Exercises — 8

Stellar feedback and the evolution of the gas content in the GAEA SAM:

How can strong stellar-driven outflows affect

1. the evolution of the cold gas fractions vs stellar mass over cosmic time?
2. the evolution of the mass-metallicity relation over cosmic time?

How does this compare to observations. Explain your results.

Helpful instructions:

- You'll get galaxy catalogues at z=0,1,2 from the GAEA model, each of them adopting a strong and a weak stellar fb model; they have the following format:

M_halo, M_stellar, M_coldgas, M_Cgas, M_Ogas, M_Fegas, M_rest, SFR

- All masses are in code units (1e10/h), SFR in Msolar/yr; Select only galaxies with M_stellar > 9. M_coldgas > 0, and log(sSFR) > -11 (no emission lines otherwise!)
- Plot the median cold gas fractions $\langle M_{cold}/(M_{cold}+M_{stellar})\rangle$ as a function of galaxy stellar mass at z=0, 1, 2 and compare to observations (e.g. Peeples+11, Popping+15)
- Plot the mean oxygen gas-phase metallicities <12+log(O/H)> as a function of galaxy stellar mass at z=0,1,2, and compare to observations (e.g. Maiolino+08, Zahid+14)
- Remember that gas metallicity in observations as commonly given in Oxygen abundances in units of 12+log(O/H), i.e. you need to convert mass abundances in number density abundances!

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Information for exercise:

- Galaxy catalogues are constructed with the new *GAEA semi-analytic model* *(Hirschmann+16)*
- GAEA was run over merger trees from the famous *Millennium simulation* *(Springel+05)*, having a box length of 500 Mpc
- Your GAEA catalogues include only 1/10 of the original volume
- WMAP1 cosmology is adopted (main difference to modern cosmological model is the lower sigma_8)
- “Strong feedback” catalogues correspond to a run adopting a strong stellar feedback model based on hydro-simulations
- “Weak feedback” catalogues correspond to a run adopting the “fiducial”, energy-driven wind model

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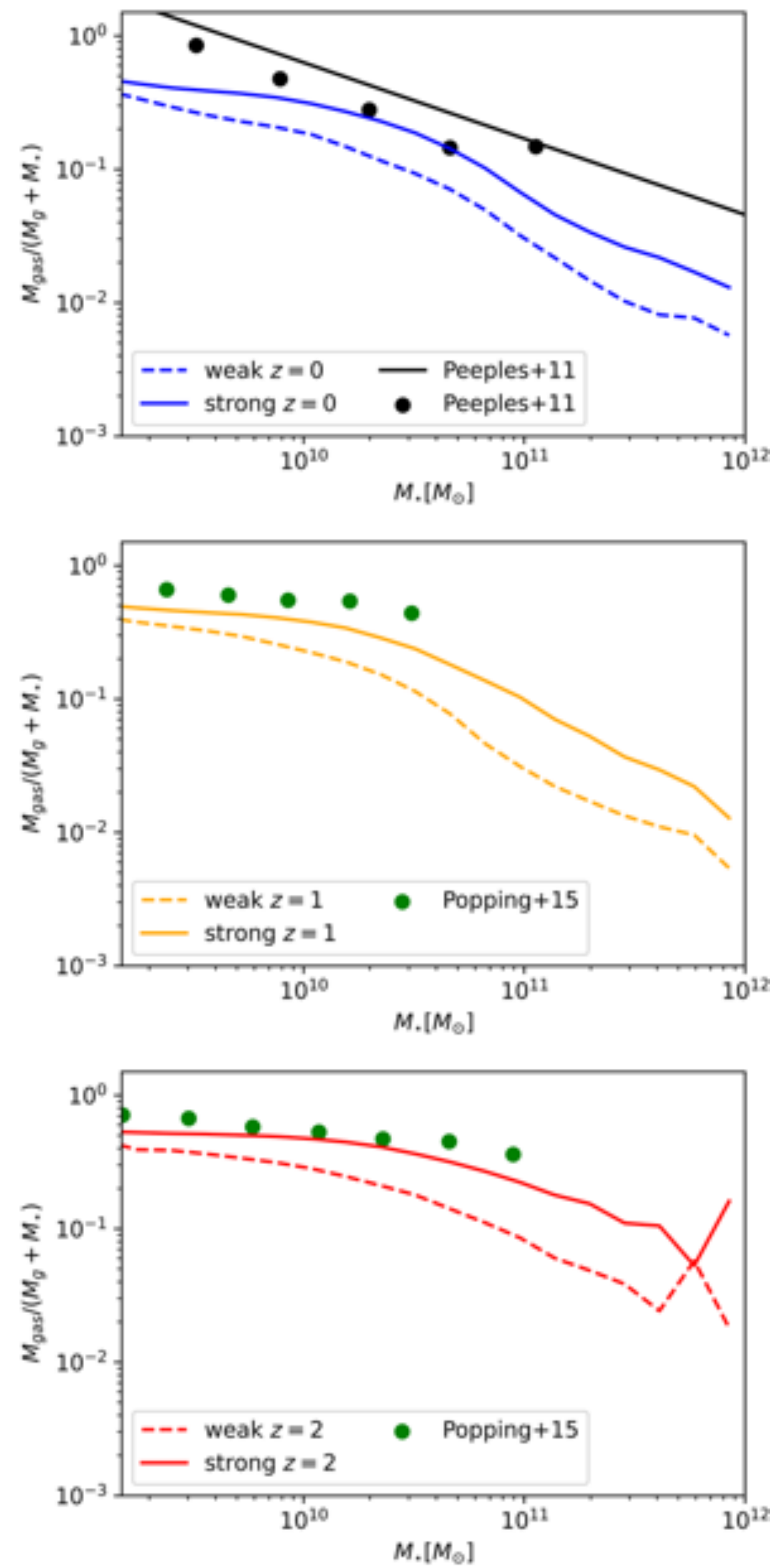
1. Evolution of the cold gas fractions vs stellar mass

As a result of gas consumption via star formation (and AGN feedback in massive galaxies), the fraction of cold gas generally decreases at a given mass from high to low redshift.

Also irrespective of the stellar feedback scheme, there is fractionally more cold gas on low-mass galaxies (because of more previous SF and AGN fb in massive galaxies)

Strong stellar feedback leads to higher cold gas fractions at a given stellar mass at z~2 and below — more consistent with observed trends, even if at z=0, at the lowest and highest masses, the cold gas mass is still slightly under-predicted compared to observations.

The increased cold gas fractions in the strong feedback case is because the model for strong stellar-driven outflows expels a lot of gas out of the galaxy at at high redshift (particularly at z>3), which is then re-accreted back onto the galaxy at later times ("galactic fountains").



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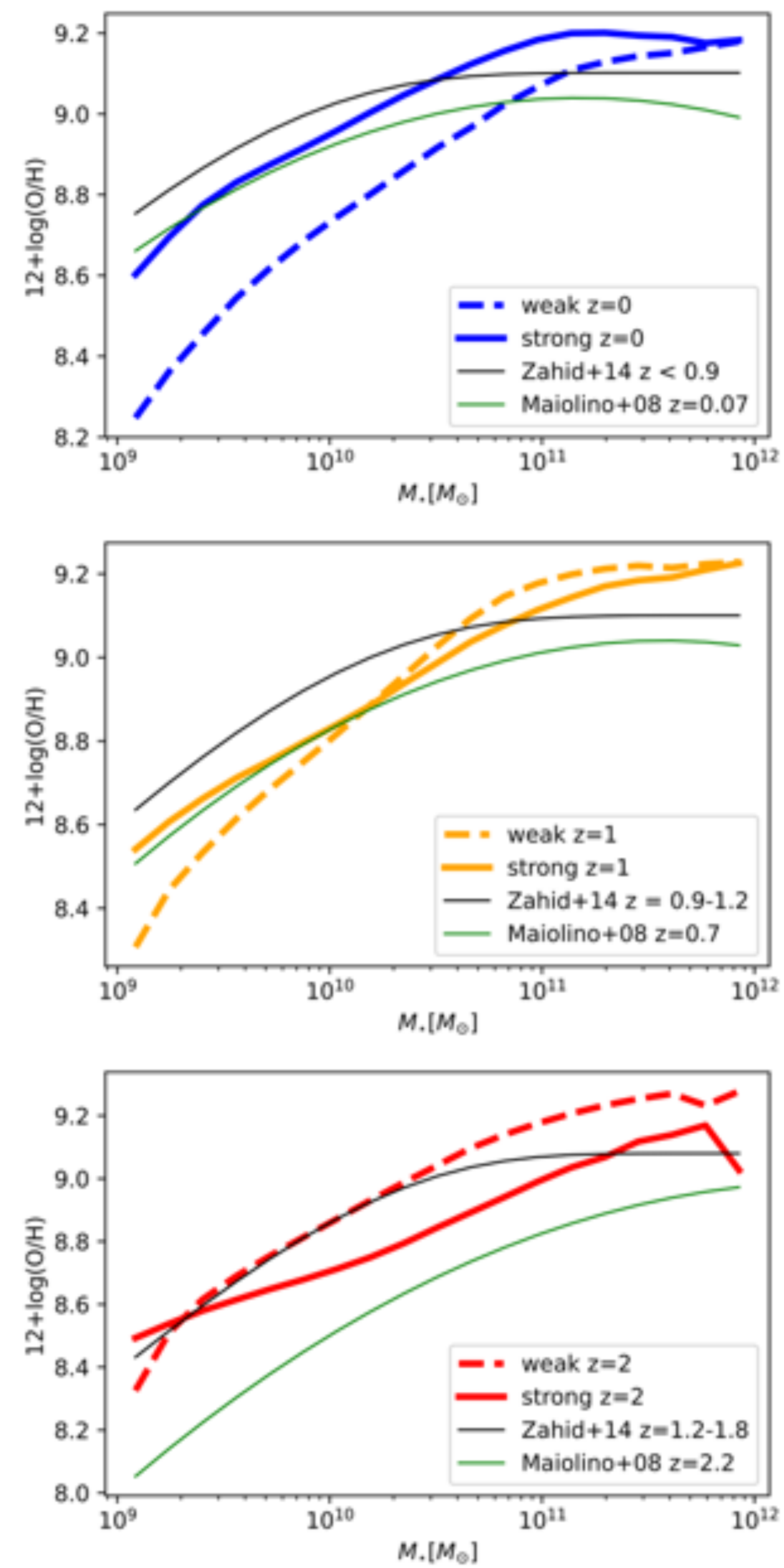
2. Evolution of the mass-metallicity relation over cosmic time

In general, gas metallicity and mass correlate, as low-mass galaxies had less SF and therefore less SN explosions enriching the gas with metals. Together with more metal-rich outflows and metal-poor gas inflows, low-mass galaxies have, overall, a lower gas metallicity.

For strong feedback, the metallicity increases at a given galaxy stellar mass from high to low redshift, as more and more gas is chemically processed by repeated stellar cycles (combined with less outflows, and inflows of more pre-enriched gas) towards later times.

In other words, strong stellar-driven outflows delay early star formation towards later times. This means that at z=2, there have been less stars formed than with the weak feedback scheme and therefore less metals have been synthesized and injected into the ISM. This evolution is qualitatively in agreement with Zahid+14/Maiolino+08, but there is also a large scatter in the observational estimates of gas metallicity (due to assumptions when deriving Z from emission-line ratios).

Under the weak feedback scheme, the gas metallicity instead decreases at given stellar mass from high to low redshift, likely due to accretion of metal-poor (not previously expelled, and thus, not pre-enriched) gas with no additional star formation. This trend is qualitatively inconsistent with observations!



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READING SUGGESTIONS — NOT PART OF THE EXAM!!!

- Baugh (2006) — Review
- Somerville et al. (2008) — Description of Santa Cruz SAM
- Henriques et al. (2015) — Munich SAM with MCMC approach
- Hirschmann et al. (2016) — GAEA SAM, Effect of stellar feedback

One of the most influential studies using the SAM approach:

- Croton et al. 2006 "The many lives of active galactic nuclei: cooling flows, black holes and the luminosities and colours of galaxies"
    - Which solution is proposed for the "over-cooling" problem in galaxy formation?
    - Which are the consequences for other galaxy properties?