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Outflows and rotation in Lyman alpha emitting galaxies

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ABSTRACT
Star-forming Compact Dwarf Galaxies (CDGs) resemble the expected pristine conditions of the first galaxies in the Universe and are the best systems to test models on primordial galaxy formation and evolution. Here we report on one of such CDGs,

Key words: galaxies: dwarf — galaxies: individual:Tololo 1214-277 — radiative transfer — Methods: numerical

1 INTRODUCTION

Distant galaxies are key to understand early evolutionary stages of our Universe. Physical conditions in those galaxies allows the emergence of Lyman-α line emission at 1216 Å**?**. Galaxies detected through its Lyman-α emission receive the name of spectra at and named Lyman Alpha Emitters (LAEs).

Currently LAEs are commonly targetted in wide area galaxy surveys. They have been effectively used to study galaxy evolution, cosmology and the thermal history of the Universe. This has been able through the study of their spatial distribution and the shape of the Lyαemission line.

Recent imptovements in instrumentation have revolutionized the kind of studies that can be performed on LAEs. It is now possible to infer detailed kinematic maps for nearby galaxies. The study of these maps would allow us to build data-driven models to interpret the Lyαspectra of unresolved galaxies, helping us to constrain the physical conditions of the interstellar medium (ISM) processing the Lyαradiation.

On the ISM's features that plays an important role in shaping the Ly$\alpha$is HI kinematics. In a static HI medium the Lyαline has two equal and symmetric peaks around the natural Lyαwavelength and zero intensity at the line's center. For an outflowing ISM, the line becomes asymmetrical with a more pronounced read peak. If the galaxy rotates, the line shows different amounts of Doppler shifts modifying the overall line profile Garavito-Camargo et al. (2014).

In this paper we present for the first time a study of the joint effects of galaxy outflows and rotation. We study a simplified geometrical configuration corresponding to an spherical gas cloud with symmetrical radial outflows and a rotation profile corresponding to a solid body. We base our modelling on a Monte-Carlo radiative transfer code called CLARA (Code for Lyman Alpha Radiation Analysis) presented for the first time in Forero-Romero et al. (2011). Besides modelling the impact of joint rotation and outflows, we also want to check to what extent the analytical model presented by Garavito-Camargo et al. (2014) to explain the effects of rotation can also be applied in our case.

In this paper we introduce first our theoretical tools and assumptions in Section 2, then we present the numerical results and comparisons against the analytical solution in 3. In Section 4 we discuss our results and their possible implications for observational analysis to finally present our conclusions in Section 5.

2 THEORETICAL MODELS

2.1 Monte-Carlo Radiative Transfer Model

CLARA follows the propagation of individual photons through a neutral Hydrogen medium characterized by its temperature, velocity field and global optical depth. The code assumes an homogeneous density throughout the simulated volume. In the current implementation we neglect the influence of dust. Our basic models is an spherical distribution of neutral hydrogen, an approximation commonly used in the literature, as it explains a wide variety of observational features (Ahn et al. 2003; Verhamme et al. 2006; Dijkstra et al. 2006).

The central element in this paper is the velocity field that captures outflows and rotation. Outflows are captured by a Hubble-like radial velocity profile with the velocity magnitude increasing linearly with the radial coordinate; the outflow model is fully characterized by $V_{\rm out}$, the velocity at the sphere's surface. Rotation follows a solid body rotation profile, which is fully characterized by $V_{\rm rot}$, the linear velocity at the sphere's surface.

The total velocity field corresponds to the superposition of rotation and outflows. The cartesian components take the form

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$$v_x = \frac{x}{R}V_{\rm out} - \frac{y}{R}V_{\rm rot}, \tag{1}$$

$$v_y = \frac{y}{R}V_{\rm out} + \frac{x}{R}V_{\rm rot}, \tag{2}$$

$$v_z = \frac{z}{R}V_{\rm out}, \tag{3}$$

where x, y and z are the cartesian position coordinates with the origin at the sphere's center R is the radius of the sphere and the direction of the angular velocity vector corresponds to the $\hat{k}$ unit vector.

For each model setup we follow 10^4 individual photons generated at the center of the sphere at the Lyα line's center as they propagate through the spere and finally scape. We store the final frequency and propagation direction for each photon at its last scattering.

2.2 Analytical Model for Bulk Rotation

Rotation induces two main effects on the Lyαline morphology. First. Break of spherical symmetry due to the preferential direction introduced by the rotation axis. This symmetry break is reflected in the observed spectra as a dependency on the viewing angle, θ, between the line of sight of a distant observer and the rotaional velocity. Second. Line blurring as the rotational velocity increases. At a fixed viewing angle, faster rotation induces makes the observed line wider and increases the flux around the line's center.

Garavito-Camargo et al. (2014) presented in the Appendix an analytical model that accounts for these two features. The basic assumption of the analytical model is that each differential surface element on the sphere Doppler shifts the photons that it emmits.

3 RESULTS

3.1 Monte-Carlo Radiative Transfer Model

3.2 Analytical Model for Bulk Rotation

4 DISCUSSION

4.1 Theoretical Insights

4.2 Observational Perspectives

5 CONCLUSIONS

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