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LARGE SCALE DISSOCIATION OF MOLECULAR GAS IN THE SPIRAL ARMS OF M51

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Abstract. In this paper we compare the distribution of the atomic and ionized hydrogen along the inner spiral arms of M51. As is the case in M83, the location of both these phases of the interstellar medium with respect to the major dust lanes suggests that molecular hydrogen is dissociated on kpc scales in active star-forming regions, and that this dissociation process may strongly affect the observed morphology of atomic hydrogen in spiral arms.

1. INTRODUCTION

Since the introduction of the notion of spiral density-waves by C.C. Lin and F.H. Shu in the mid-1960's the gaseous spiral arms observed in galaxies have been explained as shocked gas arising from the non-linear response of the gaseous disk to a relatively weak density-wave disturbance in the gravitational field of the old stellar disk (summarized e.g. in Shu 1982). In this picture the shock is thought either to stimulate the formation of giant cloud complexes or to cause the collapse of pre-existing clouds, eventually resulting in the formation of new stars downstream from the the shock. Young, bright stars and giant HII complexes are distributed like 'beads on a string' along the outer edges of spiral arms. The position of the shock front is outlined by the dust lanes, which thus represent the locus of highest (total) gas density. However, in several cases, e.g. M81 (Visser 1980) and M83 (Allen et al. 1986), the highest density of the <u>atomic</u> gas is observed to be shifted downstream with respect to dust lanes. In the case of M83 the shift puts the atomic gas along the same locus as the HII complexes. Visser has shown that such a shift could arise from beam-smoothing, but we have ruled out this possibility in the case of M83 (Allen et al. 1986). We suggest that, since no atomic and ionized gas is observed at the position of the dust lane, the interstellar gas is apparently mostly molecular there and remains molecular for some time downstream of the shock. After the formation of sufficiently hot stars the molecular gas is dissociated giving rise to the observed arm of atomic gas, or ionized yielding giant HII complexes. In this scenario the correspondence between the ridge of highest HI density and the 'string' of HII regions is thus explained quite naturally.

We have emphasized however that the region studied in M83 is exceptional in that the displacements described are very clear. Our interpretation of this fact is that, for this region, the density-wave streaming is well-ordered enough to allow the time sequence of star formation to be stretched out in space. Since such large-scale ordered motions have been identified previously in M51 (Segalovitz 1976), we have obtained high resolution HI and Hα observations of this galaxy.

2. OBSERVATIONS

High resolution HI observations of M51 were carried out using the Westerbork Synthesis Radio Telescope in a 2 x 12 hrs. observation. The data have been Hanning smoothed resulting in a resolution of 16.5 km s^{-1}, the 63 channels spanning a total range in velocity of 520 km s^{-1} centered on the systemic velocity of 440 km s^{-1}. The spatial resolution is 12" x 18" (α x δ). The data showed some moderate phase errors resulting in extra grating rings at 10′, and we are still in the process of removing these errors. The inner parts presented appear to be unaffected by these problems, except possibly for a region close to the nucleus. The continuum has been formed by averaging the channels free from line emission. Subsequently the continuum-subtracted line channels have been added using a cutoff of 3σ. The resulting total HI map is shown in Figure 1, with the contours representing -4, 4, 8, 14, and 20 mJy/beam (4 mJy/beam $\simeq$ 3σ; for this resolution, 1 mJy/beam $\simeq$ 4.6 x 10^{19} atoms/cm^2 along the line of sight through M51).

Hα observations were obtained using the TAURUS imaging Fabry-Pérot spectrometer (Atherton et al. 1982) attached to the Isaac Newton telescope on La Palma. The total velocity range observed is 400 km s^{-1} over 72 channels, the resulting resolution in velocity is 15 km s^{-1}, sampling slightly less than 3 channels per resolution element. Again the continuum was formed by averaging line-free channels and a total Hα map was obtained adding the continuum-subtracted line channels using a cutoff of 3σ. The distribution of the Hα emission in the inner region of M51 is shown in Figure 2, where the contours are -250, 250, 500, 1000, 2000, 4000, and 6250 in units which scale linearly with the number of photons observed. This map and a velocity integrated map of the original cube showing also the continuum sources are in excellent agreement with broad-band Hα observations of M51 by Kennicutt (1986, private communication). We have used his observations and positions of reference sources from Mathewson et al. (1972) to obtain a position calibration of the TAURUS observation accurate to approximately 1". Figure 3 shows the Hα distribution of Figure 2 smoothed to the resolution of the HI observation (Figure 1).
The thick lines in Figures 1,2 and 3 represent the major dust lanes along the inner spiral arms of M51, obtained from overlaying a large scale optical photograph with the Hα observations.
We emphasize that a more thorough analysis of both the Hα and HI data is in progress, using more advanced methods of treating the data.

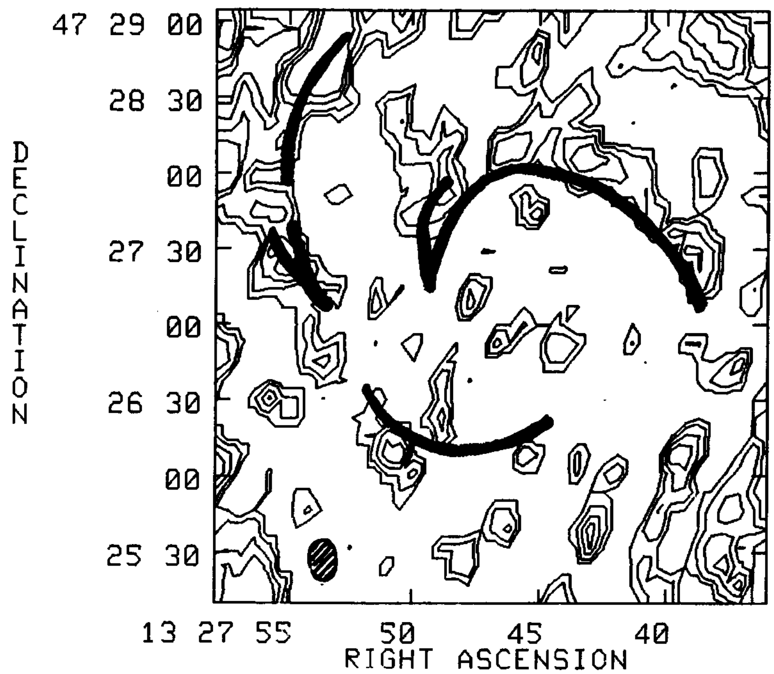

Fig. 1 HI density distribution in the central region of M51.
contours: -4, 4 (=3σ), 8, 14, and 20 mJy/beam.
The beam (12"x18") is shown in the bottom left corner. The thick contours indicate the main dust lanes.

3. DISCUSSION

Although the separation is not as pronounced as in M83, comparing Figure 1 with Figures 2 and 3 shows that the ridge of highest HI density is more closely coincident with the Hα distribution than with the dust lanes, in particular along the inner northern arm. This suggests that in the inner parts of M51, as in M83, the interstellar gas is molecular at the position of the shock and remains molecular downstream of the shock until the newly formed stars dissociate or ionize the molecular gas on a kpc scale. Furthermore, our observations indicate that this dissociation process may significantly affect the HI morphology in the inner regions of galaxies and that the HI clouds need not always have key role as precursors of molecular clouds.

More so than in M83, the observed distribution of the ionized gas is likely to be affected by obscuration effects. High resolution radio continuum observations at several frequencies have been obtained which should be free of obscuration, allowing a precise indication of the location of both the thermal (HII regions) and the non-thermal (shock region) radio continuum (van der Hulst 1986, private communication).

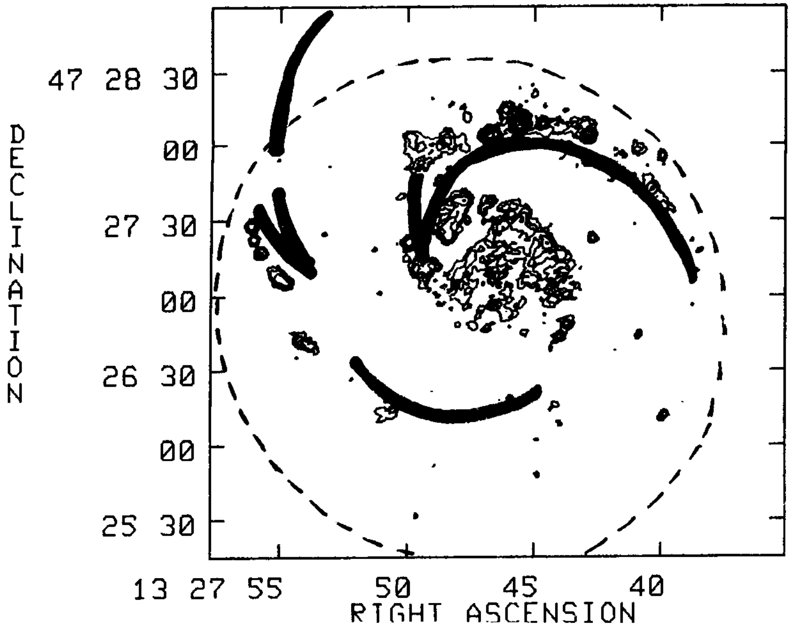

Fig. 2 Hα emission in the central region of M51 (continuum subtr.). contours: -250, 250, 500, 1000, 2000 4000, 6250 (units scale linearly with the number of photons detected). The thick contours indicate the main dust lanes, the broken contour shows the field of view.

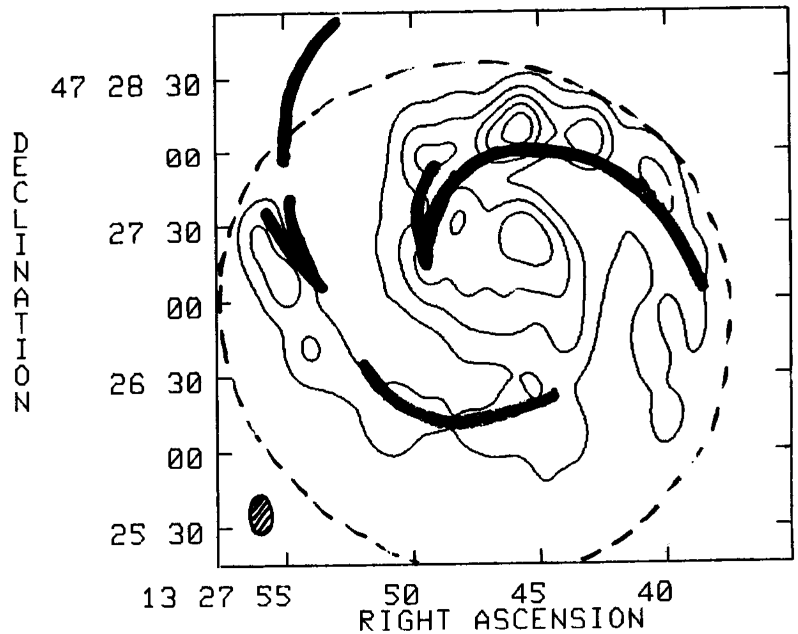

Fig. 3 The Hα emission of fig. 2 smoothed to a resolution of the HI distribution shown in fig. 1. contours: 45, 135, 270, 450, 675 units. The beam (12"x18") is shown in the bottom left corner. The thick contours indicate the main dust lanes, the broken contour shows the field of view.

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REFERENCES

Allen, R.J., Atherton, P.D., Tilanus, R.P.J. 1986, Nature **319**, 296

Atherton, P.D., Taylor, K., Pike, C.D., Harmer, C.F.W., Parker, N.M., Hook, R.N. 1982, MNRAS **201**, 661-696

Mathewson, D.S., van der Kruit, P.C., Brouw, W.N. 1972, Astr. Ap. **17**, 468-486

Segalovitz, A. 1976, Astr. Ap. **52**, 167-174

Shu, F.H. 1982, The Physical Universe (University Science Books, Mill Valley, California), p. 281-284

Visser, H.C.D. 1980, Astr. Ap. **88**, 159-174