Homework 2 GCE 2025, IAG-USP. Deadline: March 27, 2025

1. In the paper "Big-Bang Nucleosynthesis after Planck" (https://ui.adsabs.harvard.edu/abs/2020JCAP...03..010F/abstract), Fields et al. (2020) predict the following primordial BBN abundances, adopting Planks' baryon-to-photon ratio ($\eta = 6.13 \times 10^{-10}$):

$$
\begin{aligned}
Y_p &= 0.24691 \pm 0.00018 \\
\mathrm{D/H} &= (2.57 \pm 0.13) \times 10^{-5} \\
{}^{3}\mathrm{He/H} &= (10.03 \pm 0.90) \times 10^{-6} \\
{}^{7}\mathrm{Li/H} &= (4.72 \pm 0.72) \times 10^{-10}
\end{aligned}
$$

The ^{4}He abundance is given by mass fraction, but the others are by number. Compute the primordial ^{4}He abundance in the linear scale, n(^{4}He)/n(H), and compute the others in the log scale where $A_H = 12$.

2. Kislitsyn et al. (2024, https://ui.adsabs.harvard.edu/abs/2024MNRAS.528.4068K/abstract) determined the deuterium abundance in a metal-poor sub-DLA system towards quasar J 1332+0052. The following data, extracted from their Table 4, includes their measurement and other values from the literature.

QSO	[O/H]	log (D/H)	Reference	Meet criteria?
HS 0105+1619	−1.771 ± 0.021	−4.589 ± 0.026	Cooke et al. (2014)	✓
Q0913+072	−2.416 ± 0.011	−4.597 ± 0.018	Cooke et al. (2014)	✓
SDSS J1358+6522	−2.335 ± 0.022	−4.588 ± 0.012	Cooke et al. (2014)	✓
SDSS J1419+0829	−1.922 ± 0.010	−4.601 ± 0.009	Cooke et al. (2014)	✓
SDSS J1558-0031	−1.650 ± 0.040	−4.619 ± 0.026	Cooke et al. (2014)	✓
Q1243+307	−2.769 ± 0.028	−4.622 ± 0.015	Cooke et al. (2018)	✓
SDSS J1358+0349	−2.804 ± 0.015	−4.582 ± 0.012	Cooke et al. (2016)	✓
J1444+2919	−2.042 ± 0.005	−4.706 ± 0.067	Balashev et al. (2016)	✓
CTQ 247	−1.990 ± 0.100	−4.560 ± 0.100	Noterdaeme et al. (2012)	×
PKS 1937–1009(1)	−1.870 ± 0.200	−4.610 ± 0.050	Riemer-Sørensen et al. (2015)	×
J1337+3152	−2.640 ± 0.170	−4.930 ± 0.150	Srianand et al. (2010)	×
J1134+5742	<−1.9 (adopt -1.9)	−4.690 ± 0.130	Fumagalli et al. (2011)	×
Q2206-199	−2.070 ± 0.050a	−4.786 ± 0.100	Pettini & Bowen (2001)	×
Q0347-3819	−0.820 ± 0.060	−4.426 ± 0.028	Levshakov et al. (2002)	×
PKS 1937–1009(2)	−2.250 ± 0.250	−4.581 ± 0.008	Riemer-Sørensen et al. (2017)	×
Q1009+2956	−2.500 ± 0.200	−4.606 ± 0.066	Zavarygin et al. (2018)	×
J1332+0052	−1.725 ± 0.019	−4.622 ± 0.014	this paper	✓

Use the whole dataset to compute in the linear scale, the following quantities for (A) to (C):
A) average linear D/H value
B) median linear D/H value
C) weighted mean of linear D/H (as weights, use the square of the inverse error bars, $1/\sigma^2$).
D) Compute the average value using only the results recommended in the last column.
E) Which value from (A) to (C) agree better with the result from (D)?
F) Which value from (A) to (C) agree better with the BBN prediction from Fields et al. (2020)?
G) Using the table above, make a plot of D/H vs. [O/H] including the error bars in D/H. Plot a horizontal solid red line showing the central value of the BBN prediction from Fields et al. (2020) and horizontal red dashed lines with +/- the error of the prediction. Include also a dotted blue horizontal line with your answer from (F).

3. Dors et al. (2022, https://ui.adsabs.harvard.edu/abs/2022MNRAS.514.5506D/abstract) estimated the ^{4}He abundances in both Seyfert galaxies and extragalactic star forming (SF) regions. Use the SF results given in their table A3 (https://academic.oup.com/view-large/365429778), to estimate the primordial He

abundance, by performing a linear fit of n(^{4}He)/n(H) vs n(O)/n(H). Notice that you first have to convert the log abundances given in columns 5 (oxygen) and 9 (helium) to the linear scale. **The linear fit must be performed considering both error bars** (in oxygen and helium). Give your resulting primordial He abundance and error bars in:
A) linear scale, n(He)/n(H)
B) log scale, A(He)
C) mass fraction, Y
D) How your primordial A(He) compares with:
D1) the predicted primordial BBN ^{4}He abundance (does it agree within the errors?)
D2) The solar He abundance from Asplund et al. (2021), A(He) = 10.914+/-0.013. If the abundances do not agree within the errors, explain the possible reason for the mismatch.

4) Estimate the primordial Li abundance by performing a linear fit of A(Li) vs n(Fe)/n(H) in metal-poor stars, and extrapolate to n(Fe)/n(H) = 0. Use the iron and lithium abundances below, obtained from Asplund et al. (2006, https://ui.adsabs.harvard.edu/abs/2006ApJ...644..229A/abstract).

How your primordial Li abundance compares with the primordial Li predicted from BBN by Fields et al. (2020)? If the abundances do not agree, give one possible explanation for the mismatch.

Star ,[Fe/H],[O/H],A(Li)
HD3567 ,-1.14,-0.79,2.32
HD19445 ,-2.02,-1.38,2.20
HD59392 ,-1.61,-1.04,2.24
HD102200 ,-1.25,-0.85,2.25
HD106038 ,-1.35,-0.76,2.48
HD140283 ,-2.40,-1.74,2.20
HD160617 ,-1.76,-1.43,2.28
HD213657 ,-1.90,-1.34,2.25
HD298986 ,-1.33,-0.98,2.24
HD338529 ,-2.26,-1.68,2.22
G013-009 ,-2.30,-1.71,2.19
G020-024 ,-1.89,-1.35,2.18
G075-031 ,-1.02,-0.68,2.30
G126-062 ,-1.51,-1.05,2.24
G271-162 ,-2.30,-1.79,2.25
BD+092190 ,-2.66,-2.22,2.10
BD+030740 ,-2.65,-2.06,2.11
BD-133442 ,-2.71,-2.09,2.14
CD-3018140 ,-1.90,-1.28,2.22
CD-331173 ,-2.92,-2.33,2.05
CD-333337 ,-1.31,-0.76,2.24
CD-3514849 ,-2.27,-1.70,2.24
CD-482445 ,-1.93,-1.40,2.19
LP815-43 ,-2.74,-2.20,2.13