Optical views of dense gas clouds at the circum-nuclear region in AGNs

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Schematic view of the AGN structure

BLR clouds: $n_H > 10^8$ cm^{-3} at R < ~1 pc

typical total mass of the BLR: < 10 M_{sun} (e.g., Peterson's textbook)

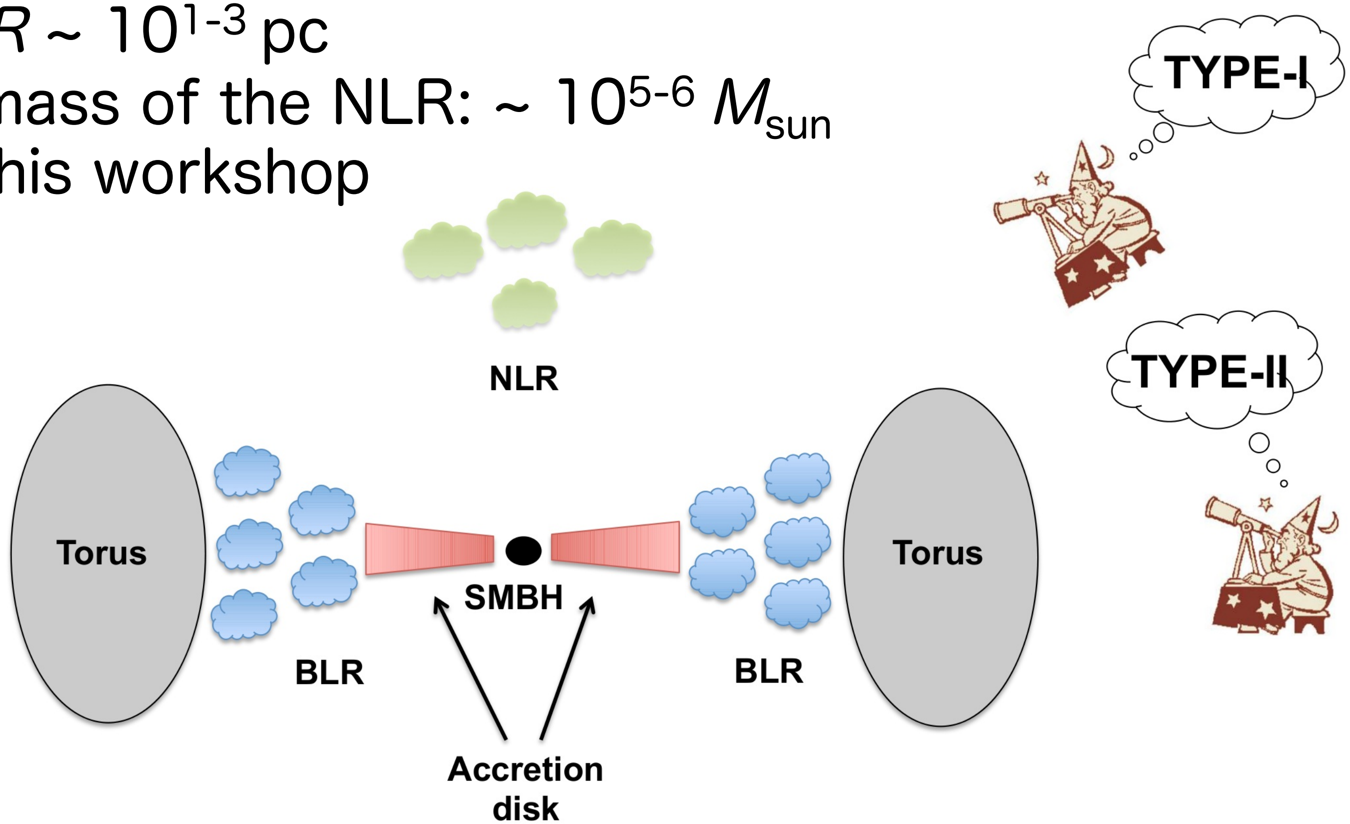
→ not important for circum-nuclear SF and mass reservoir

→ (probably) not important in this workshop

NLR clouds: at $R \sim 10^{1\text{-}3}$ pc

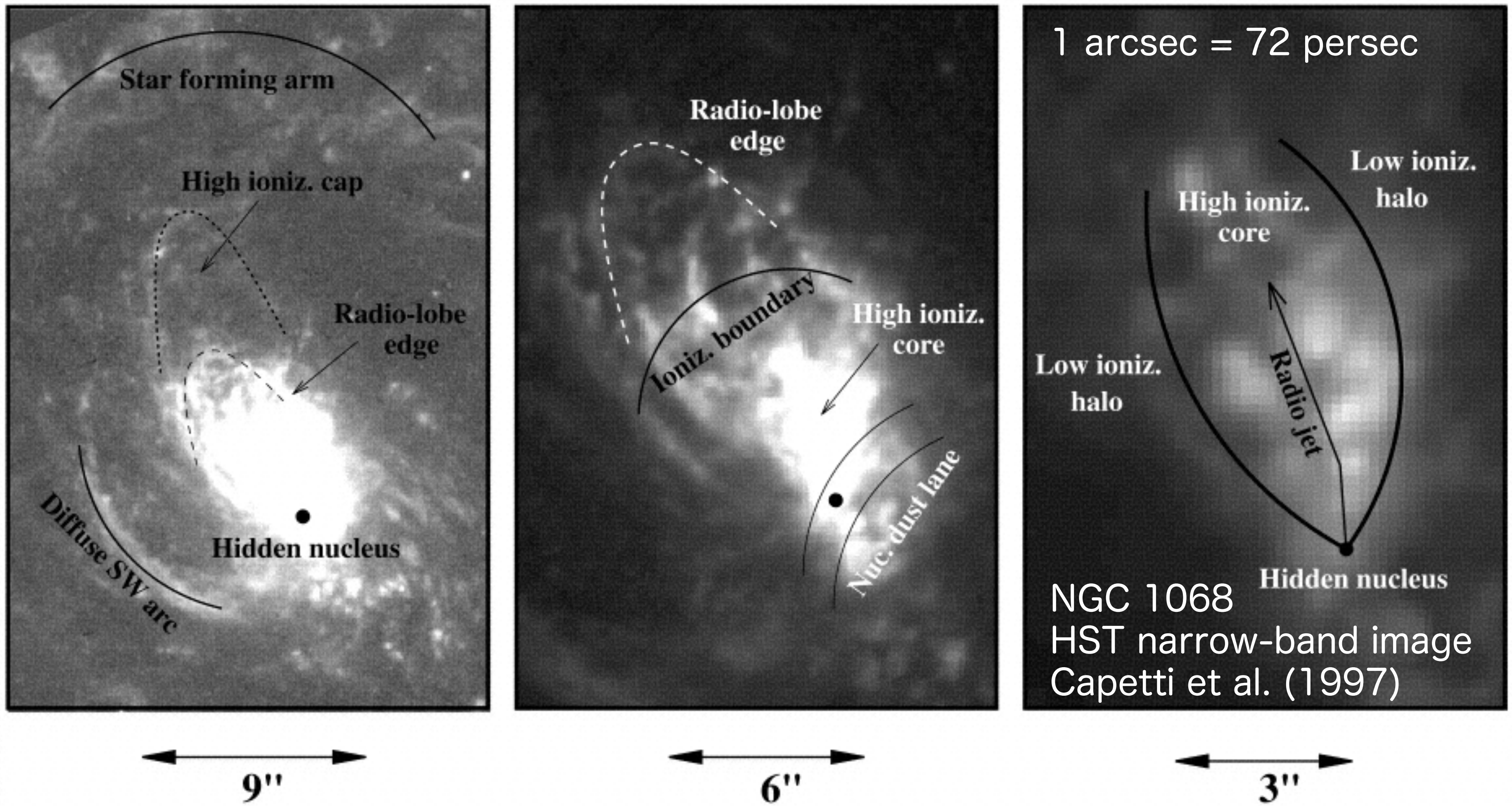
typical total mass of the NLR: ~ $10^{5\text{-}6}$ M_{sun}

→ target of this workshop



C. Ricci's webpage (http://www.isdc.unige.ch/~ricci/Website/Active_Galactic_Nuclei.html)

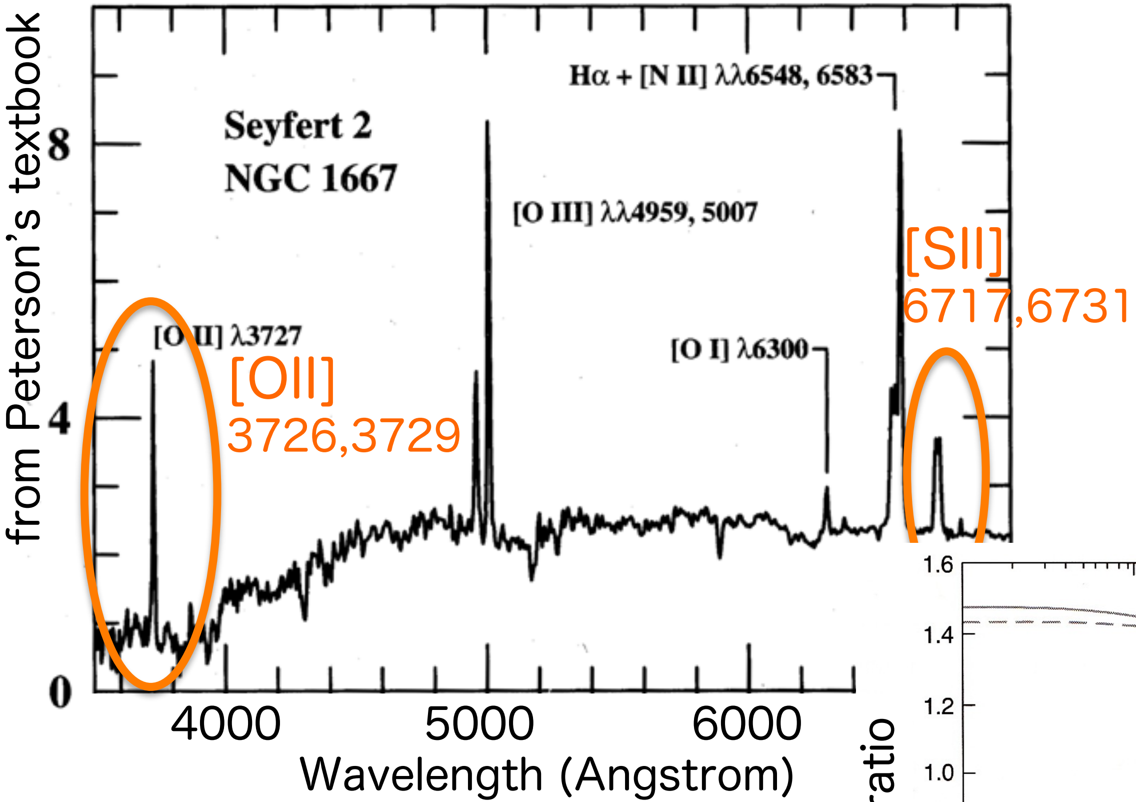
Narrow-Line Regions (NLRs) in AGNs

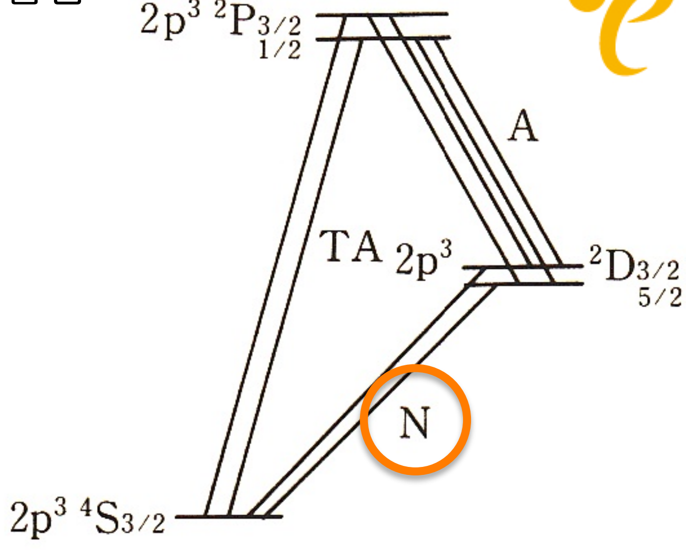


Clumpy gas seen in the direction of the torus opening angle
→ NLRs are photoionized by anisotropic ionizing radiation

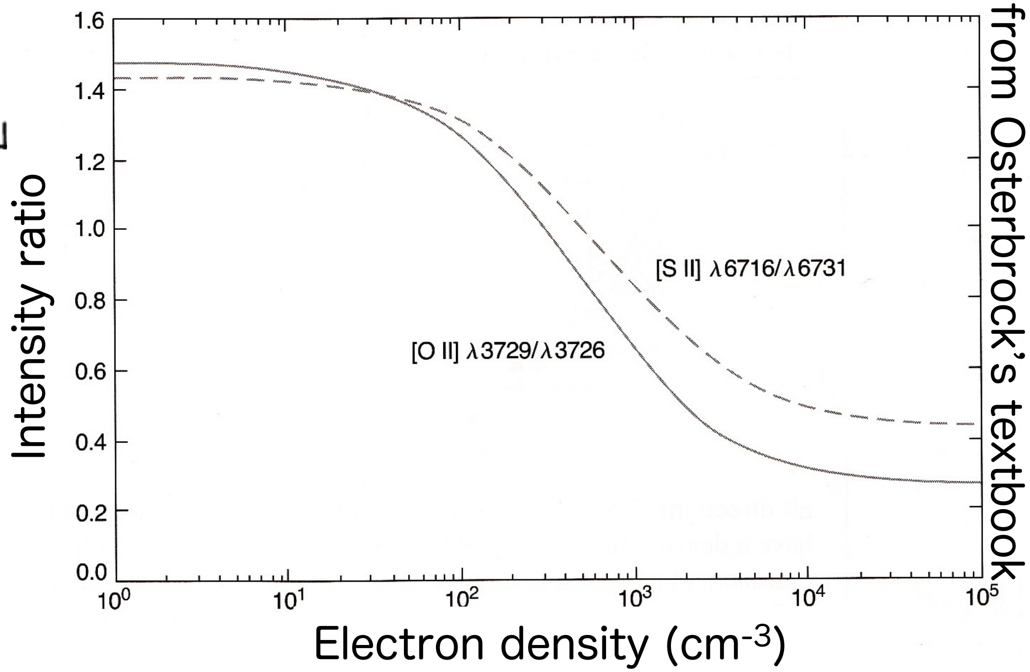
from「星間物理学」小暮智一

Optical spectrum of NLR clouds



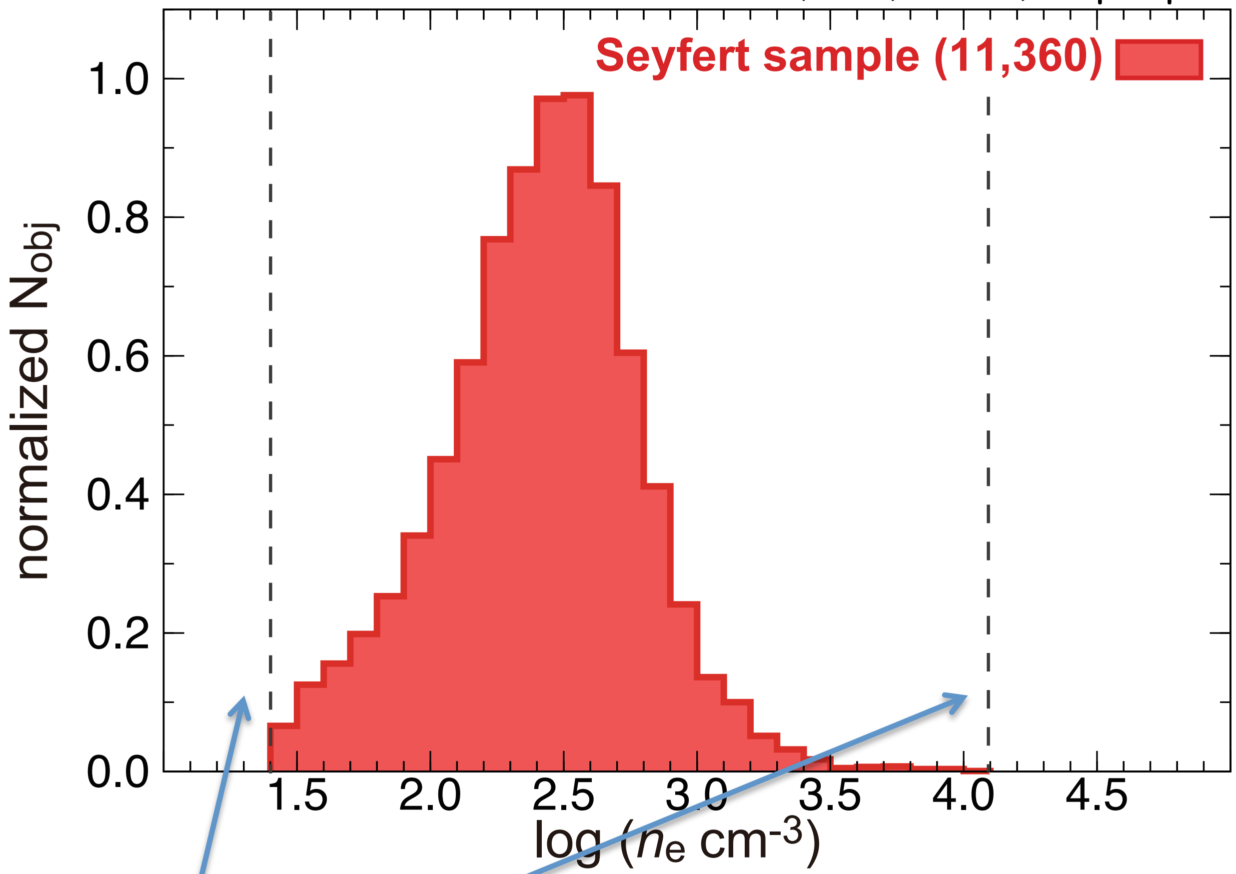


(b) $2p^3$配置
〔OII〕,〔SII〕



Gas density of NLR clouds

Kawasaki, TN, et al., in prep.



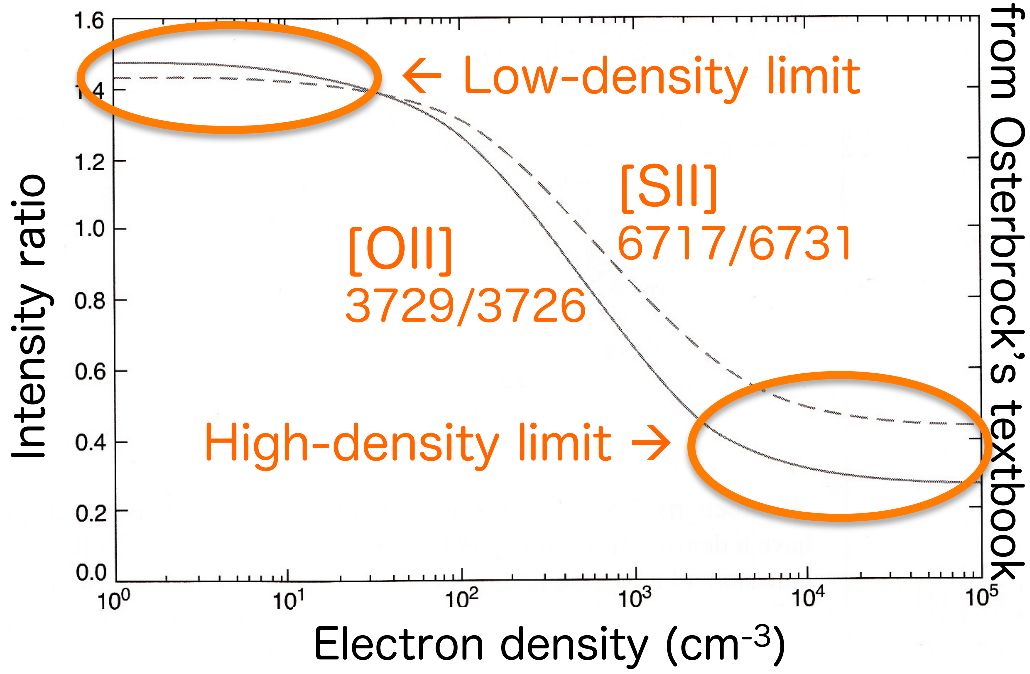
What are these dashed lines?

[SII] flux ratio of SDSS Seyferts

$n_{NLR} \sim 10^{2\text{-}3}$ cm^{-3}

※ measurements of the [OII] flux ratio are very difficult for NLRs due to the line blending

Gas density of NLR clouds: Caveat



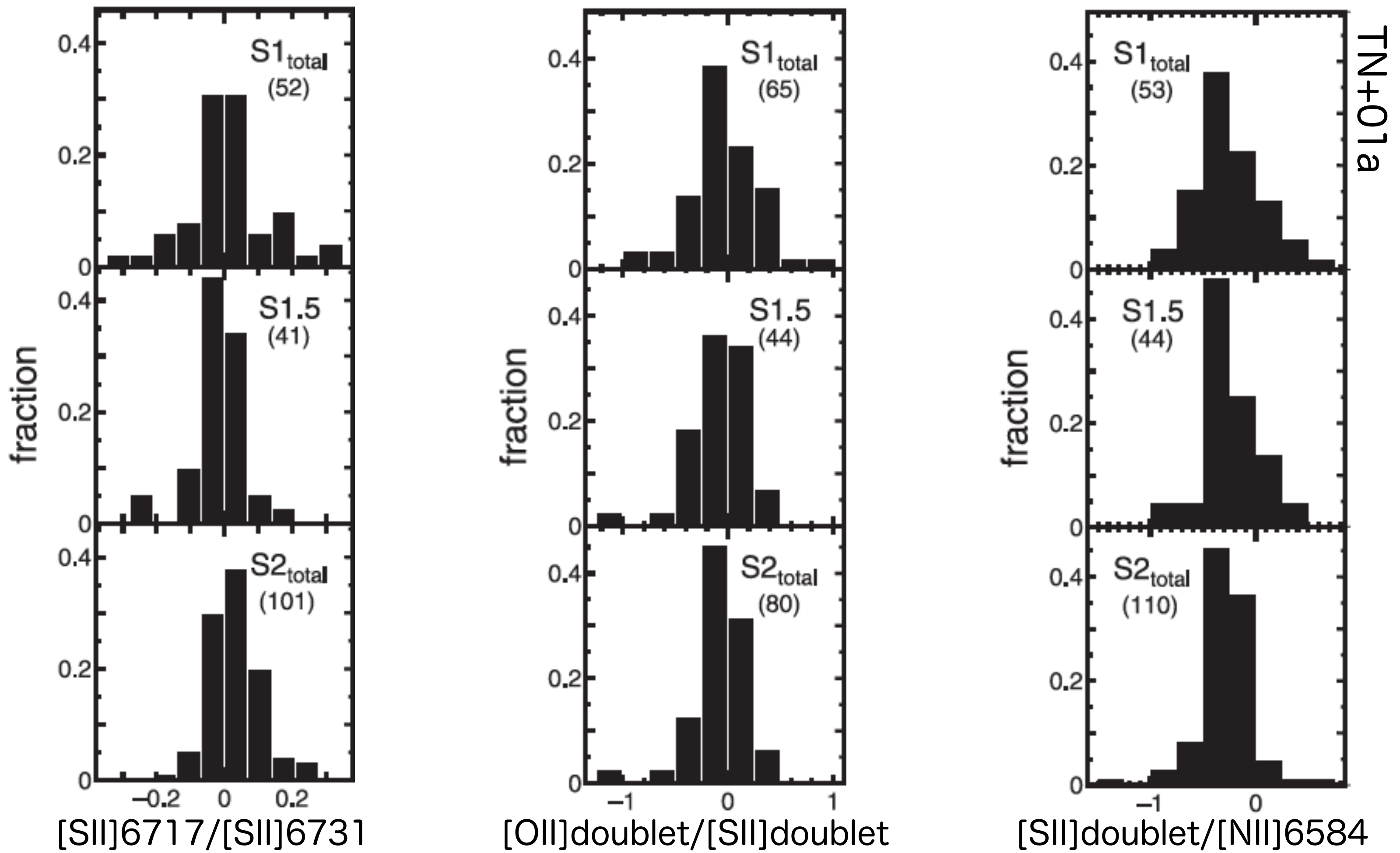
[SII] and [OII] flux ratios are saturated at low- and high-density limits

These indices work at
- ~ $10^{1.5\text{-}4.0}$ cm^{-3} for [SII]
- ~ $10^{1.0\text{-}3.5}$ cm^{-3} for [OII]

We cannot recognize possible dense clouds ($n_H > 10^{5\text{-}6}$ cm^{-3}) with [SII] and [OII] flux ratios, even if they exist in the NLR.

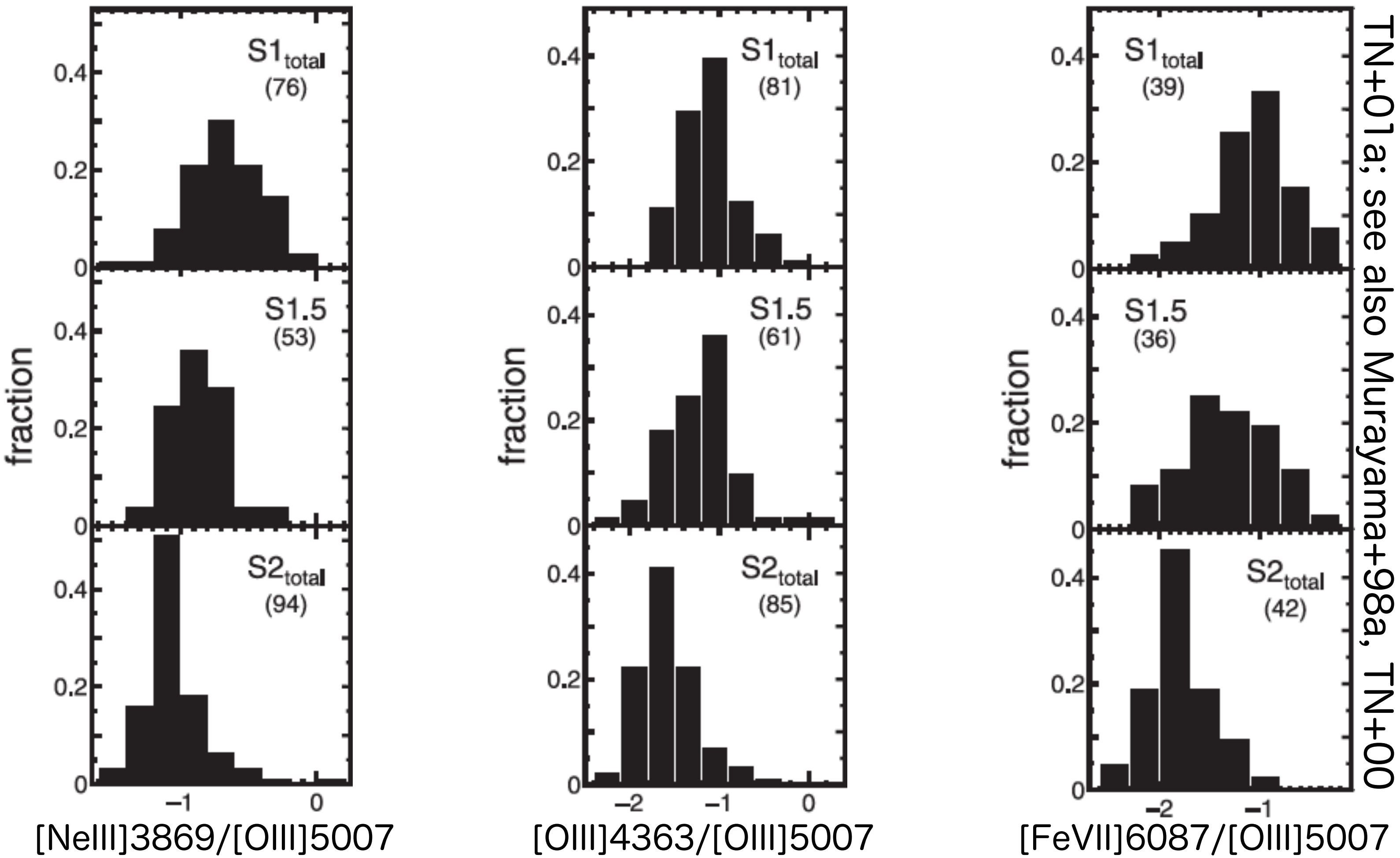
~ due to the saturation at the high-density limit
~ due to the collisional de-excitation effect

Seyfert-type dependence of NLR line flux ratios



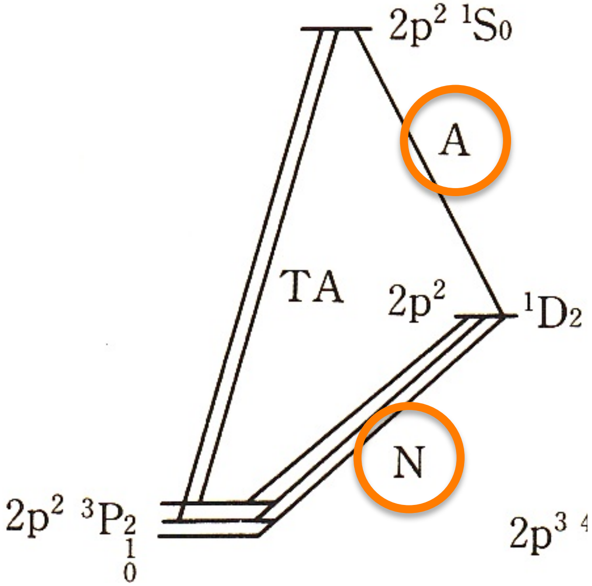
No Seyfert-type dependence in the [SII]6717/[SII]6731 ratio.
No Seyfert-type dependence in other NLR line flux ratios.

Seyfert-type dependence of NLR line flux ratios

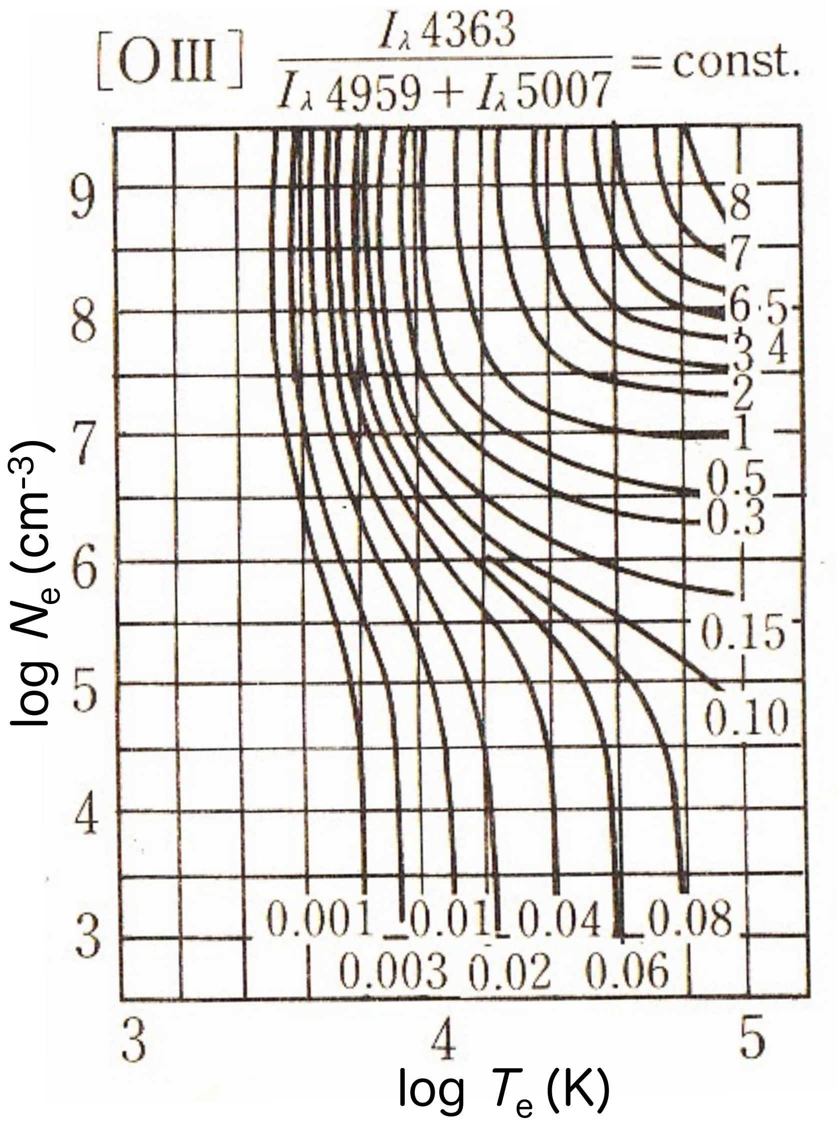


Lines with a high critical density are stronger in Sy1.
Lines with a high ionization potential are stronger in Sy1.

Note: [OIII]4363/[OIII]5007 in AGNs



$$[\mathrm{OIII}]\frac{F_{4959+5007}}{F_{4363}} = \frac{7.90\exp(3.29\times10^{4}/T_e)}{1+4.5\times10^{-4}\cdot n_e/T_e^{1/2}}$$



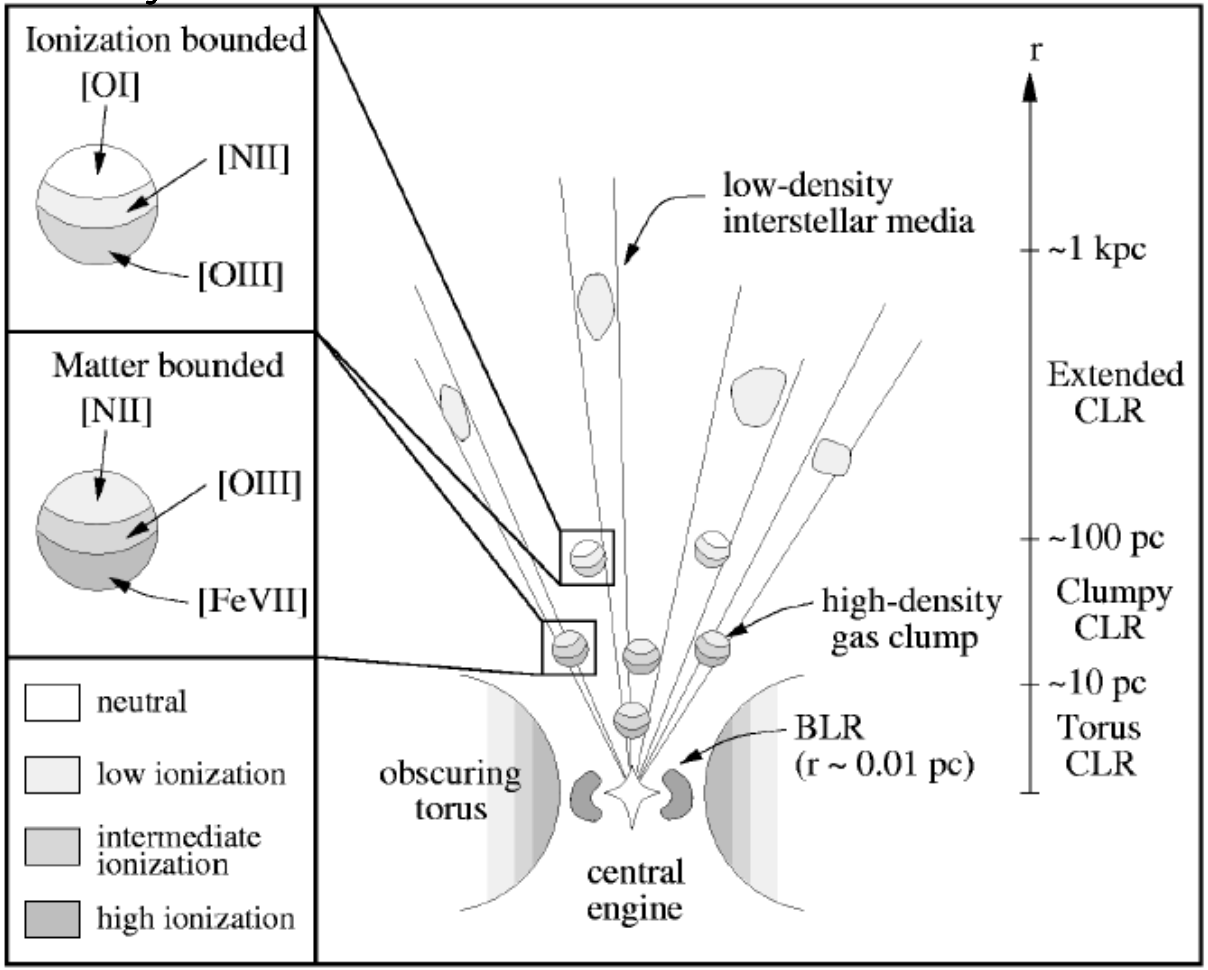
[OIII]4363/5007: A reliable T_e indicator for HII regions and star-forming galaxies, whose gas density is always below 10^5 cm^{-3}.
This may not be true for NLRs.

(also [NII]5755/6584, [SIII]6312/9532, etc.)

from「星間物理学」小暮智一

A two-component NLR model: An idea

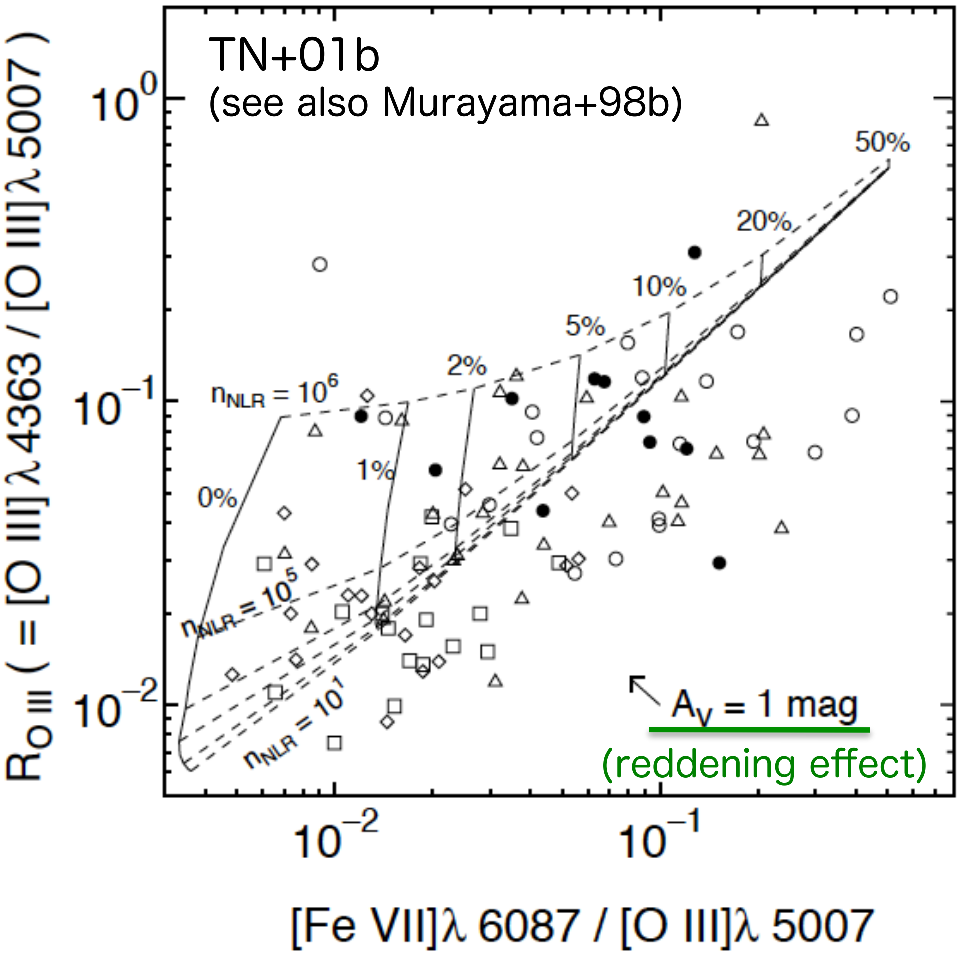
Murayama+98a



The innermost part of the NLR is also obscured by the dusty torus, where the gas clouds are characterized by very high density and high ionization.

What are those clouds? Probably dense gas clump or inner wall of torus.

A two-component NLR model: Cloudy results



A photoionization model

A classical NLR component
- ~ $n_H = 10^{1\text{-}6}$ cm^{-3}
- ~ $U = 10^{-2}$
- ~ ionization-bounded (opt. thick)

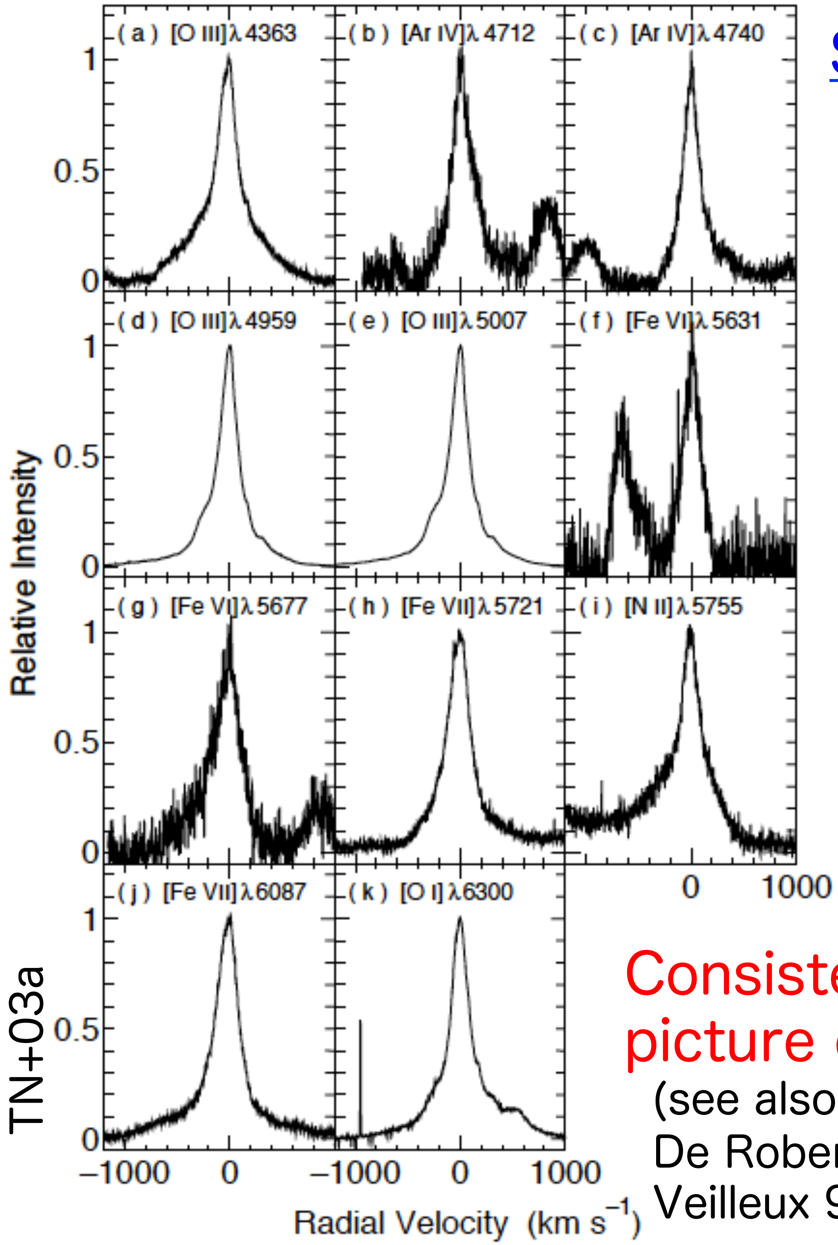
A dense gas component
- ~ $n_H = 10^7$ cm^{-3}
- ~ $U = 10^{-1.5}$
- ~ $N_H \sim 10^{21}$ cm^{-2} (truncated)

$$\left(U = \frac{\int_{13.6\mathrm{eV}}^{+\infty} \frac{L_\nu}{h\nu} d\nu}{4\pi r^2 c n_H} \right)$$

Combining these two components
- ~ Contribution of dense gas to [OIII]5007, from 0% to 50%
- ~ both solar metallicity
- ~ a typical AGN SED adopted

Photoionization model explains well the observed trend.
Nuclear dense gas explains the AGN-type dependence.

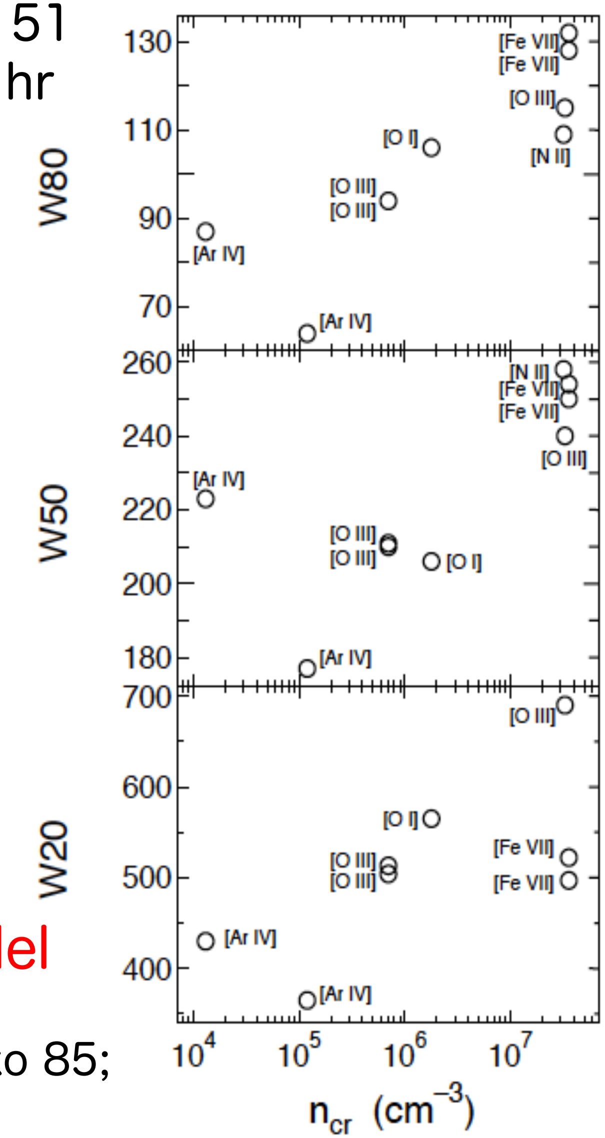
A two-component NLR model: Kinematics



TN+03a

Subaru high-dispersion spectroscopy

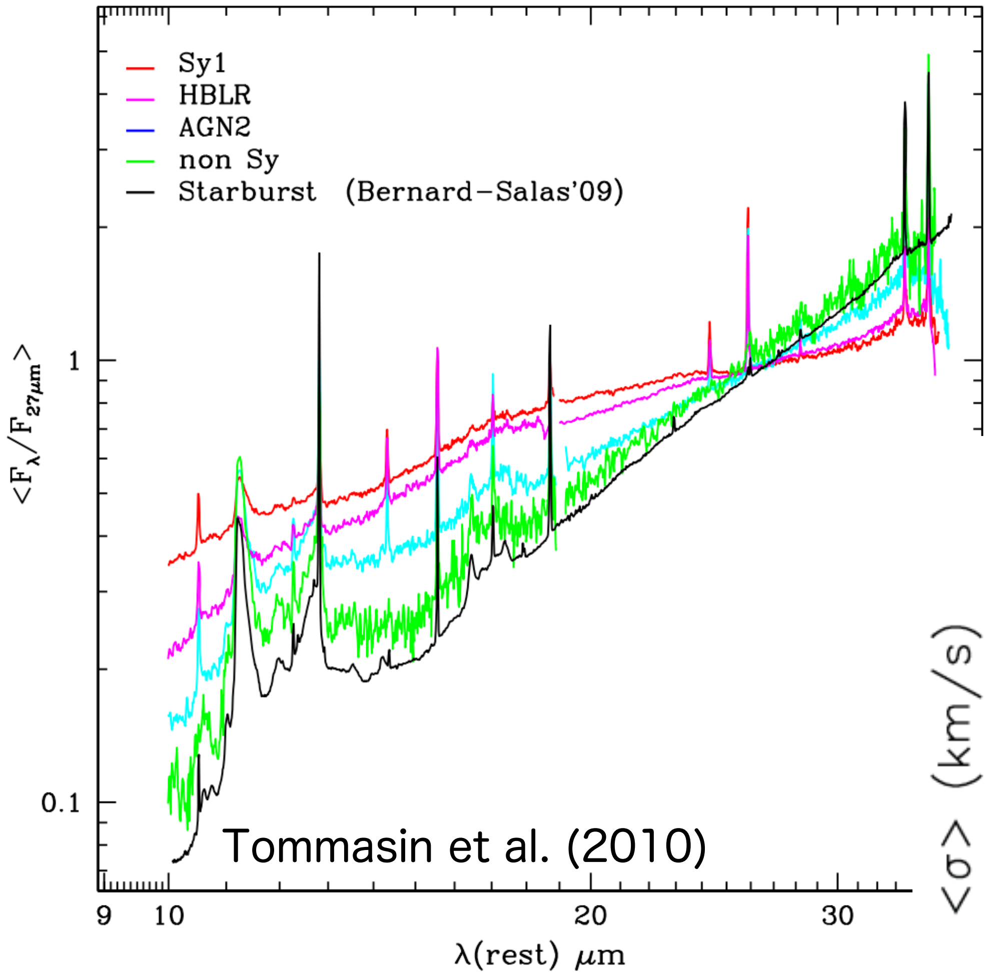
- ~ target: NGC 4151
- ~ 900sec x 4 = 1hr
- ~ R = 45,000
- ~ Δv ~ 7 km s^{-1}



Consistent with the picture of 2 comp. model

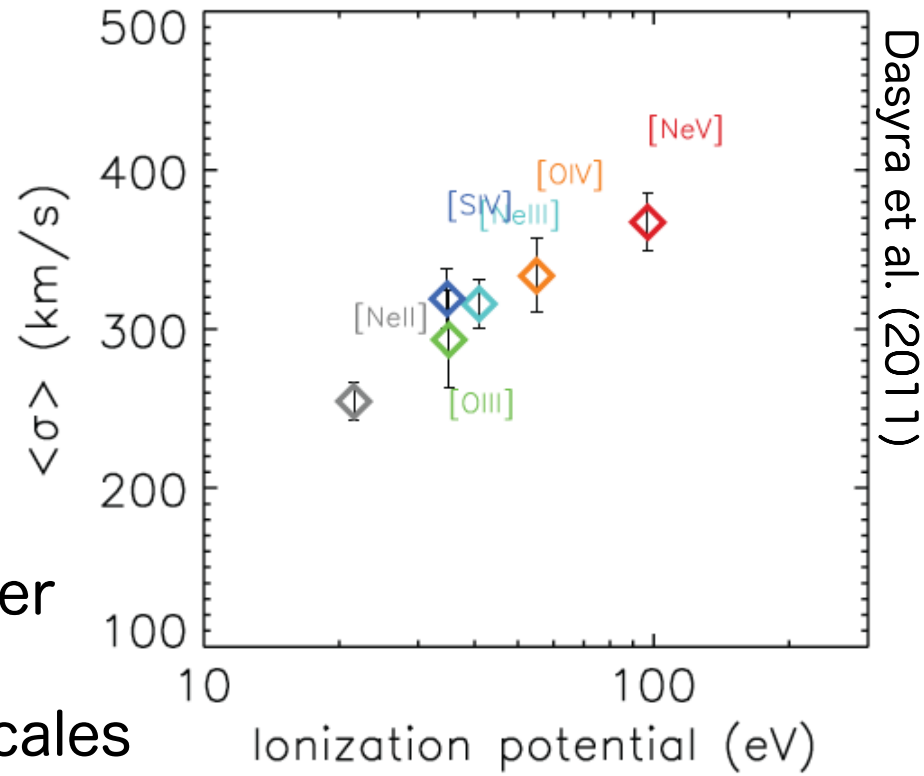
(see also Filippenko+84; De Robertis+84,86; Filippenko 85; Veilleux 91; Alloin+92; etc...)

A two-component NLR model: Kinematics in IR



Spitzer/IRS spectra

- ~ 10-37 micron
- ~ R = 600 (⊿v ~ 500 km/s)
- ~ stacking analysis of various populations of galaxies



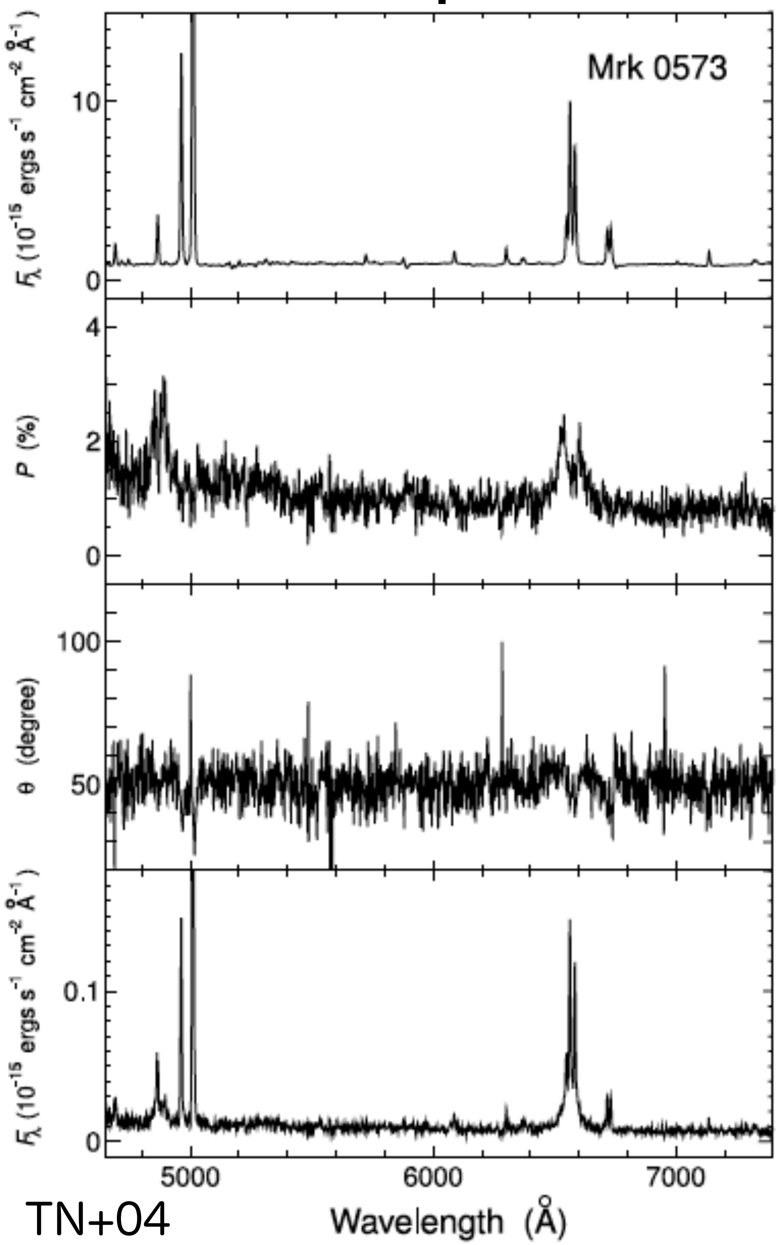
High-ionization lines show larger velocity dispersion

→ more ionization at smaller scales

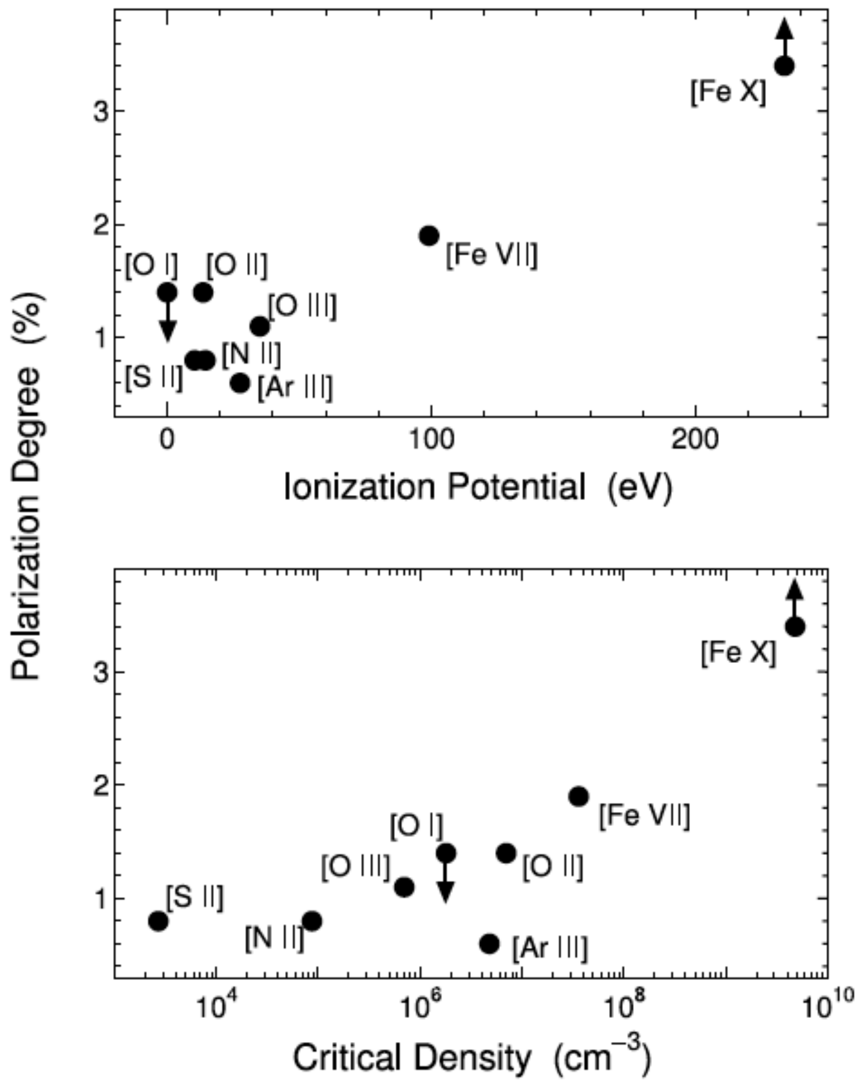
A two-component NLR model: Spectro-pol.

Subaru spectropolarimetry

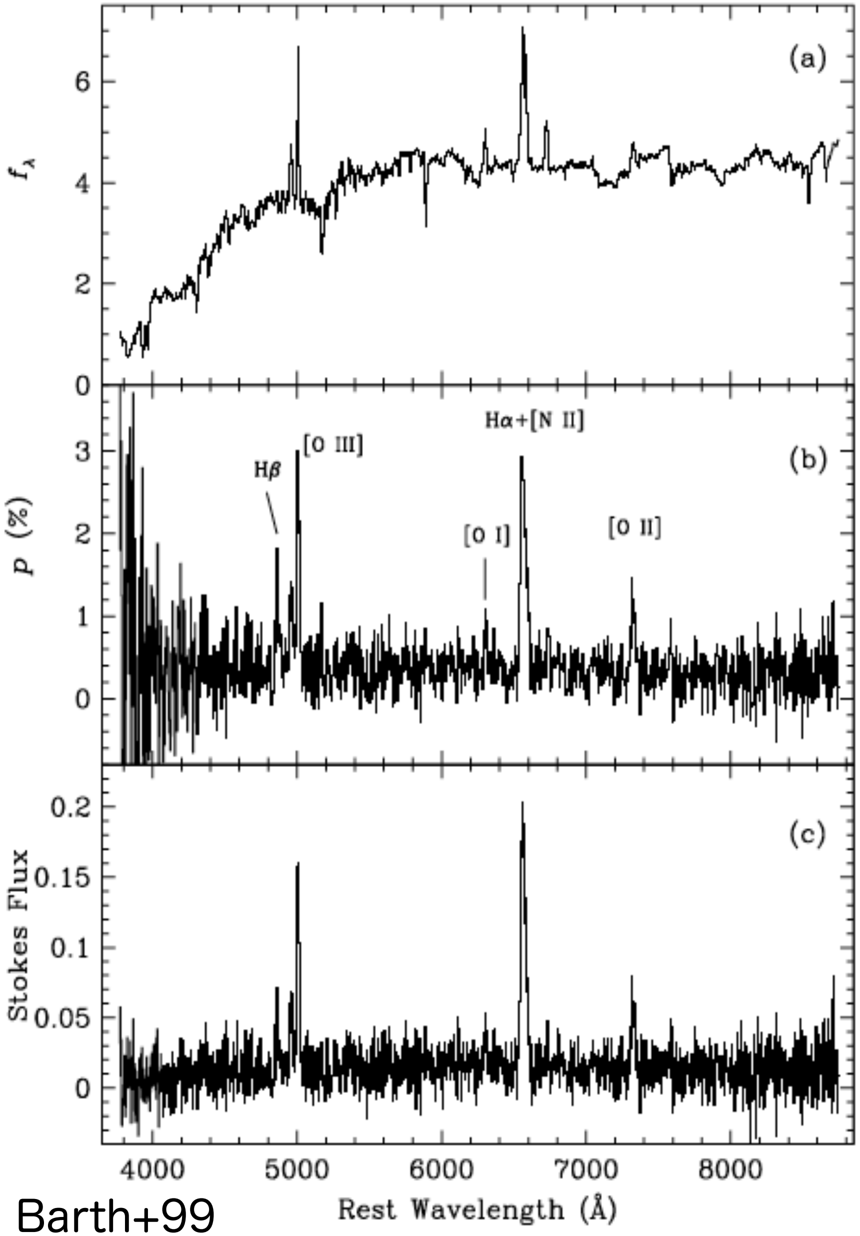
~ Mrk 573, 208 min in total



TN+04



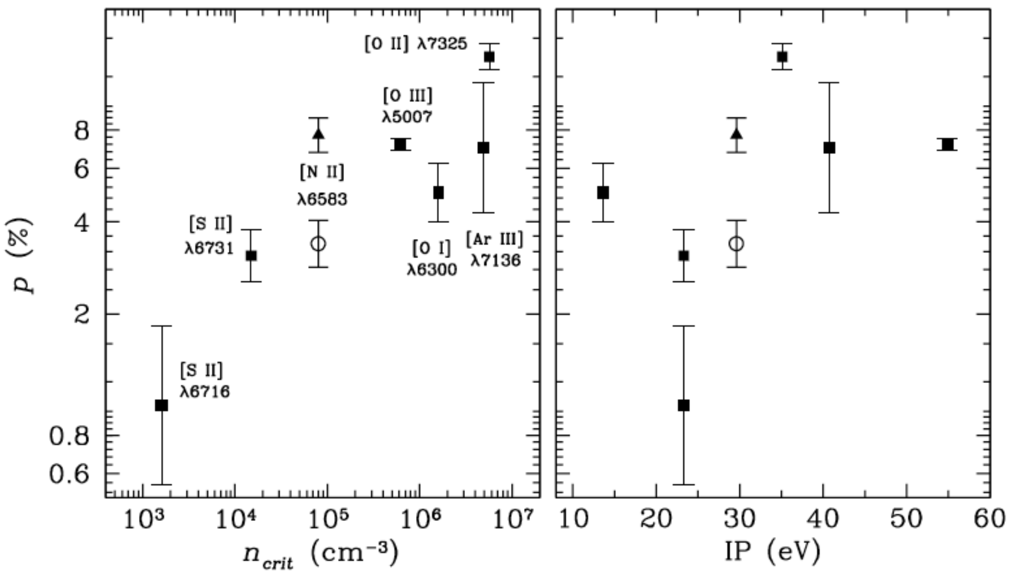
A two-component NLR model: Spectro-pol.

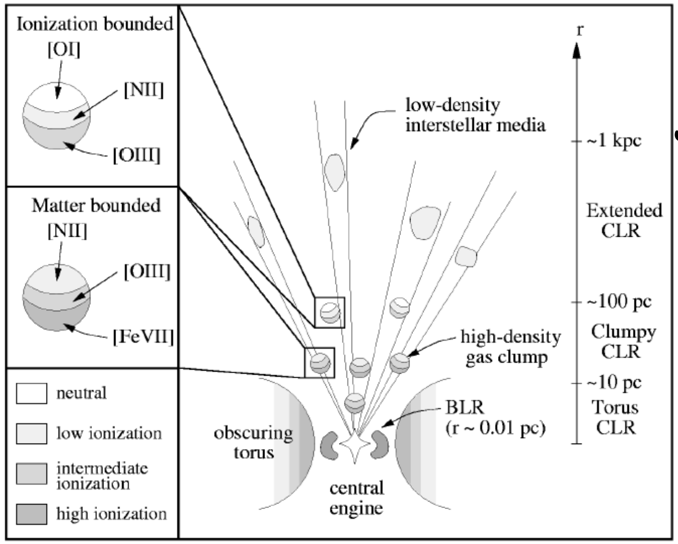


Barth+99

Keck spectropolarimetry

~ NGC 4258



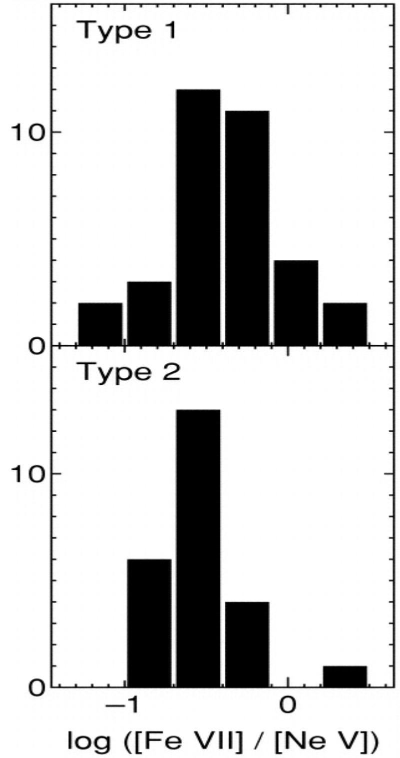


Murayama+98a

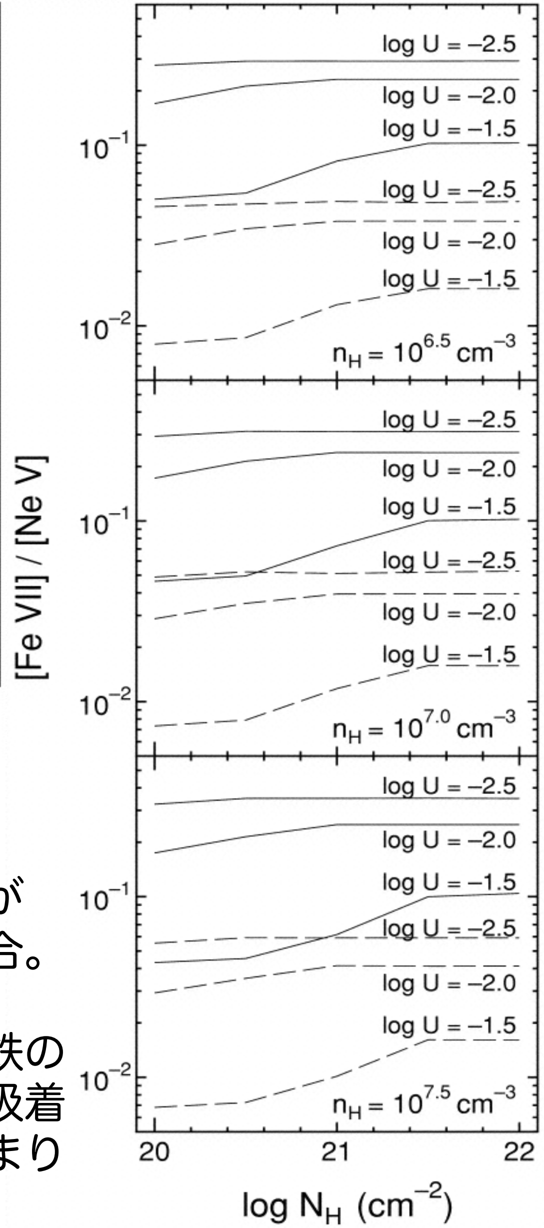
A two-component NLR model: Dust grains?

TN+03b

物理状態に寄らず化学組成比に敏感な輝線の組合せとしては、[Ne V]3426 と [Fe VII]6087 の組合せがある。
これらはいずれも電離度が高く、NLR の中で最も中心核に近い領域から放射される。
この輝線強度比の観測値と光電離モデル計算を見比べると、高電離輝線を放射する領域にはダストが存在しないことが示唆される。
これは、NLR 中の高電離輝線放射領域がトーラス内壁あたりに相当するという二成分モデルと合致。



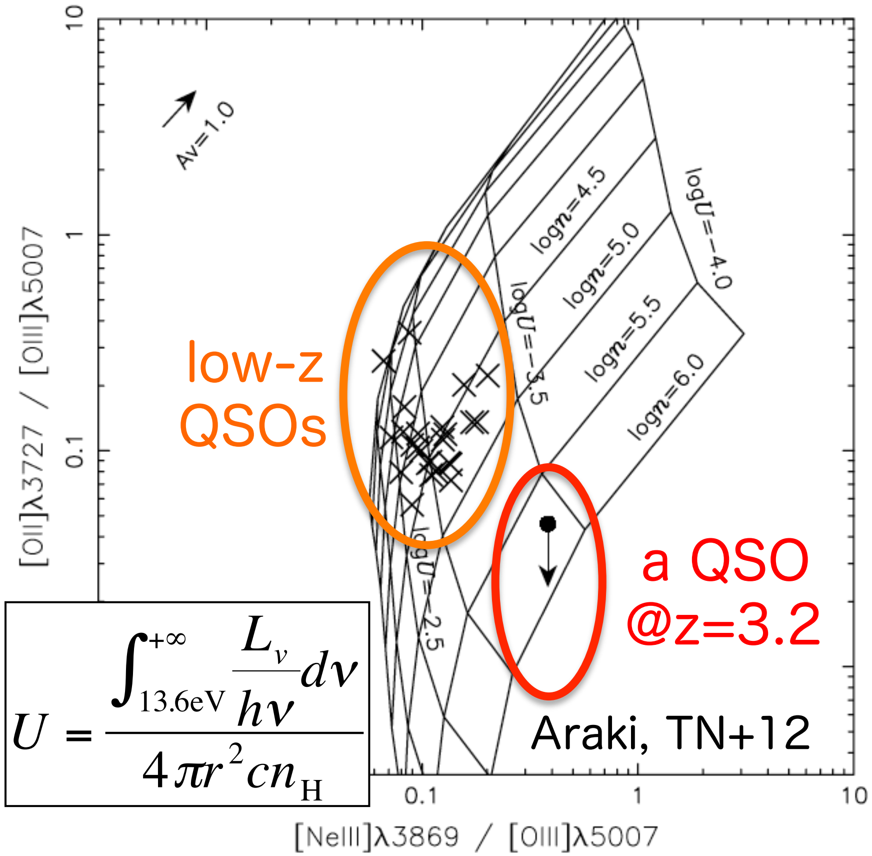
[右図のモデル]
実線：
ダストがなく、鉄が気相に存在する場合。
破線：
ダストが存在し、鉄の大部分がダストに吸着して、気相にはあまり存在しない場合。



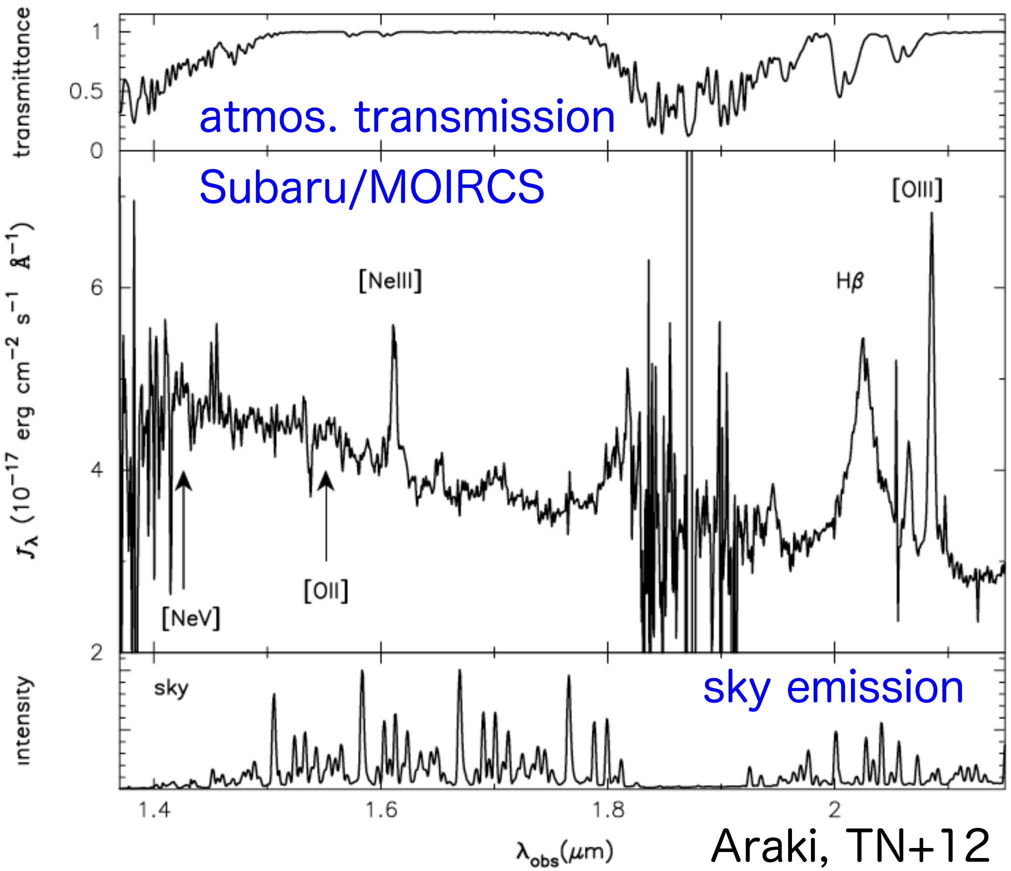
At high redshift

A “strange” rest-opt spectrum is obtained through near-infrared spectroscopy serendipitously (SDSS J1707+6443 @ z=3.2)

Very strong [NeIII] but no [OII]...



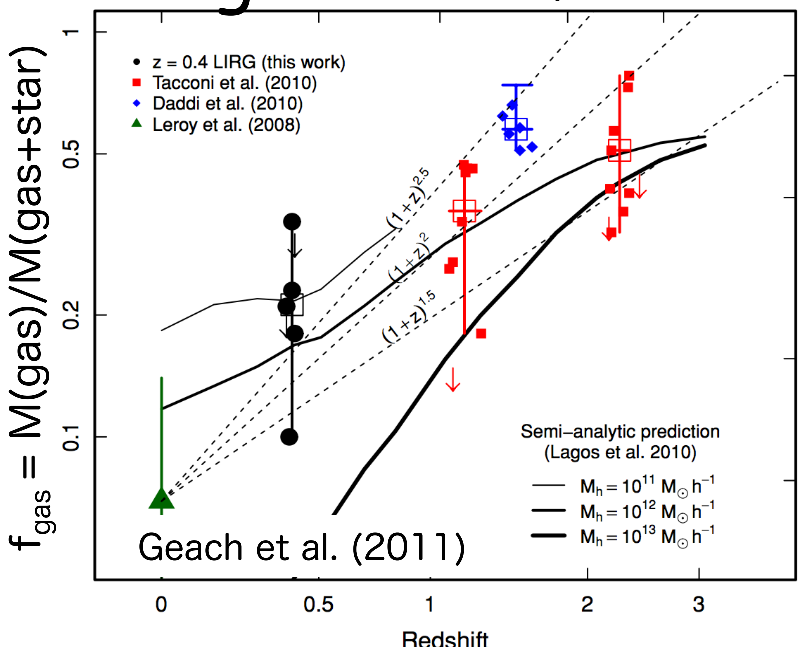
$$U = \frac{\int_{13.6\mathrm{eV}}^{+\infty} \frac{L_\nu}{h\nu} d\nu}{4\pi r^2 c n_{\mathrm{H}}}$$



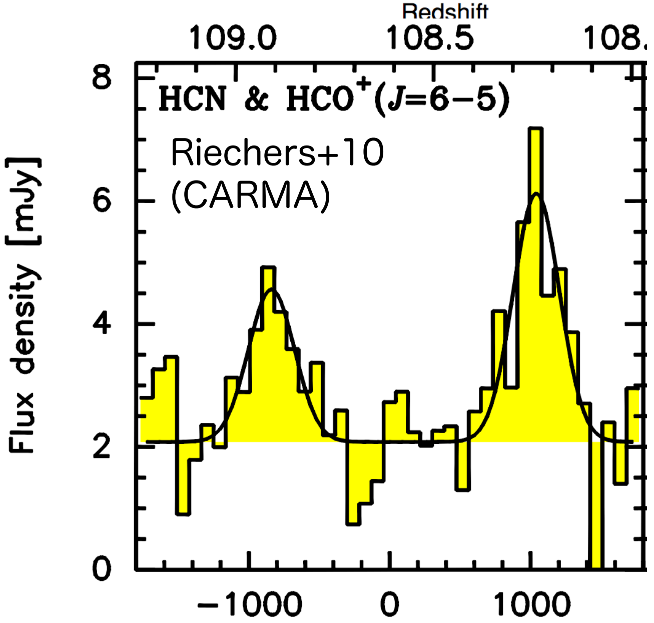
Araki, TN+12
Nitta, TN, in prep.

Photoionization model says that the NLR in this QSO is characterized by a very high density (>10^5 cm^{-3}), but probably distributed in the host. But this is out of the scope of this meeting...

At high redshift



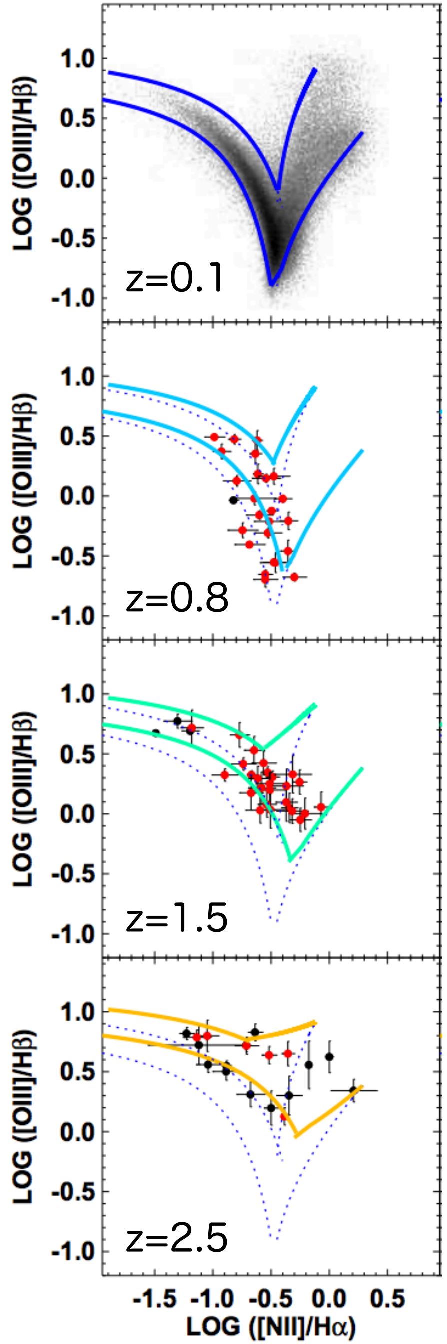
(Upper Left)
Higher gas fraction at higher redshift, measured through CO



(Right)
BPT diagram at various redshifts; higher-z data may be (?) consistent with models with higher gas density and harder ionizing SED

(Lower Left)
HCN & HCO+ molecular lines detected in a lensed quasar APM 0879+255 at =3.91, suggesting the presence of abundant dense gas clouds in the host galaxy (??)

Kewley et al. (2013)



Expectations to ALMA

- Both Sy1 and Sy2 are expected to have dense clouds at the circum-nuclear region
  - ~ should be tested with ALMA (no extinction!!)
  - ~ comparison of the frequency distribution of dense-gas tracers between Sy1s and Sy2s
  - ~ is the nuclear dense gas seen in "all" Seyferts?
  - ~ but... NGC 1097 (?) Has LLAGN a different picture?
- How dense?
  - ~ multi-lines + LVG analysis
- How compact is their spatial distribution?
  - ~ now ALMA achieve higher resolution than optical
  - ~ <10pc expected from optical high-ionization lines but should be tested
- *And... at higher redshifts?*