THE SHAPING OF THE OPTICAL JET OF THE GALAXY NGC 4258

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SUMMARY. Hα + [NII] and red continuum CCD images as well as high resolution aperture synthesis CO maps were obtained in order to study the optical jet of the barred spiral galaxy NGC 4258. The CO observations show two clouds near the center of the galaxy; these clouds outline a channel and the Hα jet follows this channel. The observations are consistent with the jet being in or making a small angle with the galaxy plane. It is concluded that the interstellar medium may play an important role in making jets detectable optically and in shaping their forms.

I. OBSERVATIONS

We have obtained narrow-band images at Hα + [NII] of the remarkable galaxy NGC 4258 (M 106) with the Mont Mégantic 1.6 m telescope using a f/8 to f/3.5 focal reducer and a RCA CCD camera (≈ 1.1 arcsec/pixel). The stellar continuum derived from images at 7020 Å ($\Delta\lambda$= 200 Å) was subtracted to produce a pure emission line image of the galaxy at Hα + [NII]; CCD frames were obtained at several redshifts to cover a velocity range of about 800 km/s centered on the systemic velocity of the galaxy.

Figure 1 shows the Hα image of NGC 4258 thus obtained. The most striking feature is an elongated and S-shaped feature centered on the nucleus and detectable only as line emission. This structure discovered by Courtès and Cruvellier (1961) has been called "anomalous arms", and coincides with a radio jet identified by van der Kruit, Oort, and Mathewson (1972). Figure 2 shows our Hα image superposed with a 21-cm radio contour map obtained by van Albada and van der Hulst (1982). In the following, we refer to this unusual optical structure as the "optical jet" of NGC 4258, in the sense that it is due to emission from material shocked and excited by the energetic particles which are also responsible for the radio jet.

Although the jet bends in the same direction as the spiral arms, its structure is quite different, being more continuous and less knotty. Moreover the spectrum of the jet (Figure 3) displays strong [OI], [NII] and [SII] lines relative to Hα. Despite the difficulty of estimating the strength of the underlying stellar Hα absorption, the spectrum is clearly typical of shock-excited emission. In this article, we focus on the interaction between the jet and the interstellar medium.

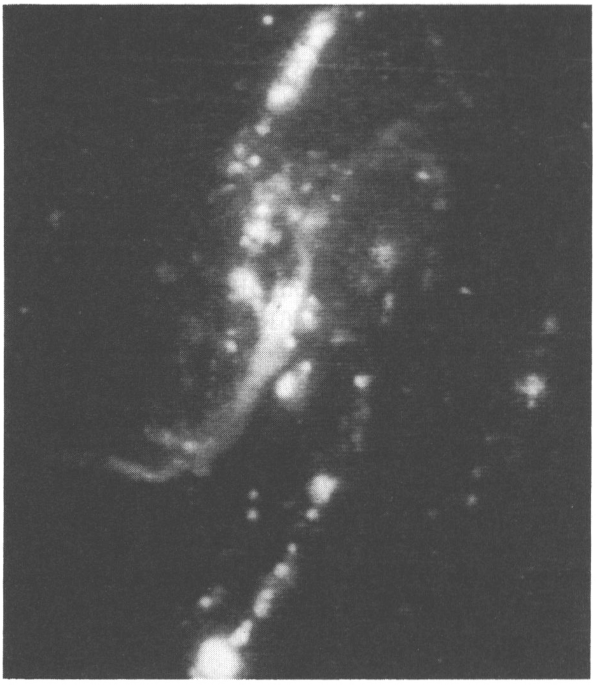

Figure 1. Image at Hα + [NII] of the giant barred spiral galaxy NGC 4258. The field shown is about $5' \times 5'$. North is at the top and east at left.

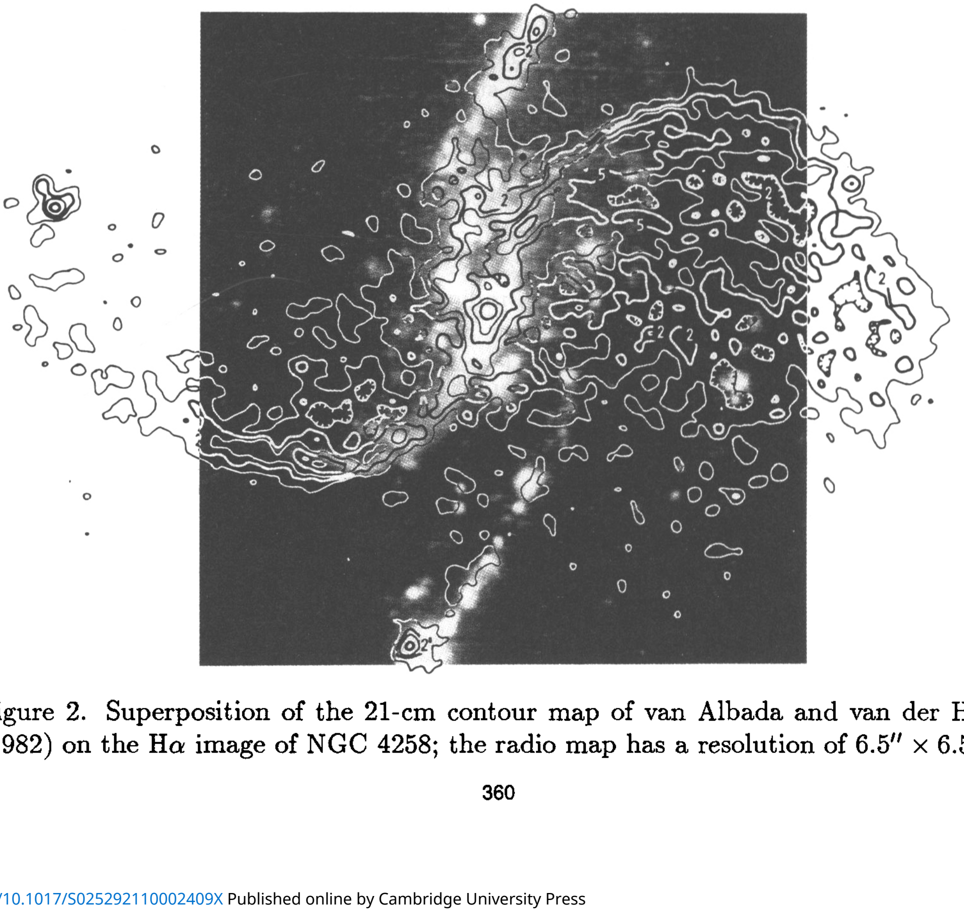

Figure 2. Superposition of the 21-cm contour map of van Albada and van der Hulst (1982) on the Hα image of NGC 4258; the radio map has a resolution of $6.5'' \times 6.5''$.

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II. THE NATURE OF THE OPTICAL JET OF NGC 4258

A jet of material expulsed from the center of a galaxy would be bent by the ram pressure of the interstellar medium and would normally appear as a "leading" structure (Wilson and Ulvestad 1982). The jet of NGC 4258 appears to be "trailing". In agreement with previous investigators (see in van Albada and van der Hulst 1982), we present evidences that the jet is in the plane of the galaxy and is indeed "trailing", a behavior that we will explain in section III.

Several characteristics of the jet betrays the role of the interstellar medium in shaping the jet, and demonstrate that the jet is not a pair of spiral arms.

1. Where Hα + [NII] is bright, 21 cm continuum emission is always strong (Figures 1 and 2). The converse is not true however: the radio jet remains visible much further away from the nucleus than the optical jet. Nevertheless this emphasizes that optical line emission is most probable in the inner parts of the galaxy where the density of the interstellar medium is high.

2. Splitting and bending of the optical jet at its SE and NW ends take place at the co-rotation radius as determined from HI observations (van Albada 1980).

3. A weakening in surface brightness and broadening of the SE portion of the optical jet (just before the splitting) is associated with a region of low density HI (van Albada 1978).

4. An integrated ^{12}CO (2.6 mm) intensity map of the central $1' \times 1'$ of NGC 4258 (Figure 4) obtained with the Owens Valley interferometer reveals molecular clouds outlining a well-defined channel. The optical-radio jet falls like a stream in this elongated gap. Moreover the optical jet closely espouses the shape of the CO channel; to the north, the jets bends eastward for a short distance alike the wall formed by the CO western CO clouds. The Hα brightness of the jet is high there; then the optical jet appears to dim in intensity and the radio jet fans out much more in the NW quadrant (Figure 2) when compared with the SE quadrant. The close match between the jet and molecular cloud morphology strongly suggests that the energetic particles responsible for the jet have bored a channel (or a tunnel) in the interstellar medium, and that the particles are maintaining the tunnel by a snow-plough action.

5. The optical jet has a smooth morphology indicating continuous interaction between energetic particles and the diffuse interstellar medium of NGC 4258. The optical jet is also relatively narrow, suggesting that the interstellar medium has a confining effect on the jet. The role played by interstellar magnetic fields may be important in confining such a structure.

III. DISCUSSION

Observational evidences are that the jet of NGC 4258 is flowing within the plane of the galaxy and that it is strongly interacting with the interstellar medium. We propose that the optical jet is made of interstellar gas which has been shocked and entrained

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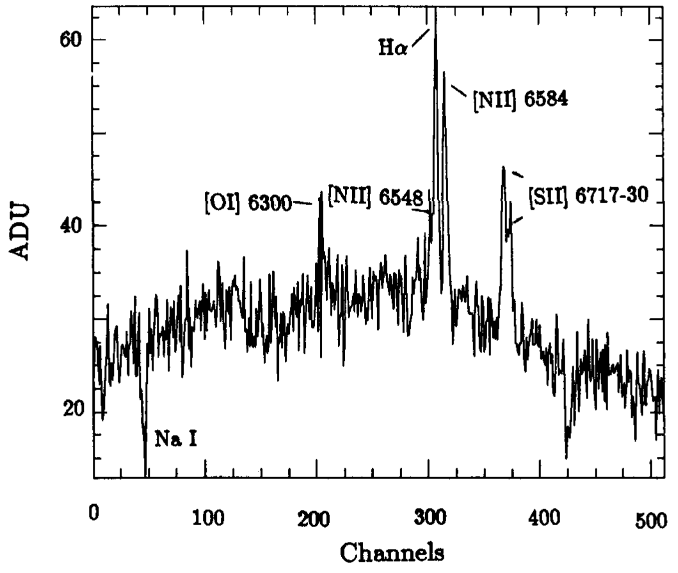

Figure 3. Spectrum in the red of the optical jet of NGC 4258 in the central region. The spectrum has not been corrected for atmospheric extinction nor for the detector spectral response, but sky background has been subtracted.

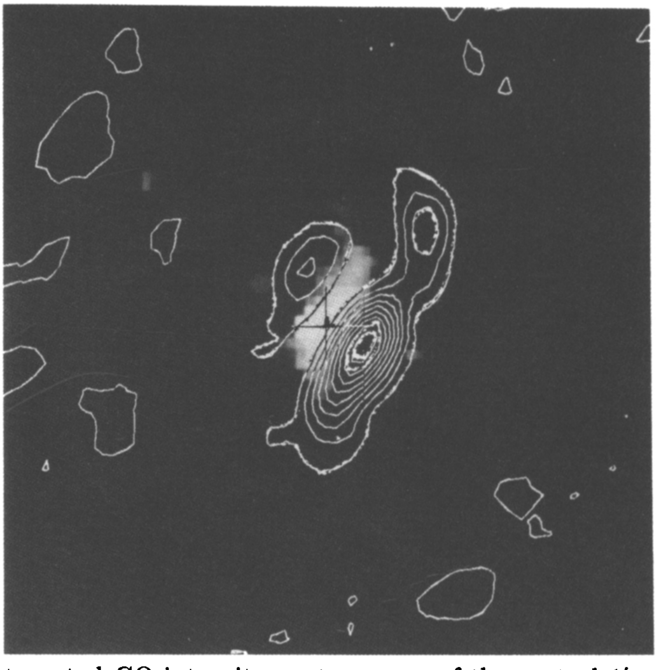

Figure 4. An integrated CO intensity contour map of the central $1' \times 1'$ of NGC 4258 obtained with the Owens Valley interferometer superposed on the Hα image of NGC 4258 selecting only the brightest levels of optical emission.

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by the high-energy particles responsible for the radio jet (Martin *et al.* 1989); such entrainment has been discussed by de Young (1986). It is unlikely that the material visible optically originates from the nucleus; although it is not known how far interstellar gas can be entrained by a jet of energetic particles, one can say the optical emission is probably due to gas being excited locally. Detailed velocity maps of the optical jet are needed.

The particles originating in the nucleus have bored a tunnel through the interstellar medium. This tunnel offers a path of least resistance to the beam of particles. However this tunnel is subjected to the rotational motion of the galaxy interstellar medium forcing the jet to "trail". Through its action on the tunnel, the interstellar medium shapes the morphology of the jet in the inner parts of NGC 4258. The jet in turn affects the interstellar medium of NGC 4258. It has hollowed out molecular clouds near the galaxy center and has evacuated a channel at larger galactocentric distances. Even at the edges of the galaxy, the disk emission seems to be disturbed in the regions intersected by the jet (van Albada and van der Hulst 1982).

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