The lowest end and the primordial He abundance

Elena Terlevich, INAOE, México

Roberto Terlevich, INAOE, México

Evan Skillman, Minnesota, USA

Fabián Rosales, IoA, UK

Hot Big-bang nucleosynthesis

- Gamow, Alpher, Herman (1945-1953)

(but expansion, Hubble)

=> created all the elements

- Hayashi (1950)

High ρ and T → n,p freezing, + no stable nuclei with A=5,8

=> no nucleosynthesis after ^{4}He.

Successes in stellar evolution and nucleosynthesis…

BBNS abandoned for 10 years.

Hot Bing-bang nucleosynthesis revived

…Till Penzias and Wilson (1964) CMB

(predicted by Gamow et al.)

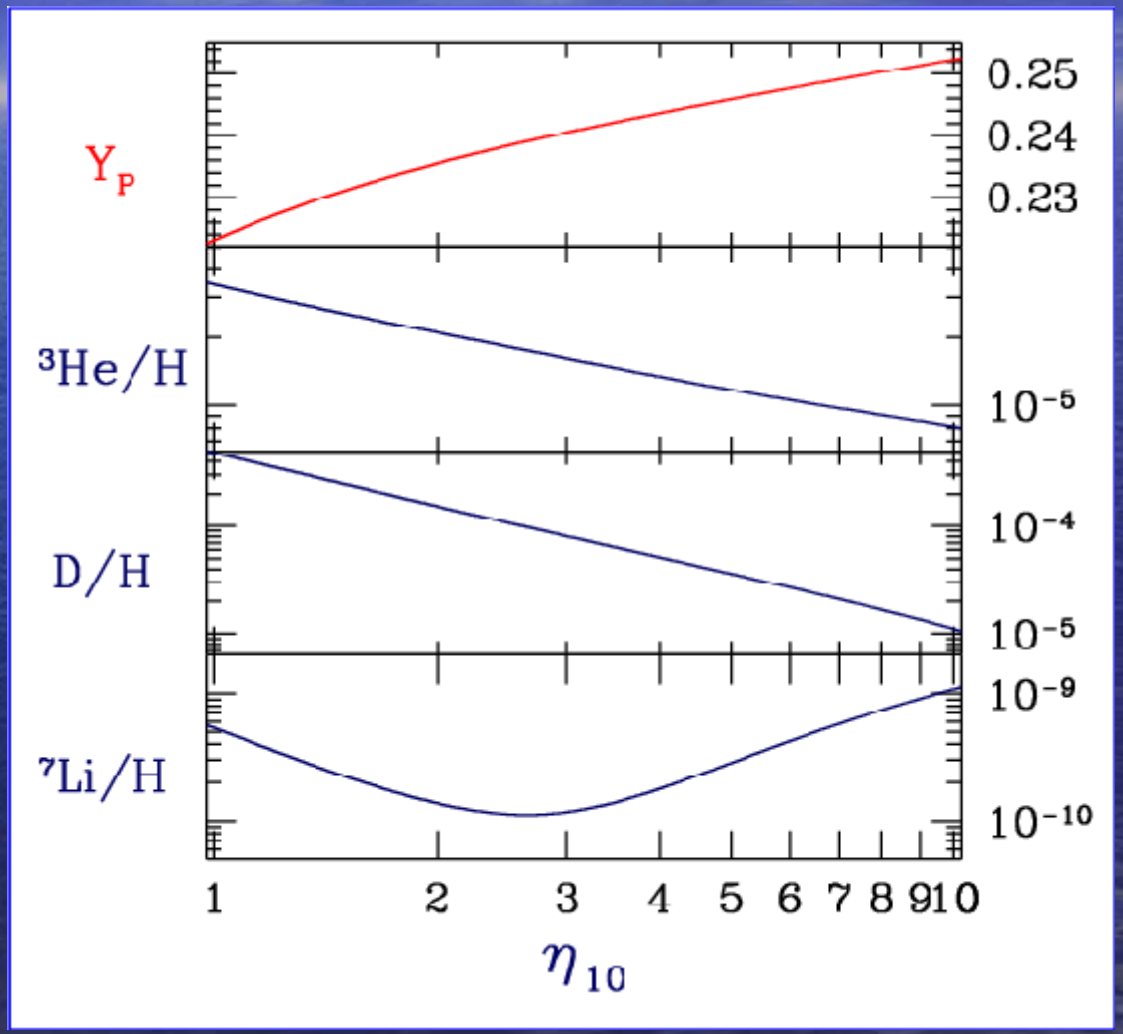
⇒SBBN … Peebles, Wagoner, Fowler, Hoyle, Schramm, Steigman, etc…

⇒Successful:

- Predicts primordial abundances of D, ^{4}He, ^{3}He, ^{7}Li covering 9 orders of magnitude.
- Predicts number of neutrino species.
- Predicts neutron half life.

The primordial abundances can be used to determine the baryon-to-photon density η

the abundances of the first elements depend on the interplay between the reaction rates and the expansion of the Universe

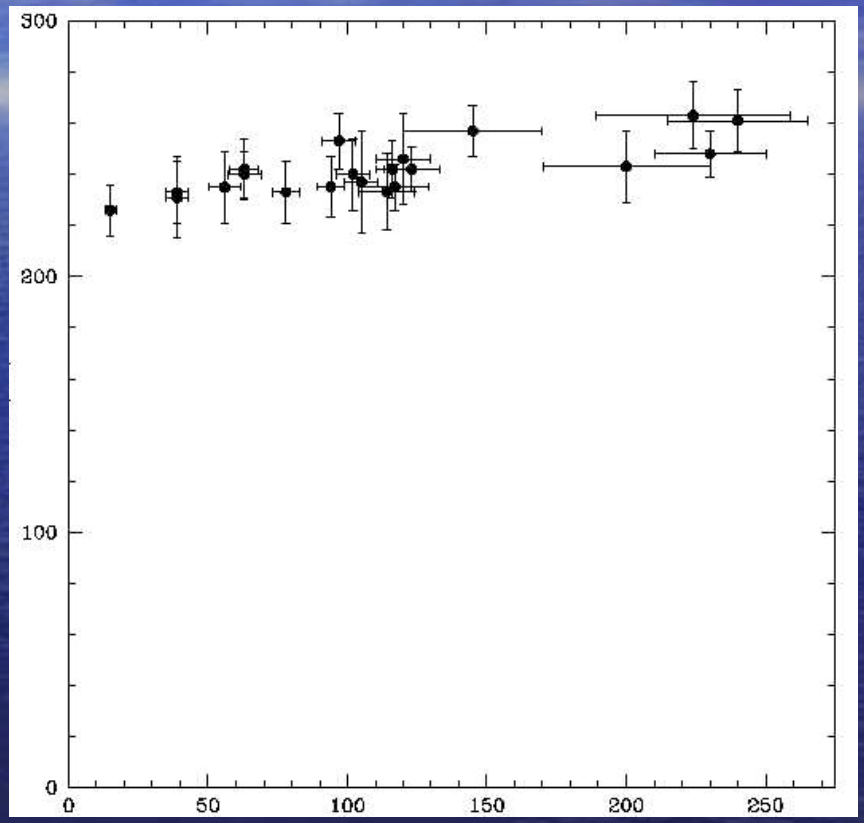


(Fiorentini et al. 1998, PhRD 58, 63506)

^{4}He is the easiest to measure

but is the one least sensitive to η

Y_P is found by extrapolation of the dY / dZ relation to $Z = 0$



since the Universe was born with no heavy elements,

$Y_P = Y(Z=0)$

(Peimbert & Torres-Peimbert 1974)

➡ high-quality measurements of Y and Z are required!

Uncertainties

physics	**atomic parameters, gal.chem.evolution**
stellar parameters	**underlying stellar absorption**
	ionization structure
nebular parameters	**temperature structure**
	H I collisional enhancement

Atomic coefficients

Brocklehurst (1972)

Smits (1991, 1996)

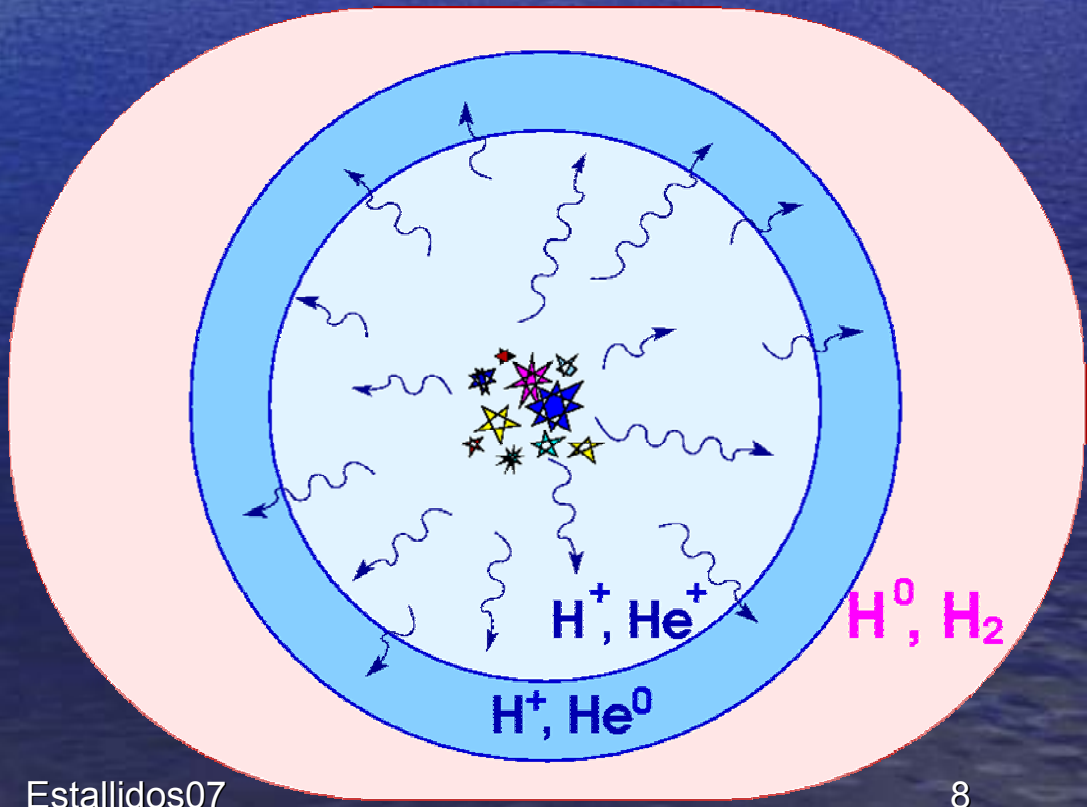
Benjamin, Skillman & Smits (1999)

Porter et al. (2005)

Incomplete knowledge of the ionization structure

$$\frac{N(\mathrm{He})}{N(\mathrm{H})} = \frac{N(\mathrm{He}^{+})}{N(\mathrm{H}^{+})} + \frac{N(\mathrm{He}^{++})}{N(\mathrm{H}^{+})}$$

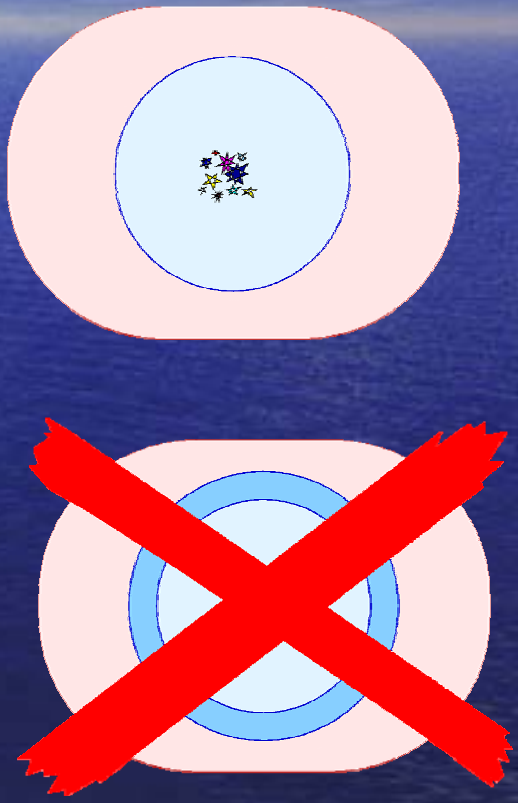
If the Strömgren radii of H and He do not coincide, the abundance ratio He / H is either underestimated or overestimated



Ionization structure, solutions

Apply selection criteria,

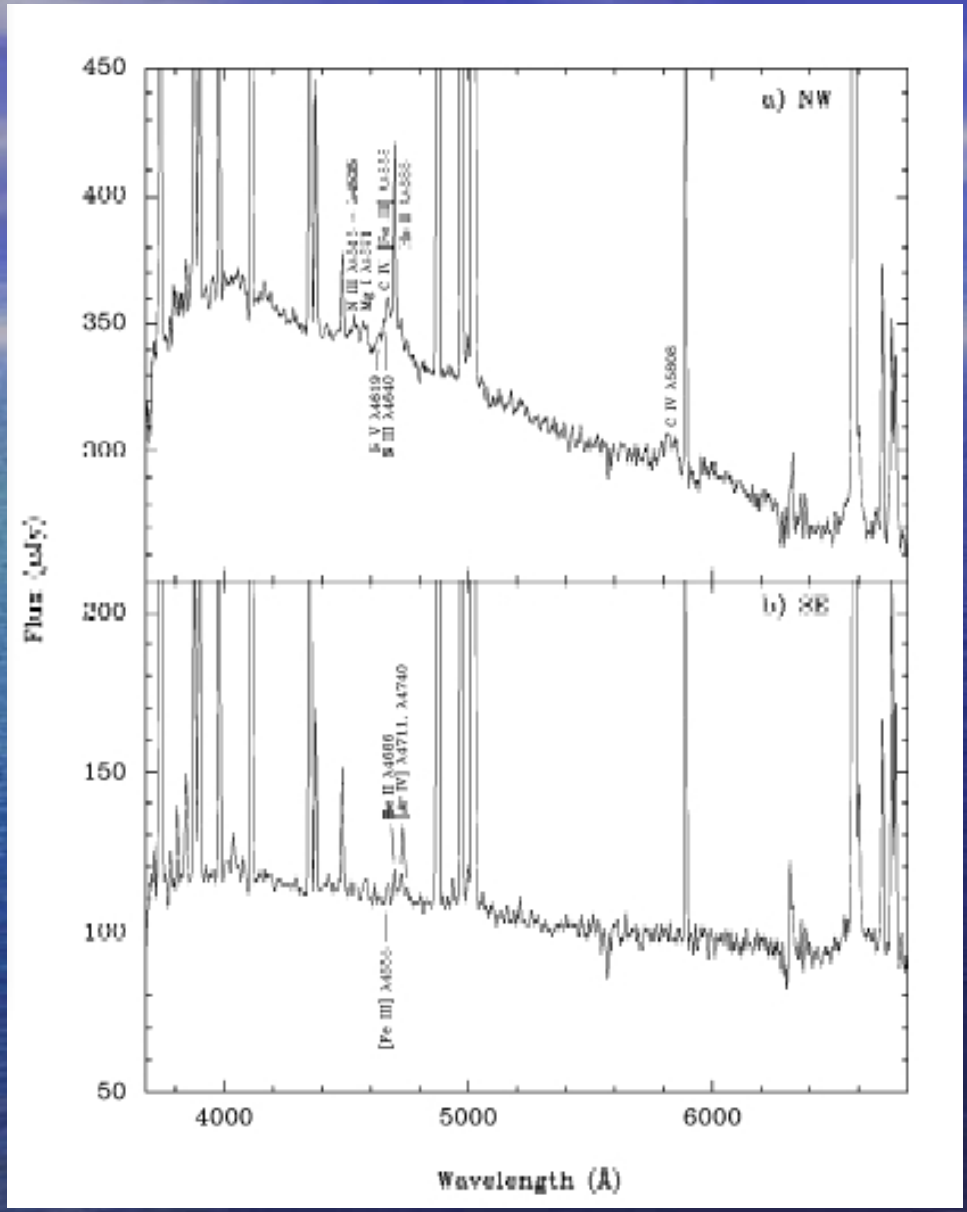
(Pagel et al. 1992)



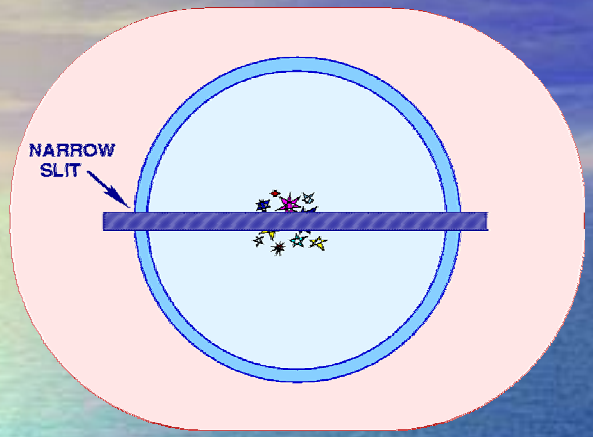
I Zw 18

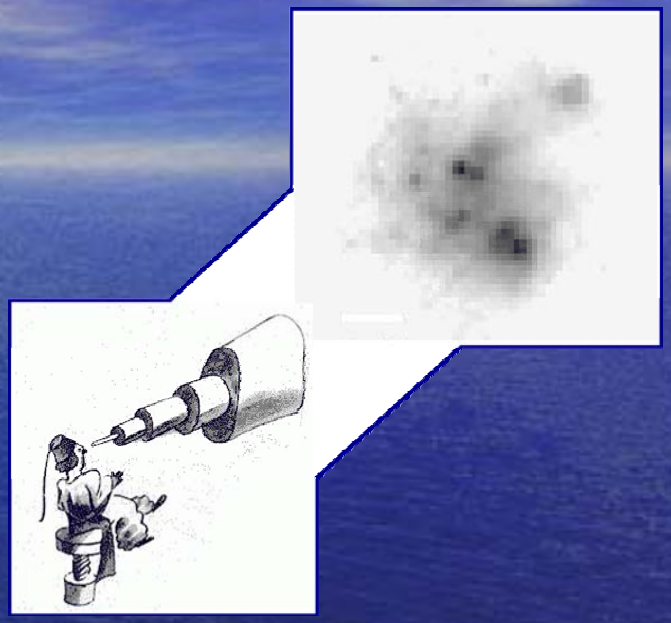
NW

SE


a) NW
b) SE
C IV λ5808
[Fe III] λ4658
Flux (μJy)
Wavelength (Å)
450
400
350
300
200
150
100
50
4000
5000
6000

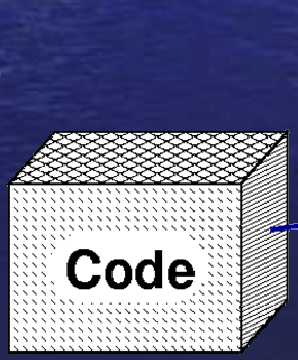
Ionization structure, solutions

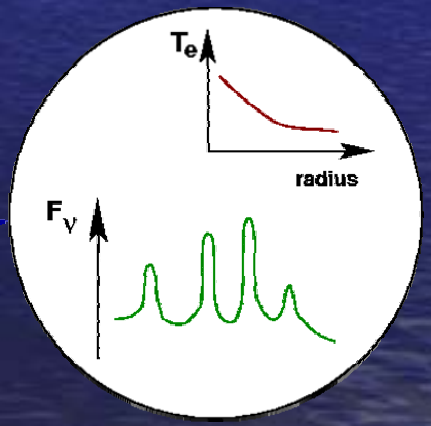




Tailored photoionization models and narrow slit data

(Luridiana et al. 2003)





Temperature fluctuations

One T_e fits all?

$$\frac{N(\mathrm{X})}{N(\mathrm{H}^+)} = f(T_e)\ \frac{I(\lambda)}{I(\mathrm{H}\beta)}$$

No! **Each ion is associated to a typical temperature, and adopting a different one introduces a bias in the derived abundance (Peimbert, t^2) ; recombination vs. collisional lines**

(García-Rojas, Peimbert)

Collisional excitation of Balmer lines

$$\frac{N(\mathrm{He}^+)}{N(\mathrm{H}^+)} \approx_T \alpha \frac{I(\lambda)}{I(\mathrm{H}\beta)}$$

$$\frac{j(\mathrm{H}\beta)_C}{j(\mathrm{H}\beta)_R} \propto \frac{N(\mathrm{H}^0)}{N(\mathrm{H}^+)} e^{-\Delta E/KT}$$

(e.g. Luridiana et al. 2003)

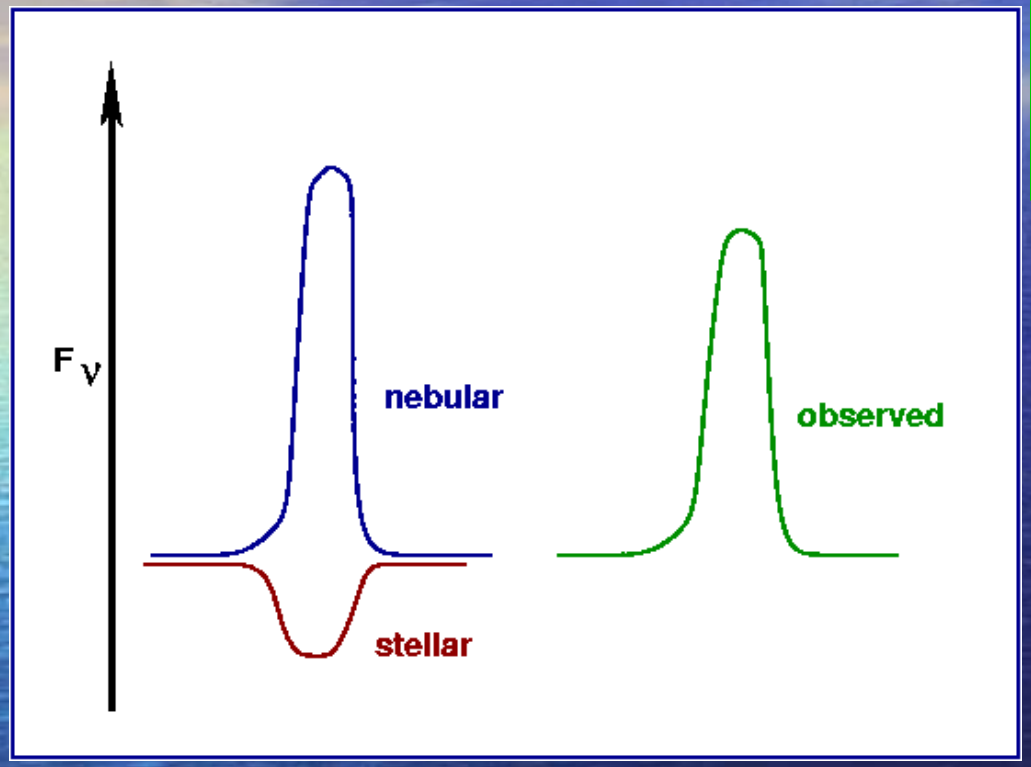
(But then chemical evolution model dependent; dY/dZ)

Or, new coeff. including coll.excitation

(Benjamin et al. 1999, Porter et al. 2005)

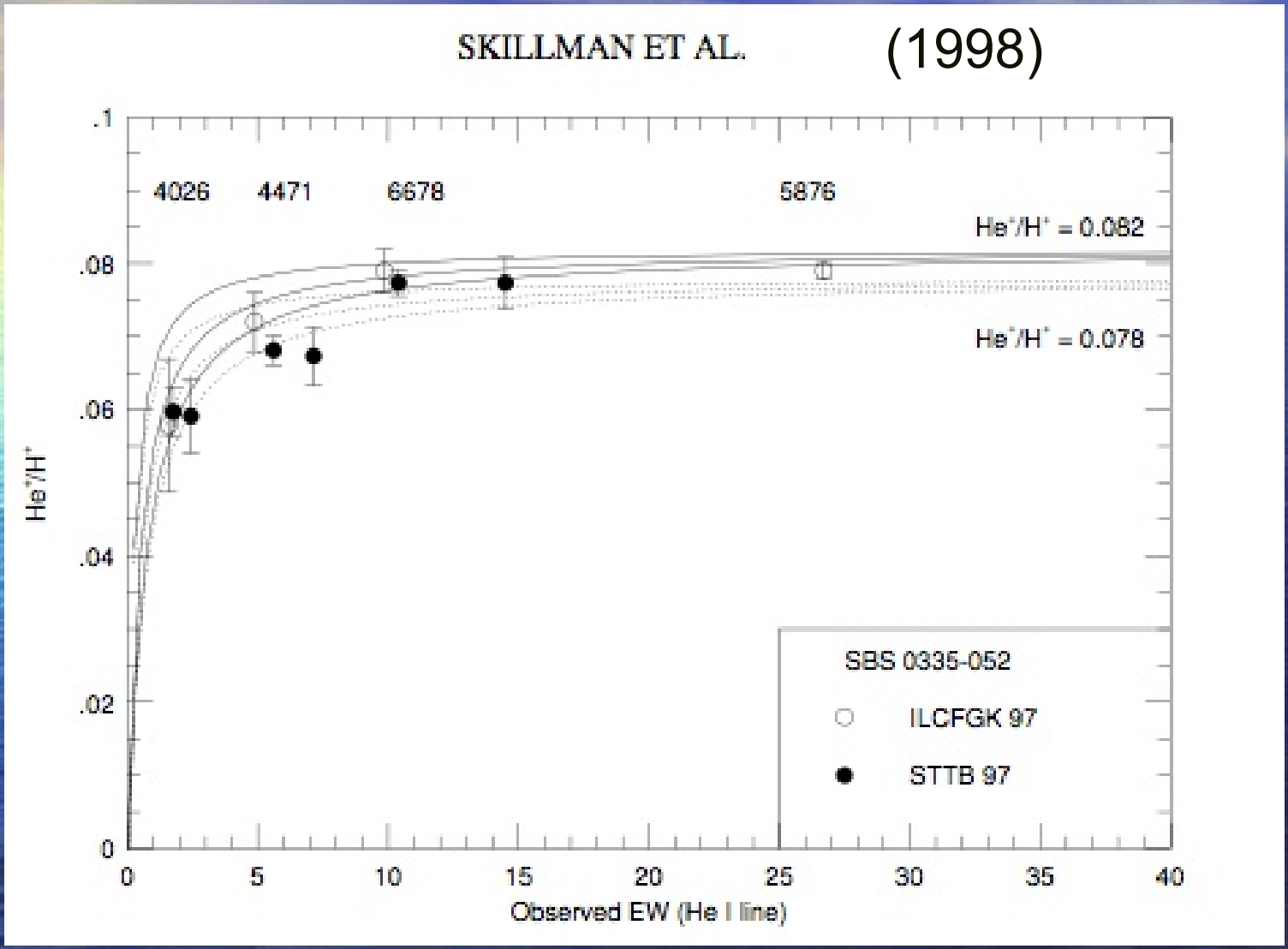
T_e	$e^{-\Delta E/KT}$
10000	3.7E-7
12500	7.2E-6
15000	5.2E-5
17500	2.1E-4
20000	6.1E-4

Underlying absorption

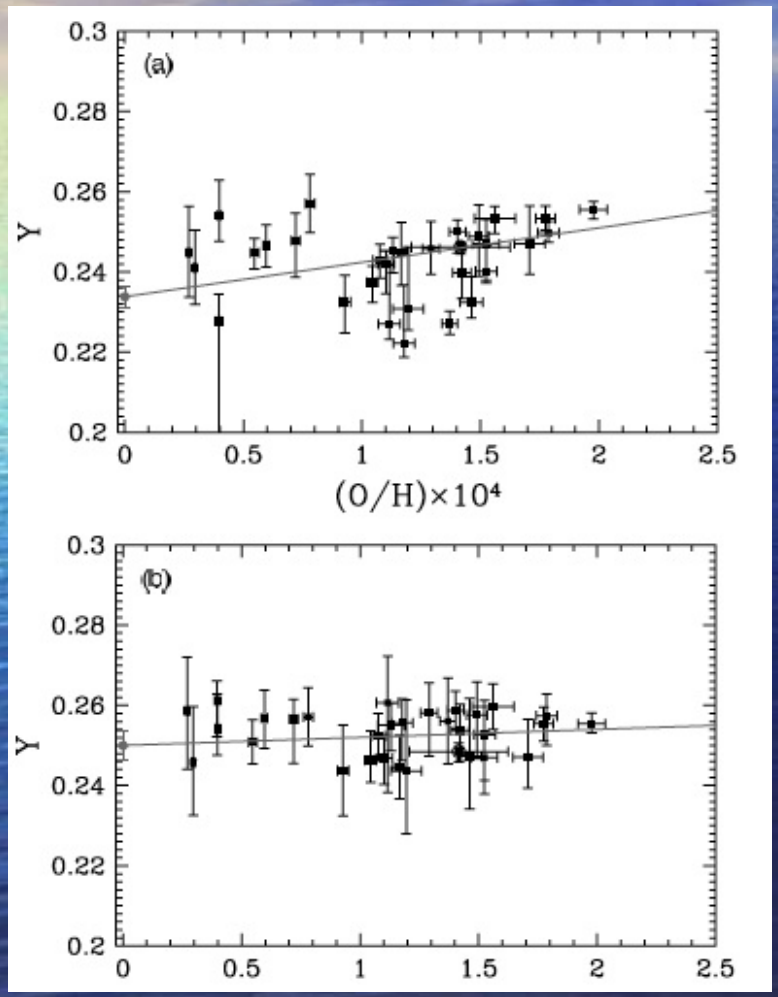


$$\frac{N(\mathrm{He}^+)}{N(\mathrm{H}^+)} \approx_T \alpha \frac{I(\lambda)}{I(\mathrm{H}\beta)}$$

Underlying absorption



Underlying absorption



Izotov and Thuan (2004) data (top),

χ^2 dramatically reduced by

Fukugita & Kawasaki (2006) (bottom)

correcting for underlying absorption.

=EW for all HeI lines

≠ EW for each galaxy

Olive & Skillman (2001,2004)

Underlying absorption, solutions

1-Keep to high EW (HeI and Hβ) objects (Skillman, Fukugita & Kawasaki)

and correct =EW for all HeI lines but

≠ EW for each galaxy.

2- Keep to high EW objects (Izotov, Thuan)

and correct ≠ EW for all HeI lines but

= EW for all galaxies.

3- Observe nearby objects for large spatial res.

(30 Dor, Peimbert)

Underlying absorption, solutions

- Fabián Rosales (MSc Thesis 2006), 70 starforming galaxies from SDSS-DR4,
- Different methods to correct for underlying absorpion
- Different methods to obtain linear regressions

SDSS 4 - selection criteria

Main characteristics:

- Prominent emission lines with high Ha / Hb EW's

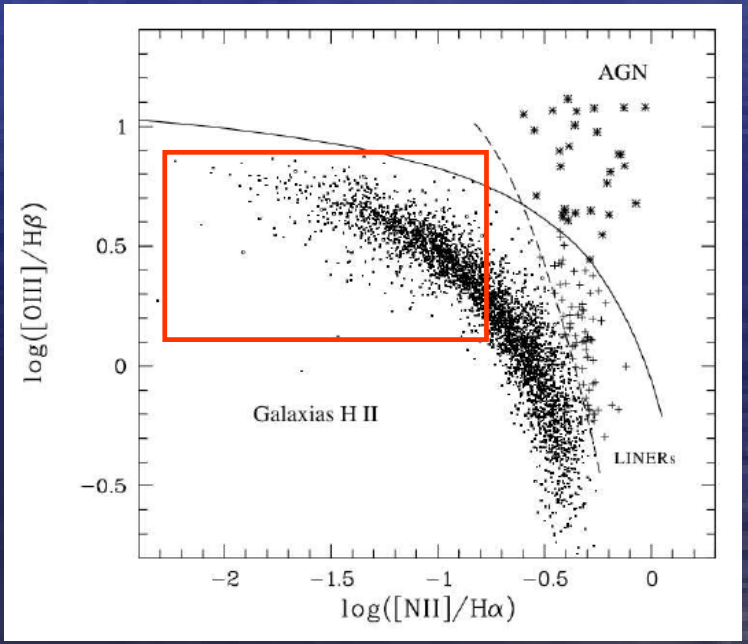
Low abundance:

[N II] 6584 / H α < 0.2

High ionization level

[O III] 4363 / H β □ 0.1

70 high quality objects identified

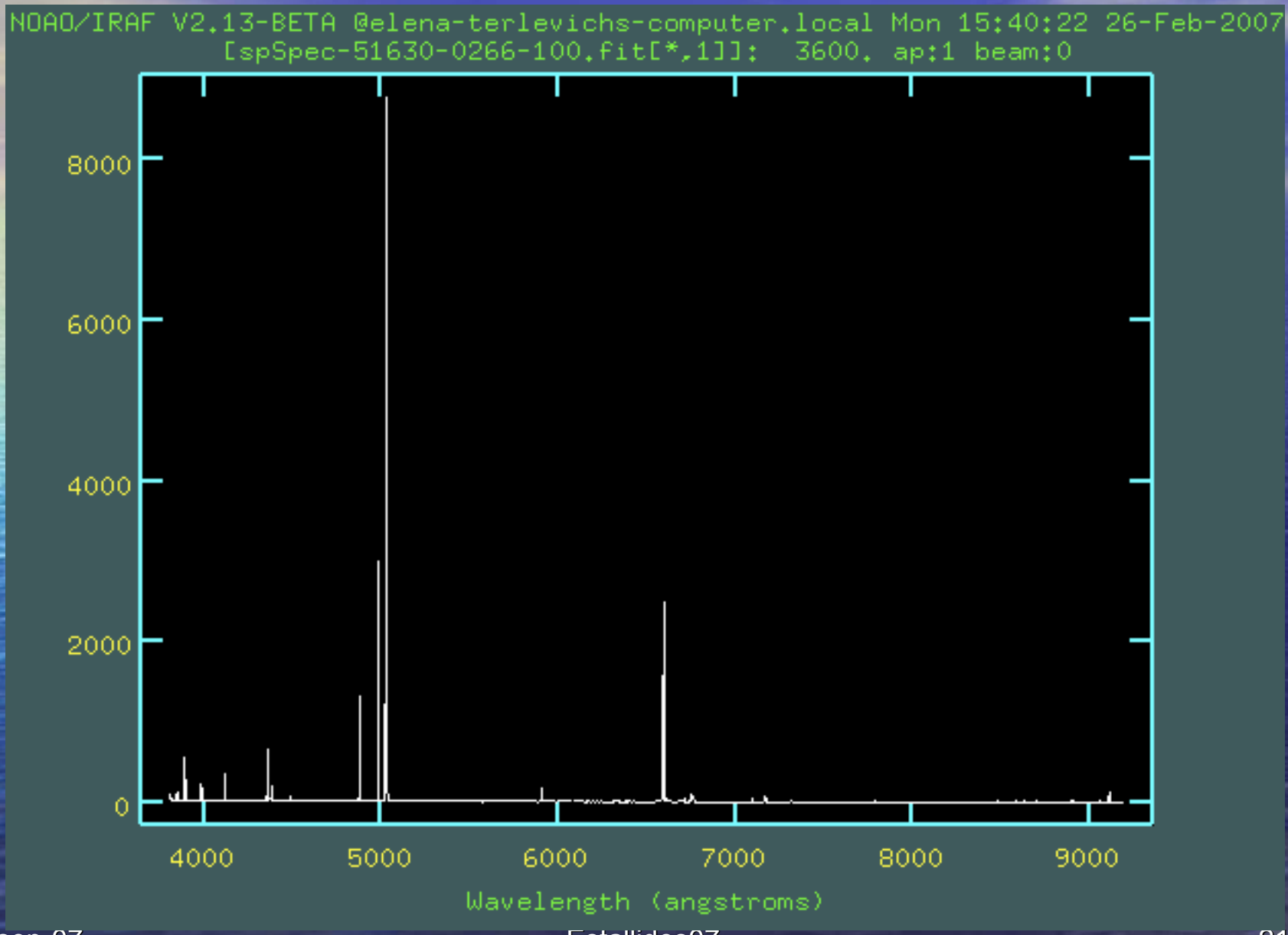


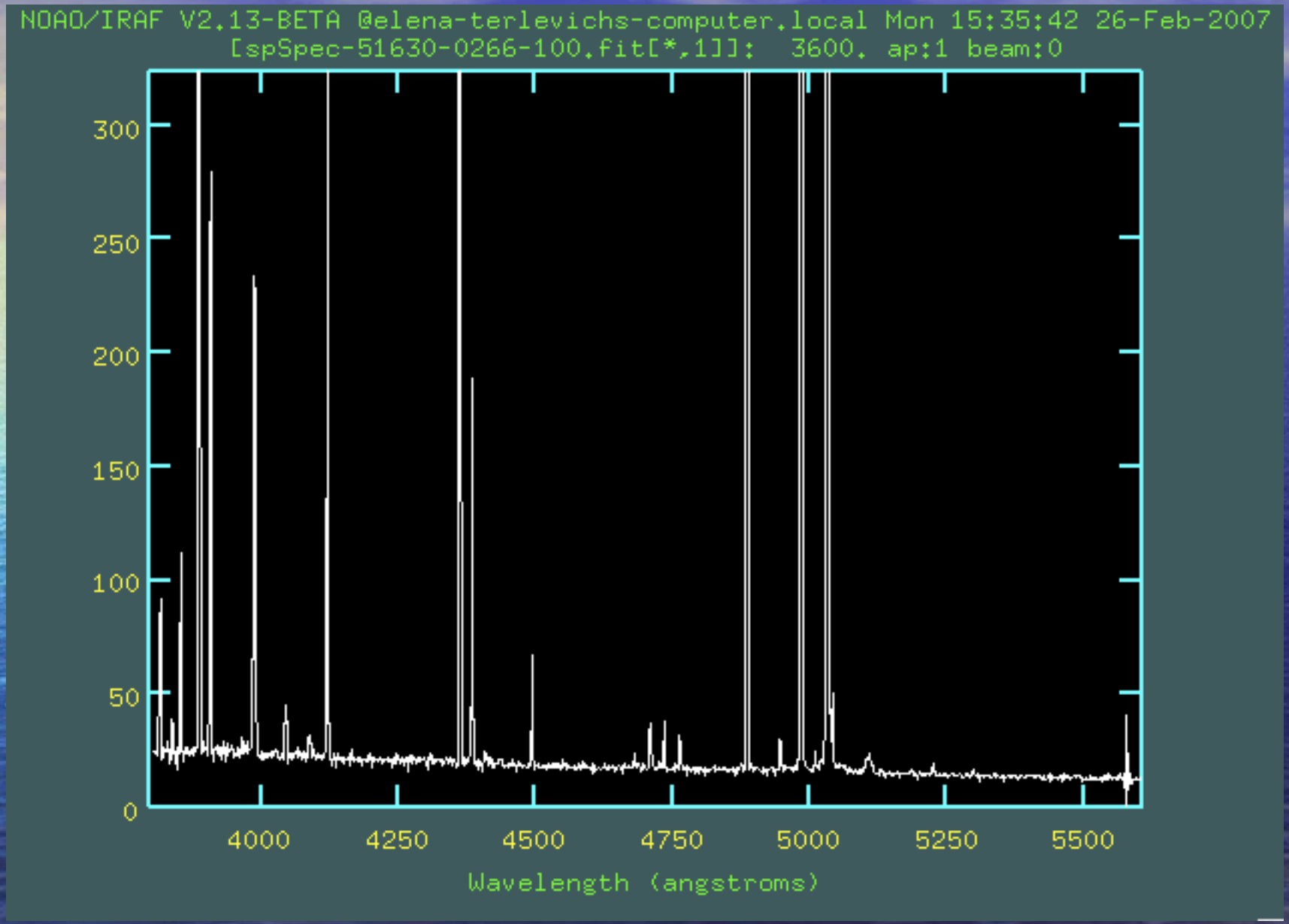
STARLIGHT Method

- Code developed by Cid Fernandes et al. (2004)
- High resolution evolutionary synthesis models (Bruzual & Charlot 2003)
- Fits a synthetic model to an observed spectrum through a lineal combination of N $_\star$ SSP's

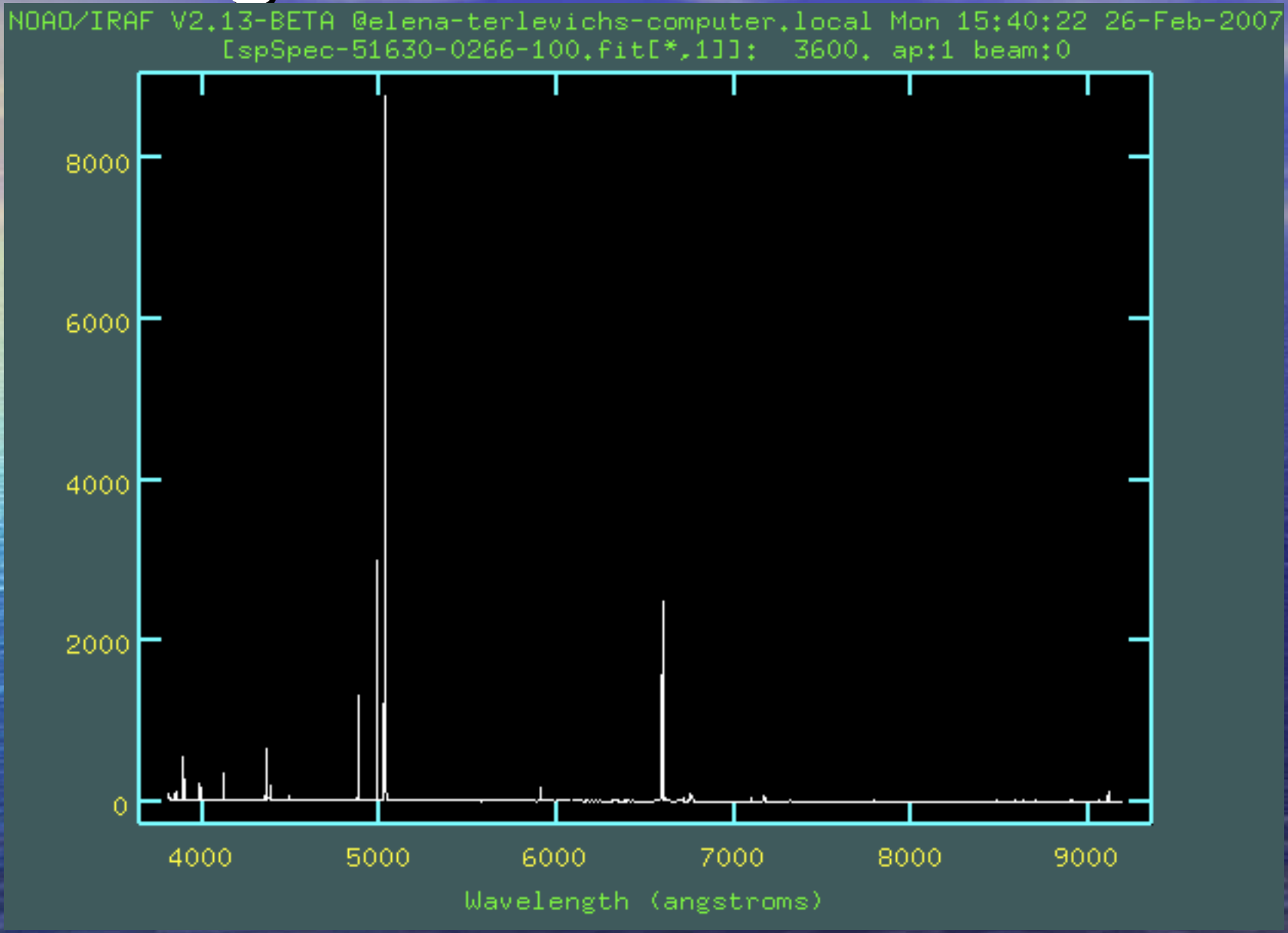
$$M_\lambda = M_{\lambda_0} \left(\sum_{j=1}^{N_*} x_j b_{j,\lambda} r_\lambda \right) \otimes G\left(v_*, \sigma_*\right),$$

SDSS HII galaxy

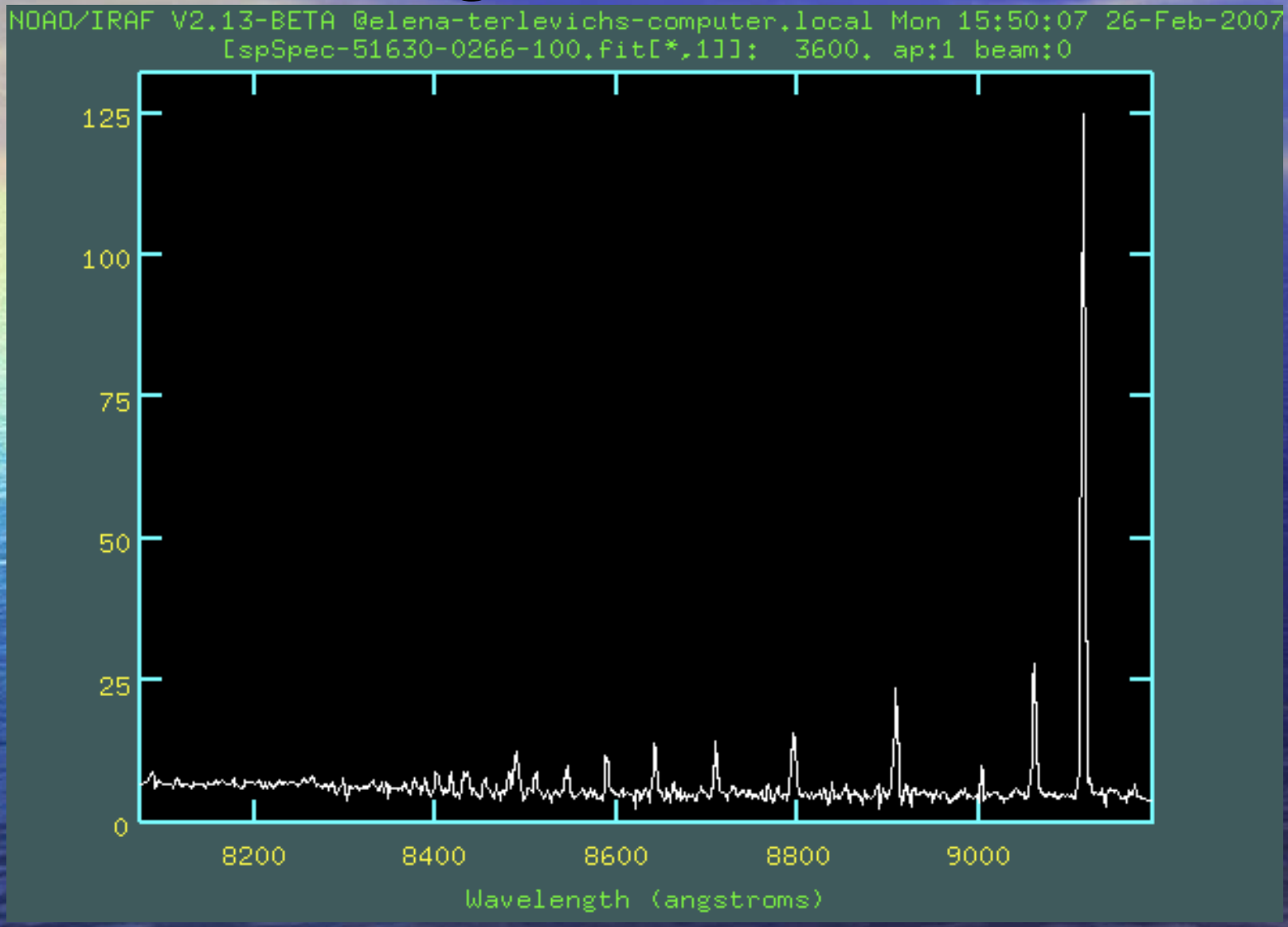



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300
250
200
150
100
50
0
4000
4250
4500
4750
5000
5250
5500
Wavelength (angstroms)

Hα region


NOAO/IRAF V2.13-BETA @elena-terlevichs-computer.local Mon 15:40:22 26-Feb-2007
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8000
6000
4000
2000
0
4000
5000
6000
7000
8000
9000
Wavelength (angstroms)

Near-IR region



1- Classical method;

2- Stellar population synthesis to subtract =>

pure emission; better measurement of faint emission lines and detection of WR features (Cid Fernandes);

no quantification of the stellar population.

3- O, N, ionic and total, plus a minimization code =>

T_e from HeI/Hβ ratio

radiative transfer,

optical depth,

collisional excitation,

HeI underlying absorption

self-consistent method (Olive and Skillman 2004)

4- Library of stellar atmospheres (Gonzalez-Delgado et al 2005, Martins et al. 2005)

high resolution 3000-7000 Å, 2.5 - 1/20 $Z_{\odot}$

Pop. Synthesis (SSP) using Sed@ (Cerviño)

EW (HeI) from T_{eff}, g

EW (H_{balmer}) Sed, Z=27 O/H (mass fraction in metals)

age

Iteration to obtain best fit;

lines measured and subtracted from observed spectra

STARLIGHT Method

Fit:

$$\chi^2\left(x, M_{\lambda_0}, A_V, v_*, \sigma_*\right) = \sum_{\lambda=1}^{N_\lambda} \left[\left(O_\lambda - M_\lambda\right) w_\lambda\right]^2,$$

Masking out specific spectral regions

Pros:

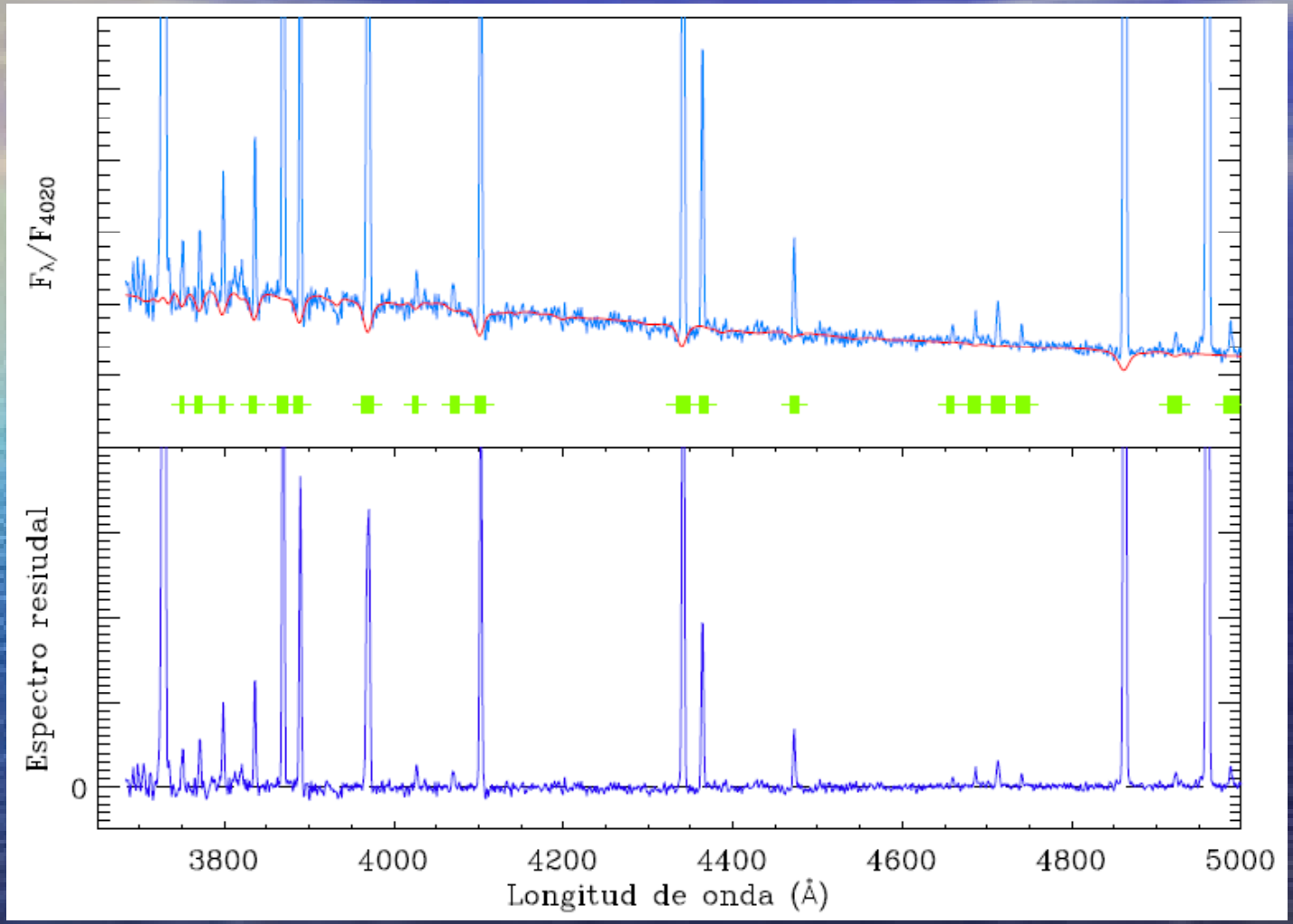
Infers the properties of the stellar populations

Accurate measurement of emission lines through the:
spectral residuals:

$$O_\lambda - M_\lambda$$

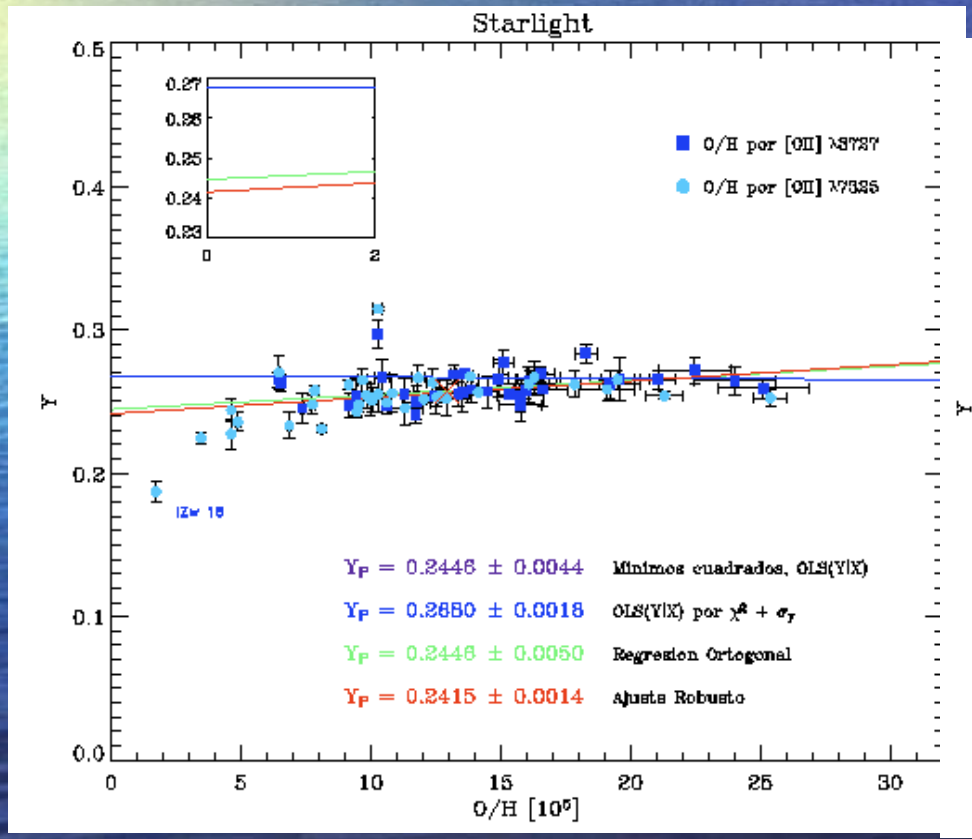
(Kauffmann et al 2003, Cid Fernandes et al 2005, Gu et al 2006)

STARLIGHT Method

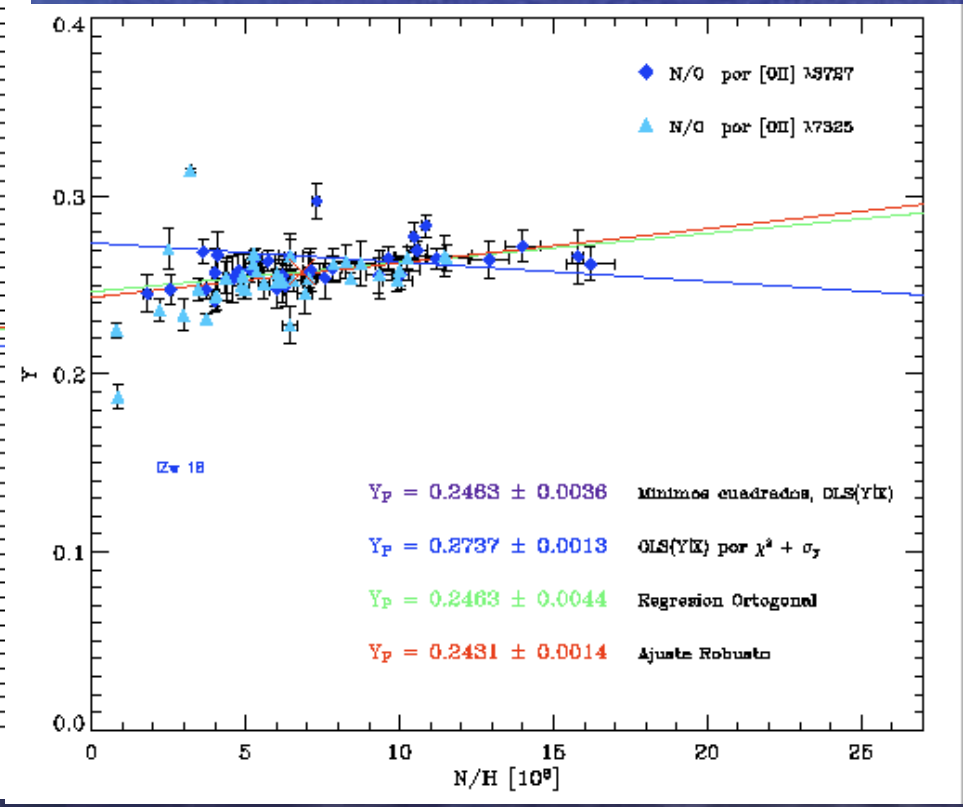


Linear regressions (using Starlight, Cid Fernandes…)

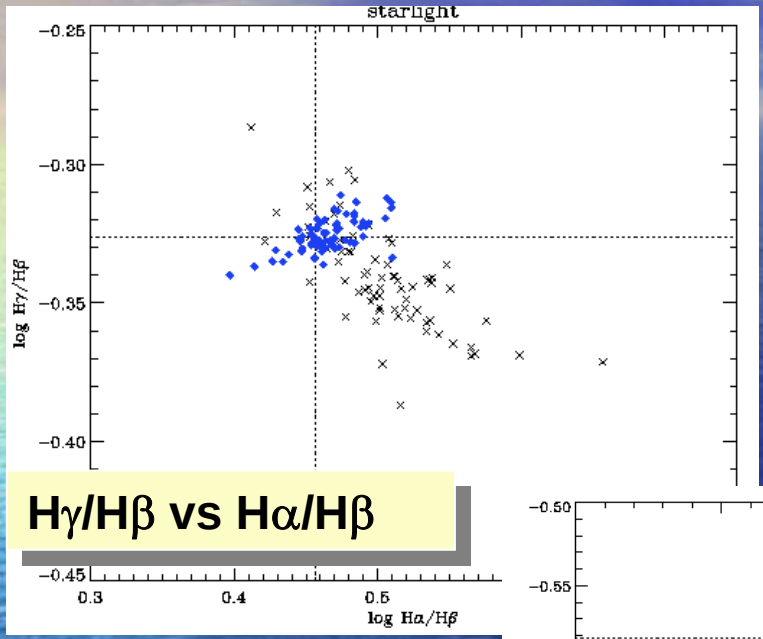
Y vs O/H



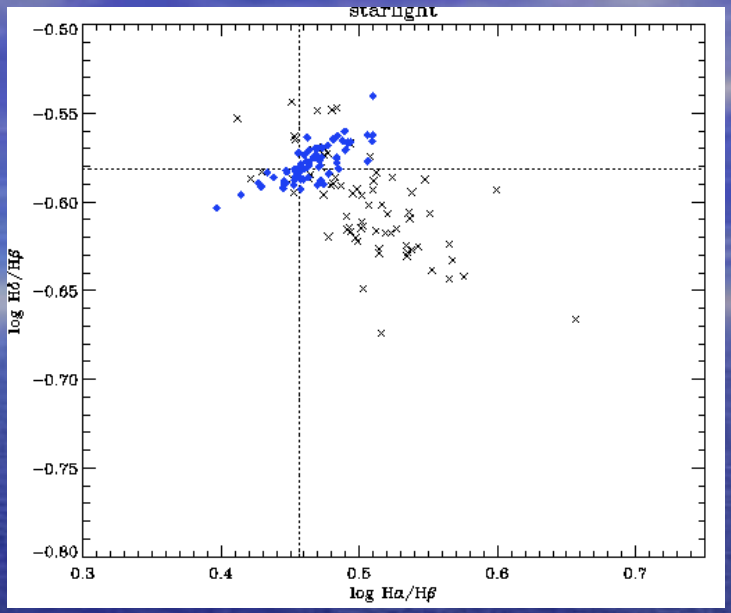
Y vs N/H



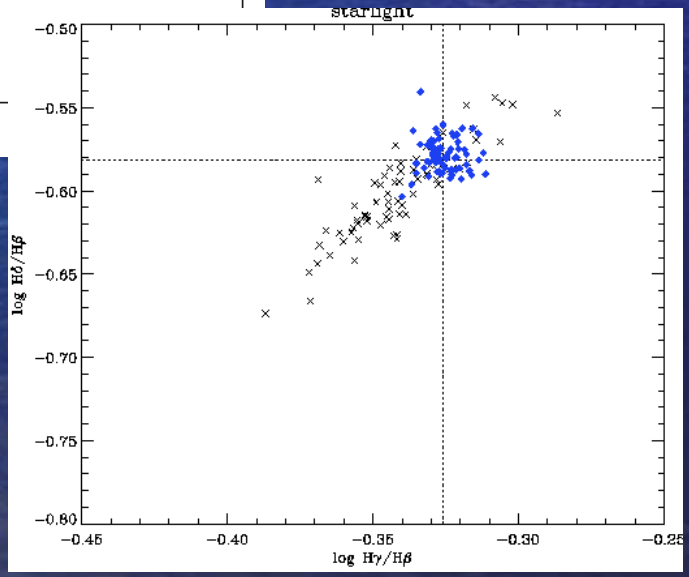
Balmer line ratios



Hγ/Hβ vs Hα/Hβ



Hδ/Hβ vs Hα/Hβ



Hδ/Hβ vs Hγ/Hβ

Underlying stellar absorption correction

Model determination

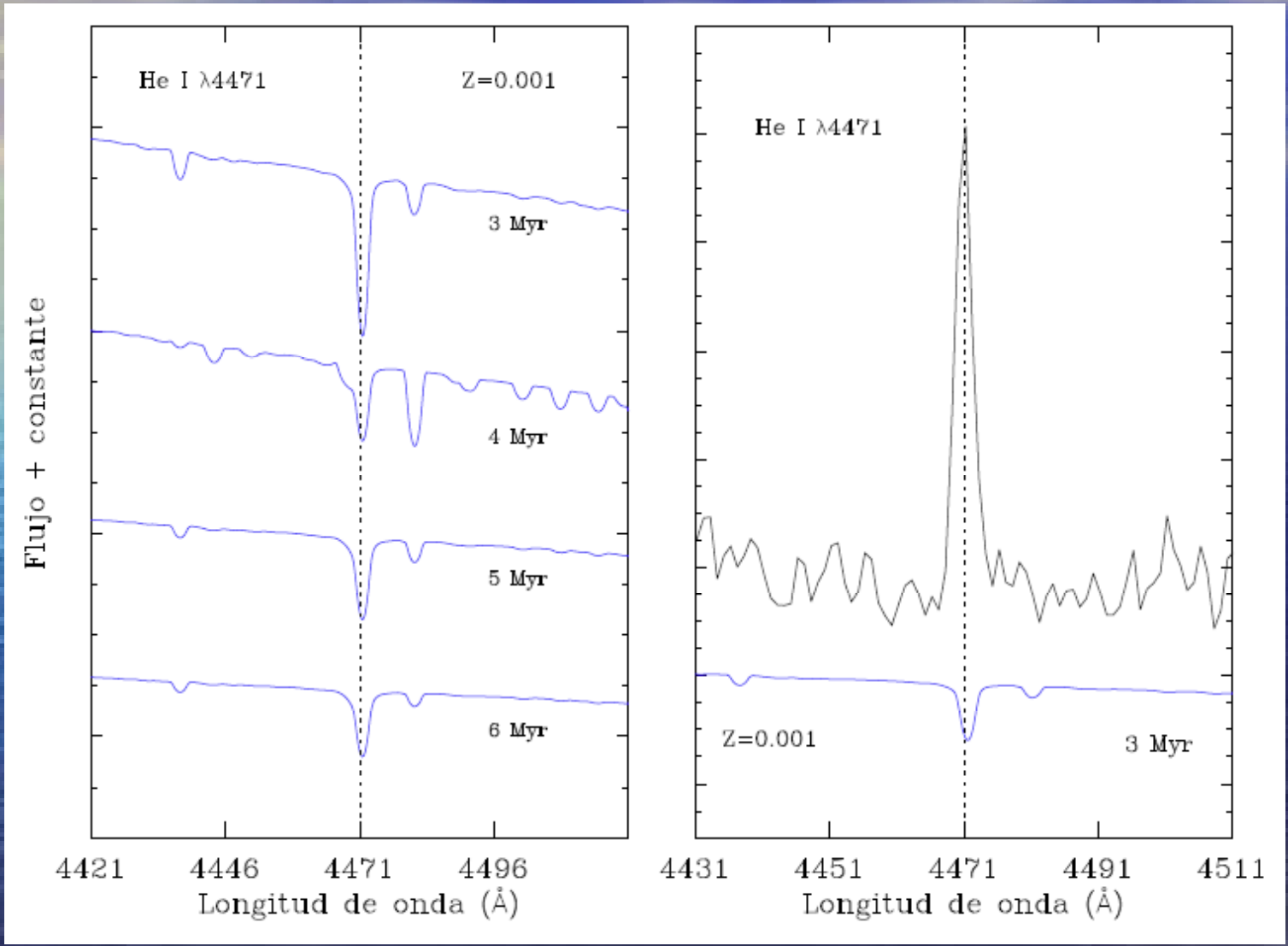
1. Individual selection per object
2. Determination of Z
3. Approximate age determination through H β and Sed@
   (Cervino Åc)

   $3 \times 10^6 < t < 8 \times 10^6$ years

   spectra dominated by type B stars

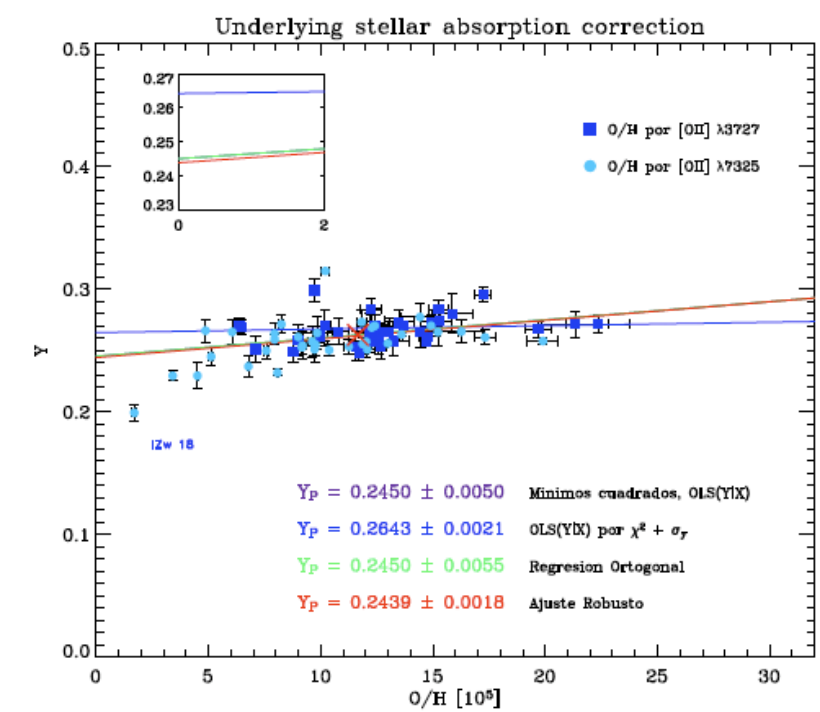
   SSP model chosen accordingly to the closest combination of Z and age found in PGos3, OV INAOE

Underlying stellar absorption correction

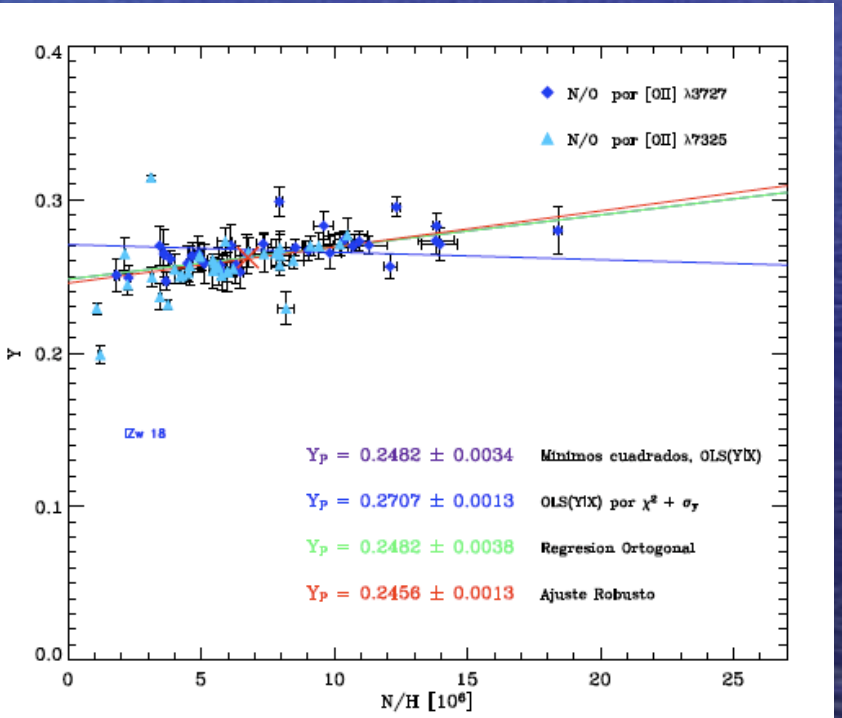


Linear regressions
(using Sed@, Cerviño …)

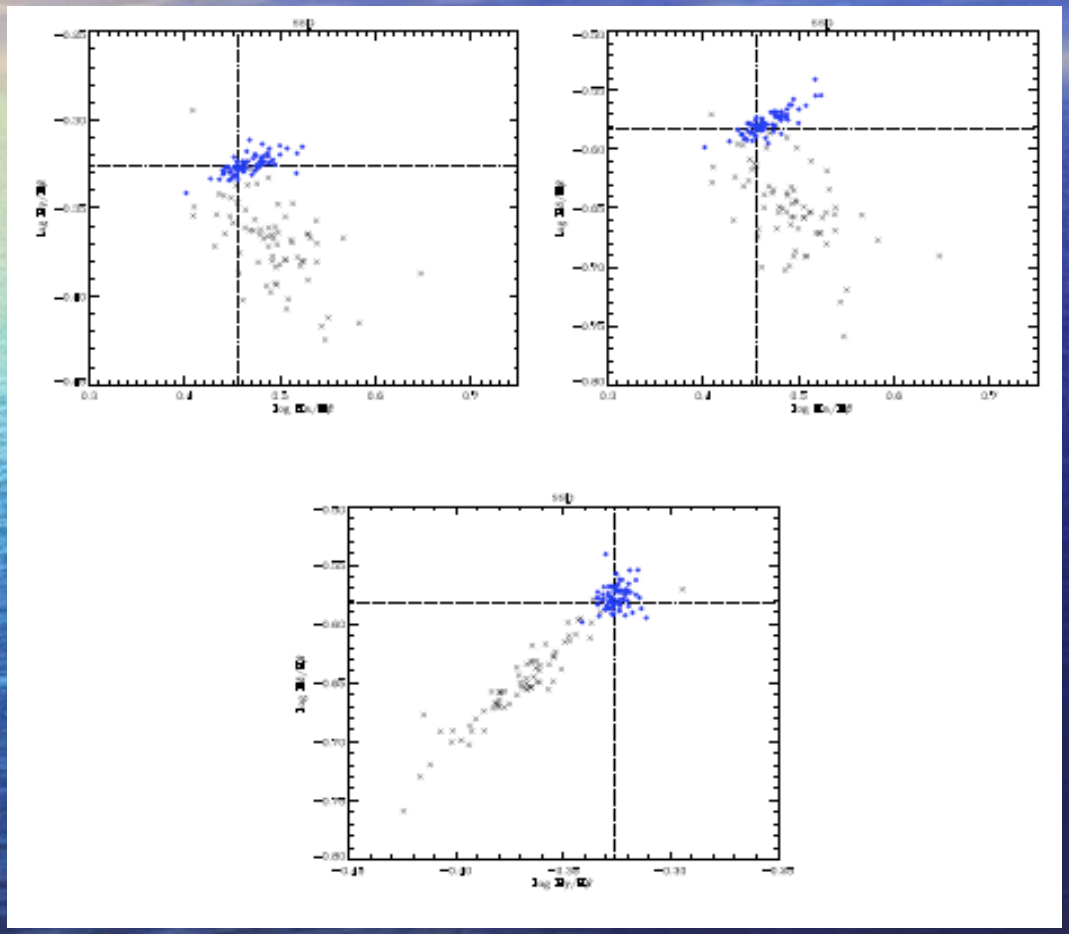
Y vs. O/H



Y vs. N/H

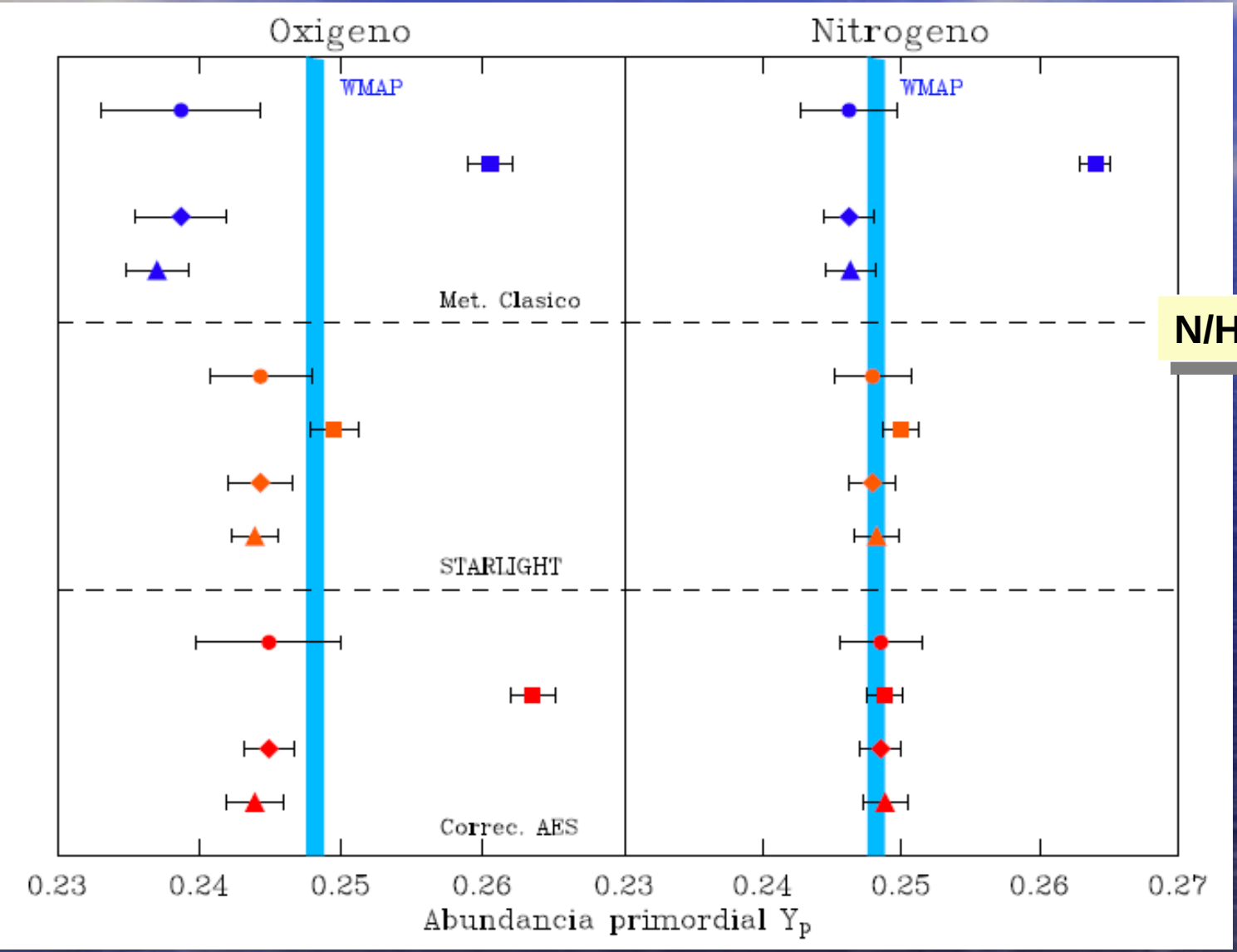


Balmer line ratios



- "Observed ": Black points
- Corrected for underlying absorption: Blue points

Concordance with WMAP predictions

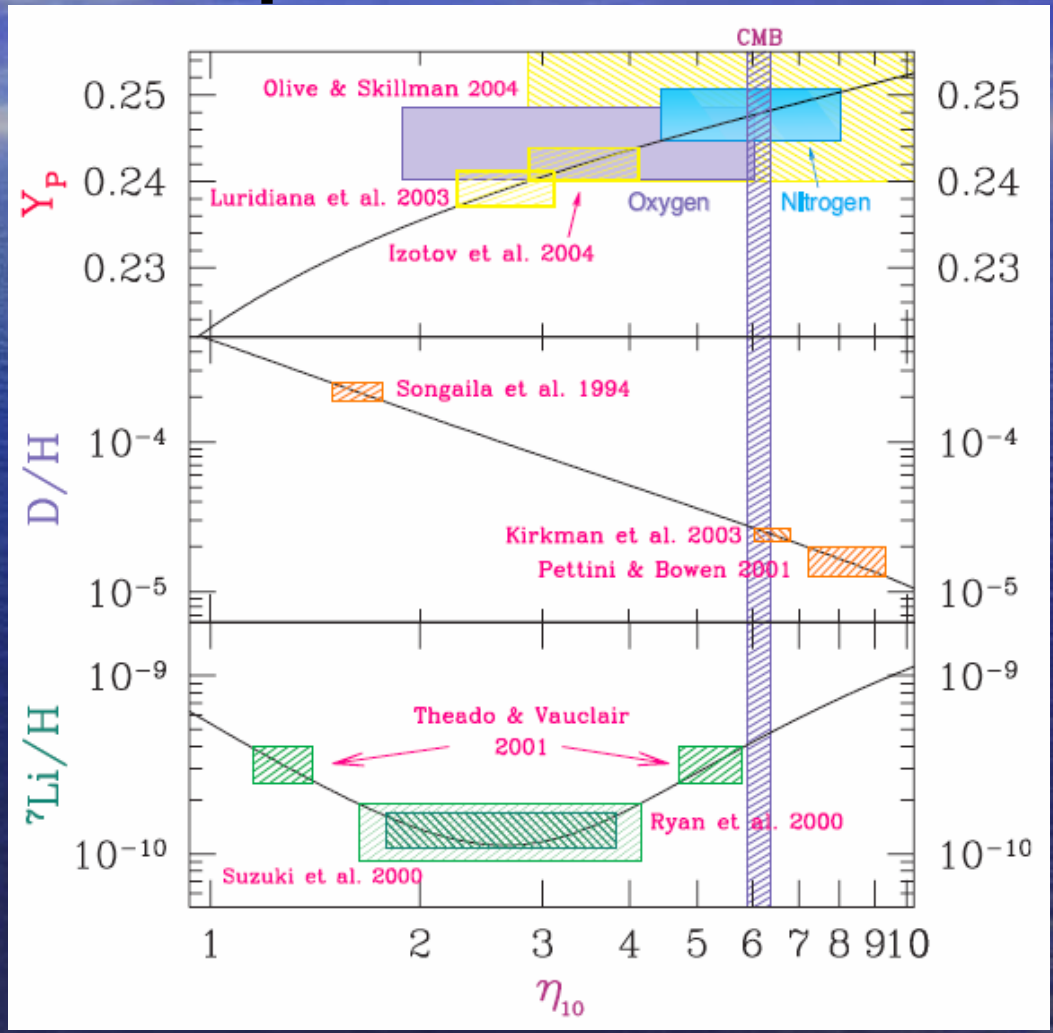


N/H !

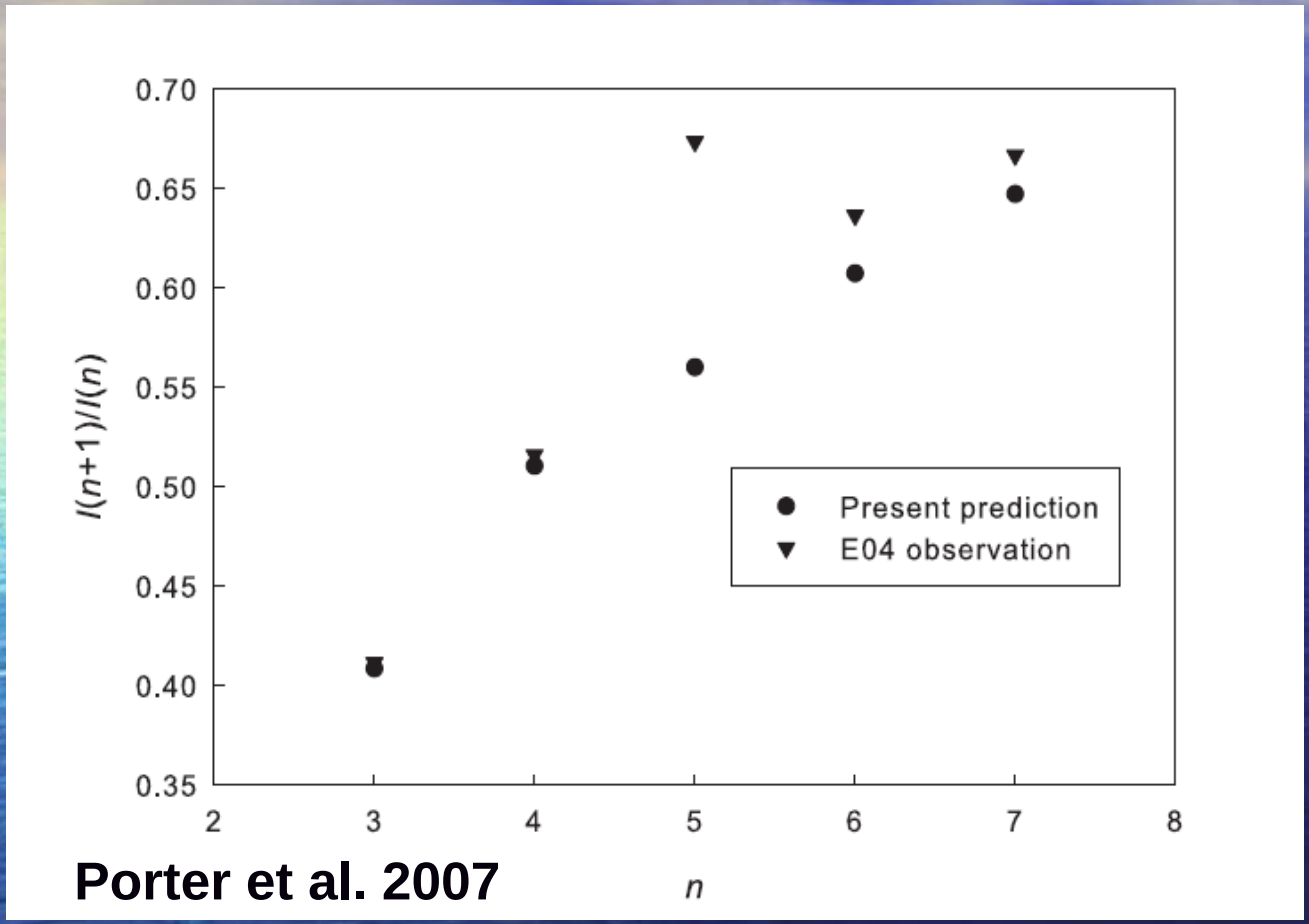
Cosmological implications

Our Yp determination particularly from N, agrees with WMAP 3rd year predictions.

And so do the new values from Peimbert et al. 2007 and from Izotov et al. 2007.



FANTASTIC WORKSHOP!



Porter et al. 2007