Helium and Me and Keith (and Erik)

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Fine Theoretical Physics Institute Olivefest
May 18, 2017

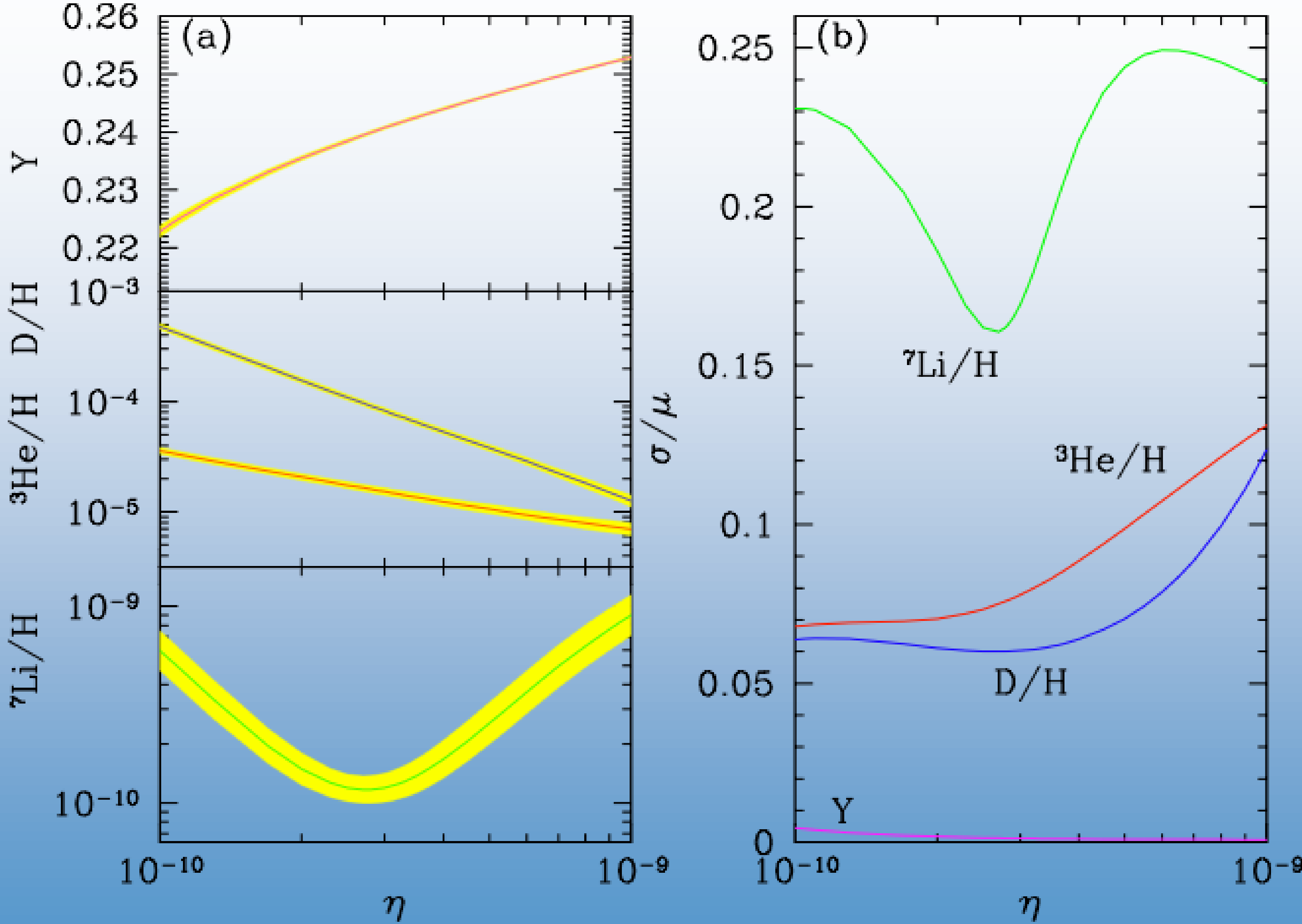
Primordial Helium: Yp

Uses:

- Sensitive to the baryon-to-photon ratio
- Sensitive to the effective number of neutrino families

Predicted via SBBN and CMB

Measured via extrapolation of He/H versus O/H in low chemical abundance star forming regions



Y_p as a Baryometer

It all started in Paris (for me)

Star Forming Dwarf Galaxies and Related Objects

Paris, July 1985

Final Panel Discussion: D. Kunth: ... Coming back to IZw18, I find intriguing that after so many efforts and after many years no more objects like this one has been found! It is true however given the characteristics of this object (low redshift, and low apparent magnitude) together with the space density of emission line galaxies that large fractions of the sky have to be explored before the number of such objects will significantly increase. However, more objects should be found since after all IZw18 was the object number 18 in Zwicky's first list ...

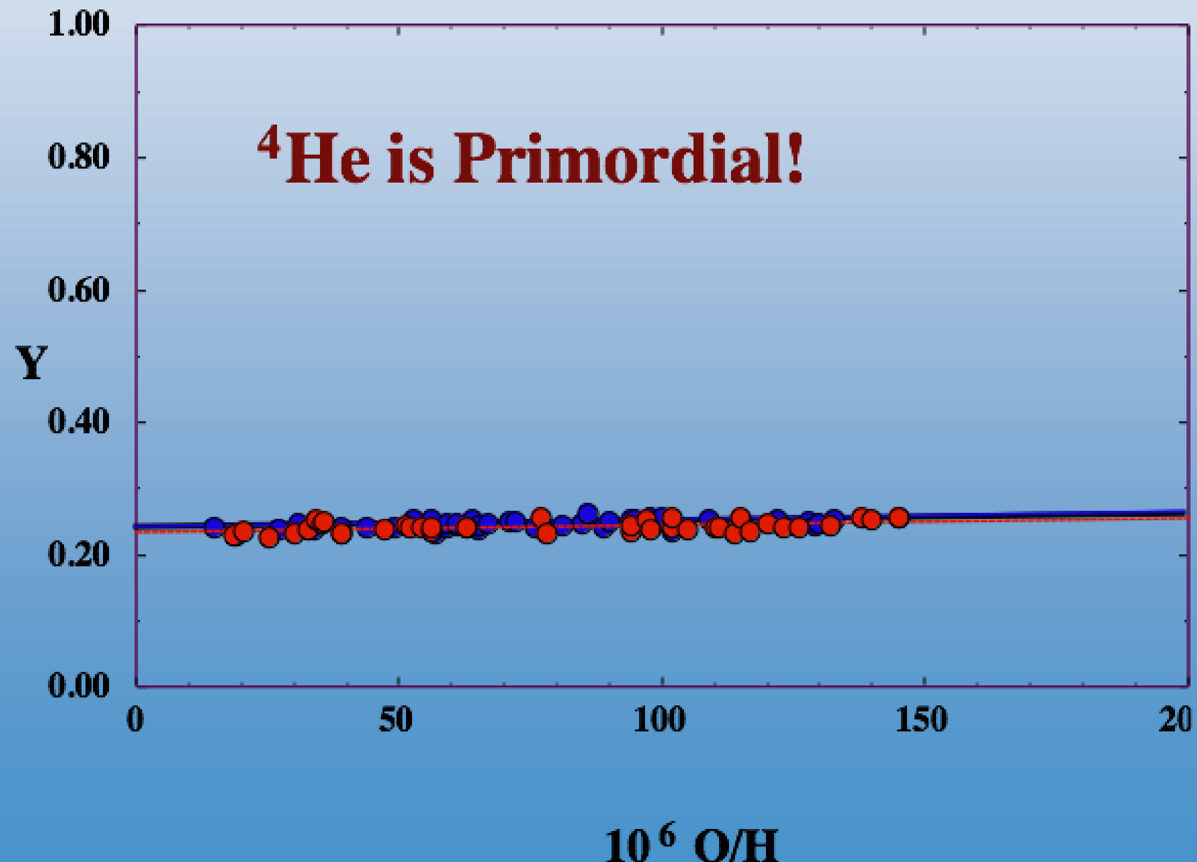
W.L.W. Sargent: What we need is a reincarnation of Zwicky!


I Zw 18

^{4}He

Measured in low metallicity extragalactic HII regions (~100) together with O/H

$$Y_P = Y(O/H \to 0)$$



The GR8 Story

So, my take-away from the Paris meeting was that if one could find more metal poor star forming galaxies, then the problem is solved.

The Real Story

I was incredibly naïve.
Really, there are two challenges:
(1) Finding appropriate low metallicity galaxies
(2) Converting the spectra into reliable He/H abundances with reliable uncertainties

^4He

How is this done?

(1) Take an emission line spectrum.

(2) Measure a temperature.

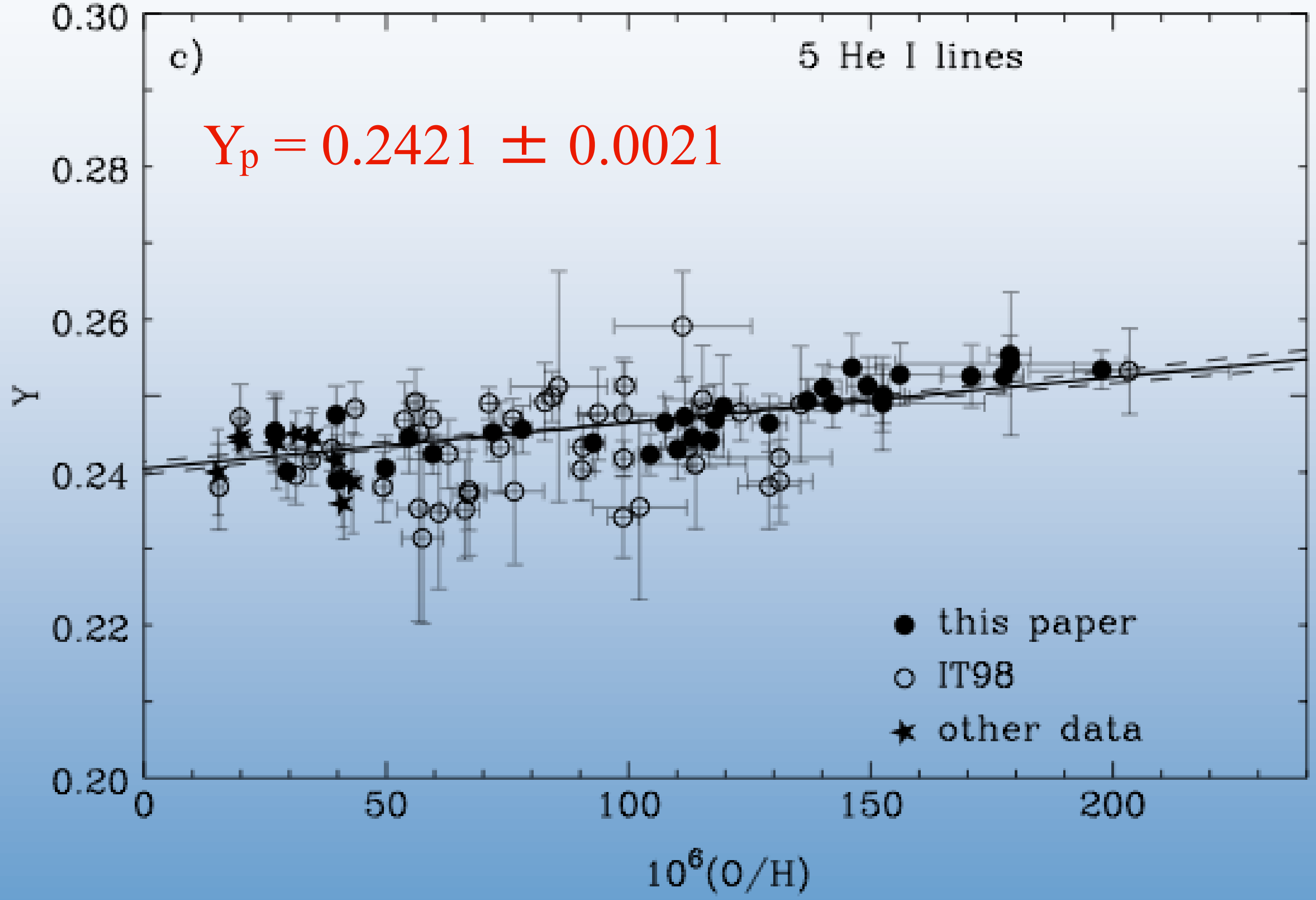
(3) Measure a density.

(4) Calculate (theoretical) emissivities.

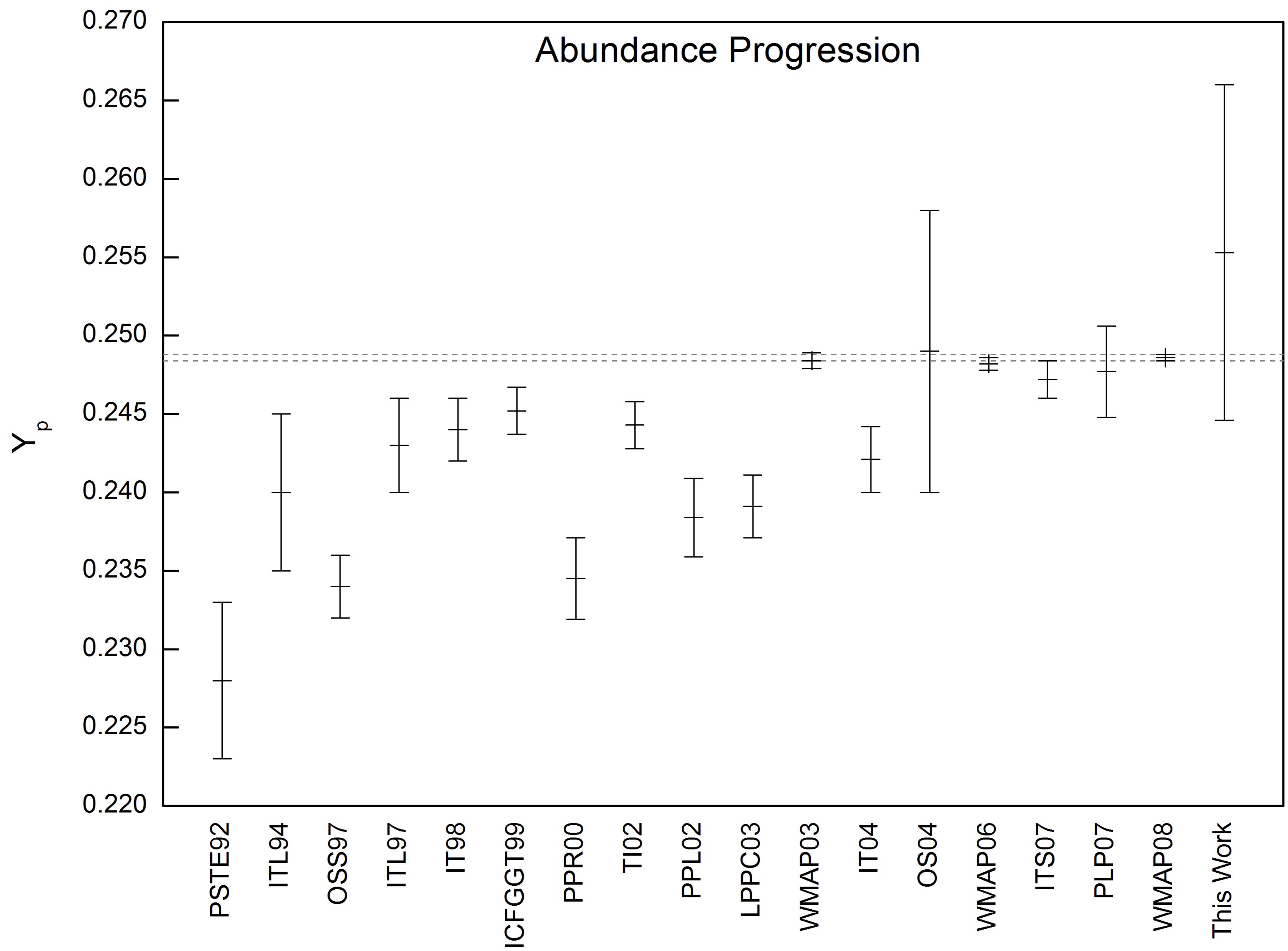
(5) Convert relative emission line fluxes into relative abundances.

(6) Plot regression of He/H vs. O/H and extrapolate to O/H = 0

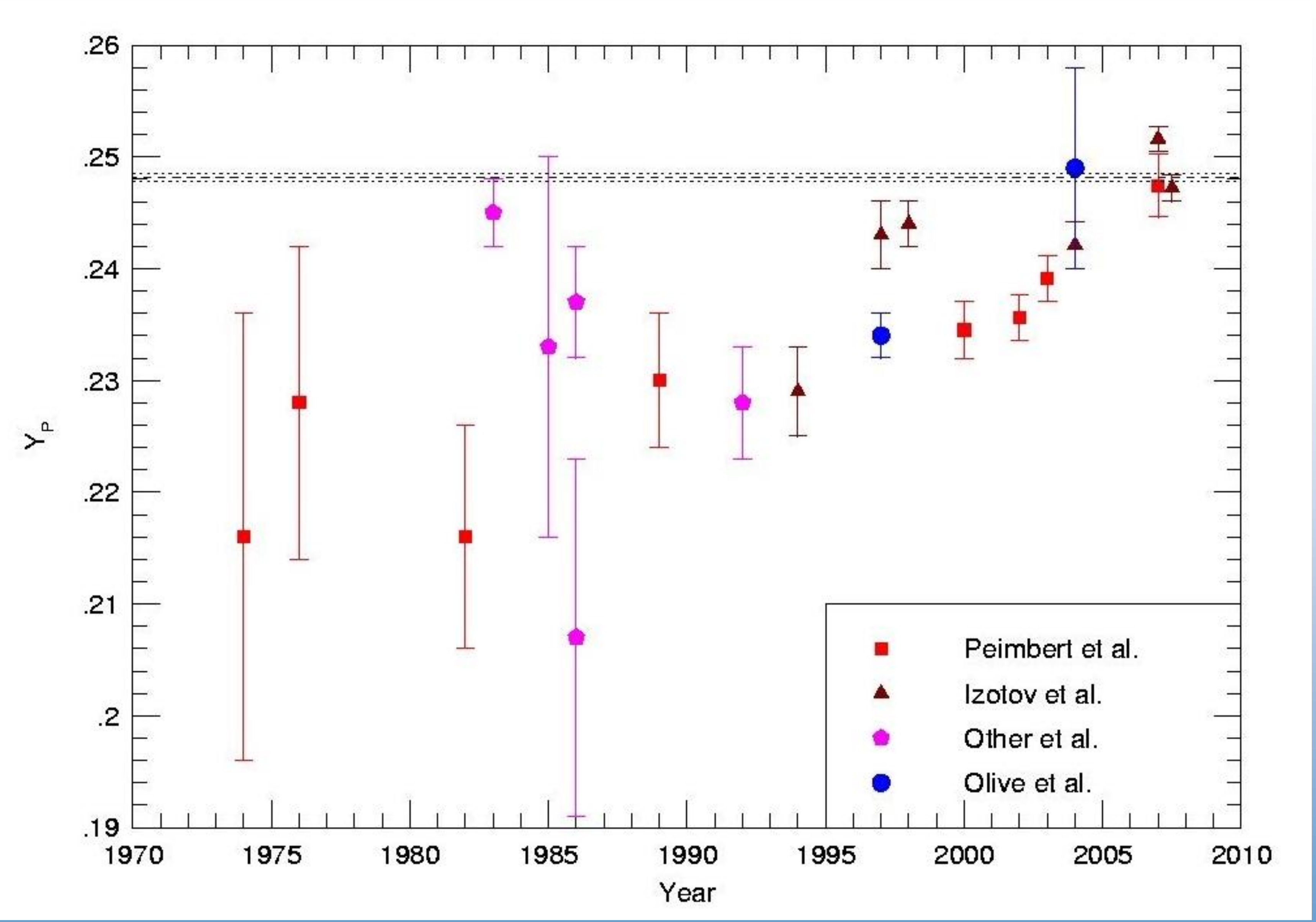
^{4}He



Izotov & Thuan (2004)



The History of Primordial Helium Measurements



The History of Primordial Helium Measurements

Increasing the Uncertainty

A closer look into that second challenge:
Converting the spectra into reliable He/H abundances with reliable uncertainties resulted in:
Olive & Skillman 2001, 2004

TABLE 7

ERROR BUDGET IN THE Y_p(SAMPLE) DETERMINATION

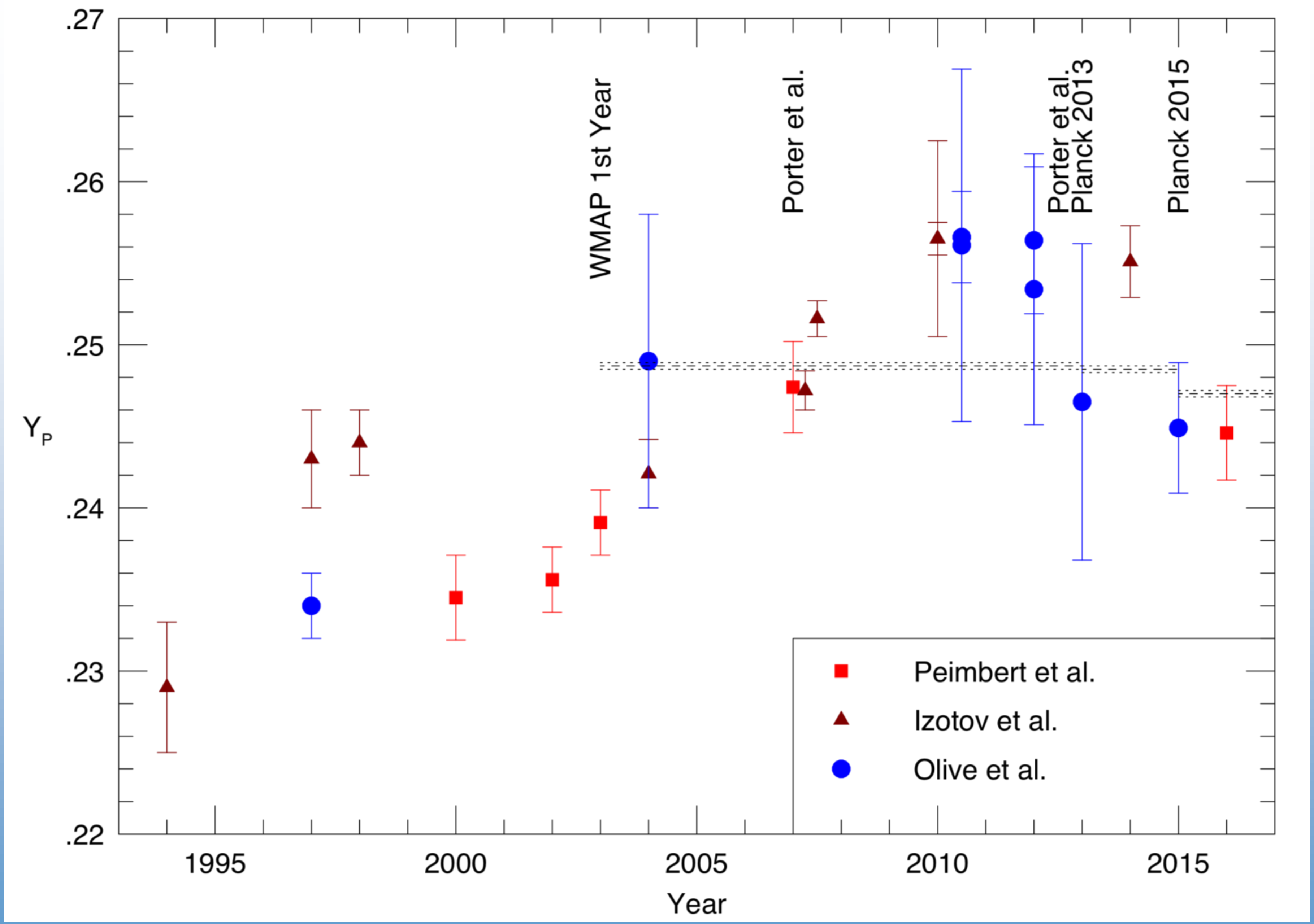
Problem	Estimated Error
Collisional excitation of the H I lines	±0.0015[a]
Temperature structure	±0.0010[b]
$O(\Delta Y/\Delta O)$ correction	±0.0010[a]
Recombination coefficients of the He I lines	±0.0010[a]
Collisional excitation of the He I lines	±0.0007[b]
Underlying absorption in the He I lines	±0.0007[b]
Reddening correction	±0.0007[a]
Recombination coefficients of the H I lines	±0.0005[a]
Underlying absorption in the H I lines	±0.0005[b]
Helium ionization correction factor	±0.0005[b]
Density structure	±0.0005[b]
Optical depth of the He I triplet lines	±0.0005[b]
He I and H I line intensities	±0.0005[b]

[a] Systematic error.
[b] Statistical error.

Table 7 from Peimbert, Luridiana, & Peimbert 2007

And then there was Erik

Working with Erik Aver resulted in:
Aver et al. 2010, 2011, 2012, 2013, 2015



The History of Primordial Helium Measurements

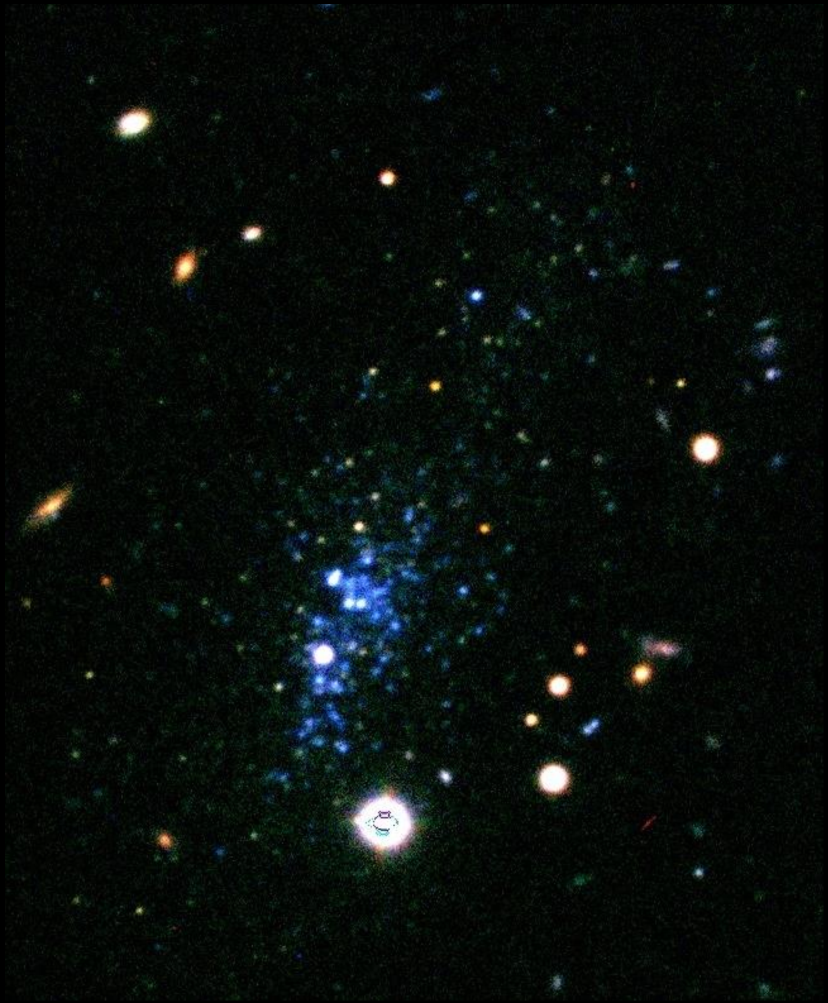
Finding New Targets

A return to that first challenge:
Finding new appropriate low metallicity targets

Look for new IZw18s?
From the 1.5 million galaxy spectra in the SDSS
(through DR12)
3 galaxies at O/H < IZw18
(Guseva et al. 2017)

IS THERE A BETTER WAY?

Leo P: An Extremely Metal Deficient Galaxy



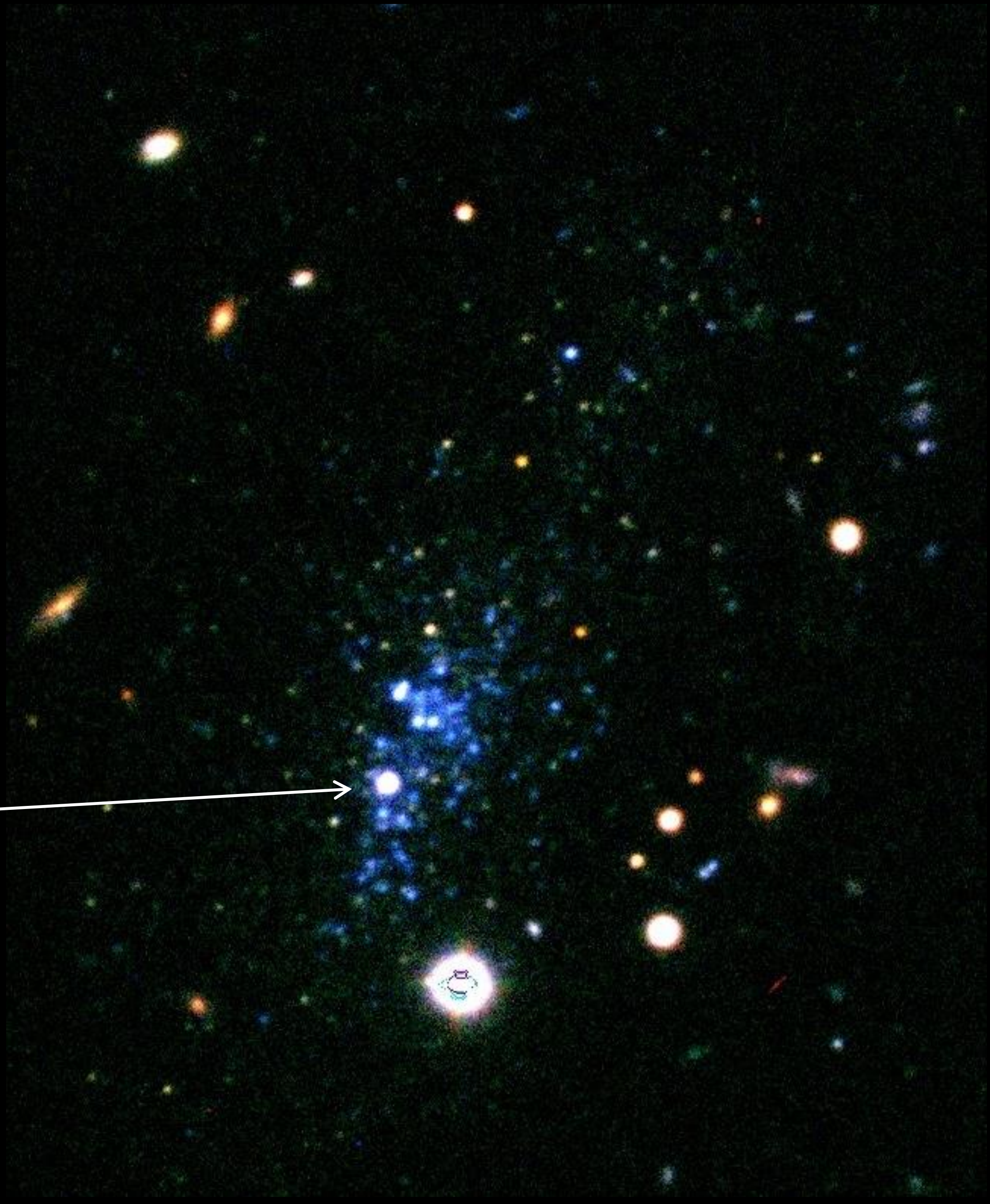
Riccardo Giovanelli, Martha Haynes, Betsey Adams (Cornell)
John Cannon, Elijah Z. Bernstein-Cooper (Macalester)
Danielle Berg, Kristy McQuinn, Keith Olive, Evan Skillman (Minnesota)
John Salzer, Nathalie Hauerberg, Kathy Rhode, Angela van Sistine (Indiana)
Rick Pogge (OSU), Erik Aver (Gonzaga)

Leo P: A New XMD Galaxy Discovered in the ALFALFA Survey

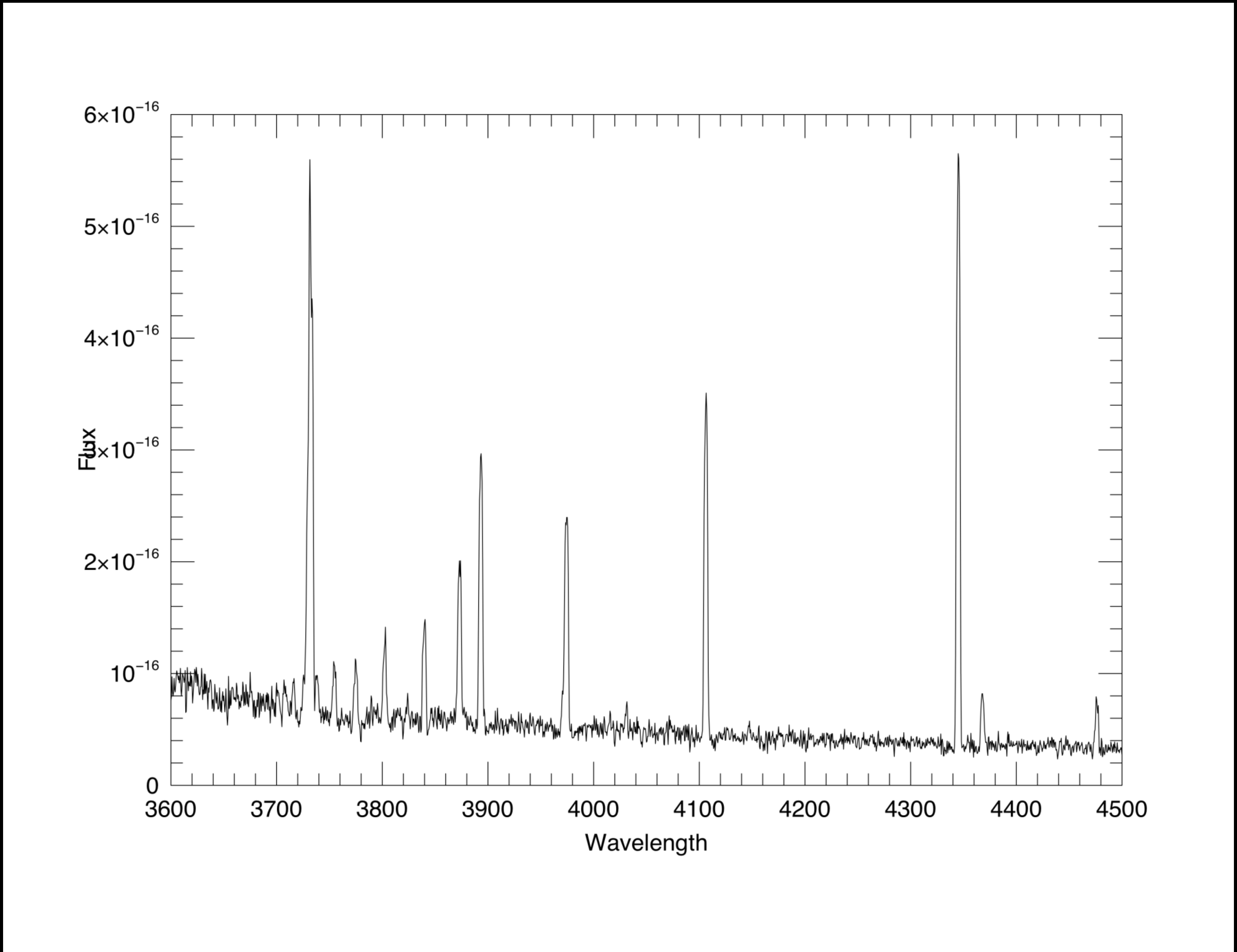
•WIYN 3.5m images obtained in March, 2012 (Rhode et al. 2013)

• Highly resolved stellar population

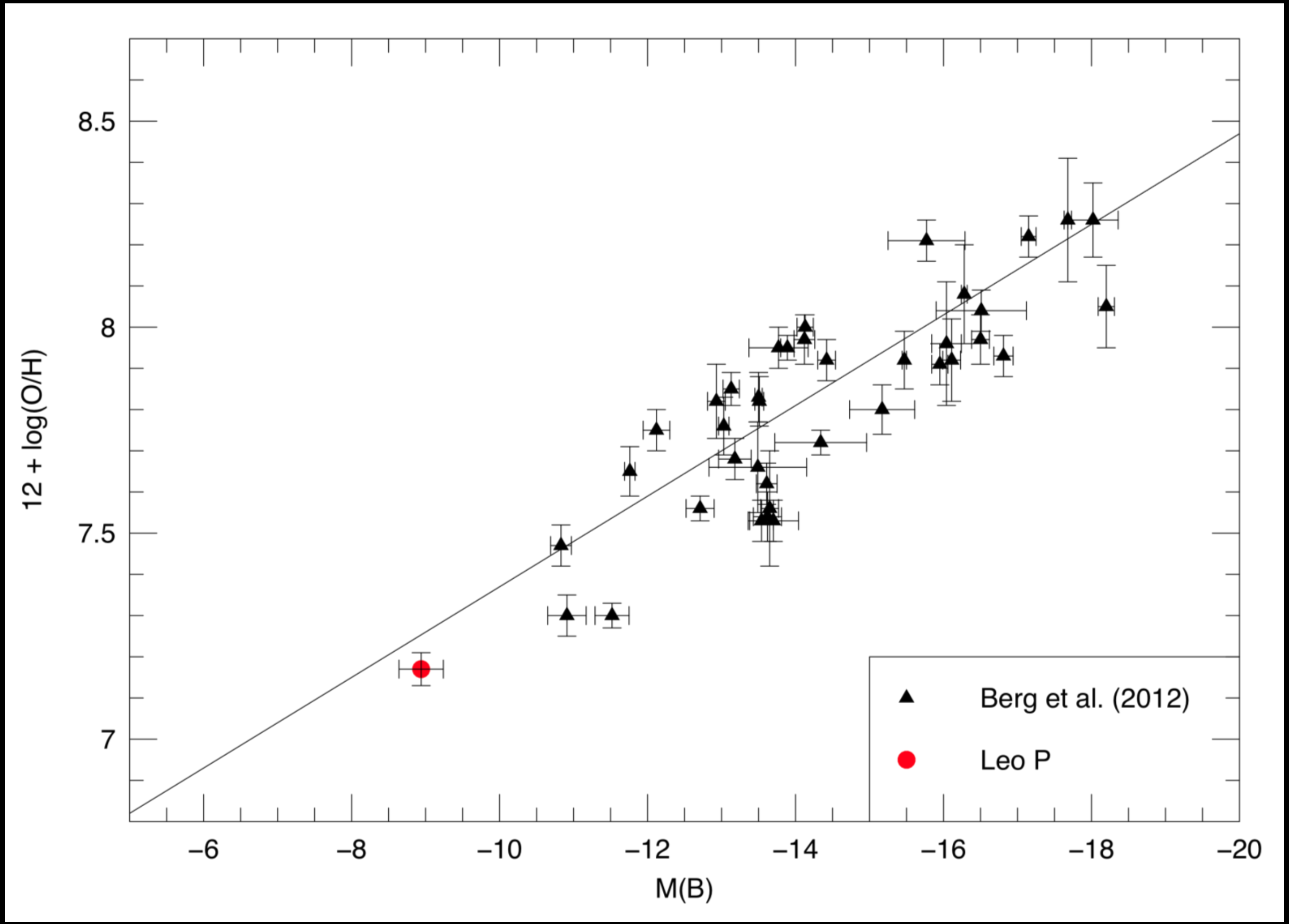
Ha emission detected around brightest star



LBT/MODS 3 x 15 minutes



Leo P: A New XMD Galaxy Discovered in the ALFALFA Survey

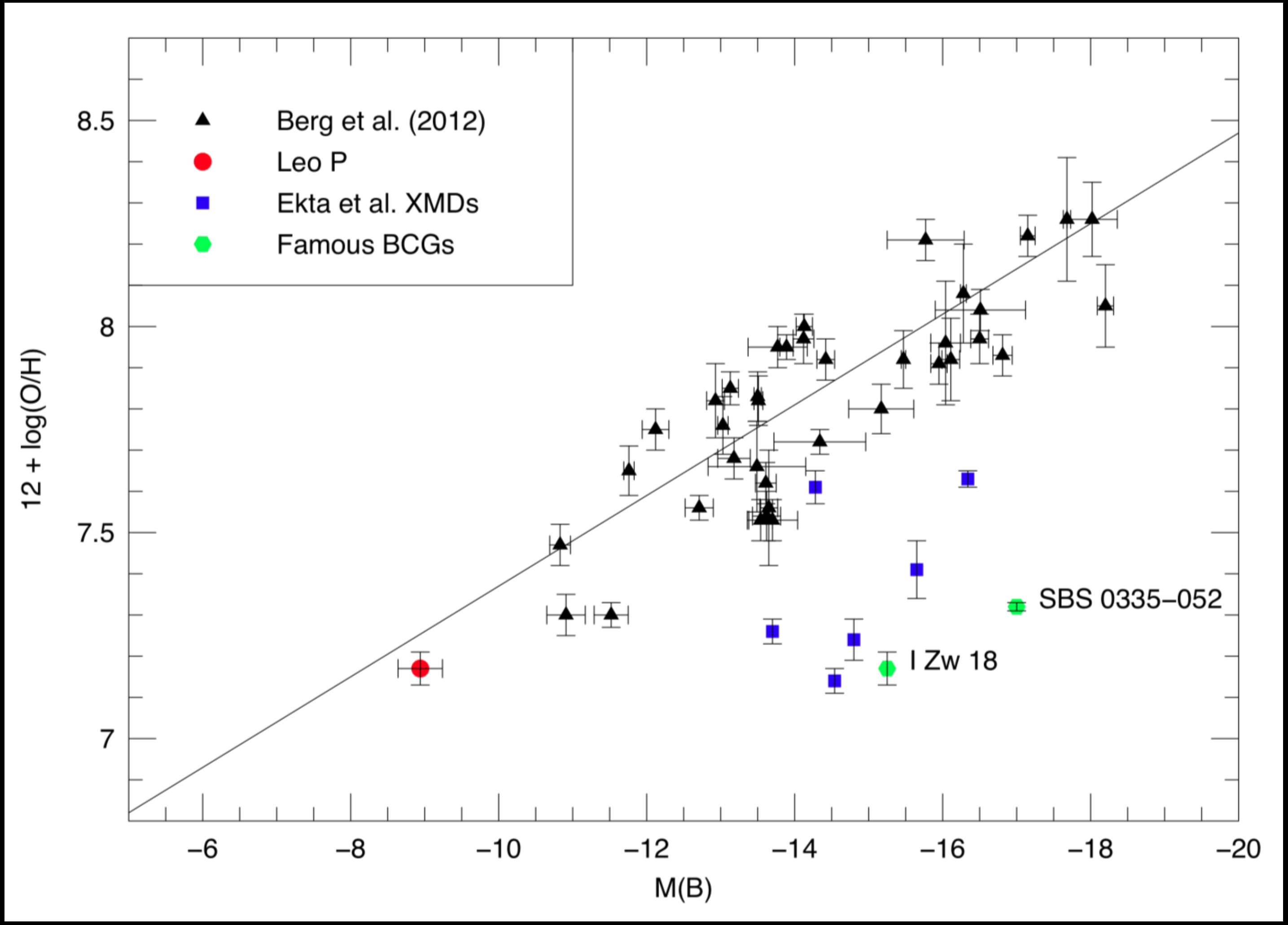


Very low oxygen abundance fits the relationship with luminosity defined by observations of local volume galaxies (Berg et al. 2012).

Leo P: A New XMD Galaxy Discovered in the ALFALFA Survey

Ekta et al. have proposed that the XMD galaxies which are outliers from the L-Z relationship defined by observations of local volume galaxies are due to infall of metal poor gas from interactions.

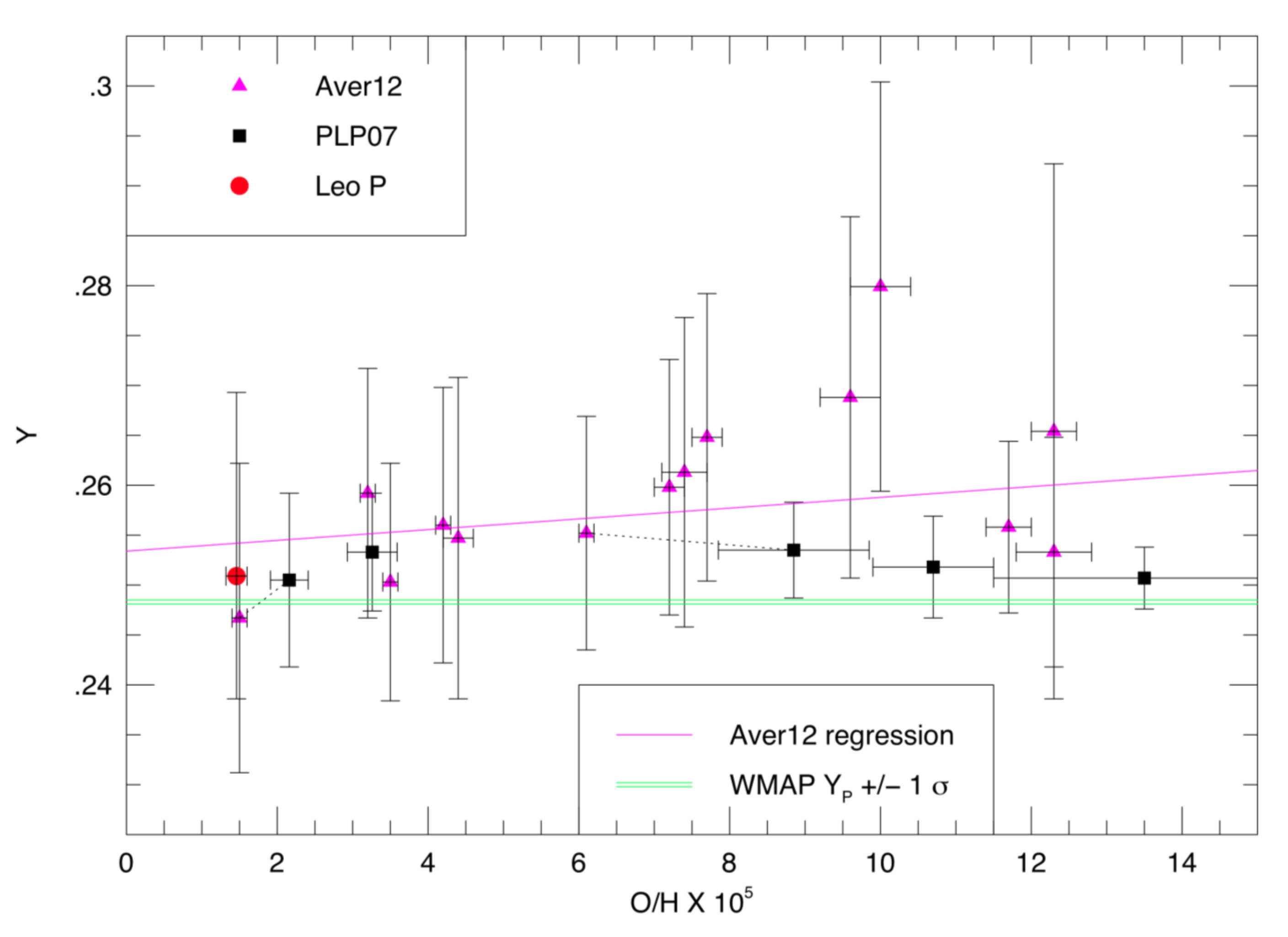
The very low O/H in Leo P indicates that a galaxy can still be at this chemically unevolved state today through "normal" evolution



Leo P: A New XMD Galaxy Discovered in the ALFALFA Survey

The helium abundance for Leo P is in excellent agreement with the value of the primordial helium abundance predicted by Big Bang Nucleosynthesis theory and the observation of the baryon-to-photon ratio by WMAP.

The He/H in Leo P is also in excellent agreement with the previous values for I Zw 18.



Yp Going Forward

As more sensitive, large scale blind HI surveys (SKA pathfinders) are conducted, more low metallicity targets will be found.

With optical+near-IR spectra of the best candidates, uncertainties on He/H on individual target will fall to a few percent.

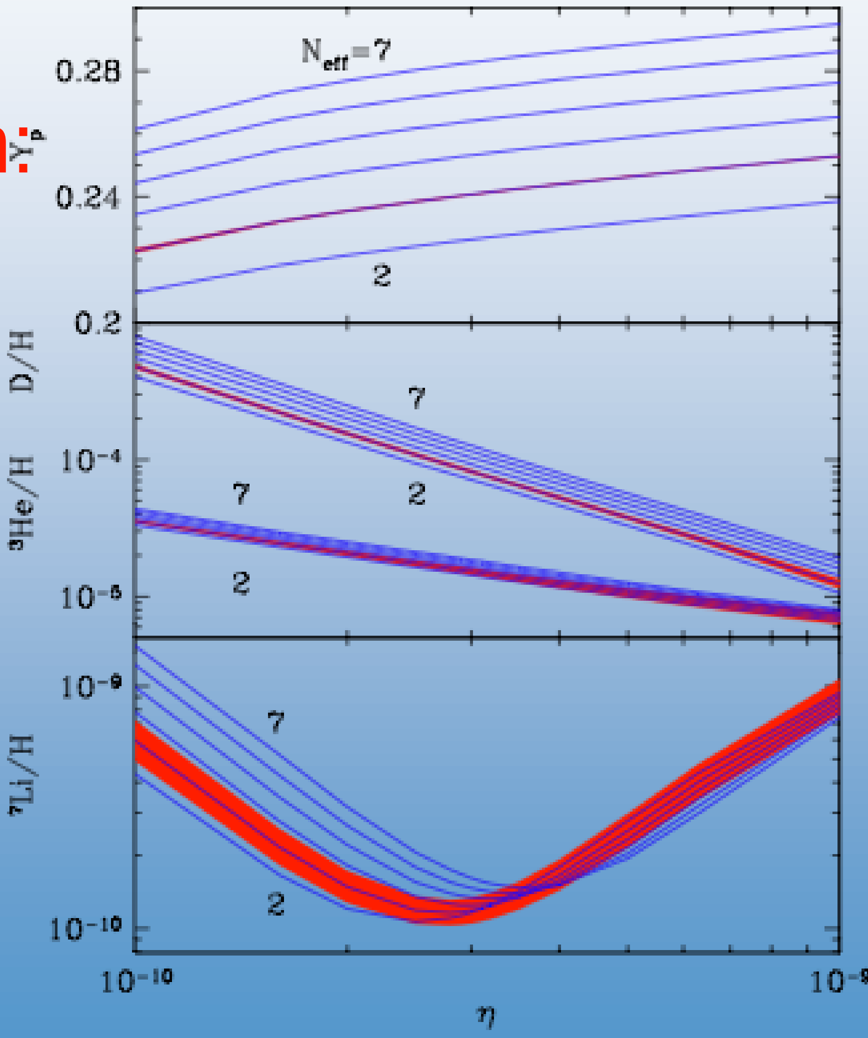
But is it too late?

D/H is now competitive for Neff constraint.

Future CMB will measure Yp directly competitively.

Sensitivity to Neff

- BBN Concordance rests on balance between interaction rates and expansion rate.
- Allows one to set constraints on:
  - Particle Types
  - Particle Interactions
  - Particle Masses
  - Fundamental Parameters



Cyburt, Fields, Olive

CMB Results on Yp

- WMAP7 Komatsu et al. (2010) "We detect the effect of primordial helium on the temperature power spectrum and provide a new test of big bang nucleosynthesis by measuring Yp = 0.326 +/- 0.075 (68% CL)."
- Planck 2015 Yp=0.251 +/- 0.026 !!

Back in Paris (1985)

From: G. Shields: Helium in Dwarf Emission Line Galaxies
Discussion: G. Shields: At what point does cosmology have a problem with the 4He abundance?

K. Olive: Coming from the side of theory, I know that there are at least two light (<1 MeV) neutrinos with lifetimes longer than 1 sec. This tells me that Yp > 0.22+/-0.23. If indeed there are three light neutrinos, then Yp>0.24. If you tell me that Yp=0.245+/- 0.003, I am very happy, there is complete consistency. If Yp =0.23+/-0.01, I take that to be 0.24 and again I am satisfied. Only when you tell me that Yp<0.22 with your most generous uncertainties then I would claim a serious discrepancy with cosmology.

Summary

- Yp from metal poor galaxies – nice BBN consistency check, good constraint on Neff
- Future progress is possible; will it be enough to merit the effort?
- Thanks to everyone for attending.
- Thanks to Keith for really great times.