Mapping multi-phase mixing of metals in Star Forming Galaxies: Insights from spatially-resolved UV and optical observations

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What are the spatial and timescales of metal mixing in the ISM of actively SFGs?

Are there significant localized variations in metals between the different gas phases?

Multiwavelength spatially resolved studies

Local, metal poor BDGs as laboratories to investigate metal enrichment

I Zw 18

Aloisi+2008

DDO 68

Sacchi+2016

NGC 5253

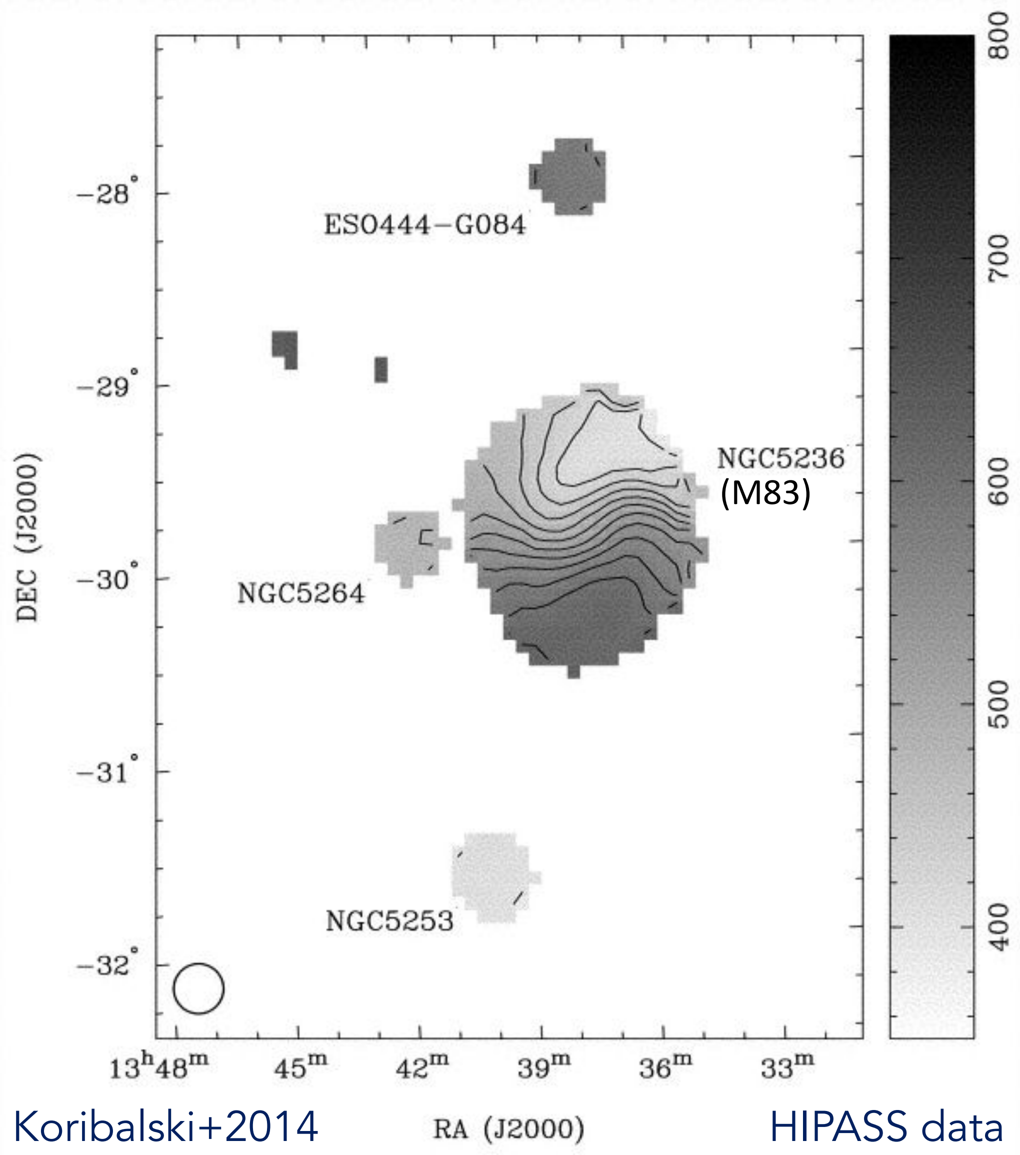
Monreal-Ibero+12, , Westmoquette +13, James+14, Calzetti+15

- Analogs of high-z systems in terms of Masses, metallicities and SFRs
- Nearby □ Allow high resolution imaging and spectroscopic studies at pc scales
- The bulk of the baryonic mass in BDGs is contained in the neutral gas phase
- Comparing multi-phase abundance allows to constrain on the mixing of heavy elements from SF episodes

NGC 5253 a local high-z analog

Physical characteristics reminiscent of a SFG at z~2-3 (Monreal-Ibero+2012)

- Morphology: Irr or SBm type, PA=43.3 and incl=85.4. Clumpy structure
- Distance: 3.77 Mpc □ z~0.001360
- Metallicity: 12+log(O/H)= 8.2, ~0.35 $Z_\odot$ (Lopez-Sanchez+2007, Monreal-Ibero+2012).
- Part of Centaurus A galaxy group with M83
- Diameter: 8.37 Kpc
- $M_* = 11.4 \times 10^8 M_\odot$ (Lopez-Sanchez+2012)
- SFR ~0.1 $M_\odot$/yr (Calzetti+2015)
- High localized N/O ratios (Westmoquette+2013)



NGC 5253: Excellent test for chemical abundance studies

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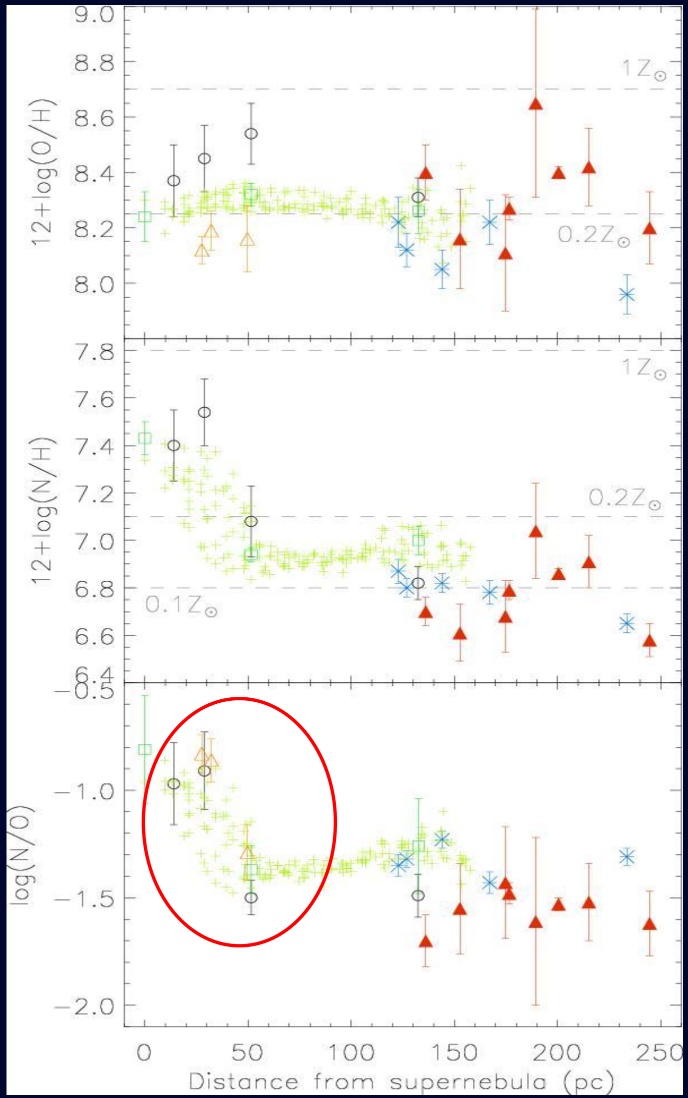
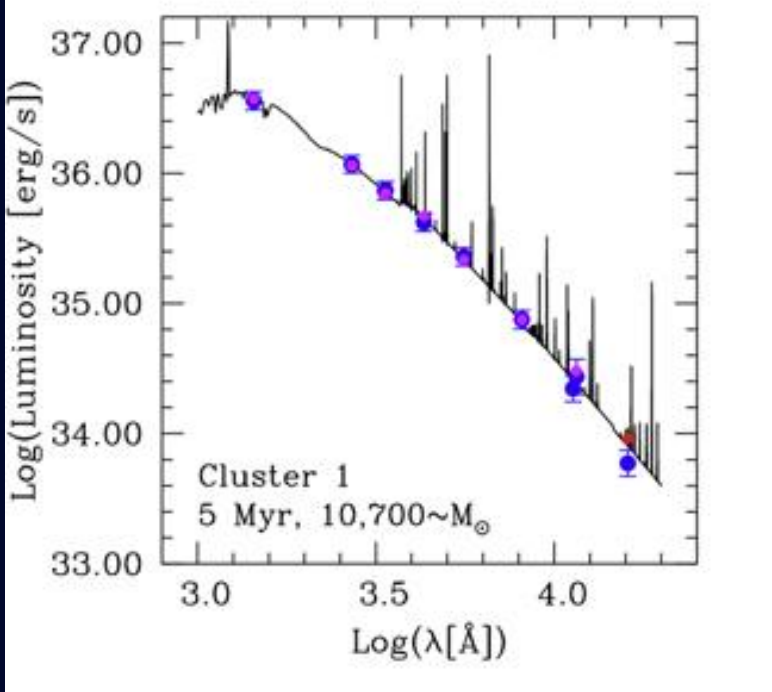


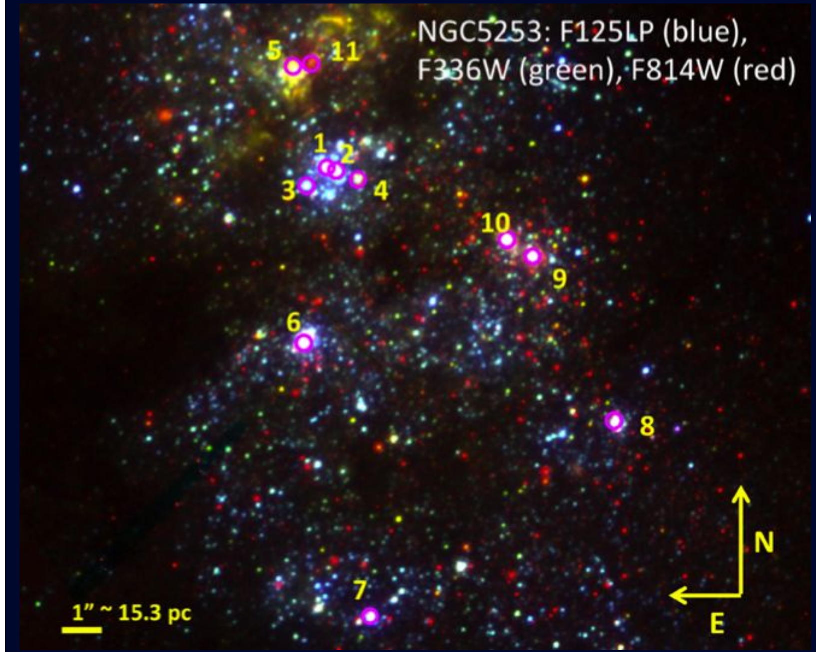
Westmoquette+13

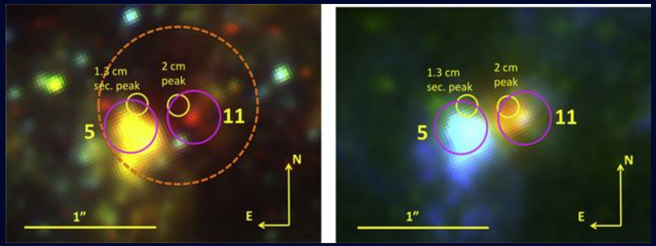
HIPASS data

Why NGC 5253 is an excellent target?

Calzetti+2015





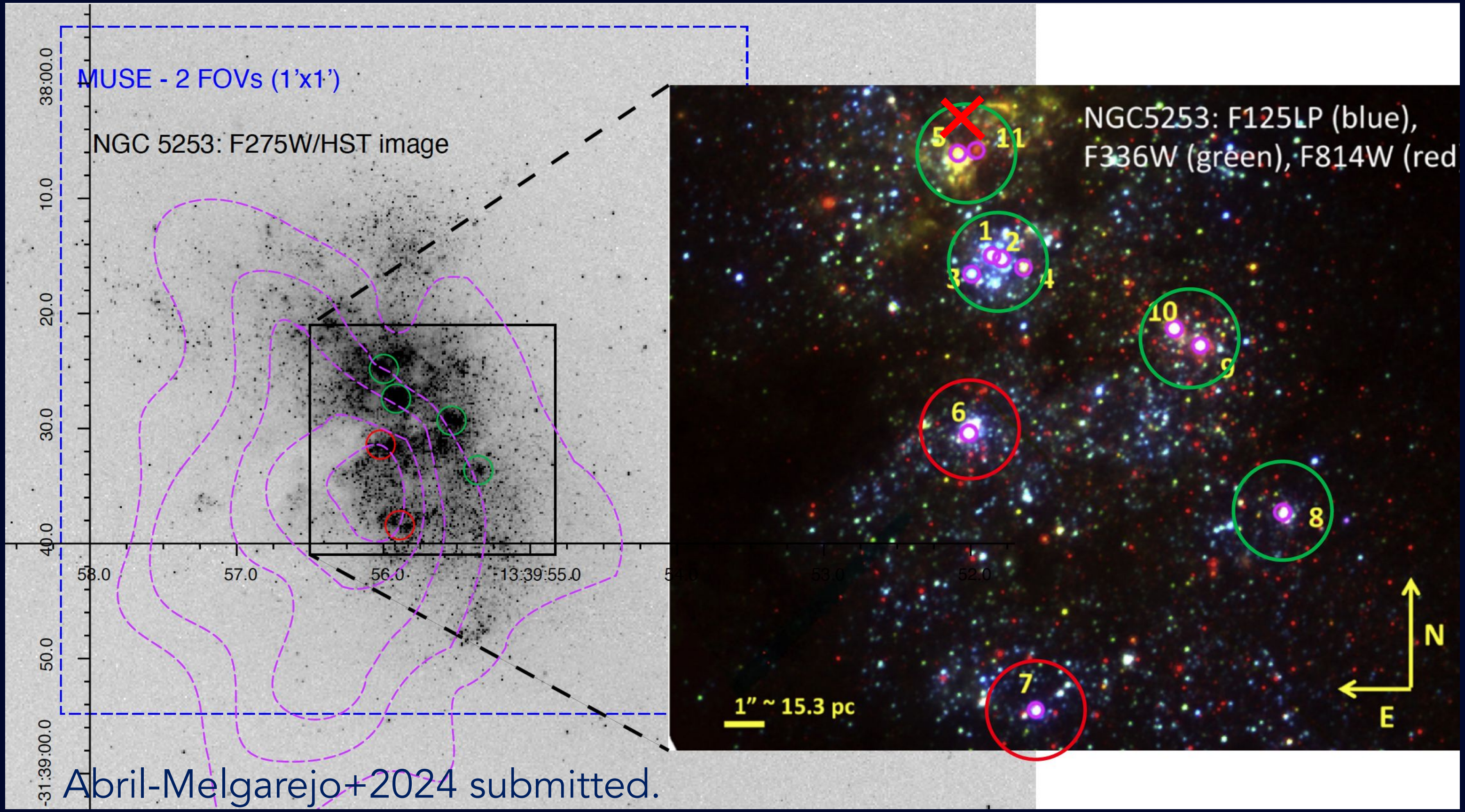


Using SED fitting on multiwavelength imaging on 11 bright UV stellar clusters

- Ages 1 -15 Myrs
- Masses 1 x 10^4 – 2.5×10^5 $M_\odot$
- Clusters radially distributed along the galaxy

The youngest (1Myr) and most massive clusters 5 and 11 are surrounded by a thermal radio emission nebula. Presence of VMS (Smith+2016).

COS-HST targets + MUSE-VLT coverage



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OBSERVATIONS

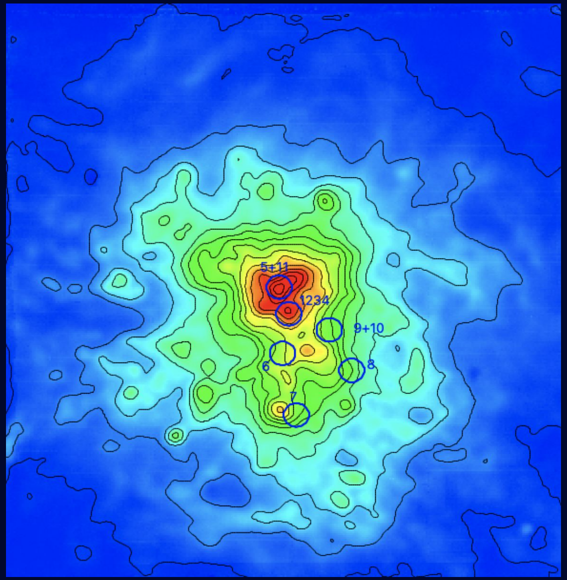
UV
- COS aperture: 2.5" diameter
- 6 COS targets using the set-up G130M / 1222, 1291
- Spectral coverage of ~1066 – 1430 A
- PIDs: 11579 and 15193 (PI: Aloisi), 16240 (PI: James)

Optical
- Archival MUSE datacube FoV of 1'x1'
- Spectral coverage of ~4750 – 9352 A
- ESO ID 094.B-0745 (PI. Garcia-Benito)

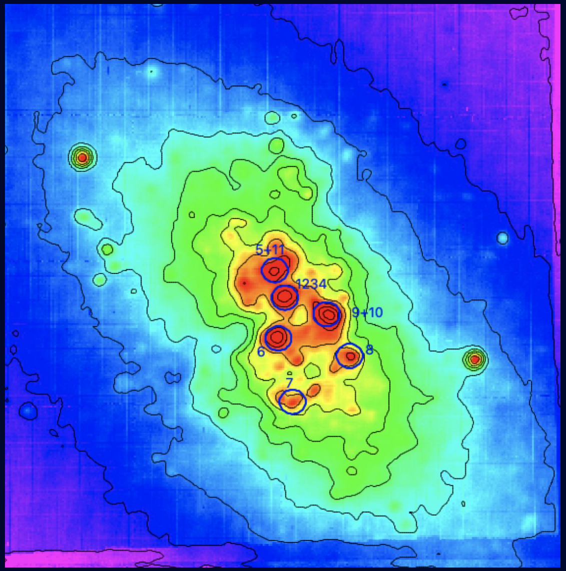
Goal: To perform a simultaneous analysis of the abundance distribution of individual Elements in the cold neutral and warm ionized phases.

MUSE-VLT optical data

MUSE Hα map



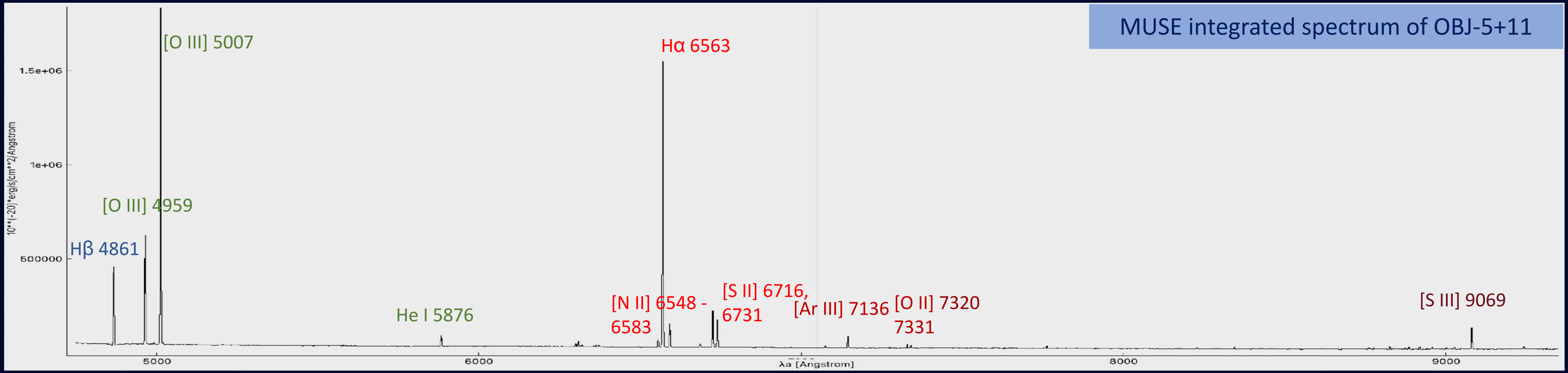
MUSE stellar continuum



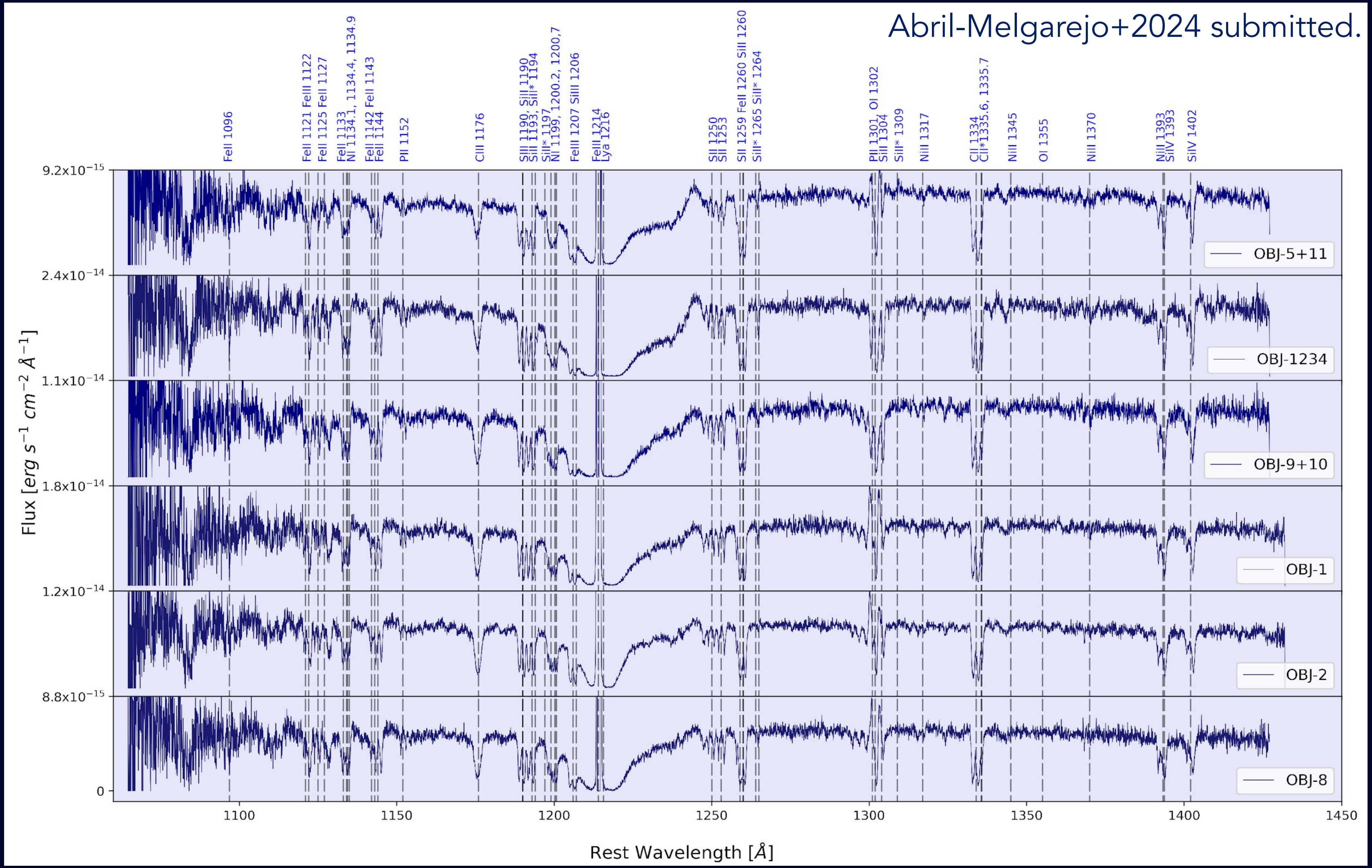
Ionized gas emission line fitting

Emission line fitting taking into account the absorption by the stellar populations (pPXF) and the dust reddening, using the Method described in Mingozzi+2022.

We used the direct method to compute chemical abundances from the integrated fluxes for each element



COS spectra



Coadded G130M, 1222+1291

Age (Myr)		D to center (pc)
1	VMS	23
5	WR s	53
9		103
10		119
10		225
15		179

Absorption Line fitting

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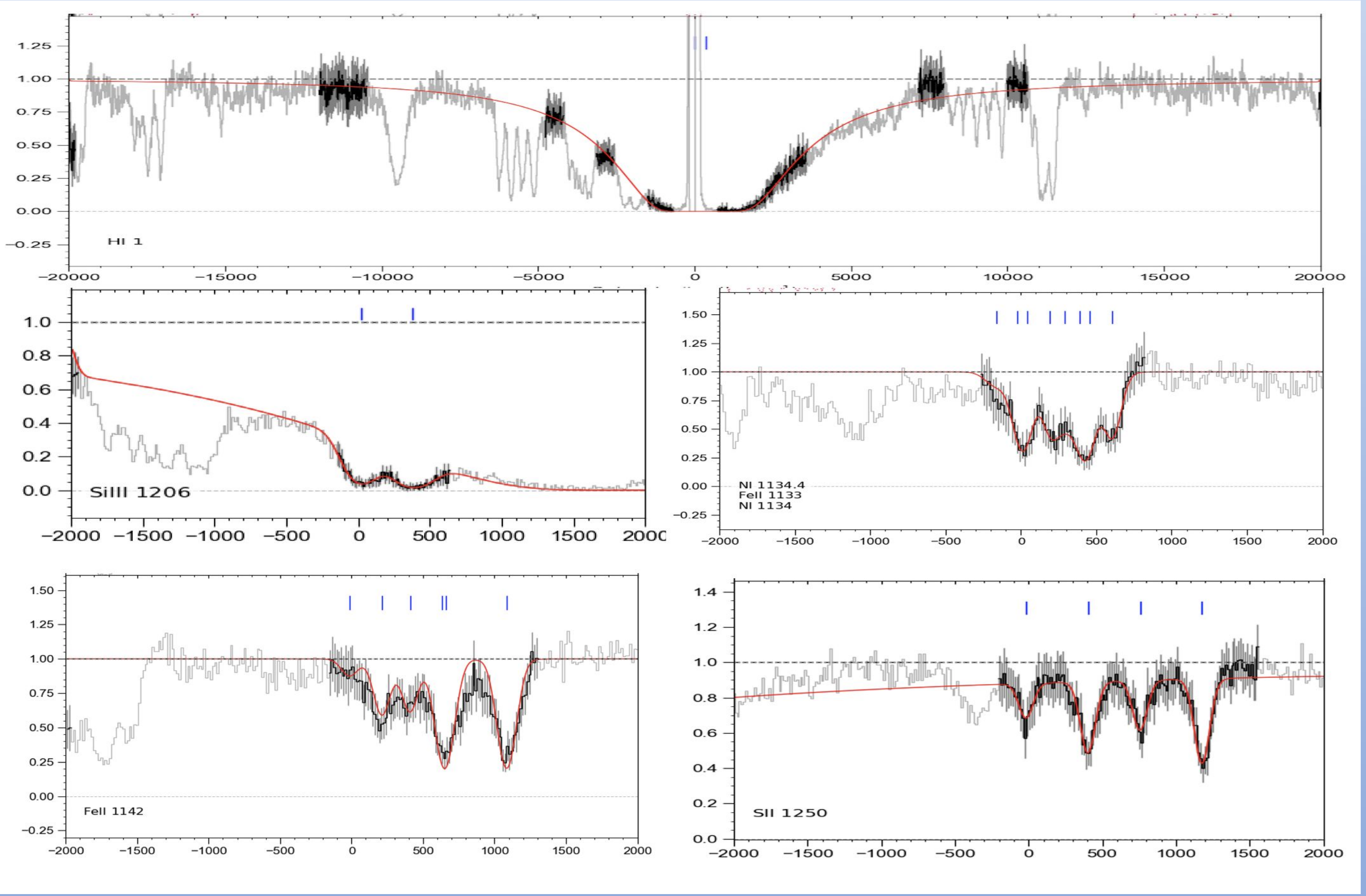

Characterization of the Neutral gas

- Theoretical Voigt profiles using VoigtFit (Krogager+2018)
  - Provide model for each absorber
    Multi-components → MW, HVC, galaxy species
  - Interactive fitting for each complex

Inputs: Redshift of the absorption system, velocity span, spectral data (normalized), ion (ion list)

Outputs: Column densities N(X) (cm^{-2}), the broadening parameter b, systemic velocity (km s^{-1})

Column densities in the neutral gas

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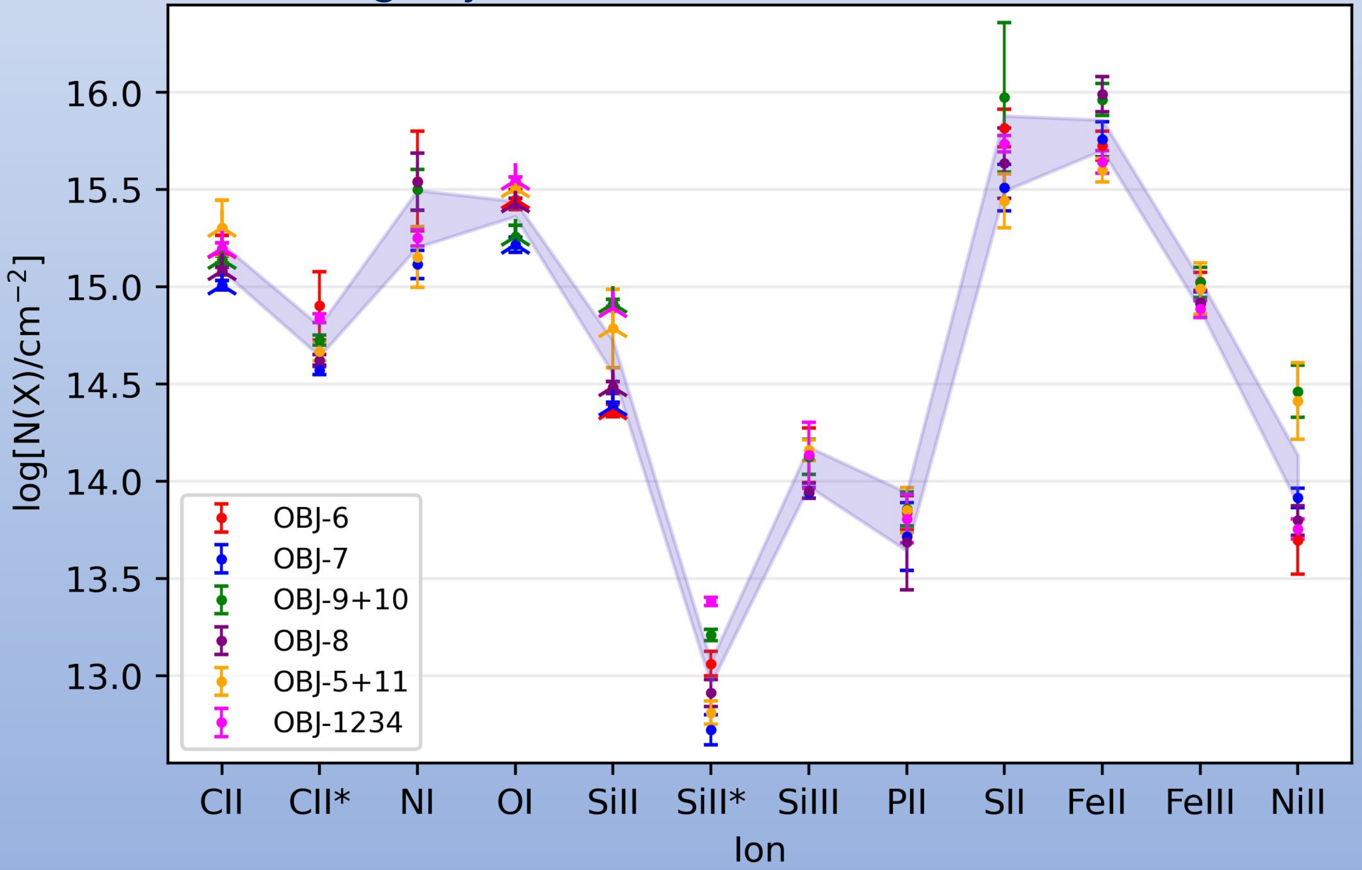
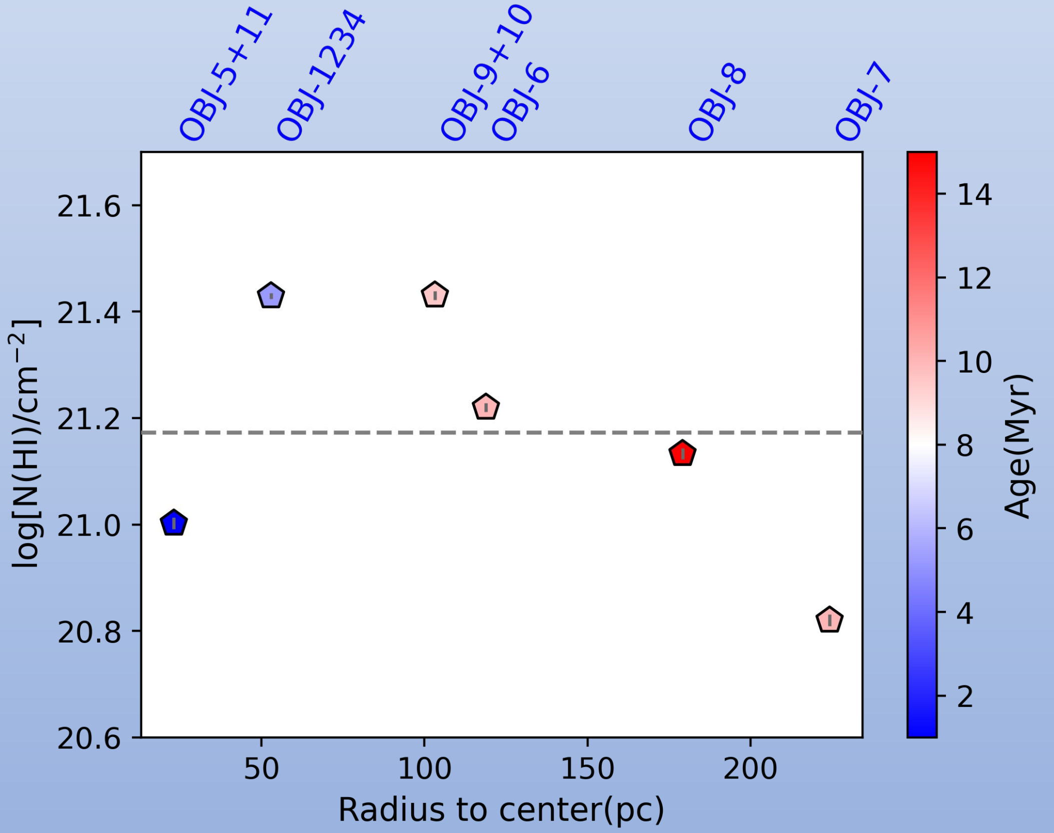
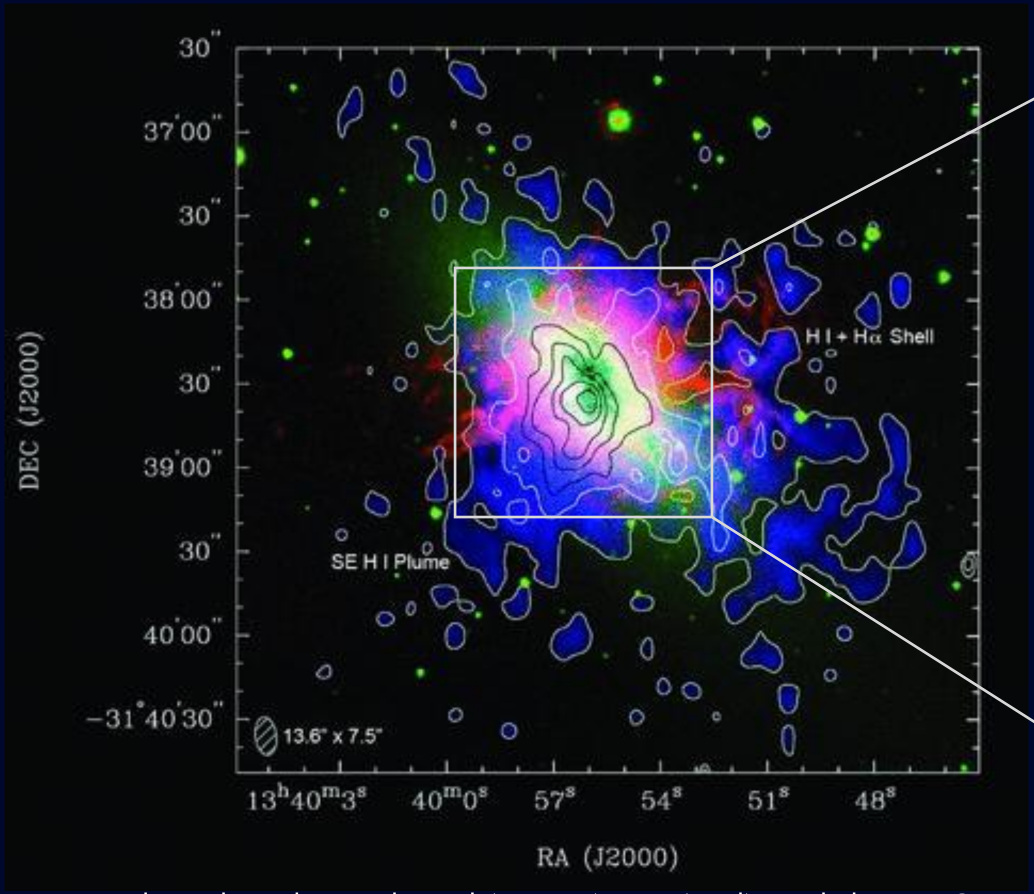




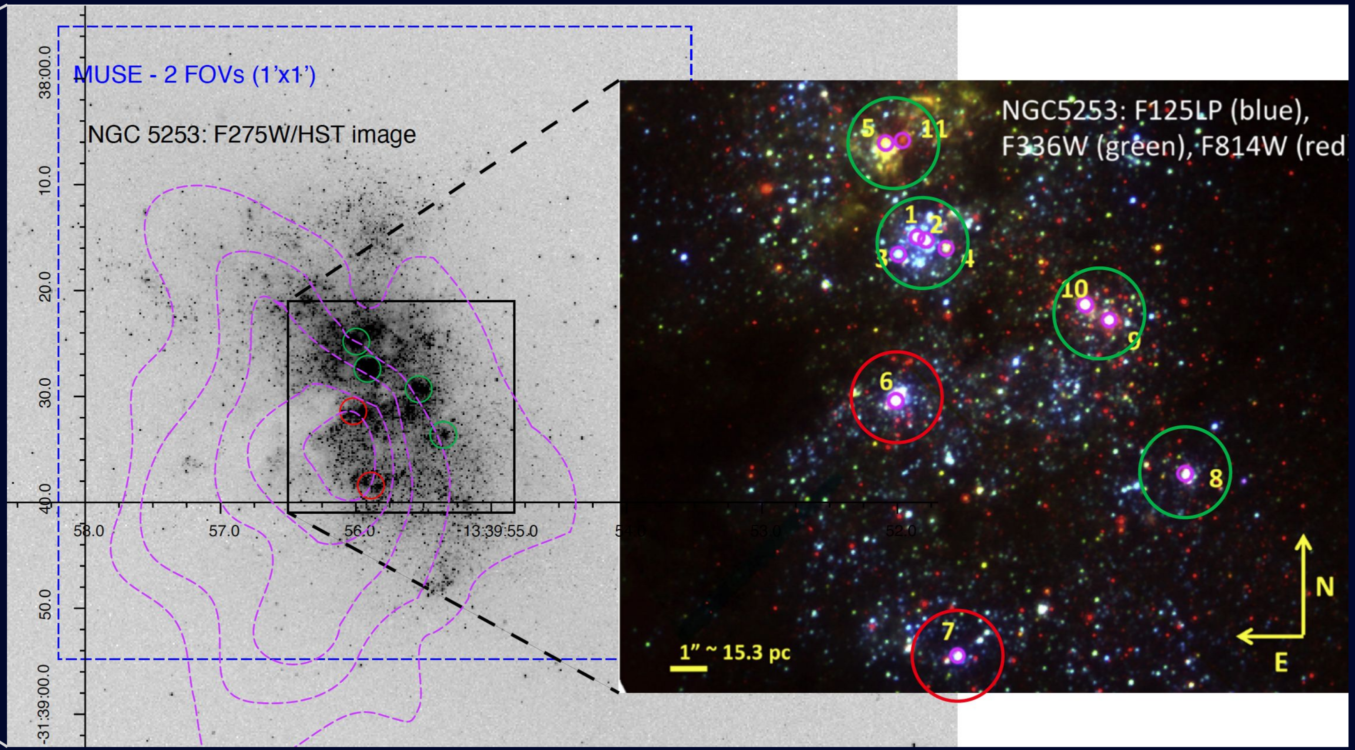
- Distribution of column densities per ion for the different targets.
- The values for CII, SiII and OI are lower limits due to line saturation
- N(H) values are close to the average varying from logN(H)~20.8 - 21.4 cm^{-2} correspond to OBJ-

HI structure in NGC 5253

Lopez-Sanchez+12   Infalling pristine gas cloud hypothesis



R band and *FUV* band (green), Hα (red) and the ATCA high-resolution HI map (blue).



According to Lopez-Sanchez+12 the maximum of the HI infalling cloud is located around OBJ-6 and OBJ-7
But we detect maximum HI column density at OBJ-1234 nearby the center of the galaxy

Neutral gas Abundances

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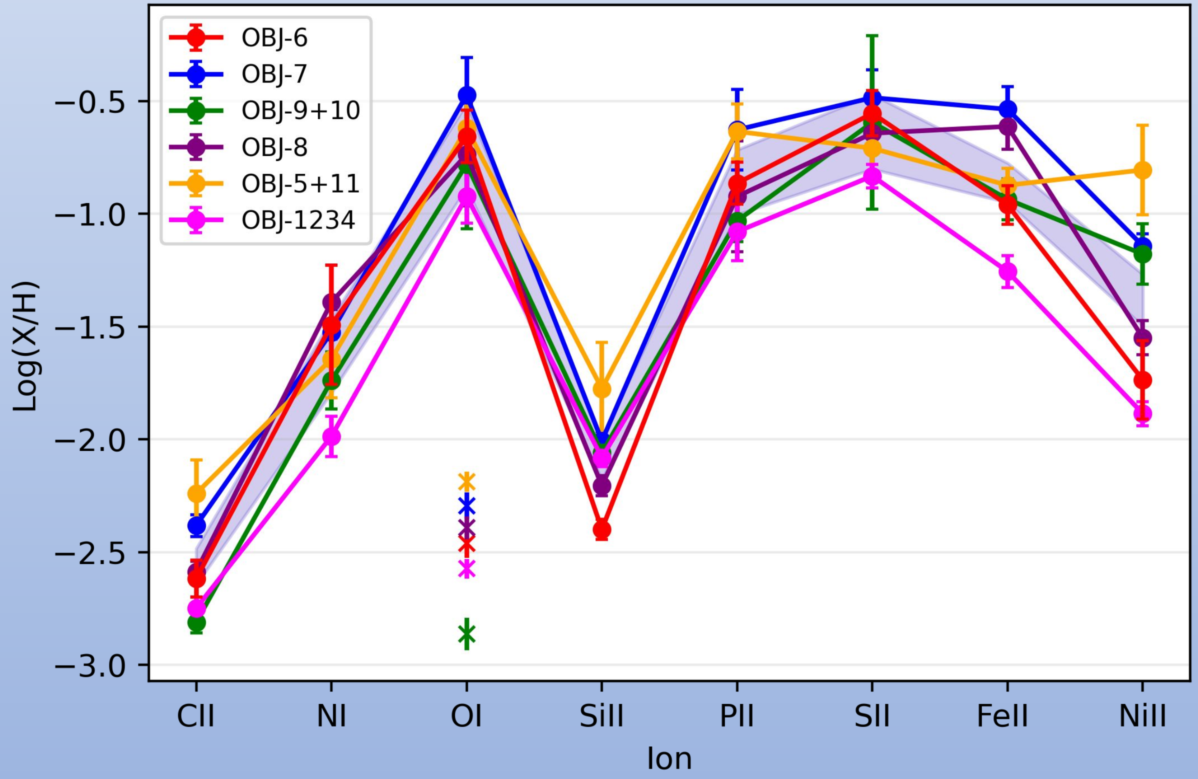
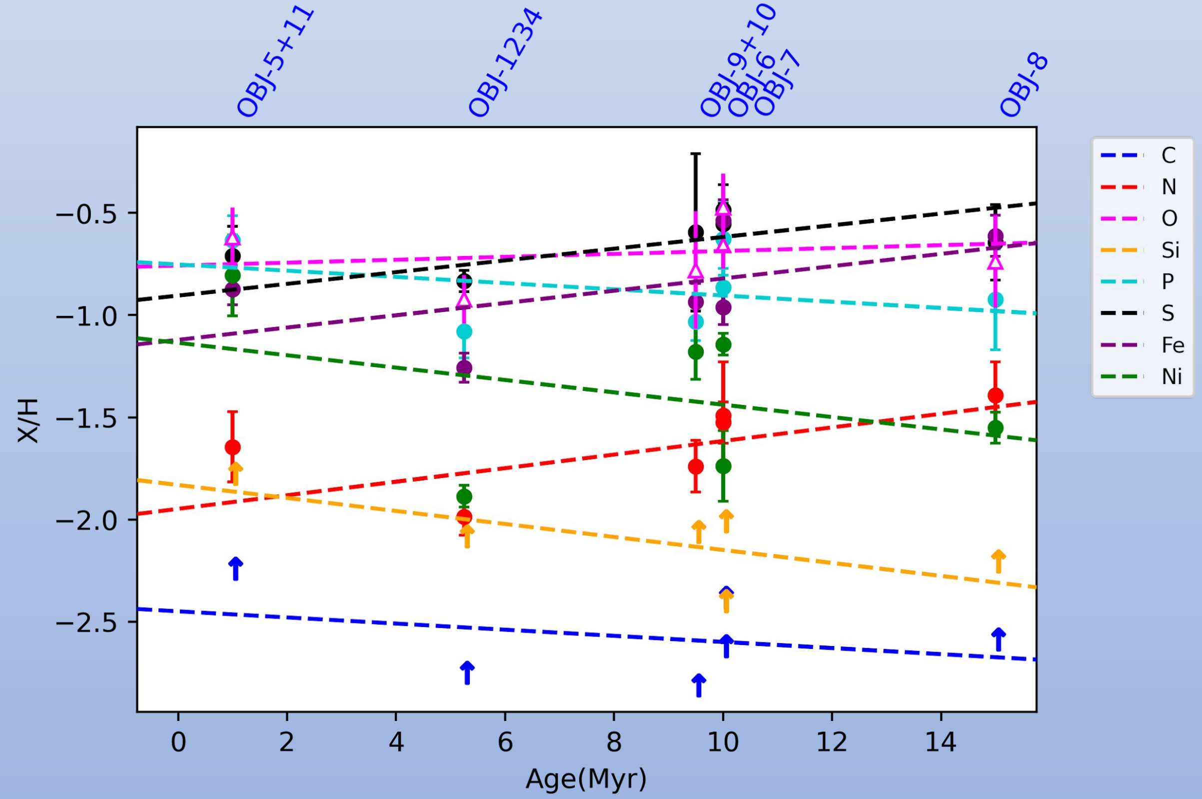


Most of ion abundances are inside the average. The lowest abundances are detected in OBJ-1234 (5 Myrs)

Crossing lines to check on differences among abundances for the different targets.

X/H vs. Age



We applied a least squares linear regression (ltsfit) and a Pearson correlation test Evaluation on correlation between X/H distribution with the Age of the targeted SF regions

Strongest correlations with age found for N, S and Fe (p values 0.60, 0.52 and 0.52 respectively)

Age and radial distribution of N/O neutral gas abundances

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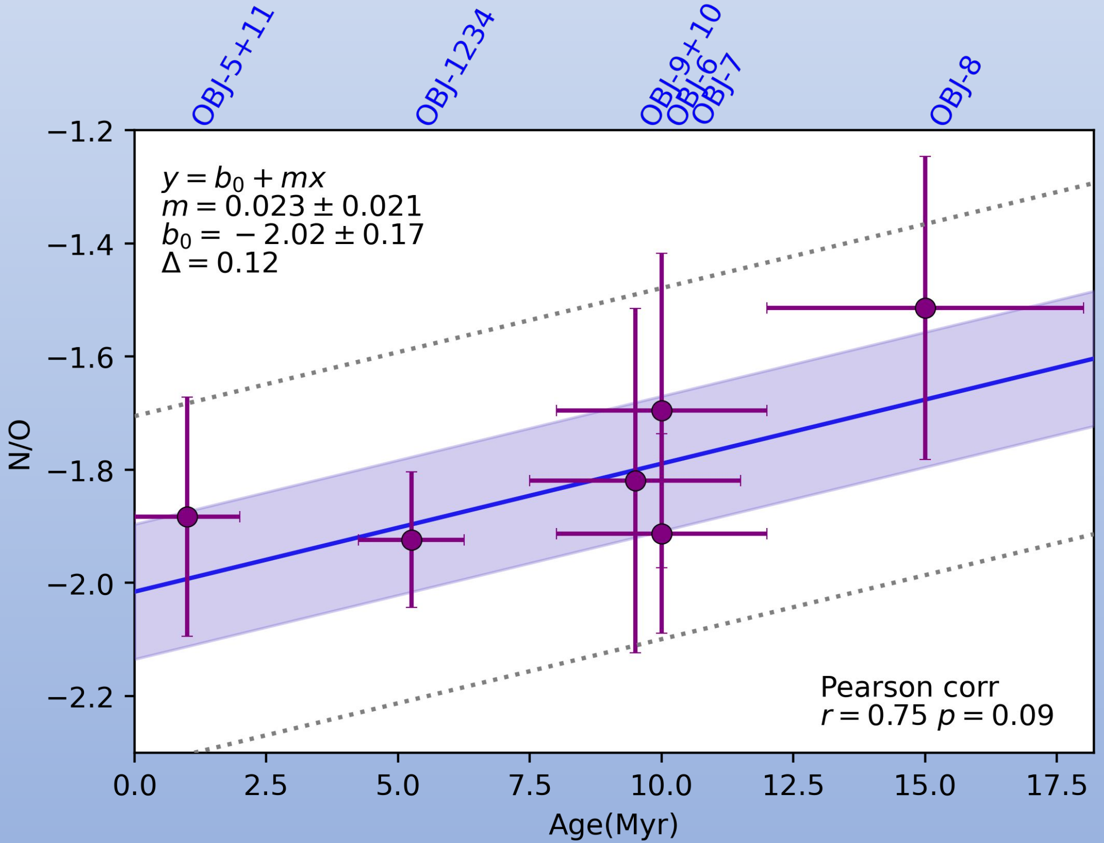
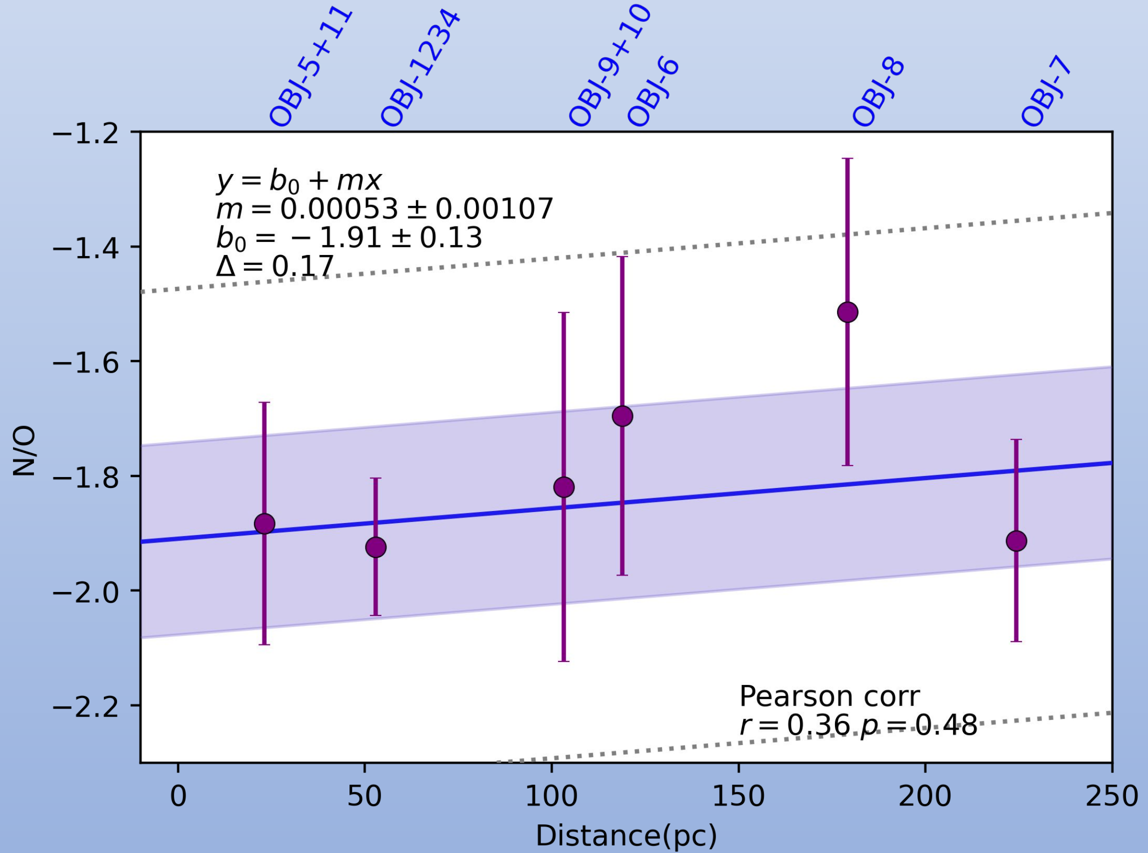
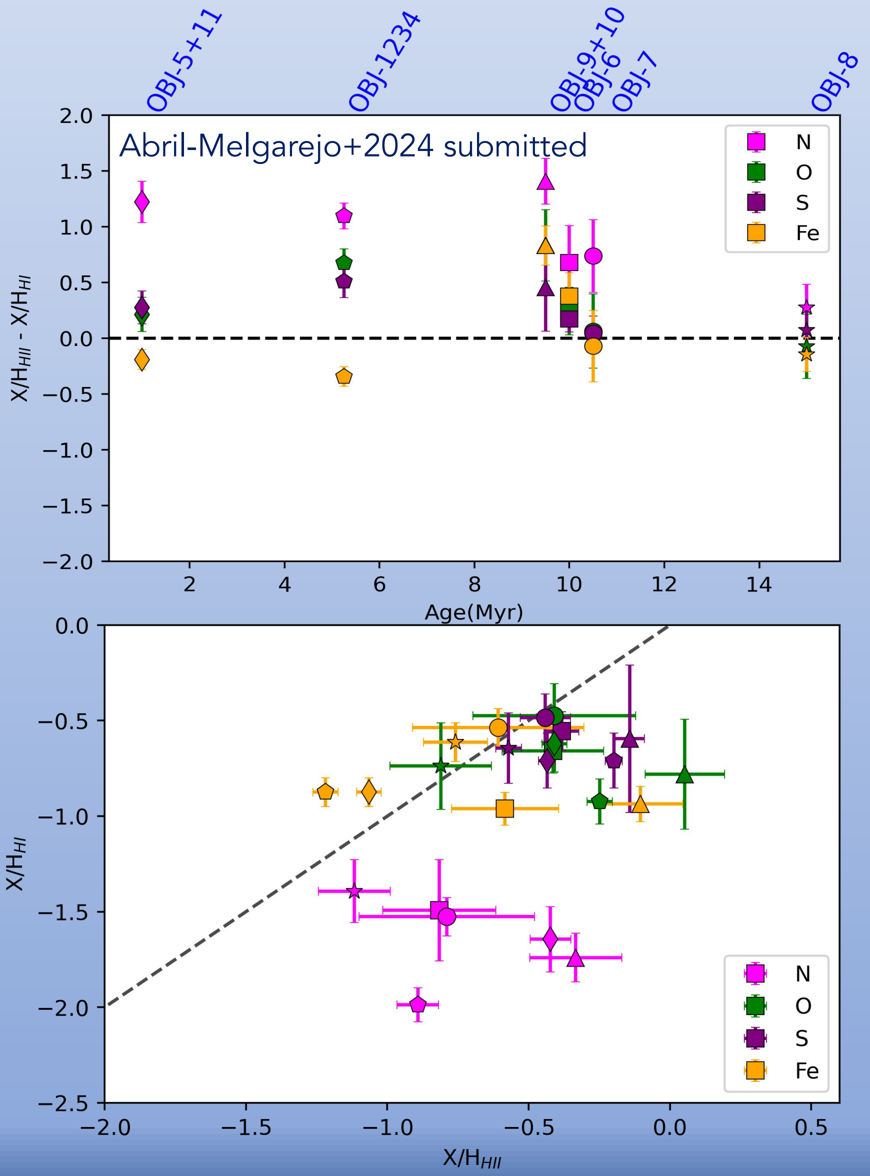


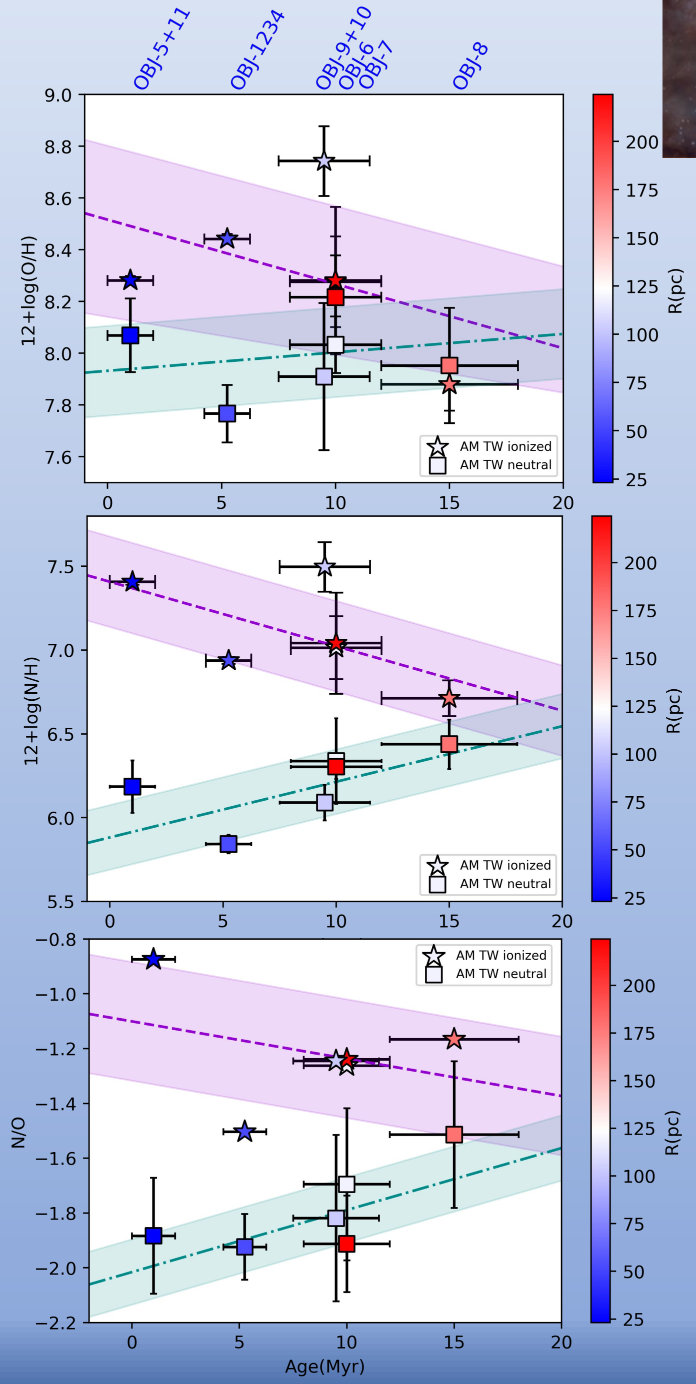


- There is an increase of 0.4 dex in the N/O relative abundance as a function of age, this could be due to the time scales at which N is produced mainly by WR stars. which is observable some Myrs after the WR enrichment.
- Highest correlation coefficients for N/O vs Age.

Neutral vs. Ionized gas Abundances



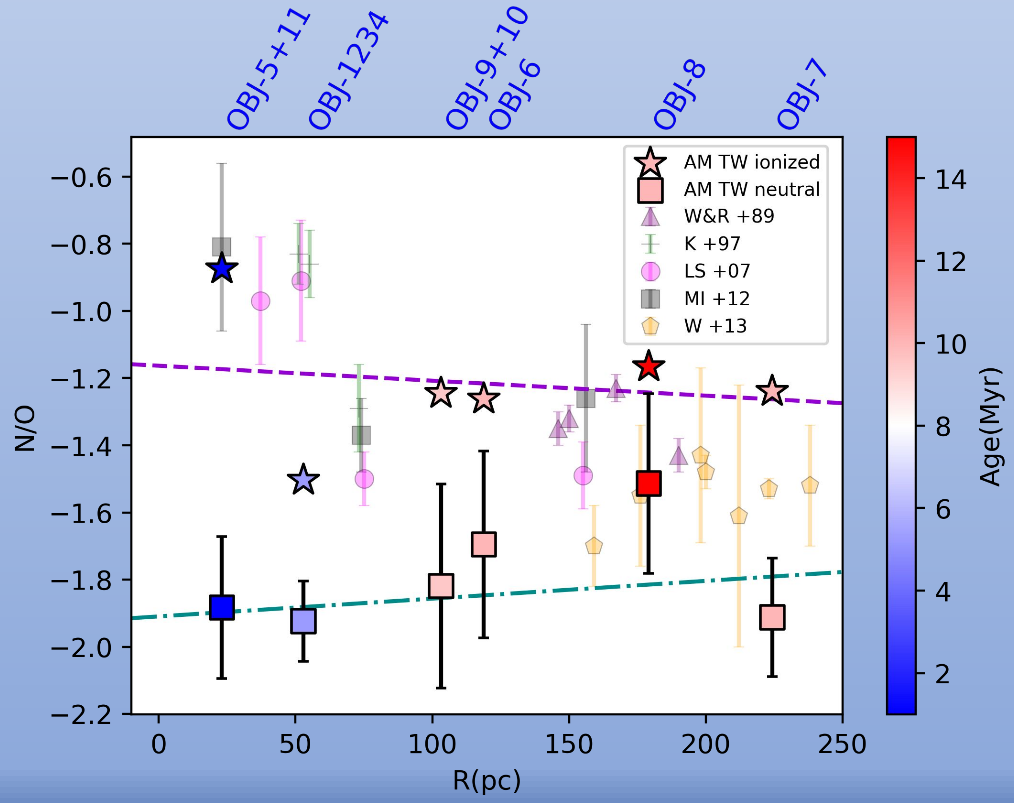
- Most of the elements have higher abundances in the ionized phase except for Fe Fe is depleted into dust in the neutral phase, dust gets destroyed in SN Type Ia remnants (1Gyr)
- Dispersion in the abundance offsets diminishes with age
- N shows the highest difference between gas phase abundances.
- N enrichment from the WR stars (2 – 5Myrs) is visible in the ionized gas, but not yet in the neutral gas longer mixing time-scales for the cold gas phase



Age and radial distribution of multi-phase O/H, N/H and N/O gas abundances

Abril-Melgarejo+2024 submitted

Form UV spectroscopy □ neutral gas abundances for 13 ions sampling 8 elements (N, O, S, P, Ni, C, Fe and Si)
From Optical IFU □ the ionized gas abundances (O, N, Fe and S) measured along the same sightlines



Metal mixing time scales

Linear regression fitting (ltsfit Capellari+2013) and a Pearson correlation test for the metallicity, N/H and N/O abundances as a function of the age.

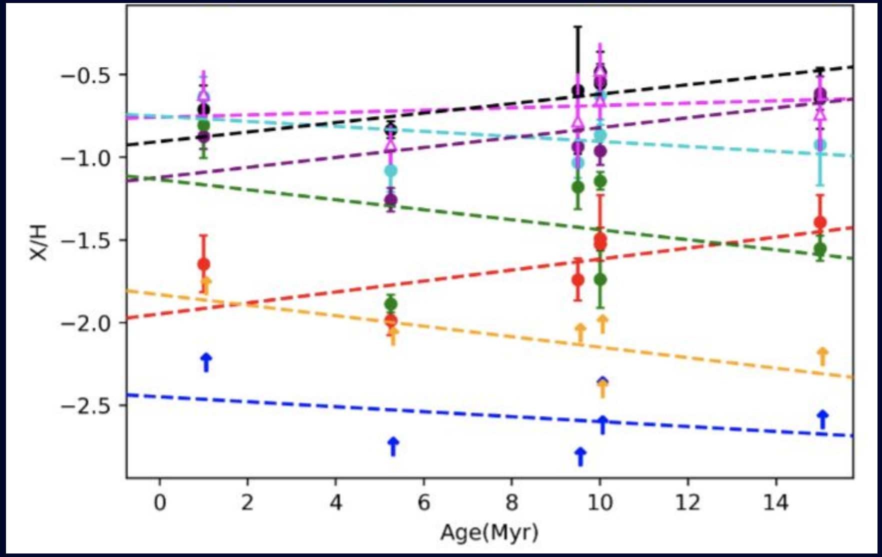
Neutral gas abundances are lower than those of the ionized phase by:
0.37 dex for 12+log(O/H)
0.95 dex for 12+log(N/H)
0.58 dex for N/O

Positive slopes for the neutral gas and anticorrelation for the ionized phase □ distributions converge around ~10 -15 Myrs.

Correlations factors are higher for the neutral gas than for the ionized gas.

Summary and Conclusions

We performed a spatially resolved study on the distribution of chemical abundances of the neutral and ionized phases in the high-z analog NGC 5253



Neutral gas abundances

- The distribution of abundances as a function of age is mostly uniform. Strongest positive correlations found for N, S and Fe
- There is and increase of N/O in function of age and distance to the center related with longer time mixing scales from the WR episodes to the cooling down of the gas

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Neutral gas abundances

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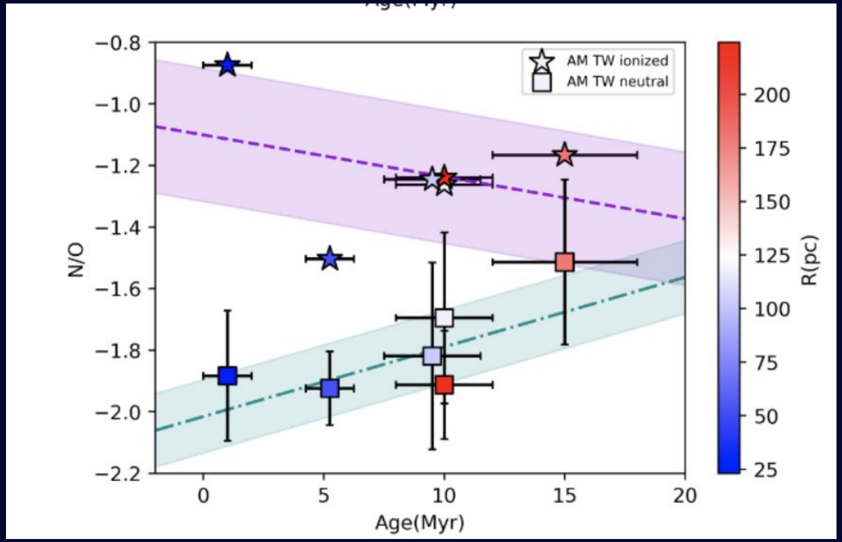
Comparison of multiphase abundances

- Most of the elements have higher abundances in the ionized phase except for Fe □ strong Fe depletion effect
- Enrichment episodes (ex. WR stars) visible in the ionized gas, require longer time scales to be mixed in the neutral gas phase.

❖ Chemical enrichment happens differentially, first in the ionized gas (2 – 5 Myrs) phase and then mixing out into the cold neutral gas at longer timescales (10 – 15 Myrs)



Multi-phase analysis is necessary to understand the complete context of metal enrichment evolution