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Neutral Hydrogen and Star Formation in Irregular Galaxies

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Abstract

VLA and WSRT H I synthesis observations of seven irregular galaxies are presented. The total H I images of four Local Group dwarf irregular galaxies and three larger more distant irregular galaxies are constructed at the identical resolution of 500 pc (FWHM). When compared to H II region distributions derived from Hα images, all galaxies studied show an excellent correlation between the H I surface density and the presence of H II regions. This correlation is most easily interpreted in terms of a requisite threshold H I surface density for massive star formation. This threshold is 1 x 10^{21} H I atoms/cm^2 for a resolution of 500 pc. Giant extragalactic H II regions - star formation events of the magnitude of 30 Doradus or more luminous - are only found near H I surface densities of a factor of three to five times this threshold level. The observed threshold implies a Jeans length of 150 pc, which is the same as the size scale at which the structure in the H I complexes correlates well with the H II region distribution. This, combined with the fact that in none of the galaxies observed is there H I above the threshold level without concomitant H II regions, implies an exclusively gravitational origin for the star formation events. That is, there is no need to involve a "trigger" as in the SSPSF theory (Seiden 1983) or feedback as in Dopita (1985).

Introduction

Since neutral hydrogen represents the ultimate raw material for star formation, it is natural to study the relationship of the spatial distribution of the source to that of the product. It is possible to do this in external galaxies by measuring the H I 21cm emission and comparing it to a tracer of massive star formation - the Balmer emission. Irregular galaxies provide a logical starting point for this type of investigation, since the interpretation is not complicated by the presence of spiral density waves or abundance gradients.

Method

H I synthesis maps of seven irregular galaxies were produced at a resolution of 500 pc (FWHM). In order for valid inter-galaxy comparisons to be made, it is important that all galaxies be analyzed at the same resolution because surface density varies as a function of resolution. The inclinations of the galaxies were determined by studying the total H I distributions and velocity fields and modelling the H I distribution as a thin disk in dominantly circular motion. Images representing the H I surface density were then produced by scaling the column density maps by cos(inclination). H II region catalogues derived from Hα photography were then taken from the literature, and the H II region distributions were compared with the neutral hydrogen surface density images.

Results

The observed galaxies divide into two groups. Four of the galaxies are Local Group dwarf irregular galaxies with $M_B > -16$ (NGC 6822, IC 1613, DDO 75 - Sextans A, DDO 216 - Pegasus). The other three irregulars are more luminous with $M_B < -18$ (NGC 4214, NGC 3239, NGC 4449). In addition to luminosity, the two groups are distinguished by one other feature, velocity field. The velocity fields of the dwarf galaxies were very regular, showing predominantly solid body rotation. The velocity fields of the more luminous irregulars range from very disturbed (NGC 4449) to moderately disturbed (NGC 3239) to warped (NGC 4214). (Images of the H I surface densities with superposed H II region distributions were presented in the poster, but, since there is insufficient space to display those images here, a written description follows.)

The H I distributions in the Local Group galaxies are highly clumped. Both holes (minima reching the zero level) and dense clouds (surface densities > 2 x 10^{21}atoms/cm^2) are observed. In NGC 6822 and IC 1613, there is an obvious correlation between the presence of H II regions and high H I surface density. This is especially striking in IC 1613 where there is one strong H I concentration with an H I surface density higher by a factor of two than anywhere else in the galaxy. Clustered around this H I concentration are 15 of the 18 catalogued H II regions. Most of the H II regions in NGC 6822 and IC 1613 are associated with regions of H I surface density in excess of 1 x 10^{21}atoms/cm^2. The H I distribution in Sextans A is dominated by two large H I concentrations exceeding the 10^{21} atoms/cm^2 level. Although there is no available deep Hα photography of Sextans A, Hodge (1974) has reported detections of 3 H II regions, and optical images of the galaxy show three obvious stellar associations. The reported H II regions and associations are coicident with the H I maxima. There are no immediately obvious H II regions in the Pegasus dwarf galaxy, although there exists no published Hα photography. The H I surface density in Pegasus is everywhere low (< 0.5 x 10^{21} atoms/cm^2 throughout the disk).

From the four Local Group irregulars two trends emerge. The first is a very good correlation between the presence of H II regions and peaks in the H I surface density distribution. The second is a threshold effect. No H II regions are found in regions with peak H I surface densities less than about 1 x 10^{21} atoms/cm^2.

The three high luminosity irregular galaxies all show strikingly large numbers of H II regions. Here the correlation between H I surface density and the presence of H II regions is again very good. These galaxies also support the idea of an H I surface density threshold. In NGC 4214, H I is detected across a disk of 10' extent, but the H II regions are confined to a narrow strip through the galaxy where the H I surface density exceeds 1 x 10^{21} atoms/cm^2. All three galaxies have regions of H I surface density in excess of 3 x 10^{21} atoms/cm^2. Coincident with these regions are giant H II regions (NGC 4214 and NGC 3239) or a large complex of H II regions (NGC 4449).

Discussion

The proposed threshold surface density value of 1 x 10^{21} atoms/cm^2 can be converted to a characteristic central volume density by assuming an exponential distribution in z. An assumed scale height of 200 pc yields a central volume density of 0.8 atoms/cm^3. Next, this characteristic volume density can be used to estimate a Jeans length (assuming the effects of magnetic fields and the galactic gravitational potential are not important). From:

$$\lambda_J \approx 6 \times 10^7 \left(T/\mu\rho_o\right)^{.5} \text{ cm}$$

and values of T = 100 K and μ = 1, a Jeans length of ≈ 150 pc is derived. This is comparable to the resolution in the highest resolution maps available for NGC 6822. At this resolution the correspondence of the presence of H II regions to H I surface density peaks is even more striking than in the lower resolution images discussed earlier. This suggests that gravitational instability is the cause of the massive star formation in these irregular galaxies.

The observed threshold may have an additional significance. It is most likely that the formation of molecular cloud cores is an intermediate step between the formation of the large neutral hydrogen clouds and the onset of star formation. It may be that the observed threshold represents a requisite column density of dust for shielding the molecular cores from the ambient uv radiation field of the galaxy. If this is the case, one would predict a lower threshold value in regions of higher abundance where the dust to gas ratio is higher. Finding appropriate galaxies to test this hypothesis may prove difficult as dwarf irregular galaxies span a range of only about one decade in heavy element abundance. This picture also suggests an upper limit to the surface density of H I, as any atomic gas in excess of the requisite shielding thickness is quickly converted to molecular gas. Note that in the larger irregular galaxies the disturbed kinematics imply that large scale dynamical processes are most likely responsible for piling up large column densities of H I, and therefore fueling the observed prodigious star formation.

Having assembled a collection of H I distributions of irregular galaxies, it is of interest to assess them in light of current theories of star formation. The stochastic self propagating star formation (SSPSF) theory of Gerola and Seiden (1978) has been attributed with the ability to produce an accurate picture of the global properties of dwarf galaxies (Gerola, Seiden, and Schulman 1980). This theory has been laid on a more credible structure by the inclusion of a gaseous component in the models. However, this inclusion dramatically altered the interpretation of the modeling experiments. It was shown that it is more appropriate to think in terms of stochastic self propagating cloud formation (Seiden 1983). The key words then become self-propagating. Is it reasonable to link the cloud building stage causally to the star formation events in dwarf galaxies? Whereas the compression of small clouds by supernova blast waves and stellar winds must certainly be occuring, can the construction of the large (200 pc to 1000 pc) H I clouds typically seen in irregulars be attributed to the older star formation events? Or alternatively, are the majority of the star formation events in the models of dwarf galaxies initiated stochatically in pre-existing neutral clouds, while the self-propagating mechanism merely insures that the "burst" has access to all of the available fuel. If the latter explanation holds true, then it may be that the self-propagating aspect of the theory is without a physical basis. It could be that the gravitationally bound aspect of the H I complexes insures that most of the constituent gas is available for star formation.

Finally a comment on the recent paper of Dopita (1985) regarding a law of star formation in disk galaxies. If the concept of an H I surface density threshold is valid for not only irregular galaxies, but all disk galaxies, then a tight relationship between the star formation rate and the product of the total mass and H I surface density (his figure 1) is difficult to understand. A requisite H I surface density for star formation implies that the star formation rate will be determined by the amount of gas above the threshold value, and not the total H I content of a galaxy (the H I surface density used by Dopita is really the total H I divided by the optical area of the galaxy). Dopita notes that the scatter in the diagram may be attributable to several factors. Perhaps the clumpiness of the gas distribution is an additional factor causing the scatter. A threshold effect would predict a good correlation between the star formation rate and the total neutral hydrogen above the cutoff.

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