Measurements of 4He in Metal-Poor Extragalactic H II Regions: *Yp* and the *ΔY/ΔO* Ratio

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Outline

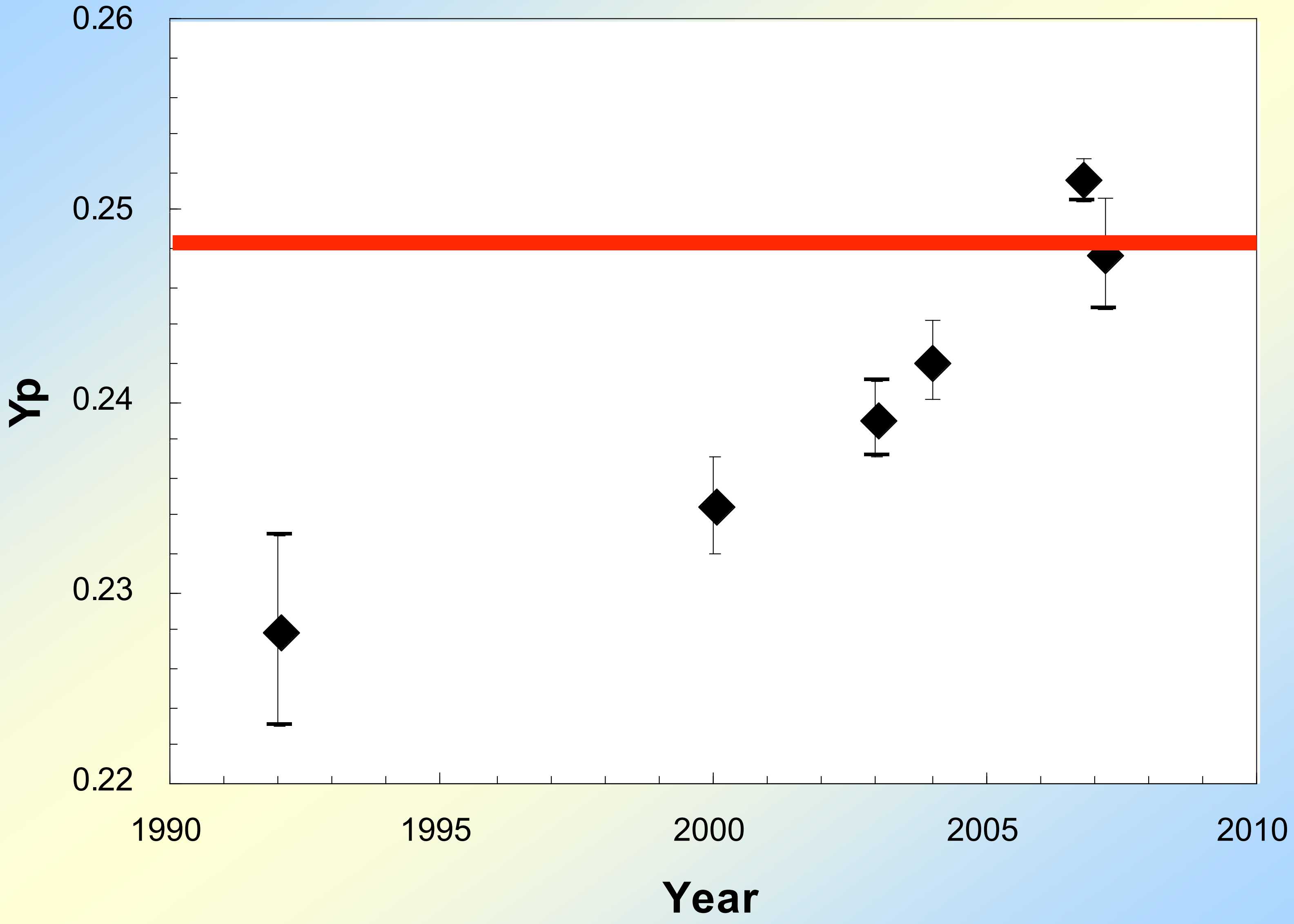
- Recent *Yp* determinations
- Comparison of the directly determined *Yp* with those *Yp* values derived under the assumption of SBBN and WMAP
- Recent *ΔY/ΔO* determinations
- Comparison of *Yp* and *ΔY/ΔO* with models of Galactic chemical evolution
- Conclusions

Why Y_P?

- Y_P and Big Bang Cosmology
- Y_P and the Standard Model of BBN
- Y_P and Physical Conditions in H II Regions
- Y_P and the Chemical Evolution of Galaxies

Recent results by Izotov et al. 2007

and Peimbert et al. 2007



Source	Systematic Error	Statistical Error
Fluorescent Excitation of H I and He I Lines		
Collisional Excitation of the H I Lines		
Temperature Structure		
***O* (ΔY/ΔO)** Correction		
Recombination Coefficients of the He I Lines		
Density Structure		
Underlying Absorption in the He I Lines		
Reddening correction		
Recombination Coefficients of the H I Lines		
Underlying Absorption in the H I Lines		
Ionization Structure		
Collisional Excitation of the He I Lines		
Optical Depth of the He I Triplet Lines		
He I and H I Line Intensities		

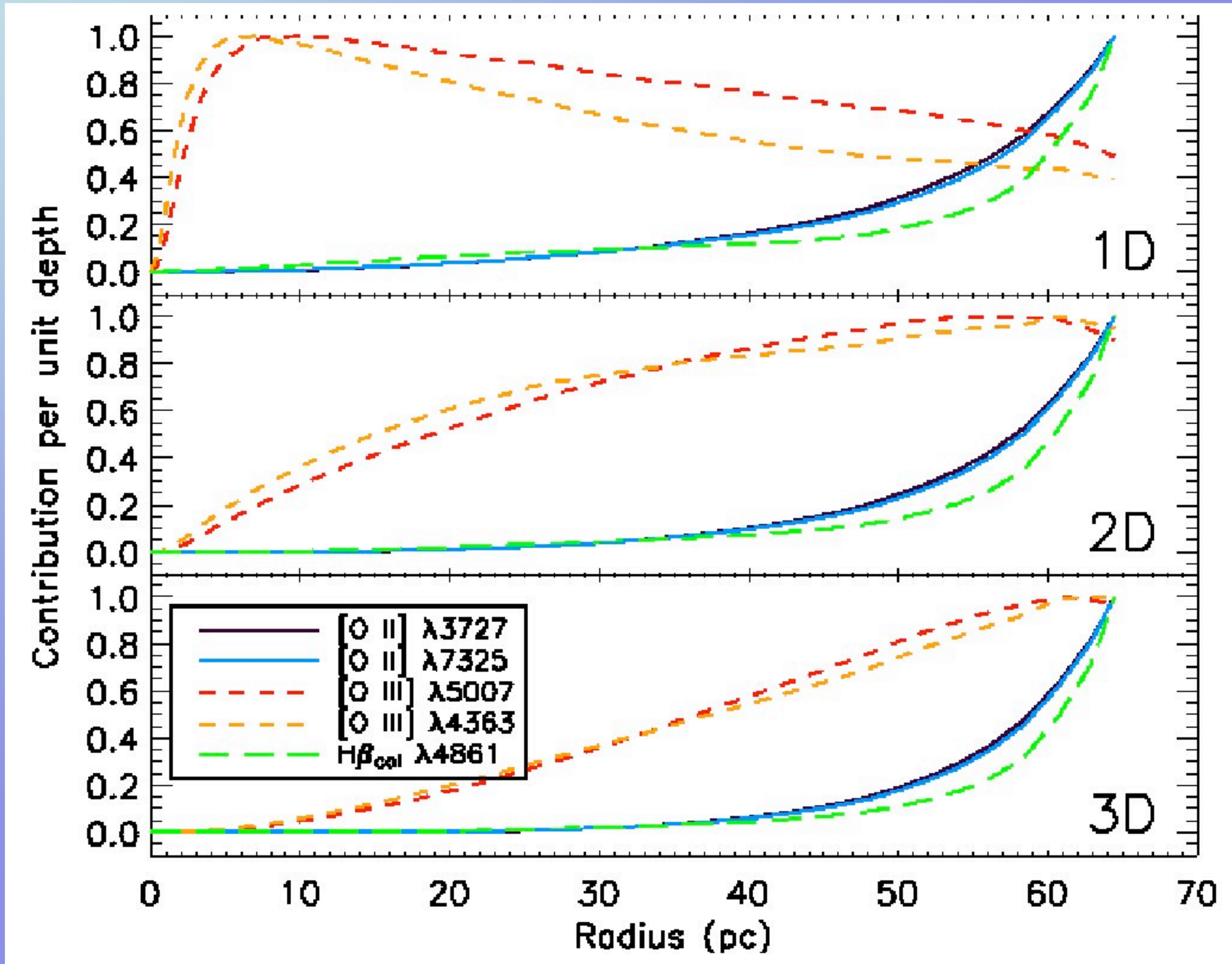
Collisional Excitation of the H I lines

- Davidson & Kinman (1985).
- Stasinska & Izotov (2001).
- Luridiana, Peimbert, & Peimbert (2003).
- Peimbert, Luridiana,& Peimbert (2007).

•This is one of the two least studied problems related to the Y_P determination (the other is case D).
•It requires tailor-made models for each object.
•Notice that simple photoionization models predict electron temperatures smaller than observed.
•It is extremely sensitive to temperature.
•It is very important for objects with T(O II)> 14 000K.
•It is negligible for objects with T(O II) < 12000K.

T(O II)	***I***(Hβ)
15 500 K	5-7%
14 000 K	2-3%
12 000 K	0.5-1%

CLOUDY photoionization model for NGC 346



Peimbert et al. 2007

Temperature Structure

$$T_0 = \frac{\int T_e n_e n_i \, dV}{\int n_e n_i \, dV}$$

$$t^2 = \frac{\int (T_e - T_0)^2 n_e n_i \, dV}{T_0^2 \int n_e n_i \, dV}$$

$$T_e(4363/5007) = T_0 [1 + (90800/T_0 - 3)\, t^2/2]$$

$$T_e(\mathrm{Bac/H\beta}) = T_0 (1 - 1.70\, t^2)$$

$$T_e(4649/5007) = f_1 (T_0, t^2)$$

Using He I Lines to Determine Physical Conditions

- The intensity of each He I is:

[illegible]

- In principle, with 4 He I line intensities relative to $I(\mathrm{H}\beta)$ it is possible to derive 4 unknowns: T_e (He I), n_e(He I), $\tau_{(3889)}$, and $\mathrm{He}^+/\mathrm{H}^+$.
- In practice, this works better using 8+ lines, with s/n up to 50+

The Y_P Determination

Error Budget (For the Peimbert et al. 2007 sample)

Source	Error
Collisional Excitation of the H I Lines	±0.0015
Temperature Structure	±0.0010
O (ΔY/ΔO) Correction	±0.0010
Recombination Coefficients of the He I Lines	±0.0010
Density Structure	±0.0007
Underlying Absorption in the He I Lines	±0.0007
Reddening correction	±0.0007
Recombination Coefficients of the H I Lines	±0.0005
Underlying Absorption in the H I Lines	±0.0005
Ionization Structure	±0.0005
Collisional Excitation of the He I Lines	±0.0005
Optical Depth of the He I Triplet Lines	±0.0005
He I and H I Line Intensities	±0.0005

Systematic effects

Peimbert et al. 2007

Determination of the Primordial Helium Abundance, Y_P, with $t^2 = 0.000$ and $t^2 \neq 0.000$

	ΔY (Hc)	Y ($t^2 = 0.000$)	Y ($t^2 \neq 0.000$)	Y_P ($t^2 \neq 0.000$)
NGC 346	0.0015 ± 0.0005	0.2537	0.2507 ± 0.0027 ± 0.0015	0.2453 ± 0.0027 ± 0.0019
NGC 2363	0.0057 ± 0.0016	0.2551	0.2518 ± 0.0047 ± 0.0020	0.2476 ± 0.0047 ± 0.0022
Haro 29	0.0047 ± 0.0013	0.2577	0.2535 ± 0.0045 ± 0.0017	0.2500 ± 0.0045 ± 0.0019
SBS 0335-052	0.0144 ± 0.0038	0.2594	0.2533 ± 0.0042 ± 0.0042	0.2520 ± 0.0042 ± 0.0042
I Zw 18	0.0114 ± 0.0031	0.2529	0.2505 ± 0.0081 ± 0.0033	0.2498 ± 0.0081 ± 0.0033
Y(sample)	0.0056 ± 0.0015	0.2554	0.2517 ± 0.0018 ± 0.0021	0.2477 ± 0.0018 ± 0.0023

$$Y_P = Y - O(\Delta Y/\Delta O)$$

Peimbert et al. 2007

The Y_P Determination

Y_P, D_P, and WMAP Comparison

Cosmological predictions based on SBBN and observations
For τn = 885.7 ± 0.8 s

Method	Y_P	$D_P \times 10^5$	η_{10}	$\Omega_b h^2$
Y_P	0.2477 ± 0.0029*	$2.78^{+2.28}_{-0.98}$	5.813 ± 1.810	0.02122 ± 0.00663
D_P	0.2476 ± 0.0006	2.82 ± 0.28*	5.764 ± 0.360	0.02104 ± 0.00132
WMAP	0.2484 ± 0.0003	2.49 ± 0.11	6.225 ± 0.170	0.02273 ± 0.00082*

***Observed values**

Peimbert 2008

The Y_P Determination
Y_P, D_P, and WMAP Comparison

Cosmological predictions based on SBBN and observations for τn = 878.5 ± 0.8 s

Method	Y_P	$D_P \times 10^5$	η_{10}	$\Omega_b h^2$
Y_P	0.2477 ± 0.0029*	$1.86^{+2.28}_{-0.98}$	6.937 ± 1.810	0.02532 ± 0.00663
D_P	0.2458 ± 0.0006	2.82 ± 0.28*	5.764 ± 0.360	0.02104 ± 0.00132
WMAP	0.2466 ± 0.0003	2.49 ± 0.11	6.225 ± 0.170	0.02273 ± 0.00062*

***Observed values**

Peimbert 2008

Neutron lifetime and *Yp*

τ_n	Y_P
885.7 ± 0.8 s [a]	0.2484
881.9 ± 1.6 s [a,b]	0.2475
875.8 ± 0.8 s [b]	0.2468

a) Arzumanov et al. (2000)
b) Serebrov et al. (2005, 2008)

Primordial Helium Abundance: H II Regions

(T(4363/5007); t^2=0.00) Izotov et al. 2007	0.2533 ± 0.0011
(T(5007/4363); t^2=0.00) Peimbert et al. 2007	0.2523 ± 0.0027
Observational t^2 Method (Balmer continuum and He I lines with MLM) Peimbert et al. 2007	0.2477 ± 0.0029
Primordial Deuterium + SBBN O´Meara et al. 2006	0.2476 ± 0.0006
Wilkinson Microwave Anisotropy Probe + SBBN WMAP 2008	0.2484 ± 0.0003

Yp for a given t^2

	t^2	Y_P	
Peimbert et al. (2007)	0.01	0.2505	5 objects
Izotov et al. (2007)	0.01	0.2516	86 objects
Izotov et al. (2009)	0.01	0.2514	2 objects

$\Delta Y / \Delta O$

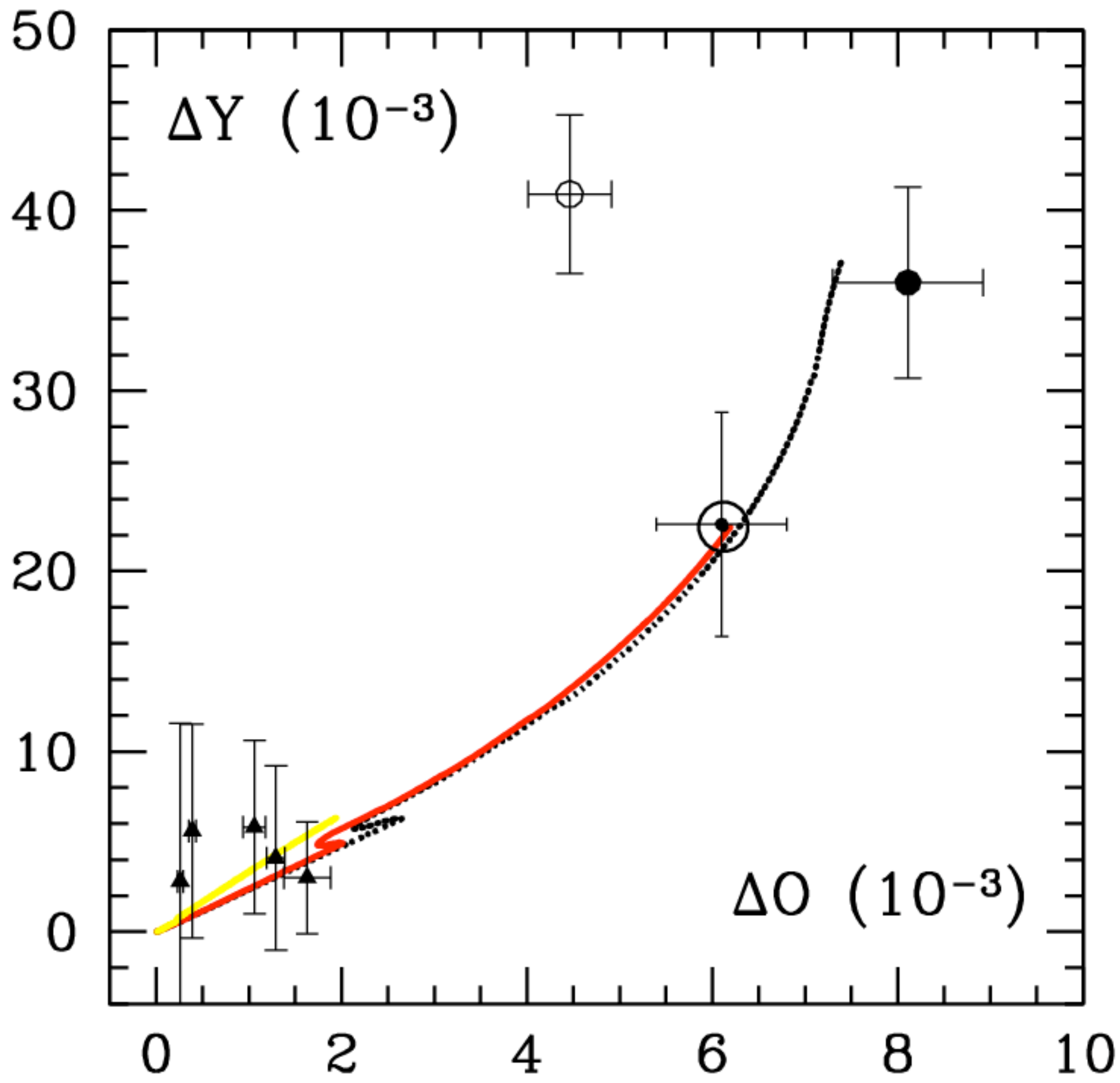
Observations		Irregulars	The Galaxy
Carigi et al.	(1995)	4.5 ± 1.0	. . .
Peimbert A.	(2003)	2.93 ± 0.85	3.57 ± 0.67
Izotov & Thuan	(2004)	4.3 ± 0.7	. . .
Peimbert et al.	(2006)	3.4 ± 0.7	. . .
Models		Irregulars	The Galaxy
Carigi et al.	(1995)	2.95	. . .
Chiappini et al.	(1997)	. . .	3.15
Carigi et al.	(1999)	4.2	. . .
Carigi & Peimbert	(2007)	2.4-4.0	3.3-4.0

$$\Delta \boldsymbol{Y}/\Delta \boldsymbol{O} = 3.3 \pm 0.7$$

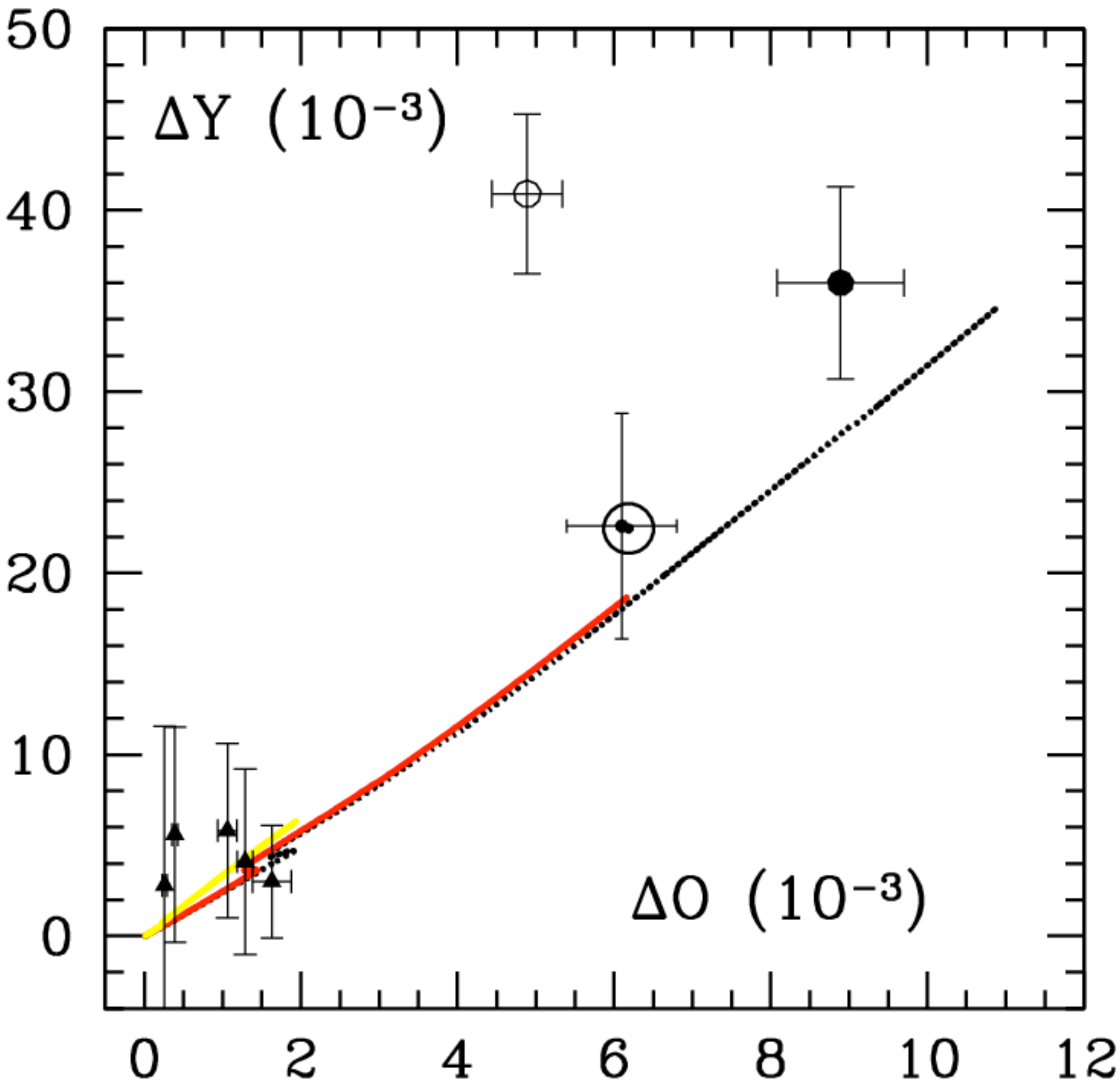
$$\boldsymbol{Y_P} = \boldsymbol{Y} - \boldsymbol{O}(\Delta \boldsymbol{Y}/\Delta \boldsymbol{O})$$

Irregulars: closed box models and outflow models of well mixed material. For O-rich outflows the models enter in contradiction with observed C/O values.

Galaxy: two infall models with an inside-out formation scenario



Carigi & Peimbert 2009



Carigi & Peimbert 2009

Summary 1/2

- The use of *T*(HeI) instead of *T*(4363/5007) reduces *Yp* by ~ 0.0046.
- The total increase in *Yp* due to H I collisions amounts to ~ 0.0030.
- The total increase in *Yp* due to the new He I atomic physics computations amounts to ~ 0.0040.
- The $\Delta Y / \Delta O$ adopted value is 3.3 ± 0.7
- The derived *Yp* value is 0.2477 ± 0.0029 (without considering case D)

Summary 2/2

- The *Yp* derived from H II regions is in good agreement with the *Yp* derived from the *Dp* and WMAP measurements assuming SBBN. There is still some room for the possibility of new physics.
- There are Galactic chemical evolution models that adjust the observed O/H ISM values and the O/H abundance gradient. These models also adjust the C/O observed abundance gradient.
- These models are also in good agreement with the *Yp* and the *Y* and *O* presolar and M17 values.
- Models of nearby low metallicity galaxies predict constant $\Delta Y / \Delta O$ ratios.

THE END