Lyman-alpha emission reveals an unusual fastly rotating compact dwarf galaxy

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

[1] Bogota

[2] Tucson

[3] Oslo

Star-forming Compact Dwarf Galaxies (CDGs) resemble the expected pristine conditions of the first galaxies. Until these early galaxy generations are observationally detected, 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 features in its Lyman-α emission thad had evaded theoretical interpretation so far. We show that these special features, a symmetric triple peaked emission line, are naturally explained by gas rotation. We find that the Lyman-α emission region in Tololo 1214-277 should have a rotational velocity of $V_r = 300$ km s^{-1} and a neutral Hydrogen column density of $\log N_{HI}/\text{atoms cm}^{-2} = 20.5$. Using archival observational information we find that the diameter for that region should be in the range of 110 pc $< D < 340$ pc and its total dynamical mass should be between $2.1\times10^{9}\mathrm{M}_{\odot} < M_D < 6.6\times10^{9}\mathrm{M}_{\odot}$. This dynamical mass is at least 16 ± 9 times larger than the neutral mass hydrogen. We argue that a possibility to explain the excess in dynamical mass is the presence of a super-massive black hole.

1. [General paragraph about the first galaxies and CDGs]

2. [General paragrph about the expected Lyman-alpha emission, LARS]. Almost fifty years ago [6] it was realized that young galaxies could be detected through a stron Lyman-α line emission. This theoretical prediction was only confirmed XX year later. Currently, Lyman Alpha Emitting galaxies are commonly measure in surveys. The presence of this line provides confirmation of the distance of a galaxy and also provides clues about the stellar population powering the emission.

Lyman alpha emission is not exclusive of high redshift galaxies. It does, require a low dust content to avoid complete extinction and an source of ionizing radiation. This has motivated the creation of local Universe surveys to perform a detailed study of the Lyman-alpha emission [5]. A nearby simple permits 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.

3. [Observations require interpretation, common features and models]. The Lyman-α line is resonant. A yman-α photon will follow a difussion-like process before escaping the galaxy or being absorbed by dust. This makes it hard to interpret Lyman-alpha line observations as the reulting profile is sensitive to the dynamical, chemical and thermal conditions in the interstellar medium.

State-of-the-art models use mon

4. [Rotation and the expected features.] It has been shown that rotation also imprints an effect on the Lyman-alpha morphology. The most important consequence of rotation is that spherical symmetry is broken. 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 as it is observed in Tololo 1214-277, a unique feature that other theoretical models find impossible to reproduce.

5. [The charachteristics of the dwarf galaxy of interest as a puzzling system]

Tololo 1214-277was first observed by ... it is a compact dwarf galaxy and does not have old stars.

The Lyα emission line was first observed in the Tololo 1214-277galaxy by [8]. It has two main important features which make this a very uncommun LAE. First it shown a symmetric profile which is , Second the Lyα line is not shifted with respect to the Hβ line. Blue compact Dwarf Galaxy

6. [The results of the fit + Physical picture using other results]

Figure 1. shows the observational data for Tololo 1214-277with the overplot from our best fit model from the full radiative transfer simulation. The parameters for the best fit are $v_{max} = 300$km s^{-1}, $\tau = 1 \times 10^7$, $T = 1.5 \times 10^4$K and a viewing angle $\theta < 30$ degrees.

Figura Observed line + fit.

Assuming spherical symmetry and a homogeneous gas distribution we estimate the total neutral hydrogen mass to be on the order of $M \approx m_H \tau^3 \sigma^{-3} n^{-2}$, where m_H is the mass a Hydrogen's atom, τ the optical depth, σ is the cross section at the line's center and n is the number density of neutral Hydrogen atoms. For this system we estimate that for average values of $n = 1 \times 10^3$ the total hydrogen mass is $M \times 10^{14}$M$_\odot$. However, blind HI surveys have put an upper limit in the neutral hydrogen mass of ???

7. [Possible interpretation of this results]

8. [Implications for outflow+rotation in existing samples.]

9. [Future outlook]

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$\alpha(2000)^a$	12h17min17.1s
$\delta(2000)^b$	-28d02m32s
l, b (deg)	294, 34
m_V	17.5
v(km s^{-1})	7795

Table 1: Observational characteristics of TOL1214-277 [8]

Tololo 1214-277 characteristics

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

The observed flux for the Lyman alpha line is $\sim 8.1 \times 10^{-14}$ erg cm^{-2} s^{-1} [8] and a Equivalent Width of 70Åand its Hβ flux is 1.62×10^{-14} erg cm^{-2} s^{-1} cm-2 [3] which gives a Lyα/Hβ flux ratio of 4.9$\pm$0.1. 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 ?? [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 tipical values of the Hydrogen number density and our constrain on $\tau = 10^7$. Using a range of $1 < n/\text{atoms/cm}^{-3} < 10^{-3}$. 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:

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

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 $2.1 \times 10^9 \mathrm{M}_\odot < M_D < 6.6 \times 10^9 \mathrm{M}_\odot$.

which is at least 7 to 25 times larger than the HI mass.

Joint Effect of Rotation and Outflow

The almost complete absence of outflows is a central requirement for reproducing the lyman 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 ($V_{\mathrm{rot}} = 100$ km s^{-1}), b) pure outflow ($V_{\mathrm{out}} = 100$ km s^{-1}), c) mixed outflow with rotation ($V_{\mathrm{rot}} = 100$ km s^{-1})($V_{\mathrm{rot}} = 25$ km s^{-1}).