1. Introduction

Low-mass spiral galaxies exist within the luminosity range $0.1L^*-0.01L^*$, between the standard giant spirals and the typical dwarf irregulars. These objects have morphological types of Sc-Sdm, are reasonably organized, sometimes have thin stellar disks, display modest spiral structure, and often contain large amounts of HI gas (e.g., Matthews & Gallagher 1997). Under normal conditions their star formation rates tend to be low, but their substantial gas contents make them excellent hosts for starbursts.

In this paper we first consider quiescent star formation in low-mass spiral galaxies as observed in nearby, dynamically cool ‘superthin’ disk galaxies. We then turn to properties of high surface brightness, blue starbursts, which frequently occur in small disk systems, and may be an important contributor to the large populations of faint blue galaxies found at moderate redshifts.

2. Star Formation in Slowly Evolving Galactic Disks

2.1. Basic Characteristics

The low mass Sd spirals include excellent examples of pure disk galaxies; galaxies which show no evidence for a stellar spheroid. Observationally we most readily identify such galaxies when they are seen near edge-on, allowing us to judge the thickness of the stellar disk. Some low-mass spirals have thin stellar disks—i.e., they are superthin galaxies with little or no stellar halo, and large ratios of radial to vertical disk scale lengths (Gallagher & Hudson 1976, Goad & Roberts 1981,
Matthews et al. 1999, Dalcanton & Bernstein 2000, Matthews 2000). These objects are also rich in HI gas, and may have low metal abundances (Bergvall & Rönnback 1995, Giovanelli et al. 1997, Matthews & van Driel 2000). Figure 1 compares WIYN Telescope R-band and Hα images of UGC 7321, an outstanding example of a superthin disk.

This class of galaxy is of special interest since they would appear to have been assembled from objects containing only gas, and therefore experienced only minimal star formation before their disks were fully formed. Such galaxies are difficult to make in standard cold dark matter (CDM) scenarios (Gnedin et al. 2000, Wyse 2000). The presence of a thin stellar disk further indicates that little dynamical heating occurred over most of the lifetime of the disk, while the presence of large gas content demonstrates that in a global sense star formation has been inefficient (Matthews 2000). Low-mass Sd spirals are thus the least evolved examples of well-organized disk galaxies in the nearby universe.

### 2.2. Star Formation Patterns in UGC 7321

Figure 1 shows the overall pattern of star formation in UGC 7321 as traced by its HII regions. These extend over almost the entire optically visible disk, but are most frequent and brightest in the central regions of the galaxy. Further insight into products of recent star formation and the state of the ISM come from high angular resolution HST WFPC2 images. As seen in Figure 2, the central region of UGC 7321 looks like a normal galactic disk. While there is no continuous dust lane, dusty dark clouds are obvious and suggestive of the presence of molecular gas, a view that is supported by the detection of molecular CO 1-0 emission by Matthews & Gao (2001). The HST images also reveal distinct clusters and associations of luminous stars in the inner parts of this galaxy.

The outer parts of the UGC 7321 exhibit somewhat different characteristics (Figure 2). Dark nebulae are larger and have lower contrast, while the distribu-
tion of luminous stars becomes more diffuse. Possibly two modes of star formation exist within the same galaxy. At radii of <2 kpc, star formation appears to occur in a normal cycle of well-defined clouds embedded within a stellar disk. In this region we could be seeing self-regulated star formation, where energy supplied by massive stars limits the overall density of the gaseous disk. Further out, where the scale height of the gaseous component becomes comparable to that of the stars, we are probably observing an internally supported gas disk (e.g., by turbulence; Elmegreen & Parravano 1994), where star formation could be playing less of a role in the vertical support of the ISM. The slow evolution of the outer parts of this galaxy then is a natural result of inefficient star formation in a diffuse gaseous disk (see Gallagher et al. 2001 for details).

Gallagher et al. (2001) also estimate a star formation rate from the number of dark clouds to be $\psi = 10^{-1.5 \pm 0.5} \, M_\odot \, \text{yr}^{-1}$. For a stellar mass of $2 \times 10^9 \, M_\odot$ the Roberts time to form the existing mass of stars is roughly a Hubble time. UGC 7321 is most likely an example of a slowly evolving galaxy rather than a young galaxy, a model that also is supported by the complex vertical structure of its stellar disk (Matthews 2000).

3. Interactions and Starbursts in Small Disks

3.1. The Basics

In the transition region between giant spirals and star-forming dwarfs we find galaxies with a variety of structures, including the Magellanic irregulars with their thick stellar disks and frequently asymmetric structures, as well as dwarf S0 systems where star disk star formation appears to be winding down. Yet in other ways, such as peak rotation velocities, these galaxies appear to be similar types of objects. A natural suggestion then is that interactions join with
initial conditions in determining the structures of the current populations of intermediate luminosity disk (and possibly dwarf E; Mayer et al. 2001) galaxies.

To test this hypothesis we consider observational signatures of interactions and of any possibly associated starbursts:

♦ **Interactions** between galaxies directly perturb the outer regions of the systems which collide, and may yield wide-spread changes in cases where mergers occur. After-effects may include an increase in disk vertical scale height, shell or ripple structures, or tidal tails (Schweizer & Seitzer 1988, Howard et al. 1993, Velázquez & White 1999). Even a distant collision can suffice to drive gas inwards thereby triggering a starburst (e.g., Mihos & Hernquist 1994, Barton et al. 2000).

♥ **Starbursts** occur when there is a major (factor of $\sim 10$) and unsustainable increase in a galaxy’s star formation rate. Ongoing starbursts are obvious from the signatures of their huge populations of high mass stars, including strong emission lines, large scale gas outflows, and high power outputs per unit baryonic mass. Products of starbursts include compact super star clusters which may be long-lived.

### 3.2. Starbursts in Small Disk Galaxies

In the nearby Universe, small galaxies host high surface brightness, compact starbursts. That these starbursts reside in disk galaxies can be established from the kinematics and presence of spirals arms and other kinematic features associated with dynamically cool stellar populations (e.g., NGC 3310: Mulder et al. 1995; NGC 7673: Homeier & Gallagher 1999). This class of starburst also includes the nearby archetype M82, where due to its highly inclined orientation the disky structure of the system is obvious while much of the starburst is hidden from optical view.

Preliminary results from a small survey of nearby compact starburst galaxies include evidence for starburst triggering through interactions; e.g., structural or kinematic features that suggest a minor merger or recent interaction or the presence of obviously disturbed companions. In these systems it often appears that a relatively minor perturbation has led to large scale starbursts. Furthermore, the starbursts sometimes persist well after the interaction is past; e.g., in NGC 7673.

A complete picture of the conditions leading to compact starbursts is not yet in hand. However, it has been known for some time that these systems frequently contain large amounts of HI (Smoker et al. 2000); we suspect their gas-rich nature is a key factor in their susceptibility to starbursts. Our model is that compact starbursts take place in gassy disks that were on the margins of stability before they were perturbed (e.g., galaxies like UGC 7321). The external perturbation then drives gas inwards, either directly or via the production of bars or spiral arms, thereby fueling the starburst (e.g., Noguchi 1988).

The presence of large amounts of gas also provides a basis for understanding the large scale clumpy patterns of star formation which are frequently seen in this class of starburst. As emphasized by Elmegreen & Efremov (1997) and Noguchi (1999), a disturbed, gas-rich disk will be unstable and tend to break up into large bound clumps, which we may see as huge regions of star formation. Our high angular resolution observations with HST of NGC 7673, for example,
reveal that the clumps often are associations of dense star clusters embedded in backgrounds consisting of luminous massive stars (see also de Grijs et al. 2001). Evidently in these circumstances the star forming hierarchy has gone one level beyond that found in OB associations with dense star clusters paralleling the role of the most massive stars under more normal circumstances.

3.3. The Initial Mass Function

In most astrophysical environments where the stellar mass function can be constrained, it appears to be relatively normal. A similar initial mass function (IMF) appears to hold from low density dwarf spheroidal galaxies to dense star clusters, such as R136a. However, as the locations and conditions of star formation become more extreme, might the IMF change?

One well studied case is that of M82, where some data suggested a deficiency of low mass stars within the starburst, while later work implied a relatively normal IMF. In the latest round of this saga, Smith and Gallagher (2001) find the dense super star cluster M82-F appears to be \( \sim 7 \) times more luminous than predicted for a model of its age with a Salpter IMF. Evidently this object currently lacks the usual population of low mass stars, a situation that also seems to occur in the Galactic center Arches star cluster.

Even if IMF peculiarities in starbursts were limited to only some super star clusters, they could have important observational consequences. For example, the clusters would then be over-luminous for their mass and boost the intensity of a starburst for a fixed astration rate. This would also imply short lifetimes for the super star clusters as bound objects. As a result, much of the evidence of a starburst could dissolve in only a few Gyr.

3.4. Starbursts, Tully-Fisher Relation, & Global Properties

M82 provides a useful example of the relationship between starbursts and global properties of galaxies. Figure 3 shows an observed Tully-Fisher (TF) diagram, including the approximate location of M82. We have made no correction for internal absorption and so the K-band luminosity of M82 is a lower limit. As expected, M82 lies well above the standard Tully-Fisher correlation, but as it is involved in a short-lived starburst, galaxies in this state should be rare.

It is then interesting to ask how M82 will evolve on this diagram? Note that if M82 were on the correlation before its starburst and its velocity width does not change during the starburst, then the postburst galaxy, that must be more luminous than the pre-burst system, will lie above the TF relationship mean. This presents a problem; post-burst galaxies should be neither obviously peculiar (and thus excluded from normal galaxy TF samples) nor particularly rare. Yet there is little evidence for an asymmetric upwards scatter in the TF diagram that would result from postburst versions of M82.

How can this be? The problem mainly occurs if the velocity width for a galaxy like M82 does not change during a starburst cycle. For example, if starbursts increase both the luminosity and rotation velocity, then galaxies would move up roughly along the mean TF relationship after a starburst. Large deviations would occur only when the stellar luminosity was high, near the peak of a burst, as in M82. This process, shown schematically in Figure 3, is similar to the requirements set by theoretical models of galaxy formation (cf. Steinmetz
Figure 3. Infrared Tully-Fisher relationship showing the estimated location of M82 (filled circle) as compared with galaxies from the Verheijen (1997) Ursa Majoris "normal spiral" sample. The K magnitude for M82 is from Ichikawa et al. 1995, and the dashed line shows an evolutionary path for M82 that would allow it to remain on the TF relationship in its pre- and post-starburst phases.

& Navarro 1999, van den Bosch 2000). We should be able to test this type of model in the rich populations of small disk galaxies in the Local Supercluster, which include objects covering the full range of starburst evolutionary cycles.

4. Conclusions

Low-mass spiral galaxies with similar global properties, such as rotation speeds, sizes, or HI masses, can be found with star formation rates extending from \( \lesssim 0.1 \) to \( \gtrsim 1 \, M_{\odot} \, yr^{-1} \). The range in levels of star formation activity within these galaxies covers an even wider span. We observe examples of minimal star formation rates in the outer disks of some superthin Sd systems, where the gas disks probably are largely self-supported, and normal, feedback-dominated star formation in their central regions.

At the other extreme, low-mass disks tend to be gas-rich and thus are prime targets for starbursts. When in this runaway mode of making new stars, large star forming 'clumps' are common features, possibly resulting from the
presence of huge, gravitationally bound gas complexes within their disks. The star-forming clumps are prime locations for the formation of super star clusters, which in turn could have unusual properties, such as top-heavy IMFs.

Most starbursts in low-mass disks are associated with some form of collisional perturbation, which is likely to modify the mass distribution within the starbursting system. Some form of dissipation to concentrate mass within the optical galaxy seems to be essential to preserve the Tully-Fisher relationship for postburst galaxies. Interactions may also play a role in converting low-mass disk galaxies from slowly evolving systems with superthin disks into more ragged and more active forms of late-type galaxies, such as the Magellanic irregulars.

Acknowledgments. We thank NASA for support of much of this work through funding associated with various Hubble Space Telescope projects. JSG also acknowledges partial funding for this research by the National Science Foundation grant AST-9803018 to the University of Wisconsin and by the Vilas Trustees through the University of Wisconsin Graduate School. LDM thanks the National Radio Astronomy Observatory for her Jansky Postdoctoral Fellowship.

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