Hα VELOCITY FIELDS OF H II REGIONS IN NEARBY DWARF IRREGULAR GALAXIES

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Received 1997 December 29; revised 1998 March 16

ABSTRACT

We present Hα velocity fields of 13 giant H II regions in four nearby dwarf irregular galaxies: NGC 2366, Holmberg II, IC 2574, and WLM (the Wolf-Lundmark-Melotte system). We classify the velocity features, as well as the morphologies, of the H II regions. The Hα velocity features are divided into three categories; three H II regions show chaotic features with a typical scale of variation of a few hundred parsecs in size and a few times 10 km s⁻¹ in velocity, one region exhibits an expanding-bubble feature, and the remaining nine have calm velocity fields. There is a correlation between the Hα velocity features and the morphology of the H II regions. We measured the bulk motion of the H II regions relative to the ambient H I velocity for the H II regions with calm velocity fields and found a typical velocity difference of about 5 km s⁻¹. We discuss a model for the origin of star-forming regions based on the presence of the velocity difference between Hα and H I gas, as well as the H I characteristics.

Key words: galaxies: dwarf — galaxies: individual (NGC 2366, Holmberg II, IC 2574, WLM) — galaxies: irregular — galaxies: ISM

1. INTRODUCTION

Since dwarf irregular galaxies are slow and nearly rigid rotators, they are suitable for studying kinematic and morphological properties of star-forming regions and their interaction with the surrounding interstellar medium (ISM). Some dwarf irregular galaxies have many H I holes (see, e.g., Puche et al. 1992); the relation between the H I holes and the star formation activity has been discussed, but it is not yet clear. Roy et al. (1992) claimed that an extremely high velocity exploding component is commonly associated with H II regions in dwarf irregular galaxies, but the nature of the high-velocity component has not been understood. The star formation activity of some dwarf irregular galaxies, even of isolated ones, are as high as those of spiral galaxies (Hunter & Gallagher 1986), though the dwarfs do not have spiral arms. Saitō et al. (1992) proposed a model based on observations of the Hα velocity field in IC 10 in which collision of H I clouds from an extended H I envelope with a dense H I disk could be a star formation trigger. Tomita, Ohta, & Saitō (1993, 1994) presented the Hα velocity fields in another four dwarf irregular galaxies and showed results that are consistent with the model by Saitō et al. (1992). However, the number of samples is still small, and it is necessary to obtain more data to examine this model.

In this paper, we present Hα velocity fields in H II regions of another four nearby dwarf irregular galaxies and study the connection between the Hα velocity field and the characteristics of the H II regions. In § 2, we describe the sample galaxies, observations, and data reduction. We show the resultant position-velocity diagrams of the Hα emission in § 3; discussions are given in § 4.

2. OBSERVATIONS

2.1. Sample

We observed four galaxies, NGC 2366, Holmberg II, IC 2574, and WLM (the Wolf-Lundmark-Melotte system). They were selected from nearby (within about 3 Mpc) well-studied dwarf irregular galaxies at the location observable at the Okayama Astrophysical Observatory (OAO), in Japan. We also preferred a small apparent inclination of the galaxy in order to avoid overlapping the H II regions along the line of sight.

Table 1 lists basic characteristics of the four observed galaxies. The second column tabulates the distance. NGC 2366, Holmberg II, and IC 2574 are members of the M81 Group, and the distances are about 3 Mpc. WLM is a member of the Local Group, and the distance is about 1 Mpc. Column (3) tabulates physical size of diameter of the galaxy. Three galaxies in the M81 Group have diameters of about 8 to 12 kpc, and WLM has a smallest diameter of about 3 kpc. The fourth column tabulates the apparent inclination, where 90° refers to edge-on. Column (6) tabulates far-infrared (FIR) luminosity, which is an indicator of the present star formation rate of the galaxy. The seventh column tabulates the B-band luminosity, which is a measure of the luminous mass of the galaxy. The eighth column tabulates the dynamical total mass of the galaxy inferred from the H I observations. Column (9) tabulates the H I mass.

We use H I velocity field data from the literature to compare with our Hα velocity fields. High-resolution synthetic H I observations were made for NGC 2366 by Wevers, van der Kruit, & Allen (1986) and Braun (1995), for Holmberg II by Puche et al. (1992), and for IC 2574 by Martimbeau, Carignan, & Roy (1994). For WLM there is

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1 Based on observations made at Okayama Astrophysical Observatory, which is a branch of the National Astronomical Observatory of Japan, an interuniversity research institute operated by the Ministry of Education, Science, and Culture of Japan.

2 Research Fellow, Japan Society for the Promotion of Science.
no synthetic observation; therefore, we do not have a H\alfa velocity field map with suitably high spatial resolution for comparison with our H\alfa data. We searched for the velocity data of CO molecular emission in the literature and found only one report for NGC 2366 by Hunter & Sage (1993) with no detection of the emission.

2.2. Observations and Reduction

Long-slit H\alfa spectroscopy was carried out in 1994 at the OAO using the 1.88 m reflector with the “Spectro-nebulagraph” (an automatic slit scanning system; see Kosugi et al. 1995). We observed giant H\alfa regions in four galaxies: in NGC 2366, most of the giant H\alfa complexes at the southern part of the galaxy with some positions at the northern part of the galaxy; in Holmberg II, about half of the H\alfa regions that concentrate at the central part of the galaxy; in IC 2574, about half of the most prominent H\alfa complexes at the northwestern part of the galaxy; and in WLM, most of the H\alfa regions. The observed slit positions are shown on the H\alfa map of Figure 1, and the observed H\alfa regions are summarized in Table 2. A detailed description about individual H\alfa regions is given in § 3.2.

A spectrograph with a grating of 1200 grooves mm\(^{-1}\) blazed at 7500 Å and a Photometrics CCD with 512 × 512 pixels (pixel size of 20 × 20 μm) was equipped at the Cassegrain focus. The dispersion was 0.7 Å pixel\(^{-1}\), or 30 km s\(^{-1}\) pixel\(^{-1}\) at the H\alfa line. The slit was 5:0 in length and 1\prime8 in width, and the instrumental broadening corresponded to about 1.3 Å in FWHM. The slit length was longer than the size of each H\alfa-emitting region, and by using the spectra of the sky we could make a sky subtraction as well. A CCD pixel corresponds to 0.75μ. Typical seeing was 2"–3".

A log of the observations is given in Table 3.

The data reduction and analysis were performed with IRAF\(^3\) in the usual manner. We binned the spectra in four adjacent CCD pixels (3:0) along the slit length at all of the positions, except for the positions where the spectra have low signal-to-noise ratios, which we binned in 8 pixels (6:0).

\(^3\) IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
Fig. 1a

Fig. 1b

Fig. 1.—Slit positions superposed on the Hα images. The length of each line corresponds to the length of the abscissa in Fig. 2. (a) NGC 2366: the Hα image is taken from Fig. 1 in Roy et al. (1991). The length of the line corresponds to 160°. (b) Holmberg II: the Hα image is taken from Fig. 1 in Hodge et al. (1994). The length of the line corresponds to 250°. (c) IC 2574: the Hα image is taken from Fig. 3 in Miller & Hodge (1994). The length of the line corresponds to 200°. (d) WLM: the Hα image is taken from Fig. 1a in Hodge & Miller (1995). The length of the line corresponds to 200°.
3.2. Results for Individual Galaxies

3.2.1. NGC 2366

The resultant 16 position-velocity diagrams are shown in Figure 2, where the length of abscissa corresponds to 160", or 2.7 kpc at the distance of NGC 2366. The H II regions are concentrated at the southern part of the galaxy, and the most prominent H II complex has another name, NGC 2363. There is the second prominent H II complex at the east of NGC 2363; following Arsenault & Roy (1986), we call this H II region NGC 2366 III.

In NGC 2363 the Hα velocity field is calm at the central regions where the intensities of the Hα emission are most powerful; in the diagrams the central regions are located on 20" to -10" at the slit position IA, 150" to 130" at the slit positions SE, SF, SG, and SH. The Hα velocity is almost the same as the H I velocity, and the line width is almost constant at 20 km s⁻¹. The FWHM of about 20 km s⁻¹ and the calm velocity field at the central regions of NGC 2363 are consistent with the measurement by Arsenault & Roy (1986), who obtained the velocity dispersion of the integrated Hα profile of NGC 2363 (denoted as NGC 2366 I in their paper) of 23 km s⁻¹. Terlevich & Melnick (1981) showed that NGC 2363 obeys the size–velocity dispersion relation of the extragalactic H II regions, which is expected for self-gravitating systems.

Unlike at the central regions, the Hα velocity field is curved at the outer regions in NGC 2363; see the slit positions IC, ID, SA, SB, SC, and SD. The typical scale of the variation of velocity is 20" to 30" corresponding to about 200 pc in size, and 10 to 30 km s⁻¹ in velocity. An expanding shell-like velocity feature is seen at the position of 180" to 150" on the slit SB, the east side of NGC 2363. In comparison with the Hα image of Figure 1a, the location of the shell-like velocity feature corresponds to Hα filaments.

The slit positions of IA to ID were located crossing the northwestern part of NGC 2363. From the center to outer region of NGC 2363 (from IA to ID), the Hα velocity rises from 85 to 110 km s⁻¹, drifting away from the H I velocity. The line width is almost constant at 20 km s⁻¹ except for the regions with poor signal-to-noise ratios. The increase of
the Hα velocity is also shown in diagrams of
the slit positions SA to SC as an upturn velocity
gradient at around 150° to 130°. The variation of
the position-velocity diagrams is consistent with the [O III] velocity field given by
Figure 7 of Roy et al. (1991), in which a high-velocity ridge with an altitude of about 10 km s^{-1} appears in the north-west direction from the core of NGC 2363.

The Hα velocity of the second prominent H II region, NGC 2366 III, is shown at around the position of 90° to 50° on the slits SA to SH. The velocity field is calm in general,
though the Hα velocity is curved at the slit positions SF to SH. The Hα velocities at the intense Hα regions are blue-shifted by several to 10 km s^{-1} more than the H I velocity.

The H II regions at the northern part of the galaxy are 1 to 2 orders of magnitude less intense in the Hα light compared with the two southern prominent ones. The Hα velocity field shown on the slit positions NA to ND is not so curved and nearly the same as the H I velocity, though the signal-to-noise ratio is poor. Only two regions, at the position of 170° to 190° on the slit NA and at the position of
180° to 200° on the slit ND, have sufficient signal-to-noise ratios. Each of these two regions corresponds to small circular H II regions (see Fig. 1a); hereafter we call them the H II region NGC 2366 NA and ND, respectively; see Figure 1a and Table 2.

3.2.2. High-Velocity Expanding Component in NGC 2363

Roy et al. (1991) showed that at the central region of NGC 2363 the profiles of the emission lines split corresponding to an expansion velocity of 45 km s⁻¹, and that overall NGC 2363 has a high-velocity expanding component with a velocity width of about 1000 km s⁻¹. Roy et al. (1992) and González-Delgado et al. (1994) reported confirmations of the high-velocity expanding component, and Roy et al. (1992) claimed that no model could explain the large expansion velocity. Hunter et al. (1993) presented a deep Hα imaging and found many Hα filaments around NGC 2363, though the connection with the high-velocity expanding component is unknown.

In the present observations, we could detect neither the broad-line component with a few times 1000 km s⁻¹ nor the splitting profile with the expansion velocity of 45 km s⁻¹ at the central region of NGC 2363. Both Roy et al. (1992) and González-Delgado et al. (1994) extracted the high-velocity expanding component by picking up the residuals after fitting the emission-line profile with a single Gaussian, and the peak intensity of the broad component is only 1% of that of the original observed line. We should note that the observed line profile deviates from the complete Gaussian in general and that the shape of the wing of the profile depends on the conditions of the spectrograph; in our data we could not confirm the existence of the broad-line component with more than 1000 km s⁻¹. The expanding bubble with the velocity of 45 km s⁻¹ was clearly shown by Roy et al. (1991) in [O III] emission. The region where the [O III] line splits has an area of about 5” × 5” as shown in Figure 5 of Roy et al. (1991). In our spectroscopy, one data point in Figure 2 sampled an area of 1.8” × 3.0”, and the spacing of

\begin{table}[h]
\centering
\small
\caption{Observed slit positions}
\begin{tabular}{llllllllll}
\hline
ID Name & R.A. (B1950.0) & Decl. (B1950.0) & P.A. (deg) & CSD & R.A. (B1950.0) & Decl. (B1950.0) & P.A. (deg) & CSD \\
(1) & (2) & (3) & (4) & (5) & (2) & (3) & (4) & (5) \\
\hline
NGC 2366: & & & & & & & & \\
IA …… & 07 23 25.0 & +69 17 29 & 45 & 13163.002 & A …… & 10 25 40.5 & +68 43 56 & 90 & 10497.002 \\
IB …… & 07 23 24.2 & +69 17 33 & 45 & 13163.005 & B …… & 10 25 40.5 & +68 43 50 & 90 & 10497.005 \\
IC …… & 07 23 23.4 & +69 17 37 & 45 & 13164.001 & C …… & 10 25 40.5 & +68 43 44 & 90 & 10497.008 \\
ID …… & 07 23 22.6 & +69 17 42 & 45 & 13168.004 & D …… & 10 25 40.5 & +68 43 38 & 90 & 10508.003 \\
SA …… & 07 22 59.1 & +69 17 58 & 90 & 13187.005 & E …… & 10 25 40.5 & +68 43 32 & 90 & 10508.006 \\
SB …… & 07 22 59.1 & +69 17 52 & 90 & 13187.008 & F …… & 10 25 40.5 & +68 43 26 & 90 & 10508.002 \\
SC …… & 07 22 59.1 & +69 17 46 & 90 & 13187.011 & & & & & \\
SD …… & 07 22 59.1 & +69 17 40 & 90 & 13189.002 & & & & & \\
SE …… & 07 22 59.1 & +69 17 34 & 90 & 13189.005 & & & & & \\
SF …… & 07 22 59.1 & +69 17 31 & 90 & 13202.004 & & & & & \\
SG …… & 07 22 59.1 & +69 17 28 & 90 & 13202.007 & & & & & \\
SH …… & 07 22 59.1 & +69 17 25 & 90 & 13203.001 & & & & & \\
NA …… & 07 23 10.8 & +69 20 10 & 90 & 13209.001 & & & & & \\
NB …… & 07 23 10.8 & +69 20 01 & 90 & 13192.003 & & & & & \\
NC …… & 07 23 10.8 & +69 19 45 & 90 & 13210.004 & & & & & \\
ND …… & 07 23 10.8 & +69 19 06 & 90 & 13210.007 & & & & & \\
Holmberg II: & & & & & & & & & \\
A …… & 08 14 05.6 & +70 52 26 & 90 & 10494.002 & I …… & 23 59 20.7 & +65 43 35 & 90 & 13201.016 \\
B …… & 08 14 05.6 & +70 52 20 & 90 & 10494.005 & J …… & 23 59 20.7 & +65 43 35 & 90 & 13201.019 \\
C …… & 08 14 05.6 & +70 52 14 & 90 & 10496.001 & & & & & \\
D …… & 08 14 05.6 & +70 52 08 & 90 & 10496.007 & & & & & \\
E …… & 08 14 05.6 & +70 52 02 & 90 & 10196.010 & & & & & \\
F …… & 08 14 05.6 & +70 51 56 & 90 & 10503.004 & & & & & \\
G …… & 08 14 05.6 & +70 51 50 & 90 & 10503.007 & & & & & \\
\hline
\end{tabular}
\end{table}

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
Fig. 2.—Position-velocity diagrams for NGC 2366. Sixteen panels are presented, and the slit position names are labeled at the top of each panel. The abscissa indicates the position along the slit in arcseconds, and the coordinates of the origin are listed in Table 4. The ordinate indicates the heliocentric radial velocity and the FWHM of the H\textalpha emission line. A filled circle indicates the central velocity of the line, and an open circle indicates the FWHM of the line. The scales for the central velocity and the FWHM of the line are shown by the left-hand and right-hand ordinates, respectively. The horizontal and vertical error bars on a filled circle show the binning width and the error of measurement of the central velocity, respectively. The instrumental broadening is reduced from the observed line width to derive the FWHM. The dotted line shows the 0 km s\(^{-1}\) level for the FWHM. The solid line indicates the H\textsc{i} velocity. The data are taken from Wevers et al. (1986). The cross in the top left-hand corner of the panel shows the accuracy of the H\textsc{i} observations. The full length of the horizontal line of the cross, 24\textdegree, indicates the FWHM of the beam for the H\textsc{i} isovelocity map. For four positions of NGC 2366 IA to ID, the FWHM is 25\textdegree, since the size of the beam depends on the position angle. The half-length of the vertical line of the cross, 8.25 km s\(^{-1}\), indicates the channel spacing of the H\textsc{i} observations.
Continued
Fig. 3.—Same as Fig. 2, but for Holmberg II. The H I data are taken from Puche et al. (1992). The beam size and the channel spacing of the H I observations are 4'5 and 2.58 km s⁻¹, respectively.
Fig. 4.—Same as Fig. 2, but for IC 2574. The H I data are taken from Martimbeau et al. (1994). The beam size and the channel spacing of the H I observations are 30′ and 8.24 km s⁻¹, respectively.
Fig. 5.—Same as Fig. 2, but for WLM. There are no synthetic H I observations in the literature so far.
slit scan was 6′0. Because of the sparse spatial sampling in our scanning, we may miss the regions showing the line splitting.

3.2.3. Holmberg II

The resultant seven position-velocity diagrams are shown in Figure 3. The width of the abscissa corresponds to 250′ or 3.9 kpc at Holmberg II. The observed H II regions are divided into the eastern, central, and western blocks. The eastern block consists of northern (slit positions A to D) and southern (F and G) parts, and the western block consists of northern (A and B) and southern (D to F) parts as shown in the Hα map of Figure 1b. Hereafter we call these five regions Holmberg II NE, SE, Center, NW, and SW; see Figure 1b and Table 2.

Holmberg II Center has a steep V-shaped velocity feature as shown in the diagrams for the slit positions A and B. The velocity gradient is 30 km s⁻¹ in 200 pc, and the most blueshifted Hα velocity has a smaller velocity than does the Hβ velocity by about 15 km s⁻¹. The Hα velocity fields for NE, SE, NW, and SW are relatively calm.

3.2.4. IC 2574

The resultant six position-velocity diagrams are shown in Figure 4. The width of the abscissa corresponds to 200′ or 2.9 kpc at IC 2574. This galaxy has a prominent H II complex in the northeastern part of the galaxy; this complex consists of several giant H II regions. Among them the observed positions cover the H II regions denoted IC 2574 I and IC 2574 IV in Drissen, Roy, & Moffat (1993); see Figure 1c and Table 2.

The Hα velocity crosses the Hβ velocity upward and downward on the position-velocity diagrams, and the typical scale of the velocity variation is 20–30 km s⁻¹ over a scale of 200 pc, which is similar to that observed at the outer regions in NGC 2363 as mentioned in § 3.2.1. Unlike in NGC 2363, the Hα velocity field is chaotic over all of the observed H II regions in IC 2574. Two V-shaped velocity features are prominent in the diagrams for the slit positions B to D; the eastern (170′ to 140′) and the western (130′ to 100′) parts correspond to the H II regions IC 2574 IV and IC 2574 I, respectively. In IC 2574 I, the velocity gradient at the slit position D is steep, 50 km s⁻¹ in 400 pc, and the velocity difference between Hα and Hβ at the most intense Hα region is 20 km s⁻¹. The line width is about 30 km s⁻¹, a little larger than those in NGC 2366 and Holmberg II and rises to about 35 km s⁻¹ at the most Hα-blueshifted position in IC 2574 I, as shown in the diagrams for the slit positions B to D. Drissen et al. (1993) found three candidate W-R stars in IC 2574 I. The sharp edge of the velocity feature and the broad FWHM of the line in IC 2574 I seem to be related to the W-R stars.

3.2.5. WLM

The resultant 10 position-velocity diagrams are shown in Figure 5. The width of the abscissa corresponds to 200′ or 0.9 kpc at WLM. As shown in Figure 1d, the H II regions are in two blocks, the southern ring-shaped block and the northern barred-shaped block; hereafter we call them southern ring and northern bar, respectively (see Fig. 1d and Table 2).

Both blocks of the H II regions are the least luminous in the Hα light among 13 observed H II regions. The velocity fields are flat and the calmest among four observed galaxies. The line widths are about 15 km s⁻¹, which are smaller than those in the other three observed galaxies. The slit positions D to F cross the hole of the southern ring and an expanding shell-like feature is seen at −100′ to −50′ in the diagram for the slit position E.

4. DISCUSSION

4.1. Characteristics of the Hα Position-Velocity Diagrams

We investigate characteristics of 13 observed H II regions, the data of which are summarized in Table 2. We classify the morphologies of the H II regions into three types; the first is of circular shape filled with Hα emission, the second is ring-shaped, and the third is filamentary. We call them type C, R, and F morphologies, respectively. Some H II regions with the type F morphology seem to be a chain of small H II regions with the type C morphology. The Hα luminosities of the H II regions with the type F morphology is less than 2 × 10³⁸ ergs s⁻¹. We divide the type C morphology into two subgroups; type C1 and type C2 for the Hα-luminous [L(Hα) ≥ 2 × 10³⁸ ergs s⁻¹] one and Hα–less luminous [L(Hα) < 2 × 10³⁸ ergs s⁻¹] one, respectively.

The velocity features in the position-velocity diagrams are classified into four types and schematically shown in Figure 6; we call them type I, II, III, and IV velocity features, respectively. The two classifications of the 13 H II regions are listed in the two rightmost columns of Table 5. Table 6 summarizes the classifications of 13 H II regions, as well as eight H II regions that we previously observed in dwarf irregular galaxies I Zw 36, Sextans A, NGC 6822, IC 1613, and NGC 1569 (Tomita et al. 1993, 1994). Table 6 shows that the morphological type and the velocity feature of the H II regions correlate well with each other; we characterize the H II regions into only five categories according to our classifications.
Type I and type F or C2.—The position-velocity diagrams for five less luminous H II regions from NGC 2366 NA to WLM northern bar in Table 5 are flat. This is probably due to either a lack of energetic stars that can generate strong wind or being at a young stage of evolution. IC 1613 S3, and probably IC 1613 S2 and Sextans A (the H II region at the eastern part of the galaxy) belong to this category (Tomita et al. 1993).

Type I and type C1.—The velocity fields of powerful H II regions without sharp velocity bumps suggest that the ages of the H II regions are too young to generate many evolved stars; examples are NGC 2366 III and Holmberg II NE and SE. At the central part of NGC 2363 the velocity field is flat, though it is chaotic at the outer part. The velocity field, which is calm in the central regions and chaotic at the outer regions in the luminous H II region, is also observed in NGC 6822 HV (Tomita et al. 1993).

Type II and type C1.—Roy et al. (1991) suggested that the ridge of the [O III] velocity field in NGC 2363, shown as a bump in the position-velocity diagrams at the positions NGC 2366 IA to ID (see Figs. 2a and 2b), is related to a chimney. I Zw 36, a well-studied blue compact dwarf galaxy, has a type II velocity feature (Tomita et al. 1994). Viallefond & Thuan gave the Hb flux of I Zw 36, $f(\text{H}b) = 3.65 \times 10^{-13}$ ergs s$^{-1}$ cm$^{-2}$, and the distance of 4.6 Mpc. Assuming $f(\text{H}a)/f(\text{H}b) = 3$, we get $L(\text{H}a) = 3 \times 10^{39}$ ergs s$^{-1}$. The relatively mild velocity field in spite of intense Hb luminosity suggests the H II regions are at a young stage.

Type III and type C1.—The V-shaped velocity feature associated with two H II regions in IC 2574 may indicate blowout motions away from the galactic disk. The H II region HX in NGC 6822 also shows this kind of feature (Tomita et al. 1993).

Type III or IV and type R.—The HX ring shows an expanding bubble feature in the position-velocity diagrams; we discuss the kinematics following the analysis given by McCray & Cafatos (1987). The kinetic age of the bubble is

### Table 5

| H II Region      | $L(\text{H}a)$ ($10^{38}$ ergs s$^{-1}$) | Morphology | Velocity |
|------------------|----------------------------------------|------------|----------|
| NGC 2363         | 95                                     | C          | II       |
| NGC 2366 III     | 14                                     | C          | I        |
| IC 2574 I        | 12                                     | C          | III      |
| Holmberg II center | 9.2                                   | C, R      | III      |
| Holmberg II NE   | 7.3                                     | C          | I        |
| IC 2574 IV       | 5.3                                     | C          | III      |
| Holmberg II SE   | 3.0                                     | C          | I        |
| NGC 2366 NA      | 1.4                                     | C          | I        |
| NGC 2366 ND      | 1.4                                     | C          | I        |
| Holmberg II NW   | 1.3                                     | F          | I        |
| Holmberg II SW   | 1.1                                     | C          | I        |
| WLM northern bar | 0.4                                     | F          | I        |
| WLM southern ring| 0.3                                     | R          | IV       |

### Table 6

| Morphological Velocity Feature | Filamentary (F)       | Circular (less luminous) (C2) | Circular (luminous) (C1) | Ring (R)                |
|-------------------------------|-----------------------|-------------------------------|--------------------------|-------------------------|
| Flat (I)                      | Ho II NW              | NGC 2366 NA                   | NGC 2366 III             |                         |
|                               | WLM N Bar             | NGC 2366 ND                   | Ho II NE                 |                         |
|                               | IC 1613 S3            | Ho II SW                      | Ho II SE                 |                         |
|                               | (IC 1613 S2?)         | (Sex A?)                      | NGC 6822 HV              |                         |
| Upper-bumpy (II)              |                       |                               | NGC 2363                 |                         |
|                               |                       | I Zw 36                       | I Zw 36 (NGC 1569 arcs?) |                         |
|                               |                       |                               | IC 2574 I                |                         |
|                               |                       |                               | IC 2574 IV               |                         |
|                               |                       |                               | NGC 6822 HX              |                         |
|                               |                       |                               | (NGC 1569 arcs?)         |                         |
| Valley-like (III)             |                       |                               | Ho II Center*            |                         |
|                               |                       |                               | NGC 1569 Ss*             |                         |
|                               |                       |                               | WLM S Ring               |                         |

* The morphology is between type C1 and type R.
$t = 0.6 (R/V)$ Myr, and the kinetic energy of the bubble is $E = 1.3 \times 10^{42} R^2 V^2 n_0$ ergs, where $R$ is the radius in kiloparsecs, $V$ is the expansion velocity in km s$^{-1}$, and $n_0$ is the number density of the ambient interstellar matter in cm$^{-3}$.

The number of supernovae ($N_{SN}$) responsible for the bubble kinetic energy is derived as

$$N_{SN} = \frac{E}{(0.2 \times 10^{51} \text{ ergs})},$$

assuming that 20% of the supernova energy of $10^{51}$ ergs contributes to the bubble's kinetic energy. Though we did not observe whole regions of Holmberg II Center, we take the expansion velocity for Holmberg II Center as 30 km s$^{-1}$ from the data at the position-velocity diagram for the position A. With a radius of 200 pc, we get $t = 4$ Myr, $E = 2 \times 10^{51}$ ergs, and $N_{SN} = 50$, assuming $n_0 = 1$ cm$^{-3}$.

The bubble feature seen in the position NGC 2366 SB has the same radius and expansion velocity as those for Holmberg II Center, 200 pc and 30 km s$^{-1}$, respectively. Hunter et al. (1993) pointed out a possible connection between the Hz filamentary structure around NGC 2363 and the extraordinarily high velocity feature claimed by Roy et al. (1991). The bubble feature seen at NGC 2366 SB corresponds to a part of the Hz filament (see Fig. 1a and mentioned in § 3.2.1), therefore, this filament was generated by a local bubble, off the central part of NGC 2363. WLM Southern ring has a radius of 150 pc and an expansion velocity of 20 km s$^{-1}$. Then $t = 4.5$ Myr, $E = 2 \times 10^{51}$ ergs, and $N_{SN} = 10$ are obtained, assuming $n_0 = 1$ cm$^{-3}$. The age derived is consistent with the result by Ferraro et al. (1989) that the star formation stopped a few Myr ago in the region including this H II region (denoted as region 2 by them). $N_{SN}$ is similar to those for expanding shells in NGC 1569 (denoted as SSs in Tomita et al. 1994). The bubbles in our sample have much larger $N_{SN}$ than those observed by Oey & Massey (1994) in M33.

Puche et al. (1992) found many H I holes in Holmberg II. Puche et al. (1992), Mashchenko & Silich (1995), and Tongue & Westpfahl (1995) argued that they are cavities generated by the star formation activity, and Hunter et al. (1993) claimed a possibility that the holes were made by the penetration of the high-velocity clouds because the Hz emission does not encircle the H I holes as is the case in LMC, which is expected for cavities by violent star formation. We do not detect the expanding-bubble velocity features for the H II regions that surround the H I holes in Holmberg II as we observe in WLM. Our data do not support the idea that the star formation cavities are responsible for the H I holes in Holmberg II.

### 4.2. Comparison of the Velocity Field between Hζ and H I

The ratio of FIR to blue luminosity, $L_{FIR}/L_B$, is an indicator of the present star formation activity of the galaxy per luminous mass (Tomita, Tomita, & Saito 1996). The ratios are 0.3, 0.2, 0.05, and 0.01 for IC 2574, NGC 2366, Holmberg II, and WLM, respectively (see Table 1); the activity ranges over 1.5 orders of magnitude. The ratio of the H I mass to $B$-band luminosity ($M_H/L_B$), on the other hand, is about 0.1 for all four galaxies (see Table 1). Huchtmeier, Seiradakis, & Materne (1981) presented H I extents for Holmberg II, NGC 2366, and WLM. At a level of $10^{19}$ cm$^{-2}$ of the H I column density, the radii of the H I extent are 27', 30', and 45', respectively, and correspond to 3.3, 3.6, and 3.8 times the Holmberg radius, respectively; the ratios of H I to optical size are similar among the three galaxies. The average H I surface densities are several to 10 times $10^3 M_\odot$ kpc$^{-2}$ and are also similar to each other among the three galaxies. No correlation between the star formation activity, such as $L_{FIR}/L_B$, and the H I density suggests that some external causes or internal but intermittent causes trigger the generation of the star-forming regions, as well as cloud formation by self-gravity or shell sweeping (e.g., Oey & Massey 1995).

Saito et al. (1992) proposed a model based on observed Hz and H I velocity fields of IC 10 in which infalling clouds from the extended H I envelope of the galaxy may cause the intense star formation. In their model, the H II regions made by infalling H I clouds have bulk motions of about 10 km s$^{-1}$ relative to the ambient H I disk. The chaotic velocity fields, with bubbles or blowout features through the intense star formation, presented by types III and IV, would disturb the information about the original bulk motion of star-forming clouds. On the other hand, the calm Hz velocity...
field, types I and II, is suitable to measure the original bulk motion of the H II regions. We investigate eight H II regions: NGC 2363 (the slit position of NGC 2366 SG), NGC 2366 III (the slit position of NGC 2366 SD), NGC 2366 NA, NGC 2366 ND, Holmberg II NE, SE, NW, and SW.

Table 7 lists the H I and Hα radial velocities, as well as the velocity difference between them. In three out of the eight, NGC 2363, Holmberg II NE, and Holmberg II NW, we detect little or no velocity difference. In three other H II regions in NGC 2366, we detect velocity differences of about 10 km s$^{-1}$. We detect velocity differences of 15 to 20 km s$^{-1}$ for another two H II regions in Holmberg II. The distribution of the velocity differences among the eight H II regions ranges from $-10$ to $20$ km s$^{-1}$, and the average is several km s$^{-1}$. In the previous study by Tomita et al. (1993), five H II regions, I Zw 36, Sextans A, IC 1613 S2 and S3, and NGC 6822 HV in four galaxies have type I or II velocity features (see Table 6). Figure 7 summarizes the observed velocity differences of Hα for H II regions with type I or II velocity features including above five H II regions. The standard deviation of the velocity difference is about 5 km s$^{-1}$, which is consistent with the expectation from the model by Saito et al. (1992). Though marginal and inconclusive because such a velocity difference may be generated by internal motion through star formation activity, this suggests that some of the H II regions in dwarf irregular galaxies formed through the infall of clouds onto the galactic disk. A search for high-velocity clouds around the galaxies is needed to confirm this hypothesis.

We would like to thank Yoh-ichi Kanamori for his help with the observations and the OAO staff members for their hospitality during our stay. T. T. T. acknowledges the Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists. Finally, we are grateful to the anonymous referee for improving the paper.

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