A new tool to derive chemical abundances in Type-2 Active Galactic Nuclei

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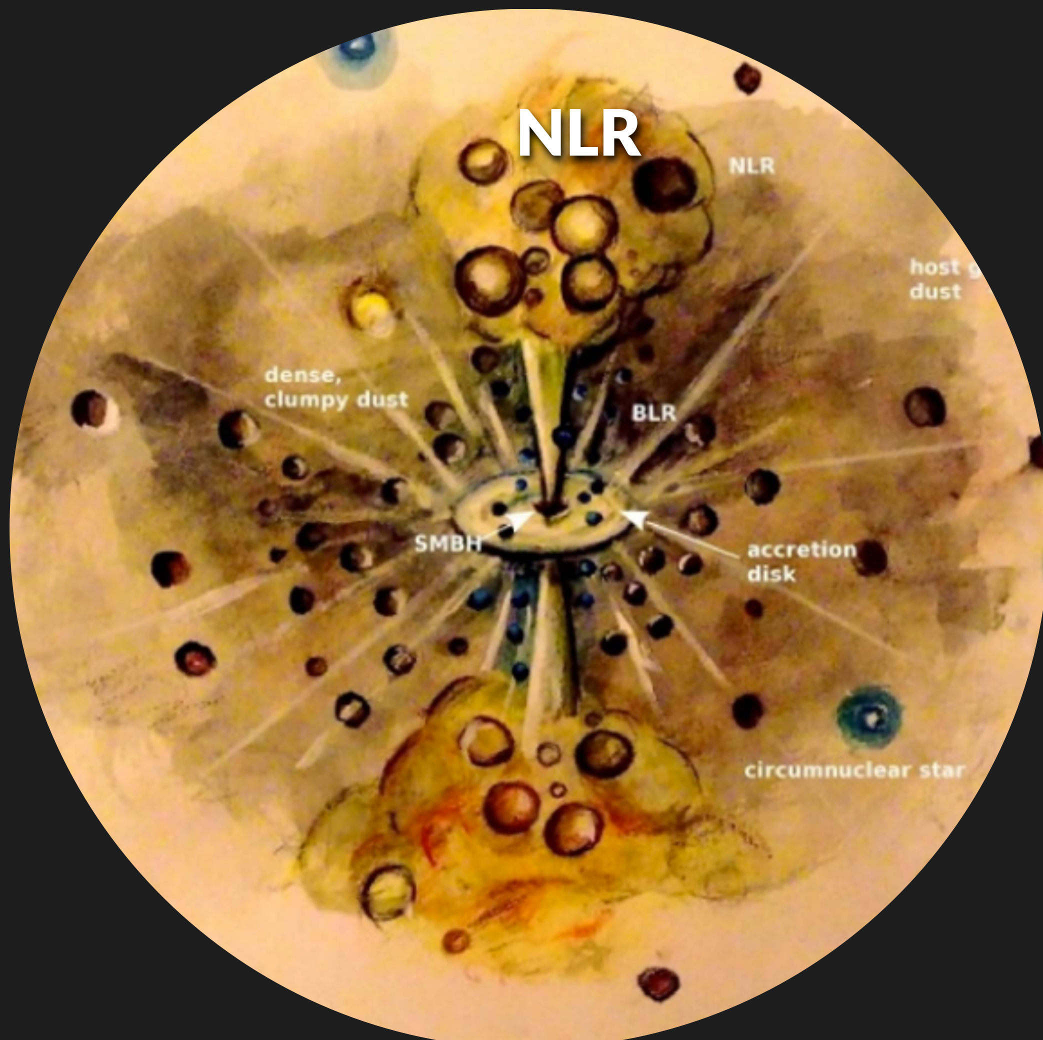
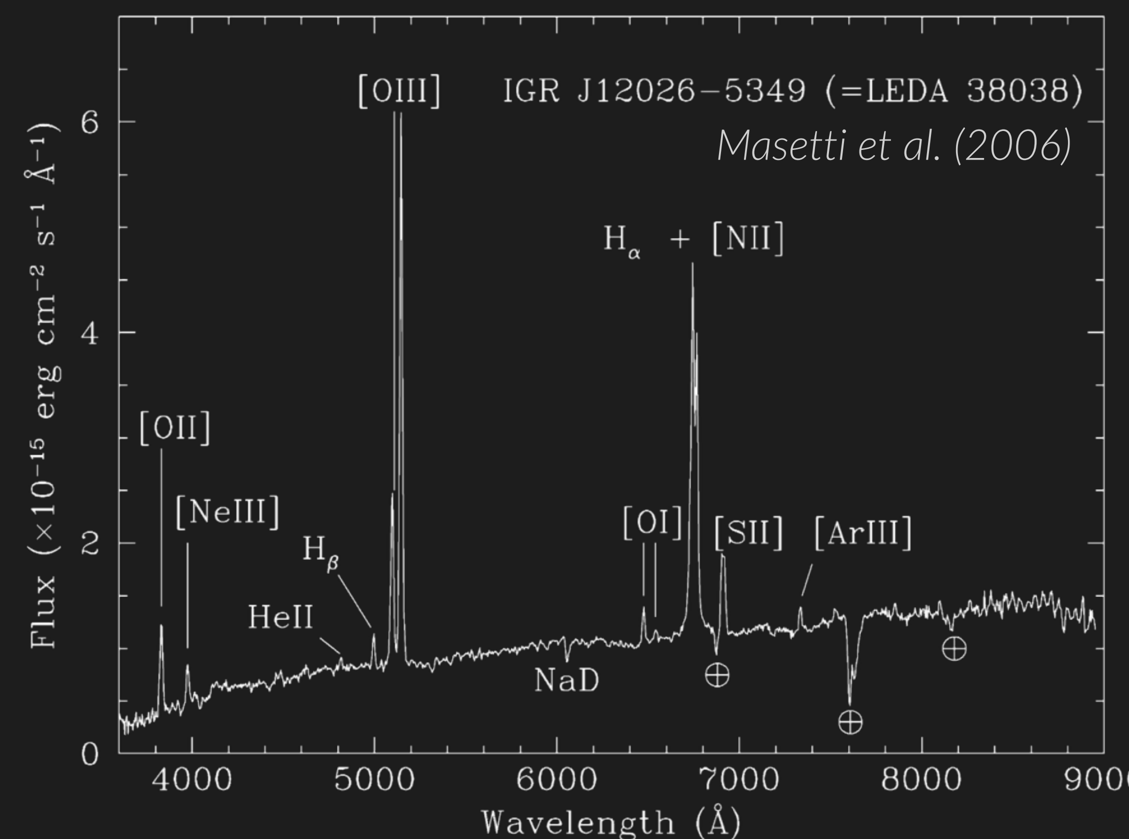
EXCELENCIA SEVERO OCHOA

NARROW LINE REGION (NLR) IN AGNS

- Up to ↑ redshifts
- Bright emission-lines
- Chemical abundances (O/H)
- Physical conditions of the gas



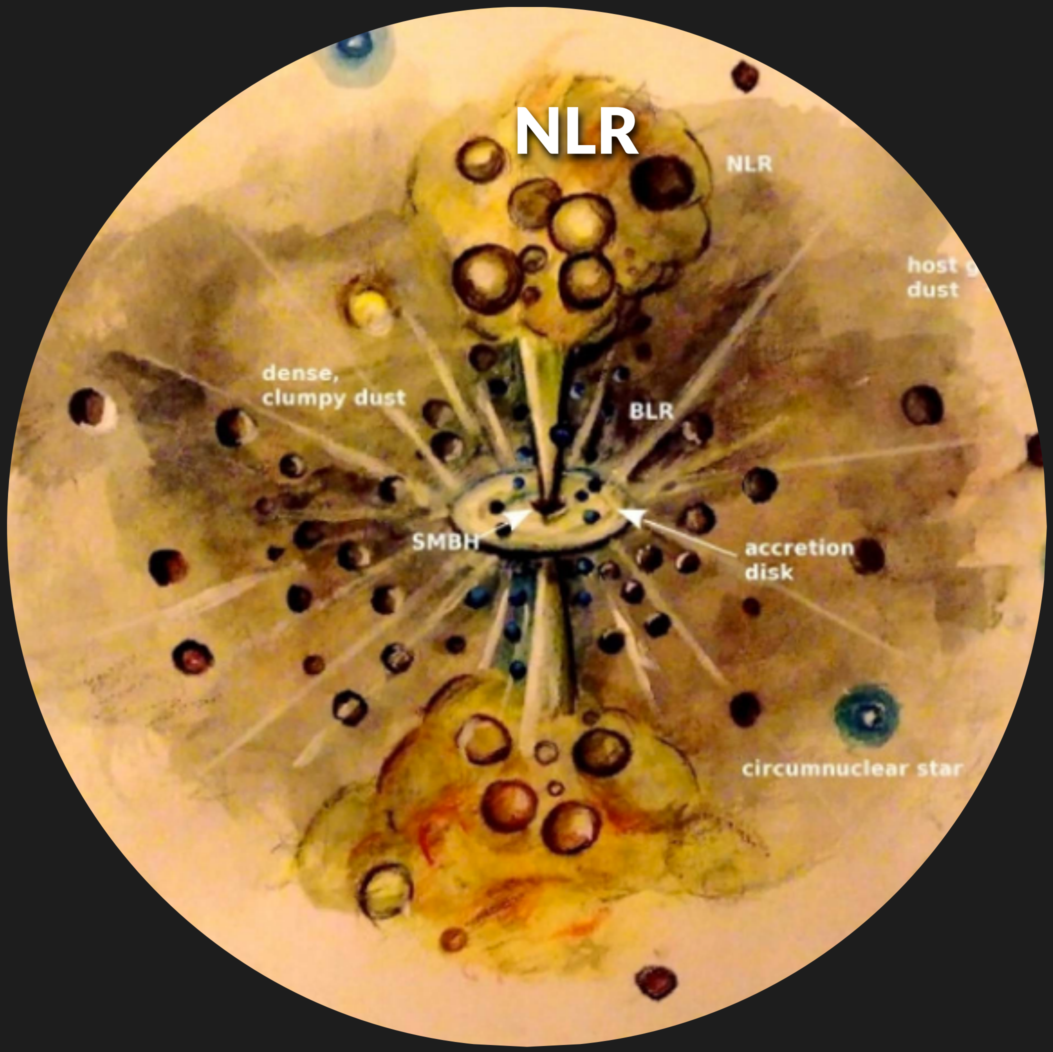
Villarroel et al. (2017)



Narrow Line Region (NLR) → Photoionization

Ferland & Netzer (1983); Halpern & Steiner (1983)

NLR & ABUNDANCES IN TYPE-2 AGNS



Villarroel et al. (2017)

T_e method

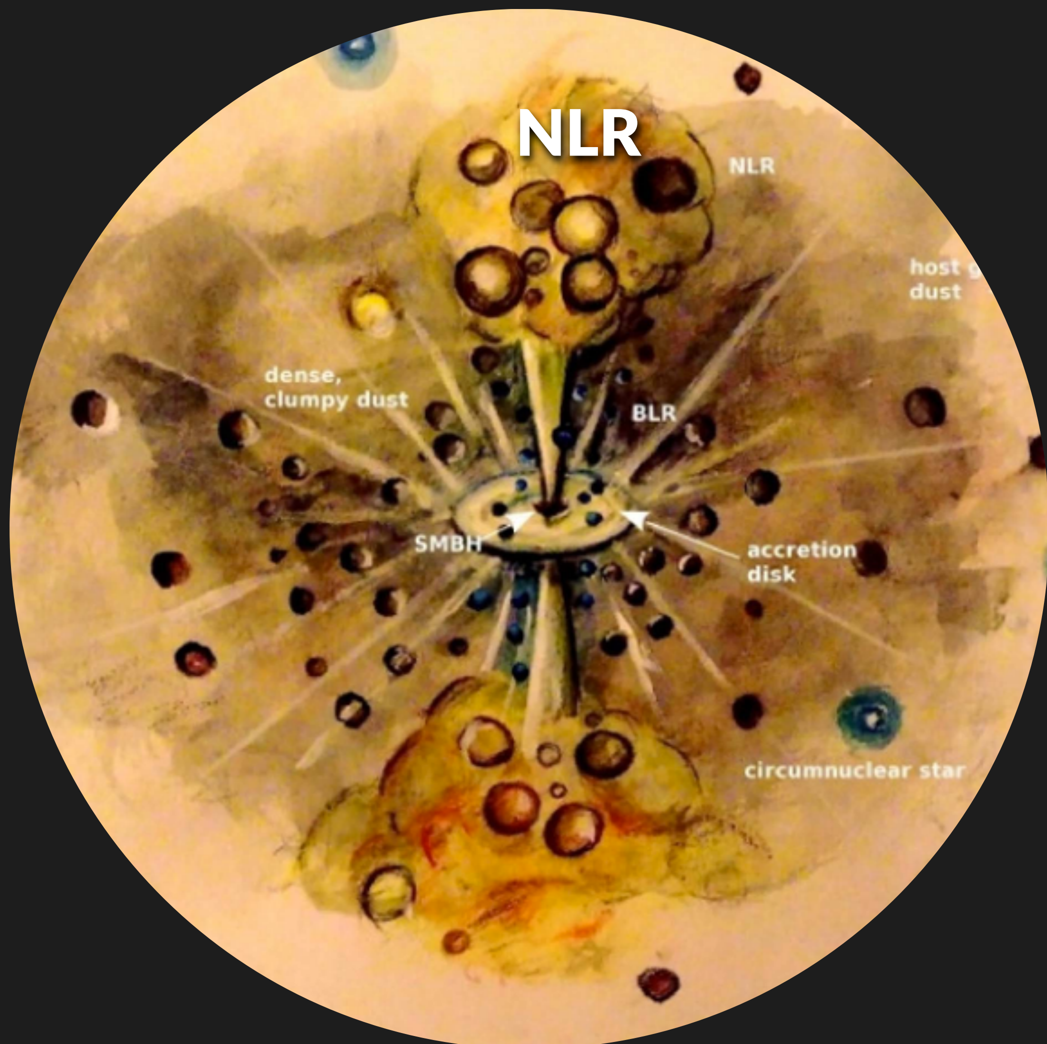
1 Total abundances « photoionization models

IN AGNS

2 Hydrodynamical effects can affect:

- O/H
- [NII] *(Pérez-Montero & Contini 2009)*

CHEMICAL ABUNDANCES CODE FOR TYPE-2 AGNS



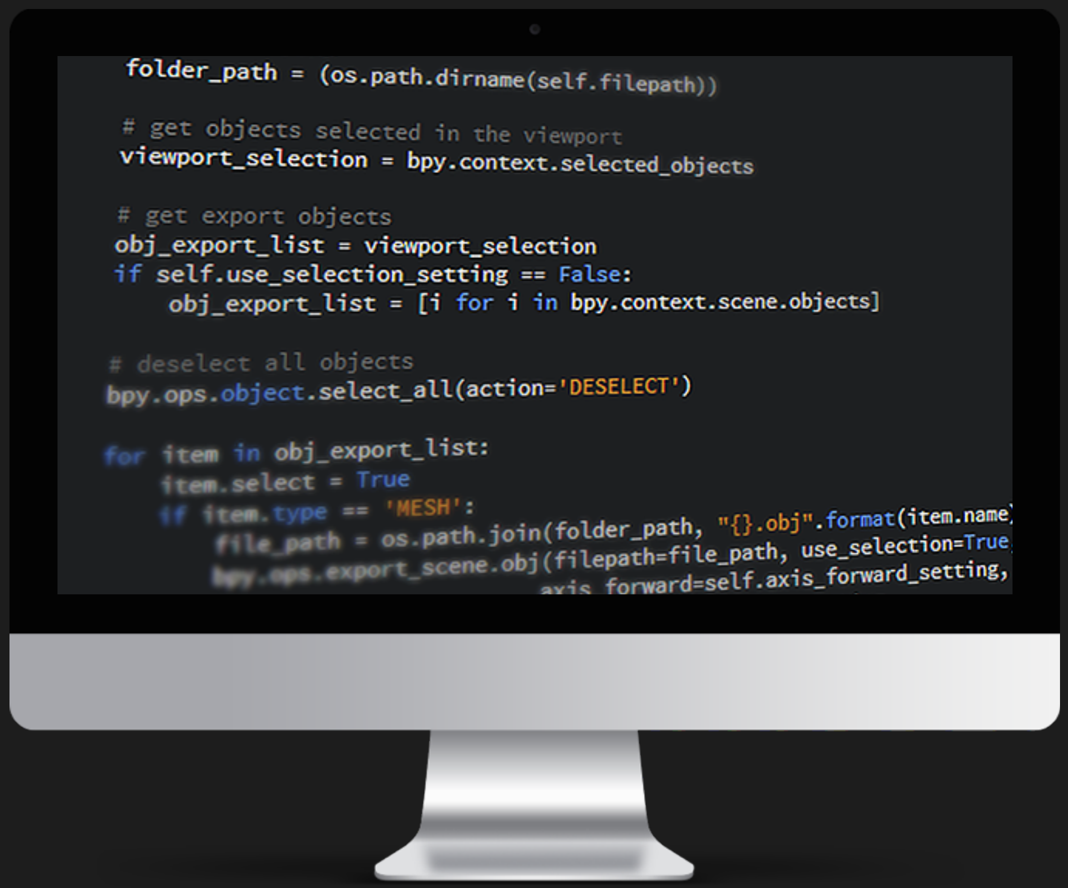
Villarroel et al. (2017)

Advantages

1. Automatic → Large number of objects
2. Consistent → Same procedures
3. Uncertainties
4. Independent estimation of N/O ratio
5. Consistent with T_e method

HII-CHI-MISTRY CODE FOR AGNS *Pérez-Montero et al. (2019)*

https://www.iaa.csic.es/~epm/HII-CHI-mistry.html



HCM

Charateristics and input data

1. Python *(Pérez-Montero 2014)*
2. Photoionization models (Cloudy)
3. Reddening-corrected
   - [OII] λ3727 Å
   - [Ne III] λ3868 Å
   - [O III] λ4363 Å
   - [O III] λ5007 Å
   - [N II] λ6583 Å
   - [SII] λλ6717+6731 Å
4. Uncertainties

GRID OF MODELS

- ✓ Filling factor: 0.1
- ✓ Density: 500 cm^{-3} *(Dors et al. 2014)* [2000 cm^{-3}]
- ✓ SED:
  - Big Blue Bump @ 1 Ryd
  - Power laws:
    - Non thermal X-rays → $\alpha_x = -1$
    - Continuum 2 keV - 2500 Å → $\alpha_{ox} = -0.8$ [-1.2]
- ✓ Chemical abundances scaled to oxygen with ⊙ proportions (except N)

Cloudy v.17.01

(Ferland et al. 2017)

GRID OF MODELS

Cloudy v.17.01 *(Ferland et al. 2017)*

Usual conditions NLRs

# models	5865	
12 + log(O/H)	6.9 ⇔ 9.1	0.1 dex
N/O	-2.0 ⇔ 0.0	0.125 dex
log U	-4.0 ⇔ -0.5	0.25 dex

AGN-HCM WORKFLOW

N/O → O/H, U

$$\log(\mathrm{N/O})_f = \frac{\sum_i \log(\mathrm{N/O})_i / \chi_i^2}{\sum_i 1/\chi_i^2}$$

$$\chi_i = \sum_j \frac{(O_j - T_{ji})^2}{O_j}$$

Observed vs models

$$\mathrm{N2O2} = \log\left(\frac{[\mathrm{N\,II}]\lambda 6583}{[\mathrm{O\,II}]\lambda 3727}\right)$$

OR

$$\mathrm{N2S2} = \log\left(\frac{[\mathrm{N\,II}]\lambda 6583}{[\mathrm{S\,II}]\lambda\lambda 6717 + 6731}\right)$$

No dependence on excitation

AGN-HCM WORKFLOW

N/O → O/H, U

$$12 + \log(\mathrm{O/H})_f = \frac{\sum_i (12 + \log(\mathrm{O/H}))_i / \chi_i^2}{\sum_i 1/\chi_i^2}$$

$$\log(U)_f = \frac{\sum_i \log(U)_i / \chi_i^2}{\sum_i 1/\chi_i^2}$$

$$\chi_i = \sum_j \frac{(O_j - T_{ji})^2}{O_j}$$

Constrained by N/O

Observed vs models

$$\mathrm{N2} = \log\left(\frac{[\mathrm{N\,II}]\lambda 6583}{H\alpha}\right)$$

$$\mathrm{R23} = \frac{[\mathrm{O\,II}]\lambda 3727 + [\mathrm{O\,III}]\lambda\lambda 4959 + 5007}{H\beta}$$

OR/AND

$$\mathrm{RO3} = \frac{[\mathrm{O\,III}]\lambda 5007}{[\mathrm{O\,III}]\lambda 4363}$$

OR

$$\mathrm{O2Ne3} = \frac{[\mathrm{O\,II}]\lambda 3727 + [\mathrm{Ne\,III}]\lambda 3868}{H\beta}$$

AGN CONTROL SAMPLE *(Dors et al. 2017)*

1 Seyfert 1.9 & 2 galaxies z ≲ 0.1

2 44 Cloudy **tailored** photoionization models from *Dors et al. (2017)* ➜ **D17**

3 Reddening corrected emission-line fluxes:

- [OII] λ3727 Å
- [Ne III] λ3868 Å
- [O III] λ4363 Å
- [OIII] λ5007 Å
- [N II] λ6583 Å
- [SII] λλ6717+6731 Å

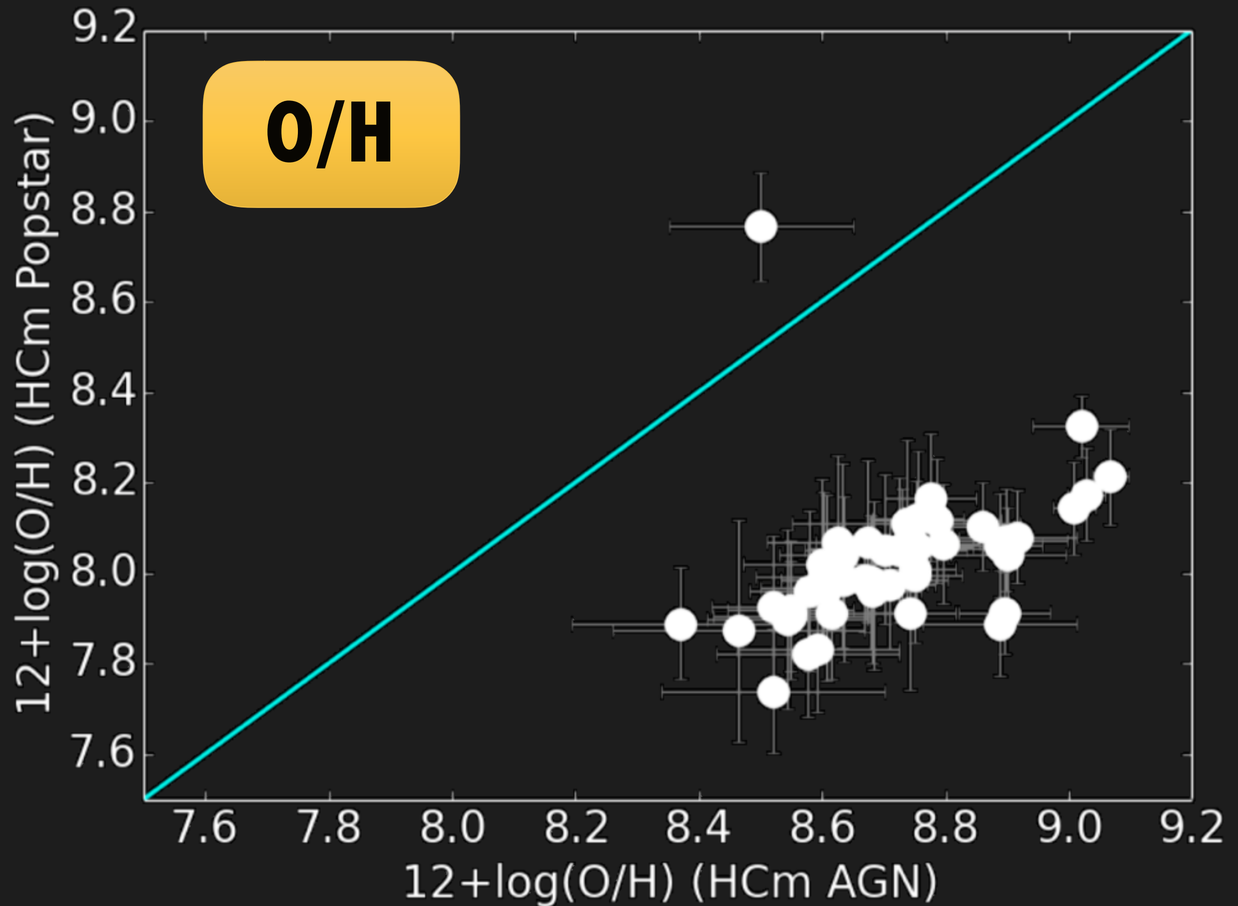
4

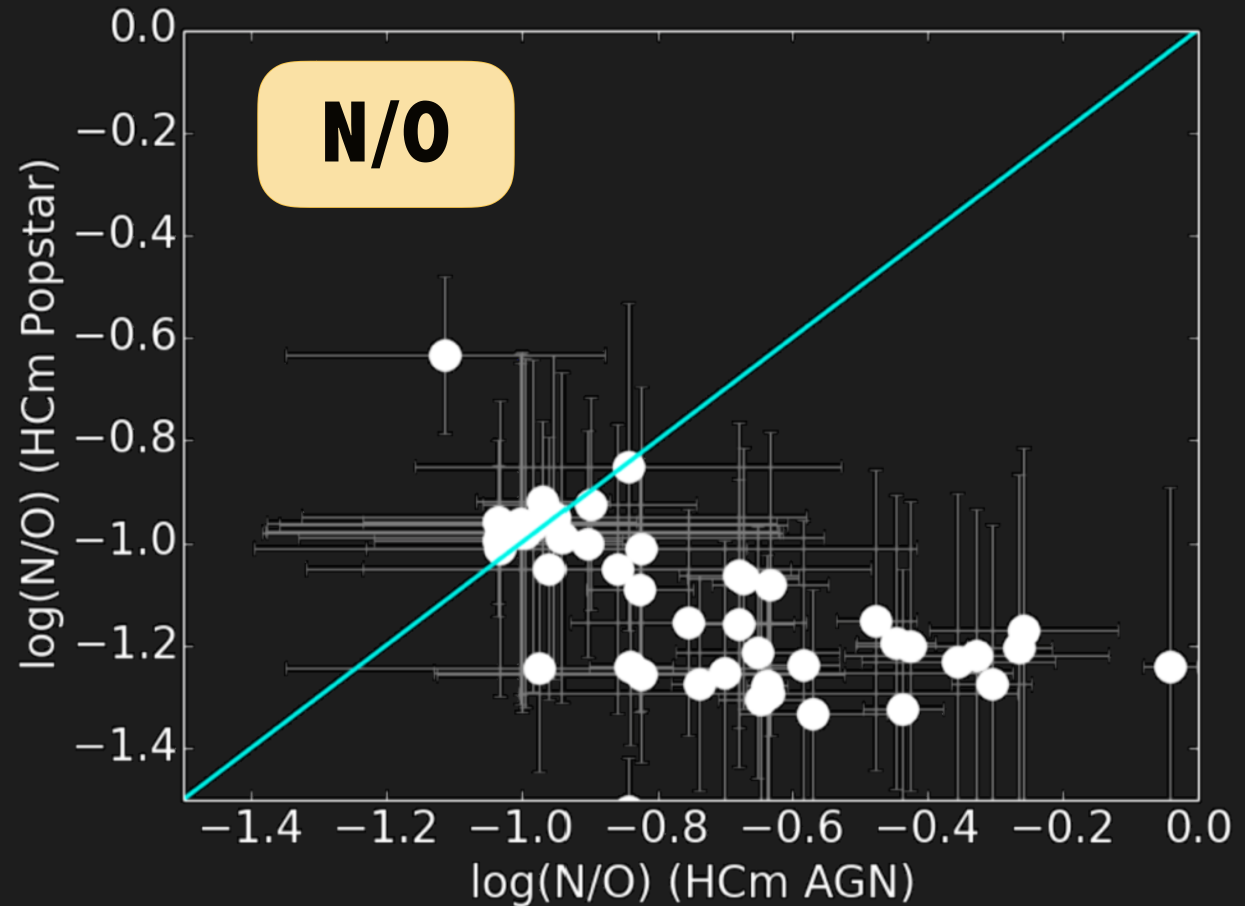
$[O/H]_\odot$	0.4 ⇔ 2
$[N/O]_\odot$	0.3 ⇔ 7.5

No errors in abundances

TESTING THE SED

0.7 dex ⬇ O/H for non-AGN SED



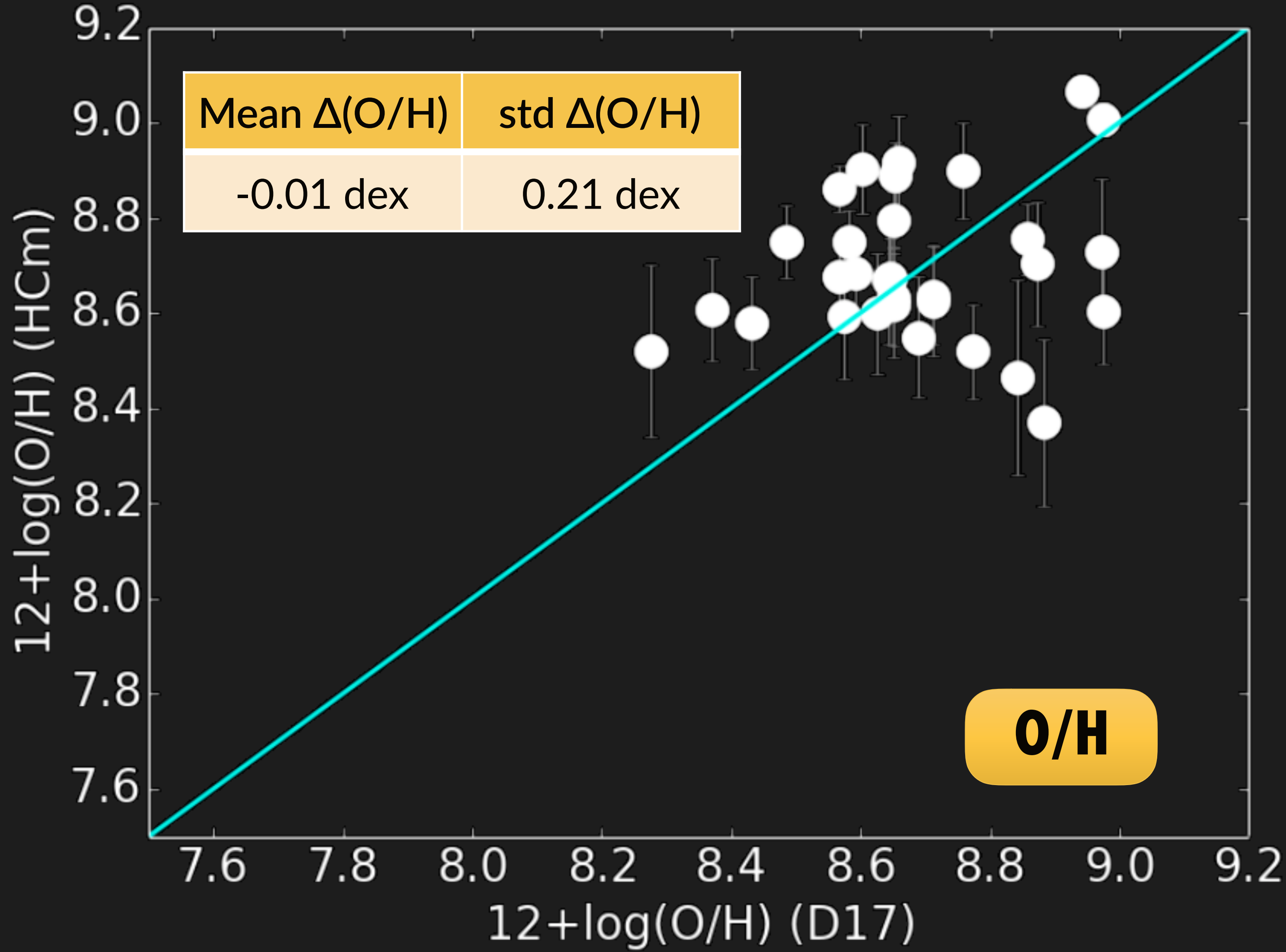


x-axis: AGN SED (power law)
y-axis: HII region SED

both HCM outputs

HCM: ALL LINES

[OII]	λ3727 Å
$[O\ III]_a$	λ4363 Å
$[O\ III]_n$	λ5007 Å
[N II]	λ6583 Å
[SII]	λλ6717+6731 Å

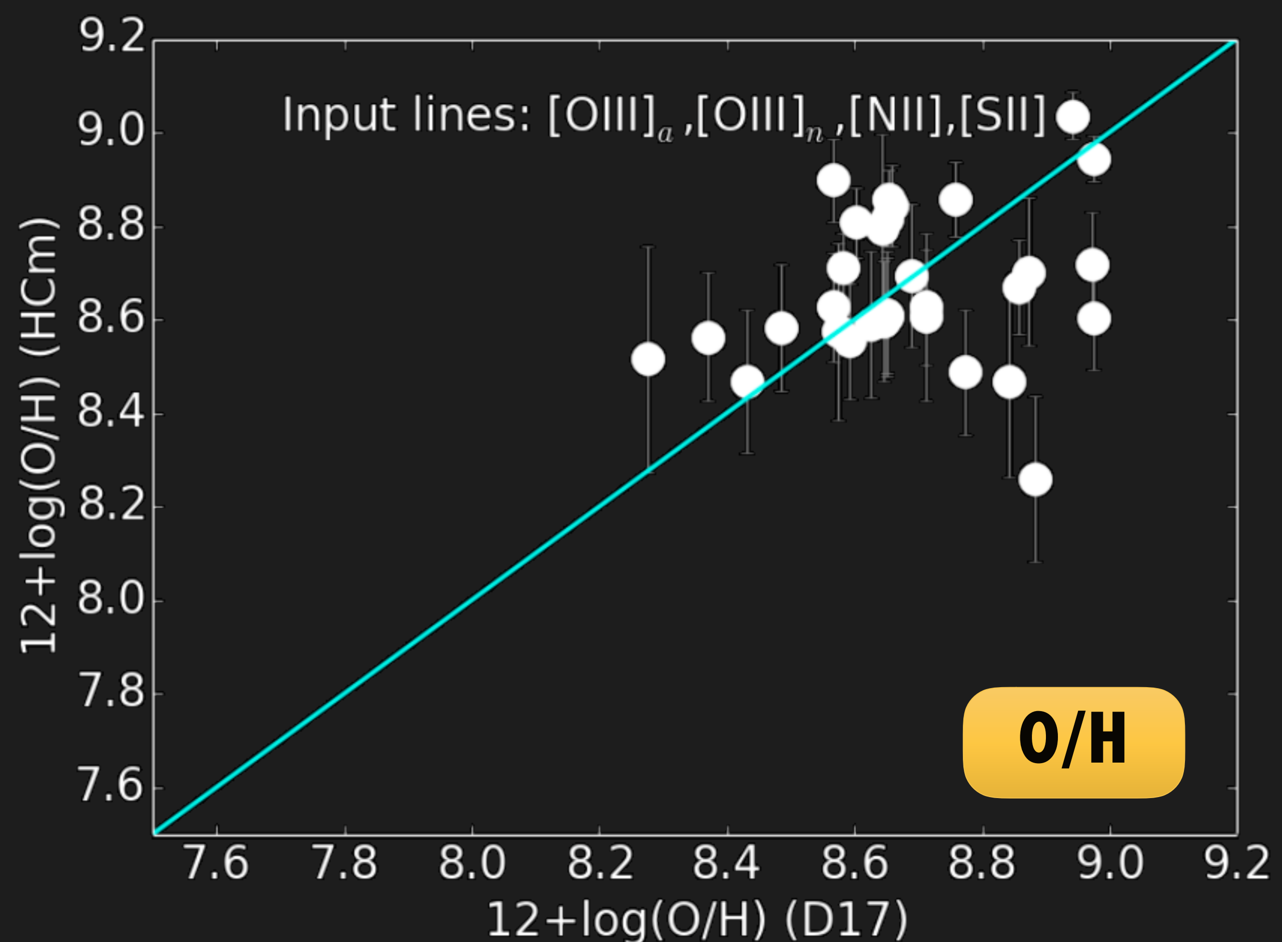


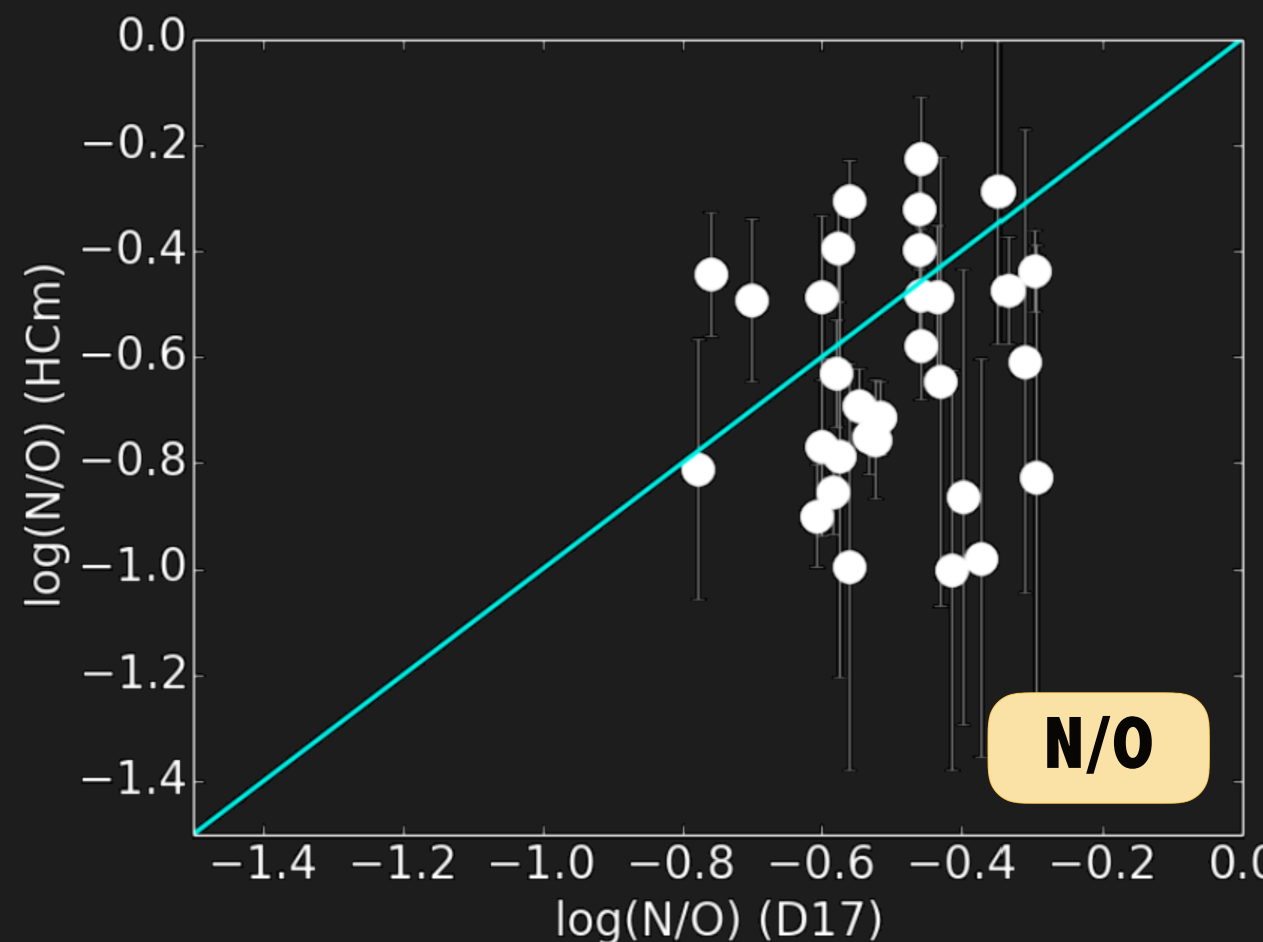
Mean Δ(O/H)	std Δ(O/H)
-0.01 dex	0.21 dex

x-axis: D17 → No errors!
y-axis: HCM

HCM: USING A FEW LINES (1)

~~[OII] λ3727 Å~~
[O III]$_a$ λ4363 Å
[O III]$_n$ λ5007 Å
[N II] λ6583 Å
[SII] λλ6717+6731 Å



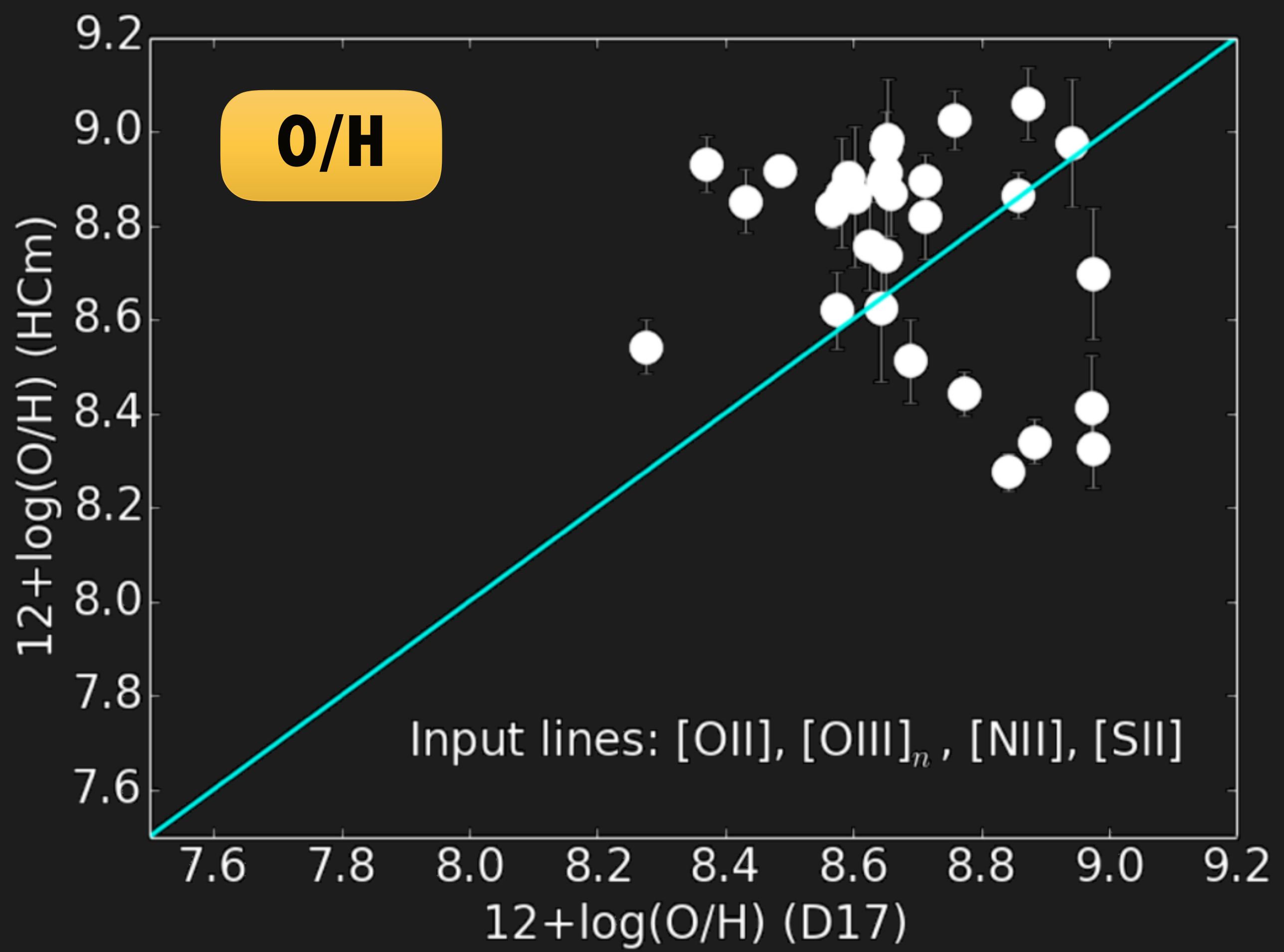


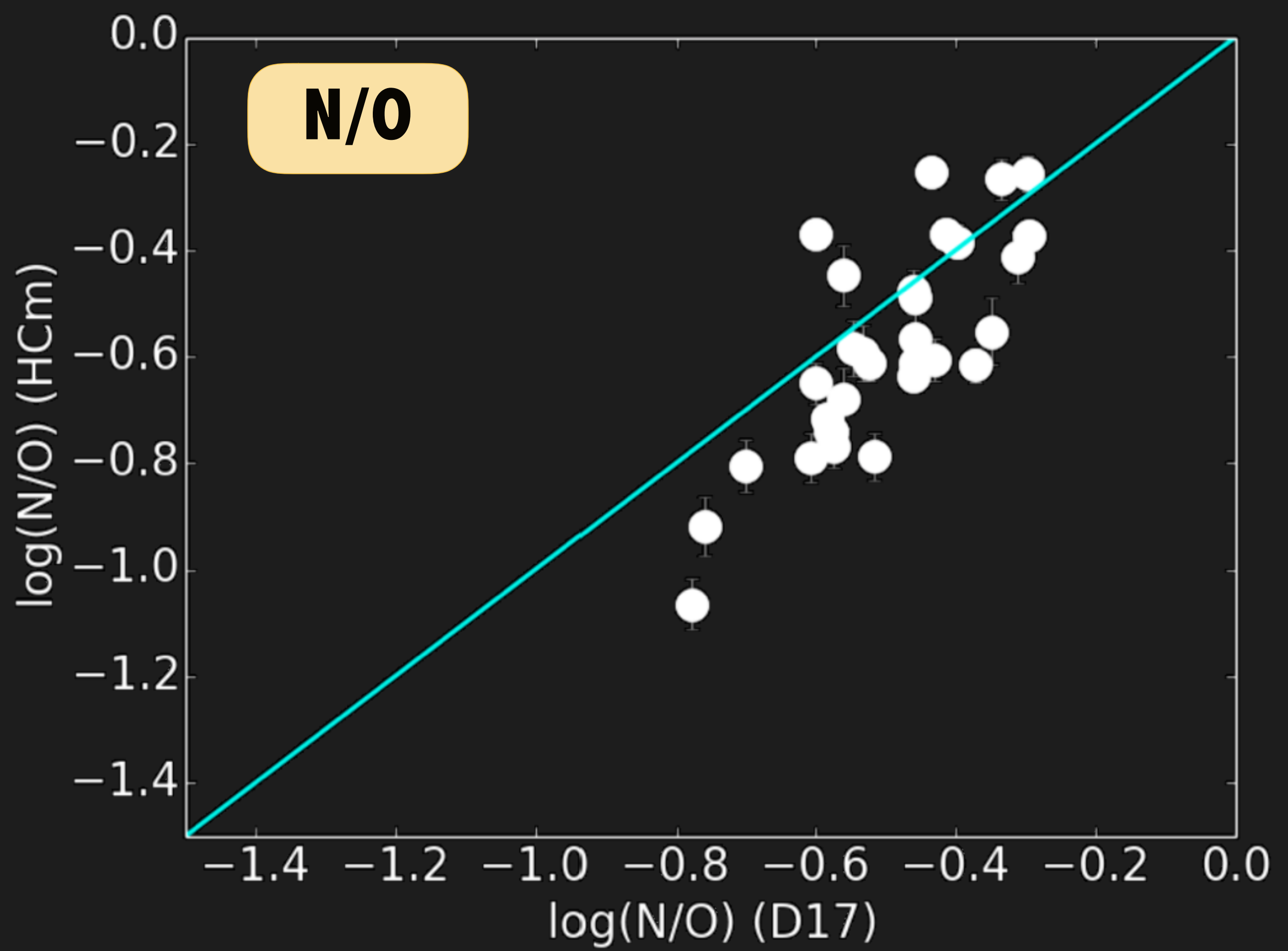
Mean Δ(O/H)	std Δ(O/H)
+0.02 dex	0.21 dex

x-axis: D17 → No errors!
y-axis: HCM

HCM: USING A FEW LINES (2)

[OII]	λ3727 Å
~~[O III]a~~	~~λ4363 Å~~
[O III]n	λ5007 Å
[N II]	λ6583 Å
[SII]	λλ6717+6731 Å



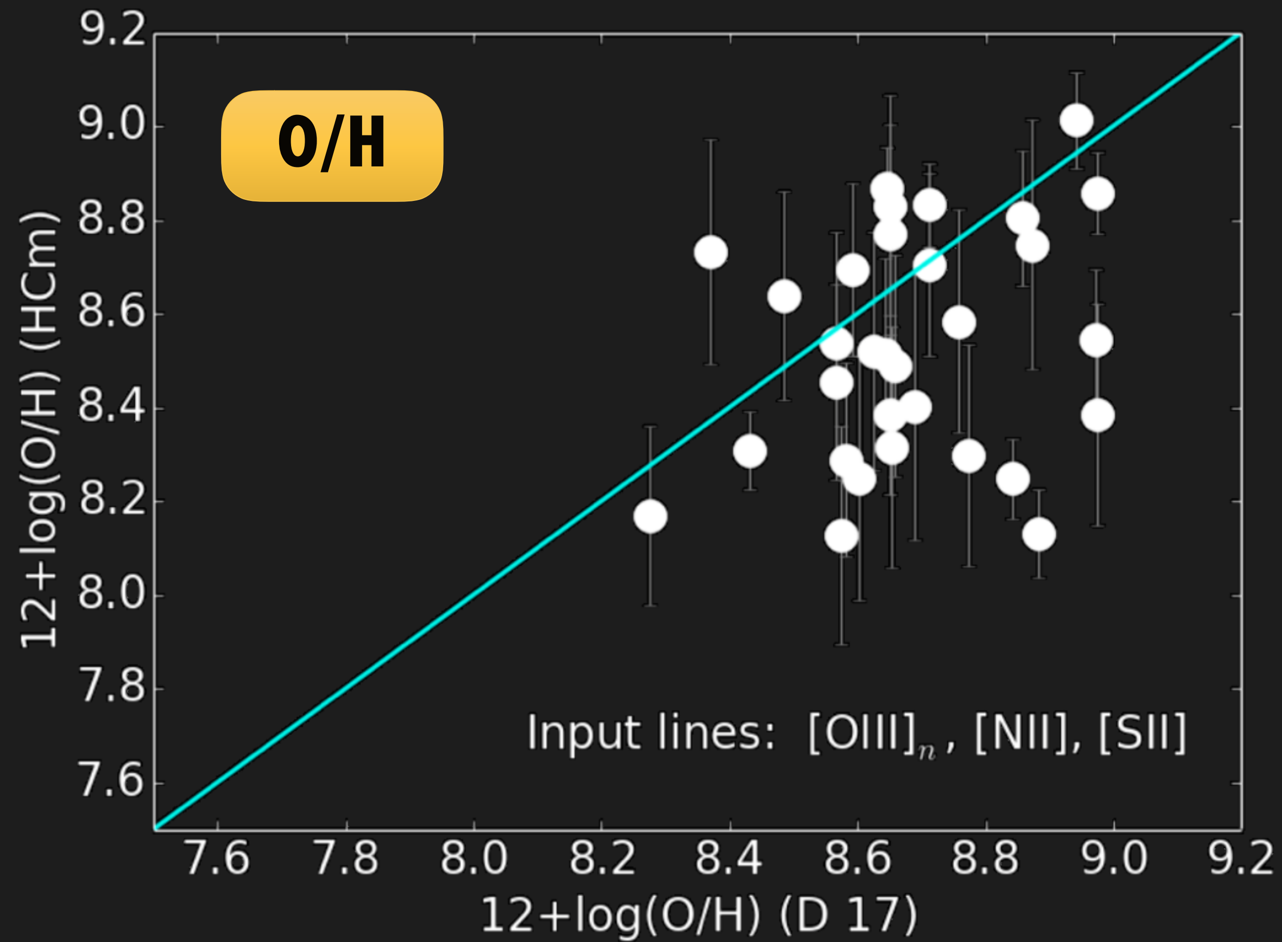


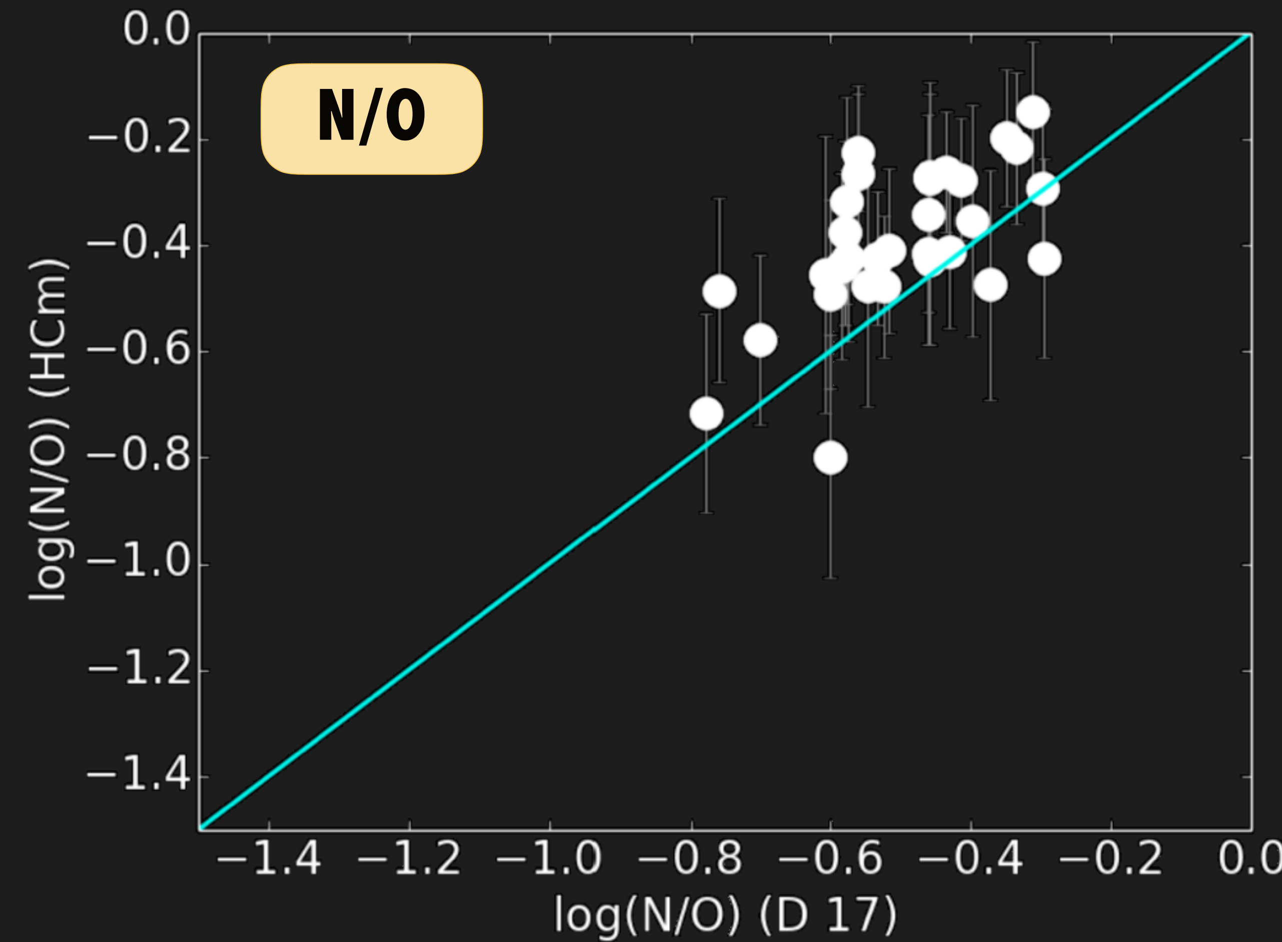
Mean Δ(O/H)	std Δ(O/H)
-0.08 dex	0.32 dex

x-axis: D17 ➔ No errors!
y-axis: HCM

HCM: USING A FEW LINES (3)

~~[OII] λ3727 Å~~
~~$[O\ III]_a$ λ4363 Å~~
$[O\ III]_n$ λ5007 Å
[N II] λ6583 Å
[SII] λλ6717+6731 Å



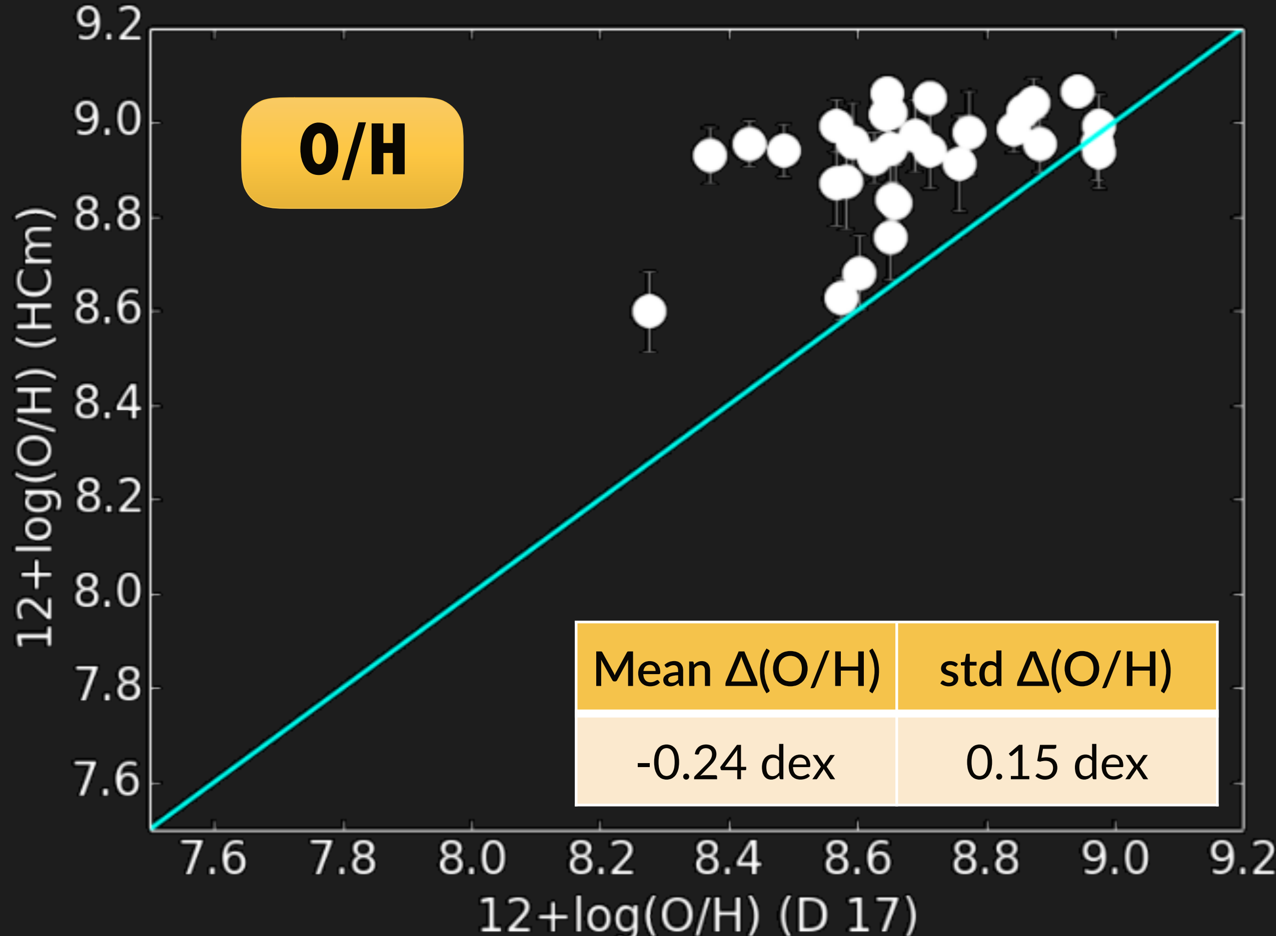


Mean Δ(O/H)	std Δ(O/H)
+0.15 dex	0.26 dex

x-axis: D17 → No errors!
y-axis: HCM

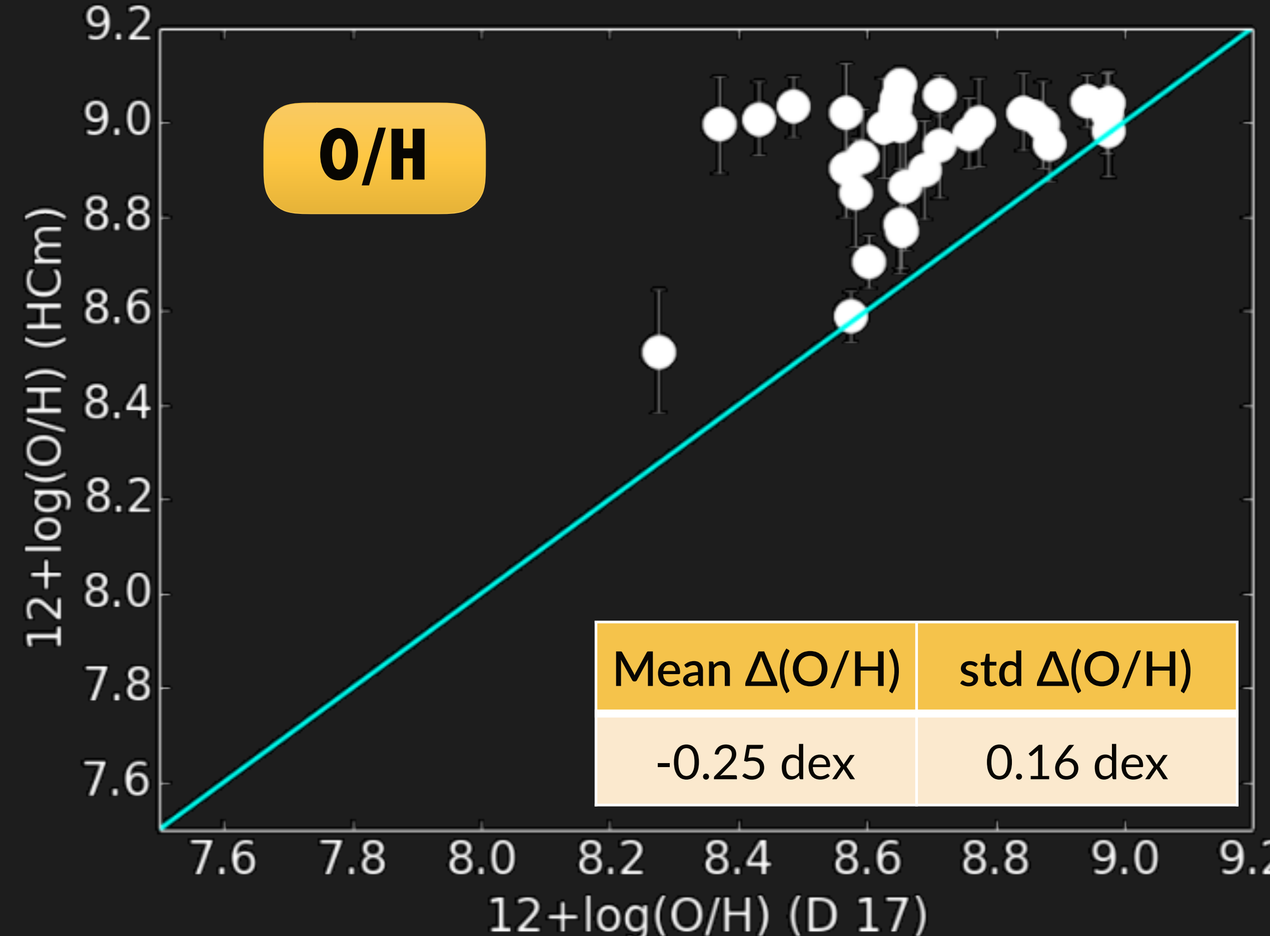
HCM: USING A FEW LINES (4)

~~[OII] λ3727 Å~~
~~[O III]a λ4363 Å~~
[O III]n λ5007 Å
[N II] λ6583 Å
~~[SII] λλ6717+6731 Å~~



Mean Δ(O/H)	std Δ(O/H)
-0.24 dex	0.15 dex

~~[OII] λ3727 Å~~
~~[O III]a λ4363 Å~~
~~[O III]n λ5007 Å~~
[N II] λ6583 Å
~~[SII] λλ6717+6731 Å~~

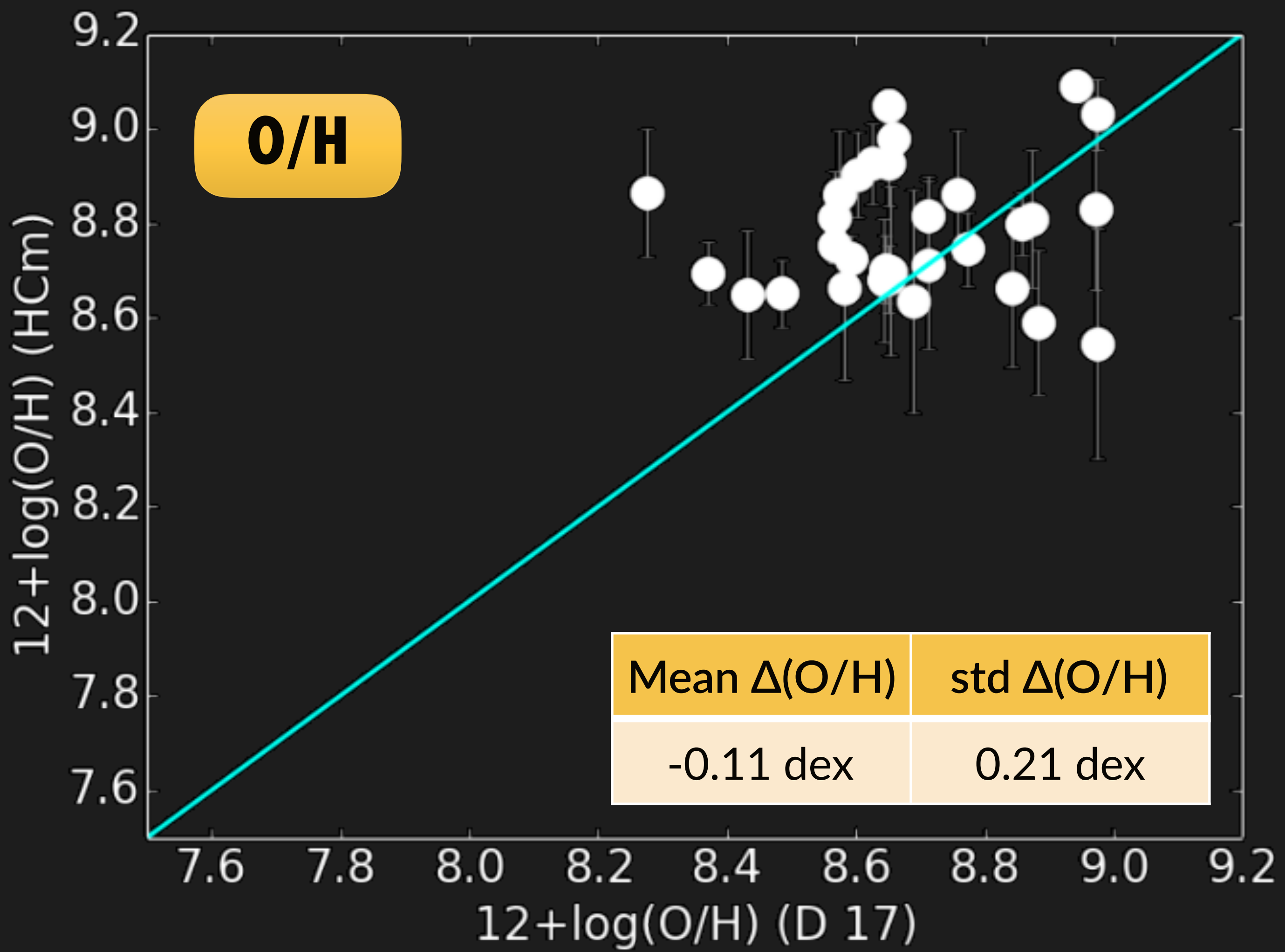


Mean Δ(O/H)	std Δ(O/H)
-0.25 dex	0.16 dex

x-axis: D17 ➜ No errors!
y-axis: HCM

HCM: USING A FEW LINES (5)

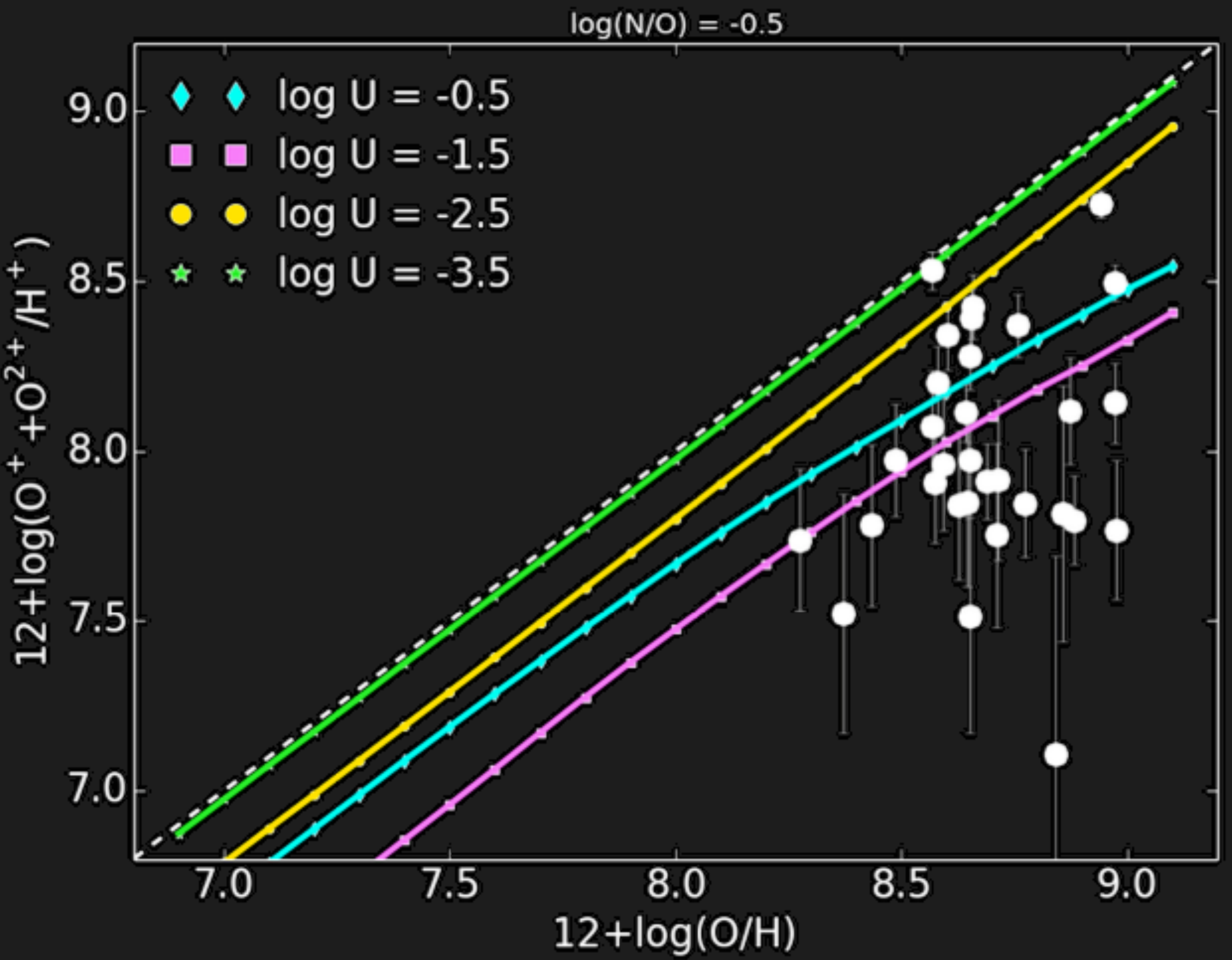
[OII] λ3727 Å
~~[O III]a λ4363 Å~~
[O III]n λ5007 Å
~~[N II] λ6583 Å~~
~~[SII] λλ6717+6731 Å~~



Mean Δ(O/H)	std Δ(O/H)
-0.11 dex	0.21 dex

x-axis: D17 → No errors!
y-axis: HCM

ABUNDANCES: CONSISTENCY WITH THE T_E METHOD



Total (O/H) ➜ *Dors et al. (2017)*

Optical Ionic ($O^+ + O^{2+}$) ➜ T_e method

Difference depends on:

- Total metallicity
- Ionization parameter

ICF for ($O^+ + O^{2+}$) NOT negligible for NLRS of AGNS!

≠ HII regions

Significant amount of Oxygen in higher ionized species

CONCLUSIONS

https://www.iaa.csic.es/~epm/HII-CHI-mistry.html

2019MNRAS.489.2652P

- ✓ AGN-HCM code base on photoionization models
- ✓ Estimation (and **errors!**) of:
  - Total oxygen abundances
  - N/O
  - Ionization parameter
- ✓ Few optical lines needed:
  - [OII] λ3727 Å
  - [Ne III] λ3868 Å
  - [O III] λ4363 Å
  - [O III] λ5007 Å
  - [N II] λ6583 Å
  - [SII] λλ6717+6731 Å
- ✓ Can be apply to a large number of objects
- ✓ Consistent with the T_e method
- ✓ Need of ICFs for NLRs if using only optical lines

A new tool to derive chemical abundances in Type-2 Active Galactic Nuclei

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