THE H(I) VELOCITY WIDTHS OF GIANT H II REGIONS AS DISTANCE INDICATORS

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ABSTRACT

The mean velocity widths <W> of the H(I) line profiles of the largest giant H II regions in 10 or more galaxies are compared with the mean diameters <D> of the same H II regions to evaluate the relative merits of <D> and <W> as distance indicators. Diagrams of relations M_B versus log <D> and M_B versus log <W> are constructed using distance parameters from Sandage and Tammann (1981) and from de Vaucouleurs (1979a, b). It is shown that the mean velocity widths deduced from integrated H(I) line profiles correlate more strongly with the absolute magnitudes of galaxies than the mean diameters of the three largest H II regions; this also holds when isophotal diameters of H II regions are used. Absolute magnitudes and distance moduli of de Vaucouleurs give statistically more significant relationships than the distance parameters of Sandage and Tammann.

Subject headings: galaxies: distances — line profiles — nebulae: H II regions

I. INTRODUCTION

Several distance indicators involving complex weighting techniques have been used to determine the distances of nearby individual galaxies, each indicator and its relative weight being subject to controversy (cf. review by Hodge 1981). Giant extragalactic H II regions are such a controversial distance indicator that several investigators would prefer to do without them. Sersic (1960) and Sandage (1962) made the first use of the mean sizes of the largest H II regions in a galaxy as a standard candle. Because of their crucial role as primary indicators for distances where stellar indicators such as Cepheids or red supergiants are no longer detected, H II regions provide an important standard candle. Unfortunately, the difficulty of defining and measuring reliable angular diameters for H II regions has made elusive and difficult the calibration of H II region linear diameters as distance indicators (Kennicutt 1979a; van den Bergh 1980; Hanes 1982; Teerikorpi 1985). In addition, and not the least linear dependence of apparent diameter on distance makes the mean linear diameters <D> of the largest H II regions a poor distance indicator. Kennicutt (1979a, b) concluded that the use of isophotal diameters offered a superior alternative to the more subjective visual diameters. Nevertheless, in a later paper (Kennicutt 1981), he made an almost desperate plea to discourage investigators from using H II regions as standard candles. Hanes (1982) showed the pitfalls of using the diameters of H II regions as extragalactic distance indicators. This situation is unfortunate because objects of this class can be detected in distant galaxies, making them crucial in determining the Hubble constant at cosmological distances.

The finding by Melnick (1977) of a tight relationship between the diameters of giant extragalactic H II regions (GEHRs) and their internal velocity dispersions raised the hope of using this more objective parameter of H II regions, instead of diameter, as a distance indicator. The internal velocity dispersion is deduced from the width of line profiles integrated over whole H II regions (Smith and Weedman 1972); the e-folding width of the Gaussian profile which, convolved with the thermal broadening function, best fits the observed profile gives the velocity dispersion. In principle, such velocity dispersions can be reliably deduced from high-resolution spectroscopic scans obtained by Fabry-Perot interferometry or echelle spectroscopy. Calibrations of such velocity dispersions as distance indicators were attempted by Melnick (1978) and de Vaucouleurs (1979c). However, following a recent spectroscopic investigation of giant H II regions, Gallagher and Hunter (1983) failed to confirm the above correlation between velocity dispersions and diameters in their study of 28 H II regions belonging to a set of dwarf Magellanic irregulars and related galaxies. Because of the uncertain state of the extragalactic distance scale, we feel that promising avenues for new indicators should be vigorously explored.

Using a large-aperture Fabry-Perot spectrometer, we recently completed an investigation of the H(I) line profiles of 47 GEHRs in 16 nearby late-type spirals and Magellanic irregulars. Results of this research have been presented in Roy, Arsenault, and Joncas (1986, hereafter Paper I). We confirmed the trend found by Melnick (1977) and Terlevich and Melnick (1981); we found, however, a much weaker correlation between velocity dispersion and size from our much larger sample of H II regions, which included several of Terlevich and Melnick’s objects. Moreover, the slope of the relationship we found is less steep, and its shape is, not unexpectedly, most sensitive to the adopted distances to the target galaxies. As first discovered by Melnick (1978), there is also a strong correlation between the corrected galaxian absolute magnitudes, M_B and the logarithm of the mean velocity widths <W> of the largest H II regions. In the present paper, we wish to analyze further the relationships between the absolute magnitudes and the mean diameters and mean velocity dispersions of the largest H II regions in galaxies, to evaluate their respective merits as distance indicators. Because we consider only the mean values of at most three H II regions in each galaxy, we define a subset of 39 GEHRs in 15 galaxies from our original sample. Relationships for the distances of Sandage and Tammann (1981) using data from the Revised Shapley-Ames Catalog of Bright Galaxies and for the distances of de Vaucouleurs (1978, 1979a, b) are also established and compared.
such measurements. Instances in which linear diameters were
isophotes brighter than $5 \times 10^{-2}$ arcsec$^{-2}$ in column (9) of Table 1. The isophotal diameters chosen corre-
the less reliable visual estimates. Sources of angular diameters
diameters $D$ were deduced from angular diameters; for a
Ho II and IC 2574, where the ST81 parameters were
taken from Kraan-Korteweg and Tammann (1979). Linear
have been used to calculate the linear diameters of the GEHRs,
devaucouleurs (1979a, b, hereafter dV79a, b respectively,
this level coincides roughly with the diameter obtained from
for the remaining objects, which were visual estimates, can be
was taken as the one given by an
instrumental profile was found to be well approximated by a
Lorentzian function. The observations were made with the 3.60
m Canada-France-Hawaii Telescope and with the 1.60 m tele-
scope of the Observatoire astronomique du mont Mégantic (Québec). Further details on the Fabry-Perot spectrometer and
on the observing procedures are given in Arsenault and Roy
(1984) and in Paper I. Velocity widths and their uncertainties
are also listed in Paper I. For example, the smallest velocity
width that we measured was $13.4 \pm 0.8$ km s$^{-1}$ in the H II
region NGC 6822 I, while the highest was $35.6 \pm 1.6$ km s$^{-1}$ in
NGC 5194 I; the typical uncertainty of a velocity width is
about $\pm 1$ km s$^{-1}$, which is much smaller than the spread
between the velocity widths among the three largest H II
regions in a galaxy, which vary from a few km s$^{-1}$ (e.g., NGC
2403) up to $15$ km s$^{-1}$ (e.g., NGC 4236). Standard least-squares
fitting techniques were used to adjust the observed profiles.
Although several profiles did display a slight asymmetry, we
adjusted them with a single Gaussian for the purpose of the
present study (cf. Paper I). Detailed analysis of the individual
profiles will be given in Arsenault and Roy (1986). The mean
Hz velocity widths for each galaxy are listed in Table 1 as
log $\langle W \rangle$.

II. DIAMETERS AND H2 VELOCITY WIDTHS OF GIANT
H II REGIONS

Table 1 lists the observed galaxies. Two sets of parameters,
corresponding to true distance moduli $\mu$ and corrected absol-
ute magnitudes $M_\mu$ (which stands for $M_\mu^a$ throughout this
text) from Sandage and Tammann (1981, hereafter ST81) and
de Vaucouleurs (1979a, b, hereafter dV79a, b), respectively,
have been used to calculate the linear diameters of the GEHRs,
except for Ho II and IC 2574, where the ST81 parameters were
taken from Kraan-Korteweg and Tammann (1979). Linear
diameters $D$ were deduced from angular diameters; for a
majority of objects, isophotal angular diameters from Ken-
nicutt (1978) were used following the effort we made to include
in our Fabry-Perot program as many objects as possible with
such measurements. Instances in which linear diameters were
deduced from isophotal measurements are indicated by “yes”
in column (9) of Table 1. The isophotal diameters corres-
cord to the flux level defining the solid angle enclosing all H2
isophotes brighter than $5 \times 10^{-18}$ ergs cm$^{-2}$ s$^{-1}$ arcsec$^{-2}$; this
level coincides roughly with the diameter obtained from
the less reliable visual estimates. Sources of angular diameters for
the remaining objects, which were visual estimates, can be
found in Paper I. The weights in column (10) of Table 1 corre-
spond to the number of H II regions used to compute the mean
value of $\langle D \rangle$ and $\langle W \rangle$; these weights were also used in the
calculation of the coefficients of correlation and of the linear
regressions. Most means were deduced from three objects per
galaxy; however, in some instances, only one object (NGC
4214 and Ho II) or two (NGC 5194 and IC 2574) were avail-
able. The direct effect of this is a probable slight overestimate of
$\langle D \rangle$ and $\langle W \rangle$ for these four galaxies.

We have defined the velocity dispersion as the “velo-
city width” $W$ of the Gaussian profile $F(V) = F_0 \exp \left[-(V - V_0)^2/2W^2\right]$ which, combined with the thermal
d broadening function and the instrumental profile, best adjust
the observed profiles; $V_0$ is the radial velocity of the object.

The $e$-folding width is related to, but is different from, the
 dispersion and the FWHM of a Gaussian. Values of temperature
used for removing the thermal broadening are listed for each
H II region in Paper I. Temperatures deduced from spectral
measurements were used wherever available; otherwise we
assumed a temperature of $10^4$ K. The instrumental profile of the
Fabry-Perot spectrometer was taken as the one given by an
entrance diaphragm, whose projected size on the sky was
roughly equal to the angular size of the specific GEHR; the
instrumental profile was found to be well approximated by a
Lorentzian function. The observations were made with the 3.60
m Canada-France-Hawaii Telescope and with the 1.60 m tele-
scope of the Observatoire astronomique du mont Mégantic (Québec). Further details on the Fabry-Perot spectrometer and
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profiles will be given in Arsenault and Roy (1986). The mean
Hz velocity widths for each galaxy are listed in Table 1 as
log $\langle W \rangle$.

III. RELATIONS OF ABSOLUTE MAGNITUDES TO MEAN DIAMETERS
AND MEAN VELOCITY WIDTHS

Following the suggestion of de Vaucouleurs (1979c), we have
calculated linear regressions of the form $M_\mu = a \log \langle D \rangle + b$, and $M_\mu = c \log \langle W \rangle + d$, using the distances of ST81 for 15
galaxies and the distances of dV79a, b for 12 galaxies of Table
1. The parameters of the linear regressions, the Pearson
product-moment coefficient of correlation $r$, and the probabil-
ity $P$ that a noncorrelated set of data points will give the
observed correlation are shown in Table 2 (relations for mean
diameters $\langle D \rangle$) and Table 3 (relations for mean velocity widths
$\langle W \rangle$). The probability $P$ was calculated from formulae given
in Bevington (1969); $N$ is the number of data points. Values of
TABLE 2

GALAXIAN ABSOLUTE MAGNITUDES AS A FUNCTION OF \langle D \rangle OF H II REGIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ST81 (Fig. 1a)</th>
<th>dV79a, b (Fig. 1b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set A: All Diameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_B$</td>
<td>$-(6.25 \pm 0.71) \log \langle D \rangle - (2.55 \pm 1.87)$</td>
<td>$-(7.62 \pm 0.98) \log \langle D \rangle + (0.64 \pm 2.44)$</td>
</tr>
<tr>
<td>$r$</td>
<td>0.74</td>
<td>0.86</td>
</tr>
<tr>
<td>$P$</td>
<td>$1.6 \times 10^{-3}$</td>
<td>$2.9 \times 10^{-4}$</td>
</tr>
<tr>
<td>$N$</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>rms dispersion</td>
<td>1.31 mag</td>
<td>0.92 mag</td>
</tr>
<tr>
<td>$r_{mb , w}$</td>
<td>0.35</td>
<td>0.57</td>
</tr>
</tbody>
</table>

| Set B: Isophotal Diameters Only | | |
| $M_B$ | $-(7.14 \pm 0.87) \log \langle D \rangle - (0.08 \pm 2.26)$ | $-(7.45 \pm 1.05) \log \langle D \rangle + (0.22 \pm 2.60)$ |
| $r$ | 0.82 | 0.85 |
| $P$ | $1.8 \times 10^{-3}$ | $1.9 \times 10^{-3}$ |
| $N$ | 11 | 10 |
| rms dispersion | 1.13 mag | 0.99 mag |
| $r_{mb \, w}$ | 0.35 | 0.13 |

rms dispersion of the calculated regressions are also given in Tables 2 and 3.

For both sets of distances of ST81 and dV79a, b, we distinguish two sets of relationships. Sets A correspond to correlations and regressions obtained by using all values of $\log \langle D \rangle$ and $\log \langle W \rangle$ of Table 1. Sets B are more restricted sets of relations obtained only for those galaxies with H II regions having isophotal measurements from Kennicutt (1978) for their diameters. Sets B, which are included in sets A, define smaller samples of galaxies for both ST81 and dV79a, b, but these restricted samples allow a fairer evaluation of the relative merits of $\langle D \rangle$ versus $\langle W \rangle$ as distance indicators. Furthermore, these subsets of about 10 galaxies represent a group of galaxies with probably some of the most reliable distances in the respective distance scales because of their strong dependence on primary and secondary indicators. Figure 1 shows the $(M_B, \log \langle D \rangle)$ relation, where the values of $\langle D \rangle$ are the mean isophotal diameters of the largest H II regions. Figures 1 and 2 are restricted to objects defined by sets B. Figure 1a refers to the distance parameters of ST81, and Figure 1b to those of dV79a, b. The $(M_B, \log \langle W \rangle)$ relations, defined for the same restricted sample of galaxies, are shown in Figure 2a for the absolute magnitudes from ST81, and in Figure 2b for the absolute magnitudes from dV79a, b.

Comparison of Figures 1 and 2 and examination of Tables 2 and 3 reveal that, for both ST81 and dV79a, b, the strongest relations are generally obtained with $M_B$ versus $\log \langle W \rangle$; the $(M_B, \log \langle D \rangle)$ relations are more dispersed. Furthermore, the relations obtained by using dV79a, b distance parameters are tighter than those obtained by using the parameters of ST81; this is shown by the coefficients of correlation, by the probability of zero correlation, and by the rms dispersion in magnitude of the regressions.

For dV79a, b, the quality of fit does not change much in going from $M_B$ versus $\log \langle D \rangle$ (all diameters) to $M_B$ versus $\log \langle D \rangle$ (isophotal diameters only); this is probably due to the fact that only two galaxies of dV79a, b have no isophotal radii for their H II regions. For ST81, set B gives stronger relations than set A, probably because the galaxies NGC 3938, NGC 4258, NGC 4449, and NGC 4656, which are not included in set B, have poorer distance determinations. Indeed, neither of these four galaxies has had its distance established with primary or secondary indicators.

As pointed out by the referee, the reality of the $(M_B, \log$
The relationship $M_B$ versus log $W$ while eliminating variations of $M_B$ due to variations in diameters. It is equivalent to investigating the relation $M_B$ versus log $W$ in a subgroup of H II regions having the same diameters. Although our sample is not large enough to do this, the partial coefficient of correlation method simulates this.

The partial coefficients of correlation were calculated using the formulae of Edwards (1976). The partial coefficients of correlation shown in Tables 2 and 3 are generally higher for the relations of $M_B$ with $\langle W \rangle$ than with $\langle D \rangle$. For example, the coefficient $r_{MW} D$ is the partial coefficient of correlation between $M_B$ and $\langle W \rangle$ with the influence of $\langle D \rangle$ removed. These coefficients are smaller than the Pearson coefficient of correlation because the dependence on two variables is reduced to dependence on one variable. The results shown in Tables 2 and 3 support the existence of a direct correlation between $M_B$ and $\langle W \rangle$, and comparison of the partial coefficients of correlation suggests that $M_B$ correlates more strongly with the velocity widths than with the diameters of giant H II regions.

IV. DISCUSSION

Our comparative study of the $(M_B, \log \langle D \rangle)$ and $(M_B, \log \langle W \rangle)$ relations shows that the mean Hz velocity widths $\langle W \rangle$ of GEHRs provide a more reliable distance indicator than the mean diameters $\langle D \rangle$ of GEHRs. This is expected because the measurements of velocity widths of spectral lines are less prone to several of the observational complications affecting the measurements of angular diameters. Moreover, velocity widths of line profiles are not distance dependent. However, pitfalls may be present. Ideally, all spectral measurements should be made with the same instrument to make them instrument independent; observed profiles should certainly be reduced using identical procedures. In particular, great care ought to be taken in deconvolving the instrumental profile of a Fabry-Perot spectrometer; aperture effects (e.g., object not filling the entrance aperture) can affect the value of the deduced velocity width (Flynn 1966; Arsenault and Roy 1984). When comparing velocity widths measured by observers using different instruments, caution must be taken to find out how the instrumental profile was treated. For example, assuming a Gaussian instead of a Lorentzian profile for Fabry-Perot spectrometer measurements through a small aperture may lead to an underestimate of the velocity width by several kilometers per second; this effect would affect more severely the velocity widths of the smaller giant H II regions. Consequently, velocity widths are not totally free from experimental bias; this is especially true when results from various investigators and apparatus (e.g., Fabry-Perot spectrometer versus echelle spectrograph) are compared.

Obtaining the velocity widths of several giant H II regions requires high-resolution spectroscopic tools and access to a large telescope because galaxies of interest are likely to be at distance moduli greater than 30. Because of the amount of time required to obtain high S/N profiles in distant H II regions, the method of using mean isophotal diameters might be more economical as long as angular diameters of these objects are larger than the seeing disk.

Our work offers no justification for endorsing one distance scale rather than the other. If we assume that a true physical relationship exists between $M_B$ and $\log \langle W \rangle$ (cf. Paper I) and that intrinsic fluctuations of $M_B$ and $\langle W \rangle$ are small compared with the observational uncertainties, one can conclude that distances of $dV79a$, $b$ to the galaxies of Table 1 are relatively

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V. CONCLUSION

We have compared the reliability of mean diameters $\langle D \rangle$ with mean velocity widths $\langle W \rangle$ of giant H II regions as extragalactic distance indicators. Assuming that a physical relationship exists between $M_B$ and $\log \langle W \rangle$, and that intrinsic variations of $M_B$ and $\langle W \rangle$ are smaller than the observational uncertainties affecting the measurement of these parameters, we have shown that mean velocity widths are better distance indicators than isophotal diameters of giant H II regions. Our analysis also shows that the distances of de Vaucouleurs (1979a, b) to the galaxies of Table 1 have a better relative internal consistency than those of Sandage and Tammann (1981). Finally, we emphasize that the measurements of Hz velocity widths suffer from certain difficulties, and economy of telescope time can, in certain cases, make isophotal diameters preferable for objects larger than the seeing disk.

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