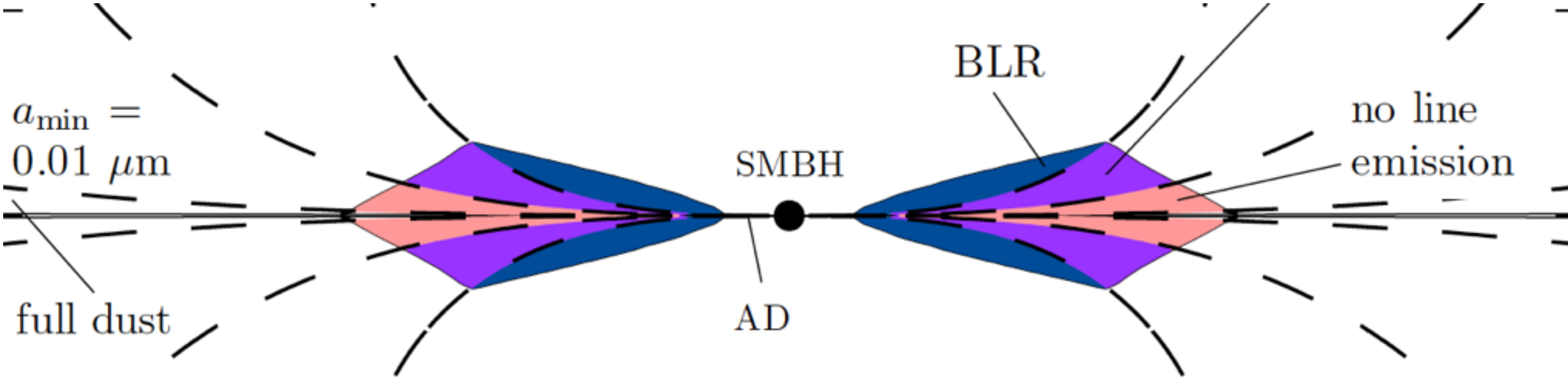
The Origin of the BLR - and a Wind?

+ a reminder about Radiation Pressure Confinement

Alexei Baskin & Ari Laor



The similar values of the radiation pressure incident on the BLR, and the pressure of the gas at BLR, suggest the gas is being compressed by the incident radiation pressure. This radiation pressure compression (RPC) may also provides a natural solution to the overionization problem for the BAL outflow.

How can one test the RPC solution?

What is the source of gas which forms the BLR?

What are the expected properties of a wind formed by the ablation of the RPC BLR gas?

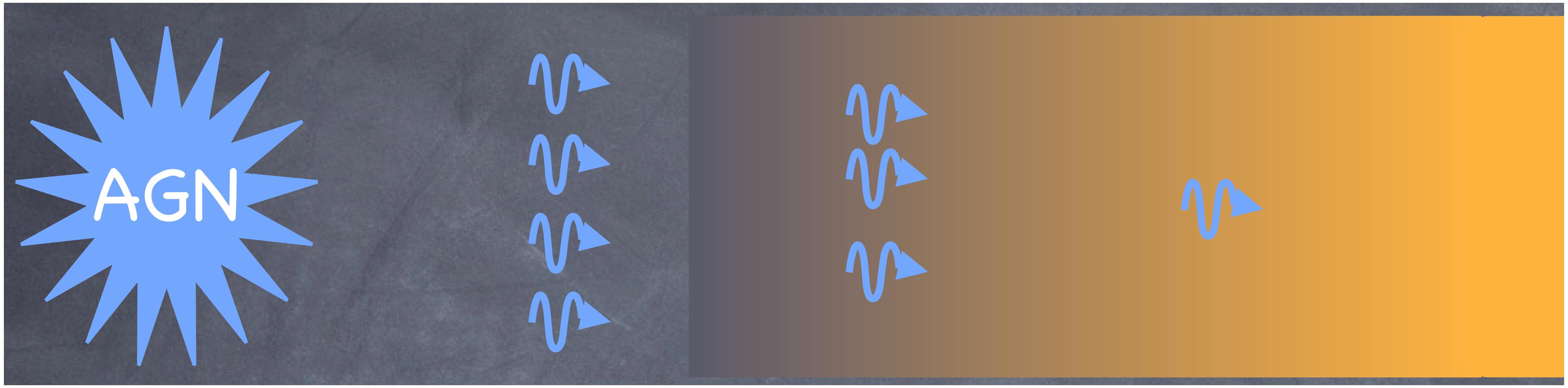
Can RPC ablation explain the low fraction of LBALQs?

Can RPC ablation explain a smooth outflow in velocity space, yet highly clumped in real space?

In general, how can one tell that an outflow is driven by radiation pressure?

What sets n_e?

Radiation carries energy and momentum
If the gas is not outflowing, P_{rad} must be balanced by P_{gas}

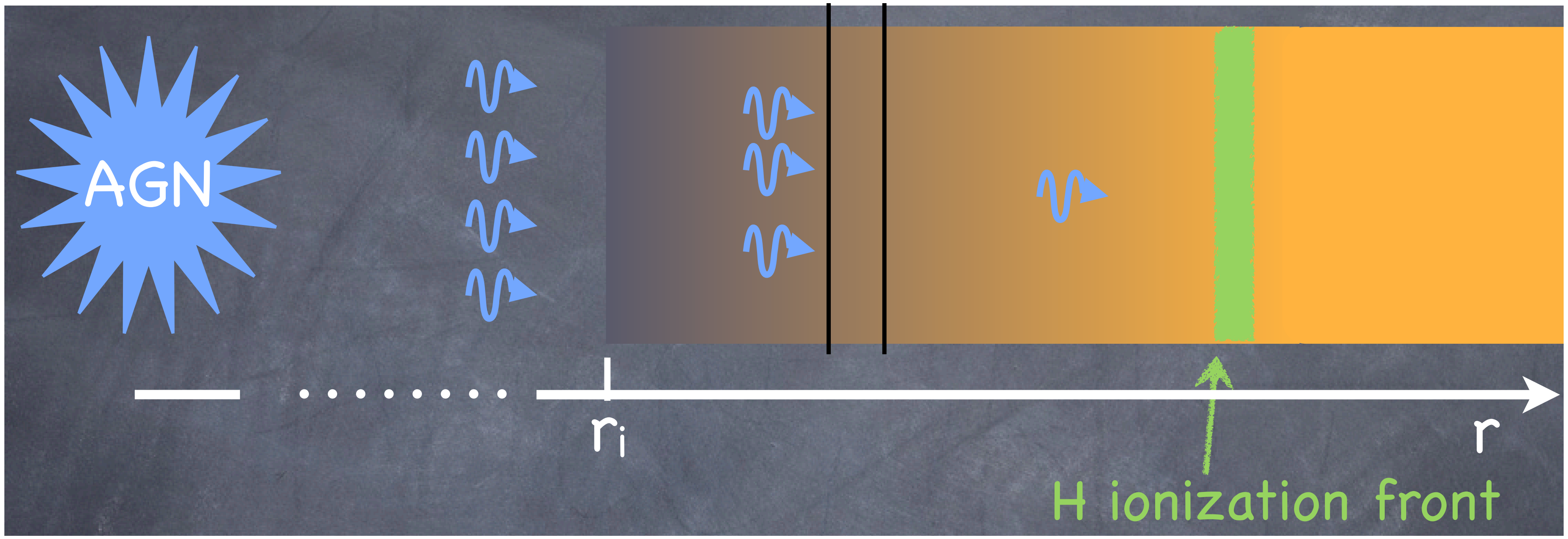


At the 0’th order level $P_{rad}=P_{gas}$

$2n_ekT=n_{ph}<h\nu>$, $n_{ph}/n_e=U=2kT/<h\nu>$
$2kT\sim3eV$, $<h\nu>\sim30eV$

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

What is the structure of the absorbing layer?

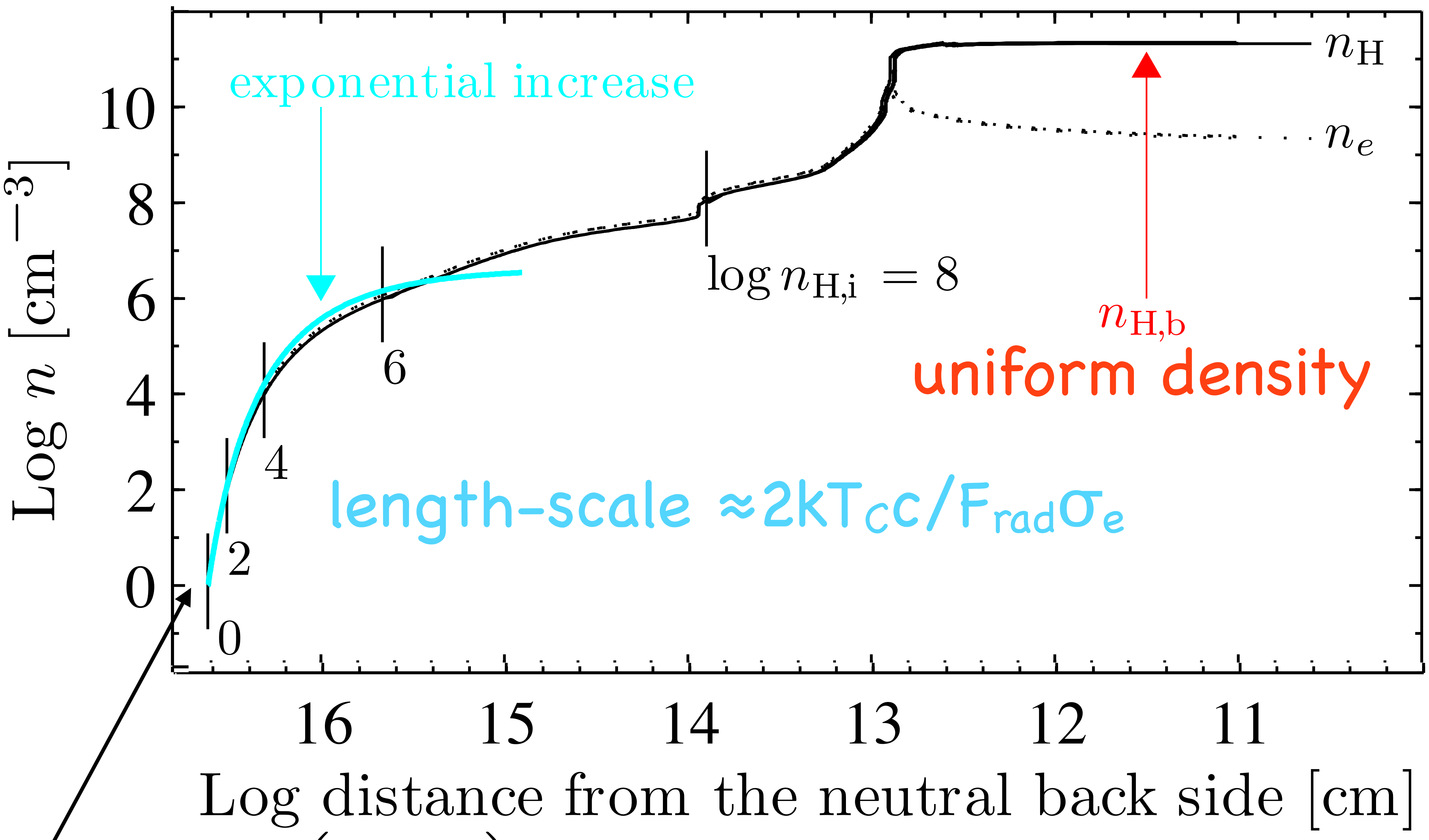


$$\mathrm{d}P_{\mathrm{gas}}(r) = \frac{F_{\mathrm{rad}}}{c} e^{-\tau(r)} \mathrm{d}\tau \quad \text{—>} \quad P_{\mathrm{gas}}(r) = P_{\mathrm{rad}}(1 - e^{-\mathrm{tau}(r)}) + P_{\mathrm{gas}}(r_{\mathrm{i}})$$

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

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

Radiation Pressure Confinement - RPC



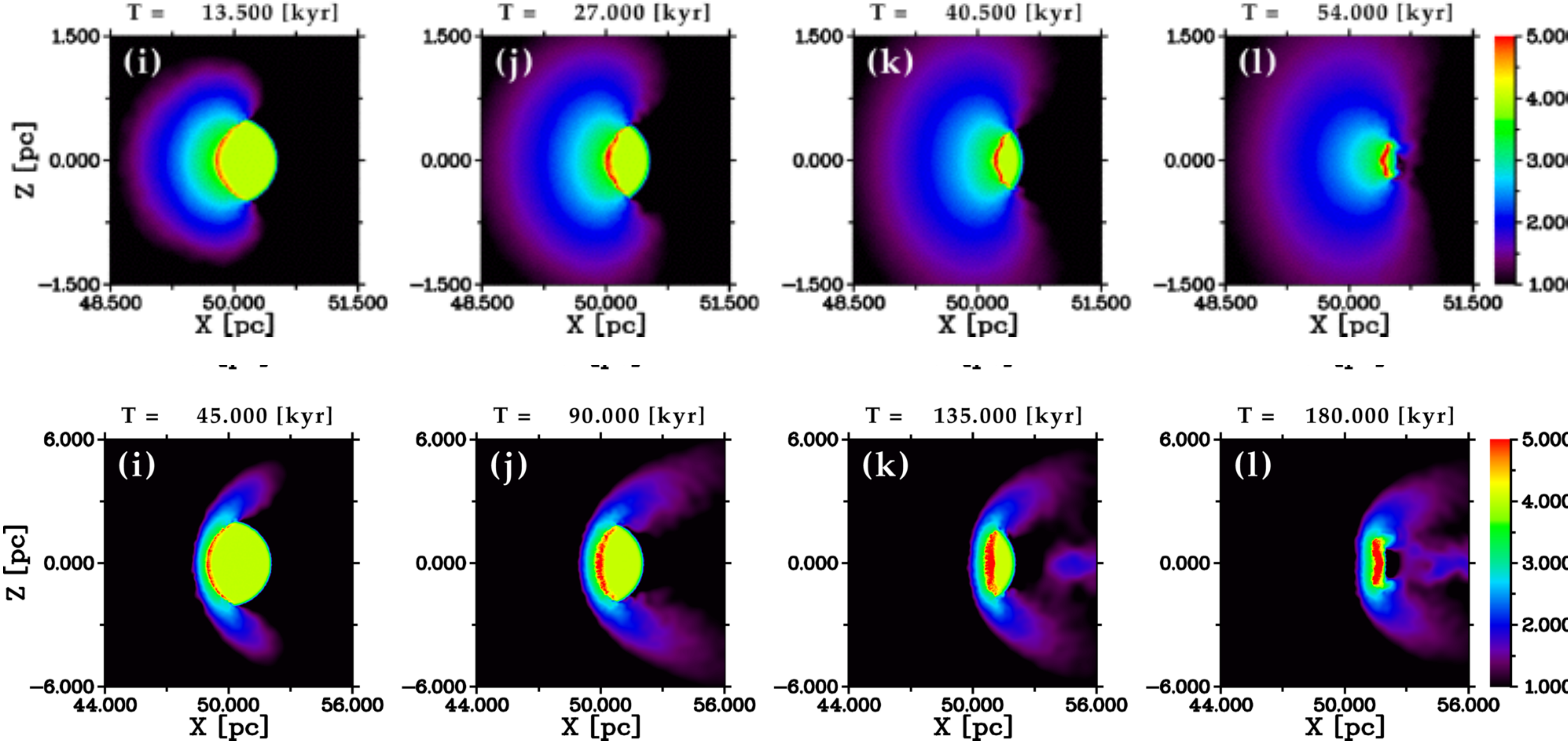
$$n_e(r) = n_{e,\mathrm{i}} \exp\left(\frac{r - r_\mathrm{i}}{l_\mathrm{pr}}\right)$$

Need *dr/r* ~ 10^{-5} to resolve the RPC structure

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

(2014)

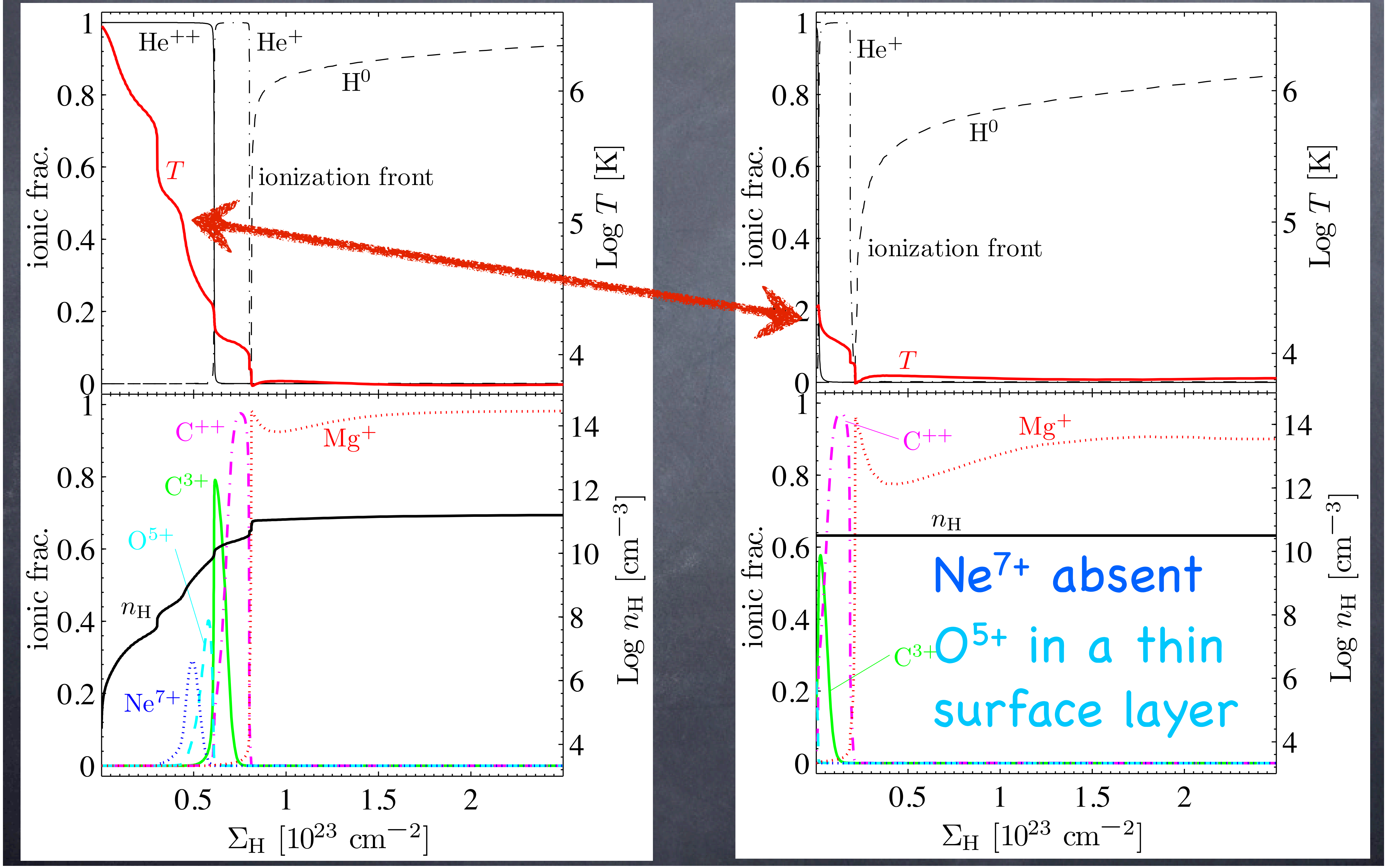
D. Namekata[1]⋆, M. Umemura[1] †, and K. Hasegawa[1]‡



Comparison to a constant-n slab

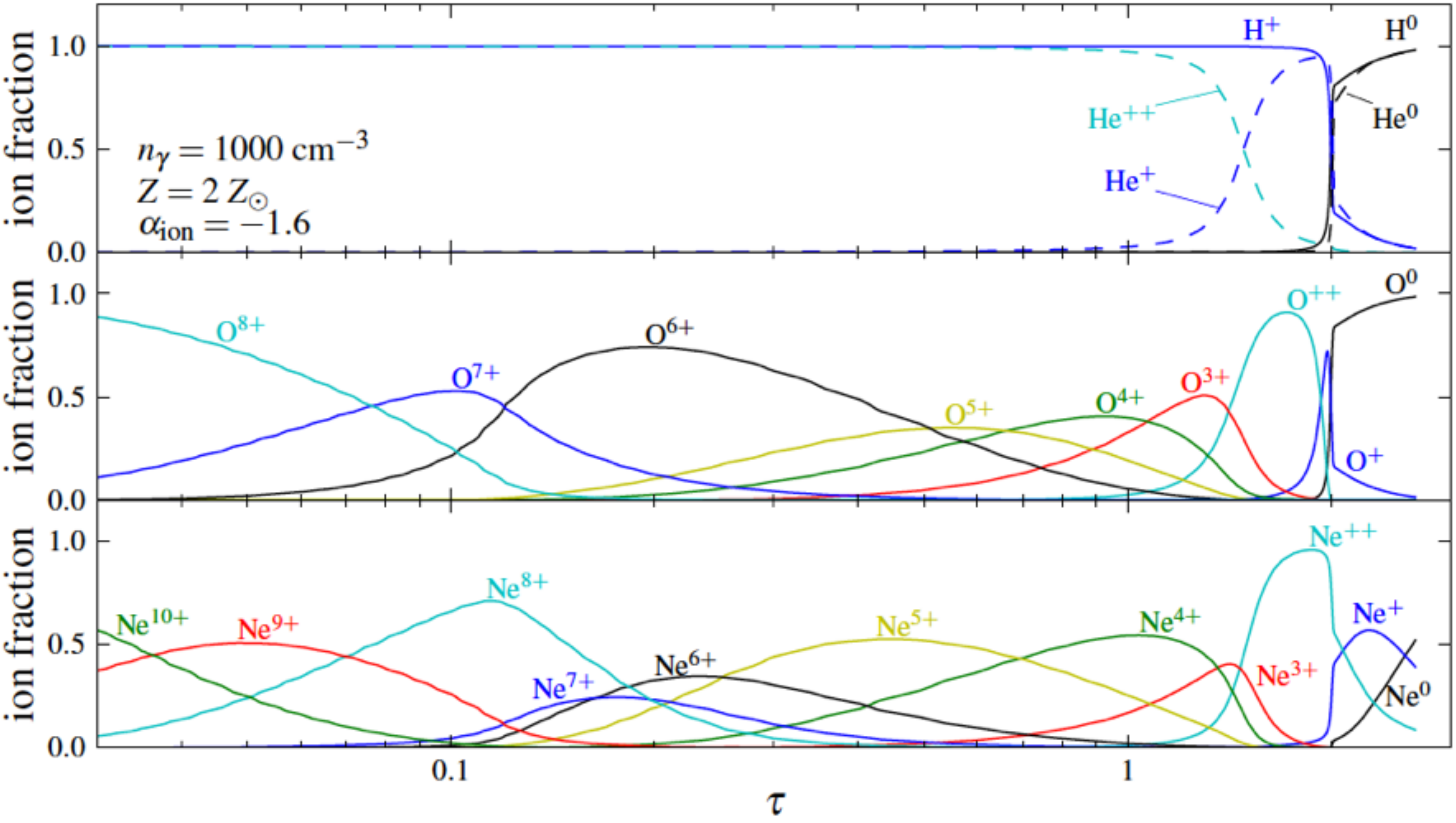
RPC slab

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

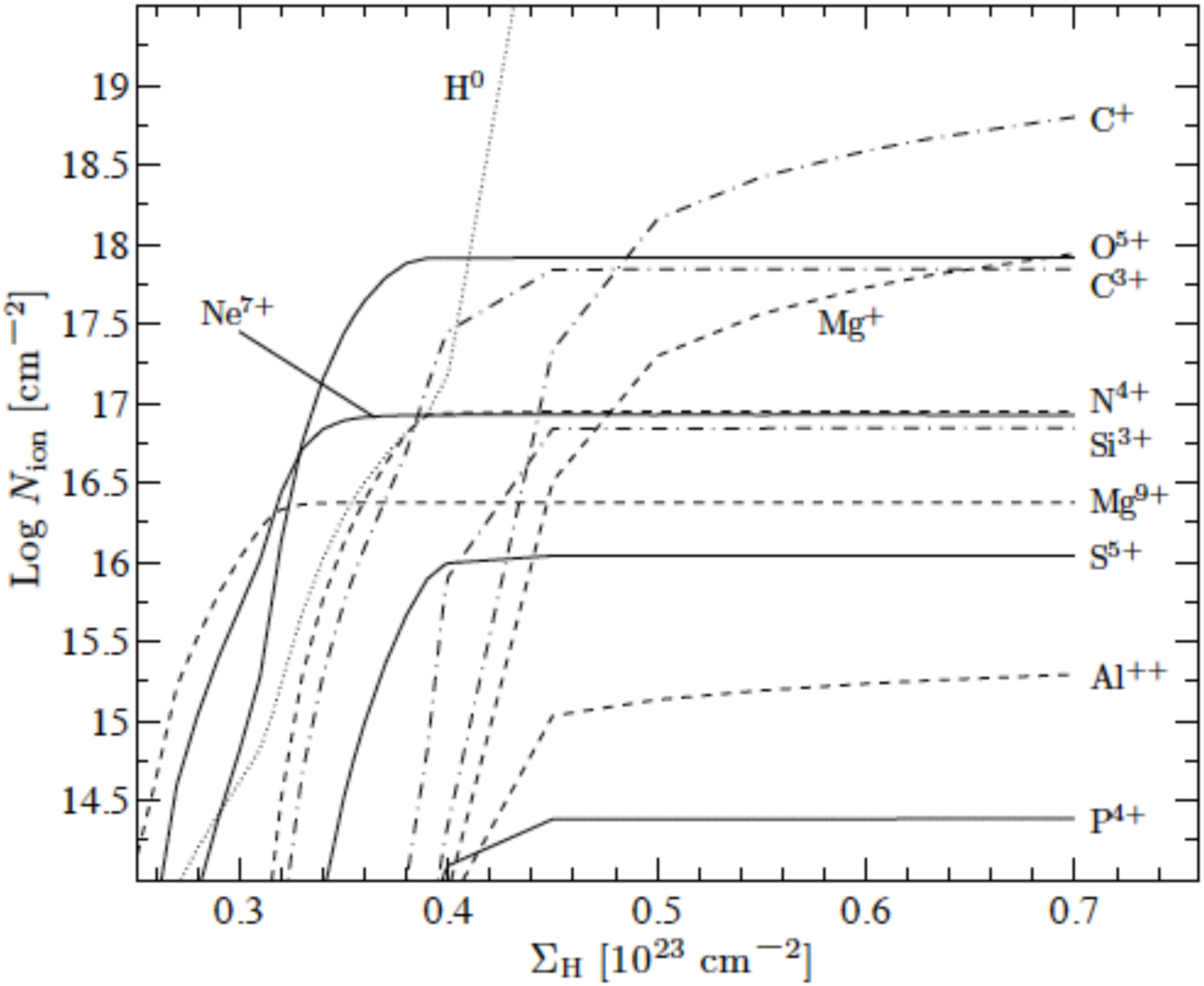


Ne^{7+} absent

O^{5+} in a thin surface layer

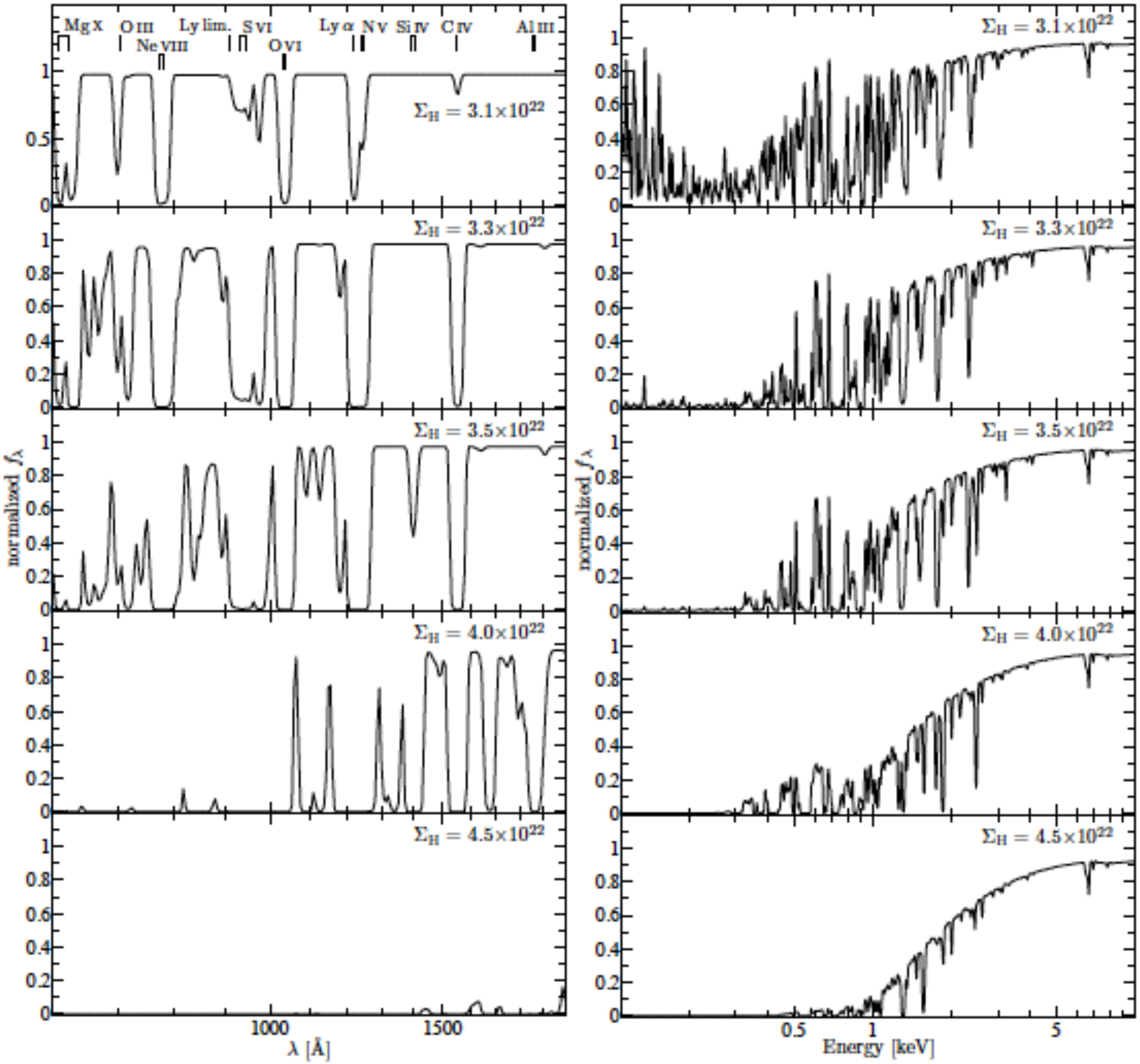


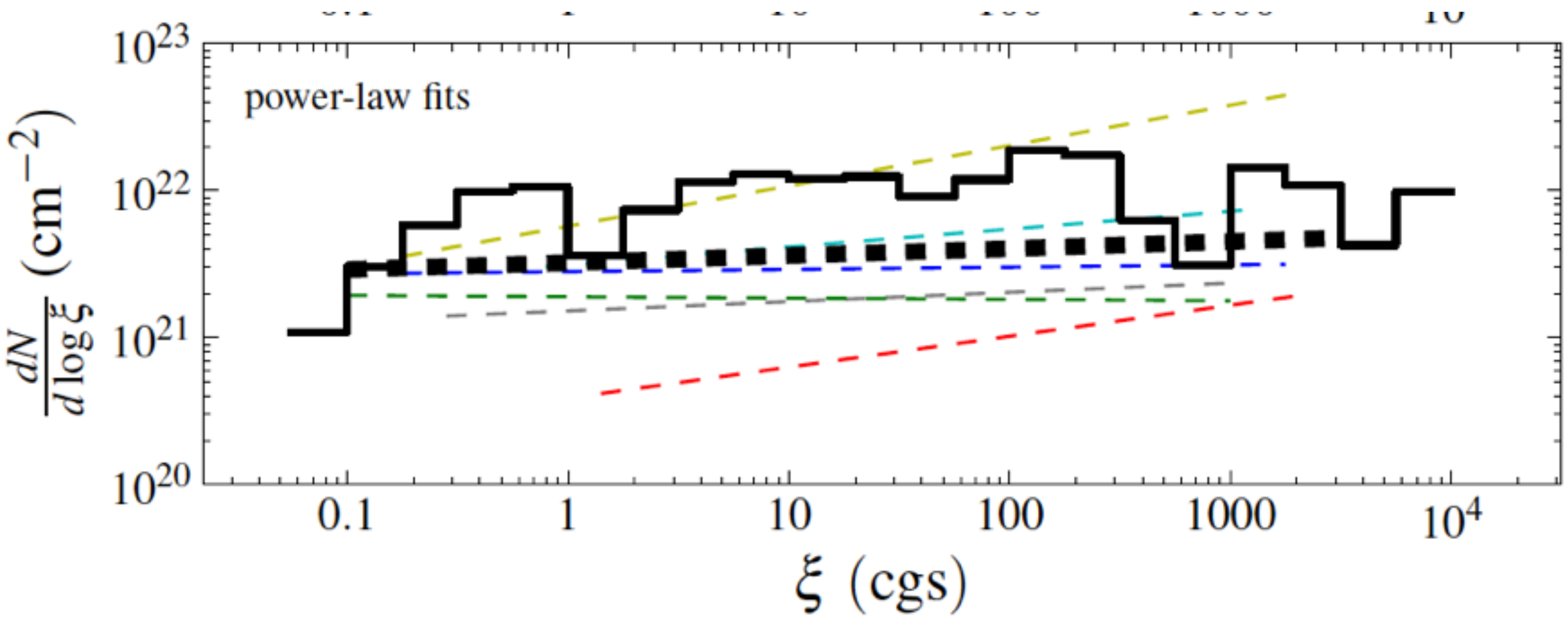
ion fraction
1.0
0.5
0.0
$n_\gamma = 1000\ \mathrm{cm}^{-3}$
$Z = 2\,Z_\odot$
$\alpha_{\mathrm{ion}} = -1.6$
H^+
H^0
He^{++}
He^0
He^+
O^{8+}
O^{7+}
O^{6+}
O^{5+}
O^{4+}
O^{3+}
O^{++}
O^0
O^+
Ne^{10+}
Ne^{9+}
Ne^{8+}
Ne^{7+}
Ne^{6+}
Ne^{5+}
Ne^{4+}
Ne^{3+}
Ne^{++}
Ne^+
Ne^0
0.1
1
τ



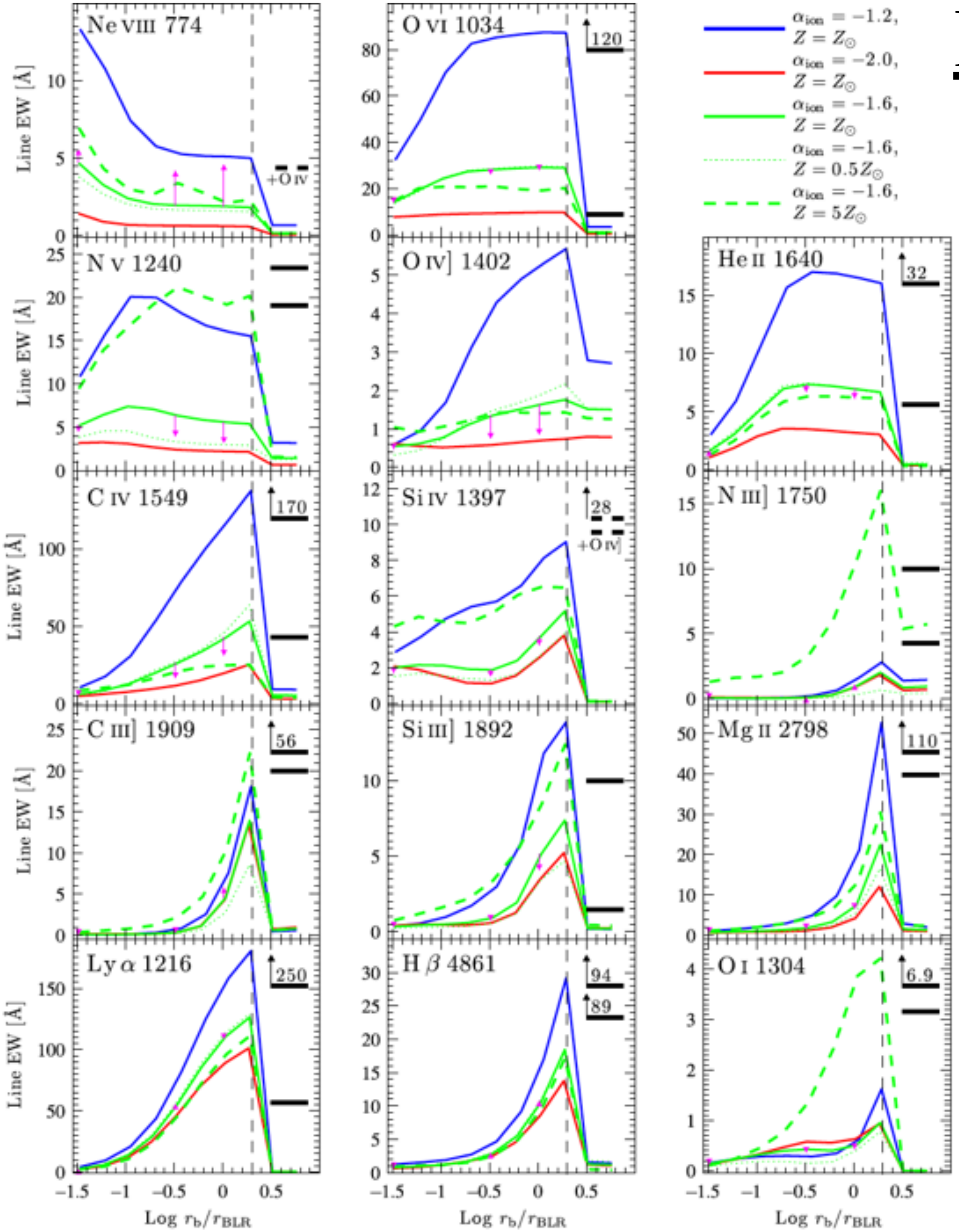
Low BALQs alway have high U BALs

High BALQs should always have very high U lines


Mg X
O III
Ne VIII
Ly lim.
S VI
O VI
Ly α
N V
Si IV
C IV
Al III
$\Sigma_H = 3.1\times10^{22}$
$\Sigma_H = 3.3\times10^{22}$
$\Sigma_H = 3.5\times10^{22}$
$\Sigma_H = 4.0\times10^{22}$
$\Sigma_H = 4.5\times10^{22}$
normalized f_λ
0
0.2
0.4
0.5
0.6
0.8
1
1000
1500
λ [Å]
0.5
1
5
Energy [keV]


power-law fits
$\frac{dN}{d\log\xi}$ (cm^{-2})
10^{23}
10^{22}
10^{21}
10^{20}
0.1
1
10
100
1000
10^4
ξ (cgs)

Predicted Emissivities



The remaining free parameters are the SED and Z

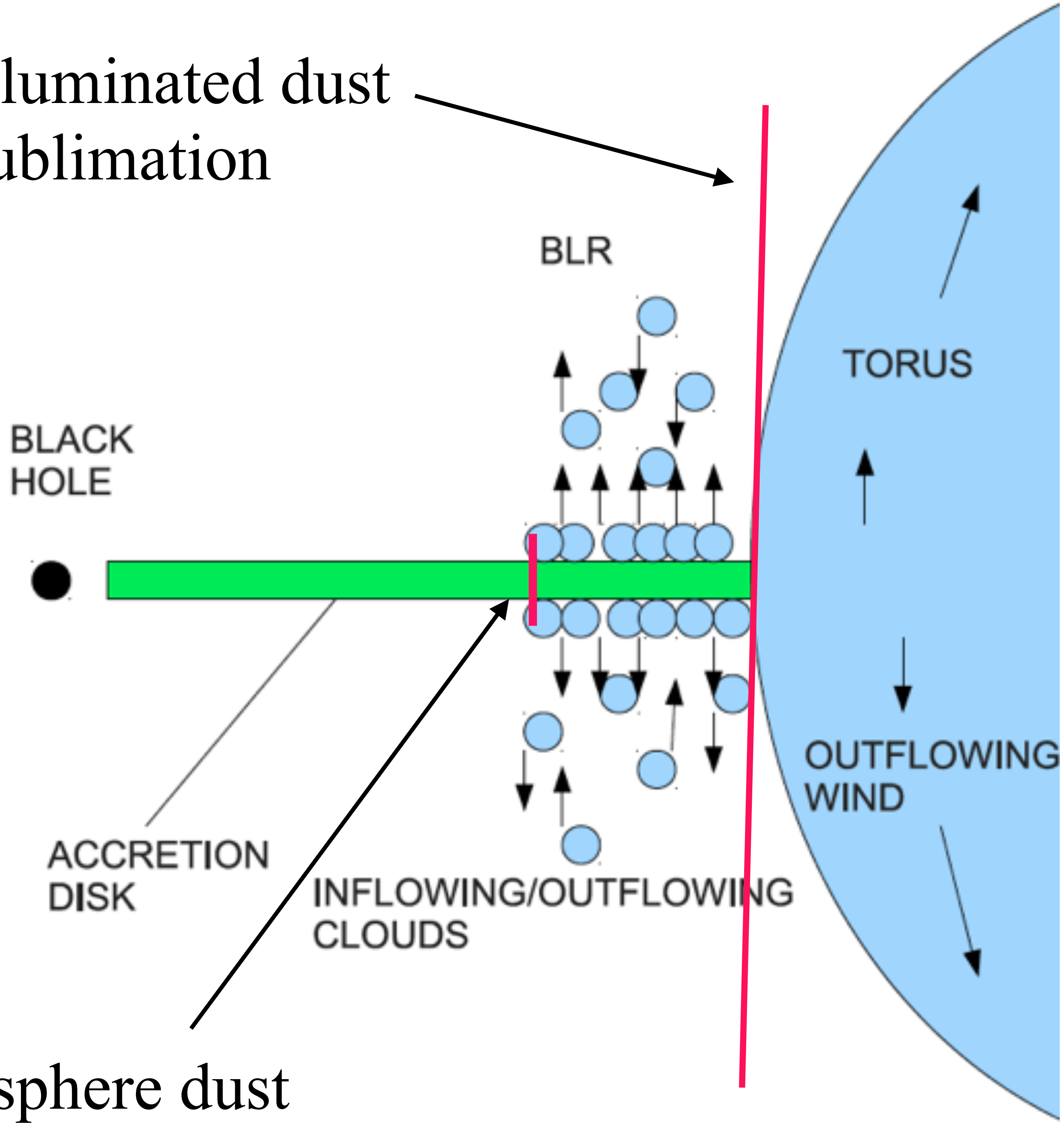
Use RM to test the predicted line response function

Baskin, Laor & Stern (2014)

BLR- A failed dusty disk wind?

Czerny & Hryniewicz 2011

Illuminated dust sublimation



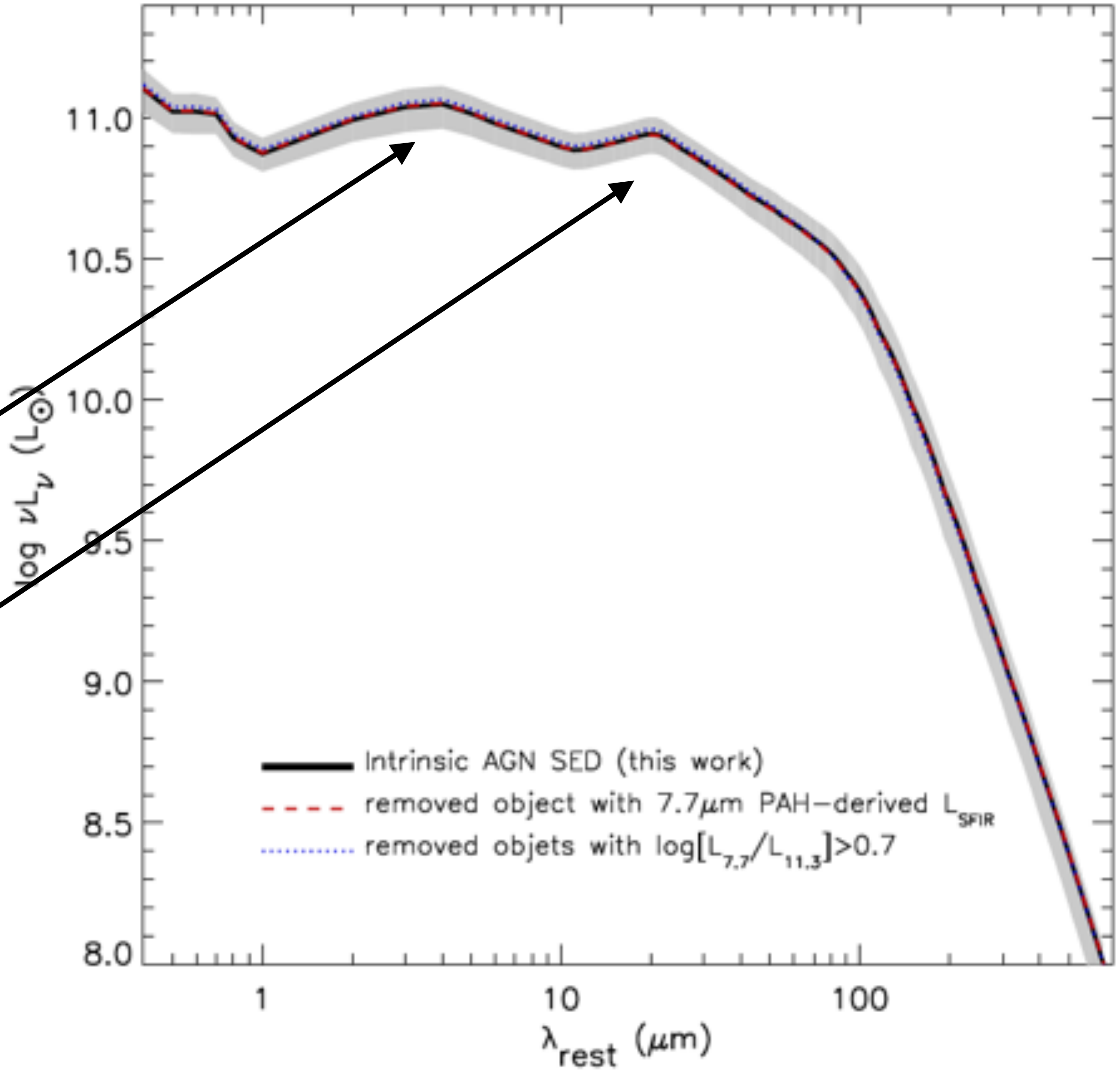
AD atmosphere dust sublimation

Not the regular torus models

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

Symeonidis+ (2016)

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



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)

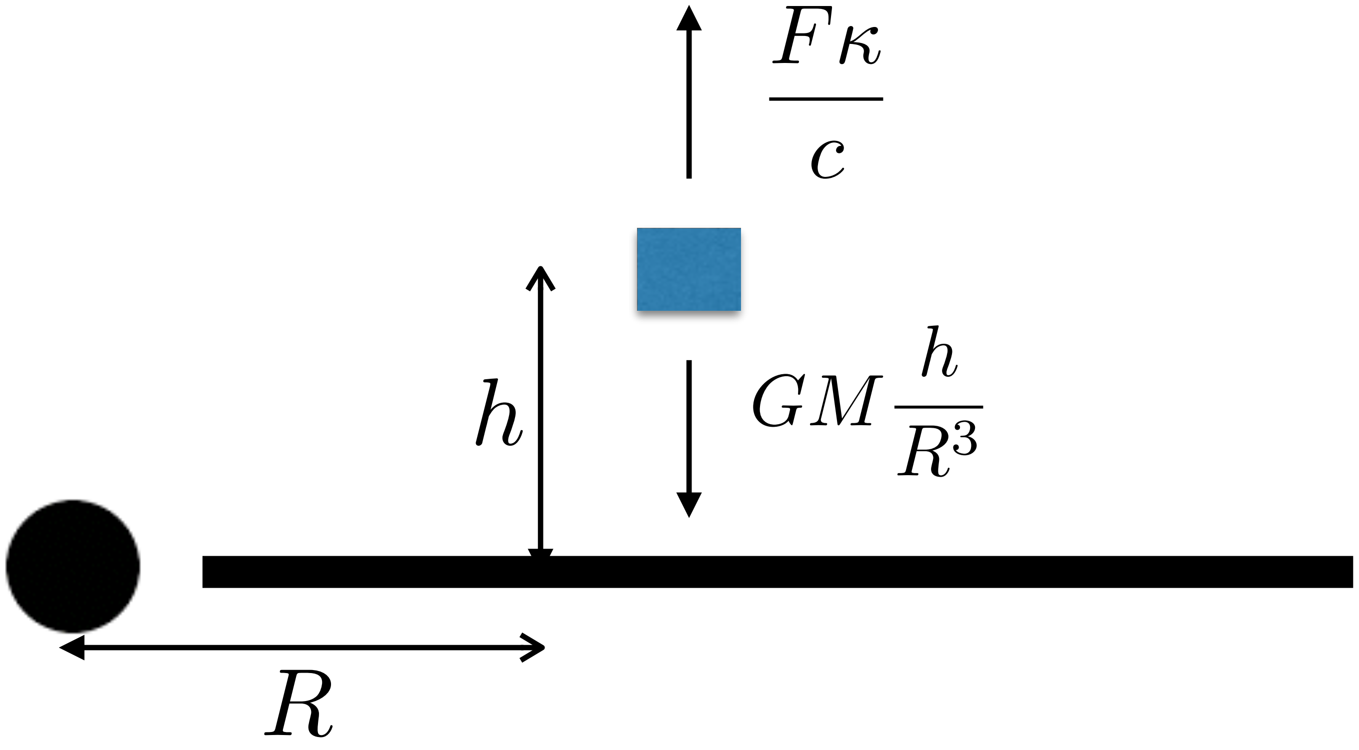
……

Inner radius set by dust sublimation at the disk surface

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

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

How thick is the dusty disk?



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

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

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

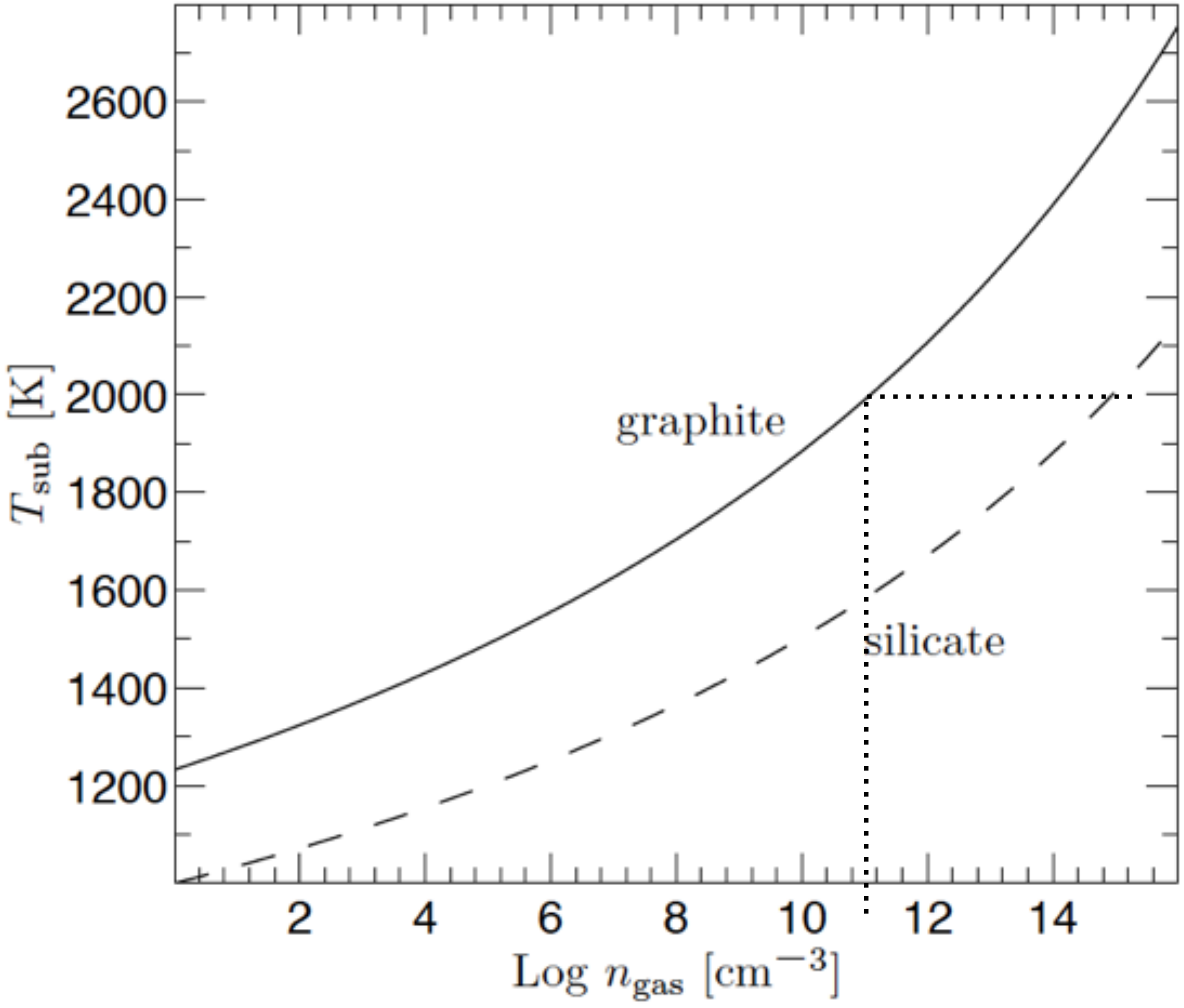
What is kappa?

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

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

What is T_{sub}?

Guhathakurta & Draine (1989)



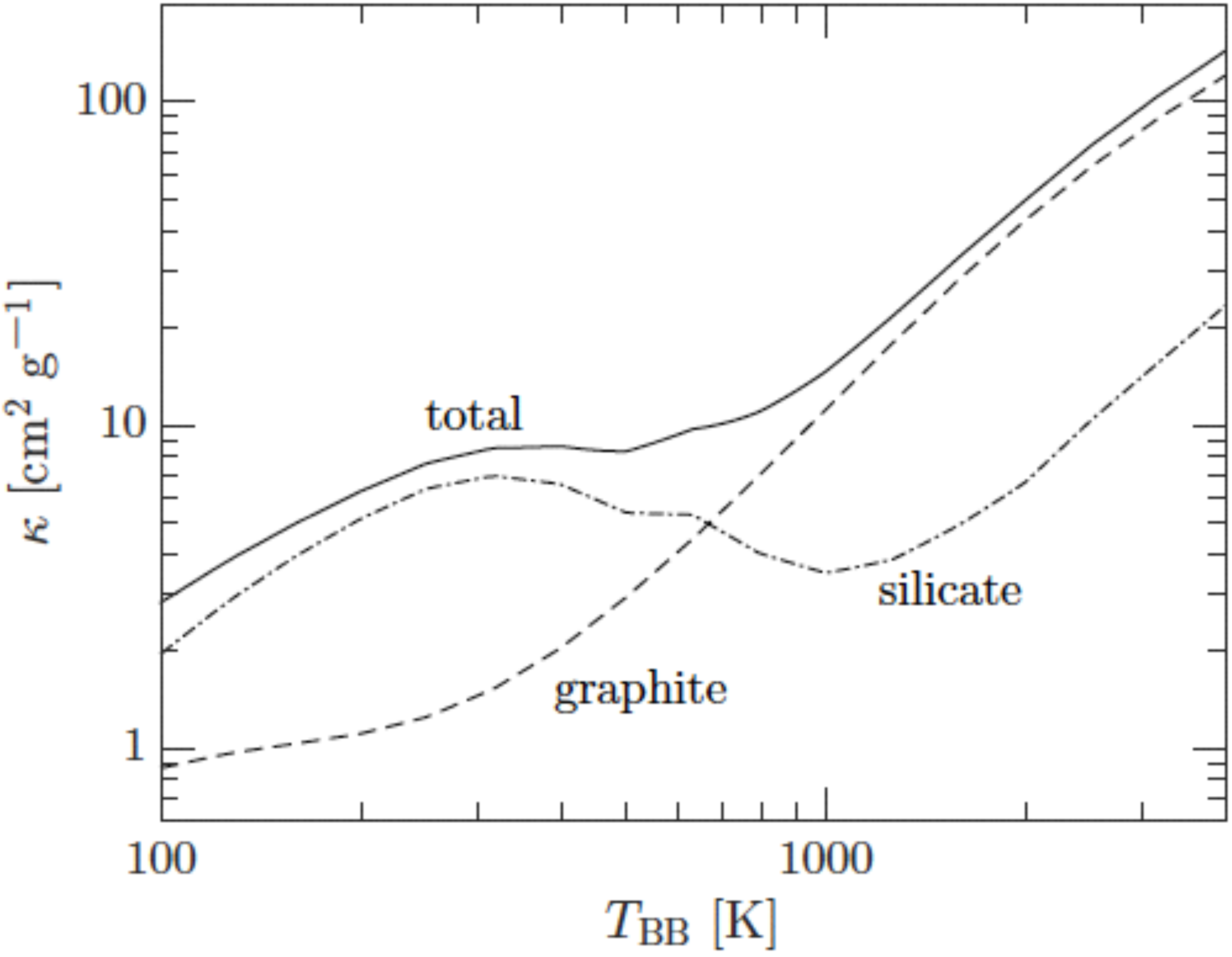
At BLR density ~10^{11}

Graphite - 2000K
Silicate - 1600K

→

Only graphites survive at the BLR

What is the wavelength dependence of κ ?



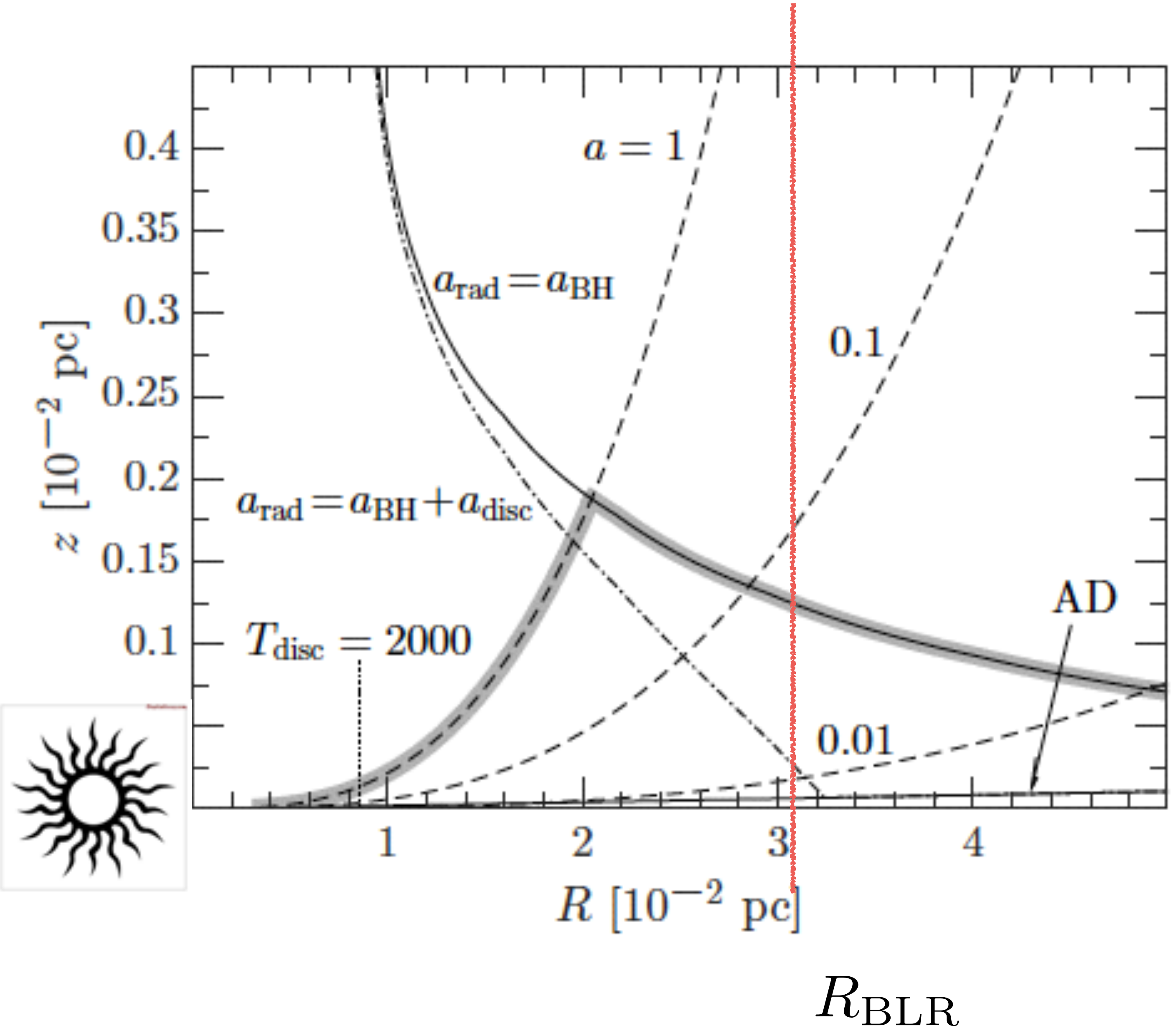
A sharp rise with T_{BB}
Graphites win again

κ can reach ~ 100

But, this is for MRN
(Galactic dust)

The illuminating radiation

What happens when the dust sees the real light?



When

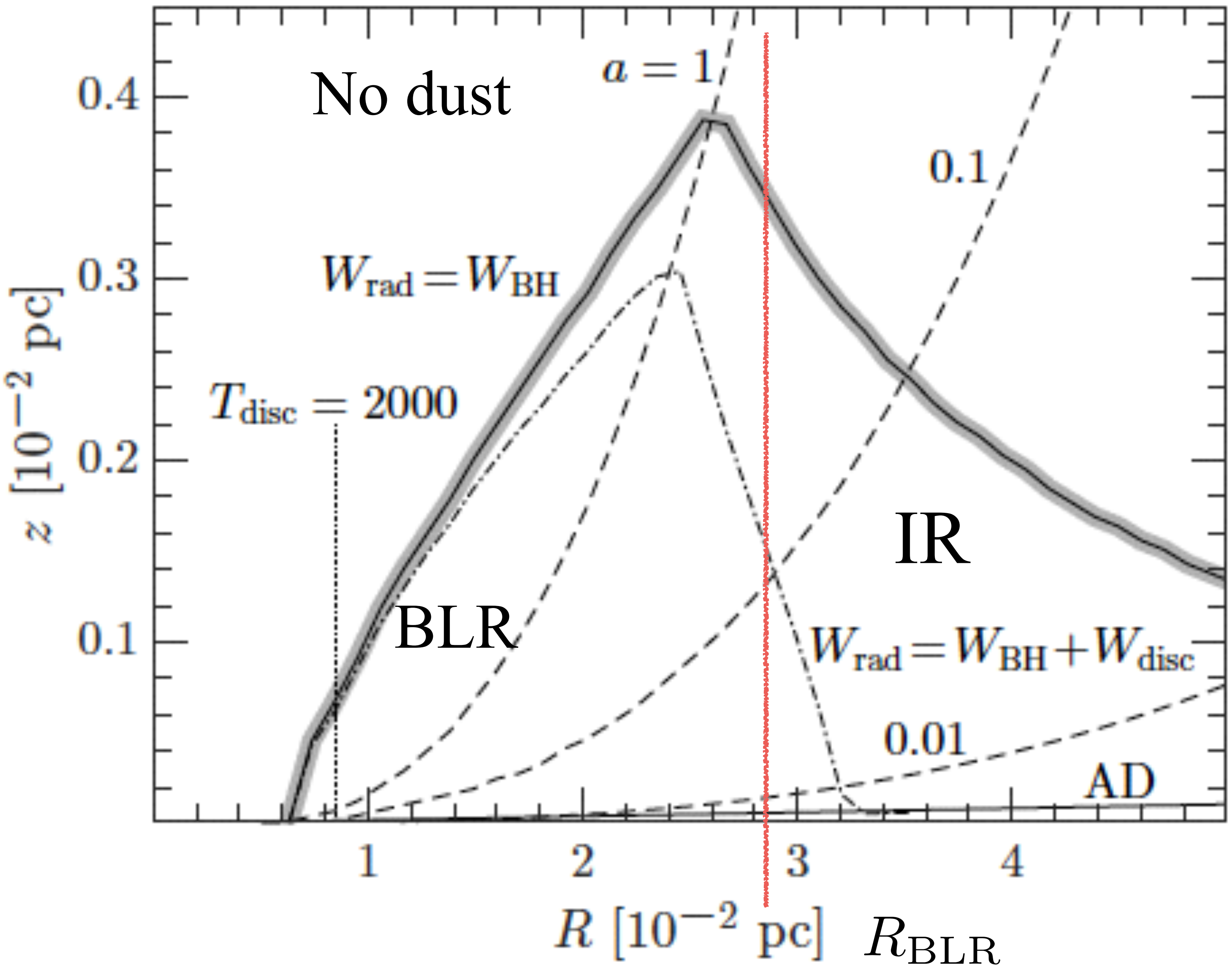
$$\frac{L_{\rm bol}}{4\pi R^2}\cos\theta > 4\sigma T_{\rm sub}^2$$

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

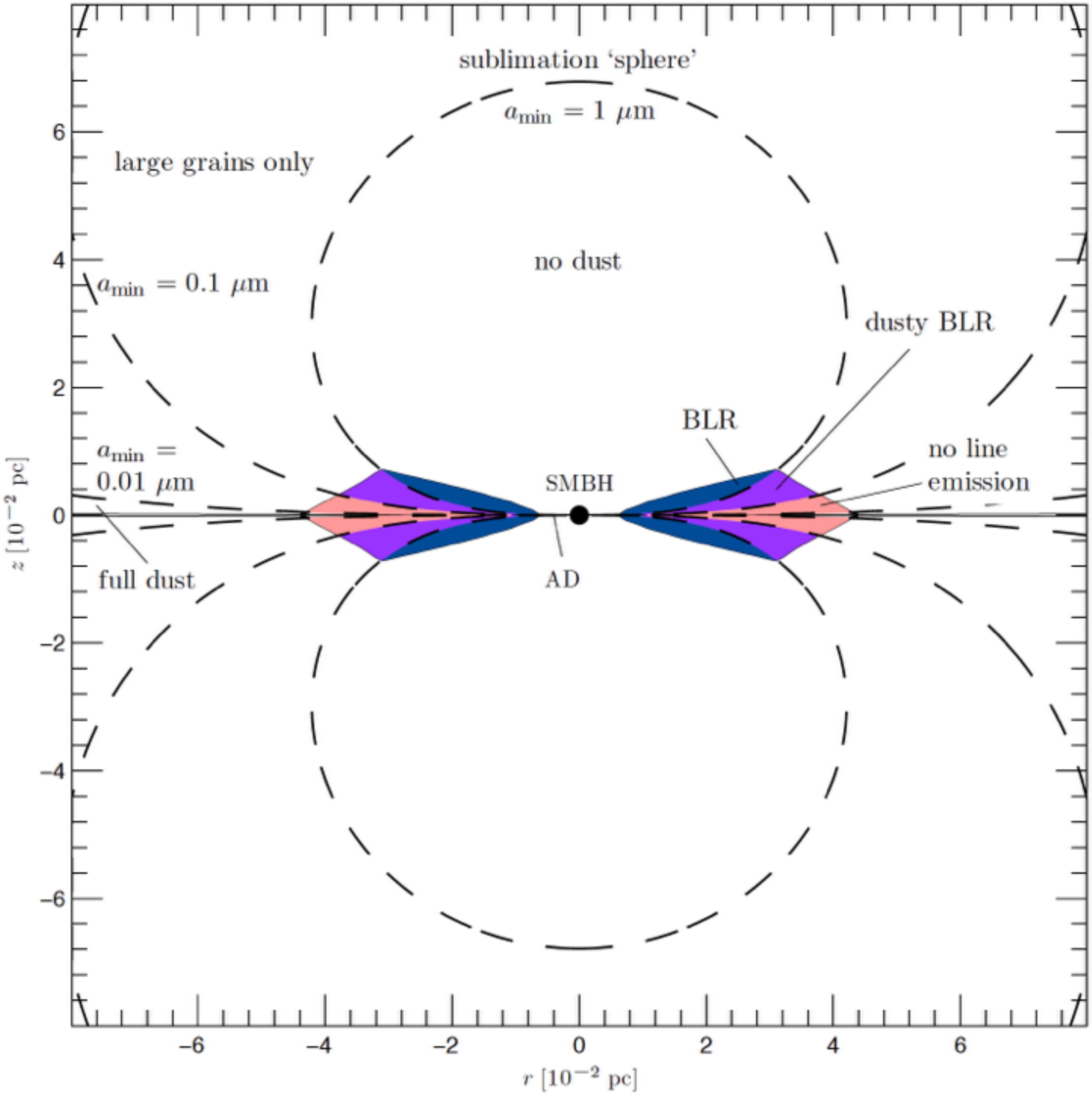


$$L_{\rm bol} = 10^{45}\ \rm erg/s$$

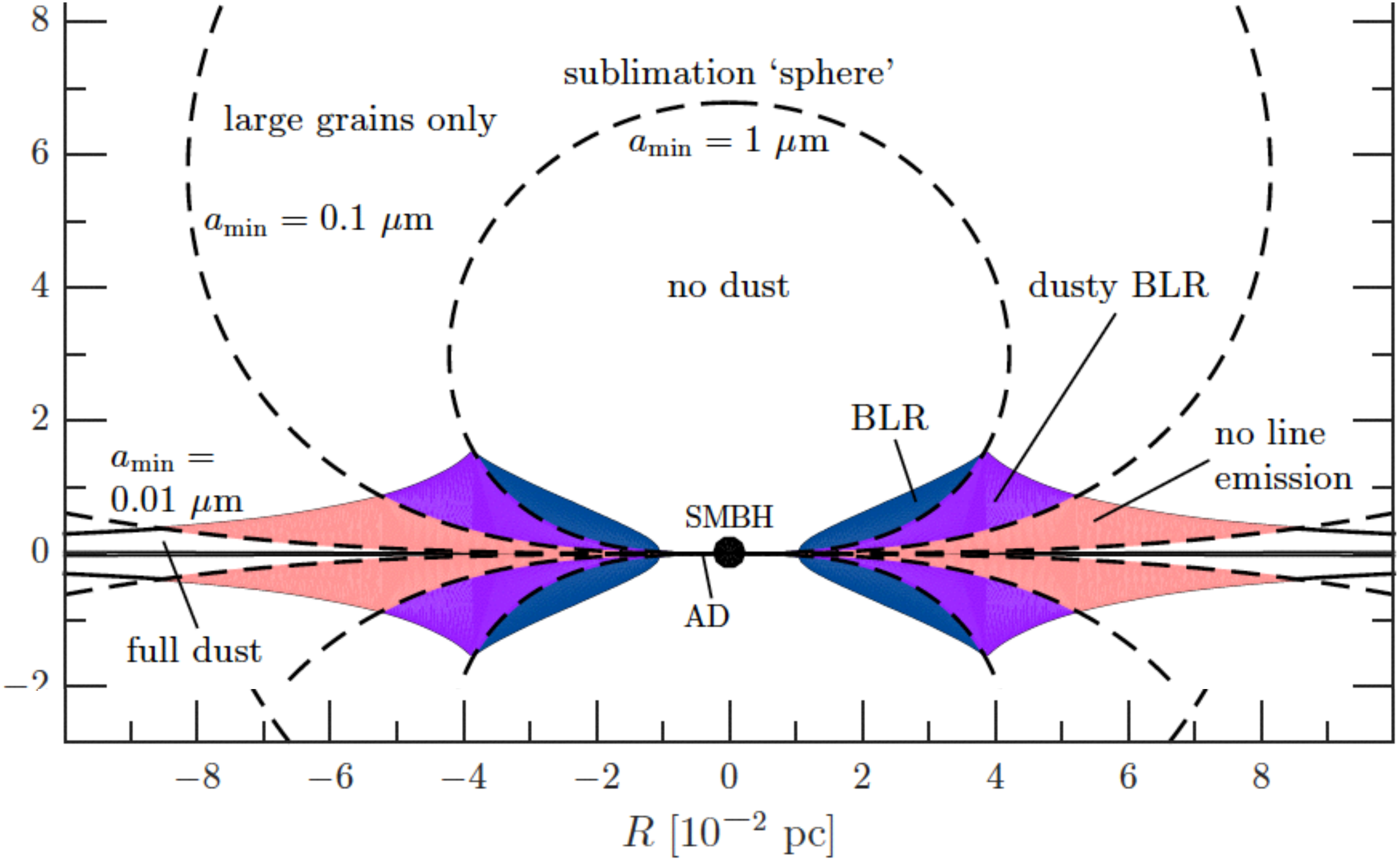
$$M = 10^8 M_\odot$$

$$\kappa = 200$$

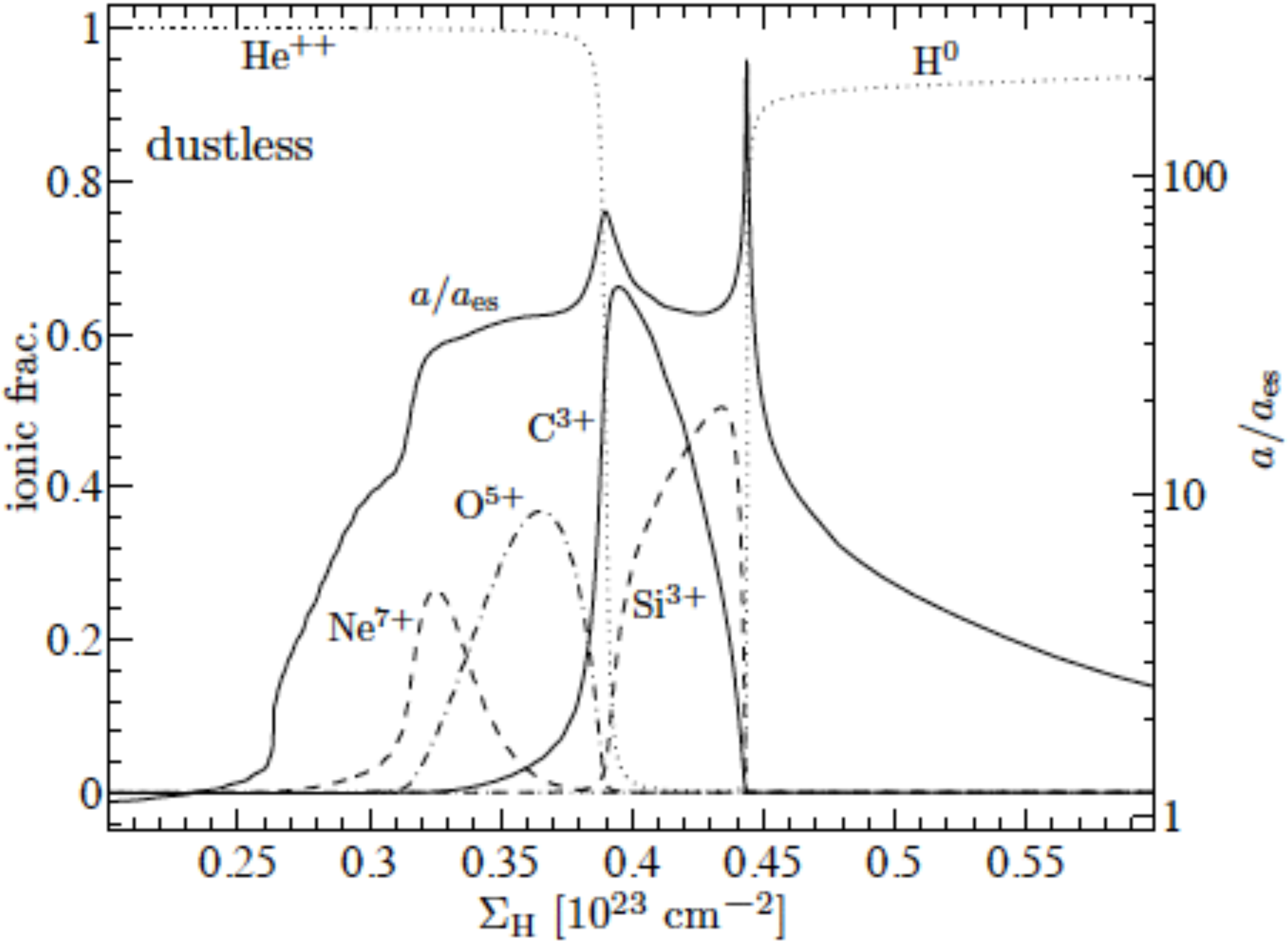
$$\Omega_{\rm BLR} = 0.15 L_{\rm bol,45}^{1/3} \eta_{0.1}^{-2/3} \kappa_{100}^{2/3}$$

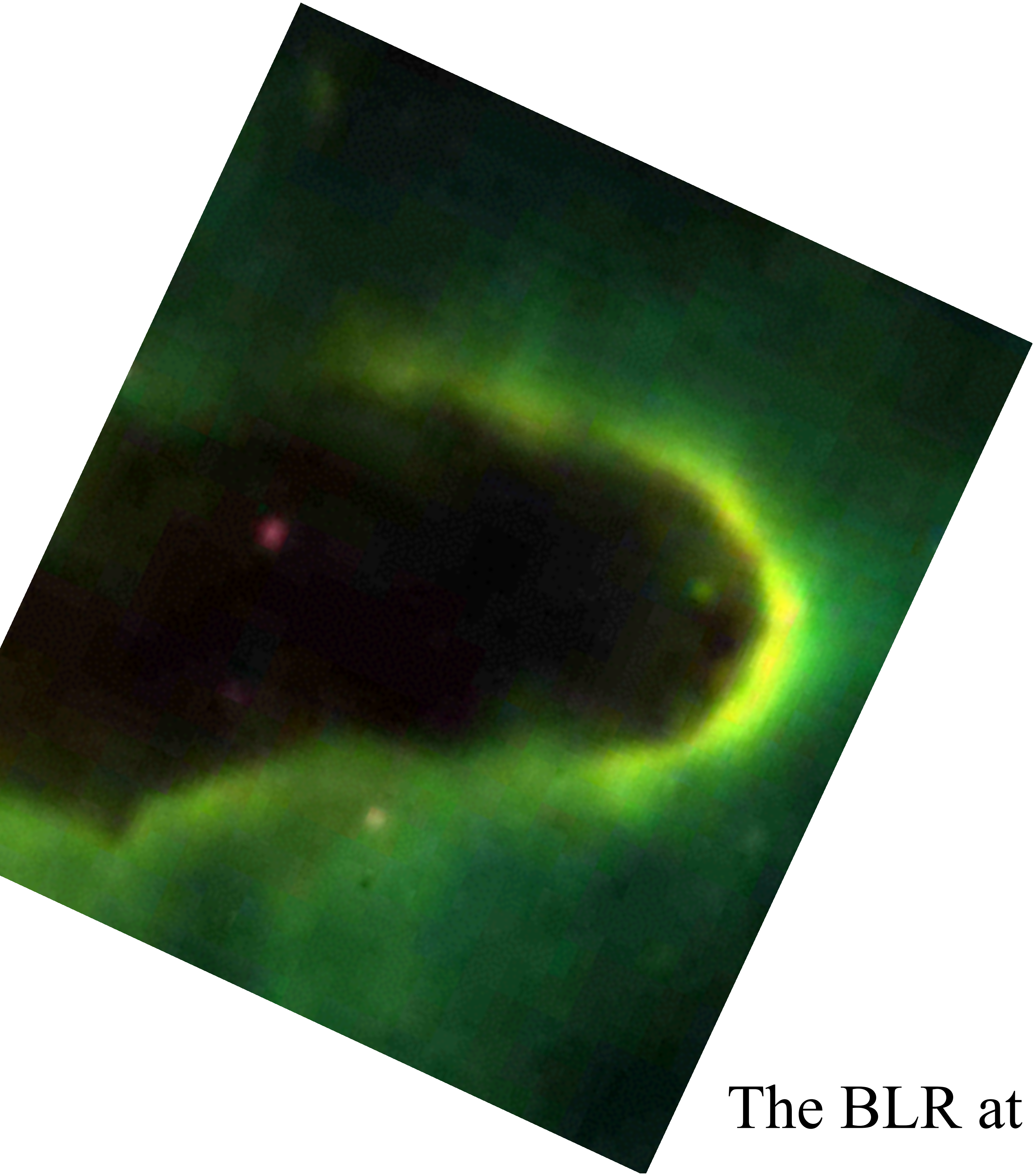


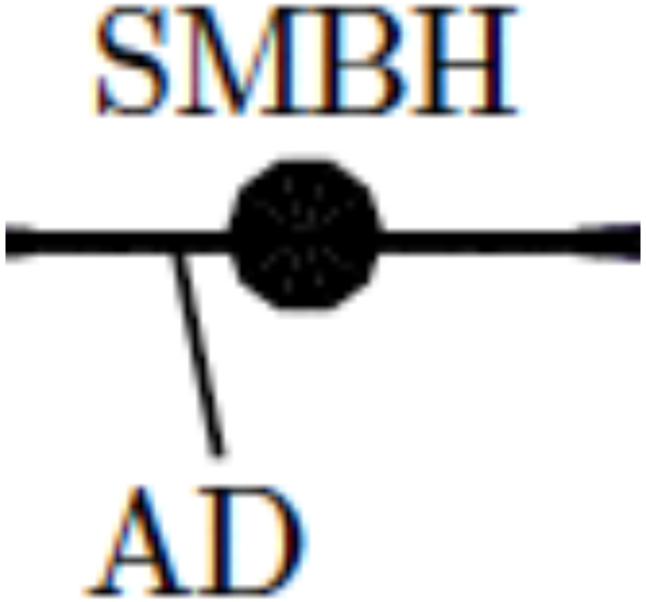
sublimation 'sphere'
$a_{\rm min} = 1\ \mu$m
large grains only
no dust
$a_{\rm min} = 0.1\ \mu$m
dusty BLR
BLR
no line emission
$a_{\rm min} =$ 0.01 μm
SMBH
full dust
AD
z [10^{-2} pc]
r [10^{-2} pc]
6
4
2
0
−2
−4
−6
−6
−4
−2
0
2
4
6


sublimation 'sphere'
large grains only
$a_{\min} = 1\ \mu$m
$a_{\min} = 0.1\ \mu$m
no dust
dusty BLR
BLR
no line emission
$a_{\min} = 0.01\ \mu$m
SMBH
AD
full dust
8
6
4
2
0
−2
−8
−6
−4
−2
0
2
4
6
8
$R\ [10^{-2}$ pc]

Shear in the ablation layer



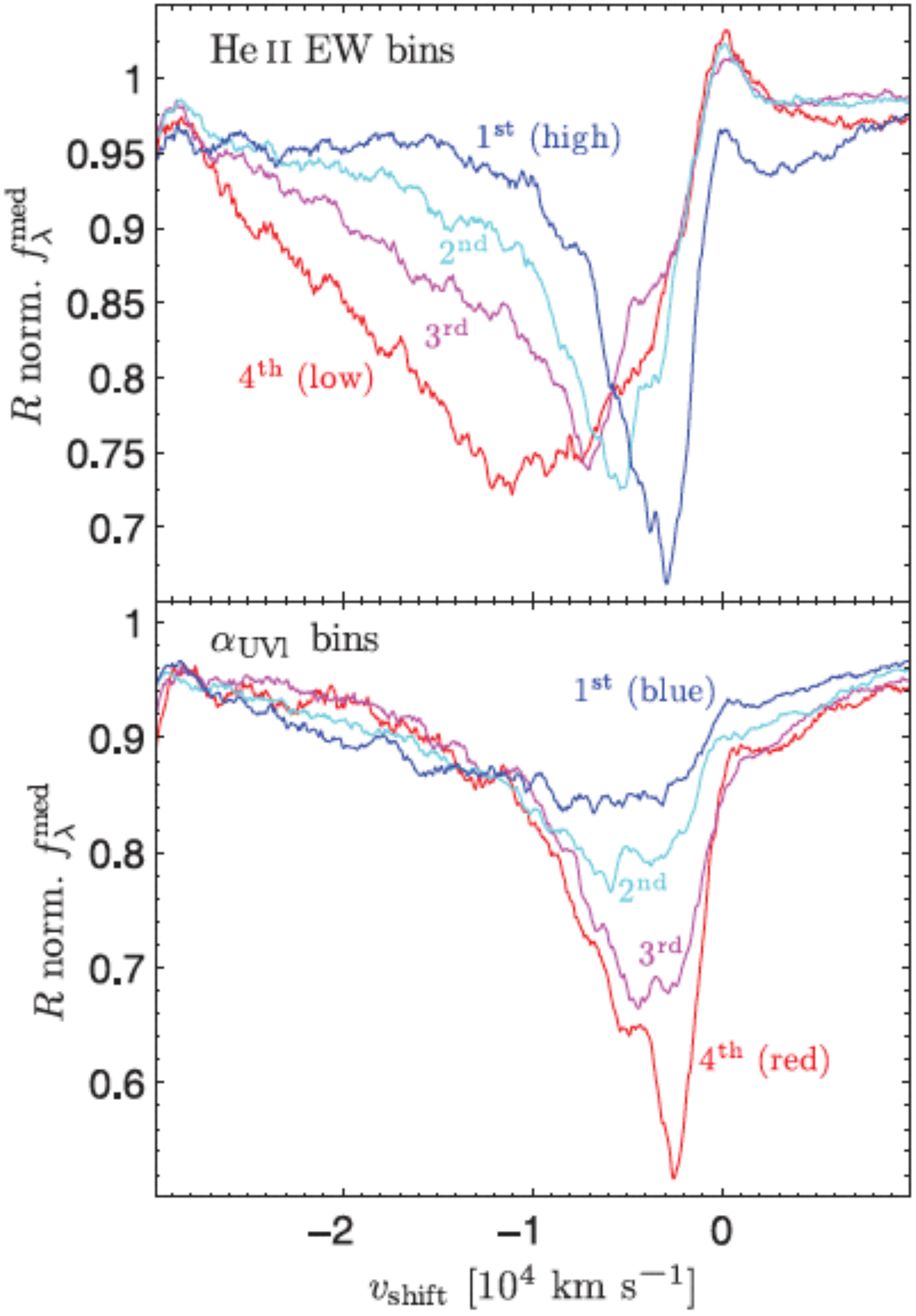


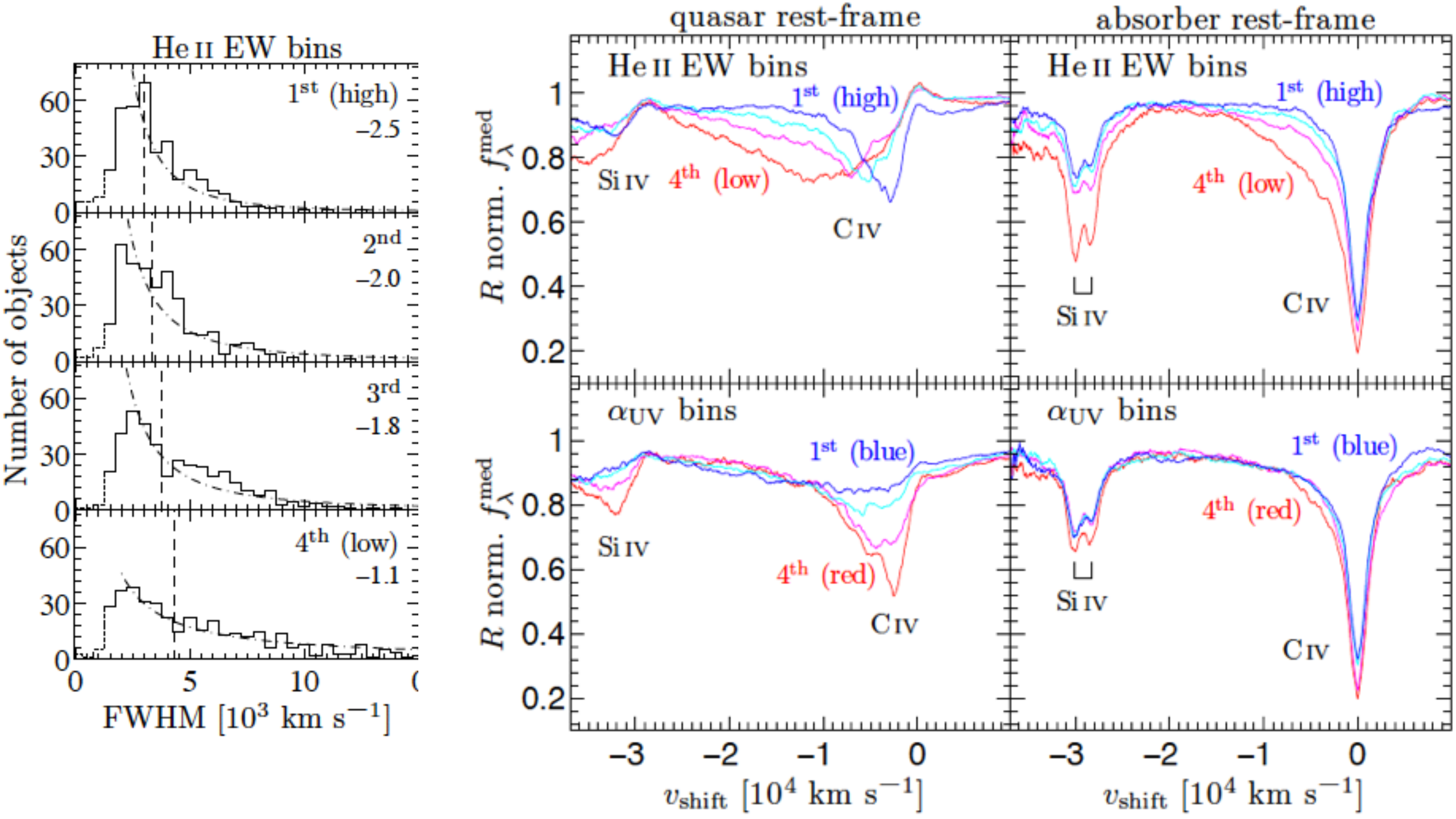


The BLR at micro arc sec resolution…

Stronger HeII —> weaker CIV abs’

Redder SED —> deeper abs’

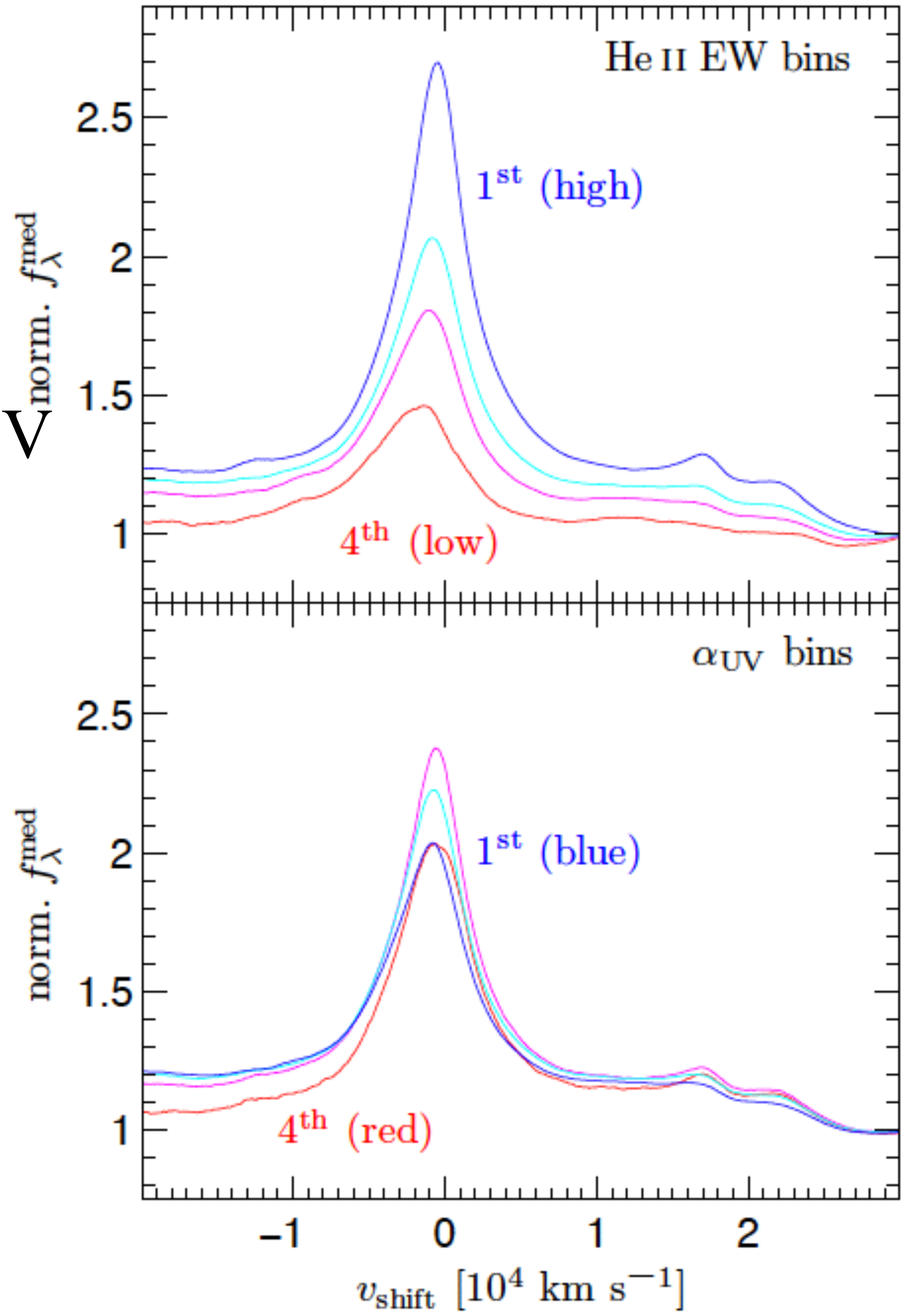




BAL Absorption profile - generally narrow

Weak HeII
weak blueshifted CIV
BAL emission?

Inclination effect



Do BALQs disappear at low L/Ledd?