New Constraints of Galactic Infall From Deuterium Observations

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Abstract

Local deuterium observations have shown large variations over different lines of sight. However, it has been recently proposed that such variations can be explained by strong depletion of deuterium onto dust grains. Consequently, recent Far Ultraviolet Spectroscopic Explorer (FUSE) deuterium observations represent only a lower bound on the true local deuterium abundance which has thus been estimated to be as high as $\sim 85\%$ of the primordial D abundance, as opposed to previous estimates of $\sim 55\%$. Such high local deuterium abundance could be explained with Galactic infall. Within our analytical model we demonstrate that such hight local D abundance in fact *requires* a *significant* infall. Our constraint comes from the FUSE deuterium observations AND Galactic gas fraction estimates, which, when used in concert, demand infall rate comparable to the star-formation rate. Moreover, our analysis also constrains the fraction of stellar mass that is returned to the ISM to a range $0.1 < R \lesssim 0.4$ which is just marginally consistent with modern initial mass functions. Finally, the requirement of infall is broadly consistent with hierarchical structure formation. Thus, our results offer new qualitative and quantitative ways of placing Galactic evolution in the larger cosmological context.

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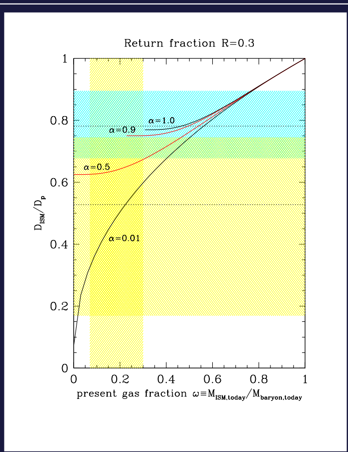
1 Introduction

- Deuterium is only created in the big bang nucleosynthesis (BBN) while all other processes destroy it [1, 2] – its abundance should monotonically decrease after the BBN.
- Measurements of the D abundance in the interstellar medium (ISM) have revealed large variations over different lines of sight, that can be greater than the factor of 3!
- Linsky *et al.*(2006) [3] claim – these local variations are due to efficient D depletion onto dust grains.
- Linsky *et al.*(2006) determine the true ISM deuterium abundance $(D/H)_{\rm ISM+dust} \geq (2.31 \pm 0.24) \times 10^{-5}$ which is almost at the level of the primordial value.
- Need some level of infall of primordial gas in order to explain such high D abundance [4].
- We combine the local D and Galactic gas fraction observations to constrain different infall models.



2 Model

- We construct a model for Galactic evolution with infall and no outflow.
- Adopt infall rate arbitrarily proportional to the star formation rate [5]; baryonic mass of the Galaxy thus increases with time as

$$\dot{M}_{\rm baryon} = \alpha\psi \quad (1)$$

where $\psi(t)$ is the star formation rate, while α is the infall proportionality constant.
- Assume primordial infalling material and complete destruction of D in stars.
- Define the ratio of gas at time t to the initial baryonic mass $M_{\rm baryon,0}$ as $\mu \equiv M_{\rm ISM}(t)/M_{\rm baryon,0}$.
- Find deuterium evolution from its primordial D_p to present day value $D(t)$, as a function of the return fraction R – the fraction of stellar mass that is returned to the ISM in the instantaneous recycling approximation, and α, as

$$\frac{D(t)}{D_p} = \frac{R}{\alpha + R}\left(\frac{\alpha}{R} + \mu^{\frac{\alpha+R}{1-\alpha-R}}\right) \quad (2)$$

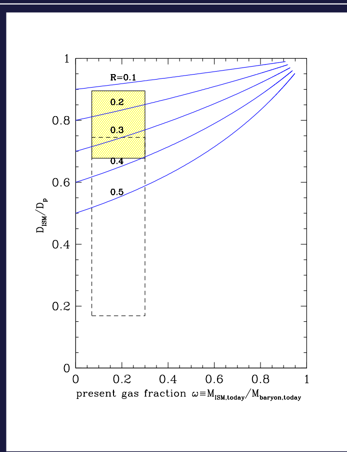
where D is the deuterium mass fraction for a given epoch, while D_p is the primordial deuterium mass fraction.
- Present gas mass fraction defined as $\omega \equiv M_{\rm ISM}(t)/M_{\rm baryon}(t)$, can, in our model, be expressed as

$$\omega(t) \equiv \frac{M_{\rm ISM}}{M_{\rm baryon}} = \frac{1-R-\alpha}{1-R-\alpha\mu(t)}\,\mu(t) \quad (3)$$

- Equations (2) and (3) relate observables D and ω to the model parameters α and μ, which together respectively quantify the current and integrated rates of Galactic infall.
- At late times, D and ω approach *minimum* values and combine to give the limiting curve above which no solutions can be found. We find the limiting curve to be

$$\frac{D_{\rm min}}{D_p} = \frac{1}{1+R(1-\omega)(1-R)} \quad (4)$$

- Equation (4) includes the return fraction R as a parameter – it can be used to discriminate between different IMFs which all directly determine the value of R.



3 Results

- Figure 1 (left) – deuterium mass fraction *vs.* the gas mass fraction (equation 2).
- $R = 0.3$ follows from using the Salpeter IMF [6].
- Shaded horizontal bands – observed D values with (top, cyan) and without (bottom, yellow) accounting for the dust depletion.
- Shaded vertical yellow band – observed range of gas mass fractions $\omega = 0.07 - 0.3$ [7].
- Red curves fall within the observed limits – infall almost comparable to the star formation rate with the infall parameter $0.5 \lesssim \alpha \lesssim 1$.
- Figure 2 (right) – limiting curves above which no solution can be found.
- Overlap ranges between observed D and ω are presented as boxes.
- *Only* return fractions that are allowed are $0.1 < R \lesssim 0.4$.

4 Conclusion

- Local D and gas mass observations *demand* significant infall rate $0.5 \lesssim \alpha \lesssim 1$ of pristine material, consistent with hierarchical assembly of galaxies by accretion.
- Modern IMFs [8] which demand high return fractions $R \sim 0.4$ are just marginally allowed by these observations (right panel).
- Large depletion of deuterium onto dust might have important consequences for D observations at high-redshift systems and its the concordance with the BBN theory.

References

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