GAS FRACTION AND DEPLETION TIME INFORMING STELLAR FORMATION

NO CHANGE IN GLOBAL STAR FORMATION PROCESS OUT TO Z>3

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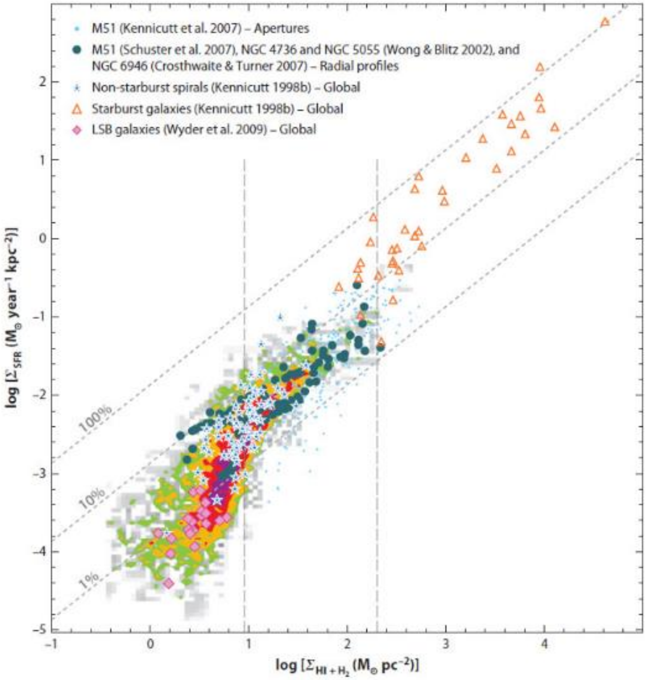
GAS FRACTION/DEPLETION TIME TO STAR FORMATION PROCESS CORRELATION

- 2-Star Formation Mode:
  - (i) Kennicut-Schmidt Relation: Universal log-linear relation between Stellar Formation Rate (SFR) and gas mass (M_gas).
  - (ii) Redshift evolution of specific SFR (sSFR) of MS galaxies.
- Gas Fraction = μ_gas = (M_gas)/(M_stell)
  - M_gas include cold neutral molecular and atomic gas.
- Depletion Time = t_depl = (M_gas)/(SFR) [Gyr]
  - SFR determined from MagPhys.



SFR to M_gas relation (Kennicutt-Schmidt) [Fig 1]

Schinnerer et al. (2016)

- Data Specifications
  - ALMA detections of rest-frame ~300μm continuum.
  - Observed normal star forming massive MS galaxies.
  - z ~= 3.2 in COSMOS field
  - "[…] we assume a cosmology with $H_0 = 70$, $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$ (for ease of comparison to other work in the literature) and use a Chabrier initial mass function for the stellar mass and SFR determination."
  - After thinning and cross-referencing other surveys for flux, star formation activity, and presence of AGN there were 45 sources that met specifications.
- Aim to determine main mode of star formation beyond the peak epoch (z>2).
  - Recent studies extending to z=4 and z=4.4 (Bethermin et al. (2015) and Scoville et al. (2016)) suggest MS galaxy star formation proceeds similar to low redshift galaxies.

DETERMINING GAS MASS (COLD NEUTRAL)

- Direct cold molecular/atomic observations using CO emissions require long integration times with ALMA.
- Instead use large bandwidth of continuum detections available and derive gas mass using the cold dust mass and neutral gas mass relation (Hildebrand (1983)).
  - Re-evaluation by Groves et al. (2015) accounted for metallicity, dust temperatures, and stellar mass.
  - Following conversion using cold dust luminosity was linearly interpolated from Groves et al. (2015) to match rest-frame wavelengths at ALMA.

$$\log_{10}(\mathrm{M_{gas}}(\mathrm{M_\odot})) = (1.57 - 8 \times 10^{-4}\Delta\lambda) + (0.86 + 6 \times 10^{-4}\Delta\lambda) \times \log_{10}(\nu \mathrm{L_{nu}}(\mathrm{L_\odot})) \quad (1)$$

Schinnerer et al. (2016)

$$\Delta\lambda = \lambda_{\mathrm{ALMA,restframe}} - 250\,\mu\mathrm{m}$$

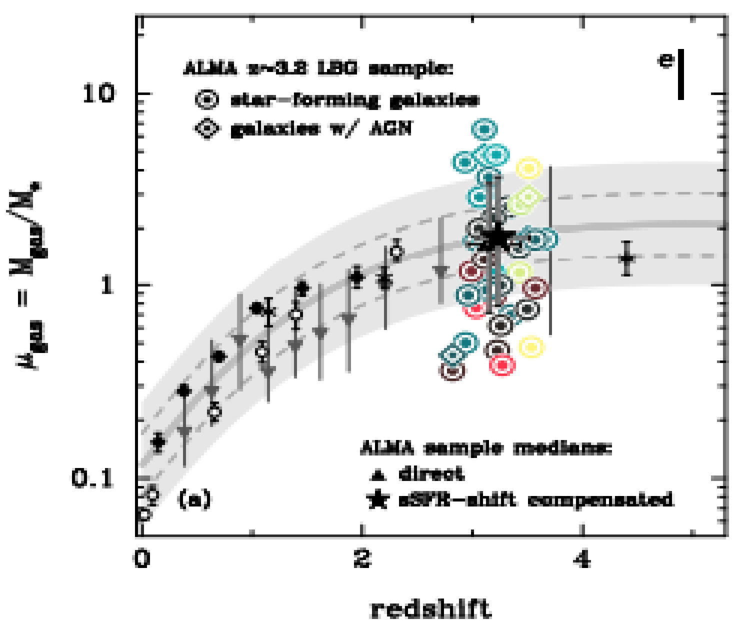
$$\nu \mathrm{L}_\nu = \nu_{\mathrm{obs}} \times \mathrm{S}_{\nu,\mathrm{obs}} \times 4\pi \times \mathrm{D_L^2}.$$

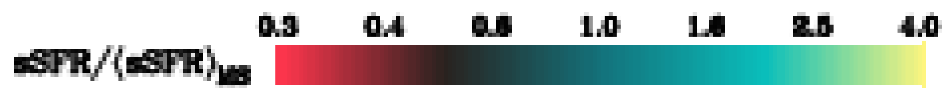
DEPLETION TIME AND MAGPHYS

- The amount of cold neutral gas divided by the SFR yields the depletion time, essentially the time it would take for all existing M_gas to form into stars at the observed rate.
- MagPhys is a program written for simple Spectral Energy Distribution (SED) analysis.
  - Using observed redshift and photometric band data MagPhys assembles library of stochastic models for SED.
  - Using the chi2 value for the observed galaxies' SED's and the model's SED's it builds likelihood distributions for each parameter marginalized.
  - Optimized for constraints on parameters related to star forming activity and dust content (SFR, M_stell, Temp_dust, etc.).
  - Returns maximized likelihood distribution for SFR.
  - Helpful examples from E .da Cunha et al. (2011) [http://www.ifa.hawaii.edu/gradprog/ASTR736F15/SEDs/daCunha+12_MAGPHYS.pdf]

GAS FRACTION RESULTS

- For the gas fraction determined from our gas mass derivation it can be seen that when plotted against the redshifts over which it was determined (fig. 2) there is a flattening that occurs at z~3. There is also a dependence on sSFR that is independent of the redshift we're at, and can be seen in fig. 2. Both results imply that our massive star forming MS galaxies do in fact follow the SFR and gas mass relation determined for lower redshift galaxies.



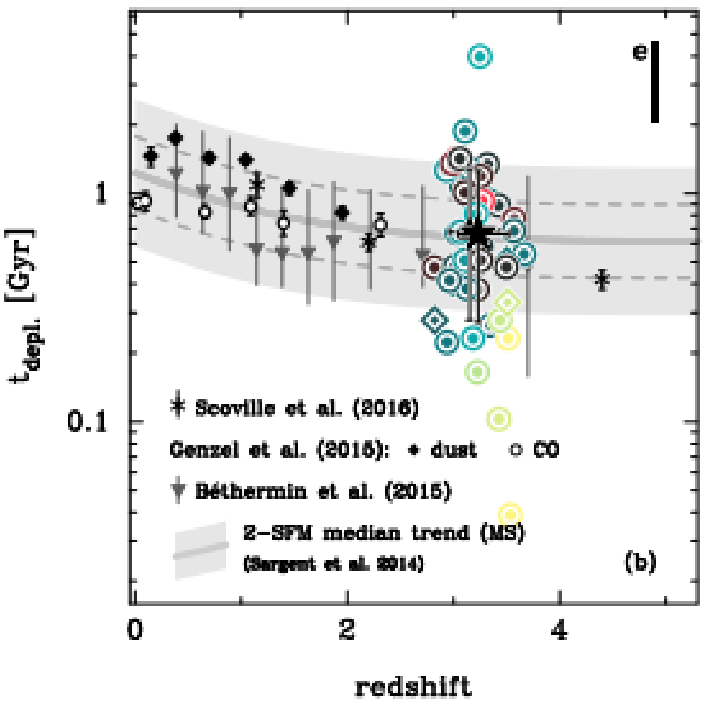


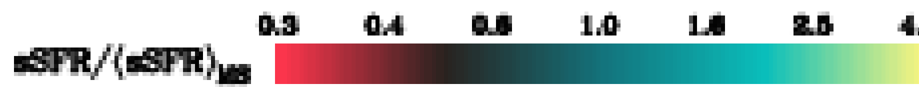
- The gray line and area represent the predicted values for the 2-SFM model for MS galaxies and the associated scatters. Given the error bar "e" the determined gas fractions match the predictions with scatter.

[Fig. 2]
Schinnerer et al. (2016)

DEPLETION TIME RESULTS

- The t_depl. of our z=3.2 sources was calculated to have a mean of t_depl. = 0.68 [Gyr] and when compensated for location on the MS a value of t_depl. = 0.67 [Gyr]. These values and their associated trends match the 2-SFM model trends as seen in fig. 3.



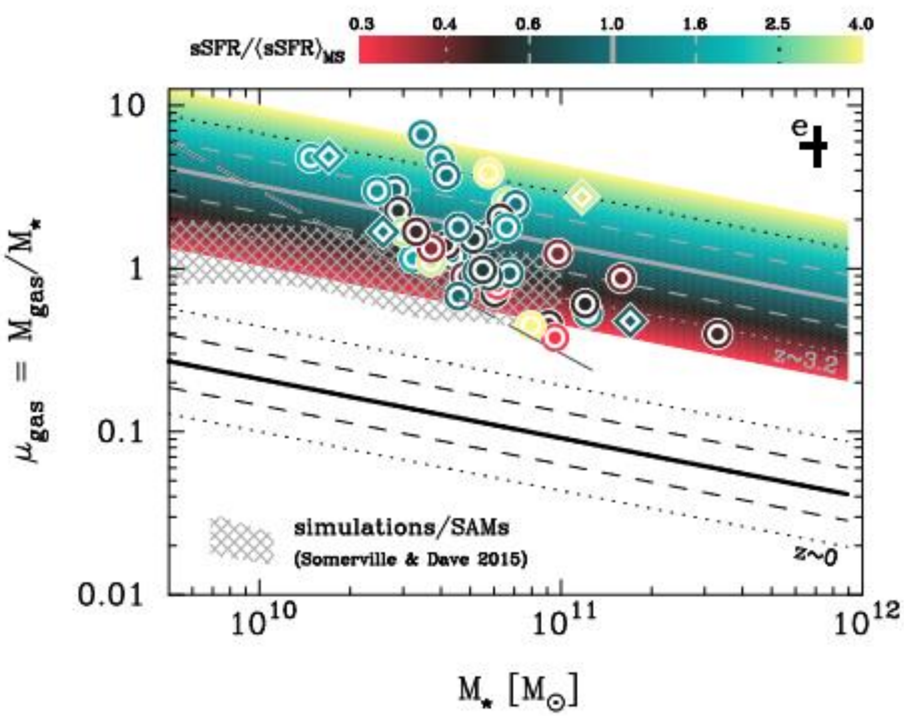


- Again the gray line and area represent the 2-SFM model's predictions for MS galaxies derived from small redshift observations. The outliers in this case may be explained by being AGN host candidates (based on their selection parameters). This influences their SEDs used in MagPhys and thus the derived SFR.

[Fig. 3]
Schinnerer et al. (2016)

STELLAR MASS TRENDS

- For the gas fraction we find an anti-correlation with stellar mass as shown below in fig. 4. The gray dashed line represents the completeness limit dictated by a 3 sigma flux limit imposed on our sample set. The color spectrum behind the data is the 2-SFM model predictions. While in general the data agreed with the model in the sense that the higher sSFR values lie above the average trendline (the solid gray line) and the low values lie below, the data does differ in color from the background. This means that there is non-negligible scatter in the SFR vs. M_gas relation we determined.



[Fig. 4]
Schinnerer et al. (2016)

GLOBAL STAR FORMATION PROCESS

- These results of flattening in redshift evolution models and a dependence of specific Stellar Formation Rate for both the gas fraction and the depletion time suggest that at redshifts $z>3$ for massive MS galaxies the star formation process remains largely the same compared to that which was determined for local galaxies at low redshifts.
- They also follow the Kennicutt-Schmidt relation meaning that there is a correlation between the molecular and atomic gas mass and star formation activity of these higher redshift galaxies.
- Methods used here account for atomic and molecular cold gas, whereas most simply account for molecular. However, agreement between the results here and the results of other methods published as well as an expected low atomic gas content at $z>3$ implies that atomic gas inclusion does not introduce any large uncertainties.

QUESTIONS

- What new surveys would be required to extend this hypothesis to less massive MS galaxies? What are the flux limits on this survey?
- Is the use of 45 sources robust enough? Did the exclusion of galaxies with possible contributions from AGN unfairly skew the result?

REFERENCES

(1) Schinnerer et al. (2016)

(2) Annual Review Astronomy and Astrophysics (https://ned.ipac.caltech.edu/level5/March15/Kennicutt/Kennicutt6.html)

(3) Bethermin et al. (2015)

(4) Scoville et al. (2016)

(5) Hildebrand, R. H. 1983, Quarterly Journal of the Royal Astronomical Society

(6) Groves et al. (2015)

(7) from E .da Cunha et al. (2011) (http://www.ifa.hawaii.edu/gradprog/ASTR736F15/SEDs/daCunha+12_MAGPHYS.pdf)

(8) MagPhys (http://www.iap.fr/magphys/magphys/MAGPHYS.html)