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Median Statistics Analysis of Deuterium Abundance and Spatial Curvature Constraints

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Abstract

Deuterium abundance in interstellar gas clouds, recorded as the ratio of Deuterium to Hydrogen (D/H), has been measured by many cosmologists. A recent paper analyzed its and other's own D/H measurements and calculated a weighted mean of (2.544 ± 0.025)×10^{-5}. However, there is evidence supporting the use of median statistics to find a central estimate for D/H. Using the same set of D/H measurements, we calculate a median central estimate of $2.48^{+0.05}_{-0.08}$×10^{-5}. D/H values are correlated to, and can be used to determine, the average baryonic density of the universe, $\Omega_b h^2$. When our median value is compared to current CMB measurements, it is found to only deviate by (0.267-2.142)σ as opposed to the (1.354-4.140)σ deviations of the weighted mean value. This is further proof that median statistics is a viable means of calculating central estimates for D/H measurements.

Introduction

- Big Bang Nucleosynthesis (BBN) created all light elements up to lithium in the moments just after recombination
- Deuterium, created during BBN, has been the focus of many research projects
- Deuterium abundance is measured as the ratio of deuterium to hydrogen (D/H)
- D/H is correlated to the ratio of photons to baryons, $\Omega_b h^2$
- $\Omega_b h^2$ helps determine the curvature of the universe
- We want to find an accurate D/H central estimate in order to get $\Omega_b h^2$ values that are consistent with current CMB predictions

Data

- Zavarygin et al. (2018), hereafter Z18, compiled a list of D/H measurements (found in Table 1)
- Z18 also used the Least Trimmed Squares method to remove two outliers from the list (Srianand et al. 2010 & Pettini et al. 2001)
- This created a set of measurements, known as Truncated 13, that Z18 estimated to have a weighted mean of (2.545 ±0.025)×10^{-5}
- We find this weighted mean to be 2.544 instead of 2.545

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Table 1. *D/H measurements from Z18*

Quasar	D/H(×10^5)	References
HS 0105+1619	$2.58^{+0.16}_{-0.15}$	Cooke et al. (2014)
J0407-4410	$2.8^{+0.8}_{-0.6}$	Noterdaeme et al. (2012)
Q0913+072	$2.53^{+0.11}_{-0.10}$	Cooke et al. (2014)
Q1009+2956	$2.48^{+0.41}_{-0.13}$	Zavarygin et al. (2018)
J1134+5742	$2.0^{+0.7}_{-0.5}$	Fumagalli et al. (2011)
Q1243+3047	2.39 ±0.08	Cooke et al. (2018)
J1337+3152	$1.2^{+0.5}_{-0.3}$	Srianand et al. (2010)
SDSS	2.62 ±0.07	Cooke et al. (2016)
J1358+6522	2.58 ±0.07	Cooke et al. (2014)
J1419+0829	2.51 ±0.05	Cooke el al. (2014)
J1444+2919	$1.97^{+0.33}_{-0.28}$	Balashev et al. (2016)
J1558-0031	$2.40^{+0.15}_{-0.14}$	Cooke et al. (2014)
PKS1937-1009	$2.45^{+0.30}_{-0.27}$	Riemer-Sørenson et al. (2015)
PKS1937-101	2.62 ±0.05	Riemer-Sørenson et al. (2017)
Q2206-199	1.65 ±0.35	Pettini et al. (2001)

Analysis

- We analyze Z18's Truncated 13 data set as well as the entire set, known as All 15, which includes the outliers
- We create error distributions based on the weighted mean and the median
- Median statistics can be used to analyze non-Gaussian distributions
- We utilize the Kolmogorov-Smirnov Test (KS Test) to check for Gaussianity in the error distributions
- The *p*-Value is the probability that the error distribution doesn't not come the distribution it's tested against
- Once a central estimate is decided, it is used in the fit equation below to determine $\Omega_b h^2$

$$(D/H)_p = (2.45 \pm 0.04) \times 10^{-5} \left(\frac{\Omega_b h^2}{0.02225}\right)^{-1.657}$$

Table 2. *KS Test Probabilities*

	Truncated 13	All 15
Distribution	*p*	*p*
Median		
Gaussian	0.999	0.809
Cauchy	0.385	0.921
Weighted Mean		
Gaussian	0.997	0.613
Cauchy	0.604	0.950

Results

- Table 2 shows that the Truncated 13 values are Gaussian and the All 15 values are non-Gaussian
- We performed the $\Omega_b h^2$ calculations on the weighted mean for Truncated 13, as Z18 does, and the median for All 15, due to its non-Gaussianity
- We calculated a weighted mean central estimate of $\Omega_b h^2$ = 0.02175 and a median central estimate of $\Omega_b h^2$ = 0.02209
- Table 3 shows the results of calculating the σ invariance between our measured central estimates and multiple CMB predictions

Table 3. *The σ invariance of central estimates compared to CMB data*

CMB Prediction			
Prediction	$\Omega_b h^2$	WM σ	Median σ
Flat ΛCDM	0.02225 ±0.00023	1.472	0.361
Nonflat ΛCDM	0.02305 ±0.0002	4.061	2.122
Flat XCDM	0.02229 ±0.00023	1.590	0.446
Nonflat XCDM	0.02305 ±0.0002	4.061	2.122
Flat ϕCDM	0.02221 ±0.00023	1.354	0.276
Nonflat ϕCDM	0.02303 ±0.0002	3.998	2.078
	CMB w/ Other Cosmological Data		
Flat ΛCDM	0.02232 ±0.00019	1.815	0.530
Nonflat ΛCDM	0.02305 ±0.00019	4.140	2.142
Flat XCDM	0.02233 ±0.00021	1.776	0.542
Nonflat XCDM	0.02238 ±0.0002	4.061	2.122
Flat ϕCDM	0.02238 ±0.0002	1.968	0.656
Nonflat ϕCDM	0.02304 ±0.0002	4.029	2.100

Conclusion

- Using median statistics allows us to take all data points
- The All 15 dataset is clearly Non-Gaussian
- The weighted mean central estimate computed by Z18 not only omits data points, but is also less-consistent with CMB predictions
- The median central estimate we measure is, in all cases, more consistent with CMB predictions
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