WOLF-RAYET GALAXIES

and the interplay between stars and gas in star-forming objects

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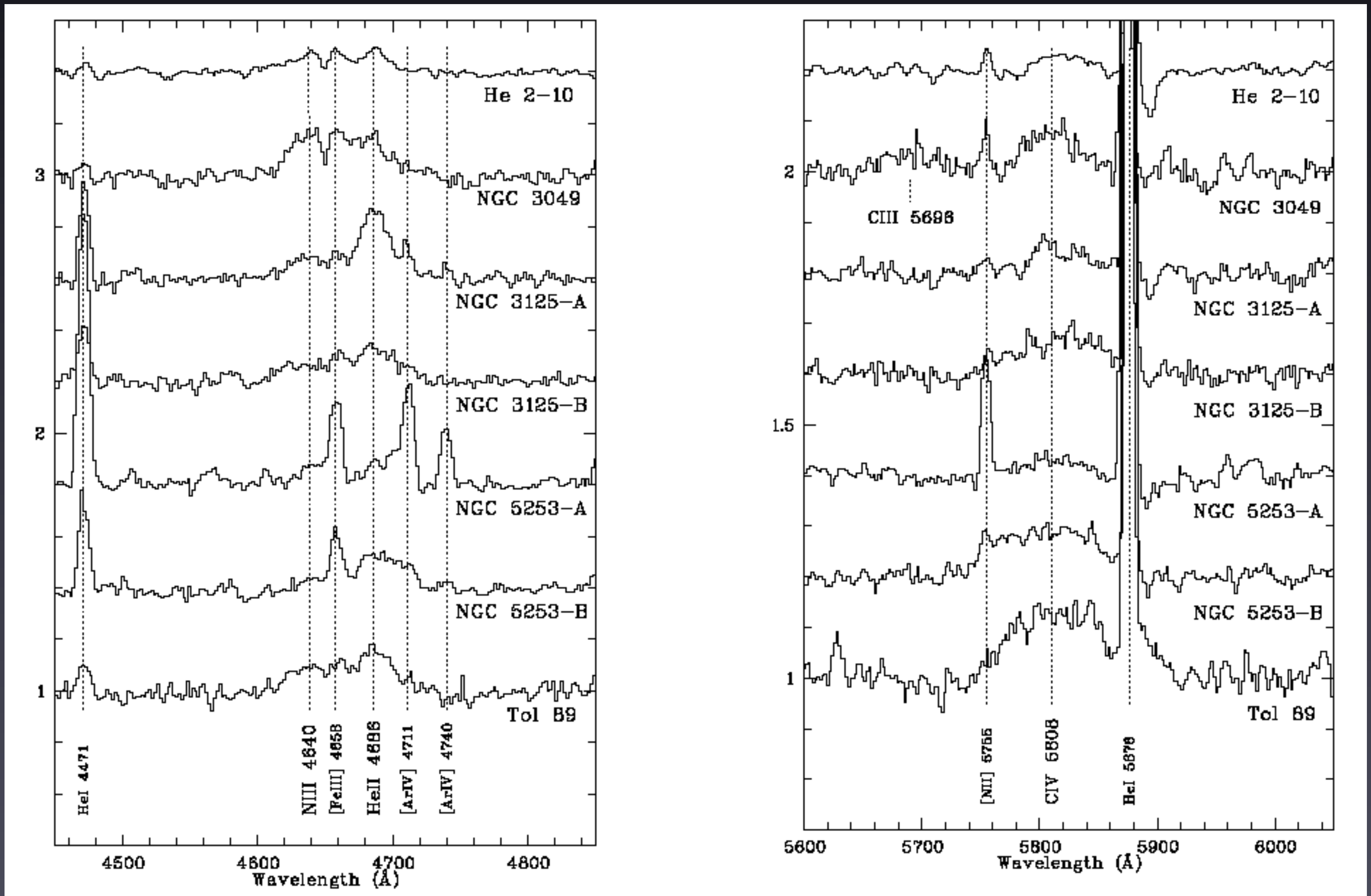
Proyecto ESTALLIDOS DE FORMACIÓN ESTELAR

Galaxies meet GRBs at Cabo de Gata. September 24th 2013.

WHAT ARE WOLF-RAYET GALAXIES?

Objects whose integrated optical spectrum shows the broad emission lines generated in the winds from WR stars (Osterbrock & Cohen 1982)



Schaerer, Contini, & Kunth (1999)

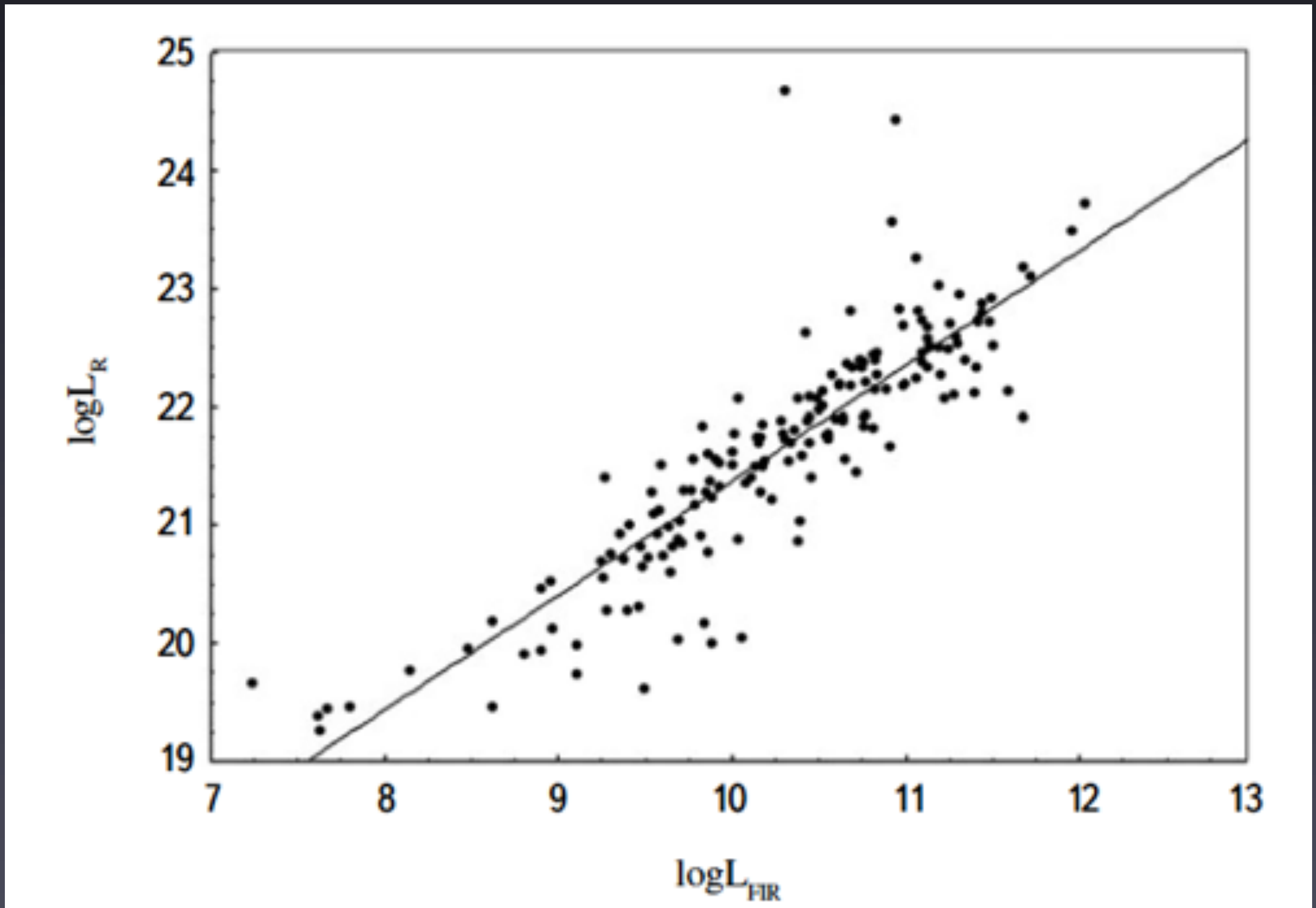
Blue bump (~ 4650 Å): NIII, CIII/IV, HeII from WN and WC stars.

Red bump (~ 5808 Å) CIV emission from WC stars.

Other features:
CIII at 5696 Å
HeII at 1640 Å

WR GALAXIES ARE STAR-FORMING OBJECTS

Although integrated WR bumps have been detected in all classes of objects (Blue Compact Dwarfs, LINERS, Sy2, ULIRGs, ...) the integrated properties of the hosting galaxies are in average those of systems undergoing violent and massive episodes of SF.



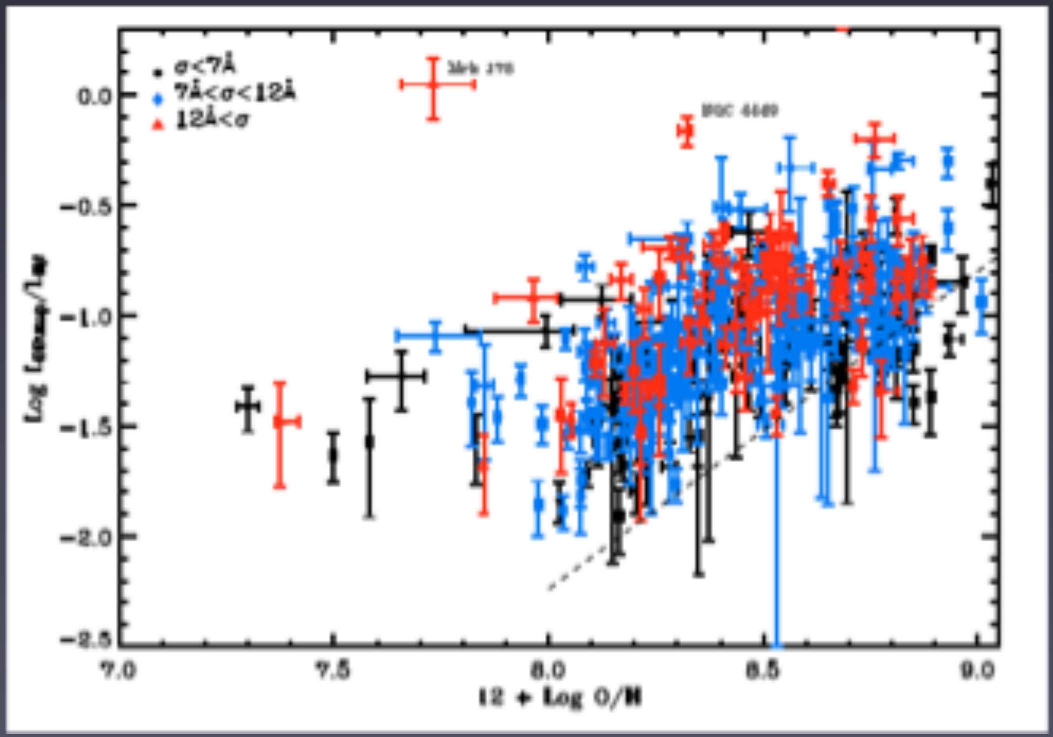
Malumyan & Martirosian (2013) show that the slope in the relation between L at 1.4 GHz and FIR for WR galaxies is the same as for SPIRALS (at left).

SO MANY WR GALAXIES ...

The number of known WR galaxies has been hugely increased from the discovery of the first one (He 2-10, Allen+ 1976).

- Conti (1991) found 37 objects. First evidences of the relation with Z
- Schaerer+ (1997). WN and WC stars in NGC5253
- Legrand+ (1997). WN and WC stars in IZw18 ($Z \sim 1/50\ Z_{\odot}$)
- Schaerer, Contini & Kunth (1999). 139 objects (40% with the red bump)
- Guseva+ (2000), blue and red bumps in 39 BCDs
- Schaerer+ (2000), WR galaxies with $Z > Z_{\odot}$
- Zhang+ (2007). First compilation from the SDSS: 174 galaxies.
- Brinchmann, Kunth, & Durret (2008). 570 objects from the SDSS

Brinchmann, Kunth, & Durret (2008)



WHY STUDYING WR GALAXIES?

The detection of the WR bump(s) and the measurement of their properties (total and relative luminosity, EW, dispersion, etc ...) put observational constraints on the nature of the burst of SF.

- AGE. Assuming instantaneous SF, the WR-phase appears 2-5 Myr after the beginning of the burst, once passed the MS of massive stars.
- MASS OF THE BURST. L(NII+CIII+HeII) depends on N(WR) and Z
- STAR FORMATION HISTORY. N(WR)/N(O) quite different for instantaneous bursts or continous star formation.
- METALLICITY. If L(CIV) is measured, N(WC)/N(WN) can be used.
- HIGH MASS END OF THE IMF. WR stars form only for $M > 30 \cdot M_\odot$
- STELLAR ATMOSPHERES OF MASSIVE STARS. Broad blue and red emission constrain dynamics of massive stars.
- GRBs. They are the main candidates to host long soft GRBs (Woosley & Bloom 2006, Hammer+ 2006).

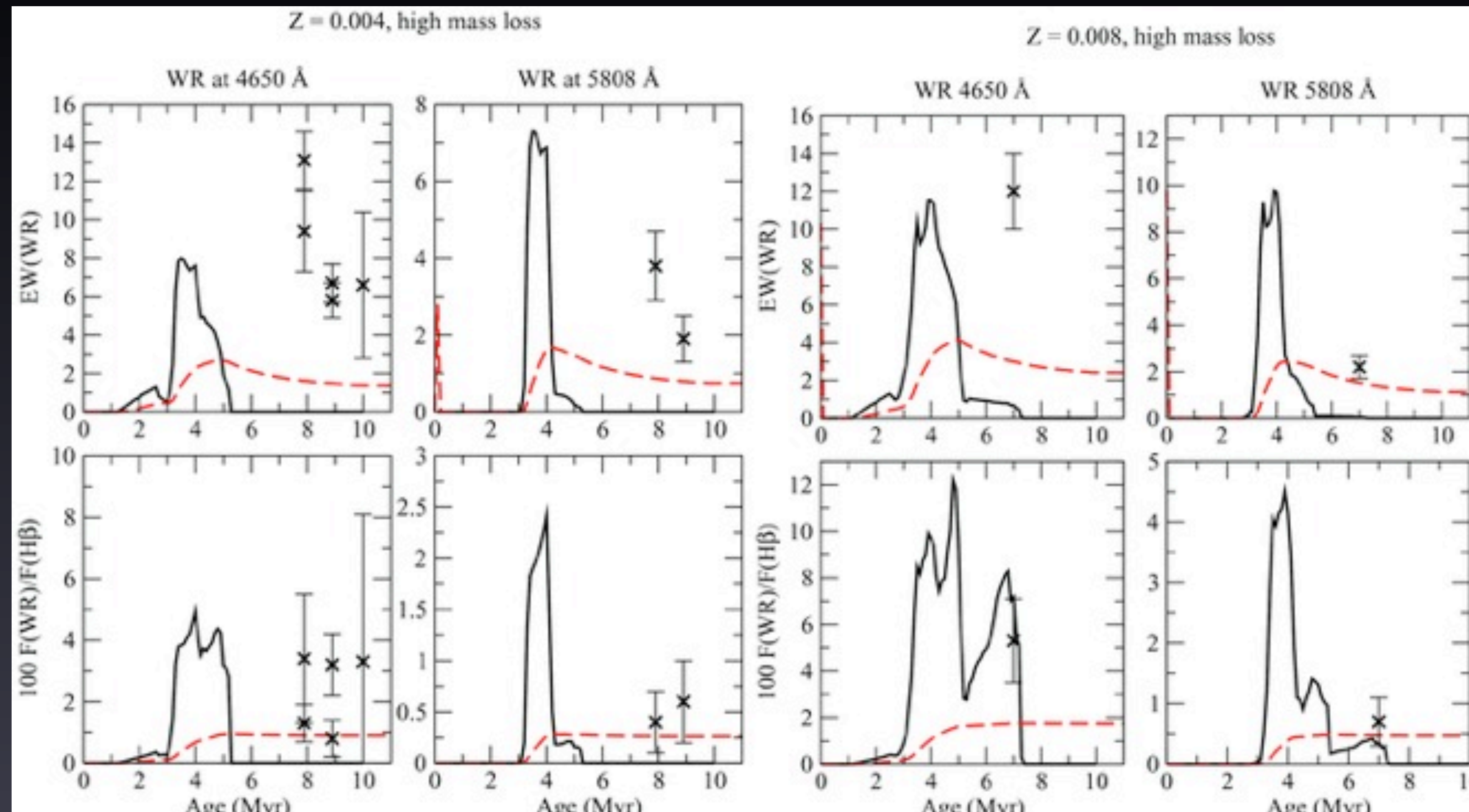
However, this requires the L(WNL) and L(WCE) at all Z and, so far, they are only available for MW and MCs.

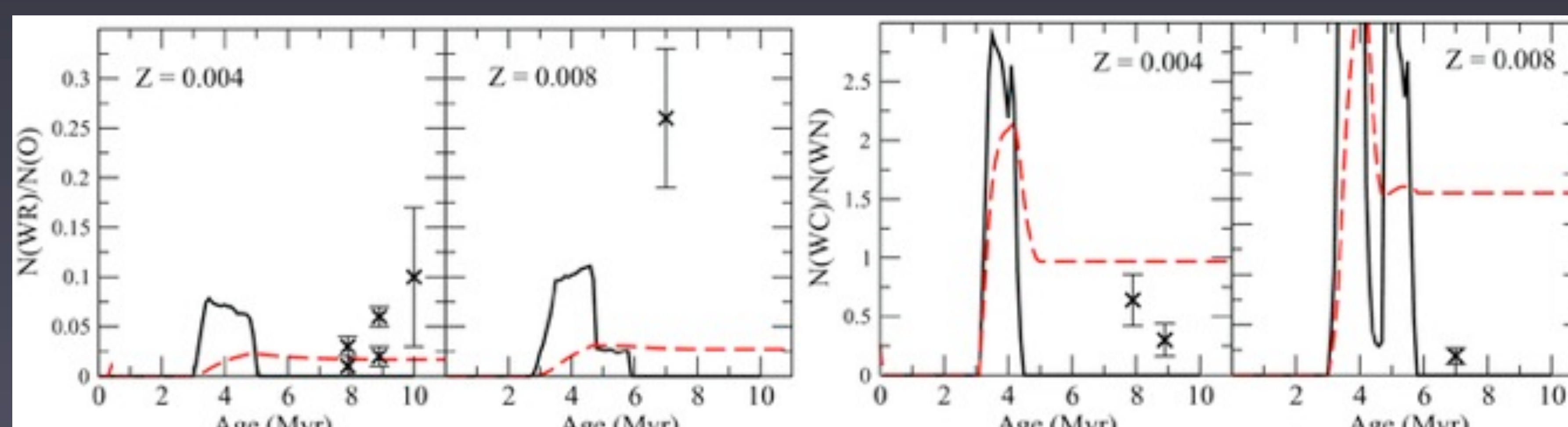
AN OPTIONAL STRATEGY

Pérez-Montero+ (2010):
Tailor-made models
of HII galaxies using
SB99.

Ages derived from
EW(Hß) corrected for
underlying stellar pop.
and dust absorption.

Dust absorption, age, N(O),
can also be
derived from UV
(e.g. NGC3125,
Hadfield & Crowther, 2006)





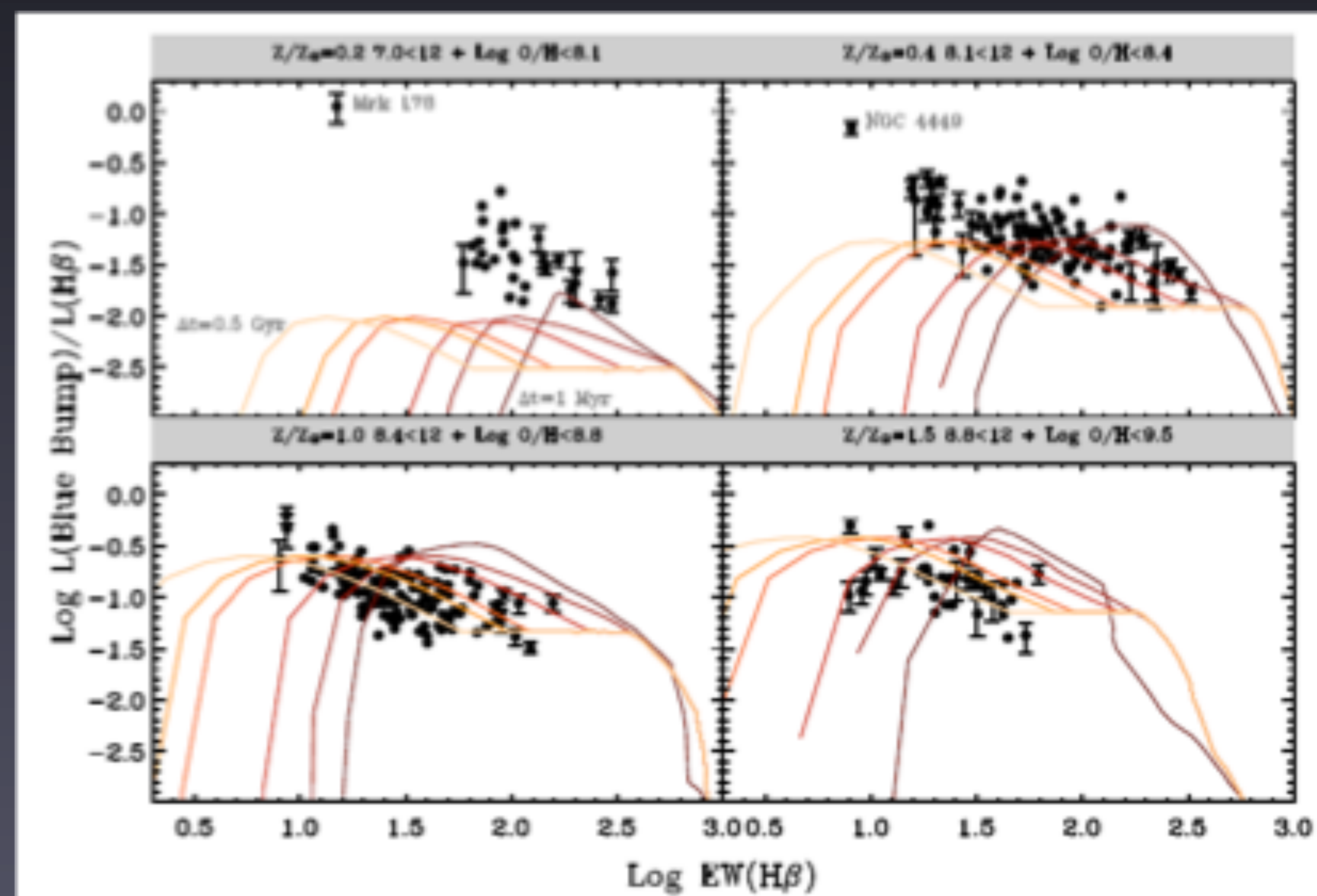
BUT MODELS DO NOT FIT OBSERVATONS ...

A great deal of work has been made to improve WR stellar atmospheres:

- Schmutz+ (1992): non-LTE
- Hillier & Miller (2001): blanketing
- Meynet (2005): rotation
- Eldridge+ (2008): binary channel.

HOWEVER, models still do not fit fluxes, EWs of broad integrated WR emission, above all at low Z (e.g. the number of WCE in IZw18 not clear so far, Izotov+ 1997, de Mello+ 1998, Crowther & Hadfeld 2006)

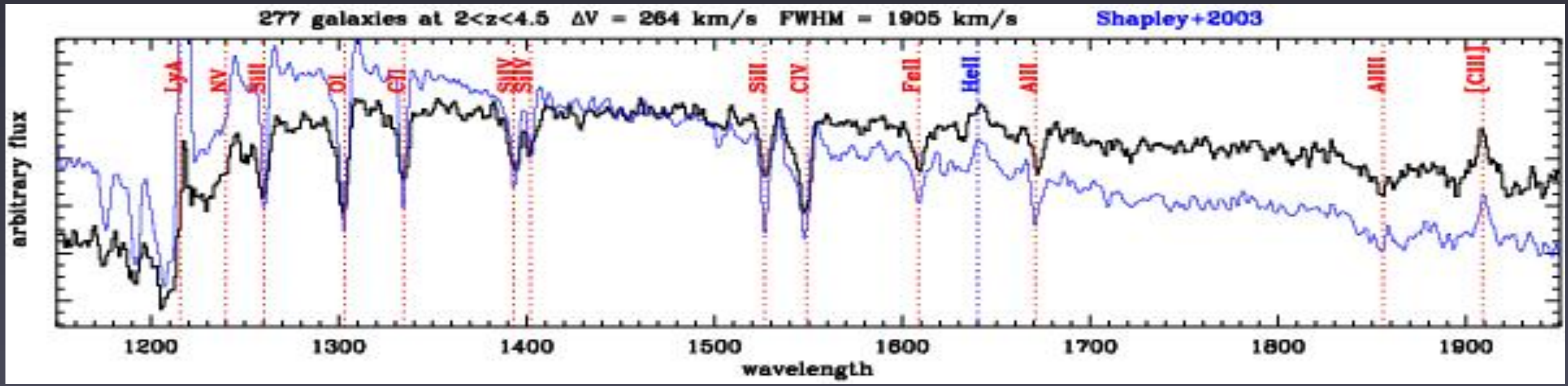
Brinchmann, Kunth, & Durret (2008)



BUT MODELS DO NOT FIT OBSERVATONS ...

A large sample of Lyman Break Galaxies with both broad and narrow HeII 1640 Å has been found (e.g. Shapley+ 2008, Cassata+ 2013). Trustable WR models for low-Z are required in order to search for Population III stars.

In all case no clear direct relation exists between nebular HeII emission and WR stars (e.g. Shirazi & Brinchmann 2010, Kehrig+ 2011)



Cassata+ 2013

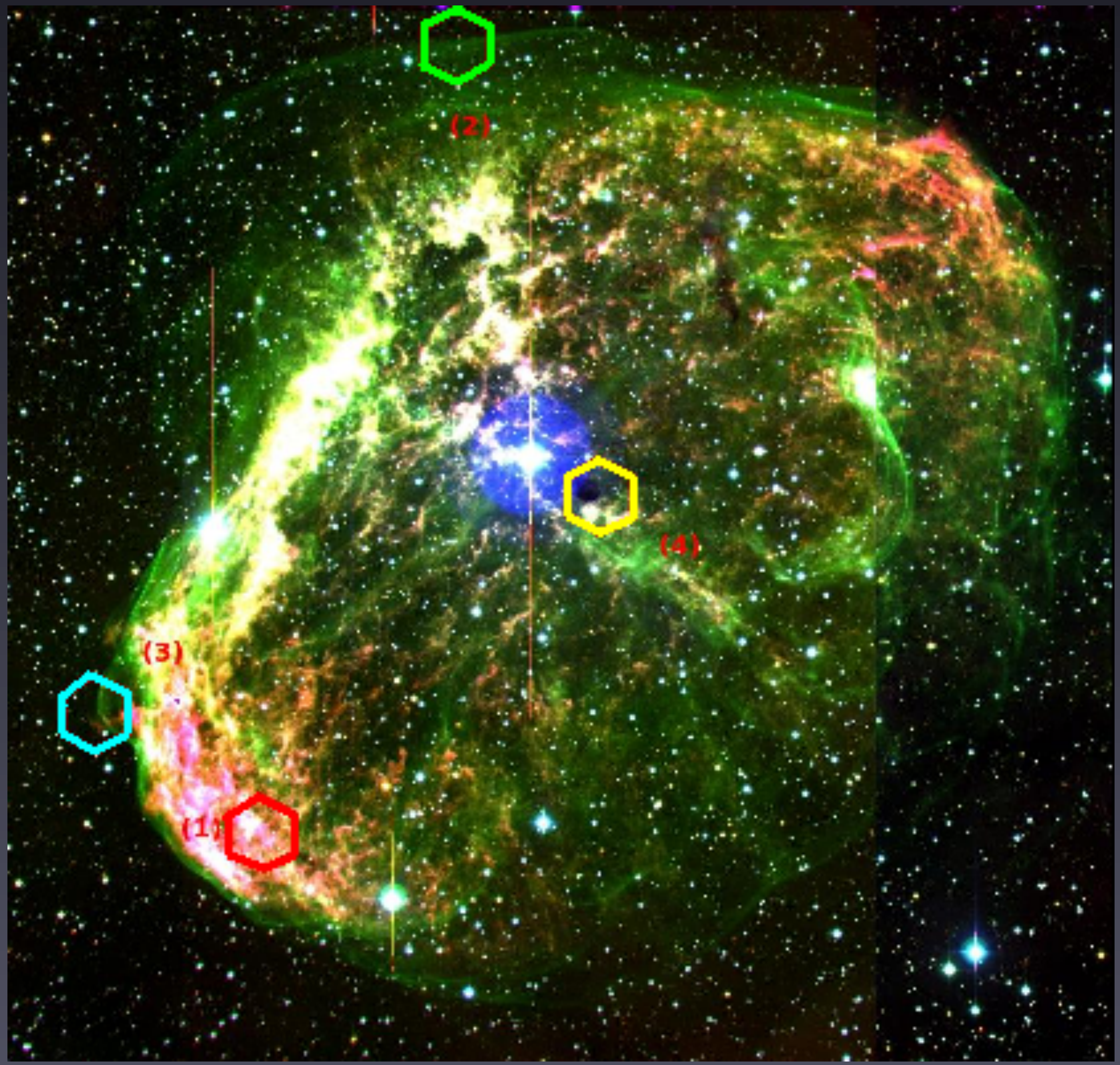
SOME OBSERVATIONAL CAVEATS

Besides, some considerations must be taken into account regarding integrated spectra of SF objects:

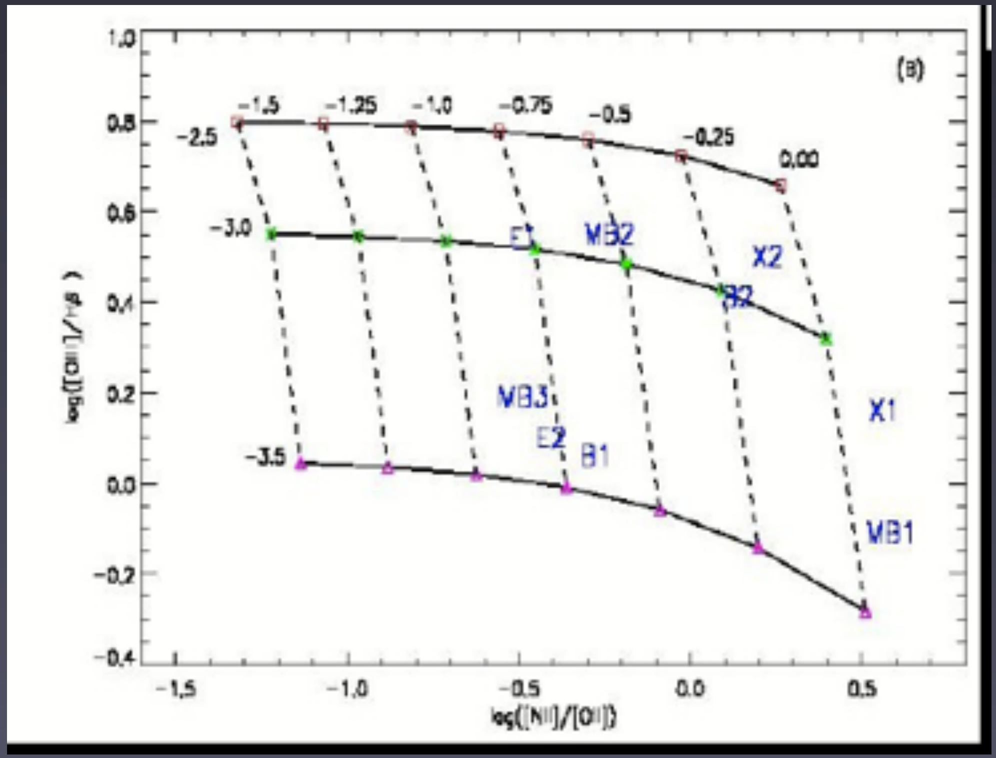
- Nebular emission above the blue bump (e.g. [FeIII] 4658 Å, HeII 4686 Å, [ArIV] 4711 Å, 4740 Å) must be correctly removed.
- Template fittings to the bumps difficult for low spectral resolution.
- Geometrical effects: different coverage for old stars, massive stars, WR stars, gas, extinction ...
- Dilution of emission for long-slit and large fibers (e.g. SDSS)
- Effects to L(Hß) to derive N(O): underlying stellar population, dust absorption, photon leakage.
- Different Z for gas and stars.
- The number of WN stars is sometimes underestimated and hence WC/WN does not match the models (e.g. Neugent & Massey 2012)

CHEMICAL POLLUTION OF THE ISM

WR stars eject the products of CNO-cycle in their winds (He, C, and N) … but only N/O can be studied with precision in the optical.
e.g. Fernández-Martín+ (2012) PPak observations of the WR nebula NGC6888: different N/O for ejections at different stages of star evolution.

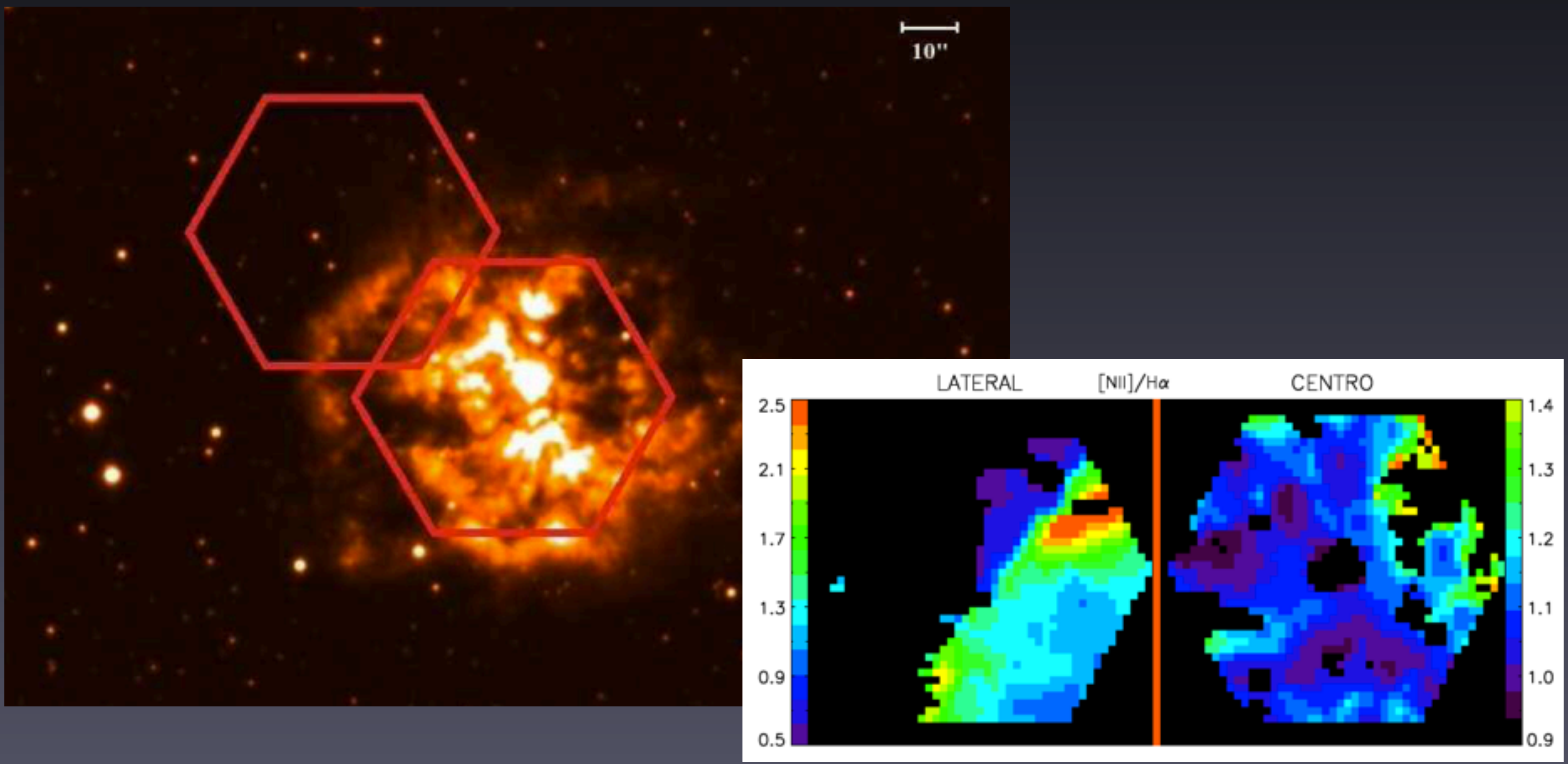


(1) X-Ray zone
(2) Edge
(3) Mini Bubble
(4) Bullet



CHEMICAL POLLUTION OF THE ISM

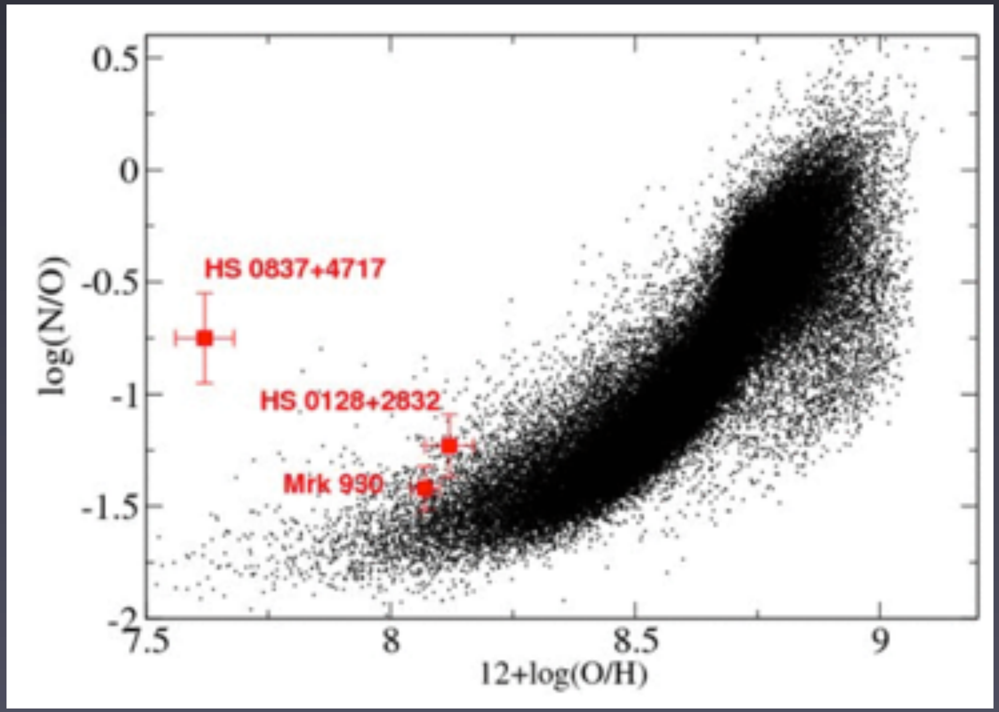
e.g. Fernández-Martín+ (2013) PPak observations of the WR nebula M1-67: The large N pollution is likely owing to the LBV stage.



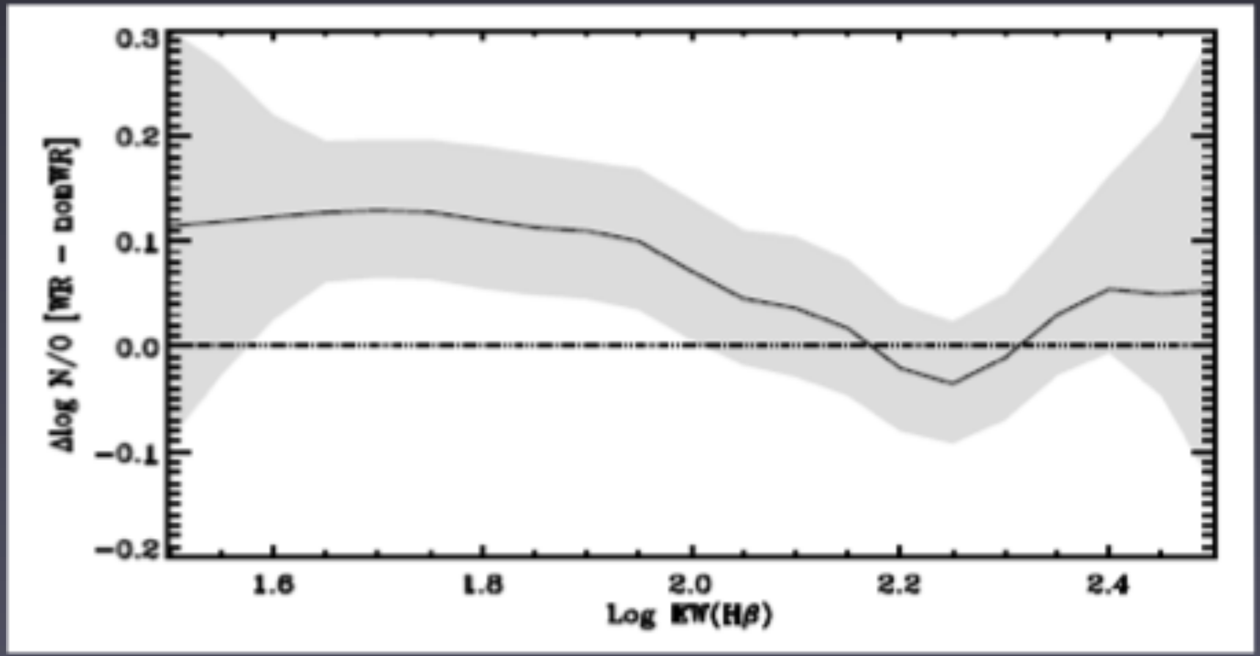
HIGH N/O IN WR GALAXIES

Some evidence of N overabundance in WR galaxies has been found: e.g. Pustilnik + 2004 (HS0837+4717, Hägele+ 2006, 2008 (HII galaxies), Kobulnicky+ 1999, López-Sánchez+ 2007 (NGC5253), Brinchmann+ (2008).

In the low-Z regime, it is easy to find unexpected high values of N/O if the galaxies are in the production regime of primary N (constant with O/H)



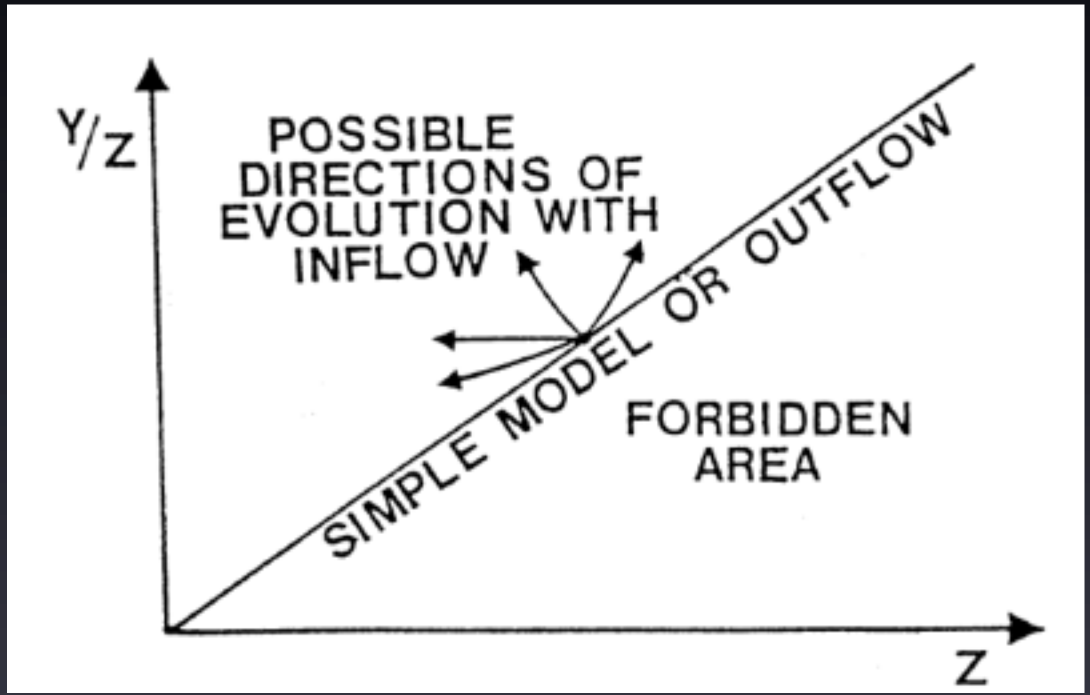
Pérez-Montero+ (2011)



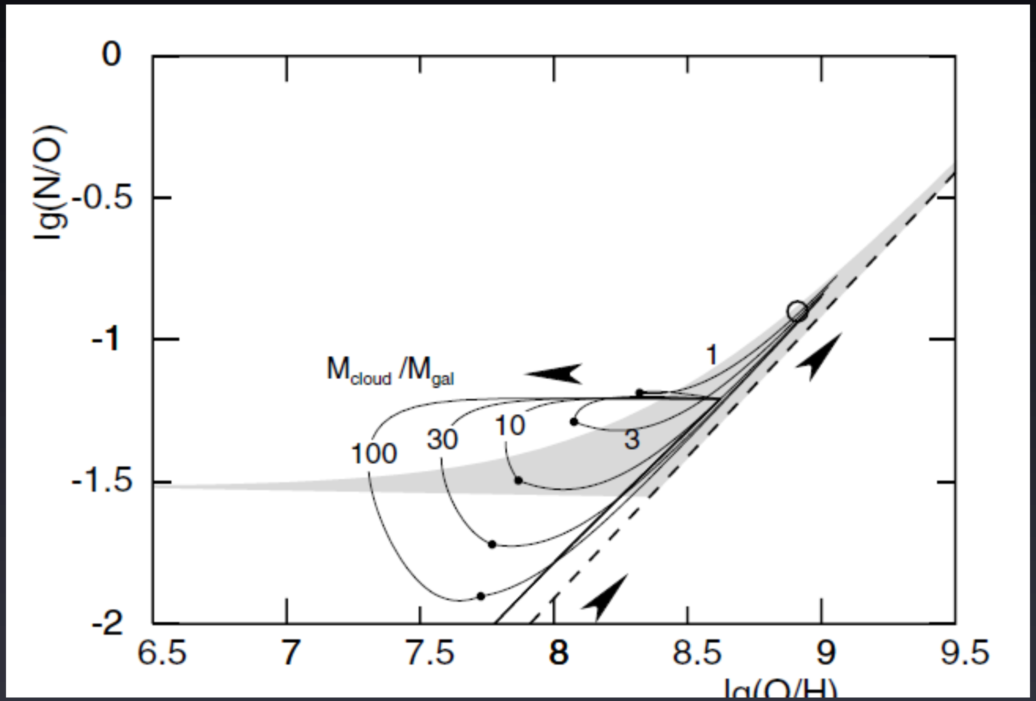
Brinchmann, Kunth, & Durret (2008)

BUT CHEMODYNAMICS ALSO AFFECTS N/O

Edmunds 1990



Köppen & Hensler 2005

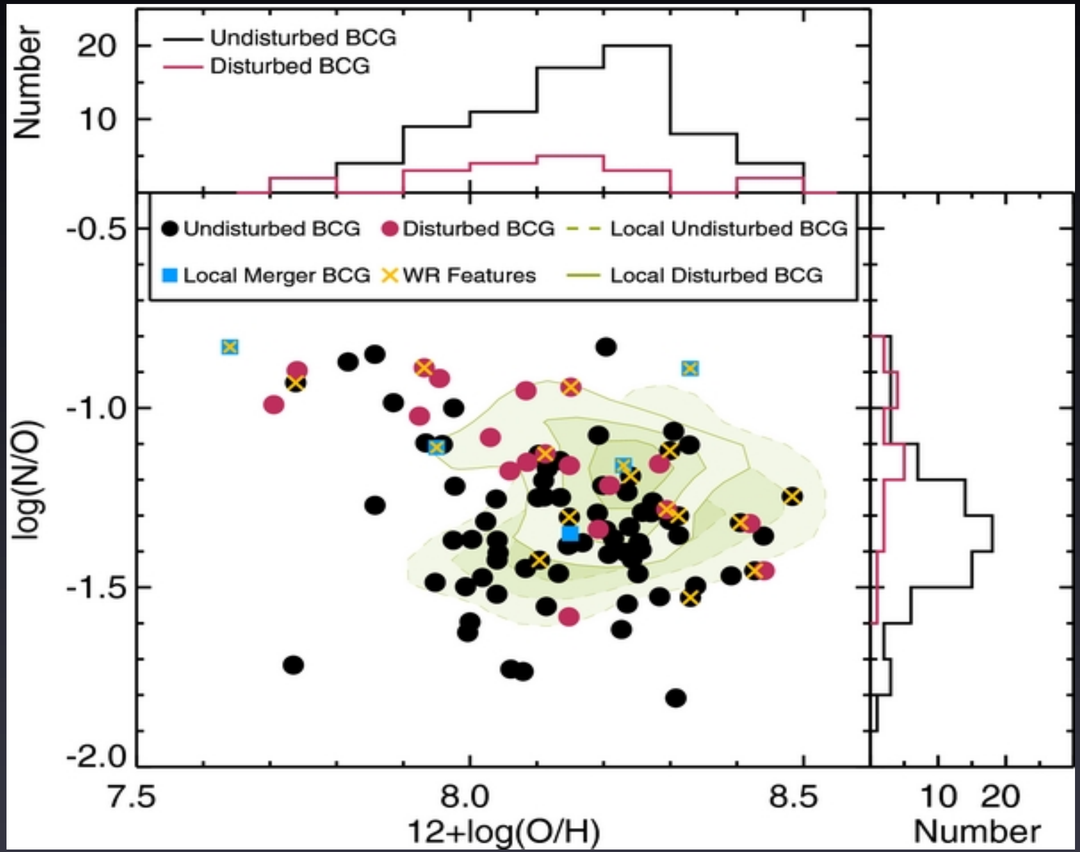


As N can have also a secondary origin, N/O is relatively unaffected by processes of inflows of unenriched gas and/or outflows of enriched gas (e.g. Edmunds 1990).

Hence, according to Köppen & Hensler (2005) a dwarf galaxy affected by a collision with a high velocity cloud of pristine gas would reduce Z, enhance SFR, but keeps N/O high.

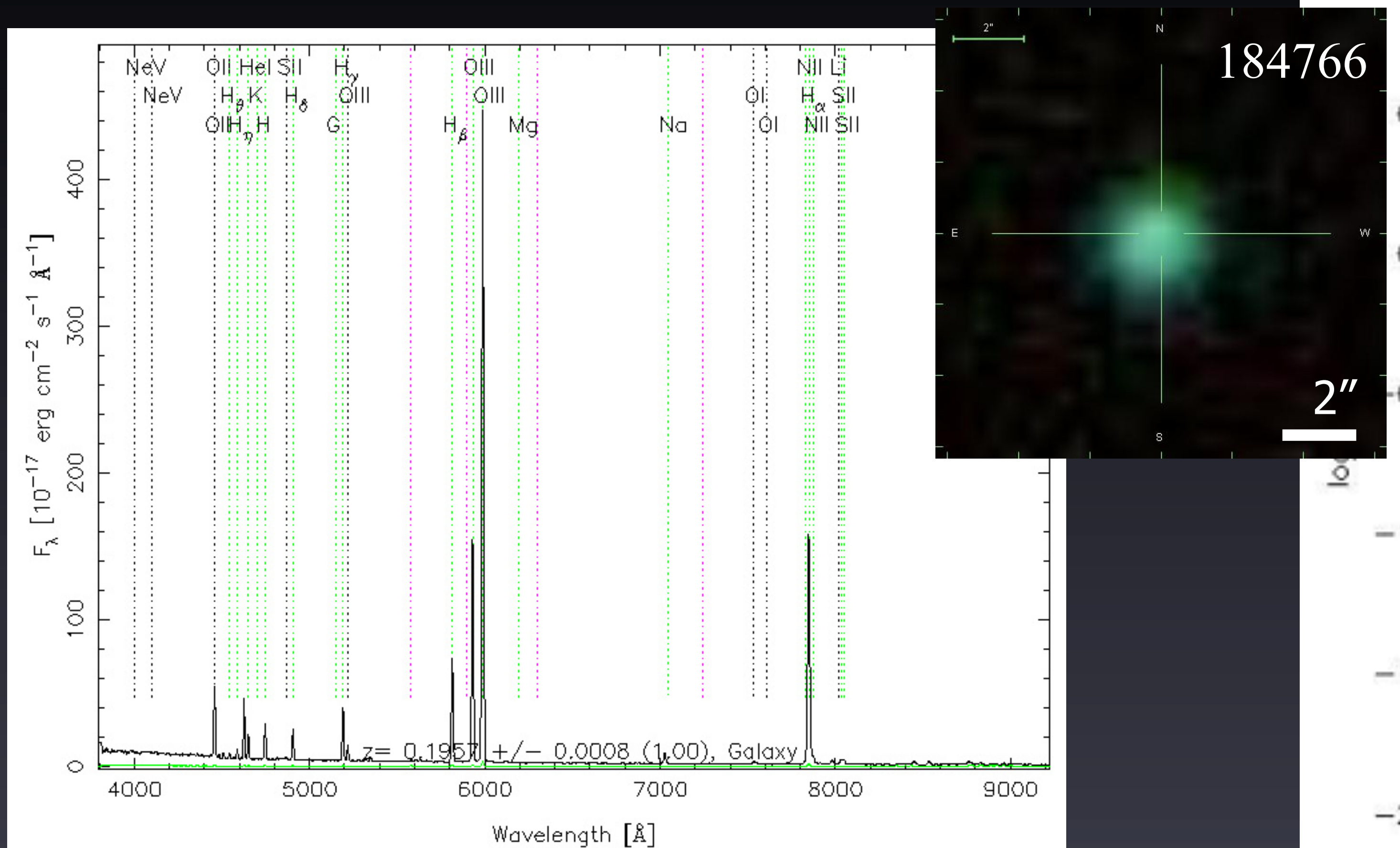
SHOCKS can also be responsible for O+ collisional de-excitation and a higher N/O could be wrongly derived (Raymond 1979)

BUT CHEMODYNAMICS ALSO AFFECTS N/O

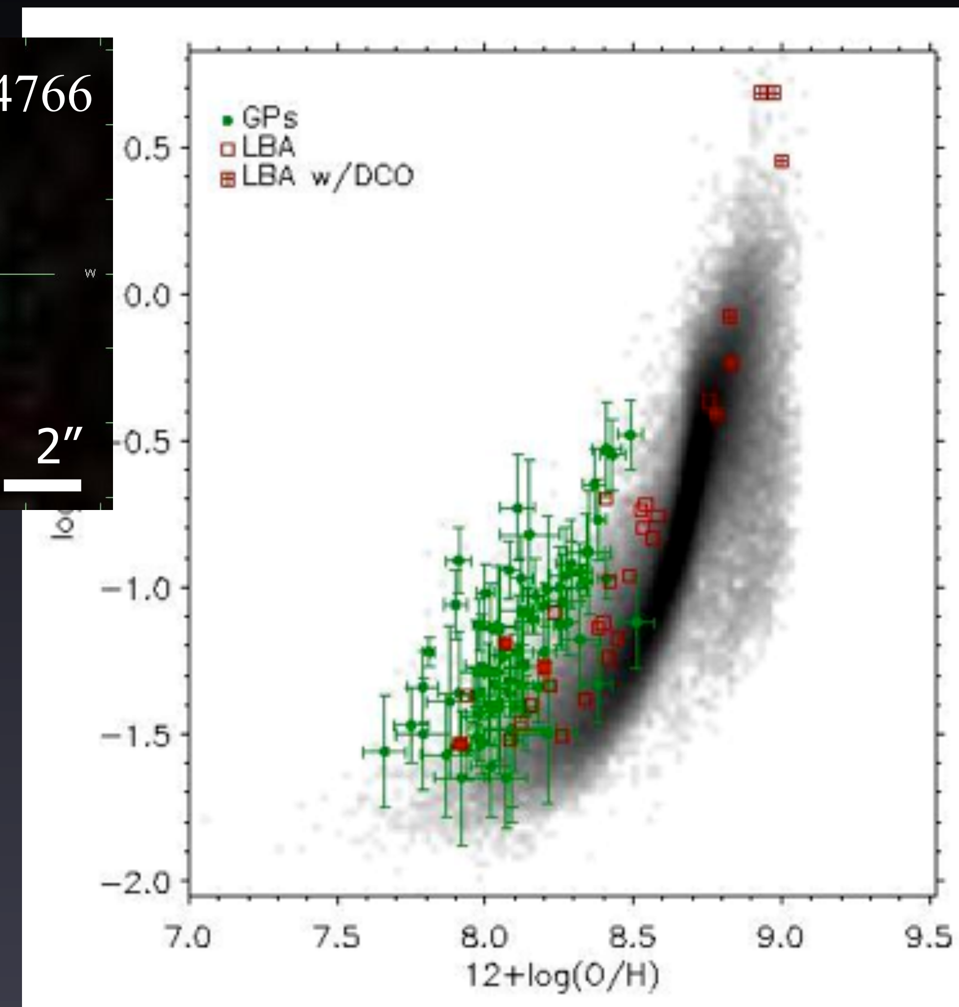


In this way, Chung+ (2013) show that N/O is higher than expected for BCGs in SDSS with a disturbed morphology, although they also find that their SFR is lower in average, so they conclude that SF is more continuous in these object and that N has a secondary origin.

THE CASE OF GREEN PEAS



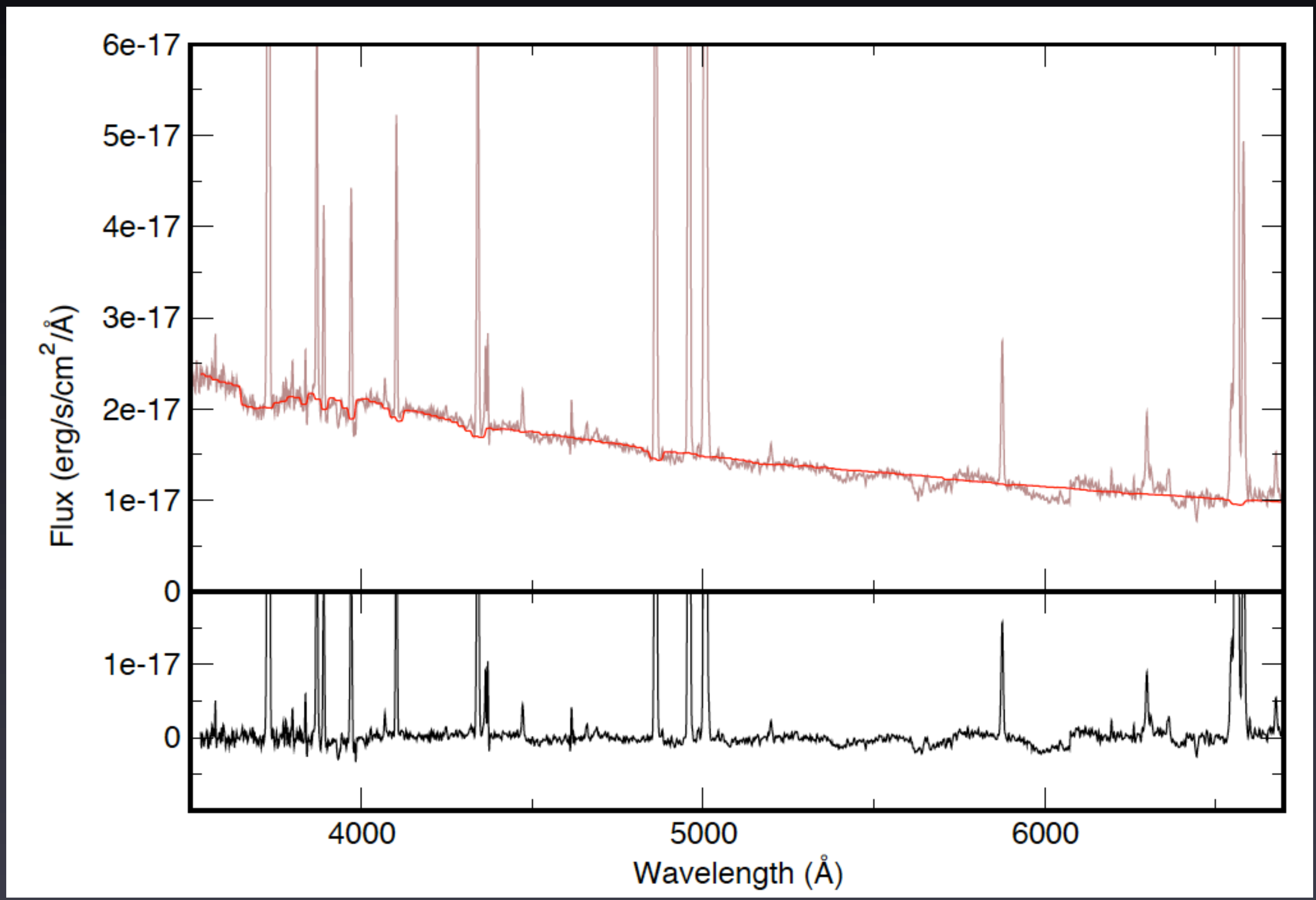
Cardamone+ 2009

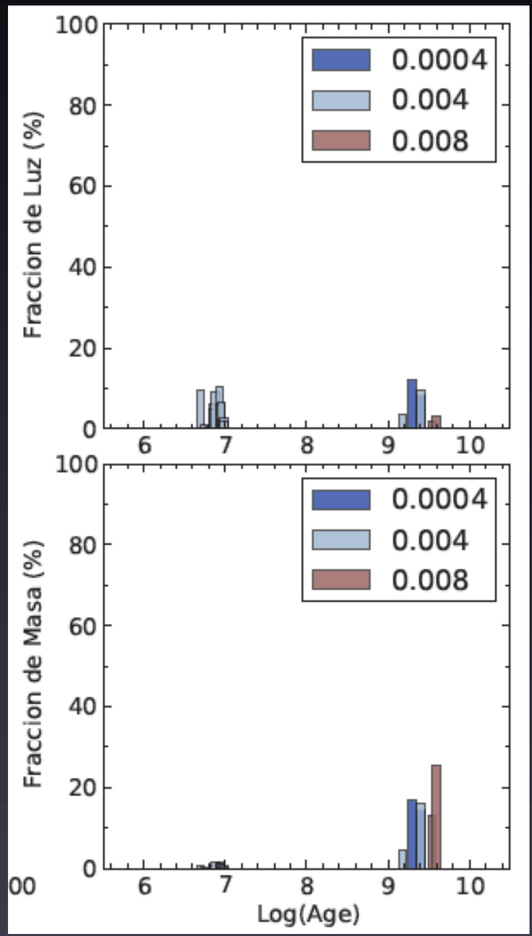


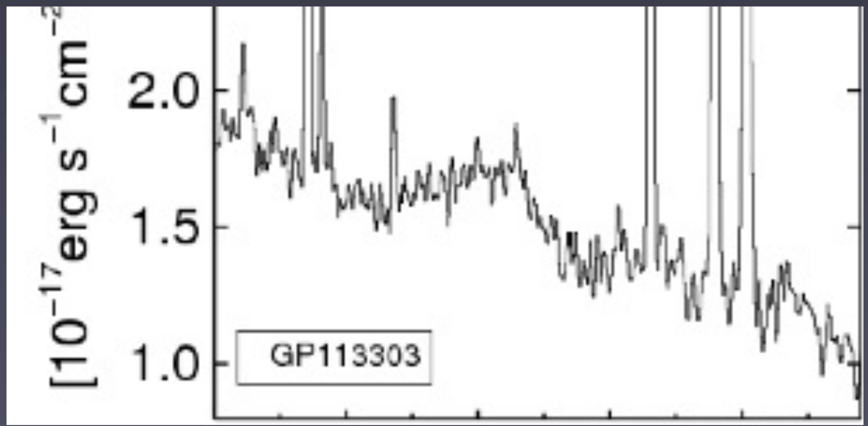
Amorín, Pérez-Montero & Vílchez 2010

GPs are compact galaxies of high sSFR. They present very large EW(OIII) in the r-band as selected in the SDSS.
According to Amorín, Pérez-Montero & Vílchez their N/O is larger than expected for their O/H as derived from the direct method.

THE ORIGIN OF EXTRA N IN GPs



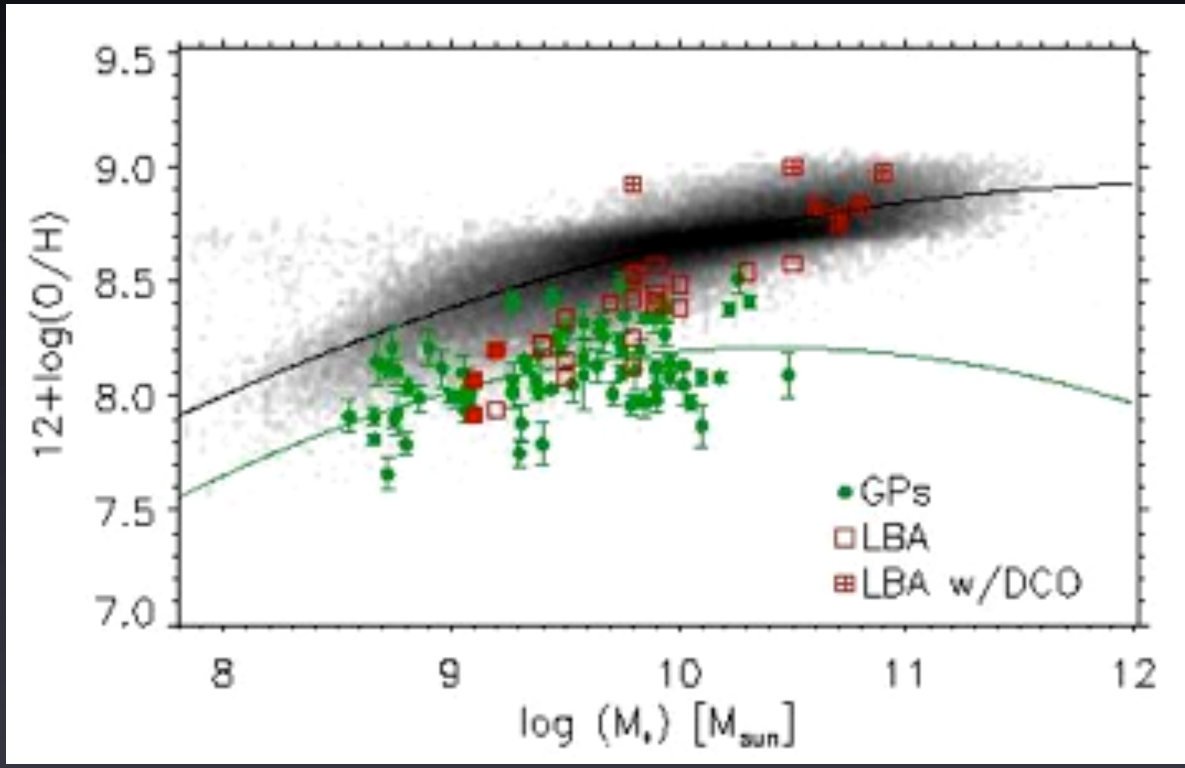


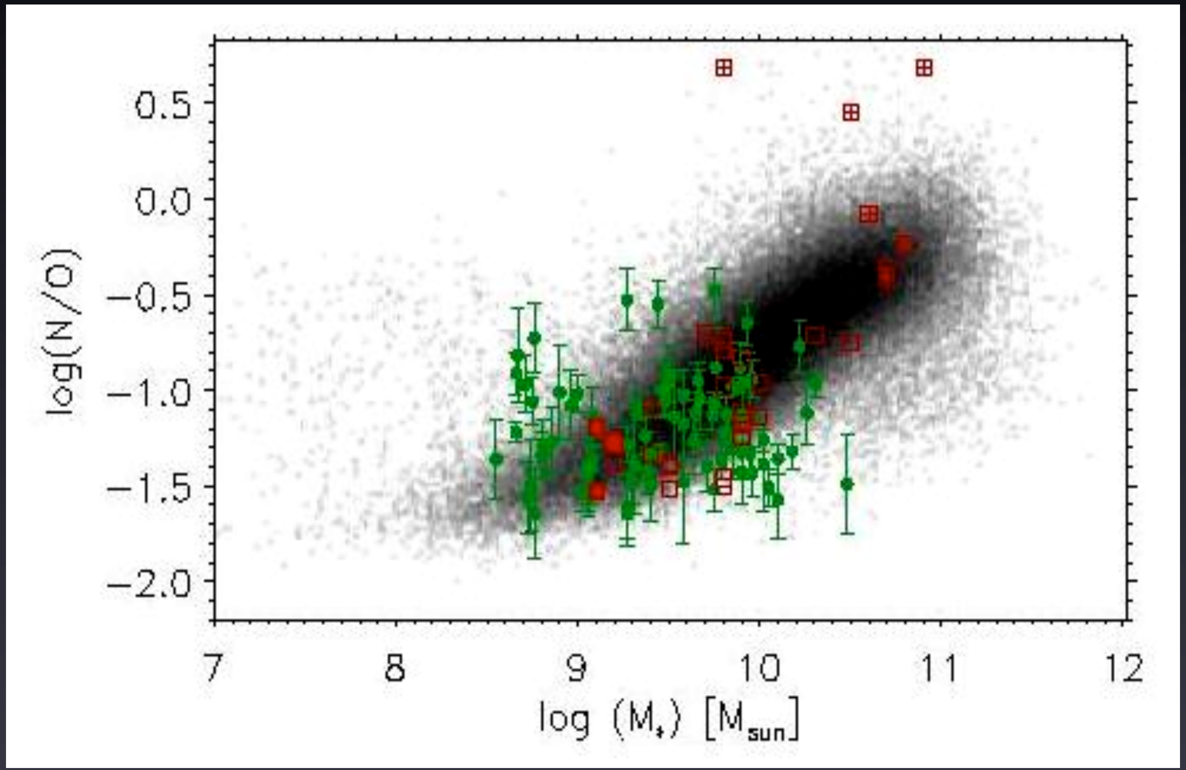


The analysis of deep optical spectra taken with GTC-OSIRIS of 3 GPs (Amorín+ 2012) reveals a very old stellar population responsible for the secondary N ... but also WR stars.

USING STELLAR MASS AS A CONSTRAINT

Amorín, Pérez-Montero, Vílchez 2010

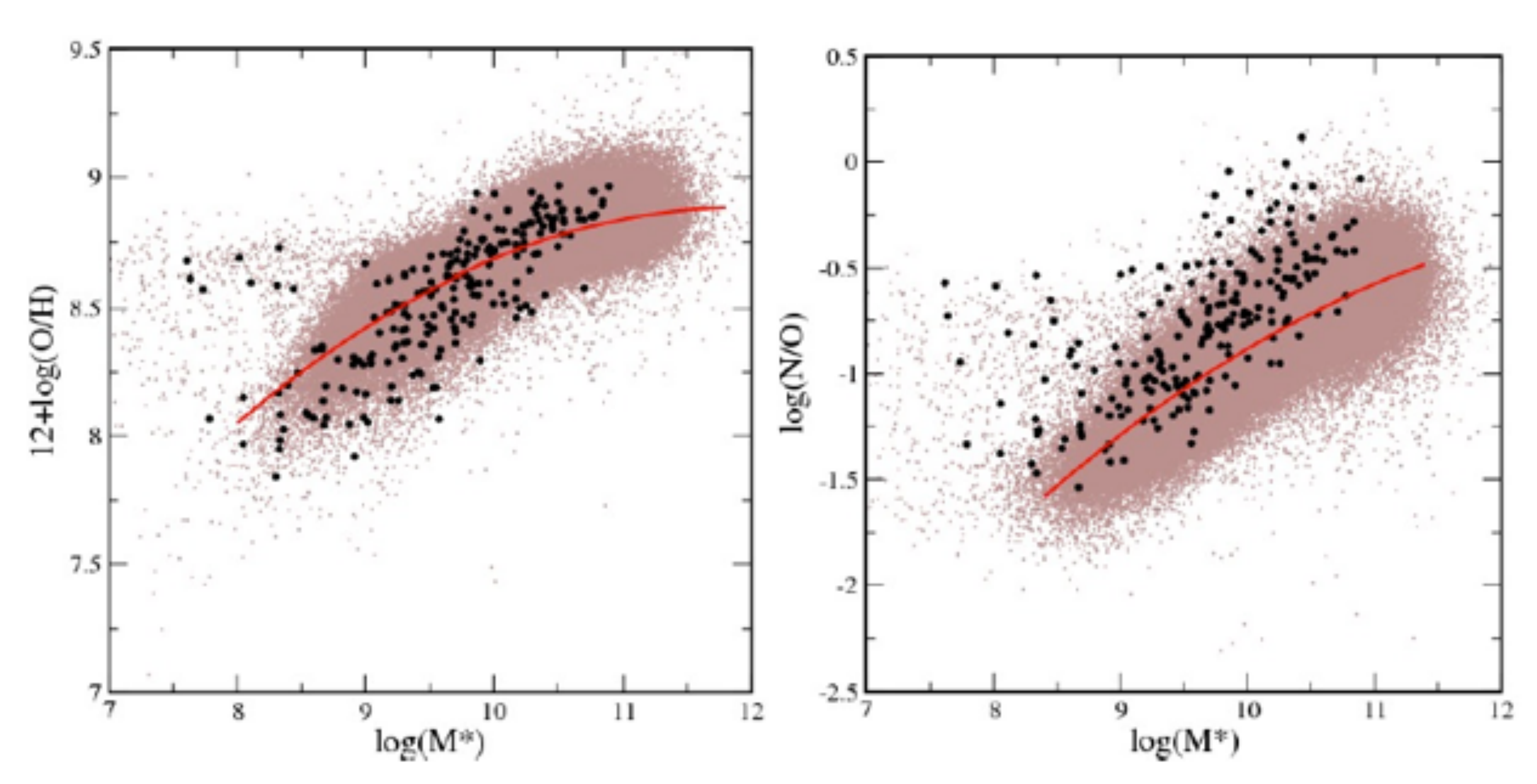




The combined use of the stellar mass - metallicity relation (MZR) and the stellar mass- N/O ratio (MNOR) gives important clues.
For GPs, Z is sensibly lower than expected for their mass, but not N/O, so hydrodynamical processes are probably behind their high N/O.

USING STELLAR MASS AS A CONSTRAINT

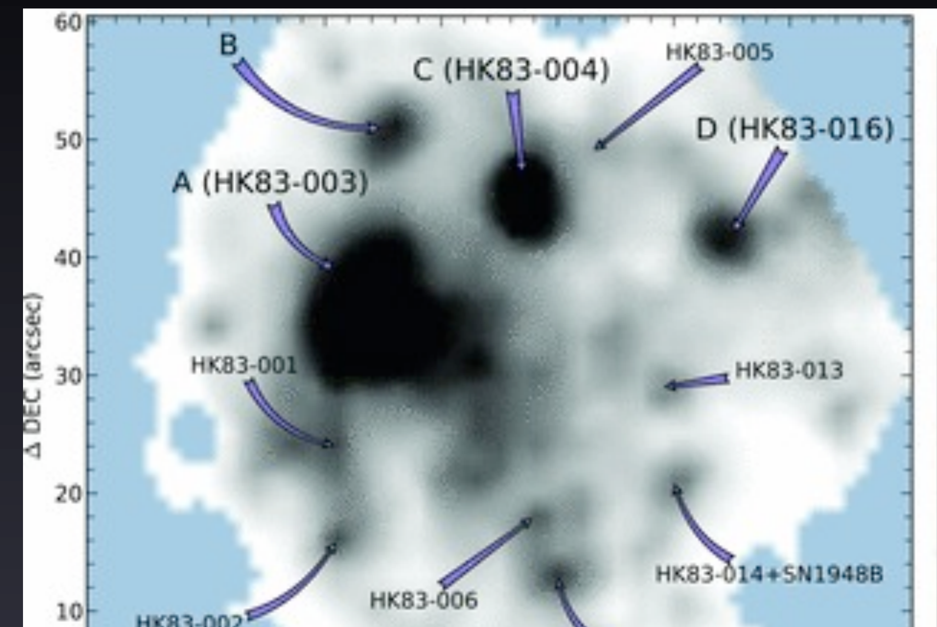
Pérez-Montero+ 2013

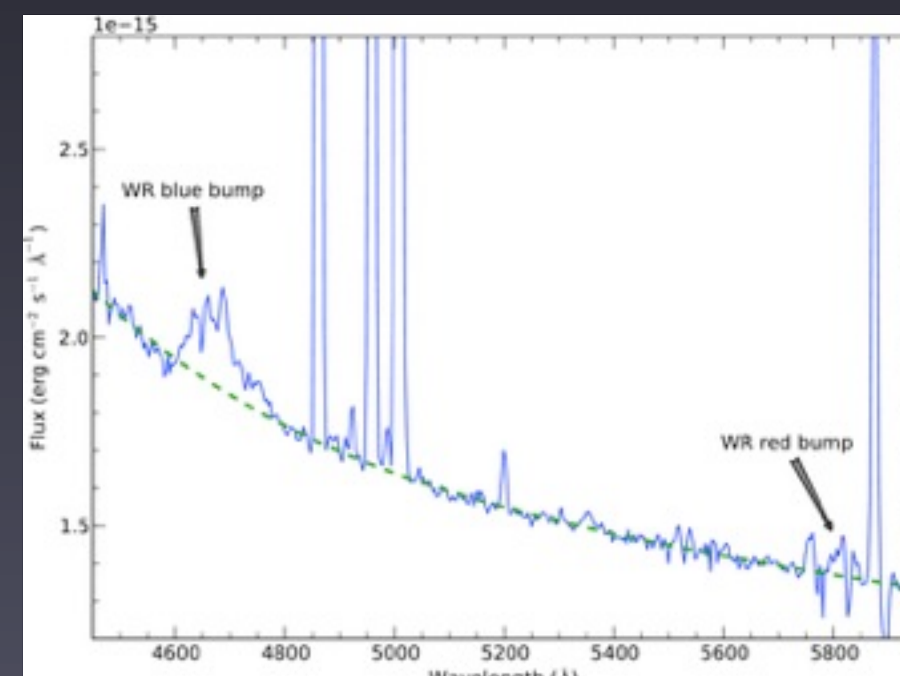


ON THE CONTRARY, WR galaxies of SDSS in Brichmann+ (2008) present in average high N/O values for their stellar mass and normal values of Z. Possibly, the abundances measured in the SDSS fiber cannot be taken as representative of the whole galaxies.

IFUS: AN IDEAL TOOL TO STUDY WR GALAXIES

Integral field units (IFUs) allow us to:
- Measure the total emission of WR bumps.
- Relate it to the corresponding Balmer emission from the gas.
- Locate and resolve the position of WR stars
- Discover new WR stars (e.g. IIZw70, Kehrig+ 2008; NGC6946, García-Benito+ 2010).
- Link the presence of WR stars with chemical pollution and dynamical effects on the gas.



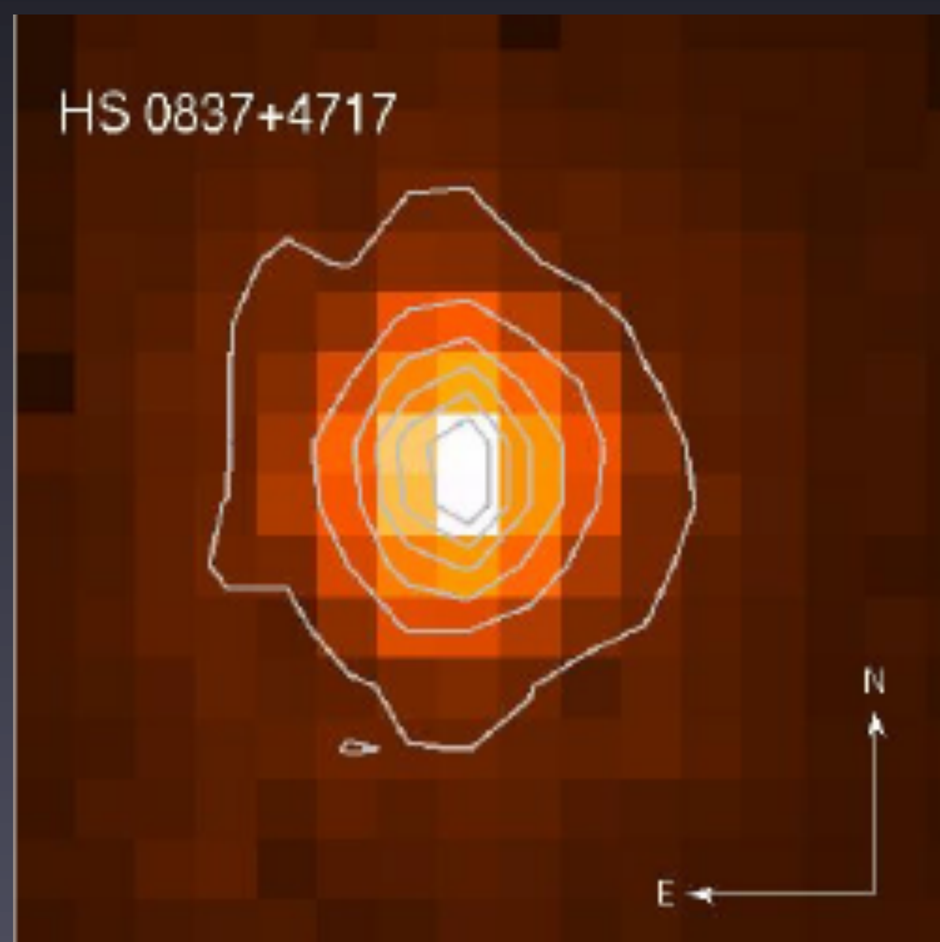


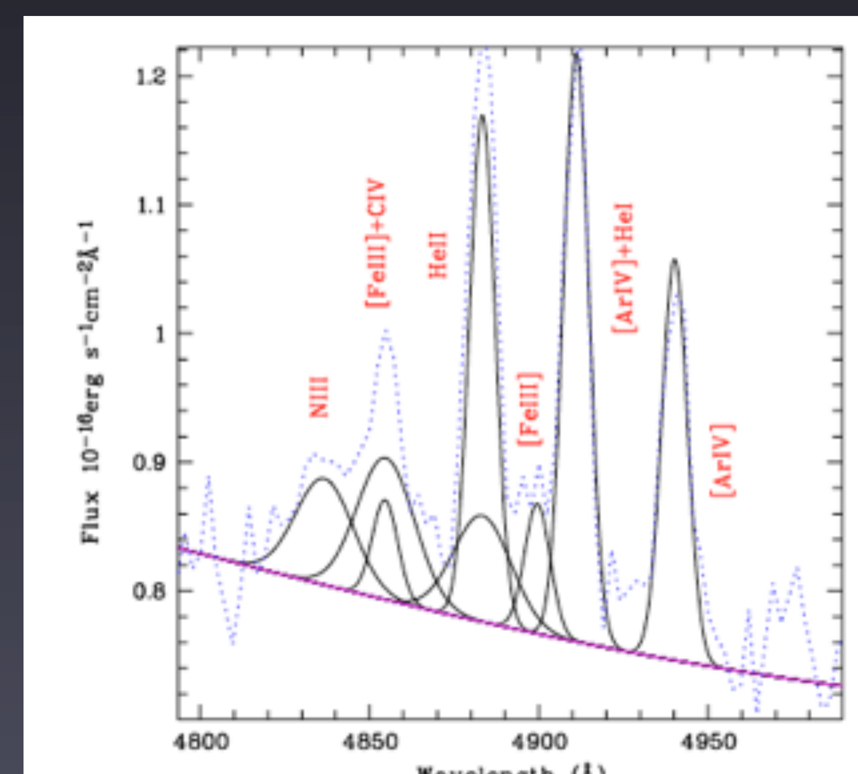
García-Benito+ 2010

IFUS LEAD TO DIFFERENT SCENARIOS

i) HOMOGENEOUS N/O IN SCALES OF SEVERAL KPC
This scenario implies that WR stars cannot be responsible for the high N/O and probably hydrodynamical effects are related, as in GPs

e.g. Pérez-Montero+ 2011: PMAS CAHA 3.5 m. observations of HS0837+4717





Pustilnik+ 2004

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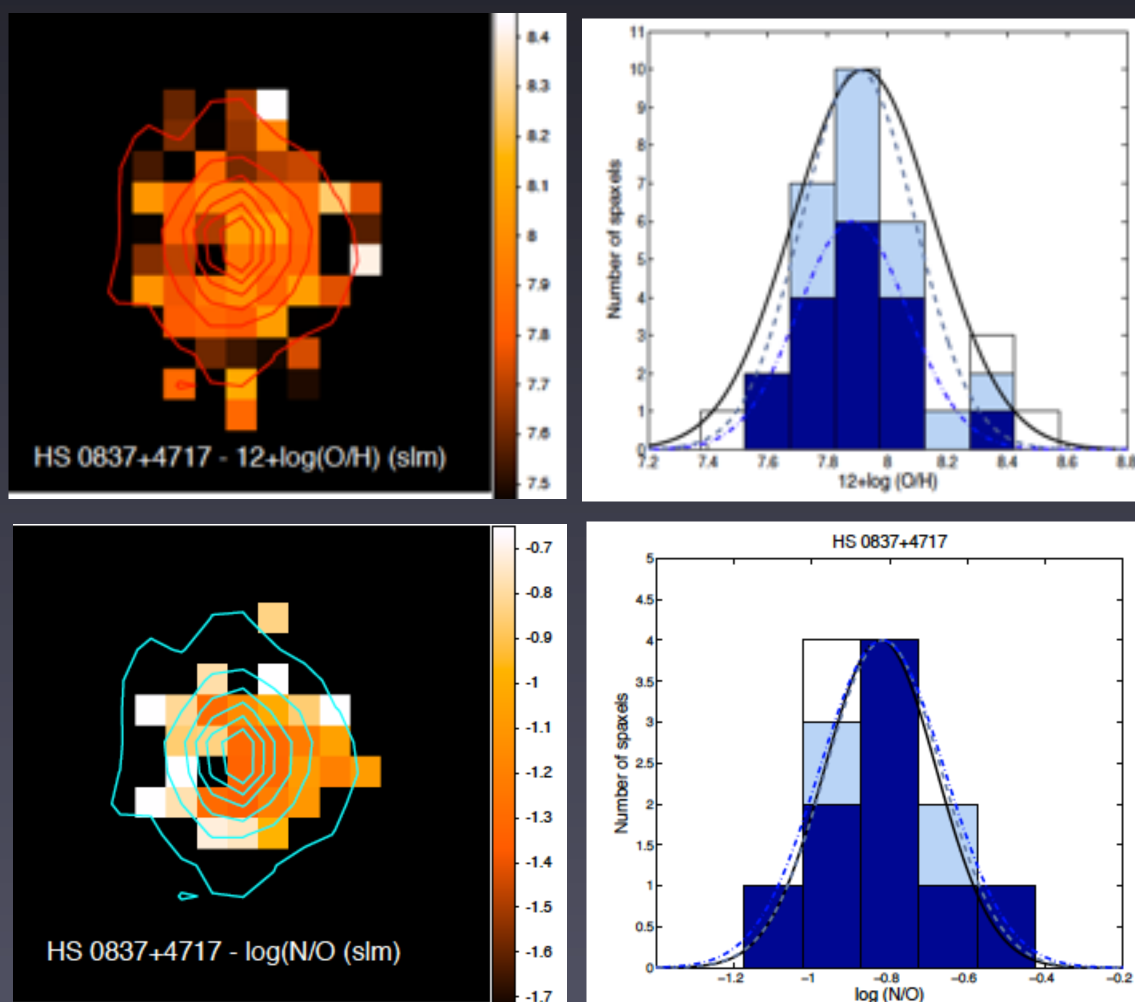

The use of appropriate statistical methods lead to the conclusion that very low Z and very high N/O are homogeneous in spatial scales of 3-4 kpc.

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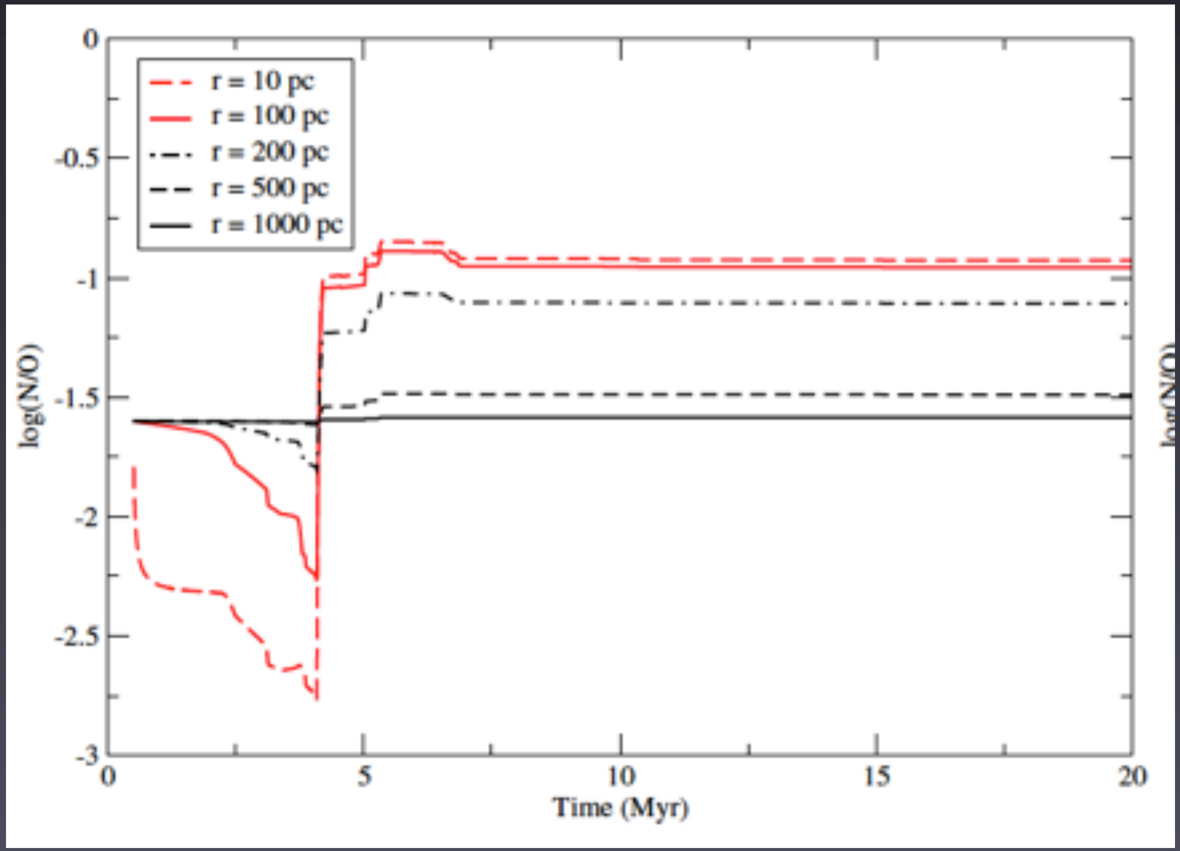

Using synthetic yields of massive stars from Mollá & Terlevich (2012), can be seen that WRs have a limited power to pollute the ISM of a galaxy (i.e. A 10^7 $M_\odot$ cluster can pollute about 100-200 pc assuming instantaneous mixing).

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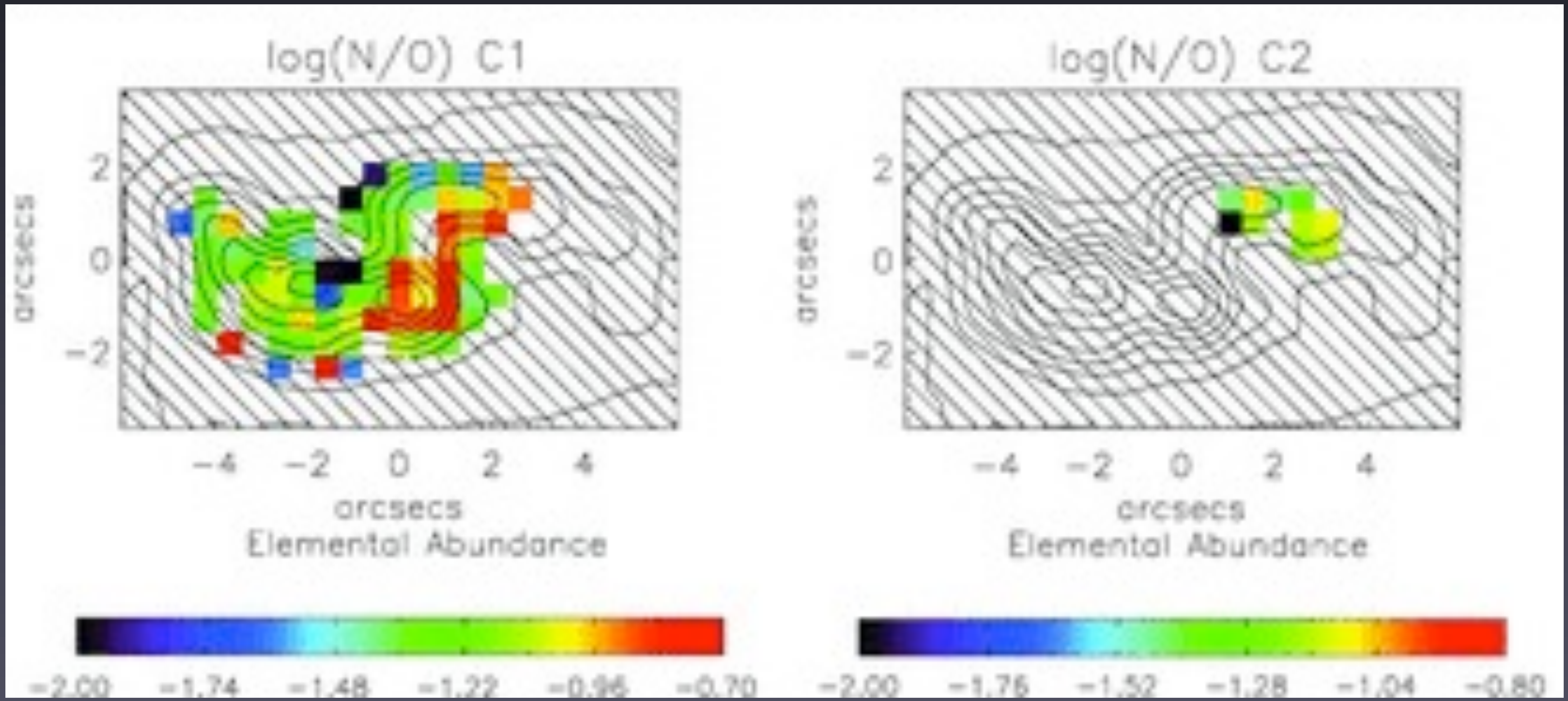
e.g. James+ 2013: VLT-FLAMES observations of the merging galaxy UM448



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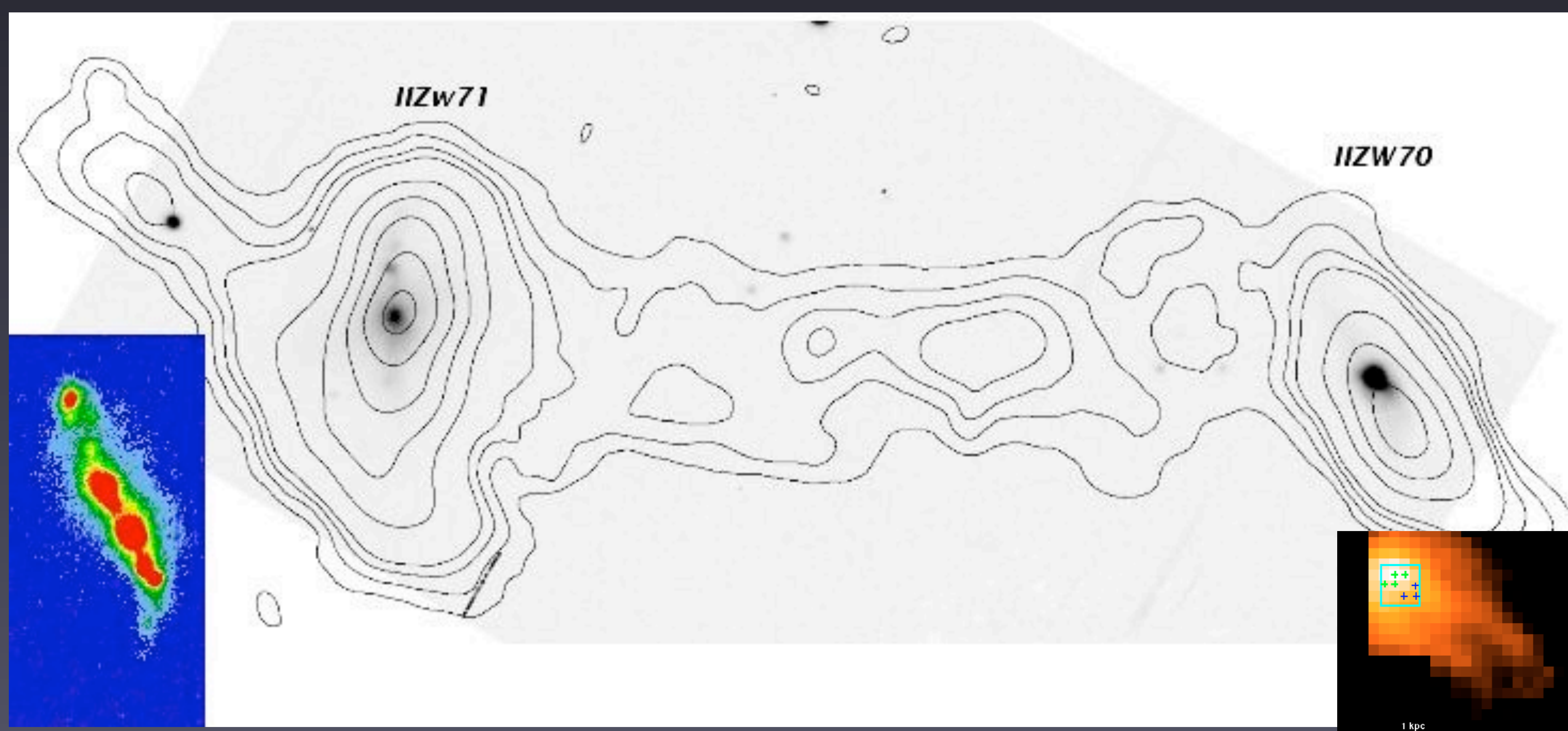
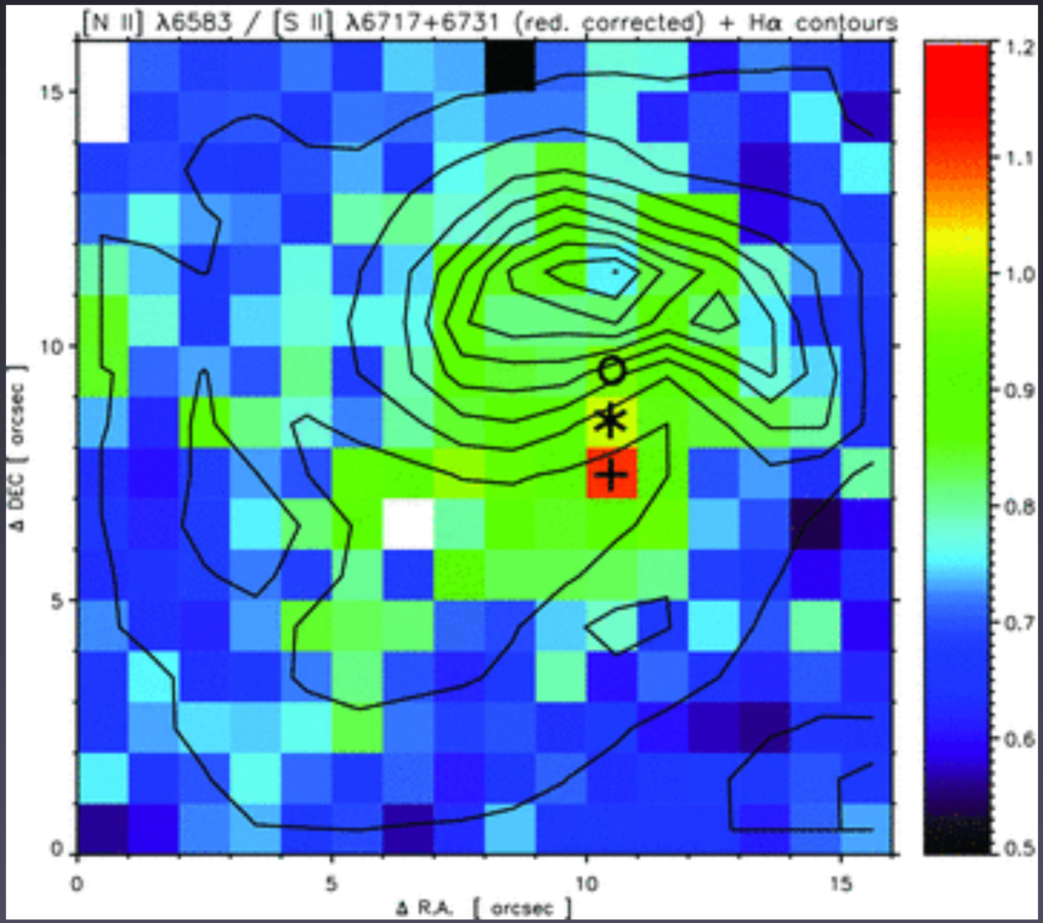
e.g. Kehrig+ 2008: PMAS CAHA 3.5m. Evidence of WR stars and very high N/O at scales of 1 kpc. A HI bridge connects it with IIZw71.



IFUS LEAD TO DIFFERENT SCENARIOS

ii) LOCAL N/O POLLUTION AROUND WRs POSITION
The high N/O is found spatially related to broad WR emission and so could be originated by the ejected material in dense winds from massive stars.

e.g. López-Sánchez+ 2011: PMAS CAHA 3.5 m. observations of IC-10



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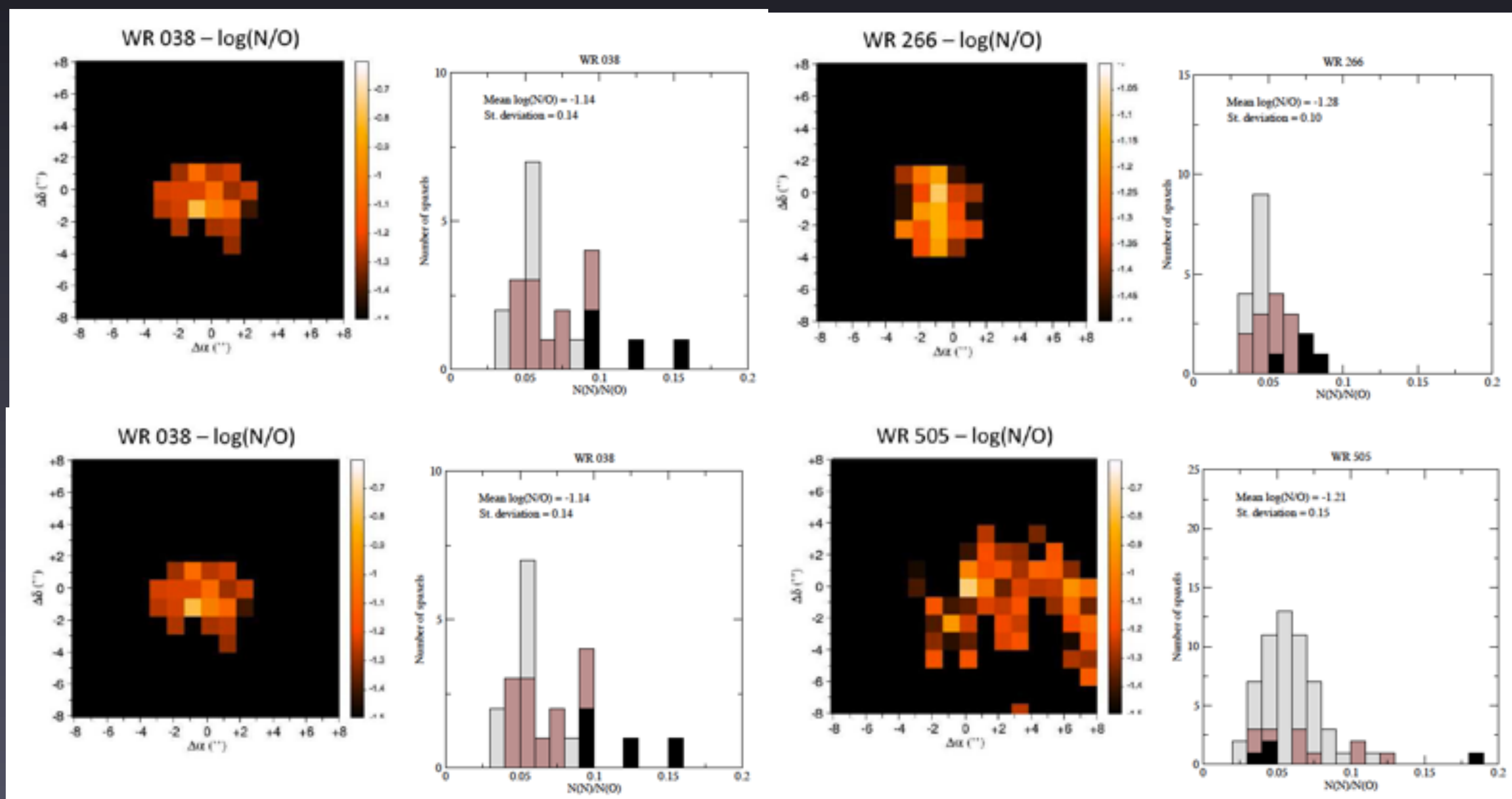
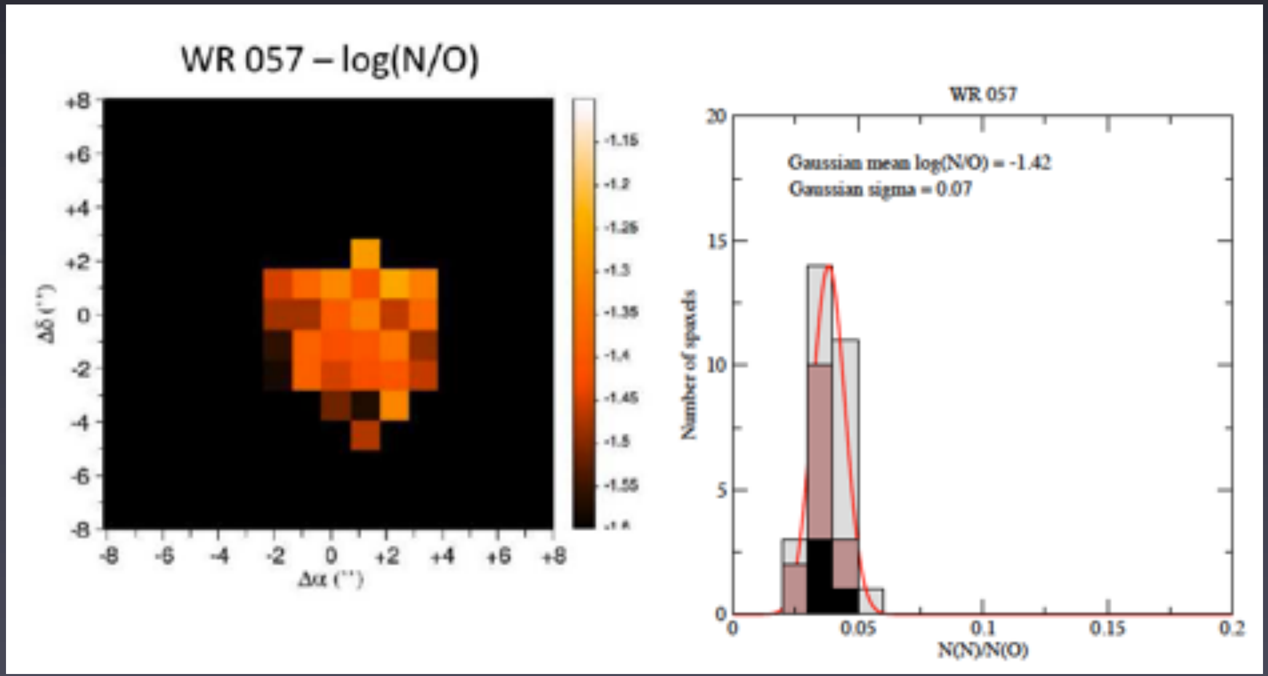
e.g. Pérez-Montero+ 2013: PMAS CAHA 3.5 m. observations of WR-SDSS galaxies

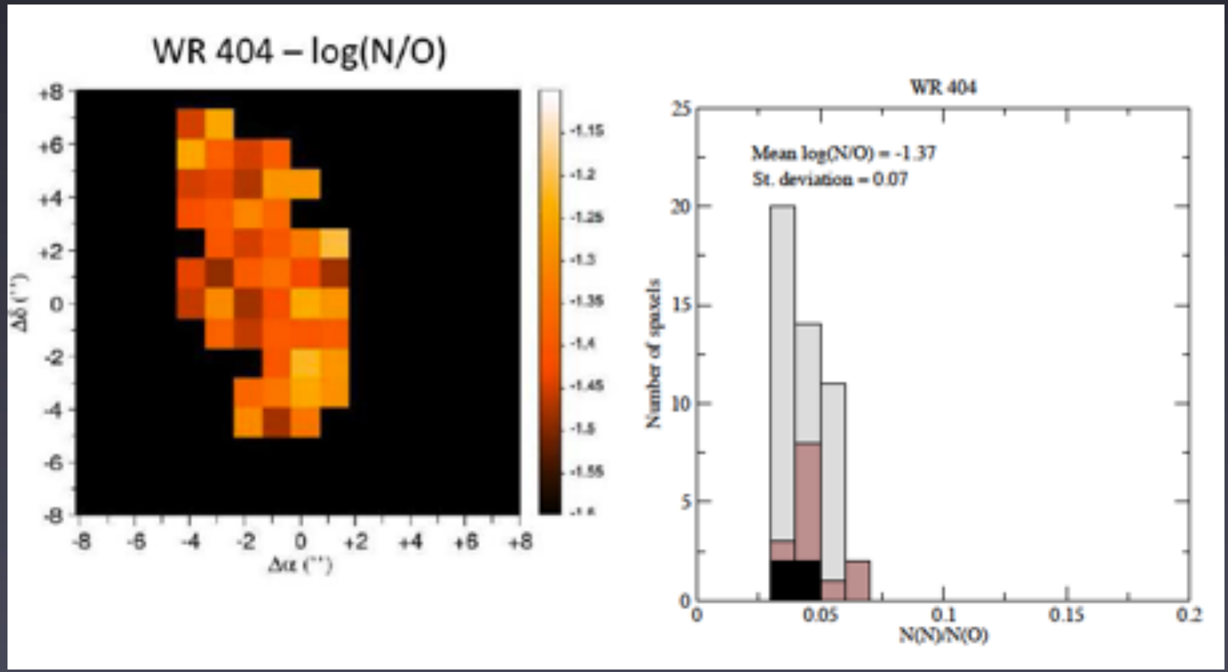


IFUS LEAD TO DIFFERENT SCENARIOS

iii) NO N OVERABUNDANCE AROUND WR POSITIONS.
The same average N/O is found in the positions where the broad WR bumps are detected as in the rest of the galaxy.

e.g. Pérez-Montero+ 2013: PMAS CAHA 3.5 m. observations of WR-SDSS galaxies .... but other two with no higher N/O in the WR positions.





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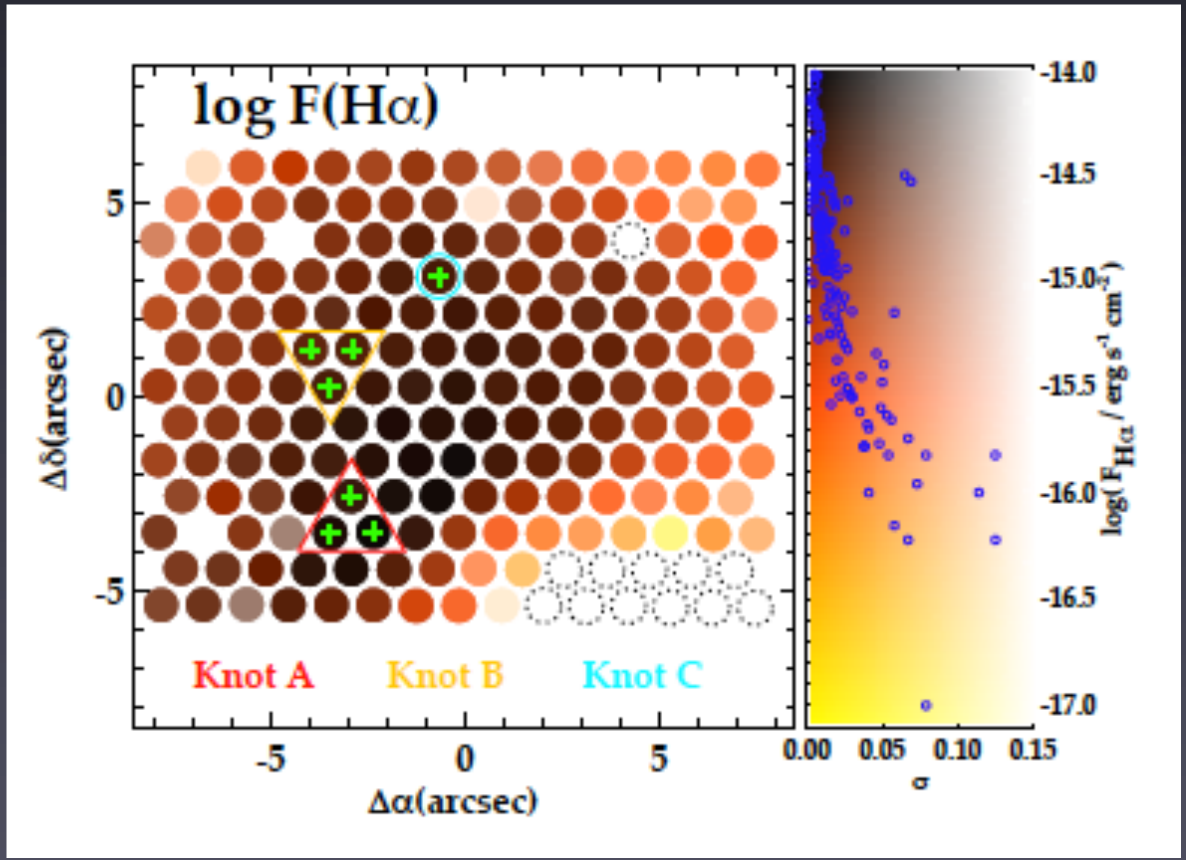
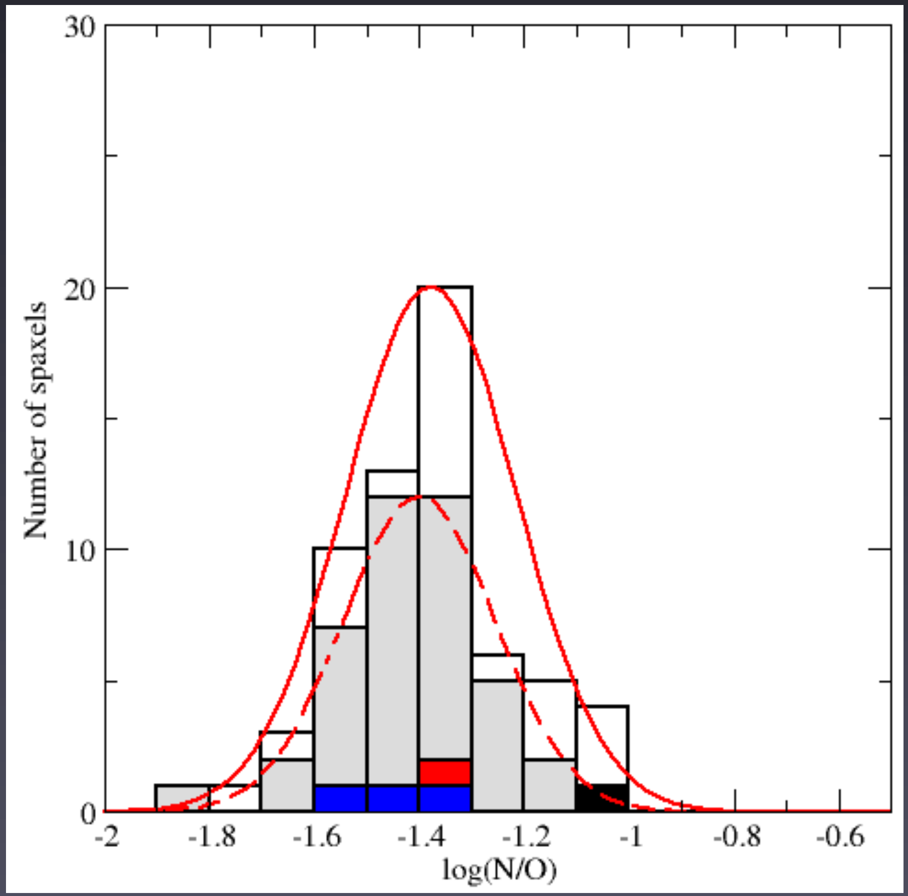
e.g. Kehrig+ 2013, INTEGRAL observarions of Mrk178: only possible N and He local enrichment around 1 out of 3 knots.

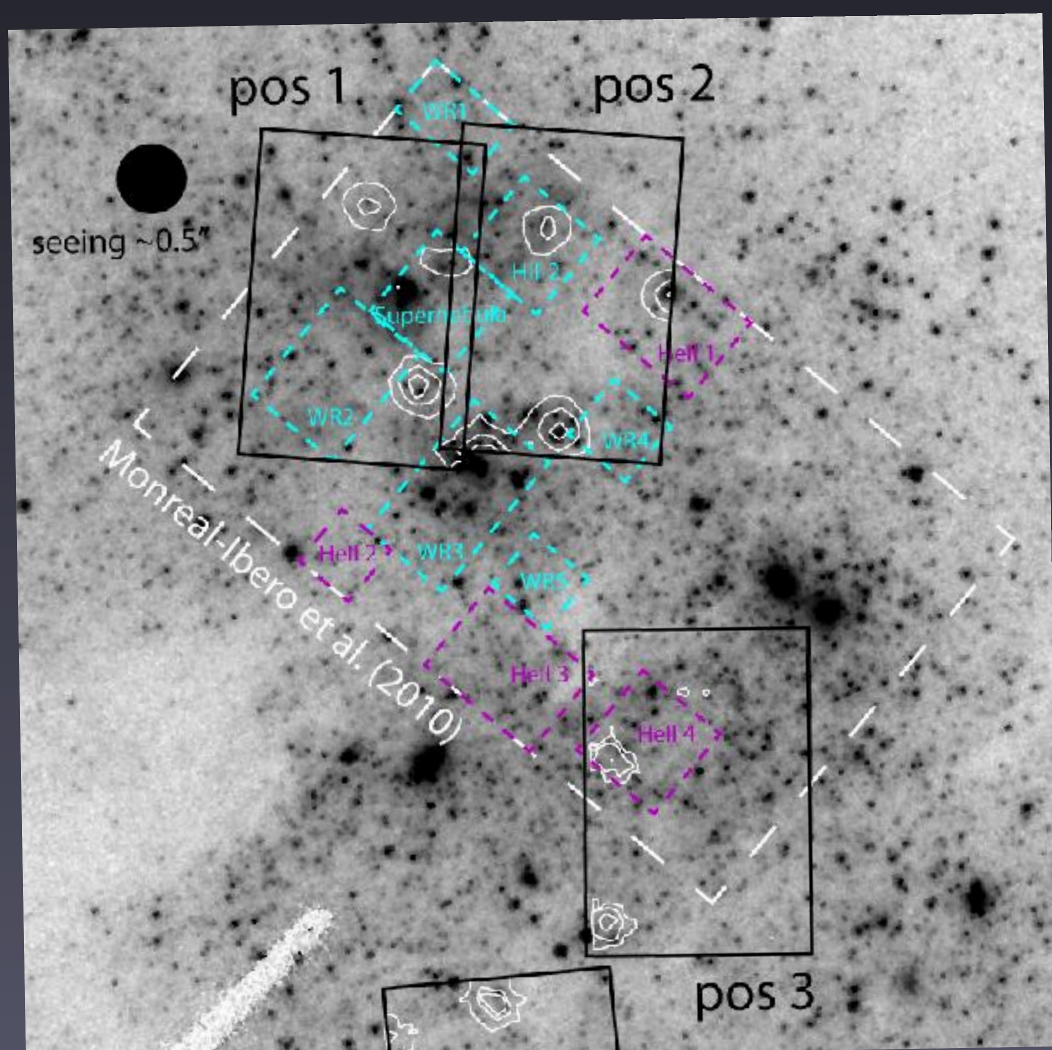


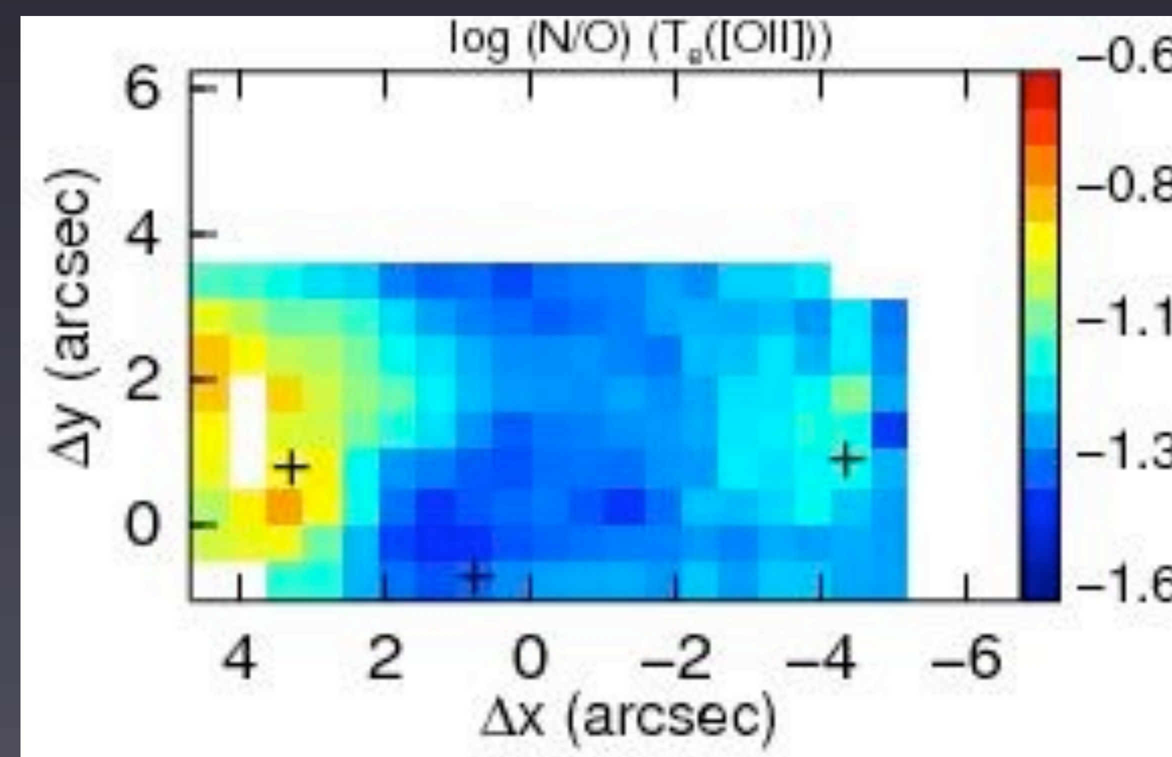


IFUS LEAD TO DIFFERENT SCENARIOS

iv) HIGH N/O IN POSITIONS DIFFERENT THAN WR STARS.

e.g. Monreal-Ibero+ 2010, 2012 using VLT-VIMOS and FLAMES found high N/O in positions SW of the WR stars in NGC5253. Later work by Westmoquette+ 2013 using GMOS find a flow of dense rapid gas between stars and these regions.





SUMMARY AND CONCLUSIONS

✔ Integrated WR bumps in galaxies can be used to study the bursts of star-formation if the burst is massive enough ($M>10^4\ M_\odot$).

✔ Models canot fit the bump luminosities and expected number of WC and WN, above all at low Z.

✔ Observational caveats owing to different covering and aperture of the WRs and the rest of the ionizing population -> IFUS can solve this.

✔ Good spectral resolution is required to remove nebular emission and resolve broad components.

✔ No direct relation can be stablished between the presence of WR stars and high N/O in low-Z galaxies as chemodynamical effects also play a role: relationships with stellar mass and/or IFUs can aid to characterize the chemical status of galaxies.