Panchromatic Study of Nearby Ultraviolet-Bright Starburst Galaxies: Implications for Massive Star Formation and High-Redshift Galaxies

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Received 1999 July 27; accepted 1999 September 29

Abstract

We present a panchromatic study of nearby starburst galaxies from the ultraviolet to the visible, including narrowband Hα data, to determine how star formation processes affect the morphologies and integrated fluxes of nearby starbursts. We find that the UV and Hα morphologies of starbursts tend to differ, although not in a standard or predictable manner. From our sample of six nearby starbursts, three systems show good correlations between UV and Hα fluxes, but we find differences in UV and Hα morphology among the other three. Occasionaly we find systems with well-defined H II regions without the corresponding brightness in the UV, and vice versa. We discuss the likely mechanisms behind these differences, which include starburst ages, dust absorption, stellar energy ejecta through supernovae and winds, and leakage of UV photons from stellar clusters. We conclude that the large-scale morphological features in starbursts are primarily due to both age and absorption from a “picket-fence” dust distribution. We further demonstrate the similarity and differences between these nearby starbursts and high-redshift star-forming galaxies. The overall morphology of our sample of starbursts changes little between UV and visible wavelengths. If high-redshift galaxies are similar to these starbursts, their morphologies should change little between rest-frame UV and optical. We also show that FIR and UV spectral energy distributions and slopes can be used to determine large-scale morphological features for extreme starbursts, with the steepest FIR slopes correlating with the most disturbed galaxies.

Key words: galaxies: individual (NGC 3310, NGC 3351, NGC 3690, NGC 3991, NGC 4861, NGC 7673) — galaxies: interactions — galaxies: starburst — galaxies: structure

1. Introduction

Starbursts are typically defined either as galaxies where star formation rates are substantially enhanced, with a significant portion of the light output originating from distinct star-forming regions (Weedman et al. 1981) or as galaxies whose ISM is being disproportionately affected by star formation properties (Leitherer 1997). These galaxies are extremely important for understanding a host of astrophysical problems. It is estimated that at least 25% of all star formation in the local universe is occurring in starburst galaxies (e.g., Gallego et al. 1995), with potentially a significantly larger fraction in the past (Lilly et al. 1996; Madau et al. 1996). Likewise, nearby starbursts have some of the highest surface brightnesses of any galaxies in the universe and have morphological and spectroscopic properties similar to those of high-redshift galaxies (Gallagher, Hunter, & Bushouse 1989; Cowie, Hu, & Songaila 1995; Giavalisco et al. 1996; Hibbard & Vauc 1997; Heckman et al. 1998; Meurer, Heckman, & Calzetti 1999). It is possible that a significant fraction of all stars were created in starburst-like events. Detailed studies of nearby starbursts are therefore important for understanding the interactions between the ISM of a galaxy and young stars, as well as for understanding the processes of galaxy evolution.

There are, however, several very basic questions about starburst galaxies that are just beginning to be answered. It seems likely that a fraction of all starburst galaxies are caused by the interaction and possible mergers of two galaxies (Schweizer 1987; Jog & Das 1992). These starbursts usually have obvious companions producing an interaction in part responsible for triggering the starburst. However, some starbursts appear relatively isolated and are either merger remnants of two galaxies or have a starburst mechanism not related to dynamical effects from other galaxies. Starbursts can be triggered from self-contained internal processes, such as from energy ejecta from superwinds and supernova (SN) explosions (Heckman, Armus, & Miley 1990). Alternatively, starbursts in the nuclei of galaxies can be triggered by bar instabilities (Shlosman, Begelman, & Frank 1990). If there are different methods of triggering a starburst, which seems likely, then there are also differences in the morphological and physical properties of galaxies that have different starburst creation scenarios?

Some UV bright starburst galaxies are also bright in far-infrared wavelengths, revealing the presence of large amounts of dust (e.g., Hunter et al. 1989). Since UV light is strongly absorbed by dust, on the surface this is an apparent contradiction that can be solved if the dust in galaxies exists in a “picket-fence” geometry (Calzetti 1997). These are nearby examples of starburst galaxies undergoing vigorous star formation that have high far-IR fluxes but little to no ultraviolet (UV) flux (Sanders & Mirabel 1996). These ultraluminous infrared galaxies (ULIGS) have become increasing important objects for understanding high-redshift submillimeter galaxies (e.g., Barger, Cowie, & Sanders 1999). The number of known submillimeter sources in areas such as the Hubble Deep Field are few, and it is difficult to determine if any correspond to UV-bright star-forming systems at high redshifts (> 2).
source counts if most high-redshift galaxies resemble nearby starbursts.

Previous morphological studies of UV-bright starbursts have included the characterization of luminosity functions of super star clusters (SSCs; e.g., Meurer et al. 1995; Maoz et al. 1996; Johnson et al. 1999) to test the idea that these objects are young globular clusters. Meurer et al. (1995) investigated the UV morphology using Faint Object Camera (FOC) images for nine galaxies, finding a highly irregular appearance of the starburst region of each galaxy and most of the SSCs in the core of the starburst. Maoz et al. (1996) used FOC UV images, taken with the Hubble Space Telescope, to investigate star formation properties in ringed starburst galaxies. Like Meurer et al. (1995), Maoz et al. find a large percentage of the UV light in starburst galaxies, up to 50%, to originate in star clusters. That is, a significant portion of star formation seen in the UV-visible spectral region occurs in dense clusters distributed throughout the starburst.

In this paper, we investigate the large-scale physical morphologies of UV-bright star-forming zones in nearby starbursts and explore how the UV morphology compares to the optical appearance. This will help determine the morphological evolution of these objects and will reveal any implications for high-redshift galaxies. We also investigate how the spectral energy distributions of starbursts relate to their morphological appearance.

For this study, We have obtained archival FOC/WFPC2 Hubble Space Telescope ultraviolet imaging data, coupled with R, B, and Hα images taken with the 3.5 m Wisconsin-Indiana-Yale-NOAO (WIYN)3 telescopes for the starburst galaxies NGC 3310, NGC 3351, NGC 3690, NGC 3991, NGC 4861, and NGC 7673. These galaxies represent a range of starburst galaxy host morphologies at luminosities near those of typical giant spirals. All of these galaxies, with the exception of NGC 4861, are both bright in the UV and have high far-infrared fluxes as measured by IRAS. We examine the morphologies of these galaxies, including the comparison between the Hα and UV emission from star-forming regions. H II regions mark the locations where a mixture of stars with ages of less than about 3 Myr are present; if the region is sufficiently dusty, then the UV emission can be absorbed. It is therefore useful to determine if there are any morphological differences at various wavelengths and what they imply for the physics of starbursts. This is also important for understanding if nearby starbursts are similar to high-redshift ones, since many high-redshift galaxies are most easily observed in their UV rest frame.

We find for our small sample that the starburst morphologies remain similar at different wavelengths, although some differences exist between the UV and Hα morphologies. We attribute these to aging and dust absorption effects within star-forming complexes. The similarity between morphologies is a confirmation of the picket-fence model of dust distribution in starbursts. The high FIR fluxes from these galaxies are the result of dust extinction occurring at places other than the UV-bright star formation sites.

We also show that the slope of the spectral energy distribution in some cases correlates with morphological features of a starburst. Our best example is NGC 3690, which has a disturbed morphology, the highest dust content, and the largest FIR SED slope. We conclude, based on similar panchromatic studies of high-redshift galaxies, that nearby starbursts and high-redshift star-forming galaxies have similar morphological properties.

In § 2 we describe the motivation for this study; § 3 gives our observations and the data used. In § 4 we explain in detail properties of the various starbursts and discuss the morphological differences between the wavelengths used in this study. Section 5 is a description of our results, while § 6 is an attempt to explain the observed morphologies by invoking various physical scenarios. Finally in §§ 7 and 8 we examine how the morphologies are related to both the spectral energy distributions and how these galaxies are related to star-forming systems at high redshift. Section 9 is a summary of our conclusions.

2. PHYSICAL MOTIVATION

The study of nearby starburst galaxies is extremely important for understanding how star formation occurs—a basic question in contemporary astronomy. Although active star formation in most galaxies is quiescent, localized, and may differ from the intense star formation found in starburst galaxies, the basic processes should be similar on the microscopic scale. Studies of galaxies where star formation is dominating the optical appearance may reveal general features of star formation unobtainable from more quiescent galaxies.

The modeling of how star formation occurs on large scales is complicated by many factors, the least of which is how massive individual stars collapse to begin the nuclear fusion process. Other factors that will affect the panchromatic morphology of a starbursting region are dust, photon ionization of the surrounding ISM, stellar winds, SN energy ejecta, and ionizing photon leakage from other star-forming regions. Combined with these on-going directly measurable features (in principle) are the history and age of the starburst, the star formation rate of the burst (continuous as opposed to instantaneous star formation), and the details of the star formation process, such as the initial mass function, initial metallicity, spatial distributions, and the evolutionary history of the new stars. Synthesis models have recently made efforts to reproduce photometric parameters of starbursts as a function of time (e.g., Leitherer & Heckman 1995; Leitherer et al. 1999). These models consider all of the above parameters to derive measurable quantities such as colors and luminosities throughout the history of the burst.

By combining morphological information with physical data known for these galaxies, we can determine if the panchromatic morphological differences in these starbursts are due to an active force, such as the effects of stellar ejecta, aging effects of the cluster, or alternatively to dust obscuration effects. Likewise, we want to understand how the morphologies of UV-bright starbursts reflect the star formation process and/or the dynamical state of the system.

3. OBSERVATIONS AND DATA

This paper uses images taken with the WIYN 3.5 m telescope in broadband Harris B and R and narrowband Hα filters and Hubble Space Telescope (HST) WFPC2 and

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3 The WIYN Observatory is a joint facility of the University of Wisconsin-Madison, Indiana University, Yale University, and the National Optical Astronomy Observatories.
seen by (Soifer et al. 1989) to determine which starbursts have both

Considered benchmark starbursts. A detailed description starbursts are relatively nearby and for the most part can be

Table 1 lists the galaxies in our sample with the filters used in the imaging. The sample consists of six galaxies of various starburst morphologies that were picked based on the following criteria. We used the UV spectral catalog of Kinney et al. (1993) and the IRAS bright galaxy catalog (Soifer et al. 1989) to determine which starbursts have both high flux in the far-UV (FUV) and high far infrared flux as seen by IRAS. From this sample we then narrowed our candidates to the ones that were imaged in the UV at \( \lambda < 0.3 \) \( \mu \)m by the Hubble Space Telescope. Each of the starbursts are relatively nearby and for the most part can be considered benchmark starbursts. A detailed description and background of the individual starbursts will be given in §4.

The WIYN optical observations were carried out between the nights of 1998 March 21 and March 24. The WIYN CCD images were obtained with a 2048\(^2\) pixel thinned S2K device, producing images with a scale of 0.2 pixels \(^{-1}\). The field of view of each image is 6.8 x 6.8. Seeing conditions for most of the images are less than 1\(''\), with a few exceptions. While the seeing was good, the conditions were not photometric. The analysis presented in this paper is therefore based on morphology and relative photometry.

A major purpose of this study is to compare the Hz structures of starbursts to those in the UV, hence adequate angular resolution UV images are necessary for this work. Most previous UV imaging studies of galaxies (e.g., Buat, Donas, & Deharveng 1987; Donas et al. 1987; Chen et al. 1992) investigated mainly nominal normal galaxies and were limited in resolution to a few arcminutes. The Ultraviolet Imaging Telescope (UIT) has in particular produced a unique archive of moderate angular resolution far-ultraviolet images of galaxies but has observed only a few starbursts (e.g., NGC 3310; Smith et al. 1996). The superb resolution offered by HST offers the additional advantage of allowing us to study the fine details of starburst morphology.

Four of the six galaxies in our sample, NGC 3310, NGC 3690, NGC 3991, NGC 4861, have UV images taken with the FOC in the f/96 mode. This gives a 14" field of view with a resolution of 0.014 pixels\(^{-1}\). The filter used was the

\begin{table}[h]
\centering
\caption{Galaxies Observed}
\begin{tabular}{llllll}
\hline
Galaxy & R.A. (J2000) & decl. (J2000) & Morphology & Distance (Mpc) & Filters \\
\hline
NGC 3310 & 10 38 45.6 & +53 30 12 & SAB(r)bc & 18.7 & \(R, B, F220W\) \\
NGC 3351 & 10 43 58.0 & +11 42 14 & SB(r)b & 8.1 & \(R, B, F218W\) \\
NGC 3690 & 11 28 31.0 & +58 33 41 & SBm & 41.6 & \(R, B, F220W\) \\
NGC 3991 & 11 57 30.4 & +32 20 01 & ... & 42.6 & \(R, B, F220W\) \\
NGC 4861 & 12 59 01.8 & +34 51 40 & SB(m) & 17.8 & \(R, B, F220W\) \\
NGC 7673 & 23 27 41.6 & +23 35 31 & (R')SBac? pec & 45.4 & \(R, B, F220W\) \\
\hline
\end{tabular}
\end{table}

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

\begin{table}[h]
\centering
\caption{UV/Optical Fluxes (W m\(^{-2}\) Hz\(^{-1}\))}
\begin{tabular}{llllllll}
\hline
Galaxy & 1482 Å\(^a\) & 1913 Å\(^a\) & 2373 Å\(^a\) & 2700 Å\(^a\) & \(U\) (3600 Å)\(^b\) & \(B\) (4400 Å)\(^b\) & \(V\) (5530 Å)\(^b\) \\
\hline
NGC 3310 & \(7.47 \times 10^{-29}\) & \(9.11 \times 10^{-29}\) & \(9.10 \times 10^{-29}\) & \(1.23 \times 10^{-28}\) & \(9.33 \times 10^{-28}\) & \(1.48 \times 10^{-27}\) & \(1.74 \times 10^{-27}\) \\
NGC 3351 & \(1.44 \times 10^{-29}\) & \(2.48 \times 10^{-29}\) & \(3.93 \times 10^{-29}\) & \(5.43 \times 10^{-29}\) & ... & \(2.61 \times 10^{-27}\) & \(4.67 \times 10^{-27}\) \\
NGC 3690 & \(1.71 \times 10^{-29}\) & \(2.05 \times 10^{-29}\) & \(2.03 \times 10^{-29}\) & \(2.48 \times 10^{-29}\) & ... & ... & \(2.61 \times 10^{-27}\) \\
NGC 3991 & \(3.83 \times 10^{-29}\) & \(3.67 \times 10^{-29}\) & \(3.89 \times 10^{-29}\) & \(4.16 \times 10^{-29}\) & \(9.76 \times 10^{-29}\) & \(1.70 \times 10^{-28}\) & \(2.07 \times 10^{-28}\) \\
NGC 4861 & \(7.28 \times 10^{-29}\) & \(6.69 \times 10^{-29}\) & \(6.28 \times 10^{-29}\) & \(5.97 \times 10^{-29}\) & ... & \(2.95 \times 10^{-28}\) & \(4.30 \times 10^{-28}\) \\
NGC 7673 & \(1.68 \times 10^{-29}\) & \(1.86 \times 10^{-29}\) & \(1.94 \times 10^{-29}\) & \(2.44 \times 10^{-29}\) & \(1.32 \times 10^{-28}\) & \(2.30 \times 10^{-28}\) & \(2.87 \times 10^{-28}\) \\
\hline
\end{tabular}
\end{table}

\(^{a}\) All UV fluxes from Kinney et al. 1993.

\(^{b}\) Optical Data from de Vaucouleurs et al. 1991.

\(^{c}\) Optical V for NGC 3690 from Huchra 1977a, 1977b.

\begin{table}[h]
\centering
\caption{Infrared Fluxes (W m\(^{-2}\) Hz\(^{-1}\))}
\begin{tabular}{llllllll}
\hline
Galaxy & \(J\) (1.26 \(\mu\)m) & \(H\) (1.60 \(\mu\)m) & \(K\) (2.22 \(\mu\)m) & 12 \(\mu\)m\(^d\) & 25 \(\mu\)m\(^d\) & 60 \(\mu\)m\(^d\) & 100 \(\mu\)m\(^d\) \\
\hline
NGC 3310 & \(5.45 \times 10^{-28}\) & \(5.35 \times 10^{-28}\) & \(4.22 \times 10^{-28}\) & \(1.13 \times 10^{-26}\) & \(4.58 \times 10^{-26}\) & \(3.05 \times 10^{-25}\) & \(3.92 \times 10^{-25}\) \\
NGC 3351 & \(3.51 \times 10^{-28}\) & \(4.74 \times 10^{-28}\) & \(3.79 \times 10^{-28}\) & \(6.59 \times 10^{-27}\) & \(2.09 \times 10^{-26}\) & \(1.17 \times 10^{-25}\) & \(3.35 \times 10^{-25}\) \\
NGC 3690 & \(5.26 \times 10^{-28}\) & \(9.71 \times 10^{-28}\) & \(1.01 \times 10^{-27}\) & \(3.81 \times 10^{-26}\) & \(2.32 \times 10^{-25}\) & \(1.04 \times 10^{-24}\) & \(1.07 \times 10^{-24}\) \\
NGC 3991 & ... & ... & ... & ... & \(2.44 \times 10^{-27}\) & \(2.73 \times 10^{-26}\) & ... \\
NGC 4861 & ... & ... & ... & ... & ... & ... & ... \\
NGC 7673 & ... & ... & ... & \(1.33 \times 10^{-27}\) & \(5.17 \times 10^{-27}\) & \(4.91 \times 10^{-26}\) & \(6.89 \times 10^{-26}\) \\
\hline
\end{tabular}
\end{table}

\(^{d}\) IR fluxes from Moshir et al. 1990.
F220W, giving an effective wavelength of 230 nm for these observations. Figure 1 shows a WIYN image of each galaxy, and the locations of the UV images are marked by filled circles. Usually the UV images cover only small parts of the star-forming areas of these galaxies. The exposure times for these galaxies were 200, 900, 400, and 1000 s. The basic parameters for these observations are shown in Table 1. The UV measurements for the other two galaxies, NGC 7673 and NGC 3351, are Wide Field Planetary Camera 2 (WFPC2) images with fields of view 2.5 on a side with a resolution of 0.10. The WFPC2 filters used for these galaxies are F255W and F218W with exposure times of 600 and 800 s, respectively. Photometry is performed on these UV images of our sample by using the STMAG system, where \( m = -2.5 \log_{10} f_i - 21.10 \). We use an aperture that covers the entire UV image; this is usually well defined in

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**Fig. 1.**—Large-scale image of each of the starburst in our sample. The dark circle outlines the area observed in the UV images presented in Figs. 2–7.
the cases of these starbursts, where most of the flux comes from centralized well-defined star clusters.

For the spectral energy distributions, we use the International Ultraviolet Explorer (IUE) UV fluxes. The Infrared Astronomical Satellite (IRAS) data are used for the far-infrared, and various sources, including the RC3 (de Vaucouleurs et al. 1991), are used to obtain the optical and near-infrared data. Without a homogeneous data set, it is nearly impossible to obtain fluxes within the same aperture over a wide range of wavelengths. This is the case here, although we tried to match apertures as closely as possible for the UV and optical. UV/optical fluxes are shown in Table 2, and infrared fluxes in Table 3. The plots used to show the SEDs (Figs. 8, 9, and 10) have substantial uncertainties in their aperture corrections, and in no other part of this paper are different data sets compared.

4. INDIVIDUAL GALAXIES

4.1. NGC 3310

NGC 3310 is one of the best examples of a local UV-bright starburst of moderately high luminosity whose unusual outer structure is probably the result of a recent merger with a smaller galaxy (Balick & Heckman 1981; Mulder & van Driel 1996). NGC 3310 is also extremely bright in far-infrared emission (e.g., Braine et al. 1993) and X-rays (Zezas, Georgantopoulos, & Ward 1998) and was one of the first known FUV-bright starbursts (Code & Welch 1982).

In the optical NGC 3310 displays a striking “bow and arrow” appearance in its outer parts. This feature is one of the better studied morphological peculiarities in any starburst galaxy (Walker & Chincarini 1967; Balick & Heckman 1981; Bertola & Sharp 1984; Mulder, van Driel, & Braine 1995). It was once thought that this bow part was a spiral arm (Walker & Chincarini 1967), but it has been shown to be part of a shell or ripple pattern, possibly caused by the accretion of a low-mass companion galaxy (e.g., Balick & Heckman 1981; Schweizer & Seitzer 1988; Smith et al. 1996).

NGC 3310 has an inner, symmetric spiral pattern and a significant amount of star formation tracing the spiral arms. A large portion of the star formation, based on Hα images, is in a central ring surrounding an off-center nucleus (Fig. 2). Some star formation is occurring within the ring, but the nucleus is either dominated by an older population or is dusty (compare UV and R-band images in Fig. 2).

The FOC UV image of NGC 3310 shows a similar morphology to the Hα image; there is a ring of hot stars surrounding the central parts of the cluster. However, when comparing directly the UV, R, and Hα morphologies, there are some obvious differences (Fig. 2). There is a double ring
structure in the core of the galaxy, with the inner one composed of gas (Hα emission) and the outer one composed of slightly older stars. The inner Hα ring is immediately interior to the redder outer ring and is offset from the center of the galaxy. However, this outer ring is not dominated by Hα emission as much as the arms leading away from the center are. Additionally there are stellar regions in the center that have little or no Hα emission; likewise there are several regions near the western part of the center that are dominated by Hα flux, with no continuum R light.

In comparison of the Hα and UV images of this galaxy (Fig. 2), several regions at the upper left are found to be brighter in Hα than in the UV. These are also areas with considerable Hα flux but little UV flux in comparison to the other bright UV regions. There is an asymmetry in the difference, with the northwest region having less UV flux than the southwest region of the central ring around the galaxy. We conclude that this starburst is probably a result of star formation induced by a bar instability. The color map of this galaxy does not show large variations or the clumpy appearance of dust.

4.2. NGC 3351

NGC 3351 appears to be symmetric in both its outer and inner portions, and, with the exception of the nuclear starburst, it appears quite regular, with none of the tidal features that are observed in many of the other galaxies in our sample (Fig. 3). The classical morphological description of this galaxy is a ringed-barred Sb, while most UV-bright starbursts have classically been defined as either irregular or peculiar galaxies. The regular morphology of NGC 3351 suggests that this galaxy’s starburst has a different origin than the others in our sample. NGC 3351 has a prominent bar, and the dynamical influence of the bar is a likely source of this starburst (Shlosman et al. 1990).

Previous work on NGC 3351 (e.g., Alloin & Nieto 1982; Maoz et al. 1996) found three Hα bright H II regions surround the nucleus. Kinney et al. (1993) also find highly ionized species of heavy elements, indicating the presence of intense radiation, consistent with the central starburst interpretation. Colina et al. (1997) previously observed NGC 3351 in the UV with WFPC2, finding a star formation ring composed of individual stellar clumps. Circumnuclear molecular gas was also found in NGC 3351 by Planesas, Colina, & Perez-Olea (1997).

In our Hα images, we find four circumnuclear H II complexes and several UV star clusters that have neither corresponding H II regions nor any significant Hα flux. One interpretation for the existence of the star burst in NGC 3351 is that the gas is being driven into the ring around the nucleus, creating the starburst in the inner Lindblad resonance (Alloin & Nieto 1982). The lifetimes of intensely star-
forming nuclear rings in giant disk galaxies are not very well
known, and this class of UV-bright starburst may be funda-
mentally different from those produced by interactions.

4.3. NGC 3690

NGC 3690 is the most disturbed galaxy in our sample
and is morphologically classified as peculiar (see Fig. 4). It is
the only galaxy in our sample that is interacting strongly
with another galaxy, in this case a probable merger with IC
694 (Gehrz, Sramek, & Weedman 1983).

H I mapping of this galaxy finds no disk structure, and its
optical morphology can be accounted for primarily by
bright star-forming regions (Nordgren et al. 1997). Of our
entire sample, NGC 3690 has the largest difference between
ultraviolet and Hα morphologies in the inner portions of
the starburst. It has both H II regions and UV star clusters
without the corresponding presence of the other.

There are four main star-forming regions in the inner
parts of this galaxy pair, called nuclei A, B, C, and C′ follow-
ing Sargent & Scoville (1991). These clumps are thought to
be the main source of the prodigious far-infrared luminosity
of this system. The mid-infrared emission (10 μm) from
these sources is extended (Miles et al. 1996), and compared
with 3.4 μm emission, source C is bluest, followed by B, with
A and C′ the reddest. NGC 3690 is one of the brightest
galaxies in the local universe in X-rays, with a luminosity
$L_X \approx 10^{42}$ ergs s$^{-1}$ and an X-ray spectrum consistent with a
superwind (Zezas et al. 1998).

Given the very peculiar morphology, the starburst of this
galaxy is a result of the on-going galaxy merger with IC 694.
The color map of this far-infrared–bright galaxy also shows
that a significant amount of dust is present (Fig. 4). Not
surprisingly, this galaxy has the largest ratio of FIR to star-
burst UV flux (see § 7).

4.4. NGC 3991

Cataloged as a peculiar galaxy by Arp (1966), NGC 3991
has also been classified as a Magellanic irregular (see Fig. 5).
NGC 3991 has an optical spectrum similar to that of an H II
galaxy (Keel et al. 1985; Kennicutt 1992). NGC 3991 also
has low-metallicity H II regions (Arnault et al. 1988), and
from our images it does not appear to contain an extended
shell or an outer portion distinct from its inner starburst
area. However, it is generally believed that the starburst in
this galaxy was triggered by an interaction with the neigh-
boring galaxies NGC 3994 and NGC 3995 (Keel et al.
1985). A detailed optical and spectroscopic study of NGC
3991 (Hecquet et al. 1995) found several separate knots in
NGC 3991, each with extreme star formation and a size of
around 300 pc. A comparison of the colors of these knots
indicates that star formation is concentrated within and
occurring rapidly in these clumps (Hecquet et al. 1995).

Fig. 4.—Panchromatic morphologies for NGC 3690. See Fig. 2 for explanation of frames.
NGC 3991 also has a high radio and X-ray flux (Seaquist & Bell 1968; Fabbiano, Feigelson, & Zamorani 1982). The UV spectrum of this galaxy contains features associated with recently formed stars such as Ly $\alpha$ and He $\pi$ emission (Kinney et al. 1993). Although detected by IRAS, NGC 3991 is not classified as an IRAS bright galaxy (Soifer et al. 1989). Therefore, the morphology of NGC 3991 is probably not dominated by dust. We verify this by finding that the UV morphology is similar to that in the optical $R$ band. However, the southern H $\pi$ regions associated with a relatively bright UV cluster are faint in H$\alpha$ as compared with the northern star-forming clumps.

4.5. NGC 4861

NGC 4861 (Arp 266) has no regular structure or obvious outer stellar envelope and appears to be a strand of H $\pi$ regions. NGC 4861 is classified as a Magellanic irregular (Sandage & Tammann 1981; see Figs. 1 and 6). The northern part of this galaxy has occasionally been considered a separate system, IC 3961. The southern area, appearing as a bright knot, is sometimes referred to as NGC 4861. The knot is usually interpreted as an H $\pi$ region or OB association (Huchra 1977a). From H $\beta$ maps, this galaxy is an edge-on and rotating disk system (E. Wilcots 1999, private communication.)

NGC 4861 has been studied as an example of a compact blue galaxy (Thuan & Martin 1981), having a high UV continuum and strong absorption features, indicating the presence of young O and B stars (Kinney et al. 1993; Calzetti 1997). Radio continuum work on NGC 4861 finds a deficiency of nonthermal emission (Sramek & Weedman 1986), possibly indicating a lack of supernova remnants.

The $R$ and $B$ WIYN images clearly show the southern knot to be very compact and unresolved in 1" seeing, while the northern part of this galaxy is resolved into stars or stellar clusters. The FOC image of NGC 4861 resolves the southern knot into six stellar condensations, although these probably do not completely account for its bright optical appearance. The OB clusters are generally on the outskirts of the southern knot, and it is likely that the ionizing photons from these clusters are the source of ionization for the surrounding H $\pi$ region. The ionized gas, delineated by the H$\alpha$ flux in and surrounding the knot, is more diffuse and has a larger extent than the stellar light; this behavior is typical of giant H $\pi$ regions. The morphological appearance of the southern knot is largely the result of this ionized gas.

The FOC image includes also a part of the northern part of the starburst, where only one small UV source (OB association or cluster) can be seen, with a considerable amount of diffuse UV light caused by unresolved OB stars. For the most part the morphology of NGC 4861 is “simpler” than those of the other galaxies in our sample since there are very few major H $\pi$ regions resolved in our
Hα image. From what we can determine, there is no significant difference between the UV and optical morphologies of this edge-on starburst.

4.6. NGC 7673

NGC 7673 is a nearby, luminous starburst galaxy with an inner asymmetric spiral structure and an outer structure showing evidence of ripples. This ripple structure of NGC 7673 is similar to that in NGC 3310, possibly caused by a merger or interaction with another galaxy (see Homeier & Gallagher 1999). NGC 7673 also contains an extensive array of clumpy star-forming regions throughout its disk (Casini & Heidmann 1976). The starburst is occurring in the inner portions of the galaxy within huge clumps embedded within an abnormal spiral pattern (Huchra 1977b; J. S. Gallagher et al. 2000, in preparation). There is also an extended, somewhat disturbed H I disk (Nordgren et al. 1997). The most likely scenario for the creation of the starburst in NGC 7673 is either through a minor merger or, more likely, from an interaction with a nearby galaxy, NGC 7677.

Although a massive starburst is occurring in the disk of NGC 7673, the Hα-line kinematics are relatively quiescent, with a low velocity dispersion (Duflot-Augarde & Alloin 1982; Homeier & Gallagher 1999) consistent with a rotating disk. Figure 7 shows the UV/Hα and optical images for this galaxy. We find that NGC 7673 has similar structures in its UV and Hα images, with most H II regions following the locations of the bright UV star clusters. A more detailed discussion of star formation patterns in NGC 7673 will be presented by J. S. Gallagher et al. 2000, in preparation.

5. COLOR MAPS AND MORPHOLOGICAL BAND DIFFERENCES

A color map of a galaxy, showing the relative proportion of light from one band to another, is useful for determining the presence of several features in a starburst. First, by examining these maps, it can become clear whether or not dust screens are strongly affecting the light distribution. This is typically revealed by narrow or localized features (e.g., dust lanes) where the redder band dominates the bluer one. These features will generally increase in prominence at shorter wavelengths, until the background becomes too faint in the UV. Likewise, a color map will also reveal the locations of the bluest, and hence the least obscured massive stars. In this study, we display the color maps for the starburst regions of interest to demonstrate the existence or lack thereof, of dust and the locations of star formation activity.

From our multiple wavelength images, we can also study the changes in morphology from long to short wavelengths, between 220 and 660 nm. We find that, although the
host galaxy for the starburst essentially disappears in the UV image, the star bursting region's large-scale morphology is usually similar in all bands.

Of course, when comparing the rest-frame morphologies of galaxies in the FUV with visible wavelengths, differences do exist (Marcum & O'Connell 1996), which can be attributed to the sampling of different stellar populations. What is the behavior of the panchromatic morphology for distant star-forming galaxies? When examining high-redshift galaxies, the structure will also change because of cosmological surface brightness dimming. When observing galaxies at high redshifts, such as those in the Hubble Deep Field, the brightest portions of objects are seen; these are likely to be the most active sites of star formation. The intensity of star formation in some distant galaxies is much greater than in local starbursts by up to a factor of 4 (Weedman et al. 1998). While the total intensities and rates of star formation are different, other macroscopic morphological features are similar. No large morphological changes are observed between the morphologies of Hubble Deep Field galaxies in the NICMOS infrared images (rest-frame optical) and in the WFPC2 visible bands (rest-frame UV; M. Dickinson et al. 2000, in preparation). Either these images are too shallow to find fainter host galaxy-like components or these galaxies are dominated by stars emitting in the UV.

We discuss other implications of studies of nearby starbursts for high-redshift galaxies in a separate section.

6. PHYSICS AND GEOMETRY

Although our sample of UV and H$\alpha$ images is small, we can still draw useful conclusions about the ways in which multiwavelength images sample different aspects of the distribution of stars and gas in these starbursts. The H$\alpha$ images reveal the presence of ionized gas and the locations of the most recent star formation events ($< 10$ Myr), while the UV star clusters reveal the presence of young stars recently formed over the last 50–100 Myr (O'Connell 1997). Since young stars are formed out of gas, it might be expected that the light from UV clusters would trace that of H$\alpha$ gas ionized by the high-energy UV photons. Yet, we do see luminous H II regions without FUV sources and FUV regions without H$\alpha$.

Possible explanations for these differences include dust absorption of the UV light, aging effects, UV photon leakage into areas of previously neutral hydrogen gas, and intense winds from young stars and supernovae that could rearrange interstellar gas from which OB stars formed. We will discuss below each possibility in detail and arguments for and against explanations for describing the different morphologies.
The fact that we often do not see a major difference between the UV and optical morphologies tells us about the geometry of the stars and dust in these starbursts. If there were significant interstellar clouds along the line of sight toward a starburst, then these would introduce strongly wavelength-dependent morphologies. Since we do not see this effect, we conclude that for the most part the structures of these starbursts reflect the localized concentrations of dust and young stars in clumps or relatively thin sheets.

7. EFFECTS FROM DUST

Dust is one of the key components of starburst galaxies at both high and low redshifts (e.g., Calzetti, Kinney, & Storchi-Bergmann 1996; Calzetti 1997, 2000). The presence of dust is a critical aspect of star formation, and it is not surprising that a very significant amount is found associated with it in all environments. Besides absorbing light, dust also re-radiates the bulk of its energy at temperatures around 30–60 K, thermally producing a high far-infrared flux from starburst galaxies, effectively transferring flux from short UV wavelengths to longer far infrared ones. If a starburst (or any object) were to have high UV and FIR fluxes, this could be construed as a potential paradox if we believe that the dust is absorbing a significant amount of the UV light.

An important factor in resolving this apparent paradox is how the dust in starbursts is distributed. The common assumption is that some of the dust is distributed in an inhomogeneous foreground screen, which has been verified by both observations and numerical modeling (e.g., Calzetti, Kinney, & Storchi-Bergmann 1994, 1996; Meurer et al. 1995; Calzetti 1997; Gordon, Calzetti, & Witt 1997). This picket-fence distribution of dust can explain several features of the starbursts in our sample.

Absorption of light by dust will affect the stellar continuum from the UV to the IR, but its impact on morphologies is larger at shorter wavelength images. For our sample we can directly determine the obscuration and dust distributions by examining both the morphology and integrated fluxes of the UV images as compared with the optical. If dust is directly affecting each starbursting region the same way with similar geometries, and if the composition of the dust is the same, then we should expect the wavelength dependence of obscuration for each region to be similar. Any deviations between regions would indicate that the properties of the dust are varying, or more likely that the dust and stars are distributed differently in different star bursting regions. We find that, for the most part, the UV morphologies of the galaxies are almost identical to the optical morphologies. Foreground dust screens are therefore not major absorbers of UV light in most of our sample. Counterexamples are UV-dim H II regions, where dust screens are evidently blocking the UV light.

This however, does not imply that dust is an insignificant component of the SED of these galaxies. We know that dust is present from the high far-infrared fluxes of these galaxies. A more likely explanation is that the dust is either destroyed at locations of intense star formation (Draine & Salpeter 1979; Calzetti et al. 1996) or is being moved to other parts of the galaxy from energy ejecta from stellar winds and supernova (Heckman et al. 1990; Calzetti et al. 1996). The galaxies where we can see distinct patchy dust absorption all show these features away from the areas of the star clusters and H II regions. The dust is probably being removed from the star-forming regions into the more hospitable environments away from the starburst clumps. Dust in areas away from the star clusters allows a starburst to be both a high UV and FIR emitter and have a largely unextincted UV morphology. It is worth mentioning that some of the FIR emission might arise from young clusters completely surrounded in dust and invisible in any of our images. This component would make up only a small fraction of the FIR emission, however, and most of it must be coming from these intercluster regions.

8. UV/IONIZING PHOTON LEAKAGE

A less studied effect on the panchromatic morphology of galaxies than either dust or winds is the effect of Lyman continuum photon leakage from active H II regions. These photons can ionize gas in otherwise quiescent pockets of gas. The leakage of photons from star-forming regions has been documented for several galaxies (e.g., Ferguson et al. 1996). The leakage of photons from H II regions has long been a popular explanation for the significant amount of diffuse ionized gas (DIG) found in nearly all types of galaxies with star formation, including dwarfs (e.g., Hunter, Hawley, & Gallagher 1993; Martin 1998), starbursts (e.g., Calzetti et al. 1999), irregulars (e.g., Hoopes, Walterbos, & Greenwalt 1996; Otte & Dettmar 1999), and late-type spirals (e.g., Wang, Heckman, & Lehnert 1997), as well as the Milky Way (Reynolds 1985).

The study here is not designed or suited to study the diffuse interstellar gas present in these starbursts, except to note that a diffuse component does exist, especially in NGC 4861 and NGC 3690. We are interested in trying to explain an observed H II region without a corresponding UV star cluster by this method of ionization. These H II regions appear roughly symmetrical, but we do not see a corresponding UV star cluster in the region. If ionizing photons were responsible for producing this H II region, they would have to do so in the observed symmetrical pattern, an event that seems unlikely. The diffuse Hα gas detected away from the regions of star formation are probably ionized by photon leakage from UV star clusters. However, we discount photon leakage from neighboring star clusters as a possibility for explaining an H II region without a corresponding UV star cluster. The likely cause is either from dust absorption, or aging effects.

9. KINEMATIC EFFECTS FROM WINDS AND SUPERNOVAS

A very significant physical component to the evolution of any star-forming region, particularly regions with high-mass star formation, are the kinematic effects from stellar winds and SN explosions. As mechanical energy from SNe and strong stellar winds from both OB and WR stars act on the gas in a star-forming region, it will input a certain amount of kinetic energy. This energy will interact with the ISM from which the star form. When this occurs, it is likely that a fraction of the gas surrounding the newly formed stars will be expelled away from the area of star formation. Likewise, the effects of winds and SNe combined to create superwinds can also be responsible for triggering star formation, as in the well-known case of M82 (e.g., Satyapal et al. 1997). While most of our starburst sample seem to be triggered by an interaction or bar instability, the resulting winds maybe partially responsible for the starburst morphology. This would require kinematic data to prove.
We do not claim that any of our sample starbursts are triggered solely by a wind, but the fact that we can see clearly the UV star clusters is due in part to stellar winds and energy ejecta clearing away dust grains. Mass outflows from young stars is an adequate method for removing or destroying the dust near the bright star clusters (Heckman et al. 1990). The morphological signature for a starburst extremely affected by energy ejecta would be a very bright young UV star cluster with no corresponding H II region.

We see this in the case of NGC 3351, which is also the only galaxy in our sample that does not have any tidal features. The other UV star clusters appear similar in the UV and optical, and therefore a significant amount of UV light is not being absorbed. The dust that was originally associated with the young star clusters is being either destroyed or, more likely, based on a high FIR flux, moved to other areas of the starburst where the star formation is more quiescent. This scenario allow the UV star clusters to remain bright in the UV, with the galaxy still emitting a high FIR flux because of the absorption of photons from the intercluster areas. This is confirmed by the measurement of a low temperature for most of the dust in starbursts at around 20–25 K (Calzetti et al. 2000). This low temperature for the dust implies it lies quite far away from the site of the starburst. Dust heavily associated with the starbursting regions would have higher temperatures, $T > 30$ K.

10. SPECTRAL ENERGY DISTRIBUTIONS AND UV MORPHOLOGIES

The spectral energy distribution of a starburst tells us at what wavelengths most of the energy of a starburst is coming from. From Figures 8, 9, and 10 it can be seen that, for all the starbursts in our sample except NGC 4861 and NGC 3991, most of the energy is originating from the far infrared region. This is not surprising since these galaxies are known to be bright in the FIR and to be starburst galaxies. We know from previous work (e.g., Soifer et al. 1989) that the FIR emission from a galaxy is largely due to the dust grains. A simple question to ask is how the UV morphology correlates with the spectral energy distribution of a starburst galaxy.

One of the ways to characterize the FIR flux from dust is to compute a star formation rate based on the 12–100 $\mu$m emission, particularly by using the longer wavelengths. This method assumes that most of the FIR emission from a galaxy is a direct result of energy reradiated by the grains after being heated by UV radiation coming from recently created stars. There are, however, problems with this assumption (Calzetti et al. 1995) that may lead to an imprecise value for the star formation rate.

To answer this we compare spectral energy distribution slopes with morphologies. We define $\alpha$ as the spectral slope

![Fig. 8.—SEDs for NGC 3310 and NGC 3351](image)

![Fig. 9.—SEDs for NGC 3690 and NGC 3991](image)

![Fig. 10.—SEDs for NGC 4861 and NGC 7673](image)
of the UV emission, as measured by the IUE between the wavelengths of 1500 and 2700 Å. We further define ω as the FIR emission slope between 25 and 60 μm. For both of these, the slopes are computed by taking the difference in the luminosities and dividing this by the change in the wavelength. Using these two spectral indexes (see Table 4), we can get an idea of how morphology relates to the spectral energy distribution. The majority of spectral energy distributions. One is the merger/interaction (Table 4). The log of the ratio between the FIR and UV spectral energy distributions. The NGC 3690, which has both a very high FIR slope shows the greatest differences in morphology between different wavelengths. The morphological differences are probably due to dust, as shown in both the SED, and the UV morphology.

Another interesting case is NGC 4861, the only galaxy in our sample that is not a bright IRAS source and is a low-metallicity Magellanic system. This galaxy is also the only galaxy with a negative UV spectral slope. This indicates that FUV photons are escaping the regions of star formation. If this is the case, then compared with the other galaxies in our sample NGC 4861 is less dusty in the sense of having lower UV obscuration optical depths. This would also explain the lack of a significant FIR flux coming from this galaxy. Other galaxies may behave in a similar way, and by knowing the spectral slopes of a galaxy it is possible to begin understanding its morphology.

11. MORPHOLOGICAL FEATURES OF UV BRIGHT STARBURSTS

Our UV-bright sample contain examples of morphological features such as rings and star clumps that can illuminate the star formation process; we briefly discuss these here. For a more detailed discussion of the relationship between ringed UV starbursts and star-forming regions see Maoz et al. (1996). Two of our galaxies, NGC 3310 and NGC 3351, have nuclear ring structures, with NGC 3310 being the more regular and symmetric of the two. Maoz et al. (1996) conclude, as we do for our two ringed starbursts, that these starburst rings are not produced by active nuclei but are from bar instabilities.

The prominent Hz morphology of NGC 3310 relative to the UV morphology (Fig. 2) suggests that the starburst in this ring is very young. It seems likely that such a large configuration, 1 kpc across, could not have formed after this young starburst triggered, because of the timescales involved, but that the starburst has occurred in this ring formation. NGC 3310 is a barred galaxy, as is NGC 3351, and models of star formation predict that bars can drive gas into the inner Lindblad resonance to produce a starburst. The 1 kpc ring in NGC 3310 is the scale size predicted for such a ringed star formation effect (e.g., Athanassoula 1992; Piner, Stone, & Teuben 1995). Previous observations have begun to verify dynamical effects of gas inflows due to bar instabilities (e.g., Regan, Vogel, & Teuben 1997; Reynaud & Downes 1997). In light of its young age and size, it seems likely that the starburst in NGC 3310 was produced by a similar effect. The UV structure of NGC 3310 is also dominated by diffuse light, or unresolved star clusters. This is especially true in comparison to the other galaxies in our sample. The clusters in NGC 3310 have sizes that range in size from 10 pc for the super star clusters down to unresolved clusters that are less than 1 pc. This is a rather large range in cluster sizes and may be a further indication of their youth.

The ring in NGC 3351 is not as symmetric as that in NGC 3310, resembling more a horseshoe than a ring (see Fig. 3). The size of this ring is about 1/4 kpc, with most of the UV light output originating in the star clusters, which have sizes smaller than the clusters in NGC 3310. The largest UV clusters in NGC 3351 are only about 3 pc. The Hz and UV morphologies for the starburst in NGC 3351 also resemble each other, indicating that this starburst is probably older than that in NGC 3310. This starburst was probably also produced by a bar instability.

12. STARBURSTS AT HIGH REDSHIFT

Star-forming galaxies at moderate to high redshifts, such as the compact blue galaxies, or CNELGs (Jangren et al. 2000), and the recently discovered Lyman-break galaxies.
are undergoing star formation and are significant populations at these redshifts (Steidel et al. 1996; Lowenthal et al. 1997).

Nearby starburst galaxies have similar properties to the these distant star-forming galaxies (Gallagher et al. 1989; Cowie et al. 1995; Giavalisco et al. 1996; Hibbard & Vacca 1997; Heckman et al. 1998; Meurer et al. 1999). Although the Lyman-break galaxies are forming stars at a much faster rate than the galaxies in this paper (e.g., Weedman et al. 1998), both types are examples of starburst galaxies in a broad sense and are believed to be similar in terms of both stellar populations and structure. Local and high-redshift starbursts also contain a similar star formation rate per unit area, although the distant galaxies can have total star formation rates up to 10 times as high.

This consensus is based on large-scale characteristics, such as star formation rates, magnitudes, and apparent morphologies, but there may be additional, deeper problems with associating nearby starbursts with high-redshift galaxies, particularly if there are any metallicity differences (see Leitherer 1997). Measurement of the metallicities for these Lyman-break galaxies is still in its infancy, but damped Ly$\alpha$ systems are significantly more metal poor than nearby starbursts (Pettini et al. 1997). Measuring metallicities in distant galaxies is difficult, but some early measurements (e.g., D. de Mello 2000, in preparation) find Lyman-break galaxies with metallicities $\frac{1}{4}$--$\frac{3}{4}$ solar. If there are other physical differences between local and distant starbursts, they can be found by comparing multi-wavelength photometric and spectroscopic features.

In terms of morphology and star formation rates, nearby starburst galaxies are similar to high-redshift galaxies when artificially redshifted (Hibbard & Vacca 1997). The spectral features of starbursts also imply they have similar stellar populations as distant galaxies (e.g., Heckman et al. 1998; Meurer et al. 1999). The high surface brightness and spectrum dominated by early type O and B stars is physical evidence that abundant star formation is occurring in these galaxies. However, it is nearly certain that some properties of high-redshift galaxies differ from nearby starbursts, and these features may have an effect on the star formation process. It is also largely uncertain what the dust content of these high-redshift galaxies are, but methods have been able to estimate it (e.g., Meurer et al. 1999).

Recently a set of high-redshift galaxies that are very bright in the submillimeter and radio wavelengths have been observed (e.g., Barger et al. 1999). These galaxies, most of which were discovered with the Submillimeter Common-User Bolometer Array (SCUBA) array at the James Clerk Maxwell telescope, are referred to as SCUBA sources. These SCUBA sources have spectral energy distributions implying high amounts of rest-frame far-infrared light and possibly very little to no emission in the rest-frame ultraviolet and are very red objects when observed in the near-infrared (Smail et al. 1999). Extreme high-redshift submillimeter sources are therefore probably analogous to nearby ultraluminous infrared galaxies (Meurer et al. 1999), rather than to UV-bright starbursts. However, the classical starburst M82 and our sample have properties that suggest a possible similarity with the submillimeter galaxies. The spectral energy distributions for the galaxies in this paper (Figs. 8, 9, and 10) have distributions indicating high Far-IR flux, as well as bright-UV flux. We have however already discussed how these two can be reconciled. The question remains, however, whether the high-redshift submillimeter sources are a distinct population from the Lyman-break galaxies, or if high-$z$ galaxies can be both bright in the rest-frame UV and in the far-infrared, as are the galaxies in this study. Further optical identifications of submillimeter galaxies at high redshift are necessary before this question can be answered.

Furthermore, because of $k$-corrections, when viewing high-redshift galaxies in optical wavelengths the light being sampled is originating from the rest-frame ultraviolet light. This rest-frame UV flux and morphologies of high-redshift galaxies are being used in a variety of programs that could be biased if the assumptions about the UV light are incorrect or misleading. As shown in this paper, the UV morphology of nearby starbursts is similar to the optical morphology. If high-redshift galaxies have properties similar to nearby UV-bright starbursts, as has been supported by many different observations (Gallagher et al. 1989; Cowie et al. 1995; Giavalisco et al. 1996; Hibbard & Vacca 1997; Heckman et al. 1998; Meurer et al. 1999), then optical images of distant galaxies sampling the UV should be morphologically very similar to their rest-frame optical images. Morphological $k$-corrections are therefore small on large scales, a conclusion supported by HST NICMOS near-infrared observations of the Hubble Deep Field (M. Dickinson et al. 2000, in preparation). Although it can be argued that our sample is too small to establish general trends for all starbursts, it is likely that similar morphological differences will appear in other nearby UV-bright starbursts (see also Dey et al. 1999; Lilly et al. 1999).

13. CONCLUSIONS

By examining the panchromatic morphologies and spectral energy distributions of six nearby UV-bright starburst galaxies we have come to the following major conclusions.

1. The locations of H$\Pi$ regions and bright UV star clusters are generally the same. We interpret exceptions as being dustier, and therefore often younger, H$\Pi$ complexes, or older UV clusters.

2. The UV morphology of starburst regions in starbursting galaxies is on large scales remarkably similar to the morphology in optical bands. This is also true for galaxies at high redshift in the Hubble Deep Field, further evidence that nearby starbursts morphologically resemble high-redshift star-forming galaxies.

3. The dust creating the high far-infrared flux for our sample is not in general obscuring the bright UV star clusters but must exist in other more hospitable areas of the host galaxy, allowing these starbursts to be bright in both the UV and FIR. However, different mechanisms may be occurring in more dust-obscured UV dim galaxies, such as the ultraluminous infrared galaxies.

4. The spectral energy distributions slopes of starbursts can indicate morphology in the sense that large FIR slopes correlate with disturbed morphologies affected by dust. Likewise, negative UV slopes reveal small amounts of dust.

We are pleased to thank the crew at WIYN for the excellent operation of the telescope during our programs and Stephan Jansen for his continuing support of astronomical
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