Star Formation in Low-Metallicity Dwarf Galaxies

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Importance of low metallicity galaxies

Low metallicity galaxies represent two different frontiers in studies of galaxy evolution — local, low mass dwarf galaxies and galaxies at high redshift (z > 6).

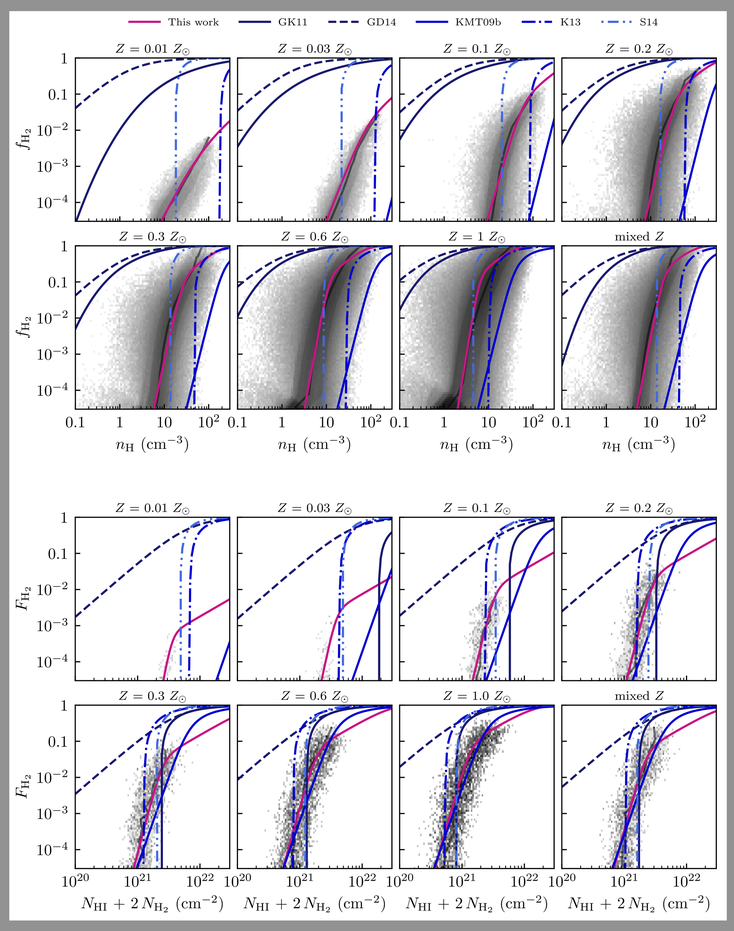
Due to chemical differences, some physical prescriptions that are calibrated on more metal-rich galaxies will not apply properly to this regime, either returning inaccurate results or making assumptions that introduce errors.

HI-H_2 transition models, for instance, will generally overpredict the abundance of H2 in low metallicity gas. We expect that with decreasing metallicity, the proportion of H_2 in the gas also drops (Krumholz 2012), as molecular hydrogen forms on timescales comparable to the lifetime of star forming regions for Z < 0.1 $Z_\odot$.

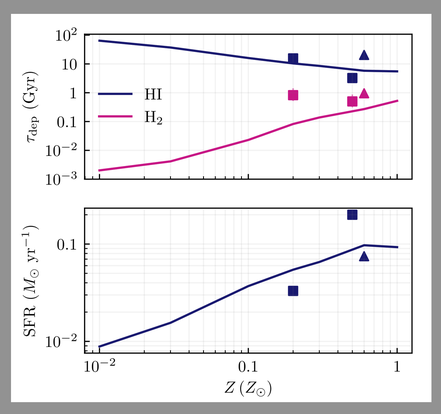
Calibrating on state-of-the-art simulations

We use a suite of state-of-the-art isolated disk simulations (Semenov et al. 2021) that reproduce detailed star formation properties observed in local dwarf galaxies (i.e., the molecular KS relation and the tuning fork; Semenov et al. 2019, 2021). These simulations are high resolution (~10 pc) and realistic, with star formation and feedback not based on H2, and self-consistent modeling of hydrodynamics and UV radiative transfer. We run this simulation for seven different fixed metallicities between 0.01 and 1 $Z_\odot$ in addition to the fiducial mixed metallicity run. Aside from disallowing metallicity evolution in our fixed Z runs, all other physics is kept the same.

Our accurate models for the fraction of molecular hydrogen ($f_{H2} = \rho_{H2}/(\rho_{HI} + \rho_{H2})$; $F_{H2} = \Sigma_{H2}/(\Sigma_{HI} + \Sigma_{H2})$) return masses accurate to within a factor of 1.25 (1.5 in the projected case) across the tested range of properties (0.01 and 1 $Z_\odot$, ~5 orders of magnitude in UV field strength, and for the smoothed projected model, scales between 10 and 1000 pc). These models can be used with high resolution galaxy simulations or cosmological simulations and semi-analytic models.

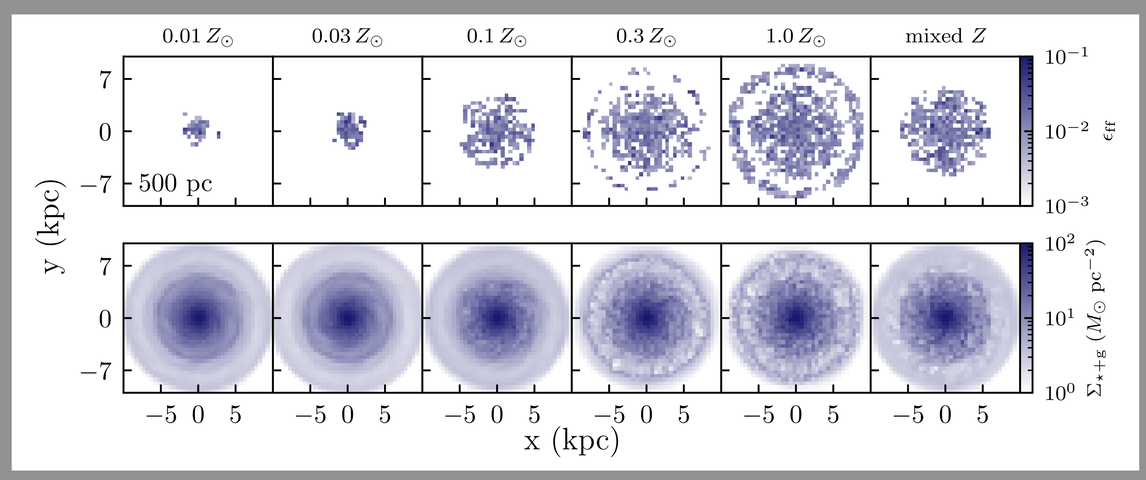


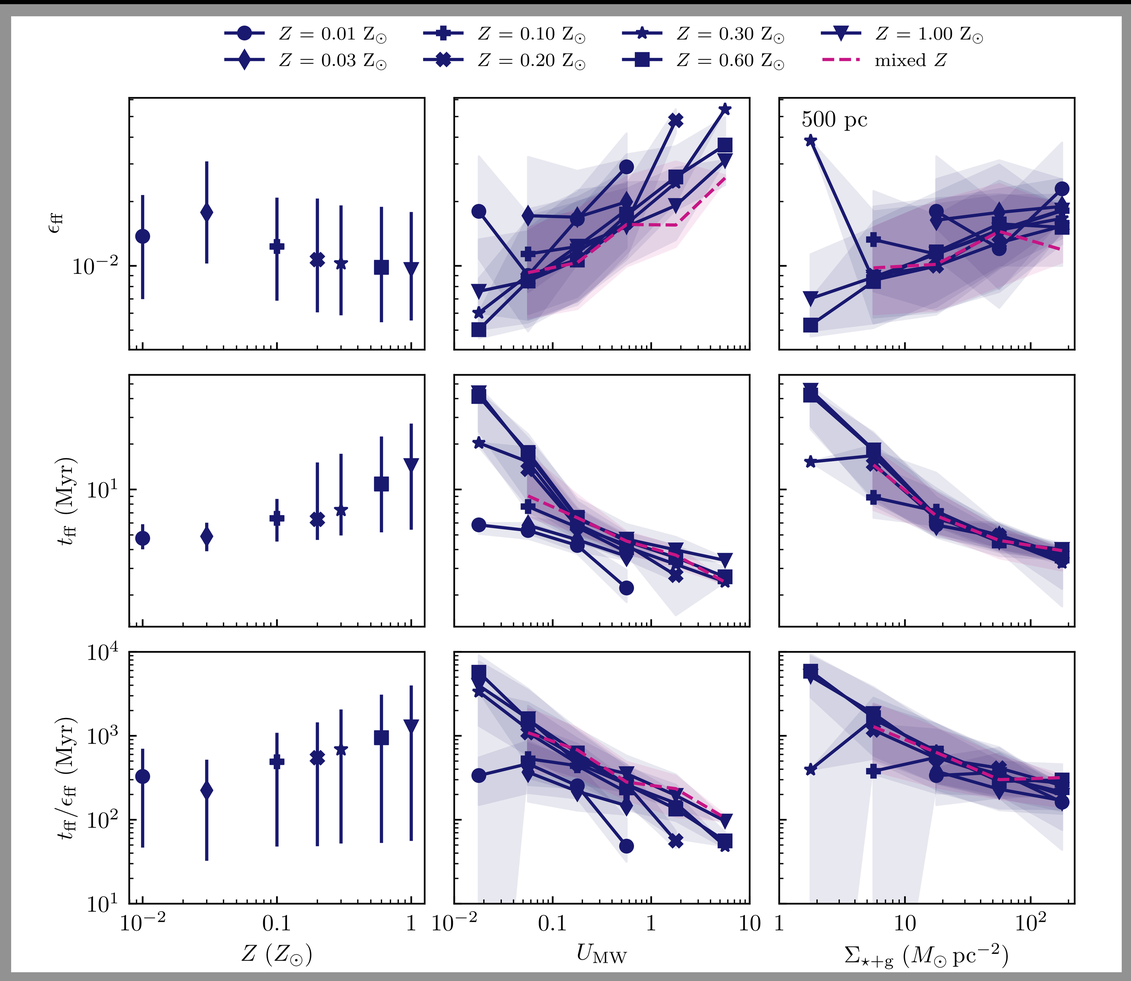
Our simple prescriptions (pink) for the H_2 fraction outperform existing models in the literature (shades of blue). At the top, we show our grid cell-by-grid cell volumetric model overplotted on simulation data; at the bottom, we show the same for the smoothed projected model on 100 pc scales. From Polzin et al. (2024a; arXiv:2310.10712).



While the average H_2 depletion time (top) changes by a factor of ~200 over two orders of magnitude in metallicity, the SFR changes by a factor of only ~10, suggesting that star formation is decoupled from H2 abundance at low Z. From Polzin et al. (2024a; arXiv:2310.10712).

Instead of using H_2 abundance as a (flawed) star formation indicator, it is best to model star formation directly based on relevant tracers, such as ε_{ff}.





New paper! See Polzin et al. (2024b; coming soon to arXiv!)

We have reproduced the uniformity of star formation efficiency per free fall time (ε_{ff}) with local galaxy properties (metallicity, UV field strength, surface density) with *no fine tuning*. This uniformity comes from turbulence-driven self-regulation of star formation in the interstellar medium.

If we ignore the role of turbulence in setting the star formation efficiency, we find a strong metallicity and surface density dependence.