INTERSTELLAR MATTER IN ELLIPTICAL GALAXIES

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I. INTRODUCTION

This contribution concentrates on the properties of the large gas structures in elliptical galaxies, those seen in dust and HI. The distribution and kinematics of ionized gas, which is generally confined to a small region in the center of the galaxy, are discussed at this conference by Illingworth and by Ulrich.

The study of the interstellar matter in ellipticals has been approached from two directions over the past few years. The study of the global gas content of normal ellipticals using sensitive observations of the HI 21-cm line has been carried out by several groups. These searches have resulted in the detection of small amounts (several x 10^8 $M_\odot$) of gas in a few galaxies and in the setting of low upper limits for a great many more. At the same time, attention has been drawn (Bertola and Galletta 1978; Hawarden et al. 1981) to a class of galaxies containing dust lanes but no stellar disks (e.g. NGC5128); for these galaxies, the dust lanes are often not aligned with the major axis of the galaxy.

In this contribution, objects from both of these studies will be considered to represent examples of the same general phenomenon, and I am going to be somewhat casual with the morphological classification of the galaxies - galaxies with dust lanes are frequently classified as SO and IO, but will herein be considered along with the ellipticals. This paper is also going to concentrate on the observational aspects - the theory of orbits in these galaxies is discussed in this symposium by Binney and by de Zeeuw.

II. THE HI-RICH ELLIPTICALS

As is well known, the HI-rich ellipticals contain but small amounts of HI and the certain detection of the gas is correspondingly difficult. A great deal of observing time has been spent in an effort to provide convincing detections. A census of all the ellipticals with

E. Athanassoula (ed.), Internal Kinematics and Dynamics of Galaxies, 297–304.

well-established detections of HI in emission is given in Table 1; the list is roughly in inverse order of discovery date. Also given are indications of whether the object is a known radio continuum source, whether HI absorption is also seen, and whether dust is known to be present.

TABLE 1. HI DETECTIONS FOR ELLIPTICAL GALAXIES

NGC4278 (c,na,d)	NGC3998 (c,na,nd)	NGC205 (nc,-,d)
NGC1052 (c,a,d)	NGC5173 (nc,-,?)	A1230+09
NGC5128 (c,a,d)	(?)NGC4105 (nc,-,nd)	NGC4370
UGC01503 (nc,-,?)	UGC09114 (c,na,?)	NGC3265
NGC5363 (c,a,d)	NGC2768 (c,na,nd)	NGC3608
NGC5506 (c,a,d)	NGC185 (nc,-,d)	

c = radio continuum a = HI absorption d = dust

Table 1 contains the respectable number of seventeen detections. In addition to providing the last four detections in Table 1, Lake and Schommer (1982) find possible emission from NGC4318, 4551 and 5576. HI absorption at or near the intrinsic redshift is found for a further three galaxies, 3C293, NGC315 and UGC06671 (Shostak et al. 1982; Dressel et al. 1982a,b). There are, in addition, several HI-rich galaxies of quite uncertain type which may be related to the class of HI-rich ellipticals, including NGC5666, 1800, 520, 3773, 1315, 1275, IC5063 and possibly M82. Finally, there are several ellipticals suspected at one time of being HI-rich whose detections have not been confirmed by subsequent observations. These are NGC1587/88, 2974, 3156, 3226, 3904, 3962, 4636, and 5846.

Good upper limits have been set for many more galaxies; some interesting examples are NGC4472 ($M(HI)/L_B < 0.005$), NGC3665 (<0.006), and NGC4374 (<0.005). As a class, then, the ellipticals have a great variation in HI content. Most are undetectable; those which are contain only small amounts of HI (typically between 10^8 and 10^9 $M_\odot$).

III. THE NATURE OF THE INTERSTELLAR MEDIUM

There is not yet much information on this topic, but what there is carries the interesting implication that the ISM in these galaxies is not too different from that seen in spirals. For several radio galaxies, absorption lines are seen against the continuum source, and are resolved into discrete components such as are produced by diffuse clouds in the Galaxy (Haynes and Giovanelli 1981; Thuan and Wadiak 1982). Synthesis observations of NGC4278 (Figure 1) also suggest that the HI in this galaxy is clumpy (Raimond et al. 1982). That the gas is not primordial in all cases is demostrated by the presence of dust; the observation of NGC5128 by van Gorkom et al. (this conference) suggests that the HI and dust are well mixed. There is a qualitative suggestion in the survey data that the gas-to-dust ratio may vary among galaxies, in that HI is

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not detected from every dusty galaxy, and vice-versa.

The study of the molecular gas content of ellipticals has barely gotten underway, and few CO observations exist except for the work of Johnson and Gottesmann (1979). No CO emission has yet been detected. An upper limit of $M(H_2) < 5 \times 10^4$ $M_\odot$ is inferred for NGC185 (Knapp, unpublished). OH, H_2CO and CH are seen in absorption against the nucleus of NGC5128 (Gardner and Whiteoak 1976; Whiteoak et al. 1980) and OH in NGC5363 (Rickard et al. 1982) with the molecular gas being in discrete clouds similar to those in the Galaxy.

IV. DISTRIBUTION AND DYNAMICS

To date, synthesis observations of the HI distribution exist for six of the galaxies listed in Table 1. NGC185 and 205 contain unresolved clouds near, but not coincident with, the centers of the galaxies (Gottesmann, this symposium). NGC5128 (van Gorkom et al., this symposium), and NGC3998 (Knapp et al. 1982) have their HI in roughly ring-like structures close to the minor axis, while NGC4278 (Raimond et al. 1981, 1982) and NGC5173 (Knapp and Raimond 1982) have the HI in disks.

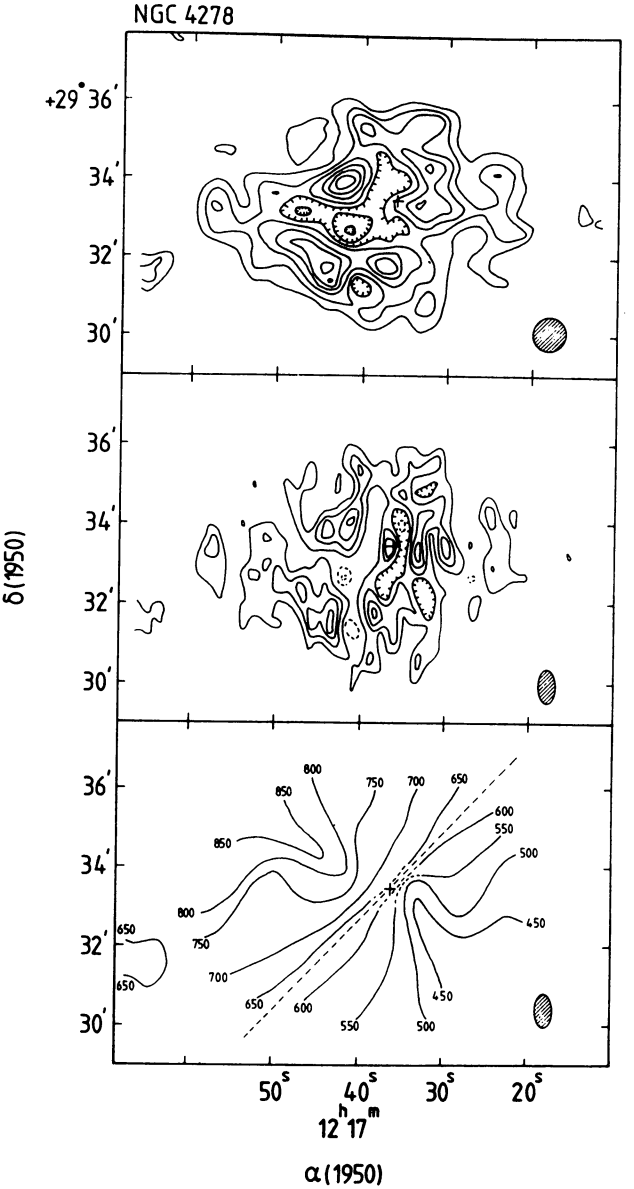

Figure 1. HI synthesis map of NGC4278 (Raimond et al. 1982), showing the smoothed (50"x50") total HI map, the unsmoothed (30"x50") map and the velocity field. The position of the radio continuum source is marked by a cross.

In NGC3998, the HI is in a ring inclined at ∿70° to the optical major axis. The ring appears to be in prograde rotation with respect to the stellar component; the relatively rapid rotation of the latter suggests that the HI is in a polar distribution around an oblate galaxy (Blackman et al. 1982). The position angle of the HII emission lies between that of the stellar component and that of the HI (Blackman et al. 1982; Bertola, this conference).

The HI in NGC4278 is distributed in a disk inclined to the stellar bulge by about 40°, again in prograde rotation. The center of the disk is empty (Figure 1) and no absorption is seen against the central continuum source (Shostak et al. 1982). The velocity field in the

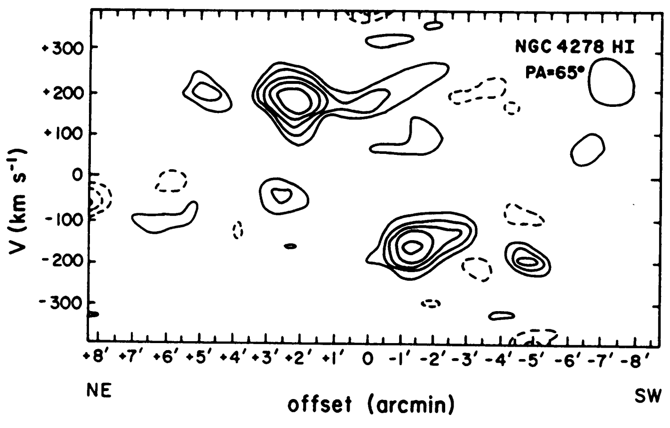

Figure 2. HI velocity-position map along the kinematic major axis, centered on the position and systemic velocity of the galaxy.

HI disk (Figures 1 and 2) suggests that the circular velocity is constant with radius, so that, at least out to a radius of 10 kpc (D = 10 Mpc), the mass-to-light ratio of the galaxy is increasing with radius. The position angle of the extended HII emission (Ulrich, this conference) is intermediate between that of the stars and of the HI, suggesting that the mass distribution in NGC4278 is triaxial.

Hawarden et al. (1981) have shown that, for a much larger sample of galaxies (those with dust lanes but no disks) misalignments between the stellar and gaseous components are common. In Figure 3 is plotted a histogram of the relation between the position angles of these two components, using the sample of Hawarden et al. plus some twenty additional galaxies from the literature. The notation and classification is that of Hawarden et al., with the addition of the class M (mixed), i.e. galaxies such as NGC2685 with both polar and equatorial rings. The situation is strikingly different from that in disk galaxies and suggests that the gas in ellipticals takes up more or less random orbits. Orbits

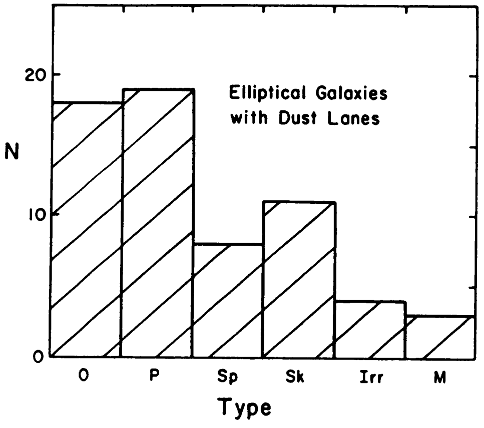

Figure 3. Distributions of relative orientations of dust/ gas lanes and the galactic major axis in ellipticals. O = lane along major axis. P = lane along minor axis. Sp = dust lane circular in projection. Sk = lane inclined to major axis. Irr = irregular dust lane M = both perpendicular and parallel lanes present.

for gas in these systems are discussed by Richstone and Potter (1982) and Merrit and de Zeeuw (1982).

V. RADIO ACTIVITY AND HI ABSORPTION

It is by now reasonably well established that nuclear activity in early-type galaxies and the presence of extended structures of cold gas are closely related, at least in nearby galaxies (Hummell 1980; Dressell et al. 1982a). Kotanyi and Ekers (1979) have shown that the extended radio structures in a sample of active galaxies such as Cyg A are roughly perpendicular to the dust lanes in these galaxies, in good agreement with the predictions of models of the radio activity involving accretion onto a central massive engine (e.g. Blandford 1979). The difficulties of accreting hot gas onto the engine are much discussed; Gunn (1979) showed that cold gas from a surrounding disk could be accreted in adequate amounts. Recent observations of HI absorption lines towards the nuclei of some of these active galaxies have shown the presence of redshifted components, interpreted as due to individual cold clouds falling towards the nucleus (Thuan and Wadiak 1982; Dressell et al. 1982b; Shostak et al. 1982; van der Hulst et al. 1982); accretion rates of $\sim 0.2\ M_{\odot}/yr$ are estimated from these observations, enough to fuel the radio source. Thus the causes of intense activity in radio galaxies (and quasars?) seem, at least in a first-order sense, to be understood.

VI. THE ORIGIN OF THE GAS

The lack of correspondence between the dynamics and distribution of the gas and stars argues against the material having its origin as mass loss from evolving stars, as does the bimodal distribution of the gas contents of ellipticals (Sanders 1980 - though see Sanders 1981).

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These considerations also argue against ejection from the nucleus. The most tenable explanation still seems to be the accretion of gas from the outside (c.f. Silk and Norman 1979), although the presence of gas in so many ellipticals strains this somewhat, and there appears to be no correspondence between gas content and environment (Dressell et al. 1982a; Gallagher et al. 1982). However, if Larson, Tinsley and Caldwell (1980) are correct in their inference that spirals must be continuing to accrete gas, then early-type systems are presumably also accreting material. The low gas content of the early-type systems may be due to self-sweeping by the stellar component - note that the gas distributions are generally rings around the light systems. A similar situation is found for the SO galaxies (van Woerden et al., this symposium). The "disks" of ellipticals could then cover a wide range of ages, and, in a sense, like the outer disks of spirals, be still in the process of formation.

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DISCUSSION

RICHSTONE : One remark about the polar ring type galaxies : it is very doubtful that the gas comes from the stars because the angular momentum vector of the gas is orthogonal to that of the stellar component for the three cases in which both are known. It seems much more likely that the gas comes from outside the system.

DRESSLER : A paper by you, Balick, Faber and Gallagher showed that SO galaxies with relatively large M_{HI}/L_B have a wide range of optical colors, and are often much bluer than gas-free SO's. Is there a similar effect for this sample of relatively gas-rich ellipticals ?

KNAPP : No. Such data as exist suggest no systematic color differences between gas-rich and gas-free ellipticals.

VAN WOERDEN : Thonnard's Arecibo map of HI in NGC4636, refutes 3 earlier single-dish detections. At Westerbork, Huchtmeier and Shostak also failed to find the HI. Is there a new Green Bank observation ?

KNAPP : Yes ; Gallagher, Faber and I have a new 91m observation with about 50 % better sensitivity than our previous observations and find no trace of emission.

KENNICUTT : Is there any correlation between the HI detection rate and the presence of nearby gas-rich companion galaxies ?

KNAPP : No. Statistical studies by Dressell et al. suggest no correlation with nearby galaxy density. Indeed, Haynes and Giovanelli (1980, Astrophys J. 240, L87) found HI emission in isolated early-type systems. NGC4278 and 5173 lie in small spiral-containing groups, but the synthesis observations give no sign of tidal distortions and the like. The only possible counter-example is the HI-SO galaxy NGC2859 described by Shane at this symposium, which is surrounded by HI-containing dwarfs.

SANDERS : If the gas in these systems is rotating, then it is hard to argue that in any system the gas has come from the stars in the ellipticals since the specific angular momentum of the gas is much larger than the specific angular momentum of the stars. Is it possible that the gas in well-observed galaxies like NGC4278 could have a substantial component of non-circular motion-inflow, for example ?

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KNAPP : The best information on this question comes from the absorption-line observations. A strong, narrow component is always seen at the systematic velocity of the galaxy, which, with the large-scale velocity fields seen in NGC4278 and 5128, suggests rotation. But the absorption-line observations also show redshifted components -at the implied accretion rates of a few tenths of 1 $M_\odot$ per year the HI disks are not going to last long ! So the answer is yes, but I believe that rotation is dominant.