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AN OPTICAL COUNTERPART TO THE H I CLOUD IN THE LOCAL SUPERCLUSTER

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ABSTRACT

We report the detection of an optical counterpart to the large H I cloud recently discovered by Giovanelli and Haynes in the Local Supercluster. The peak of the H I flux corresponds to a low surface brightness, dwarf irregular galaxy. The counterpart was discovered on a photographically amplified image from the UK Schmidt Telescope, and its maximum extent is 180″ at the 27 mag arcsec^{-2} isotope. We suggest that the H I and optical data can be explained by a pair of LSB dwarf irregular galaxies that have similar velocities. Some star formation appears to be taking place in this system, but the H I column density is below the threshold for extensive star formation. A kinematic study is required to determine the total mass. This galaxy is similar to other LSB dwarfs and dI pairs which have enormous mass-to-light ratios and H I sizes far in excess of the optical scale length.

Subject headings: galaxies: formation — galaxies: individual (1225+018) — galaxies: stellar content — galaxies: structure

III. INTRODUCTION

Systematic searches for low surface brightness (LSB) galaxies by Bingelli, Sandage, and Tammann (1985), Impey, Bothun, and Malin (1988), Schombert and Bothun (1988), and Irwin *et al.* (1990) have discovered a significant number of H I–rich galaxies. These galaxies may be rather young in the sense of having inefficient disk formation (e.g., Impey and Bothun 1989). This inefficiency probably reflects a surface density of gas which is below the threshold for the formation of molecular clouds and subsequent coherent star formation. The threshold surface density is $n_{\rm H\,I} \approx 10^{21}$ cm^{-2} (Skillman 1987). If this is the case, then the evolution of these disk galaxies is quiescent (see van der Hulst *et al.* 1987; Bothun 1989; Kennicutt 1989). The most extreme version of a LSB disk galaxy would be one which has been detected only in H I and has no optical counterpart down to some isophotal limit. The best known example is the H I ring in Leo which remains undetected optically (Schneider, Schombert, and Bothun 1990). However, this cloud is likely to be tidal debris associated with the nearby Leo group and is therefore not a galaxy in the conventional sense.

Recently, Giovanelli and Haynes (1989) detected a large H I cloud in the Virgo supercluster which has no apparent optical counterpart. If this is the case, and if the gas in that cloud is undergoing ordered rotation, then a bona fide case of a nearby protogalaxy has been discovered. The other leading contender for a protogalaxy (or more accurately, a failed disk) is the giant, LSB galaxy Malin 1 discovered using photographic amplification by Bothun *et al.* (1987) and discussed by Impey and Bothun (1989). Malin 1, however, lies at a redshift of $z = 0.083$, whereas the Giovanelli and Haynes object has a redshift of $z = 0.0042$. Moreover, Malin 1 has an H I mass which is 200 times larger ($\sim 10^{11}\ M_\odot$) and an H I velocity width which is 10 times larger (~ 300 km s^{-1}) than the Giovanelli and Haynes cloud. The objects can be legitimately compared in their manner of selection. Both are easy to detect in H I surveys but require deep plate material for optical detection. Taken together, they illustrate that low surface brightness galaxies with an enormous range of properties are accessible to the Malin technique.

Giovanelli and Haynes (1989) characterize their incompletely mapped H I distribution as being 200 kpc in diameter. The observed signal has a line width of 30 km s^{-1}. They present a pseudo–rotation curve in support of the ideas that the gas is in circular rotation. However, if 30 km s^{-1} is the true rotation velocity, then one orbital period is 20 Gyr! On the other hand, if this cloud has a mass of a typical spiral galaxy, then its true rotation velocity would be 200–300 km s^{-1}, and the cloud must therefore be orientated almost perfectly face-on. Inspection of the H I map of Giovanelli and Haynes (1989) does not indicate a face-on orientation. We note that full two-dimensional kinematical information will be required to make definitive statements about the inclination and mass.

An alternative to the protogalaxy hypothesis is the detection of a large H I envelope associated with a LSB dwarf irregular galaxy. This is not unprecedented in the Local Supercluster, as galaxies like DDO 154 (Carignan and Freeman 1988) and DDO 170 (Lake, Schommer, and van Gorkom 1989) have H I extents that are several times the optical scale length. Carignan and Freeman quote a H I–to–Holmberg diameter ratio for DDO 154 of 5; the same ratio for this galaxy is about 20. The observed velocity width favors the second interpretation, since 30 km s^{-1} is a typical line width for gas-rich dwarf irregulars in the Virgo Supercluster (e.g., Bothun *et al.* 1985; Hoffman, Helou, and Salpeter 1988). In this *Letter*, we report the optical discovery of a LSB dwarf irregular which is spatially coincident with the strongest H I signal detected by Giovanelli and Haynes (1989). Note that this position is displaced by nearly 11′ from the apparent rotation center of the H I cloud.

II. THE OPTICAL COUNTERPART

Unfortunately, the announcement of this putative Local Supercluster protogalaxy came when the object was behind the Sun. Therefore, we have not yet had the opportunity to acquire a good CCD picture at the location of the 21 cm measurement. However, there is existing plate material both from the new Palomar Sky Survey (Djorgovski 1990) and the UK Schmidt survey. We have searched for an optical counterpart using a photographically amplified UK Schmidt plate of the region of interest and have clearly detected a galaxy. The plate was taken with the UK Schmidt Telescope at Siding Spring Observatory on 1985 May 12, with a IIIa-J emulsion that had been hypersensitized in nitrogen and hydrogen. The exposure time was 75 minutes, exposed through a GG 395 filter. Photographic amplification was carried out as described by Malin (1978).

Figure 1 (Plate L10) shows an area of 1°.5 × 1°.2 centered on the optical counterpart. The solid line superposed on the photograph is the extent of detectable H I emission measured by Giovanelli and Haynes (1989). Figure 2 (Plate L11) shows an expanded view of the galaxy, a field covering 20′ × 16′. The galaxy has an overall irregular morphology with a fairly bright and compact nucleus. The galaxy may be resolved into its brightest stars, but there is a possibility of contamination by foreground stars. The morphology is clearly suggestive of ongoing star formation. With a central surface brightness of ~25 B mag arcsec^{-2}, the diffuse component of this galaxy is below the sensitivity threshold of the original Palomar Sky Survey (Schombert and Bothun 1988). The surface brightness of the nucleus is about 23.5 B mag arcsec^{-2}. The limiting isophote is around 27 B mag arcsec^{-2} or under 1% of the sky background level of 21.6 B mag arcsec^{-2}.

The position of the galaxy was measured using the Monet measuring machine at NOAO. A grid of nine SAO stars gave an astrometric solution with an accuracy of 0″.6. At the center of the diffuse envelope, there is an unresolved component that we have assumed to be the nucleus. The position of the nucleus is 12^{h}25^{m}12^s.77, +1°52′36″.1 (1950). This corresponds to the position of the peak H I flux within 50″, which is a fraction of the Arecibo beam size. There is no detectable optical counterpart at the secondary peak in H I flux (see cross on Fig. 1). In addition, the positions of nine other features in the galaxy were measured and are presented in Table 1. The features are labeled on Figure 3 (Plate L12), which is a gray-scale plot of the amplified photograph. Some of these features may be foreground stars, but others are expected to be complexes of star formation in the galaxy. The three highest surface brightness regions of diffuse emission away from the nucleus are b, c, and d. Further observations, including broad and narrow band CCD imaging, and spectroscopy are needed to clarify the optical structure of this newly discovered Local Supercluster galaxy.

TABLE 1

ASTROMETRY OF OPTICAL COUNTERPART

Feature	R.A. (1950)	Decl. (1950)
a (nucleus)	12^{h}25^{m}12^s.77	+1°52′36″.1
b	12 25 12.01	+1 52 15.2
c	12 25 12.36	+1 53 31.5
d	12 25 13.34	+1 52 27.4
e	12 25 14.22	+1 52 26.2
f	12 25 10.68	+1 53 10.9
g	12 25 11.02	+1 52 00.7
h	12 25 15.11	+1 52 49.0
i	12 25 13.20	+1 52 48.8
j	12 25 12.63	+1 53 02.5

III. DISCUSSION

The position and velocity of this galaxy make it difficult to unambiguously derive its distance using the Virgocentric flow model of Aaronson *et al.* (1982). There are three possibilities: it could be located at the Virgo cluster distance (~15 Mpc), or it could be infalling from either the front or the back of the cluster. If the galaxy is resolved into brightest stars (Fig. 2), the distance is probably no more than 5 Mpc, and therefore it would be infalling to Virgo with a velocity of about 600 km s^{-1}. We can consider this a lower limit to the distance, since current low-infall models with a Local Group velocity of 150 km s^{-1} would predict a Virgocentric infall of 225 km s^{-1} at 5 Mpc (Peebles 1988; Staveley-Smith and Davies 1989). On the other hand, a good argument against a Virgo distance of 15 Mpc is the relatively undisturbed nature of the H I cloud. Tidal forces and collisions in a cluster environment would be expected to disrupt any slowly rotating object of this size. Giovanelli and Haynes (1989) originally used a distance of 20 Mpc. A much reduced distance estimate eases the apparent conflict between the rotation velocity, the orientation of the H I, and the age of the Universe. We believe the most likely distance is in the range 5–9 Mpc.

The dI galaxy is located at one of the flat portions of the pseudo–rotation curve of Giovanelli and Haynes (1989), with a velocity of ~1300 km s^{-1}. The secondary H I peak has no optical counterpart and is near the other flat portion, with a velocity of ~1250 km s^{-1}. Therefore, we believe that the H I data can be accounted for by a pair of gas-rich dwarf galaxies, similar to the DDO 170 system (Lake, Schommer, and van Gorkom 1989). The DDO 170 system has a large H I extent (H I–to–Holmberg diameter ratio of 3), a velocity separation of 85 km s^{-1}, a physical separation of 62 kpc, and one-third of the visible mass in the form of gas.

It is difficult to be very quantative about the nature of this galaxy, using only a photograph. However, the mean diameter at the 27 mag arcsec^{-2} isophote is 75″. The limit to the total apparent magnitude is therefore $B \leq 17.9$. The optical luminosity must be at least $M_B = -11.6$ for our preferred distance of 8 Mpc, or -13.6 for the larger distance used by Giovanelli and Haynes (1989). Independent of distance, the gas-to-stars ratio may be as high as $M_{\rm H\,I}/L_B \sim 100$. If the analogy with DDO 170 is appropriate, then a deep CCD search at the position of the second H I peak will be fruitful. Few other galaxies are visible in Figure 1, and we note that this gas-rich system may be in a region of low galaxy density.

Star formation has obviously been inefficient in a galaxy with such a large fraction of mass in gas. The peak H I column density is 2×10^{20} atoms cm^{-2}, identical to the peak column density in the giant, LSB galaxy Malin 1 (van Gorkom *et al.* 1990), and well below the threshold thought to be required for extensive star formation (Kennicutt 1989). Lake and Schommer (1984) have studied pairs of dI galaxies and have found enormous mass-to-light ratios (~1000 in solar units) on prodigous scales (100–900 kpc). Overall, the properties of this galaxy seem to be similar to the well-studied galaxy DD0 154

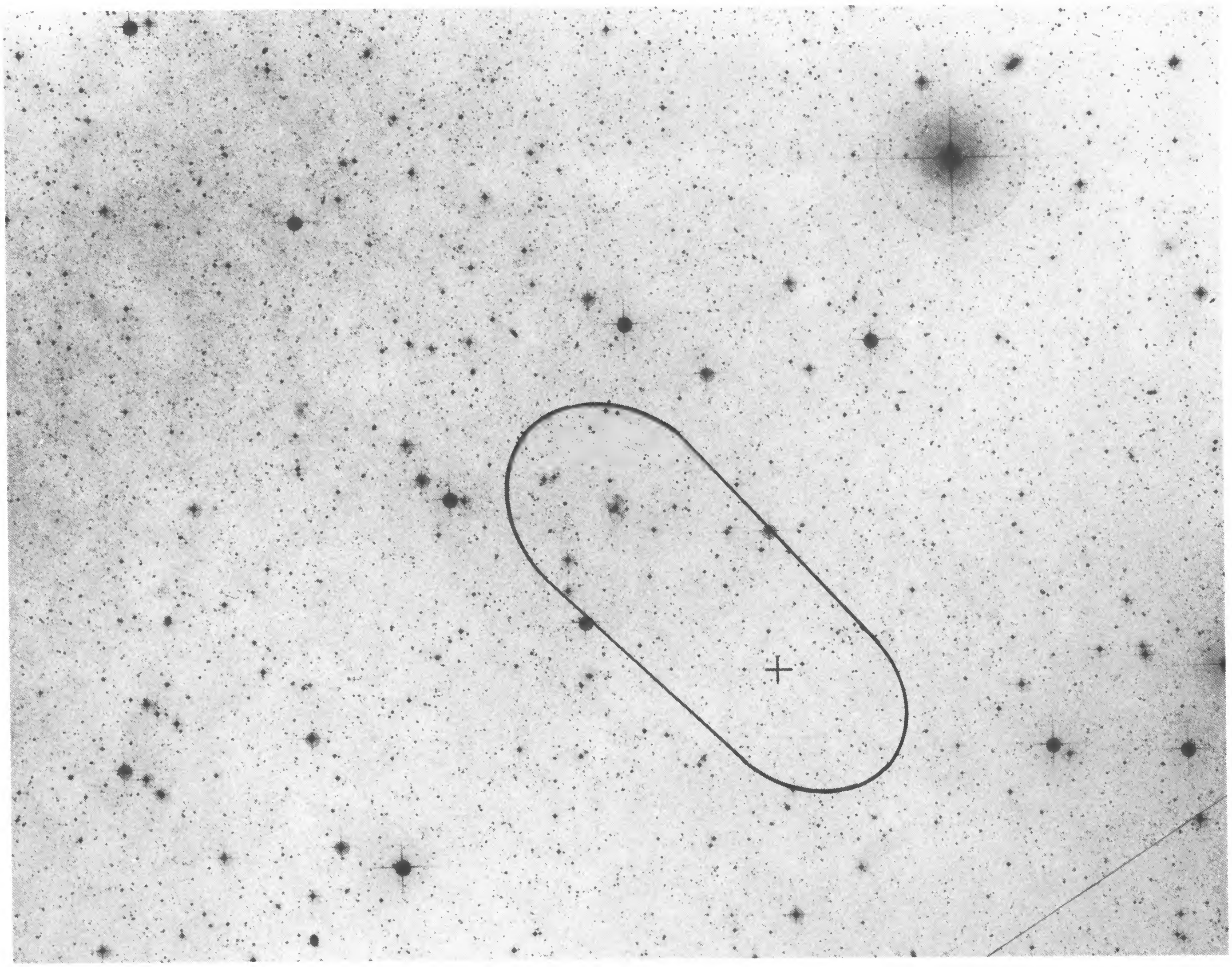

FIG. 1.—Amplified UK Schmidt photograph of a 1°.5 × 1°.2 area centered on the peak of the H I cloud detected by Giovanelli and Haynes (1989). The dwarf irregular galaxy corresponds to the peak H I column density, and the cross marks the position of a secondary peak in H I emission. The solid line gives the extent of the H I cloud. North is up, and east is to the left.

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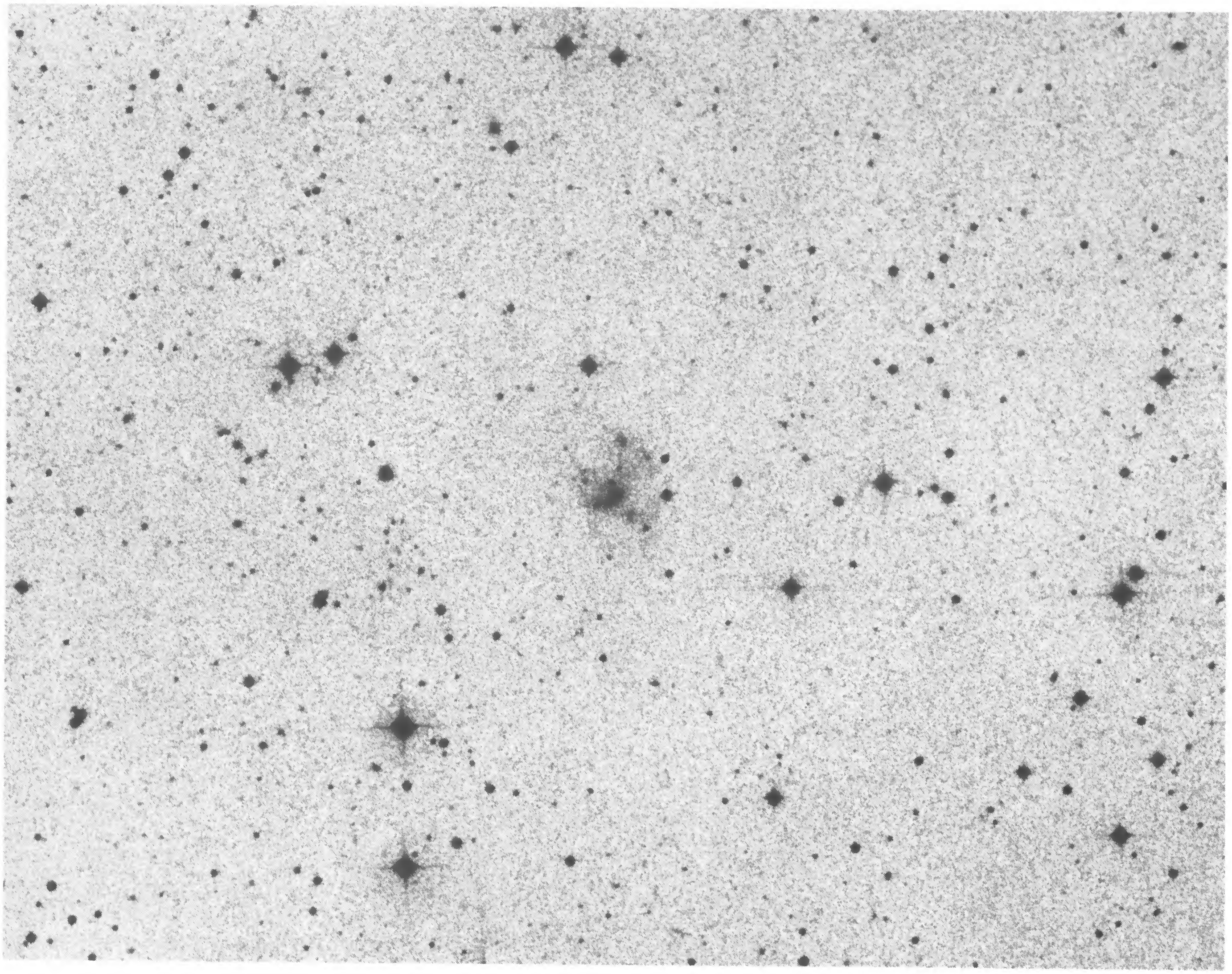

FIG. 2.—Enlargement of the central 20′ × 16′ of Fig. 1. North is up, and east is to the left.

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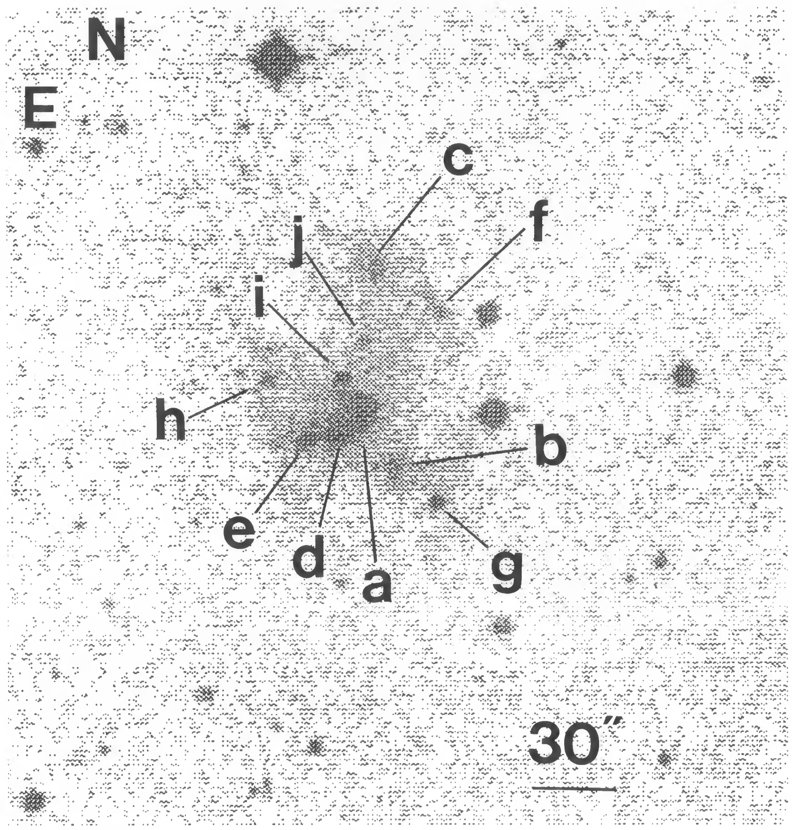

FIG. 3.—Gray-scale digitization of the UK Schmidt photograph, with principal features in the dwarf irregular marked. The field size is 5′ × 5′.

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(Krumm and Burstein 1984; Carignan and Freeman 1988; Carignan and Beaulieu 1989), which is located at a distance of 4 Mpc. An accurate rotation curve will be required to see if this galaxy, like DD0 154, has a kinematic halo of dark matter.

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