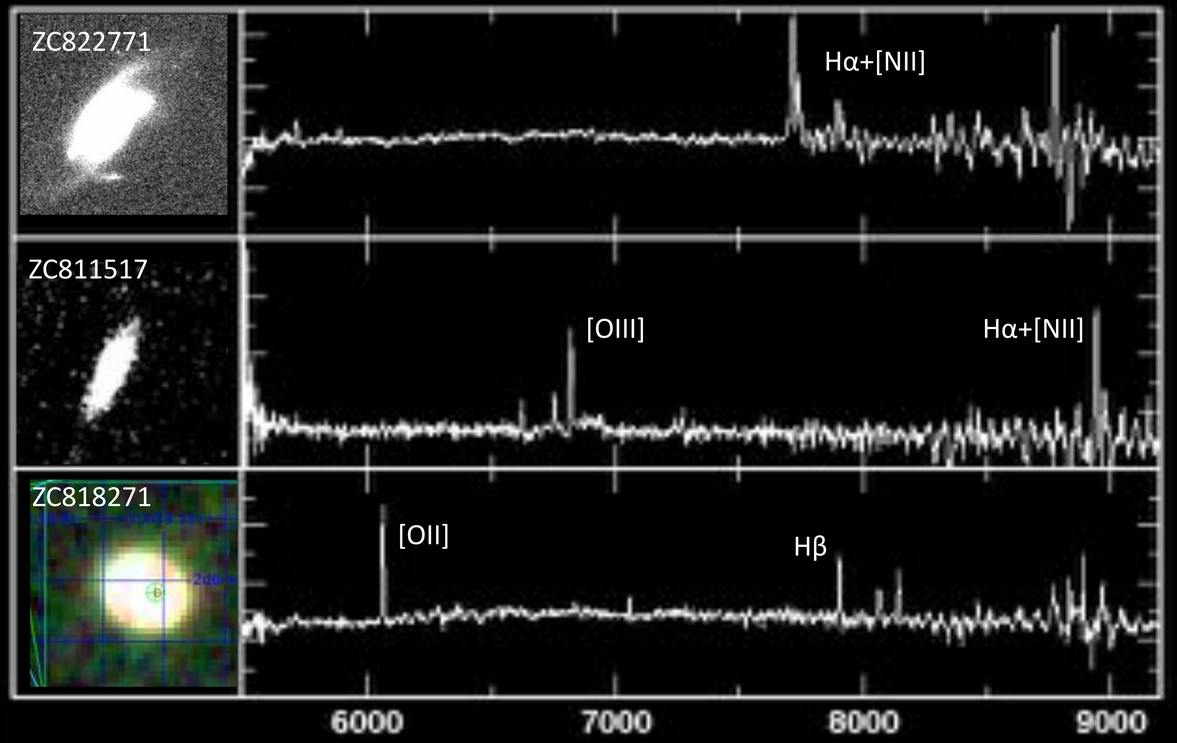
HII-CHI-mistry-IR: Deriving chemical abundances in star-forming galaxies using infra-red emission lines

E. Pérez-Montero, J.A. Fernández-Ontiveros, J.M. Vílchez,
R. Amorín, B. Pérez-Díaz, L. Spinoglio
Instituto de Astrofísica de Andalucía - CSIC

Why models are useful to derive Z?

Models complement observations in order to:

- **Derive total abundances from some ionic fractions (i.e. ICF)**
- **Deerive all functional parameters (Z, Teff, U, dust, leaking)**
- **Compare objects or regions consistently with different observational coverage**



The importance of nitrogen

The knowledge of the N/O ratio can complement that of O/H, since N/O gives extra information about the SFE and it is relatively independent of hydrodynamical effects

Additionally, when [NII] lines are used to derive O/H a previous determination of N/O is essential

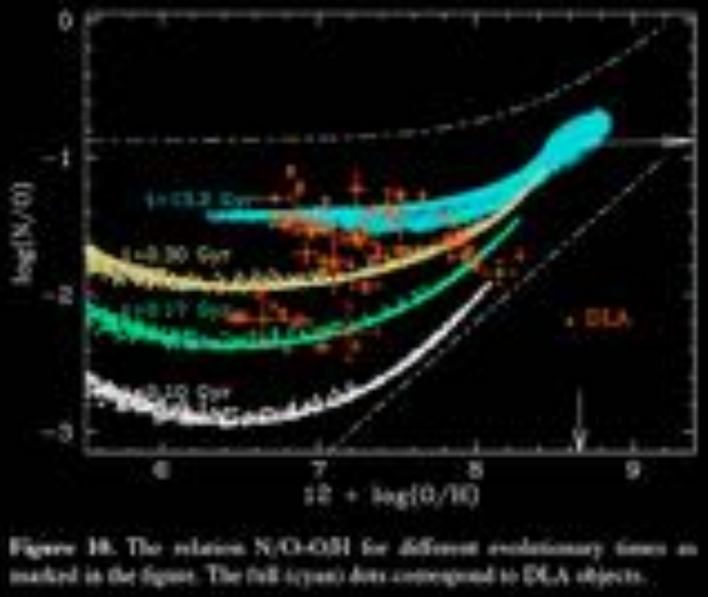
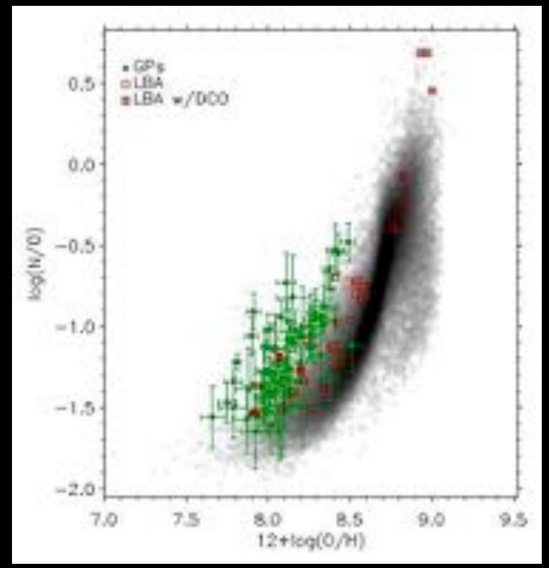


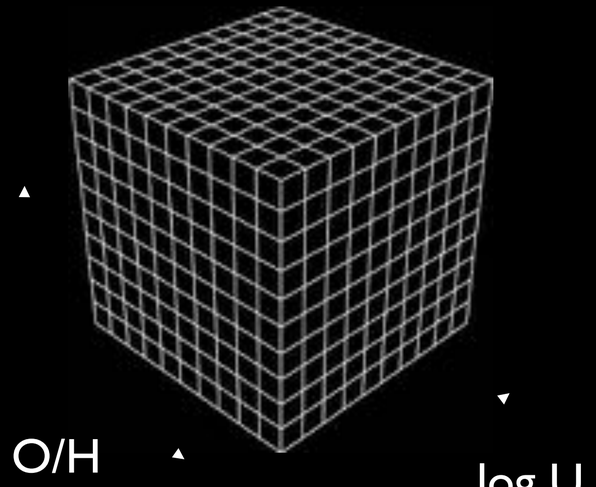
Figure 10. The relation N/O-O/H for different evolutionary times as marked in the figure. The full (cyan) dots correspond to DLA objects.

Mollá et al. (2006)



Amorín et al. (2010)

Abundance derivation: HII-CHI-mistry



HCm

Model-based abundances with HII-CHI-mistry (Pérez-Montero 2014)

- Cloudy v. 17.00 (Ferland et al. 2017)
- POPSTAR (Mollá et al. 2010) model stellar atmospheres (same Z as the gas, age = 1 Myr, Chabrier IMF)
- Constant density
- Radiation-bounded geometry
- All elements scaled to O, except N
- Standard MW dust-to-gas ratio
- Variation of input parameter:
  - 12+log(O/H): [6.9, 9.1] 0.1bin
  - log(N/O): [-2.0,0.0] 0.125bin
  - log U: [-4.00,-1.50] 0.25bins

This gives a total of 3,927 models

HII-CHI-mistry: A new model-based tool to derive abundances

HII-CHI-mistry (Pérez-Montero 2014, http://www.iaa.es/~epm/HII-CHI-mistry.html) is a code to derive O/H, N/O and log U using a χ2 weighted mean of the differences with the reddening corrected [OII], [OIII] (4363 and 5007), [NII] and [SII] optical emission lines.

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

STEP 1

N/O is calculated using as observables adequate emission-line ratios (e.g. N2O2, N2S2) insensitive to O/H and U

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

Errors are calculated as the standard deviation of the weighted distribution

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

STEP 2

The grid of models is constrained for the closest values of N/O and [NII[can be used in a new iteration to derive O/H and log U in a similar way.

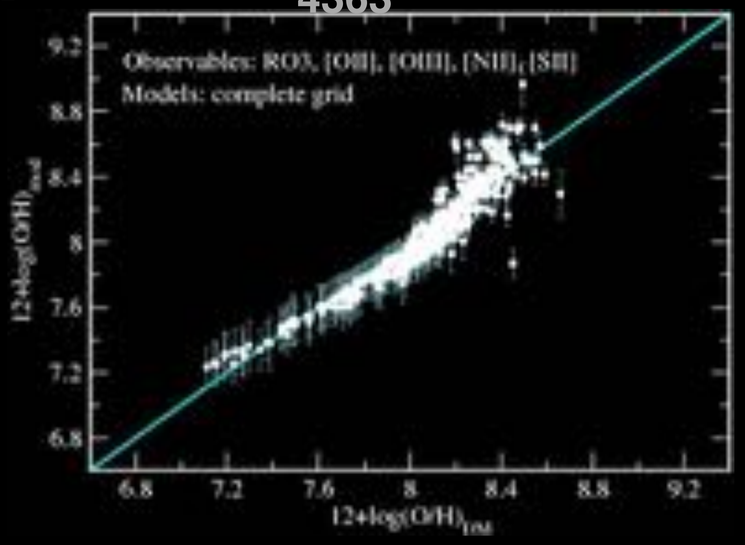
$$12 + \log(O/H)_f = \frac{\sum_k (12 + \log(O/H))_k/\chi_k}{\sum_k 1/\chi_k}$$

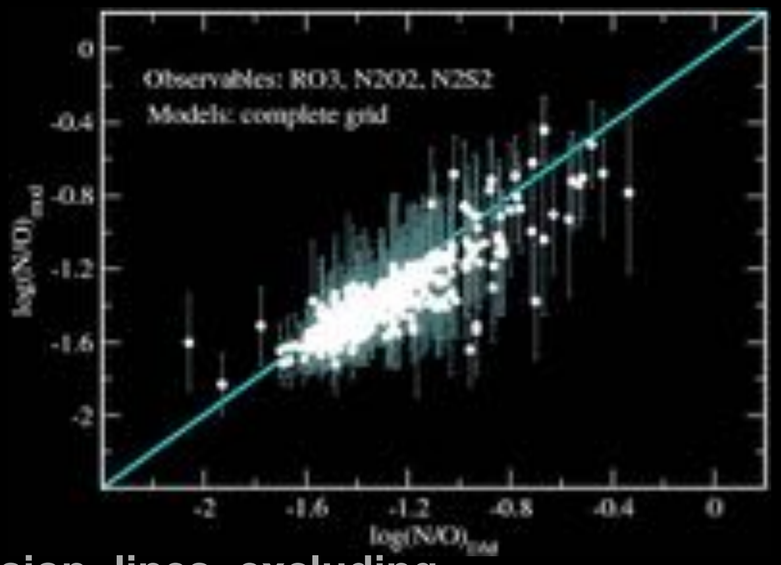
$$\log U_f = \frac{\sum_k \log U_k/\chi_k}{\sum_k 1/\chi_k}$$

HCm

Full consistency between HCM and the direct method

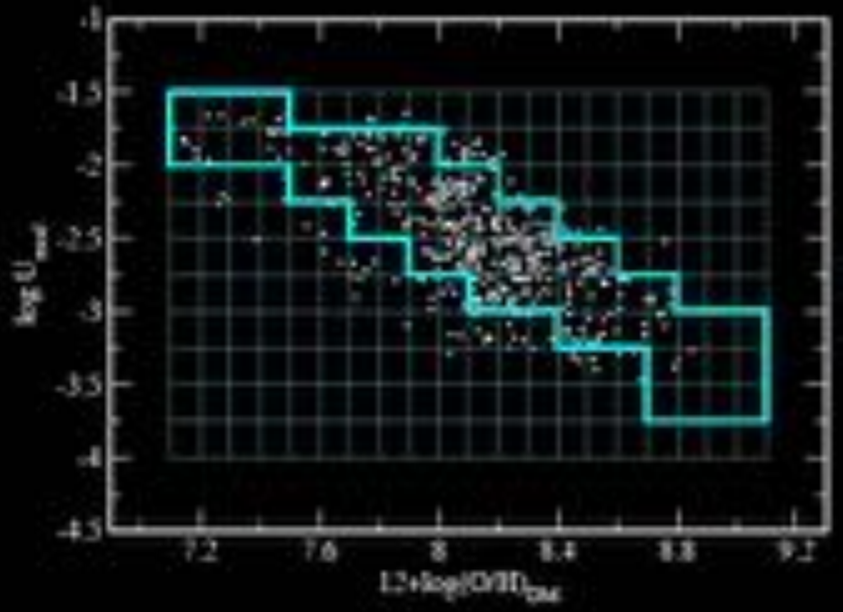
Comparison using all emission lines including [OIII] 4363

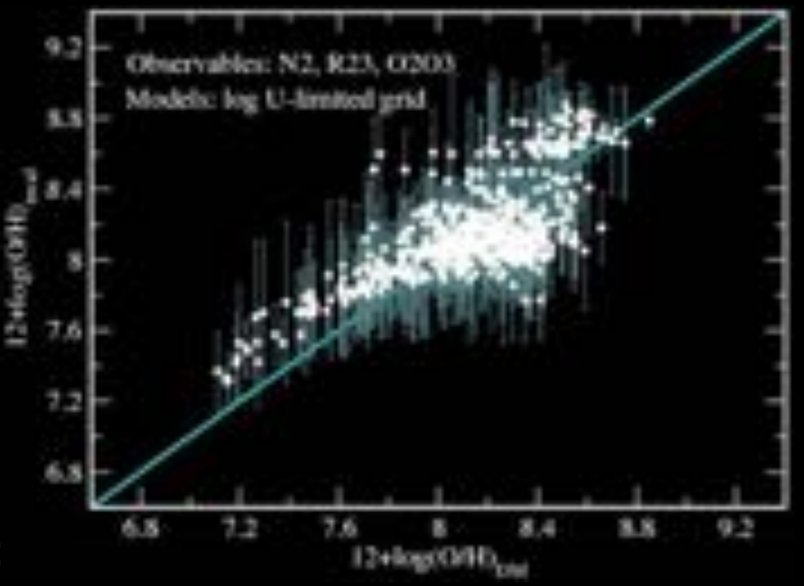




HCM

Comparison using all emission lines excluding



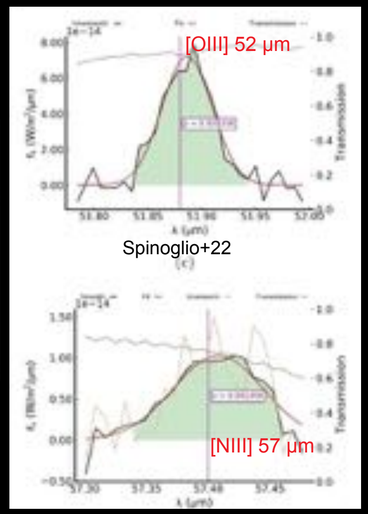


Why IR lines?

Archival data from...

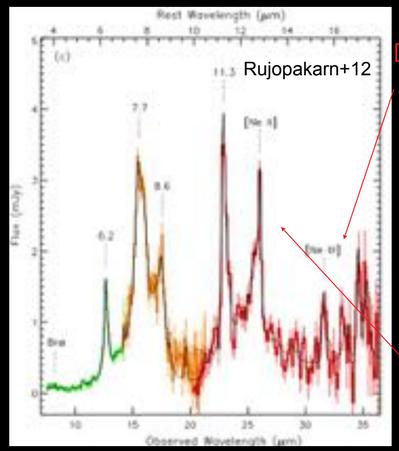
Chemical abundances in nearby galaxies

SOFIA: 50 – 205 μm



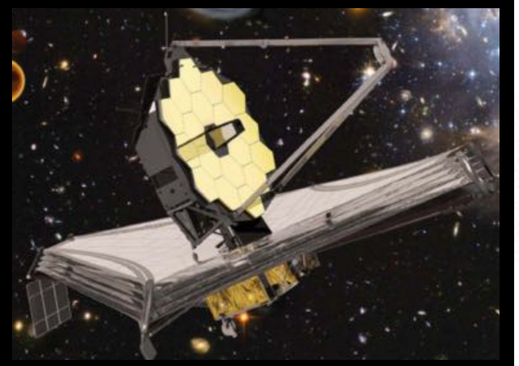
Spinoglio+22

Spitzer: 5 – 39 μm

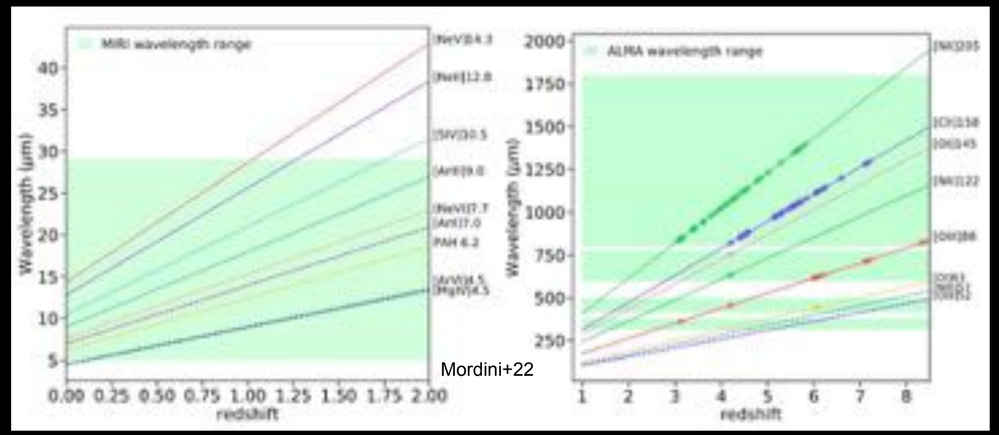


+ other facilities: ISO, HST

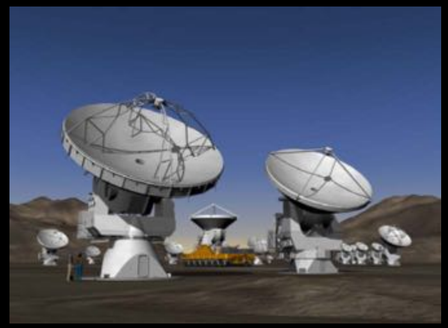
And newcoming data from...



JWST: 4.9 – 28.9 μm

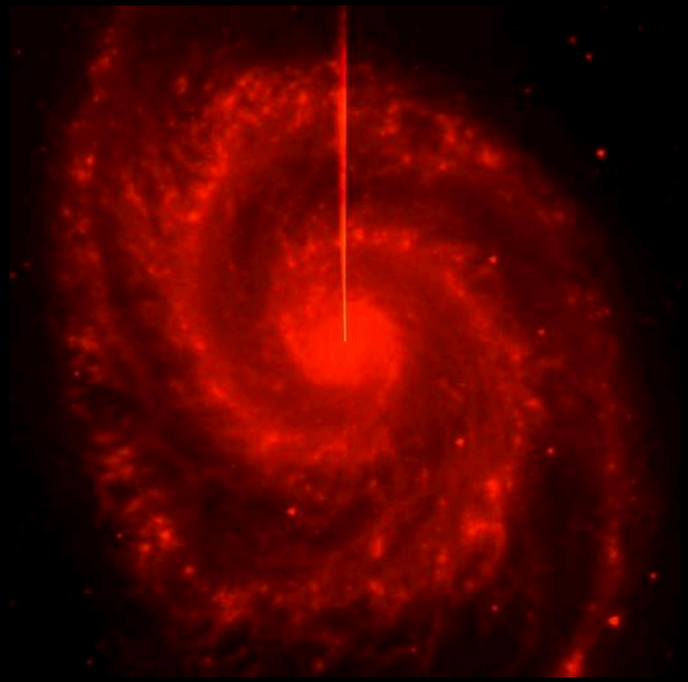


Mordini+22

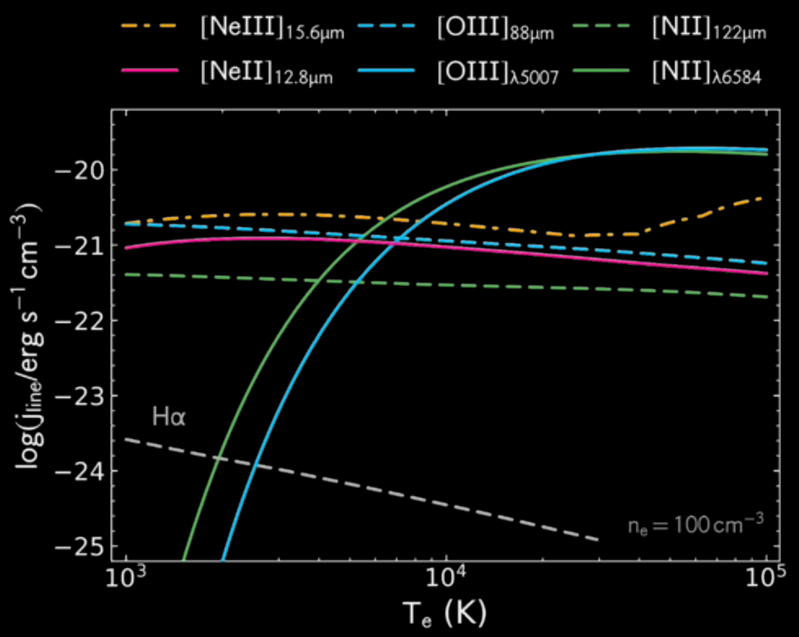


ALMA: 0.3 – 3 mm

Why IR lines?

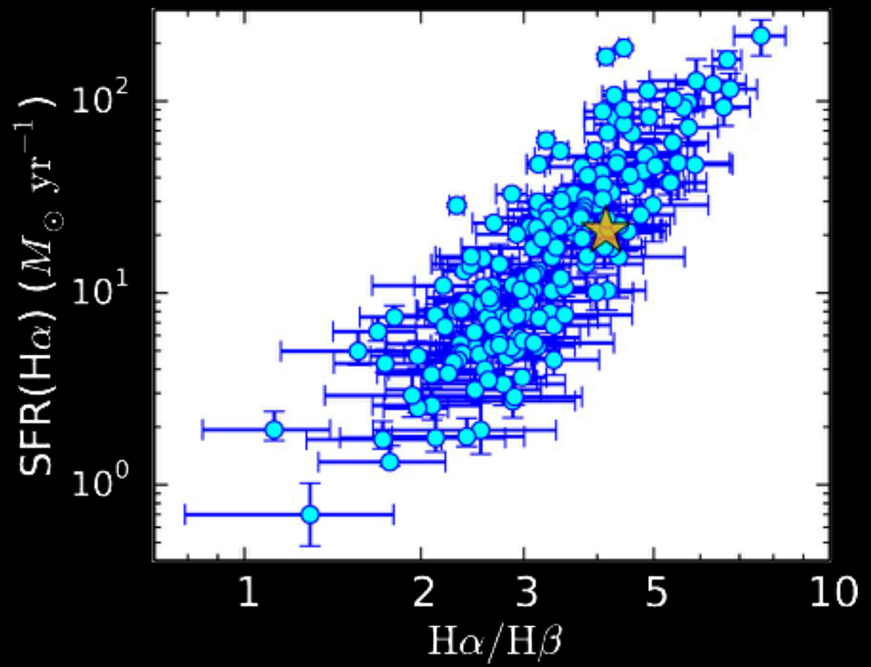


Why IR lines?



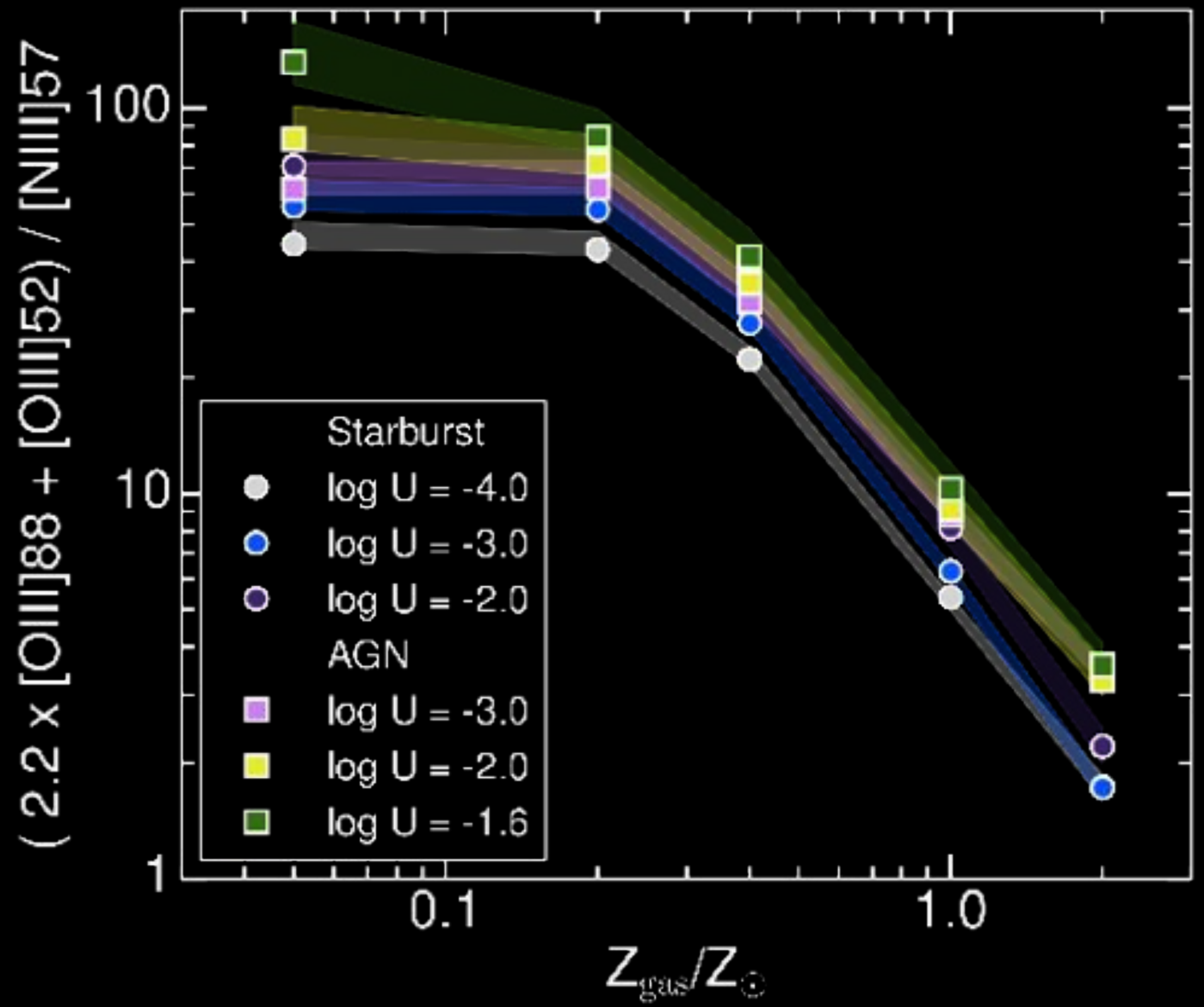
Reddy et al (2015)

Fine estructure IR lines have little dependence on temperature, so no ADF are expected.



Since the IR range is less affected by dust absorption, IR lines can trace better the gas properties in dense Str clouds.

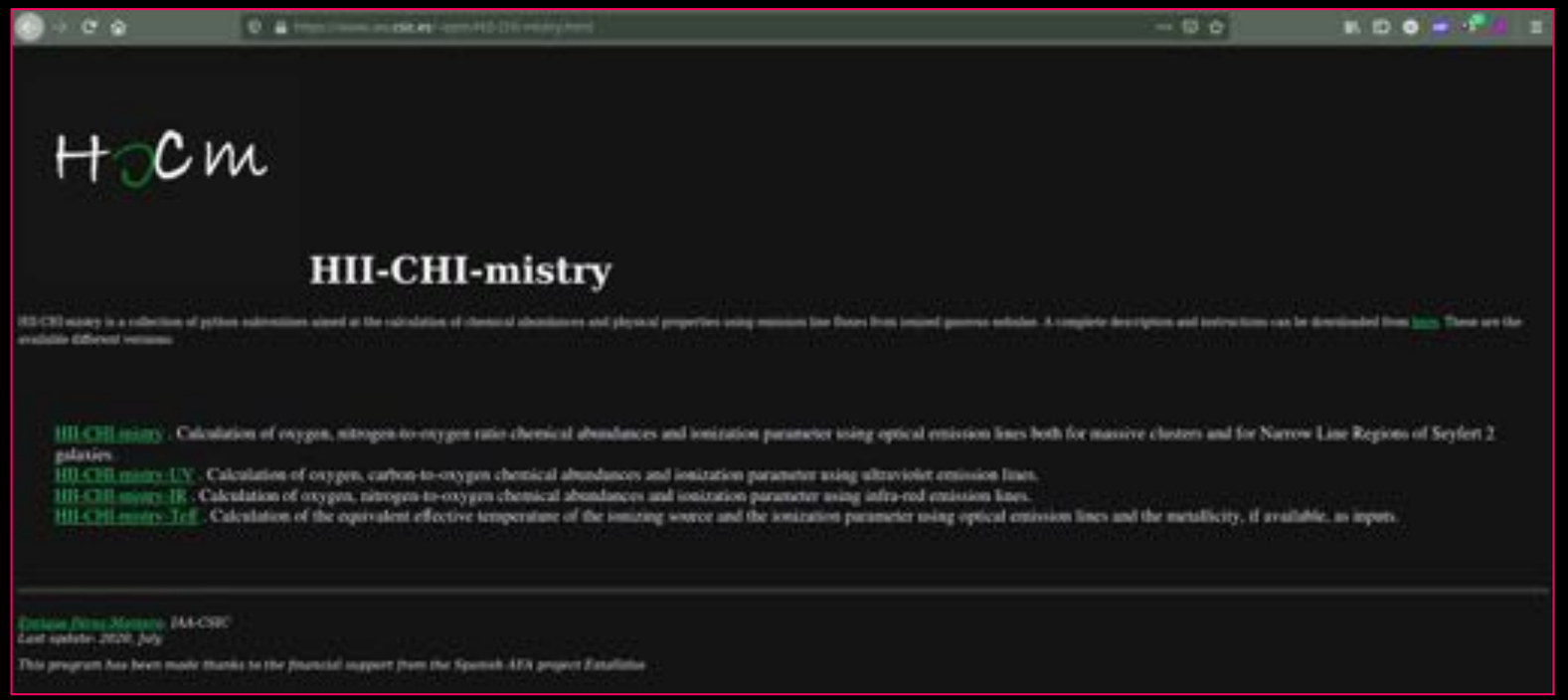
Not many Z indicators in the IR



Pereira-Santaella (2017)

… but remember N2O2 for the optical, are they really estimating O/H?

HII-CHI-mistry for IR



Nebular IR lines:
$[NeII]_{12.8}$ $[NeIII]_{15.6}$ $[SIII]_{18.7,33.5}$ $[SIV]_{10.5}$ $[OIII]_{52,88}$ $[NIII]_{57}$ $[NII]_{122,205}$

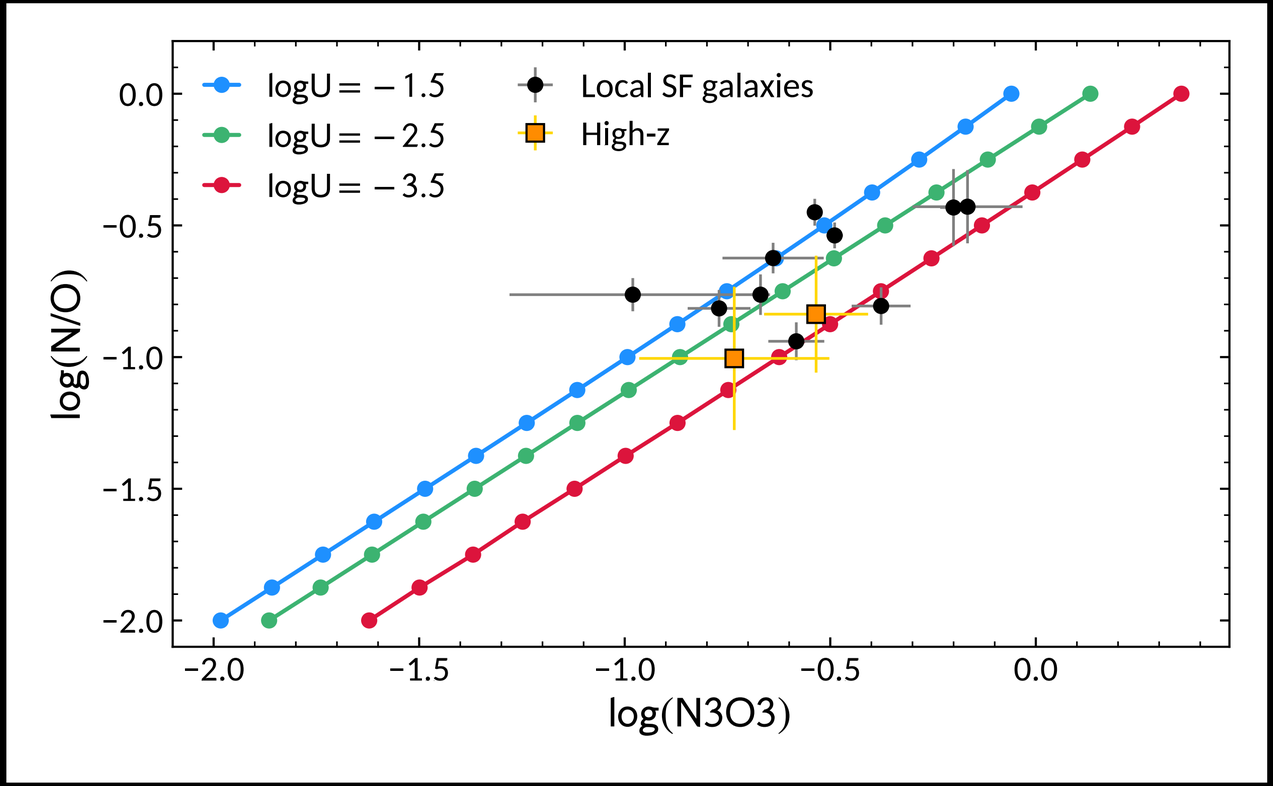
Faint H recombination lines:
Brα 4.05μm, Pfα 7.46μm, Huα 12.4μm

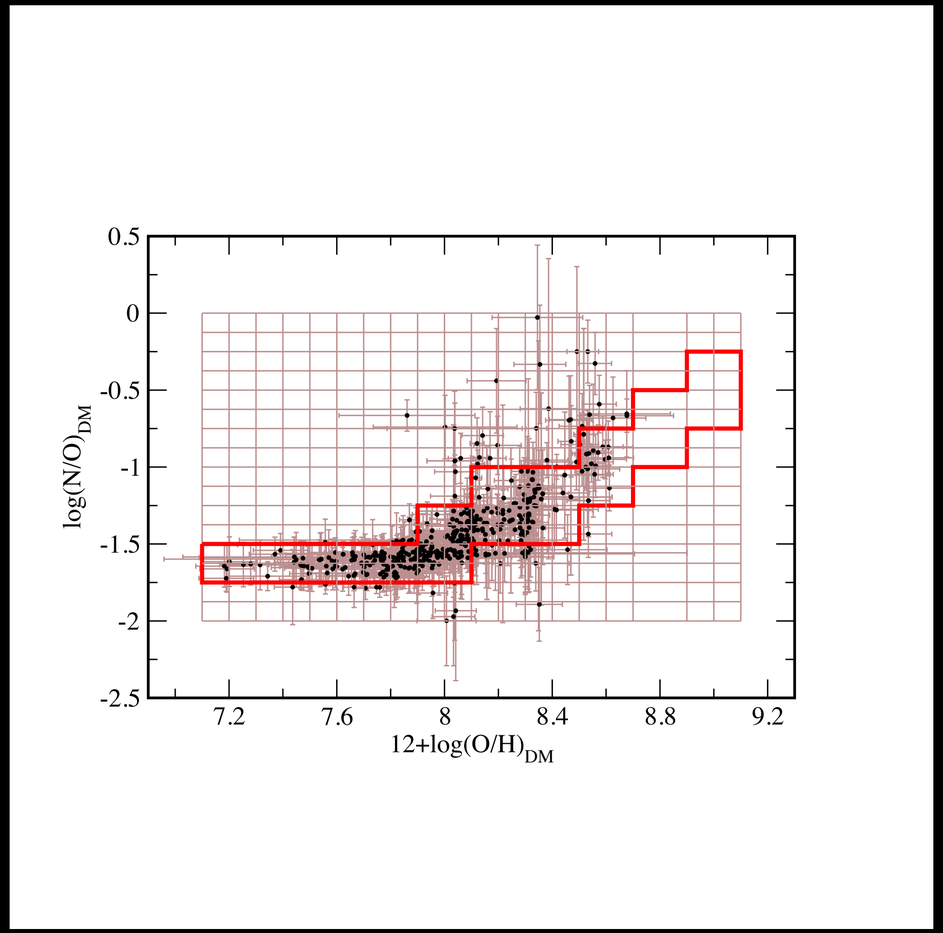
4301 photoionisation models (O/H, N/O, logU)
Based on HII-CHI-MISTRY (Pérez-Montero 2014)

O/H - logU consistent with DM

Details in Fernández-Ontiveros, Pérez-Montero+21

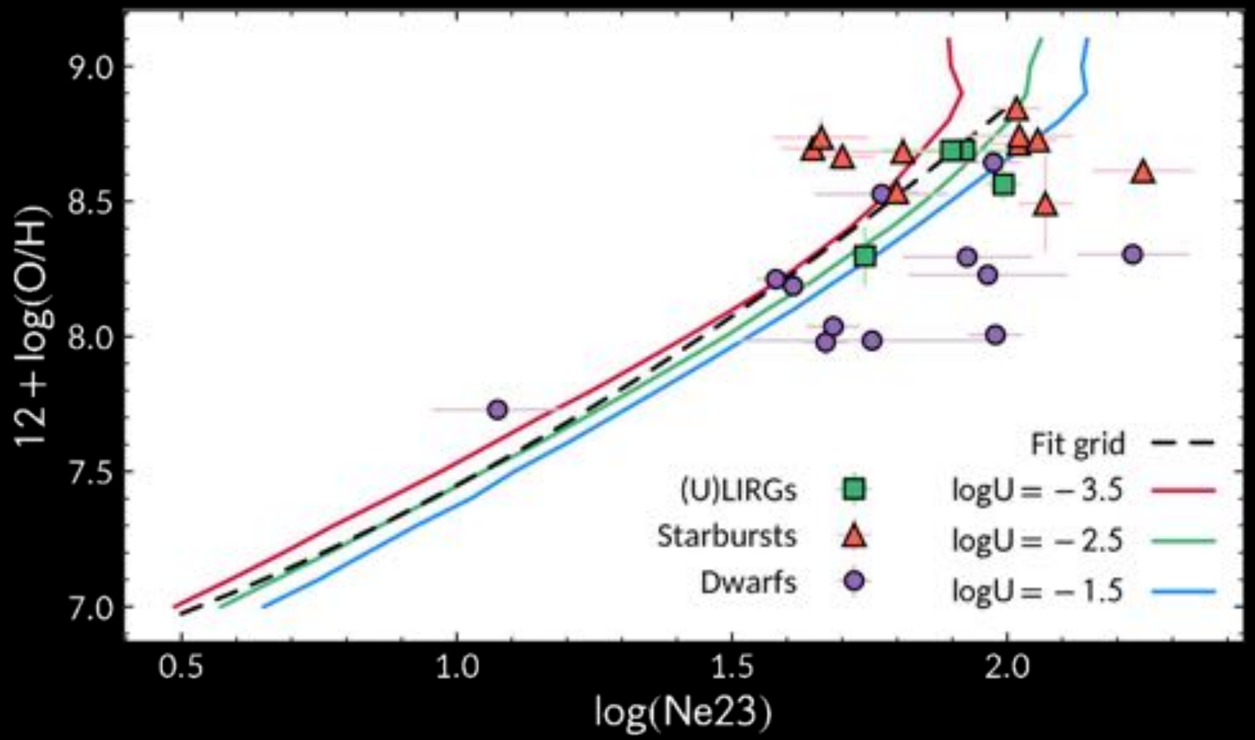
The question of nitrogen in the IR

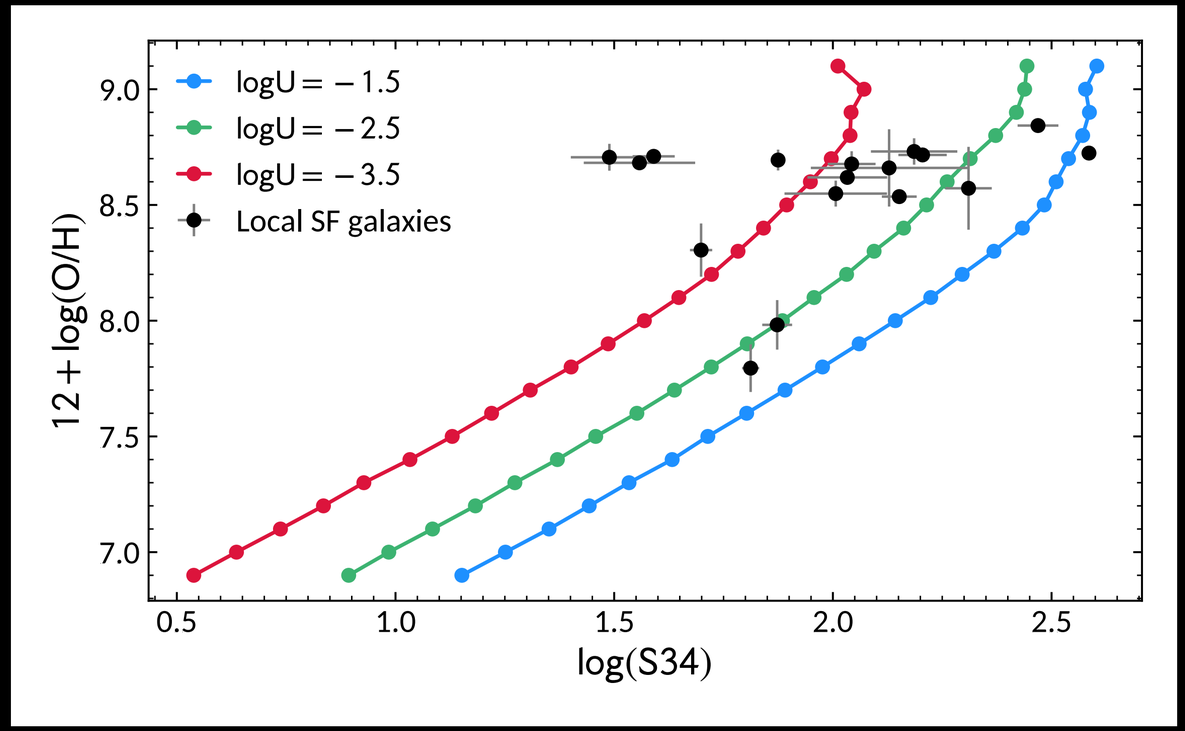




In a first step, N/O is fixed in the grid. If N3O3 (or N3S3) is given, an arbitrary O/H-N/O is used.
Notice that in the las t versions of HCm, this law can be edited.

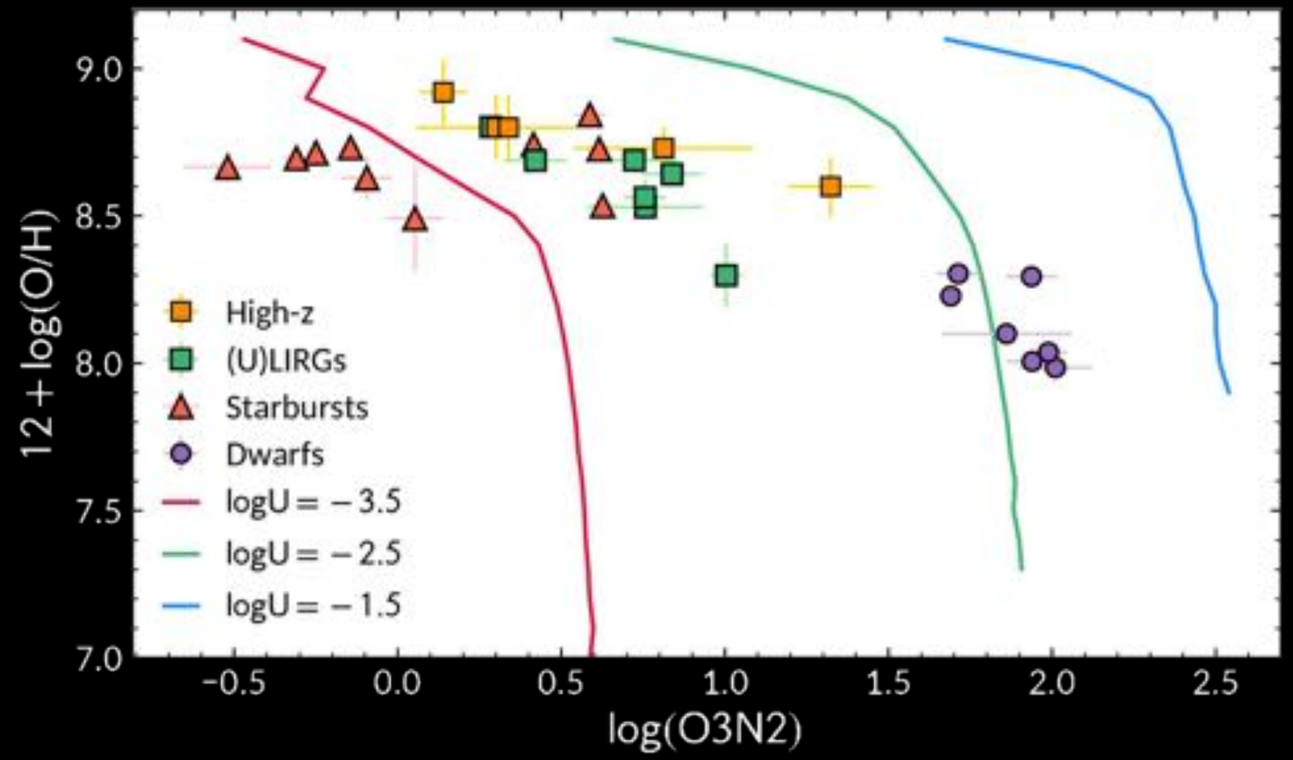
Defining observables for O/H

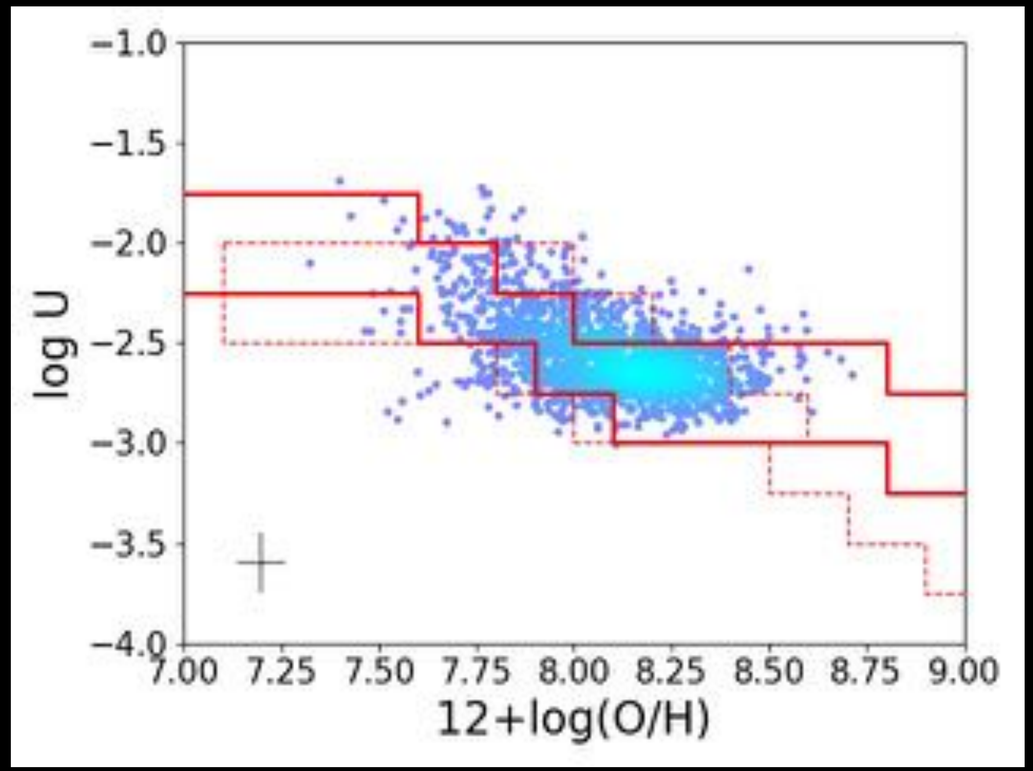




Once N/O is fixed, the code uses other lines to derive O/H and U.
In upcoming versions S34 will be used to derive independently S(H.

Exploiting excitation as a proxy for Z





When no HI line is given, the code uses the O/H-U relation, based on ratios such as Ne2Ne3, S3S4 or O3N2. Notice that this relation can be also edited in the last versions.

Data compilation in the IR

Local sample **64 galaxies** with **mid-** to **far-IR lines** (Spitzer + Herschel)
Wide metallicity range: **12 + log(O/H) ~ 7.2 - 8.9**

28 dwarfs, low-metallicity (Madden+13,Cormier+15)

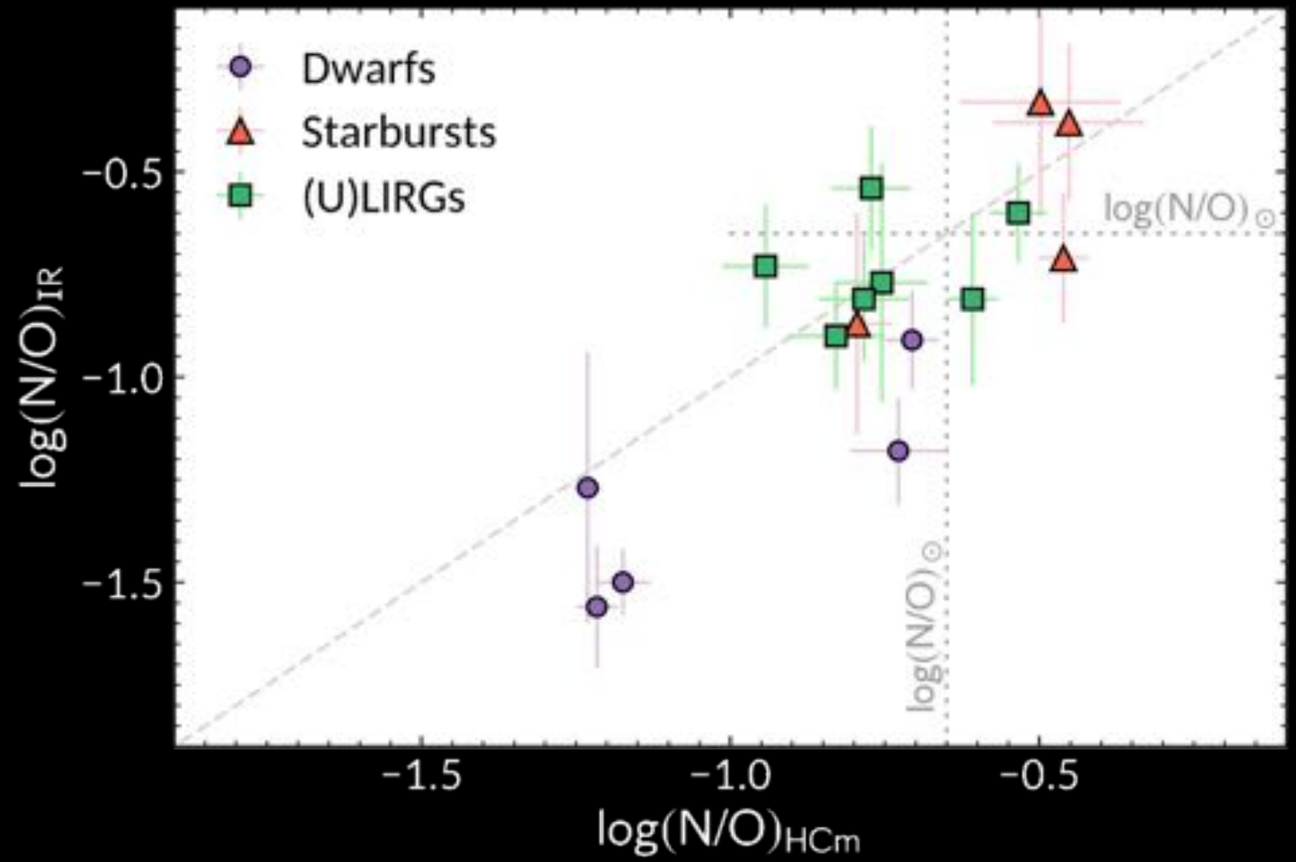
19 solar-like **starbursts** (Fernández-Ontiveros+16)

9 (U)LIRGs (Pereira-Santaella+17)

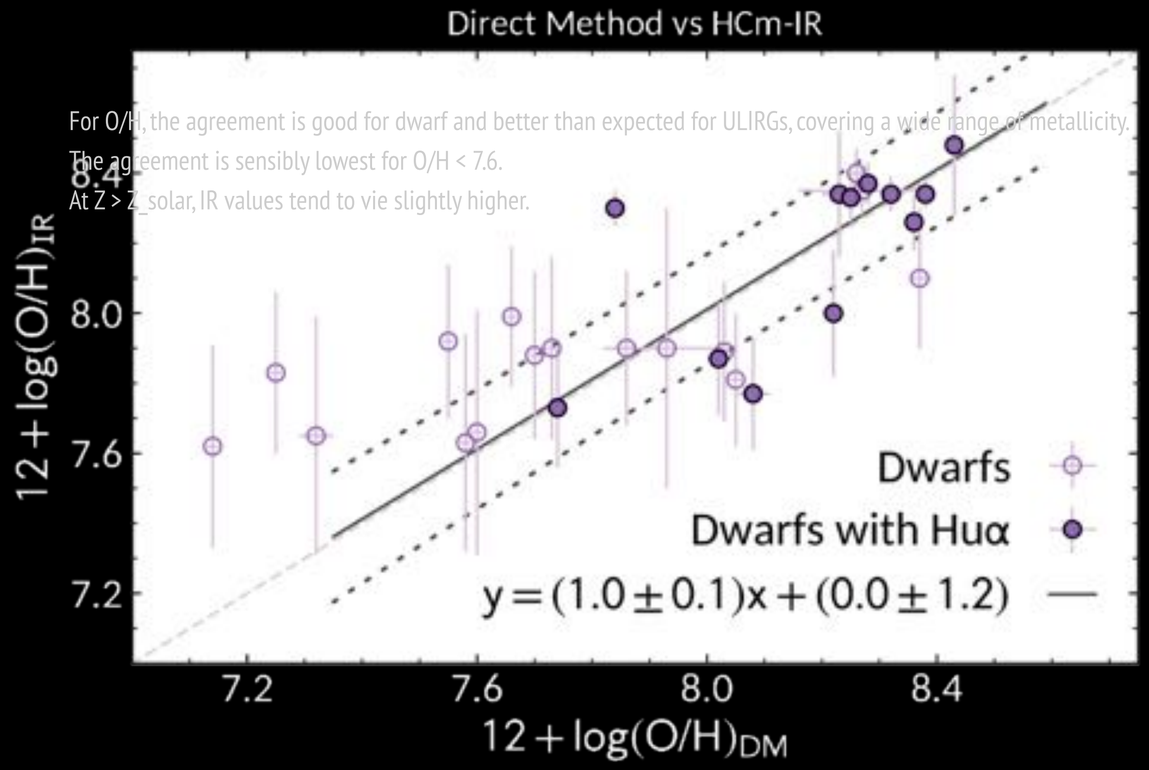
8 High-z galaxies ($1.8 < z < 7.5$)
(ALMA, Herschel, APEX, etc.)

Comparison with optical abundances

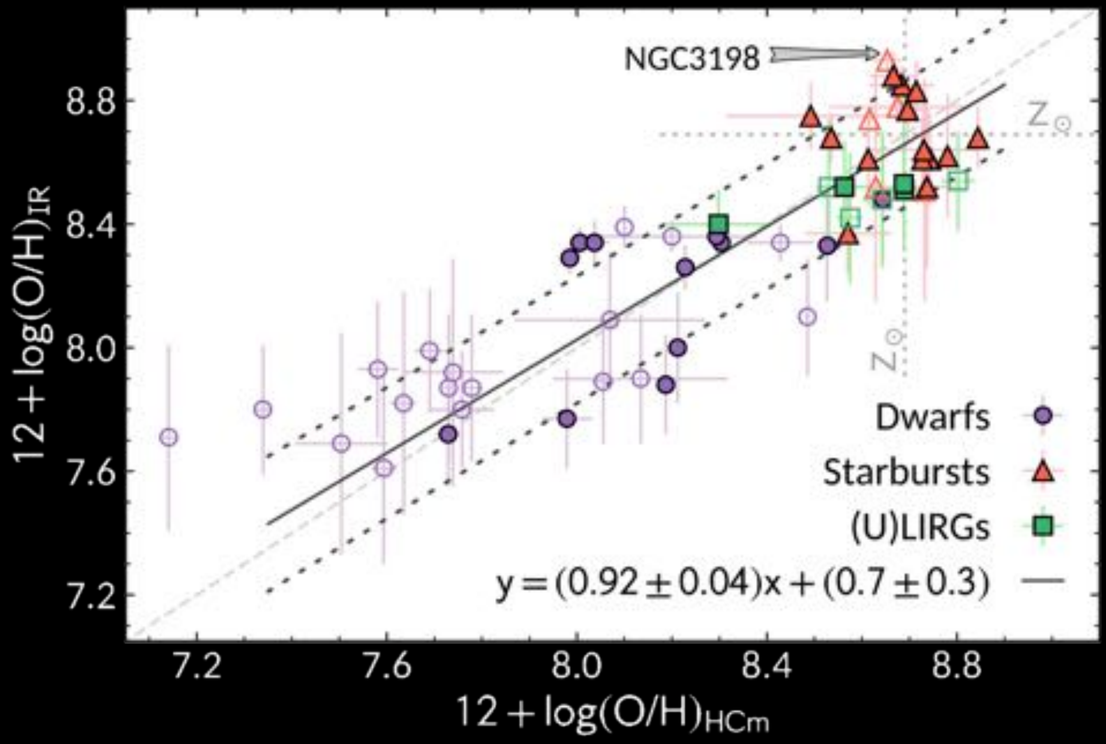
Although the statistics is poor for N/O (only 10 objects), the agreement between IR and optical is good.



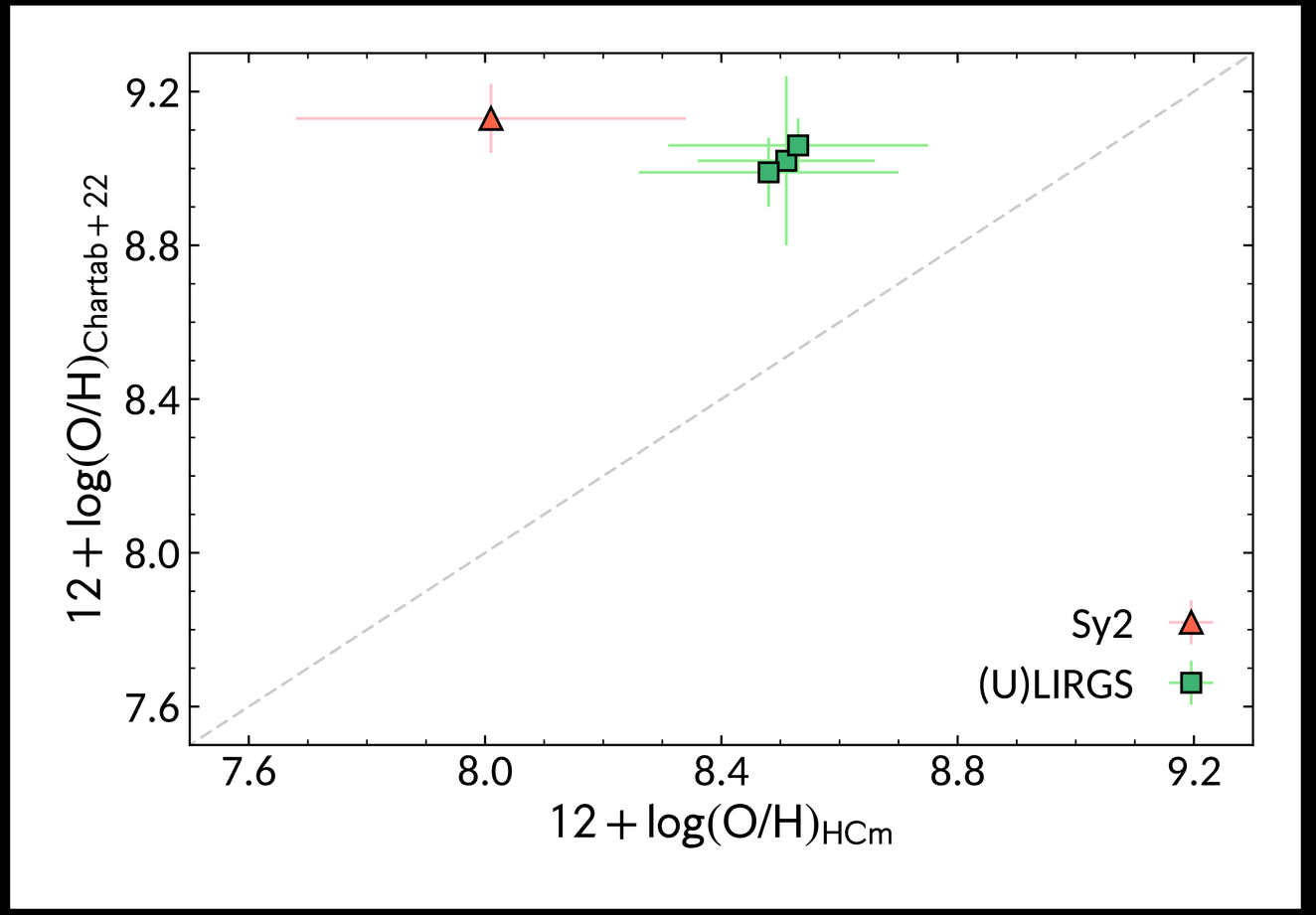
Comparison with optical abundances



For O/H, the agreement is good for dwarf and better than expected for ULIRGs, covering a wide range of metallicity.
The agreement is sensibly lowest for O/H < 7.6.
At Z > Z_solar, IR values tend to vie slightly higher.



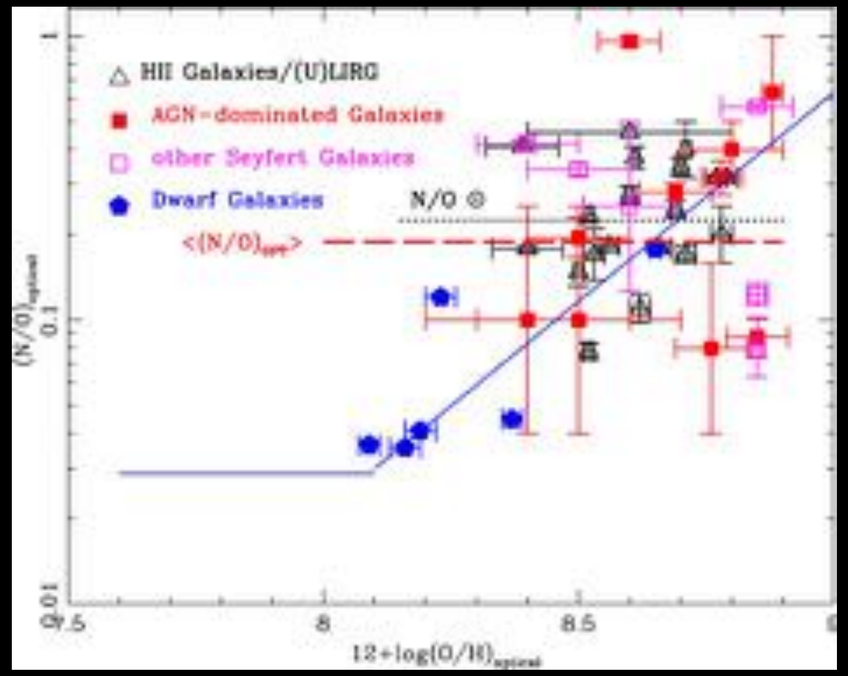
The effect of N in ULIRGs

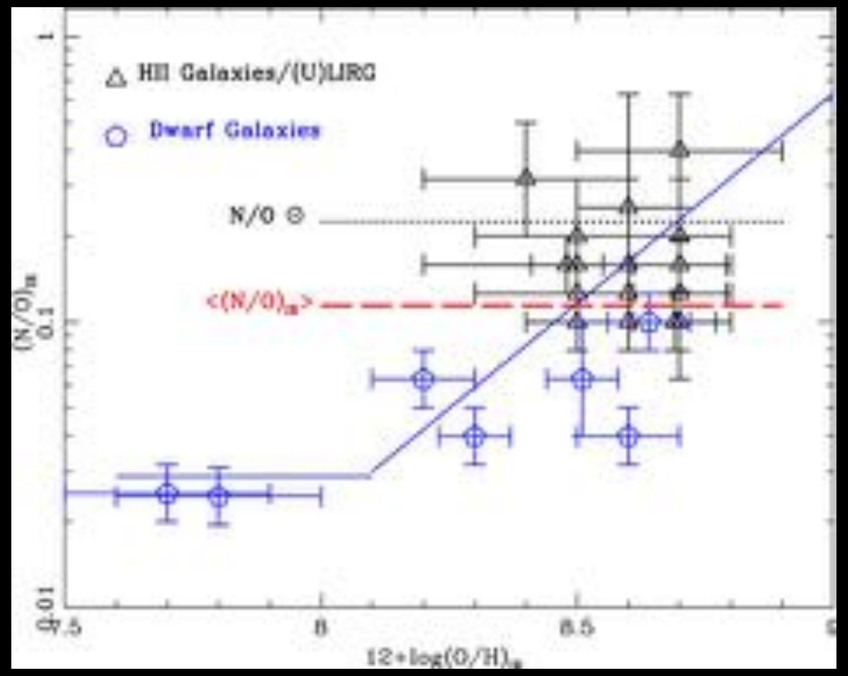


Assuming very high N/O ratios have important consequences for Z derivation when N3O3 is used. Z values from Chartab+22 assuming a Charlot & Longhetti (2001) relation between O/H and N/O lead to metallicities around 0.5 dex higher for ULIRGS.

Results from SOFIA

Spinoglio et al. (2022)





[NIII] and [OIII] mid-IR from archival SOFIA leads to systematic lower (~0.2 dex) N/O abundances as compared with the optical.
Extinction, DIG emission are discarded. Inner disk metal-poor accretion?

Summary and conclusions

- HCm provides chemical abundances in SF regions both for optical and IR consistent with the direct method.
- Ir lines present crucial advantages given their independence on temperature and extinction.
- As in the optical, HCm offers an unique solution to overcome the dependence of N IR lines on N/O
- It is difficult to establish a comparison between optical and IR lines as they are not tracing the same position in depth.

Thank you!

Measuring chemical abundances with infrared nebular lines: HII-CHI-MISTRY

J.A. Fernández-Ontiveros, E. Pérez-Montero, J. M. Vílchez, R. Amorín, L. Spinoglio

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HII-CHI-mistry-IR, along with version in the other spectral ranges, can be found in he web of HII-CHI-mistry at

http://www.iaa.es/~epm/HI-CHI-mistry.html

Enrique Pérez Montero

epm@iaa.es