POWER SPECTRA IN \( V \) BAND AND H\( \alpha \) OF NINE IRREGULAR GALAXIES

**Kyle W. Willett**\(^1\)

Lowell Observatory, 1400 West Mars Hill Road, Flagstaff, AZ 86001; willettk@carleton.edu

**Bruce G. Elmegreen**

IBM T. J. Watson Research Center, P.O. Box 218, Yorktown Heights, NY 10598; bge@watson.ibm.com

**And**

**Deidre A. Hunter**

Lowell Observatory, 1400 West Mars Hill Road, Flagstaff, AZ 86001; dah@lowell.edu

Received 2004 November 5; accepted 2005 February 15

**ABSTRACT**

Fourier transform power spectra of major axis cuts in \( V \) and H\( \alpha \) images were made for a sample of nine irregular galaxies. These power spectra reveal structure over a wide range of scales. For six of the galaxies the power spectrum slopes at intermediate scales (10–400 pc) in the \( V \)-band images range from −1.3 to −1.5. The similarity of slopes suggests that the same processes are structuring these systems. These slopes are slightly shallower than those observed in other galaxies in H\( \alpha \), molecular emission, dust extinction, and optical light. Three of the galaxies have flat power spectra like sky noise; these three galaxies are relatively indistinct in the direct images. The power spectrum slope for H\( \alpha \) steepens with increasing star formation rate, ranging from a shallow value comparable to the noise at low rates to a steeep value with a slope of \( \sim -1.5 \) at high rates. This change reflects the increasing areal filling factor of H\( \alpha \) emission with increasing star formation rate and an apparently universal slope inside the H\( \alpha \) regions that is comparable to that for Kolmogorov turbulence. The power spectrum of H\( \alpha \) in one galaxy has a steeper power law, with a slope of \( \sim -2.9 \). The fact that the power laws of star formation are about the same for dwarf galaxies and giant spiral galaxies suggests the microscopic processes are the same, independent of spiral density waves and galaxy size.

**Key words:** galaxies: evolution — galaxies: irregular — ISM: structure — methods: data analysis — turbulence

---

1. INTRODUCTION

Fourier transform power spectra of gas and stars in a variety of galaxies have shown power laws over a factor of \( \approx 100 \) in scale. This includes observations of local H\( \alpha \) (Crovisier & Dickey 1983; Green 1993; Dickey et al. 2001) and CO emission (Stutzki et al. 1998), local H\( \alpha \) absorption (Deshpande et al. 2000), H\( \alpha \) emission from the Small (Stanimirovic et al. 1999) and Large Magellanic Clouds (Elmegreen et al. 2001), dust extinction in the Small Magellanic Cloud (Stanimirovic et al. 2000), galactic nuclei (Elmegreen et al. 2002), and optical light from nearby galaxies (Elmegreen et al. 2003a, 2003b). Other evidence for fractal structure in the interstellar gas comes from perimeter-area relations (e.g., Falgarone et al. 1991) and box-counting methods (e.g., Westpfahl et al. 1999).

The most likely cause of this scale-free structure is a combination of gravitational collapse, compressible MHD turbulence, and nested shells from multiple supernovae (see review in Elmegreen & Scalo 2004). Cluster formation and star formation occur in the compressed regions (see reviews in Mac Low & Klessen 2004; Klessen 2004).

Although the technique of using Fourier transform power spectra to analyze structure on galactic scales has been widely used, there has been no previous work on irregular (Im) galaxies outside the Local Group. Availability of images in multiple passbands of a large sample of irregular galaxies (Hunter et al. 2001; D. Hunter & B. Elmegreen 2005, in preparation) now gives us the opportunity to carry this type of analysis to a larger number of Im systems. Thus, we undertook a study of the Fourier transform power spectra of a sample of Im and blue compact dwarf (BCD) galaxies. The irregulars previously examined—the LMC and SMC (Stanimirovic et al. 1999; Elmegreen et al. 2001)—offer higher spatial resolution than our images, but our galaxies offer a more diverse sampling of the Im class. Comparison of this sample to the LMC, SMC, and spiral galaxies allows us to determine whether Im galaxies as a group are homogeneous and to examine similarities and differences with larger galaxies. Spectra that follow a power law have resembled the power spectrum of velocity for Kolmogorov turbulence in an incompressible medium. The reasons for this similarity are unknown (see discussion in Elmegreen et al. 2003a). Deviations from the Kolmogorov spectrum in different galaxies may indicate different types of turbulent activity or excitation mechanisms.

This paper presents Fourier transform power spectra of one-dimensional linear cuts along the major axes of nine irregular galaxies. The data include \( V \)-band and H\( \alpha \) images and one H\( \alpha \) map. Optical passbands give information about stellar structure with a large range of spatial scales; H\( \alpha \) tracks the current star formation, and H\( \alpha \) shows the distribution of diffuse gas.

2. GALAXY DATA

The \( V \)-band and H\( \alpha \) images of our sample galaxies were obtained as part of a larger survey of the star-forming properties of 140 Im and Sm galaxies. The H\( \alpha \) observations are described by Hunter & Elmegreen (2004). These images were obtained through narrowband (FWHM \( \sim 30 \) \( \AA \)) filters and a continuum-only off-band filter centered at 6440 \( \AA \) with a FWHM of 95 \( \AA \). Most were obtained using the Perkins 1.8 m Telescope at Lowell Observatory and an 800 \( \times \) 800 TI CCD. Large galaxies were imaged.
in multiple fields that were mosaicked into a single image. Usually multiple images through the H\textalpha{} filter, and sometimes also through the offband filter, were obtained and combined to remove cosmic rays. The offband image was shifted, scaled, and subtracted from the H\textalpha{} image to remove the stellar continuum. The pixel scale (given in Table 1) for the H\textalpha{} image of DDO 50 was 0".433, and the rest were 0".488. The final field of view of the H\textalpha{} images was 5'5 for DDO 43, DDO 88, NGC 1156, NGC 1569, NGC 3738, and VII Zw 403. The field of view of the DDO 50 image was 9'7; for DDO 133, 6.3; and for NGC 2366, 12'.5. The resulting seeing (FWHM of an isolated star) on these images was 1".6–1".8 for DDO 43, DDO 50, NGC 1156, and VII Zw 403; the rest had a seeing of 2".2–2".6.

The V-band observations are described by D. Hunter & B. Elmegreen (2005, in preparation). The images of NGC 2366 are described in detail by Hunter et al. (2001). Most V images were obtained with the Lowell Observatory 1.1 m Hall Telescope using a SITe 2048 × 2048 CCD. VII Zw 403 was observed at the Perkins 1.8 m telescope, and images of NGC 1569 and NGC 2366 were obtained for us by P. Massey using the Kitt Peak National Observatory (KPNO) 4 m telescope and a Tektronix 2048 × 2048 CCD. Several images were obtained of each galaxy with offsets of 20"–30" to improve the final flat-fielding. The electronic pedestal was subtracted using the overscan strip, and the images were flat-fielded using sky flats. Foreground stars and background galaxies were edited from the V-band images before surface photometry was performed in fixed ellipses that increase in semimajor axis length in approximately 10" steps. The surface photometry of the V-band image was fit with $\mu = \mu_0 + 1.086r/R_D$, which represents an exponential disk and where $R_D$ is the scale length of the disk. All of the galaxies discussed here show an exponential falloff in V-band surface photometry, and the $R_D$ values are given in Table 1.

### Table 1: Galactic Properties

| Galaxy       | Typea | Distanceb (Mpc) | V-bandc (arcsec) | H\textalpha{}c (arcsec) | R_Dc (kpc) | log SFR_Dc (M\odot yr\(^{-1}\) kpc\(^{-2}\)) | AVG. Surface Brightnessc (mag arcsec\(^{-2}\)) |
|--------------|-------|----------------|------------------|-------------------------|------------|-------------------------------------------|-----------------------------------------------|
| DDO 43       | Im    | 5.5            | 1.134            | 0.488                   | 0.43       | -2.19                                     | 22.01                                         |
| DDO 50       | Im    | 3.4            | 1.134            | 0.433                   | 1.11       | -1.83                                     | 21.65                                         |
| DDO 88       | Im    | 7.4            | 1.134            | 0.488                   | 0.77       | -2.60                                     | 21.60                                         |
| DDO 133      | Im    | 6.1            | 1.134            | 0.488                   | 2.15       | -2.93                                     | 23.14                                         |
| NGC 1156     | IB(s)m| 7.8            | 1.134            | 0.488                   | 0.82       | -0.87                                     | 19.02                                         |
| NGC 1569     | IBm   | 2.5            | 0.420            | 0.488                   | 0.28       | 0.11                                      | 17.14                                         |
| NGC 2366     | IB(s)m| 3.2            | 0.420            | 0.488                   | 1.28       | -1.73                                     | 21.77                                         |
| NGC 3738     | Im    | 4.9            | 1.134            | 0.488                   | 0.77       | -1.72                                     | 9.63                                          |
| VII Zw 403   | BCD(Pec)| 4.4  | 0.608            | 0.488                   | 0.52       | -1.82                                     | 21.82                                         |

- \(^a\) See Hunter & Elmegreen (2004) for references.
- \(^b\) From D. Hunter & B. Elmegreen (2005, in preparation). The average surface brightness is that in V band within $R_D$.
- \(^c\) From Hunter & Elmegreen (2004). SFR$_D$ is the star formation rate normalized to the size of the galaxy as given by $\pi R_D^2$.

3. DATA ANALYSIS

Table 1 shows a summary of the global properties of the galaxies in our sample. Galaxies were selected based on their diverse sizes and star formation rates, as well as their large apparent sizes relative to the pixel scale of the CCD. Our choice of galaxies was also restricted to those that were not heavily resolved into point sources, which would have distorted the power spectra at high spatial frequencies. Foreground stars and background galaxies in the images were removed using a routine that interpolates across a circle centered on the object being removed.

The images were processed and transformed into power spectra using a combination of the IRAF software package and a FORTRAN program of our construction. The FITS images were transformed into ASCII arrays with values corresponding to the intensities of each pixel. The FORTRAN program then extracted linear scans of the array along the major axis of the galaxy. Ten strips were chosen parallel to the major axis of each galaxy and separated by 1 pixel. Regularly spaced points along each strip were taken to have intensity values equal to the values of the pixels in which the points lay, without interpolation. The regions over which the strips were taken are outlined on the V and H\textalpha{} images in Figure 1 and on the H\textgamma{} map of NGC 2366 in Figure 2.

Exponential disks were removed from the V and H\textalpha{} images by dividing each intensity strip by the average exponential profile:

$$I_{\text{ex}}(n) = I(n)/(10^{-0.46}|n|),$$

(1)
Fig. 1.—The $V$-band (left) and H$\alpha$ images (right) of the irregular galaxies examined in this study. The rectangle in each image outlines the area where single pixel wide linear strips were taken and used to produce an average one-dimensional power spectrum. The scale of the image is shown in the bottom left corner. In most images north is at the top, and east is to the left. However, some images were rotated 90$^\circ$ to more easily facilitate taking the strips, and in those images north is to the left and east is down. Most foreground stars and background galaxies have been edited from the images. Images are from Hunter & Elmegreen (2004; 2005, in preparation). The galaxies are from top to bottom: (a) DDO 43, DDO 50, and DDO 88; (b) DDO 133, NGC 1156, and NGC 1569; and (c) NGC 2366, NGC 3738, and VII Zw 403.
Fig. 1b
where $I(n)$ is the observed count in the $n$th pixel out to the sky limit, $n_c$ is the pixel number of the center of the galaxy, and $b$ describes the exponential falloff of the disk (determined at $V$ band). For the H I map we normalized with an exponential fit to the H I surface density radial profile. In Figure 3 we show the result for one power spectrum of removing the underlying exponential disk. One can see that the exponential disk contributes to a steepening at higher relative spatial frequency.

The choice of linear scans rather than azimuthal was influenced by the lack of obvious symmetry in many of the galaxies, as well as concerns that deprojecting the galaxy would introduce interpolation errors at high spatial frequencies. The linear scans suffer from edge effects, however, as dissimilar values at the two ends cause a broad erroneous response in the Fourier transform. To remove these edge effects, a cosine taper with a length of 20 pixels was added to each strip end. When fitting the entire spectrum with a power law, tapering of the ends changed the overall slope by less than 0.1 for each image tested, mitigating an observed turn up at the lowest $k$. These lowest $k$ spatial frequencies were not considered in our final analysis since they reflect effects from galaxy disk gradients.

Several of the galaxies have sparse Hα, and the linear cuts do not go through the brightest emission regions even though they go through the main part of the $V$-band emission. These cases also have noisy power spectra for Hα that do not show clear power laws. This situation leads to our eventual conclusion that the power spectrum of Hα emission resembles a Kolmogorov power law wherever the filling factor of Hα emission is high enough to see the turbulent structure above the noise; this tends to occur in the galaxies with the highest star formation rates per unit area. This conclusion is true even though other cuts, specially chosen for the faint cases, might show power laws over small regions. We considered taking two-dimensional power spectra for our survey to include all of the emission, but then the edge effects become more prominent (a high fraction of the area is at the edge) and the sparse galaxies are still dominated by noise in the two dimensional spectra. Our choice in the end was to be systematic rather than selective, taking major axis cuts over a broad swath (10 pixels wide) to include as much of the emission as possible.

Fourier sine and cosine transforms

$$I_s(k) = \sum_{n=1}^{N} \sin \left(\frac{2kn\pi}{N}\right)I_{\text{cor}}(n),$$

$$I_c(k) = \sum_{n=1}^{N} \cos \left(\frac{2kn\pi}{N}\right)I_{\text{cor}}(n).$$

were applied to the intensity strips. In these equations, $N$ is the total number of pixels in the intensity scan, given in Table 2, and $k$
is the wavenumber. The power spectrum is computed by summing the squares of the individual sine and cosine transforms:

\[ P(k) = L_s(k)^2 + L_c(k)^2. \] (4)

The final power spectra used here are the averages of the power spectra obtained for each of the 10 scans along the major axis.

The power spectra were plotted in log-log space as a function of their relative spatial frequency \( \text{RSF} = k/(N/2) \). The RSF is the spatial frequency normalized to the highest value that can be measured, \( N/2 \). Values of RSF \( = 1 \) correspond to the smallest full sine wave of structure, having a wavelength of 2 pixels. (Note that our convention is to include \( 2\pi \) explicitly inside the argument of the sine and cosine functions, so wavelength is \( 1/k \).)

Linear fits to the average power spectra are taken for RSF between 0.03 and 0.8. High \( k \) are avoided because stars and other point sources contaminate the power spectrum there. Seeing was generally 2\(^\circ\)–3\(^\circ\) FWHM (2–3 pixels) for the \( V \)-band images, corresponding to \( k \sim 1/2.5 = 0.4 \). Low \( k \) are avoided because they are affected by galaxy gradients and the imposed cosine taper. The cosine taper has a wavelength of 40 pixels and so contributes a small spike in the power spectrum at \( k = 1/40 = 0.025 \).

4. RESULTS

4.1. \( V \)-Band Images

Power spectra for the nine galaxies observed in \( V \) band are shown in Figure 4. The lengths of the power spectra vary with the number of pixels in the strip. The spectra are offset from each other for clarity. Sky noise is shown at the bottom. Sky noise comes from 10 strips outside of NGC 2366, which give an average slope of \(-0.3\). All of the images have about the same sky power spectrum, with slopes varying by \( \pm 0.2 \). The reference line in the bottom left corner has a slope of \(-5/3\), which would be the slope of the power spectrum for idealized Kolmogorov turbulence.

The power spectra along the \( V \)-band major axes vary widely for our sample. We estimated the intrinsic variations by determining the power spectra of many strips with different position angles through the center of NGC 1156. This is a round galaxy in the outer parts with no outstanding characteristics in any direction. The standard deviation of power spectrum slopes was \( 0.2 \). Differences in strip alignment and variations within a galaxy suggest the uncertainty in any individual slope is \( \pm 0.3 \). We take this to be our uncertainty for all of the power spectra presented here.

Table 3 gives the slopes of lines fit to the power spectra. The spectra of DDO 43, DDO 50, NGC 1569, and NGC 3738 were determined by eye to roughly follow a two-part power law; the “Fit Division” column gives the dividing point at which the two slopes were measured. “Low RSF” are fits to the portion of the power spectrum less than the “Fit Division” RSF, while “High RSF” are fits to the portion greater than the division. NGC 2366 is fit most closely by a three-part power law; both divisions are given in the second column. Overall, the galaxies’ slopes divide into two groups: \( \sim -1.3 \) and \( \sim -0.5 \). All slopes in the \( V \) band are flatter than the Kolmogorov value of \(-1.66\).

NGC 2366 and NGC 3738 have clear power laws with relatively few features. DDO 43, DDO 50, DDO 133, and NGC 1569 also have power laws but with more random deviations. The bump in NGC 1569’s spectrum at RSF \( \sim 0.1 \) is from the two super star clusters near the center of the galaxy.

\[ \text{TABLE 2} \]

| Galaxy       | \( N_v \) (pixel) | \( L_v \) (arcmin) | \( N_{H\alpha} \) (pixel) | \( L_{H\alpha} \) (arcmin) | \( N_{H\beta} \) (pixel) | \( L_{H\beta} \) (arcmin) |
|--------------|------------------|-------------------|--------------------------|---------------------------|--------------------------|---------------------------|
| DDO 43..     | 192              | 3.6               | 617                      | 5.0                       | ...                      | ...                       |
| DDO 50..     | 431              | 8.1               | 937                      | 6.8                       | ...                      | ...                       |
| DDO 88..     | 370              | 7.0               | 647                      | 5.3                       | ...                      | ...                       |
| DDO 133..    | 325              | 6.1               | 550                      | 4.5                       | ...                      | ...                       |
| NGC 1156..   | 279              | 5.3               | 555                      | 4.5                       | ...                      | ...                       |
| NGC 1569..   | 702              | 4.9               | 660                      | 5.4                       | ...                      | ...                       |
| NGC 2366..   | 1267             | 8.9               | 809                      | 6.6                       | 106                      | 8.8                       |
| NGC 3738..   | 254              | 4.8               | 225                      | 1.8                       | ...                      | ...                       |
| VII Zw 403.. | 471              | 4.8               | 657                      | 5.3                       | ...                      | ...                       |

\[ \text{a} \] The expression \( N \) is the number of pixels in the strip extracted from the \( V \)-band, H\alpha, or H i image; \( L \) is the length of that strip in arcminutes.
O’Connell et al. 1994; Hunter et al. 2000); when the clusters are removed, the bump disappears.

DDO 88, NGC 1156, and VII Zw 403 have flat power spectra, resembling noise. The 10 individual spectra that went into these averages have larger deviations than they do for the other galaxies. VII Zw 403 has a two-part exponential disk with a steeper exponential in the center—not uncommon for BCDs. However, NGC 3738 also has a two-part exponential disk and does not show the low-frequency features of VII Zw 403. DDO 88 has a relatively high sky-to-galaxy ratio in the image used. All three galaxies with flat power spectra are round and relatively homogenous in $V$. Presumably these power spectra are measuring cluster and pixel noise in the images, rather than any large-scale star formation patches.

The power spectrum slope of the $V$-band images does not correlate with galaxy absolute magnitude $M_V$, central surface brightness $\mu_0$, disk scale length $R_D$, or average surface brightness within $R_D$. To examine the importance of shear, we determined the radii at which the solid-body parts of the rotation curves ended and normalized these radii to the disk scale lengths (Hunter et al. 2001; Simpson et al. 2005a, 2005b; Stil & Israel 2002; Swaters 1999; McIntyre 2003). Rotation curves of DDO 133, NGC 3738, or VII Zw 403 were not available. We found no correlation between the power spectra and these relative radii for shear.

![Power spectra](image)

**TABLE 3**

| GALAXY      | $V$ Fit Division | Low RSF | Mid RSF | High RSF | Total | $H\alpha$ Fit Division | Low RSF | High RSF | Total | $H_i$ Total |
|-------------|------------------|--------|--------|---------|-------|------------------------|--------|---------|-------|-------------|
| DDO 43......| 0.2              | −2.0   | ...    | −0.7    | −1.4  | ...                    |        |         |       |             |
| DDO 50......| 0.4              | −1.1   | ...    | −1.9    | −1.3  | ...                    |        |         |       |             |
| DDO 88......| ...              | ...    | ...    | −0.3    | ...   | ...                    |        |         |       |             |
| DDO 133......| ...              | ...    | ...    | −1.5    | ...   | ...                    |        |         |       |             |
| NGC 1156....| ...              | ...    | ...    | −0.3    | ...   | ...                    |        |         |       |             |
| NGC 1569....| 0.2              | −1.7   | ...    | −1.3    | ...   | ...                    |        |         |       |             |
| NGC 2366....| 0.05, 0.3        | −1.0   | −2.0   | −0.7    | −1.4  | 0.1                    | −1.7   | −0.9    | −1.5  | −2.9        |
| NGC 3738....| 0.08             | −2.9   | ...    | −0.8    | −1.3  | 0.1                    | −1.0   | −0.2    | −0.7  | ...          |
| VII Zw 403...| ...              | ...    | ...    | −0.4    | ...   | ...                    |        |         |       |             |

* Divisions in RSF for galaxies whose power spectra were fit with multipart power laws.

$^b$ "Total" is the slope fit to the power spectra between RSF of 0.03 and 0.8.
4.2. Hα Images

Power spectra of Hα images also have a variety of shapes, as shown in Figure 5. The slopes are given in Table 3. The average lengths of the Hα strips were larger by a factor of \( \sim 1.5 \) than the lengths for the \( V \) band because the Hα pixels were smaller. Power spectra of sky noise in the Hα images varied from 0 to \(-0.2\), with an average of \(-0.1 \pm 0.06\). The sky noise shown in Figure 5 has this slope and is from NGC 2366.

The relative scale for the power spectra of \( V \) band and Hα are the same; absolute power is not shown in Figures 4 and 5. The scale of distance relative to the RSF depends on the length of the major axis cut measured in pixels; these are given in Table 2. Absolute sizes of individual features can be calculated using the original dimensions of the strip. Power-law behavior is independent of the pixel size of the image.

The large variety for the Hα power spectra is related to the great diversity of the Hα images. Several galaxies, such as NGC 1569 and NGC 2366, have many large H ii regions and steep power spectra, while others, such as DDO 88 and DDO 50, have sparse H ii regions along the extracted strip and flat power spectra resembling noise. When the H ii regions are sparse, other intensity strips that pass through individual emission regions could have been analyzed instead of the major axis strips used here. These emission regions are probably turbulent like most interstellar gas, and their power spectra might have shown the appropriate power spectra if they had enough spatial resolution, but here they contain far too few pixels to give sensible power spectra by themselves, and in two-dimensional maps they are only a small fraction of the total structure, which is still dominated by noise in these cases.

NGC 1569 follows a two-part power law with a ledge at RSF \( \sim 0.1 \), corresponding to a scale of \( \sim 190 \) pc. At low RSF, the slope for NGC 1569 is \(-1.7\), and at high RSF the slope is \(-0.9\). NGC 3738 also has a two-part power spectrum, with a slope at low RSF of \(-1.0\) and flat slope at high RSF. NGC 1156 has many large H ii regions and a relatively straight power spectrum with a slope of \(-1.1\). It flattens at high RSF, presumably due to the presence of giant H ii region NGC 2363 and does not give a complete representation of structure at all scales in the galaxy.

![Fig. 5.—Power spectra in Hα for the nine surveyed galaxies, plotted as in Fig. 4.](image1)

![Fig. 6.—Star formation rate per unit area (SFR\(_D\)) vs. the slope of the power spectrum in Hα. SFR\(_D\) is calculated from the Hα luminosity according to the formula given in Hunter & Elmegreen (2004) and normalized to the area \( \pi R_D^2 \). The slope for NGC 2366 is skewed because of the presence of the giant H ii region NGC 2363 and does not give a complete representation of structure at all scales in the galaxy.](image2)
examined. On scales of 10–400 pc, six galaxies have $V$-band power spectra with power-law slopes of $-1.4 \pm 0.3$. This similarity suggests that the same processes are structuring star formation regions in these systems. Three galaxies, which are all relatively round and indistinct, have flat power spectra similar to noise.

The H$_\alpha$ images have power spectra with slopes that steepen for greater star formation rates. This is presumably the result of a greater angular filling factor for H$_\alpha$ at higher star formation rates, along with a near universal intrinsic power spectrum for H$_\alpha$ and other interstellar regions that is close to that for Kolmogorov turbulence. At low H$_\alpha$ filling factors, the power spectrum is dominated by noise.

An H$_\alpha$ map of NGC 2366 yielded a power spectrum with a relatively steep slope, but this could be the result of low-frequency contamination by a giant H$_\alpha$ ring and part of the giant H$_\alpha$ cloud associated with NGC 2363.

Differences between the $V$-band and H$_\alpha$ power spectra are usually the result of the influence of a few bright regions that show up in one band and not the other. These differences are to be expected for small galaxies where the number of emission regions is small and the age of each one differs. In larger galaxies there is a wider sample of structure at each age, so particular regions do not stand out in the power spectra. Even so, there could be a difference between $V$-band and H$_\alpha$ power spectra in large galaxies. If, for example, the largest regions form stars for the longest times and have the weakest H$_\alpha$ emission compared to optical (i.e., they have lower H$_\alpha$ equivalent widths), then the power spectrum for $V$ band would be steeper than for H$_\alpha$. Alternatively, the stars that make up the $V$ band could diffuse to a more uniform structure over time, while the turbulence seen in H$_\alpha$ is always rejuvenated; then the power spectrum for $V$ band would be shallower than for H$_\alpha$. These possible differences are not expected to show up in small galaxies where a few individual sources dominate.

Power spectra give new insight into galactic structure. For images with a large number of pixels and few foreground stars, the power spectra of the azimuthal profiles and major axis cuts are all approximately power laws when the emission is dominated by star formation. The power spectra resemble noise when the emission is dominated by old dispersed clusters and field stars. This result implies that star formation in the optical and H$_\alpha$ passbands is approximately scale-free, which means there is no characteristic mass or luminosity for OB associations and star complexes. The scale-free nature also implies that the gas processes leading to star formation are scale-free, as would be the case for gravitational instabilities (Semelin et al. 1999) and turbulence compression (Elmegreen & Scalo 2004). Most likely a combination of self-gravity and turbulence structures the gas, triggering star formation. The driving force for the turbulence may be self-gravity as well, with a substantial contribution from supernovae and other young stellar pressures. The fact that the power laws of star formation are about the same for dwarf galaxies and giant spiral galaxies suggests the microscopic processes are the same, independent of spiral density waves and galaxy size.

K. W. W. would like to thank Kathy Eastwood and the 2004 Research Experience for Undergraduates program at Northern Arizona University, which is funded by the National Science Foundation (NSF) under grant 9988007. Funding for this work was also provided by the NSF through grants AST 02-04922 to D. A. H. and AST 02-05097 to B. G. E.
REFERENCES

Crovisier, J., & Dickey, J. M. 1983, A&A, 122, 282
Deshpande, A. A., Dwarakanath, K. S., & Goss, W. M. 2000, ApJ, 543, 227
Dickey, J. M., McClure-Griffiths, N. M., Stanimirovic, S., Gaensler, B. M., & Green, A. J. 2001, ApJ, 561, 264
Elmegreen, B. G., Elmegreen, D. M., & Leitner, S. N. 2003a, ApJ, 590, 271
Elmegreen, B. G., Leitner, S. N., Elmegreen, D. M., & Cuillandre, J.-C. 2003b, ApJ, 593, 333
Elmegreen, B. G., Kim, S., & Staveley-Smith, L. 2001, ApJ, 548, 749
Elmegreen, B. G., & Scalo, J. S. 2004, ARA&A, 42, 211
Elmegreen, D. M., Elmegreen, B. G., & Eberwein, K. S. 2002, ApJ, 564, 234
Falgarone, E., Phillips, T. G., & Walker, C. K. 1991, ApJ, 378, 186
Green, D. A. 1993, MNRAS, 262, 327
Hunter, D. A., Elmegreen, B. G. 2004, AJ, 128, 2170
Hunter, D. A., Elmegreen, B. G., & van Woerden, H. 2001, ApJ, 556, 773
Hunter, D. A., O’Connell, R. W., Gallagher, J. S., & Smecker-Hane, T. A. 2000, AJ, 120, 2383
Klessen, R. S. 2004, Habilitation thesis, Potsdam Univ.

Mac Low, M.-M., & Klessen, R. S. 2004, Rev. Mod. Phys., 76, 125
McIntyre, V. 2003, Ph.D. thesis, Univ. Wollongong
O’Connell, R. W., Gallagher, J. S., & Hunter, D. A. 1994, ApJ, 433, 65
Semelin, B., de Vega, H. J., Sánchez, N., & Combes, F. 1999, Phys. Rev. D, 59, 125021
Simpson, C. E., Hunter, D. A., & Knezek, P. M. 2005a, AJ, 129, 160
Simpson, C. E., Hunter, D. A., & Nordgren, T. E. 2005b, AJ, submitted
Stanimirovic, S., Staveley-Smith, L., Dickey, J. M., Sault, R. J., & Snowden, S. L. 1999, MNRAS, 302, 417
Stanimirovic, S., Staveley-Smith, L., van der Hulst, J. M., Bontekoe, T. R., Kester, D. J. M., & Jones, P. A. 2000, MNRAS, 315, 791
Stil, J. M., & Israel, F. P. 2002, A&A, 392, 473
Stutzki, J., Bensch, F., Heithausen, A., Ossenkopf, V., & Zielinsky, M. 1998, A&A, 336, 697
Swaters, R. 1999, Ph.D. thesis, Rijksuniversiteit Groningen
Westpfahl, D. J., Coleman, P. H., Alexander, J., & Tongue, T. 1999, AJ, 117, 868