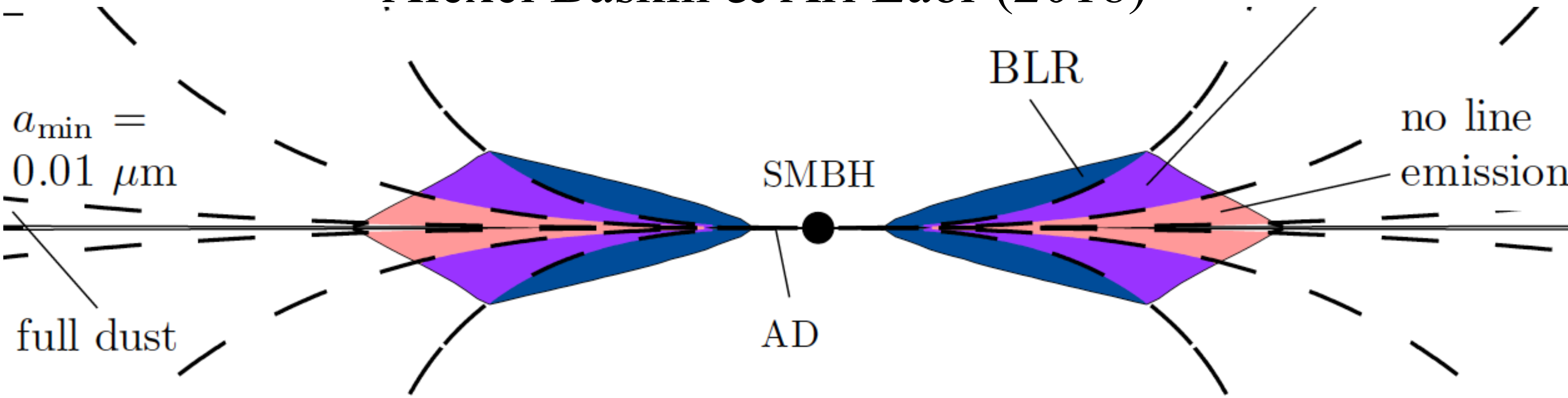
The Broad Line Region = Torus
Is it The Torus?

Alexei Baskin & Ari Laor (2018)



1. The outer AD is a torus - *unavoidable*
2. The torus is a BLR - *unavoidable*
3. Is there an additional torus?

What is the BLR?

The hard facts:

Dense photoionized gas, $n \sim 10^{10}$-10^{12} cm^{-3}
based on line ratios + photoionization models

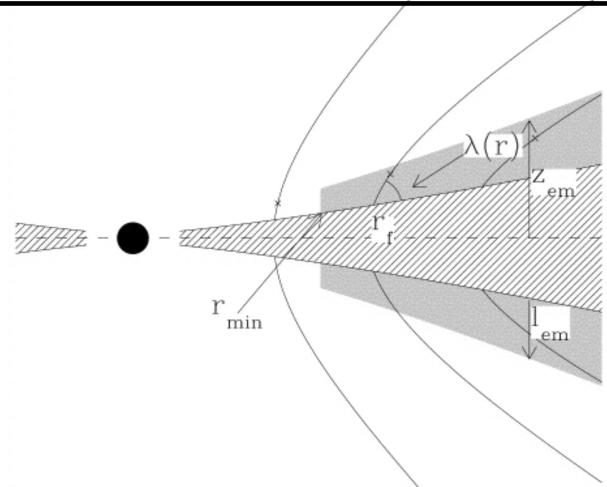
Size: $R_{\rm BLR} = 0.1 L_{\rm bol,46}^{1/2}$ pc
based on reverberation mapping at $L \sim 10^{39}$-10^{47} erg s^{-1}

Velocity: ~ Keplerian
based on consistent M_{BH} - bulge relations in galaxies

Why? and where does it come from?

Some earlier suggestions

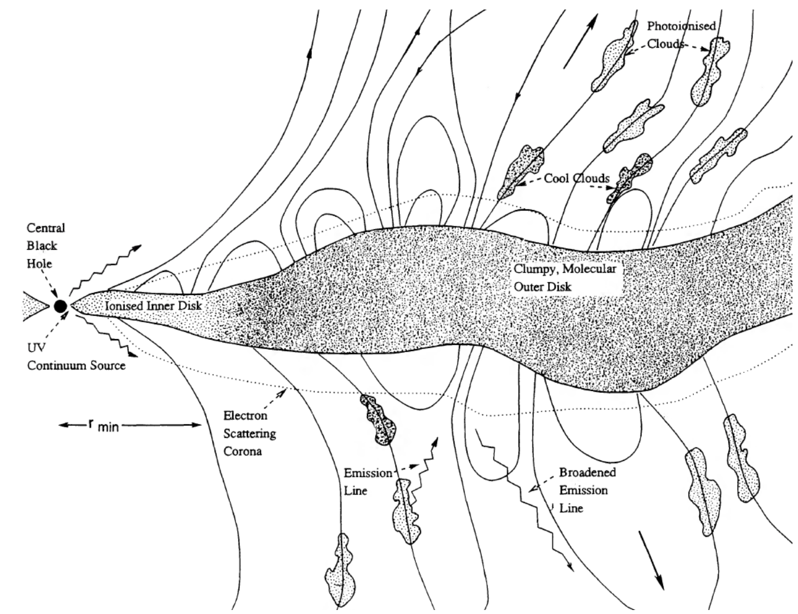
UV line driven disk wind



Shlosman+, Murray+, Proga+

Excluded, size x100 too small

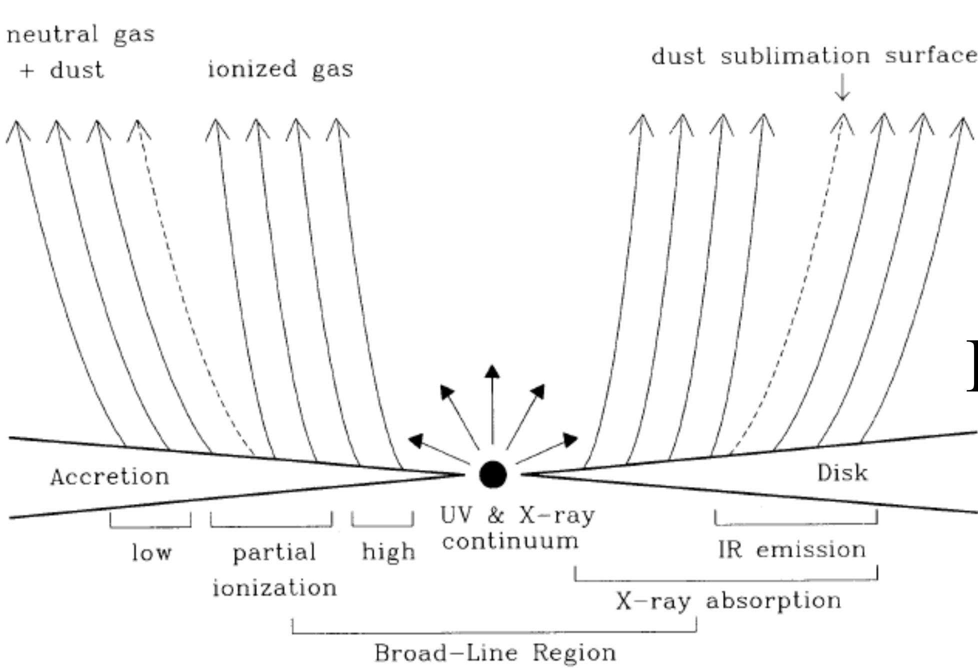
MHD driven disk wind



Emmering+, Lovelace+

Excludable?

MHD + radiation driven disk wind

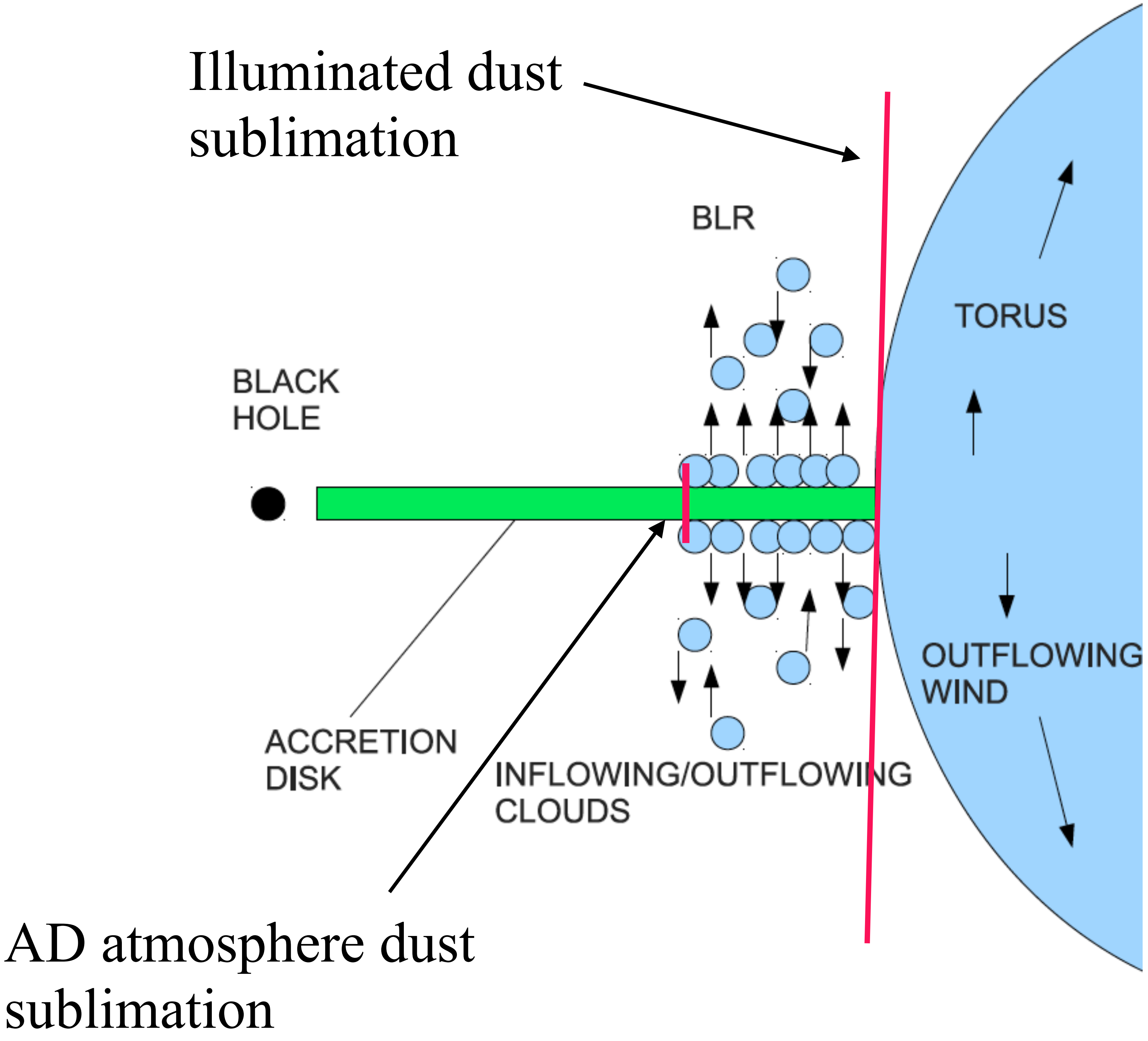


Konigl+, Everett+, Keating+

Excludable?

BLR = A failed dusty disk wind?

Czerny & Hryniewicz (2011)



What is the predicted size of the BLR?

Outer radius set by dust sublimation due to $L_{\rm bol}$

$$\frac{L_{\rm bol}}{4\pi R_{\rm out}^2} = 4\sigma T_{\rm sub}^4 \quad \rightarrow \quad R_{\rm out} = 0.2 L_{\rm bol,46}^{1/2}\ {\rm pc}$$

Predicted: Netzer & Laor (1993), Observed: Suganuma et al. (2006)

....

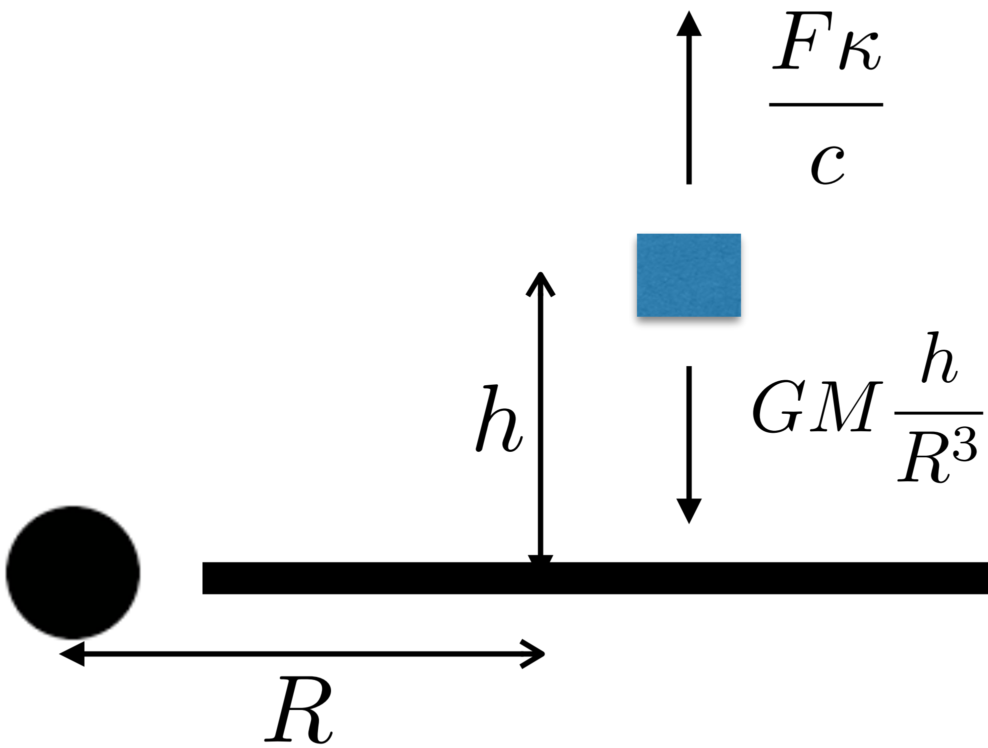
Inner radius set by dust sublimation at the disk surface

$$\sigma T_{\rm eff}^4 = \frac{3}{8\pi}\frac{GM\dot{M}}{R^3} \longrightarrow R_{\rm in} = 0.018 L_{\rm opt,45}^{1/2}\ {\rm pc.}$$

Reverberation mapping results: $R_{\rm BLR} = 0.1 L_{\rm bol,46}^{1/2}$ pc

First principles, no free parameters!

How thick is the dusty disk?



$$F = \frac{3}{8\pi}\frac{GM\dot{M}}{R^3}$$

$$\frac{3}{8\pi}\frac{GM\dot{M}}{R^3}\frac{\kappa}{c} = \frac{GMh}{R^3}$$

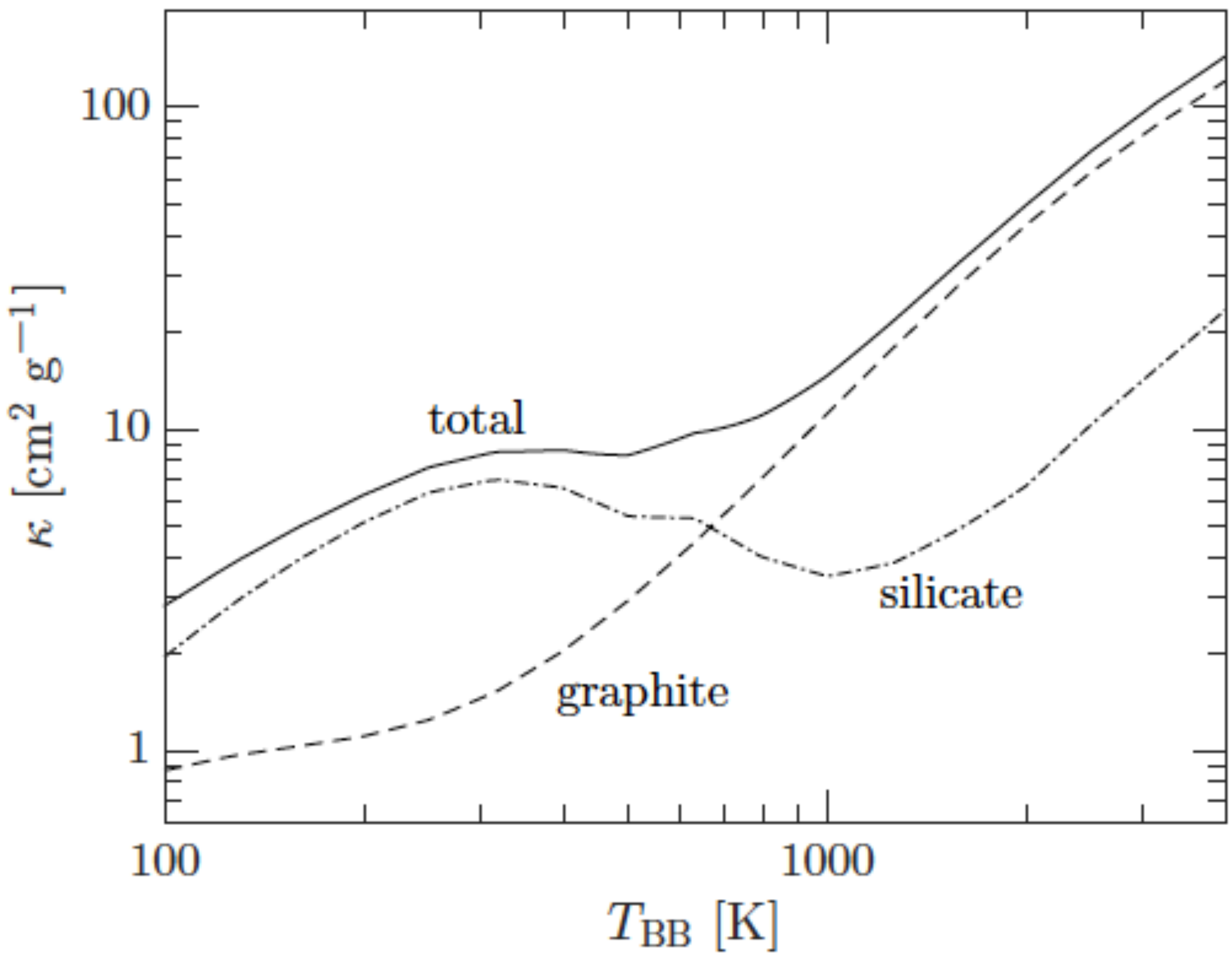
$$\boxed{h = \frac{3}{8\pi}\frac{\dot{M}\kappa}{c}}$$

What is the dust kappa in the IR?

For electron scattering $\kappa_{\rm es} = 0.4$ —> h is constant

For dust, depends on grain composition, grain size, wavelength

What is the IR wavelength dependence of κ ?



The illuminating radiation

Semenov+03 includes silicates only

A sharp rise with T_{BB}
Graphites dominate

κ can reach ~ 100

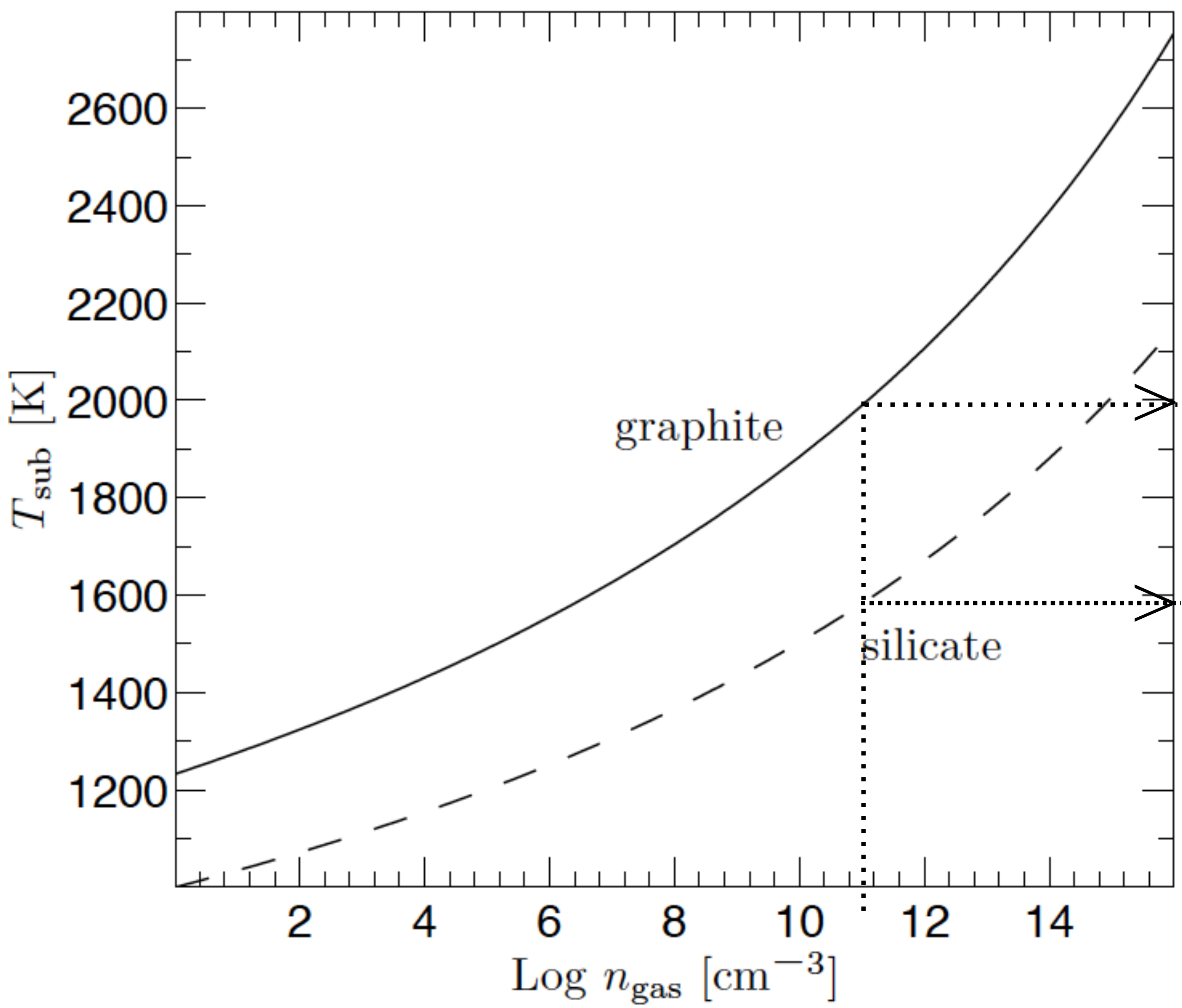
(note literature values include silicates only)

But, this is for MRN (Galactic dust)

What is the dust opacity at the BLR?

What is T_{sub}?

At T_{sub} sublimation = condensation
—> T_{sub} is set by the gas density



Guhathakurta & Draine (1989)

Silicates are less resilient

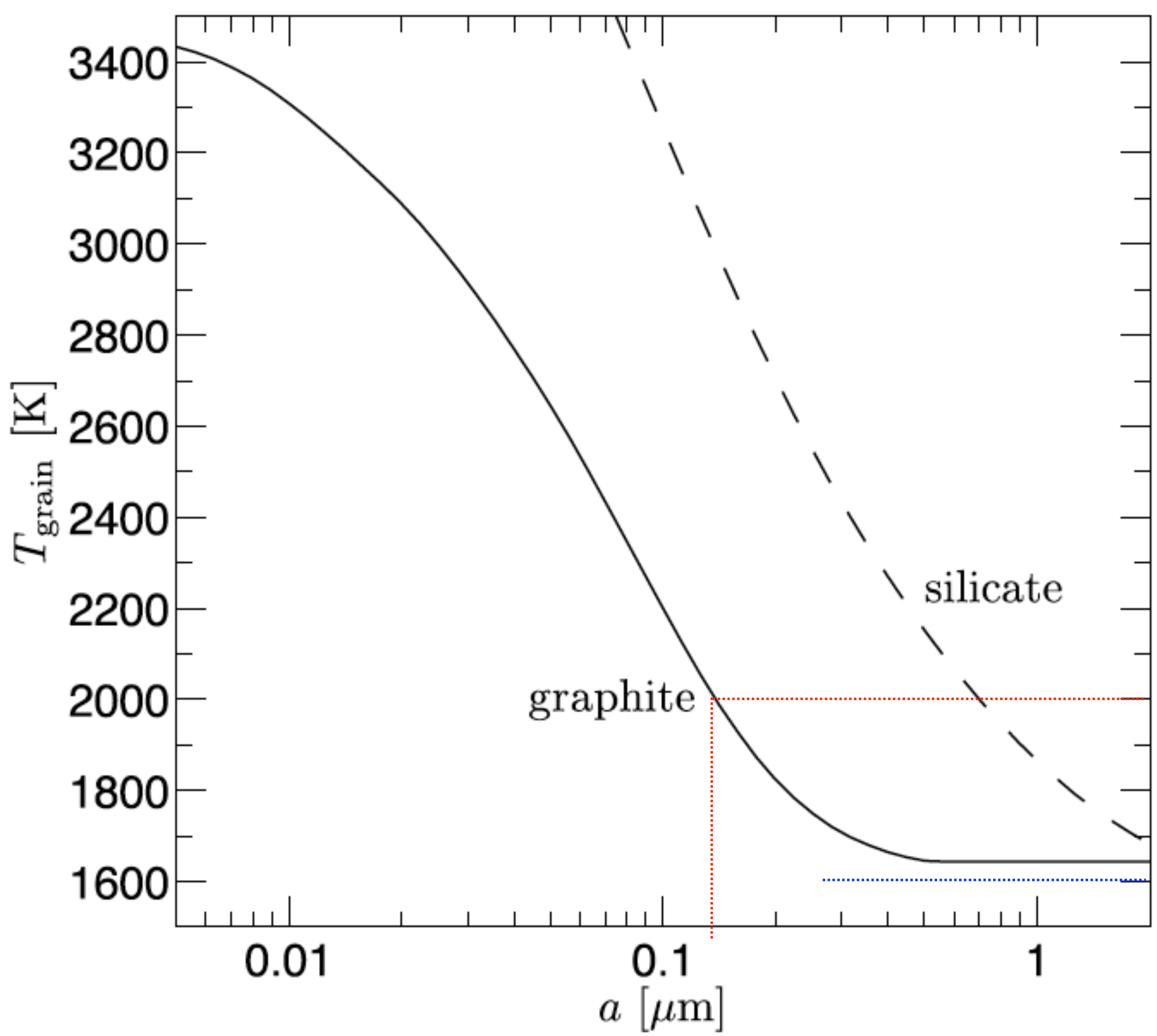
At the BLR density $\sim 10^{11}$

Graphite - 2000K
Silicate - 1600K

What is the grain Temp' at the BLR?

Can some dust survive at the BLR?

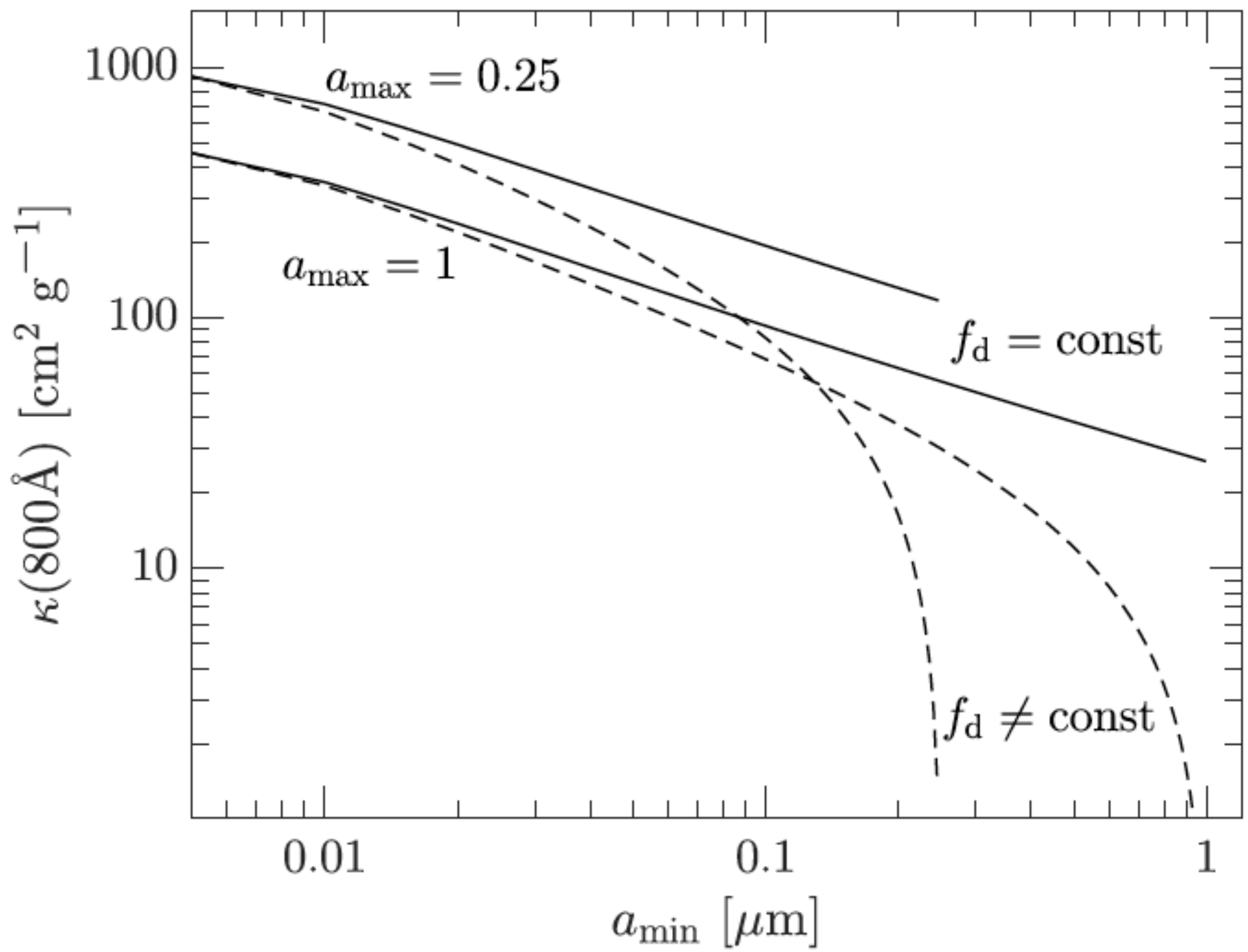
At $R_{\rm BLR} = 0.1 L_{\rm bol,46}^{1/2}$ pc ⟶ fixed flux



Smaller grains are hotter
Silicate grains are hotter

Large graphite grains (>0.15mic) survive at the BLR

The EUV dust opacity

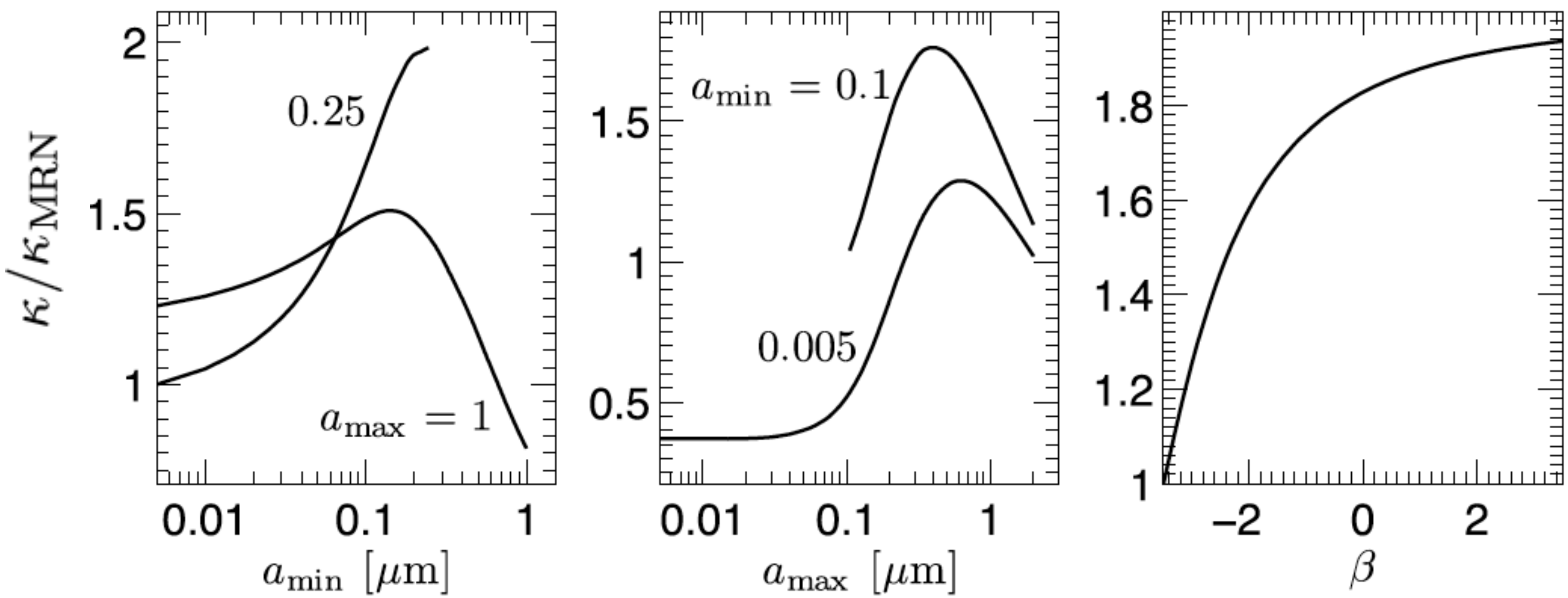


Dust opacity drops by a factor of 10, or larger, as small grains are destroyed.

—> Gas opacity dominates, no dust suppression

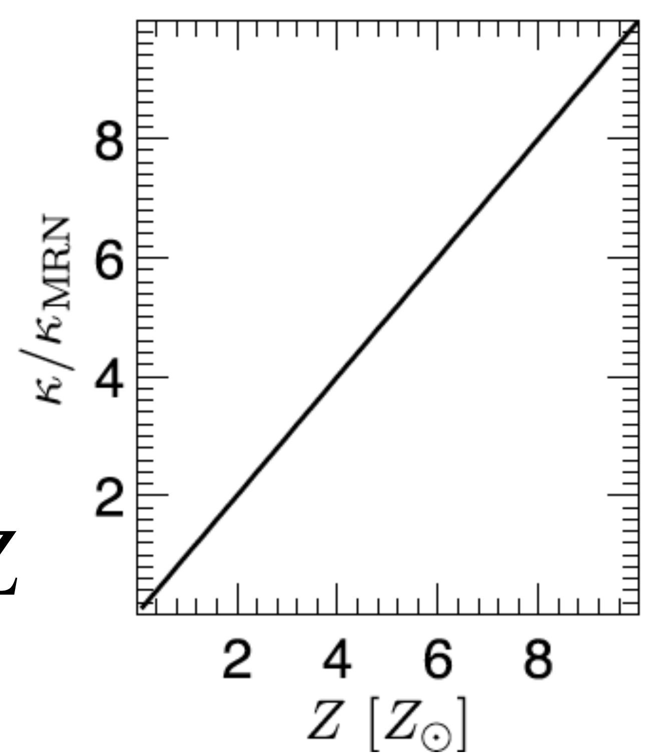
Efficient line emission

The near IR (2000K BB) dust opacity

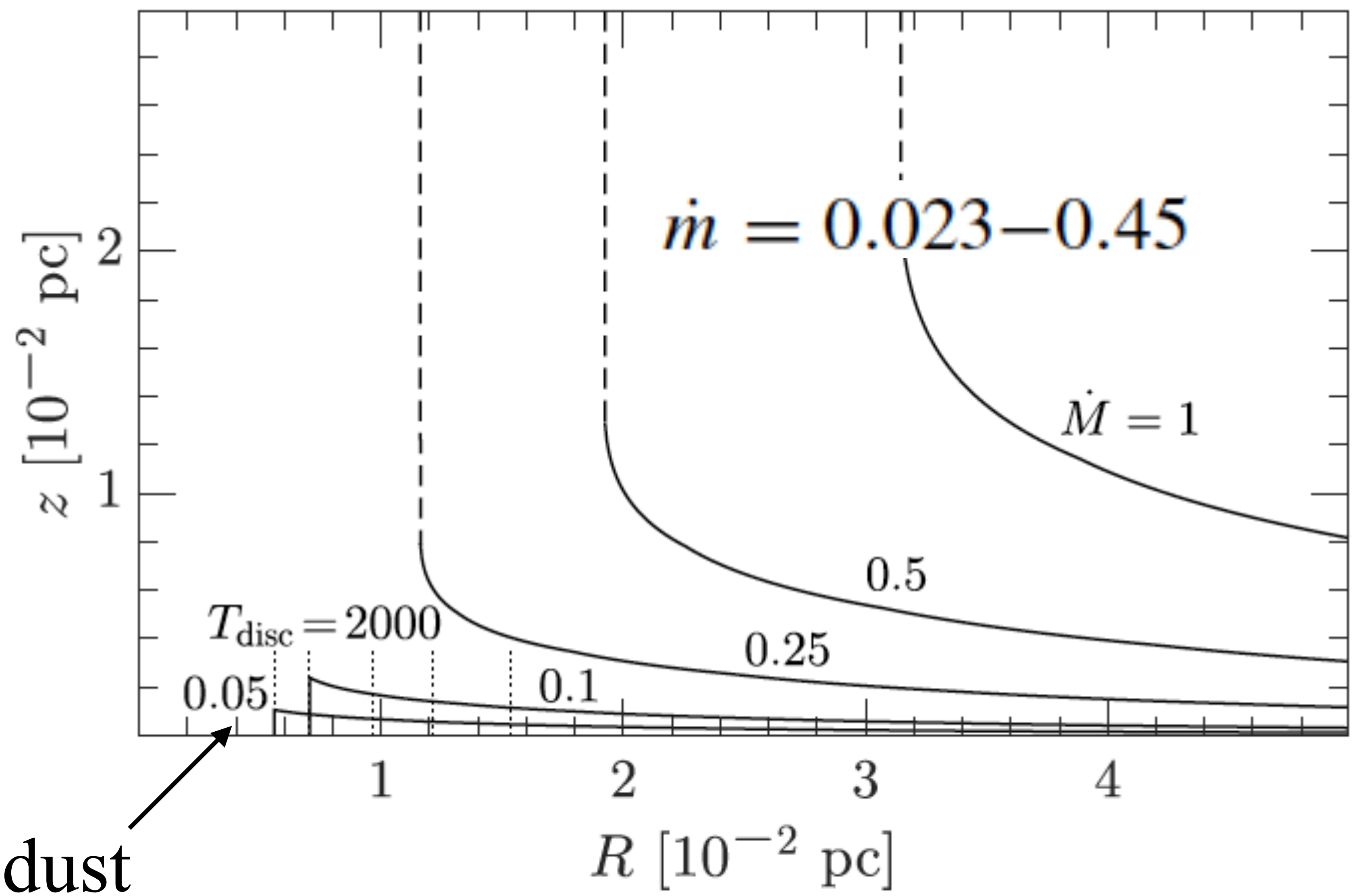


IR opacity **increases** slightly
(IR absorbed in the grain volume)

Linear dependence on Z



The accretion disk H(R) with dust opacity

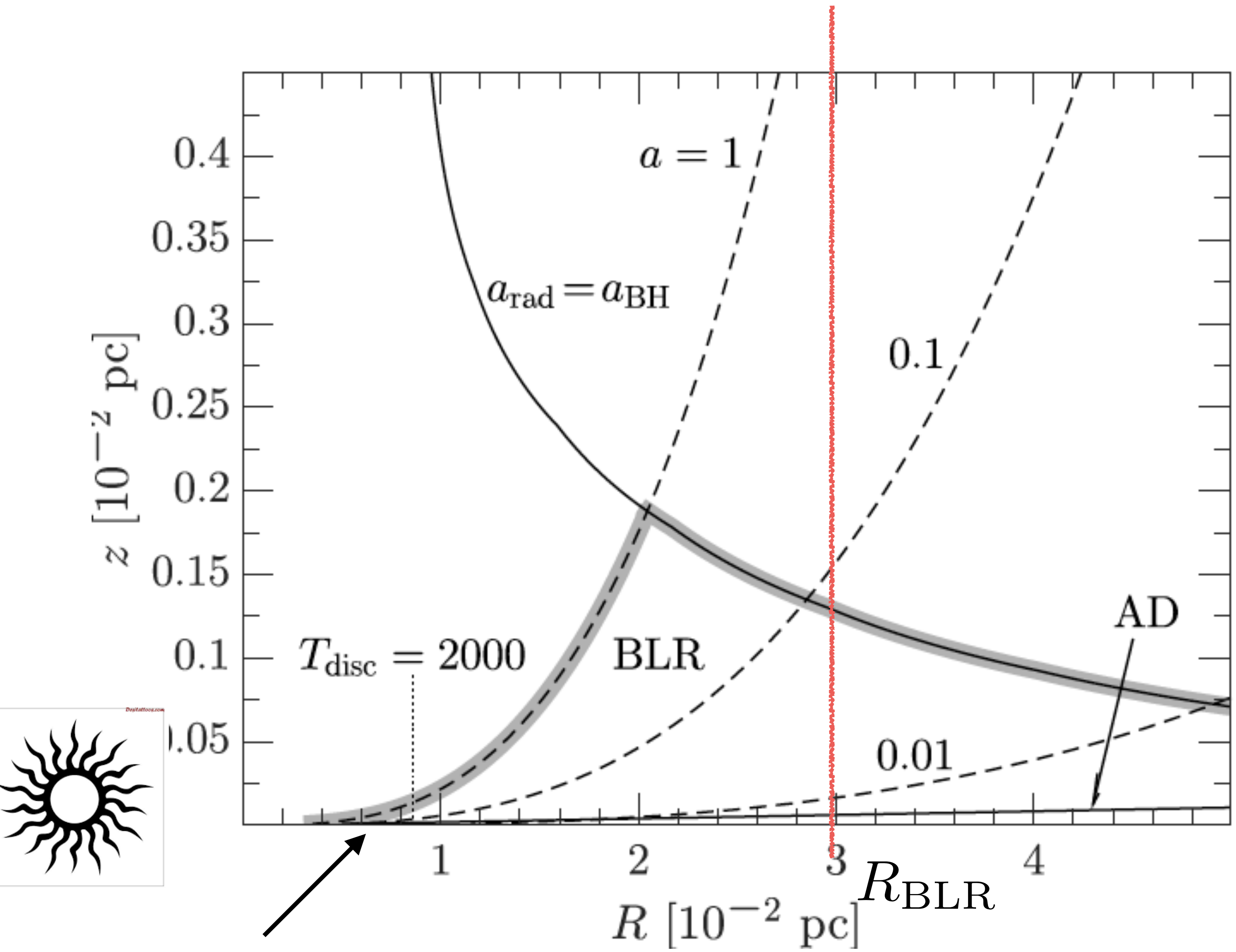


No dust

Dust inflated accretion disk

Radiation pressure support vertical structure

What happens when the dust sees the real light?



No dust

When

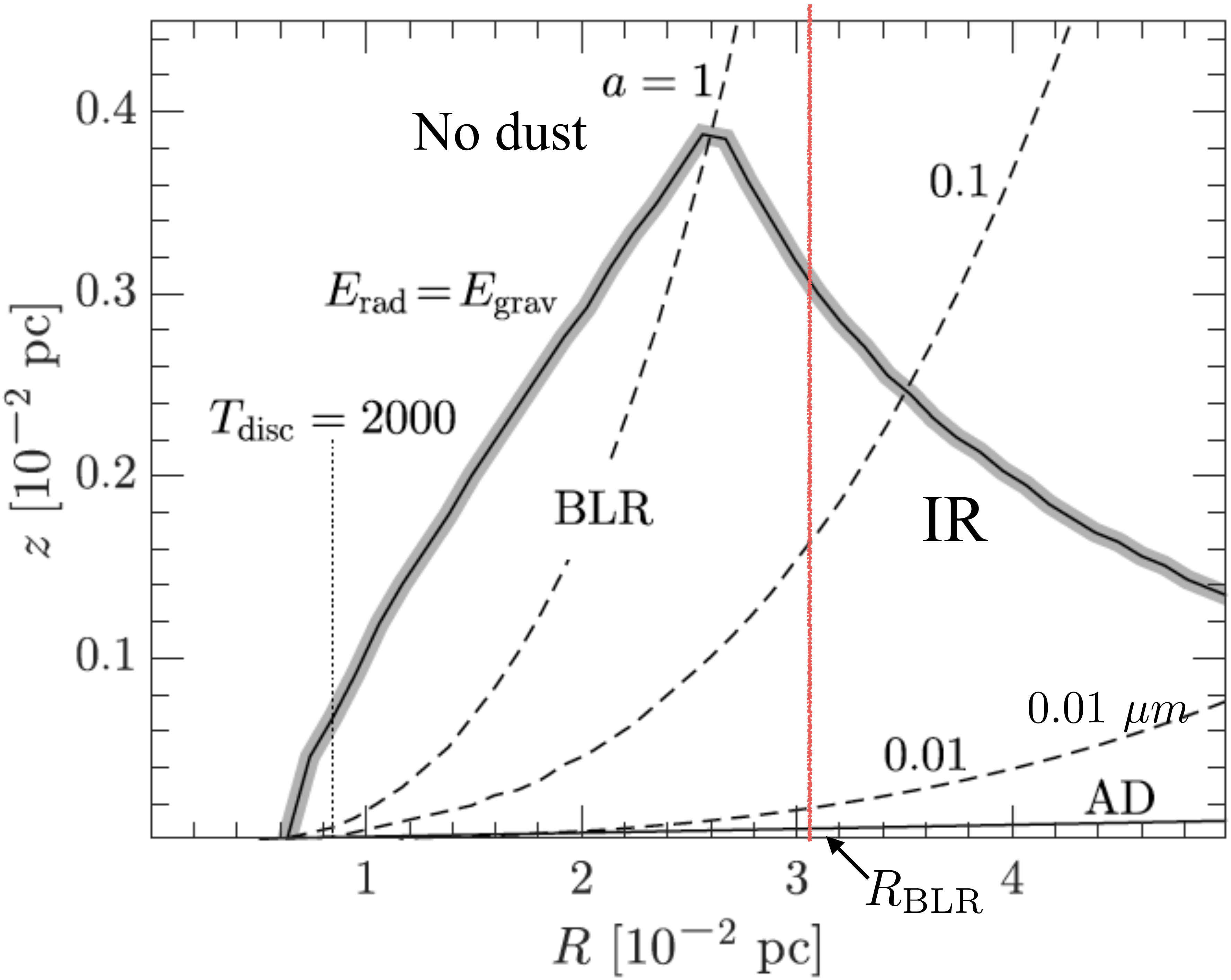
$$\frac{L_{\rm bol}}{4\pi R^2}\cos\theta > 4\sigma T_{\rm sub}^2$$

the grains sublimate right away (<1h).

The implied maximal height

$$h = \frac{16\pi R^3 4\sigma T_{\rm sub}^2}{L_{\rm bol}}$$

Dynamic Solution

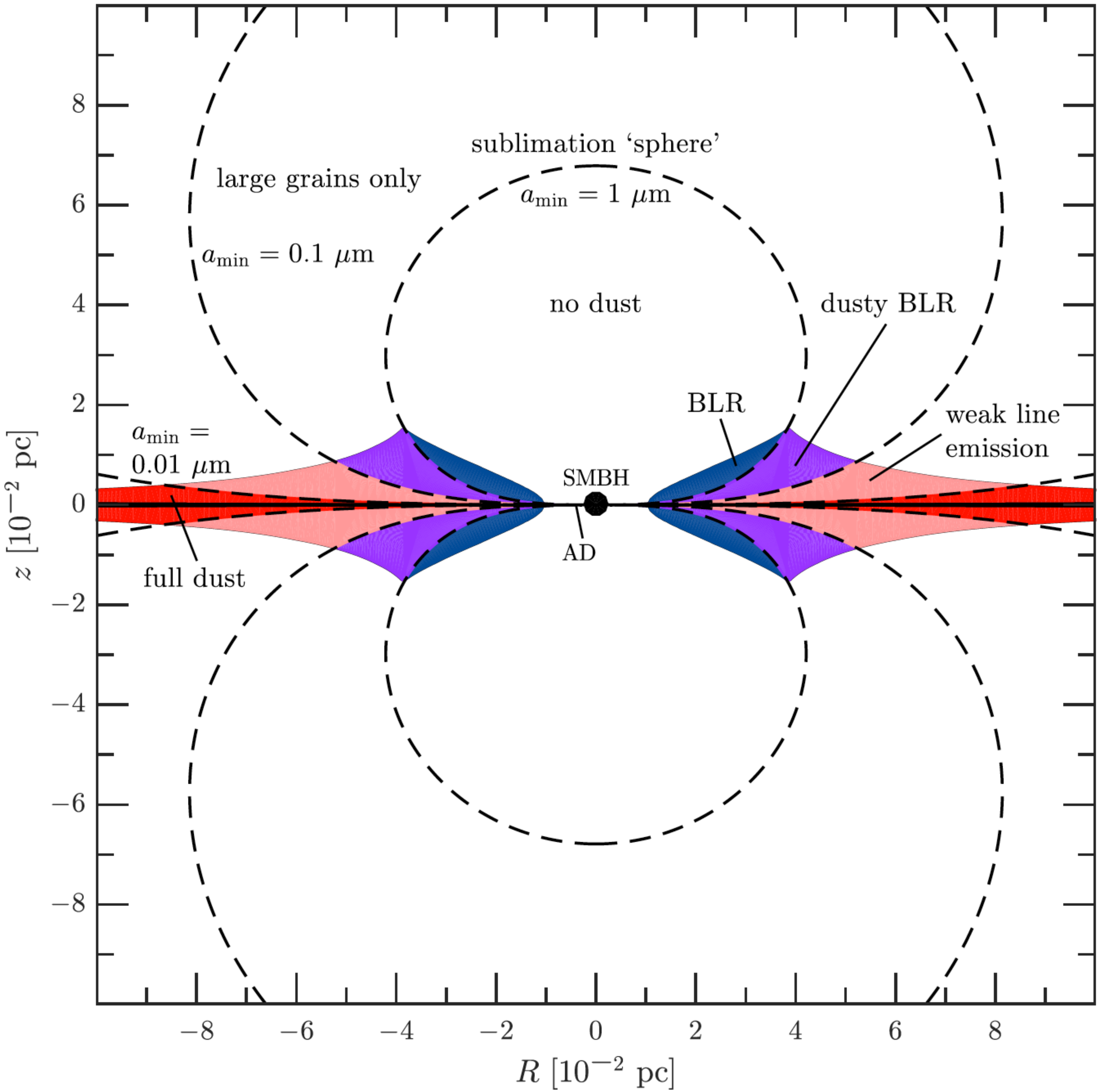


$L_{\rm bol} = 10^{45}$ erg/s

$M = 10^8 M_\odot$

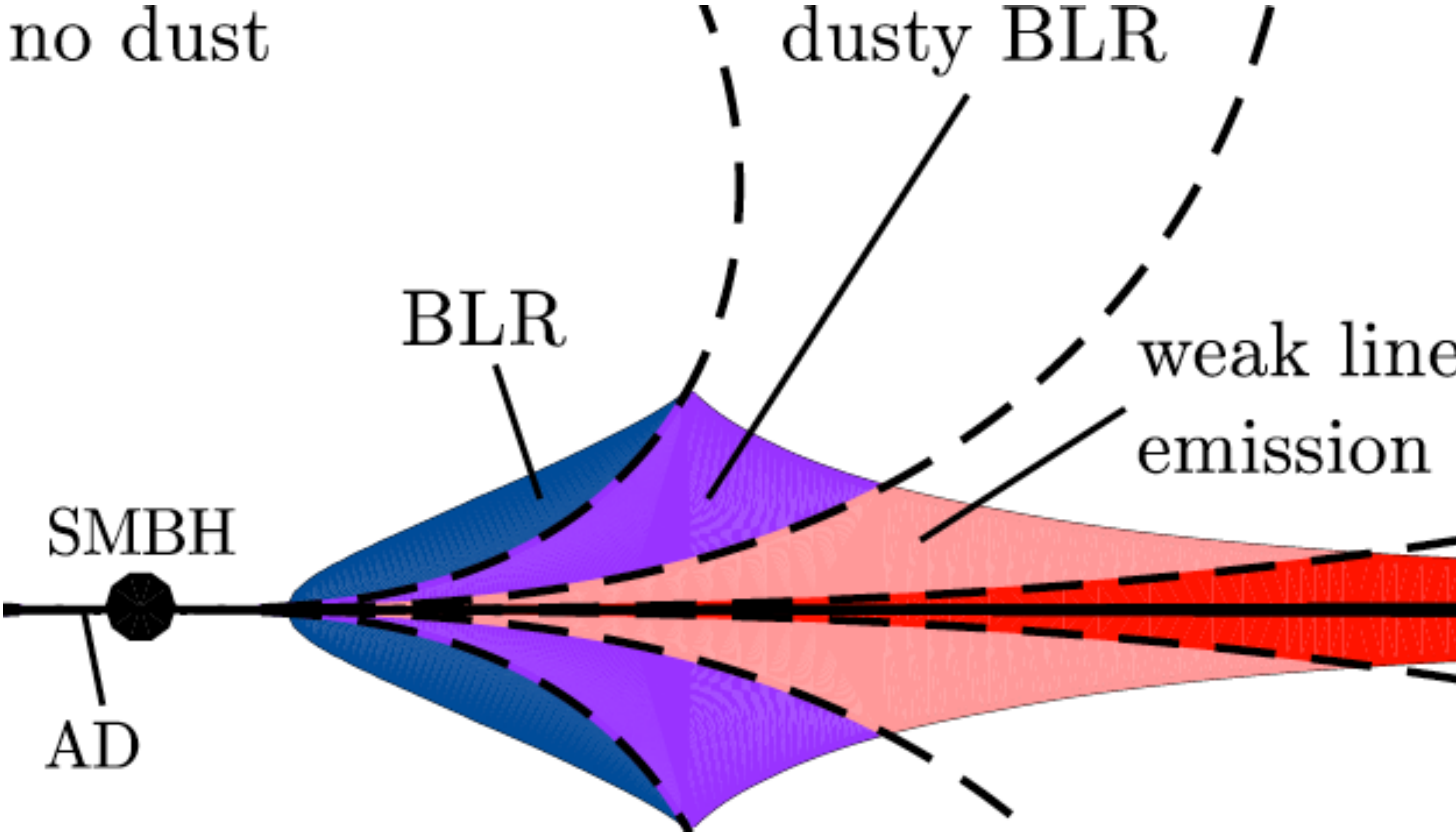
$\kappa = 200$

$$\Omega_{\rm BLR} = 0.15 L_{\rm bol,45}^{1/3} \eta_{0.1}^{-2/3} \kappa_{100}^{2/3}$$



sublimation 'sphere'
large grains only
$a_{\min} = 1\ \mu$m
$a_{\min} = 0.1\ \mu$m
no dust
dusty BLR
BLR
weak line emission
$a_{\min} =$ 0.01 μm
SMBH
AD
full dust
z [10^{-2} pc]
R [10^{-2} pc]

The BLR is likely a dust inflated outer disc



$n\Delta r \sim 10^{10} \times 10^{17}\,\mathrm{cm}^{-2}$ CF ~ 0.3 ***The Torus?***

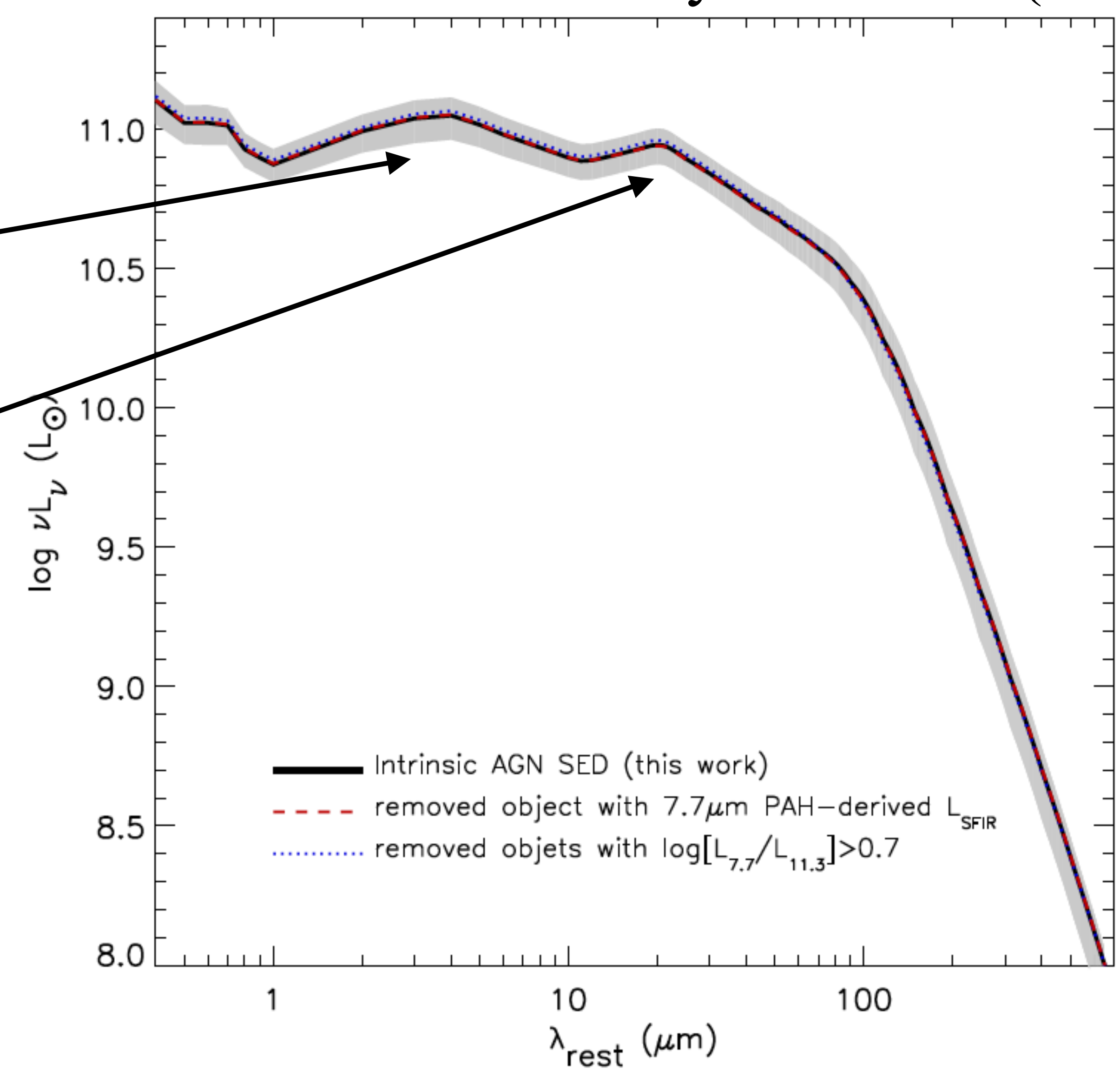
Not the regular torus models

Vertical support
Local accretion disk IR
versus
UV/X-ray illumination (assuming initially thick)

Size
The innermost torus, 0.1-0.2 pc
versus
A “regular torus”, 1-10 pc

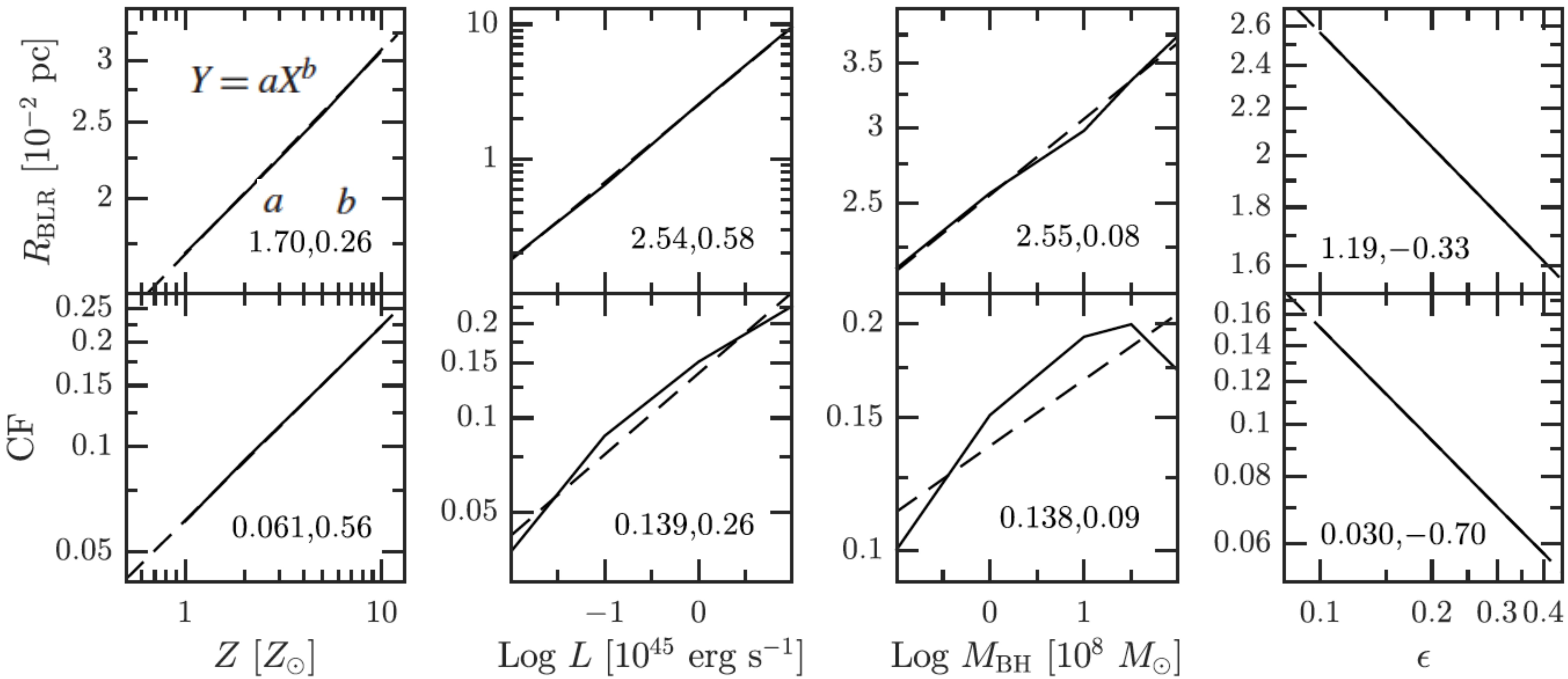
Does the 10-20μm come from the NLR?

Symeonidis+ (2016)



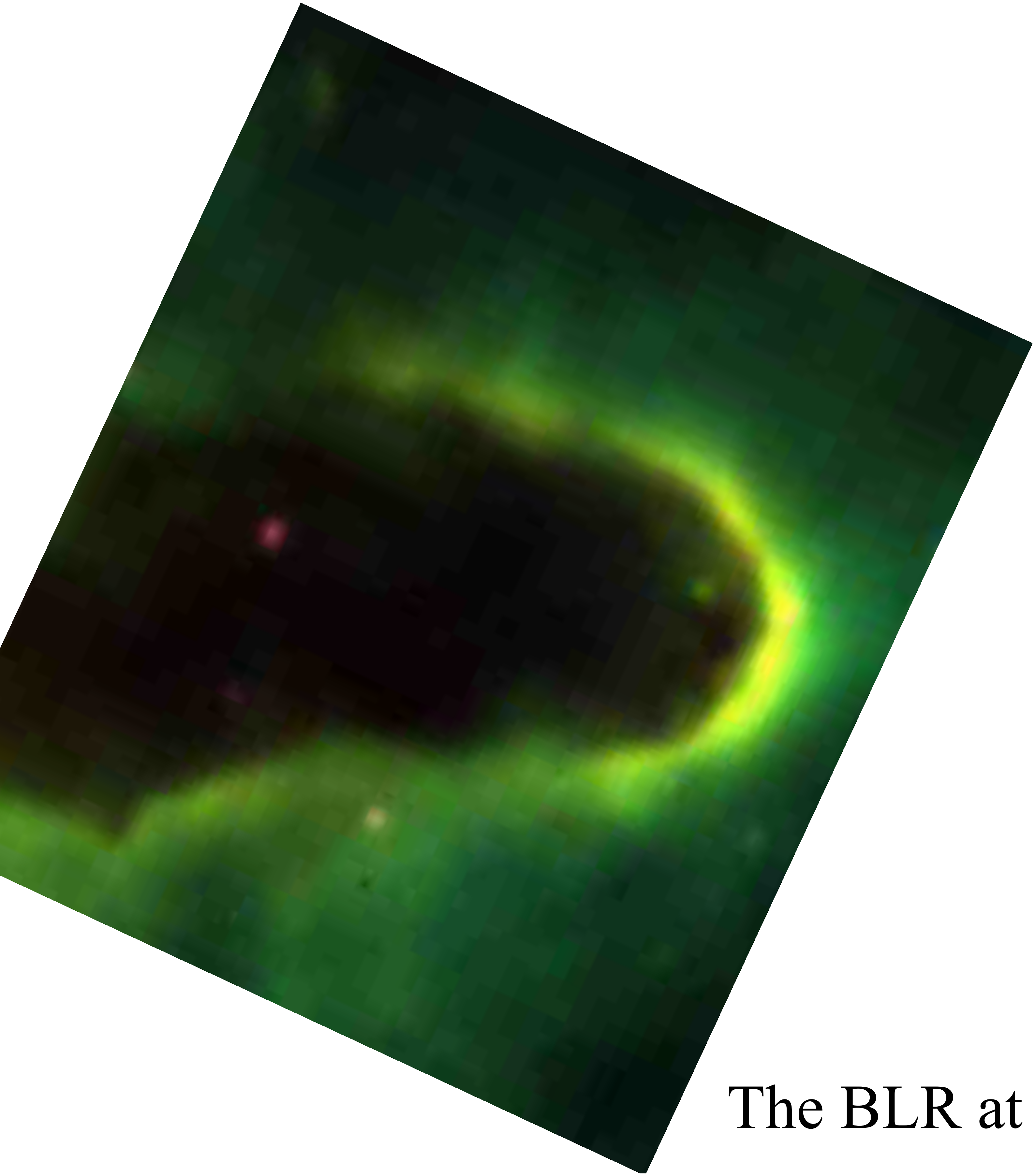
Predictions

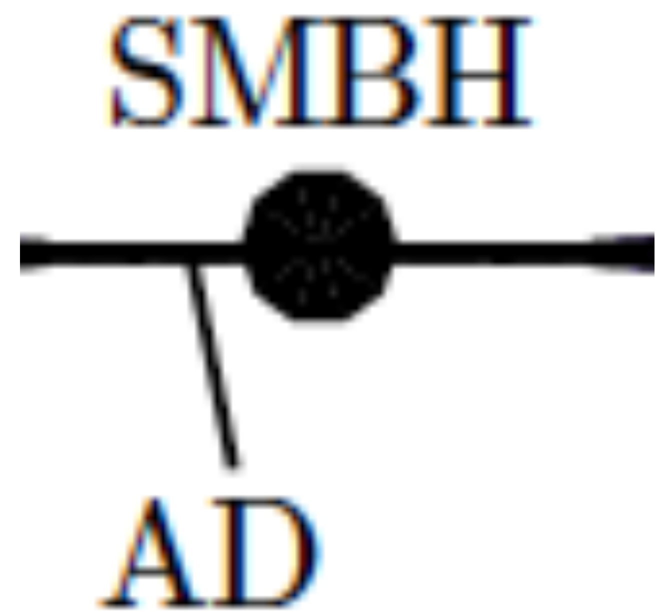
$Z/Z_\odot = 5$, $L_{46} = 0.1$, $M_8 = 1$ and $\epsilon = 0.1$



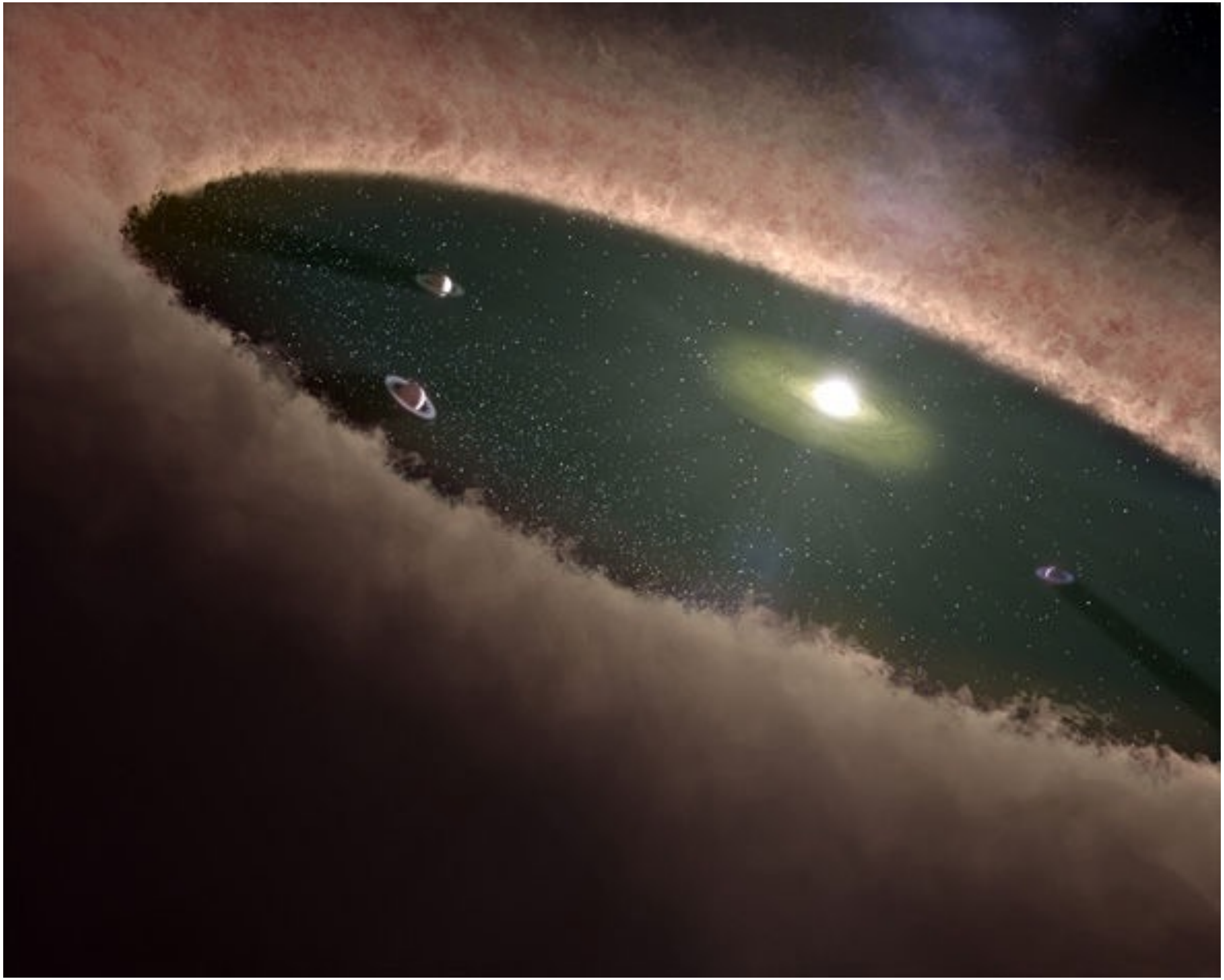
$$R_{\rm max} \propto L_{46}^{0.58} M_8^{0.08} \epsilon^{-0.33} (Z/Z_\odot)^{0.26}$$

$$\mathrm{CF} \propto L_{46}^{0.26} M_8^{0.09} \epsilon^{-0.70} (Z/Z_\odot)^{0.56}$$





The BLR at micro arcsec resolution…



Predictions

1. The BLR **cannot** extends inwards of $0.2R_{BLR}$

2. A maximal CF ~ 0.3

3. The BLR disappears (but NLR remains)

   $\dot{m} < (0.025, 0.0065, 6.5 \times 10^{-4}) \times (Z/Z_{\odot})^{-1}$

4. If $\dot{M}_{BLR} \gg \dot{M}$

   one can get an IR only source

5. If $\dot{M}_{BLR} \ll \dot{M}$

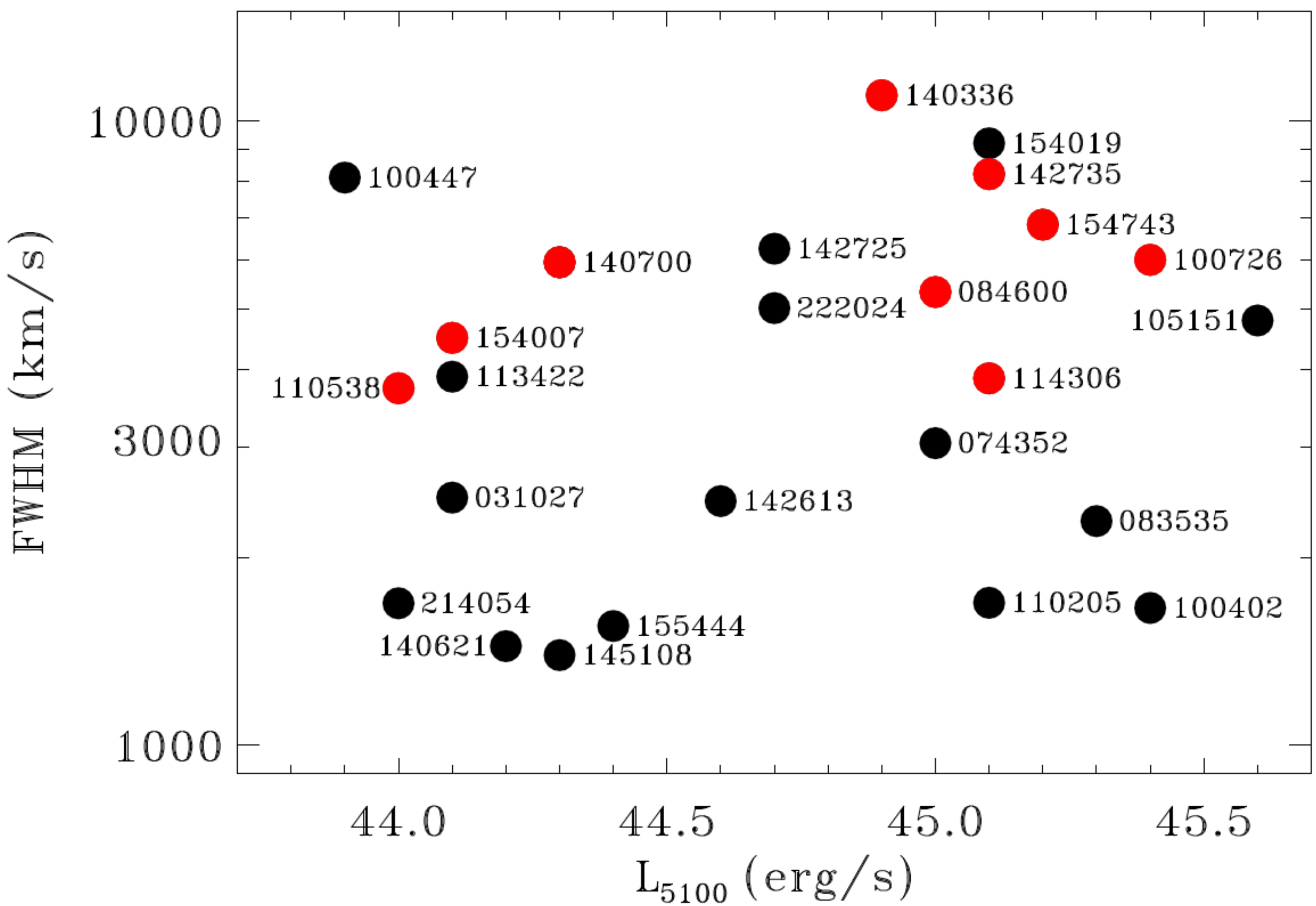
   The BLR disappears, despite high $\dot{m}$

(see Baskin & Laor 2018)

Spectropolarimetric evidence

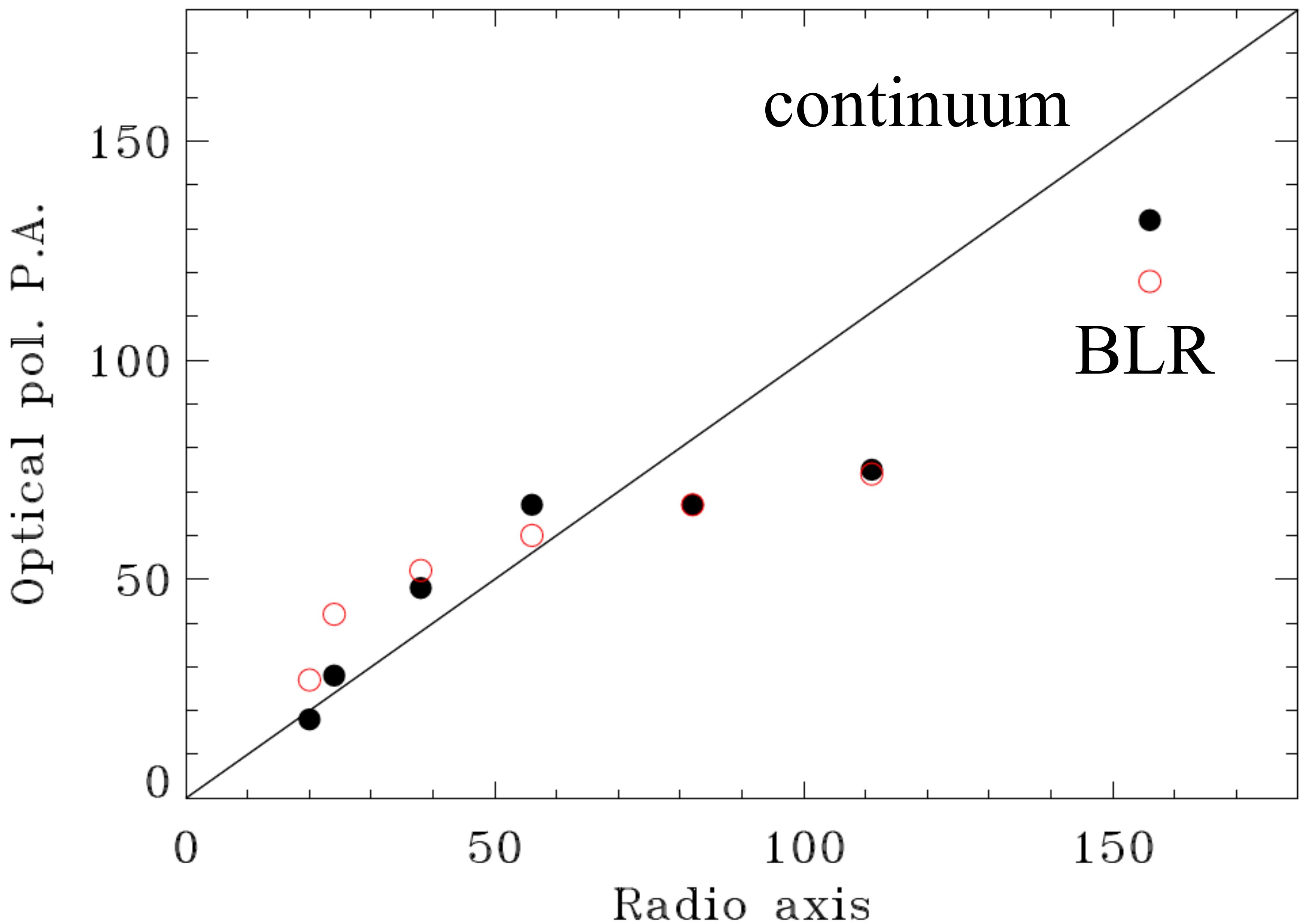
Capetti, Robinson, Marconi, Baldi, Laor

25 h on the VLT



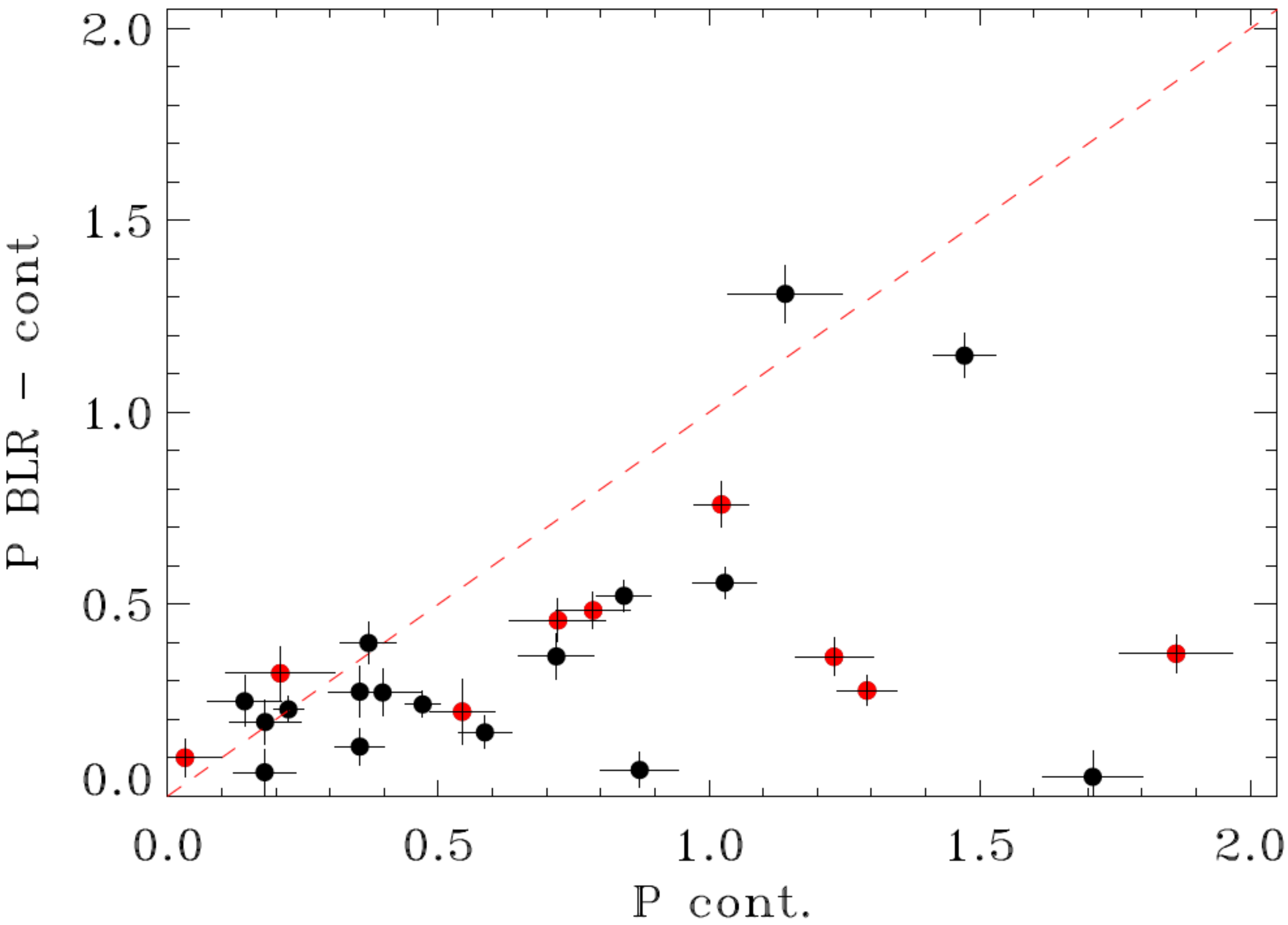
A complete sample of type 1 AGN

Polarization P.A. || Radio axis



→ **Planar scattering** (not polar scattering)
for both the continuum and the BLR

$P_{BLR} < P_{cont}$



Geometric dilution ⟶ scattering **close to the BLR**
(+ P.A. rotation)

The BLR itself? and nothing but the BLR?