Notes on Primordial Helium-4 Measurements

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Abstract

The purpose of these notes is to summarize recent progresses in measuring the primordial helium-4 abundance in the literature. Comparisons between different studies are presented and discussed.

1 Methods to Measure Helium-4

There are currently two methods to measure Y_{P}:

1. **From the CMB damping tail.**
   In the period after helium recombination, but before hydrogen recombination, the number density of free electrons in the plasma can be expressed in terms of the number density of baryons via $n_e = (1 - Y_{\mathrm{P}})n_b$. This means that a larger helium fraction Y_{P} leads to fewer free electrons, which in its turn increases the free-streaming length of CMB photons. Eventually, this results in a dampening of the temperature anisotropies, and thus the CMB power spectrum, at small angular scales. This suppression of the CMB power spectrum at such small scales (also known as Silk damping) provides an independent probe of the primordial helium abundance Y_{P}. The latest result from Planck 2018 reads [1]:

   $$Y_{\mathrm{P}}^{\mathrm{CMB}} = 0.241 \pm 0.025 \quad (95\%,\ \mathrm{TTTEEE{+}lowE})\,, \tag{1}$$

   if only Y_{P} is varied along the 6 base ΛCDM parameters. If, in addition, N_{eff} is also varied (because there is a degeneracy in the effect on the damping tail due to Y_{P} and N_{eff}), the Planck 2018 result reads [1]:

   $$Y_{\mathrm{P}}^{\mathrm{CMB}} = 0.247^{+0.034}_{-0.036} \quad (95\%,\ \mathrm{TTTEEE{+}lowE})\,. \tag{2}$$

2. **By observing hydrogen and helium recombination lines in low-metallicity regions.**
   This is the classical method in determining the primordial helium abundance. Usually, a single element (often chosen as oxygen O) is used as metallicity tracer in a chemically unevolved region that consists of ionized gas. The method involves the linear extrapolation of the current helium abundance down to zero metallicity, using this tracer. Naturally, this method works better the lower the overall metallicity of the gas region. The most suitable objects for this kind of study are low-metallicity HII clouds and local HII galaxies. Table 1 and Figure 1 show the results of recent studies.

Study	Y_{P}
Izotov et al. (2014) [5]	0.2551 ± 0.0022
Aver et al. (2015) [2]	0.2449 ± 0.0040
Peimbert et al. (2016) [6]	0.2446 ± 0.0029
Fernández et al. (2018) [4]	0.245 ± 0.007
Valerdi et al. (2019) [8]	0.2451 ± 0.0026

Table 1: Recent determinations of the primordial helium abundance Y_{P}.

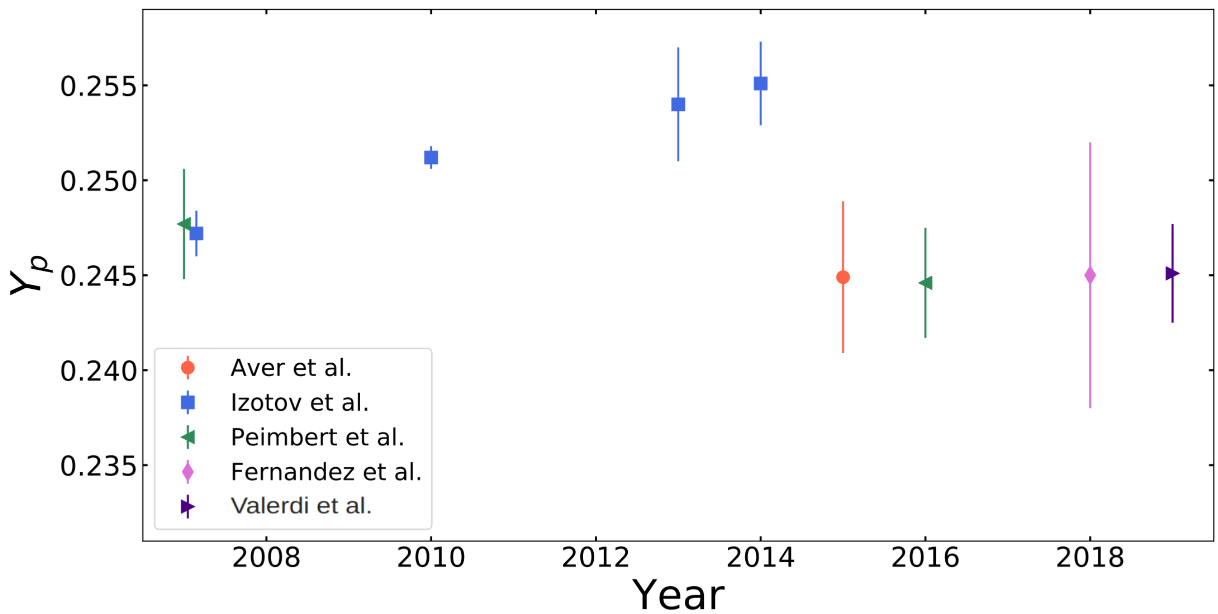

Figure 1: Recent determinations of the primordial helium abundance Y_{P}.

In Table 7 of Valerdi et al. [8], thirteen potential sources of error are listed and only very accurate analysis on restricted HII samples (even single HII regions) could address for all of them. This is indeed attempted by Aver et al. [2], Peimbert et al. [6] and Valerdi et al. [8]. On the other hand, Izotov et al. [5] prefer to use a large data base and infer a rather small error in the extrapolation – theirs is the only discrepant value. In fact, a possible unaccounted for systematic error is identified in their adopted temperature structure by Valerdi et al. [8].
For the interested reader, a discussion about measurement errors of the helium-4 abundance in HII regions is presented in [3].

2 PDG

Recent conversation with the author of the PDG BBN section, suggested that the PDG uses the results of Aver et al. [2] and Peimbert et al. [6]. They recommend a value of [7]:

$$Y_{\mathrm{P}}^{\mathrm{PDG}} = 0.245 \pm 0.003 \, . \tag{3}$$

It seems that they have not included the results of Fernandez et al. [4] (which was already online before PDG 2018 publication). And, of course, the most recent analysis by Valerdi et al. [8] should be considered too. Therefore, I expect that the value in their 2019 edition will be updated a bit. However, Figure 1 suggests that the updated value would not differ too much from the one in Eq. 3.

References

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