SPIRAL STRUCTURE AND KINEMATICS OF HI AND HII IN EXTERNAL GALAXIES

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ABSTRACT

Compression of the interstellar gas by a passing density-wave is thought to be responsible for triggering the presently observable star formation processes in the arms of spiral galaxies. We present new observations of the distribution and kinematics of the Hβ emission in the spiral arms of M83, obtained with the TAURUS imaging Fabry-Pérot system. These results, when combined with observations of the neutral and molecular components with sufficiently high resolution, should contribute to our understanding of the time sequence by which stars form out of the interstellar gas.

1. INTRODUCTION

Until recently our knowledge of the spiral structure and kinematics in external galaxies, and the basis on which we are able to construct and test models of Density-Wave-Induced Star Formation (DWISF), has been largely obtained from detailed HI mapping of a few nearby galaxies with radio-synthesis telescopes. The analyses by Rots and Shane (1975) and by Visser (1980a, b) of the distribution and motions of HI in M81 several years ago indicated the presence of streaming motions across spiral arms consistent with the predictions of Spiral Density-Wave Theory (SDWT). Some models of DWISF predict that the kinematics of the ionized gas may be different from the neutral gas (Bash & Visser, 1981) and there are observational indications that this is so (Bash 1983, Allen et al. 1983). These differences are of great interest for the study of the mechanisms and the time-scales for the formation of massive stars from the interstellar HI.

Improvements in sensitivity and angular resolution of radio synthesis telescopes and the advent of Imaging Fabry-Pérot Spectrometers in the visible (e.g. TAURUS) now enable a more comprehensive study of the star formation process in nearby galaxies.

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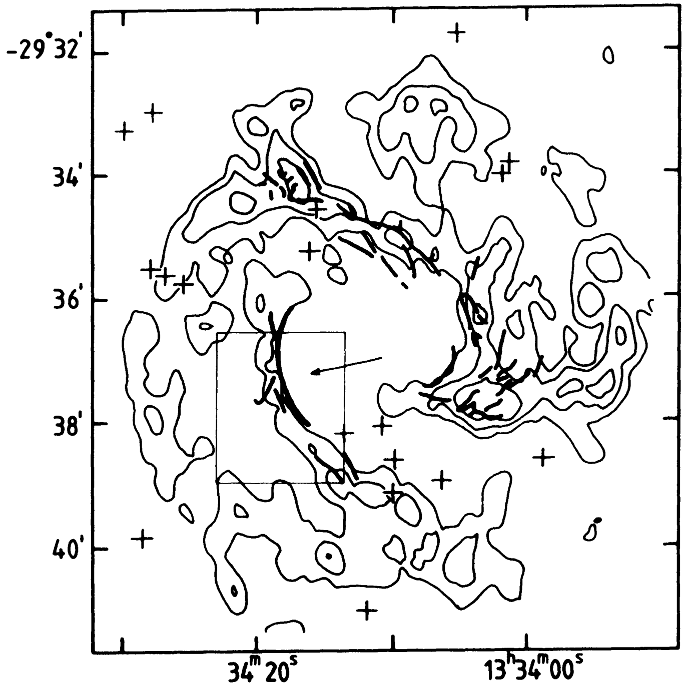

Figure 1 - The distribution of HI and dust lanes in M83. Contours are taken from the VLA-HI synthesis observations at 25" resolution by Ondrechen and van der Hulst. The dust lanes have been drawn from inspection of an optical photograph kindly provided by R.M. Humphreys. The crosses refer to a set of secondary standard stars whose positions have been determined by us to an accuracy of about 1". The arrow indicates the inner eastern arm which is the subject of this paper; the frame drawn here corresponds with the frames of Figures 2a and 2b.

We report here on a continuing study of the galaxy M83, combining radio continuum and 21 cm observations with optical Hβ emission. This study is aimed at determining the relative positions and kinematics of the neutral and ionized hydrogen.

2. DISCUSSION

In order that we might make an adequate observational test of the predictions of SDWT and DWISF, we need to choose a part of the galaxy in which we can be reasonably sure that this is the dominant mechanism for the formation of the massive stars. These stars become observable through the ionization which they produce on the neighbouring gas clouds. It seems likely that various other star formation processes will be superposed on DWISF in a particular galaxy (Elmegreen 1979) and this will tend to confuse the picture. Indeed, massive gas clouds will cause local gravitational perturbations to the underlying spiral

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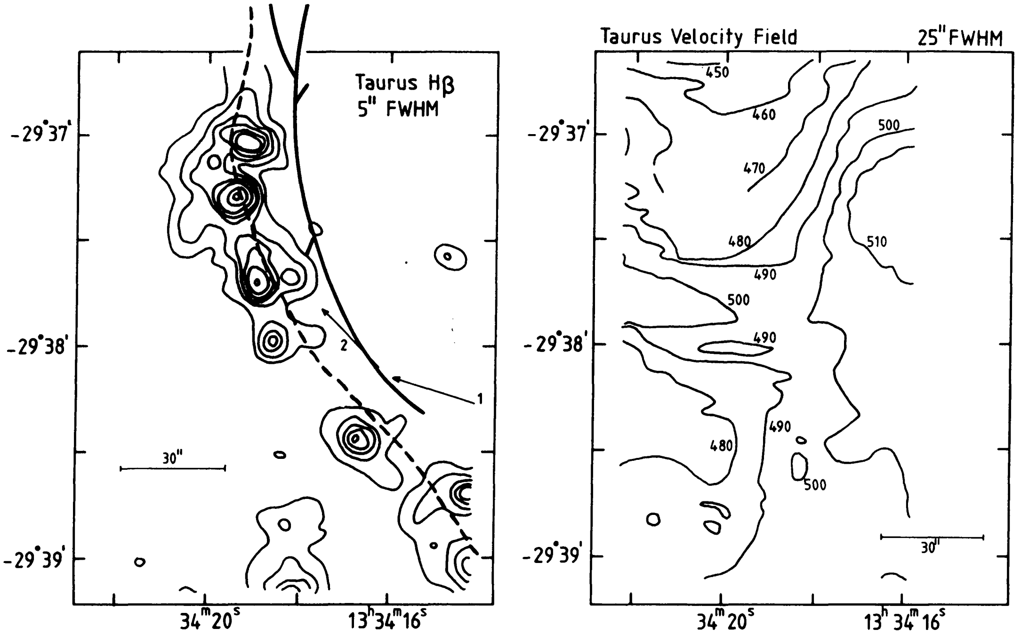

Figure 2
a) (left panel). The distribution of dust (thick solid line), Hβ emission (contours, 5" resolution), and the ridge line of the HI from the contours in Figure 1 (dashed line) are shown here for a section of the inner eastern spiral arm in M83. The horizontal bar at the lower left indicates 30", corresponding to 530 pc or 1280 pc along the major axis of M83 for assumed distances of 3.7 and 8.9 Mpc, respectively. The arrows marked 1 and 2 indicate schematically the pre- and post-shock gas flow. The Hβ (λ4861 Å) observations were obtained at the AAT using the TAURUS imaging Fabry-Pérot system (Atherton et al. 1982).
b) (right panel). Isovelocity contours (km s^{-1}, heliocentric) of the Hβ kinematics at 25" resolution in the area of Figure 2a.

potential of the old stellar population, and these pertubations could substantially reduce or enhance the strength of the shock locally in different parts of the galaxy. Furthermore one might expect that, once stars have begun to form, they might induce further star formation, through the interaction of strong stellar winds from OB associations with the surrounding material. Following Roberts (1969) and Shu (1984), we assume that the dust lane is the interstellar material that has been shocked and compressed by the locally changing spiral potential of the underlying old stellar population. This in turn is thought to induce the formation of giant molecular clouds, which may be launched from the shock as ballistic particles (Bash & Visser 1981), and wherein stars are formed which begin to radiate ionizing flux some 10^7years later, finally appearing as HII regions downstream of the shock. Secondary star formation processes may now be triggered (Elmegreen 1979) producing the chaotic structures observed in some parts of galaxies. In order to select against these secondary processes, we choose to study a part of the galaxy where the dust lane is long, clean and unfragmented. This is a matter of degree rather than division as seen in Fig. 1, where we superimpose a sketch of the dust-lane structure (from an optical photograph by R.M. Humphreys) on a VLA map of the HI. We interpret the long, unbroken dust lane on the inside of the eastern spiral arm as evidence that DWISF is predominant in this area, i.e., the large-scale organisation of the shock front is determined mainly by the spiral potential. Note that the western spiral arm appears considerably more chaotic both in the HI and in the appearance of the dust lanes.

In Figure 2a we show part of the inner eastern spiral arm in more detail, comparing the location of the Hβ emission (contours) with the position of the dust lane (solid line) and the ridge line (dashed) of the HI emission. From the picture of DWISF sketched above, we expect that the interstellar gas (mostly molecular in this region of the galaxy) streams into the shock (dust lane) as indicated for example by arrow #1 in Figure 2a. Upon leaving the shock (arrow #2) we might expect the spatial separation to follow the time sequence from molecular gas in the region of the dust lane through neutral (i.e. dissociated molecular) gas to ionized gas, and in a general sense this is clearly evident in the observations. The exact position of the HI ridge line is, however, uncertain owing to the relatively low resolution (25") of the VLA data presently available. Visser (1980b) has explained the shift of the HI ridge to the downstream side of the dust lane in M81 as arising from beam-smearing on an HI distribution which is intrinsically asymmetric on the two sides of the shock. The choice between these two different interpretations of the position shift between the HI and the dust lane requires new HI observations with an angular resolution of 10" or better.

The separation of dust lane and HII in Figure 2a is very clear. It seems unlikely that geometric projection effects could account for the lack of a clear separation in the other parts of M83. We suspect that these differences are due to variation in the potential, shock strength and secondary processes of star formation. Similar variations in separation can be seen in for example NGC 628, which is almost face-on.

In Figure 2b we show the velocity field of the ionized gas as determined from TAURUS observation at Hβ with a resolution of 25". These confirm in more detail our previous Hα results (Allen et al. 1983), indicating deviations in the kinematics of the ionized gas from those expected from SDWT for the neutral gas. At the seeing limit there is also evidence for much turbulence and disorder in the velocity field at the 5-10 km sec^{-1} level. Future work on M83 will include a more detailed comparison of the HI and HII kinematics.

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DISCUSSION

W.H. Waller: Have you looked at the radio-continuum distribution in the same region?

Allen: We have a rough continuum map of M83. It shows a ridge along the dust lane, possibly indicating that the density of relativistic gas reaches a maximum there.

In M51, a much better VLA map by Van der Hulst, Kennicutt and others shows thermal emission (that is, HII regions) on the outside of the spiral arms, and nonthermal emission on the inside, in agreement with our findings for M83.

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Top: R.J. Allen welcomes participants to the new home of the Kapteyn Institute.
CFD

Bottom: At conference dinner, clockwise: Terzides, unidentified, Dame, Kathryn Mead, Leisawitz, Bash, Twarog, Kutner, Cohen, Jelena Milogradov
LZ

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