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Structure and Evolution of Nearby UV-bright Starburst Galaxies

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Abstract. Nearby ($D \leq 100$ Mpc) luminous blue starburst galaxies frequently show morphological evidence for recent involvement in mild collisions, or minor mergers where the disk survives. As a consequence UV-bright starbursts are preferentially seen in near face-on galaxies, and the postburst systems may become star-forming late-type galaxies. If this starburst evolutionary channel is important at moderate redshifts, then descendants of the faint blue galaxies could be the very common Sm-Sd field galaxies.

1. Objectives

Starburst galaxies provide unique opportunities to study rapid phases of galactic evolution. The Wisconsin starburst project focuses on nearby ultraviolet-bright starbursts selected from the spectrophotometric sample of Gallagher et al. (1989). They resemble intermediate redshift ($z \approx 0.5-1$) “compact narrow emission line galaxies” (CNELGs, e.g. Guzman et al. 1998) in terms of their small sizes, blue luminosities, and [OII] emission line equivalent widths; e.g., $M_B < -18$, and $EW([OII]) > 25 \text{ \AA}$ with $U - B < -0.2$.

Our strategy is based on the analysis of multi-band imaging and area spectroscopy obtained with the WIYN 3.5-m telescope¹ and high angular resolution WFPC2 and FOC *HST* images. Images provide global morphologies, colors, and the small scale structures of star-forming sites. Spectra from the WIYN Densepak multi-fiber array are used to measure global velocity fields in the ionized gas (eg., Homeier & Gallagher 1999; HG99).

2. Interactions and Starbursts

Interactions are well-established starburst triggers. Because of the huge range of possible interaction parameters, we expect and observe considerable variance in the responses of galaxies to interactions. Our emphasis is on weak interactions,

¹The WIYN Observatory is a joint facility of the University of Wisconsin-Madison, Indiana University, Yale University, and the National Optical Astronomy Observatories.

such as minor mergers, or mild collisions, in which at least one member of the colliding pair survives with its initial structure relatively intact.

The signatures of recent galaxy interactions are well-known, and in the optical include: luminous tails of tidal debris, or ripples in post-interaction systems. These features often have low surface brightnesses and/or small angular sizes; imaging with telescopes like WIYN, that combine excellent surface brightness sensitivity with good angular resolution (0.7 arcsec seeing), is valuable for determining the structures of these types of systems. The signposts of interactions evolve on galaxy orbital time scales of $\sim 10^8$ yr with infall of tidal debris possibly continuing for $\sim 10^9$ yr; after this, evidence of a collision will be difficult to detect.

Starbursts are found from their prominent populations of high mass stars, which are the products of upward spikes in star formation rates. This is obvious when the starburst is optically visible, and gives rise to high surface brightnesses, blue optical colors, and strong emission lines. Starbursts also produce supergiant HII complexes, massive and compact “super star clusters”, and the peculiar kpc-scale “clumps” of OB stars, whose existence was emphasized more than 20 years ago by J. Heidmann and collaborators as symptoms of ‘hyperactive star formation’. While the evolutionary time scales of individual star-forming complexes within starbursts are not well known, data from M82 suggest this occurs in less than 10^8 yr (Satyapal et al. 1997; Gallagher & Smith 1999). The internal structure of a starburst evolves more quickly than structural perturbations induced by the dynamical influence of a colliding galaxy.

3. Four Examples of Luminous Blue Starbursts

The optical structures of four luminous starbursts within 100 Mpc provide some examples of star formation produced in a variety of collisions:

Markarian 8 is a strongly interacting system (Figure 1). It apparently consists of two small disk galaxies. Our WFPC2 images show one of these to be strongly disturbed, while the other remains an organized, coplanar system (Gallagher et al. 2000). Both objects have high inclinations, but the system still has blue colors and strong [OII] emission.

Haro 1, a nearly face-on galaxy, can be seen in Figure 2 to be experiencing a weak interaction with a dwarf companion. Even though only mild optical distortions are present in Haro 1, it is in a late phase of an intense starburst (the integrated spectrum shows strong Balmer absorptions).

NGC 3310 is one of the nearest examples of a luminous UV-bright starburst and has been extensively studied in the optical and IR and mapped in HI. The starburst probably was caused by a minor merger (Mulder et al. 1995, Conselice et al. 2000). Large scale organization of star formation in NGC 3310 is located in a nearly symmetric two-arm spiral pattern, and around a mildly distorted circum-nuclear ring, as shown in the color map in Figure 2. Evidently a strong starburst was initiated with little collisional disruption to the surviving gas-rich disk galaxy, seen at low inclination.

NGC 7673, an archetypical ‘clumpy irregular’, has a highly disturbed inner structure dominated by four huge star-forming complexes (Figure 2). WFPC2 optical and UV imaging resolve the clumps into clusters of compact star clusters,

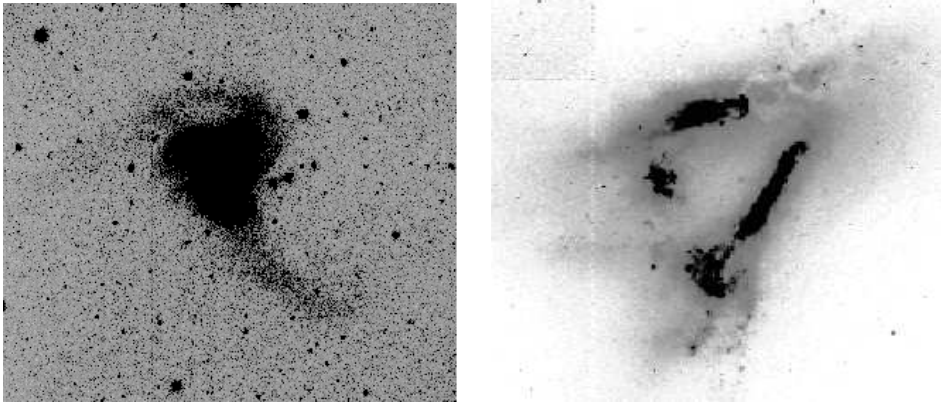


Figure 1. The Markarian 8 pair of colliding galaxies. View of the tidal tails from a WIYN R-band image (left) and high resolution image of the center from WFPC2.

similar to conditions in M82 (O’Connell et al. 1995). The clumps are located within a faint, relatively symmetric outer disk that also contains a faint stellar arc, or ripple (HG99). This starburst is a remnant of a past interaction with NGC 7678 (Nordgren et al. 1997), or a minor merger.

HG99 measured the $H\alpha$ velocity field of NGC 7673 with WIYN using the Densepak array. They found that the inner part of the galaxy is almost exactly face-on and dynamically cold. The wings of the line are broadened; most likely by gas outflows from the disk, and the integrated $H\alpha$ line profile closely resembles those observed in CNELGs by Guzman et al. (1996). However, in this case we know that we are *not* seeing a spheroidal system in formation, but rather a nearly face-on disk.

4. Summary of Observed Properties

Our data demonstrate the production of intense starbursts in weak interactions in which at least one of the original disks survives. One channel for the production of compact luminous galaxies therefore modifies rather than destroys stellar disks, and some post-starburst systems will be small disk galaxies.

Disk geometries introduce a prejudice for optically- or UV- bright starbursts to be seen at low inclinations where disk obscuration is minimized. M82 is a nearby example; from our perspective it is an IR-starburst, but the brilliant UV reflection nebula seen above the disk in FOCAS images imply that when seen at low inclination, M82 is a UV-bright starburst. This is a statistical trend; some galaxies, such as Markarian 8 or chain galaxies at moderate redshifts, are blue and inclined. A bias to select blue starbursts in low inclination disks will also lead to narrow velocity line widths in integrated optical spectra; these are not necessarily signatures of low mass dwarf galaxies.

Our data do not show a simple relationship between the stage of an interaction and starburst properties; intense starbursts occur in both the ongoing Markarian 8 and very late NGC 7673 interactions. This complicates our ability to distinguish collisionally induced starbursts, since the clear signatures of an

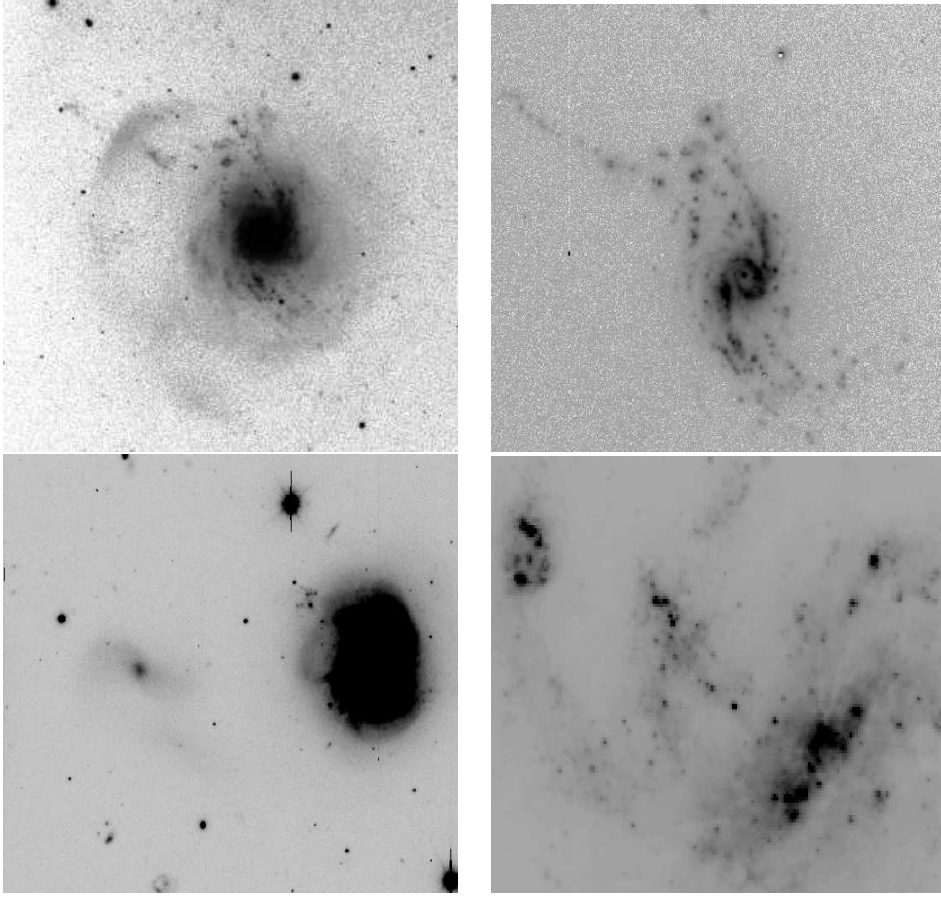


Figure 2. NGC 3310 WIYN R-band image (upper left), showing outer disk ripples and the ‘bow and arrow’, left above the galaxy. The WIYN image in $H\alpha + [NII]$ emission lines (upper right) displays the nuclear ring and star formation along the spiral arms and arrow. A WIYN R-band view of Haro 1 (burned out) and its distorted dwarf companion is in the lower left. A WFPC2 F555W image of NGC 7673 showing resolved giant star-forming clumps (lower right).

ongoing interaction may not be present during the peak starburst phase. This problem is especially severe when dealing with faint blue galaxies at moderate redshifts, where information is often sparse (Ellis 1997).

5. Discussion

A simple model assumes that luminous blue starbursts take place in gas-rich late-type disk galaxies that remain as disks after the event. Many nearby starbursts are rich in HI and have the fuel to support post-burst star-formation. These types of post-burst objects would be less easily distinguished than extreme cases where star formation is truncated after a burst, giving rise to distinctive ‘E + A’ spectra. The ingredients of our simple recipe for luminous starbursts follows:

1. Store gas in a dynamically cold, low density disk. Such disks are excellent storage places to keep gas as they have low intrinsic rates of evolution, and populations of such thin, cold disk galaxies exist at the current epoch (Matthews et al. 2000).

2. Perturb the disk with an interaction; a merger with a galaxy having 10% or less of the total mass, or even a near miss from a comparable or larger neighbor should suffice. What we require is that gas be driven to the central few kpc of the disk where it can support intense star formation. Gas transport can be produced directly by the perturber, or indirectly through production of a bar.

3. Orient galaxy to be nearly face-on and observe a blue, UV-bright starburst with narrow emission lines. Otherwise, observe an edge-on system to see an M82-type moderately-luminous IR-starburst.

4. Wait a few Gyr until done. The result may be a late-type system with a moderately thick stellar disk, a product of collisional disk heating during the interaction (Reshetnikov & Combes 1997). The interaction also could produce an off-center bar, yielding a Magellanic irregular. This channel for making Magellanic systems is observationally suggested by the preference for such galaxies to have companions (Odewahn 1994) and theoretical models that produce characteristic off-center bars during collisions (Levine & Sparke 1998).

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