Observations of the irregular galaxies IC 1613, NGC 6822 and M 82 with the Dwingeloo radio telescope have given radial velocities of $-234 \text{ km/sec}$, $-50 \text{ km/sec}$ and $+190 \text{ km/sec}$ with respect to the local standard of rest, and hydrogen contents $4.9 \times 10^3 c^2$, $1.5 \times 10^3 c^2$ and $1.2 \times 10^3 c^2$ solar masses for the three nebulae, if the distances are $630 \epsilon \text{ kpc}$, $500 \epsilon \text{ kpc}$ and $2600 \epsilon \text{ kpc}$, $\epsilon$ being an unknown factor by which the assumed distances have to be corrected. An estimate of the total mass of IC 1613 has been derived from the width of the hydrogen line using the virial theorem. Rotation has been observed in NGC 6822. The observations of M 82 indicate a radial velocity which is $90 \text{ km/sec}$ lower than that determined optically; a possible explanation for this is that the apparent optical centre has a superimposed rotational velocity. The ratio of hydrogen mass to total mass is about $15 \epsilon \%$ in IC 1613, $10 \epsilon \%$ in NGC 6822 and $5 \epsilon \%$ in M 82. The mass-luminosity ratios are $5 \epsilon ^{-1}$, $12 \epsilon ^{-1}$ and $16 \epsilon ^{-1}$ respectively.

Some preliminary results on the spiral galaxies M 81 and NGC 4258 are given.

The 25-metre radio telescope at Dwingeloo has been used to observe 21-cm line radiation from several extragalactic nebulae; the results on M 31, M 32, M 33, M 101 and the Coma Cluster have been published (van de Hulst, Raimond and van Woerden 1957, Wentzel and van Woerden 1959, Volders 1959, Muller 1959). The present paper describes the observations of the three irregular galaxies IC 1613, NGC 6822 and M 82. The first two nebulae are members of the local group; M 82 belongs to a small group of galaxies, of which the most prominent member is the large spiral M 81. The results on the spiral galaxy M 51 are presented separately (Heidmann 1961).

The observations were carried out in the same way as those referred to above. The receiver bandwidth was $140 \text{ kc/s} (= 30 \text{ km/sec})$ and the power within the measuring channel was automatically compared in the receiver with that within one or both of two equally wide comparison channels. The distance between these and the measuring channel was changed from $1.08 \text{ Mc/s}$ to $1.44 \text{ Mc/s}$ in November 1959. About half of the measurements were taken before that date.

The 21-cm line radiation from the direction of the measured field was compared with that from a comparison field some distance from the object. Each measurement consisted of four fifteen-minute intervals during which the telescope was pointed alternately at the measured field $(M_1, M_2)$ and at the comparison field $(C_1, C_2)$. The sequence of observations was usually $M_1, C_1, M_2, C_2$, and the excess deflection due to the measured field calculated as $\frac{1}{2} (M_1 + 3M_2 - 3C_1 - C_2)$; later these were changed to $M_1, C_1, M_2, C_2$ and $\frac{1}{2} (M_1 + M_2 - C_1 - C_2)$ respectively. Linear drifts are eliminated in both cases, but the latter procedure gives equal weight to all the four fifteen-minute intervals.

The intensity is measured in “units of intensity”. The definition of this unit is consistent with the intensity scale used in the Kootwijk 21-cm survey (Muller and Westerhout 1957), where the top of the daily calibration profile at the position $l^\prime = 50^\circ$, $b^\prime = 0^\circ$ was assumed to be $100^\circ \text{K}$. However, as this value is still rather uncertain, the top intensity of the Kootwijk calibration profile will from now on be defined as $100$ units in all 21-cm work. The top of the profile at $l^\prime = 50^\circ$, $b^\prime = 0^\circ$, as measured with the narrower beam of the Dwingeloo telescope and a bandwidth of $40 \text{ kc/s}$, is then 108 units. In the previous papers on extragalactic nebulae this intensity was assumed to represent a brightness temperature of $108^\circ \text{K}$; from this it follows that what was then called degrees Kelvin is the same as what is now called units. A complete survey of calibration and intensity
problems will be published shortly in the B.A.N.  

The accuracy of the measured intensities can be derived from a statistical treatment of the measurements. Let the r.m.s. error in a twelve-minute measurement using two comparison channels be \( \mu \) units; a one-hour measurement of the difference in intensity between the measured field and the comparison field will then have a r.m.s. error of \( \sqrt{3} \mu \) units for the sequence \( M, C, M, C \) and \( \mu \) units for the sequence \( M, C, C, M \). Only one comparison channel was used in most of the measurements described here and the corresponding r.m.s. errors are higher by a factor \( \sqrt{2} \). The statistics of the measurements gave a mean value \( \mu = 0.17 \) units for observations made before November 9, 1959, and \( \mu = 0.14 \) units for measurements made after this date. Assuming a spill-over of 30\% and assuming that 1 unit = 1 \(^\circ\)K in brightness temperature, this corresponds to 0.12 and 0.10 \(^\circ\)K respectively, in antenna temperature, which agrees well with the theoretical values of 0.11 and 0.09 \(^\circ\)K in \( T_A \) calculated from measurements of the receiver parameters (B.A.N., in preparation).

All the velocities were reduced to the local standard of rest, with the aid of the tables of MacRae and Westerhout (1956).

The most important optical data about the three nebulae are summarized in Table 1. Some of the results of the present paper are given in Table 2.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>IC 1613</th>
<th>NGC 6822</th>
<th>M 82</th>
</tr>
</thead>
<tbody>
<tr>
<td>type of nebula</td>
<td>Irr. I</td>
<td>Irr. I</td>
<td>Irr. II</td>
</tr>
<tr>
<td>co-ordinates (1950)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \alpha = 1^{h} 22^{m} 3^{s} )</td>
<td>7</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>( \delta = +3^\circ 11' )</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( \beta = 90^\circ )</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>rad. vel. (red. to l.s.r.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( -242 \pm 10 \text{ km/sec} )</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>distance</td>
<td>630 ( \epsilon ) kpc</td>
<td>500 ( \epsilon ) kpc</td>
<td>2600 ( \epsilon ) kpc</td>
</tr>
<tr>
<td>dimensions</td>
<td>23' \times 23'</td>
<td>20'0' \times 20'0'</td>
<td>13'4' \times 8'5'</td>
</tr>
<tr>
<td>photographic magnitude</td>
<td>10( m).00</td>
<td>9( m).21</td>
<td>9( m).20</td>
</tr>
<tr>
<td>app. distance modulus</td>
<td>24m.2</td>
<td>24m.1</td>
<td>27m.1</td>
</tr>
</tbody>
</table>


### Table 2

<table>
<thead>
<tr>
<th></th>
<th>IC 1613</th>
<th>NGC 6822</th>
<th>M 82</th>
</tr>
</thead>
<tbody>
<tr>
<td>rad. vel. ( (\text{km/sec}) )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( -234 \pm 5 )</td>
<td>-50 \pm 5</td>
<td>+190 \pm 5</td>
<td></td>
</tr>
<tr>
<td>( M_\alpha / M_\odot )</td>
<td>4.9 \times 10^{+2}</td>
<td>1.5 \times 10^{+2}</td>
<td>1.1 \times 10^{+2}</td>
</tr>
<tr>
<td>( M / M_\odot )</td>
<td>3.3 \times 10^{-1}</td>
<td>2 \times 10^{-1}</td>
<td>2 \times 10^{-1}</td>
</tr>
<tr>
<td>( M / L )</td>
<td>5 ( \epsilon ) &amp; 12 ( \epsilon ) &amp; 10 ( \epsilon )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Observations of IC 1613**

Nineteen fields (Figure 2) have been measured during a total observing time of 500 hours. The difference in position between the nebula and the radio source reported earlier (Volders and Van de Hulst 1959) is due to an error in the NGC; the positions now agree. Within the limits of error, all the profiles measured (Figure 2) can be described by similar gaussian curves centred on the velocity \( V = -234 \pm 5 \text{ km/sec} \) relative to the local standard of rest; the profiles have halfwidths of \( 42 \pm 4 \text{ km/sec} \). The true profile, corrected for the 30-km/sec bandwidth, is then \( 29 \pm 6 \text{ km/sec} \) between half-intensity points. There is no evidence for a systematic shift of the profiles with the position of the field measured. If there is a general rotation, the velocity component in the line of sight must be very small.

**Radio position.** The large number of fields measured makes it possible to determine the position of the radio source with high accuracy. A contour map was made of the distribution of the integrated hydrogen radiation as observed with the telescope beam. This agreed very well with a corresponding map of the antenna polar diagram, showing that the source is smaller than the beam. The half-power contour was 6% wider than that of the polar diagram; this corresponds to a width of radio-brightness distribution which is 12' between half-intensity points.

The position of the centre of gravity of the neutral hydrogen was found to be:

\[
\alpha_{1950} = 15^\circ.56 \pm 0^\circ.04 = 1^h.24 \pm 0^m.16 \\
\delta_{1950} = +1^\circ.83 \pm 0^\circ.04 = 1^\circ.49 \times 2^\prime.4
\]

The errors given are estimated maximum errors. The
IC 1613, 200" photograph. North is at the top, East at the left. 1 mm = 5".8.
NGC 6822, 200" photograph. North is at the top, East at the left. 1 mm = 6".7.
The observed profiles for IC 1613. All points have equal weight and represent one-hour measurements with one comparison channel and one comparison field (α = $\alpha^h\alpha^m.\alpha^s$, δ = $\delta^h\delta^m.\delta^s$). Insert: the positions of the fields measured; the small square corresponds with the photograph in Figure 1; the cross indicates the position of the centre of gravity of the neutral hydrogen.
agreement with the optical position (Table 1) is satisfactory for such a diffuse object.

Hydrogen content. The mass of atomic neutral hydrogen in a nebula which is small compared to the antenna beam, is given by the formula (Wentzel and van Woerden 1959):

\[ M_H = 1.53 \times 10^6 \int_{-\infty}^{+\infty} T_b dV \text{ solar masses} \]

where \( s \) is the distance in kiloparsecs, \( T_b \) the apparent brightness temperature in degrees Kelvin and \( V \) the velocity in km/sec. In the case of IC 1613 we are not dealing with a point source, since the contour map was wider than the polar diagram by about 6%; this introduces an additional factor \((1.06)^2\) in the equation. The integral under the central profile is \( 72 \pm 7 \) units. \( \text{km/sec} \). With the present calibrations the unit of intensity equals \( 1.00 \times 10^3 \text{K} \), and, therefore,

\[ M_H = (4.9 \pm 0.5) \times 10^7 \text{e}^2 M_\odot \]

Total mass. The observations show no sign of rotation in the nebula. We shall use the virial theorem to get an estimate of the total mass, \( M \), taking a simple model for the mass distribution in the nebula. We assume spherical symmetry and a gaussian density distribution \( \rho = \rho_0 e^{-r^2/2a^2} \), where \( r \) is the distance from the centre. The potential energy \( \Phi \) is:

\[ \Phi = -\frac{G M^2}{2V \pi a} \]

The kinetic energies equals:

\[ T = \frac{1}{2} b^2 M \]

The quantity \( b \) is defined in such a way that the mass of hydrogen with a velocity between \( V \) and \( V + dV \) parallel to the line of sight is proportional to \( e^{-V^2/2b^2} dV \). According to the virial theorem \( 2T + \Phi = c^2 \), this gives an expression for the total mass in terms of the measurable quantities \( a \) and \( b \):

\[ M = 6V \pi \frac{ab^2}{G} \]

At a distance of the nebula of \( 630 \text{ kpc} \), \( a = 2.8 \times 10^{21} \text{ cm} \), and the halfwidth of the line profile (29 \( \pm \) 6 km/sec) corresponds to a value of the mean-square velocity \( b \) equal to \( 1.2 \times 10^6 \text{ cm/sec} \). These values give:

\[ M = 3.3 \times 10^8 \text{ e} M_\odot \]

An application of the virial theorem in this way can only give an order of magnitude estimate. The nebula may, for instance, rotate in a plane nearly at right angles to the line of sight, in which case the assumptions about random motions and spherical symmetry evidently would give wrong results; furthermore, the corrected width of the line profile is known to \( \pm 20\% \) only and enters squared in the expression for \( M_\odot \).

The ratio of hydrogen mass to total mass is seen to be of the order of \( 15 \text{ e} \%). With the luminosity \( L = 6.73 \times 10^7 \text{e}^2 L_\odot \), computed from the apparent magnitude and distance modulus as given in Table 1, assuming the absolute photographic magnitude of the sun to be \( +5.37 \) (Stebbins and Kron 1957), it follows that \( M/L = 5 \text{ e}^2 \).

Observations of NGC 6822

This nebula has been observed for a total of 350 hours and 11 fields have been measured (Figure 4). All the profiles are to some extent disturbed by galactic foreground radiation close to the zero velocity. The central profile shows a maximum at a velocity of \( -50 \text{ km/sec} \) relative to the local standard of rest. Some special observations were made in order to make sure that the position of the maximum had not been influenced by the galactic foreground radiation. The field measured was compared with eight nearer comparison fields situated on a circle around the nebula at a distance of \( 1.4 \) from the centre. These points are marked \( \times \) in Figure 4. The negative intensity values observed for velocities close to \( +15 \text{ km/sec} \) are obviously due to excess galactic foreground radiation at the position of the comparison field. At \( +15 \text{ km/sec} \) the measurements with the eight comparison fields give results which differ considerably from those obtained with the more distant comparison fields, but at \( -25 \text{ km/sec} \) the difference is small. This shows that the maximum at \( -50 \pm 5 \text{ km/sec} \) is probably real and can be taken to represent the radial velocity of the nebula.

Evidence for rotation. The maxima of the various other profiles are systematically displaced relative to that of the centre field. This is easily seen in the profiles taken at the field 6, which are situated on a circle around the centre. The outer fields 7, 8, 9 and 10 follow the same trend. The axis of rotation projected on the celestial sphere is parallel to a line joining the fields 4-0-1 (position angle 30°). This shows little relation to any structure seen on photographs; the nebula seems to contain a bar aligned approximately North-South (Figure 3). The observed rotation shows that it cannot be a disc seen in projection.

It is possible to estimate the angular size of the nebula in the plane of rotation from a comparison of the profiles taken in different fields. Consider the hydrogen having a certain radial velocity \( V \). If the solid angle occupied by this gas is small compared with the antenna beam, one can determine its centre of gravity from the heights of the different profiles at
The observed profiles for NGC 6822. The symbols have the following meanings:

- one comparison field, one comparison channel (low-velocity side).
- one comparison field, one comparison channel (high-velocity side).
- one comparison field, two comparison channels.
- two comparison fields, one comparison channel (low-velocity side).
- two comparison fields, one comparison channel (high-velocity side).
- two comparison fields, two comparison channels.
- eight comparison fields, two comparison channels.

Insert: the positions of the fields; the small rectangle gives the limits of the photograph in Figure 3.
The inclination angle $i$ between the axis of rotation and the line of sight is not known; for an intermediate value ($45^\circ$) $M = 1.5 \times 10^8 \, M_\odot$. This should give the mass within a factor of two if the inclination $i$ is not less than $30^\circ$.

**Hydrogen content.** The integral of the centre profile is $315 \pm 30$ units, km/sec. Using equation (1) with $s = 500 \, \epsilon$ kpc we obtain

$$M_H = 1.53 \times (500 \epsilon)^2 \times 315 \times 1.25 \, M_\odot = 1.5 \pm 0.2 \times 10^8 \epsilon^2 M_\odot.$$  

The factor 1.25 is a correction to the point-source formula due to the angular size of the nebula; the brightness distribution has a halfwidth of about $20^\prime$ in the plane of rotation (Table 3). The corresponding figure for the direction 4-o-1 has been arbitrarily set equal to $15^\prime$. The correction factor is not very sensitive to changes in this figure. The ratio $M_H/M$ for this nebula is seen to be of the order of $10 \epsilon^\%$. Using $L = 1.27 \times 10^8 \epsilon^3 L_\odot$, the mass-luminosity ratio is found to be $M/L = 12 \, \epsilon^{-1}$.

**Observations of Messier 82**

This nebula is considerably smaller than the beam and only one field centred on the optical position has been measured. Four comparison fields have been used and the influence of the galactic foreground radiation is believed to be negligible for velocities $> 40$ km/sec. The total time of observation was

---

**Figure 6**

- a) The observed profile. The meaning of the symbols is explained under Figure 4.
- b) Average points, each representing six hours observations.
- c) The positions of the fields and outline of the photograph in Figure 5.
160 hours. The main part of the observed profile (Figure 6) is symmetrical about the velocity \( V = +190 \text{ km/sec} \). This is far outside the limits of error of the optically determined radial velocity of \( +281 \text{ km/sec} \) (Figure 7). This discrepancy can be explained if the irregular absorption in front of the nebula is heavier on the SW-side of the centre than on the other side, so that the apparent optical centre does not coincide with the centre of gravity of the system. If this is so, the optical radial velocity contains a rotational component. This has already been proposed by Holmberg (1952) in order to explain the unusually high velocity of this system relative to the other nebulae in the same group. The discrepancy between the optical and the radio measurements disappears if the real centre of the nebula is about 1' SW of the apparent optical centre. The line profile covers the same velocity range as the optical measurements by Mayall: +100 km/sec to +400 km/sec. One might expect the profile to be symmetrical; however, a low-intensity extension of the profile similar to that on the high-velocity side cannot be detected at velocities \( < +40 \text{ km/sec} \) because of confusion with the galactic foreground radiation.

Hydrogen content. The integral of the profile is \( 102 \pm 20 \text{ units km/sec} \). The nebula is small compared to the beam and with the adopted distance of 2600 \( \epsilon \) kpc:

\[
M_H = (1.1 \pm 0.2) \times 10^9 \epsilon^2 M_\odot.
\]

Mayall's curve (Figure 7) gives a total mass of \( 1 \times 10^{10} M_\odot \) (Volders 1959, eq. 14, with \( k = 1 \) and \( i = 90^\circ \)); if the real centre is 1' SW of the apparent optical centre the mass must be about twice this value. The ratio of hydrogen mass to total mass is in this case 5 \( \epsilon \)%, and the mass-luminosity ratio is then 10 \( \epsilon^4 \). The luminosity corrected for absorption is likely to be considerably higher than the observed luminosity; the corresponding mass-luminosity ratio would be rather lower than 10 \( \epsilon^4 \).

Observations of NGC 4296

This has been classified as an Sc nebula seen nearly edge-on \( (i = 75^\circ) \). The optical radial velocity, +33 km/sec with respect to the local standard of rest, was measured from an emission patch at some distance from the centre and may therefore have been influenced by rotation (Humason, Mayall and Sandage 1956).

The nebula has been observed during 200 hours. A weak maximum of about 0.5 units at \( V = +65 \pm 15 \text{ km/sec} \) with a halfwidth of 30 km/sec was found at the centre and in a field \( \frac{1}{4} \text{ SE of the centre} \). A search for a similar feature in a field \( \frac{1}{4} \text{ NW of the centre} \) over the velocity range \( -450 \text{ km/sec} \) to \( +500 \text{ km/sec} \) yielded negative results (intensity < 0.3 units). Two fields along the major axis at \( \frac{3}{4} \text{ on either side of the centre showed no emission (intensity < 0.2 units) within the observed velocity range} \), \( +30 \text{ km/sec} < V < +100 \text{ km/sec} \). As the observed maximum is close to the zero velocity, it is dangerous to draw any conclusions. Many more observations are needed.

Observations of Messier 81

This large spiral has been observed during 150 hours, but the observations are not yet complete. The maximum intensity is about 0.5 units. The radial velocity of the centre is about \( -40 \text{ km/sec} \) and the mean rotational velocity is about \( 190 \text{ km/sec} \); this is compatible with the optical measurements by Münch (1959). Further preliminary results are:

\[
9 \times 10^8 M_\odot < M_H < 18 \times 10^8 M_\odot
\]

and

\[
M_H / M_\odot = 1 \text{ to } 2 \%.
\]

The measurements by Heeschen (1957) show much higher intensities over a more extended area. However, these features show no relation to the nebula and are probably due to galactic foreground radiation or other spurious effects.

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