The Disturbed ISM of the Local Group Dwarf Galaxy NGC 6822

W.J.G. de Blok
Australia Telescope National Facility, PO Box 76, Epping NSW 1710, Australia, email: edeblok@atnf.csiro.au

F. Walter
California Institute of Technology, Astronomy Department 105-24, Pasadena, CA 91125, USA, email: fw@astro.caltech.edu

Abstract.
We present a first wide-field, high spatial and velocity resolution map of the entire extended HI distribution of the nearby Local Group dwarf galaxy NGC 6822. The observations were obtained with the Parkes single-dish telescope and the Australia Telescope Compact Array in mosaicing mode. NGC 6822 has an extended HI-disk which is shaped by the presence of numerous HI holes and shells, including a supergiant shell, and the effects of tidal interaction, in the form of a tidal arm and an infalling or interacting HI complex. These tidal features are not obvious in lower resolution data, and only the proximity of NGC 6822 enables us to see them clearly. This suggests that the importance of minor interactions in dwarf galaxies may be larger than previously assumed.

1. Introduction

Dwarf irregular galaxies are ideal laboratories to study galaxy evolution. Their relatively simple structure, without dominant spiral arms, bulges, and other complicating properties make it less difficult to disentangle the various physical processes occurring in these galaxies. Their low metallicities and gas-richness suggest that they are still in an early stage of their conversion from gas into stars, and that they could therefore provide information about galaxy evolution as it took place in normal galaxies at earlier epochs.

NGC 6822 is one of the closest gas-rich dwarfs in our Local Group and is a proto-typical dwarf irregular. Discovered by Barnard (1884), it was studied in detail by Hubble (1925) who showed that its distance placed it well outside our Milky Way galaxy, making NGC 6822 the first galaxy to be recognized as an “extra-galactic” system.

No nearby companions are known (Mateo 1998, van den Bergh 1999). The galaxy is at a distance of 490 ± 40 kpc (Mateo 1998), giving a linear resolution of $1^\prime = 2.5$ pc. Its absolute magnitude is $M_B = -15.85$ (Hodge et al. 1991) making it $\sim 1.5$ mag fainter than the SMC. The optical diameter $d_{25}$ is 18.3′ (2.7 kpc). Its optical appearance is dominated by a Magellanic bar and star forming
regions. The metallicity is low: the oxygen abundance is $12+\log O/H = 8.3\pm0.1$ (Skillman et al. 1989) and its stellar metallicity is $0.004 Z_\odot$ (Gallart et al. 1996a).

In the past, NGC 6822 has already been the subject of many studies investigating its stellar population, sites of star formation and star formation history. (e.g. Gallart et al. 1996abc, Hodge et al. 1991). Due to its proximity such studies are already feasible using ground-based optical telescopes. Other studies have investigated possible relations between star formation and molecular content (e.g. Petitpas & Wilson 1998, Israel 1997) and the galaxy has been extensively studied in X-rays using the ROSAT and Einstein satellites (e.g. Eskridge & White 1997).

While its low galactic latitude ($b = -18.4^\circ$) is a nuisance for optical studies (because of the high stellar density, foreground extinction, reddening $[E(B-V) = 0.24 \pm 0.03; \text{Gallart et al. 1996a}]$), its low recession velocity of $-55 \text{ km s}^{-1}$ has proven to be a potential problem for 21-cm neutral hydrogen HI observations as the velocities of the local Galactic emission partly overlap those of NGC 6822. This confusion, as well as NGC 6822’s large size, may be the reason why to date only surprisingly few HI studies of this galaxy have appeared in the literature, even though its inclination, gas-richness, isolation and proximity make it an ideal candidate for studying the rotation curve, dark matter content and relation between the stellar population and gaseous ISM.

The earliest HI study of NGC 6822 is that by Volders & Högboom (1961) who used the 25m Dwingeloo telescope to probe NGC 6822 and its environs. They found evidence for a large amount of neutral hydrogen ($1.5 \times 10^8 M_\odot$) rotating in ordered fashion around the optical center. Later studies by Davies (1970) and Roberts (1970), confirmed these results. The first interferometer study was done by Gottesman & Weliachew (1977; G&W hereafter) who observed the optical centre in HI using the Owens Valley Radio Observatory interferometer. Their observations, with a resolution of $2.3' (330 \text{ pc})$ already showed a highly structured ISM as was later confirmed by Brandenburg & Skillman (1998) (see also Hodge et al. 1991).

To trace the full extent of NGC 6822’s neutral hydrogen distribution we present first results of new wide-field and high-velocity-resolution observations obtained with the narrowband filterbank and the multibeam system at the Parkes Telescope and multiple configurations of the Compact Array synthesis radio telescope. The high velocity resolution allows us to separate Galactic from galaxy emission and therefore gives us the clearest view yet of the HI in NGC 6822.

2. Single Dish data

NGC 6822 was observed on 16 December 1998 using the ATNF Parkes Telescope in Australia utilising the narrow-band back-end system and the multi-beam system. We used a bandwidth of 4 MHz and channel width of 0.8 km s$^{-1}$. The telescope beam size is $14.4' \times 21.0'$. An area of $4 \times 4$ degrees was observed. The individual bandpass-corrected single-beam, single-polarization spectra were gridded into a data cube. Because of the small amount of smoothing that is intrinsic to the gridding process the effective beam size ended up being $16.7' (2.5 \text{ kpc})$. As expected, confusion with the Galaxy was present in a number of
Figure 1. Total HI column density map of NGC 6822 (contours) overlaid on an optical image from the DSS (grayscale). Contours are 0.2, 0.5, 1, 2, 3, 4, 5, 6, 7, 8 × 10^20 atoms cm^{-2}. The effective beam size is 16.7'. The HI distribution is clearly more extended than the optical distribution.

channels — in these we were able to isolate the NGC 6822 signal by determining in each channel map the median flux in a ring surrounding the NGC 6822 signal and subtracting that value from the channel map.

A total HI column density map is shown in Fig. 1 overlaid on an image obtained from the Digital Sky Survey (DSS). Note that the HI is much more extended than the optical galaxy. Even when taking the large beam size of 16' (2.5 kpc) into account the extent of HI along the major axis is still more than a degree (9 kpc). Compared to the optical d25 diameter the HI disk is about three times more extended. The disk looks asymmetrical with the SE (receding) side less extended than the NW (approaching) side. This suggests that the HI disk is intrinsically asymmetric, as hinted at by the G&I (1977) observations of the inner 20'. We derive a total HI mass of (1.3 ± 0.1) × 10^8 M⊙ from these data.

A full dynamical analysis of NGC 6822 is beyond the scope of this paper. This would require a detailed analysis of the rotation curve at higher resolution as well as a mass decomposition using the various mass components. We can
however still estimate the dark matter content of NGC 6822. This only depends on \( V_{\text{max}} \), which is a well-determined quantity. We find \( V_{\text{max}} = 57 \, \text{km} \, \text{s}^{-1} \) at \( R_{\text{max}} = 5.7 \, \text{kpc} \). This yields a dynamical mass within that radius of \( M_{\text{dyn}} = 4.3 \times 10^9 \, M_\odot \).

For computing the visible mass we use the \( \text{HI} \) mass derived above, multiplied by 1.4 to take the helium contribution into account. For the stellar mass we use the absolute \( B \)-band magnitude\(^1\) and assume a stellar mass-to-light ratio \( M/L_B = 1 \), which is not an unreasonable value for dwarf galaxies. This yields \( M_{\text{HI}}/L_B = 0.7, \) \( M_{\text{dyn}}/L_B = 23, M_{\text{dyn}}/M_{\text{vis}} = 11 \). It is clear that dark matter dominates the dynamics of NGC 6822.

The global properties of NGC 6822 are those of a typical dwarf irregular galaxy. The single dish data presented here have the same linear resolution as those made of a dwarf galaxy at 30 Mpc using an instrument like the VLA, WSRT or ATCA. We are now in the position to use follow-up high-resolution ATCA data to “zoom in” on NGC 6822 and see what the low resolution is hiding from us.

3. Compact Array Observations

NGC 6822 was observed with the Australia Telescope Compact Array for 15×12 hours in its 375, 750D, 1.5A, 6A and 6D configurations over the period from June 1999 to March 2000. A total of 8 pointings was observed covering the entire \( \text{HI} \) extent of the galaxy. We used a bandwidth of 4 MHz, divided into 1024 channels, giving a channel separation of 0.8 km s\(^{-1} \). In this paper we will restrict ourselves to the data set that does not include the 6km configurations. Also this data is not yet corrected for missing short spacings. The clean synthesized beam of this medium resolution data set measures 89\(^{\prime}\) × 24\(^{\prime}\) (222 × 60 pc).

Figure 2 shows the integrated \( \text{HI} \) column density map as derived from our data. Also shown is the column density map overplotted on an optical DSS image. The \( \text{HI} \) is much more extended than the optical distribution, extending out to galactocentric radii of 40 arcmin (\( \sim 6 \, \text{kpc} \)). We find a total \( \text{HI} \) mass of \( 1.1 \times 10^8 \, M_\odot \). A comparison with the single dish Parkes \( \text{HI} \) mass of \( (1.3 \pm 0.1) \times 10^8 \, M_\odot \) shows that we are missing only a small fraction of the flux due to missing short spacings.

4. Features in the neutral ISM

A lot of structure in the form of holes and shells is present in the \( \text{HI} \) disk. The three striking features are apparent that we will discuss briefly: these are the hole and arm in the SE, and the cloud in the NW. For a more extensive discussion of these features we refer to de Blok & Walter (2000).

**A supergiant \( \text{HI} \) hole** In the SE a giant \( \text{HI} \) hole or shell is dominating the appearance of the galaxy. Its angular size is 14\(^{\prime}\) × 10\(^{\prime}\) (as indicated in

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\(^1\) Unfortunately \( M_B \) is not very well constrained. Hodge et al (1991) use \( M_B = -15.85 \); Gallart et al. (1996a) quote \( M_B = -14.1 \); G&W (1977) use \( M_B = -15.1 \). In the following we have used the mean of these three numbers.
Figure 2. Top: Integrated H\textsubscript{i} column density map. Contours are $(1, 4, 7, 10, ..., 31) \times 10^{20}$ cm$^{-2}$. The beam of $89'' \times 24''$ is indicated in the lower-right corner. Bottom: Integrated H\textsubscript{i} column density contours overlaid on optical image from the DSS. Contour values are same as in left panel. Note how the inner edge of the hole is traced by the optical emission, notably in the south. The three features of hole, cloud and arm as discussed in the text are indicated. The outline of the hole is shown by the grey dashed ellipse.
Fig. 1), corresponding to $2.0 \times 1.4$ kpc, measured at a column density level of $10^{21}$ cm$^{-2}$ (see also Brandenburg & Skillman 1998).

In the standard picture, H\textsc{i} shells and supershells are caused by the stellar winds of the most massive stars in a cluster as well as subsequent SN explosions (for reviews see Kulkarni & Heiles 1988, van der Hulst 1996 and Brinks & Walter 1998). If the hole was indeed created by past massive star formation, we can derive some approximate numbers regarding the energies and ages involved. If we assume that the expansion velocity of the hole has reached values similar to the dispersion of the ambient ISM in NGC 6822 ($\sim 7$ km s$^{-1}$), we derive a kinematic age of 130 Myr. The kinematic age is an upper limit for the actual age since the shell was presumably expanding more rapidly in the past. Using Chevalier’s equation (Chevalier 1974), we derive an energy of $10^{53}$ erg needed to create the H\textsc{i} shell, equivalent to 100 Type II supernovae (using $V_{\text{exp}} = \sigma_{\text{gas}} = 7$ km s$^{-1}$, $n_{\text{HI}} = 0.1$ cm$^{-3}$ and $r_{\text{hole}} = 850$ pc). Note that it is not necessary that these supernovae go off at the same time, which would need a massive parent cluster. It is more likely that many sequential events created a big hole by superposition.

**An H\textsc{i} companion?** The extreme NW of the galaxy contains an H\textsc{i} complex with a morphology different from the rest of the galaxy. Unfortunately, it is difficult to tell whether it actually belongs to the main disk of NGC 6822 or whether it is a companion which happens to be at a similar heliocentric velocity. The H\textsc{i} mass of the NW complex is $\sim 1.4 \times 10^7$ $M_\odot$, i.e. $\sim 10\%$ of the total H\textsc{i} mass of the NGC 6822-system.

That the NW complex is a separate system is supported by the asymmetry in the H\textsc{i} disk of NGC 6822. The NW half contains 20\% more H\textsc{i} than the SE half (a difference of $\sim 1.2 \times 10^7$ $M_\odot$) as measured with respect to a minor axis passing through the geometrical center. Assuming that the disk of NGC 6822 is symmetric to begin with, this asymmetry can be explained by assuming that the NW cloud (with a mass of $\sim 1.4 \times 10^7$ $M_\odot$) is a separate system contributing to the mass in the NW half.

**Tidal effects** A third interesting feature, resembling a tidal arm, is visible in the SE. We think it is unlikely that it is a conventional spiral arm, due to the absence of star formation in this part of the galaxy, the absence of any spiral structure in the optical and the inner H\textsc{i} disk, and the asymmetric H\textsc{i} morphology in the NW and SE. Whether the material in this arm was stripped off NGC 6822’s main disk or belonged to an interaction partner is difficult to tell based on our data. Future numerical simulations may shed light on this situation. As NGC 6822 is isolated, at the outskirts of the Local Group, and not associated with any of the subgroups, it is unlikely that it interacted with any of the known Local Group galaxies. One important caveat is, however, that a lot of Galactic emission and HVC structures are present in this region of the sky between heliocentric velocities $+25$ and $-15$ km s$^{-1}$. This velocity range coincides with that of the SE arm. It is very well possible that possible companions of NGC 6822 are hidden in the strong galactic emission.

The most likely possibility though is that the NW cloud is the interaction partner. An upper limit to the time scale for this encounter is of the order of half the rotation period at the radial distance of the cloud (i.e., the time to move from SE to NW), which is $3 \times 10^8$ yr. A rough estimate for the timescale can
also be derived from the tidal feature itself: the arm measures some 20′ which corresponds to about 2.8 kpc. It is difficult to estimate what the velocity of the arm is with respect to the galaxy. The data suggests a value between 10 and 30 km s\(^{-1}\). Using 20 km s\(^{-1}\) we then derive a kinematic age of \(1.4 \times 10^8\) yr, but any number between 100 and 200 Myr is probably reasonable. The interaction described here was a minor one, as it did not result in a large starburst and the ejection of large amounts of gas. Dwarf galaxies can apparently undergo such minor interactions without a noticeable effect on their *global* properties. It is the small distance to NGC 6822 that enables us to study this process in so much detail. The Parkes single-dish maps presented in Sect. 2 and low resolution maps made using data from only the 375m ATCA configuration show that if NGC 6822 had been a factor of \(\sim 5\) further away, it would have been impossible to distinguish the NW complex from the main body, nor would the tidal arm and the hole have been obvious. The number of minor interactions in dwarf galaxies may therefore be much larger than one would guess on the basis of low to medium resolution HI observations of more distant galaxies.

5. Summary

NGC 6822 is one of the very few dwarf systems in the local universe that allows such a detailed study of its ISM and stellar population. We have presented low and high resolution data showing that NGC 6822 is not a quiescent non-interacting dwarf galaxy, but that it is undergoing an interaction with a possible companion. The timescale for this interaction is of order \(10^8\) years, comparable to the timescale for formation of the giant hole, suggesting that these two events are related. The passage of the companion may have been the trigger for star formation so far out in the disk. Similar timescales have been derived from optical studies: Hodge (1980) finds evidence for an enhancement in star formation between 75 and 100 Myr ago, while the extensive study by Gallart et al. (1996c) shows that the SFR in NGC 6822 increased by a factor 2 to 6 (depending spatial position) between 100 and 200 Myr ago. Follow-up HI, optical and infrared observations (allowing stellar population studies) currently in progress and the added benefit of very high resolution in the complete HI dataset (beam of \(6'' = 15\) pc), will enable us to study the dynamics of the ISM in NGC 6822 from pc to kpc scales.

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