DYNAMICAL CONSTRAINTS ON MASSIVE STAR FORMATION

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ABSTRACT. Extragalactic HII regions and their ionizing star clusters are the most prominent signposts of recent starbirth activity in galaxies. In this paper, we present optical measurements of nearby extragalactic HII regions with the aim of investigating possible relationships between the newborn ionizing clusters and their dynamical environment. Evidence for variations in the measured HII region properties (size, Hα luminosity, and Hα equivalent width) are presented as a function of galaxy type and of position within individual galaxies. These variations, in turn, are compared with the corresponding kinematic and dynamical variations. The apparent sensitivity of the ionizing activity to the dynamical environment suggests that the total masses and upper stellar mass limits of the ionizing clusters are somehow constrained by the ambient tidal stresses and shear flows within the galaxies. We speculate that regions of high tidal stress and kinematic shearing tend to suppress the formation and maintenance of giant molecular clouds, thereby hindering the creation of giant clusters and massive stars therein.

1. Introduction

Given the topic of this symposium, there is bound to be much discussion regarding the dynamical orchestration of giant cloud growth in gas-rich galaxies. Such coherent forcing of the cold gaseous phases (HI & H_2) can lead to luminous starbirth activity along spiral arms and to the even more intense starburst activity that is evident in the centers of some galaxies. In this paper, we touch on the *flip-side* of the dynamical coin — namely, the dynamical *suppression* and *disruption* of giant cloud formation, leading to fewer high-mass clouds... and by statistical inference, fewer high-mass star clusters formed inside the clouds... and again by statistical inference, fewer high-mass stars formed inside the clusters. We can only touch on this idea of *dynamical constraints* on cloud/cluster/star formation, because very little is currently known about molecular cloud properties as a function of galaxian environment. However, we can present some observations that seem to indicate the presence of dynamical constraints on *ionizing* cluster formation and on high-mass star formation within the clusters.

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2. Observational Evidence

A casual inspection of Hα images reveal that early-type galaxies do not contain the giant HII regions and HII region complexes that characterize many Sc and Irregular-type galaxies (Hodge and Kennicutt 1983). This is borne out by a comparison of the Hα luminosity functions: The early types are proportionately poorer in the higher luminosity HII regions, leading to a steepening of their luminosity functions (Kennicutt, Edgar, and Hodge 1989). Moreover, the brightest HII regions in early-type galaxies are a factor of ten less luminous than their later-type counterparts – after normalization to a common galaxy luminosity (Kennicutt 1988; Smith and Kennicutt 1989). These effects are summarized in Table 1.

TABLE 1. HII Regions and Associated Kinematics in Galaxies

Galaxy Type	Sa - Sb	Sbc - Sc	Sm - Irr
	HII Region Properties[a]		
$\langle \log L(H\alpha) \rangle_3^b$ (erg s^{-1})	38.5	39.5	40.2
$\langle \log \text{Diameter} \rangle_3^b$	2.5	2.9	2.9
<Slope of Lum. Fn.>	−2.4	−2.0	−1.8
<N(HII)/L(B)>	25	175	240
	Associated Kinematics[c]		
<max V(rot)> (km s^{-1})	304	230	80

[a]Kennicutt 1988: Smith and Kennicutt 1989.

[b]Refers to an average of the 3 brightest HII regions in each galaxy, after normalization to a common "Galactic" luminosity of $M_v = -20.2$.

[c]Rubin *et al.* 1978; Brosche 1971.

Steeper luminosity functions are also evident outside of spiral arms (Kennicutt, Edgar, and Hodge 1989) and – at least in the case of M101 – near the galaxy's central bulge (Waller 1990). This latter effect is illustrated in Figure 1.

The Hα equivalent widths of the ionizing clusters in M101 also decrease near the central bulge (see Figure 2). Selection, obscuration, and evolution effects seem unable to account for this behavior. The lower equivalent widths are more likely due to a significant decrease in the initial upper stellar mass limits of the ionizing clusters. A simple model yields $EW(H\alpha) \propto M_u^{1.1\pm0.3}$ and thus a corresponding decrease in $< M_u >$ by a factor of about 1.5 (Waller 1990).

The measurable changes in $EW(H\alpha)$ seem restricted to the inner 5 kpc of M101, whereas the O/H abundance ratio decreases *monotonically* by ~1 dex from 2 to 17 kpc. The dissimilarity in form between these two galactocentric distributions weakens previous arguments for abundance-sensitive initial mass functions (IMFs). Closer similarities in form can be found between the galactocentric distribution of Hα equivalent widths and the galactocentric profile of differential rotation in the disk. The sense is to have lower equivalent widths, where the differential rotation (and associated shear and tidal stress) is more pronounced.

3. Possible Dynamical Constraints

The observed variations in Hα size, luminosity, and equivalent width appear to scale with both galaxy type and galactocentric radius. We propose that the central bulges of galaxies may be affecting the growth of ionizing stellar populations in the galaxian disks by driving the differential rotation $d\Omega/dR$ and consequent levels of shearing and tidal stress.

Massive bulges produce high $d\Omega/dR$ that scale as v_{max}/R^2 for galaxies with nearly flat rotation curves. The resulting shear rate is

$$A = -(R/2)d\Omega/dR \approx v_{max}/2R \quad (km\ s^{-1}\ kpc^{-1}). \tag{1}$$

The tidal acceleration shows a similar dependence on v_{max} and R, with

$$T = -(2v)d\Omega/dR \approx 2\ v_{max}^2/R^2 \quad (km^2\ s^{-2}\ kpc^{-2}). \tag{2}$$

Even Toomre's 'Q parameter' for kinematic vs. gravitational instability follows suit, with

$$Q = c\kappa/\pi\sigma G \approx \sqrt{2}\ c\ v_{max}/\pi\sigma G R. \tag{3}$$

All of these parameterizations of dynamical disruption are most effective at small galactocentric radii and in galaxies with fast rotation speeds, *ie.* early-type galaxies (see Table 1).

Given the basic disk dynamics, as outlined above, we speculate that the high shear rates and tidal stresses in bulge-dominated environments suppress the formation and sustenance of giant molecular clouds (*cf.* Stark and Blitz 1978; Blitz and Glassgold 1982; Elmegreen 1987a, 1987b, 1987c), thereby hindering the creation of giant ionizing clusters (Waller *et al.* 1987; Scoville *et al.* 1987). The smaller clusters, in turn, are unable to fully populate their upper stellar mass limits, thus explaining the lower Hα luminosities *and* Hα equivalent widths that are observed in the central 5 kpc of M101 (Waller 1990). By creating regions of relatively low shear, spiral density wave fronts may represent dynamical "sanctuaries," where giant clouds can grow and ultimately spawn giant ionizing clusters (*cf.* Elmegreen 1987a, 1987b, 1987c). In the slowly rotating irregular galaxies, shear rates and tidal stresses are low, and massive cloud/cluster/star formation can proceed without the need for spiral waves.

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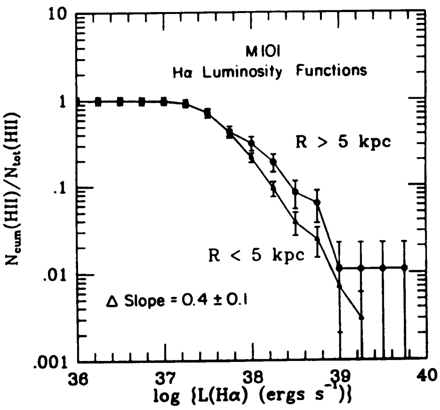

Figure 1.

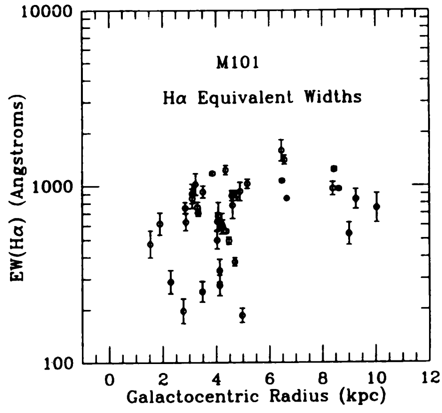

Figure 2.

4. References

Blitz, L. and Glassgold, A. E. 1982, *Ap. J.*, **252**, 481.

Brosche, P. 1971, *Astr. Ap.*, **13**, 293.

Elmegreen, B. G. 1987a, *Ap. J.*, **312**, 626.

Elmegreen, B. G. 1987b, in *Physical Processes in Interstellar Clouds*, eds. G. E. Morfill and M. Scholer (Dordrecht: Reidel), p. 1.

Elmegreen, B. G. 1987c, in *Comets to Cosmology*, ed. A. Lawrence (Berlin: Springer-Verlag), p. 186.

Hodge, P. W. and Kennicutt, R. C. 1983, *A. J.*, **88**, 296.

Kennicutt, R. C. Jr. 1988, *Ap. J.*, **334**, 144.

Kennicutt, R. C. Jr., Edgar, K. B., and Hodge, P. W. 1989, *Ap. J.*, **337**, 761.

Rubin, V. C., Ford, W. K. Jr., and Thonnard, N. 1978, *Ap. J. (Letters)*, **225**, L107.

Scoville, N. Z., Yun, M. J., Clemens, D. P., Sanders, D. B., and Waller, W. H. 1987, *Ap. J. Suppl.*, **63**, 821.

Smith, T. R. and Kennicutt, R. C. Jr. 1989, *Pub. A. S. P.*, **101**, 649.

Stark, A. A. and Blitz, L. 1978, *Ap. J. (Letters)*, **225**, L15.

Waller, W. H., Clemens, D. P., Sanders, D. B., and Scoville, N. Z. 1987, *Ap. J.*, **314**, 397.

Waller, W. H. 1990, *Recent Starbirth and Starburst Activity in Nearby Galaxies*, Ph.D. Dissertation, University of Massachusetts.