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TITULO

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ABSTRACT

MISSING: The abstract

Subject headings: Galaxies: high-redshift, Lyman Alpha Emission, Galaxy Rotation, Galaxy Outflows ....MISSING....

1. INTRODUCTION

In 1967 Partridge & Peebles (1967) predicted a population of galaxies with a strong Lyman Alpha (Ly-α) emission, nowadays galaxies who are selected using the Ly-α line are known as Lyman Alpha Emitters (LAEs). Since the first observed LAE by Djorgovski & Thompson (1992) different teams have observed several LAEs Kulas et al. (2012); Östlin et al. (2014) , become a very important tool to explore the extragalactic Universe *cite*. Specially at $z >= 2$ since it is when the line is redshifted into the optical regime. it is specially useful to study the properties of the high redshift Universe, such as the large scale structure. and new projects are beeing planned for the near future .

A variety of Astrophysical problems can be studied using LAEs; clustering of galaxies at high redshift, Interstellar (ISM) and intergalactic (IGM) medium properties and cosmological reionization among others. This motivates to study in detail the processes that model the morphology of the Ly-α line.

To fully understand the observed spectra of LAEs this galaxies must be modeled. however the resonant nature of the lines makea this a challenging task. Neufeld et 90 the outcoming spectra of galaxies through static mediums Recent hydrodynamical simulations have been explored the properties of the IGM/ISM in large scale simulations, while some others have studied detailed galaxies. On the other hand RT computations have been in order to understand the effect of the gas kinematics in the Line, special attention have been devoted to model the presence of outflows in the galaxy. here different models have attempt to (name the models, shell cavities etc.) . Most recently Garavito-Camargo et al. (2014) have studied in detail the effect of rotation on the lyman alpha line.

As many previous studies have shown outflows are present in LAEs (**References**), the outflows are mainly a consecuence of the intergalactic medium (IGM) being ejected from the galaxy due to supernova explotions. However rotation should also be present in this galaxies. The joint effect of the two above properties should have a direct effect on the morphology of the Ly-α line.

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This effect is the motivation of this paper in which we combine the effect of rotation follow by an outflow. We proposed a simplyfied model in which the galaxy is modeled as an sphere, with an homogeneous mixture of dust and hydrogen at a constant temperature and undergoing solid-body rotation.

The solid-body rotation does not induce any spatial anisotropy in the integrated line flux, the escape fraction or in the average number of scatterings. This symmetry allows to the creation of an analytic approximation for the galaxy spectrum proposed, see Garavito-Camargo et al. (2014) for details. In this model the optical depth τ_H, the rotation velocity V_{max} and the inclination angle θ are free parameters.

The outcoming spectra of the rotating galaxy is then affected by a symmetric thin shell of expanding gas at a constant velocity following the model proposed by Verhamme et al. (2014); Orsi et al. (2012).

This paper is structured as follows. In §2 we explain in detail the model of rotation and outflow that we use as well of our joint model (Rotation & Outflow). In §3 we present the results of our model. In §4 we compare our results with recent observations of LAEs with special attention of those morphologies that present features of galaxy rotation and outflows. In the latest section we present our conclutions.

2. THEORETICAL BACKGROUND

In this section we describe the two different models that together are used to reproduce a real and consistent Ly-α profile. The first one is a rotation model for the galaxy and the second is a thin shell model for the outflow.

2.1. *Rotation Model*

We use the simplified rotation model developed by (Garavito-Camargo et al. 2014) in which a rotating galaxy is modeled as a solid rotating sphere, with a homogeneous mixture of hydrogen and dust. Photons can be initially at the center or can be homogeneously distributed inside the sphere. The equations governing this solid-body rotation sphere in which the axis of rotation is defined to be align with the z-axis are:

$$v_x = -\frac{y}{R} V_{\max}, \tag{1}$$

$$v_y = \frac{x}{R} V_{\max}, \tag{2}$$

$$v_z = 0, \tag{3}$$

Where R is the radius of the sphere and $V_{\max}$ is the linear velocity at the sphere's surface. The minus/plus sign in the x/y-component of the velocity indicates the direction of rotation. In this case we take the angular velocity in the same direction as the $\hat{k}$ unit vector.

In this work we use the analytical expression for rotation derived in (Garavito-Camargo et al. 2014) where a rotating sphere can be seen as a static sphere in the laboratory frame with a bulk velocity difference in each surface element with respect to a distant observer. With the previous analysis the outcoming spectra can be expressed as:

$$J(x,i) \approx 2\pi \int_0^R db\, b \int_0^{2\pi} d\phi\ J(x,b,\phi,i), \tag{4}$$

Where $J(x,b,\phi,i)$ is the spectrum of the flux emerging from the surface at point (b,ϕ) and is expressed as:

$$J(x,b,\phi,i) = \frac{\sqrt{\pi}}{\sqrt{24} a\tau_0} \left(\frac{(x - x_{\rm b})^2}{1 + \cosh\left[\sqrt{\frac{2\pi^3}{27}\frac{|(x-x_{\rm b})^3|}{a\tau_0}}\right]} \right) \tag{5}$$

2.2. *Outflow Model: ThinShell*

We use the outflow model stated in (Orsi et al. 2012) in which the outflow consists of a homogeneous, expanding, isothermal spherical shell surrounding a central galaxy. The inner radius R_{in} is related to the outer radius R_{out} by the expression $R_{in} = f_{th} R_{out}$, where $f_{th} = 0.9$. The temperature of the medium is assumed constant and equal to $T = 10^4 K$ and it is expanding at a constant velocity v_{out} . This outflow is composed by dust and gas uniformly mixed described by the column density n_H and the metallicity Z as follows:

$$n_H = \frac{X_H M_{shell}}{4\pi m_H R^2{}_{out}} \tag{6}$$

Where M_{shell} is the mass of the outflow, m_H is the mass of the hydrogen atom and $X_H = 0.74$ is the fraction of hydrogen in the cold gas.

$$Z = f_Z \langle Z_{cold} \rangle \tag{7}$$

Where $\langle Z_{cold} \rangle$ is the average metallicity of the cold gas and it is weighted by the product of the mass of cold gas and the Ly-α luminosity of the disc and bulge f_Z.

We decided to choose this model for two main reasons. First, when we analyze observed spectra we can se that the line is spread around the place where line should be when already taking into account the redshift due to the distance to the LAE. This implies that the photons before escaping the composed system suffer a change in frequency themselves, which we explain by making them rebound over the inner surface of the shell such as some of them suffer blueshift and other redshift, that even small, is significant and observed.

The second reason is because as the space between the shell and the galaxy is said to be void, the photons that escape from it suffer the scattering process at a far distance from the center, in a way such as if they rebound the chances that it happens in the normal direction to the surface are lower than in any other model. This implies that the photons are less likely to re-enter the galaxy so there is no need to start the diffusion inside again, allowing us to divide the spectrum creation process into 2 independent events, saving computational time and simplifying the model to its best.

2.3. *Joint Model*

The joint model consists of combining the two models that were just explained. A rotating spherical galaxy is placed at the center with a thin shell outflow surrounding it as seen in Fig. 1. What happens is that the photons that escaped the galaxy enter now into the outflow with the same radial direction that they came out with. At the end only a fraction of those manage to get out of the outflow and their wavelengths are measured to find the final spectrum.

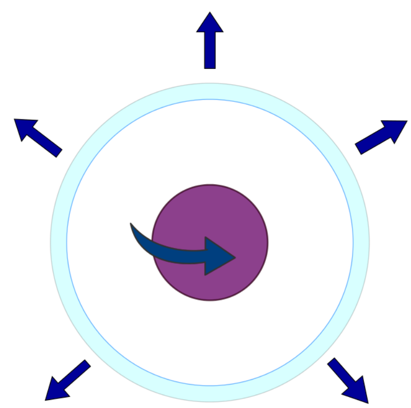

FIG. 1.— **Model:** A central rotating galaxy surrounded by an expanding thin shell outflow.

In order to simulate all the possible cases we set some key parameters for the program to vary, and some others fixed which are defined by the characteristics of LAEs. This are chosen as follows.

2.3.1. *Fixed Parameters*

For the first stage there are two fixed parameters: the optical depth $\tau = 10^8$ and the galaxy rotation velocity $v_{gal} = 100$ km s^{-1}. For the second stage there is one fixed parameter: the metallicity of the outflow $Z = -4.0$. This 3 fixed values are selected because the characteristics of observed LAEs, especially their low mass and their highest star formation rate of all.

2.3.2. *Free Parameters*

We have then 3 parameters left that are going to vary along a wide range. These are: the galaxy viewing angle θ_{gal} , the hydrogen column density n_H and the outflow expanding velocity v_{out} .

θ_{gal} covers 3 different angles: 0°, 45° and 90°. $\log n_H$ takes 41 different values from 20.0 to 22.5. And v_{out} covers 5 equidistant velocities from 100 km s^{-1}to 500 km s^{-1}. The permutations of these three are analyzed in section 3.

3. RESULTS

The results of this project consist of emulating a LAE spectrum basing on its physical characteristics defined by the 3 free parameters we stated before. When defined the combination of those three.

MISSING:
- What are the compact results.
- Not a physical analysis yet.
- Write better (prettier)

In the following subsection each free parameter is explained deeper.

3.1. *Influences of the Free Parameters*

In order to study the influence of each of the three free parameters, we fix two of them and see how the final spectrum varies along the other one left. In each case we will state these changes.

3.1.1. *Influence of the Galaxy Viewing Angle: θ_{gal}*

If one sets fixed outflow v_{out} and $\log n_H$ in each case the viewing angle has the same effect: it increases proportionally the intensity. However this change is not that significant. The resulting spectra are completely the same, but enlarged vertically by a small factor. Fig. 2 helps visualize this effect in a better way.

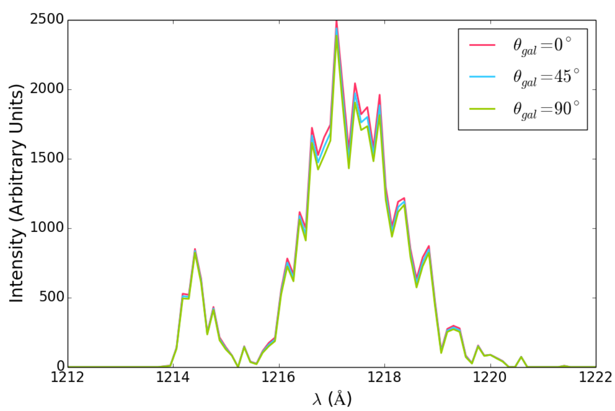

FIG. 2.— **Influence of Galaxy Viewing Angle:** The values of the fixed parameters are v_{out} = 100 km s^{-1}and $\log n_H = 21.3125$. The 3 possible angles are shown in the plot with different colors. The increase is visible as well as its small enlargement factor.

3.1.2. *Influence of the Outflow Hydrogen Column Density: $\log n_H$*

The effect of the $\log n_H$ is the creation of 2 peaks: the left one very thin, tall and pronounced, and the right one very wide, small and soften. When the $lognH$ is increased, the left peak starts to decrease while mixing with the right one, decreasing their height ratio until the left peak completely disappears. The resulting spectrum, with high column density, is a wide single mountain with intensity significantly less than at the beginning. Fig. 3 helps visualize this effect in a better way.

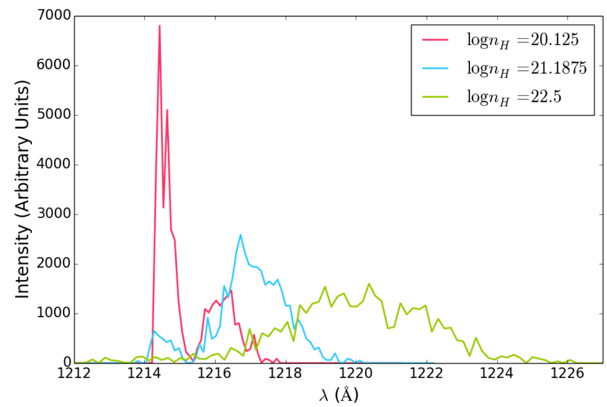

FIG. 3.— **Influence of Outflow Hydrogen Column Density:** The values of the fixed parameters are v_{out} = 100 km s^{-1}and $\theta_{gal} = 90°$. There are three stages of the $\log n_H$ value shown: initial, intermediate and final, with the values shown on the plot.

3.1.3. *Influence of the Outflow Expanding Velocity: v_{out}*

The effect of this parameter consists in a shift of the initial spectrum in the column density. The more v_{out} the outflow has, the more the spectrum simulates the previous velocity but with a greater $\log n_H$. If one compares with Fig. 3 the similarities are really clear.

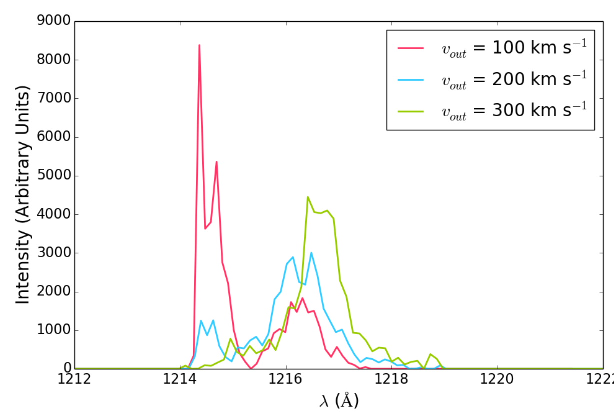

FIG. 4.— **Influence of Outflow Expanding Velocity:** The values of the fixed parameters are $\log n_H = 20.0625$ and $\theta_{gal} = 90°$. If one increases $\log n_H$ for an outflow with v_{out} = 100 km s^{-1}it will create similar spectra to these in certain points.

4. DISCUSSION

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- Comparison with some other result (probably observations).
- Why is this result useful?
- What possible implications can this model have?

Ideas:

The decrease of the intensity while increasing the column density is caused because the second is proportional to the absorption of light in the gas. The more $\log n_H$, the less photons get out of the outflow.

5. CONCLUSIONS

Here goes the conclusions....

ACKNOWLEDGMENTS

We acknowledge Alvaro Orsi and Julian Mejia for collaborating with us offering their time, advice and especially data. We used their outflow simulations in order to get our results.

The data, source code and instructions to replicate the results of this paper can be found here `https://github.com/mariacamilaremolinagutierrez/LymanAlpha/`. Most of our code benefits from the work of the IPython and Matplotlib communities (Pérez & Granger 2007; Hunter 2007).

MISSING:
- More acknowledgments.

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