Sub-millimeter Flux as Probe for Molecular Mass in High-z Galaxies

Lichen Liang, Robert Feldmann, and the FIRE team
Institute for Computational Science, University of Zurich

Universität Zürich[UZH]

Introduction

Molecular gas is a key component of the interstellar medium (ISM) affecting the physics of galaxy and star formation. Traditionally, CO line emission has been used to measure molecular gas masses. In recent years, there have been emerging effort to use Rayleigh-Jeans (RJ) tail of dust thermal emission to probe the dust and ISM mass in high-z galaxies, as an alternative to the CO method. This approach is time-efficient and powerful for observations of high-z objects owing to the "negative K-correction" effect.

We apply 3D radiative transfer (RT) modelling to a set of cosmological zoom-in galaxies from the MassiveFIRE sample to reproduce the sub-mm flux of high-z galaxies and to compare our results with the recent observational data. The high fidelity and resolution of our simulations allows us to resolve the complex gas and dust geometry in the ISM, on the scales of tens of parsecs.

From Sub-mm Flux to Dust Mass

The dust continuum is typically optically thin at sub-mm and assembles a "modified blackbody" spectra. The flux density is expected to follow the scaling (Scoville et al. 2016)

$$S_\nu \propto \kappa_D(\nu) T_D \nu^2 \frac{M_D}{d_L^2},$$

where k_D is the opacity of dust grain, T_D is the mass-weighted temperature, M_D is the total dust mass and d_L is the luminosity distance from the galaxy. Therefore, M_D can be estimated by measuring the sub-mm flux density. M_{ISM} can subsequently be derived with the observationally-constrained dust-to-gas ratio (typically ~ 1/100 in massive galaxies).

Data and Methods

Our galaxy sample is extracted from the cosmological zoom-in suite MassiveFIRE, part of the Feedback In Realistic Environments (FIRE) project (Hopkins et al. 2014). These simulations explicitly include various forms of stellar feedback, resulting in galaxies in reasonable agreement with observations.

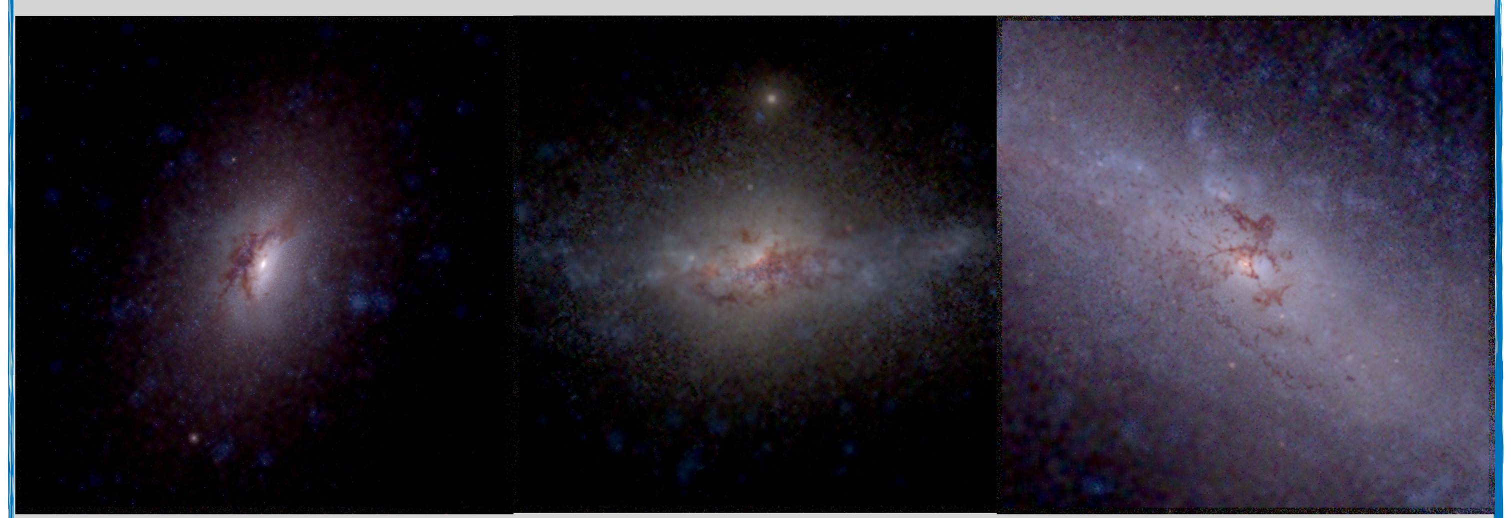

Fig.1 The UVJ images of three selected galaxies at z=2 in our sample, with the effects of dust scattering and absorption included.

We use the RT code SKIRT to post-process the selected MassiveFIRE galaxies and produce the complete (continuum) spectral energy distribution (SED) from UV to sub-mm wavelengths. The RT modelling includes both scattering and absorption processes. We assume a constant dust-to-metal mass ratio in the ISM, and the dust grain size function from Weingartner & Draine 2001. The PDR models are constrained by recent observations of FIR colours of SMGs.

Results

We produce the $L_{850\mu m}$ / M_{H2} of the selected high-z galaxies in our simulations and compare it with the recent observational data compiled by Scoville et al. 2016. At z = 2, our sample includes 2 SMGs and over 10 faint SMGs (S_{850} = 0.1 ~ 1 mJy). The brightest system has stellar mass $M_* \sim 5 \times 10^{11}$ M⊙ and a SFR ~ 350 M⊙ yr^{-1}.

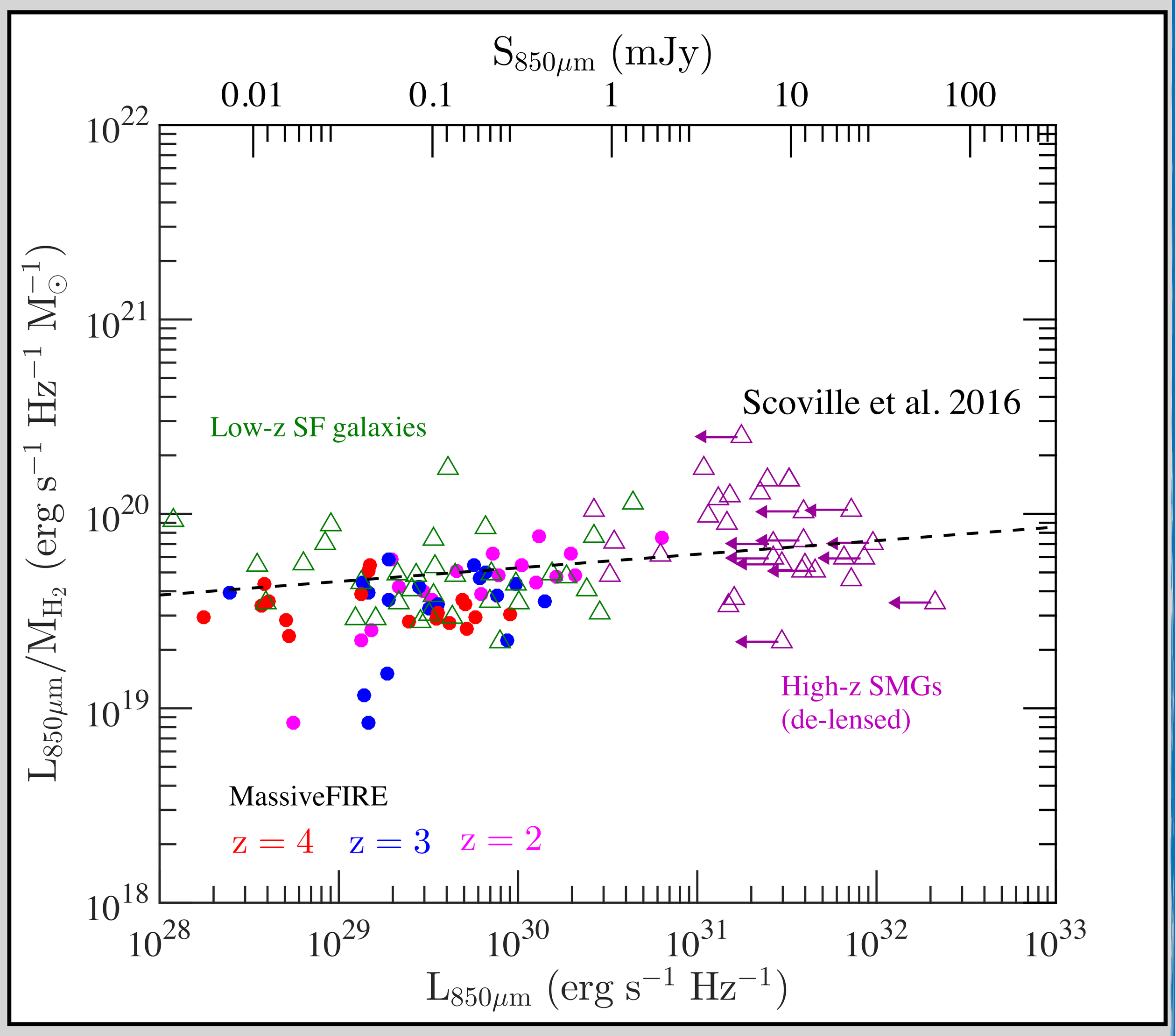

Fig.2 $L_{850\mu m}$ / M_{H2} against $L_{850\mu m}$. The observed data of low-z ULIRGs and star-forming galaxies are shown as green triangles while the z=2 SMGs are shown as magenta triangles. The $L_{850\mu m}$ of the SMGs has been corrected by their reported magnification factor. Those with no reported factor are marked with left arrows. The filled red, blue and magenta circles show the results of the simulated sample at z=4, z=3 and z=2, respectively.

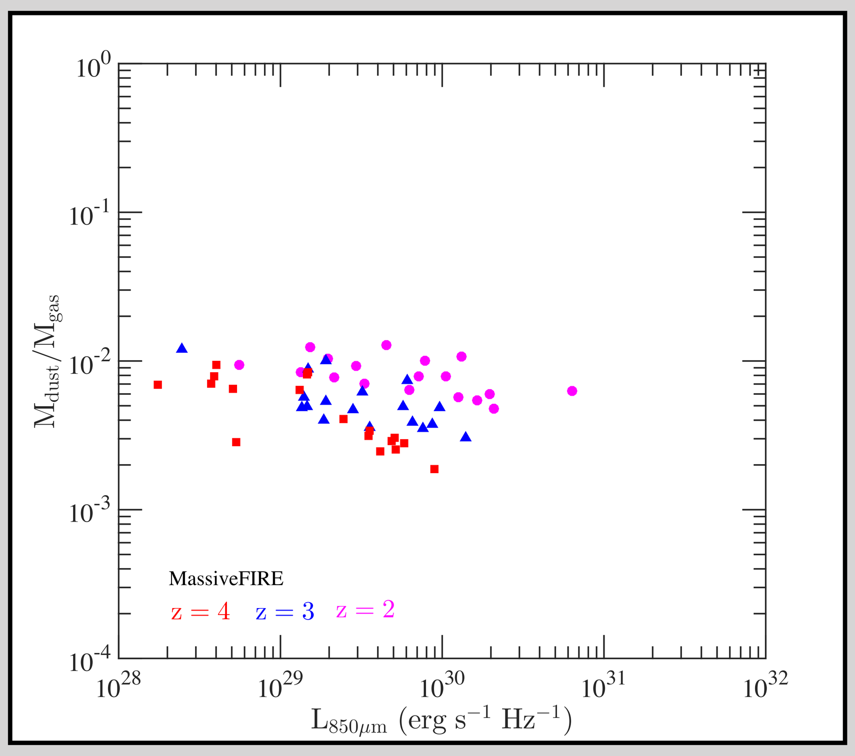

Fig.3 Dust-to-molecular mass ratio against $L_{850\mu m}$ of the selected galaxies at z = 2 (magenta), z = 3 (blue) and z = 4 (red) from the MassiveFIRE simulations.

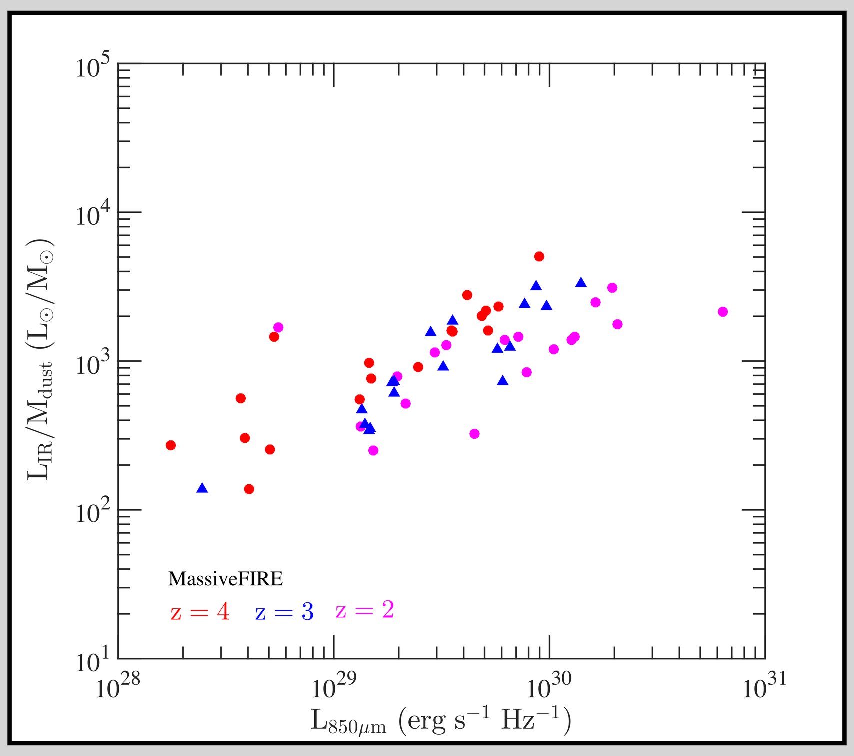

Fig.4 L_{IR} / M_{dust} ratio against $L_{850\mu m}$ of the selected galaxies at z = 2 (magenta), z = 3 (blue) and z = 4 (red) from the MassiveFIRE simulations.

Main Findings:

- In general, the simulated data of the brightest z = 2 galaxies in our sample is in good agreement with the observational data of the SMGs. The scaling of $L_{850\mu m}$ / M_{H2} to $L_{850\mu m}$ extends to fainter end and shows only mild redshift evolution from z = 4 to z = 2. These regimes can be probed by future observations with ALMA.
- The scatter of $L_{850\mu m}$ / M_{H2} in our simulated galaxies appears to be smaller than the observational data. We find that this scatter is largely driven by the variance of the dust-to-gas (H_2) ratio in the simulations (see Fig. 3).
- The L_{IR} / M_{dust} ratio, a proxy for the dust temperature, increases with redshift in our simulations, which is consistent with recent observations (see Fig. 4).

Explanation:

We show that the dust-to-H_2 ratio declines with redshift. This reflects that galaxies at higher redshift are more H_2-rich while their ISM is poorer in metals (dust). The dust temperature, however, increases with redshift in our simulations. The evolution of T_{dust} and dust-to-H_2 mass ratio offset each other, leading to only a weak evolution of the $L_{850\mu m}$ / M_{H2} ratio across the redshift range of interest.

Conclusions

- The FIRE physics module predicts galaxies with sub-mm properties in agreement with observations.
- The simulations predict a relatively small intrinsic scatter in the $L_{850\mu m}$ / M_{H2} ratio.
- The simulations reproduce the observed trend that dust temperature increases with IR luminosity and with redshift.
- The $L_{850\mu m}$ - to - M_{H2} ratio shows a very mild evolution with redshift from z = 4 to z = 2 and the scaling extends to the faint end and over two orders of magnitude of luminosity in our simulations.

References

Feldmann R., Hopkins P. F., Quataert E., Faucher-Giguere C.-A., Keres D., 2016, MNRAS, 458, L14

Feldmann R., Quataert E., Hopkins P. F., Faucher-Giguere C.-A., Keres D., 2017, MNRAS, 470, 1050

Hopkins P. F., Keres D., Onorbe J., Faucher-Giguere C.-A., Quataert E., Murray N., Bullock J. S., 2014, MNRAS, 445, 581

Scoville N., et al., 2014, ApJ, 783, 84

Scoville N., et al., 2016, ApJ, 820, 83

Contact

Lichen Liang
lliang@physik.uzh.ch