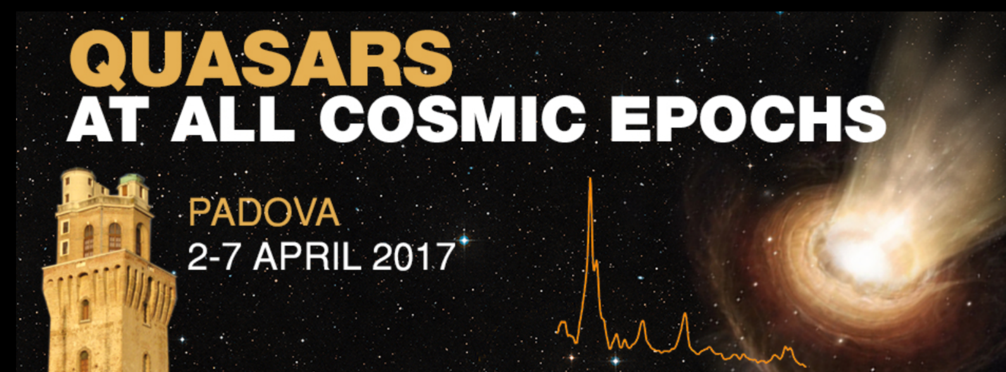
The nature of Intermediate Line Region (ILR) in AGN

based on Adhikari et al. 2016, ApJ, 831, 68A



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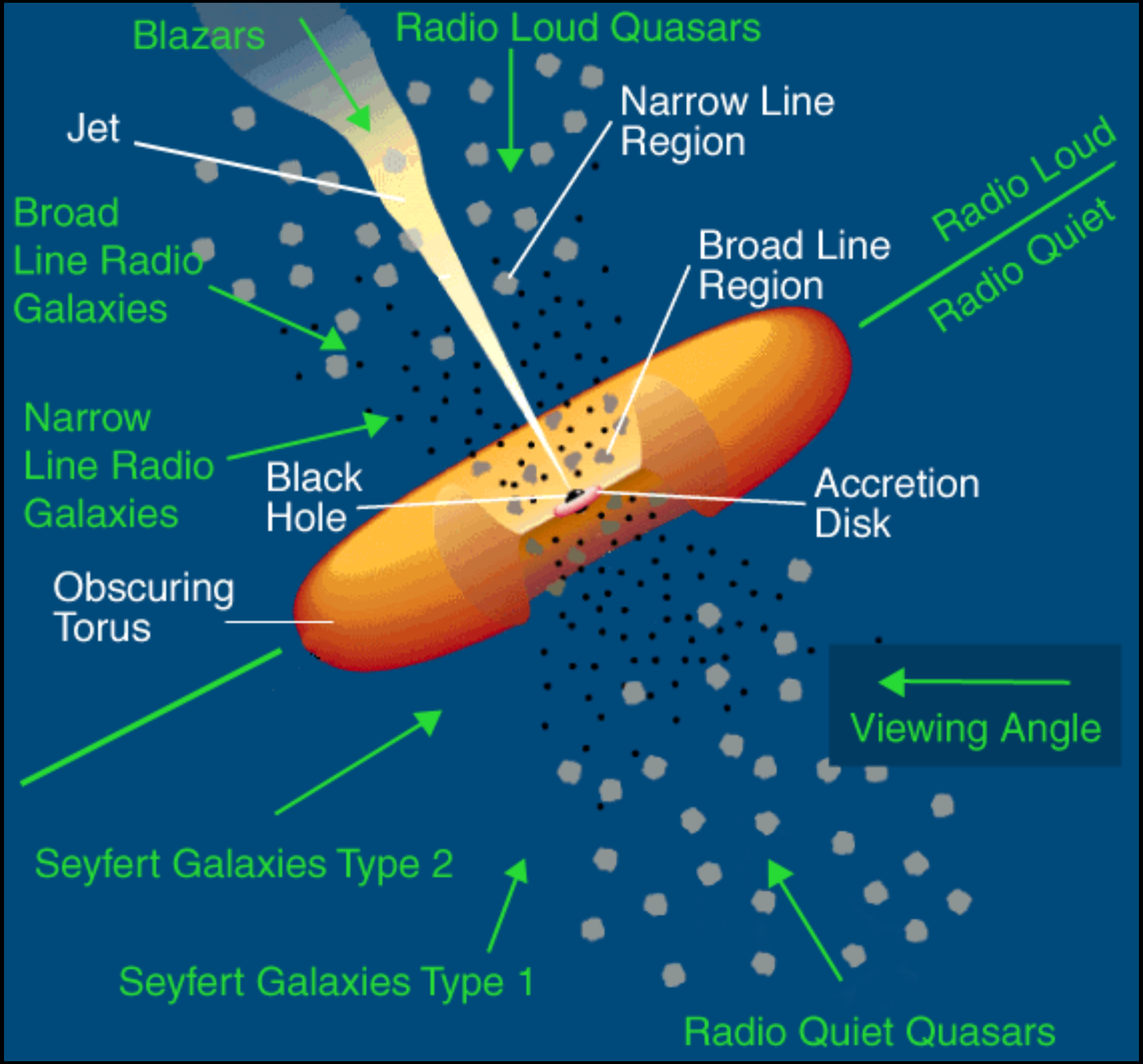
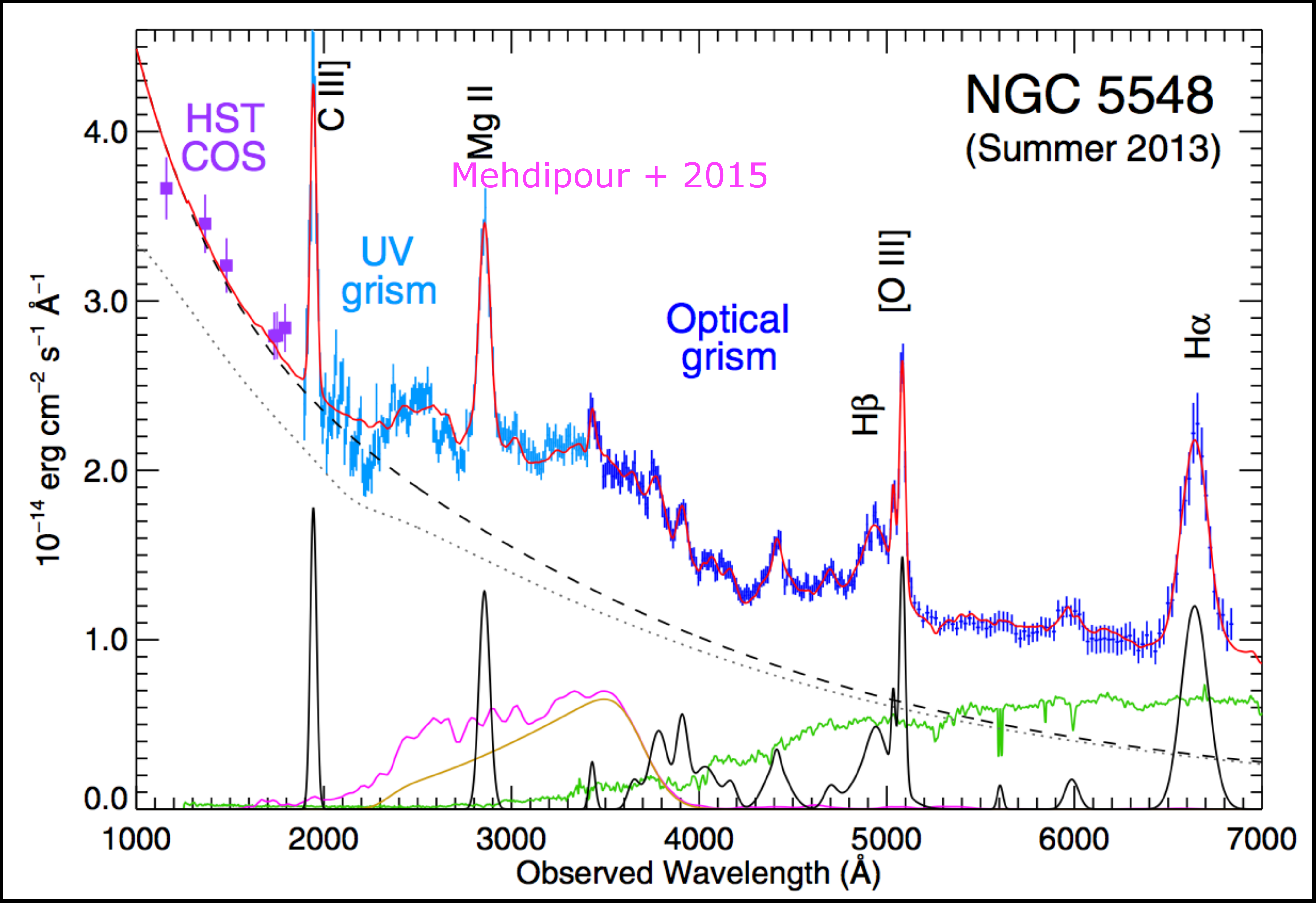


Urry & Padovani 1995

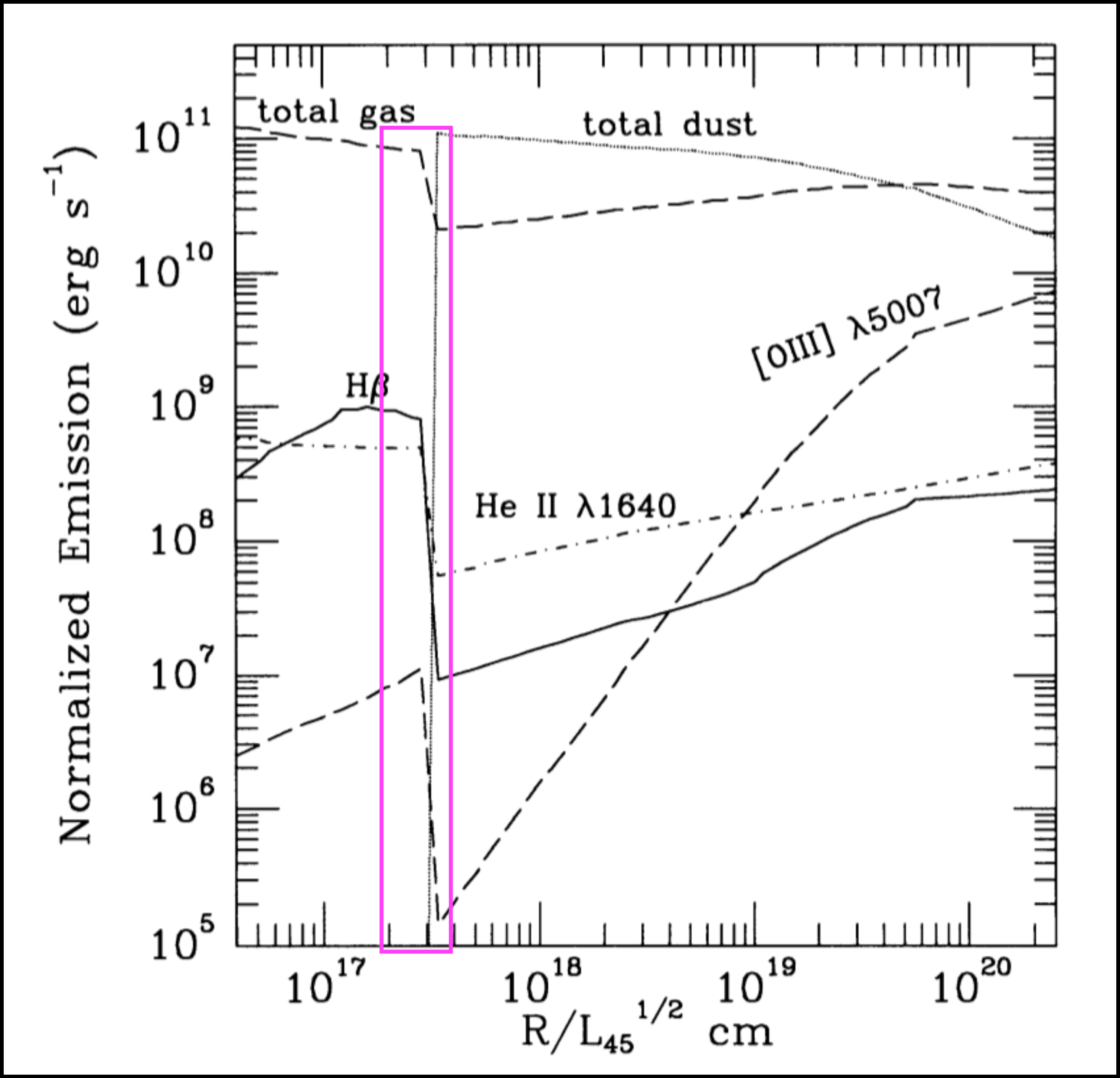
Emission lines in the spectra of AGN

narrow lines: FWHM~500 km /s

broad lines: FWHM>2500 km /s



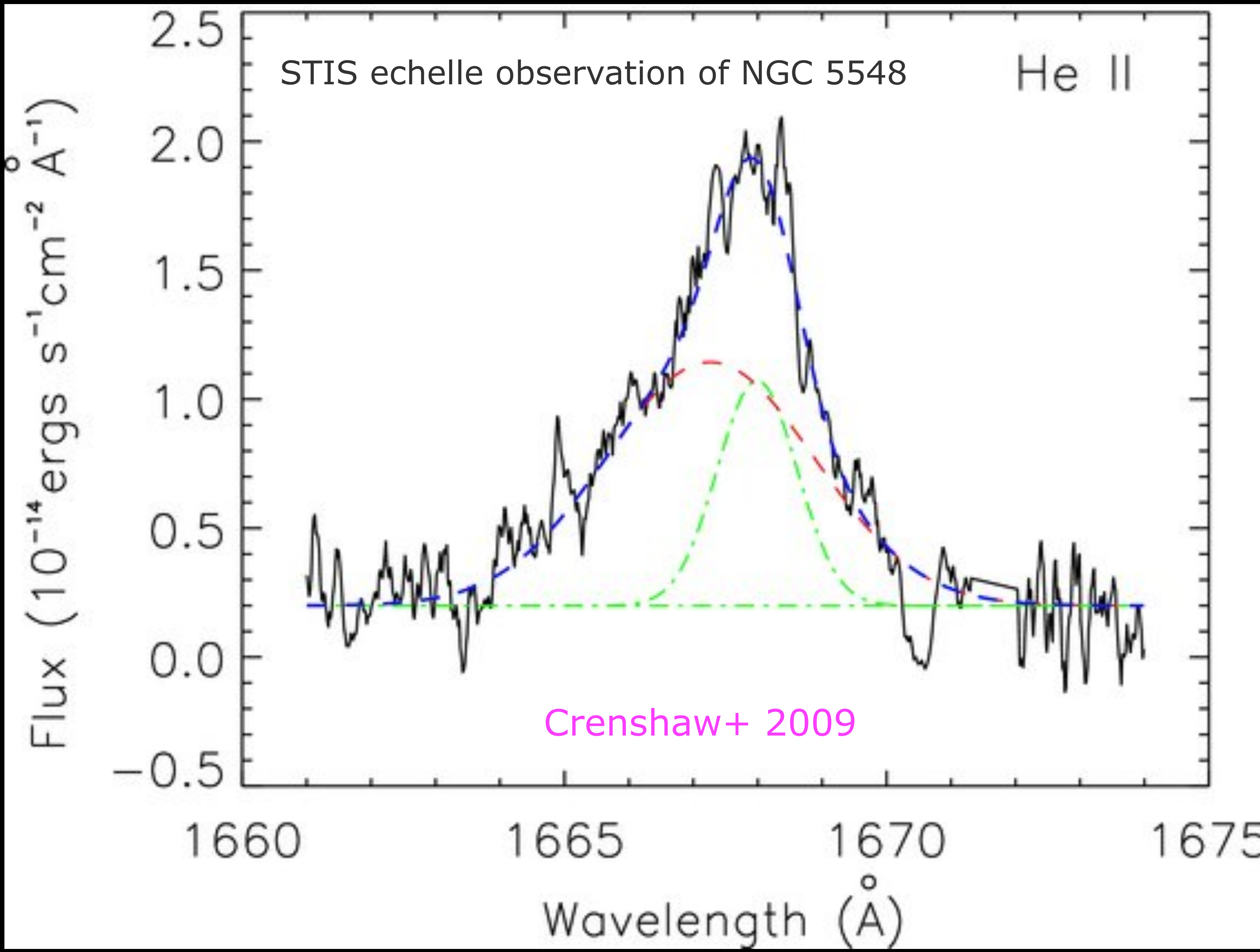
"Line emission vs radius" in AGN



Netzer & Laor 1993 model

- constant density gas clouds
- $n_H \propto R^{-3/2}$, $N_H \propto R^{-1}$
- n_H, N_H at 0.1 pc = $10^{9.4}$ cm^{-3} & $10^{23.4}$ cm^{-2}
- Solar composition <=0.1 pc
- ISM composition with dust grains >0.1 pc

Recent observations (Brotherton+1994, Puchnarewicz & Jones 1996, Crenshaw & Kraemer 2007, Hu+ 2008a,b, Crenshaw+ 2009, Zhu+ 2009, Li+ 2015) of some AGN shows intermediate line emission

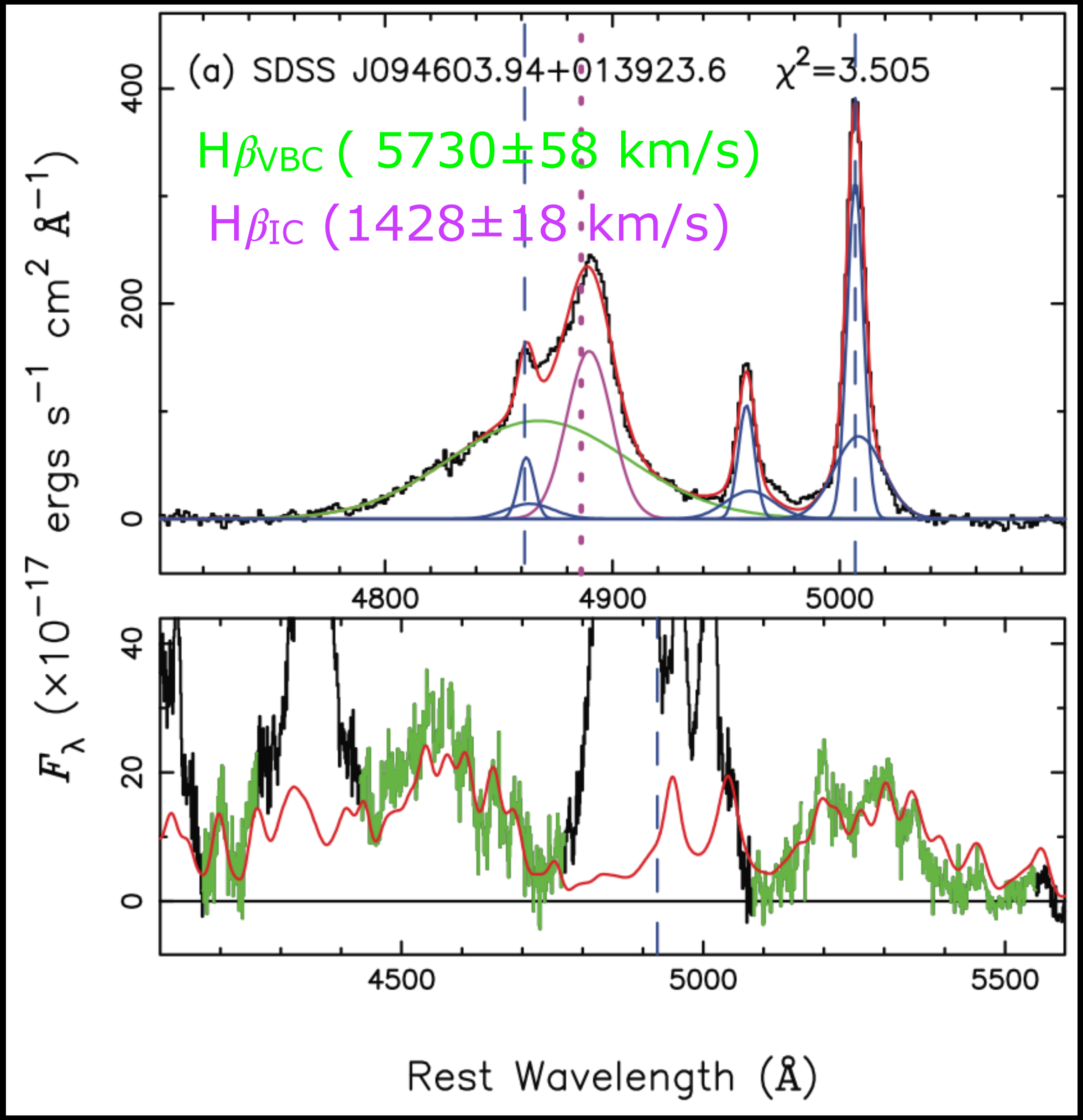


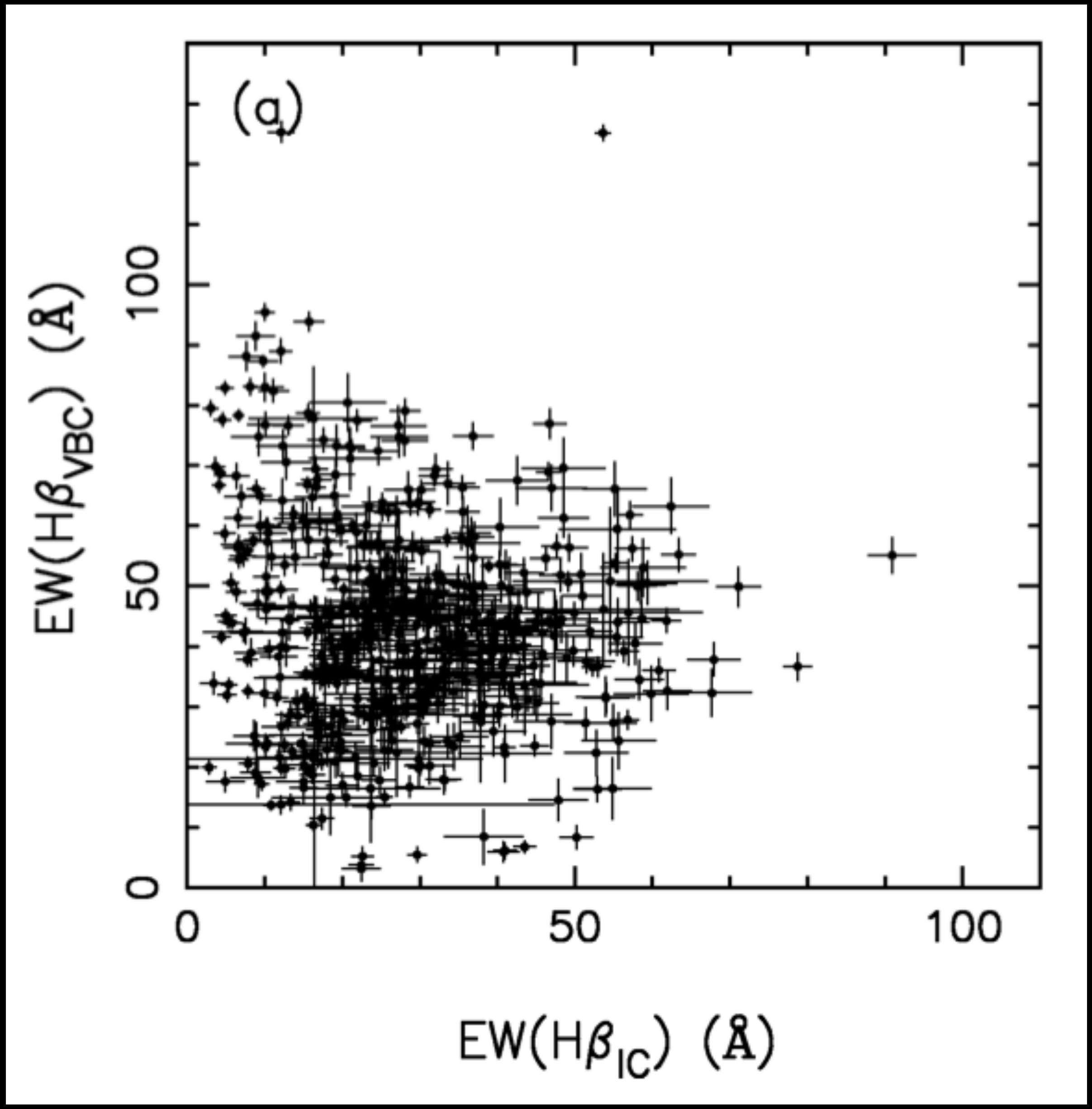
Intermediate lines: FWHM ~690 km /s

continuum + BLR (lower dotted–dashed green), continuum + BLR+ NLR (upper dotted–dashed green), continuum + BLR + ILR (dashed red) and continuum + BLR + ILR + NLR (upper dashed blue)

Hβ decomposed into $H\beta_{VBC}$ and $H\beta_{IC}$ (Hu + 2008)

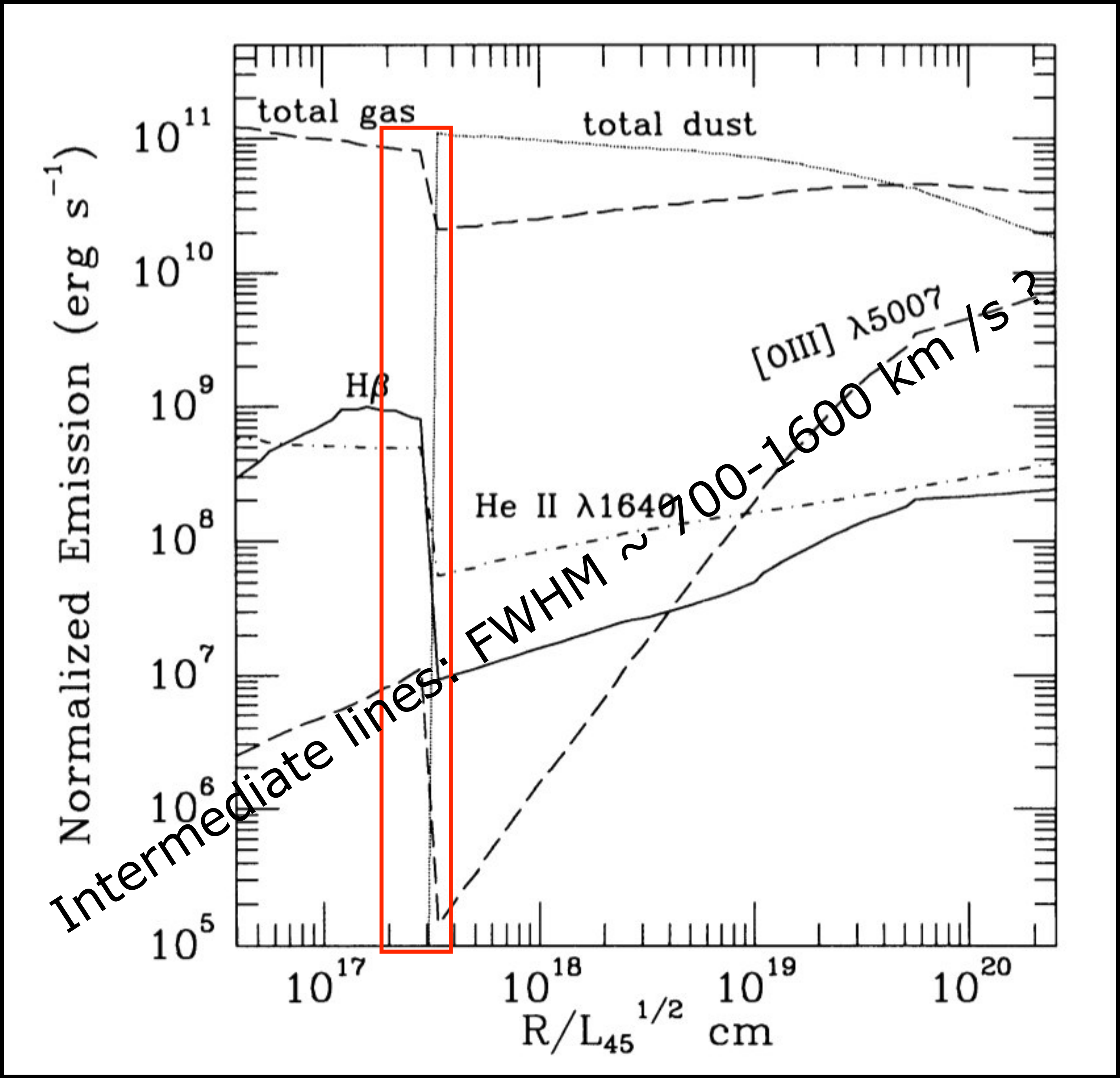
568 quasars Z<0.88





The lack of correlation between the EWs of $H\beta_{VBC}$ and $H\beta_{IC}$ strongly suggests that the two components are emitted from different regions.

"Line emission vs radius" in AGN



Netzer & Laor 1993 model

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- $n_H \propto R^{-3/2}$, $N_H \propto R^{-1}$
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- Solar composition <=0.1 pc
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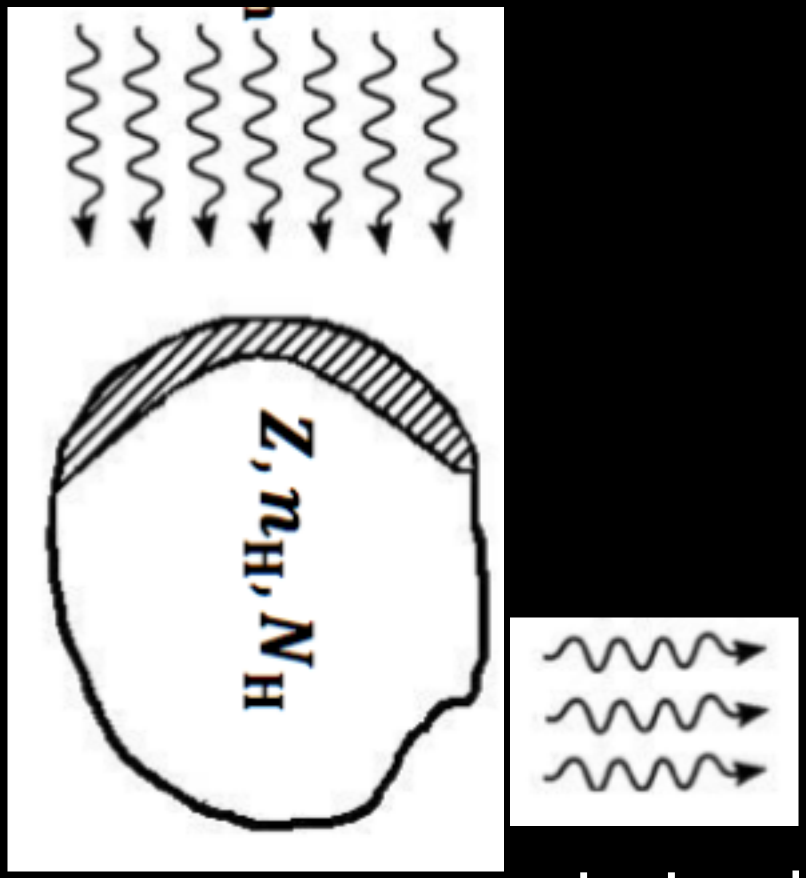
Photoionisation modelling of the emitting gas

- Broad band SED
- Gas density n_H
- Metallicity Z
- Column Density N_H
- Ionisation parameter U
- Radiative transfer, ionisation equilibrium and thermal balance
- Main Codes: CLOUDY, TITAN, XSTAR,..

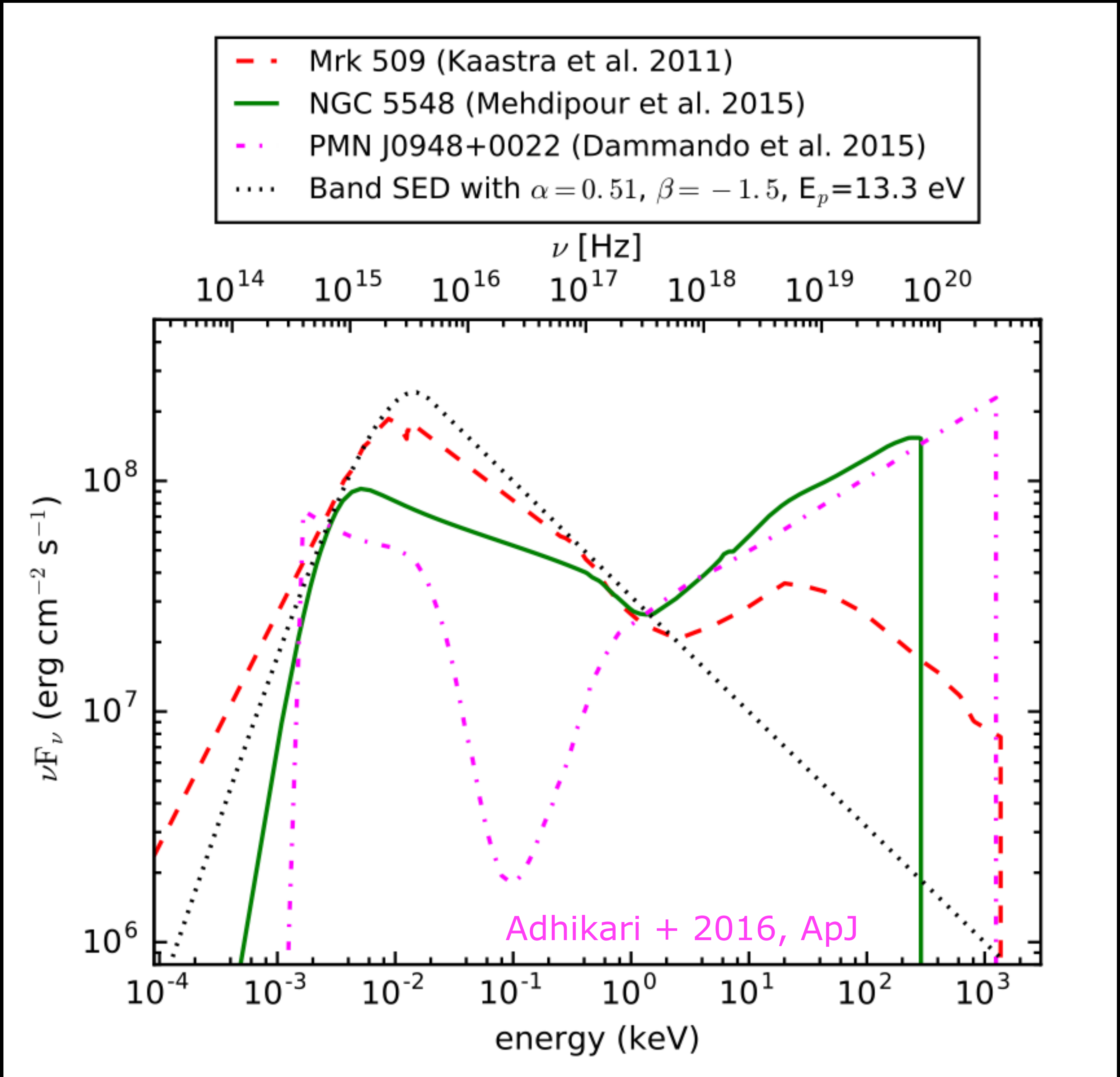
incident SED



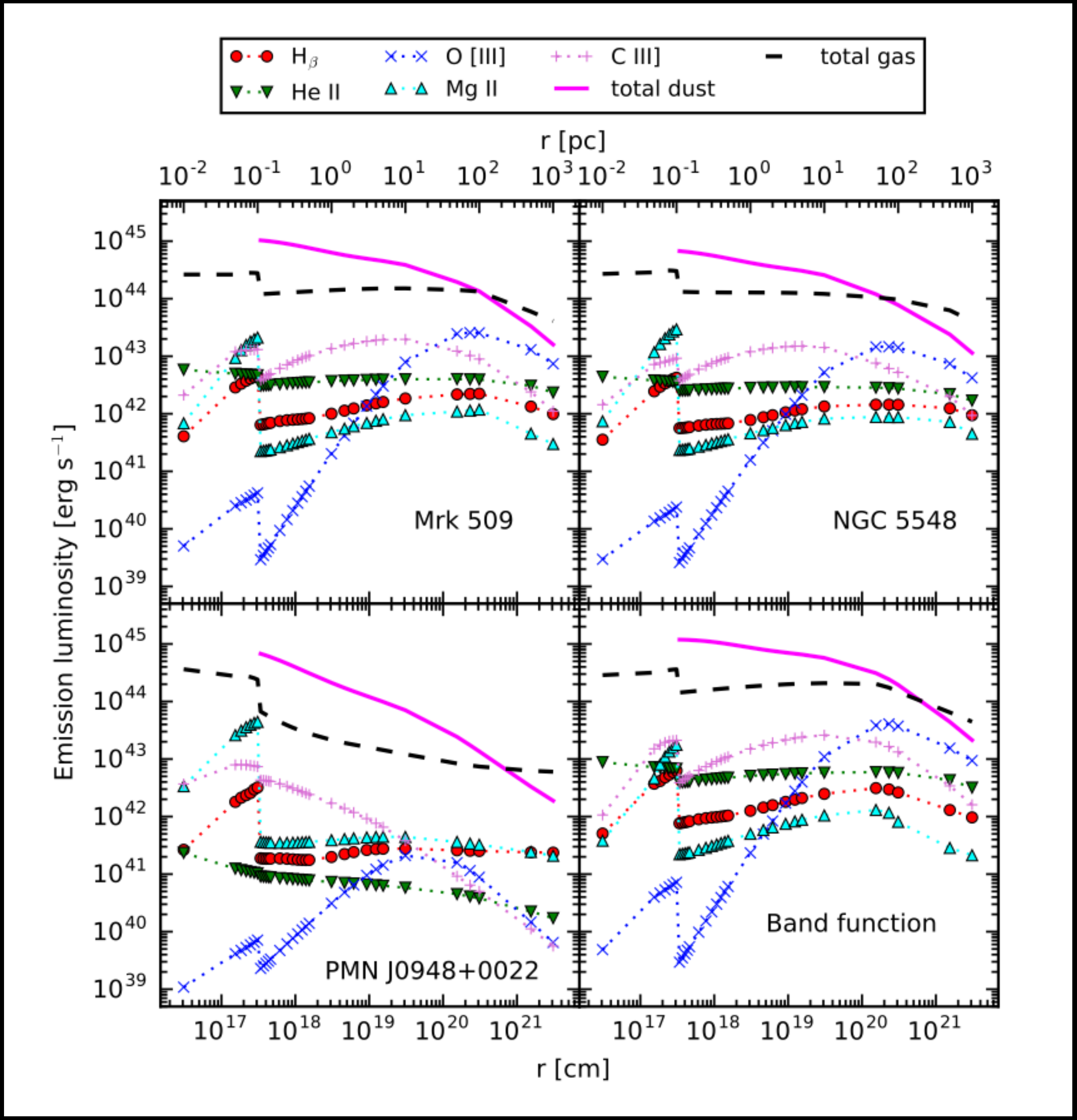
emission lines

Cloudy 13.03 (Ferland + 2013)

Is the presence of ILR in some AGN connected with the shape of SED?



The answer is no!



Adhikari + 2016, ApJ

Our model assumptions

Netzer & Laor 1993

- constant density clouds
- $n_H \propto R^{-3/2}$, $N_H \propto R^{-1}$
- N_H at 0.1 pc = $10^{23.4}$ cm^{-2}

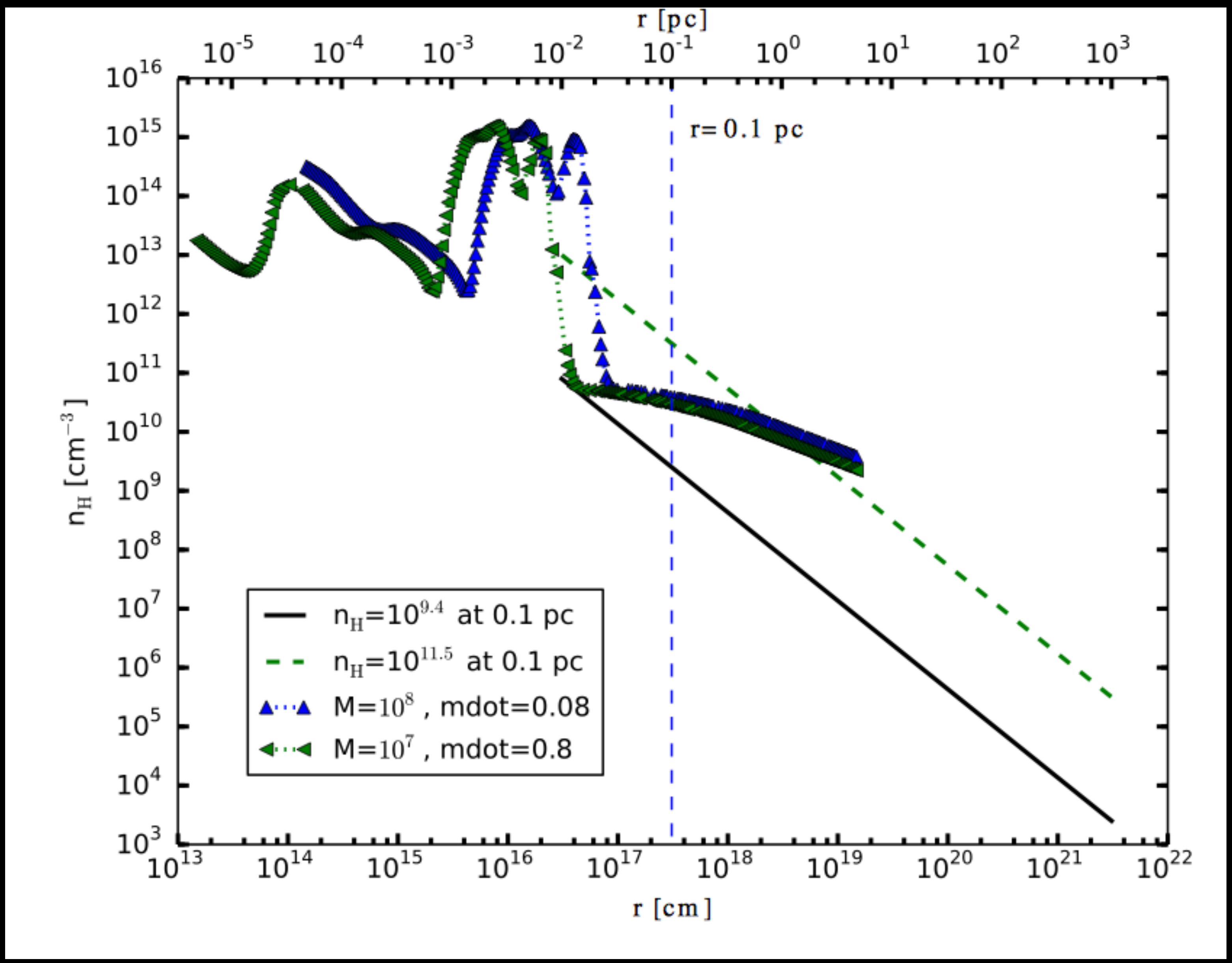
- n_H, N_H at 0.1 pc = $10^{9.4}$ cm^{-3} & $10^{23.4}$ cm^{-2}
- Solar composition <=0.1 pc
- ISM composition with dust grains >=0.1 pc

- n_H at 0.1 pc = $10^{11.5}$ cm^{-3}

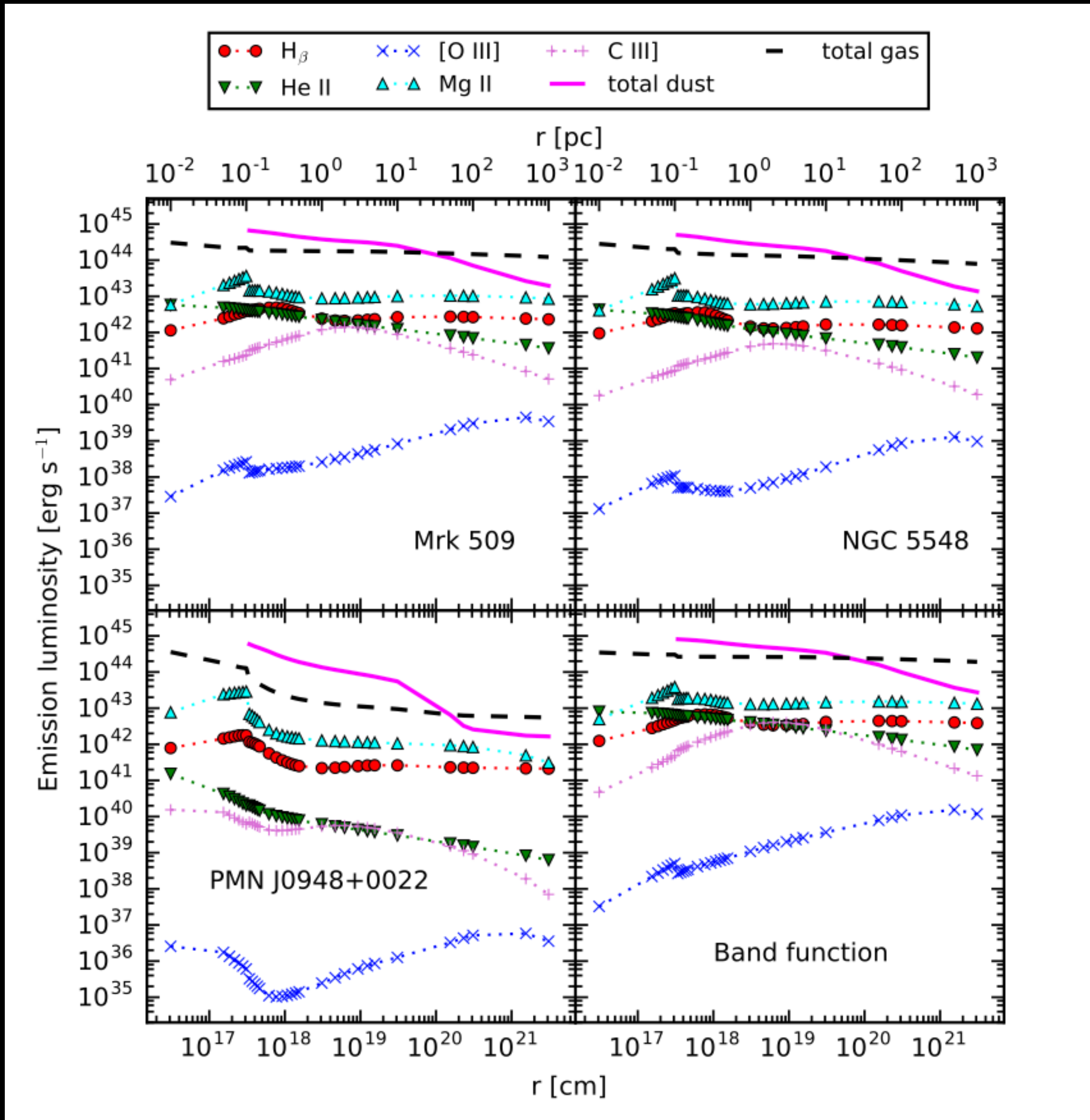
High local densities (~ 10^{11} -10^{12} cm^{-3}) of emitting and absorbing clouds in AGN have been inferred for several sources (Leighly 2004, Bruh- weiler & Verner 2008, Rozanska+ 2014, Hryniewicz + 2014, Modzelewska+ 2014, Sredzinska + 2016)

Dense clouds: potentially formed from an accretion disk atmosphere

disk vertical structure calculations (Pojmanski + 1996, Rozanska +1999)



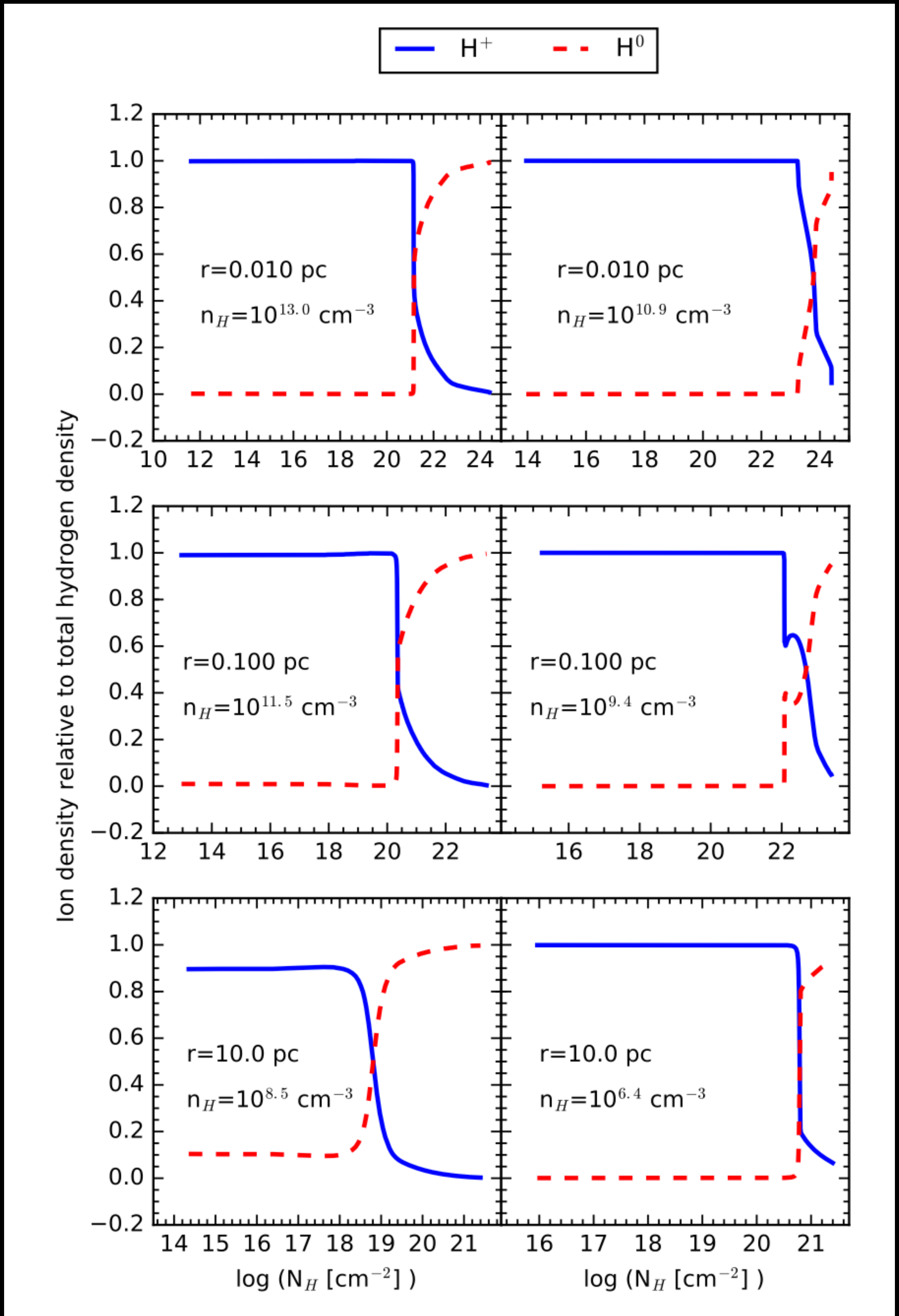
BLR emission clouds may be connected with the wind from an accretion disk atmosphere (Gaskell 2009, Czerny & Hryniewicz 2011)



No suppression in line emission !

ILR at distances 0.1-1 pc

Adhikari + 2016, ApJ

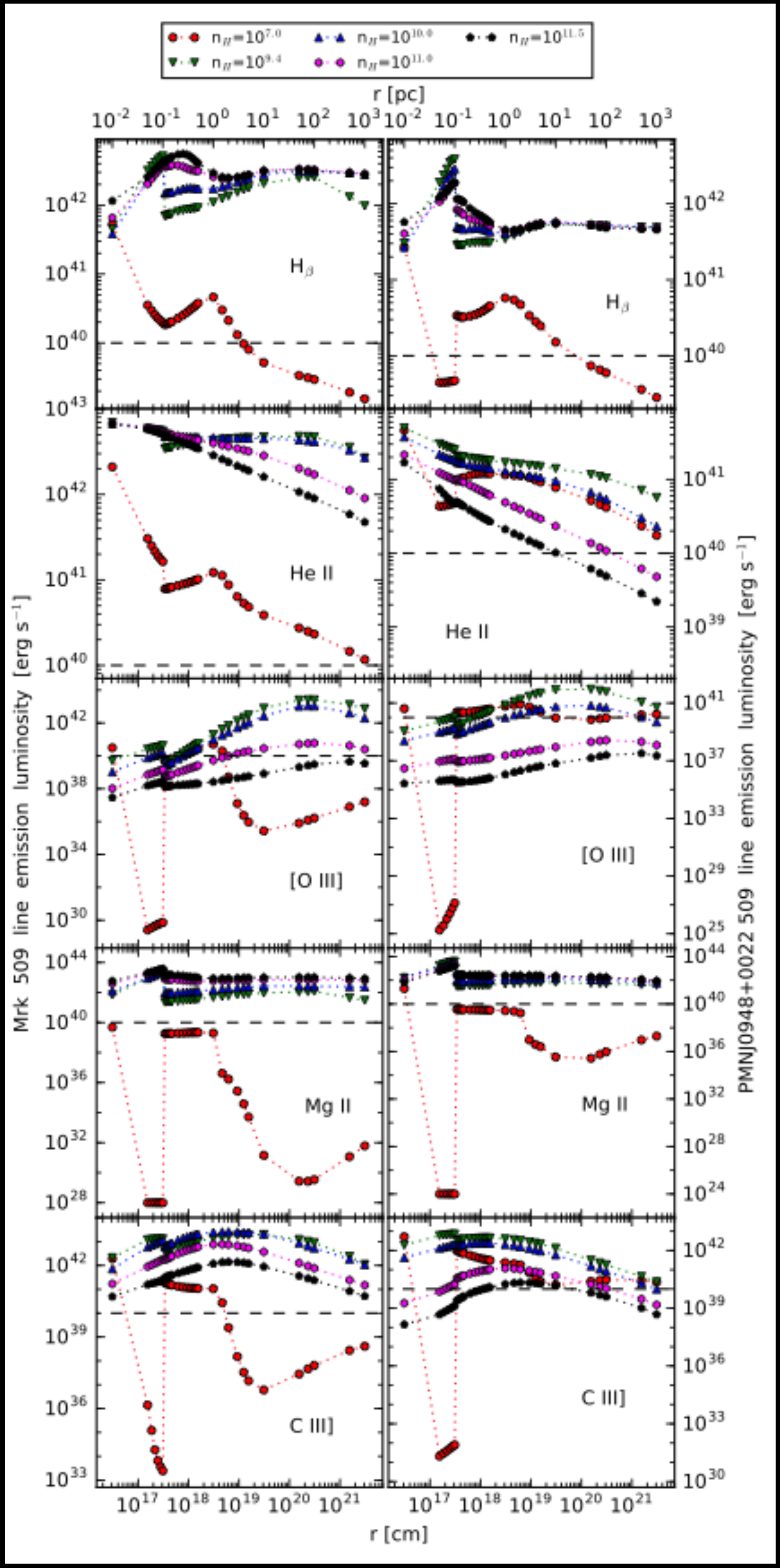


Adhikari + 2016, ApJ

High density clouds have lower H^+ column

$$N_{\mathrm{H}^+} \equiv n_p l = \frac{\phi_{\mathrm{H}}}{n_{\mathrm{e}}\alpha_{\mathrm{B}}(T)} = Uc\ \alpha_{\mathrm{B}}(T)^{-1}$$

gas opacity always dominates for higher densities and it does not matter if the gas is dusty or not



Hβ peak: 0.1<r<0.4 pc

He II peak: r<0.1 pc

Mg II peak: r<0.1 pc

O [III] peak: r~60 pc

consistent with the results inferred from Reverberation Mapping (RM) studies (Bentz + 2009, Koshida+2014)

Adhikari + 2016, ApJ

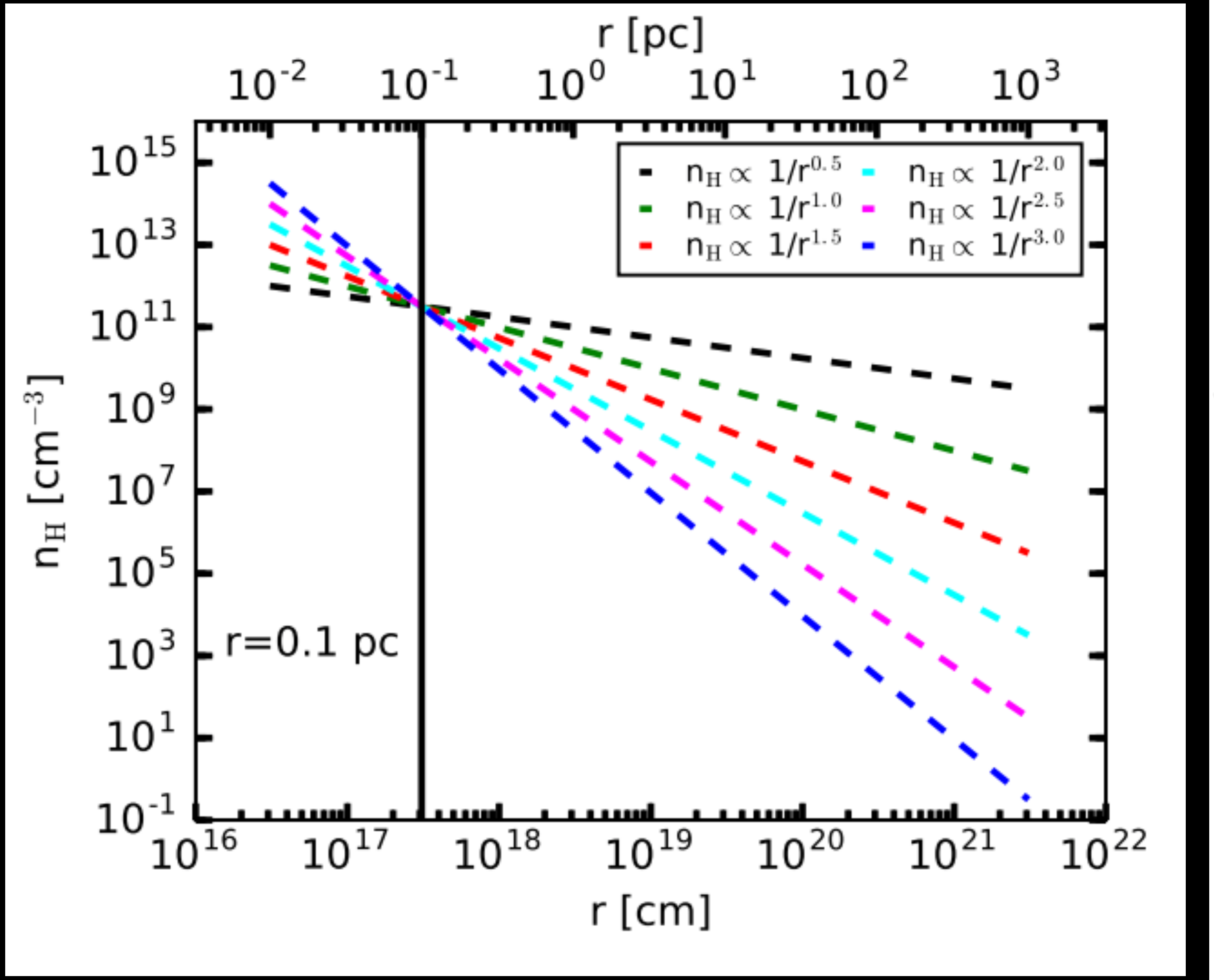
Two important predictions of our model

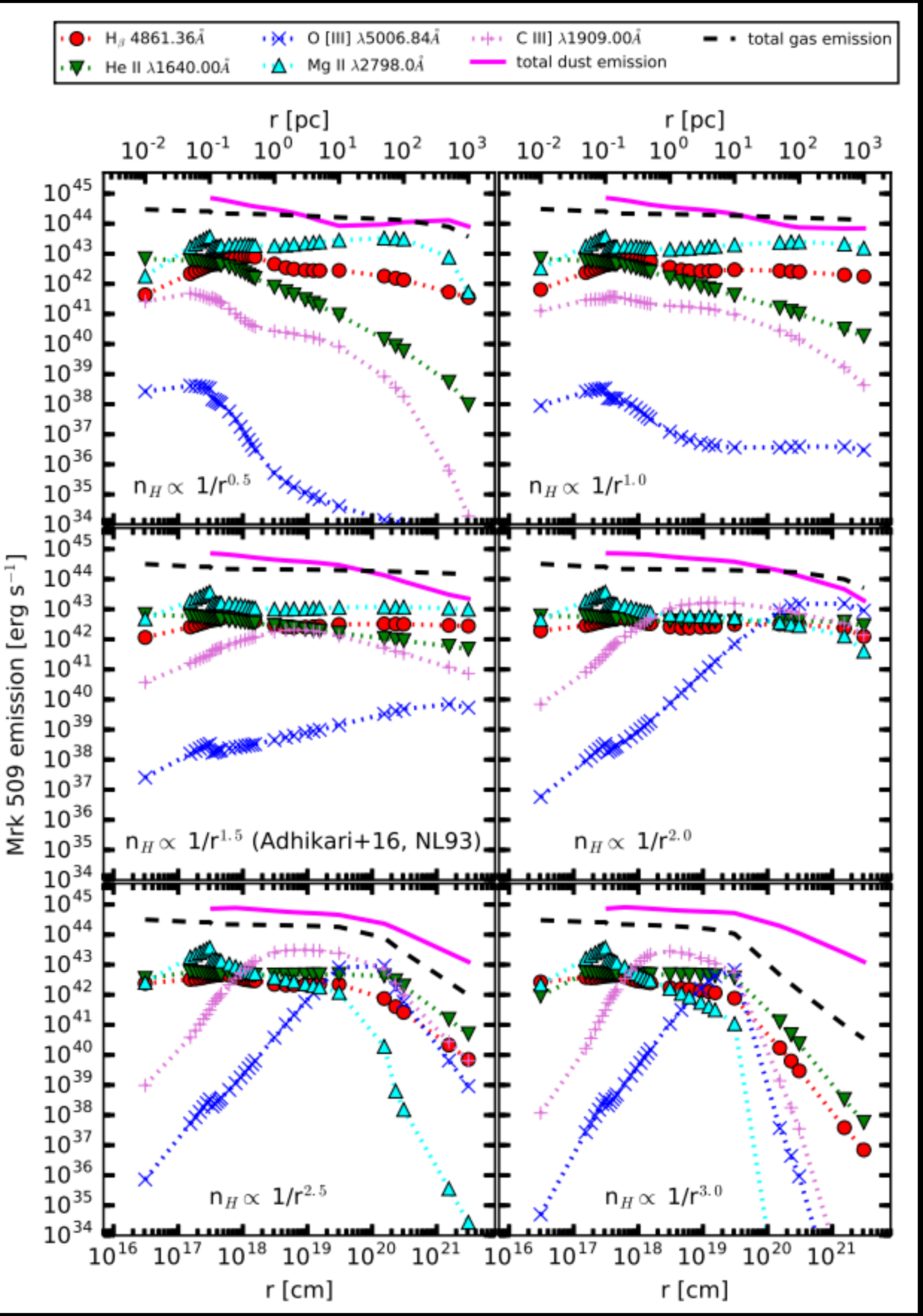
- Existence of ILR at distances 0.1-1 pc predicts the RM lag of ILR to be 100-1000 light-days

- In our case, the effect of dust disappears if U is less than 0.01 (threshold value). So, in LINERS where the emission lines are produced by the photoionisation of the gas at U ≤ 10^{-3} (Ferland & Netzer (1983)), our result clearly predicts the presence of ILR in LINERS. The presence of ILR in 33 LINERS is also shown by Balmaverde + 2016

Ongoing Work…..

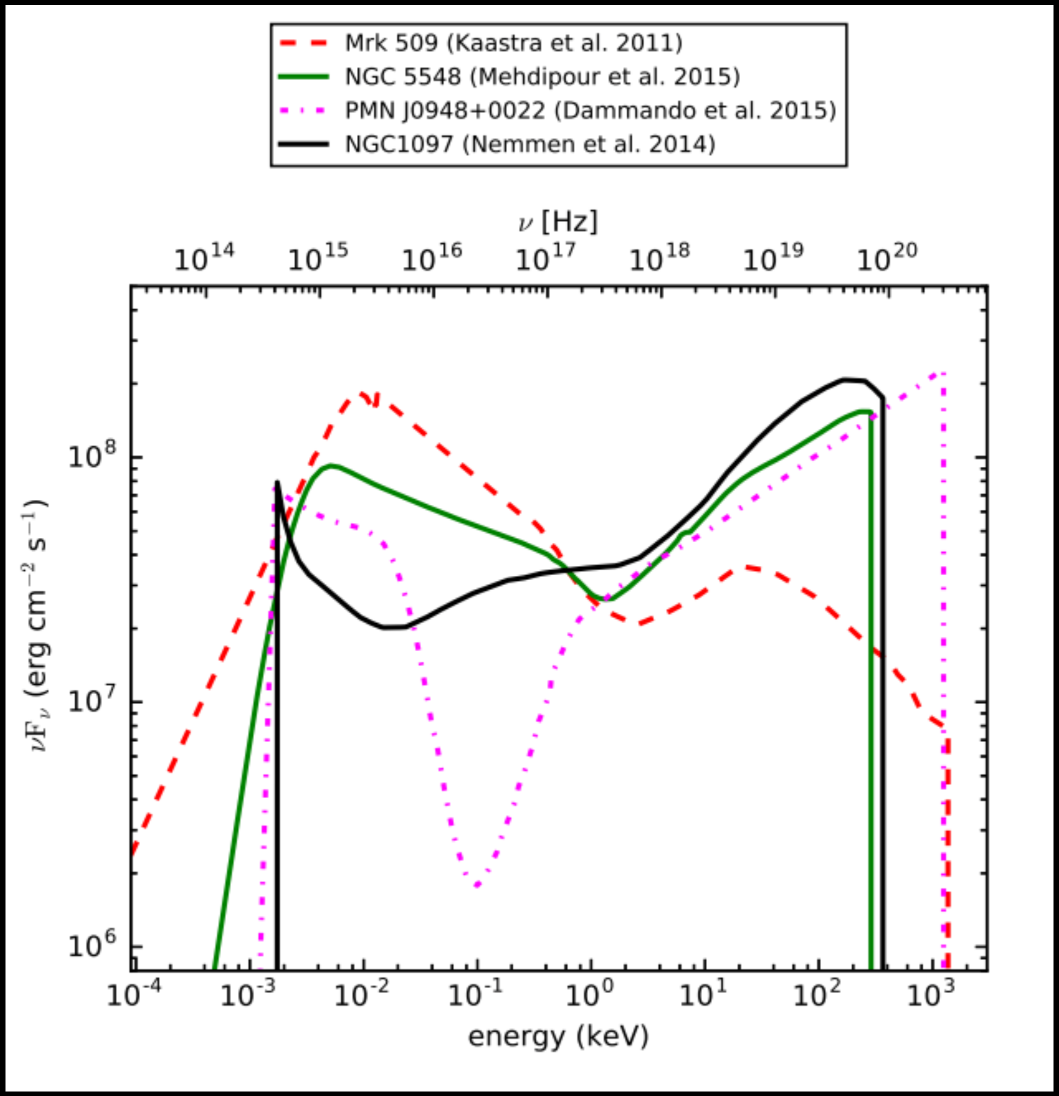
density profile dependence



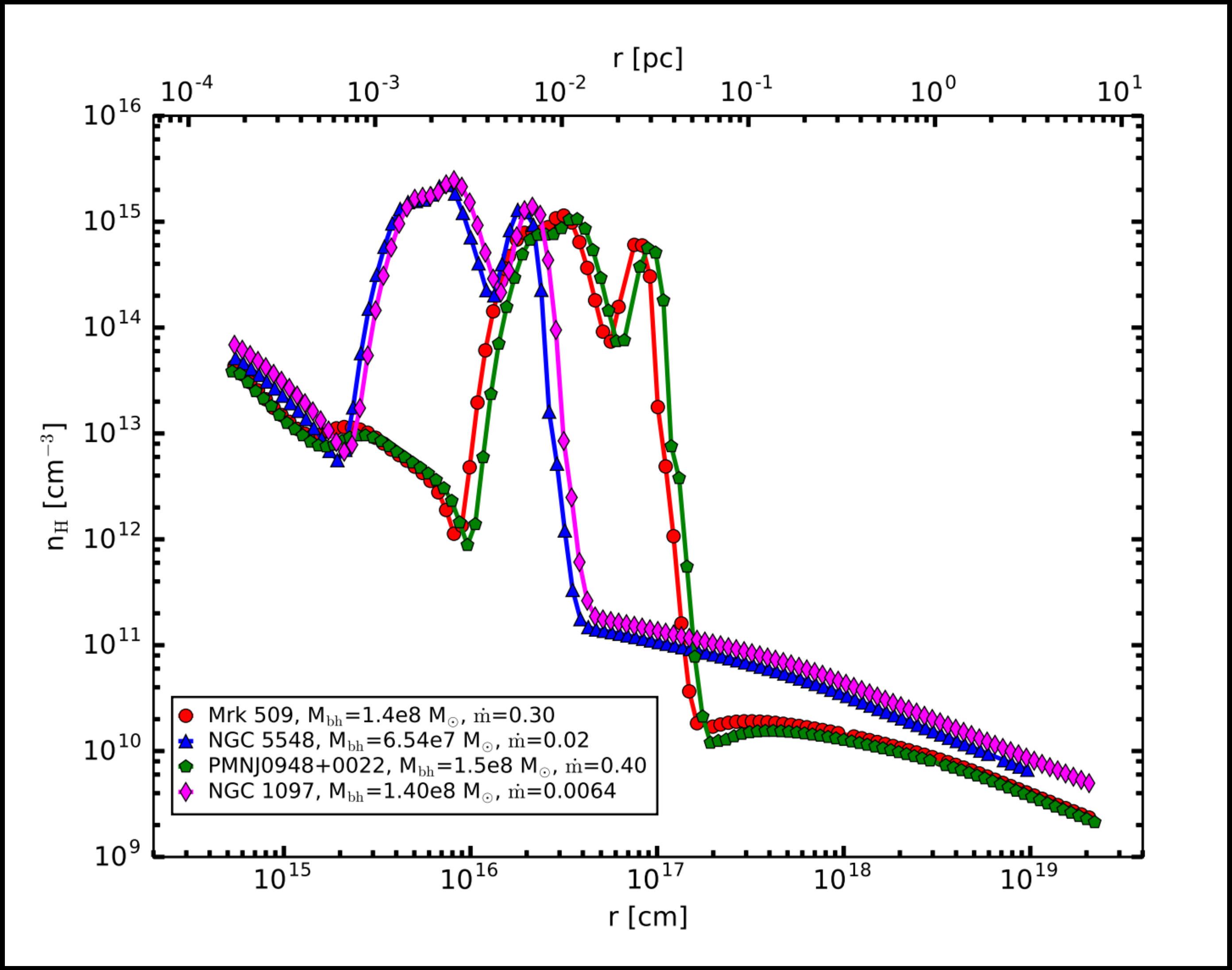


Ongoing Work .....

LINER NGC1097 SED included

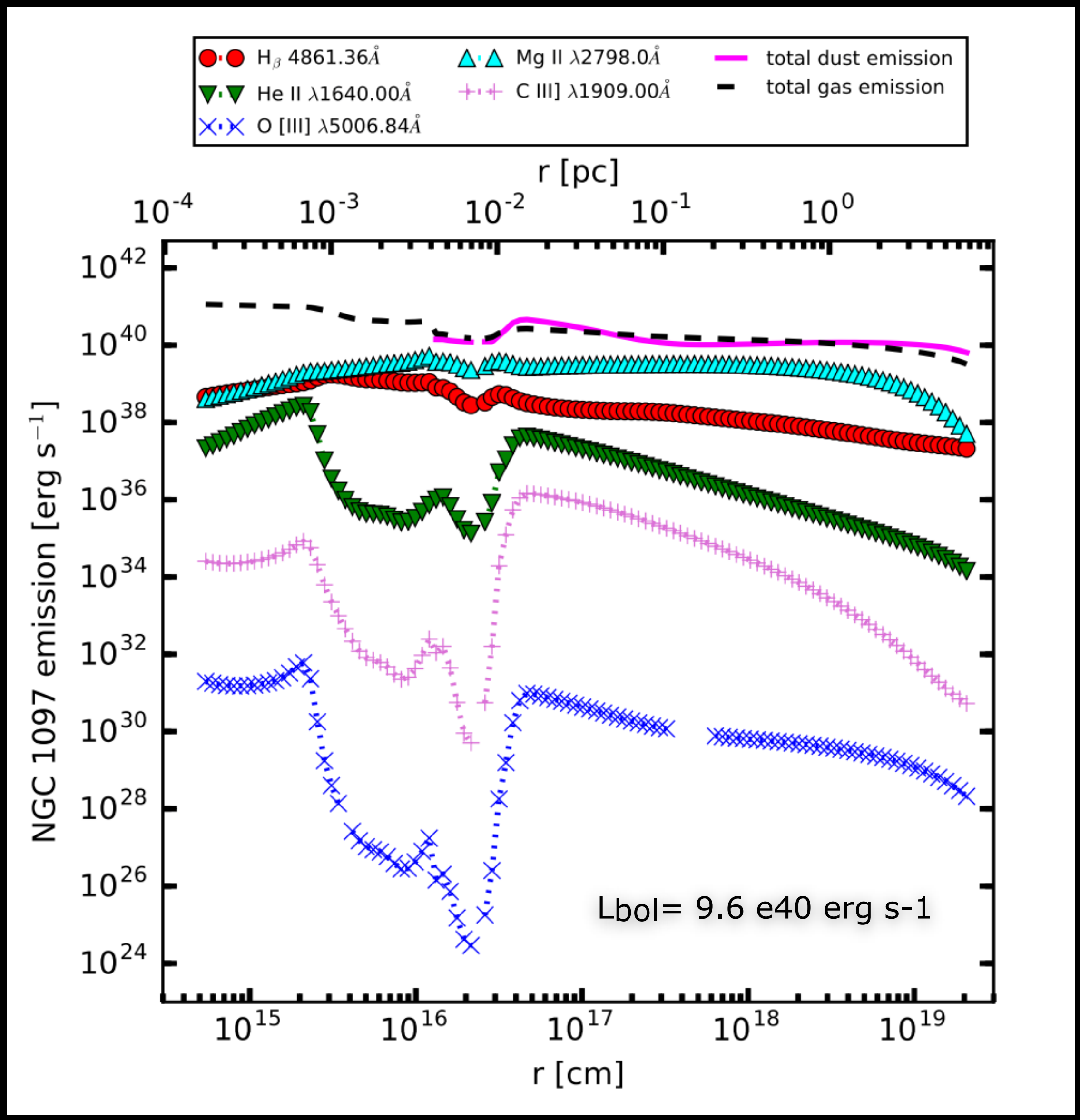


realistic density profile expected from disk vertical structure

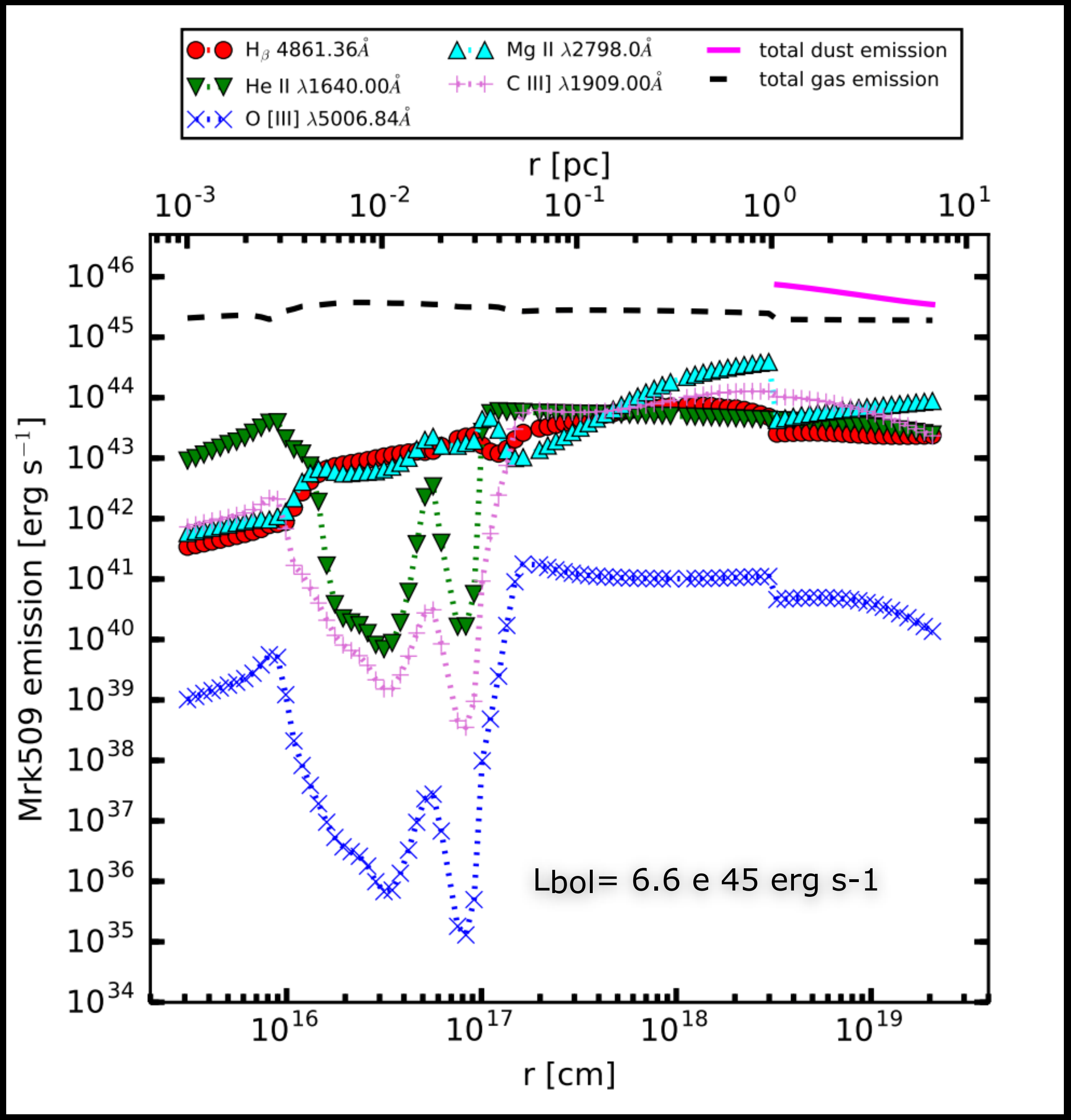


Ongoing Work .....

LINER NGC 1097



Seyfert 1: Mrk 509



ILR is possible in both sources??

Summary

- The presence or absence of ILR is not determined by the spectral shape of the incident continuum.

- With high density at sublimation radius i.e., $10^{11.5}$ cm^{-3}, we obtained a continuous "line emission vs radius" showing the existence of ILR. So the density of the gas should be high enough for the intermediate line emission

- The dense cloud can be potentially formed from an accretion disk atmosphere which is dense enough below the sublimation radius in the accretion disk

- Such ILR is predicted to be located at radial distances r ~ 0.1 – 1 pc, then the RM lag expected from our model would be of the order of 100-1000 light-days

- More to be explored !!

Back up slides

Hβ decomposed into Hβ_{VBC} and Hβ_{IC} (Hu + 2008)

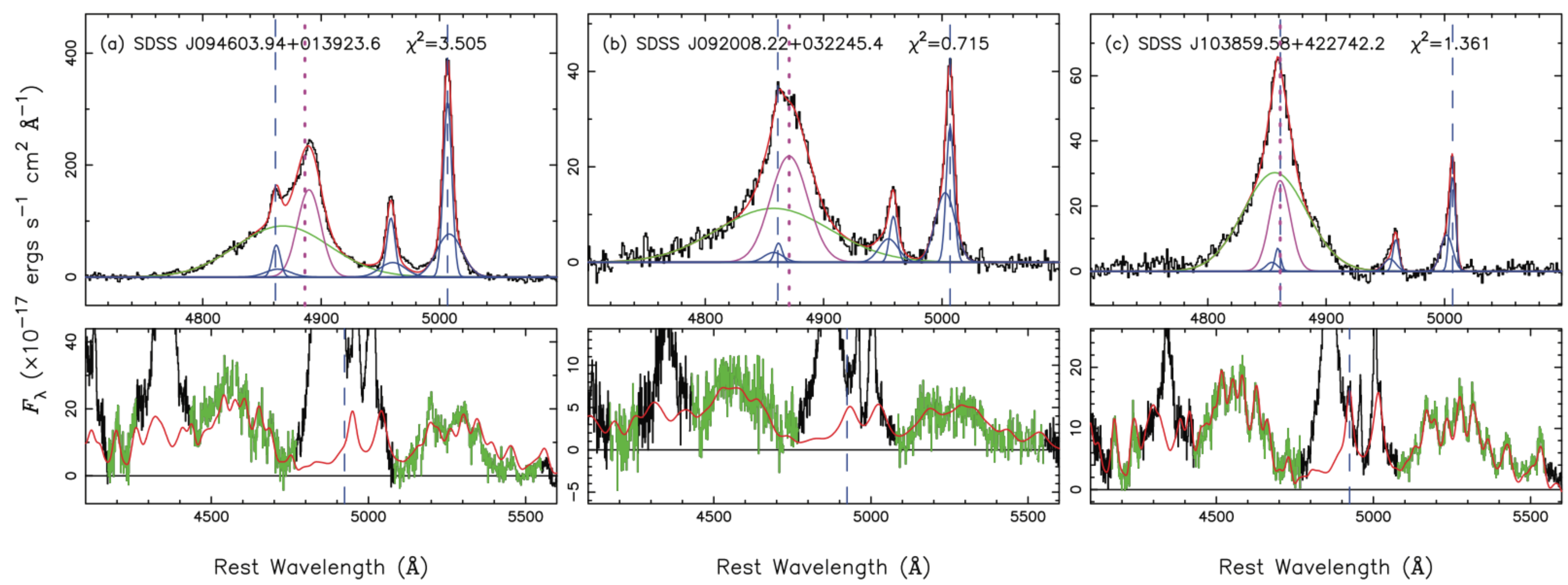


FIG. 2.—Examples of Fe II measurement and emission-line fitting for (*a*) SDSS J094603.94+013923.6, (*b*) SDSS J092008.22+032245.4, and (*c*) SDSS J103859.58+422742.2. For each source, the top panel shows multi-Gaussian fitting for Hβ and [O III]. Hβ_{VBC} is in green and Hβ_{IC} is in magenta. The two blue dashed lines mark the rest-frame wavelength of Hβ and [O III] λ5007. The magenta dotted line is the position of Hβ at the same velocity as Fe II. Note the consistency between the Hβ_{IC} peak and the dotted line. Hβ_{NC} and [O III] are in blue. The red line is the sum of each component. The bottom panel shows the emission-line spectrum after subtracting the power-law continuum. The green portions of the spectrum denote the windows for fitting the Fe II emission, whose model is given in red. The blue dashed line marks the peak of Fe II λ4924 at zero velocity shift.

TABLE 1

LINE MEASUREMENTS

		Fe II			Hβ_{IC}			Hβ_{VBC}			
SDSS NAME	z	EW (Å)	FWHM (km s^{-1})	Shift (km s^{-1})	EW (Å)	FWHM (km s^{-1})	Shift (km s^{-1})	EW (Å)	FWHM (km s^{-1})	Shift (km s^{-1})	χ^2
094603.94+013923.6	0.220	60 ± 1	1543 ± 55	1533 ± 24	54 ± 1	1428 ± 18	1754 ± 7	125 ± 1	5730 ± 58	400 ± 25	3.506
092008.22+032245.4	0.334	45 ± 2	2548 ± 251	590 ± 98	27 ± 2	2281 ± 103	589 ± 42	42 ± 2	6924 ± 332	−195 ± 109	0.715
103859.58+422742.2	0.221	72 ± 1	1297 ± 40	−10 ± 18	13 ± 1	1259 ± 71	−16 ± 26	44 ± 1	3893 ± 87	−279 ± 29	1.361

NOTE.—Table 1 is published in its entirety in the electronic edition of the *Astrophysical Journal*. A portion is shown here for guidance regarding its form and content.

be of the order of 100–1000 light days.

The physical reason for the density dependence is connected with the value of the column density at which the ionization front is located. Below, we explain this in the example of hydrogen Hβ line. Let us assume simple ground-state hydrogen photoionization, and set the ionization balance equation

$$n_{\rm p}\, n_{\rm e}\, l\, \alpha_{\rm B}(T) = \phi_{\rm H}. \tag{4}$$

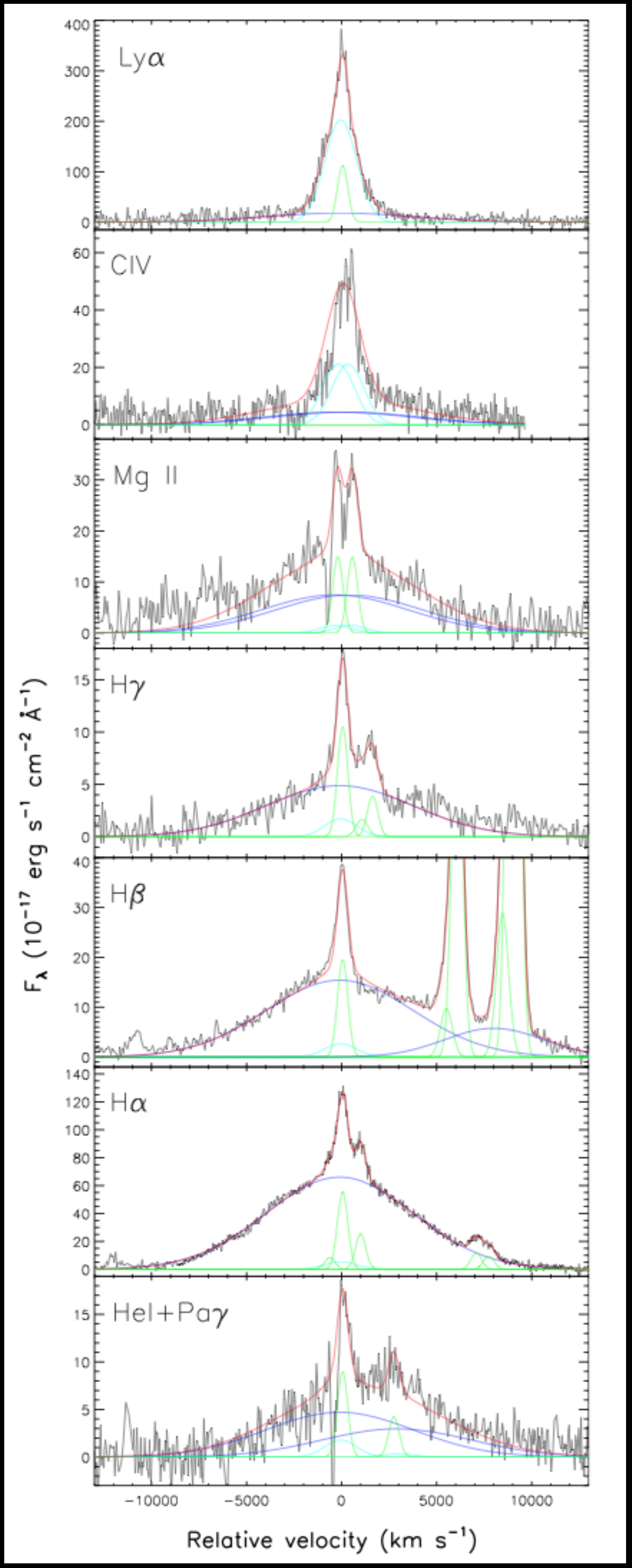
(Osterbrock & Ferland 2006). The first two terms are the proton and electron density in the H^+ layer of the cloud, l [cm] is the thickness of the H^+ layer, and $\alpha_{\rm B}(T)$ [cm^3 s^{-1}] is the Case B recombination coefficient. The physical interpretation is that the flux of hydrogen-ionizing photons incident on the cloud, $\phi_{\rm H}$ [cm^{-2} s^{-1}], equals the number of hydrogen recombinations that occur over the thickness l.

The hydrogen column density across H^+ layer is then

$$N_{\rm H+} \equiv n_p l = \frac{\phi_{\rm H}}{n_{\rm e}\alpha_{\rm B}(T)} = Uc\, \alpha_{\rm B}(T)^{-1}. \tag{5}$$

The gas column density $N_{\rm H+}$, and resulting line and continuum optical depths, all scale with the ionization parameter. At very high values of U, whole cloud is ionized, and the line emission comes from the whole volume, in this case limited by the fixed adopted total hydrogen column, $N_{\rm H}$. As the cloud density increases, the ionization parameter decreases, ionization front forms, and the cloud consist of two zones. The line emission comes from the first zone, and only the dust in this zone competes with the gas for the photons. The high-density clouds studied here have smaller column densities and optical depths of H^+ layer, since ionization parameter is lower. This is clearly demonstrated in Fig. 5, which

Strong permitted emission lines of OI 287. Toward shorter wavelengths, BELs become weaker, while IELs become more prominent. Broad (blue), narrow (green), and intermediate-width (cyan) component.



Li + 2015

Name	AGN type	$L_{\rm bol}$ (erg s^{-1})	$M_7^{\rm bh}$ ($M_\odot$)	$\dot{m}$	$R_{17}^{\rm sub}$ (cm)
Mrk 509	Sy1,5	6.62×10^{45}	14	0.30	31.6
NGC 5548	Sy1	1.28×10^{44}	6.54	0.02	4.41
PMN J0948	NLSy1	2.28×10^{46}	15.4	0.40	58.9
NGC 1097	LINER	9.62×10^{40}	14	0.0064	0.12

dust sublimation radius depends on luminosity

$$R_d \simeq 0.4 L_{45}^{1/2}\,\mathrm{pc}, \text{ where } L_{45} = L/(10^{45}\,\mathrm{erg\,s^{-1}}).$$

Nenkova + 2008