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EFFICIENT STAR FORMATION IN THE BRIGHT BAR OF M83

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ABSTRACT. We have detected the bright molecular bar in M83 standing out as a 100% enhancement of molecular emission with respect to the off-bar emission at the same radii. We compare the spatial variations in the star formation efficiency, as traced by Hα emission and the surface density of the interstellar gas, in M83 and M51. Both the central bar of M83 and the spiral arms of M51 are regions characterized by high massive star formation rates. For M83, we ascribe the fact that both the gas surface density and the star formation efficiency are high to the hydrodynamics of the central region.

1. INTRODUCTION

In recent years, detailed molecular studies of nearby disk galaxies have helped to identify the role played by the molecular cloud population in the presence of spiral density waves and central bars. The detection of molecular bars in optically barred and unbarred galaxies, such as IC342 (Lo et al. 1984), NGC 6946 (Ball et al. 1985), NGC 1530 (Solomon 1985), and possibly NGC 4548 (Kenney 1986), demonstrates the propensity of this phenomena to occur. Here we report the detection of a luminous molecular bar, extending 8 Kpc (assuming a distance of 8.9 Mpc) in the nearby spiral M83 (SAB) and examine the galaxy's star formation efficiency as traced by the Hα emission and gas surface density. We compare our results to a similar study in the galaxy M51, and contrast the efficiency of massive star formation in a bar and in spiral arms.

2. OBSERVATIONS

We have observed the grand design spiral galaxies M83 and M51 in the ($J=1\rightarrow0$) transition of CO using the 13.7 m telescope of the Five College Radio Astronomy Observatory during 1984 to 1985. Emission was detected in 21 positions (HPBW = 45") for M83 and 57 positions for M51, with the observations extending out to a radius of 2.6' in each galaxy. The observed positions (spaced radially by 1 HPBW) and contours of integrated intensity are shown for M83 in Figure 1. We have compared the intensity of molecular emission in each aperture with Hα intensities obtained from the photometric database of Talbot, Jensen, and Dufour (1979). These data had been corrected for extinction by the authors using their detailed UBVR color results and the Whitford reddening law. Contours of Hα intensity are displayed in Figure 2, with the same spatial scale as Figure 1. We have used the initial mass function (IMF) of Jensen, Talbot, and Dufour (1981) to relate the Hα flux in each aperture to the star formation rate, and have converted the CO emission to an H_2 mass surface density (as per Dickman et al. 1986). Likewise, for M51, we have used the calibrated Hα data of Kennicutt (see van der Hulst and Kennicutt, this volume), corrected with their radial extinction estimate, to obtain the star formation rate in each aperture. A Saltpeter IMF was choosen in this case, because it has been found to consistently model the integrated colors of this galaxy (Kennicutt 1983). The

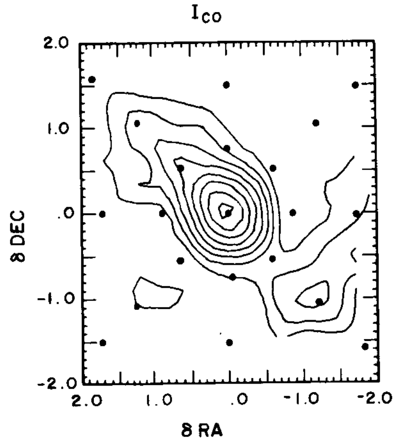

Figure 1. The CO integrated intensity in M83. Points marks the aperture positions separated 45" (1 HPBW) apart. The contours start at 15 K km s^{-1} and are separated by 5 K km s^{-1}.

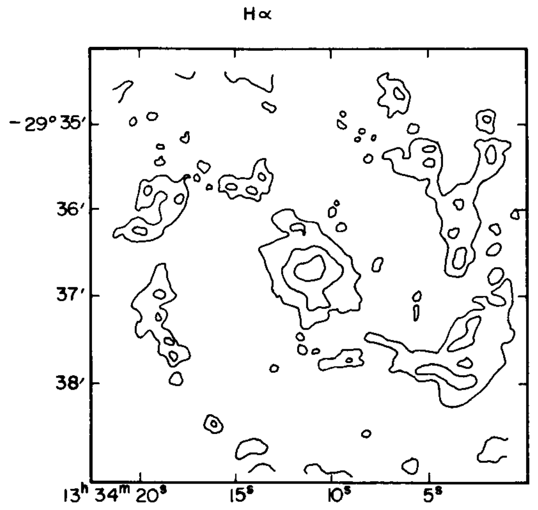

Figure 2. The Hα flux in M83. The contour levels are 23.5, 22.0, and 20.5 mag arcsec^{-2}. (Adapted from de Vaucouleurs, et al. 1983).

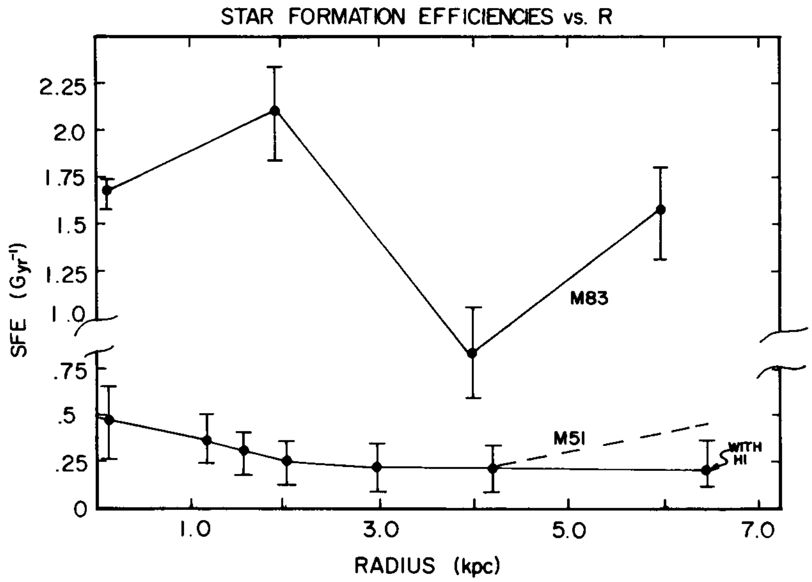

Figure 3. The star formation efficiency for M83 and M51 plotted as a function of galactic radius after azimuthal averages have been made. The vertical scale shows the SFE for all stellar types. Considering the relative freedom involved in choosing an IMF for each galaxy, we advise caution, and have placed a break in the axis. We do however conclude that the massive star formation efficiency in M83 is a factor of 4 higher than in M51.

star formation rates (SFRs) and star formation efficiencies (SFEs) have been calculated for each aperture. Here the SFE is defined as the ratio of the star formation rate in $M_\odot$ pc^{-2} Gyr^{-1} to the total surface density of the ISM, σ(HI) + $\sigma(H_2)$, in $M_\odot$ pc^{-2}. In this sense, the SFE may be thought of as measuring the reciprocal gas depletion time, measured in Gyr^{-1}, given the current rate of star formation and no gas recycling. The results are discussed in detail in Lord and Young (1986) for M51, and Lord (1986) for M83, with the major results given below.

3. RESULTS

In Figure 2 it can be seen that the HII regions in M83 delineate its central bar, the spiral arms, and the "cusp" regions where the inner arms connect to the bar (see also Rumstey and Kaufman 1983). The Hα brightness in this galaxy is very strong in comparison to other spiral galaxies, and about a factor of 10 higher than that of M51 at comparable radii. Likewise, the CO brightness in the barred inner region of M83 is strong (in molecular emission this galaxy is among the brightest spiral galaxies known) and the emission is seen to be clearly organized into a central bar (c.f. Sofue, this volume) as well as a region at the end of the bar in the southwest, displaced about 30" closer to the nucleus than the corresponding Hα feature (Figure 1). Dynamical information is provided by our observations. The molecular isovelocity contours show a weak S-shaped distortion in crossing the central bar, characteristic of oval orbits in the presence of a bar potential, and the velocity dispersions of the line profiles along the bar are found to be greater in general than those measured off-bar. The bar of M83 lies nearly colinear with the major axis, so our dispersion results are just the opposite of the situation usually encountered in unbarred disk galaxies, where the major axis profiles are the narrowest due to the minimal projection of non-circular motions into the line of sight. Our results for the M83 SFE calculations are presented as an azimuthal average in Figure 3, with the star formation along the bar dominating the results.

In M51 we find an extremely high point-to-point spatial correlation between the spiral pattern and regions exhibiting a high SFE. This high efficiency is manifested in the production of massive stars and HII regions in the absence of any correspondingly large excess in the gas surface density. At any given radius in this galaxy, the molecular surface density remains a constant in azimuth to within about 40% while the Hα intensity makes 200% departures from a mean value, if regions 45" (2.2 Kpc) in diameter are considered. However, if the Hα and CO emission are averaged azimuthally, the star formation efficiency is found to be a constant, SFE = 0.25 Gyr^{-1}, as function of radius, as shown in Figure 3.

Only in the region from R=1.5' to R=2.6' in M51 do we clearly see an enhancement in molecular emission (of 80%) when crossing the spiral pattern, as displayed in Figure 4. This is also the radius at which the HI surface density begins to become an appreciable fraction of the molecular density, with $\sigma(HI)/\sigma(H_2) = 0.2$, and increasing outward. The inclusion of the HI component in the SFE calculation serves to maintain a constant SFE, as shown in Figure 3. In M83 the HI contribution is negligible throughout the the area under consideration (Allen _et al._ 1986).

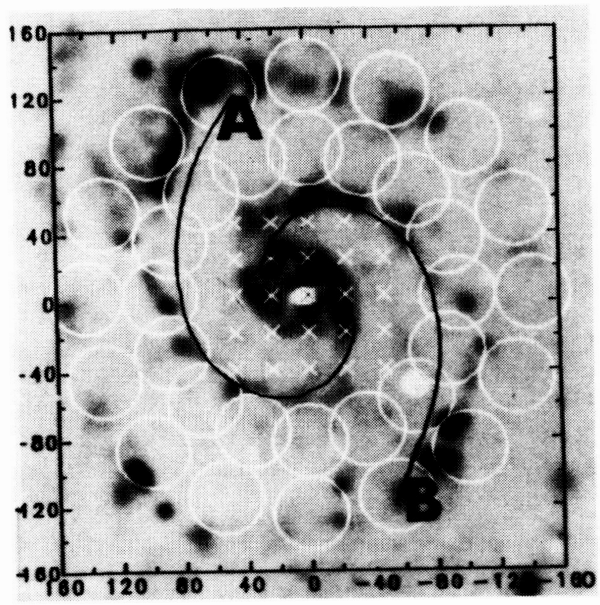

Figure 4a. Hα image of M51 showing the aperture positions (white) and the spiral pattern. The Hα emission was smoothed to the resolution of the CO observations and sampled at the same points for the analysis below.

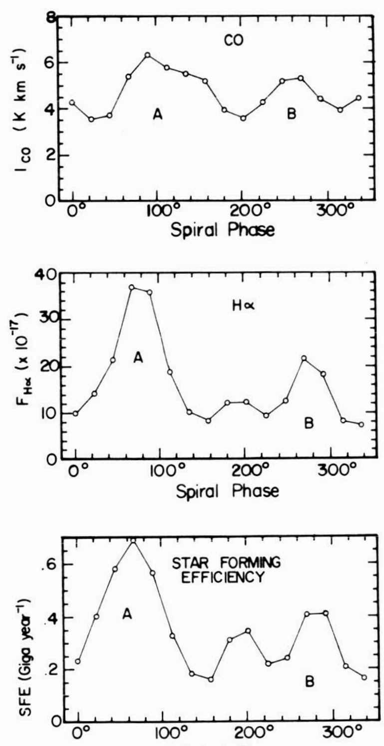

Figure 4b. CO emission, Hα emission, and SFE for the annulus $1.5' < R_{gal} < 2.6'$. The data were interpolated to give intensity as a function of position angle relative to the spiral pattern in the plane of the galaxy, with arm crossings at 90° and 270°. The regions around the HII complexes A and B stand out in emission in both in Hα and CO.

4. DISCUSSION AND CONCLUSIONS

What causes the molecular cloud population to form a bar in M83? It is, most likely, the convergence of the oval streamlines in the gas motions thought characteristic of barred spirals and evidenced dynamically in spectroscopic studies. Of the hydrodynamic models for barred spirals we have considered, the model of Roberts et al. (1979), seems favored by these results. This model, incorporating a disk and spheroidal potential, manifests "shock focusing", where disk material from both inner and outer regions tends to converge at the ends of the central bar in hook shapes that connect with the spiral pattern. The convergence of gas streamlines can set up a shock front along the leading edge of the arm and bar. We think that the molecular material at the southwest end of the bar may have arrived there as a result of such focusing action.

In comparison to M83, M51 shows a constant SFE with radius in the disk, a high efficiency on the arms, and an overall lack of molecular spiral structure. The last result is in part an effect of the spatial resolution employed, since Rydbeck, et al. (this volume), with finer resolution, find 20% on-arm enhancements typical. Even so, the result still holds that the molecular cloud population is largely ubiquitous. The dominant portion of the molecular distribution is uniformly distributed in azimuth and monotonically falling-off in radius. It scarcely resembles the Hα distribution, even when the latter is smoothed to comparable resolution. We must therefore conclude that the principle action of the spiral density wave in this galaxy is not in gathering clouds, but triggering the star formation within them.

5. ACKNOWLEDGEMENTS

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