A VIEW OF THE M81 GALAXY GROUP VIA THE Hα WINDOW

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Received 2006 September 11; accepted 2006 December 23

ABSTRACT

We present images for 36 galaxies of the M81 Group obtained in the Hα line. Estimates of the Hα flux and star formation rate (SFR) are now available for all the known members of the group with absolute magnitudes down to $M_B = -10$ mag. The character of distribution of the galaxies over three parameters, $M_B$, SFR, and total hydrogen mass, permits us to draw the following conclusions as to the evolutionary status of the group population: (1) Spiral and irregular-type galaxies have time to generate their luminosity (baryon mass) during the cosmological time $T_0 = 13.7$ Gyr, but dwarf spheroidal objects are capable of reproducing only $\sim 5\%$ of their observed luminosity. (2) S and Im/blue compact dwarf (BCD) galaxies possess a supply of gas sufficient to maintain their observed SFRs only during the next $(1 - T_0)/T_0$ yr, while dIrr and dSph populations have a mean gas depletion time of about $3T_0$. (3) There is indirect evidence that the star formation in Im/BCD and dIrr galaxies proceeds in a mode of vigorous burst activity rather than in the form of a sluggish process. We note that the dwarf tidal system near NGC 3077, the Garland, has the highest SFR per unit luminosity among 150 galaxies of the Local Volume with known SFRs. Being averaged over the local "cell of homogeneity" of 4 Mpc in diameter around M81, the rate of star formation of the group, $\dot{\rho}_{\text{SFR}} = 0.165 \, M_\odot \, yr^{-1} \, Mpc^{-3}$, proves to be 5–8 times higher than the average global rate at $z = 0$.

Key words: galaxies: evolution — galaxies: ISM — stars: formation

Online material: color figures

1. INTRODUCTION

In recent years a great deal of observational effort has been undertaken to understand how star formation in a galaxy depends on its luminosity, age, and environment. One of the basic tools for this is measurement of fluxes that are emitted by galaxies in the Hα line. Madau et al. (1996) have shown that the average star formation rate (SFR) has smoothly increased with redshift from $z \approx 5$ to $z \approx 1$ and then has decreased steeply up to the present time ($z = 0$). In order to reliably fix the star formation density in a unit volume at the present epoch, it is necessary to measure the Hα fluxes in a sufficiently representative sample of nearby galaxies limited by a fixed distance. The most appropriate sample for this purpose is the catalog of 450 neighboring galaxies situated in a sphere of radius 10 Mpc around the Milky Way (Karachentsev et al. 2004).

We have undertaken a comprehensive Hα survey of these galaxies on the northern sky with the Big Telescope Alt-azimuthal (BTA) 6 m telescope. The first results have been published for galaxies in the groups around NGC 6946 (Karachentsev et al. 2005) and M31 (Kaisin & Karachentsev 2006). This program has also been supported by observations of southern objects (Kaisin et al. 2007). The data obtained allow the rates of star formation in galaxies to be studied in a uniquely wide range of luminosities, as high as 4 orders of magnitude.

In this paper we present a complete summary of the data on Hα fluxes for galaxies in a neighboring group around the giant spiral galaxy M81. An atlas of large-scale images of 20 dwarf galaxies of this group in the B band was presented by Karachentsev et al. (1985). Another seven dwarf systems have been discovered in this group since then. According to Karachentsev et al. (2002), about 30 galaxies are associated with M81, including the bright spiral galaxy NGC 2403 and five of its satellites. At present, accurate distances from the luminosity of the red giant branch stars have been measured for almost all the members of M81, which has made it possible to reconstruct the three-dimensional structure of the complex. The loose clump of dwarf galaxies around NGC 2403 is situated at the front boundary of the complex and is moving away from us toward M81. On the opposite, more distant side there are the spiral NGC 4236 and a few irregular galaxies, which are not dynamically associated with M81 but take part in the cosmic expansion. On the whole, this entire complex of galaxies looks like a diffuse filament somewhat resembling the nearby loose filament in Sculptor (Karachentsev 2005).

Unfortunately, no one has ever undertaken a systematic overview of the M81 Group population in the Hα line. The brightest members of the group were observed in Hα by Hodge & Kennicutt (1983), Kennicutt et al. (1989), Miller & Hodge (1994), and Young et al. (1996). Later on, the Hα fluxes in several M81 companions were measured by Gil de Paz et al. (2003), James et al. (2004), Hunter & Elmegreen (2004), and Lozinskaya et al. (2006). Miller (1996) has noted that the SFRs in the galaxies of the M81 Group look, on average, higher than those in the Sculptor Group and the Local Group. However, about two-thirds of the galaxies in the M81 Group did not have measured Hα fluxes at that time. The survey of the dwarf population of this group, which we have carried out, gives grounds for a correct comparison of star formation processes in the most nearby groups.

2. OBSERVATIONS AND DATA REDUCTION

We obtained CCD images in the Hα line and continuum for 36 members of the M81 Group in the period from 2001 March to 2006 May with a median seeing of 2.0″. All the observations were made at the BTA 6 m telescope of the Special Astrophysical Observatory using the SCORPIO device (Afanasiev et al. 2005) with a CCD chip of $2048 \times 2048$ pixels and a scale of 0.18″ pix$^{-1}$, which provides a total field of view of 6.1′ × 6.1′. The images in Hα + [N II] and the continuum were obtained via observing the galaxies through a narrowband interference Hα filter (Δλ = 75 Å) with an effective wavelength $\lambda = 6555$ Å and medium-band filters.
for the continuum: SED607 with $\lambda = 6063$ Å, $\Delta \lambda = 167$ Å and SED707 with $\lambda = 7063$ Å, $\Delta \lambda = 207$ Å, respectively. Typical exposure times for most of the galaxies were $2 \times 300$ s in the continuum and $2 \times 600$ s in H\textalpha. Since the range of radial velocities in our sample is small, we have used the same H\textalpha filter for all the observed objects. The procedure of data reduction was standard for direct images obtained with the CCD. For all the data the bias was subtracted, and then all the images were flat-fielded, after which cosmic rays were removed and the sky background was subtracted. The next operation was to bring all the images of a given object into coincidence. Then all the images were normalized to the H\textalpha continuum were normalized to the H\textalpha line.

The size of the presented frames is $4' \times 4'$, the north and east directions are marked by the arrows, and the names of the galaxies are given in the upper right corners of the frames. For two large galaxies, M82 and IC 2574, we present a mosaic of the images of three frames; these are at the end of Figure 1.

Some basic parameters of the galaxies that we have observed are given in Table 2. To make the picture complete, we have also added into the table a few bright members of the group whose fluxes in the H\textalpha line were measured earlier by other authors. The conditions of our observations are given in Table 1. The columns of Table 2 contain the following data, taken, as a rule, from the Catalog of Neighboring Galaxies (CNG; Karachentsev et al. 2004): (1) the galaxy name, (2) and (3) the equatorial coordinates for the epoch J2000.0, (4) the distance to a galaxy in megaparsecs with allowance made for new measurements (Karachentsev et al. 2006), (5) the blue absolute magnitude of the galaxy with the given distance after correction for the Galactic extinction $A_v$, (6) the major linear diameter in kiloparsecs corrected for the galaxy inclination and the Galactic extinction in the manner adopted by de Vaucouleurs et al. (1977), (7) the morphological type, and (8) the tidal index (TI) following from the CNG; i.e., for every galaxy $i$ we have found its main disturber (MD), producing the highest tidal action

$$T_i = \text{max}\left[\log\left(M_i/D_{i}\right)\right] + C \quad (i = 1, 2, \ldots, N),$$

where $M_i$ is the total mass of any neighboring potential MD galaxy (proportional to its luminosity with $M_i/L_B = 10 M_\odot/L_B$) separated from the considered galaxy by a space distance $D_{i}$. The value of the constant $C$ is chosen so that $T_i = 0$ when the Keplerian cyclic period of a galaxy with respect to its MD equals the cosmic Hubble time $H_0$; therefore, positive values correspond to galaxies in groups, while negative values correspond to field galaxies. Column (9) gives the logarithm of the hydrogen mass of the galaxy,

$$\log(M_{H_i}/M_\odot) = \log(F_{H_i}) + 2\log D_{N_{mpc}} + 5.37,$$

defined from its flux $F_{H_i}$ in the 21 cm line; in some dwarf spheroidal (dSph) galaxies the upper limit of the flux was estimated from the observations by Huchmeier et al. (2000). Column (10) gives the integral flux of the galaxy in the H\textalpha + [N ii] lines expressed in terms of $10^{-16}$ ergs cm$^{-2}$ s$^{-1}$ with an indication of a typical measurement error; the asterisks denote data sources of SFRs according to other authors, reduced to the distance of the galaxy adopted in column (4). Column (11) gives the SFR in the galaxy on a logarithmic scale, SFR($M_\odot$ yr$^{-1}$) = $1.27 \times 10^4 F_{H_i}(H\alpha)D^2$ (Gallagher et al. 1984), where the integral flux in the H\textalpha line is corrected for extinction as $A(H\alpha) = 0.538A_V$, while the galaxy distance is expressed in megaparsecs. Columns (12) and (13) give the dimensionless parameters $p_i = \log(\text{SFR}/T_0/L_B)$ and $f_i = \log(M_{H_i}/\text{SFR}_0)$, which characterize the past and the future of the process of star formation; here $L_B$ denotes the total blue luminosity of the galaxy in units of solar luminosity, while $T_0$ is the age of the universe, assumed to be equal to 13.7 billion years (Spergel et al. 2003).

In the following we note some features of the emission regions in the galaxies that we observed:

**KKH 34.**—This dwarf irregular galaxy at the farthest outskirts of the M81 Group (from the side of the neighboring group IC 342/Maffei) shows faint diffuse emission in its central part.

| Galaxy    | Date       | Seeing (arcsec) | $T_{exp}$ (s) |
|-----------|------------|----------------|---------------|
| KKH 34    | 2002 Nov 13| 1.7            | 1200          |
| KKH 37    | 2001 Oct 9 | 2.3            | 1200          |
| DDO 49    | 2002 Nov 13| 1.8            | 1200          |
| Holmberg II | 2004 Jan 27| 2.1            | 1200          |
| KDG 52    | 2002 Dec 5 | 1.8            | 1200:         |
| DDO 53    | 2003 Nov 28| 1.5            | 1200:         |
| U4483     | 2003 Nov 28| 1.5            | 1200:         |
| VKN       | 2002 Dec 5 | 1.8            | 1200:         |
| Holmberg I | 2006 May 21| 2.3            | 600:          |
| F8D1      | 2005 Feb 1 | 4.3            | 1200          |
| FM 1      | 2005 Feb 1 | 4.3            | 1200          |
| N2976     | 2003 Nov 3 | 1.5            | 600:          |
| KK 77     | 2006 May 20| 2.2            | 600:          |
| BK 3N     | 2004 Jan 27| 2.0            | 1200          |
| M82       | 2006 May 23| 2.2            | 1200          |
| KDG 61    | 2006 May 21| 1.6            | 600:          |
| A0952 + 69| 2004 Jan 27| 2.0            | 1200          |
| KKH 57    | 2006 May 20| 1.8            | 900:          |
| N3077     | 2003 Nov 3 | 1.5            | 1200:         |
| The Garland | 2003 Nov 3 | 1.5            | 1200:         |
| BK 5N     | 2005 Feb 2 | 2.8            | 1200          |
| KDG 63    | 2005 Feb 3 | 1.8            | 1200          |
| U5423     | 2006 Feb 4 | 2.1            | 1200          |
| KDG 64    | 2005 Feb 3 | 1.7            | 1200          |
| IKN       | 2002 Dec 5 | 1.2            | 1200:         |
| HIJASS    | 2004 Jan 29| 1.9            | 600:          |
| HS 117    | 2004 Jan 29| 2.5            | 1200          |
| DDO 78    | 2005 Feb 4 | 1.7            | 600:          |
| I2574     | 2006 Feb 4 | 4.4            | 1200:         |
| DDO 82    | 2003 Feb 7 | 1.9            | 1200          |
| BK 6N     | 2006 May 21| 4.1            | 1200          |
| DDO 87    | 2006 May 21| 1.7            | 600:          |
| KDG 73    | 2003 Feb 7 | 2.1            | 1200          |
| U6456     | 2003 Feb 7 | 2.2            | 1200          |
| U7242     | 2006 May 20| 2.7            | 300:          |
| N4605     | 2004 Jan 29| 2.0            | 1200          |
| DDO 165   | 2001 Mar 17| 3.9            | 900:          |
KKH 37.—This is another dIrr galaxy located halfway between M81 and IC 342. Apart from the diffuse Hα emission, KKH 37 shows the presence of a compact H II region near the center, which has been used by Makarov et al. (2003) to determine the radial velocity of the galaxy.

DDO 44.—This dSph companion of the spiral galaxy NGC 2403 does not show emission in the neutral hydrogen line H I. We have not detected Hα emission within the optical boundary of DDO 44. However, there is a compact patch (Fig. 1, circle) at the northeast edge of the galaxy. It may be a peculiar background galaxy rather than an emission knot belonging to DDO 44. The Hα flux presented in Table 2 refers exactly to it. Apparently, to establish its nature, spectral observations are needed.

Holmberg II.—This is an irregular galaxy with powerful star formation sites whose periphery is beyond our frame. The Hα flux presented in Table 2 takes into account the correction for the...
incomplete field ($\Delta \log F = 0.20$) under the assumption that distribution of the H$\alpha$ emission is proportional to the galaxy blue surface brightness.

*KDG 52.*—The detailed distribution of neutral hydrogen and the radial velocity field in this dIrr galaxy have been obtained by Begum et al. (2006). Judging by the images taken with the Hubble Space Telescope (HST) (Karachentsev et al. 2002), KDG 52 contains a young blue stellar population. However, Figure 1 does not show any noticeable H$\alpha$ emission above a detection limit of $5 \times 10^{-16}$ ergs cm$^{-2}$ s$^{-1}$.

*DDO 53 and UGC 4483.*—These are known dIrr and blue compact dwarf (BCD) galaxies with bright H$\alpha$ regions (Hunter & Elmegreen 2004; Gil de Paz et al. 2003).

*VKN.*—This is an object of extremely low surface brightness in the vicinity of UGC 4483, which is likely to be a part of the faint Galactic cirrus.
Holmberg I.—This is an irregular galaxy of low surface brightness with a lot of compact and diffuse emission knots on its periphery.

F8D1, FM 1, and KK 77.—These are dSph companions to M81 of very low surface brightness. In the vicinity of F8D1 one can see three faint knots (Fig. 1, circles) whose possible emission nature needs to be especially checked. The Hα flux for F8D1 given in Table 2 refers to these knots.

NGC 2976.—This is a late-type Sdm galaxy with unclear spiral structure outlined by bright sites of star formation and dust complexes (James et al. 2004).

BK 3N.—This is the faintest of the known M81 companions. Judging by the images obtained with the HST, it has a population of young stars but does not show signs of Hα emission above the detection limit of $2 \times 10^{-16}$ ergs cm$^{-2}$ s$^{-1}$. The value of the
Hi flux in BK 3N is also rather uncertain because of the projected Hi envelope of M81.

KDG 61.—The compact emission region discovered by Johnson et al. (1997) on the northern side of this galaxy is not typical of dSph objects. A very faint filament structure is also seen in Figure 1 around this compact bright Hi region.

A0952+69.—This is a part of the Arp Loop resolved into stars by means of the WFPC2 on the HST (Karachentsev et al. 2002). The presence of numerous small H II regions is evidence of the star formation process occurring at low rates in this peculiar structure at the outskirts of M81.

KKH 57 and BK 5N.—These are dSph systems with no signs of star formation.

NGC 3077 and the Garland.—The Hα emission in NGC 3077 shows a strong concentration toward the galaxy center, where dust clouds also occur. Closer to the outskirts the emission has a filament structure that looks like a crab’s claws. At the southern periphery of NGC 3077 a chain of associations

**Fig. 1—Continued**
of blue stars and H\textsubscript{\textsc{ii}} regions is seen and called the “Garland” (Karachentseva et al. 1985; Karachentsev et al. 1985). A neutral hydrogen filament and molecular clouds are associated (Yun et al. 1994; Walter et al. 2002) with this unusual structure, which is likely to be of tidal origin (Makarova et al. 2003).

**KDG 63 and KDG 64.**—Both galaxies are known as dSph systems with an old stellar population. However, on our H\text{\alpha} images of KDG 63 and KDG 64, two and one knots are seen, respectively (Fig. 1, circles), which may prove to be compact H\textsubscript{\textsc{ii}} regions.

**UGC 5423.**—Judging by the radial velocity, $V_{LG} = +496$ km s\textsuperscript{-1}, and the distance, 5.3 Mpc, this BCD/dIrr galaxy with emission knots is situated behind the M81 Group or at its farthest outskirts.

**IKN.**—This very diffuse galaxy is barely seen in the halo of a neighboring bright star to the north. The galaxy H\text{\alpha} emission is visibly absent.
HIJASS.—This intergalactic hydrogen cloud has been detected by Boyce et al. (2001) and investigated in detail at the Very Large Array by Walter et al. (2005). Its optical counterpart, if it exists, has a total apparent magnitude of about 20 mag. In the region of this object, one can see (Fig. 1) a few faint diffuse knots whose nature can be established by future spectral observations.

HS 117.—Based on its HST images (Karachentsev et al. 2006), this galaxy of regular shape contains a small number of bluish stars. However, observations of it with the Giant Metrewave Radio Telescope (A. Begum 2006, private communication) have not revealed signs of H\textsc{i} emission. Near the center of the H\alpha image of HS 117, there is a compact knot (Fig. 1, circle), a spectrum of which will be obtained soon.

DDO 78 and BK 6N.—We suspect one emission knot (Fig. 1, circles) in each of these dSph systems. However, judging by the HST images, these are artifacts caused by incomplete subtraction.
of images of distant galaxies. The Hα fluxes for them given in Table 2 refer to these knots.

DDO 82 and UGC 7242.—These are irregular galaxies whose images are strongly contaminated by neighboring bright stars. Considerable Hα emission is visible in both galaxies.

DDO 87.—This dIrr galaxy with a radial velocity $V_{LG} = +468$ km s$^{-1}$ and a distance of 7.4 Mpc (estimated from the brightest blue stars) is likely to be located behind the M81 Group. About a dozen compact H II regions are seen in the galaxy body, with a practically complete absence of diffuse emission.

KGD 73.—This is a dIrr galaxy of low surface brightness. The color-magnitude diagram for it, obtained with the WFPC2 of HST, shows the presence of blue stars. In the optical domain of the galaxy we note two very faint diffuse emission regions whose fluxes are at the limit of detection.
UGC 6456 (VII Zw 403).—Along with UGC 4483 and UGC 5423, this is the third BCD galaxy in our sample. The bright regions of star formation in it are located asymmetrically to the east with respect to the geometric center of the galaxy.

NGC 4605.—It is surprising, but this bright galaxy has never before been imaged in the H\textalpha\ line. Powerful emission is observed in its disk, which exceeds in flux the H\textalpha\ emission from another Sdm galaxy, NGC 2976. A system of fine emission filaments that attach to the emission disk of NGC 4605 makes the galaxy look like a bristled-up seahorse. A long diffuse filament extends from the southern side of the disk, while the western side of the disk is likely to contain a great amount of dust.

DDO 165.—This is an irregular galaxy on the far side of the M81 Group. There are several compact H \textsc{ii} regions in its optical domain, along with the common emission envelope.

As we have already noted, the H\textalpha\ fluxes in a number of galaxies in the M81 Group were measured earlier by other authors.
In Table 3 we present the data on the SFRs in 12 members of the group obtained from our measurements (6 m), as well as from estimates by other authors reduced to the distances indicated in Table 2. As can be seen, the agreement of log(SFR) proves to be quite satisfactory. The only exception is the discrepancy with the data by Walter et al. (2002, 2006) for NGC 3077 and the Garland, the cause of which is not clear to us. For the rest of the galaxies, the average difference of our estimate and others is $\langle \Delta \log(\text{SFR}) \rangle = -0.02 \pm 0.02$, with a typical external error of a single measurement of the H$\alpha$ flux of about 10%.

4. DISCUSSION

The H$\alpha$ line images of galaxies in the M81 Group obtained by us and other authors show that the star formation processes in the galaxies belonging to the same group are characterized by great variety. In some relatively luminous galaxies (NGC 3077 and
M82) the main emission comes from the galaxy core. In other bright spiral galaxies (NGC 2976, NGC 4605, NGC 2403, and M81) the Hα emission is distributed more or less uniformly over the whole disk. In irregular galaxies with the typical luminosity of the Magellanic Clouds (Holmberg II, IC 2574, and NGC 2366) one observes the presence of powerful sites of star formation, and rather often such superassociations are located at the outskirts of these galaxies. In dIrr and BCD galaxies of low luminosity, small compact H II regions (Holmberg I, DDO 87, UGC 4483, and DDO 165) or separate diffuse emission knots (KK 34 and KKH 37) are characteristic features. The presence of emission knots in dwarf galaxies that have been classified as spheroidal (KDG 61, KDG 63, and HS 117) proved to be unexpected, although some of the detected emission details need additional spectral confirmation. At least, we note the cases in which dIrr galaxies have very low (−10 or −11 mag) luminosity: KDG
52 and BK 3N do not show any detectable Hα flux, although they contain a blue stellar population, seen on the images taken with the HST. Apparently, the potential well in these pygmy galaxies is so shallow that it is unable to hold ionized gas.

The distribution of 41 galaxies in the region of M81 versus their absolute magnitude $M_B$ and SFR is presented in Figure 2 (squares). The dwarf galaxies with only an upper limit for the Hα flux are indicated by open squares. For comparison, we also present another 150 galaxies from the Local Volume ($D < 10$ Mpc), shown by circles. The SFR data for them are taken from Hodge & Kennicutt (1983), Kennicutt et al. (1989), Miller & Hodge (1994), Young et al. (1996), Gil de Paz et al. (2003), James et al. (2004), Hunter & Elmegreen (2004), Karachentsev et al. (2005), and Kaisin & Karachentsev (2006). Here objects with a low SFR, $<3 \times 10^{-9} M_\odot$ yr$^{-1}$, are all companions to the neighboring spiral M31.
As can be seen from this “giraffe-like” diagram, most of the galaxies with magnitudes from $-13$ to $-21$ mag, situated along the giraffe’s neck, follow a linear relationship, $SFR \propto L_B$ (Fig. 2, dashed line), with an rms scatter $\sigma[\log(SFR)] \approx 0.5$. The M81 Group members on this diagram follow the common relation without significant displacement with respect to other Local Volume galaxies.

Among the galaxies of the M81 suite, the Garland is distinguished by the highest SFR per unit luminosity (i.e., specific SFR). Apparently, we observe this tidal structure at the peak of the star formation process, in a burst. Among the other 150 galaxies of the Local Volume, only one BCD galaxy, UGCA 281 (Mrk 209), approaches the Garland in its very high specific SFR.
Another useful diagram, showing the evolutionary status of the galaxies, is presented in Figure 3, where the global SFR of the galaxies is compared with their mass of neutral hydrogen. The designations of the M81 Group members and other galaxies of the Local Volume are given here, as in Figure 2. Many authors, such as Kennicutt (1989, 1998), Taylor & Webster (2005), Taylor (2005), Juneau et al. (2005), Tutukov (2006), Feulner et al. (2006), and Gutierrez et al. (2006), have been concerned with the interpretation of the character of the distribution of galaxies over the diagram SFR $\propto M_{H\text{I}}$. As has been noted by these authors, spiral and irregular galaxies follow, on average, the relation SFR $\propto M_{H\text{I}}^{1.4}$; that is, a higher SFR is observed in galaxies with larger...
| Name          | R.A. (J2000.0) | Decl. (J2000.0) | $D$ (Mpc) | $M_B$ (mag) | $A_{25}$ (kpc) | Type | TI | $\log M_{H_1}$ ($M_\odot$) | Flux ($M_\odot$ yr$^{-1}$) | $\log(SFR)$ ($M_\odot$ yr$^{-1}$) | $p^*$ | $f^*$ |
|---------------|----------------|----------------|-----------|-------------|--------------|------|---|----------------------------|--------------------------|--------------------------------|-------|------|
| KKH 34        | 05 59 41.2     | +73 25 39      | 4.61      | -12.30      | 1.34         | Ir   | -1.8 | 7.08                       | 36 ± 3                   | -3.78                           | -0.72 | 0.72 |
| KKH 37        | 06 47 45.8     | +80 07 26      | 3.39      | -11.59      | 1.17         | Ir   | 1.2  | 6.66                       | 110 ± 13                  | -3.73                           | -0.39 | 0.25 |
| N2366         | 07 28 52.0     | +69 12 19      | 3.19      | -16.02      | 5.71         | IBm  | 1.0  | 8.85                       | ...                       | -0.85                           | 0.72  | -0.44|
| DDO 44        | 07 34 11.3     | +66 53 10      | 3.19      | -12.07      | 2.67         | dSph | 1.7  | <6.0                      | 6 ± 6                     | -5.07                           | -1.92 | 0.93 |
| N2403         | 07 36 54.4     | +65 35 58      | 3.30      | -19.29      | 19.43        | Scd  | -0.9 | 9.52                       | ...                       | -0.04                           | 0.22  | -0.58|
| Holmberg II   | 08 19 05.9     | +70 42 51      | 3.39      | -16.72      | 7.78         | Im   | 0.6  | 8.99                       | 56950 ± 330               | -1.05                           | 0.24  | -0.10|
| KDG 52        | 08 23 56.0     | +71 01 46      | 3.55      | -11.49      | 1.35         | Ir   | 0.7  | 7.12                       | 5 ± 5                     | -5.08                           | -1.70 | 2.06 |
| DDO 53        | 08 34 06.5     | +66 19 45      | 3.56      | -13.37      | 1.67         | Ir   | 0.7  | 7.61                       | 5310 ± 41                 | -2.04                           | 0.59  | -0.49|
| U4483         | 08 37 03.0     | +69 46 31      | 3.21      | -12.73      | 1.04         | BCD  | 0.5  | 7.51                       | 3168 ± 29                 | -2.35                           | 0.54  | -0.28|
| VKN           | 08 40 08.9     | +68 26 23      | ...       | ...         | ...          | ...  | ... | ...                         | ...                      | ...                             | ...   | ...  |
| Holmberg I    | 09 40 28.2     | +71 11 11      | 3.84      | -14.49      | 4.03         | Ir   | 1.5  | 8.13                       | 3565 ± 31                 | -2.13                           | 0.05  | 0.12 |
| F8D1          | 09 44 50.0     | +67 28 32      | 3.77      | -12.59      | 2.58         | dSph | 2.0  | <6.2                      | 24 ± 4                    | -3.86                           | -0.92 | -0.08|
| FM 1          | 09 45 10.0     | +68 45 54      | 3.42      | -10.48      | 0.93         | dSph | 1.8  | <6.1                      | 7 ± 6                     | -4.92                           | -1.13 | 0.88 |
| N2976         | 09 47 15.6     | +67 54 49      | 3.56      | -17.10      | 5.57         | dSph | 2.7  | 8.27                       | 57870 ± 300               | -0.97                           | 0.17  | -0.90|
| KK 77         | 09 50 10.0     | +67 30 24      | 3.48      | -12.03      | 2.61         | dSph | 2.0  | <6.1                      | 6 ± 2                     | -4.90                           | -1.73 | 0.86 |
| BK 3N         | 09 53 48.5     | +68 58 09      | 4.02      | -9.59       | 0.60         | dSph | 1.5  | 6.50                       | 3 ± 2                     | -5.14                           | -1.00 | 1.50 |
| M81           | 09 55 33.5     | +69 03 60      | 3.63      | -21.06      | 26.85        | Sab  | 2.2  | 9.46                       | ...                       | ...                             | -0.10 | -0.56|
| M82           | 09 55 53.9     | +69 40 57      | 3.53      | -19.63      | 10.93        | dSph | 2.7  | 8.90                       | 4.02                      | 0.42                            | 0.55  | -1.66|
| KDG 61        | 09 57 02.7     | +68 35 30      | 3.60      | -12.85      | 2.40         | dSph?| 3.9  | <6.2                      | 439 ± 13                  | -3.08                           | -0.24 | -0.86|
| A0952         | 09 57 29.0     | +69 16 20      | 3.87      | -11.51      | 2.14         | Ir   | 1.9  | 7.0                       | 351 ± 5                   | -3.10                           | 0.28  | -0.04|
| Holmberg IX   | 09 57 32.4     | +69 02 35      | 3.7      | -13.68      | 2.77         | Ir   | 3.3  | 8.50                       | ...                       | -2.65                           | -0.14 | 1.01 |
| KKH 57        | 10 00 16.0     | +63 11 06      | 3.93      | -10.19      | 0.67         | dSph | 0.7  | <6.3                      | 7 ± 6                     | -4.85                           | -0.95 | 1.01 |
| N3077         | 10 03 21.0     | +68 44 02      | 3.82      | -17.76      | 6.14         | lI0p | 1.9  | 8.79                       | 52950 ± 180               | -0.95                           | -0.07 | -0.40|
| The Garland   | 10 03 42.0     | +68 41 36      | 3.82      | -11.40      | 6.60         | dSph | 4.0  | 7.54                       | 4210 ± 390                | -2.05                           | 1.37  | -0.55|
| BK 5N         | 10 04 40.3     | +68 15 20      | 3.78      | -10.61      | 0.87         | dSph | 2.4  | <6.4                      | 5 ± 4                     | -4.99                           | -1.25 | 1.25 |
| KDG 63        | 10 05 07.3     | +66 33 18      | 3.50      | -12.12      | 1.84         | dSph?| 1.8  | <6.3                      | 47 ± 3                    | -4.65                           | -0.92 | 0.21 |
| U5423         | 10 05 30.6     | +70 21 52      | 5.3       | -14.54      | 1.37         | BCD? | -0.9 | 7.40                       | 1601 ± 23                 | -2.17                           | -0.01 | -0.57|
| KDG 64        | 10 07 01.9     | +67 49 39      | 3.70      | -12.57      | 1.85         | dSph?| 2.5  | <6.3                      | 24 ± 5                    | -4.33                           | -1.38 | 0.49 |
| Name       | R.A. (J2000.0)  | Decl. (J2000.0)  | $D$ (Mpc) | $M_{B}$ (mag) | $A_{25}$ (kpc) | Type | $T_{I}$ | $\log(M_{HI})$ (M$_{\odot}$) | Flux | $\log(SFR)$ (M$_{\odot}$ yr$^{-1}$) | $p^*$ | $f^*$ |
|------------|-----------------|-----------------|-----------|---------------|----------------|------|---------|-------------------------------|------|--------------------|------|------|
| IKN........... | 10 08 05.9      | +68 23 57       | 3.75      | −12.13        | 3.19           | dSph | 2.7     | <6.3                         | 8 ± 5 | −4.79             | −1.66 | 0.95  |
| HIASS........... | 10 21 00.2      | +68 41 60       | 3.7       | −7.93         | ...            | H+eld | 2.2     | 8.18                         | 54 ± 3 | −4.01             | 0.80  | 2.05  |
| HS 117......... | 10 21 25.2      | +71 06 58       | 3.96      | −11.98        | 1.72           | dSph | 1.0     | <5.0                         | 8 ± 2  | −4.70             | −1.51 | −0.44 |
| DDO 78......... | 10 26 27.9      | +67 39 24       | 3.72      | −12.17        | 2.20           | dSph | 1.8     | <6.2                         | 7 ± 7  | −4.89             | −1.78 | 0.95  |
| I2574......... | 10 28 32.4      | +68 24 58       | 4.02      | −17.46        | 13.35          | Im   | 0.9     | 9.23                         | ...   | −0.62             | 0.38  | −0.29 |
| DDO 82......... | 10 30 35.0      | +70 37 10       | 4.00      | −14.63        | 3.70           | Im   | 0.9     | <6.8                         | 1717 ± 34 | −2.42       | −0.29 | −0.92 |
| BK 6N.......... | 10 34 31.9      | +66 00 42       | 3.85      | −11.08        | 1.14           | dSph | 1.1     | <6.3                         | 7 ± 3  | −4.87             | −1.32 | 1.03  |
| DDO 87......... | 10 49 36.5      | +65 31 50       | 7.4       | −14.42        | 5.11           | Ir   | −1.5    | 8.03                         | 603 ± 8 | −2.37             | −0.16 | 0.26  |
| KDG 73......... | 10 52 55.3      | +69 32 45       | 3.70      | −10.83        | 0.63           | Ir   | 1.3     | 6.51                         | 13 ± 4 | −4.63             | −0.98 | 1.00  |
| U6456.......... | 11 28 00.6      | +78 59 29       | 4.34      | −14.03        | 1.72           | BCD  | −0.3    | 7.79                         | 7343 ± 62 | −1.72       | 0.65  | −0.63 |
| U7242.......... | 12 14 07.4      | +66 05 32       | 5.42      | −14.15        | 2.56           | Ir   | −0.5    | 7.70                         | 597 ± 230 | −2.64        | −0.32 | 0.20  |
| N4236.......... | 12 16 43.3      | +69 27 56       | 4.45      | −18.59        | 23.58          | Sdm  | −0.4    | 9.46                         | ...   | −0.65             | −0.11 | −0.03 |
| N4605.......... | 12 40 00.3      | +61 36 29       | 5.47      | −18.07        | 7.79           | Sdm  | −1.2    | 8.54                         | 65770 ± 160 | −0.59      | 0.16  | −1.01|
| DDO 165........ | 13 06 26.8      | +67 42 15       | 4.57      | −15.09        | 4.20           | Im   | 0.0     | 8.14                         | 1121 ± 36 | −2.51       | −0.57 | 0.51  |

**Note.**—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

a N2366; James et al. (2004).
b N2403; Kennicutt et al. (1989).
c M81; Kennicutt et al. (1989).
d M82; Young et al. (1996).
e Holmberg IX; James et al. (2004).
f I2574; Miller & Hodge (1994).
g N4236; Kennicutt et al. (1989).
### Table 3
Comparison of SFR Estimates for the M81 Group Galaxies

| Galaxy      | log(SFR$_{15}$) | log(SFR)$_{21}$ | $\Delta$ | Source                        |
|-------------|------------------|-----------------|----------|-------------------------------|
| Holmberg II | -1.05            | -1.01           | -0.04    | Hunter & Elmegreen (2004)     |
| KDG 52      | -5.08            | < -4.64         | ...      | Miller & Hodge (1994)         |
| DDO 53      | -2.04            | -2.04           | 0.00     | Hunter & Elmegreen (2004)     |
| U4483       | -2.35            | -2.33           | -0.02    | Gil de Paz et al. (2003)      |
| Holmberg I  | -2.13            | -2.09           | -0.04    | James et al. (2004)           |
| N2976       | -0.97            | -0.93           | -0.04    | James et al. (2004)           |
| N3077       | -0.95            | -0.86           | -0.09    | James et al. (2004)           |
| U5423       | -2.17            | -2.21           | 0.04     | van Zee (2000)                |
| DDO 82      | -2.42            | -2.40           | -0.02    | James et al. (2004)           |
| DDO 87      | -2.37            | -2.30           | -0.07    | James et al. (2004)           |
| U6456       | -1.72            | -1.86           | 0.14     | Gil de Paz et al. (2003)      |
| DDO 165     | -2.51            | -2.44           | -0.07    | James et al. (2004)           |
| N3077       | -0.95            | -1.15           | 0.20     | Walter et al. (2002)          |
| The Garland | -2.05            | -2.53           | 0.48     | Walter et al. (2006)          |

**Fig. 2.** — SFR vs. blue absolute magnitude for 150 nearby galaxies of the Local Volume (circles). Members of the M81 Group are shown by squares. The open squares indicate the M81 dwarf companions with only an upper limit for their SFR. The line corresponds to a constant SFR per unit luminosity. [See the electronic edition of the Journal for a color version of this figure.]
hydrogen masses. In other words, the using up of the present reserve of gas to form a stellar component occurs in dwarf galaxies in a retarded (“lethargic”) mode in comparison with spiral galaxies, which favor a long life for dwarf galaxies. An extreme example is KDG 52, in which there is a young stellar population but the Hα flux is not amenable to measurement at the usual (20 minutes) exposure times. An attempt to detect the Hα emission in KDG 52 and BK 3N at much longer exposures seems to be of interest. It should be noted here that from the data by Appleton et al. (1981) and Yun et al. (1994), the central region of the M81 Group is filled with H i clouds and filaments, which makes the estimates of the H i mass in BK 3N, Holmberg IX, A0952+69, and the Garland rather uncertain.

As we have already noted, the parameters suitable for describing the past and future star formation processes in a galaxy are dimensionless quantities: \( p_\star = \log([SFR]T_0/L_\star) \) and \( f_\star = \log[M_{HI}/(SFR)T_0] \). The former characterizes the proportion of its luminosity the galaxy would produce during the Hubble time \( T_0 \) at the current rate of star formation and the mass-to-luminosity ratio \( 1 M_\star/L_\star \). The latter parameter shows how much Hubble time the galaxy will need to spend the present supply of gas if star formation proceeds at the currently observed rate. The distribution of all members of the M81 Group on the \( (f_\star, p_\star) \)-plane is displayed in Figure 4. The open squares correspond to the objects in which only the upper limit of the Hα flux or of the hydrogen mass was measured.

The average star formation indicators for the M81 Group members of different morphological types are given in Table 4. Its last row indicates the mean specific SFR attributed to 1 kpc².

The following conclusions can be drawn from the data obtained for the M81 Group galaxies:

1. The global SFR in the galaxies correlates well with their luminosity, linear diameter, and hydrogen mass. However, when it is normalized to the luminosity, the specific SFR, \( SFR/L_\star \), has an appreciably lower scatter than when it is normalized to the galaxy hydrogen mass or attributed to 1 kpc².

2. Judging by the mean value \( \langle p_\star \rangle = -0.02 \pm 0.15 \), the spiral galaxies in the M81 Group would have time to generate their luminosity (baryon mass) during the cosmological time \( T_0 = 13.7 \) billion years. About the same conclusion may be drawn regarding the Im/BCD galaxies \( \langle p_\star \rangle = +0.21 \pm 0.14 \), as well as the dIrr galaxies \( \langle p_\star \rangle = -0.26 \pm 0.23 \). However, the dSph galaxies, with \( \langle p_\star \rangle = -1.29 \pm 0.13 \), are capable of reproducing only \( \sim 5\% \) of their observed luminosity (mass).

3. According to the mean quantities \( \langle f_\star \rangle \), which equal \( -0.62 \pm 0.17 \) and \( -0.48 \pm 0.18 \) for S and Im/BCD galaxies, respectively, these galaxies possess a supply of gas sufficient to maintain their observed SFRs for only the next \( \frac{1}{3} T_0 \) yr. On the other hand, dIrr and dSph galaxies have a mean gas depletion time of about \( 3T_0 \).

4. The mean specific SFR per square kiloparsec is almost the same for spiral galaxies \( -2.77 \pm 0.18 \) as it is for Im/BCD types \( -2.66 \pm 0.20 \). However, for dIrr galaxies this quantity turns out to be 1 order of magnitude lower \( -3.85 \pm 0.21 \), and for dSph members of the group it drops down to the detection threshold \( -5.03 \pm 0.16 \).

5. All dIrr and BCD galaxies with absolute magnitudes fainter than \( -17.5 \) mag tend to be located on the \( (p_\star, f_\star) \)-plane along the diagonal \( f_\star = -p_\star \). Because the typical error of measuring \( \log(SFR) \) is rather small \( \pm 0.06 \), the observed diagonal alignment can be naturally explained by a stochastic burstlike variation of star formation in this type of galaxy.

6. Curiously, in Figure 4 the quadrant \( p_\star > 0, f_\star > 0 \) is almost empty, containing only one peculiar object, the hydrogen cloud HIJASS, with its rather uncertain values of \( p_\star \) and \( f_\star \). It would be
The nearest group of galaxies around M81 appears to be a typical group of the local universe in its population, size, velocity dispersion, and luminosity of the brightest member (Karachentsev 2005). In contrast to the Local Group, for which the value of the SFR for the Milky Way remains unknown, the values of Hα fluxes (or their upper limits) have been measured for all known members of the M81 Group. Beyond the radius $R = 2$ Mpc around M81, this group borders on our Local Group and the group around the bright galaxies IC 342, Maffei 1, and Maffei 2. Assuming a sphere of radius 2 Mpc around M81 to be the local "cell of homogeneity," we derive the total SFR, $\Sigma (SFR) = 5.5 \pm 0.1$ M$_\odot$ yr$^{-1}$, which falls within a volume of 34 Mpc$^3$. Consequently, the density of the SFR in this cell is $\dot{\rho}_{SFR} = 0.165$ M$_\odot$ yr$^{-1}$ Mpc$^{-3}$. According to Nakamura et al. (2004), Martin et al. (2005), and Hanish et al. (2006), the average global rate of star formation per unit volume at the present epoch ($z = 0$) lies in the range 0.02–0.03 M$_\odot$ yr$^{-1}$ Mpc$^{-3}$. Therefore, the M81 Group demonstrates star formation activity 5–8 times as high as the typical neighboring volume. Note that half of the total Hα flux of the group falls on one hyperactive galaxy, M82. However, even after its exclusion, the excess in $\dot{\rho}_{SFR}$ for the M81 Group and its surroundings is preserved. In this sense, the statement of Miller (1996) that the star formation process in the M81 Group is highly active holds true. The vigorous activity of this group has two possible causes: the close approach of massive galaxies M81 and M82 and the high abundance of neutral hydrogen in the group core.

The authors are grateful to B. Tully and A. Moiseev for useful discussions. Support associated with HST program 10905 was provided by NASA through a grant from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. This work was also supported by RFFI grant 04-02-16115.

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### TABLE 4

| Parameter | Sa–Sm | Im/BCD | dlr | dSph |
|-----------|--------|--------|-----|------|
| Number... | 5.00   | 10.00  | 12.00 | 13.00 |
| $M_B$ (mag) | $-18.82 \pm 0.68$ | $-15.86 \pm 0.65$ | $-12.40 \pm 0.46$ | $-11.76 \pm 0.24$ |
| $A_25$ (kpc) | $16.64 \pm 4.25$ | $5.59 \pm 1.31$ | $2.50 \pm 0.54$ | $1.90 \pm 0.22$ |
| log(SFR) ($M_\odot$ yr$^{-1}$) | $-0.47 \pm 0.18$ | $-1.42 \pm 0.31$ | $-3.28 \pm 0.33$ | $-4.56 \pm 0.17$ |
| $P^{\star}$... | $-0.02 \pm 0.15$ | $+0.21 \pm 0.14$ | $-0.26 \pm 0.23$ | $-1.29 \pm 0.13$ |
| log($\frac{\dot{\rho}_{SFR}}{A_25}$) ($M_\odot$ yr$^{-1}$ kpc$^{-2}$) | $-2.77 \pm 0.18$ | $-2.66 \pm 0.20$ | $-3.85 \pm 0.21$ | $-5.03 \pm 0.16$ |