The Impact of Resolution on Observed H\textsuperscript{II} Region Properties from WFPC2 Observations of M101 *

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Abstract. Two continuum subtracted H\textalpha\ HST frames of M101 are used to determine the positions, angular sizes and absolute fluxes of 237 H\textsuperscript{II} regions using a semi-automated technique. From these we have constructed the luminosity and diameter distribution functions.

We repeat this process on the images after artificially reducing the linear resolution to that typically obtained with ground based imaging. We find substantial differences in the luminosity function and diameter distribution. The measured internal properties, such as central surface brightness and radial gradient are dominated by the PSF at linear resolutions less than roughly 40 pc FWHM. From the ground such resolutions are currently only obtainable for the nearest galaxies.

Further support for the dominant role played by the seeing is provided by simple analytical models. We also study the clustering properties of H\textsuperscript{II} regions and their effect on the luminosity function by construction of a Minimal Spanning Tree (MST). We find evidence for two regimes of clustering of the H\textsuperscript{II} regions and diffuse emission. These intrinsic clustering properties in combination with the spatial resolution typically obtainable from ground based observations might be responsible for the break in the H\textsuperscript{II} region luminosity function which is usually found at log$L_{\text{H\alpha}} = 38.6$ erg/s, suggesting two different regimes of star formation in late type spiral galaxies.

From the high resolution HST data we find a luminosity function slope of $\alpha = -1.74 \pm 0.08$. We also observe a flattening at luminosities $\log L < 36.7$ erg/s. For the diameter distribution we find a characteristic scale of $D_0 = 29.2$ pc from an exponential fit. However, a scale free power law with index $\beta = -2.84 \pm 0.16$ provides a better fit to the data.

Key words: H\textsuperscript{II} regions – Galaxies: individual: M101 – Galaxies: spiral

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1. Introduction

As tracers of recent massive star formation, H\textsuperscript{II} regions are indispensable. The radiation emitted by the hot gas carries the signature of the young hot stars to which it gave birth. Complementing the detailed spectroscopic work that has been done, are studies on the statistical properties of H\textsuperscript{II} regions. These global investigations are aimed at gaining an understanding of the connection between the large scale dynamics and the star formation properties of galaxies (e.g. interactions and mergers, bars and spirals, resonances and rings). Most of this work has focused on the luminosity and diameter distribution of the regions imaged over full galactic disks in the line of H\textalpha.

A long standing difficulty with making such measurements has been in the identification of the regions. At low resolutions the blending together of regions can be significant. An initial estimate of this effect was made by Kennicutt et al. (1989), who found that blending effects became important at linear resolutions less than 300 pc. However, at the luminosity limits now obtainable with modern CCDs, a study of resolution effects has not been made.

For the diameter distribution of H\textsuperscript{II} regions Van den Bergh (1981) found the functional form of an exponential law. Hodge (1987) confirmed this form for a sample of spiral galaxies and derived a dependence of characteristic size $D_0$ on absolute magnitude of the galaxy. A wide range of of $D_0$ between 45 and 560 pc was observed for the different galaxies. Nevertheless, in other studies a power law form fit the diameter distribution better than the exponential function (Kennicutt & Hodge 1980, Elmegreen & Salzer 1999). Likewise, Knapen (1998) found a value of $D_0$ for M100 that is 1.5 to 2.2 times smaller than found in previous determinations at lower resolutions. The reliability of available diameter measurements is highly questionable.

A systematic study of the luminosity function (LF) of the H\textsuperscript{II} regions in disk galaxies was carried out by Kennicutt et al. (1989), using a sample of 30 spiral and irregular galaxies. They found the LF could be represented by a
power law with index $\alpha = -2 \pm 0.5$. A flattening at luminosities below $\log L_{H\alpha} = 37$ erg/s was found and explained in terms of a transition from single ionizing stars to ionizing stellar clusters (McKee & Williams 1997 and Oey & Clarke 1998). The LF slope was also found to be systematically steeper for earlier Hubble types and the properties of regions in spiral arms differed to those between arms. Theoretical explanations for these variations were given by Oey & Clarke (1998), who showed that evolutionary effects and maximum number of ionizing stars per cluster can account for such differences. Some galaxies also exhibited a break in the LF at about $\log L_{H\alpha} = 39$ erg/s with a steeper slope at the high luminosity end.

Other surveys were carried out by Banfi et al. (1993) with a sample of 22 spirals located mainly in the virgo cluster and by Delgado & Perez (1997) with 27 spiral galaxies. In the later survey 25% of objects were identified as having double slope LFs. More detailed studies have also been performed on single objects. Scowen et al. (1992) have studied M101 and found an index of $\alpha = -1.85 \pm 0.05$ for a power law fit to the LF. Rand (1992) examined M51, Walterbos & Braun (1992) M31 and Wyder et al. (1997) M33. Also an example of a barred galaxy, NGC 7479, was studied by Rozas et al. (1999), where evidence for a difference in the properties of the regions located in the bar from that of the overall disk were found.

Studies of the Hα emission in grand design spirals were carried out by Cepa & Beckman (1989, 1990), Knapen et al. (1993) and continued in a series of four grand design spirals by Rozas et al. (1996a, 1996b, 1998). The LFs in all four cases showed a clear slope transition at $\log L_{H\alpha} = 38.6$ erg/s accompanied by a local maximum or “glitch”. In addition to the LF break, they also found a break at the same luminosity in the surface brightness gradient of the HII regions. The gradients of less luminous regions were about constant, whereas the gradients of more luminous regions were steeper and growing with luminosity. Yet another break has been reported at this luminosity in the central surface brightness (Beckman, priv. comm.). These features have been interpreted by Beckman et al. (1998) as representing a physical change in the HII regions at this characteristic luminosity. Specifically, they contend that a transition from ionization to density bounding occurs at $\log L_{H\alpha} = 38.6$ erg/s. They have also proposed the use of this feature as a standard candle.

Related studies of the diffuse ionized interstellar medium (DIG) have been carried out by Walterbos & Braun (1994), Ferguson et al. (1996) and Greenawalt et al. (1997). The diffuse emission was found to be spatially associated with the HII regions and exhibited a variety of different morphologies. The fraction of emission coming from this diffuse component was estimated at 20–50% (Ferguson et al. 1996). Leaking photons from HII regions, turbulent mixing and shock ionization have been suggested as possible ionization mechanisms.

This paper presents statistics on the HII regions in M101 from HST observations. The very high resolution of the images will allow us to investigate in detail the role played by resolution. We will find that the linear resolution required to perform reliable measurements of central surface brightness, radial gradients, and diameters is quite stringent and can be accomplished from the ground without the aid of adaptive optics for only the nearest galaxies. The effects of blending on the luminosity function will also be found to be significant, with the diffuse emission making an important contribution.

Also examined is the intrinsic clustering characteristics of the regions and diffuse emission and the role this plays in shaping the behavior of the blending. Evidence for a possible break at a characteristic clustering regime will be presented, which when combined with blending effects may provide a mechanism for producing the LF discontinuity along with its relative stability in luminosity.

In Sec. 2 of this paper we present the data and reduction methods. A description of the methods used to measure the properties of the HII regions is given in Sec. 3. The results and comparisons to some simple analytic models are then given in Sec. 4, followed in Sec. 5 by a discussion of their implications.

2. Observations

The galaxy studied here is the nearby grand design Sc galaxy M101. It was chosen because it is nearly face on and lies at the relatively close distance of about 7.4 Mpc (Kelson et al. 1996). These properties limit problems due to projection effects and provide for very high linear spatial resolution.

The observations of M101 were obtained with the HST-WFPC2 on the 15th and 16th of September 1994 and on April 4th 1996. Both frames are public and have been retrieved from the HST-archive. Fig. 1 shows their approximate location in the outer spiral arms. The ground based image was taken by Sandage (1961) in blue light (3300–5000 Å) at Mt. Palomar.

The pixel size is 0.1 for the WF-Chips and defines the effective resolution, i.e. the PSF FWHM is smaller. The Hα (F656N non-shifted) data consists of two sets of two exposures. The sets have combined exposure times of 4000 s and 3600 s. Continuum subtraction was carried out either with exposures taken with the wide R-Filter F675W (2 × 2000 s) or with the medium bandwidth V-Filter F547M (2 × 400 s).

Besides the HST pipeline calibration, we used the data reduction package IRAF and especially the package STSDAS for further processing. Particular care was required to remove the cosmic rays through a multiple step process. All frames were normalized to a count flux of $10^{-15}$ erg s$^{-1}$ cm$^{-2}$ using the method described in Holtzman et al. (1995). Absolute fluxes were calculated using a distance of 7.4 Mpc.