THE DETAILED VELOCITY FIELD OF THE IONIZED GAS IN NGC 4038/39 (THE "ANTENNAE")

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ABSTRACT. The pair of galaxies NGC 4038/39 (Arp, 244) has been observed at Hα wavelength with a scanning Pérot-Fabry interferometer and an IPCS at the Cassegrain focus of the 3.6 m ESO telescope. Hα profiles were thus obtained inside 256 x 256 pixels (0.91" x 0.91" each), providing 5741 velocity points with an accuracy better than 16 km s^{-1}, covering the central part of the merging system. The velocity field exhibits severe distortions, not surprising because of the strong interaction. Comparison of our data with recent CO data (Stanford et al., 1990) inside NGC 4039 show a fairly good agreement. The grand design of the velocity field of NGC 4038 more clearly reminds of a classical rotating disk. A rough estimate of the masses of the galaxies indicates that they are both around 10^{10} $M_\odot$ within a radius of 40". Comparison with the most recent model of the antennae (Barnes, 1988) shows a strong discrepancy, the observed radial velocity range being half the expected value and the nuclei velocities differing by only 30 km s^{-1} instead of the expected 300 km s^{-1}.

I. INTRODUCTION

The double system of galaxies NGC 4038/39 (the "Antennae", Arp 244, VV 245) is a prime example of galaxies in gravitational interaction. Photographs taken by Arp (1966) and Schweizer (1978) show long tails associated with these galaxies, which have a projected size of 20'. Since Toomre and Toomre (1972) making a simple three-body model until Barnes (1988) with a n-body model taking into account self-gravitating halo, disk and nucleus component, several authors have shown that the spectacular tails can be explained by the tidal interaction. In addition these two galaxies are the nearest example of a galaxy merger then affording opportunity for multiwavelength spatially resolved investigations of the effects of the interaction on the several galactic components. Optical Hα observations performed by Rubin et al. (1970) show emission knots throughout the central parts of both galaxies. The pair has been observed in the 21-cm line of neutral hydrogen by Van der Hulst (1979) showing that about 70% of the total amount of HI is associated with the luminous tails. The presence of HI in these tails where Hα is absent enables Van der Hulst to say that the main features of the Toomre and Toomre's model are in good general agreement with his HI observations. Other radio observations (6 and 20 cm) have been realized by Hummel and Van der Hulst (1986) showing that the radio emission coincides with the optical emission and the radio knots coincide with Hα knots. Infra-red observations with IRAS show a high IR total luminosity compared to the blue luminosity.

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CO observations obtained by Stanford et al. (1990) show three concentrations of CO emission. Within this region are four distinct clumps coinciding with Hα, 10 μm and radio continuum peaks, suggesting that they are extremely active sites of star formation.

II. OBSERVATIONS

The observations have been performed with the CIGALE equipment, which consists mainly of a scanning Pérot-Fabry interferometer and a two-dimensional photon counting system attached at the Cassegrain focus of the 3.60 m European Southern Observatory Telescope (see Boulesteix et al.,1983) in february 1990.

The total field of view was 4'x 4' on the 256 x 256 pixels of the camera. The redshifted Hα line was observed through an interference filter with a FWHM of 15 Å. The free spectral range of the interferometer (380 km s^{-1}) was scanned through 24 scanning steps. The total exposure time was 2 hours (24 channels exposed 300 s each). For each pixel (0.91" x 0.91" on the sky) we obtained an Hα profile from which we find the radial velocity with an expected accuracy better than the spectral sampling of 16 km s^{-1}. Details of the data reduction procedure are given in Laval et al. (1987).

III. MORPHOLOGY

Figures 1 and 2 show the isophotes of the monochromatic Hα emission and the continuum emission around Hα of NGC 4038/39. We observe Hα emission only inside the 2' x 2' central part of the merging system. Those two galaxies have approximatively equal size and luminosity but one can see on figure 1 that NGC 4039 (southern galaxy) exhibits a noticeable deficiency or extinction of Hα emission on the southern side. The very bright knots (with respect to the disk background) inside both galaxies indicate the presence of a strong component of young stars. The Hα emission area corresponds roughly with the 6 and 20 cm map of Hummel and Van der Hulst (1985).

IV. VELOCITY FIELD

Using the Hα profiles found for each pixel, we found 5741 velocity points. Figure 3 shows the isovelocity lines drawn after a smoothing with a 3" x 3" beam. The dotted lines are drawn by interpolation in the regions where there is no Hα emission.

The velocity fields of both galaxies exhibit severe distortions and it is not a simple matter to understand it. This is not surprising since the interaction is in a quite advanced state with both galaxies about to merge. NGC 4039 exhibits Hα emission only over one half of its optical disk, then we don't see its whole velocity field and it is hard to know exactly the velocity amplitude. We estimate it around 240 km s^{-1} and the position angle of the major axis roughly 55° ± 10°. It is also very difficult for NGC 4039 although we have velocities on the whole optical disk. NGC 4039 displays a velocity field with a grand design reminding of a classical rotating disk with differential rotation. However, because of the strong distortions it is very difficult to give a precise position angle for the major axis. The position angle the more perpendicular to the isovelocity lines is roughly at -20° while the position angle joining the external isovelocities and following the major axis suggested by the photographs is roughly at 15°. The radial velocities vary from 1475 km s^{-1} to the North to 1700 km s^{-1} to the South. This enables a rough estimate of the mass of NGC 4038. Within 40", assuming a maximum rotational velocity of 150 km s^{-1} (taking 50° for the inclination) and using Lequeux synthesis method (1983) we find a mass for NGC 4038

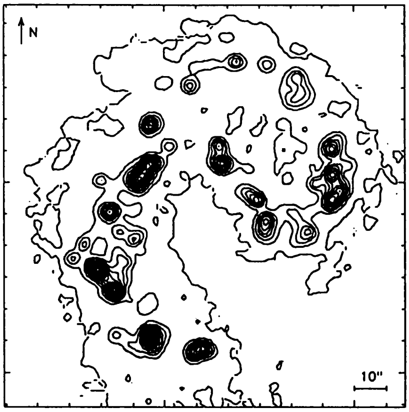

Fig. 1: H-alpha isophotes

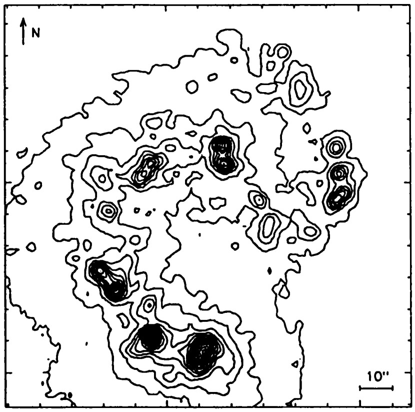

Fig. 2: Continuum isophotes

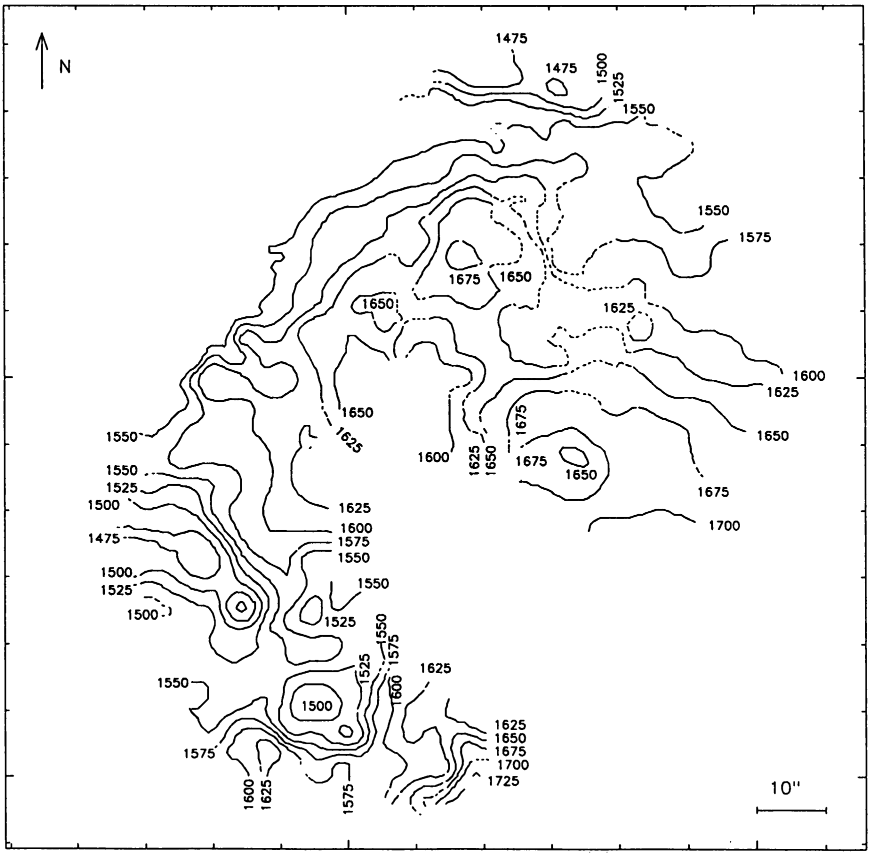

Fig 3: Isovelocity lines

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~ 1.2 10^{10} M$\odot$ at 14.5 Mpc. Although much more difficult to apply to NGC 4039 because of its strong asymmetry this method leads to a similar mass, around 10^{10} M$\odot$.

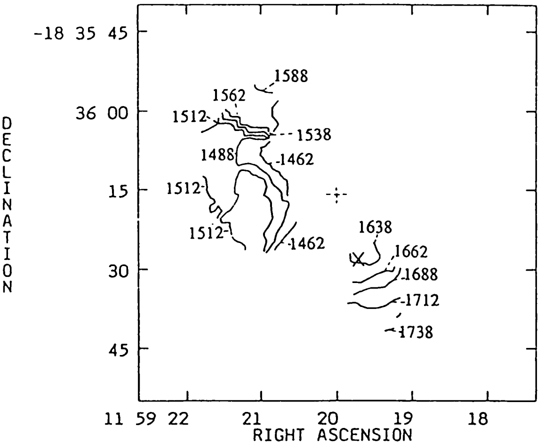

Fig. 4a. CO velocity contours (Stanford et al., 1990).

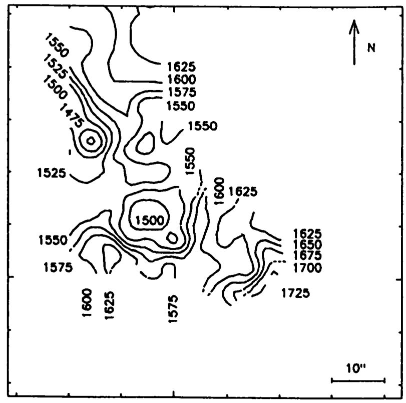

Fig. 4b. Hα velocity contours in the same area as figure 4a.

We note a good agreement with the previous optical velocities for most of the 18 emission knots detected by Rubin et al. (1970) as well as with CO velocities found by Stanford et al. (1990). On figure 4a one can see the velocity field in CO obtained by Stanford et al. and on figure 4b ours in Hα. The agreement is very good in the southern part of the field and quite good in the northern part.

Our radial velocity range is 400 km s^{-1}, less than in Barnes model (1988) where it is almost twice this value. Furthermore the nuclei of NGC 4038 and 4039 display velocities differing by only 30 km s^{-1} whereas Barnes model predict a difference of 300 km s^{-1}.

We have interesting areas where the Hα profiles clearly display two peaks, broadening or merely important asymmetry. It means that several regions are seen along the line of sight with difference in radial velocities varying from 30 km s^{-1} up to 200 km s^{-1}. But it is often hard to say to which galaxy belong the observed gas clouds, especially when there are strong velocity discontinuities. Only sophisticated models of the encounter could help to disentangle such situations.

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