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Multifrequency Study of the Blue Compact Dwarf Haro 2

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Abstract. We present VLA H I imaging of the blue compact dwarf (BCD) galaxy Haro 2 and a map of its CO(1–0) distribution obtained with the OVRO millimeter array. In addition we obtained NIR JH images with the 2.1m telescope of Mexico's National Optical Observatory (OAN) and derived surface brightness profiles. Combining all these results we find an intriguing picture: the H I reveals that the kinematical major axis lies perpendicular to the photometric major axis. Our observations support the suggestion that this configuration is due to recent capture of an important quantity of gas of external origin.

1. Observations

We mapped the H I in Haro 2 with the NRAO Very Large Array (VLA) in its C and D configurations leading to a spatial resolution of about $14'' \times 15''$. The observations have on average an H I mass detection threshold of $4.5\times10^{6}\,M_{\odot}$. These values correspond to surface brightness sensitivities of $2.5\times10^{20}\,cm^{-2}$.

We observed the CO(1–0) transition in Haro 2 with the L and H configurations of the OVRO millimeter array. Natural weighting produced a synthesized beam of $3.3'' \times 2.6''$, and an rms noise per channel of 9.6 mJy beam^{-1}. A full discussion of the H I and CO results is given in Bravo–Alfaro et al. (2004a).

NIR observations were carried out at the 2.1–m telescope of the OAN, located on San Pedro Mártir in Baja California, Mexico, with the IR Camera CAMILA. Two images in J (1.275 μ) and H (1.672 μ) were obtained with total exposure times of 2800 s and 1680 s, respectively.

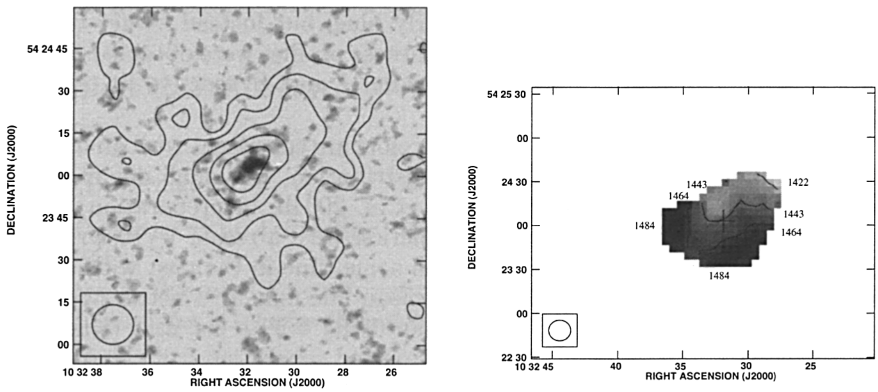

Figure 1. (a) Overlay of H I contours on a CO(1–0) greyscale representation. The contours are 2.0 (5σ), 4.0, 8.1, 12.2, and 16.2 $\times 10^{20}\,\mathrm{cm}^{-2}$. (b) Intensity–weighted mean velocity field of Haro 2. The numbers give heliocentric velocity in $\mathrm{km\,s}^{-1}$. The synthesized beam for both figures is indicated at the lower left and measures $14.8'' \times 14.1''$.

2. Results

Like most star–forming dwarf galaxies, Haro 2 is H I–rich. Fig. 1a shows the H I superposed on the CO(1–0) total intensity map. The H I appears elongated in a southeast–northwest direction. The H I disk measures some $1.3' \times 0.7'$ at a level of $5{\times}10^{20}\,\mathrm{cm}^{-2}$ (equivalent to 7.2×4.0 kpc at an estimated distance of 19.5 Mpc). The orientation of the H I coincides with that of the optical image, whose major axis has a position angle of approximately 135°. The molecular gas is restricted to the area of highest H I column density. We measured the total CO(1–0) flux to be $\mathrm{F_{CO}} = 24.3 \pm 3.2\,\mathrm{Jy\,km\,s^{-1}}$. Assuming a Galactic conversion factor of $\mathrm{X_{CO}} \equiv N_{\mathrm{H_2}}/I_{\mathrm{CO}} = 2 \times 10^{20}\,\mathrm{cm}^{-2}\,(\mathrm{K\,km\,s}^{-1})$ (Strong et al. 1988), we estimate a total molecular hydrogen mass: $M_{\mathrm{H_2}} = (7.3{\pm}0.9){\times}10^{7}\,M_{\odot}$.

Fig. 1b presents the H I velocity field, which reveals the galaxy's complex kinematics. There is virtually no velocity gradient visible along the major axis defined by the optical light and H I distribution. Instead, a clear gradient is seen at roughly right angles to this axis, which is consistent with the analysis of the central region ($30''$) by Legrand et al. (1997) using the Hα emission line. This strongly suggest an external source for the H I gas. The picture emerging is that of an early–type galaxy (possibly S0), rather than a dIrr, which has caught through an interaction or recent merger a substantial amount of gas. The fresh supply of fuel has led to a central starburst.

Star formation activity is seen in our maps above $10^{21}\,\mathrm{cm}^{-2}$ and those regions of highest H I column density coincide with the optical outline. The CO in Haro 2 follows the highest H I concentration, indicating that star formation is likely restricted to the very central regions.

Total asymptotic magnitudes in J and H were obtained by fitting standard growth curves, using circular apertures (maximum radius $19''$). We found $J = 11.9 \pm 0.1$ mag and $H = 11.21 \pm 0.03$ mag. Contrary to Thuan (1983), we do

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not find the color $J - H$ to be particularly blue, but instead rather typical of BCDs or normal S0 galaxies. Surface brightness profiles were obtained by fitting elliptical isophotes. The resulting profiles for J and H seem to fit the curves better than a power–law or an $r^{1/4}$ law.

As for the origin of the gas, the $J-H$ colors are consistent with an old stellar population. The exponential NIR light distribution, the small deviation from purely elliptical isophotes (Bravo–Alfaro et al. 2004b, in preparation) and the low level of asymmetry are all in contradiction with a recent ($\leq 10^8$ yr) merger (Mihos & Hernquist 1996). An interaction some time in the past with a nearby companion which has moved away in the meantime may be a better hypothesis. A possible donor is the putative companion lying $4.7'$ to the east (Huchtmeier et al. 1995). If at the same redshift, its projected separation from Haro 2 would be a mere 27 kpc. This possible companion could have lost all its gas in the interaction, explaining why it remains undetected in H I. As a conclusion, the capture of an important amount of external gas remains the most plausible explanation for the Haro 2 configuration.

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