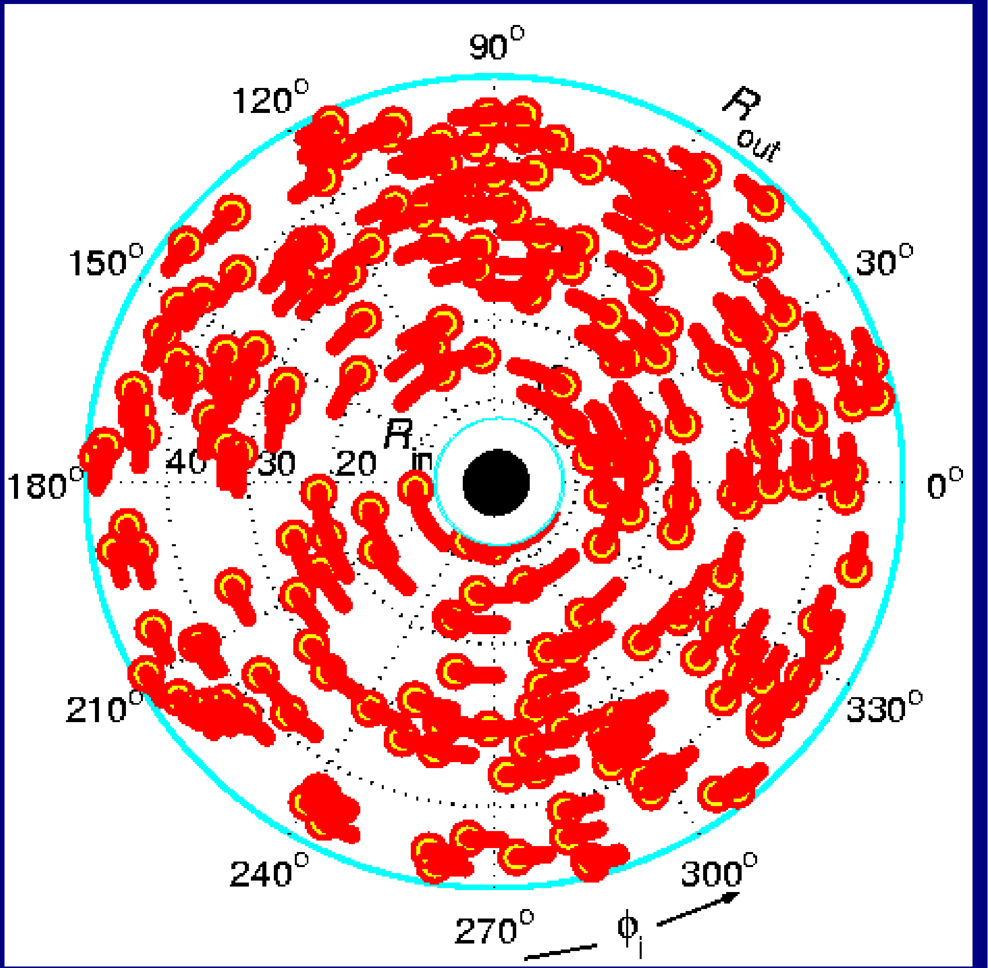
- Computing the rms variablity spectrum in two ways:

$$F^2_{var} = \Sigma \frac{\left(S_k(E) - \langle S(E) \rangle \right)^2}{(N-1) \langle S(E) \rangle^2}$$

$$F^2_{pp} = \Sigma \frac{4 [S_{k+1}(E) - S_k(E)]^2}{(N-1) [S_{k+1}(E) + S_k(E)]^2}$$

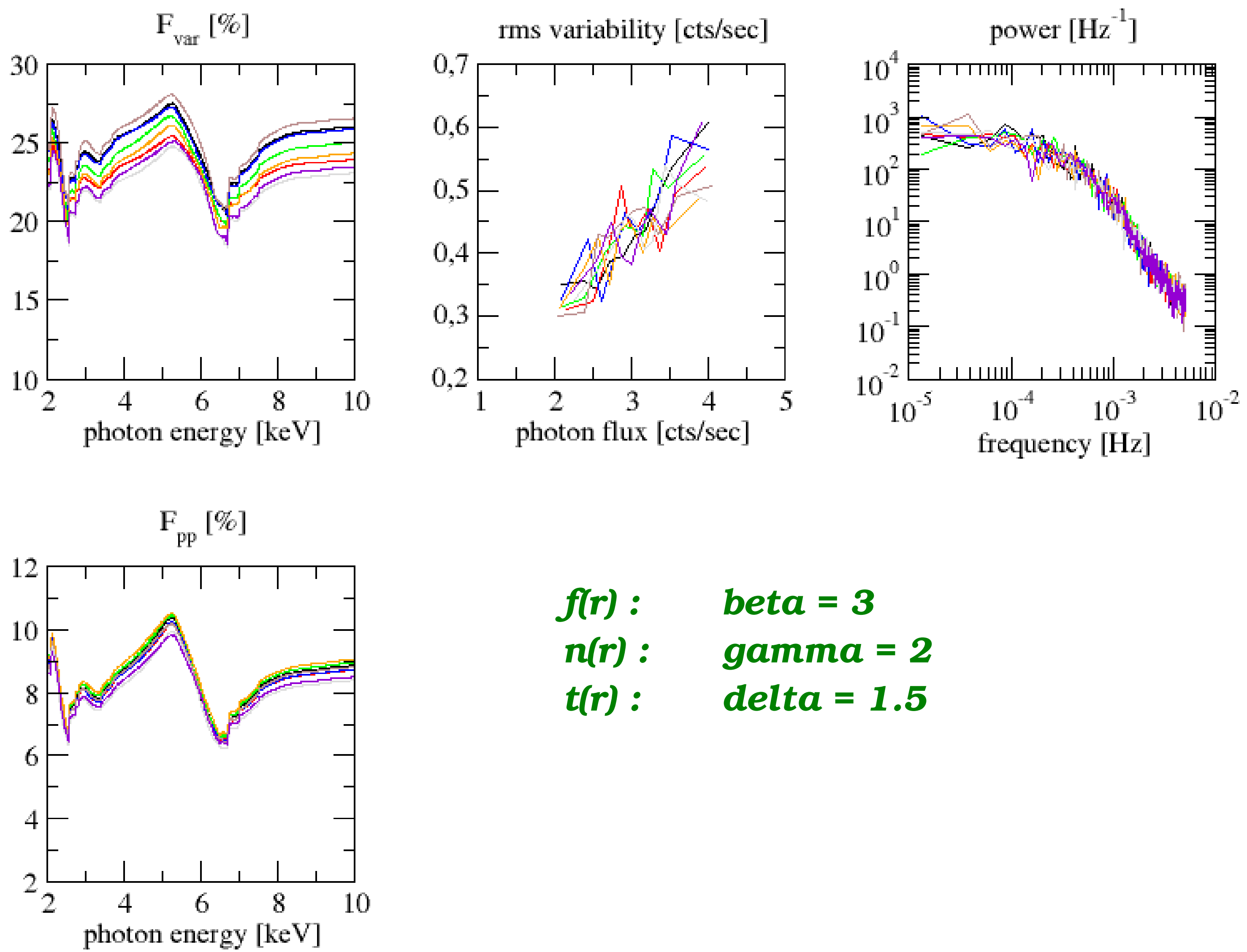
- Computing rms-flux relations

- Computing power spectra



Randomly distributed flares above an accretion disk (Czerny et al. 2004)

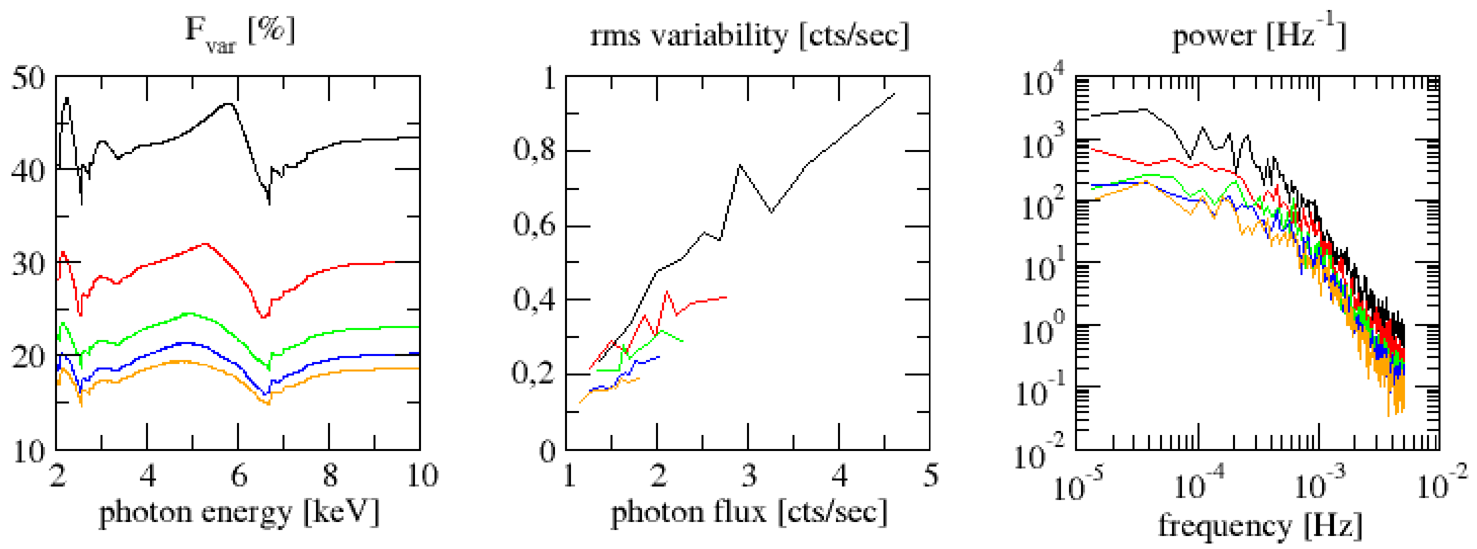
The impact of the random number generator

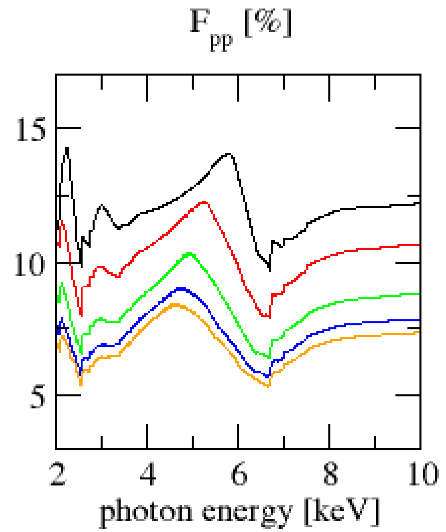


f(r) : *beta = 3*
n(r) : *gamma = 2*
t(r) : *delta = 1.5*

Goosmann et al. (in preparation)

Scaling the total average number of flares



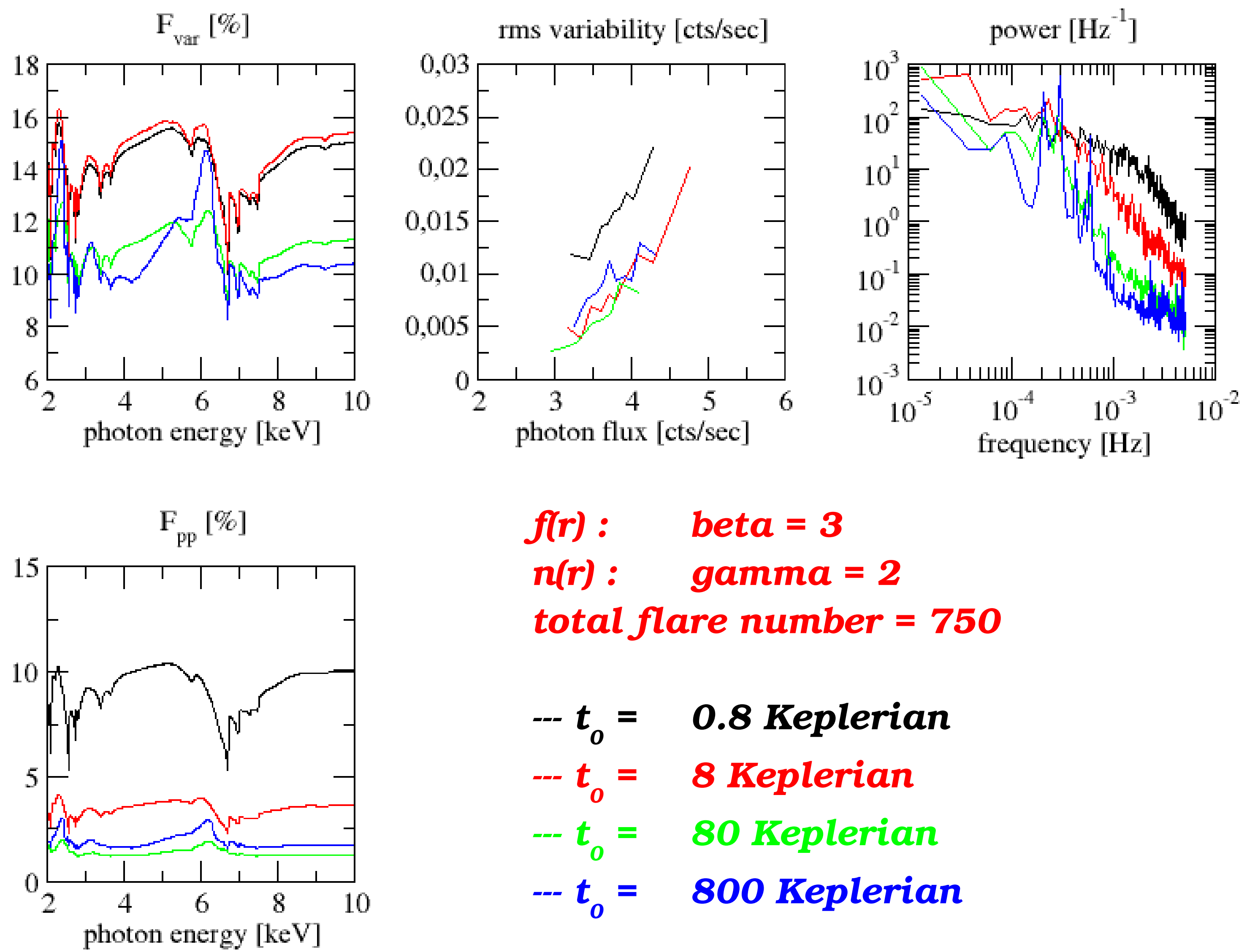


f(r) :beta = 3
n(r) : gamma = 2

total flare number = 100--500
black → orange

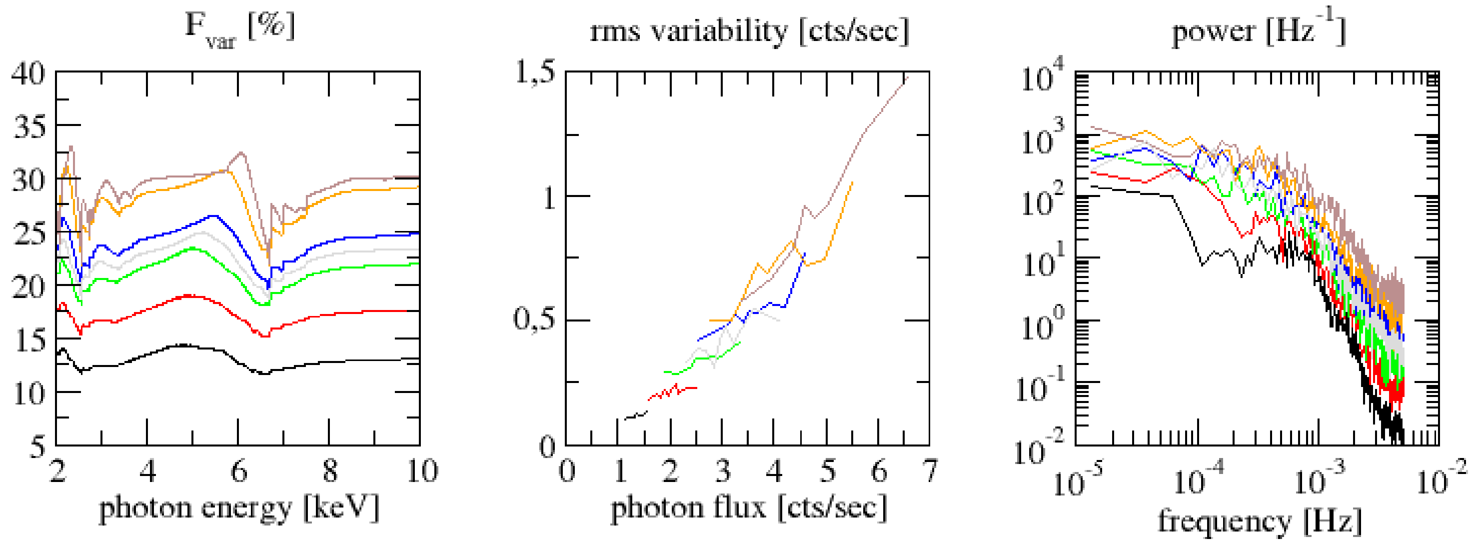
Goosmann et al. (in preparation)

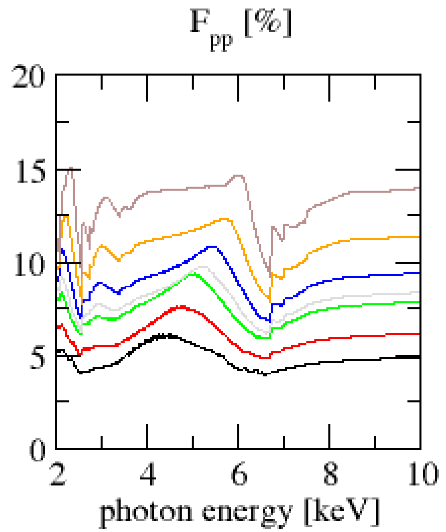
Scaling the normalization of the flare life-time



Goosmann et al. (in preparation)

Non-Keplerian scaling of the flare life-time





f(r) : ***beta = 3***

n(r) : ***gamma = 2***

t(r) : ***delta = 0.5 – 2.5***

Black → brown

Goosmann et al. (in preparation)

Investigating parameter dependencies

The overall variability level scales inversely with the average number of spots.

For steep emissivity and number density profiles, and only for this case, the observed relative drop of the rms spectrum across the iron line band is reproduced.

The shape of the power spectrum bends over around the frequency that corresponds to the orbital time scale at the inner disk radius. Changing the radial dependence of the flare lifetime does not significantly change this effect.

As soon as super-Keplerian flare lifetimes appear close to the marginally stable orbit, the power spectrum shows QPOs.

The rms-flux relation depends strongly on the model parameters but is always linear.

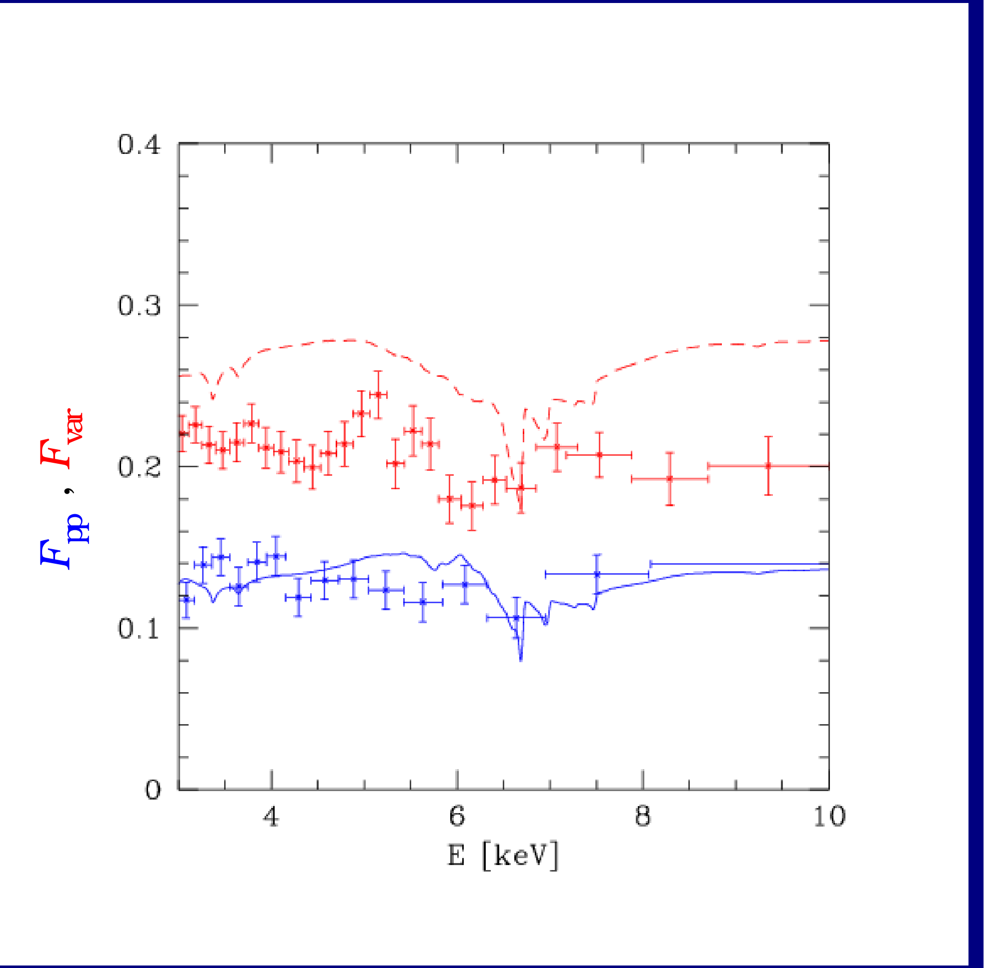
The 95 ksec XMM-observation of MCG-6-30-15

Reproducing the data

- A **good** description of the data for F_{pp} requires:
  - disk inclination ~30°
  - a strong reflection component
  - energy dissipation rising steeply toward the center of the disk
  - high black hole spin: $a/M = 0.95$

- These parameters **qualitatively reproduce** the lightcurves too

- **But:** the parameters do not reproduce the rms variability F_{var} very well.

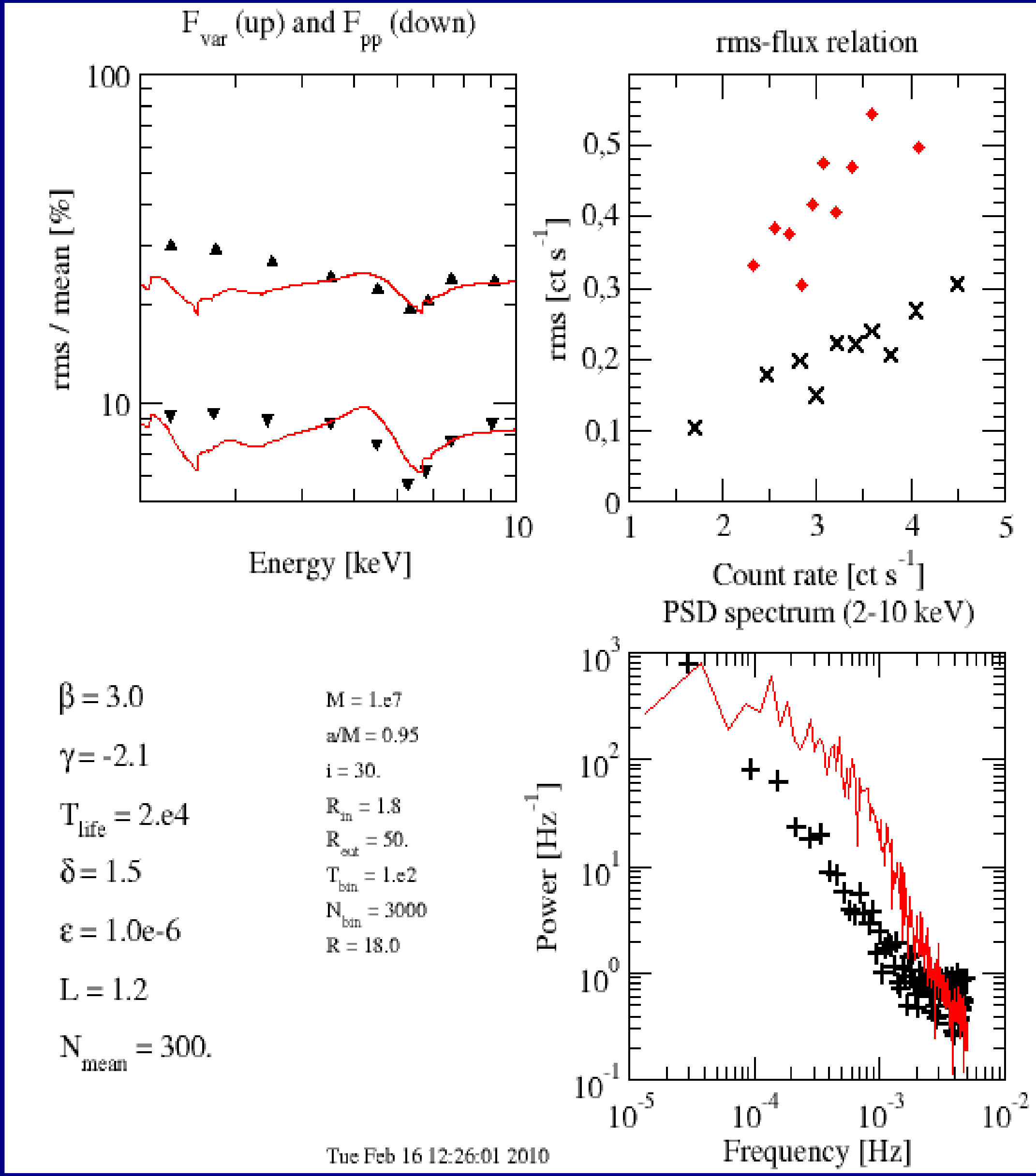


Goosmann et al. 2006, A&A, 454, 741

Confronting the model to the 300ksec data

Best representation of the observed data

- simultaneous reproduction of the rms variability *F*var and *F*pp in the iron line band
- In the soft X-ray range there is a relative lack of variability (impact of the warm absorber? reprocesssing by distant material?)
- the parameters do not quantitatively reproduce the rms-flux relation and neither the power spectrum.



Goosmann et al. (in preparation)

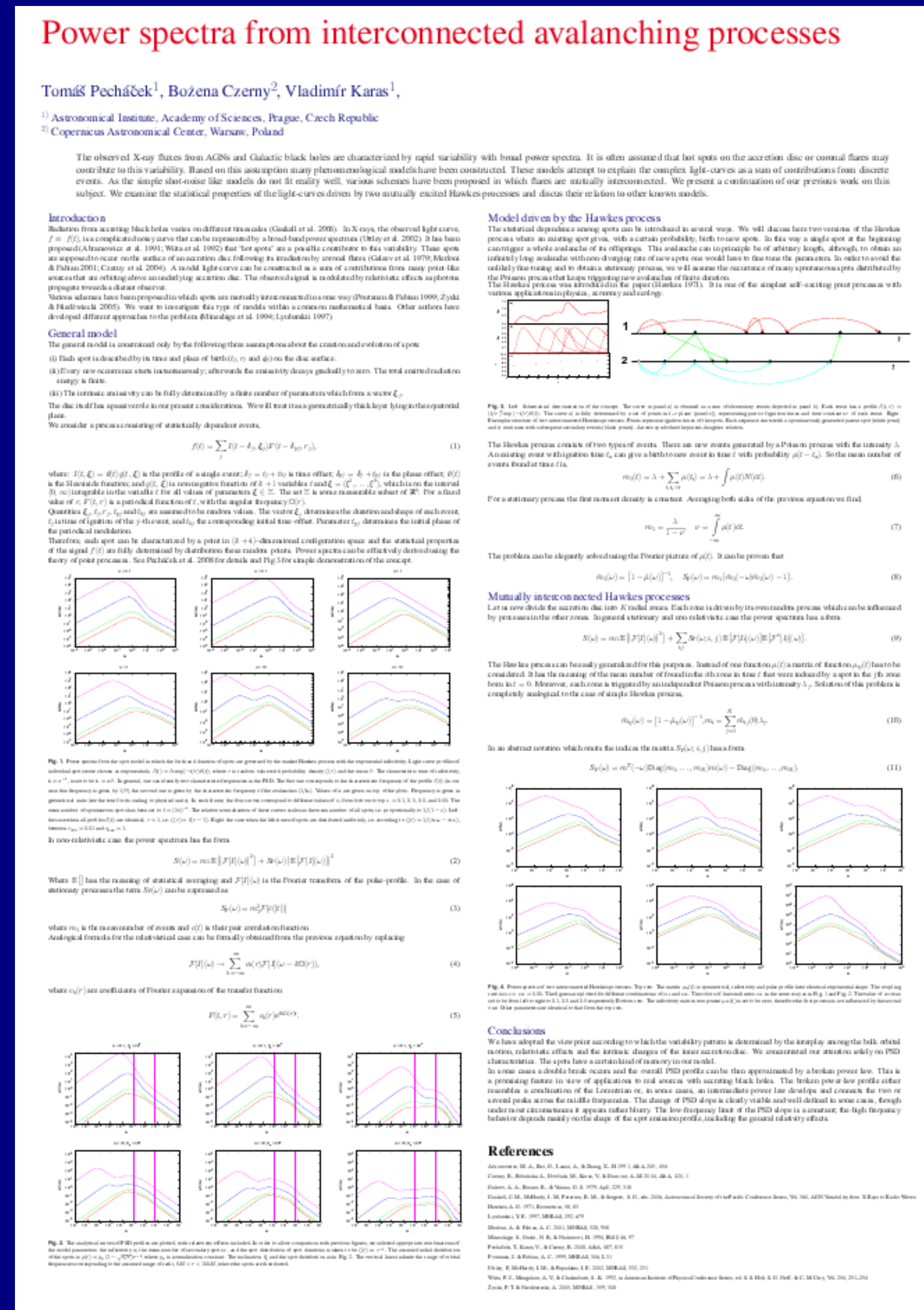
A possible way out for the power spectrum?

Broader power spectra can be constructed when assuming flare avalanches.

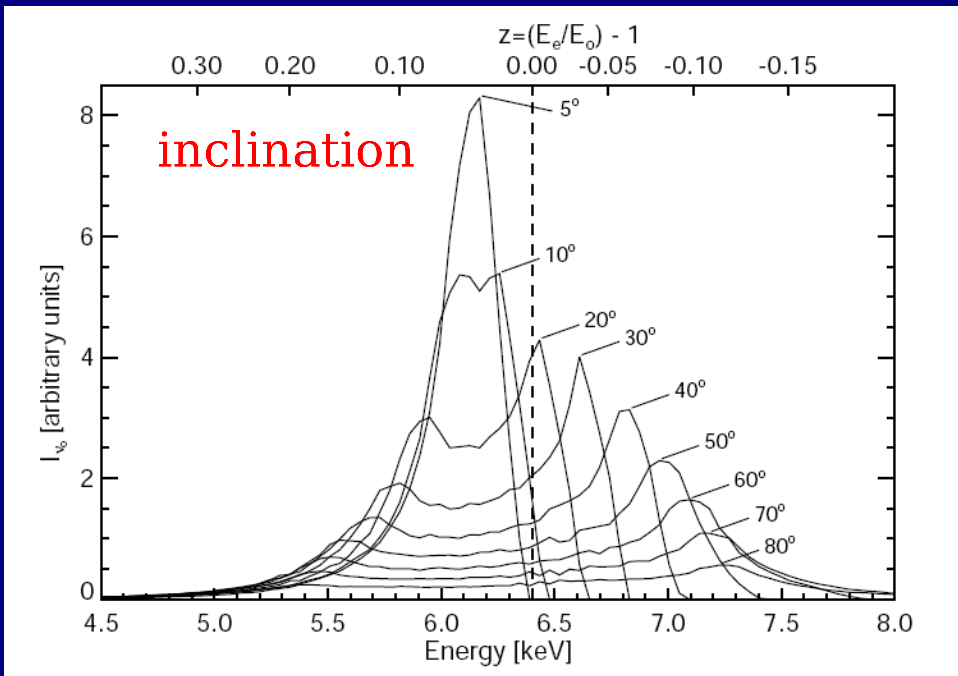
→ Follow-up work by Trzeńiewski et al. (in preperation)

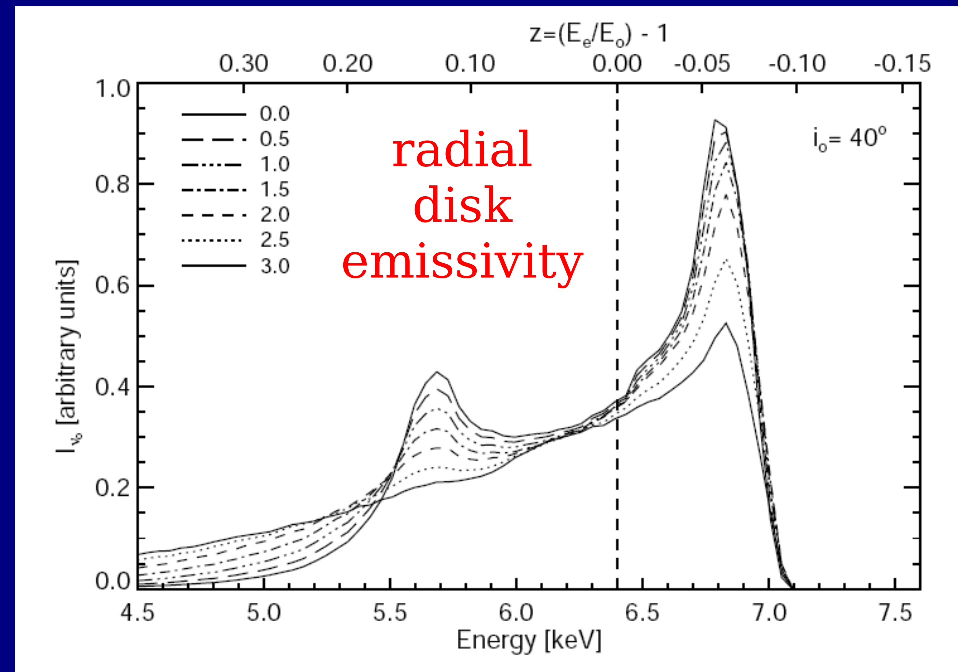
→ Poster E07
Pecháček, Czerny & Karas

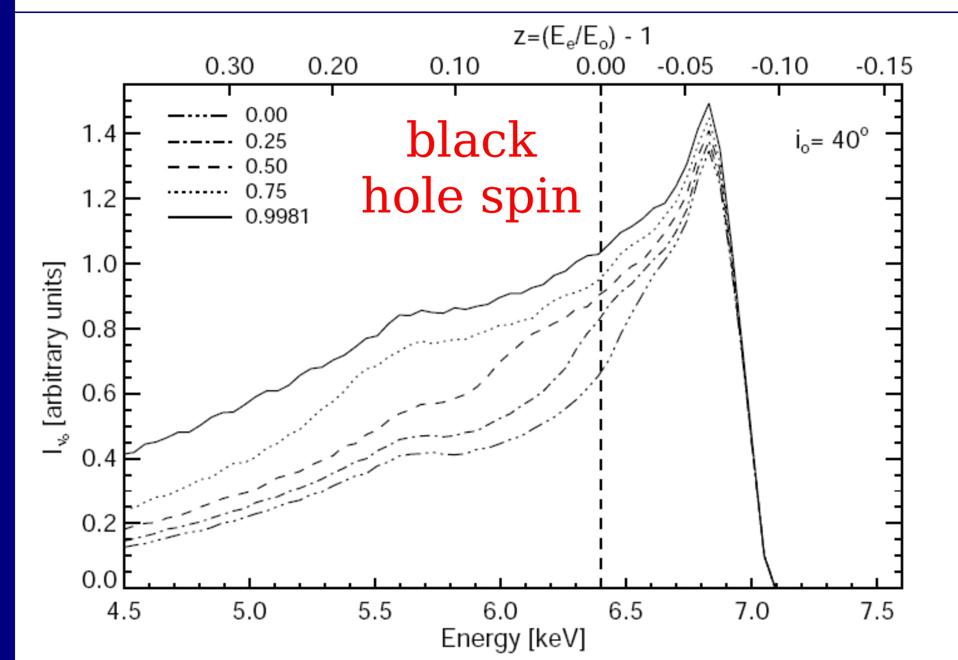
Thanks!



Constraining the spin *a* of the black hole...







...when the irradiation pattern of the disk cannot be resolved?

Problem: ***Degeneracy of parameters!***

Reynolds & Nowak (2003)

Long-term reaction of the disk

Parameterization of the irradiated disk atmosphere

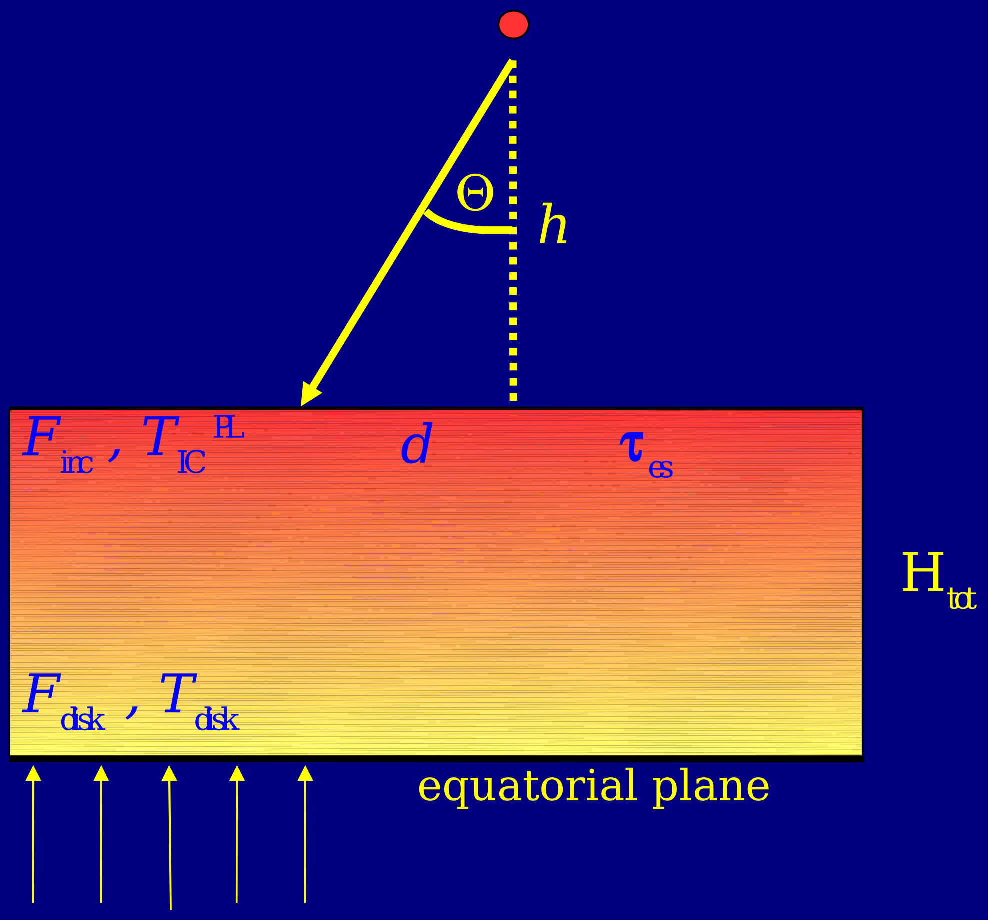
$$F_{inc} = f_0 F_{disk} \frac{h^3}{(d^2 + h^2)^{3/2}}$$

$$T_{IC} = \frac{T_{IC}^{PL} F_{inc} + T_{disk} F_{disk}}{F_{inc} + F_{disk}}$$

$$\Xi_{bot} = 1.22 \frac{T_{IC}}{[10^8 K]}$$

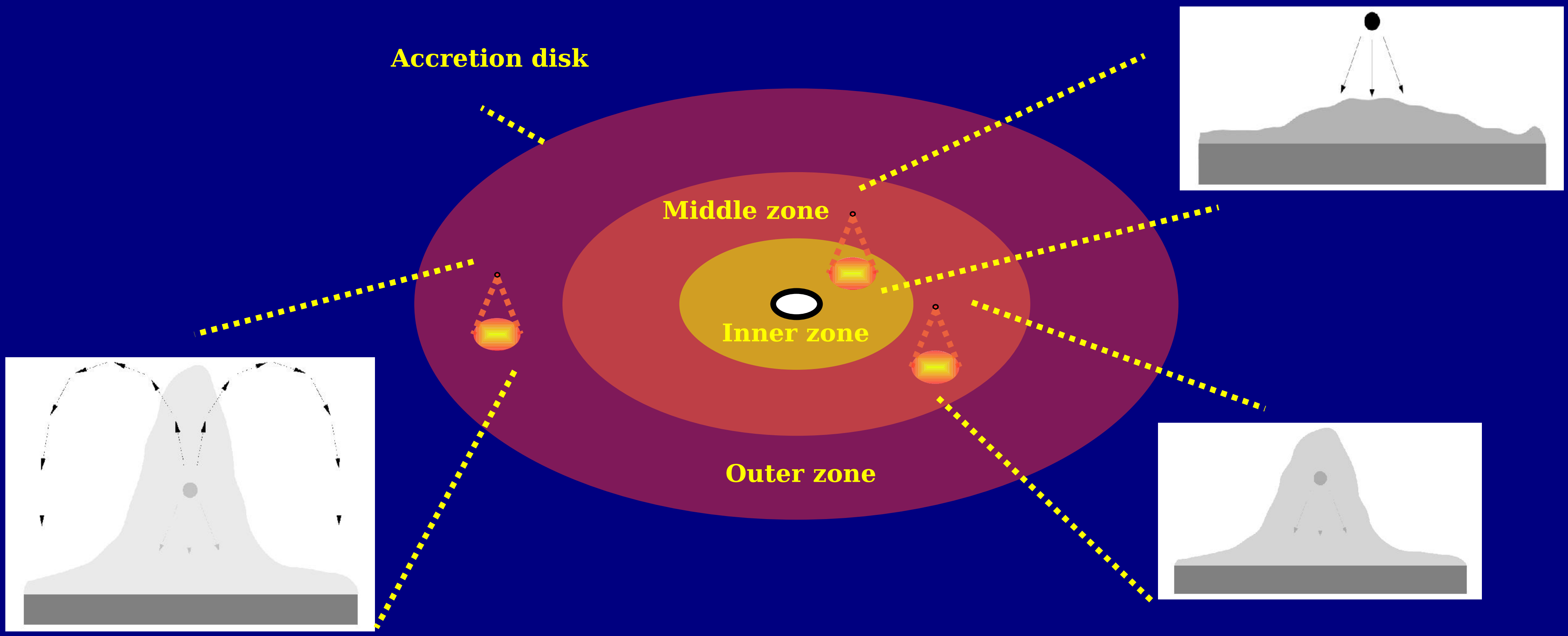
$$H_{hot} = \sqrt{\frac{k T_{IC} r^3}{m_H G M}}$$

$$\tau_{es} = \frac{F_{inc} \kappa_{es} r^3}{\Xi_{bot} c G M (H_{hot} + h)}$$



Long-term reaction of the disk

Computation of the disk height and optical depth



Czerny & Goosmann (2004)