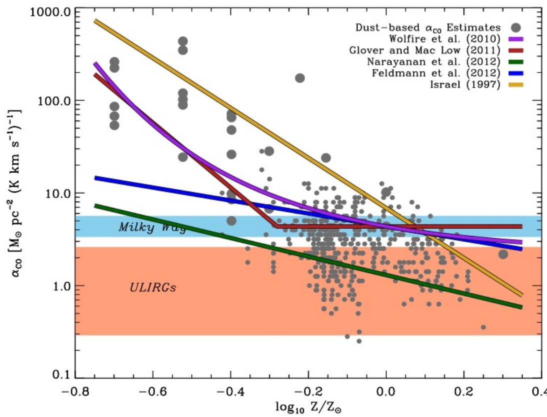
Investigating the evolution of molecular gas in galaxies across cosmic times

Molecular gas is the fuel for star formation and, therefore, understanding the evolution of the content of molecular gas in galaxies across the cosmic epochs is crucial to understand why the star formation rate has evolved in time.

Molecular gas is primarily composed of H2, however this molecule is extremely difficult to trace in the ISM as it is not easily excited in the normal ISM conditions (I can pass you my lecture notes on this), therefore astronomers typically use the second most abundant molecule CO, whose lower rotational transitions are much easier to excite (again in my lecture notes)

However, the problem is how to convert CO flux into Mass of H2, i.e. the (in)famous (and debated) CO-to-H2 conversion factor.
You can see a review in Bolatto et al. 2013
https://ui.adsabs.harvard.edu/abs/2013ARA%26A..51..207B/abstract

This conversion factor is metallicity-dependent. The review above already provides an overview of this issue (e.g. its sect 6 and Fig.9),
but a more recent dependence that we have used in recent works is the following:
equation 4 in
https://iopscience.iop.org/article/10.3847/1538-4357/ab781c/pdf
which is derived from
https://ui.adsabs.harvard.edu/abs/2017MNRAS.470.4750A/abstract



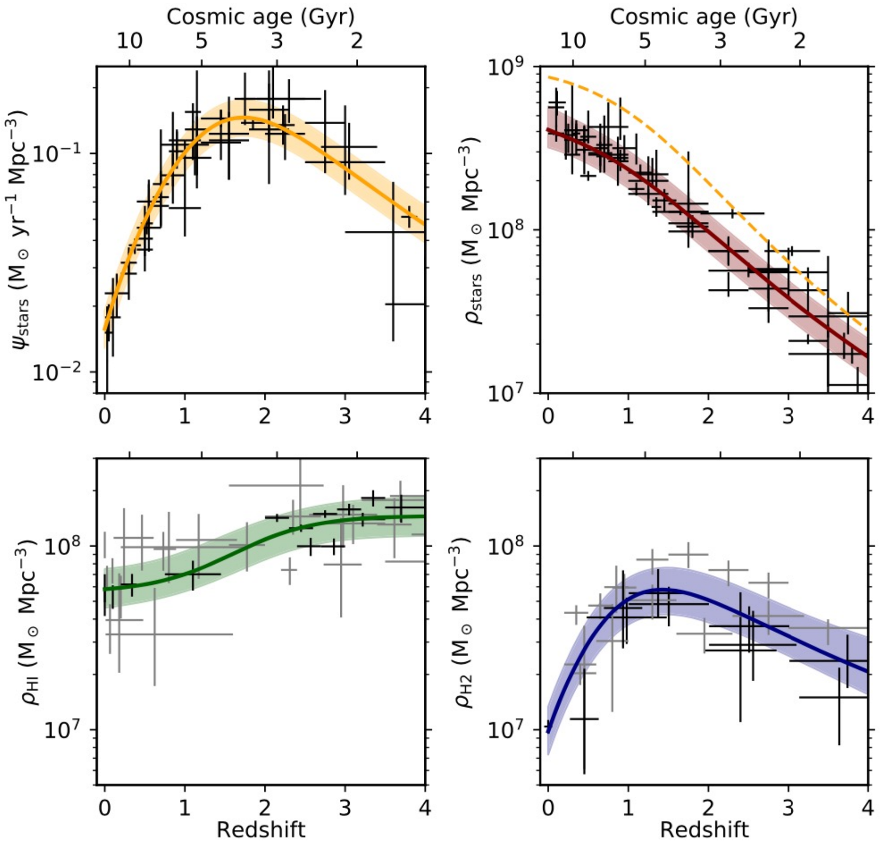
But another possibility to consider is (although theoretical) equation 11
https://ui.adsabs.harvard.edu/abs/2012MNRAS.421.3127N/abstract

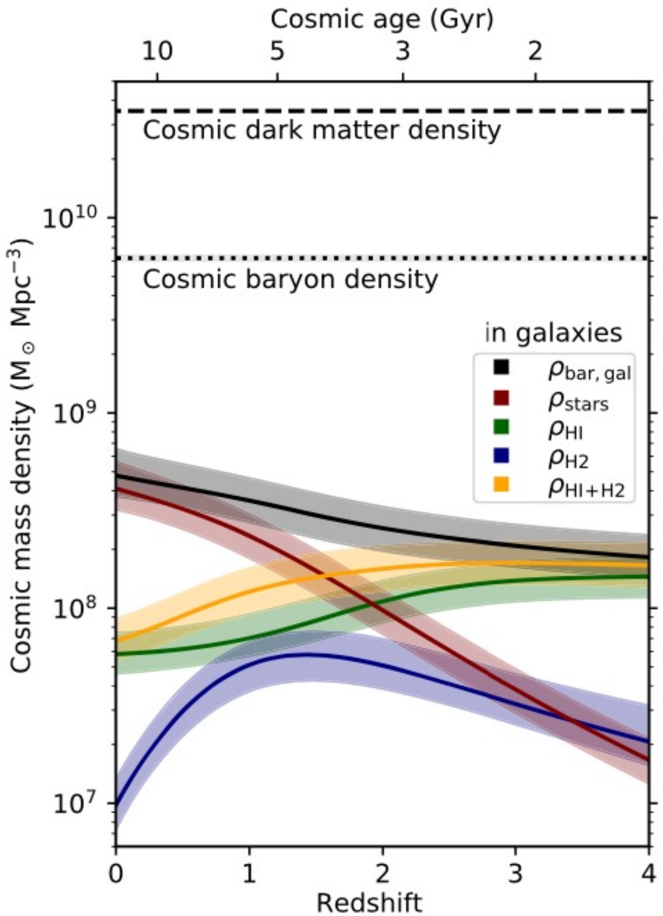
Surveys for CO at high redshift have been extensively performed with ALMA

Probably one of the most extensive of these is the ASPECS Large Programme:
http://www.aspecs.info
which is designed to blindly search for CO emission at high redshift and, by doing so, they claim that their survey is not biased (although I would claim that their survey is biased against low metallicity galaxies).

I think that their most important paper is the following one by Walter+2020 (although at their site you can find their full list of papers)
https://ui.adsabs.harvard.edu/abs/2020ApJ...902..111W/abstract

Their main outcome is the cosmic evolution of H2 in galaxies, compared with the evolution of other quantities (stellar mass, star formation rate and atomic gas, see figures below) from which they infer interesting implications about the need for accretion, about the star formation efficiency etc...

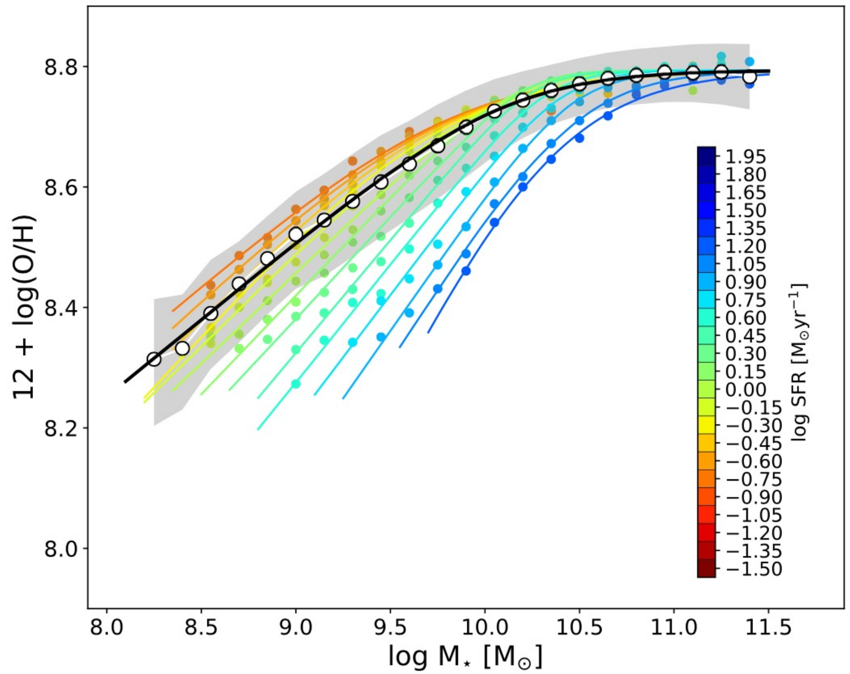




This is not the only CO survey, there are some more which could be considered

They use a standard, fixed conversion factor appropriate for solar metallicity, as they claim that
“The CO-to-H2 conversion factor is the main systematic uncertainty in the analysis.
For the ASPECS measurement, the majority of the molecular gas mass density comes from individually detected galaxies (Decarli et al. 2019). Their metallicities (consistent with solar) and stellar masses (Mstars > 10^{10} Msun) justify the choice of a Galactic conversion factor to determine the molecular gas mass (Boogaard et al. 2019).”

However, that’s not really true, as at the SFR of their galaxies (SFR~10-100 Msun/yr) the Fundametal Metallicity Relation expects a significantly lower metallicity, as indicated in
Mannucci et al. 2010
https://ui.adsabs.harvard.edu/abs/2010MNRAS.408.2115M/abstract
and in Curti et al. 2020
https://ui.adsabs.harvard.edu/abs/2020MNRAS.491..944C/abstract
see figure here



The effect on the molecular gas content can be up to a factor of 4-5

To be seen what would be the global effect on the estimate of total molecular gas mass at each cosmic epoch, but even it was a factor 1.5-2 that would actually be quite significant for the baryon budget and other implications

Outline of the project

Can be developed in multiple steps and we can decide where to stop:

Step 1

- Review the literature on this topic and other surveys and models (I would give a start reading list but searching the literature would also be needed, we have to check that no one has already investigated this aspect)
- Derive the metallicities of the ASPECS galaxies by simply using the FMR and rederiving their CO content by using the metallicity-dependent CO conversion factor (this will require some re-assessment of the scaling relations and metallicity calibrations to make sure that they are all consistent)
- Re-assess the evolution of H2 (and re-derive implications)

Step 2

- Check the metallicities of individual ASPECS galaxies by checking the availability of optical and near-IR spectra (in the ESO archive or in literature)

Step 3: can be one or more of the following

- Step 3a: Apply the same to other CO surveys, and possibly other surveys which use other tracers of molecular gas (e.g. [CI] and dust emission)
- Step 3b: Use the same metallicity-corrected information as above to investigate other aspects, such as the evolution of the star formation efficiency (SFE = SFR/M_{H2}), not only in the ASPECS sample but also in other CO surveys
- Step 3c: Investigate the bias of the ASPECS and other CO surveys in missing gas rich galaxies at low metallicities because of the strong metallicity dependence of the conversion factor