Þú ert jörðin

JEFR[1], MCRG[1], JNGC[2], MG[3], MD[3]

[1] Bogota

[2] Tucson

[3] Oslo

Star-forming Compact Dwarf Galaxies (CDGs) resemble the expected pristine conditions of the first galaxies in the Universe. Before the observational detection of the first galaxies becomes reality, CDGs are the best systems to test our ideas on primordial galaxy formation and evolution. Here we report on one of such CDGs, Tololo 1214-277, which presents a broad symmetric Lyman-α emission that had evaded theoretical interpretation so far. We explain these features by two different models: an homogeneous sphere undergoing gas bulk rotation and an interstellar medium composed by clumps with random motions. It is the first time that an observed Lyα spectrum can be explained with these physical conditions. We find that both models independently require high velocities that translate into a dynamical mass at least 10 times larger than the neutral mass hydrogen in the galaxy. We argue that a possibility to explain the high dynamical mass is the presence of a super-massive black hole. The implications of our findings for the study of LAEs, including the first generation of galaxies are manifold. It demonstrates the importance of considering rotation and multiphase physics under the possible conditions shaping the Lyα spectra of the first galaxies. Additionally, if future kinematic maps of Tololo 1214-277 confirm the high velocities postulated in our model, it would provide new evidence for dwarf galaxies as hosts of supermassive black holes.

The first generation of galaxies trace our cosmic origins. They were the first steps in the evolution of galaxies such as the Milky Way. In the standard Big Bang cosmology the only chemical elements that were created in the nucleosynthesis process were Hydrogen, Helium and Lithium. Heavier elements must have been created in stellar evolution process. Therefore, we expect the first generation of galaxies to be metal free and rich in Hydrogen. This kind of primordial galaxies have not been detected yet. However, dwarf star forming galaxies with a low metallicity content are seen as templates to understand the early galaxy evolution process.

Almost fifty years ago [6] it was realized that young galaxies could be detected through a strong Lyman-α line emission. This theoretical prediction was only confirmed thirty year later on distant, relatively young, not primordial, galaxies. Currently Lyman Alpha Emitting (LAE) galaxies are commonly targeted in surveys. The presence of the Ly-α emission line provides confirmation of the distance of a galaxy while provides clues about the stellar population and inter-stellar medium conditions regulating the Ly-α emission.

The Ly-α emission line is not exclusive of distant galaxies. Any galaxy with low dust content and ongoing star formation has the right conditions to show this line. There are, for instance, local Universe surveys that target Ly-α emission in nearby dwarf star forming galaxies [5]. The study of nearby LAE samples has allowed the study of other indicators that might be more difficult to obtain for distant galaxies such as morphology, dust attenuation, neutral hydrogen contents and ionization state.

However, the physical interpretation of Ly-α observations is not straightforward. This is due to the resonant nature of the Ly-α line. A Ly-α photon follows a diffusion-like process before escaping the galaxy or being absorbed by dust. The resulting line profile becomes sensitive to the dynamical, chemical and thermal conditions in the interstellar medium. There are very few analytically tools available to interpret the Ly-α line. They are applicable only in very few cases of highly symmetrical conditions, which are hardly met in real astrophysical systems. For these reasons the interpretation of Ly-α observations require state-of-the-art Monte Carlo radiative transfer simulations. Recent advances in these computational models have explored the effects that bulk rotation and a multiphase state in the interstellar medium should have on on the Lyman-α line.

The most important consequence of bulk rotation is that, even for a spherical gas distribution, the line morphology now depends on the viewing angle respect to the rotation axis. For a line of sight perpendicular to the rotation axis the intensity and the line center and the line width increase with rotational velocity. When the rotational velocity is close to the half-line width of the static line the line becomes single peaked and symmetric, a unique feature that other theoretical models find difficult to reproduce without introducing more complexity into the gas distribution.

This is the case of a multiphase interstellar medium. The model is more complex as it must take into account the behavior of neutral dense hydrogen clumps dispersed in a tenuous intraclump medium. Corresponding to the elaborate physical conditions in the model, there are a wide variety of possible emerging spectra. This variety includes single, double and triple peaked spectra with different degrees of symmetry around the line's center.

Tololo 1214-277 is a compact star forming dwarf galaxy that presents a strong Ly-α emission [9] with two puzzling features: it is symmetric and single peaked. Commonly, the Ly-α line has a single or asymmetric double peak. These two special features in Tololo 1214-277 had evaded a physical interpretation so far, because bulk rotation and a multiphase ISM can independently explain the Lyα line in Tololo 1214-277.

Figure 1. summarizes our findings. Dots represent the observational data for Tololo 1214-277with the overplot from our best fit models from the full radiative transfer simulations for a rotating sphere (continuous line) and a clumpy ISM (dashed line).

The best parameters in the rotation model are a rotational velocity of $v_{max} = 300^{+xx}_{-xx}$km s^{-1}, an optical depth $\log\tau = 7^{+xx}_{-xx}$ and a temperature of $T = 1.5^{+xx}_{-xx} \times 10^4$K. This translates into a column density of $\log N_{HI}/\text{atoms cm}^{-2} =$

20.5^{+xx}_{-xx}. This model is also able to constrain the angle between the rotation axis and the observational line-of-sight to $\theta = 65^{+xx\circ}_{-xx}$.

In the multiphase model the best constrained parameters are the clump velocity dispersion $\sigma_{\rm cl} = 71^{+17}_{-25}$ km s^{-1}, the clumps outflowing velocity $v_{\infty,\rm cl} = 79^{+167}_{-60}$ km s^{-1}and the fraction of the Lyαemission that is coming from the cold clumps $P_{cl} = 0.72^{+0.20}_{-0.32}$. The multiphase model assumes that the clouds are distributed over a sphere of 5kpc in radius, close to the $\approx$ 4kpc physical size of Tololo 1214-277 as determined by optical imaging. The assumed physical size and the velocity dispersion $\sigma_{\rm cl}$ correspond to a dynamical mass of $3.0^{+1.5}_{-1.8} \times 10^9$ M$_\odot$.

Radio surveys of the 21cm line have put an upper limit to the neutral hydrogen mass in Tololo 1214-277 of $M < 2.65 \times 10^8$ M$_\odot$ [7]. In the case of the rotation model, this information help us to constrain the diameter of the HI region where the Lyα emission and transfer takes place. We find this size to be in the range $0.11 < D/\mathrm{kpc} < 0.34$, one order of magnitude smaller than Tololo 1214-277's size in the optical. That size and the rotational velocity of 300km s^{-1}put a constraint on the dynamical mass of $4.5^{+2.1}_{-2.4} \times 10^9M_\odot$.

This is evidence for a dynamical mass at least 11 (multiphase case) to 17 (rotation case) times higher than the mass in neutral hydrogen. There are three main possibilities to explain the dynamical mass: stars, dark matter and a supermassive black hole. The stellar mass in old stars has been constrained by non-detections in the K-band to be $< XXX$M$_\odot$. Considering a standard dark matter halo, it can only contribute to xx M$_\odot$ in the region of interest. A super massive black hole remains an open possibility. Recent observations of ultra-compact dwarf galaxies [8] have confirmed the presence of super-massive black holes containing 15% of the total object mass, suggesting that there is a large population of undetected black holes in dwarf galaxies.

A future observational test to clarify the physical nature of Tololo 1214-277 would require integral field unit measurements spatially resolving its spatial extent. Tololo 1214-277 spans a region of 4 arcseconds, an instrument such as the Multi Unit Spectroscopic Explorer with its nominal 0.2 arcseconds spatial sampling over a 1.0 arcminute field in wide-field mode could provide a coarse mapping of different ionization lines to infer a kinematic map. Another observational test includes the measurement of the escape fraction of Ly continuum ionizing radiation. In the rotational model this fraction should be zero, while the multiphase model predicts that in this case it should be around $0.5^{+1.0}_{-0.4}$%.

All in all, the mere existence of a strong LAE galaxy with a broad, symmetric line is interesting. It raises the question whether some high redshift LAEs have asymmetric lines because the blue half was truncated by the intergalactic medium. In this case the Lyα radiation could emerge as a low surface brightness glow, which may be connected to Lyα halos, while also influencing the way LAEs can be used as a probe of reionization.

These findings demonstrate the importance of including rotation and multiphase conditions as features to model the Lyα line in high redshift galaxies. Additionally, if the hypothesis of a supermassive black hole in Tololo 1214-277 proves to be consistent with future observational kinematic maps, it could cor-

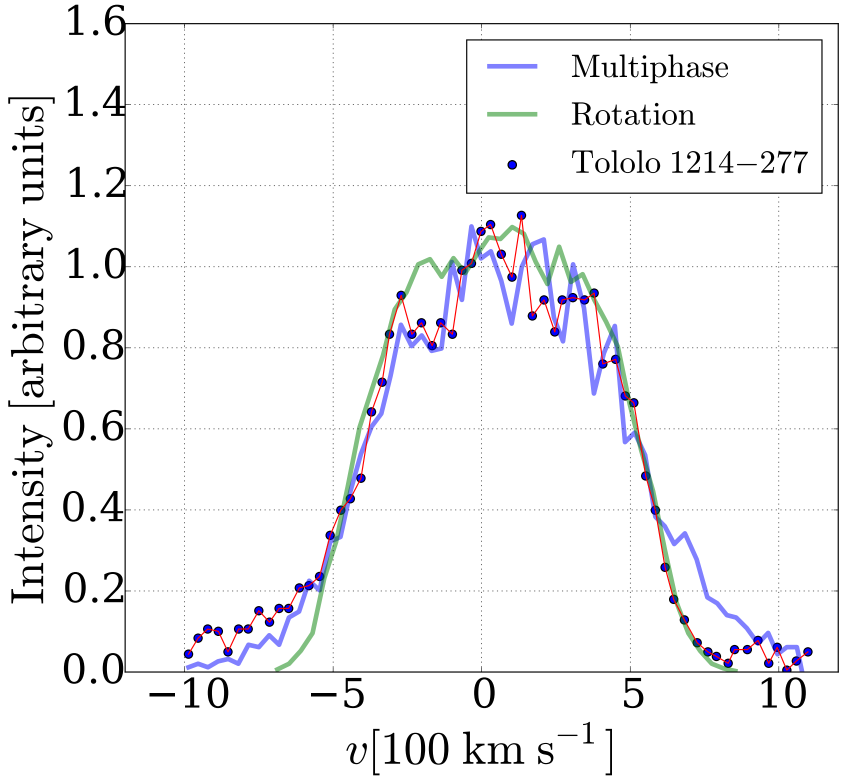

Figure 1: **Broadn, single peaked and symmetric Ly-α emission of Tololo 1214-277.** Dots correspond to the observational data. The line shows the results of our best model from a full radiative transfer simulation both for the rotation and multiphase models.

respond to a so far undetected black hole in a dwarf galaxy, providing a new way to test and probe theories on the co-evolution of galaxies and black holes in the first generation of galaxies.

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$\alpha(2000)^a$	12h17min17.1s
$\delta(2000)^b$	-28d02m32s
l, b (deg)	294, 34
m_V	17.5
M_V	-17.6
v(km s^{-1})	7795
Ly-α (erg cm^{-2} s^{-1} Å^{-1})	8.1×10^{-14}
Ly-α EW	70Å
Hβ (erg cm^{-2} s^{-1} Å^{-1})	1.62×10^{-14}
21cm (Jy km s^{-1})	< 0.10

Table 1: Basic observational characteristics of TOL1214-277 [9]

Tololo 1214-277 characteristics

FIXME: Add non detection in 2MASS

Tololo 1214-277receding velocity is 7785 ± 50km s^{-1}, which translates into a distance of 106.6 Mpc (Hubble constant 73 Mpc km^{-1} s^{1}) Its metallicity is $\sim Z_{\odot}/24$ [3] as derived from optical spectroscopy.

The observed flux for the Lyman alpha line is $\sim 8.1\times10^{-14}$ erg cm^{-2} s^{-1} [9] and a Equivalent Width of 70Åand its Hβ flux is 1.62×10^{-14} erg cm^{-2} s^{-1} Å-1 [3] which gives a Lyα/Hβ flux ratio of 4.9$\pm$0.1. The Ly-α flux values correspond to luminosities of $L_{Ly\alpha} = 2.2 \times 10^{42}$ erg s^{-1} over a 20Åbandwidth, which in turns translates into a star formation rate of 2.0 M$_{\odot}$ yr^{-1} using a standard conversion factor between luminosity and star formation rate of 9.1×10^{-43} $L_{Ly\alpha}$ M$_{\odot}$ yr^{-1}. The absolute magnitude in the V band translates into a luminosity of 8.9×10^{8} L$_{\odot}$. Comparing this ratio with the theoretical expectation from case B recombination of 23.3 [2] one can estimate an escape fraction of 20% for Lyα radiation.

The optical emission comes from a region with approximate diameter 4 kpc [1].

MCMC constraints

Physical Interpretation

Interpretation by [4].

There is an upper limit for the integrated flux of < 0.10 Jy km s^{-1}, which translates into a upper limit for the HI mass of $M < 2.65 \times 10^{8}$ M$_{\odot}$ [7]. From the optical depth of 10^{7} and the non-detection in the HI line, we have an upper limit for the size where the Lya emission comes of $D < 0.34$kpc.

For an homogeneous sphere the HI optical depth from its can be written as $\tau = \sigma_0 n D/2$, where $\sigma_0 = 5.898 \times 10^{-14}$cm^{-2} is the Lyman$\alpha$ optical depth at the line's center, n is the number density and D is the sphere's diameter. From this we can impose additional constrains on D from the typical values of the Hydrogen number density and our constrain on $\tau = 10^7$. Using a range of $1 < n/\text{atoms}/\text{cm}^{-3} < 10^{-3}$. This gives us a range of $0.11 < D/\text{kpc} < 100$. Together from the total HI mass we have thus that the HI region should have a diameter of $0.11 < D/\text{kpc} < 0.34$.

This can be rewritten in terms of the gas' temperature T and column density $N_H$as $\tau = 3.31 \times 10^{-14}(10^4\text{K}/T)^{1/2}(N_H/\text{atoms cm}^{-2})$.

This allows us to approximate the total hydrogen mass as

$$M_H = m_H N_H D^2 = 226 \times \tau \left(\frac{T}{10^4\text{K}}\right)^{1/2} \left(\frac{D}{\text{kpc}}\right)^2 M_\odot \tag{1}$$

On the other hand, we have an estimate for the dynamical mass from the galaxy size D and its rotational velocity V:

$$M_T = \frac{V^2 D}{G} = 2.16 \times 10^5 \left(\frac{V}{\text{km s}^{-1}}\right)^2 \left(\frac{D}{\text{kpc}}\right) M_\odot \tag{2}$$

From this limit and the rotational velocity of 300 km/s and the limit in the size D we have limits of for the dynamical mass of $2.1 \times 10^9\text{M}_\odot < M_D < 6.6 \times 10^9\text{M}_\odot$. which is at least 7 to 25 times larger than the HI mass. The mass to luminosity ratio is in turn between 2 to 7 times $L_\odot/M_\odot$ considering the total luminosity in the V band.

Joint Effect of Rotation and Outflow

The almost complete absence of outflows is a central requirement for reproducing the Lyα alpha line in Tololo 1214-277. In this section we present some results on the exploration of the presence of outflows join with the bulk rotation. We defer a detailed exploration of this effects for another publication.

Figure XX shows the results of four different models. a) pure rotation ($V_{\text{rot}} = 100$ km s^{-1}), b) pure outflow ($V_{\text{out}} = 100$ km s^{-1}), c) mixed outflow with rotation ($V_{\text{rot}} = 100$ km s^{-1})($V_{\text{rot}} = 25$ km s^{-1}).