Chemical abundances in the NLR of AGN based on IR emission lines

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EXCELENCIA SEVERO OCHOA

Index

Index

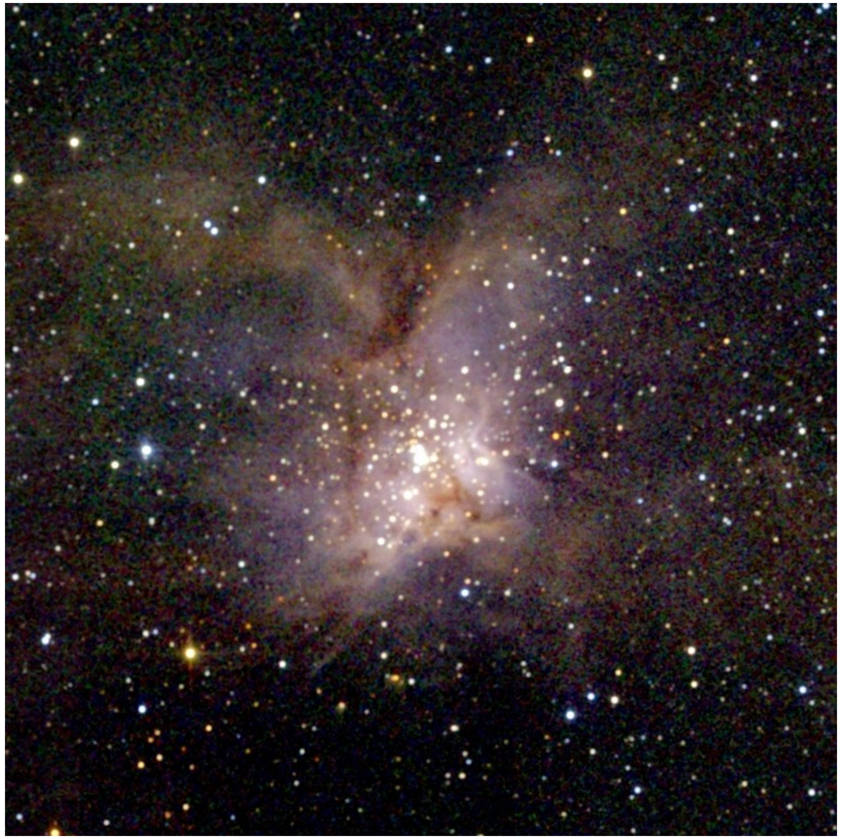
Nuclear emission in galaxies (I)

Star formation

Source of Ionization: O, B stars (T_{eff} > 15000 K).

Source of emission: Gas ionized by stars.

- $T_e \sim 10^4$ K
- $n_e \sim 10^2\text{-}10^4$ cm^{-3}
- v ~ 10 km·s^{-1}



(2MASS image of RCW 36)

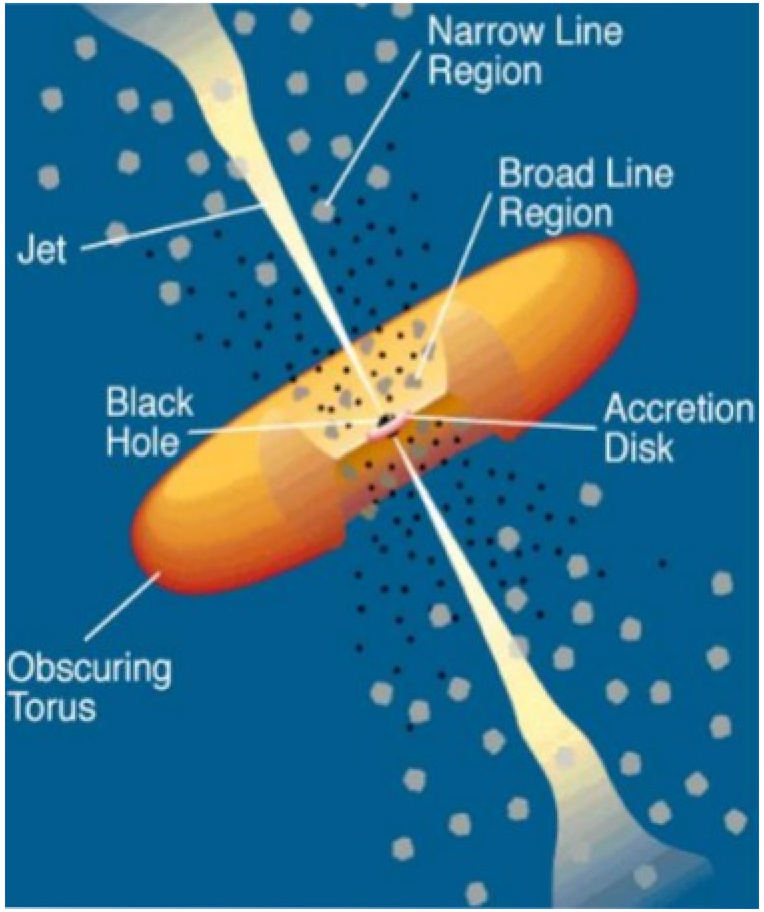
Nuclear emission in galaxies (II)

AGN Activity

Source of Ionization: Accretion disk surrounding SMBH.

Source of emission: Two regions of ionized gas, BLR / NLR

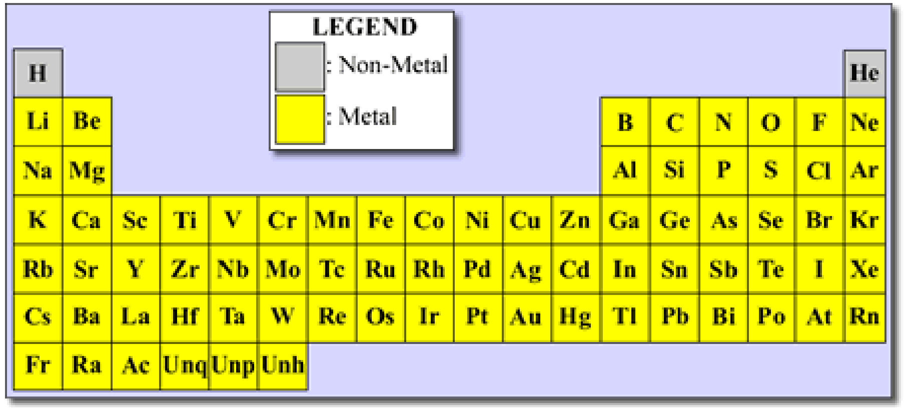
- r ~ 0.1 / 100 pc
- $T_e \sim 10^4$ K
- $n_e \sim 10^9 / 10^3$ cm^{-3}
- v ~ 10^4 / 500 $km \cdot s^{-1}$



(Urry & Padovani 1995)

Metallicity

The evolution of galaxies is related to the metallicity in their regions.



(Metals in astrophysics)

The metallicity is usually analyzed by estimating two chemical abundances ratios:

$12 + \log(O/H)$ and $\log(N/O)$

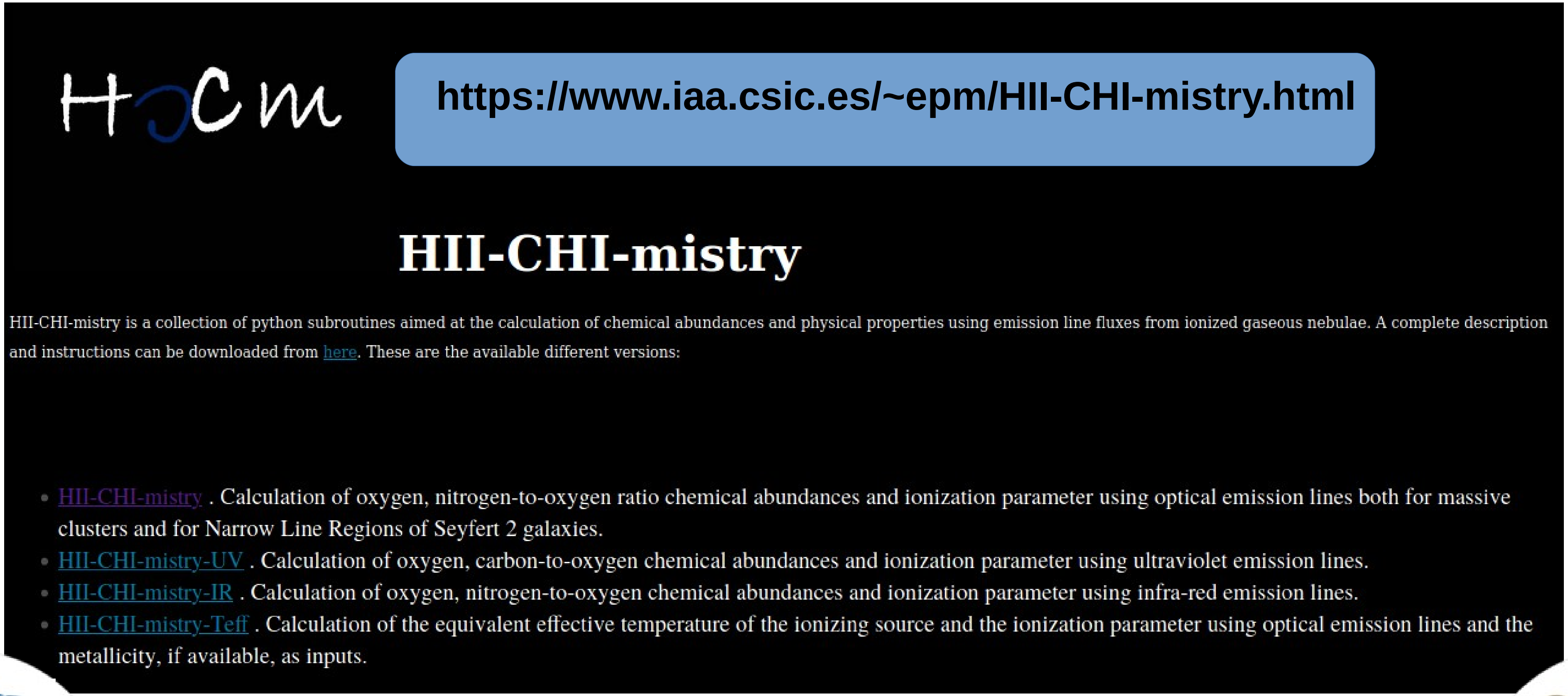
To estimate this quantities in the optical range, we have:

Star-forming galaxies
and
Seyferts 2

- Direct or T_e-method
- Photoionization models to match emission line ratios
- Optical calibrations based on strong emission lines

HII-CHI-MISTRY

We adapt the HII-CHI-MISTRY (Pérez-Montero 2014, 2015, 2019) code to estimate the abundance ratios O/H and N/O from IR emission lines. This program also provides the ionization parameter U.



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

HII-CHI-mistry

HII-CHI-mistry is a collection of python subroutines aimed at the calculation of chemical abundances and physical properties using emission line fluxes from ionized gaseous nebulae. A complete description and instructions can be downloaded from here. These are the available different versions:

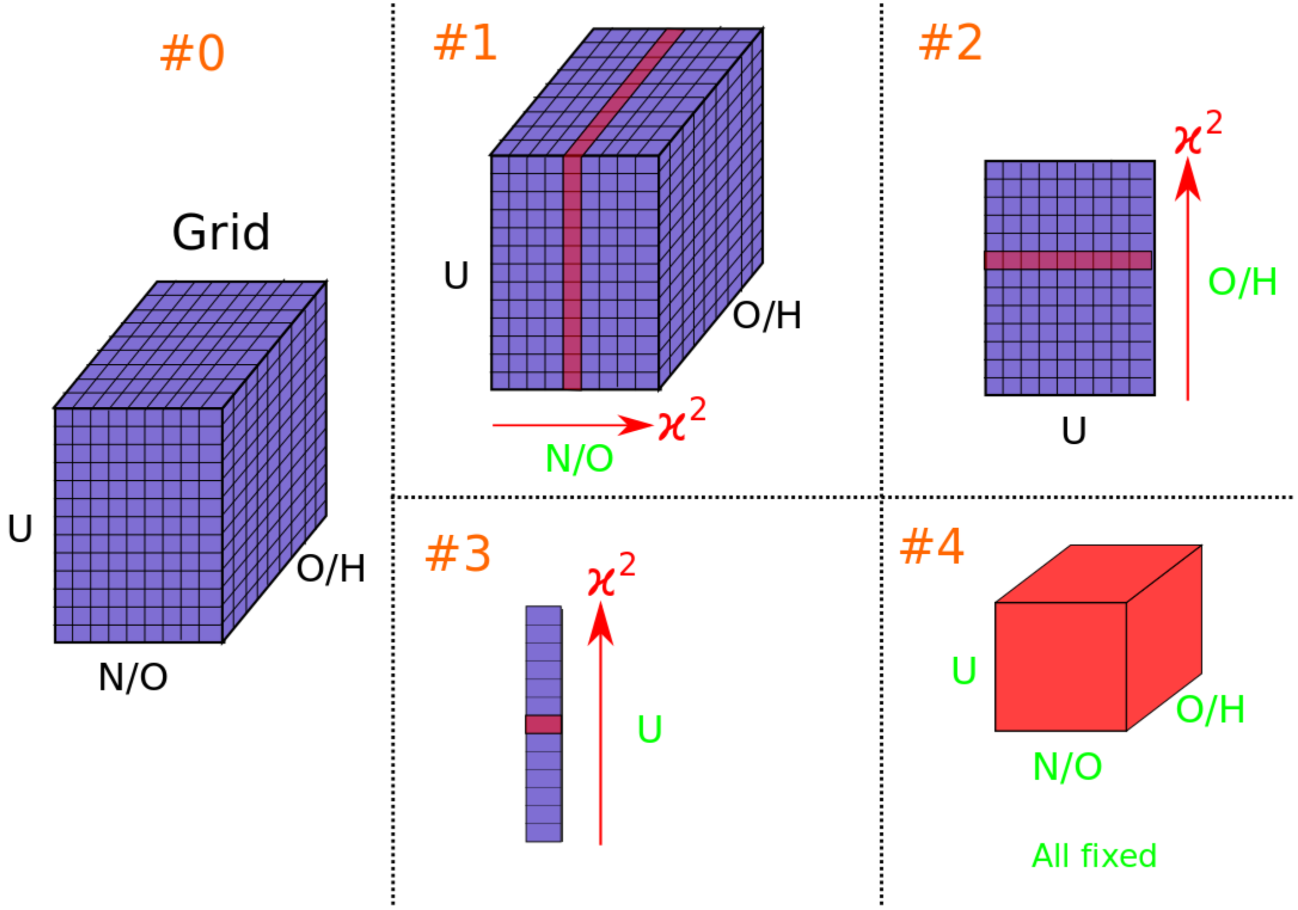
- HII-CHI-mistry . Calculation of oxygen, nitrogen-to-oxygen ratio chemical abundances and ionization parameter using optical emission lines both for massive clusters and for Narrow Line Regions of Seyfert 2 galaxies.
- HII-CHI-mistry-UV . Calculation of oxygen, carbon-to-oxygen chemical abundances and ionization parameter using ultraviolet emission lines.
- HII-CHI-mistry-IR . Calculation of oxygen, nitrogen-to-oxygen chemical abundances and ionization parameter using infra-red emission lines.
- HII-CHI-mistry-Teff . Calculation of the equivalent effective temperature of the ionizing source and the ionization parameter using optical emission lines and the metallicity, if available, as inputs.

HII-CHI-MISTRY

HII-CHI-Mistry uses photoionization models to create the grid of models. But you can choose the photoionization code that you want!!!

Spectral type	SED	Grids		
		$12+\log_{10}(O/H)$	$\log_{10}(N/O)$	$\log_{10}(U)$
Star-forming galaxies	POPSTAR Burst of 10^6 yr Ratio Dust/Gas $7.5 \cdot 10^{-3}$	[6.9, 9.1] Nº Values: 23	[-2.0, 0.0] Nº Values: 17	[-4.0, -1.5] Nº Values: 11
Seyferts	BBB max. at 13.6 eV $\alpha_X = -1$ $\alpha_{OX} = -0.8$ or -1.2	[6.9, 9.1] Nº Values: 23	[-2.0, 0.0] Nº Values: 17	[-4.0, -0.5] Nº Values: 15
LINERs	BBB max. at 13.6 eV $\alpha_X = -1$ $\alpha_{OX} = -0.8$ or -1.2	[6.9, 9.1] Nº Values: 23	[-2.0, 0.0] Nº Values: 17	[-4.0, -2.5] Nº Values: 6
Steps	-	0.1 dex	0.125 dex	0.25 dex
Nº Models	-	4301 Star-forming	5865 Seyferts	2346 LINERs

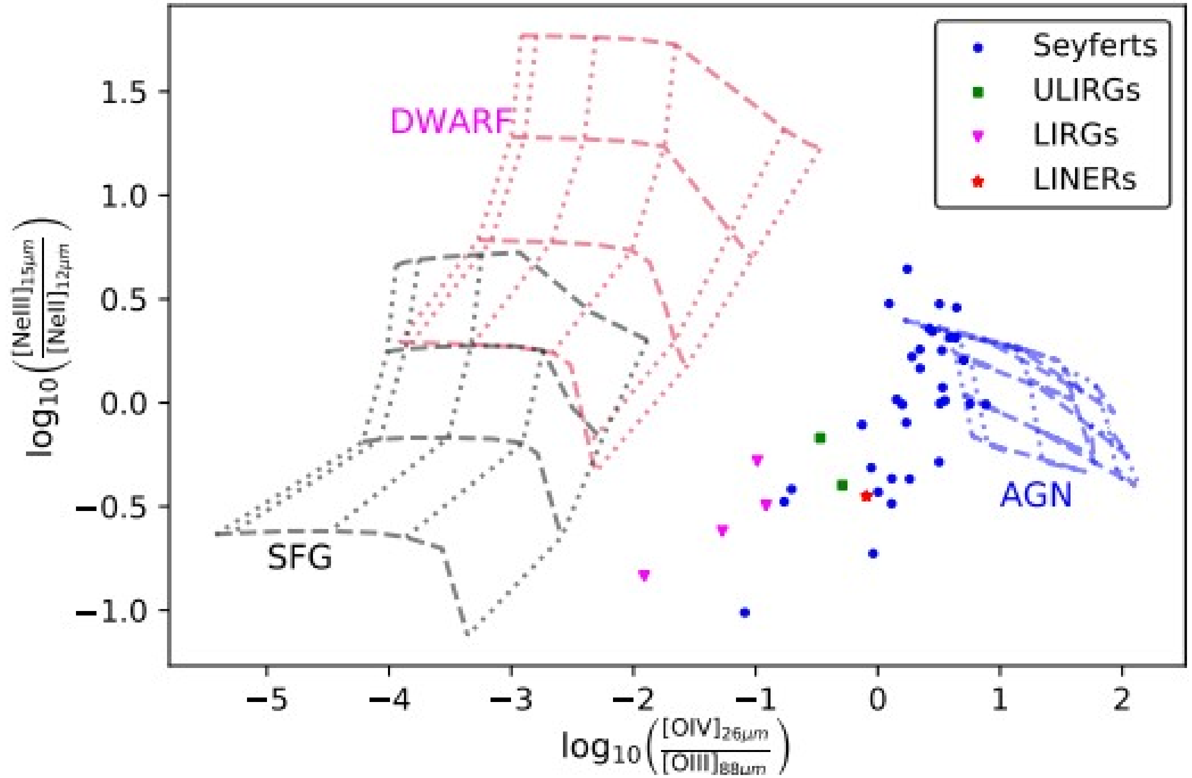
How does HCm work?



Index

Sample

Pérez-Díaz et al. (submitted)

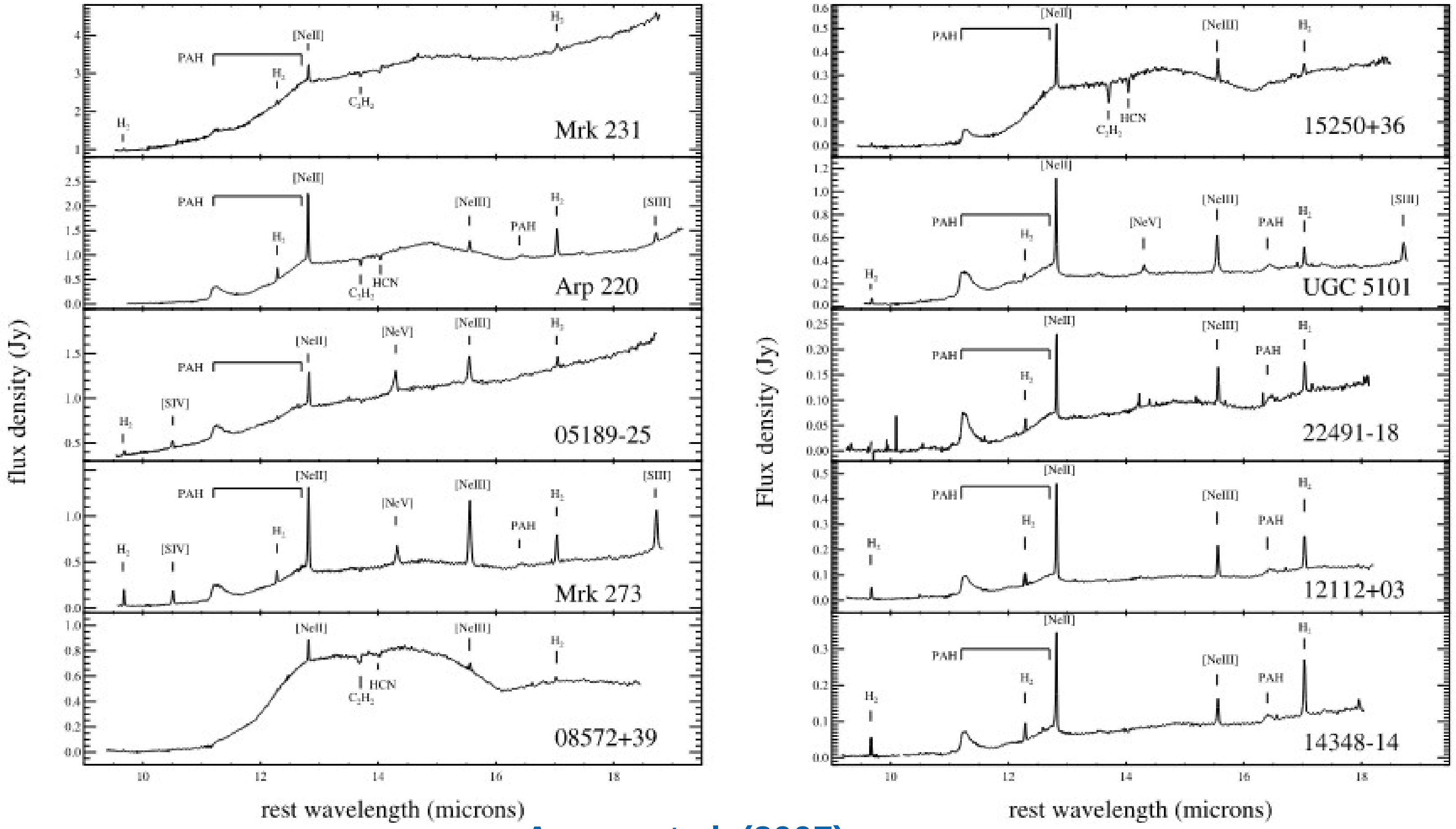


We compile a sample of **<u>58 AGNs</u>** with observations from *Spitzer*/IRS and *Herschel*/PACS, divided as:

- 43 Seyferts
- 12 (U)LIRGs (8 + 4)
- 3 LINERs

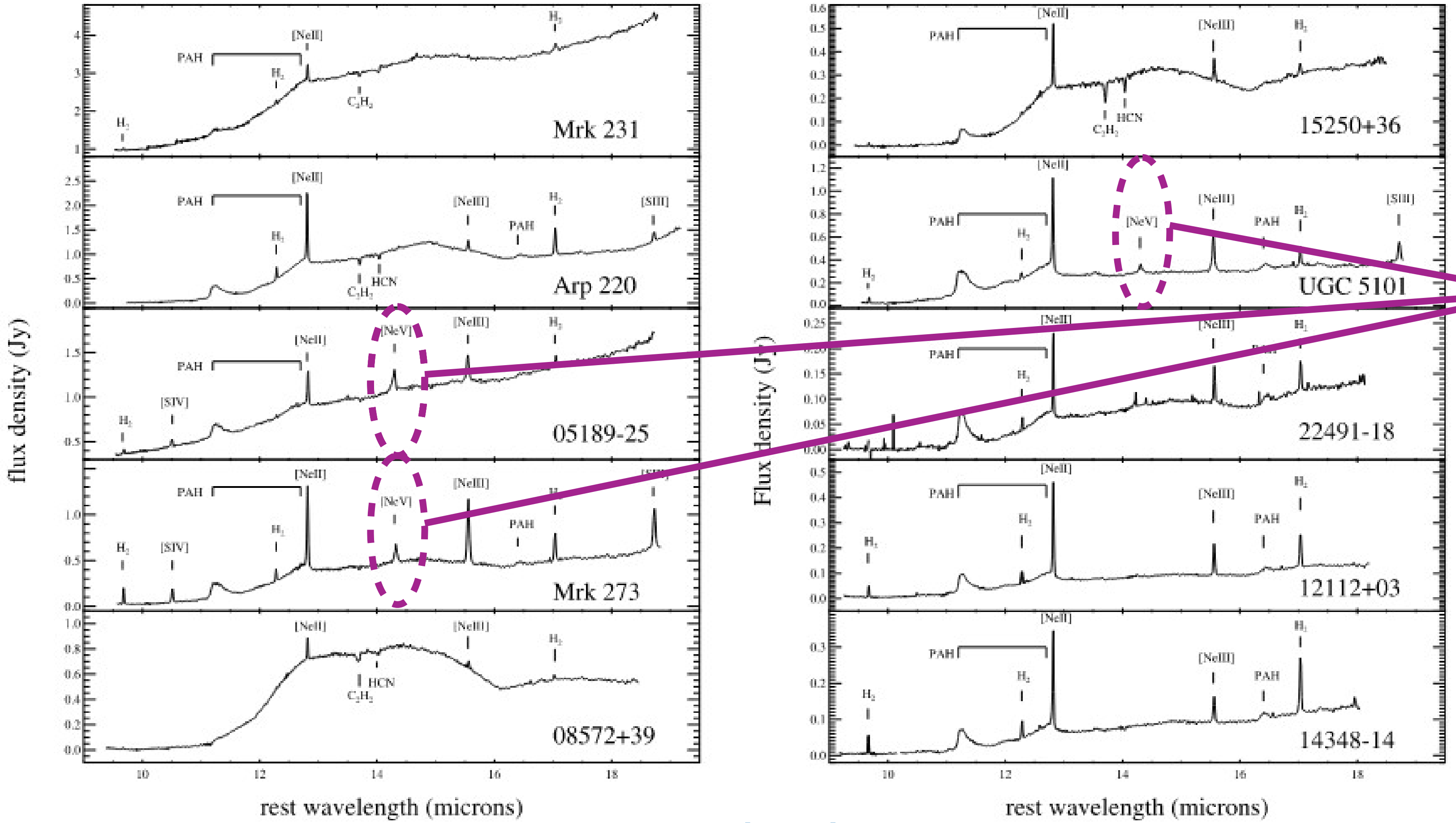
We also add spectroscopic information from SOFIA to retrieve key emission lines in the estimation of N/O such as [OIII]λ52μm and [NIII]λ57μm.

Sample



Armus et al. (2007)

Sample



Armus et al. (2007)

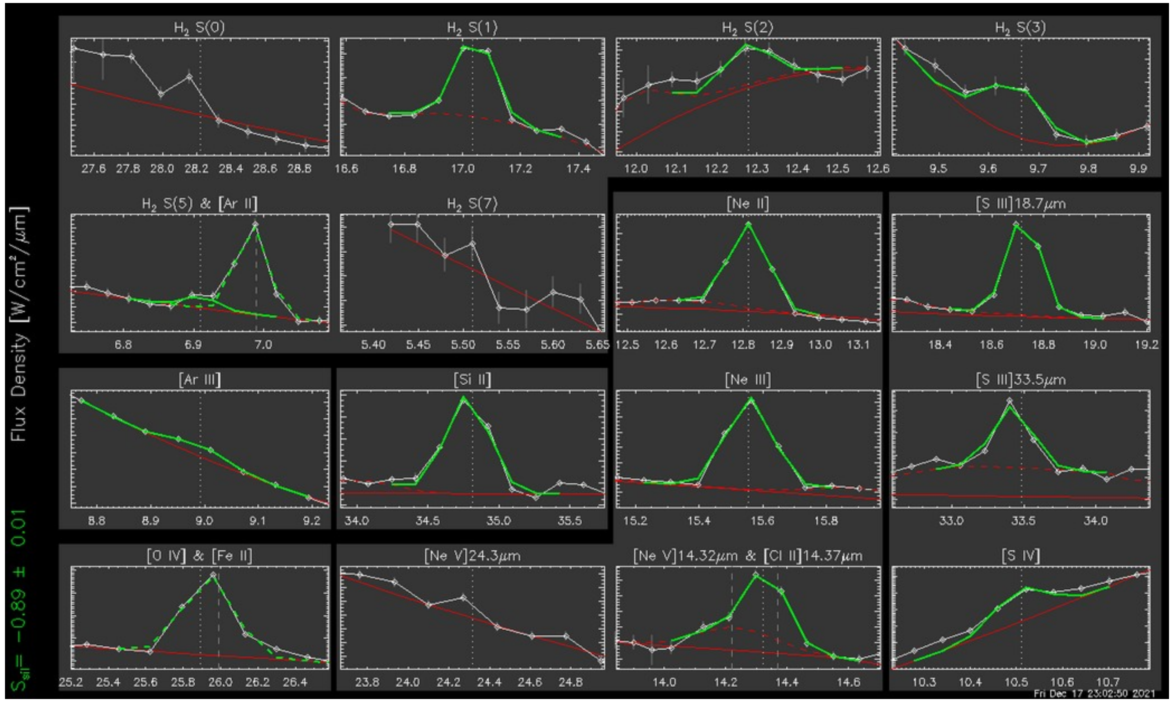
AGN activity is characterized by high ionic species, leading to [NeV] emission for instance.

Index

Metallicity estimators for AGNs

We adapt emission line ratios employed in the estimation of chemical abundances in SFG to AGN, but taking into account the differences that arise from their different SEDs:

1- Higher ionic species are found in AGNs (i.e. [NeV], [OIV], [ArVI], ...)



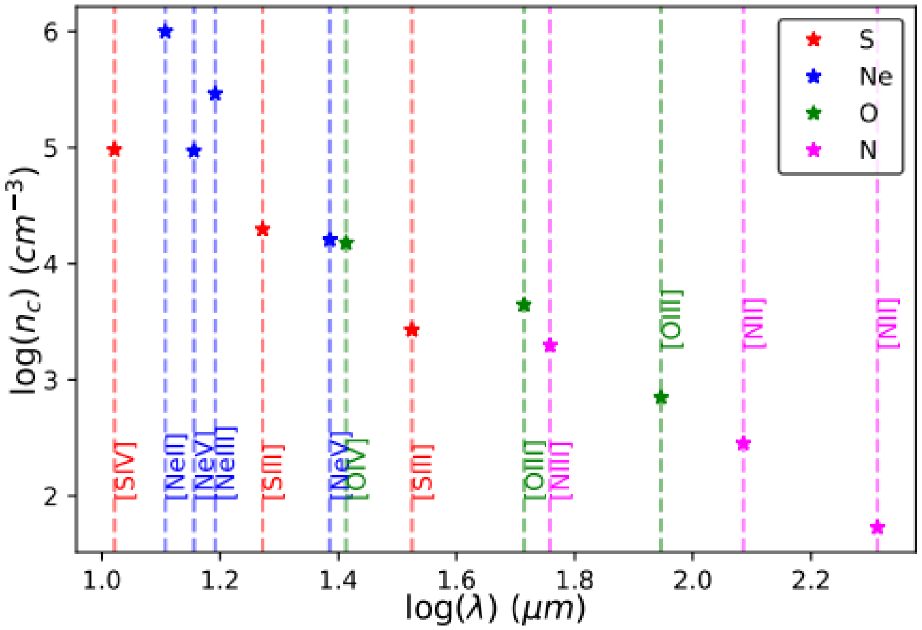
IR spectroscopic information for NGC 5128 (IDEOS)

Metallicity estimators for AGNs

We adapt emission line ratios employed in the estimation of chemical abundances in SFG to AGN, but taking into account the differences that arise from their different SEDs:

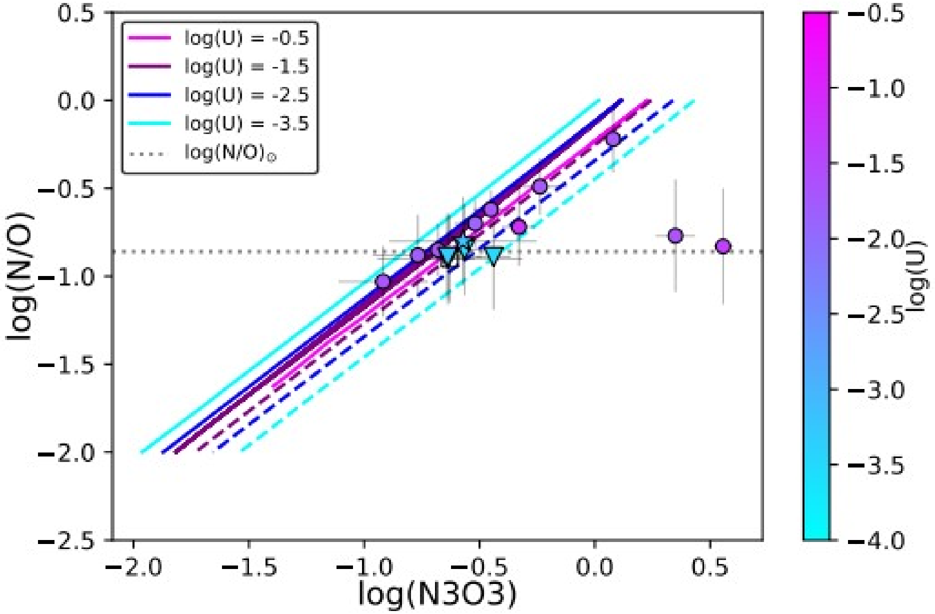
1- Higher ionic species are found in AGNs (i.e. [NeV], [OIV], [ArVI], …)

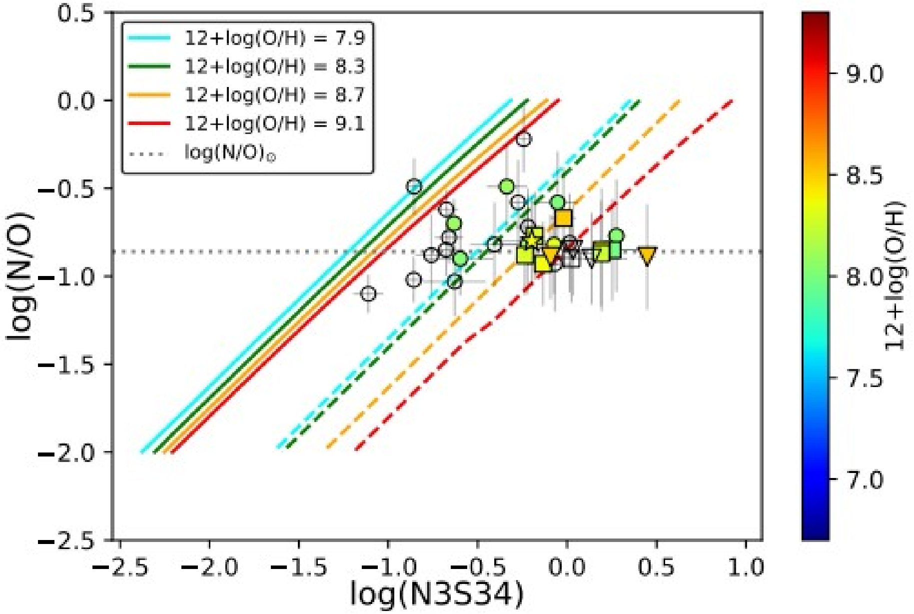
2- Gas density in the NLR is higher (~500 cm^{-3}) than in HII regions (~100 cm^{-3}), and IR emission lines are strongly affected by density conditions:



N/O estimators

Pérez-Díaz et al. (submitted)



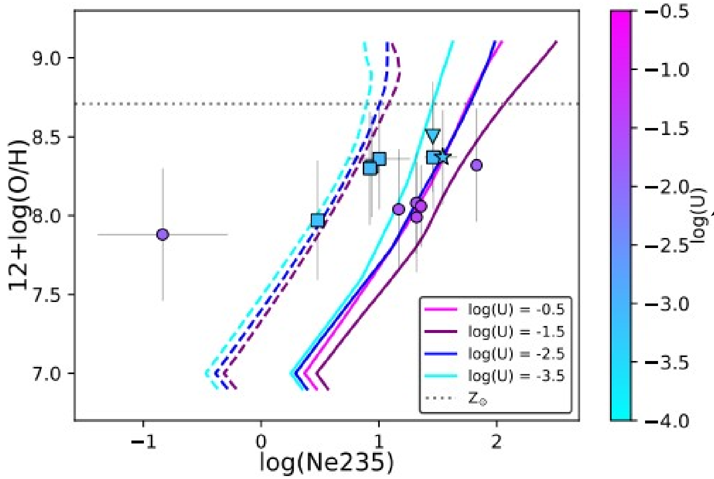


$$\log\left(\mathrm{N3O3}\right) = \log\left(\frac{\mathrm{I}\left([\mathrm{N\,III}]_{57\mu m}\right)}{\mathrm{I}\left([\mathrm{O\,III}]_{52\mu m}\right)}\right)$$

$$\log\left(\mathrm{N3S34}\right) = \log\left(\frac{\mathrm{I}\left([\mathrm{N\,III}]_{57\mu m}\right)}{\mathrm{I}\left([\mathrm{S\,III}]_{18\mu m}\right) + \mathrm{I}\left([\mathrm{S\,IV}]_{10\mu m}\right)}\right)$$

O/H estimators

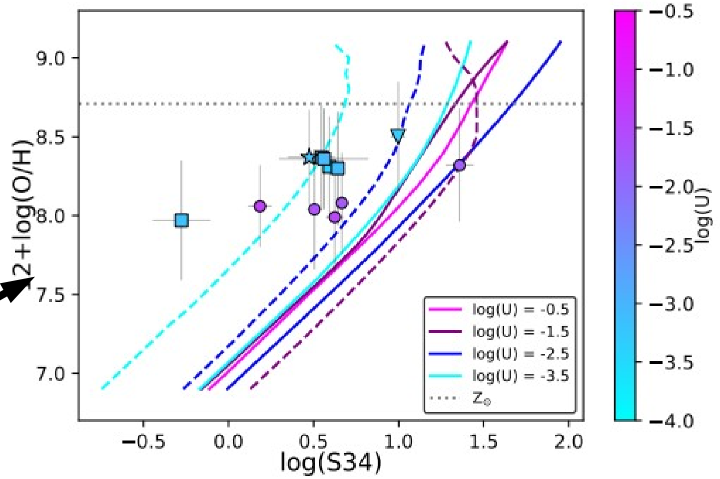
Pérez-Díaz et al. (submitted)

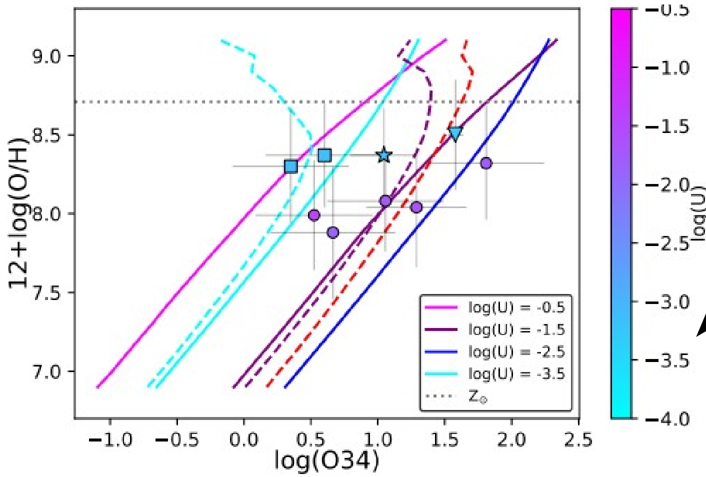


$$\log(\mathrm{Ne235}) = \log\left(\frac{I([\mathrm{Ne\,II}]_{12\mu m}) + I([\mathrm{Ne\,III}]_{15\mu m})}{I(\mathrm{H\,I}_i)} + \frac{I([\mathrm{Ne\,V}]_{14\mu m}) + I([\mathrm{Ne\,V}]_{24\mu m})}{I(\mathrm{H\,I}_i)}\right)$$

$$\log(\mathrm{S34}) = \log\left(\frac{I([\mathrm{S\,III}]_{18\mu m}) + I([\mathrm{S\,IV}]_{10\mu m})}{I(\mathrm{H\,I}_i)}\right)$$

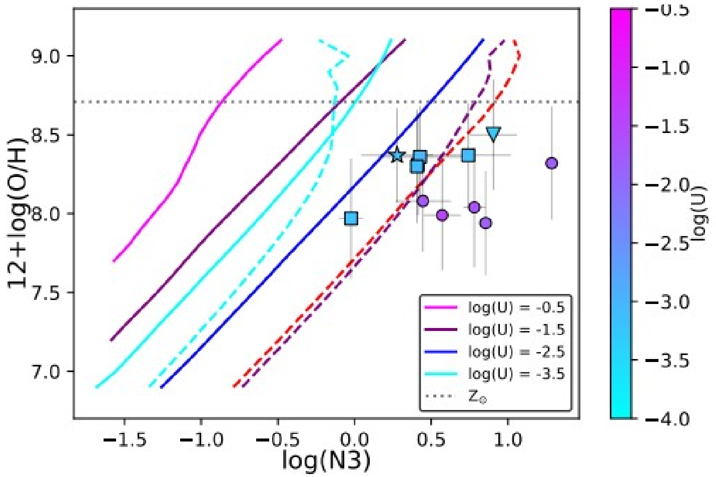
Pérez-Díaz et al. (submitted)





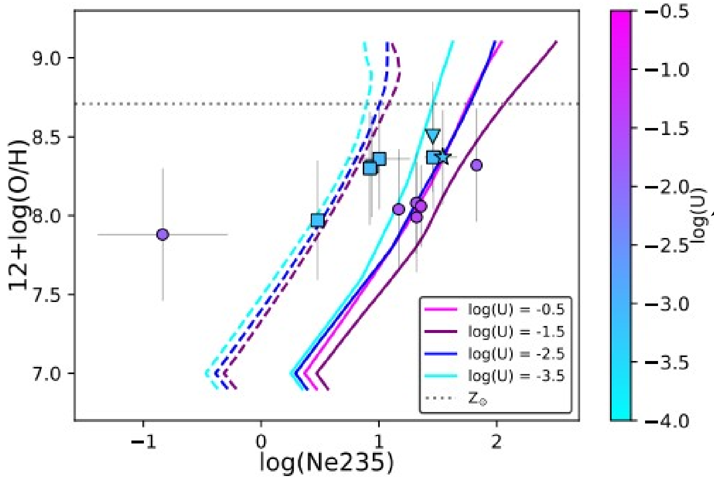
$$\log(\mathrm{O34}) = \log\left(\frac{I([\mathrm{O\,III}]_{52\mu m}) + I([\mathrm{O\,IV}]_{26\mu m})}{I(\mathrm{H\,I}_i)}\right)$$

$$\log(\mathrm{N3}) = \log\left(\frac{I([\mathrm{N\,III}]_{57\mu m})}{I(\mathrm{H\,I}_i)}\right)$$



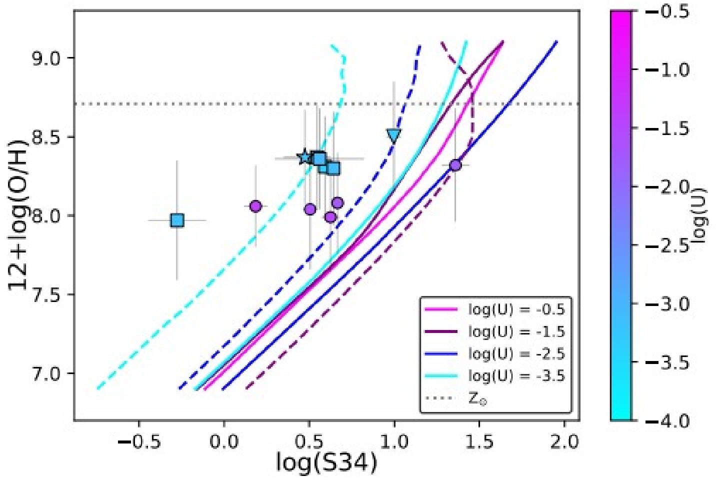
O/H estimators

Pérez-Díaz et al. (submitted)

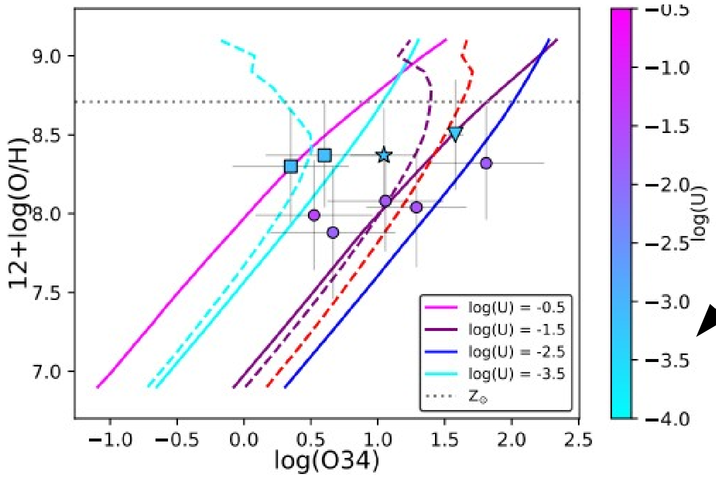


$$\log(\mathrm{Ne235}) = \log\left(\frac{I\left([\mathrm{Ne\,II}]_{12\mu m}\right) + I\left([\mathrm{Ne\,III}]_{15\mu m}\right)}{I\left(\mathrm{H\,I}_i\right)} + \frac{I\left([\mathrm{Ne\,V}]_{14\mu m}\right) + I\left([\mathrm{Ne\,V}]_{24\mu m}\right)}{I\left(\mathrm{H\,I}_i\right)}\right)$$

Pérez-Díaz et al. (submitted)

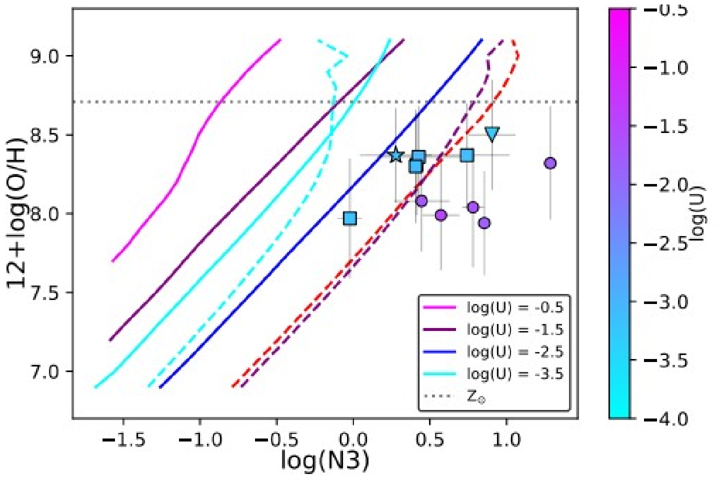


$$\log(\mathrm{S34}) = \log\left(\frac{I\left([\mathrm{S\,III}]_{18\mu m}\right) + I\left([\mathrm{S\,IV}]_{10\mu m}\right)}{I\left(\mathrm{H\,I}_i\right)}\right)$$



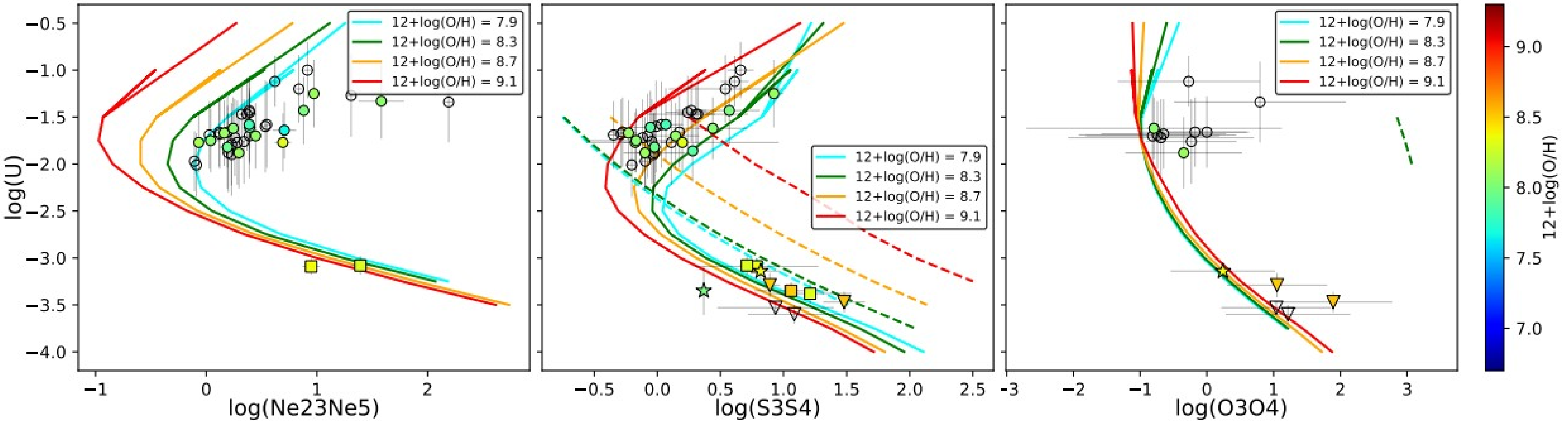
$$\log(\mathrm{O34}) = \log\left(\frac{I\left([\mathrm{O\,III}]_{52\mu m}\right) + I\left([\mathrm{O\,IV}]_{26\mu m}\right)}{I\left(\mathrm{H\,I}_i\right)}\right)$$

$$\log(\mathrm{N3}) = \log\left(\frac{I\left([\mathrm{N\,III}]_{57\mu m}\right)}{I\left(\mathrm{H\,I}_i\right)}\right)$$



log(U) estimators

Pérez-Díaz et al. (submitted)



$$\log\left(\mathrm{S3S4}\right) = \log\left(\frac{\mathrm{I}\left([\mathrm{S\,III}]_{18\mu m}\right)}{\mathrm{I}\left([\mathrm{S\,IV}]_{10\mu m}\right)}\right)$$

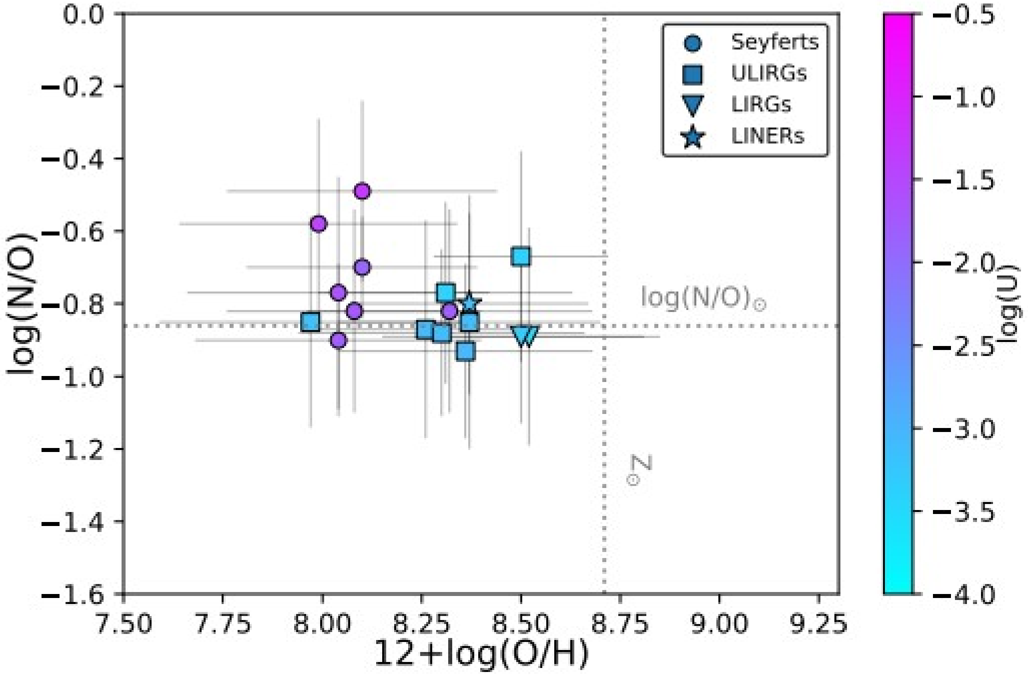
$$\log\left(\mathrm{O3O4}\right) = \log\left(\frac{\mathrm{I}\left([\mathrm{O\,III}]_{52\mu m}\right)}{\mathrm{I}\left([\mathrm{O\,IV}]_{26\mu m}\right)}\right)$$

$$\log\left(\mathrm{Ne23Ne5}\right) = \log\left(\frac{\mathrm{I}\left([\mathrm{Ne\,II}]_{12\mu m}\right) + \mathrm{I}\left([\mathrm{Ne\,III}]_{15\mu m}\right)}{\mathrm{I}\left([\mathrm{Ne\,V}]_{14\mu m}\right) + \left[\mathrm{I}\,(\mathrm{Ne\,V}]_{24\mu m}\right)}\right)$$

Index

Abundances in the NLR of AGN

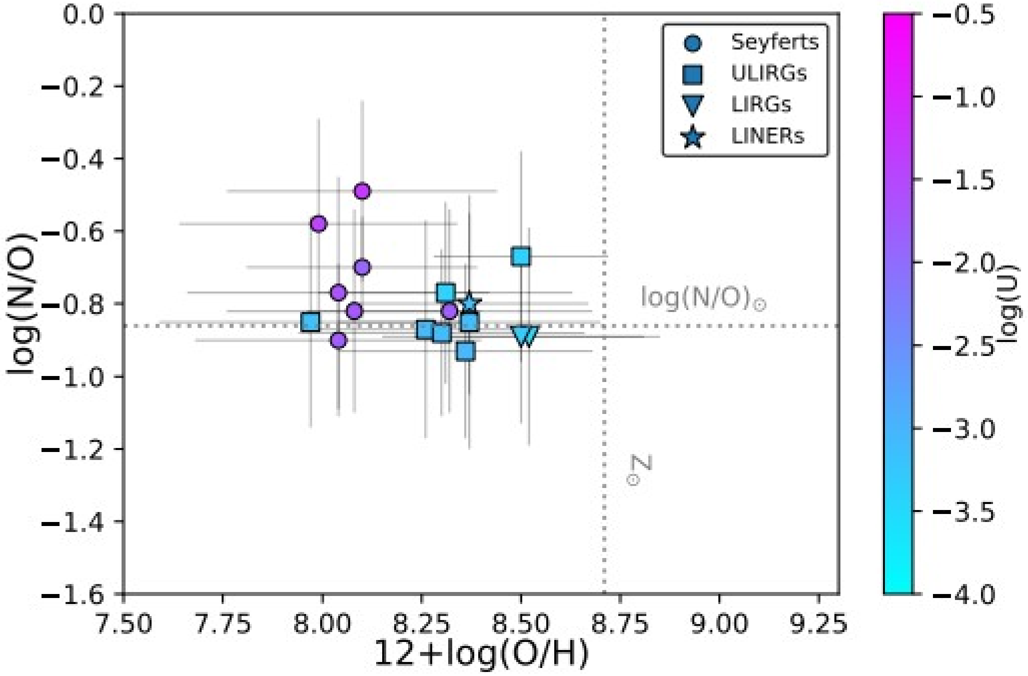
Pérez-Díaz et al. (submitted)



Abundances in the NLR of AGN

Pérez-Díaz et al. (submitted)

		$\log_{10}(N/O)$		
Sample	**N°_{tot}**	**N°**	**Median**	**Std. Dev.**
All galaxies	58	35	-0.83	0.17
Seyferts	43	22	-0.81	0.20
ULIRGs	8	8	-0.86	0.07
LIRGs	4	4	-0.885	0.019
LINERs	3	1	-0.80	-

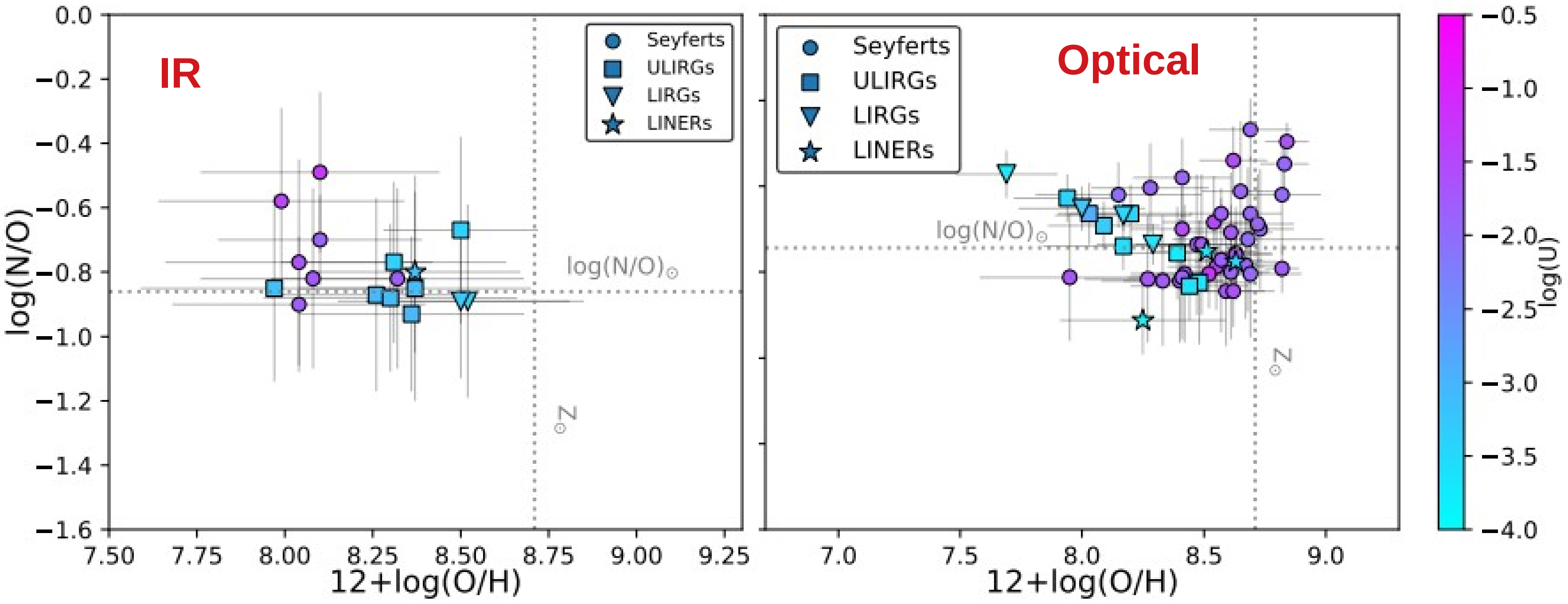


		$\log_{10}(U)$		
Sample	**N°_{tot}**	**N°**	**Median**	**Std. Dev.**
All galaxies	58	52	-1.73	0.80
Seyferts	43	39	-1.67	0.33
ULIRGs	8	7	-3.08	0.15
LIRGs	4	4	-3.58	0.14
LINERs	3	2	-3.24	0.10

		$12 + \log_{10}(O/H)$		
Sample	**N°_{tot}**	**N°**	**Median**	**Std. Dev.**
All galaxies	58	26	8.05	0.24
Seyferts	43	15	7.99	0.16
ULIRGs	8	7	8.32	0.20
LIRGs	4	2	8.495	0.005
LINERs	3	2	8.17	0.18

Abundances in the NLR of AGN

Pérez-Díaz et al. (submitted)



Abundances in the NLR of AGN

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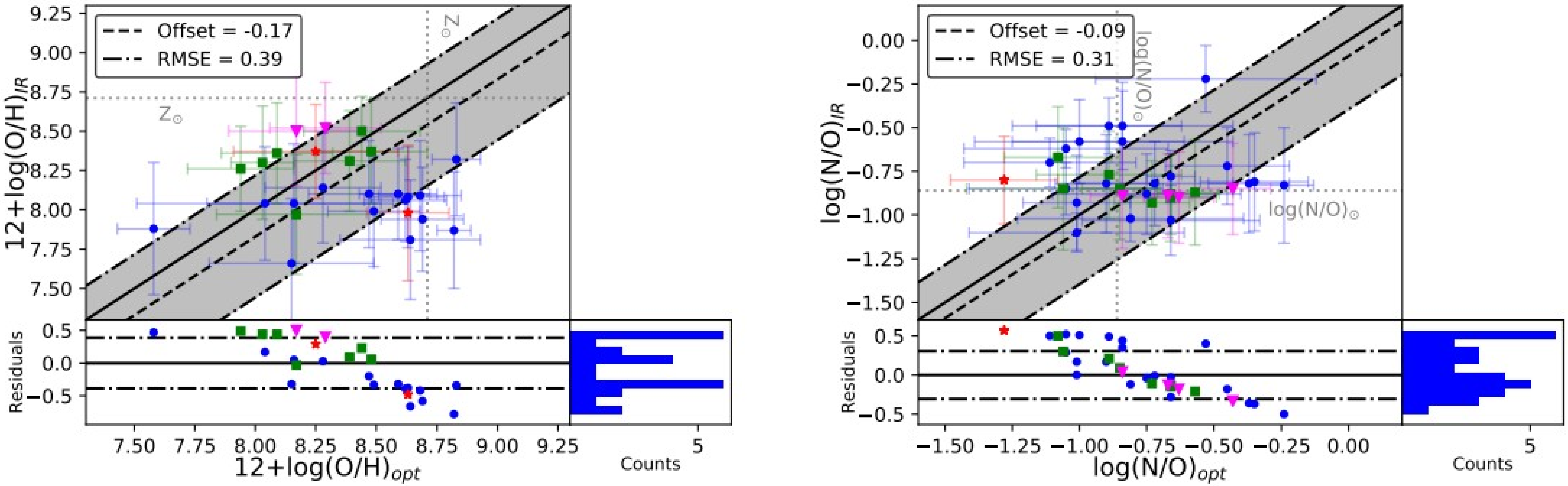
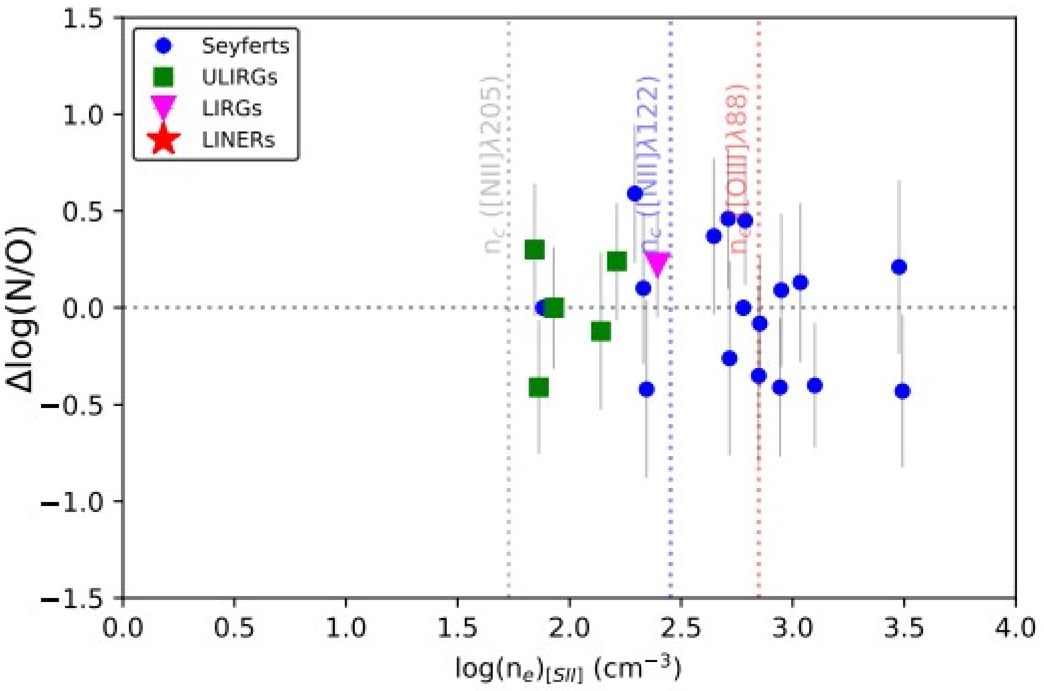
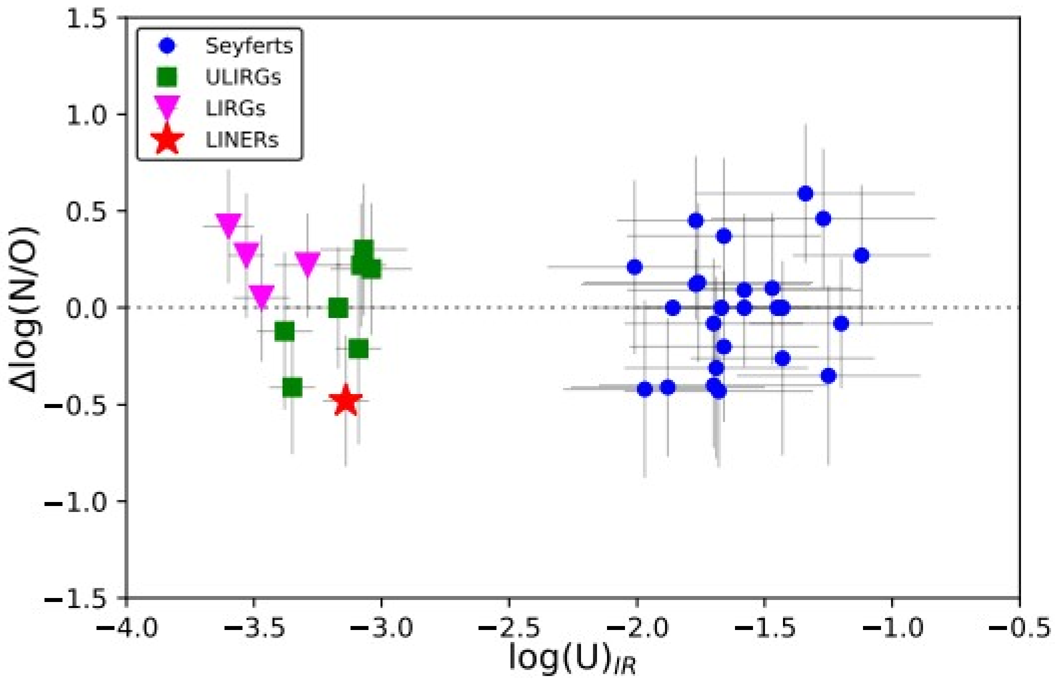


Abundances in the NLR of AGN

Pérez-Díaz et al. (submitted)



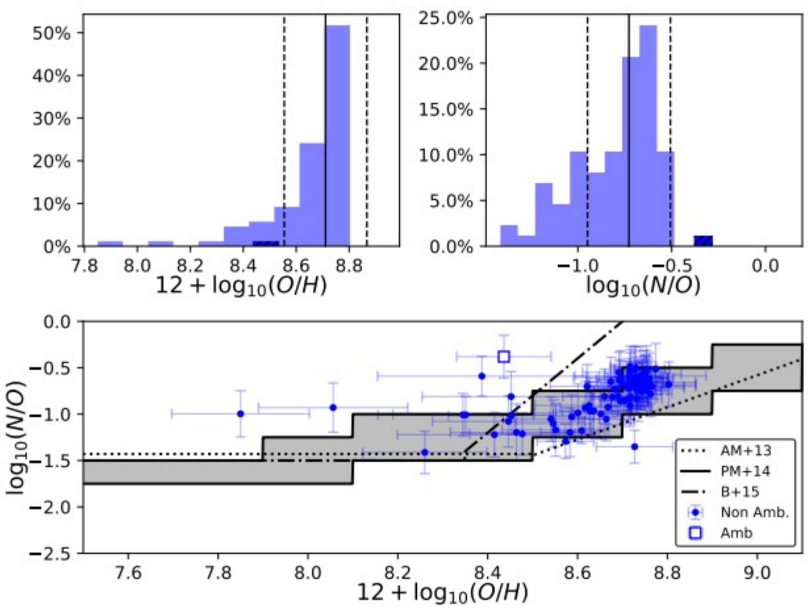


Index

Is there a wide distribution of metallicities in AGN?

Is there a wide distribution of metallicities in AGN?

Star-forming galaxies

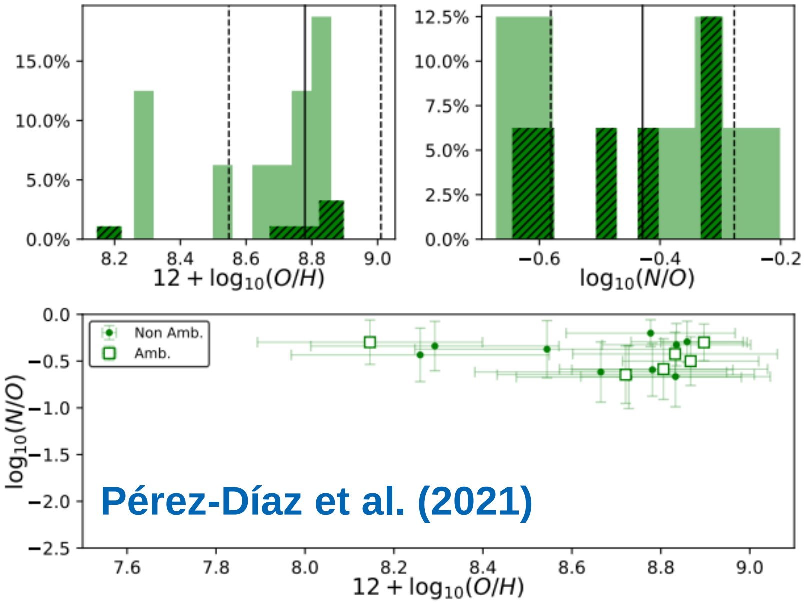


12 + log(O/H) = 8.71 ± 0.16

log(N/O) = -0.73 ± 0.22

log(U) = -3.21 ± 0.17

Seyferts 2

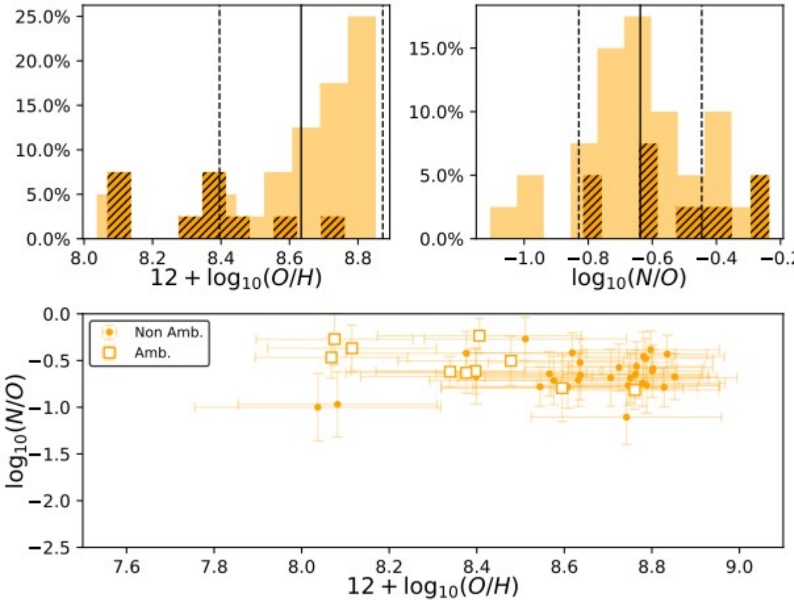


12 + log(O/H) = 8.78 ± 0.23

log(N/O) = -0.43 ± 0.15

log(U) = -1.64 ± 0.26

LINERs



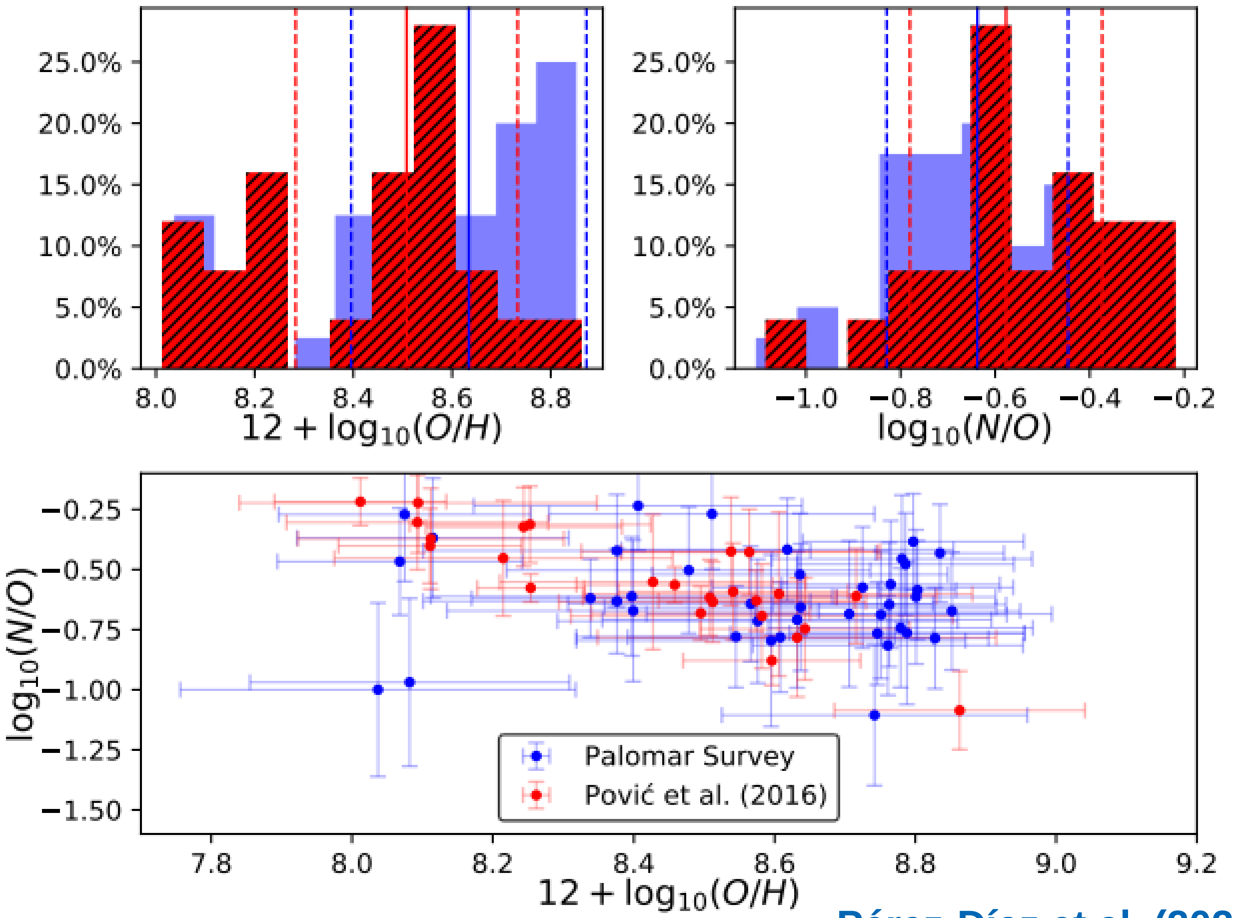
12 + log(O/H) = 8.63 ± 0.26

log(N/O) = -0.63 ± 0.19

log(U) = -3.46 ± 0.15

Is there a wide distribution of metallicities in AGN?

We also analysed another sample of infrared luminous LINERs from Povic et al. (2016):



Pérez-Díaz et al. (2021)

Is there a wide distribution of metallicities in AGN?

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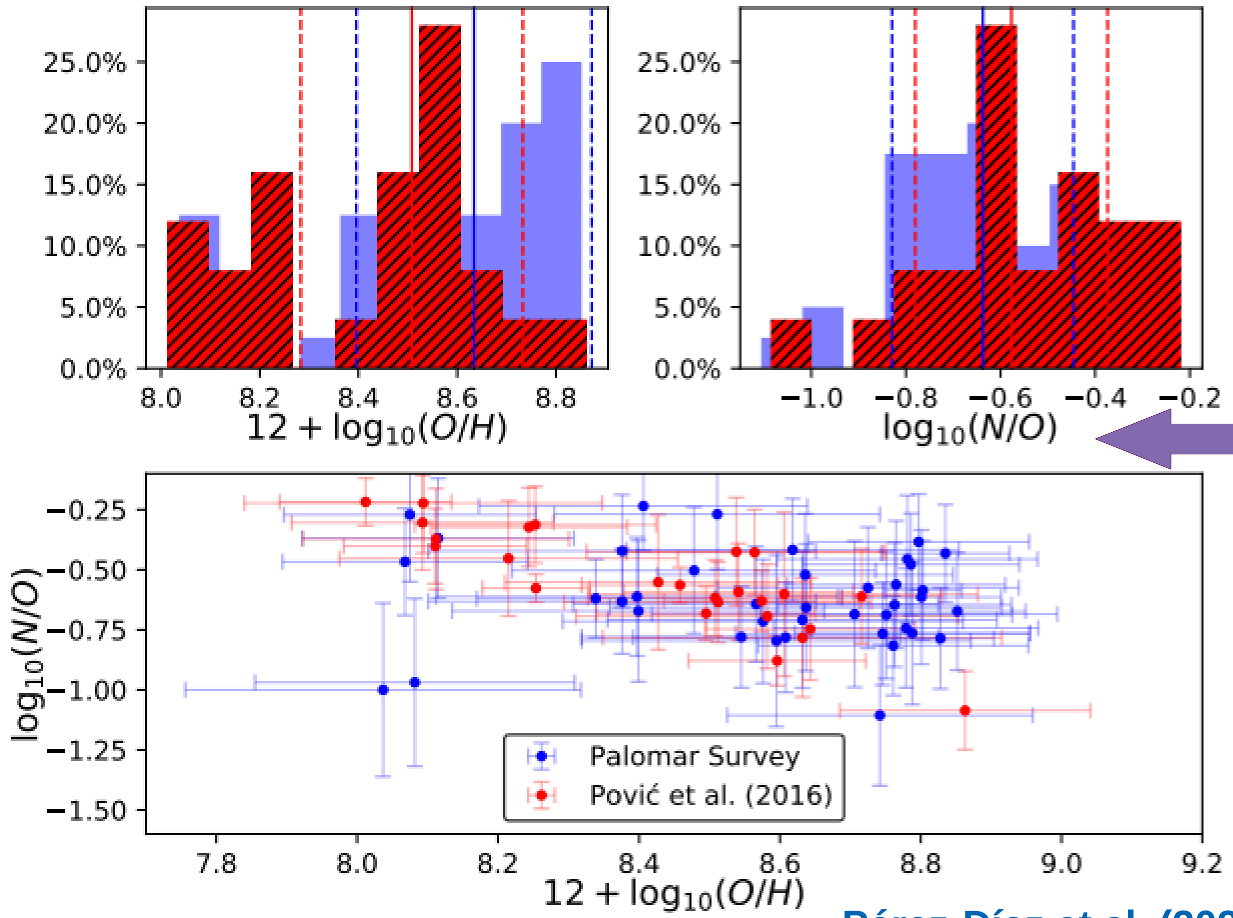
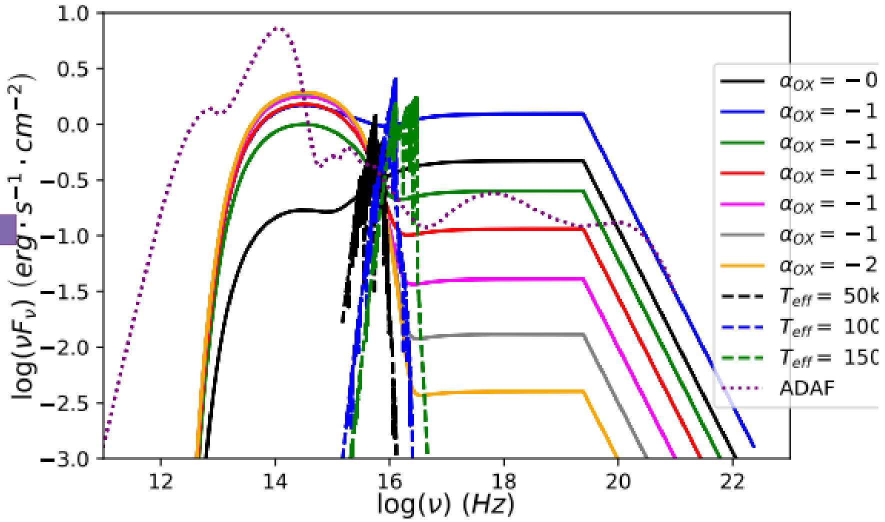


Pérez-Díaz et al. (2021)



Pérez-Díaz et al. (in prep.)

Index

Takeaway messages

1- **HII-CHI-Mistry-IR (HCm-IR)** allows us the estimation of **12+log(O/H), log(N/O) and log(U)** based only on IR emission lines and without assuming any relation.

2- Our methodology can be applied for both, **AGN and SFG**, accounting for their differences. HCm-IR is a versatile tool that can be **used in large sample** of galaxies.

3- We obtain that IR estimations of chemical abundances **tend to be lower than those retrieved** from optical emission lines, in agreement with previous studies.

4- AGNs are characterized mainly by **solar and subsolar chemical** abundances, although some of them present suprasolar abundances when optical emission lines are used.

Thank you for your attention!

"Basically all models are wrong, but some of them are useful"

George Box (1919-2013)