EVIDENCE FOR TIDAL INTERACTION AND A SUPERGIANT HI SHELL IN THE LOCAL GROUP DWARF GALAXY NGC 6822

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\textit{Draft version March 19, 2022}

\textbf{ABSTRACT}

We present a wide-field, high spatial and velocity resolution map of the entire extended H\textsc{i} distribution of the Local Group dwarf galaxy NGC 6822. The observations were obtained with the Australia Telescope Compact Array in mosaicking mode. The interstellar medium of NGC 6822 is shaped by the presence of numerous H\textsc{i} 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 H\textsc{i} complex. The H\textsc{i} shell is situated outside the optical galaxy and occupies roughly a quarter of the area of the main H\textsc{i} disk. It measures $2.0 \times 1.4 \text{kpc}$, making it one of the largest supergiant H\textsc{i} shells ever found. The giant hole shows no signs of expansion and no obvious creation mechanism is evident from our data. If star formation was the cause, an energy equivalent of $\sim 100$ supernovae ($10^{53} \text{erg}$) is needed to create the hole. We derive an upper limit for the age of order 100 Myr. The presence of a possible tidal arm indicates that NGC 6822 may recently have undergone some interaction. An H\textsc{i} complex located in the north-west of the galaxy may be the interaction partner. We argue that it is likely that these features were created about 100 Myr ago in an event that also enhanced the star formation rate.

\textit{Subject headings:} galaxies: individual (NGC 6822) — galaxies: kinematics and dynamics — galaxies: dwarf — galaxies: fundamental parameters — galaxies: irregular

1. INTRODUCTION

Located at a distance of only $490\pm40 \text{kpc}$ (Mateo 1998), NGC 6822 is, apart from the LMC/SMC system, the most nearby dwarf irregular galaxy known. Discovered by Barnard (1884), its strong resemblance to the LMC/SMC led Perrine (1922) to speculate that “Barnard’s Nebula” might be an object located outside our Galaxy. This was confirmed by Hubble (1925) who determined its distance using Cepheid measurements, making it “the first object definitely assigned to a region outside the galactic system.”

NGC 6822 has no known companions and is not associated with the concentrations of galaxies surrounding M31 and the Milky Way (see e.g. van den Bergh 1999); rather it belongs to the “Local Group Cloud”, an extended cloud of dwarf irregulars (Mateo 1998). NGC 6822 has a total luminosity of $M_B = -15.8$ (Hodge et al. 1991) and a total H\textsc{i} mass of $1.3 \times 10^8 M_\odot$ (de Blok & Walter 2000), making it relatively gas-rich. It is a metal poor galaxy, with an ISM abundance of about $0.2 Z_\odot$ (e.g. Skillman 1989). It has a low star formation rate of $\sim 0.06 M_\odot \text{yr}^{-1}$ (based on H\textalpha and FIR fluxes; Mateo 1998, Israel et al. 1996). In terms of these global properties NGC 6822 is a rather average and quiescent dwarf irregular galaxy. In the past little attention has been paid to the distribution of the neutral ISM of NGC 6822. This can partly be attributed to the fact that part of the H\textsc{i} emission of NGC 6822 is at the same heliocentric velocity as strong foreground emission from our Milky Way. This “Galactic interference” is hard to remove if only a coarse velocity resolution is employed, as was the case in the early H\textsc{i} studies. This confusion, as well as NGC 6822’s large size, may be the reasons why to date only few H\textsc{i} studies of this galaxy have appeared in the literature, even though its inclination, gas-richness 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 H\textsc{i} study of NGC 6822 is that by Volders & Högbom (1961) who used the 25m Dwingeloo telescope to probe NGC 6822 and its environs. They found evidence for neutral hydrogen rotating in ordered fashion around the optical center. Later studies by Davies (1970) and Roberts (1970), confirmed these results. Follow-up interferometric studies by Gottesman & Weliachew (1977) and Brandenburg & Skillman (1998) (see also Hodge et al. 1991) showed a structured and extended ISM in and around the optical galaxy.

Here, we present the first results of a large project to map the entire H\textsc{i} disk of NGC 6822 in unprecedented detail. We used the Australia Telescope Compact Array (ATCA) in mosaicking mode and the Parkes single dish telescope, mapping an area of $1.5 \times 1^\circ$ ($13.5 \times 9 \text{kpc}$). A preliminary inspection of the data showed that, contrary to expectations (based on the low SFR and its isolated po-
sition in the Local Group), the H\textsc{i} appearance is dramatic: it is dominated by a giant H\textsc{i} shell with extended, apparently tidal, features in the outer disk. This disturbed H\textsc{i} morphology and how it affects our view of the evolution of NGC 6822 is the subject of this Letter.

2. OBSERVATIONS AND DATA REDUCTION

NGC 6822 has been observed with the Australia Telescope Compact Array for 15 \times 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 H\textsc{i} extent of the galaxy. We used a bandwidth of 4 MHz with a channel separation of 0.8 km s\(^{-1}\). Additionally, NGC 6822 was observed with the Parkes single dish radio telescope using the multibeam receiver in December 1998. A full account of the observations will be presented elsewhere (de Blok & Walter, in prep.). In this Letter we restrict ourselves to the medium resolution data which does not include the 6-km configuration, nor the single dish data.

The data was reduced and mosaiced together using the MIRIAD data reduction package. Super-uniform weighting, reducing side lobes in individual pointings prior to mosaicing, was used. The resulting data cubes were cleaned with the MIRIAD MOSSDI task. The clean synthesized beam of this medium resolution data set measures 89'' \times 24'' (222 \times 60 pc). The noise per channel is 8 mJy, resulting in a 5\(\sigma\) column density sensitivity of 1.6 \times 10\(^{19}\) cm\(^{-2}\).

3. THE H\textsc{i} MORPHOLOGY

Figure 1 shows the integrated H\textsc{i} column density map. The map was produced by using a two times smoothed and clipped (2.5\(\sigma\)) version of the data as a mask. Also shown is the same map overplotted on an optical DSS image. The H\textsc{i} is more extended than the optical distribution, extending out to radii of 40 arcmin (\(\sim 6\) kpc). We find a total H\textsc{i} mass of 1.1 \times 10\(^{8}\) M\(_\odot\). A comparison with the single dish Parkes H\textsc{i} mass of (1.3 \pm 0.1) \times 10\(^{8}\) M\(_\odot\) shows that we are missing very little flux due to missing short spacings.

The H\textsc{i} disk contains many holes and shells. Three striking features that are the subject of this Letter are marked in Fig. 1: the hole and arm in the SE, and the cloud in the NW.

3.1. The giant H\textsc{i} hole

In the SE a giant H\textsc{i} hole or shell dominates the appearance of the galaxy. Its angular size is 14' \times 10' (as indicated in Fig. 1), corresponding to 2.0 \times 1.4 kpc, measured at a column density level of 10\(^{21}\) cm\(^{-2}\). We will adopt a mean diameter of 1.7 kpc. The deviation from a (deprojected) circle can probably be explained by shear in the outer disk of NGC 6822 since the rotation curve flattens at large radii (de Blok & Walter, in prep.).

The giant H\textsc{i} shell is hinted at in earlier interferometer maps by Gottesmann & Weliachew (1977) of the centre of NGC 6822 and more clearly mapped in VLA data presented in Hodge et al. (1991) and Brandenburg & Skillman (1998). A major axis cut through the galaxy is shown in Fig. 2. Note that the inner part of the H\textsc{i} hole seems to be completely evacuated. The hole does not seem to be expanding. The dispersion in this area (\(\sim 7\) km s\(^{-1}\)) is significantly lower than in the NW part of the galaxy (\(\sim 9\) km s\(^{-1}\)) where there are more signs of recent star formation (Fig. 2, bottom).

3.2. An H\textsc{i} companion?

It is difficult to tell whether the H\textsc{i} complex in the extreme NW actually belongs to the main disk of NGC 6822 or whether it is a companion 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 total NGC 6822 system. At the NGC 6822-cloud interface there is a sharp jump in velocity (at \(r \approx 0.3\)° in Fig. 2) which may indicate that it is indeed a separate system. In principle, the jump could have been created by an asymmetric blow-out due to star formation. However, the lack of stars, star-forming regions and the low dispersion in Fig. 2 in that region make this unlikely. Furthermore, 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 intrinsically symmetric, 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.

3.3. Signs of interaction

A third, “tidal arm” feature is visible in the SE. 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 overall asymmetric H\textsc{i} morphology. 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.

A search of a 10° \times 10° field surrounding NGC 6822 using HIPASS data did not yield unknown H\textsc{i} companions. One important caveat is, however, that there is Galactic and HVC emission present in this region of the sky between \(+25\) and \(-15\) km s\(^{-1}\). This velocity range coincides with that of the SE arm. Possible companions of NGC 6822 might be hidden in the strong galactic emission. As timescales for an interaction with a known Local Group galaxy are too large by an order of magnitude, another possibility 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 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' or 2.8 kpc. An inspection of the \(pV\) diagram in Fig. 2 suggests a relative velocity between arm and disk of 10 to 30 km s\(^{-1}\). Using 20 km s\(^{-1}\) we derive a kinematic age of 1.4 \times 10\(^8\) yr, but any number between 100 and 200 Myr is probably reasonable.

4. ORIGINS OF THE SUPERGIANT SHELL

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). At first glance, it seems unlikely that this
caused the giant shell. It is located far off the optical center and the bulk of star formation. One would need one or more massive stellar clusters at large radii to create the hole. These clusters ought to have dispersed over the past 100 Myr, as there is no sign of a young population at the current epoch.

If the hole was indeed created by star formation, we can derive the energies and ages involved. Since the hole does not expand any more and has presumably broken out, it is only possible to make order of magnitude estimates. If we assume that the expansion velocity of the hole has reached values similar to the dispersion of the ambient ISM ($\sim 7$ km s$^{-1}$), we derive a kinematic age of 130 Myr. This is an upper limit for the actual age since the shell was presumably expanding more rapidly in the past. An age of around 100 million years is therefore reasonable. Using Chevalier's equation (Chevalier 1974), we derive an energy of $10^{53}$ erg needed to create the Hi shell, equivalent to 100 Type II supernovae (using $n_{HI} = 0.1$ cm$^{-3}$). It is not necessary that these supernovae go off at the same time, which would need a massive parent cluster. Many sequential events can create a big hole by superposition. The kinetic energy of the Hi shell is $10^{51}$ erg.

An estimate for the amount of gas removed from the hole $M_h$ can be made as follows.

We estimate $z$, the scale height of the disk, following Puche et al. (1992). Using $M_{dyn} = 4.3 \times 10^8 M_\odot$ and $R_{max} = 5.7$ kpc (de Blok & Walter, in prep.), we find $z = 0.285$ kpc. This yields a total Hi mass evacuated from the hole of $M_h = 1.6 \times 10^8 M_\odot$.

The infall of small high-velocity clouds has sometimes been invoked to explain the largest Hi supershells in galaxies (Tenorio-Tagle et al. 1988). Observational evidence has been found in M 101 (van der Hulst & Sancisi 1988). However, if the hole in NGC 6822 were indeed due to infall of a high-velocity cloud we would expect to see remnants near the hole or at least some kinematical signature — neither is obvious (see the position velocity cut in Fig. 2).

5. THE IMPORTANCE OF MINOR INTERACTIONS

As briefly noted in the Introduction, based on the luminosity, gas-richness, metallicity, SFR and other global properties, one would classify NGC 6822 as a typical, quiescent dwarf irregular galaxy. There was thus no reason to suspect that NGC 6822 might have such a disturbed Hi disk. The Hi data presented here change this picture completely. They provide evidence for a recent interaction, which caused a significant increase in star formation, affecting the morphology of the disk. The results are still around in the form of the NW Hi complex, the supergiant Hi shell and the SE tidal arm. 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. Low resolution maps made using data from only the 375m ATCA configuration show that if NGC 6822 had been a factor of $5$ 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 larger than one would guess on the basis of low to medium resolution Hi observations of more distant galaxies, or on the basis of observations in other wavelengths. For example, the low current SFR in NGC 6822 does not give any indication that the galaxy was disturbed recently, in contrast with e.g. blue compact dwarf galaxies where the enhanced star formation rates clearly indicate some disturbance. This could lead to a skewed picture of the importance of minor interactions.

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. Although detailed Hi studies of nearby dwarf and LSB galaxies are needed to further investigate the influence of minor interactions on a more statistical basis (see also e.g. Taylor 1997, Pisano & Wilcots 1999, Hunter et al. 1998), NGC 6822 will remain a benchmark, as it provides the clearest view we currently have of the morphology of a dwarf irregular galaxy outside the immediate Milky Way/LMC/SMC environment.

5.1. An interaction scenario for NGC 6822

We now present a possible interaction scenario for NGC 6822 based on the observations presented above. As derived earlier, the kinematic age for the giant shell is $\sim 100$ Myr. The timescale for the NW complex to interact with NGC 6822 is $\sim 300$ Myr. The kinematical timescale based on the length of the tidal arm is $\sim 140$ Myr. 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. (1996b) shows that the SFR in NGC 6822 increased by a factor 2 to 6 between 100 and 200 Myr ago. Similarly, Hutchings et al. (1999) find evidence for a 100 Myr young population using WFPC2 imaging. These are good indications that something affected the galaxy some 100 to 200 Myr ago. This was most likely the passage of the NW complex. This may have caused the SFR to increase, triggering the formation of the giant Hi shell in the tidally disturbed SE part of the galaxy. The precise creation mechanism for the large cavity remains a mystery, as is the case with most of the other supergiant Hi holes (e.g., Walter & Brinks 1999, Puche et al. 1992, Rhode et al. 1999). The presence of hot gas around the hole would certainly help to rule out or constrain some of the scenarios discussed here. In a few other galaxies there have been successful attempts to locate the heated gas using X-ray observations (Walter et al. 1998). Unfortunately NGC 6822 is located towards an absorbing galactic Hi column density of $3 \times 10^{21}$ cm$^{-2}$ which makes a detection of soft X-ray emission originating from hot gas virtually impossible even with today’s powerful X-ray telescopes such as Chandra and XMM-Newton.

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 ($0^\prime\prime \times 15$ pc), will will shed more light on the state of the ISM in NGC 6822.

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2In this context, it should be noted that the hole in NGC 6822 has the same diameter as the hole or shell in NGC 5462, the Hi region in the eastern arm of M101 (Kamphuis, Sancisi & van der Hulst 1991).
FW acknowledges NSF grant AST 96-13717. The Australia Telescope is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by JPL, Caltech, under contract with NASA and NASA’s Astrophysical Data System Abstract Service (ADS).

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Fig. 1.— Left panel: integrated Hi column density map. Contours are (1, 4, 7, 10, ..., 31) \times 10^{20} \text{ cm}^{-2}. The beam of 89'' x 24'' is indicated in the lower-right corner. Right panel: Integrated Hi 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. 2.— Major axis position velocity diagram, taken at a position angle of $-54^\circ$ through the geometric center of the H\textsc{i} disk. The lowest contour value is $4\sigma$ and levels increase in intervals of $4\sigma$. Indicated from left to right are the SE arm, the big hole and the NW cloud. The lower panel shows the velocity dispersion along the slice. The velocity spacing is $0.8 \text{ km s}^{-1}$. The thin line indicates the local velocity dispersion sampled every $9''$. The thick line indicates the running mean of the velocity dispersion, using a boxcar smooth of $2.4''$. It is clear that the SE part of the galaxy has a much lower velocity dispersion than the NW part.