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THE VERTICAL DISK STRUCTURE OF THE EDGE-ON SPIRAL GALAXY NGC 3079

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§1. Introduction

NGC 3079 is an edge-on SB(s)c galaxy at a redshift of 1225 km s^{-1} relative to the Local Group. Duric & Seaquist (1988) found a spectacular "figure-eight" radio structure aligned along the minor axis of the galaxy, centered on the nucleus, and extending 3 kpc above and below the plane. The geometry of this structure and the evidence of unusually high nuclear gas velocities (e.g., Heckman, Armus, & Miley 1990; Filippenko & Sargent 1992) suggest that a wind-type outflow from the nucleus is taking place (see also Veilleux et al. 1990). The disk of NGC 3079 is also remarkable: it is extremely rich in H II regions and is the only unambiguous example of a galaxy outside M31 and our own Galaxy to exhibit "Heiles-like" shells (Irwin & Seaquist 1990). Heckman, Armus, & Miley (1980) also identified a nebulosity with a ragged X-shaped morphology formed by a system of lumpy filaments with individual lengths of 3 – 5 kpc. They suggest that this material is ambient halo gas entrained into the boundary layers of the nuclear outflow (see also Hester et al. 1990)

The complex structure of the line emission in NGC 3079 makes this object an ideal target for an imaging spectroscopic study. The present paper reports the preliminary results of such a study.

§2. Observations and Reduction

The Hawaii Imaging Fabry-Perot Interferometer (HIFI; Bland & Tully 1989) was used at the Cassegrain focus of the CFHT 3.6-meter telescope to produce a data cube of this galaxy covering Hα + [N II] $\lambda\lambda$6548, 6583 at a resolution of about 65 km s^{-1}. Order separating filters with flat-topped transmission profiles centered at 6555 Å and 6585 Å and 54 Å FWHM bandpass passed only one etalon order, so true emission line profiles could be synthesized. The resulting data cube is made of 137 images (velocity slices) and represents a total integration time of about 19 hours. These data were parametrized using Gaussian fitting. Spatial smoothing was used to improve the sensitivity to the fainter features. Overall, reliable fits were made to 42 000 spectra.

§3. Results

The present data combine morphological and kinematic information which are of comparable sensitivity and velocity resolution as the radio data of Irwin & Seaquist (1990, 1991). A direct comparison of their data with ours can therefore be made. First, relatively strong Hα and [N II] line emission off the plane of the disk was detected at the south-eastern optical edge of the galaxy, confirming the existence of a warp in the disk of NGC 3079. We also looked for any optical counterparts to the radio shells and filaments identified by Irwin & Seaquist (1990). Possible correspondence between Hα and [N II] features and the *base* of the H I shells B, C, and D and filaments 5, 6, 9, 10, 12, 13, 14, and 15 were found. A few of these features may coincide in position and velocity with the X-shaped structure observed by Heckman, Armus, & Miley (1990). Individual spectra along this structure indicate that [N II]/Hα is not typical of H II regions, reaching values larger than unity in some regions (especially in the north-east quadrant). The *disk* line ratio map also shows that [N II]/Hα has a tendency to decrease with galactocentric radius in the brighter H II regions and to be higher outside of these H II regions (~ 0.4) than inside of them (~ 0.2).

The velocity field derived from the present data is similar but far from identical to the mean velocity field of Irwin & Seaquist (1991). The differences are attributed to extinction effects in the optical. The optical velocity curve is fairly typical of an Sc galaxy, being characterized by a steep rise at the center and a plateau at larger radii. The total velocity amplitude is ~ 400 km s^{-1}. The gas in the shells and filaments appears to follow normal galactic rotation. The line widths in the disk are of order 130 km s^{-1} (FWHM), with a slight tendency to increase towards the center of the galaxy. In some cases, the line widths in the shells and filaments are larger than in the surrounding gas.

§4. Discussion

A number of recent studies have investigated the effects of supernovae explosions on the ISM of spiral galaxies (e.g., Mac Low, McCray, & Norman 1989; Norman & Ikeuchi 1989; Heiles 1990; Koo & McKee 1992a,b, and references therein). The presence of a large superbubble at the center of NGC 3079 and the large number of H I shells in the disk of this galaxy make it a good laboratory to compare the predictions of these models with the observations.

The results of our preliminary analysis indicate that turbulence or shell expansion is causing line broadening in some of the optical filaments. Irwin & Seaquist (1990) arrived at a similar result from their radio data and concluded that the energy deposited in the shells of NGC 3079 is somewhat higher than for shells in the Galaxy. Another important question is the origin of the spatial variations of [N II]/Hα. Clearly, a higher heating rate per ionization is required in the high-[N II]/Hα gas. Photoionization by a diffuse radiation field (Mathis 1986) *cannot* explain [N II]/Hα ratios larger than ~ 0.6. The most likely sources of extra heating are (1) photoionization by the hard ionizing continuum of the active nucleus, (2) photoionization by the hard continuum of the coronal gas ejected into the lower halo by the supernova explosions (e.g. Donahue & Voit 1991; Slavin, Shull, & Begelman 1992), (3) the interaction of the line-emitting gas with high-energy relativistic electrons (e.g., Ferland & Mushotzky 1984), and (4) shocks. Processes (1), (3), and (4) are all likely to be taking place in the central superbubble while the large [N II]/Hα in the disk filaments are likely to be due to processes (2) and (4). The possibility that the high [N II]/Hα ratio is due to a higher metal content cannot yet be excluded (especially in the filaments and the brighter H II regions near the nucleus).

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