SUPERASSOCIATIONS IN THE ARMS OF NORMAL AND ACTIVE GALAXIES

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ABSTRACT. The properties of violent star formation regions in the arms of spiral galaxies are reviewed with the aim of providing the foundations on which models of nuclear starbursts can be built. It is argued that the classical examples of extranuclear starbursts, giant HII regions and Superassociations, are closely related but fundamentally different classes of objects; their properties are reviewed and discussed in detail.

It is shown that giant HII regions are a homogeneous class of gravitationally bound objects ionized by starburst clusters and that the initial mass functions of these clusters change according to their chemical composition being flatter for metal poor systems. Superassociations are loose associations of associations which generally contain one or more giant HII regions. Star formation in superassociations is self-sustaining and therefore these structures may last much longer than individual giant HII regions.

Isolated superassociations or HII galaxies are shown to have the same global properties as giant HII regions in late type galaxies. In particular, the correlations between Hβ luminosity and emission line velocity width are similar for both classes. Since HII galaxies can be observed out to large distances this correlation provides a potentially powerful method to calibrate the extragalactic distance scale. A preliminary calibration gives $H_o = 95 \pm 9$ km/sec/Mpc.

The relations between the properties of giant HII regions and Superassociations with those of their parent galaxies are briefly discussed.

1. INTRODUCTION

Many of the properties of the nuclei of active spiral galaxies can be understood in terms of intense star formation activity or STARBURSTS (see Terlevich and Melnick, 1985 for a review and references). The aim

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of my talk here is to review what is known about extranuclear starbursts in spiral galaxies in order to provide a reference frame to which the observations of nuclear starbursts can be compared and modelled. I think that this was what the organizers had in mind when they asked me to present this review.

I will, therefore, limit the scope of the talk to a discussion of the properties of the largest star forming complexes in spiral arms which are the best studied examples of massive bursts of star formation. The properties of nuclear starbursts and their relevance to nuclear activity will be reviewed by Roberto Terlevich. I will also say only a few things about the so-called "Isolated Superassociations", which are extremely large starbursts in very small galaxies, as this subject is reviewed in detail by Danielle Alloin in this conference.

2. SUPERASSOCIATIONS IN NEARBY GALAXIES

2.1. The Byurakan Definition of Superassociations

The concept of "Superassociations" was introduced here in Byurakan by Ambartsumian and co-workers (1963) who considered it important to describe the brightest stellar complexes in late type galaxies. The importance of these objects has since been largely demonstrated by numerous observational studies which show that the largest star forming complexes in late type galaxies contribute substantial fractions of their total ultraviolet, far infrared and radio continuum luminosities (Rosa, 1986).

The original definition called Superassociations (SAs) condensations brighter than about -14.0 in absolute magnitude and with diameters of order 500 parsecs. The threshold luminosity for Superassociations is in principle arbitrary (Shakhbazyan, 1968) and was apparently chosen by Ambartsumian and his colleagues using the 30 Doradus complex as a template. It is clearly possible for galaxies of morphological types different from the host of 30 Dor (LMC, Irr) or in different environments to have smaller (or larger) SAs. It is therefore of importance to establish if the properties of condensations in late type galaxies change when they become larger or brighter than a certain threshold as well as the relation of this limit to the galaxies' mass and location (Shakhbazyan, 1968). Petrosyan and co-workers (1983) have been studying the properties of condensations selected only on the basis of morphology. Until they statistically find at what level the properties of these condensations "jump", Petrosyan et al. have defined as Superassociations all condensations brighter than $M_{pg} = -11$. At this level, their sample includes both SAs as originally defined by Ambartsumian and co-workers as well as giant HII regions (GHRs). Thus, it is becoming customary in the USSR and here in Byurakan in particular to refer to giant HII regions as Superassociations. I think, however, that, although the two are closely related, they are different and should not be mixed. I will present below the detailed study of a sample of GHRs on which this

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conclusion is based but clearly the final answer must come from statistical studies such as those now in progress in Byurakan and the work of Wray and de Vaucouleurs (1980).

2.2. The 30 Doradus Superassociation

The "inspiring" object of the paper by Ambartsumian et al. (1963) was the 30 Doradus complex as described by Shapley and Paraskevopoulos (1937). Still today, 30 Dor is the only SA (and giant HII region because it contains one) that can be studied in detail from ground based observatories. I would like to present a summary of the most relevant properties of the 30 Dor complex because I want to use 30 Dor as the prototype of this class of condensations.

Figure 1 presents a negative print of an ESO Schmidt plate exposed to ultraviolet (U) light. The profusion of young stellar associations and HII regions which pervade the region is very nicely appreciated in this photograph. The most prominent structure in the region (and indeed in the whole LMC) is the giant HII region called the Tarantula which I will discuss in detail below.

The whole complex is teeming with star formation activity as evidenced by the presence not only of numerous young OB associations (Lucke and Hodge (1970) have catalogued about 20 young OB associations and clusters in this area for which Lucke (1974) derives ages ranging from 3 to 10 Myrs) and high excitation HII regions but also of a large concentration of Wolf-Rayet (WR) and other emission line stars, large numbers of supergiants (Lortet and Testor, 1984 and references therein), and several supernova remnants (Mathewson et al., 1983). The 30 Doradus complex is a gigantic association of associations so the concept of superassociation appears very adequate for describing not only its large physical size and luminosity but also this hierarchical structure.

I would now like to briefly describe the principal components of the complex.

2.2.1. The Tarantula nebula. This giant HII region, generally known as the 30 Doradus nebula, extends more than 250 pc in diameter and is ionized by a young massive cluster which contains several hundred O stars and several remarkable stars. It has become customary to refer to this cluster as NGC 2070 although the original NGC designation refers to the nebula.

NGC 2070 is the youngest "blue populous cluster" in the LMC with an age of about 2-3 $\times 10^6$ years (Melnick, 1986). Figure 2a presents a short exposure photograph of the central region of the nebula where the cluster can be clearly seen. The bright, partially resolved, object in the centre is the cluster core (R136) at one time thought to contain a supermassive object. Although speckle observations have shown no supermassive stars in R136 (Weigelt and Baier, 1985), the cluster contains a number of remarkable stars including a large number of WR stars and the largest concentration of O3 stars known anywhere (Melnick, 1985). Figures 2b and 2c present CCD colour-colour and colour-magnitude diagrams of the cluster which show the presence of

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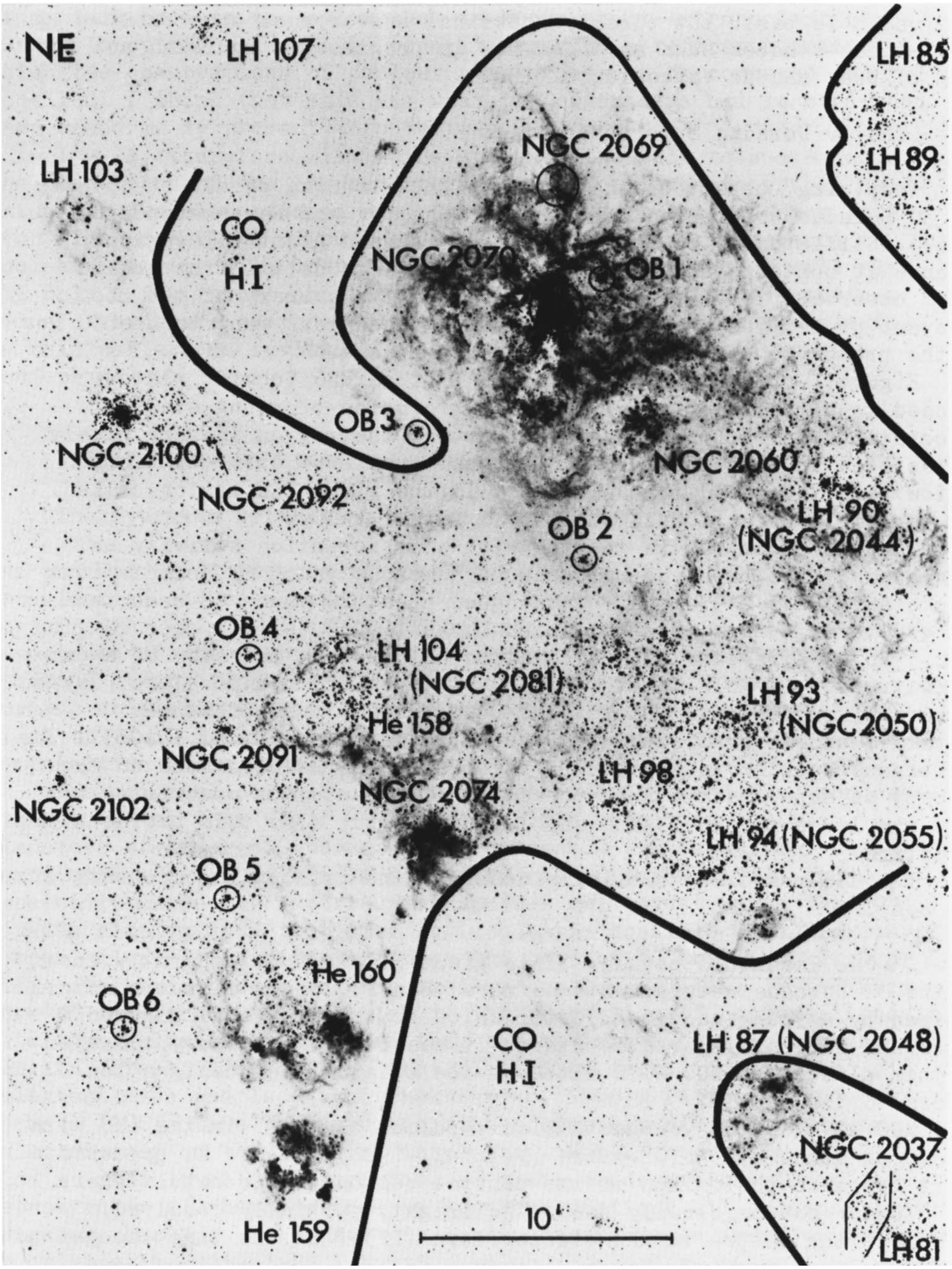

Figure 1. ESO Schmidt photograph of the 30 Doradus superassociation in U light. The most prominent clusters, OB associations and giant HII regions are coded as: LH = Lucke and Hodge, 1970; He = Henize, 1956; OB = previously not catalogued. The contours show regions of low stellar density. CO and HI indicate regions of strong ^{12}CO and/or 21cm emission.

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large amounts of dust embedded in the nebula and of large numbers of O stars in the cluster. From these data it can be shown that the cluster contains enough hot stars to balance the energetics of the nebula. Figure 2d presents the HR diagram of the cluster derived from a spectroscopic and photometric survey of the brightest stars (Melnick, 1986). The evolutionary tracks superimposed on the figure (Maeder, 1983) indicate that the most massive stars in the nebula reach close to 150 $M_{\odot}$. No stars this massive are known in our own galaxy.

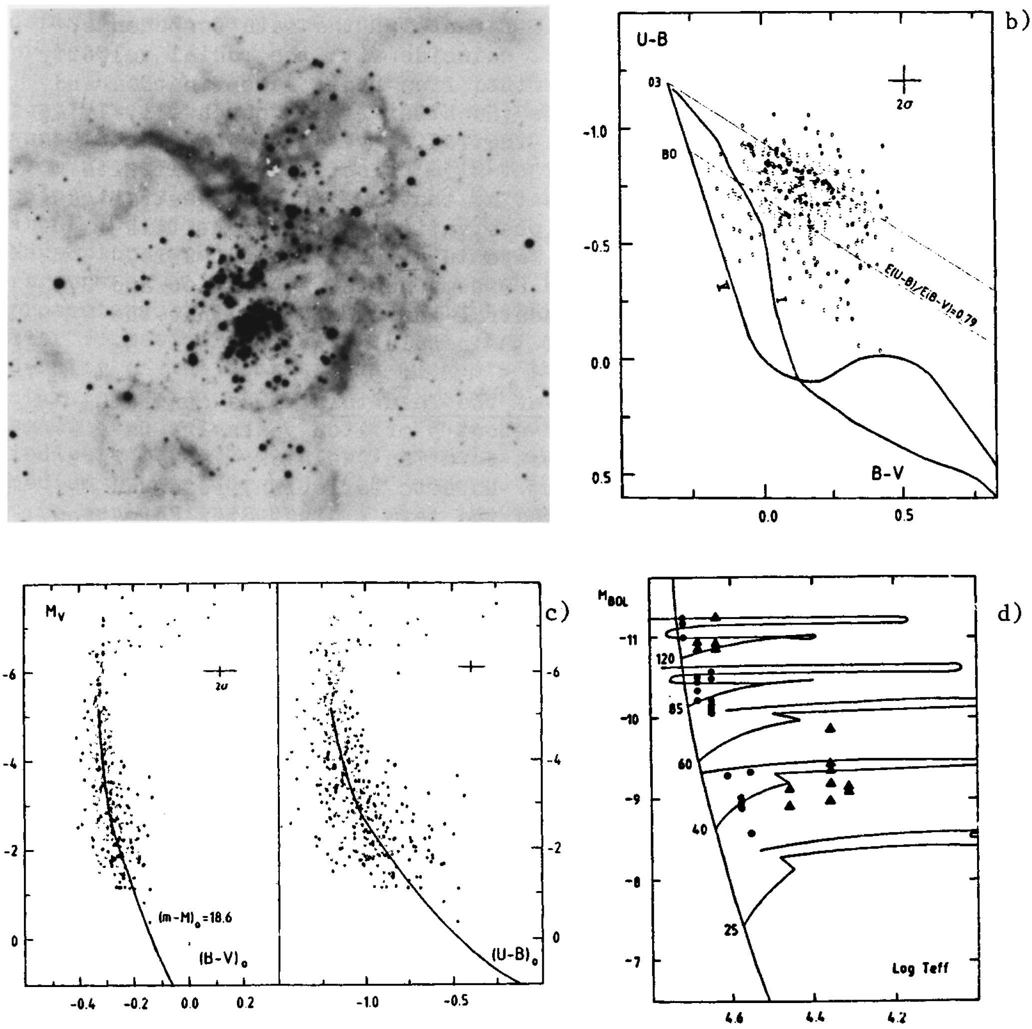

Figure 2. a): Short exposure electronograph of NGC 2070. The unresolved object in the center is R136, the cluster core. b), c), d): colour-colour, colour-magnitude and HR diagrams of NGC 2070 reproduced from Melnick (1986).

The integrated optical, infrared, and radio continuum properties of the nebula are consistent with what is expected for a normal HII region photoionized by massive stars. Supermassive stars or any kind of exotic sources are not required to explain any observational property of giant HII regions.

The 30 Doradus complex is embedded in the largest concentration of neutral hydrogen of the LMC (McGee and Milton, 1966; Rohlfs et al., 1984) but little of this gas seems to be directly associated with the Tarantula itself. The radial velocity distribution of the neutral gas is very complex and shows several components of comparable strength. Nevertheless, at the position of the Tarantula, the main components, at 270 km/sec and 280 km/sec, do not coincide with the radial velocity of the nebula (255 km/sec) as determined from radio recombination and optical interferometric observations (Huchtmeier and Churchwell, 1974; Smith and Weedman, 1972). Moreover, the radial velocities of the optical interstellar lines in front of R136 coincide very well with those of the 21 cm components indicating that most of the neutral gas is in front of the nebula. Deep CO observations show very little molecular gas in the region of the Tarantula (Melnick and Rubio, 1985); the radial velocities of the CO components, 265 km/sec and 273 km/sec coincide with those of the neutral gas suggesting that the molecular gas also lies in front of the nebula.

2.2.2. The immediate surroundings of the Tarantula. The central cluster of the Tarantula was formed about 3 million years ago in a burst of star formation of very short duration (Melnick, 1985). Thus NGC 2070 is a prototypical starburst. Roberto Terlevich, Peter Eggleton and I (1985; MTE) introduced the term Violent Star Formation (VSF) to describe large bursts of star formation and to contrast these events with the sequential star formation activity which seems to be common in our galaxy (see e.g. Elmegreen, 1985 for a review). However, sequential star formation has also taken place and is now occurring in 30 Doradus (Westerlund, 1985 and references therein).

Mendoza and Gomez (1973) identified a number of red supergiants in the immediate vicinity of 30 Doradus which were later studied by McGregor and Hyland (1981) who talked about two stellar populations in 30 Doradus. In fact, NGC 2070 is surrounded by supergiants of different ages and there seems to be an age gradient increasing outwards from the cluster core. This gives the impression that "non-violent" or sequential star formation has slowly propagated inwards in the Tarantula region and has "culminated" with the violent burst which gave birth to NGC 2070 and the Tarantula itself. This idea is supported by the presence of several OB associations substantially older than NGC 2070 in the halo of the nebula (not catalogued by Lucke and Hodge (1970) but clearly visible in figure 1).

2.2.3. The southern part of 30 Doradus. The whole 30 Doradus complex contains nearly 10^8 $M_\odot$ of neutral gas (McGee and Milton, 1966; Rohlfs et al., 1984) most of which is concentrated in the southern part of the complex. Also, a significant fraction of all the CO emission detected in the LMC comes from this area (Cohen et al., 1984). I have sketched in figure 1 the dark areas where the stellar densities are significantly lower than average. These "contours" coincide rather well with the distribution of CO emission and with the peak of the HI density. Most of the youngest HII regions and OB associations (Lucke, 1974; Henize, 1956; Davies et al., 1976) lie along the edges of this dense region of neutral material. The brightest stars in the southern region of the complex appear to form plumes roughly perpendicular to these edges (see figure 1). The same general structure appears to be present in the north-west region of 30 Doradus. This gives the impression that star formation has propagated in the directions defined by these plumes consuming most of the molecular gas in that process.

There is a well defined age gradient in the young stellar population of the southern part of the complex. The ages of the OB associations and clusters increase in the direction of these plumes from about 4 Myrs for NGC 2074 (HII region HE158c near the edge of the molecular cloud) to about 10-12 Myrs for NGC 2092 and NGC 2100 located about 400 pc away (Westerlund, 1985). Thus, star formation seems to have propagated from NGC 2100 towards the southern ridge of HII regions at an average speed of about 30 km/sec. The fact that protostars have recently been identified near this ridge suggests that star formation continues at the edge of the CO cloud although the high density of the neutral gas suggests that the propagation rate of the star formation front may have slowed down at this edge. The relatively small abundance differences found among the HII regions in 30 Doradus indicate that the enriched material injected into the interstellar medium by stellar winds and supernovae mixes with the ambient gas over time scales long compared with the propagation of star formation.

It has been argued by several authors (Westerlund, 1985 and references therein) that the star-formation propagation in the area may be causally related to the expansion of the supergiant HII shell LMC-II (Meaburn, 1980) which is expanding at some 30 km/sec about a centre not far from NGC 2092 (Caulet et al., 1982). My own impression is that the star formation front "self"-propagates (via stellar winds, supernova explosions, etc.) in small-scale "steps" and that the supergiant shell is a consequence, rather than the cause, of this self-propagation process. Similar self-propagating structures appear to be present at the other edges of the CO concentration and at the north-west side of the Tarantula (figure 1). This region overlaps with another supergiant HII shell (LMC-III, Meaburn, 1980) suggesting the same type of interaction.

The Tarantula nebula, on the other hand, appears to be in the centre of a dark region. This suggests that it was formed by the collapse of a large molecular cloud which may have been triggered by "non-violent" star formation activity on the edges of the cloud.

2.3. A General Picture of the 30 Doradus Superassociation

30 Doradus is a large complex containing many OB associations, HII regions and all known manifestations of recent star formation activity including supernova remnants, emission line stars, etc. It is a strong

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source of far UV and far IR radiation that dominates the luminosity of the LMC at these wavelengths.

The region is close to 1000 pc in diameter and is pervaded by weak Hα emission, which, in deep photographs, may hide much of its complex internal structure and give the impression of a single, very large giant HII region. The complex also contains large amounts of neutral and molecular gas which can fuel star formation for times much longer than the lifespan of a single giant HII region. The optical appearance of 30 Doradus is dominated by a large giant HII region which was formed 2-3 million years ago as a consequence of a massive burst of star formation.

Star formation in the 30 Doradus region has proceeded at its present rate for at least 10-20 million years and it will probably continue until the gas supply is exhausted - about 50 Myrs. The presence of large young clusters in the region such as NGC 2100 suggests that, although giant HII regions live only a few million years, they may be present inside superassociations for a much longer time. For example 10 Myrs ago a large HII region must have surrounded NGC 2100. That nebula has now been dispersed by winds and supernovae but in the meantime star formation has propagated to the Tarantula nebula and 30 Doradus still contains a giant HII region. I would like to speculate that a few million years from now non-violent star formation now at the edges of the large southern molecular complex may trigger the collapse of a massive molecular cloud. This could lead to another burst of star formation and to a new giant HII region in 30 Doradus. It would be very interesting to have high resolution 21 cm and CO maps of the region to see if it contains starburst candidates - large self-gravitating molecular clouds.

An important question to consider is what triggered star formation in 30 Doradus. Given the enormous supply of gas in the complex it is clear that once star formation gets going it will last for a long time. In this context, the ideas of stochastic self-propagating star formation processes may be of relevance (see e.g. Dopita, 1985 for a review and a list of references).

I think that there is little doubt that star formation is self-propagating in the region but it seems to me that star formation is coeval over too large a scale to have started by stochastic processes. Rather, a large scale triggering, such as for example a close passage of the SMC, must have intervened. (This may be of relevance to the subject of our conference, because activity in galactic nuclei - see for example talks by Yee and Hutchings in this volume - appears to be enhanced by interactions). The last close passage of the SMC however occurred about 100 Myrs ago (Murai and Fujimoto, 1980) while the oldest associations in 30 Dor appear to be not older than 15 Myrs so that, if the interaction is related to 30 Doradus at all, a delay is necessary and this may be a test of the hypothesis.

2.4. Superassociations in M101

M101 is an ScI galaxy which is much more luminous than the LMC. It contains several bright well studied superassociations which I would like to describe briefly and compare to 30 Doradus. Figure 3 presents a red photograph of M101 where the largest SAs and GHRs of that galaxy have been marked. Sandage and Tammann (1974b, STII) selected NGC 5471, NGC 5462 and NGC 5455 as the largest HII regions, while NGC 5447, and

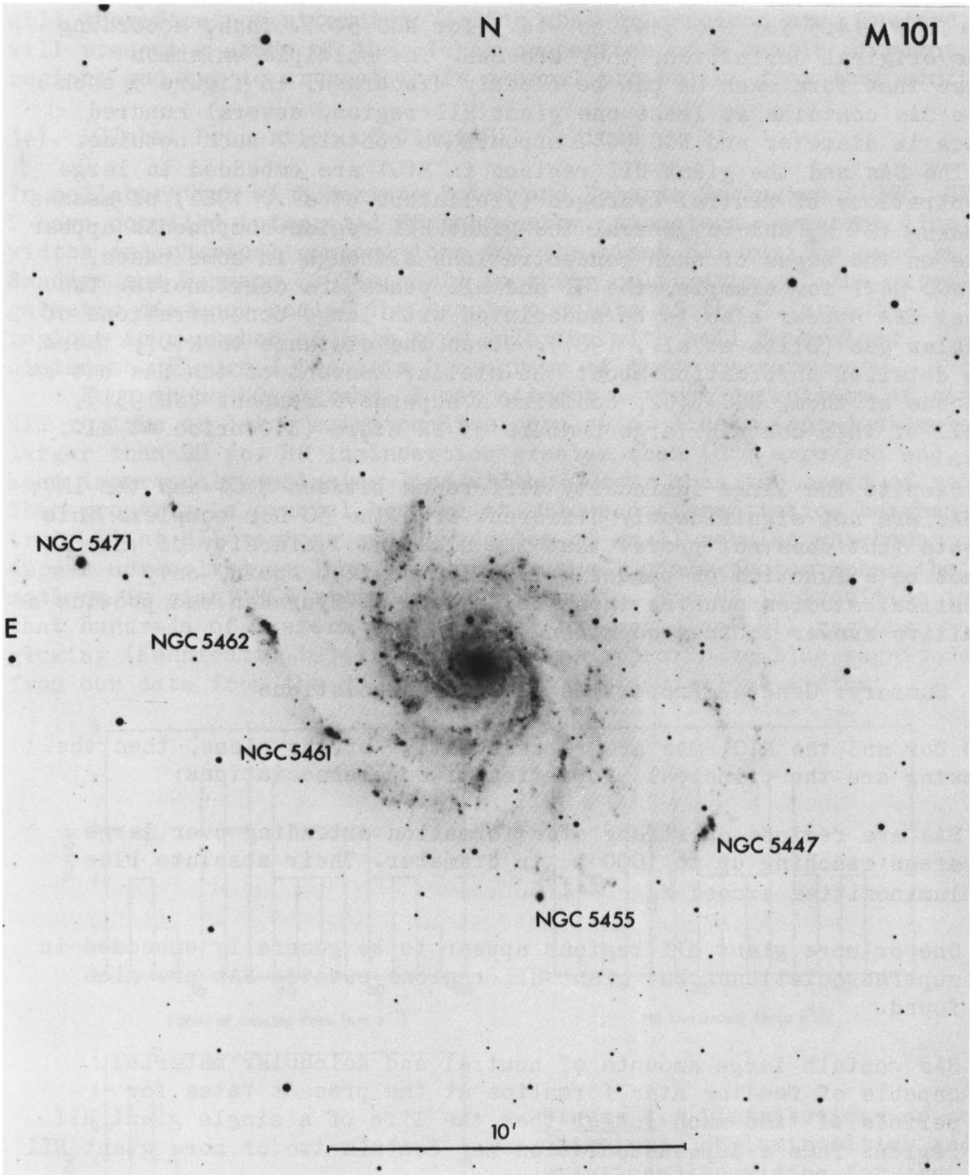

Figure 3. Negative reproduction of a Calar-Alto red photograph of M101 courtesy of R. Birkle, Max-Planck-Institut für Astrophysik. The most prominent giant HII regions and superassociations are indicated.

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NGC 5461 are the most prominent superassociations. In fact, NGC 5462 is also a superassociation and STIII have selected the largest HII region in that complex. The 3 SAs extend for about 1000 pc along the spiral arms suggesting that a spiral density wave may have triggered or at least "organized" their formation (Elmegreen, 1985 and references therein). The absolute blue magnitudes of these complexes range from -14.5 for NGC 5447 to -14.3 for NGC 5461. Thus, according to the original definition, they are SAs. The multiple emission nebulae that form each SA can be clearly discerned; in figure 3 each of the SAs contains at least one giant HII region, several hundred parsecs in diameter and NGC 5447 appears to contain 2 such nebulae.

The SAs and the giant HII regions in M101 are embedded in large concentrations of neutral hydrogen (Viellafond et al., 1981) of masses exceeding 10^7 $M_\odot$ and in general the giant HII region components appear to lie on the edges of such concentrations although in some cases, like NGC 5471 for example, the HI and HII peaks are coextensive. The largest SAs appear also to be associated with large concentrations of molecular gas (Blitz et al., 1981). Given the distance to M101, there is no detailed information about the stellar content of the SAs but at least one of them, NGC 5462, contains a supernova remnant (SN1951), and all of them contain large numbers of WR stars (D'Odorico et al., 1983).

Despite the large luminosity difference between M101 and the LMC, its SAs are not significantly different from the 30 Dor complex. This suggests (but does not prove) that the size and luminosity of the SAs may not be a function of parent galaxy luminosity. Again, only statistical studies such as those being done at Byurakan can provide a definitive answer to this question.

2.6. Summary: General Properties of Superassociations

If 30 Dor and the M101 SAs are representative of the class, then the following are the principal properties of Superassociations:

a) SAs are regions of strong star formation extending over large areas reaching up to 1000 pc in diameter. Their absolute blue luminosities exceed $M_B = -14.0$.

b) One or more giant HII regions appear to be generally embedded in superassociations. But giant HII regions outside SAs are also found.

c) SAs contain large amounts of neutral and molecular material capable of feeding star formation at the present rates for periods of time much longer than the life of a single giant HII region. Thus a Superassociation may contain two or more giant HII regions of widely different ages.

The last point may be of relevance to multiple emission line galaxies (i.e. clumpy irregulars, galaxies with multiple active nuclei, NEST galaxies etc.).

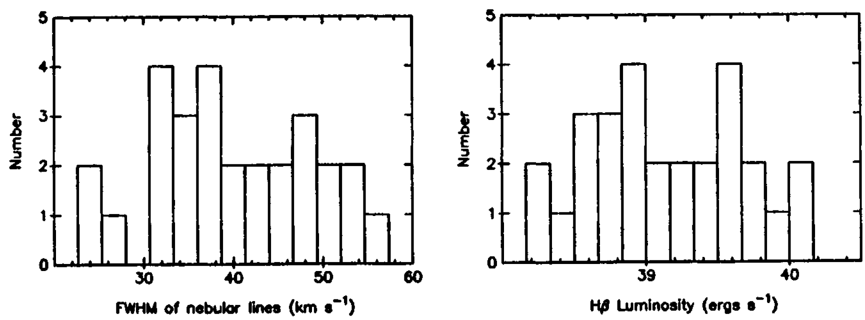
3. GIANT HII REGIONS

I have talked about giant HII regions without precisely defining what giant HII regions are. In his welcome message, Professor Ambartsumian reminded us of the work of the fifth century Armenian philosopher David the Invincible who wrote about the problems of definitions. I will therefore not attempt to define what HII regions are. Instead, I will present a study of the global properties of a sample of giant HII regions and try to extract their general properties from that study.

3.1. Global Properties of Giant HII Regions

In collaboration with Mariano Moles and Roberto Terlevich (1986, MMTG) I have compiled integrated Hβ photometry, diameters, emission line widths and chemical compositions for the giant HII regions used by Sandage and Tammann (1974a, STI) in their calibration of the extra-galactic distance scale. The sample consists of the 3 largest HII regions in a number of late type galaxies with well determined distances. Figure 4 presents histograms of these measurements.

From these histograms, I may attempt a first definition of giant HII regions as large emission line nebulae of linear (core) diameters larger than 20 pc, Hβ luminosities greater than 10^{38} ergs/sec and, most importantly, emission line widths larger than the speed of sound. This property is crucial because it allows differentiation between truly giant HII regions and aggregates of small nebulae which may appear unresolved on long exposure or small scale photographs; the gas motions in giant HII regions are supersonic. The Hβ luminosities imply that hundreds of O stars are required to keep giant HII regions glowing (Kennicutt, 1984). We can derive approximate blue magnitudes from our data from the Hβ luminosities and equivalent widths



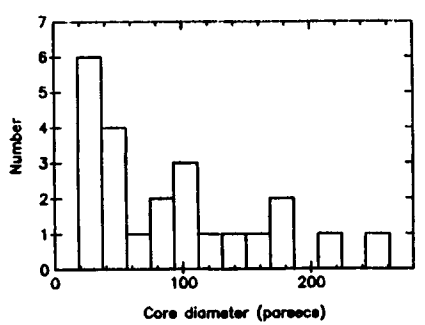


Figure 4. Distributions of core diameters, Hβ luminosities and emission line widths for the Sandage-Tammann sample of giant HII regions in late-type galaxies with accurate distances.

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(Terlevich and Melnick, 1981). We find that giant HII regions cover the approximate range $-14.2 \lesssim M_B \lesssim -10$.

Some of the HII regions in the STI sample have absolute blue luminosities in the range of Superassociations. These are N2403-II, N5462 and N5471; N2403-II appears as a single giant HII region on the Hβ photographs of STI. However, the Hβ equivalent width we measure using a small aperture centered at its brightest position is considerably larger than that measured by Fierro et al. (1986) through a larger aperture suggesting the presence of an important population of blue stars outside the nebular core. But the disk of the galaxy is very bright at the position of the nebula so that disk contamination may be responsible for at least part of its large blue luminosity and gradient in Hβ equivalent width. N5462 is, as mentioned above, really a SA and, although the core diameter of STI is that of a giant HII region embedded in the SA, our photometry covers the entire complex and overestimates the luminosity of the giant HII region. The case of NGC 5471 is very interesting (Skillman, 1985). This nebula lies very far from the centre of M101 (cf. figure 3); for some time people argued as to whether it was an M101 HII region or a blue compact galaxy projected nearby. In fact its size, luminosity and mass lie in the range of blue compact galaxies (or isolated Superassociations, Viellafond et al., 1981; Skillman, 1985). M101 is a ScI galaxy and from the work of Sersic (1960) we know that ScI's have the largest giant HII regions of all late type galaxies. Thus, the size, luminosity and velocity dispersion of NGC 5471 must be close to the maximum reached by giant HII regions as a class. Beyond lies the realm of blue compact galaxies and nuclear HII regions.

3.2. Correlations between Global HII Region Parameters

We have investigated the correlations between the integrated HII region parameters as a way of learning about violent star formation and about the nature of the supersonic motions observed in the nebular gas. Figure 5 shows plots of these correlations, there is a well-

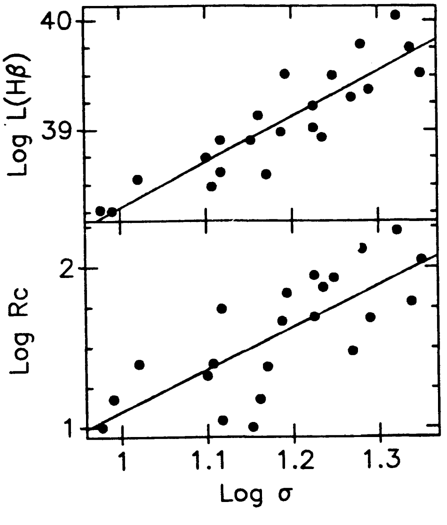

Figure 5. Relationships of core radius (R_c) and Hβ luminosities (L(Hβ)) with the emission line widths (σ) of giant extragalactic HII regions. The solid lines represent least-squares fits to the data.

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defined but rather dispersed correlation between core radius (R_c) and velocity dispersion (σ) and a good correlation between Hβ luminosity L(Hβ) and σ. Both correlations have been known for a long time although their existence and slopes have been subject to considerable controversy (see Skillman and Balick, 1984 for a review). Our new data, however, establishes these correlations beyond any doubt and clarifies these controversies (MMTG). The least-squares slopes of the relations are,

$$R_c \sim \sigma^{2.5\pm0.5}$$

$$L(H\beta) \sim \sigma^{4.2\pm0.3} .$$

The scatter in these relations, however, is not totally random but partly due to a metallicity effect. A Principal Component Analysis of the data showed L(Hβ), σ, R_c, and oxygen abundance, O/H, to be correlated as (MMTG),

$$L(H\beta) \sim \frac{(R_c\sigma^2)^{0.9}}{(O/H)^{0.7}}$$

with a scatter that is consistent with the observational errors. This led us to the conclusion that giant HII regions are gravitationally bound and that the supersonic motions are generated by their own gravity which is dominated by the ionizing stars. The ratio between Hβ luminosity and mass ($R_c\sigma^2$) depends on metallicity in such a way that metal poor nebulae have too much Hβ for a given mass. This excess cannot be produced by changes in the stellar parameters (mass loss rate, effective temperature, atmosphere) with metallicity but requires the slope of the cluster initial mass function (IMF) to vary with metallicity; the IMF must be flatter for metal poor systems (Terlevich and Melnick, 1983).

3.3. Summary: General Properties of Giant HII Regions

Sersic (1980) found that the diameters of the largest HII regions in late-type galaxies were related to the luminosities of their parent galaxies. The Sandage-Tammann sample of giant HII regions covers galaxies in the full luminosity range of the Sersic relation and therefore the properties we draw from this sample can be considered as representative of the properties of giant HII regions in late type galaxies.

The single most important characteristic of giant HII regions is that they have supersonic emission line widths that are well correlated with their sizes and the luminosities.

The nebulae in our sample for which bona fide oxygen abundances have been measured (i.e. via a direct determination of the electronic temperature) have abundances lower than the Solar neighbourhood (Orion).

The core diameters of giant HII regions range from about 20 pc for nebulae with the lowest luminosities (close to 10^{38} ergs/sec) to close to 300 pc for NGC 5471 which is the brightest HII region in the sample with L(Hβ) ~ 10^{40} ergs/sec and M = -14.2. The blue luminosity range of giant HII regions appears to end where Superassociations begin.

Giant HII regions appear to be gravitationally bound systems whose masses are dominated by the stellar components. The IMF of the ionizing stars depends on metallicity and is flatter for metal poor systems.

4. GIANT HII REGIONS IN THE ARMS OF ACTIVE GALAXIES

Most spiral galaxies with active nuclei (i.e. Seyferts and Liners) have early morphological types. This is illustrated in figure 6 which shows that the most common hosts of Seyfert and Liner activity are Sb galaxies while "active" Sc galaxies contain almost exclusively normal giant HII regions in their nuclei. The two distributions cross at Sbc.

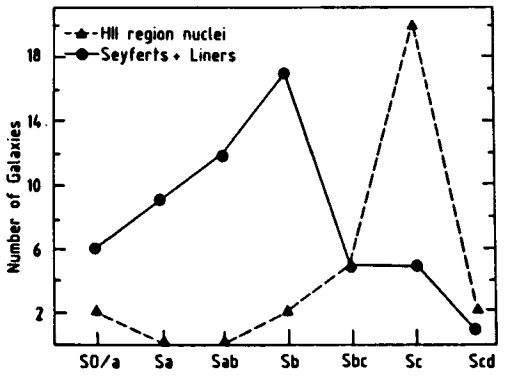

Figure 6. Distribution of nuclear morphology versus parent galaxy type.

Unfortunately for the present discussion, early type spirals (Sa-Sb) have fewer and generally smaller HII regions than later type galaxies (Sc-Irr; Sersic, 1960; Hodge, 1982) and consequently there are no systematic studies of the properties of giant HII regions in Sa or Sb galaxies and in fact very few observations of any HII regions in early type systems.

For example, the comprehensive study of the diameters and luminosities of the largest 2-3 HII regions in 41 galaxies of Kennicutt (1978) does not include any galaxy earlier than Sbc. Similarly, the spectrophotometric study of 99 HII regions in 20 galaxies by McCall et al. (1985) contains no data for galaxies earlier than Sbc and includes only 2 spirals of this type.

From the work of Roy et al. (1986) and Hippelein (1986) velocity dispersions are available for more than 50 giant HII regions, none in Sb or Sa galaxies.

Metallicities are available for a few HII regions in early type spirals (Edmunds and Pagel, 1984 and references therein) but I have not been able to find luminosities or velocity dispersion for any of them.

The only active galaxy for which integrated HII region parameters are available is M51 (Liner) for which Kennicutt (1978) gives radii and Hβ luminosities, Roy et al. (1986) velocity dispersions and McCall et al. (1985) emission line ratios from which abundances can be estimated. These HII regions fit well the MMTG correlations for late type spirals discussed above. Their radii, luminosities and velocity dispersions are close to the maximum values found for later type systems. Their metallicities, however, are substantially larger than the maximum values in our late-type sample.

Thus, on the basis of one galaxy I conclude that the HII properties of giant HII regions in active galaxies are not different from those of late-type systems.

4.1. The Relation between Parent Galaxy Type and HII Region Properties

The basic results from our investigation of giant HII regions are that they are gravitationally bound and that the IMF of their ionizing stars depends on metallicity. Terlevich and Melnick (1983) and Terlevich (1986) have argued that it is the slope of the IMF that depends on abundance while Viellafond (1986) believes that only the upper mass limit of the IMF changes with metallicity. The statistical results of Sersic (1960) and Hodge (1982) indicate that giant HII regions are rare in early type galaxies and common in later type systems.

The only systematic difference we find between HII regions in our Sc-Irr sample and those in Sbc galaxies is that the abundances of the disks of early type spirals are larger and the composition gradients shallower (Edmunds and Pagel, 1984). Thus, there is very little, if any, overlap in disk abundances at any galactocentric distance.

Probably the characteristics of spiral galaxies which are most relevant to the properties of their largest star forming regions are,

a) the gas contents,
b) the rotational velocities, and
c) the chemical composition of the disks.

While it is true that the average gas surface densities are smaller in Sbs than in Scs, there is substantial overlap between types and many Sbs can be found that have gas densities comparable to or even larger than Scs and Irrs. Thus, rather than a modulating factor, it seems to me that the gas content acts as a threshold and does not directly influence the sizes of the largest star forming regions.

The second condition leads to interesting considerations. The critical density that a very large cloud of gas must attain to become self gravitating scales as V^2_{rot}/D^2 where V_{rot} is the rotational velocity of the galaxy and D the galactocentric distance of the cloud (Elmegreen, 1985). Thus, in galaxies with large rotation velocities only the very largest clouds will reach this critical density while the majority will be disrupted by the strong shear. Also, one would expect self-gravitating proto-giant HII region clouds to be more common at large galactocentric distances. This may explain why giant HII regions and superassociations tend to lie in the outskirts of large galaxies (Shakhbazyan, 1968). As is the case for gas densities (and in fact for almost any parameter) there is considerable overlap between the rotational velocities of Sb and Sc galaxies. But the rotational velocities of Sds to Irrs are much lower.

Melnick (1978; see also Roy and Arsenault, 1986) showed that there is a good correlation between the mean velocity dispersion of the largest giant HII regions and the absolute luminosity of the parent galaxy. The diameters (STI; Kennicutt, 1981, and references therein; Kennicutt, 1984, and references therein) and Hβ luminosities (figure 7) of the largest giant HII regions are also tightly correlated with parent galaxy luminosity. Since the absolute magnitudes of spirals are well correlated with V_{rot} (the Tully-Fisher relation) fast rotating galaxies have, as expected, the most massive giant HII regions.

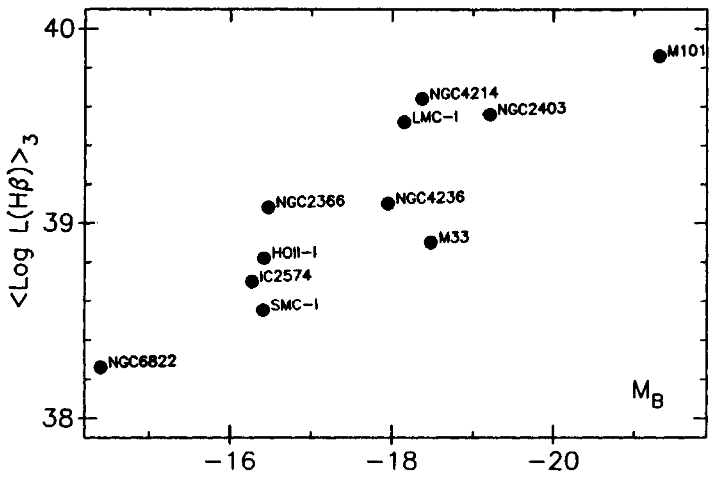

Figure 7. Relationship between the mean Hβ luminosity of the 3 largest giant HII regions and the absolute blue magnitude of the parent galaxy. In the cases of LMC, SMC and Ho II only the luminosity of the largest HII region was used.

Our results for giant HII regions suggest that the metallicities must also play an important role in determining giant HII region sizes. Early type galaxies are metal rich and therefore, at a given star formation rate late type galaxies will produce more massive stars.

5. ISOLATED SUPERASSOCIATIONS OR HII GALAXIES

This subject will be reviewed in detail by Danielle Alloin. I would like to say a few things, which I think she will not cover, regarding the correlations between integrated parameters.

HII galaxies are compact galaxies characterized by having a strong narrow emission line spectrum (Melnick, Terlevich and Eggleton, 1985), which dominates the overall spectrum of the galaxies. Clearly, while still being very young, evolved superassociations may have no emission lines and therefore HII galaxies are a subset of the class of isolated superassociations. Generally HII galaxies are unresolved on Schmidt plates. On deep photographs taken with large telescopes, however, most HII galaxies show weak diffuse components, suggesting the presence of underlying old stellar populations, but the presence of an old population has not been clearly demonstrated (Melnick, Moles and Terlevich, 1985). Thus HII galaxies are young starbursts of dwarf-galaxy scale, or very large starbursts in old dwarf galaxies. In both cases the massive starburst is all we observe at optical wavelengths.

Moles, Terlevich and I (1986) have studied the integrated properties of about 60 HII galaxies. The following are the results of that investigation.

a) HII galaxies are metal poor. The mean metallicity of our sample is <O/H> = 8.04 compared to <O/H> = 8.15 for our giant HII regions and O/H = 8.51 for the solar neighbourhood (the distribution of metallicities is reviewed by Alloin, this volume).

b) There is a well defined correlation between integrated luminosity and velocity dispersion for HII galaxies. This correlation is shown in figure 8 where giant HII regions have also been plotted. The scatter for HII galaxies alone is $\delta\log L(H\beta) = 0.30$.

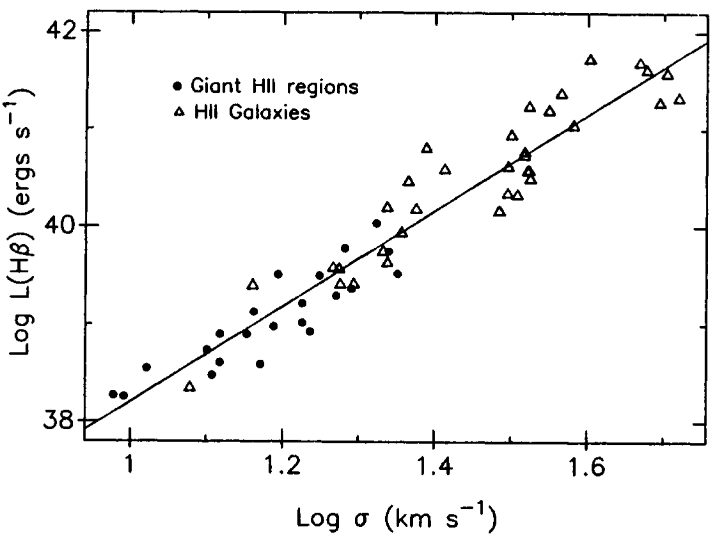

Figure 8. Relationship between Hβ luminosity and velocity dispersion for giant HII regions and HII galaxies. The solid line presents a linear least-squares fit of slope 4.9 ± 0.2.

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c) Part of the scatter in the ($L(H\beta),\sigma$) relation for HII galaxies is real and due to a metallicity effect. The relation between $L(H\beta)$, σ, and O/H has the functional form,

$$L(H\beta) \sim \frac{\sigma^5}{(O/H)}, \qquad \text{with } \delta \log L(H\beta) = 0.22.$$

We conclude from these results that the young components of HII galaxies are gravitationally bound and that the IMF of their massive stars depends on metallicity in the same way as that of giant HII regions. The scatter in the $L(H\beta),\sigma$) relation is sufficiently low to warrant its application to determine distances to HII galaxies. Using giant HII regions to fix the zero point (calibrated essentially on the local distance scale of Aaronson et al., 1986) we find a mean value of H_o = 140±10 km/sec/Mpc. This value must be corrected for systematic differences between the mean metallicities of our giant HII regions and HII galaxies samples and for Malmquist bias. From the ($L(H\beta)$, σ, O/H) relation we get H_o = 97±9 km/sec/Mpc.

The Malmquist bias corrections have yet to be properly applied to these results but preliminary estimates indicate that they are rather small (i.e. less than 5%). This is so because the scatter of the correlations is small over a large luminosity range. Thus, a preliminary estimate of H_o from HII regions gives H_o = 95±9 km/sec/Mpc.

There are some problems with the method related to contamination by multiple HII galaxies that remain to be sorted out. At the present stage of the work, however, I don't think that our final estimate for H_o will change too much.

6. CONCLUSIONS

The properties of giant HII regions of a wide range of sizes and environment seem to be reasonably well explained by the gravitational model with variable IMF. Gas rich, metal poor galaxies rotate slowly and massive stars can easily be formed. In these systems, star formation can be very contagious and these galaxies will generally be rich superassociations.

In gas rich, early type galaxies on the other hand large scale star formation is more difficult to produce. Their disks are metal rich and they rotate fast. Thus massive stars will mostly form in very massive molecular clouds which are very rare. The difficulty in forming massive stars in small associations implies that star formation will not propagate easily. Density waves may help to trigger and organize star formation in early type galaxies and thus giant HII regions and superassociations will mostly lie in spiral arms.

Close tidal interactions are well known to enhance star formation (Larson and Tinsley, 1978), in some cases dramatically, leading to extreme bursts of star formation (Londsdale et al., 1984). The present results suggest that these extreme cases should preferably occur in interactions of large galaxies with late type systems.

Nuclear HII regions fit very nicely in our general model for giant HII regions but this subject is reviewed by Roberto Terlevich (this volume).

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I would like to thank Marie Claire Lortet and Gerard Testor for sending me a wealth of unpublished information about the 30 Doradus complex.

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DISCUSSION

RUBIN: If you adopted the calibration of Aaronson et al., then it is not surprising that you reproduced their H_0 value.

MELNICK: No! It is rewarding...! However, if we use the local calibration of Sandage and Tammann we get $H_0 \simeq 87 \pm 10$ km/s/Mpc.

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Alloin with Andreassian and Terlevich
during a lunch break picnic near Byurakan

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