HI in elliptical galaxies

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Abstract. Neutral hydrogen is an important component of the interstellar medium in elliptical galaxies as well as a potentially valuable mass tracer. Until recently, HI surveys of early–type galaxies have been sparse and inhomogeneous but this has changed with the advent of the HI Parkes All–Sky Survey (HIPASS; Barnes et al. 2001). We discuss HIPASS observations of a sample of ∼2500 nearby E/S0 galaxies, as well as detailed HI imaging of a range of individual objects.

1. Background

Although elliptical and S0 galaxies are dominated by an old stellar population with few or no young stars, it has been known for more than forty years that they contain observable amounts of interstellar gas. Over the past decade it has become clear that elliptical galaxies have a complex, multiphase interstellar medium which may contain hot (X–ray), warm (ionized) and cool (HI, CO) components.

The nature of the ISM in an individual elliptical galaxy provides us with important clues to its kinematic, environmental and chemical history over the past few gigayears, but the cold gas component is in many ways the most difficult to detect and study. We present some early results from the HI Parkes All–Sky Survey (HIPASS), and also discuss the HI structures, kinematics and star–formation history of some individual elliptical galaxies.

2. How much HI in elliptical galaxies?

Although searches for HI in individual ellipticals have been carried out since the 1970s (e.g. Gallagher 1972; Bottinelli, Gougenheim & Heidmann 1973, Shostak, Roberts & Peterson 1975, Knapp et al. 1977), the first systematic attempts to determine the HI properties of elliptical galaxies as a class were made by Sanders (1980) and Knapp, Turner & Cunniffe (1985).

1. E galaxies do... have gas at low densities. The evidence is the presence of emission lines in the spectra due to forbidden [OII] at λ3727, and Hα which is probably present whenever 3727 occurs. Most E galaxies show this emission.” (Sandage 1961).
Based on a sample of 46 elliptical galaxies, 9 of which were detected in HI, Sanders (1980) suggested that the HI content of ellipticals was bimodal, with about 30% ‘gas–rich’ (\(M_{\text{HI}}/L_B \sim 0.03\)) and 70% ‘gas-free’ (\(M_{\text{HI}}/L_B < 0.003\)). Knapp et al. (1985) analysed a larger sample of 152 HI observations of E galaxies from the literature, of which 23 (15%) were detected in HI. They found a very broad distribution in \(M_{\text{HI}}/L_B\) in ellipticals.

This contrasted strongly with the distribution of \(M_{\text{HI}}/L_B\) in spiral galaxies, which has a well-defined mean value and a small dispersion. Knapp et al. concluded that, because of this decoupling of the stellar and gas content of elliptical galaxies, the gas must have an external origin and was probably acquired in an interaction or merger with a gas–rich galaxy.

Two years later, Jura et al. (1987) found that more than 50% of nearby elliptical galaxies in the Revised Shapley Ames Catalog (RSA; Sandage & Tammann 1981) were detected as far-infrared sources at 100\(\mu\)m, implying typical dust masses of \(10^5–10^6\) M\(_\odot\) and HI masses of \(10^7–10^8\) M\(_\odot\) (i.e. lower than could generally be detected with current radio telescopes). They concluded that the presence of cold gas in elliptical galaxies is “the rule rather than the exception”.

However, although modest amounts of cold gas appear to be common in elliptical galaxies, HI observations of these galaxies remain challenging because the HI mass is usually small (though some E/S0 galaxies like NGC 5266 are as gas–rich as a late–type spiral; Morganti et al. 1997) and the profile smeared out by high velocities (because these are massive galaxies). As a result, the detection rate in targeted HI surveys of nearby elliptical galaxies is low and observers have tended to focus their attention on ‘peculiar’ ellipticals (i.e. those with shells, dust lanes or other signs of recent interaction) where the probability of detecting HI is higher (Bregman, Hogg & Roberts (1992) found that only 5% of normal RSA ellipticals were detected in HI, compared to 45% of peculiar E/S0 galaxies). As a result, the HI data available in the literature for elliptical galaxies is still sparse and inhomogeneous.

There are many questions we would like to answer. What is the HI mass function for elliptical and S0 galaxies? How does the typical HI content of an early–type galaxy vary with environment? Do all the HI gas disks in ellipticals come from mergers, or are some primordial? To make progress, we need a large and homogeneous set of HI data for early–type galaxies, and the HIPASS survey makes this possible for the first time.

3. First results from HIPASS

The HIPASS survey (Barnes et al. 2001) covered the entire southern sky using a 13-beam receiver at the prime focus of the 64 m Parkes radio telescope. An earlier paper (Sadler 2001) describes HIPASS results for a sample of about 2500 E and S0 galaxies from the RC3 galaxy catalogue (de Vaucouleurs et al. 1991).

The final HIPASS detection rate is roughly 6% for RC3 ellipticals and 13% for S0s, to a flux limit of 2.6 Jy km s\(^{-1}\), and Figure 1 shows the corresponding HI mass limits for detections which were unconfused (i.e. there was only one optical galaxy in the 15 arcmin Parkes beam. However for 30–50% of early–type galaxies where HIPASS detected HI, there was more than one galaxy of similar optical velocity in the Parkes beam. Here, observations at higher spatial
resolution are needed to determine the HI mass associated with each galaxy, and a program of follow–up observations is currently underway at the Australia Telescope Compact Array. Once the confused galaxies are sorted out, we will be able to calculate the local HI mass function for both elliptical and S0 galaxies.

3.1. HI in individual galaxies

There are several reasons for studying the detailed morphology and kinematics of HI in individual E/S0 galaxies. Settled HI disks, though rare, are a powerful tracer of the mass distribution in the outer regions (e.g. Franx, van Gorkom & de Zeeuw, 1994), and the presence of large amounts of HI may indicate that the galaxy has been involved in a recent interaction or merger. The results presented here are part of a long–term project to obtain good–quality HI images for a sample of 20–30 southern elliptical galaxies, and to use them both for dynamical studies and to investigate the links between galaxy interactions and AGN fuelling. The galaxies we have studied so far fall into three main classes: galaxies with settled HI disks, galaxies with central star formation, and galaxies with disturbed HI and tidal tails.
3.2. Galaxies with settled HI disks

Many of the elliptical galaxies we observed have their HI in settled, rotating disks which can be used as mass tracers. Figure 2 shows one example, the dust–lane galaxy NGC 3108. However, not all dust–lane elliptical galaxies have measurable amounts of HI. Oosterloo et al. (2002) find that the gas–to–dust ratio $M_{\text{HI}}/M_{\text{dust}}$ in five nearby dust–lane ellipticals ranges over two orders of magnitude from $10^{8.5}$ in NGC 3108 to $< 10$ in ESO 263–G48. The reason for this is not yet clear since the dust and HI in the galaxies are expected to have a common origin. It may be that some galaxies have a large fraction of their cold gas in molecular form.

For several elliptical galaxies with settled HI disks, we used simple mass models to calculate the variation of M/L with radius. As may be seen from Figure 3, the mass–to–light ratios at large radius are similar to typical values for spiral galaxies, suggesting that the dark halos in elliptical and spiral galaxies have similar properties (Bertola et al. 1993, Morganti et al. 1999).
3.3. Galaxies with central star formation

HI is more common in low-luminosity elliptical galaxies than in luminous ones (Lake & Schommer 1984), for reasons which are not yet completely clear. Furthermore, in contrast to giant ellipticals, these low-luminosity galaxies are often forming stars in their central regions where the HI density is highest (Sadler et al. 2000). Figure 4 shows two examples of galaxies in this class. The origin of the HI in these galaxies remains unclear. In some cases the observed misalignment of the HI rotation axis with the optical photometric axes suggests that it has been accreted, but in others the gas may be primordial – the galaxy UBV colours fit a models with slowly-declining star-formation rates, and it is plausible that the bulges in these galaxies have been built up slowly over a Hubble time with some gas still remaining.

3.4. Galaxies with disturbed HI

Some of the galaxies we mapped in HI have active nuclei, disturbed HI morphology and other signs of a past interaction such as a counter-rotating stellar core. This work is still in progress, but analysis of the HI velocity field (which
is often multi–valued) may eventually allow us to ‘date’ the interactions and build up a time sequence for the triggering of AGN in nearby galaxies. Figure 5 shows an ATCA image of the HI distribution in and around the active galaxy IC 1459, which has a counter–rotating core (Franx & Illingworth 1988) as well as a central radio source.

4. What next?

HIPASS has already given us over 100 new HI detections of southern elliptical and S0 galaxies, and more will come in the near future. As a result, we now have a much larger and more homogeneous data set than has been available in the past, making it possible to study the HI properties of a large sample of early–type galaxies in a systematic way. HI imaging of elliptical galaxies, though observationally challenging at present, can provide valuable insights into both their structure and their history.

Over the decade 2005–2015, next–generation radio telescopes (the Square Kilometre Array (SKA) and its precursors) will have a huge impact on HI studies of early–type galaxies. Even distant galaxies with modest masses of cold gas will be easy to detect and image in HI, giving us a far more complete picture of the evolutionary history of these enigmatic galaxies.

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Figure 5. ATCA total HI map of the active galaxy IC 1459, which lies in a group of gas–rich galaxies. A faint HI tail to the east of the galaxy is suggestive of a tidal interaction.

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