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STAR FORMATION RATE IN HOLMBERG IX DWARF GALAXY

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SUMMARY: In this paper we use previously determined Hα fluxes for dwarf galaxy Holmberg IX (Arbutina et al. 2009) to calculate star formation rate (SFR) in this galaxy. We discuss possible contaminations of Hα flux and, for the first time, we take into account optical emission from supernova remnants (SNRs) as a possible source of contamination of Hα flux. Derived SFR for Holmberg IX is $3.4 \times 10^{-4} M_{\odot}\mathrm{yr}^{-1}$. Our value is lower then in previous studies, due to luminous shock-heated source M&H 9-10, possible hypernova remnant, which we excluded from the total Hα flux in our calculation of SFR.

Key words. galaxies: dwarf – galaxies: ISM – HII regions – ISM: supernova remnants – stars: formation

1. INTRODUCTION

One of the most important problems in extragalactic astronomy is determination of star formation history, and possible predictions for the future star births. Knowledge of the star formation histories of both the Universe and of individual galaxies provides the foundation for our understanding of the world we see today and its evolution.

Any discussion in this field must first acknowledge the extensive studies undertaken by Kennicutt and collaborators in defining the techniques for Hα measurement and deriving star formation rates (SFR) from such measurements (see Kennicutt 1998). Hα observations are, besides many other techniques (e.g, ultraviolet emission from stars, far-infrared and radio luminosities), the easiest commonly used method for SFR determination.

The Hα luminosity of HII regions around stars is direct measure of the global photoionization rate, which can be used to estimate SFR for massive (>10 $M_{\odot}$) stars. Extrapolation to total SFR, integrated over all stellar masses, is accomplished usually by adopting a priori the initial mass function (IMF). In this paper, we use the relation given by Kennicutt et al. (1994):

$$\mathrm{SFR}\ (M_{\odot}\mathrm{yr}^{-1}) = 7.94 \times 10^{-42} L_{\mathrm{H}\alpha}\ (\mathrm{erg\ s}^{-1}), \quad (1)$$

where SFR is given in solar masses per year, and $L_{\mathrm{H}\alpha}$ is Hα luminosity of galaxy. This transformation is appropriate under the assumption of average solar abundances and Salpeter initial mass function (Salpeter 1955), for a range of stellar masses from $0.1 - 100\ M_{\odot}$.

For the SFR calculation from the photoionization we need to remove all possible contaminations of the Hα emission, possibly by the non-thermal emission, stellar Hα absorption, [NII] emission, and all other sources of extinction. More about extinction, and possible confusion of the Hα emission from HII regions with the Hα emission from other emission nebulae (e.g. supernova remnants) will be given later.

Table 1. Data for Holmberg IX taken from NED*.

Right ascension α_{J2000}	Declination δ_{J2000}	Redshift z	Velocity v [km s^{-1}]	Distance** d [Mpc]	Angular size [′]	Magnitude [mag]	Gal.extinction [mag]
09 57 32.0	+69 02 45	0.000153	46	3.7	2.6×2.2	14.3	0.343 (B)

*`http://ned.ipac.caltech.edu/` **Karachentsev & Kashibadze (2006)

Previous studies about SFR typically concerned bright and most-rapidly star forming galaxies, but in recent works (e.g. James at al. 2004, Kennicutt et al. 2008) there are efforts to measure SFRs through full range of galaxy types and brightnesses. Concerning this, dwarf and irregular galaxies are the biggest challenge because of their low luminosities and small amount of data for host galaxy (internal) extinction and heavier elements abundances. This is why we have made efforts to observe a few low surface-brightness galaxies in narrow band filters, during our study of interacting M81 galaxy group. Among these galaxies is Holmberg IX, a small "satellite galaxy" of M81.

Holmberg IX (also known as UGC 5336, MCG+12-10-012, LEDA 28757, see Table 1) can be seen in the HI image of the M81 triplet in Yun et al. (1994) as a dark knot, closest to M81 galaxy. Dwarf irregular galaxy Holmberg IX could be the one of the youngest nearby tidal dwarf galaxies, perhaps formed during the last close passage of M82 around M81 (Sabbi et al. 2008). It has a very high ratio of gas to stellar mass, and it was probably formed from gas and stars stripped off during the interaction of M81 with M82.

The adopted distance to Holmberg IX is d = 3.7 Mpc, derived from cepheids distance to M81 and known membership in the M81 group (Karachentsev et al. 2004, Karachentsev and Kashibadze 2006).

2. DATA

In this paper we use Hα fluxes for Holmberg IX given in Arbutina et al. (2009). Observations were taken with the 2 m Ritchey-Chrétien-Coudé (RCC) telescope at the National Astronomical Observatory (NAO) Rozhen, Bulgaria. The galaxy was observed through Hα, [SII] and red continuum narrow band filters (see Table 2 in Arbutina et al. 2009 for details). The total exposure time through each filter was 140, 140 and 190 minutes, respectively.

Arbutina et al. (2009) reported 22 objects detected in the Hα filter (see Fig. 1). When observed through the [SII] filter, only one source showed strong emission. That is a strong X ray source, known as M&H 9-10, which is a shock-heated nebula (Miller 1995) that could be a super-shell or a possible hypernova remnant. Other 21 objects represent HII region candidates. Their absolute flux calibration was performed by using the fluxes of sources identified both by Arbutina et al. (2009) and by Miller and Hodge (1994).

3. SFR AND CONTAMINATION OF Hα FLUX

As already mentioned, there are several methods for estimating SFR, but calculation from the Hα flux is one of the simplest. When using the Hα flux from HII regions for SFR estimates, we encounter the following difficulties, which may cause systematic errors:

(i) contamination by [NII] emission lines, close to the Hα line,
(ii) contamination by the other Hα emitters (e.g, other emission nebulae, non-thermal emitters, such as active galactic nuclei (AGN)), and
(iii) internal extinction.

3.1. [NII] contamination

On both sides of the Hα line there are close [NII] lines, λ654.8nm and λ658.4nm, respectively. Depending on the filter used for imaging, both lines, or part of each [NII] line, enter the Hα filter bandwidth. Intensities of lines depend on nitrogen abundances, which are different for different types of galaxies, and which are changing with distance from the center of the galaxy. Many studies have been made regarding this question. For a long time the ratio between Hα and Hα+[NII] fluxes determined by Kennicutt and Kent (1983) was used: 0.75 ± 0.12 for spirals and 0.93 ± 0.05 for irregulars. Lately, as the number of spectroscopic measurements is increasing, more precise estimates for different galaxies about the ratio between Hα and Hα+[NII] fluxes are becoming available. More recent studies found out that the [NII] contamination is much weaker then previously thought.

The full-width half-maximum (FWHM) of the narrow band filters used for observations at NAO Rozhen is on average 3nm, which is twice smaller than usual for the narrow band Hα filters (see James et al. 2004, Karachentsev and Kaisin 2007) meaning that only a fraction of the [NII] emission is being confused with Hα emission. This is why we did not make any corrections for the [NII] emission, and we estimate that errors in our Hα fluxes due to this effect are less then 5%.

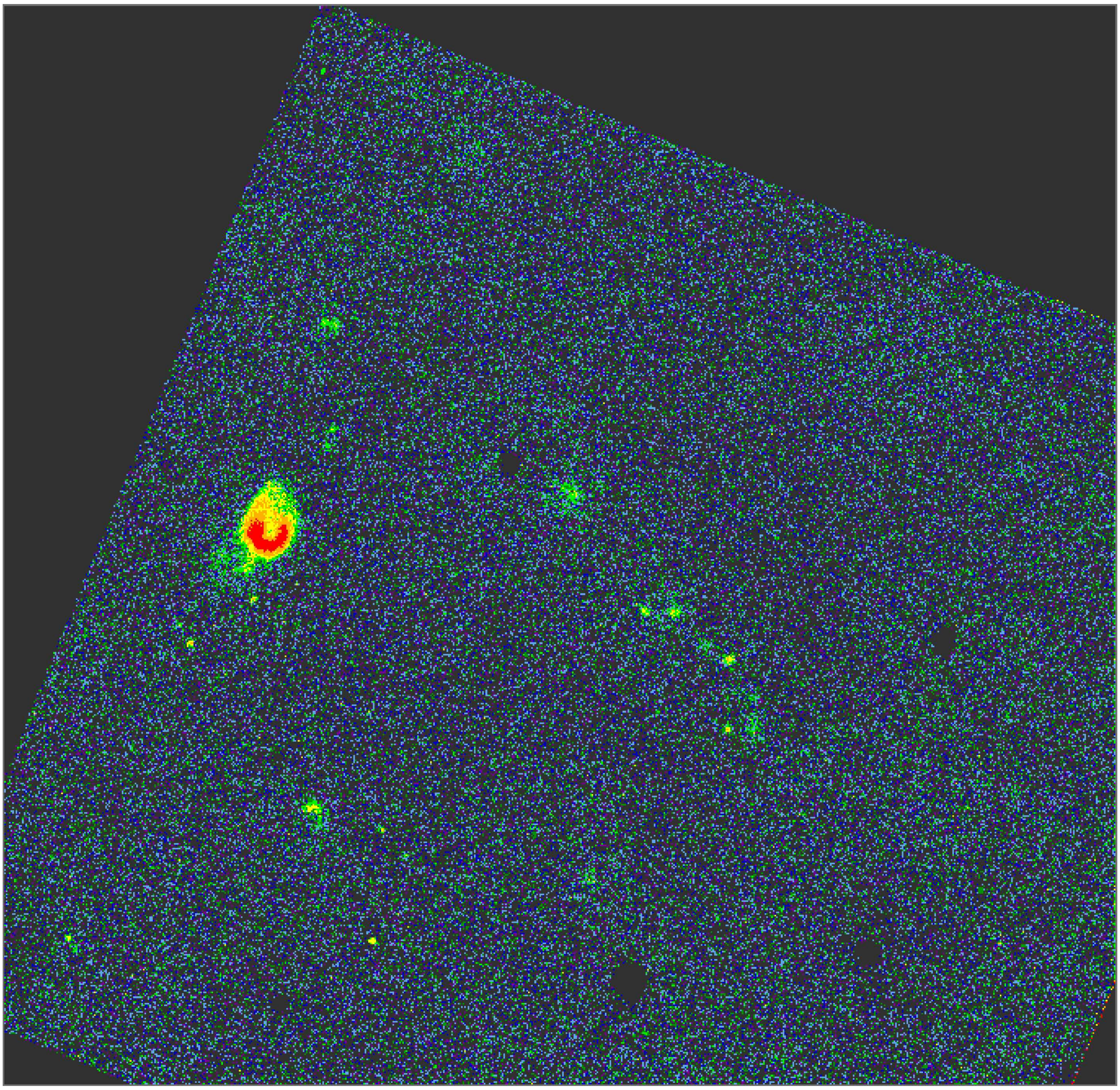

Fig. 1. *The continuum-subtracted Hα image of Holmberg IX. The strongest source is M&H 9-10. Figure kindly provided by B. Arbutina.*

3.2. SNR contamination

There is another source of error when measuring SFR from Hα luminosities, which we find more significant and interesting, especially in this particular case of Holmberg IX galaxy. When measuring Hα fluxes, we expect that HII regions are the major source of this emission, except for some diffuse component. In most previous papers, planetary nebulae (PNe) and supernova remnants, as other examples of emission nebulae, have been excluded from the discussion. They also radiate strongly in the Hα line and, therefore, can cause overestimate in SFR. In some recent papers, there are efforts to exclude emission from PNe (Azimlu et al. 2011) and also, when having a sample of many galaxies, to exclude those with non-thermal emission, such as AGNs (Villar et al. 2011). The problem with PNe and SNRs is that in optical range it is difficult to differentiate between them and HII regions. Additional observations in narrow bands are needed to distinguish between different emission nebulae types.

Observations that we use here concerned detection of SNRs in optical range. For this kind of observations, Hα, the red continuum and [SII] narrow band filters are used. The ratio of the [SII] and

Hα emission serves as indicator whether an object is an HII region or SNR (see Matonic and Fesen 1996). Objects whose ratio is higher than 0.4 (and usually much higher) are considered as SNRs while those whose ratio is less than 0.4 are taken as HII regions. This is physically justified through different ways of excitation. For SNRs we have collisional excitation by shocks, rather than by photoionization, which is the case with HII regions.

It should be mentioned that, in majority of galaxies (and especially in large spirals), the emission in Hα from SNRs would not be of great importance. But, on the other hand, there could be examples, such as Holmberg IX galaxy, where the emission from SNRs is strong in Hα.

3.3. Internal extinction

Internal extinction, or absorption by the host galaxy, could be the biggest problem for correct determination of Hα luminosities. Absorption coefficients for different galaxies are usually unknown. We only make assumptions on their emission in infrared and radio domains, galaxy type and metallicity. That is why there is a wide range of absorption coefficients used in literature. Numbers usually found in most papers are between 0.8 and 1.1 magnitude (Kennicutt 1998). Considering metallicity in Holmberg IX being as low as 0.008 (Sabbi et al. 2008), we expect that the dust absorption is almost negligible and, therefore, the absorption coefficient of about 1 magnitude to be too high. When compared to the errors made by the [NII] contamination (which are of the order 5 - 10%), significance of this effect is much higher. In many studies the internal extinction is not considered in calculation of SFRs, because of its uncertainty. With this approach, the derived SFRs are underestimated by a factor of about 2.5.

4. RESULTS

The Hα flux from Holmberg IX we used to determine SFR is 26.25×10^{-15}erg cm^{-2}s^{-1}. This is sum of Hα fluxes from 21 HII region candidates in this galaxy. Flux from source M&H 9-10 was not taken into account because it represents a possible hypernova remnant (see section 3.2). It should be mentioned that the Hα flux from this source is more than twice higher than the total flux from HII regions.

Derived SFR for Holmberg IX is $3.4 \times 10^{-4} M_{\odot}\mathrm{yr}^{-1}$. As can be seen from Fig. 1, M&H 9-10 is the strongest source in Hα in this galaxy, and its elimination from the SFR calculation resulted in much lower SFRs than previously thought.

Also, when considering SFR in dwarf galaxy Holmberg IX, one should keep in mind that there are indications (Lee et al. 2009) that the Hα luminosity will underestimate the SFR when compared to the SFR derived from the far ultraviolet (FUV) luminosity in dwarf galaxies.

When comparing to recent studies (Karachentsev and Kaisin 2007, James et al. 2004), our estimate of SFR for Holmberg IX is six to ten times lower, respectively. These studies observed the galaxy only in the continuum and Hα filters, so they did not discuss possible contamination of the Hα flux by other sources.

It should be mentioned that we used Schlegel et al. (1998) Galactic extinction in the B band, instead of Burstein and Heiles (1982), which was used in Miller and Hodge (1994), while other authors used Schlegel's expression. For calculation of Galactic extinction in Hα, we used expression given by Karachentsev and Kaisin (2007). Also, we did not correct flux for internal extinction nor this was done in Karachentsev and Kaisin (2007) and, considering low mettalicity in this galaxy, we find this appropriate. James et al. (2004) used internal absorbtion coefficient of 1.1 magnitude which led to overestimate in their SFR but it should be mentioned that they used the distance of 3.4 Mpc, which is less than the one we used.

5. CONCLUSIONS

In this paper we calculated SFR for Holmberg IX galaxy from its Hα flux but, in a way, we excluded emission from sources that are not the HII region candidates. Estimated SFR is $3.4 \times 10^{-4} M_{\odot}\mathrm{yr}^{-1}$, which is up to ten times less than in previous studies.

Also, from the example of Holmberg IX galaxy, we showed that the Hα emission from other emission nebulae (especially SNRs) can have large affect on calculated SFR. In a future paper we intend to make corrections in estimated SFRs for a sample of nearby galaxies which have optical SNRs detected.

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СТОПА ФОРМИРАЊА ЗВЕЗДА У ПАТУЉАСТОЈ ГАЛАКСИЈИ ХОЛМБЕРГ IX

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Претходно саопштење

У раду је одређена стопа формирања звезда за патуљасту галаксију Холмберг IX, користећи Hα флуксеве у овој галаксији из рада Арбутине са сарадницима (2009). Такође, дискутовани су извори који зраче у Hα линији, а који нису HII региони, и тиме узрокују грешку у процени стопе формирања звезда. По први пут, остаци супернових и њихово оптичко зрачење узети су као могући узроци контаминације Hα флукса. Добијена стопа формирања звезда у Холмберг IX галаксији је $3.4 \times 10^{-4} M_{\odot}\mathrm{yr}^{-1}$. Наша вредност је нижа од вредности добијених у претходним студијама, због сјајног објекта M&H 9-10, који је побуђен ударним таласом, и који смо ми искључили из укупног Hα флукса у нашем рачуну стопе формирања звезда.