Astron. Astrophys. 327, 963–965 (1997)

ASTRONOMY
AND
ASTROPHYSICS

*Research Note*

# The surface brightness and distance of Dwingeloo 1

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Received 28 April 1997 / Accepted 21 July 1997

**Abstract.** The Tully-Fisher distance to the galaxy Dwingeloo 1, recently discovered very close to the Galactic Plane, is highly uncertain because of the range of possible foreground extinction values which have been suggested. We show that very high values of $A_B$ ($\sim$ 10 magnitudes) or low values ($\sim$ 4 magnitudes) are unreasonable since the intrinsic surface brightness implied for Dwingeloo 1 would be unrealistically high or low for a mid type disc galaxy. Obtaining 'normal' surface brightness values requires $A_B$ close to 6 magnitudes. We therefore concur with distance estimates which suggest values $\sim$ 3 Mpc.

**Key words:** galaxies: individual: Dwingeloo 1 – galaxies: distances and redshifts – galaxies: photometry – dust, extinction

## 1. Introduction

Kraan-Korteweg et al. (1994) recently discovered a large nearby spiral galaxy hidden directly behind the Galactic Plane ($b = -0.^\circ 1$), in the same general direction as the IC 342/Maffei I group. The galaxy, known as Dwingeloo 1, was discovered with the Dwingeloo 25-m radio telescope during a concerted campaign to detect heavily obscured galaxies. It was independently detected shortly afterwards by Huchtmeier et al. (1995) with the Effelsberg 100-m telescope.

Dw1 is just visible on the red (E) POSS I plates but does not appear on the corresponding blue (O) plate and was identified as a candidate optically obscured galaxy by Hau et al. (1995). Loan et al. (1996; henceforth L96) have presented deep multicolour CCD photometry and discuss attempts to determine the distance to Dw1 via the Tully-Fisher (1977) relation. This distance obviously depends on the apparent magnitude and is thus critically dependent on the adopted foreground extinction. From various methods L96 obtain estimates of the extinction which span the range $A_B$ = 4.3 to 10.4 magnitudes. This in turn leads to distance errors of a factor 3 or more (see their Table 3).

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However, a notable feature of present epoch spiral galaxies is that there appear to be upper and lower limits to their disc central surface brightnesses (eg. van der Kruit 1990, de Jong 1995). Indeed it has often been argued that they all conform to a very narrow range in surface brightness (Freeman 1970). In the present note we discuss whether considerations of the surface brightness can place constraints on the extinction towards, and hence distance of, Dw1.

## 2. Surface brightness

From Fig. 2 of L96 we can see that the extrapolated disc central surface brightness $\mu_0$ (in magnitudes per square arc second) should be well determined from a fit to the profile in the range $r$ = 1 to 3 arc minutes (which is clearly disc dominated). We further assume that there are no intrinsic colour gradients in the disc, ie. we fit all three profiles with the same slope. (This ensures that the derived central colour matches the actual observed colour in the 1 - 3 arcmin range used). Fitting the profile in this way gives $\mu_0^V$ = 25.9, $\mu_0^R$ = 24.1, $\mu_0^I$ = 22.6. We assume that internal extinction and the inclination correction to face-on (from $\cos i \simeq$ 0.7) are small ($\sim$ 0.2 magnitudes) and, of course, in opposite directions as far as the surface brightness is concerned.

The values of $\mu_0$ are clearly much fainter than would be expected for a normal galaxy of its suggested type of SBb or SBc. The canonical Freeman (1970) value of $\mu_0^B$ = 21.65 would suggest central surface brightnesses around 21.0, 20.6 and 20.1 in $V$, $R$ and $I$. Note that from its rotation velocity we expect an absolute magnitude $M_R \simeq -18.5$ (for $H_0$ = 75km s$^{-1}$Mpc$^{-1}$) so Dw1 is a genuine giant spiral not a dwarf.

## 3. Extinction

L96 adopt three different methods for estimating the extinction towards Dw1. First, from the expected mean colour of an Sbc galaxy (Buta & Williams 1995) and their estimates of the total apparent magnitudes in each band they obtain $E_{B-V}$ = 3.0$\pm$1.5 from the $V-R$ colour and 2.1$\pm$0.6 from $V-I$. This gives them a mean (assuming $R_V$ = 3) of $A_B$ = 10.4 ± 4.0. Alternatively, from the measured HI column density towards Dw1 (Burton & Hartmann 1994) and the standard relation between HI and extinction (Burstein & Heiles 1982) they find $A_B$ = 5.8. Finally, from the Galactic diffuse $100\mu m$ IRAS flux in this direction, and the conversion factor given by Rowan-Robinson et al. (1991), they obtain $A_B$ = 4.3.

What can we say from the point of view of surface brightness? As L96 note, if the extinction really were as high as 10 magnitudes then Dw1 probably should not be visible at all. More quantitatively, it is easy to see that for our canonical surface brightness $\mu_0^B$ = 21.65, the observed surface brightnesses would never be brighter than 30 magnitudes per square arc second and Dw1 would, indeed, be totally invisible. In order to reconcile the observed surface brightnesses with the 'standard' values we would need $\Delta\mu_0^V \simeq 4.9$, $\Delta\mu_0^R \simeq 3.5$ and $\Delta\mu_0^I \simeq 2.5$. If we assume the standard reddening law such that $A_B = 1.34 A_V = 2.0 A_R = 2.3 A_I$ (Mathis 1990), used by L96, then these values of $\Delta\mu_0$ imply, respectively, $A_B$ = 6.5, 7.0 and 5.7. These values are in reasonable mutual agreement and are similar to the value deduced from the HI - the one actually adopted by L96 - and, to a lesser extent, to that from the FIR measurements.

However, they disagree dramaticaly (as expected, given that we *can* see Dw1) with L96's finding of a very large $A_B$ from the colours. (This is somewhat odd inasmuch as both our observed and expected standard disc colours are identical to the 'total' colours used by L96). If the extinction really were 10 magnitudes at $B$, then (with $A_V = 7.5, A_R = 5.0, A_I = 4.2$) we would have intrinsic central surface brightnesses of 18.4, 19.1 and 18.4 in $V$, $R$ and $I$. These are much brighter than seen in any normal spiral galaxy discs (eg. de Jong 1995), and also imply a highly implausible negative $V - R$ colour. Taking a maximum central value to be $\mu_0^B$ = 20 (de Jong 1995, chapter 3), or about $\mu_0^V$ = 19.5, we cannot allow more than 8.5 magnitudes of extinction at $B$. This would give $\mu_0^V \simeq 19.5$, $\mu_0^R \simeq 19.8$ and $\mu_0^I \simeq 19.0$, and still has the problem of a very blue $V - R$.

In fact, all reasonable choices which give sensible surface brightnesses lead to colours too blue in $V - R$ for the corresponding $R - I$. It is tempting to speculate that this may be due to a problem with the photometry reported by L96. For instance, a 0.5 magnitude shift in the zero point of the $R$ band data would give generally much more believable colours. (It would also explain why L96 obtain such a large extinction from the $V - R$ colour). For instance, the fairly extreme case $A_B$ = 8 would then give $\mu_0^V$ = 19.9, $\mu_0^R$ = 19.6, $\mu_0^I$ = 19.2, which is perhaps not too unreasonable for a high surface brightness disc. A more conventional disc would be obtained in the case $A_B$ = 6 (close to the mean of our original estimates), which gives $\mu_0^V$ = 21.4, $\mu_0^R$ = 20.6 ('corrected' from 21.1), $\mu_0^I$ = 20.0. If we finally lower $A_B$ to 4, we have $\mu_0^V$ = 22.8, $\mu_0^R$ = 21.6 (22.1 with no correction), $\mu_0^I$ = 20.9. This is both very red in at least one of the indices (with or without our putative correction) and beyond the lower limit of observed disc surface brightnesses ($\mu_0^B$ approaching 24, compared to de Jong's faintest objects at about 23).

## 4. Discussion

We conclude that on the basis of the surface brightness, an extinction $A_B$ in the range 5 to 8 seems most likely. Reducing $A_B$ below 5 (eg. to the value 4.3 deduced from the IRAS sky flux) requires Dw1 to have an exceedingly low surface brightness for a giant spiral. Similarly $A_B$ above 8 would require Dw1 to exceed the limits attained by known high surface brightness objects. $A_B$ around 6 to 6.5 would imply perfectly 'normal' properties for Dw1. This agrees well with the totally independent estimate from the Galactic HI column density in this direction, $A_B$ = 5.8, especially if we allow for a small amount of extra extinction (ie. dust) associated with molecular material. [The CO intensity in this direction $l$ = 138° is low, probably less than 2 K km s$^{-1}$ (see maps in Dame et al. 1987); if it is of order 1 K km s$^{-1}$ then this would add ∼ 0.8 magnitudes to $A_B$ (see eg. Phillipps et al. 1991)].

We might ask if there is any way in which we could refine our estimate of the extinction and hence distance. Unfortunately surface brightness correlates very weakly, if at all, with other optical properties (see Disney & Phillipps 1985). Possibilities might come from the FIR flux, however, and these also have the advantage of themselves being independent of the extinction. Since $L_{FIR}/L_B$ increases as the surface brightness increases (Phillipps & Disney 1988,), then for a given $L_{FIR}$ an underestimate of $A_B$ will force the estimated surface brightness down but $L_{FIR}/L_B$ up (and *vice versa* for overestimated extinction), ie. a shift roughly perpendicular to the intrinsic correlation. This might give a rough joint estimate of $A_B$ and the intrinsic $\mu_0^B$. Alternatively the FIR colour $L_{60}/L_{100}$ also correlates positively with surface brightness (Davies et al. 1989) so an estimate of this ratio might give a direct measure of $\mu_0^B$. Unfortunately both correlations have rather wide scatter (∼ ±1 magnitude) at fixed FIR value, but nevertheless they might provide independent support for 'high' or 'low' values of surface brightness. At present the status of the measurement of the FIR flux from Dw1 is extremely uncertain. Taking the observations reported in L96 at face value (∼ 2 Jy at $60\mu m$, ∼ 15 Jy at $100\mu m$) leads to a rather cool FIR colour, corresponding to a relatively low surface brightness, and hence a lowish extinction. However it is not in fact clear that Dw1 is the true source of the observed FIR emission since it may be confused by Galactic Plane sources, so this 'refinement' remains tentative. Our best estimate thus remains around $A_B$ = 6.

Finally, then, we can consider the actual distance determination. If we use the standard T-F relations used by L96, then clearly we will obtain values close to those which L96 quote for their model with $A_B$ = 5.8, ie. $D \simeq 3 - 4$ Mpc (cf. also Kraan-Korteweg et al. 1994). In fact, if we take our best range of extinctions to be 6 to 6.5 magnitudes in $B$ (ie. 2.6 to 2.8 magnitudes in $I$ and 3.0 to 3.2 magnitudes in $R$) then using L96's apparent magnitudes in Mathewson et al.'s (1992) $I$ band and Willick et al.'s (1995) $R$ band T-F relations we obtain 3.1 – 3.5 and 3.3 – 3.6 Mpc respectively. (If L96's $R$ band data are actually too faint, as suspected above, the latter figures are reduced by up to 25%).

An alternative route is to use the diameter version of the T-F relation. From Persic et al. (1996, and references therein) we have, roughly, rotation velocity $V$ = 200 ($R$/13 kpc)$^{0.82}$ km s$^{-1}$, so a spiral with $V \simeq 113$ km s$^{-1}$ (as used by L96) should have an optical radius $R_0$ corresponding to exponential scale size $a = R_0/3.2 \simeq 2.1$ kpc. From the profile data shown in Fig. 2 of L96, the angular scale size is close to $160''$, thus implying a distance of about 2.7 Mpc, in reasonable agreement with our above values. Note that this estimate is independent of the extinction, since it uses only the radial variation of surface brightness to determine the scale length. However, it is not really independent of our other distance estimate since it implicitly uses 'normal' surface brightness galaxies as its calibration. If lower surface brightness galaxies tend to have larger scale sizes at a given rotation speed (see Zwaan et al. 1995), then we have the same degeneracy as before; in principle, Dw1 could be a slightly lower surface brightness, physically larger galaxy suffering less extinction and correspondingly somewhat further away.

Nevertheless, we can reiterate our main conclusion that the distance to Dw1 is around 3 Mpc, not the values $\sim$ 1.5 Mpc or 5 Mpc which would be derived by extreme, and we would claim physically implausible, values of the Galactic extinction.

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