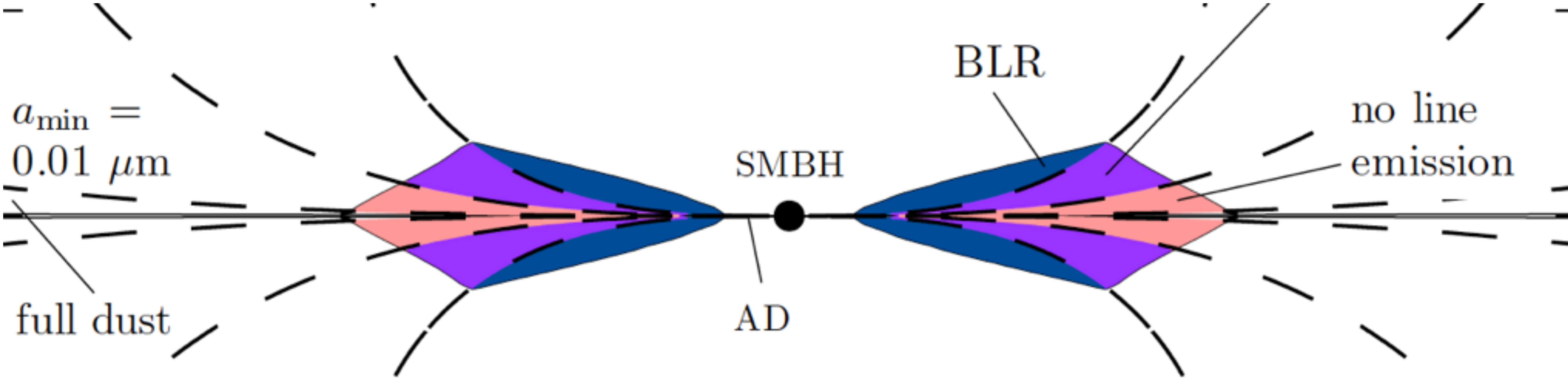
The Broad Line Region - An Innermost Torus

+ a reminder about Radiation Pressure Confinement

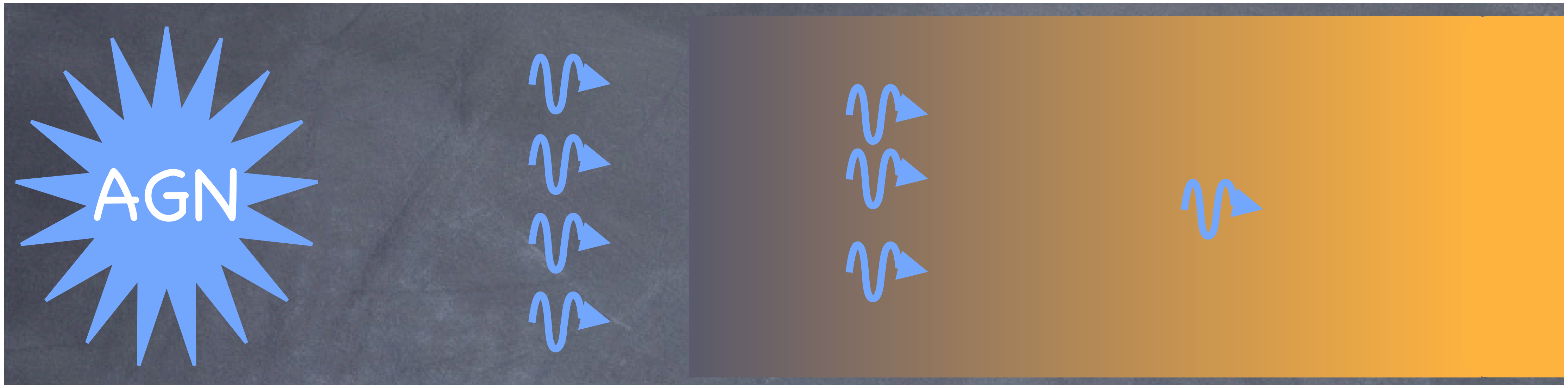
Alexei Baskin & Ari Laor



What sets n_e?

Radiation carries energy and momentum

If the gas is not outflowing, P_{rad} must be balanced by P_{gas}



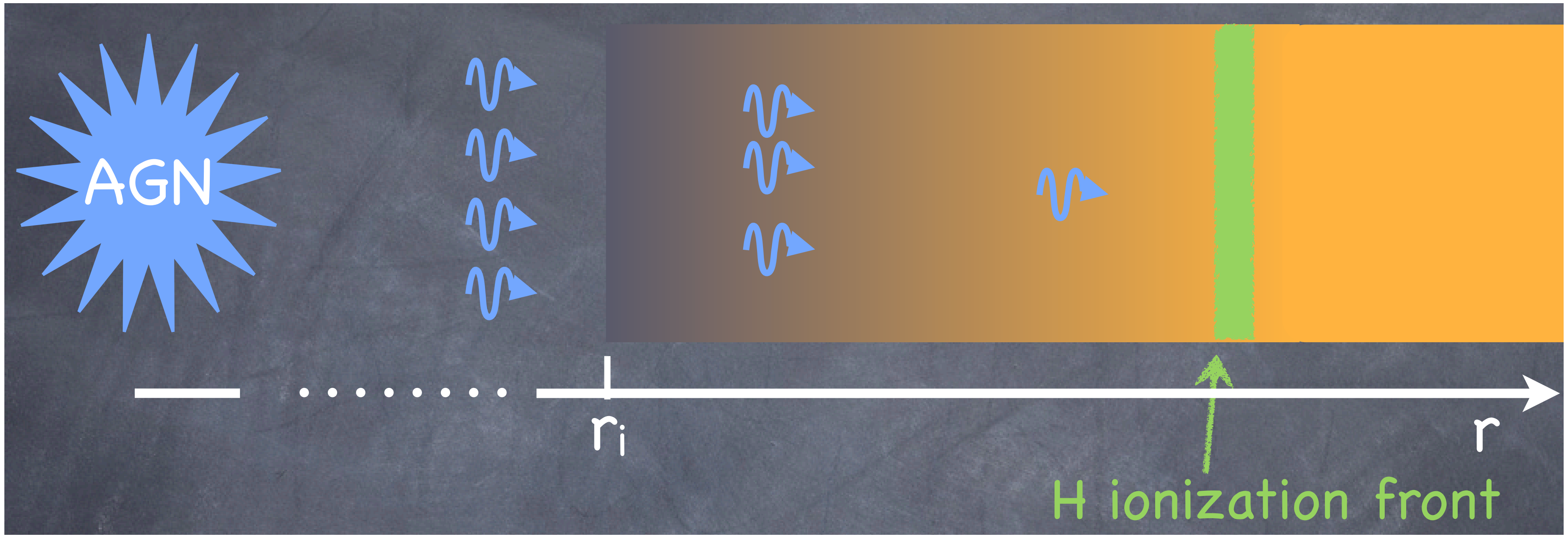
At the 0’th order level $P_{rad}=P_{gas}$

$2n_ekT=n_{ph}\langle h\nu\rangle$, $n_{ph}/n_e=U=2kT/\langle h\nu\rangle$

$2kT\sim3eV$, $\langle h\nu\rangle\sim30eV$

——> **U=0.1** Independent of distance and luminosity

What is the structure of the absorbing layer?

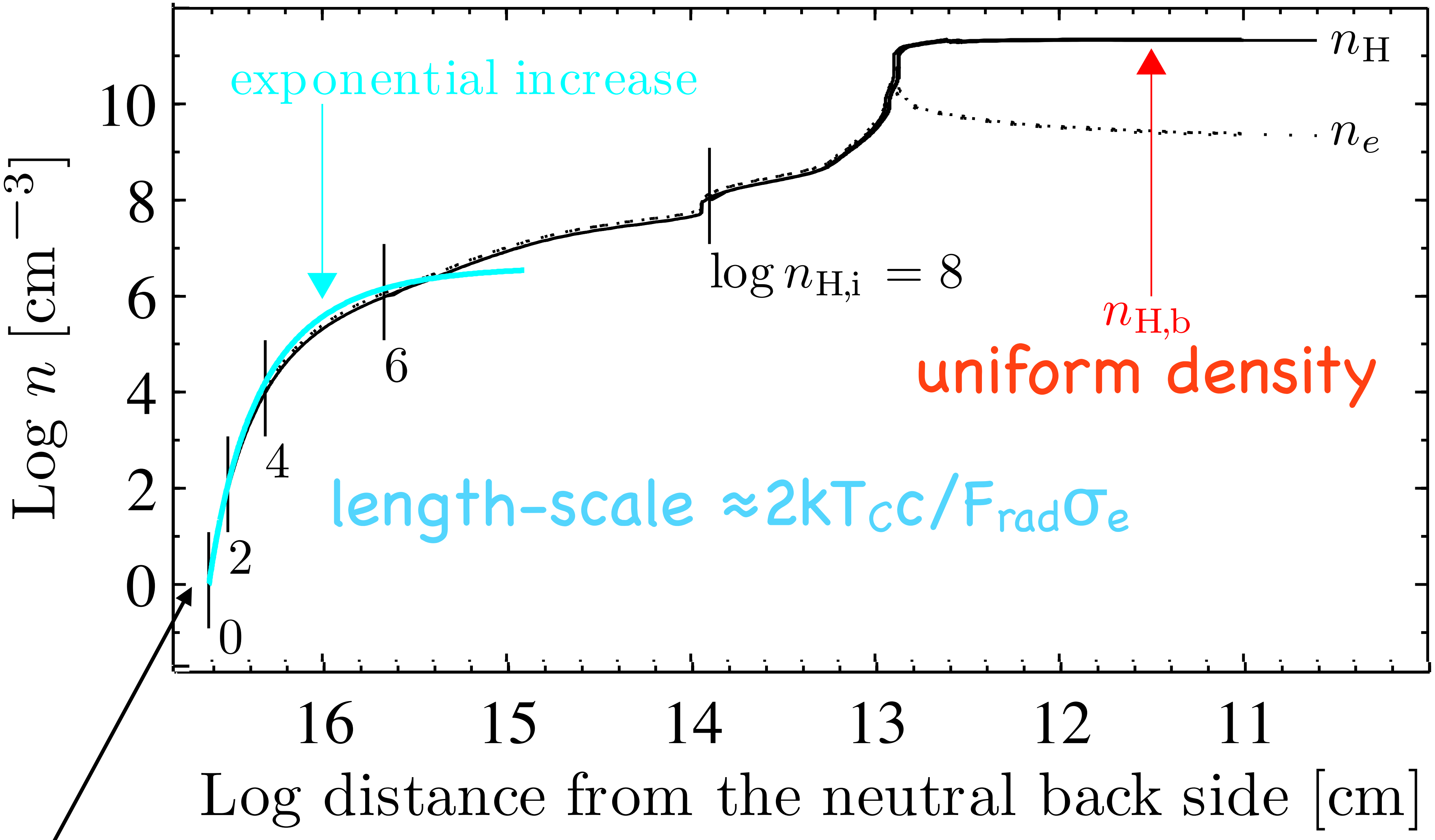


$$\mathrm{d}P_{\mathrm{gas}}(r) = \frac{F_{\mathrm{rad}}}{c} e^{-\tau(r)} \mathrm{d}\tau$$ —> $P_{\mathrm{gas}}(r)=P_{\mathrm{rad}}(1\text{-}e^{\text{-tau}(r)}) + P_{\mathrm{gas}}(r_i)$

$$2kT_{\mathrm{C}} \frac{\mathrm{d}n_e(r)}{\mathrm{d}r} = \frac{F_{\mathrm{rad}}}{c} n_e \sigma_{\mathrm{es}}$$

$$n_e(r) = n_{e,\mathrm{i}} \exp\left(\frac{r - r_{\mathrm{i}}}{l_{\mathrm{pr}}}\right) \qquad l_{\mathrm{pr}} = 2kT_{\mathrm{C}} c / F_{\mathrm{rad}} \sigma_{\mathrm{es}}$$

Radiation Pressure Confinement - RPC



exponential increase

uniform density

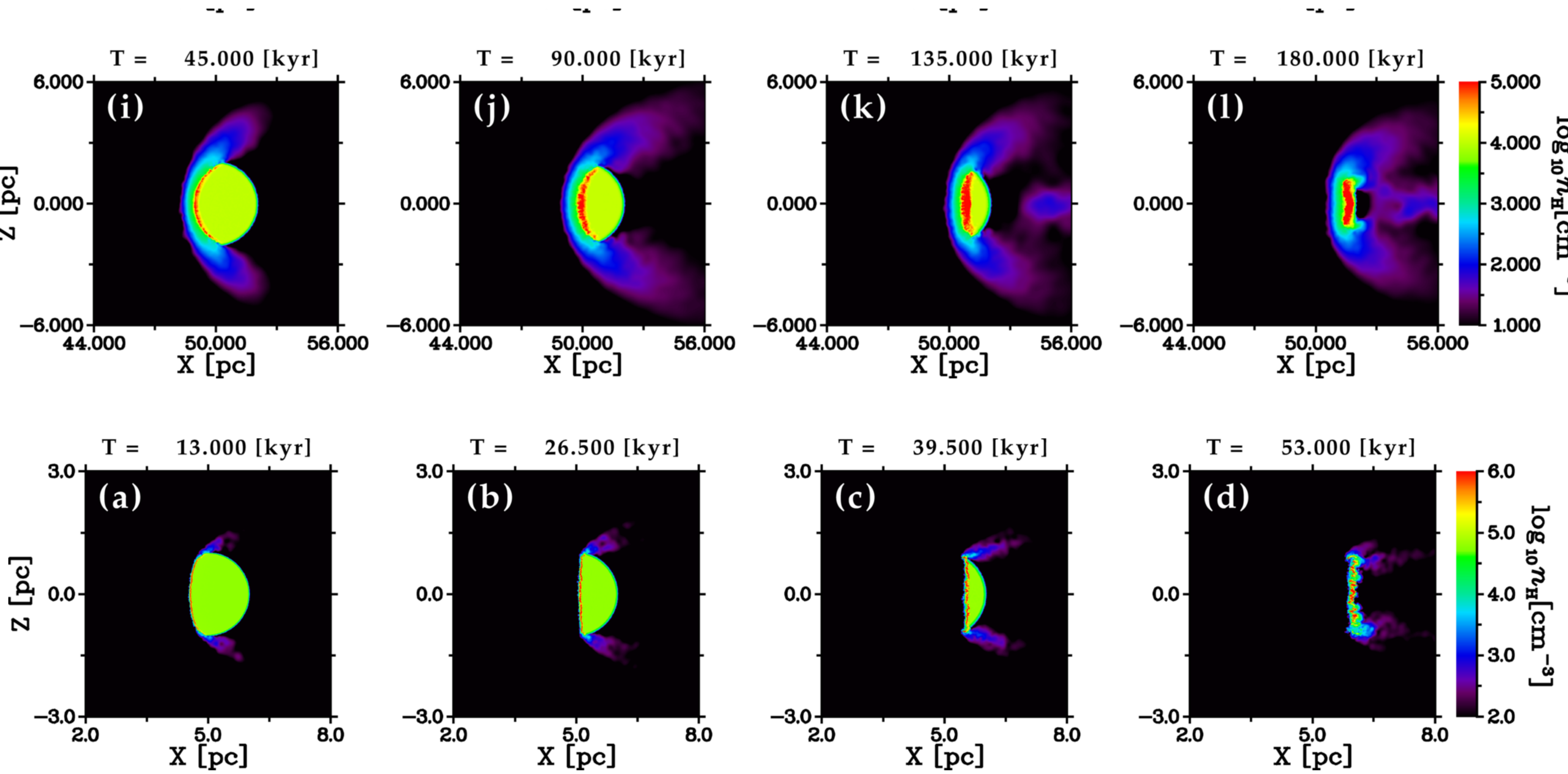
length-scale $\approx 2kT_C c/F_{rad}\sigma_e$

$$n_e(r) = n_{e,\mathrm{i}} \exp\left(\frac{r - r_{\mathrm{i}}}{l_{\mathrm{pr}}}\right)$$

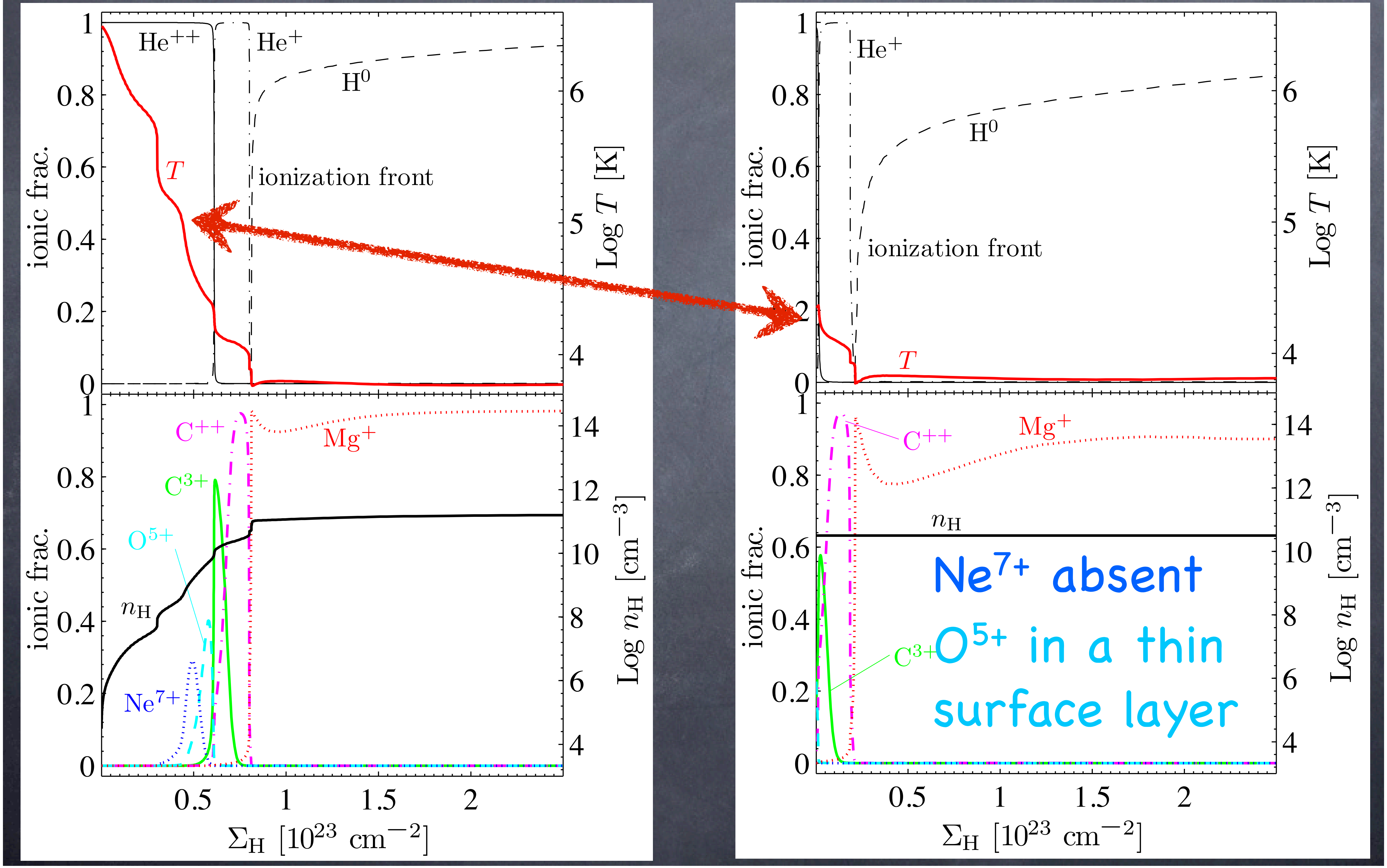
On the evolution of gas clouds exposed to AGN radiation. I. Three-dimensional radiation hydrodynamic simulations

(2014)

D. Namekata[1*], M. Umemura[1] †, and K. Hasegawa[1]‡



Comparison to a constant-n slab

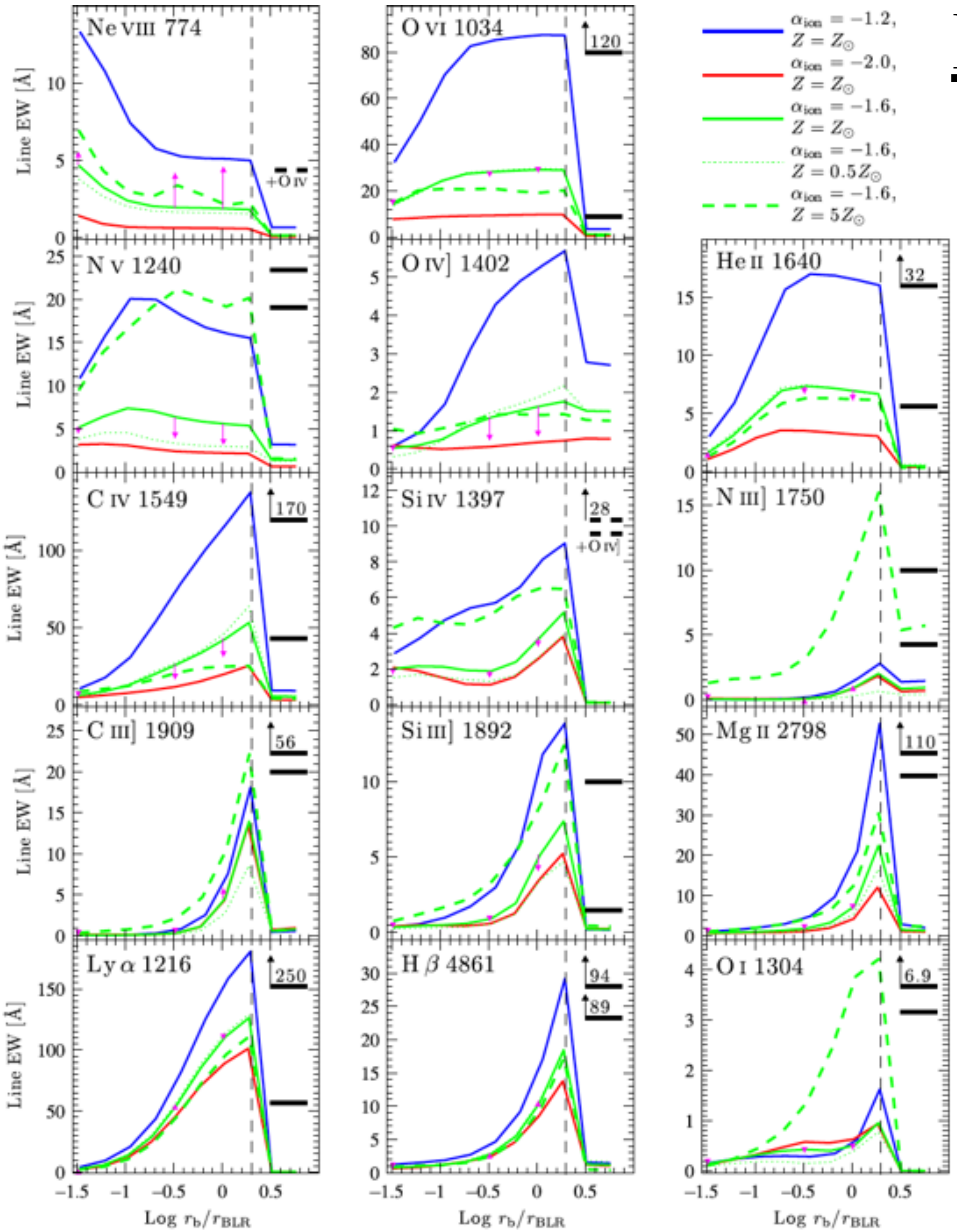


RPC slab

n=$10^{10.5}$ (U=0.05)

Ne^{7+} absent

O^{5+} in a thin surface layer



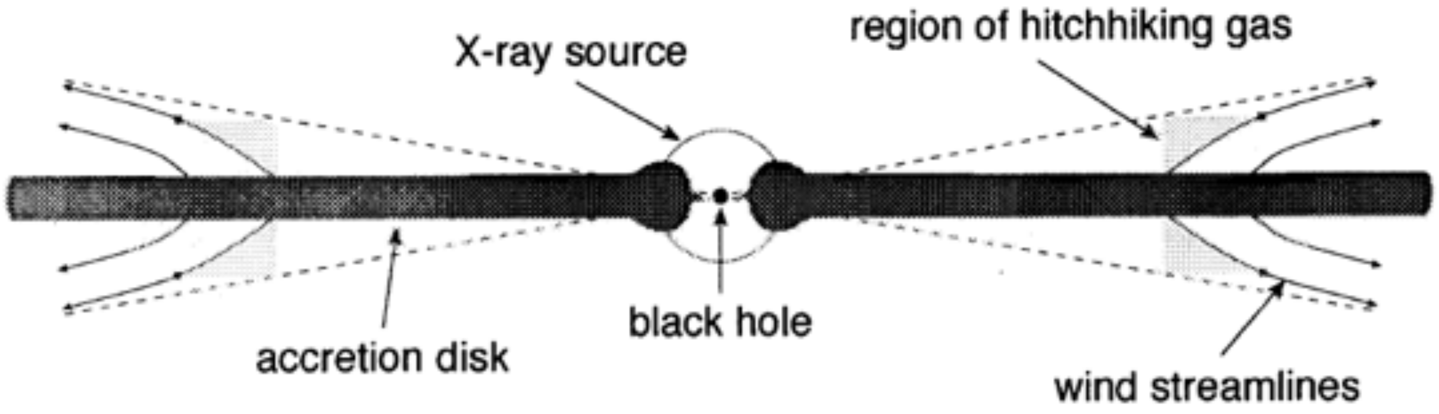
Predicted Emissivities

The remaining free parameters are the SED and Z

Use RM to test the predicted line response function

Baskin, Laor & Stern (2014)

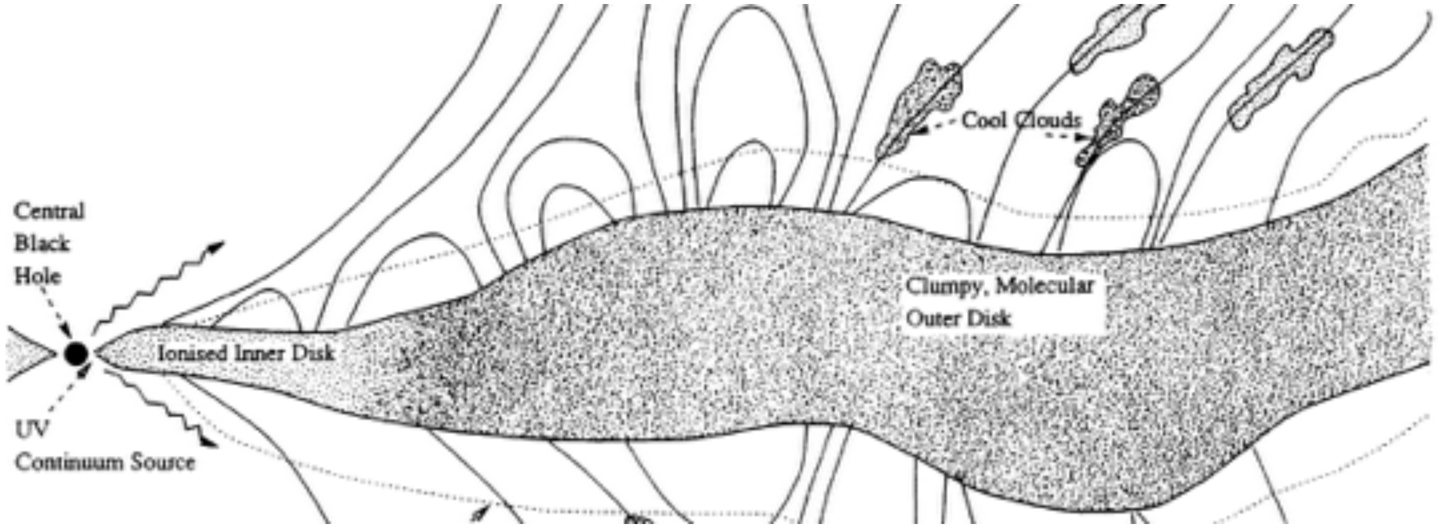
What is the Origin of the BLR?



Line driven wind

Shlosman, Vitelo & Shaviv 1985
Murray et al. 1995
Proga & Kallman 2004

Too compact.
100Rg vs. 10,000R



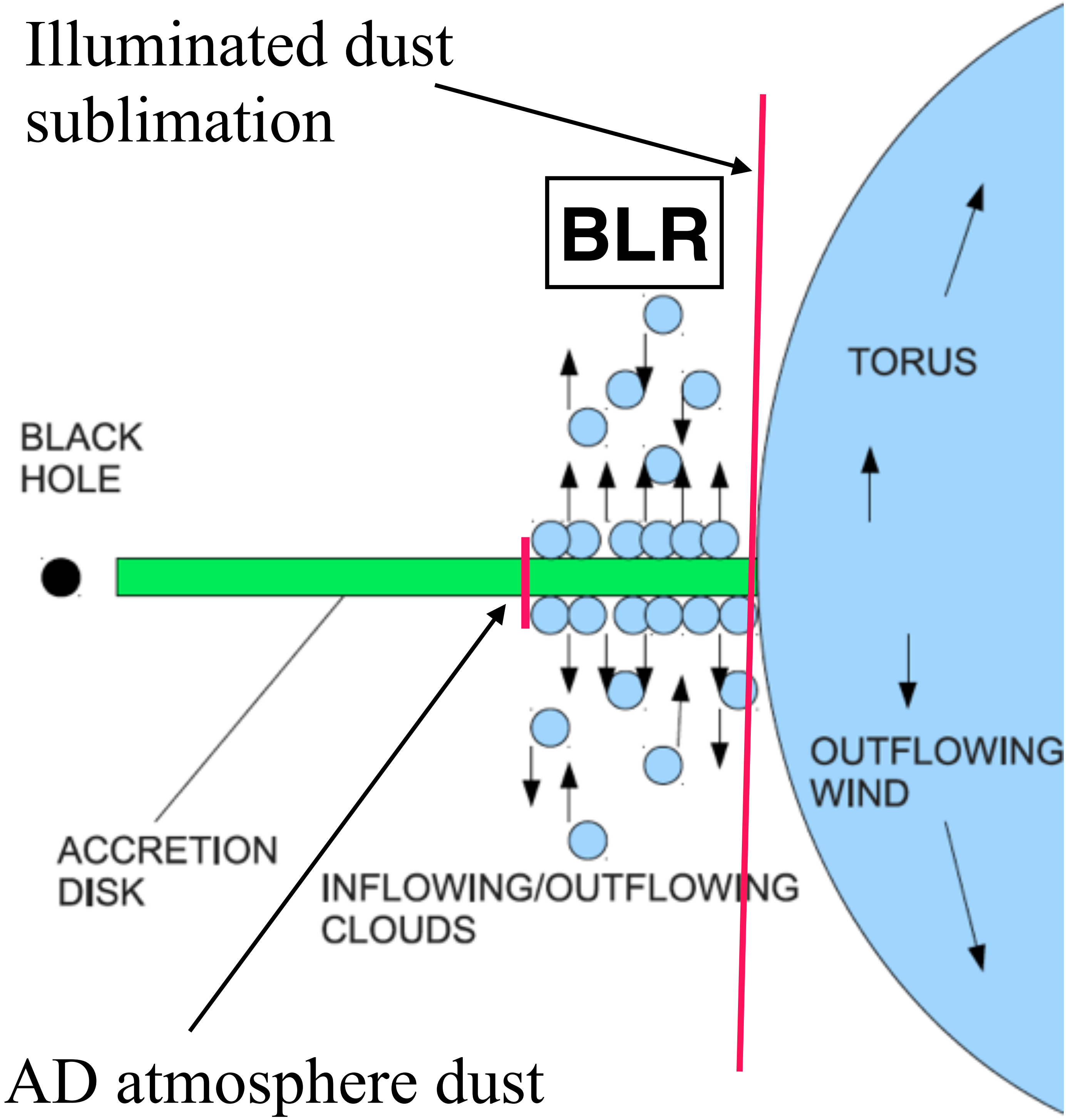
MHD driven wind

Emmering, Blandford & Shlosman 1992
Konigl & Kartje 1994
Everett 2005

Assumed solution.
Not predictive

A failed dusty disk wind?

Czerny & Hryniewicz 2011



Illuminated dust sublimation

AD atmosphere dust sublimation

Correct absolute size
Correct luminosity dependence
Unavoidable

Correct CF?
Predictions?

Need to work out the details

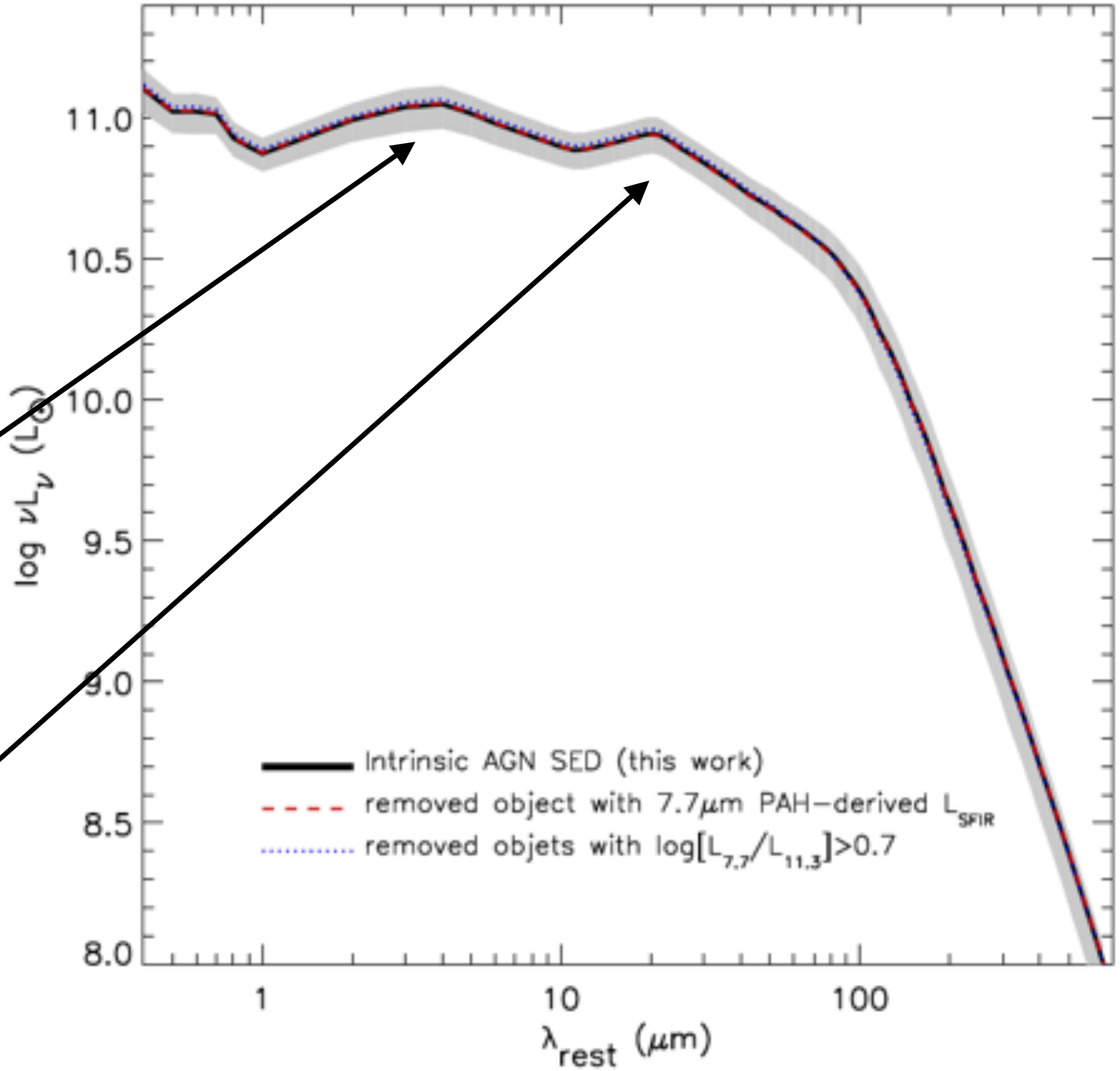
Very different from the regular torus models

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

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

Emission
NIR - hot dust, 3-5μm
versus
MIR - warm dust 10-30 μm

Symeonidis+ (2016)



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)

……

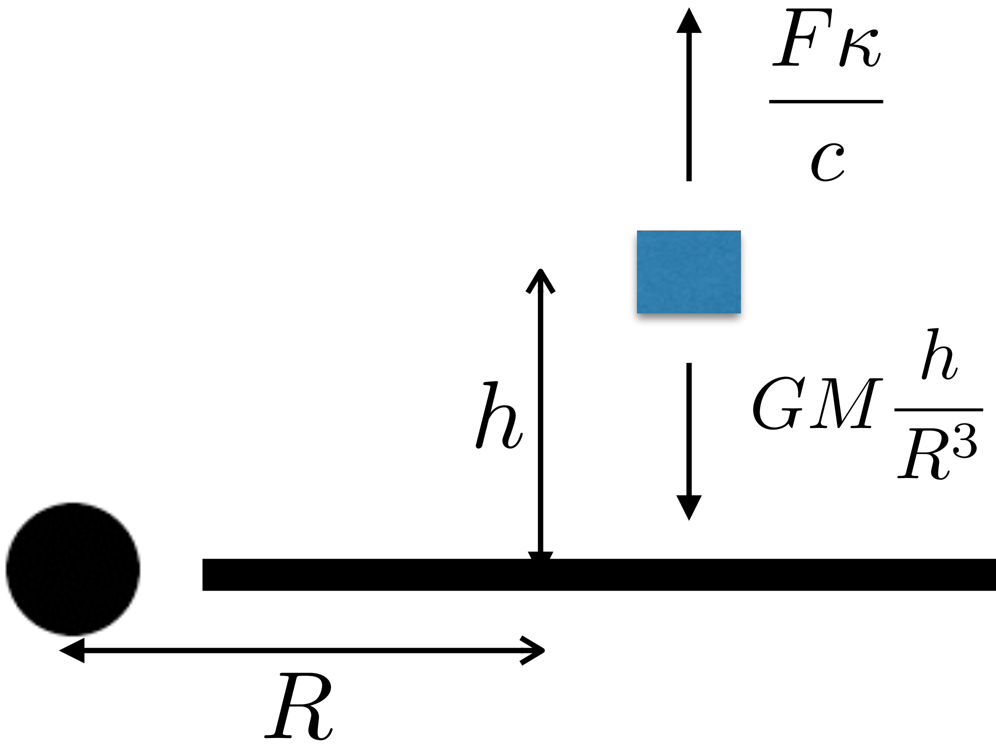
Inner radius set by dust sublimation at the disk surface

$$\frac{3}{8\pi}\frac{GM\dot{M}}{R_{\rm in}^3} = 4\sigma T_{\rm sub}^4 \quad \rightarrow \quad R_{\rm in} = 0.006 L_{\rm opt,45}^{1/2}\ {\rm pc}$$

Predicted: Czerny & Hryniewicz (2011), Observed:?

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

How thick is the inner torus?



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

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

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

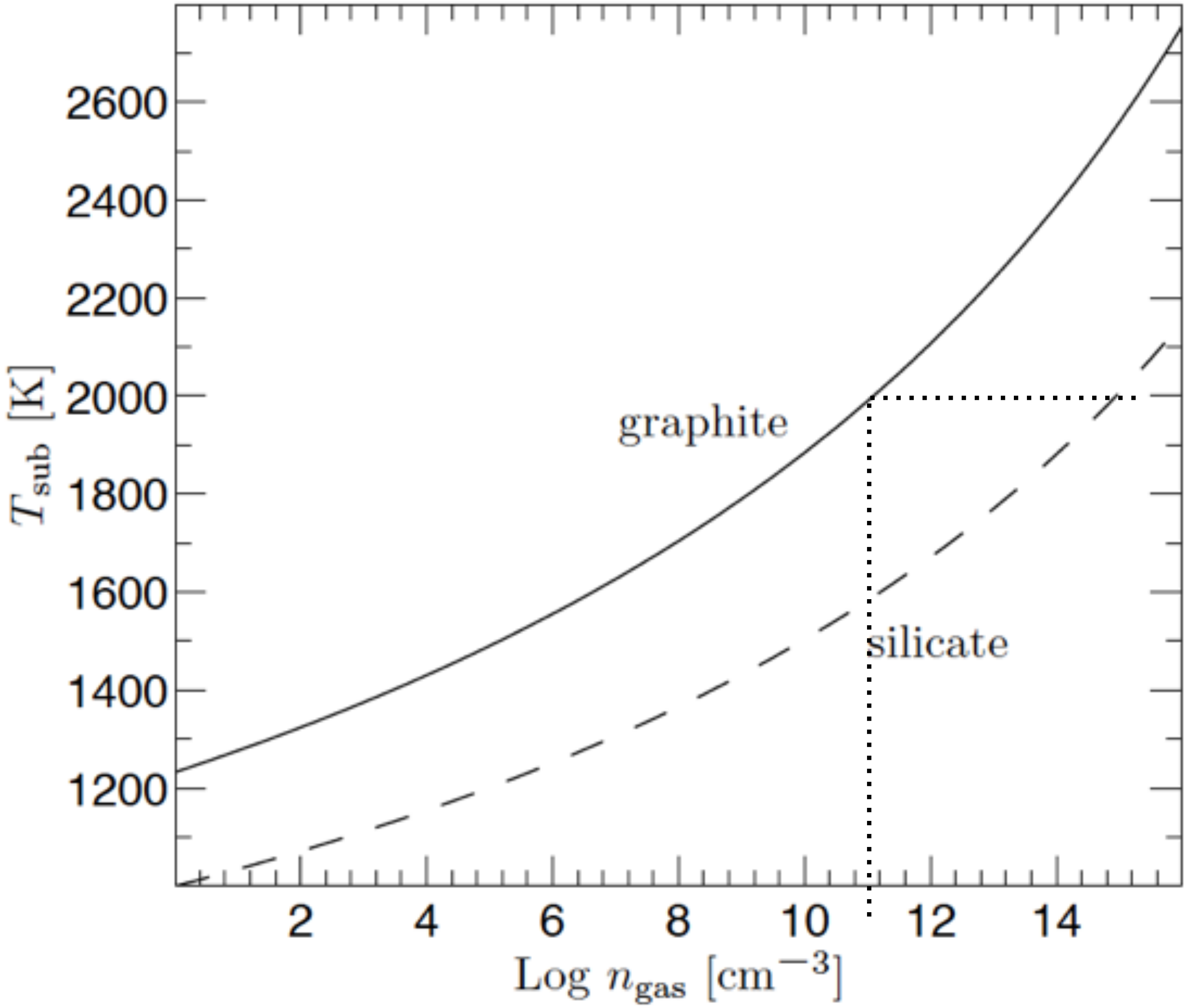
What is kappa?

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

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

What is T_{sub}?

Guhathakurta & Draine (1989)



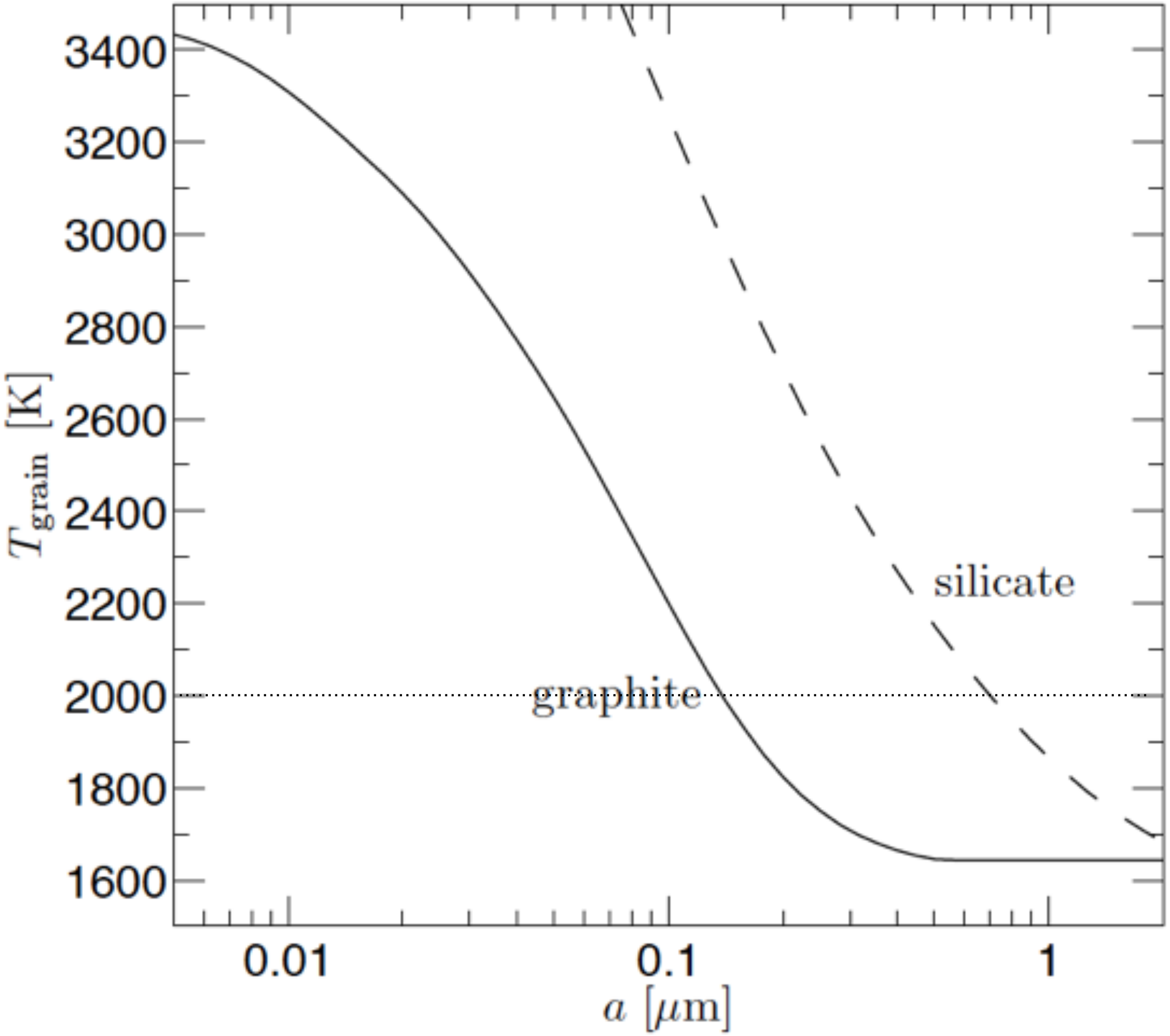
At BLR density ~10^{11}

Graphite - 2000K
Silicate - 1600K

→

Only graphites survive at the BLR

What is T_{grain}?

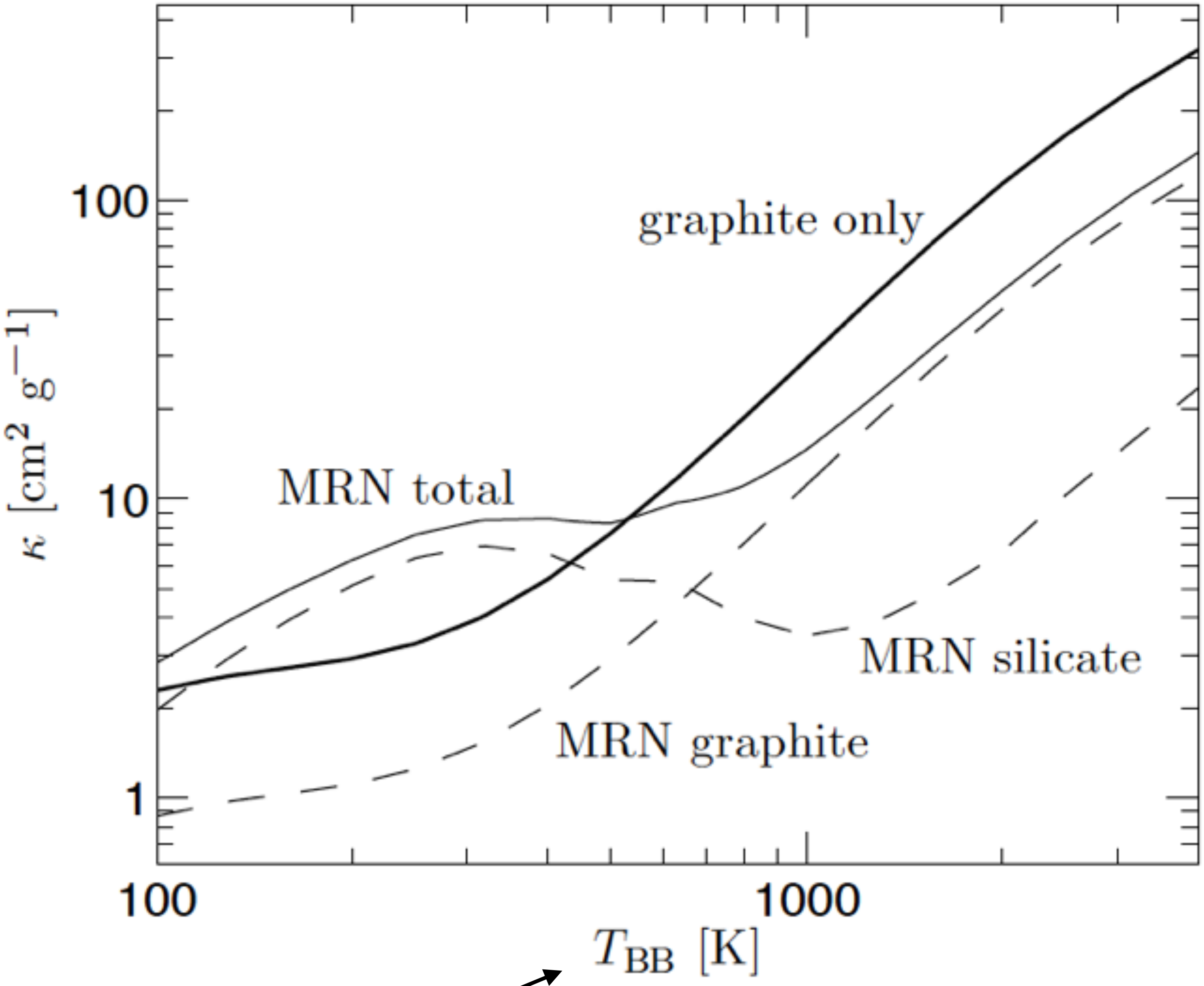


At R_{BLR}

→

Only large grains survive

What is the wavelength dependence of κ ?



→

A sharp rise with T_{BB}
Graphites win again

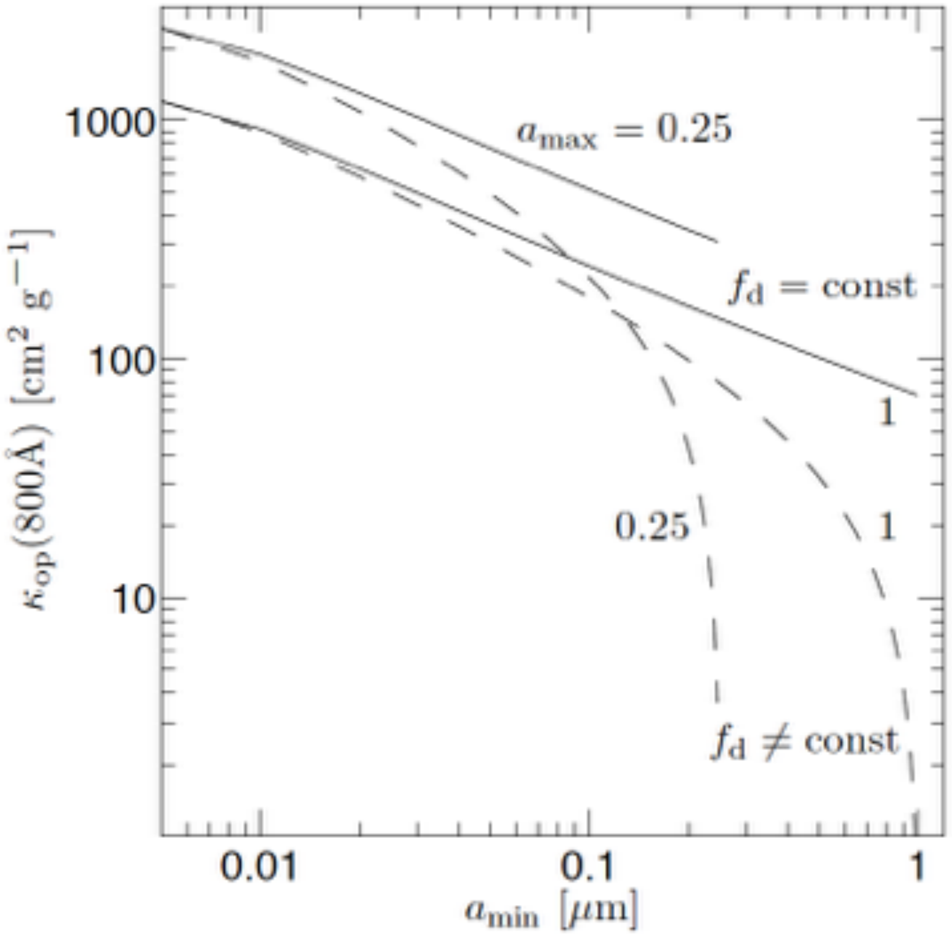
κ can reach ~ 100

But, this is for MRN
(Galactic dust)

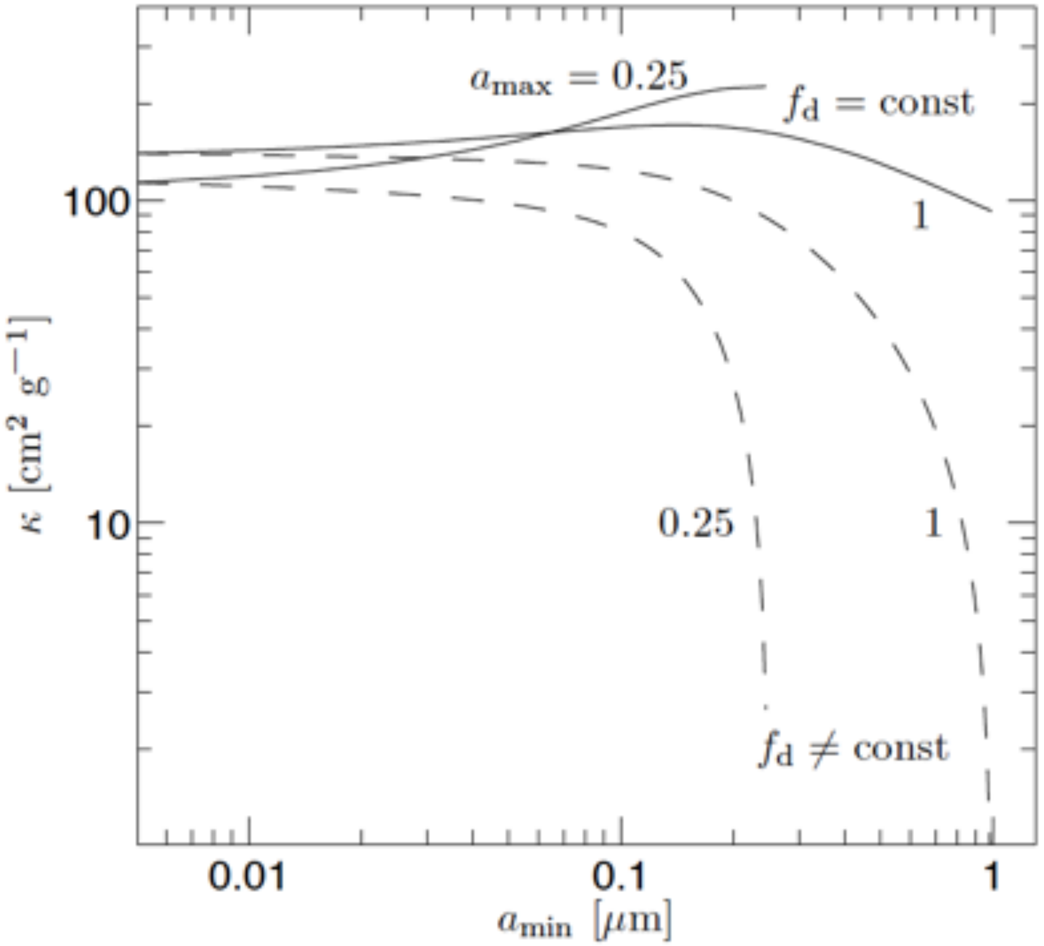
The illuminating radiation

What happen to κ when small grains are gone?

UV



IR

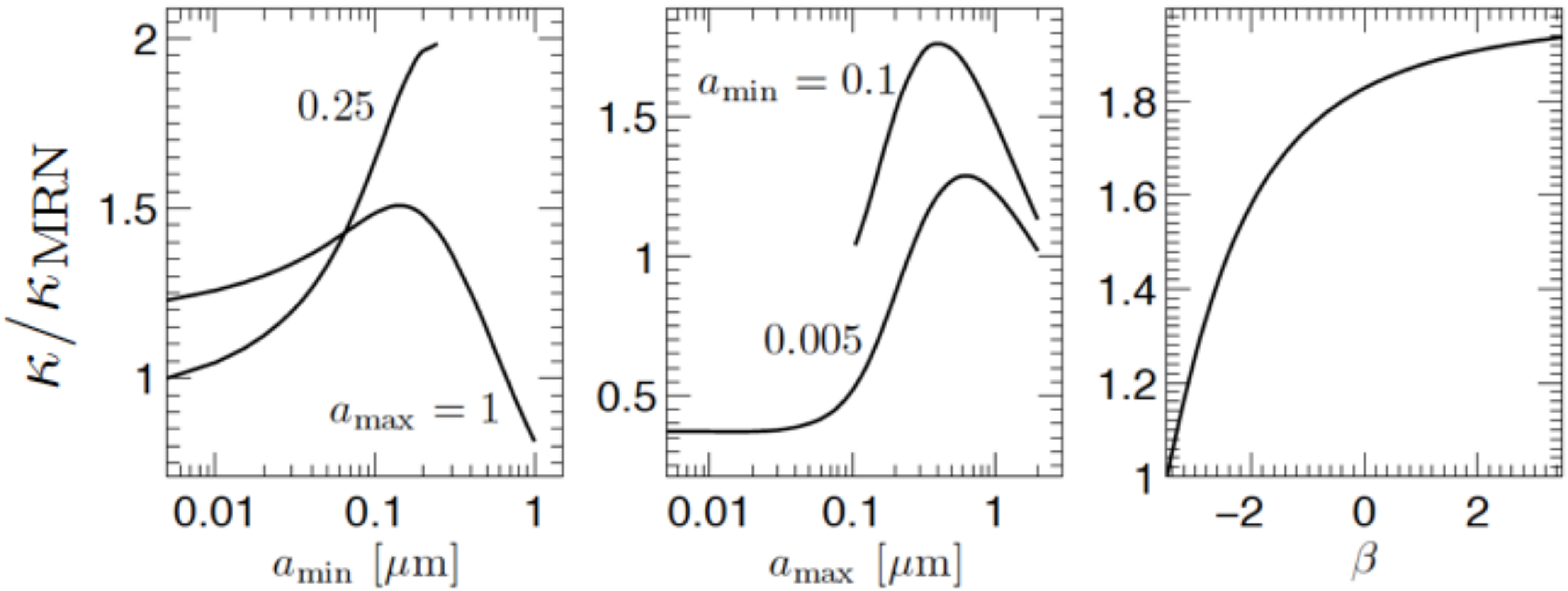


κ sharply drops in the UV, but increases in the IR

Have the cake, and eat it too!

Line suppression is gone (UV absorption)

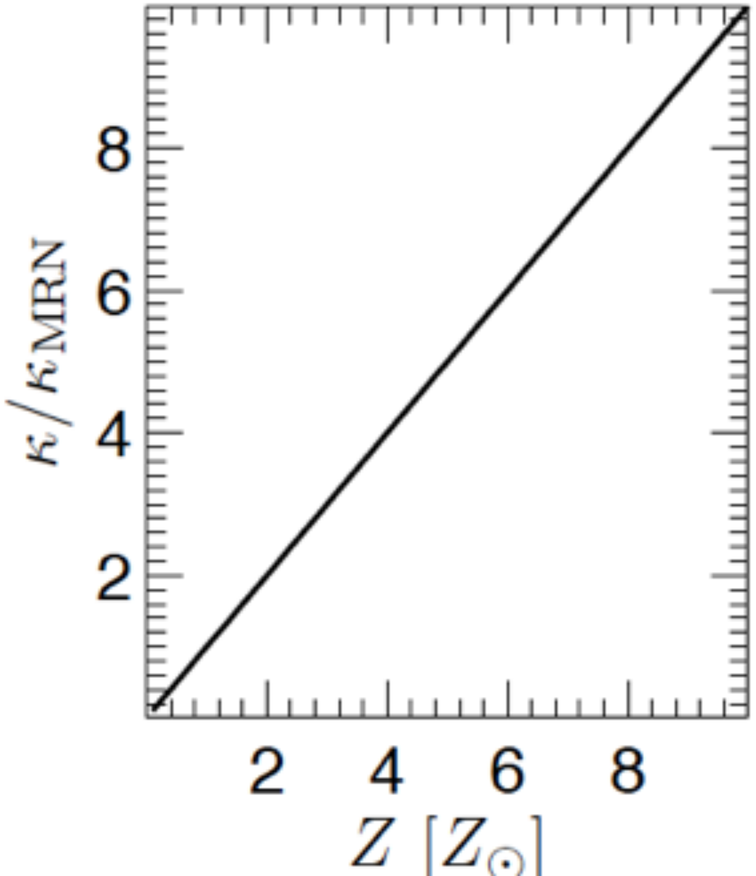
But vertical disk support remains (IR absorption)



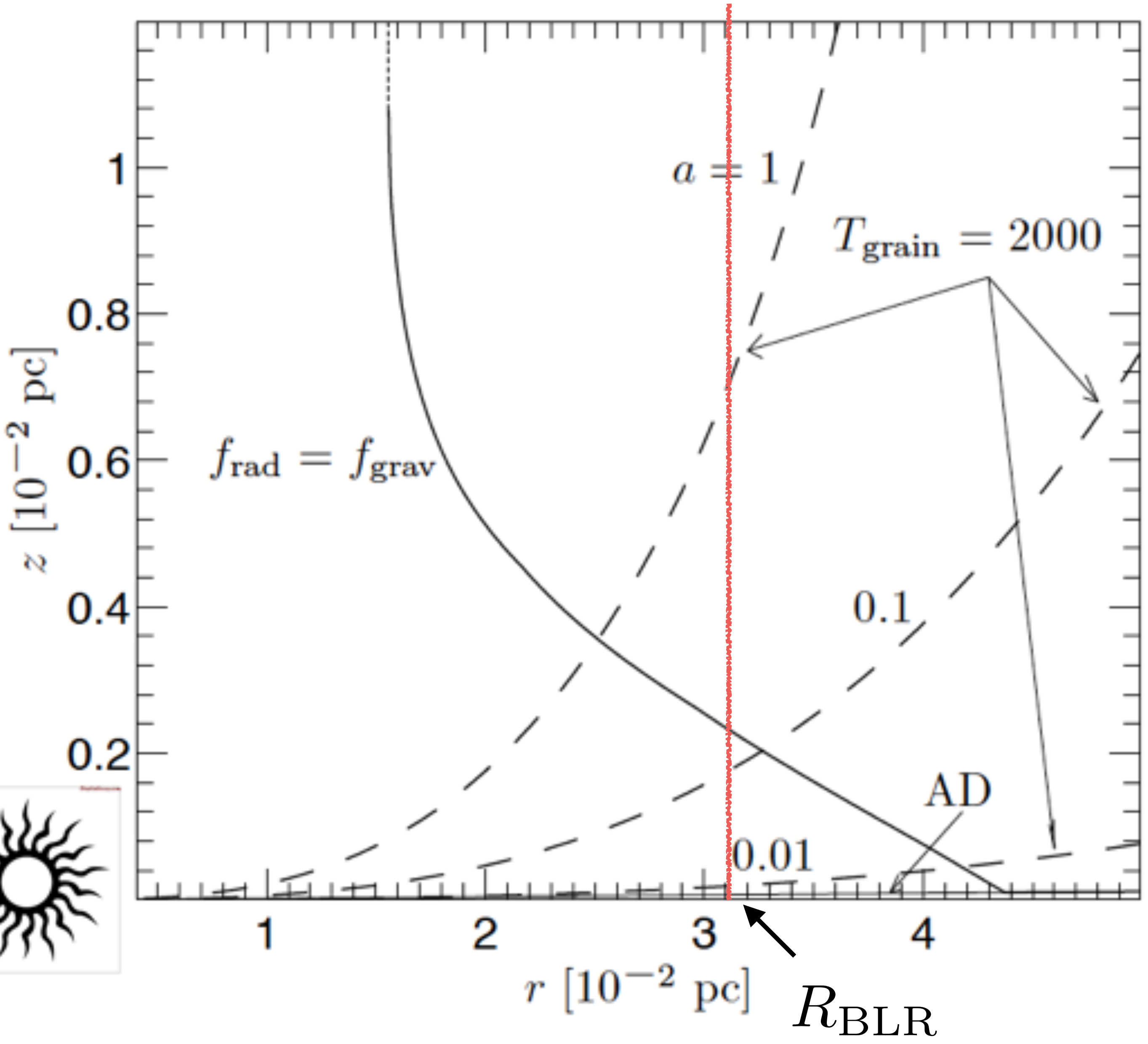
So, grain size distribution doesn't matter in the IR
Volume absorption, rather than surface absorption

……

The winner is the gas metallicity
Since dust/gas ~ Z



What happens when the dust sees the real light?



When

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

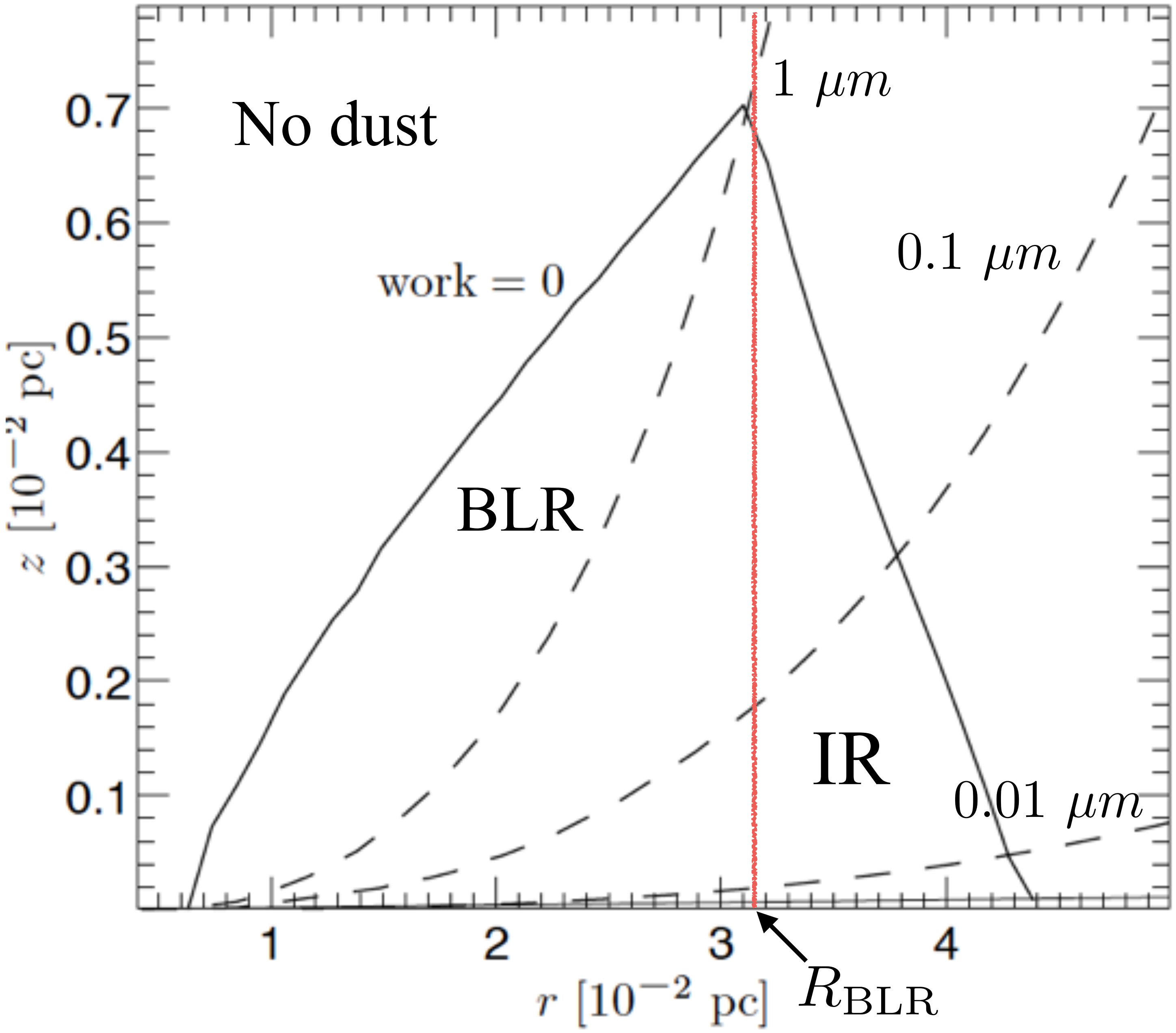
the grains sublimate right away (<1h).

The implied maximal height

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

Radiation acceleration stop at *h*,
but maximal height is reached when *v*=0

Dynamic Solution

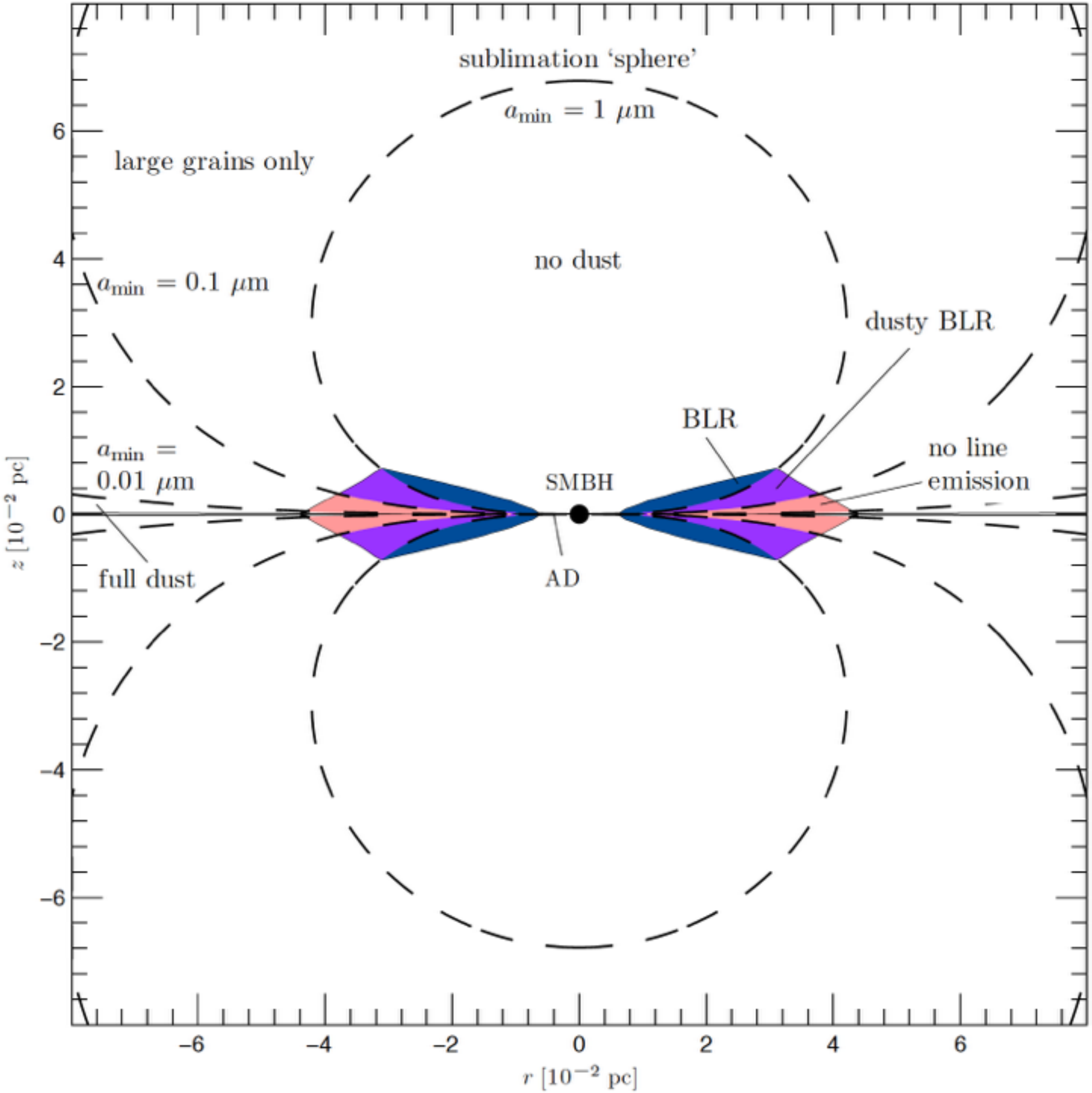


$$L_{\rm bol} = 10^{45} \text{ erg/s}$$

$$M = 10^8 M_\odot$$

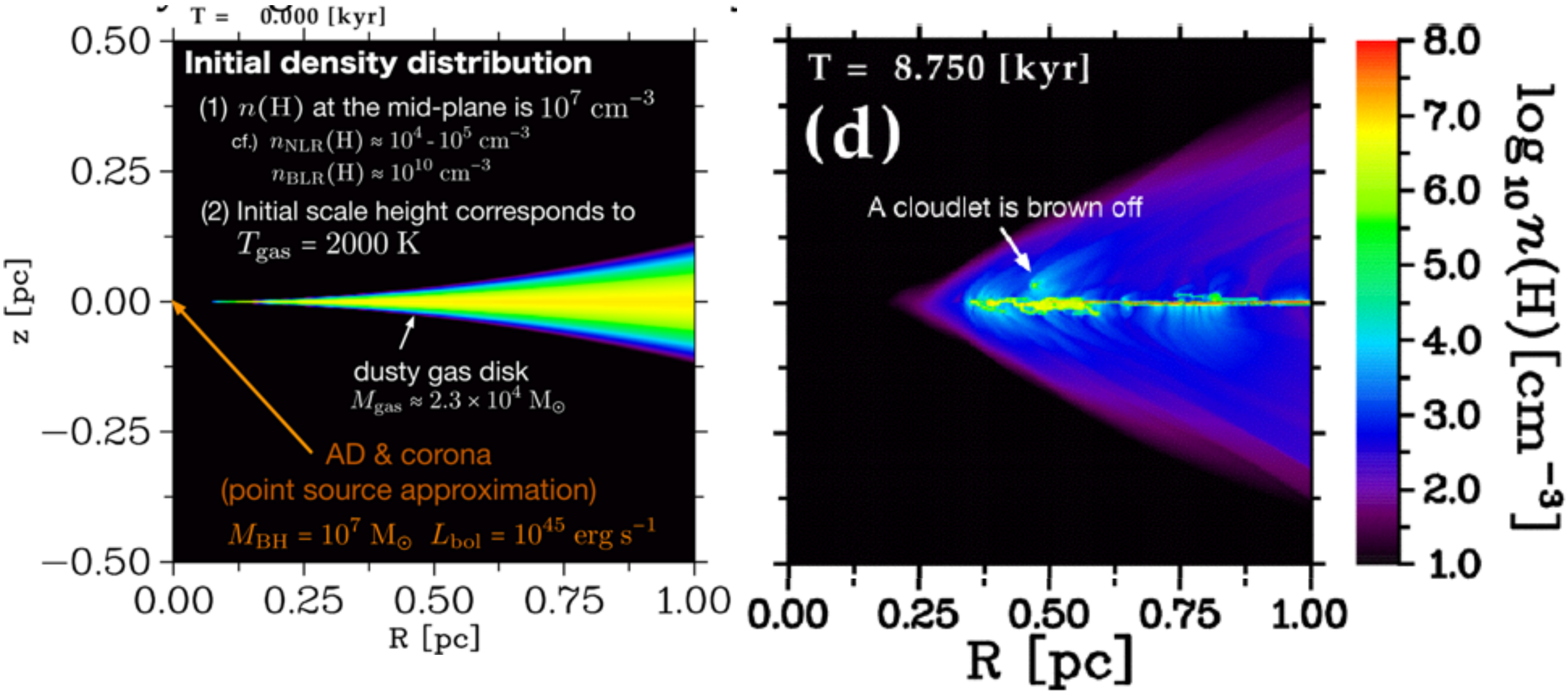
$$\kappa = 200$$

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


sublimation 'sphere'
$a_{\rm min} = 1\ \mu$m
large grains only
no dust
$a_{\rm min} = 0.1\ \mu$m
dusty BLR
BLR
no line emission
$a_{\rm min} =$ 0.01 μm
SMBH
full dust
AD
$z\ [10^{-2}$ pc]
$r\ [10^{-2}$ pc]
6
4
2
0
−2
−4
−6

Sub-parsec-scale dynamics of a dusty gas disc exposed to anisotropic AGN

Namekata & Umemura (2016)



Contrary to Krolik (2007), the radiation pressure by IR photons is not effective to thicken the disc, but rather compresses it. Thus, it seems difficult for a radiation-supported, geometrically thick, obscuring torus to form near the dust sublimation radius

To explain observed type-II AGN fraction, it is required that outflow gas is extended to larger radii (r>10 pc) or that a denser dusty wind is launched from smaller radii (r ~ 10^4 Rg).

Conclusions

1. The BLR forms an inner torus with CF ~ 0.3

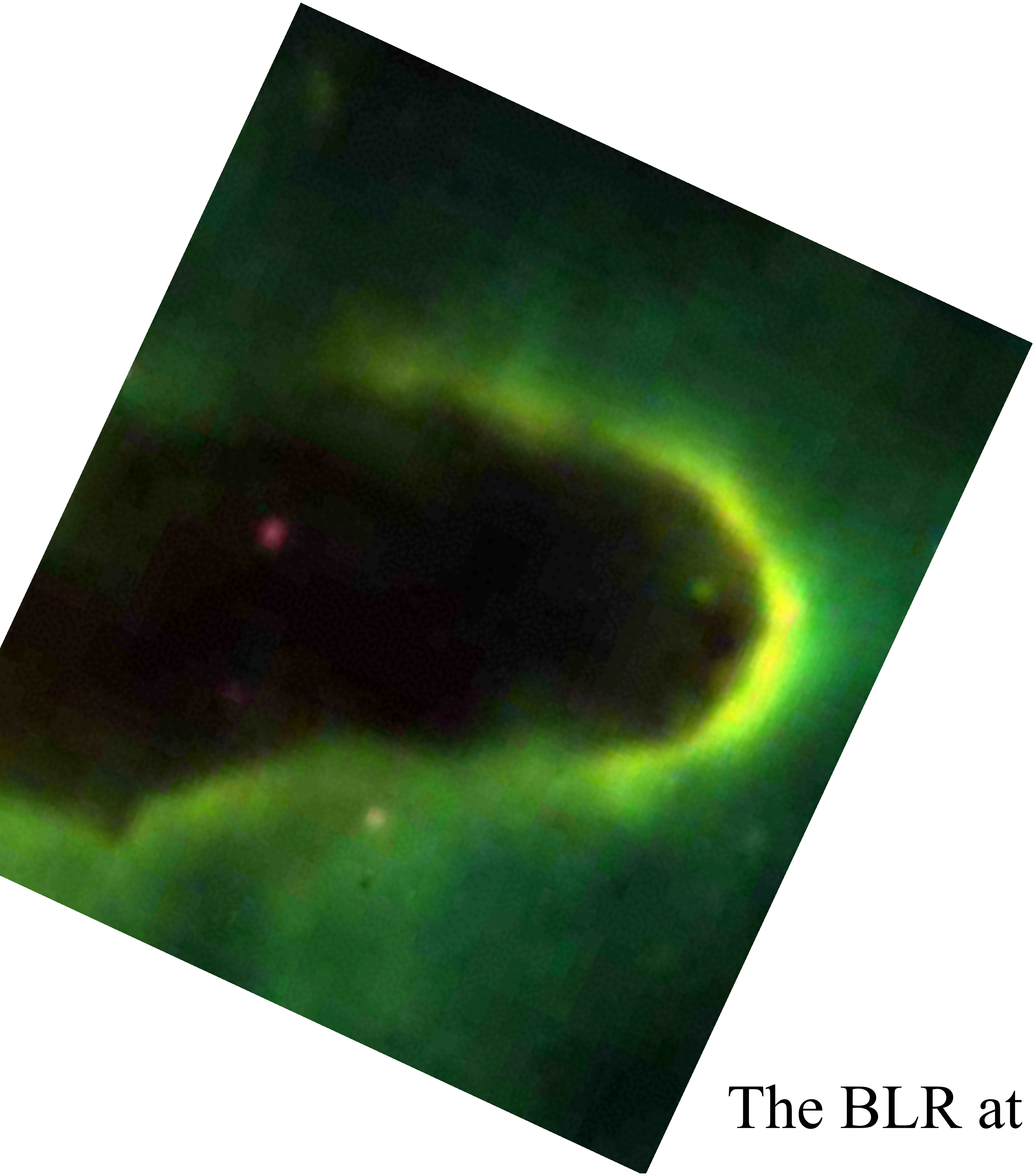
2. The illuminated side produces the BEL.

3. The back side is a source of the hot dust IR

Predictions:

$$\Omega_{\rm BLR} \sim (L/L_{\rm Edd})^{1/3}, \qquad \Omega_{\rm BLR} \sim Z^{2/3}$$

What about obscuration?



The BLR at micro arc sec resolution…