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H I GAS NEAR THE GIANT ELLIPTICAL GALAXY NGC 4472

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ABSTRACT

H I gas has been found between a dwarf irregular and the giant elliptical galaxy NGC 4472 in the Virgo Cluster. The H I deficiency of the dwarf itself suggests that the H I seen has been removed from the dwarf by either tidal stripping or the sweeping effect of the hot gaseous halo, which is known from X-ray data to be surrounding the elliptical galaxy. Hence in NGC 4472, we may be witnessing the actual process of accretion of gas into an elliptical galaxy. The small double radio source in the center of NGC 4472 may be a related phenomenon.

Subject headings: galaxies: intergalactic medium — galaxies: individual — radio sources: 21 cm radiation

I. OBSERVATIONS

Neutral hydrogen observations by Kumar and Thonnard (1983) with the Arecibo radio telescope did not reveal any H I emission in the direction of the giant elliptical galaxy NGC 4472 (M49), consistent with previous results and upper limits. A narrow emission feature was seen at a position to the southeast and was attributed to the dwarf irregular galaxy UGC 7636 (+8°33; cf. Reaves's 1983 catalog, and Sandage and Binggeli's 1984 classification and atlas) which is located 5′.6 to the southeast of NGC 4472 (see Fig. 1).

Previous 21 cm observations with the Westerbork radio telescope[1] (WSRT) covered the velocity range −100 to +1800 km s^{-1} with an angular resolution of 24″ × 173″ and an rms noise of 1.3 mJy per beam area. Although no signal was detected at the original high angular resolution, when the WSRT data were convolved to a circular beam of 3′, close to the Arecibo resolution, a 4 σ feature was seen between NGC 4472 and the dwarf at the velocity closest to that of the Arecibo narrow emission line (475 km s^{-1}). The H I map is shown in Figure 1 superposed on a photograph from Arp's (1966) *Atlas of Peculiar Galaxies* (picture 134). The peak intensity of this feature is 12 ± 3 mJy. Even though this map is at low signal-to-noise ratio, the fact that no H I can be seen in the higher resolution map (which has higher sensitivity to any unresolved H I) provides strong evidence that the feature is extended. Maps at intermediate resolutions show only a marginal increase in signal-to-noise ratio.

As a consequence of this WSRT result, Kumar and Thonnard's observations were reexamined, and it was realized that the signal detected with the Arecibo telescope could also have come from an extended region in a direction between the dwarf and the elliptical galaxy. A new observation at Arecibo[2] with the flat feed receiver, 4′.0 beam, in the direction of the Westerbork 4 σ feature gave the profile shown in Figure 2 and therefore fully confirmed both the previous detection of Kumar and Thonnard (1983) and the WSRT result. The central velocity of the emission line is 472 km s^{-1}, the peak flux density is 23.5 mJy, and the full velocity width at half-power is 29 km s^{-1}. These values agree very well with the WSRT (Fig. 1) radial velocity of 469 km s^{-1} and observed peak value 12 mJy per beam area diluted by a factor of 2 in the 66 km s^{-1} channel width. The Arecibo flux integral is 0.7 Jy km s^{-1}. This gives a value of 6.5×10^7 $M_\odot$ for the H I mass at the distance of 20 Mpc (i.e., at the distance of NGC 4472, assuming H_0 = 50 km s^{-1} Mpc^{-1}). But the WSRT data suggest that the emission may extend over a larger area than the 4′ Arecibo beam, and therefore the value of the mass given here should be regarded as a lower limit to the H I mass.

In the Arecibo profile there is a hint of emission at low levels that may have a velocity extent of ~100 to 150 km s^{-1}.

Subsequent to these H I observations the radial velocity of UGC 7636 was measured by Huchra (1985) and found to be 276 ± 78 km s^{-1}, close to but probably lower than that of the H I cloud. Both UGC 7636 and the H I have a significantly

[1] The Westerbork Synthesis Radio Telescope is operated by the Netherlands Foundation for Radio Astronomy, which is financially supported by the Netherlands Organization for the Advancement of Pure Research (ZWO).

[2] The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, which is operated by Cornell University under contract with the National Science Foundation.

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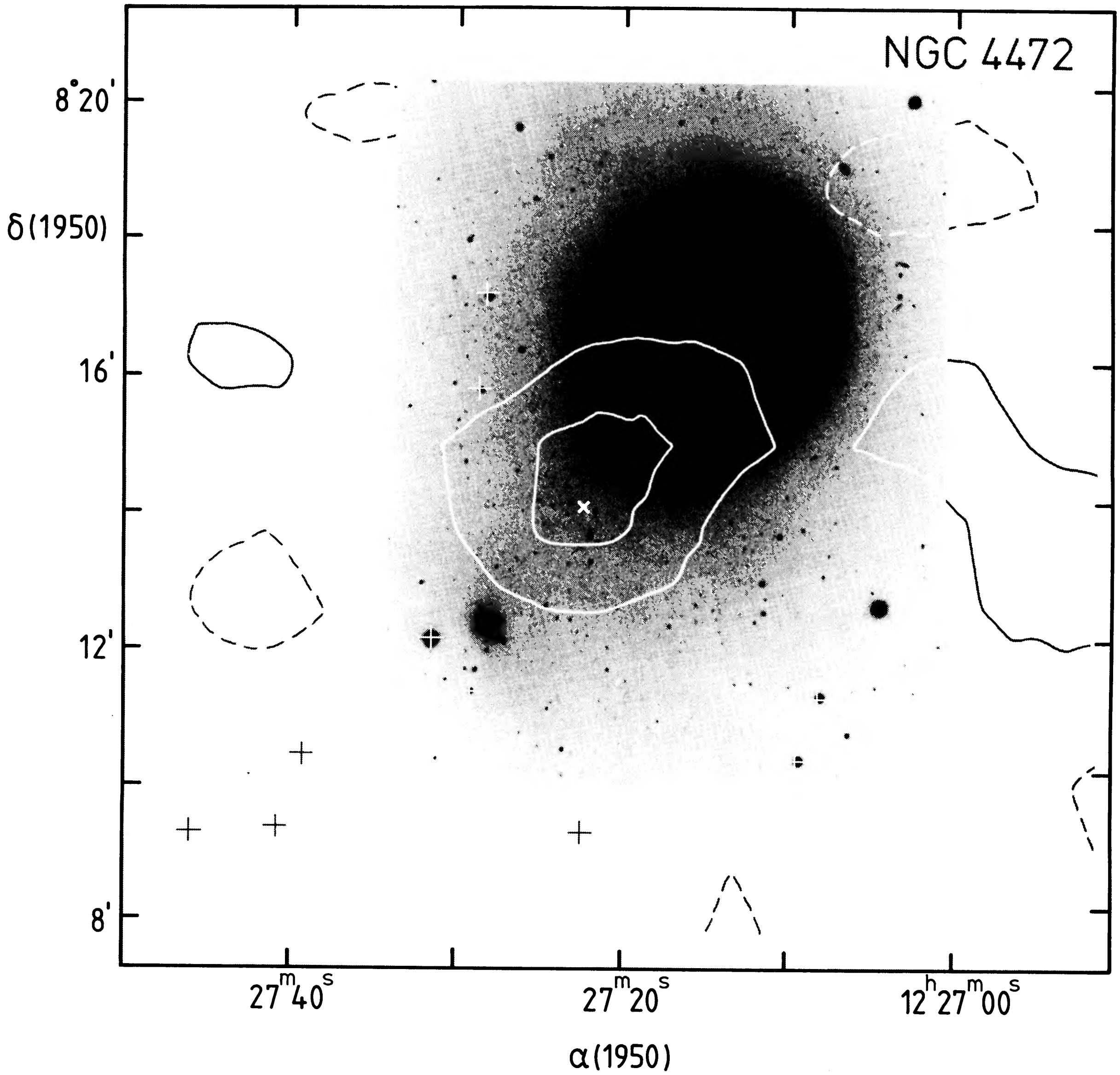

FIG. 1.—H I-line channel map at V_{hel} = 469 km s^{-1} superposed on a photograph of NGC 4472 from Arp's (1966) *Atlas of Peculiar Galaxies* (picture 134). The contour values are −5 (dashed), +5 (~ 1.5 σ), 10 mJy per beam area. The beam is circular and is 3′ wide at half-power (1 mJy per beam area = 0.02 K). The channel width is 66 km s^{-1}. The crosses mark the positions of reference stars in the field; the X shows the position at which the profile in Fig. 2 was obtained.

lower velocity than NGC 4472 (V_{hel} = 1001 km s^{-1}; cf. Schechter 1980).

II. DISCUSSION

The observations clearly show the presence of an extended cloud of neutral hydrogen between the E galaxy NGC 4472 and the dwarf irregular UGC 7636. It has a total H I mass of 6.5×10^7 $M_{\odot}$ and a narrow profile (29 km s^{-1}) with a mean radial velocity of 472 km s^{-1}, 529 km s^{-1} lower than that of NGC 4472 (V_{hel} = 1001 km s^{-1}; Schechter 1980) and perhaps somewhat higher than that of UGC 7636 (V_{hel} = 276 ± 78 km s^{-1}; Huchra 1985). Since it was not detected at the original high WSRT resolution it must be more than ~ 1′.5 in extent, probably elongated in the direction between the dwarf and the E galaxy with a projected linear size between 10 and 30 kpc. This would give a mean volume density of order 1×10^{-3} atoms cm^{-3}. The cloud could, however, have lumpy structure with much higher local densities up to 0.1 to ~ 1 cm^{-3}. Both the dwarf and the H I are seen in projection well within the optical image of the E galaxy and are approximately aligned in the direction of its major axis (PA ≈ 155°). The elliptical galaxy itself is known to have an extended, weak radio source (Ekers and Kotanyi 1978), which is oriented (PA ≈ 70°) almost orthogonally to its major axis and to the direction of the H I and the dwarf. Furthermore, it is a relatively strong X-ray source with an extended halo (Forman, Jones, and Tucker 1985).

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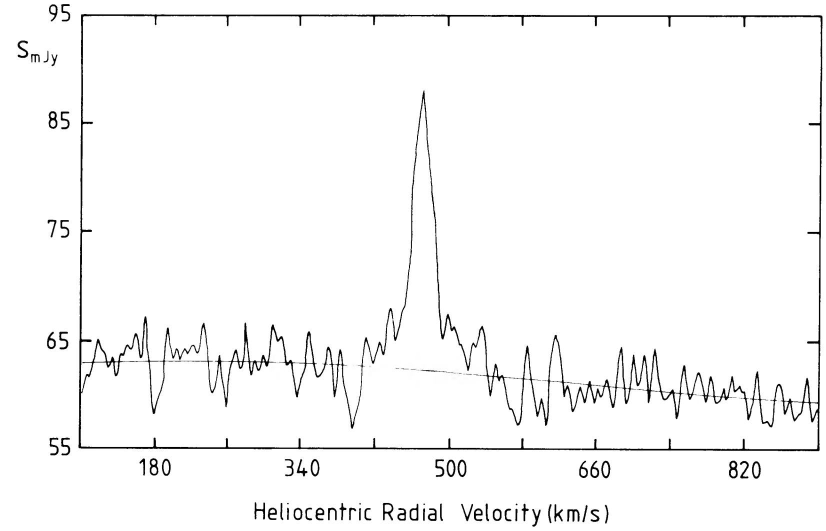

FIG. 2.—21 cm line profile obtained with the Arecibo radio telescope ($\alpha = 12^h27^m22^s.5$, $\delta = 08°14'00''$; see also Fig. 1) between NGC 4472 and the dwarf irregular UGC 7636 located 5'.6 to the SE (courtesy of R. Giovanelli).

We discuss here the possible origins of the observed H I cloud, assuming that it is physically connected with NGC 4472 and the dwarf.

There is no doubt that the H I reported here is displaced from the dwarf in the direction of NGC 4472. From the dwarf itself there is no H I emission in the WSRT data nor in a new Arecibo observation (Oosterloo and Shostak 1984) above a 3 σ value of 9 mJy per beam area in the velocity range from -500 to $+1800$ km s^{-1} (completely encompassing the dwarf galaxy radial velocity). This corresponds to a 3 σ upper limit to the H I mass of 4.2×10^7 $M_{\odot}$ (assuming $\Delta V = 50$ km s^{-1}) and implies a large deficiency of H I in the dwarf, most unusual for an object of this morphological type (Im) and luminosity. The B_T magnitude of the dwarf, as given by de Vaucouleurs and Pence (1979), is 14.72 (corrected Zwicky mag), corresponding to an absolute magnitude of -16.8 and luminosity $L = 8.1 \times 10^8$ $L_{\odot}$ at 20 Mpc. The M_H/L ratio must then be less than 0.05 $M_{\odot}/L_{\odot}$ (3 σ limit), completely outside the range of M_H/L values (0.3–1.5 $M_{\odot}/L_{\odot}$) found by Fisher and Tully (1975) for dwarfs of this magnitude.

From this we are led to conclude that H I has been removed from the dwarf, and, furthermore, that the H I observed nearby is the removed gas. The mass of H I found here (6.5×10^7 $M_{\odot}$) would give an M_H/L value of 0.08 $M_{\odot}/L_{\odot}$, still less than the canonical values for dwarfs; but this is not surprising as we probably have not detected all the gas originally associated with the dwarf. The separation of H I from the dwarf could either be gravitational or the sweeping effect of the hot gaseous halo around NGC 4472 detected in the X-ray (Forman, Jones, and Tucker 1985). We will briefly explore the observational consequences of these two mechanisms.

Tidal stripping is the accepted explanation of H I bridges and tails in a number of interacting systems, as in the case of M81 (van der Hulst 1979) where a partial displacement of the H I from the stellar body of the irregular companion, NGC 3077, is seen. The H I may well have been located in the outer parts of the dwarf, as is the case for M81 dwA (Sargent, Sancisi, and Lo 1983), and it could easily be separated from the stellar system. Further supporting evidence for the tidal hypothesis includes the following: the small velocity width of the profile, which is typical of H I bridges and tails observed in interacting systems (Haynes 1981); and a faint hint of an optical tail from the dwarf toward NGC 4472, in the photographs of Arp's (1966) and of Sandage and Binggeli's (1984) atlases. Arguing against the tidal model is the lack of any tide-countertide symmetry, although in this case the missing H I could be somewhat fainter and/or have a larger velocity dispersion.

In the alternative model the H I is stripped from the stellar component by the gaseous halo of NGC 4472. In projection the H I cloud is seen between the dwarf and NGC 4472 and well within both the optical and X-ray halo. With respect to NGC 4472 the dwarf has a radial velocity component of 725 ± 78 km s^{-1}, whereas the H I cloud appears to be somewhat slower (529 km s^{-1}). The condition for a sudden ram pressure stripping as given by Gunn and Gott (1972) will be easily met in this case since the density of the halo medium around NGC 4472 is larger than 10^{-3} cm^{-3} (Fabian 1985), the velocity of the dwarf through that medium is of order 10^3 km s^{-1}, and the dwarf has low stellar surface density. Once the gas has been separated from the dwarf it may evolve in the way described by Silk and Norman (1979) and fall toward the center of the elliptical galaxy. The X-ray observations of NGC 4472 (Forman, Jones, and Tucker 1985) imply a halo temperature of 10^7 K. A radial cooling flow of the hot gas as proposed for gas accretion in the centers of galaxy clusters (Fabian and Nulsen 1977) could also be occurring here. But the typical cooling flow velocities are much too low to influence the distribution of H I gas. A problem with the ram pressure stripping model is how to prevent the ionization of the H I by the hot gaseous halo surrounding it. The H I will be shock heated, both by the ram pressure and by the thermal pressure of the surrounding medium. Its fate may depend on

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the presence of magnetic fields and significant recombination. Without knowledge of the fine structure, and hence density, of the H I, it is difficult to estimate these effects. The faint optical emission in the bridge, if real, might be due to recently formed low-mass stars.

The morphology of the dwarf (irregular type, presence of H II regions, etc.) and the proximity of the H I indicate that the gas removal, either tidal or due to the halo, has not been complete and must be quite recent. The observed H I, which has already been captured by NGC 4472, could form a ring of gas around it similar to, but significantly less massive than, those found in spindle-type galaxies (Shane 1980; Schweizer, Whitmore, and Rubin 1983). Some of this gas may well be accreted into the central region of NGC 4472 to feed its nucleus (cf. Gunn 1979). The small (10 kpc), double-lobed core-jet radio source (Ekers and Kotanyi 1978; Laing and Kotanyi 1984) may indicate that accretion has already been occurring for $\sim 10^7$ yr. If the alignment of dwarf, H I, and major axis of NGC 4472 and the orthogonality to the radio source (PA $\approx 70°$) already noted is not a coincidence, this implies that the origin of the radio source and the event we are now witnessing are related. The stellar component of the dwarf, now devoid of H I gas and with a significant fraction of its mass removed, could evolve into a dwarf elliptical.

Finally, we should mention a third but less likely possibility which is that of primeval gas orbiting around NGC 4472. If the orbit is close to circular, the velocity of 529 km s^{-1} of the gas relative to that of NGC 4472 would imply for the latter a rotational mass of at least 1.5×10^{12} $M_\odot$ inside 4′ (23 kpc) and $M/L \gtrsim 10$ $M_\odot/L_\odot$ from the luminosity $L = 1.4 \times 10^{11}$ $L_\odot$ ($B_T^\circ = 9.1$; de Vaucouleurs, de Vaucouleurs, and Corwin 1976), at 20 Mpc. This is similar to the value of the mass estimated by Forman, Jones, and Tucker (1985) from X-ray data. The alignment of H I and major axis of NGC 4472 and orthogonality with the radio source, reminiscent of ellipticals with dust lanes, might even suggest an edge-on ring or disk of material rotating around NGC 4472 and close to its principal plane. This has, however, no further observational support as no hint of H I emission has been found on the northeast side of NGC 4472 either in the WSRT data or in the recent Arecibo measurement ($\alpha_{1950} = 12^h27^m3^s.0$, $\delta_{1950} = +8°20'00''$; velocity range +500 to +1500 km s^{-1}, 3 σ upper limit = 3 mJy) by Oosterloo and Shostak (1984). On the whole this possibility of primeval gas seems unlikely as it would also leave the H I deficiency of the dwarf unexplained.

Clearly the tentative pictures presented here could be tested and improved by means of the following: (1) a more precise, optical determination of the radial velocity and spectral characteristics of the dwarf irregular UGC 7636; (2) new photographic material to check the presence and nature of any faint optical emission or dust between the dwarf and NGC 4472 (any Hα filaments?); and (3) a more sensitive, high angular resolution study of the H I emission; this is being pursued at present with new 21 cm line observations at Westerbork.

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