The Dark Blue Compact Dwarf Galaxy NGC 2915

Gerhardt R. Meurer
The Johns Hopkins University
Department of Physics and Astronomy
Baltimore, MD 21218 **U.S.A.**
meurer@pha.jhu.edu

Abstract

Recent results on NGC 2915, the first blue compact dwarf galaxy to have its mass distribution modeled, are summarized. NGC 2915 is shown to have H I well beyond its detected optical extent. Its rotation curve is well determined and fit with maximum disk mass models. The dark matter halo dominates the mass distribution at nearly all radii, and has a very dense core compared to normal galaxies. High mass star formation energizes the HI in the center of the galaxy, but appears to be maintained in virial equilibrium with the dark matter halo. The implications of these results are briefly discussed.

Keywords: galaxies: individual: NGC 2915 – galaxies: kinematics and dynamics – dark matter

1 Introduction

Dark Matter (DM) is a ubiquitous constituent of the universe; galaxies of all morphologies are now known to contain it. However, most studies of the distribution of DM about galaxies are weighted towards spiral, irregular, and dwarf irregular (dI) galaxies. This is because these often have extended rotating H I disks which act as excellent dynamical tracers out to the large radii where DM dominates. There is one type of gas rich galaxy that has been largely ignored in DM studies: the blue compact dwarf (BCD) class. In the optical, these galaxies are characterised by blue colours, a high surface brightness, and sharp narrow emission lines: the hallmarks of intense massive star formation. In contrast, dI galaxies have similar luminosities, colours and gas content, but much lower surface brightnesses and larger sizes. Although DM has been inferred from the dynamics of BCDs (Viallefond & Thuan, 1983), the study I describe presents the first detailed mass model decomposition of a BCD rotation curve. Whatever the reasons for neglecting BCDs in the past, I hope this study demonstrates that BCDs are well worthy of further attention, and that they may tell us something new about DM halo properties of galaxies.

The BCD galaxy NGC 2915 has a low surface brightness exponential radial surface brightness profile at large radii, and a high surface brightness blue core at its center (Meurer *et al.* 1994). Although its appearance is somewhat peculiar (Sérsic *et al.* 1977), its optically determined properties are not particularly exciting compared to other spectacular examples of the BCD class (e.g. IZw18, IIZw40, NGC 1569, NGC 1705). Becker *et al.* (1988), in a study of bright southern galaxies, showed that NGC 2915 is extended in H I, has a double horned velocity profile, and a large $\mathcal{M}_{\rm HI}$ for its luminosity. It is these properties that made us decide to observe the galaxy with the Australia Telescope Compact Array (ATCA); extended H I distributions invariably reveal the

Table 1: Properties of NGC 2915

Quantity	Value	Comments
D	5.3 ± 1.6 Mpc	distance[a]
M_{B_T}	–15.90 mag	absolute magnitude
$R_{\rm Ho}$	2.93 kpc	Holmberg radius[b]
$R_{\rm HI}$	14.9 kpc	H I radius[c]
$R_{\rm HI}/R_{\rm Ho}$	2.7	
$\mathcal{M}_{\rm HI}$	$9.58 \times 10^8\,\mathcal{M}_\odot$	H I mass
$\mathcal{M}_{\rm HI}/L_B$	$2.7\ (\mathcal{M}/L_B)_\odot$	

Notes: (a) - Consistent with $H_0 = 50\,{\rm km\,s^{-1}\,Mpc^{-1}}$. (b) - Radius of isophote having B surface brightness of 26.5 mag arcsec^{-2}. (c) - Radius having face on column density $N_{\rm HI} = 5 \times 10^{19}\,{\rm cm^{-2}}$.

DM halo of galaxies. Some important properties of NGC 2915 are summarized in table 1. Details of our H I study of NGC 2915 can be found in Meurer *et al.* (1996). Here I will present the main results and their implications.

2 HI properties

In Fig. 1 the optical (I band) and H I morphologies of NGC 2915 are compared. The H I is very extended relative to the optical and has a barred spiral morphology. The optical counterpart corresponds well in size and position angle to the bar (and does not extend beyond it to our detection limits). The velocity field is dominated by the rotating disk, but also shows the oval distortion due to the bar: the kinematic major and minor axes are not aligned. The disk is quiescent beyond the optical extent, having a velocity dispersion of $\sigma \approx 8$ km s^{-1}, which is common for spiral galaxies. Near the center of the galaxy the velocity dispersion reaches $\sigma \approx 40$ km s^{-1}, and the H I line is often split. The broad and split line profiles are associated with massive star forming regions and expanding bubbles that are prominent in the Hα image of Marlowe *et al.* (1995). Thus star formation is energizing the neutral interstellar medium in the center of NGC 2915.

The rotation velocity $V_{\rm rot}$ curve of NGC 2915 is shown in Fig. 2. The raw $V_{\rm rot}$ measurements were corrected for pressure support (asymmetric drift) to obtain circular velocities V_c, which are also shown. The optical portion of NGC 2915 is wholly contained in the rising portion of the rotation curve. This is where rotational shear is minimized, hence where molecular clouds have the longest lifetime and star formation should be most efficient. The rotation curve levels off shortly beyond the Holmberg radius $R_{\rm Ho}$, remains approximately flat out to about 10 kpc, and then rises again out to the last measured point ($R = 15.2$ kpc).

3 Dark Matter Halo Properties

Figure 2 shows maximum disk mass model fits to NGC 2915's V_c curve. There are three components to the mass models: (1) a stellar disk parameterized by its mass to light ratio, here set at $\mathcal{M}_*/L_B = 1.2(\mathcal{M}/L_B)_\odot$ (the maximum allowed by the innermost V_c measurement); (2) a neutral gaseous disk whose mass distribution is determined directly from the ATCA data; and (3) a spher-

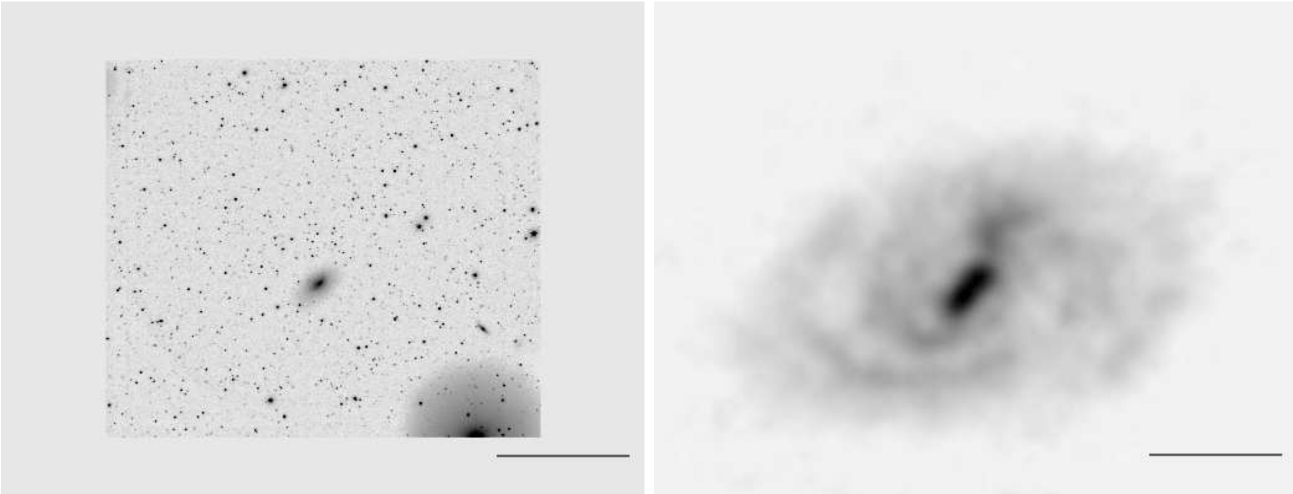

Figure 1: NGC 2915 in the I band (left) from an 800s integration using the Anglo-Australian Telescope, and in total H I emission (right) from our ATCA observations. North is up, east is to the left, and the scalebars are $5' = 7.7$ kpc long.

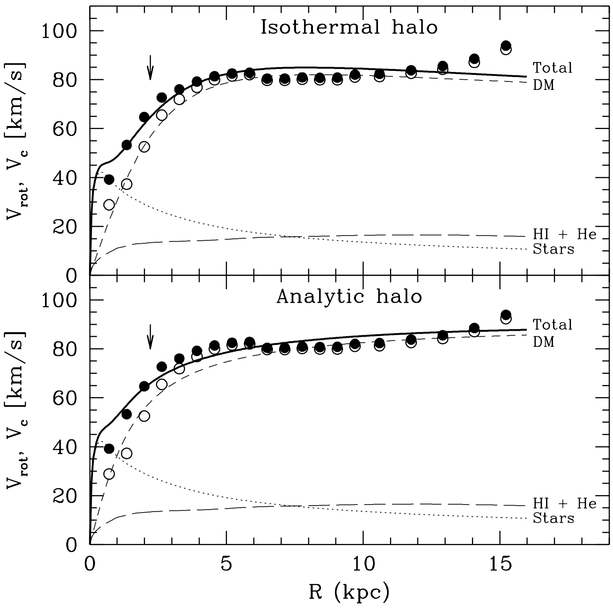

Figure 2: Rotation curve of NGC 2915 compared to two mass models. Raw rotation velocities $V_{\rm rot}$ are shown with open symbols, while pressure support corrected circular velocities V_c are shown as closed symbols. The Holmberg radius $R_{\rm Ho}$ is indicated with the vertical arrows.

Table 2: DM halo fits

Parameter	Halo model Isothermal	Analytic
R_c [kpc]	2.8 ± 0.2	1.2 ± 0.2
σ_0 [km s^{-1}]	51.7 ± 0.9	41.0 ± 1.1
ρ_0 [$\mathcal{M}_\odot$ pc^{-3}]	0.058 ± 0.009	0.10 ± 0.02
$M_T/L_B(R_{\rm Ho})$ [solar units]	10.0	9.6
$M_T/L_B(R_{\rm HI})$ [solar units]	66	76

ical dark matter halo parameterized by a velocity dispersion σ_0, which determines the level of the flat part of the rotation curve, and the core radius R_c, which determines the location of the knee in the rotation curve. These parameters yield the central DM density ρ_0. Two types of DM halo were fitted (a) a non-singular isothermal sphere, and (b) an analytic DM density distribution:

$$\rho(R) = \frac{\rho_0}{1 + (R/R_c)^2}.$$

Both forms produce flat V_c curves at large R, but have different density distributions and different scaling relations between R_c, ρ_0, σ_0 and the asymptotic V_c at $R = \infty$ (Lake *et al.* 1990; Binney & Tremaine, 1987). The parameters of the two fits are given in table 2. The isothermal halo does not fit our data as well as the analytic halo. However, many fits in the literature use this form to model the DM halo, so we include its fit for comparison.

The important things to note about the mass model fits are: (1) The neutral gaseous disk is more massive than the maximum stellar disk, hence NGC 2915 is not a very evolved galaxy. (2) DM dominates at nearly all radii. For the analytic model, $\mathcal{M}_T/L_B = 76$ within the last measured point, making NGC 2915 along with DDO 154 (Carignan and Beaulieu, 1989), the darkest known disk galaxies. (3) The DM central velocity dispersion σ_0 is equal to or greater than the $\sigma_{\rm HI}$ in the center. Thus although the H I is violently energized by star formation, it is still in virial equilibrium with the DM halo. This suggests that the DM halo may be involved in regulating NGC 2915's star formation: if the star formation rate gets too high it will over-energize the ISM so that $\sigma_{\rm HI} \gg \sigma_0$, then the ISM will be blown out of the core and star formation will be halted. (4) The halo core is an order of magnitude denser than found in "normal" disk galaxies. This is illustrated in Fig. 3 which plots ρ_0 versus M_B for disk galaxies of various types.

4 NGC 2915's oddness and how to put it in its place

NGC 2915 is an interesting galaxy because of its extremely odd qualities: its large DM content, the contrast between its optical and H I properties, and the high ρ_0 of its DM halo. It is also recalcitrant compared to normal galaxies because: (1) it does not obey the Tully-Fisher relationship; (2) its neutral gas disk is $\sim 10\times$ under dense for it to have the star formation observed in the core (Kennicutt, 1989); (3) similarly, the outer disk is $\gtrsim 2\times$ underdense for it to have the spiral arms that are observed. This suggests that some of its DM is in the disk, perhaps in a molecular form. These properties are discussed more fully in Meurer *et al.* (1996).

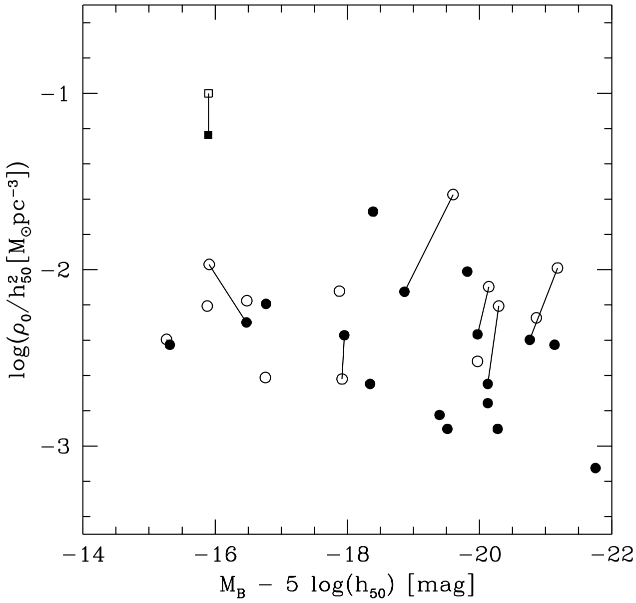

Figure 3: DM halo central density ρ_0 compared to absolute magnitude, where both quantities have been corrected (to first order) for the different distance scales. Here $h_{50} = H_0/(50\,\mathrm{km\,s^{-1}\,Mpc^{-1}})$ is the dimensionless Hubble constant used in the individual studies. Circles represent fits to dI and spiral galaxies, while the squares represent the fits to NGC 2915 presented here. Solid symbols show isothermal sphere halo model fits, hollow symbols shows analytic halo model fits. Connected points represent different halo models fit to the same object. The dI and spiral data were taken from Puche & Carignan (1991), Begeman et al. (1991) and Sanders (1996 and references therein).

NGC 2915 is an important galaxy because it is not that odd compared to other BCDs which often have very extended H I and similar radial profiles of H I surface density (often centrally peaked) and velocity dispersion, as well as flat rotation curves at large radii (Taylor *et al.* 1994; 1995; Hunter *et al.* 1994; Meurer 1994; Brinks & Klein, 1988; Viallefond & Thuan, 1983). This suggests BCDs as a class have fundamental structural differences from dI and spiral galaxies, and NGC 2915 is only odd because it is the first BCD examined in such detail.

It is therefore important to do further detailed H I studies of BCDs. There are two issues in particular that need to be addressed. Firstly, if the abnormally high ρ_0 of NGC 2915 is common to BCDs, then transformations between BCD and dI morphologies could not be accomplished by turning starbursts on and off. Fundamental structural changes to the DM distributions would also have to occur, and this seems hardly likely. Such a result would make it hard or impossible to reconcile BCDs and dIs to some common evolutionary scenario. Secondly, the near equality between $\sigma_{\rm HI}$ and σ_0 of the DM in NGC 2915 suggests that the star formation is held in equilibrium with the DM halo. This is contrary to the common perception of explosive starbursts dominating the star formation and dynamics of BCDs. Further large sample comparisons of starburst dynamics and halo properties are needed to determine if there is a feedback mechanism operating between the two structures.

There may be a more mundane explanation for NGC 2915's peculiarities. Meurer *et al.* (1994) determined D from the colour-magnitude diagram of NGC 2915's bright stars and star-clusters. If it is more distant by a factor of $\sim$ two (i.e. larger than their stated D uncertainty) many of its odd properties would disappear. A better D determination and a search for faint stellar light associated with the H I disk (both could be done with the *Hubble Space Telescope*) may reduce

NGC 2915's odd qualities to its peculiar motion relative to the Hubble flow.

So what is the relevance of NGC 2915 to the multibeam survey? NGC 2915 was painstakingly mapped by Becker *et al.* (1988) with the Parkes radio telescope, pointing at 19 positions plus sky, and requiring over three hours of telescope time. It is these observations that first indicated NGC 2915's huge H I extent. The multibeam survey is bound to uncover similar galaxies with extended H I disks using integration times of only a few minutes. This study illustrates what follow-up observations with the ATCA or *Very Large Array* may reveal about the DM distribution and dynamics of such galaxies.

Acknowledgments

I thank the coauthors of my NGC 2915 studies, Sylvie Beaulieu, Claude Carignan, Ken Freeman, and Glen Mackie for all the work they did. Sylvie Beaulieu and Chris Mihos kindly read and commented on the paper before submission. The *American Astronomical Society* generously supplied me with a travel grant to attend the multibeam workshop. I am grateful to the organizers of the workshop for arranging local funding, and to Lister Staveley-Smith and Jessica Chapman for opening their home to me during my stay in Sydney.

References

Becker, R., Mebold, U., Reif, K., & van Woerden, H. 1988, A&A, **203**, 21.

Begeman, K.G., Broeils, A.H., & Sanders, R.H. 1991, MNRAS, **249**, 523.

Binney, J., & Tremaine, S. 1987, *Galactic Dynamics*, (Princeton University Press, Princeton).

Brinks, E., & Klein, U. 1988, MNRAS, **231**, 63P.

Carignan, C., & Beaulieu, S. 1989, ApJ, **347**, 760.

Hunter, D.A., O'Connell, R.W., & Gallagher, J.S. 1994, AJ, **108**, 84.

Kennicutt, R.C. 1989, ApJ, **344**, 685.

Lake, G., Schommer, R.A., & van Gorkom, J.H. 1990, ApJ, **320**, 493.

Marlowe, A.T., Heckman, T.M., Wyse, R.F.G., & Schommer, R. 1995, ApJ, **438**, 563.

Meurer, G.R. 1994, in *ESO/OHP Workshop on Dwarf Galaxies (ESO Conference & Workshop Proceedings no. 49)*, edited by G. Meylan, & P. Prugniel, (ESO, Garching), p. 351.

Meurer, G.R., Mackie, G., & Carignan, C. 1994, AJ, **107**, 2021.

Meurer, G.R., Carignan, C., Beaulieu, S., & Freeman, K.C. 1996, AJ, **111**, 1551.

Puche, D., & Carignan, C. 1991, ApJ, **378**, 487.

Sanders, R.H. 1996, ApJ, *accepted*.

Sérsic, J.L., Bajaja, E., & Colomb, R. 1977, A&A, **59**, 19.

Taylor, C.L., Brinks, E., Pogge, R.W., & Skillman, E.D. 1994, AJ, **107**, 971.

Taylor, C.L., Brinks, E., Grashuis, E., & Skillman, E.D. 1995, ApJS, **99**, 427.

Viallefond, F., & Thuan, T.X. 1983, ApJ, **269**, 444.