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The role of dust in shaping the BLR

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Introduction, Motivation, Results and Summary – all in one!

I was always impressed by the accuracy of the measurement of the size of the BLR. The scaling was so perfect, but from my point of view is was with the wrong quantity! The expected scaling should be with the square root of the bolometric luminosity, or more accurately – with the ionizing flux. But it was with the monochromatic flux! This should not happen. Especially, for the same monochromatic flux, the ionizing fluxes of the Seyfert 1 galaxies and Narrow ine Seyfert 1 galaxies are quite different. More mathematically, the accretion process is decribed by three parameters: black hole mass, accretion rate, and spin. The monochromatic flux depends on the product of mass and accretion rate while the bolometric luminosity depends only on the accretion rate and spin. So this mismatch should lead to a large dispersion in reverberation measurements, and it did not. It puzzled me for a long time.
Then I thought that actually there is one more quantity which also depends just on the product of the mass and accretion rate, and this is the temperature at a given radius. So we can calculate the temperature at the radius implied by the reverberation studies. It should contain only some universal physical constants, and be thus the same for all sources. I told my (then) graduate student, Krzysztof Hryniewicz, to calculate all the numerical coefficients correclty. I simply thought: the only special value of the temperature is the dust sublimation temperature. So either this is this value, or … When he came back with the value of 995 K I was really happy! We published our study as Czerny & Hryniewicz (2011). I know it cannot be THAT SIMPLE but it seems like a good starting point.

If you wish to know more, read the following slajds.

Ideas for origin of the BLR

It would be nice to know the mechanism of BLR formation – it would make our discussion on the unification scheme much easier. But we are not there yet.

So far, there are a number of possibilities around:

- Magnetic winds (does not specify the inner radius)
- Disk self-gravity
- Disk transition from radiation to gas pressure
- Failed Radiatively Accelerated Dusty Outflow (FRADO)

FRADO means something/somebody rather ugly, dirty etc.

Ideas for origin of the BLR

It would be nice to know the mechanism of BLR formation – it would make our discussion on the unification scheme much easier. But we are not there yet.

So far, there are a number of possibilities around:

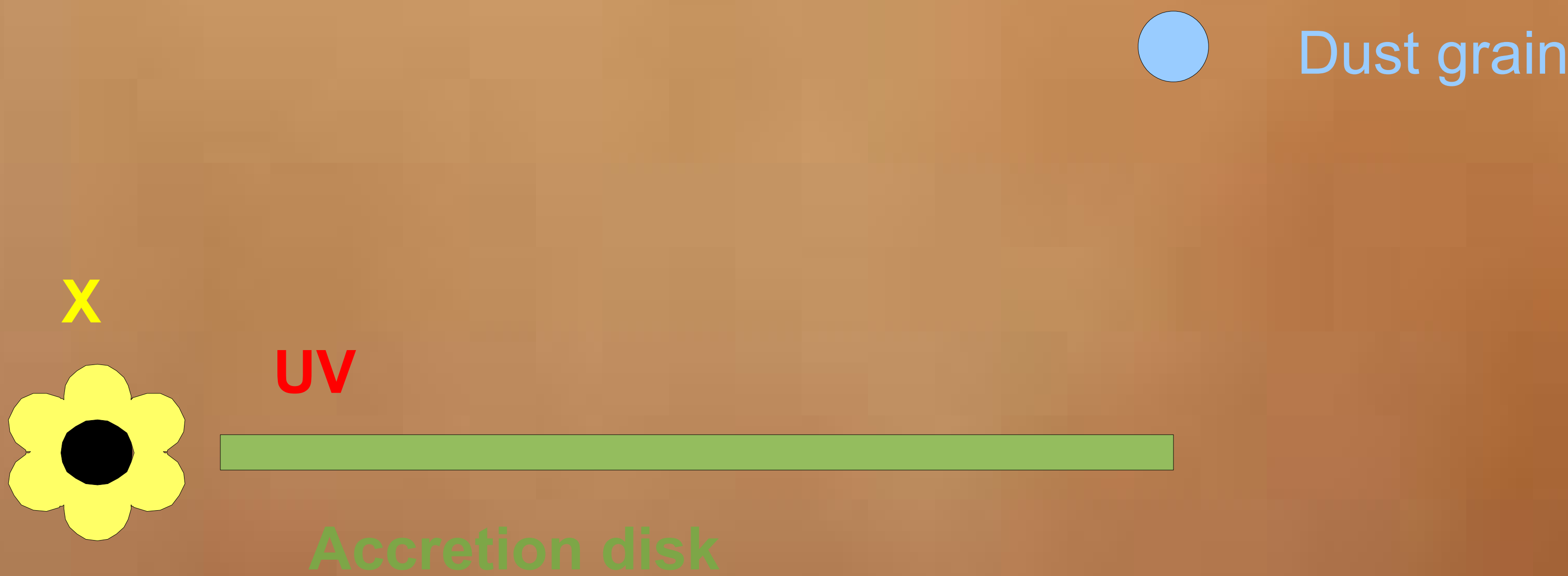
- Magnetic winds (Elitzur & Shlossmann 2006; Elitzur & Ho 2009; Elitzur et al. 2014)
- Disk self-gravity (Collin & Zahn 1999, 2008; Wang et al. 2012)
- Disk transition from radiation to gas pressure (Risaliti & Elvis 2010)
- Failed Radiatively Accelerated Dusty Outflow - FRADO (Czerny & Hryniewicz 2011; Galianni & Horne 2013)

FRADO: failed radiatively accelerated dusty outflow as an idea for LIL part of the BLR

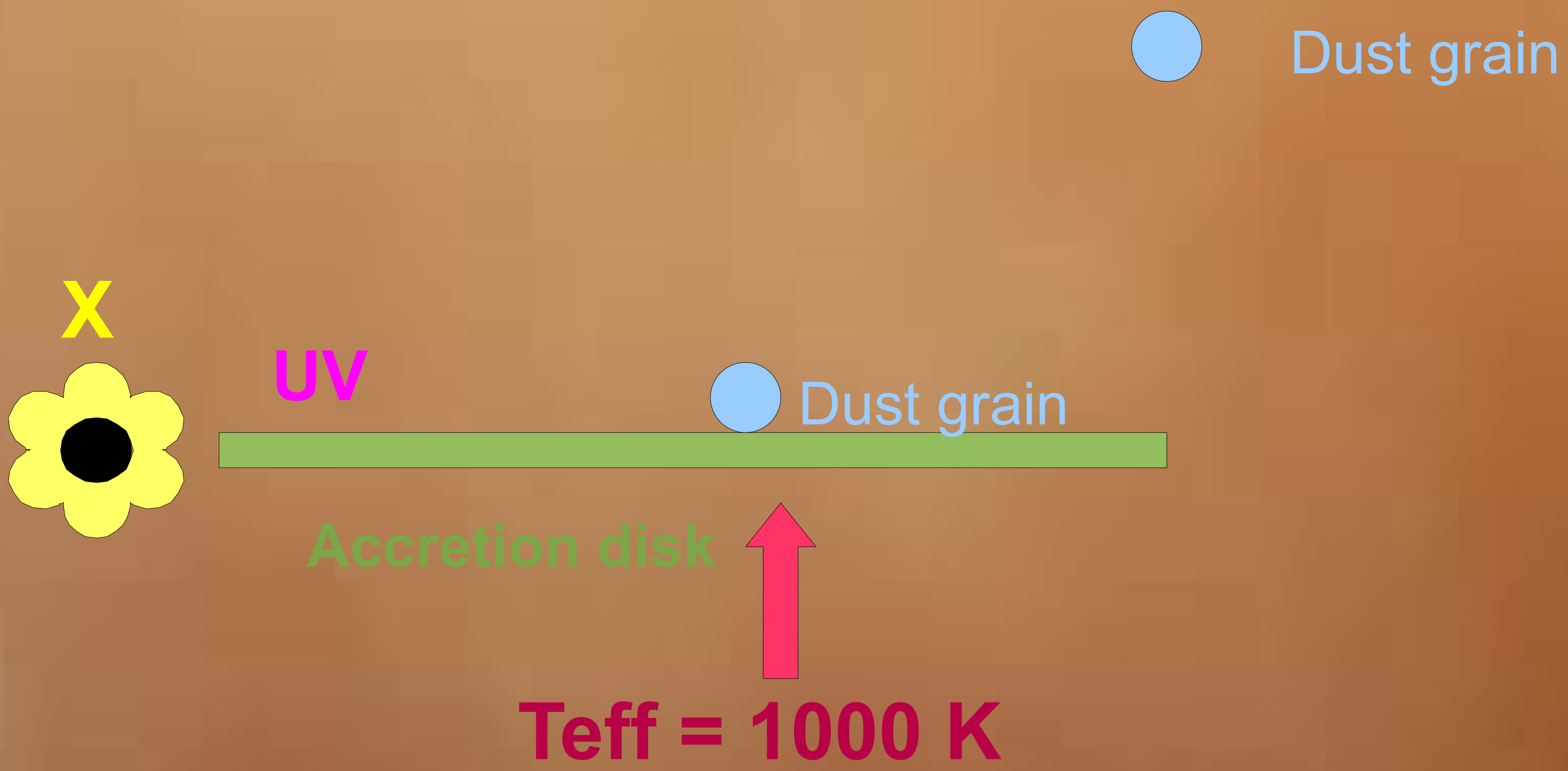
BLR → LIL (Hbeta, Mg II, Fe II)

BLR → HIL (CIV)

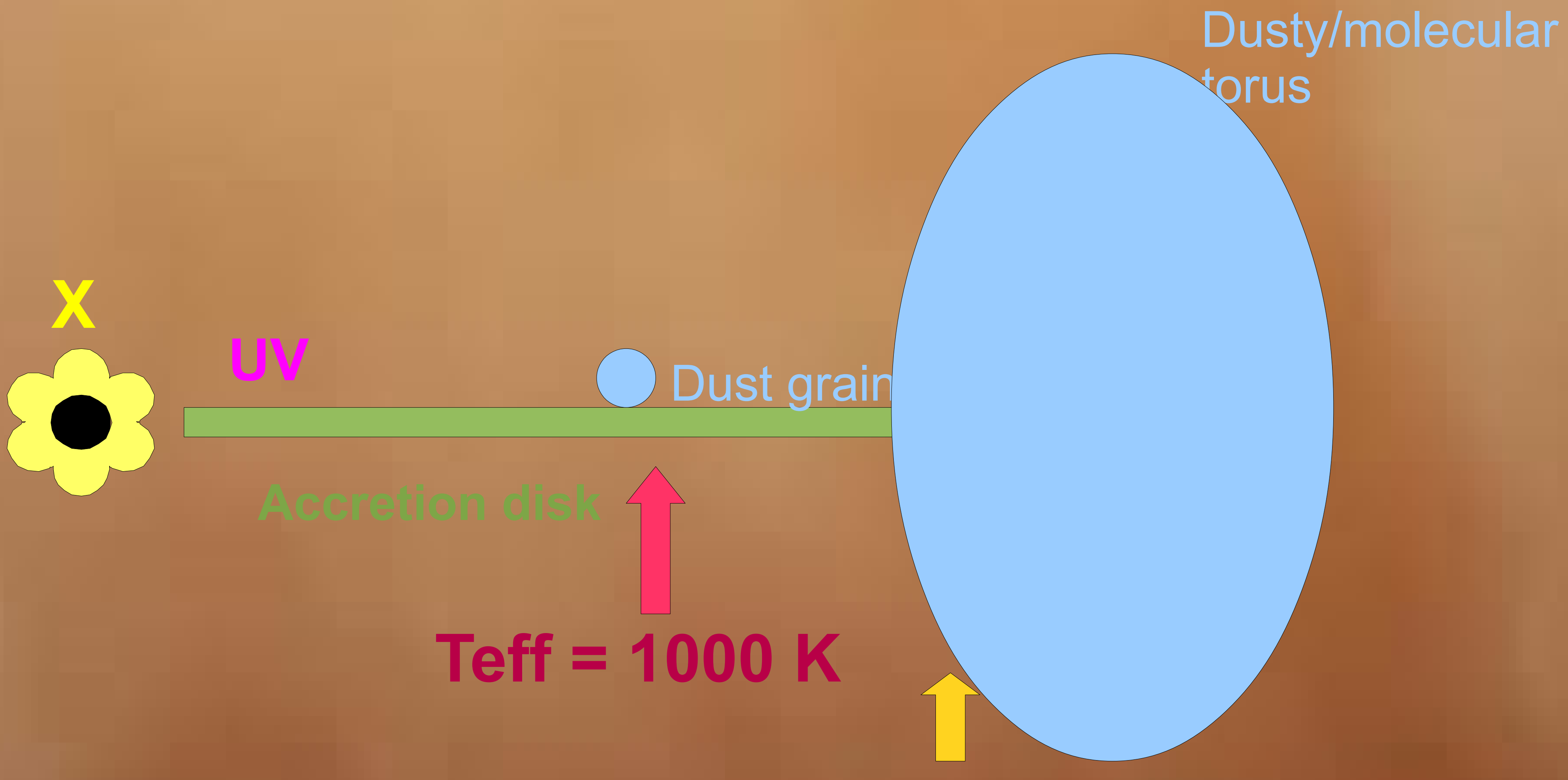
Basic idea behind FRADO: failed radiatively accelerated dusty outflow



Basic idea behind FRADO: failed radiatively accelerated dusty outflow



Basic idea behind FRADO



Laor & Netzer 1993

The advantage of locating the inner radius of LIL BLR at Teff = 1000 K

$$R \propto L_{300nm}^{1/2}$$

$$L_{300nm} \propto (M\dot{M})^{2/3}$$

$$T_{eff} \propto (\frac{M\dot{M}}{R^3})^{1/4}$$

Czerny & Hryniewicz 2011

Based on the simple accretion theory of Shakura & Sunyaev

Fixing the Teff = 1000 K reproduces the results of the reverberation studies, including the proportionality coefficients, known from the theory:

$$\log R_{\rm BLR}[{\rm H}\beta] = 1.538 \pm 0.027 + 0.5 \log L_{44,5100},$$

Bentz et al. 2009

The relation is universal, for all values of the black hole mass and accretion rate.

Our idea – BLR as failed wind

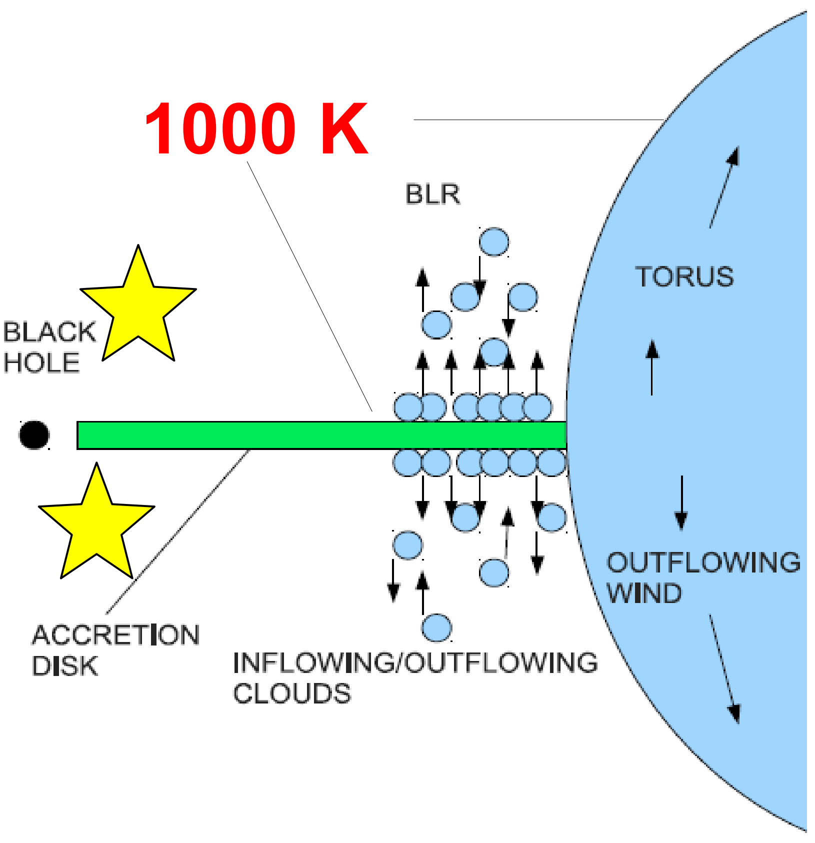


Fig. 1. The BLR region covers the range of the disk with an effective temperature lower than 1000 K: the dusty wind rises and then breaks down when exposed to the radiation from the central source. The dusty torus is the disk range where the irradiation does not destroy the dust and the wind flows out.

Dust leads to outflow but dust cannot survive in the temperature much higher than 1000 K!

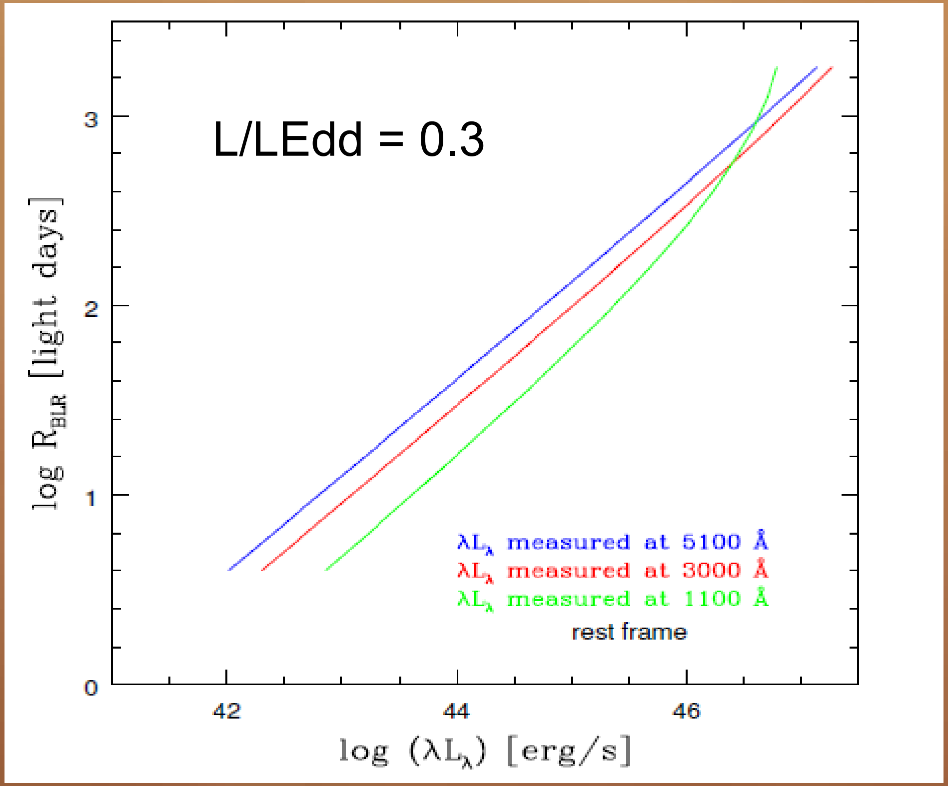
Strong radiation field kills the dust (evaporation process)

Wind, which is not a wind, is what we need!

Since we have a theory of the BLR formation we can perform or propose some tests...

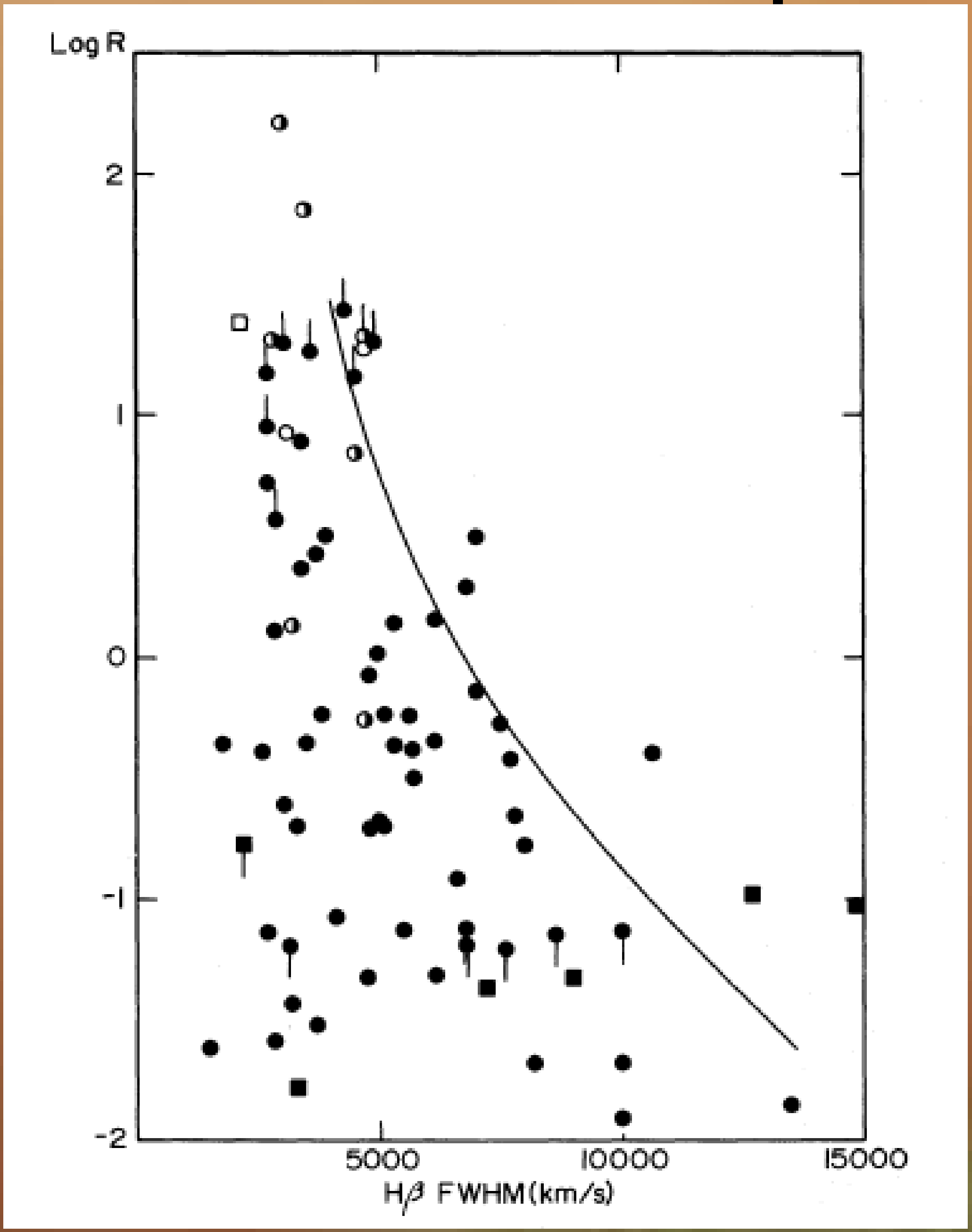
1. Deviation of the accretion disk continuum from a power law

The relation $L\nu \sim \nu^{1/3} (M \dot{M})^{2/3}$ is true only in the limit of long wavelengths



We would need high redshift high luminosity sources to test that. In addition, short-wavelength AD spectra are problematic.

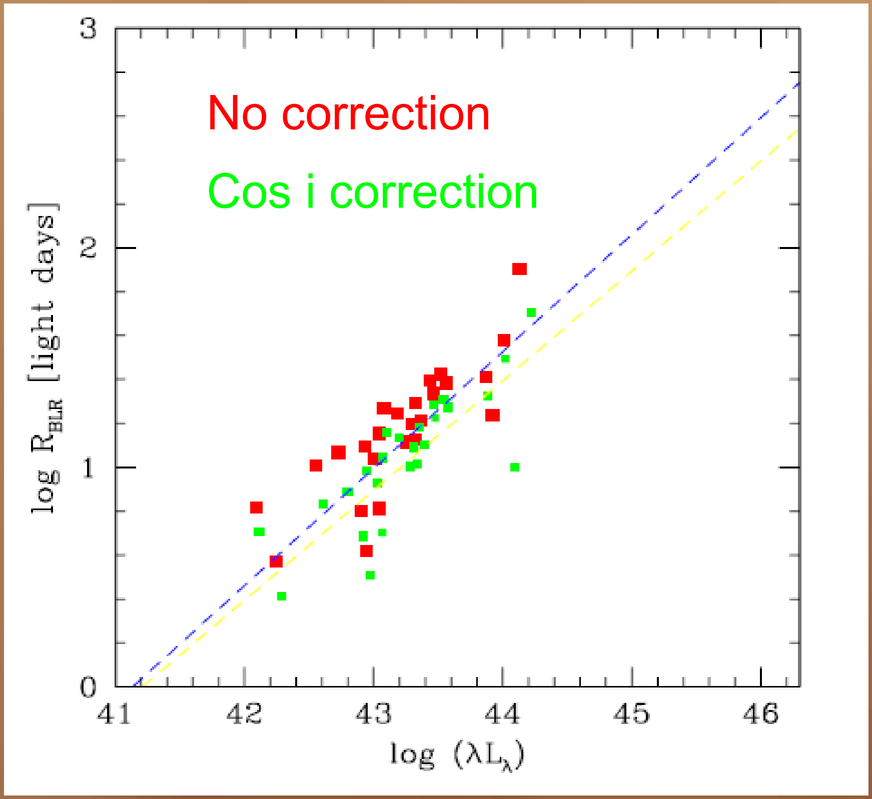
2. Dependence on the inclination



All models need to have it...

2. Dependence on the inclination angle

The relation for the disk monochromatic luminosity actually contains the inclination angle $L_v \sim \cos i \, v^{1/3} (M \dot{M})^{2/3}$ which should contribute to dispersion in a sample of monitored objects since delay ~ $L_v (\cos i)^{1/2}$. It is not a big effect – expected dispersion of 0.04 dex if the inclinations cover 0 – 45 deg. Also the delay is directly affected. Nevertheless we try:



We took a subset of reverberation measurements from Bentz et al. (2009) - sources with inclination angle determined by Nikolajuk et al. (2004) from X-ray variability.

Without cos i correction:

Slope = 1.16
Dispersion = 0.30

With cos i correction

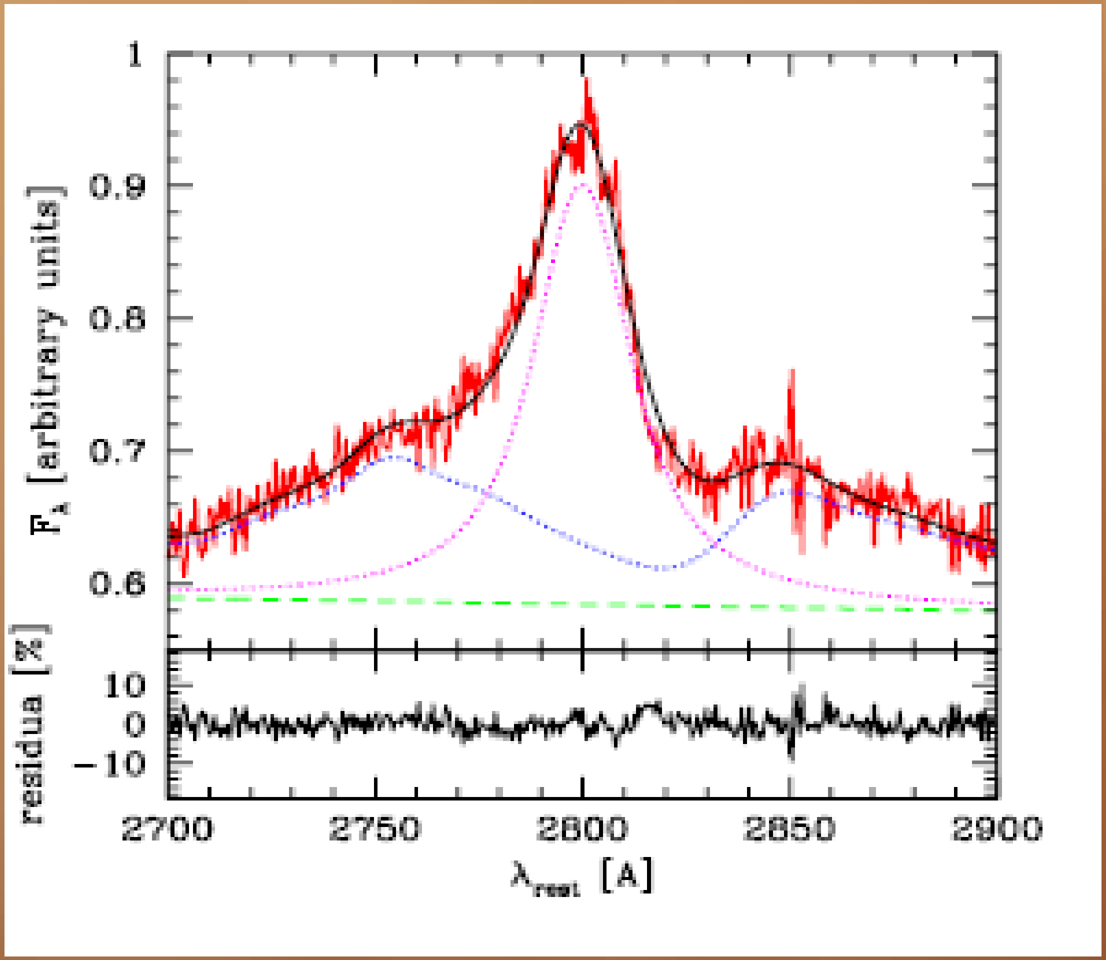
Slope = 1.03
Dispersion = 0.29

We need more objects

3. LIL line profiles: type A quasar

LBQS 2113-4538

z = 0.956



Mg II symmetric line, well modeled as a single kinematic Lorentzian component (but atomic doublet), plus PL + Fe II
SALT spectrum, LBQS 2113-4538 (z=0.956), *Hryniewicz et al. 2014*

How to get a Lorentzian shape?

We perform the simplest possible study of the dusty cloud/particle within the FRADO model.

$$m\frac{dv_z}{dz} = -\frac{GMmz}{r^3} + \frac{F\sigma_{dust}}{c}$$

$$F = \frac{3GM\dot{M}}{r^3}$$

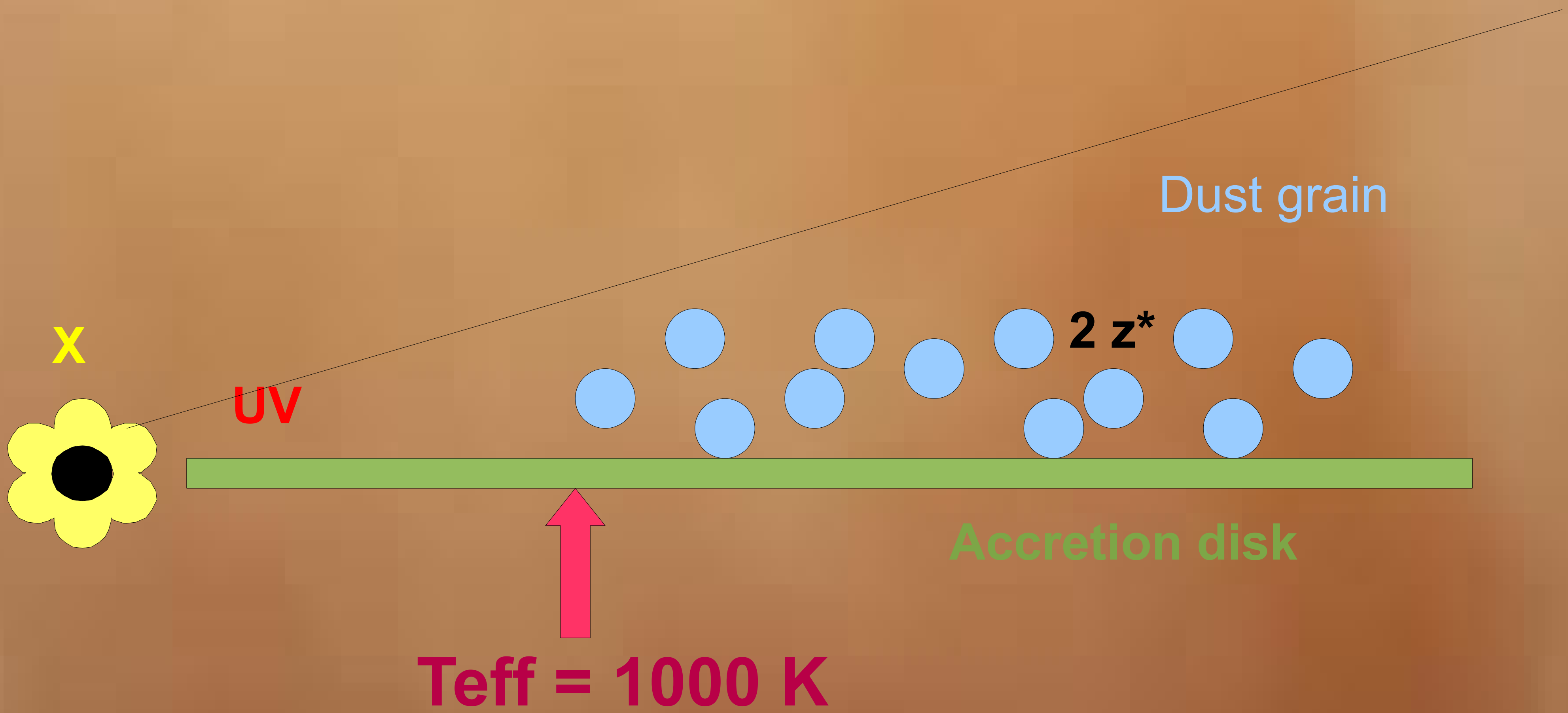
Analytic solution:

$$z(t) = z_*(1 - \cos(\Omega_K t),$$

$$v(t) = z_*\Omega_K \sin(\Omega_K t),$$

$$z_* = \frac{3\dot{M}\sigma_{dust}}{8\pi cm}.$$

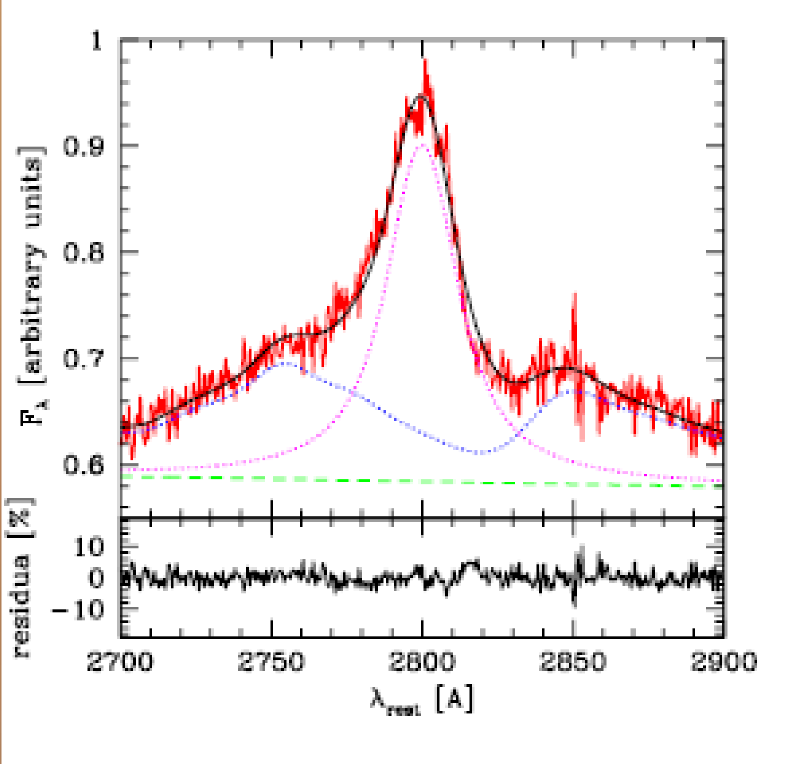
The cloud motion

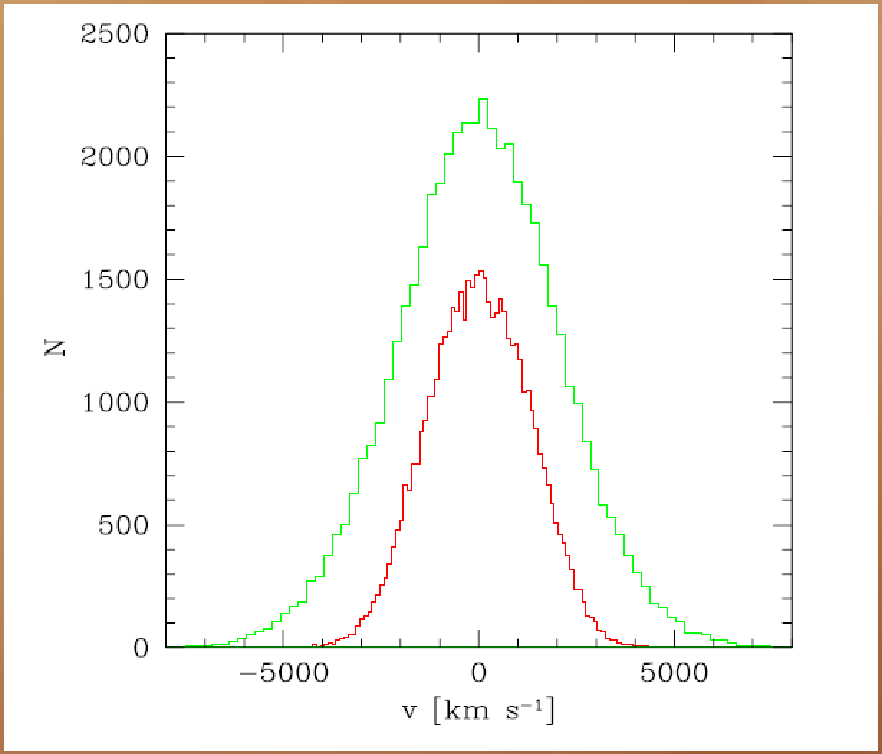


The largest opening angle is at the inner radius of the BLR, at larger radii there is no material rising considerably above the disk plane. We have modeled this kind of motion and distribution very crudely.

3. LIL line profiles: type A quasar

LBQS 2113-4538





Mg II symmetric line, well modeled as a single kinematic Lorentzian component (but atomic doublet), plus PL + Fe II

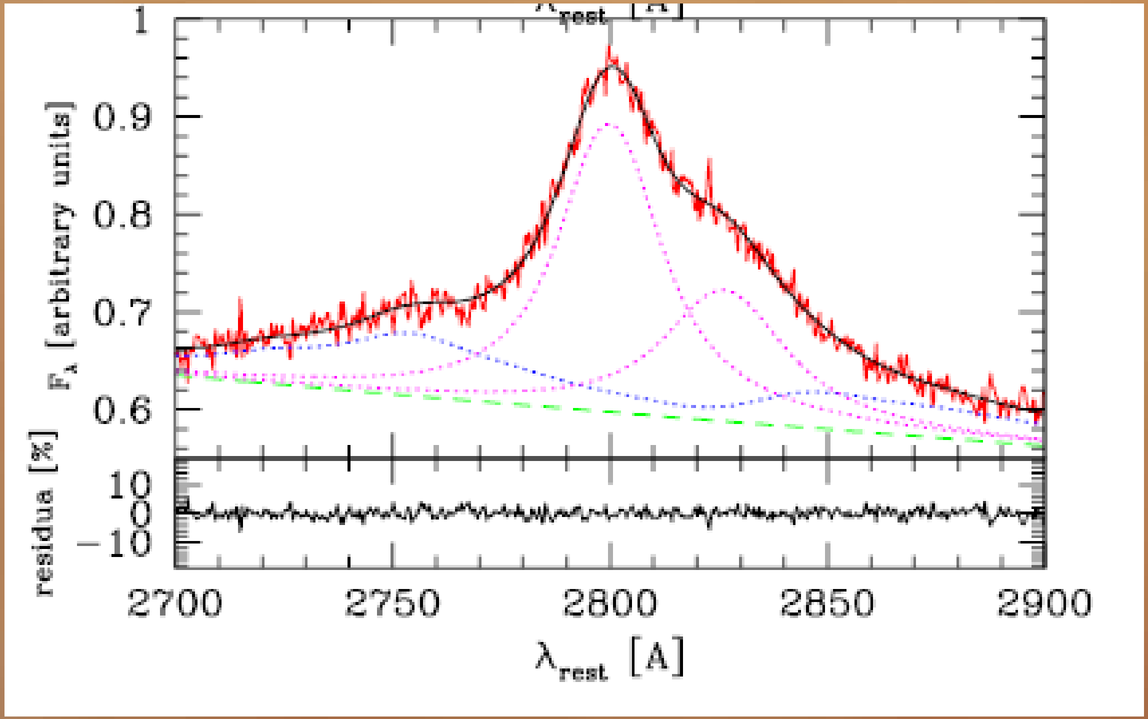
SALT spectrum, LBQS 2113-4538 (z=0.956), *Hryniewicz et al. (2014)*

VERY preliminary results of modelling the cloud motion roughly consistent with the FRADO model. Vertical cloud velocity distribution Gaussian beta*v_Kepler, beta=0.5 and beta = 1.0

Petrogalli et al., work in progress

3. LIL line profiles: type B quasar

CTS C30.10



We think that the second component comes from scattering but we did not solve the geometrical setup issue. Inflow along the axis?

Mg II assymetric, two kinematic Lorentzian components (but atomic doublet), plus PL + Fe II. Fe II underlying only the blue component! SALT spectrum, CTS C30.10 (z=0.900), Modzelewska *et al. 2014*

4. Presence or absence of the BLR

In our failed wind BLR model, the formation of the BLR requires:

- The presence of the cold disk (ADAF formation automatically truncates the disk

Balmaverde & Capetti: The HST view of the broad line region in LLAGN

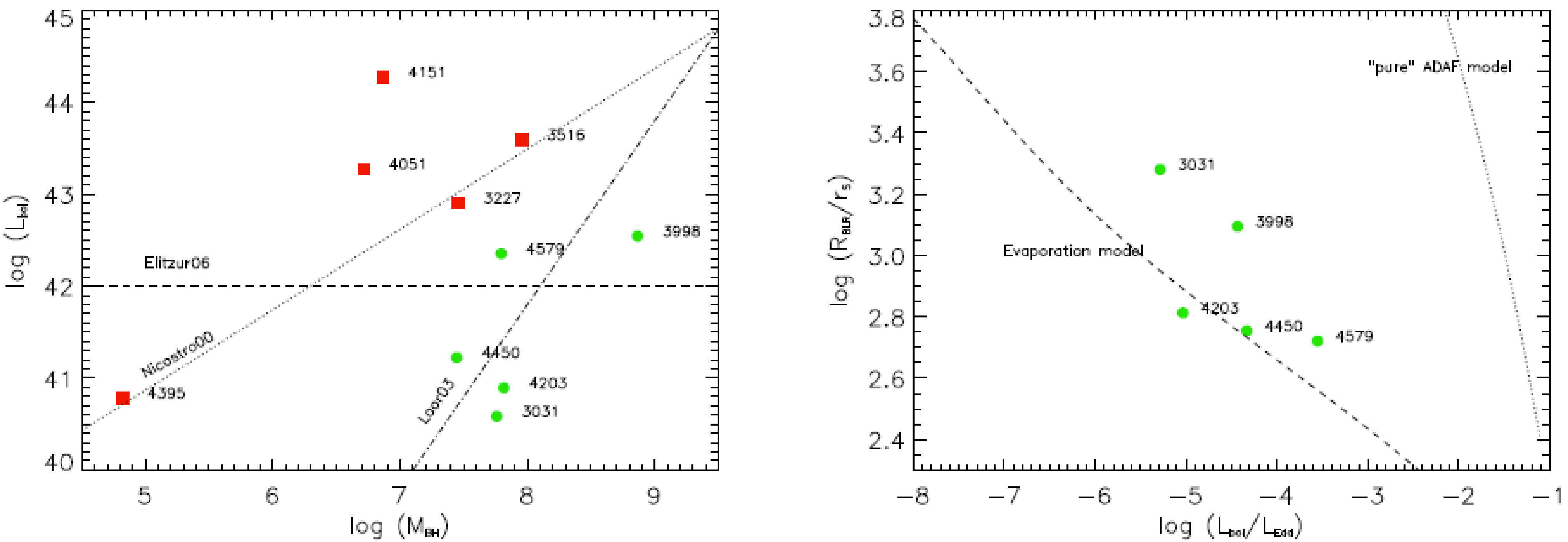


Fig. 13. Left panel: limits for the presence of a BLR from Elitzur & Shlosman (2006), Laor (2003), and Nicastro (2000). These models predict that objects located in the portion of the plane below the dashed lines cannot form a BLR. Left panel: predictions on the transition radius between the geometrically thick and thin regions of the accretion disk in a pure ADAF model and Evaporation model (model A and C from Czerny et al. 2004, adopting α=0.1 and β=0.99, see text.)

4. Presence or absence of the BLR

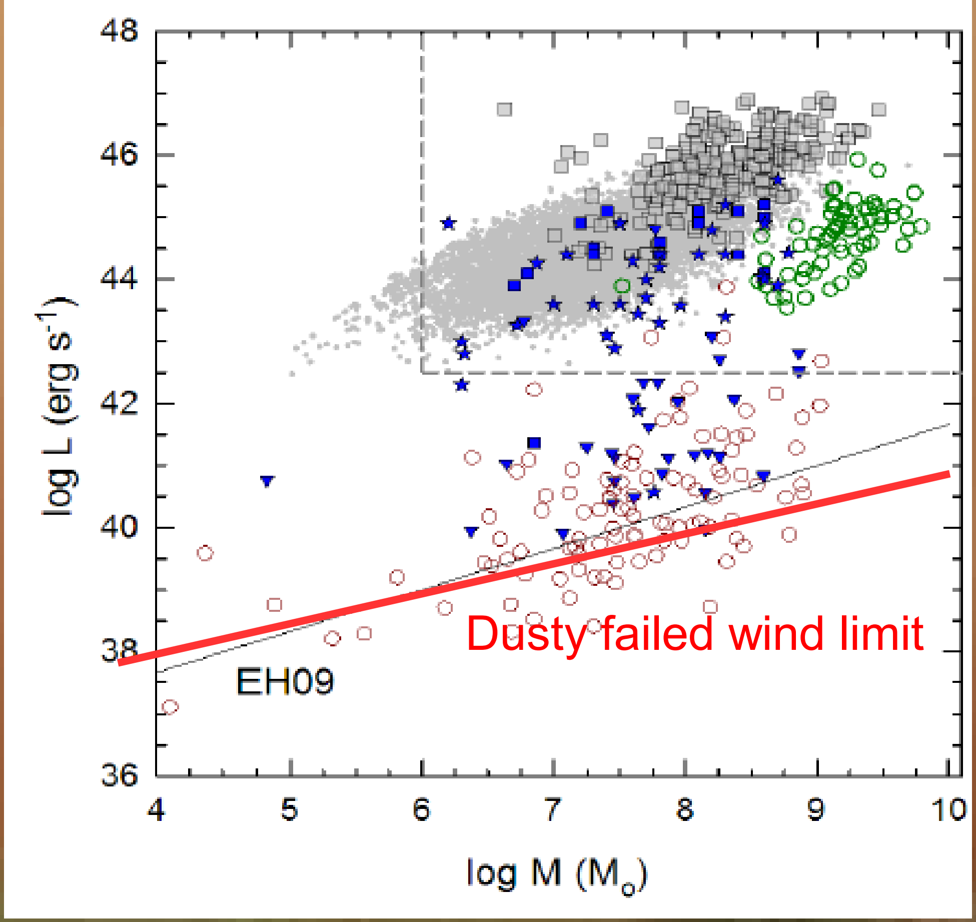
In our failed wind BLR model, the formation of the BLR requires:

- The presence of the cold disk (ADAF formation automatically truncates the disk
- Reasonably high elevation of the matter

In the failed dust wind scenario, the ratio of the maximum elevation of a cloud to the disk radius is the highest at the inner edge of the BLR and scales roughly as

$$Z_{max}/R_{BLR} \sim (L/L_{Edd})^{2/3} M^{1/3}$$

If this factor needs to achieve certain minimum value, as argued by Elitzur et al. (2014) we have similar (but different) scaling than magnetic wind model



Elitzur et al. 2014

Summary

- **FRADO: Failed Radiatively Driven Dusty Outflow mechanism automatically explains the scaling of the BLR size with the MONOCHROMATIC flux**

- This model, as well as other models, should be still further tested against the data
- We need more low luminosity objects to cover the transition between the presence and the absence of the BLR
- We need more high luminosity measurements to increase the dynamical range of the studied relations
- We need better information on the inclinations of the measured objects