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The ISM properties of massive dusty obscured during the reionization

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Abstract. In this work we investigate the ISM properties of dusty obscured galaxies during their first billion year evolution. We used the chemodynamic model from Friaça & Terlevich (1998) to simulate, in galactic scale, the hydrodynamic and chemical evolution of the stellar mass and dust. We take into account the grain growth/depletion in the ISM both by accretion and destruction in SNe events. We couple to the model a radiative transfer interface to calculate the IR SED, based on Bruzal & Charlot (2003) spectro-photometric library. We find that our model takes about 1.5 Gyr to reach the A1689-zD1 SFR, 0.03 Gyr the M_*, 0.1 Gyr to M_{dust}, and 0.1 Gyr the L_{IR}. Our analysis can be employed to constrain the time scale for the formation of the first galaxies.

Resumo. Neste trabalho foram investigadas as propriedades do meio interestelar de galáxias obscurecidas por poeira durante os primeiros bilhões de anos de sua evolução. Para tanto, foi usado o modelo quimiodinâmico de evolução de galáxias de Friaça & Terlevich (1998) para simular em escala galáctica a evolução hidrodinâmica, química, da massa estelar e da de poeira. A interação da poeira no meio interestelar (por acréscimo e choque de supernovas) também foi considerada. Acoplado ao modelo está uma interface de transferência radiativa, que, com a biblioteca espectro-fotométrica de Bruzal & Charlot (2003), para calcular a SED resultante no infravermelho. Foram calculados a massa estelar, a massa de poeira, a taxa de formação estelar e a SED para uma galáxia análoga a A1689-zD1 em $z \sim 7.5$. No modelo, a galáxia leva aproximadamente 1.5 Ga para a alcançar a SFR, M_{dust} e L_{IR} de A1689-zD1 em, respectivamente, 0.03 Ga, 0.1 Ga e 0.1 Ga. Esta análise é importante para estabelecer vínculos na escala de tempo necessária para a formação das primeiras galáxias do Universo.

Keywords. Galaxies: ISM – Galaxies: high-redshift – dust, extinction

1. Introduction

Dust obscured galaxies are crucial objects to understand galaxy evolution during the height of their formation. They have a high amount of dust accumulated in intense star-forming episodes (i.e. a starburst) and it is possible that almost all normal and massive galaxies in the local Universe have experienced this phase during their growth. In particular, ultraluminous infrared galaxies, ULIRGs, are associated with starbursts, AGNs, and morphological evolution around $z \sim 2$–2.5, Yan et al. (2007).

Even beyond, in the reionization era ($z \gtrsim 6$), galaxies with strong infrared emission and dust-to-gas ratio have been found, Strandet et al. (2017), bringing new challenges to the galaxy evolution theories. Since dust is composed by metals (such as C, O, Si, Mg, and Fe), the galaxy have first to be chemically enriched by generations of stars and supernovae.

2. Simulation

In this work we investigate the properties of the ISM of high-redshift starburst galaxies (BGs) with the aid of a chemodynamic model described in Friaça & Terlevich (1998). It is a semi-analytic multi-zonal model that couples hydrodynamics, star formation, and chemical evolution of a spheroid galaxy. The galaxy is constituted by three components: gas, stars and a dark matter (DM) halo. The stellar mass and DM distributions follow, respectively, the King and NFW profiles. We assumed a Salpeter IMF and Schmidt star formation law with $n_{\rm sf} = 1/2$ index Larson (1974). The gas inicial composition is $X = 0.76$, $Y = 0.24$ and $Z = 0$. The initial temperature is assumed to be $T_0 = 10^4$ K and gas density profile the same as DM. The galaxy is initially composed only by gas and DM with mass a ratio $M_h/M_G = 6$.

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The dust grains are composed by graphite, amorphous carbon, PAHs, and silicon. Dust is produced in AGBs stellar winds, SNIa and Core-Collapsed SNe (CCSNe), each one with a different dust formation law (following Dwek 1998, formulation). We used the Gioannini et al. (2016) formulation for grain accretion in the ISM. The complete dust model is described by Guimarães & Friaça (2005). The model is coupled to a radiative transfer interface to calculate the panchromatic SED, based on Bruzual & Charlot (2003) spectro-photometric library and in Guimarães & Friaça (2005) dust model.

We simulated a fiducial galaxy with $2.0 \times 10^{11} M_\odot$ initial gas mass. This value was set to represent an intermediate value between the dusty obscured galaxies A1689-zD1, at $z \sim 7.5$ Knudsen et al. (2016), ADFS-27, a HyLIRG at $z \sim 6$ Riechers et al. (2017) and SPT-S 0311-5823.4 $z \sim 7$ Strandet et al. (2017).

3. Results

Fig. 1 shows the evolution of the stellar, dust and gas mass for the first 3 Gyr of the fiducial galaxy. The collapse of the primordial gas feeds the star formation, but SNe feedback drives a galactic outflow, beginning to quench the star formation in ~ 0.4 Gyr. After ~ 1.0 Gyr the stellar mass reach a plateau. The growth of dust mass initially follows the stellar mass growth, but at ~ 1.0 Gyr, the dust mass decrease due to the gas mass loss in outflows and to the decrease of CCSNe.

Fig. 2 shows the metallicity-dust mass relation. The metallicity is given by the mass ratio Fe/H divided by the solar mass ratio ($Fe_\odot/H_\odot$). During the starburst phase, the total dust mass follows the metallicity, but at [Fe/H] ~ 0.3, the dust mass reaches a plateau with $\sim 2 \times 10^8 M_\odot$ due to the decrease of CCSNe rate and to the dust mass lost in outflows.

Fig. 3 shows the simulated SED for the first 1 Gyr of the galaxy evolution. Due to the UV emission of young star and dust

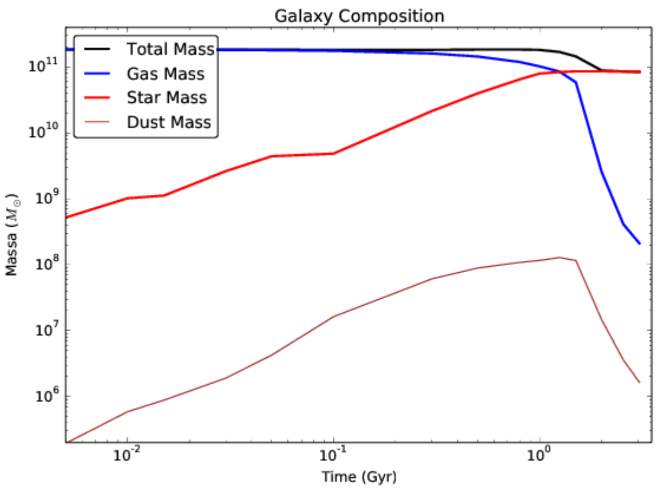

Figure 1. Evolution of barionic galactic components for the fiducial galaxy. Dust, stars, gas and the total mass.

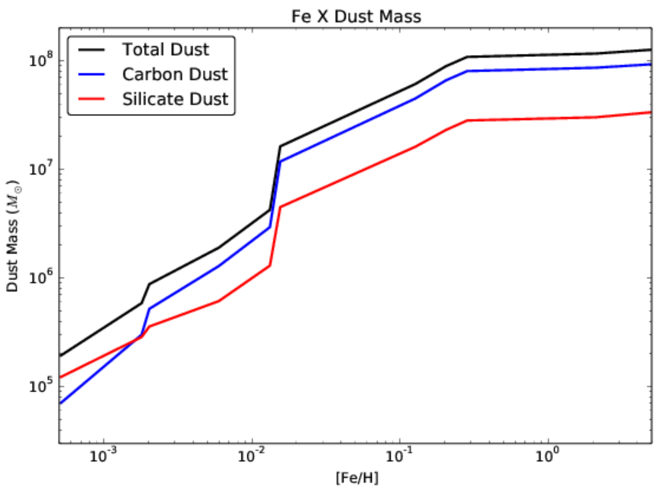

Figure 2. Metallicity × dust mass relation for the fiducial galaxy. The metallicity is given by [Fe/H] mass ratio.

mass produced mainly in CCSNe, after 0.1 Gyr the galaxy has strong FIR emission and in 0.3 Gyr the emission reaches a peak. The UV and visible components of the SED may be overestimated due to the lack of molecular clouds in the model.

Knudsen et al. (2016) estimated for A1689-zD1 a SFR $12 M_\odot$ yr^{-1}, $\log(M_*/M_\odot) = 9.4$, $\log(M_{dust}/M_\odot) = 7.2$ and $L_{IR} = 1.8 \times 10^{11} L_\odot$. Our model matches this values after the time:

- SFR $12.2 M_\odot$ a^{-1} after 1.5 Gyr;
- $\log(M_*/M_\odot) = 9.4$ after 0.03 Gyr;
- $\log(M_{dust}/M_\odot) = 7.0$ after 0.1 Gyr; and
- $L_{IR} = 1.5 \times 10^{11}$ $L_\odot$ after 0.1 Gyr

of galactic evolution. We believe that either A1689-zD1 has a very long star formation history or it is in the final stage of a very strong starburst.

4. Conclusion

In this section we summarize our main conclusions:

- Outflows quench the star formation after only ~ 1 Gyr.
- The [Fe/H] X Dust relation reaches a plateau in [Fe/H] ~ 0.3.

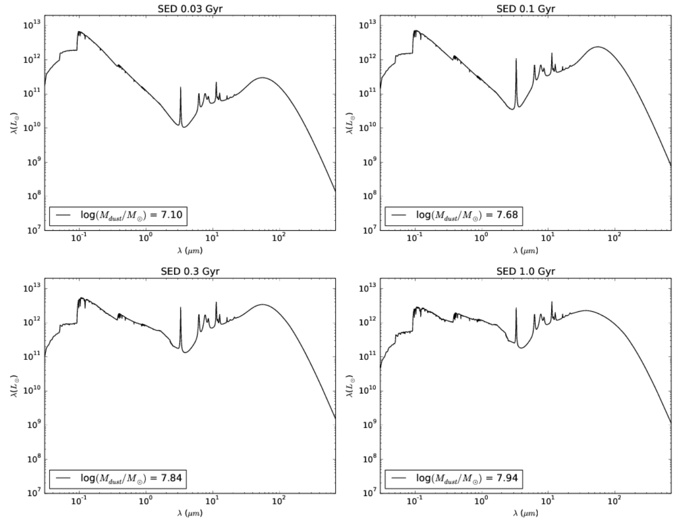

Figure 3. Simulated SED for the fiducial galaxy from 0.03 Ga to 1 Ga. The UV emission may be overestimated due to the lack of molecular clouds.

- In our simulations IR emission is strong at ~ 0.1 Gyr and reaches the peak at 0.3 Gyr.
- The simulation recovers the stellar and dust masses of A1689-zD1 in less the 0.1 Gyr.

We find that the time needed to form a obscured galaxy is ~ 0.1 Gyr and A1689-zD1 could be in the later phase of a starburst.

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