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The Critical Density for Star Formation in HII Galaxies

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Introduction

The star formation rate (SFR) in galaxies is believed to obey a power law relation with local gas density, first proposed by Schmidt (1959). Kennicutt (1989) has shown that there is a threshold density above which star formation occurs, and for densities at or near the threshold density, the SFR is highly non-linear, leading to bursts of star formation. Skillman (1987) empirically determined this threshold for dwarf galaxies to be $\sim 1 \times 10^{21}$ cm^{-2}, at a linear resolution of 500 pc. During the course of our survey for HI companion clouds to HII galaxies (Taylor, Brinks & Skillman 1992, submitted) we obtained high resolution HI observations of five nearby HII galaxies. HII galaxies are low surface brightness, rich in HI, and contain one or a few high surface brightness knots whose optical spectra resemble those of HII regions. These knots are currently experiencing a burst of star formation. After Kennicutt (1989) we determine the critical density for star formation in the galaxies, and compare the predictions with radio and optical data.

Observations

We observed nine HII galaxies at the VLA with D-array in the 21-cm line in our survey for HI companion clouds. Each galaxy was observed for 70 minutes. The 4IF mode was used to simultaneously obtain low velocity resolution data (20 km s^{-1}) over a large velocity range, and high velocity resolution data (5 km s^{-1}) over the velocity range of each galaxy. The low resolution data cubes were searched, and four galaxies were found to have companions (Taylor *et al.* 1992). For those galaxies with companions, we made follow-up observations at the higher resolution C array, at high velocity resolution (5 km s^{-1}), which were combined with the D array data. The combined data have sufficient resolution for a detailed study of the HI distribution and kinematics of the HII galaxy/companion systems.

Some Theory

The instability condition for a thin isothermal gas disk is given by (Toomre 1964)

$$\Sigma_c \geq \left(\frac{\kappa\sigma}{\pi G m_p}\right) \tag{1}$$

where Σ_c is the critical surface density for instability, σ is the velocity dispersion of the gas, κ is the epicyclic frequency and m_p is the mass of a proton. As our galaxies are dominated by solid body rotation, $\kappa = 2\Omega$ is the appropriate choice, but even outside of regions of solid body rotation $\kappa \geq \Omega$ (Binney and Tremaine 1987). For σ we use 10 km s^{-1} (Gallagher and Hunter 1984), which is at most off by a factor of two.

Results

Using a position-velocity diagram to estimate each galaxy's rotation curve, we determined κ for the solid body region, with which we estimated the critical density for star formation for three of the four galaxies (the fourth was insufficiently resolved to obtain a reliable column density estimate). This value ranged between 4×10^{20} cm^{-2} to 3×10^{21} cm^{-2}, depending on the slope of the solid body rotation curves. It should be stressed that the column densities are overestimates of surface densities, and that the rotation curve is underestimated, in both cases because no correction is made for galaxy inclination.

Comparing the HI distributions of the three galaxies with their blue POSS images, we find that the optical extent of each galaxy lies within its critical density contour. In two cases, the optical galaxy was within the $\kappa = 2\Omega$ contour, while in the third, that contour contained most of the optical image, but the $\kappa = \Omega$ contour contained it all. Apparently little or no star formation has occurred at densities under the predicted threshold densities. This must be considered cautiously, as star formation occurs on length scales an order of magnitude smaller than our beam size, which ranges from 2 to 6 kpc in size at the distance of the HII galaxies. Such a large beam size averages the column density over the area of the beam, effectively diluting it. Nevertheless, we find, as did Kennicutt, that a simple disk stability model agrees qualitatively with observations. It would be useful to increase the resolution of the observations to decrease the dilution and to get a better estimate of the inclination.

The Big Picture

This work is a follow up to a larger study, designed initially to search for extragalactic HI. Taylor, Brinks & Skillman (1992, submitted) pursued a new approach to search for extragalactic HI clouds, using HII galaxies as "pointers" to undetected companions. HII galaxies are believed to undergo bursts of star formation. One explanation of this bursting phenomenon is that they are triggered through gravitational interaction with nearby objects, such as another dwarf galaxy, a larger galaxy, or possibly an extragalactic HI cloud, as proposed by Brinks (1990). Taylor *et al.* (1992) reported the success of this approach in finding four companions in a sample of nine galaxies, and discuss the properties and implications of the companions. Of the four companions discovered, three have been identified with optical counterparts.

In the future, the high resolution data discussed here will allow for a more detailed study of the HI properties of the companions than in Taylor *et al.* . In addition we are undertaking a VLA D array survey of a complete, volume limited sample of HII galaxies. This sample will provide a statistical look at the properties of these interacting systems, both regarding the effects of interaction on star formation, and the frequency of companion occurrence.

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