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Measuring the gas reservoir for star formation in high redshift galaxies

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Abstract. Star formation occurs from the collapse of cold giant molecular gas clouds present in the interstellar medium. The physical properties of these clouds can be altered by several factors, such as metallicity, density and temperature of the gas itself. On one hand, low metallicities yield lower dust abundances which allow for the destruction of CO molecules by UV radiation; on the other hand, dense and turbulent gas excites the CO molecules, increasing line luminosities. High redshift galaxies are metal poor and have high gas densities, making the determination of total molecular gas from CO luminosities challenging. In this work, we estimate dust emission and CO luminosities for a sample of starburst galaxies at low redshift in order to provide estimates and verify the feasibility of testing these measurements for galaxies of different stellar masses and gas phase metallicities. Finally, we compare our estimates with real data already available from sub-millimetre observatories, and discuss future endeavors for fainter objects in our sample.

Resumo. A formação de estrelas ocorre a partir do colapso de gigantes nuvens de gás molecular frio presentes no meio interestelar. As propriedades físicas dessas nuvens podem ser alteradas por diversos fatores, como a metalicidade, densidade e temperatura do próprio gás. Por um lado, baixas metalicidades significam menores abundâncias de poeira, o que permite a destruição de moléculas de CO pela radiação UV, diminuindo a luminosidade de sua linha; Por outro lado, gás denso e turbulento excita as moléculas de CO, aumentando sua luminosidade. Galáxias em alto redshift são pobres em metal e possuem alta densidade de gás, tornando a determinação do gás molecular total através das luminosidades de CO desafiadora. Neste trabalho, estimamos a emissão de poeira e as luminosidades de CO através de dados reais de taxa de formação estelar para uma amostra de galáxias starburst em baixo redshift, a fim de verificar a viabilidade em testar essas medidas para galáxias de diferentes massas estelares e metalicidades. Finalmente, comparamos nossas estimativas com dados reais já disponíveis de observatórios sub-milimétricos e discutimos perspectivas futuras para objetos mais fracos em nossa amostra.

Keywords. Galaxies: starburst – Galaxies: ISM

1. Introduction

Star formation occurs from the collapse of giant molecular clouds present in the interstellar medium (ISM).

We know the comoving star formation density in the Universe peaked approximately 10 Gyr ago, at z $\approx$ 2 (Madau & Dickinson (2014)).

Galaxies at this epoch were typically more metal-poor and had higher densities that their counterparts in the local universe.

Because of the large distances involved, it is easier to study similar objects in the local universe, where we can obtain more detailed data about relevant physical parameters: the Lyman-Break Analogs (LBAs), star forming galaxies (SFGs) with redshift 0.1 - 0.3 (Heckman et al. (2005), Hoopes et al. (2007), Basu-Zych et al. (2007), Basu-Zych et al. (2009), Gonçalves et al. (2010), Gonçalves et al. (2014), Overzier et al. (2010), Overzier et al. (2011)) with same physical properties as those at high redshift, such as stellar mass, metallicity, dust extinction, star formation rate (SFR), physical size and gas velocity dispersion.

2. Data & Methodology

We have selected 30 LBAs from SDSS and GALEX, based on luminosity ($L_{FUV} > 10^{10.3} L_{\odot}$) and surface brightness ($I_{FUV} > 10^{9} L_{\odot}\ kpc^{2}$) at low redshift ($z < 0.3$) (Heckman et al. (2005), Hoopes et al. (2007)).

In this work, we attempt to understand how ISM conditions influence the determination of the molecular gas reservoir of these objects by using two methods: CO luminosity and dust emission.

2.1. CO Luminosity

Since hydrogen molecules do not hold any permanent dipole moment, they are virtually undetectable at low temperatures. Instead, we use CO as a molecular gas tracer, the second most abundant molecule in a gas cloud (Bolatto et al. (2013)). The rotational transitions of CO molecules emit radiation in a fairly transparent atmospheric window.

$$M(H_2) = \alpha_{CO} L'_{CO} \tag{1}$$

The α_{CO} $[M_{\odot}\ (K\ km\ s^{-1} pc^{2})^{-1}]$ value was determined through dynamic mass measurements to be 4.6 in the Milky Way (Solomon & Barrett (1991), Gonçalves et al. (2014)). However, in extreme environments such as starburst galaxies, this value can be as low as 0.8 (Downes & Solomon (1998)), because of high temperature and velocity dispersion of the gas that collisionally excites CO molecules.

On the other hand, low metallicity environments present lower dust shielding and a higher level of photodissociation of CO molecules by FUV radiation. The result is an increase of the α_{CO} value with a decrease in metallicity (Gonçalves et al. (2014)).

LBAs are, at the same time, dense and metal-poor, rendering the determination of α_{CO} imprecise. In this work, we estimate CO fluxes correcting for metallicity effects according to Genzel et al. (2012),

$$\log(\alpha_{CO}) = -1.3(12 + \log(O/H)) + 12 \tag{2}$$

in order to provide a baseline for future observations.

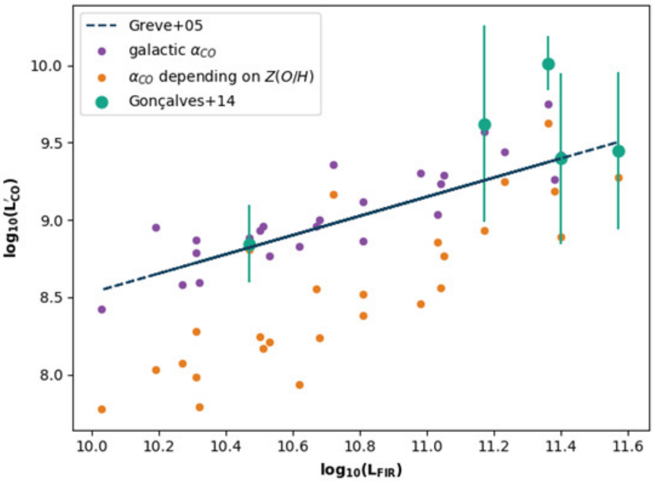

Figure 1. Relation between Far Infrared and CO line luminosities

2.2. Dust Emission

Stars heat up the dust grains in the ISM causing them to emit radiation in the far infrared (FIR). Additionally, since the amount of dust depends on the amount of gas in the ISM, we can define, approximately,

$$L_{\nu_{850\mu m}} = M_{ISM}\alpha_{850\mu m} \tag{3}$$

where $\alpha_{850\mu m} = 1.0 \pm 0.23 \times 10^{20}$ $[erg\ s^{-1} Hz^{-1} M_{\odot}^{-1}]$ as observationally determined by Scoville et al. (2014). This, of course, assumes a constant gas-to-dust ratio for all galaxies.

In metal-poor galaxies we expect dust to be relatively depleted, decreasing the FIR thermal emission. Here, we correct $\alpha_{850\mu m}$ by metallicity according to Groves et al. (2015), and estimate fluxes for all galaxies in our sample.

3. Partial Results

The galactic value of $\alpha_{CO} = 4.6$ $[M_{\odot}\ (K\ km\ s^{1}\ pc^{2})^{1}]$ predicts CO luminosities that match estimates based on the far infrared (e.g. Greve et al. (2005)). However, assuming the conversion factor varies as a function of metallicity, the estimates are decreased by a factor of 5 for metal-poor objects. This allows for a verifiable prediction of the metallicity dependence of α_{CO} [figure 1].

In order to test these hypotheses, we calculate the amount of time needed to observe each galaxy, observing simultaneously the dust continuum and CO line emission.

As seen in figure 2, using ALMA, we would need approximately 30 minutes for each object, for a total of 12 hours. This means that ALMA is the only telescope on Earth capable of completing this project.

4. Future Perspectives

We expect to compare our estimates with actual observations by sub-mm observatories, in order to assess whether metallicity corrections alone are enough to determine gas masses in metal-poor starburst galaxies.

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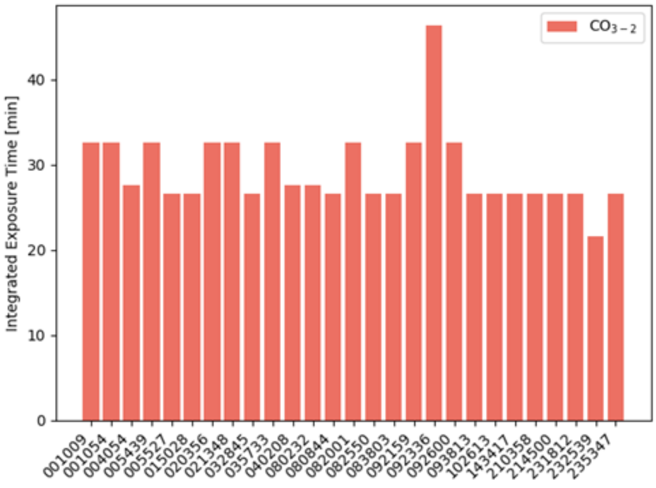

Figure 2. Time estimations with ALMA

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