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Identifying protoclusters in the distant universe

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Abstract. Protoclusters are the progenitors of the most massive structures in the Universe, galaxy clusters. They are numerically dense environments of galaxies in the early Universe and are excellent natural laboratories to investigate how environmental effects on galaxy evolution are established. These environments frequently harbor galaxies with intense star formation and, many times, dust-obscured galaxies, resulting in great luminosities in the infrared bands. A population of dusty, distant, star-forming objects is that of submillimeter galaxies (SMGs), whose copious infrared emission is redshifted to the submillimeter region. In this work, we use SMGs as targets for potential protocluster regions. We made a combination of deep imaging and multi-slit spectroscopic observations to identify Lyα emitters (LAEs) at SMG redshifts ($\Delta v \leq 2000\ km/s$) as a means to assess the more typical star-forming galaxies in SMG vicinities. We identified 4 potential protocluster regions over the redshift range $z = 1 - 5$. Preliminary analysis of the COSMOS field points to a mild excess in LAE density around SMGs at $z \sim 4.5$ when compared to the LAE density in the field. These preliminary results are consistent with SMGs tracing typical moderate-mass structures of the Universe instead of the more massive ones, that grow into Coma-like clusters. SMGs may be thus an as-yet untapped population to understand the build-up of the more modest and more typical galaxy groups and clusters.

Resumo. Protoaglomerados são os progenitores das estruturas mais massivas do Universo, os aglomerados de galáxias. Eles são ambientes numericamente densos de galáxias presentes no início do Universo, quando as grandes estruturas estavam se formando, e por isso são excelentes laboratórios naturais para investigar de que forma efeitos ambientais podem afetar a evolução das galáxias. Esses ambientes tipicamente abrigam galáxias com intensa formação estelar e, frequentemente, galáxias obscurecidas por poeira, resultando em grandes luminosidades nas bandas infravermelhas. Uma população de objetos distantes com intensa formação estelar obscurecida por poeira é a de galáxias submilimétricas (conhecidas como SMGs - submillimeter galaxies), cuja emissão no infravermelho é desviada para a região submilimétrica do espectro por efeito do redshift cosmológico. Neste trabalho, usamos SMGs como alvos para identificar potenciais regiões de protoaglomerados. Combinamos imageamento profundo e observações espectroscópicas para identificar galáxias emissoras da linha Lyman α (conhecidas como LAEs - Lyα emitters) nos redshifts de SMGs ($\Delta v \leq 2000\ km/s$), como um meio de avaliar a presença de galáxias tipicamente em formação estelar nas vizinhanças de SMGs. Identificamos 4 potenciais candidatas a protoaglomerados no intervalo de redshift $z = 1 - 5$. A análise preliminar do campo COSMOS aponta para um leve excesso de densidade de LAEs em torno de SMGs em $z \sim 4.5$ em comparação com a densidade LAEs no campo. Este resultado preliminar é consistente com um cenário em que SMGs traçam estruturas mais típicas do Universo, com massas moderadas, em vez das estruturas mais massudas, que se tornam aglomerados semelhantes a Coma no Universo local. As SMGs podem ser, portanto, uma população ainda pouco explorada para compreender a formação de grupos e aglomerados de galáxias mais típicos e não apenas os mais massudos.

Keywords. cosmology: large-scale structure — galaxies: clusters: general — galaxies: high-redshift — galaxies: starburst — submillimeter

1. Introduction

It has been known for decades that galaxies in dense environments have different characteristics from their field counterparts (e.g. Dressler 1980). However, how the environment influences the evolution of galaxies is still an open question. To understand the galaxy-environment relation in more detail, we can investigate dense environments from their early stages of formation. Galaxy clusters are the densest structures in the local Universe. They formed from density fluctuations in the primordial Universe and evolved due to gravitational collapse into today's most massive large-scale structures ($M_{DM} \geq 10^{14} M_o$). They comprise hundreds to thousands of galaxies clustered at the same redshift ($\Delta v \simeq 1000\ km/s$; Bahcall 1988), with small projected distances between them (1-5 Mpc; Bahcall 1988). Protoclusters are the early stages of the formation of these structures. They are sparse galaxy systems at high redshifts, spread over scales of tens of Mpc (Overzier et al. 2016). Identifying these sparse systems is challenging, and one strategy is to look for objects that have a high probability of inhabiting massive halos at high redshift. Searches were made with radiogalaxies, which have many properties indicative of being progenitors of local bright cluster galaxies (Collet et al. 2015), the massive ellipticals typically found at the centers of local galaxy clusters. Another class of objects used as targets are QSOs, although there is still no consensus on whether they inhabit dense halos or not (e.g. Hennawi et al. 2015; Uchiyama et al. 2017). In this work, we use submillimeter galaxies (SMGs) as targets. These objects are very dusty, star-forming galaxies at high redshift. Hickox et al. (2012) predicted that SMGs inhabit massive dark matter halos ($M \simeq 10^{13} M_o$) at $z \sim 2$. Recently Garcia-Verara et al. (2020) based on the fact that SMGs detected by single dish telescopes are often blended sources, suggested that halos harboring SMGs could be up to 4 times less massive than Hickox et al. (2012) predicted. Chapman et al. (2009) found that SMGs may inhabit typical modest-mass regions going through active episodes of star formation. This scenario suggests that SMGs can trace different kinds of environments, associated with massive halos or with more average halos. In this work, we use SMGs as tracers for potential protoclusters regions. We combine deep imaging and spectroscopic observations to identify Lyα emitters (LAEs), which are typical star-forming galaxies, at the redshifts of SMGs ($\Delta v \leq 2000\ km/s$). We investigate 4 potential protocluster re-

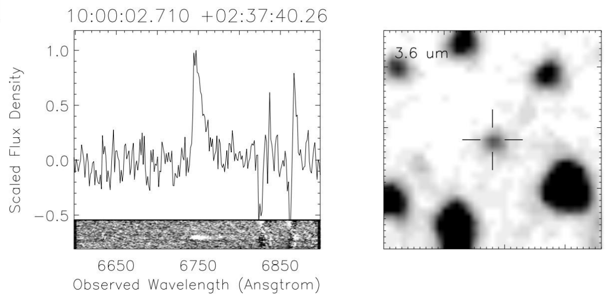

Figure 1. Left: LAE spectroscopically detected with the IMACS instrument on Baade, Las Campanas Observatory (Chile). Right: Archival multi-band imaging opens up the possibility of tracing individual galaxy properties (e.g., stellar mass, AGN content). Here, mid-IR counterpart in Spitzer/IRAC archival imaging for the spectroscopically detected LAE on the left.

gions in the redshift range $z = 1 - 5$, corresponding to a time interval of more than 4 Giga years. We are currently working on a protocluster candidate at the COSMOS field, $z = 4.56$.

2. Methodology

LAEs dominate the faint end of the galaxy luminosity function (e.g. Gawiser et al. 2007), thus allowing the identification of less extreme and more representative member galaxies in overdense regions. We use SMGs with spectroscopic redshifts (Aretxaga et al. 2011; Brisbin et al. 2017) as targets for potentially overdense regions and we combine deep imaging and spectroscopic observations to identify LAEs at these SMG redshifts. In order to verify if the regions are indeed overdense, we compare the density of detected LAEs in our study with that of LAEs in the field at the similar redshifts (e.g. Dawson et al. 2007). This allows us to unveil what kind of environment we are probing.

We are currently analyzing a region in the COSMOS field, at $z = 4.56$. The IMACS instrument on the 6.5-m Magellan Baade Telescope at the Las Campanas Observatory has a FOV $\simeq 27$ arcmin-diameter, which allows us to probe regions of ~ 10Mpc in extension, at $z \sim 4$. Based on LAE spectroscopic detections made with IMACS (see Figure 1 for an example), preliminary analysis of the LAE distribution at SMG redshifts within the COSMOS field show a group of 7 LAEs and 2 SMGs at $z = 4.56$ (± 0.03). This region volume, $1.12x10^5 cMpc^3$, is consistent with protocluster dimensions (Overzier et al. 2016). We use the work by Dawson et al. (2007) on the spatial distribution of field LAEs at these redshifts as a control sample to define the numerical density of LAEs in the field. We measure a numerical LAE overdensity of 0.26 considering the following definition

$$\delta = (n - \bar{n})/\bar{n},$$

where n is the LAE density of the region in the COSMOS field and $\bar{n}$ is the LAE density in Dawson et al. (2007). This result suggests a mild LAE density excess. Taken at face value, these preliminary results are consistent with the idea that SMGs trace moderate-mass structures (Chapman+09).

3. Next Steps

LAEs identified through narrow band observations of this protocluster candidate will be included in the analysis. With this, we will calculate mass overdensity and halo mass at z=0 of this structure. This will provide us with a better understanding of the large scale structures traced by SMGs.

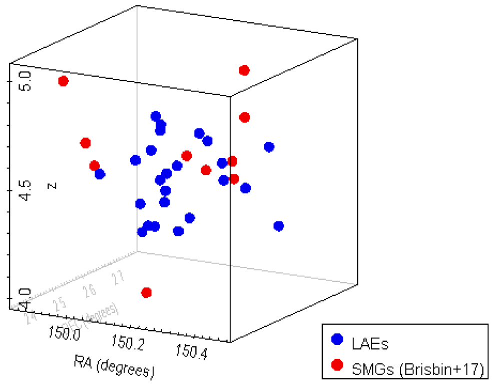

Figure 2. 3D plot of potential protocluster regions at $z \sim 4.5$, identified through LAE detections around SMGs in the COSMOS field. Red symbols show the location of SMGs with spectroscopic redshifts (Aretxaga et al. 2011; Brisbin et al. 2017); blue, LAEs spectroscopically detected by our team with the IMACS instrument at Las Campanas Observatory

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