PRIMORDIAL HELIUM ABUNDANCE BY RRL: NEW RESULT

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ABSTRACT. New results of the Primordial Helium abundance (Y_p) measurement by radio recombination lines (RRL) observations from galactic HII regions are presented. The RRL observations were carried out with two Parabolas: RT32(λ =13.5 mm and 3.5 cm, Medicina, Italy) and RT22 (λ = 8 and 13.5 mm, Pushchino, Russia). The current value was obtained on the base of five source observations with the accurate correction for both the ionization structure and dust influence. At present, the obtained $Y_p = 25.74(\pm1.0)\%$ value seems to be higher than that suggested by optical data, allowing the presence of unknown light particles, and is in agreement with the result from cosmic microwave background asymmetry.

Keywords: Cosmology: Helium abundance: Recombination Radio Lines - ISM.

1. Introduction

Nowadays, there are several papers on the light elements production (He-4, He-3, D and Li-7) during Big-Bang Nucleosynthesis (BBN) occurred in the first 2-3 minutes of Universe. While He-3/H, D/H and Li-7/H abundances strongly depend on baryon density, the primordial He-4/H abundance dependence on baryon density is weak, since it is related to the presence of light particles as neutrinos (e.g. Yang et al., 1984) at the earlier stage, when a neutrino/proton (n/p) ratio was frozen (~10-20 sec of Universe). Today, the number of neutrino species is known to be equal to 3 with high accuracy from accelerator experiments (Klapdor-Kleigrothaus & Zuber, 1997). Consequently, primordial helium abundance could be an indicator of some unknown light particles (Hot Dark Matter particles), if its amount would differ from BBN calculations. (Of course, the n/p ratio could depend on the rate of weak interaction too, but it was usually supposed to be as in standard physics.)

This paper presents further improvement of the RRLs Y_p measure in comparison with the previous report (Tsivilev et al., 2002).

2. Method to measure Yp by RRL

Today is clear that the systematical problems are playing a role in Y_p measurements at all wavelengths: optical, IR and radio. However the radio measurements have a remarkable feature: the radio recombination lines are originated by highly excited quantum states where the He atom has a Hydrogenic behavior, and the H and He coefficients, characterizing the levels population, are the same for the same H and He transitions. In this case the $y^+ = N(He^+)/N(H^+)$ ratio is measured directly from the ratio of He to H integral lines, since the corresponding levels population coefficients simplify each other. This is not the case for optical and IR observations, where these coefficients should be modeled. In order to increase the reliability of obtained data two radio telescopes (RT32, Medicina and RT22, Pushchino) have been used. Moreover, the achieved sensitivity allows to resolve the RRL of carbon (C) from the helium line profile, reducing also systematical problems.

Then, in principle, it's necessary to make two very important corrections: for ionization structure of HII regions and for stellar nucleosynthesis.

Ionization structure correction:

Usually, due to the difference of H and He ionization threshold, the sizes of He+ and H+ regions can be different. The correction for ionization structure ($\Delta y(IS)$) could be positive if the He^+ zone is smaller than the H^+ one, negative if the He^+ zone is larger, and zero if they coincide:

$$y = N(He)/N(H) = y^+ + \Delta y(IS).$$

To obtain it, a H and He RRL mapping of HII regions is very desirable, but a model $\Delta y(IS)$ calculation is also possible, by having two important parameters: the effective temperature (T_{eff}) of ionizing star (stars) and the amount and properties of dust inside the HII region. The dust properties are taken from Aannestad (1989) paper. Our investigations showed that Teff calibration by Pottash et al. (1979) together with the star

Source	y^+ %	$\Delta y(IS)$ %	T_{eff} K	y %	Z metallicity	Yp %
$OrionA^{**}$			~ 37000	10.2(0.8)	0.0112(.0022)	26.1(2.0)
$W3A^{**}$	9.9 (0.5)	-0.6	45000	9.3(0.5)	distant	26.1(1.6)
$M17^{**}$	11.1(1.1)	-0.7	45000	10.4(1.1)	0.0183(.0018)	24.7(2.7)
$NGC7538$	$7.7(1.0)^*$	+1.95	$\sim 37000^*$	9.65(1.8)	distant	$26.8(4.0)^*$
$W48$	9.6(1.3)	0.0		9.6(1.3)	$0.0183(.0019)^m$	23.3(3.3)

**) - data of the RRL mapping was also used;
distant - source at galactic distance outer than solar position;
*) - it will be further justified; m - from Galaxy Z model; for other Z see Tsivilev et al. (2002).

atmosphere models by Mihalas (1972) could be used.

Correction for stellar nucleosynthesis:

Since He4 is synthesized in stars, some of the measured helium is not primordial:

$y = y_p + \Delta y(stars)$; by atoms

or $Y = Y_p + Z * Y/dZ$; by mass

(and where $Y = 4y(1 + 4y)/ * (1 - Z)$).

To separate the Helium contribution from star nucleosynthesis two ways are proposed:

I) First way is by the observation of distant Galactic HII regions more distant than solar or Orion position from the Galactic centre, because: **a)** Observed metal abundance (Z) decreases outwards the Galaxy (i.e. Shaver et al., 1983); it can mean that interstellar matter in outer part of the Galaxy was polluted by stars nucleosynthesis products in smaller amount than that in the inner part. **b)** Hoyle&Teyler (1964) argued that the helium production in stars was small $\Delta y(stars) \sim 1\%$, ($\sim 10\%$ from stellar nucleosyntesis and $\sim 90\%$ from BBN). **c)** For simplicity, for outer part of Galaxy: $\Delta y(stars) = (0.5 \pm 0.5)\%$ (half of Hoyle&Tayler calculation) was accepted.

II) Second way uses a $Y(Z)$ dependence for the HII regions with well measured metal abundance (Z). The dY/dZ value can be taken from last accurate measurement for HII regions (in our case $dY/dZ = 2.3 \pm 1.0$ (Izotov & Thuan, 1998)). If measured value of Z is absent, it is possible to use the model Galaxy Z plot of Shaver et al. (1983), being the distance known.

3. Results

The Table reports the results of our Y_p determination. The average value is: $Yp = (25.74 \pm 1.0)\%$.

As for extragalactic radio RRL observations, it's possible to make a comparison only with 30 Doradus (LMC, Peck et al., 1997), where $y^+ = 13(2)\%$ was obtained. If one uses the max values of both IS and stellar corrections, then $Y_p = 27.2(\pm 4.3)\%$ by mass could be evaluated, which is in agreement both with our and optical Y_p, due to large errors.

However our results is in agreement with the WMAP data (Coc et al., 2004), where $Y_p = (24.79 \pm 0.04)\%$ has been obtained.

4. Summary

With respect to our previous result (Sorochenko & Tsivilev, 2000; Tsivilev et al., 2002) we obtained:

$\mathbf{Yp = 25.74(+1.0)\%,}^*$, which is :

1) Higher than from optical measurements, but in agreement with the conclusion of CMB anisotropy experiments.

2) As for amount of unknown light particles at $\sim$ 10-20 sec, it's possible to calculate using Pagel (2000) formula, which, in turn, can be rewrite as a function only of neutrino species:

$Y_p = Y_{p,o} + 0.013(N_v - 3)$,

where the zero point is from WMAP data: $Y_{p,o} = 0.2479$, and an excess over established neutrino species number (=3) will be:

$\Delta N = N_v - 3 = 0.7 \sim 1$ for $Y_p = 25.74\%$ and $\Delta N = N_v - 3 = 2.3$ for 2σ upper level. *So, it means that about 1-2 unknown light particles (similar to neutrino) can exist.*

3) Nevertheless, it's worthy to note that another possibility to explain the derivation of measured Y_p from BBN value could be:

A) Pregalactic stars of the Population III ($10^2 - 10^5 M_o$) can produce ΔY up to $\sim 20\%$ (B.J.Carr, J.R.Bond and W.D.Arnet, 1984, *ApJ.*, 277, 445.) B) Variation of Physical constants: A.V.Ivanchik, A.V.Orlov and D.A.Varshalovich, 2001, *Astronomy Letters*, **27**, 615. C) Total Helium abundance was not from Big Bang Nucleosynthesis: Burbidge G. and Hoyle F., 1998, *ApJ*, **509**, L1-L3.

Note : * - Recently Izotov&Thuan (ApJ, 2004, 602, 200) presented the new value of $dY/dZ = 2.8 \pm 0.5$, consequently, a new value of Yp will be slightly lower and with slightly less error. Further it will be recalculated.

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