H\textsubscript{I} in Low-Luminosity Early-Type Galaxies

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Abstract. We discuss the properties of the H\textsubscript{I} in low-luminosity early-type galaxies. The morphology of the H\textsubscript{I} is more regular than that of the H\textsubscript{I} in many more-luminous early-type galaxies. The H\textsubscript{I} is always distributed in a disk and is more centrally concentrated. The central H\textsubscript{I} surface densities are higher than in luminous early-type galaxies and are high enough for star formation to occur.

1. Why study H\textsubscript{I} in low-luminosity early-type galaxies

A few decades ago, elliptical galaxies appeared to form a homogeneous group. We know now that in reality they constitute a very varied family of galaxies of which many of the detailed characteristics vary from galaxy to galaxy. For many of these characteristics, elliptical galaxies can be divided into two groups, of which we list a few.

\textit{Stellar rotation vs anisotropy.} Some elliptical galaxies are purely 'pressure supported' systems, i.e. the random motions of the stars support the shape of the galaxy, while for others the rotation of the stellar component is important for understanding the dynamical structure of the galaxy.

\textit{Boxy vs Disky.} For many ellipticals, the isophotes are not perfect ellipses. For some, the deviations are boxy-shaped, while for others they are disky. For the disky galaxies, there is a continuum in bulge-to-disk ratio, from genuine spiral galaxies all the way to 'no disk' (e.g., Kormendy and Bender, 1996).

\textit{Core properties.} Imaging the centres of elliptical galaxies with HST has shown that the density distribution in the centre of ellipticals is quite different from galaxy to galaxy. Some ellipticals have relatively shallow central cusps, while others show a steep cusp. The shape of this cusp appears to depend on the luminosity of the galaxy (e.g., Lauer 1997).

\textit{AGN.} The radio continuum emission from the nuclei of elliptical galaxies varies strongly from galaxy to galaxy. The fraction of ellipticals with a radio core depends strongly on the luminosity, although for a given optical luminosity
there is still a large scatter (∼4 orders of magnitude) in the radio power (Sadler et al. 1989).

X-ray gas. The amount of X-ray emission correlates strongly with optical luminosity. In large ellipticals, part of the X-ray emission originates from a halo of hot gas, while in smaller ellipticals the X-ray is due only to X-ray binaries (e.g., Canizares et al. 1987).

**Liner vs HII spectrum.** Many ellipticals show optical emission from ionized gas. The character of the spectrum of this gas changes with luminosity. The smaller galaxies show a H II region-like spectrum and hence the emission is likely to be due to star formation. In the more massive galaxies, the character changes to that of a Liner spectrum, indicating that the ionization mechanism is different in these galaxies (e.g., Sadler 1987).

**Star formation history.** The star formation history differs between galaxies. For example, the relative abundance of Mg with respect to Fe correlates with velocity dispersion. Luminous ellipticals have [Mg/Fe] up to 0.4, while fainter ellipticals have values around zero. This could point to a different star formation history, with differences in the way the ISM is enriched. Low-luminosity ellipticals also show a larger spread in the Mg-σ relation, again pointing to a different star formation history in some of these galaxies (e.g., Bender 1996). Many low-luminosity ellipticals in fact display star formation in the central parts of the galaxies. It appears that disky galaxies have stronger Hβ indices, indicating that some star formation occurred recently (de Jong & Davies 1997).

Many of these differences between different galaxies can be explained by different amounts of gas (and hence dissipation) present in the formation/evolution, and in many models for galaxy formation the gas supply is a key factor (e.g., Kauffmann 1996). For example, the differences between boxy and disky galaxies, the importance of rotation vs. anisotropic galaxies, and the different central density distributions can all be a consequence of the relative importance of gas. Obviously, since stars form from gas, the different star formation histories must be related to different gas contents during the evolution.

From the above it follows that, to understand the reasons for the differences between galaxies, one has to know about the gas. Of course, most ellipticals formed most of their stars a long time ago and we cannot see this gas directly, but knowing about the current situation can still provide useful information. Since many characteristics appear to change systematically with mass, one would like to have a picture of the gas properties as function of mass in ellipticals. Some data (i.e. full data-cubes of the H I) are available for lower-luminosity ellipticals (e.g. Lake et al. 1987; with low-luminosity we mean galaxies with absolute magnitude in the range –16 to –19), but most of the data published are of higher-mass galaxies (and even for those galaxies the number of good datacubes is small). Since it appears that for lower-luminosity galaxies the gas was more important than for more massive galaxies, we need to have as many as possible low-luminosity, early-type galaxies well studied in H I.

In the past few years, we have been imaging the HI in a number of elliptical galaxies with the Australia telescope Compact Array (ATCA) (see also Morganti et al. these proceedings). Four of the galaxies we have observed (NGC 802, NGC 2328, ESO 118–G34 and ESO 027–G21) are of lower luminosity and here we present some of the results from these observations. They
| Galaxy Type         | Observed | Detected | % |
|---------------------|----------|----------|---|
| E                   | 64       | 3        | 5 |
| E/S0                | 23       | 4        | 17|
| S0, SB0             | 103      | 21       | 20|
| Pec E and S0        | 20       | 9        | 45|
| S0/a and pec        | 35       | 15       | 43|
| Sa and pec          | 103      | 78       | 76|

Table 1. \(^1\)H I detection rates for early-type galaxies (from Bregman et al. 1992)

are all early-type galaxies with absolute magnitude between \(-18\) and \(-19\) (for \(H_0 = 50 \text{ km s}^{-1}\text{ Mpc}^{-1}\)).

2. Optical Morphology

When discussing the HI content of early-type galaxies (or related issues like star formation), it is important to stress which early-type galaxies are considered. It is, therefore, important to first address the issue of galaxy morphology. Unlike for spiral galaxies, the HI content of early-type galaxies varies greatly from galaxy to galaxy and galaxy morphology and environment are key factors. Hence, if one studies the morphology and the kinematics of the HI in early-type galaxies, one discusses a particular subset of early-type galaxies, with biases in evolution state and environment. This is illustrated in Table 1 that gives the HI detection rates for different types of early-type galaxies.

Table 1 shows two things. If elliptical galaxies are defined as pressure-supported systems with no obvious peculiarities in their morphology, the discussion on their HI can be quite short: only 5 percent of these galaxies are detected. However, if galaxies with some peculiarity in their optical morphology (like shells, dust lanes etc.) are also considered, the detection rate increases dramatically. This means that HI-selected early-type galaxies are a certain sub-sample of the whole population, namely those that have had some interaction recently. This indicates that the presence of HI depends on certain aspects of the evolution of elliptical galaxies. This is important to keep in mind. To get a complete picture of the evolution of early-type galaxies, it is essential to include these HI-rich galaxies, and not restrict the samples to ‘pure’ ellipticals with no optical peculiarities. The issue is to some extent whether we consider galaxies like Centaurus A to be an elliptical or not. Surely, many early-type galaxies have a similar evolution history as Centaurus A and one cannot hope to understand the evolution of early-type galaxies without considering galaxies like Centaurus A.

The correlation between the HI content and the presence of peculiarities strongly suggests that in many early-type galaxies detected in HI, the neutral hydrogen is accreted or is left over from a merger (e.g. Knapp et al. 1985). But Table 1 suggests that perhaps in some galaxies this is not necessarily the explanation for the presence of HI. Table 1 shows that the HI content seems
to be related also to how much disk an early-type galaxy has. This is also an important clue, certainly in the context of some of the characteristics mentioned in the introduction (for example, the continuum from spirals to disky ellipticals, or the star formation linked to disky-ness).

3. HI content

The properties of low-luminosity early-type galaxies suggest that gas has played a more important role in the formation/evolution of these galaxies than in their more massive counterparts. Do we observe that low-luminosity early-type galaxies have more or more often HI? When one reads about low-luminosity early-type galaxies, one often gets the impression that this is the case. We think, however, that the evidence for this is not very strong. An often quoted reference is Lake & Schommer (1984) who observed a small sample of low-luminosity early-type galaxies. The HI detection rate they obtained is significantly higher that those obtained in other studies of more massive elliptical galaxies available at the time. The galaxies they observed are however relatively nearby and the sample is not very large, so it is not clear how significant the result is. Looking at larger samples available now, there is not much evidence that low-luminosity early-type galaxies are more likely to contain HI.

Figure 1 shows a histogram of the detection rate of E and E/S0 galaxies as a function of absolute magnitude. This histogram does not give an indication that early-type galaxies with $M_B$ between $-16$ and $-19$ are more likely to have HI. However, a problem is that the sample is not entirely homogeneous. Many of the galaxies in this sample are in the Virgo cluster (because Virgo passes straight over Arecibo) and Virgo ellipticals are poor in HI (as are the spirals in Virgo). The ‘contamination’ by Virgo is especially significant for galaxies fainter
Figure 2.  

left) total H I image of the field around IC 1459 (identified by the cross near the centre).  
right) Position-velocity plot of NGC 807, taken along the kinematical major axis (data taken from the VLA archive, original data taken by Dressel in 1985)

than $M_B \sim -19$, so if galaxies in this magnitude range are more likely to have H I, this could be suppressed in the sample.

This raises again the issue of biases: the depletion of H I in dense environments means that studying H I-selected early-type galaxies one biases in favour of field galaxies, and hence for galaxies that may have had a different evolution compared to cluster ellipticals.

One interesting point is that it looks like that the largest ellipticals ($M_B < -22$) are poorer in H I. This could be an environmental effect as well.

In summary, there is no evidence that intermediate luminosity galaxies are more likely to have H I, but the available sample is quite small and biased by Virgo. On the other hand, it is also quite unlikely that these galaxies are poorer in H I. Several galaxies have now been detected and the H I in these galaxies has been imaged.

4. H I Morphology and Kinematics

The main information about the morphology of the H I in low-luminosity galaxies comes from Lake et al. (1987) with 4 studied galaxies and our more recent observations of another 4 galaxies with the ATCA.

The morphology of the H I in low-luminous early-type galaxies is different from that in more luminous galaxies. In the latter, the H I morphology varies very much from galaxy to galaxy, while in low-luminosity galaxies, the range in morphologies is much smaller. In many luminous ellipticals, the morphology of the H I is quite irregular and the H I is evidently accreted. One example is the well-known galaxy IC 1459. Figure 2a shows the total H I image we obtained for this galaxy with the ATCA. All the bright H I emission comes from galaxies surrounding IC 1459, but there is also lower surface-brightness H I that is not clearly associated with any of these galaxies. The H I appears to be stripped from
the HI-rich galaxies, most likely due to interactions between these galaxies and IC 1459. Such irregular HI structures around more luminous elliptical galaxies are quite common (other examples are NGC 5077 and NGC 4936). None of the low-luminosity galaxies that have been observed show such HI characteristics.

In other luminous elliptical galaxies, the morphology of the HI is clearly associated with the galaxy, but the morphology of the HI is often still relatively irregular, although the velocity fields are more regular than one would expect from the density distribution (e.g. Schiminovich and van Gorkom 1997, Morganti et al. this proceedings). Usually, these galaxies show other indications that the HI is likely accreted (shells or dust lanes).

However, there are a few reasonably luminous galaxies known now that have a regular HI disk, where there are no obvious signs, that the HI is accreted recently. These gas disks could be the gas counterpart of a very faint stellar disk in these systems. One example of such a HI disk is NGC 807. Figure 2b shows the position-velocity diagram (taken along the kinematical major axis) of the HI disk in this galaxy. The difference between this HI disk and those in spiral galaxies is that the surface density of the HI disk is a factor 5-10 lower in elliptical galaxies. The peak surface densities are at most $2 \, M_\odot \, pc^{-2}$, even lower than observed in low surface-brightness spiral galaxies. This explains the lack of star formation in these HI disks: the density of the HI is simply too low. In fact, these HI disks will not change significantly over a Hubble time. It is still possible that this HI is accreted, but this should have happened a long time ago. Perhaps one can consider galaxies like NGC 807 very early-type spiral galaxies, where the gas mass of the disk is so low that only a very faint stellar disk developed. These galaxies could fit in the continuum of spirals to disky elliptical proposed by e.g. Kormendy and Bender (1996). Another example of such a regular, low surface-brightness HI disk in a bright elliptical is NGC 2974 (Kim et al. 1988). NGC 2974 does indeed show hints of a stellar disk.

There are HI datacubes available now for about 10 low-luminosity early-type galaxies. In Figure 3 we show the total intensity images of two of the objects we have observed (NGC 802 and ESO 118–G34) with ATCA. Comparing the HI morphology with that observed in more-luminous galaxies one can make the following two remarks:

**Figure 3.** Total HI images of NGC 802 and ESO 118–G34

1) The range of different HI morphologies seen in luminous galaxies are not observed in low-luminosity galaxies. Instead, the HI distribution, and especially the kinematics, is always that of a relatively relaxed disk-like structure, that is very extended compared to the optical image. This does not mean that the HI in these galaxies is not accreted. In several galaxies there are signs that the HI is in fact accreted. For example, in NGC 802 the kinematical major axis is perpendicular to the optical major axis, clearly suggesting that the HI is accreted (see Fig. 4). Another low-luminosity elliptical showing such a misalignment is NGC 855 (Walsh et al. 1990, Knapp priv. comm.). The velocity field of the HI in NGC 802 is very regular, so the accretion must have happened some time ago. Also the velocity field of ESO 118–G34 (see Fig. 4), although still relatively regular, shows some features indicating that the HI is accreted. Also some of the low-luminosity galaxies observed by Lake et al. (1987) show similar characteristics. In the other two galaxies we have observed (NGC 2328 and ESO 027–G21), the kinematics of the HI is very regular and does not suggest that the HI has been accreted recently.

In the four galaxies we observed, star formation is occurring in the central 10-20 arcsec. The rate of star formation, estimated from the Hα fluxes, is such that the timescale for consuming all HI is quite short in two of the galaxies (about 10⁶ yr, NGC 2328, ESO 118–G34), while in the other two it is an order...
of magnitude longer. Therefore, in two of the four galaxies the star formation has to be short-lived. This is another indication that the HI is accreted in at least some galaxies.

2) The HI disks observed extend all the way towards the centre. In fact, the HI distribution is quite peaked towards the centre, something definitely not observed in more massive galaxies. The values of the central HI surface-brightnesses are also higher compared to those observed in more luminous galaxies. Figure 5 shows the radial HI surface density profiles of two of the galaxies we have observed. These plots show that in the centres the density can go up to about at least $4 \, M_\odot \, pc^{-2}$. Given the limited resolution of our observations, the actual HI surface density is quite likely to be higher near the centre. These high HI surface densities are consistent with the fact that we do observe star formation in the central 10-20 arcsec in all four galaxies. However, in most of the galaxy, the HI surface density is below $1 \, M_\odot \, pc^{-2}$. So, contrary from the star formation near the centre, not much star formation will occur at larger radii.

5. Discussion

The predominance of the disk-like HI morphology in the low-luminosity galaxies is consistent with the observation that disky ellipticals tend to be of lower luminosity and that lower luminosity galaxies are more often rotationally supported: we observe the gas component from which faint disks can have formed. It is not entirely clear why low-luminosity early-type galaxies more often have a regular HI disk. In several low-luminosity galaxies, there is still evidence that the HI is accreted. It appears that the accretion happens in a different way in smaller ellipticals. One factor could be the environment. The luminous ellipticals with messy HI are usually near the centre of a small group, while the low-luminosity galaxies observed are more isolated. That these luminous ellipticals are sometimes near the centre of a group could be the result of the evolution of that group. Perhaps interactions happen too often in such a group for the HI to settle in a nice disk, while in the more isolated low-luminosity galaxies the HI has time to settle. The more luminous ellipticals with a regular disk (like NGC
are also relatively isolated, supporting this view. In both IC 1459 and in NGC 5077 several different HI systems are observed, indicating that more than one interaction is responsible for the HI observed around the galaxies. Another factor could be that the low-luminosity galaxies accrete at a slower, perhaps more constant rate, from smaller companions.

That the surface density of the HI in low-luminosity galaxies is more centrally concentrated, is perhaps also the result of a more ‘quiet’ accretion, but it could also mean that the centres of luminous ellipticals are more hostile to HI. Perhaps interaction with the stellar winds (as suggested by Lake et al. 1987), or with a halo of hot X-ray gas ionises the neutral gas in the central regions of luminous ellipticals, leaving a disk of ionized gas near the centre (as observed in several luminous elliptical galaxies). The different character of the spectrum of the ionized gas in high- and low-luminosity galaxies suggests that the conditions are different. This hostile environment would prevent a build-up of HI near the centre and star formation will not occur in such galaxies. In low-luminosity galaxies these interactions do not occur, or are less strong, and HI is found even close to the centre, with densities high enough for stars to form. This may also be connected to the different stellar density distributions observed in high- and low-luminosity galaxies.

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Questions

Trinchieri: Is there now enough overlap between HI- and X-ray data, so that you could test the issue that X-ray emitting gas could provide a hostile environment for the HI in more luminous systems?

Oosterloo: Yes, one would like to see if there is any correlation between the X-ray properties and the HI. Unfortunately there is only very little overlap. One could study one or two galaxies, but it would be impossible to do statistics.

Pahre: In the introduction by Gonzales, he showed how elliptical galaxies follow different scaling relations from the dwarf ellipticals and the dwarf spheroidals. Are the galaxies in your sample the low extension of the elliptical galaxy sequence, or are some or all dwarf ellipticals?

Oosterloo: They are all small versions of the luminous galaxies.

Hau: The difference between luminous and low-luminosity ellipticals, could it be because you are comparing apples with oranges? Many of the things you showed with holes in the centre are merger remnant candidates. Do high-luminosity Es without shells have centrally peaked profiles?

Oosterloo: Indeed, based on the characteristics of the HI, luminous and low-luminosity galaxies have had a different evolution, this is exactly the point. I don’t think one can say much about the HI in luminous galaxies without shells. The presence of HI correlates very strongly with optical peculiarities, so there is very little data on ellipticals without shells. The only case is perhaps NGC 807, which indeed has a centrally peaked density distribution. One should note that if there is a central hole in the HI, it is very often filled up with an disk of ionized gas. So the gas disk is there, but it is in a different state.

Goudfrooij: Do you know of any spectral data of low-luminosity ellipticals containing HII that can be used to derive the metallicities of the ionized gas?

Oosterloo: I am not aware of any such data. It would certainly be worthwhile obtaining such data.

Andernach: Do you know the kinematics from optical spectroscopy for the regular HI-disk-low-luminosity galaxies?

Oosterloo: Also for this there is no data available, we hope to be able to obtain such data soon.

Eskridge: For NGC 802 you show that the HI rotates about the optical major axis. Do you know what the optical kinematics are?

Oosterloo: No, we do not know what the kinematics of the stellar component is in this galaxy. It would be interesting to obtain optical spectra of NGC 802 and see if this is a polar ring galaxy.

Avila-Reese: 1) Is it possible to measure the thickness of the HI disks in the early-type galaxies? 2) Could the surface density profiles you have shown for the HI disks be fitted with an exponential law? Which scalelengths have these disks?

Oosterloo: 1) In principle this is possible, although in practise it would be very difficult to get data with the required S/N and spatial resolution. 2) I haven’t fitted any model to the HI distributions, so I cannot really answer this question. If one would fit a single exponential, given the central concentration of the HI, the scalelength would probably be quite small.