Highlights of Astronomy, Vol. 13
International Astronomical Union, 2003
O. Engvold, ed.

High Resolution Spectroscopy at Low Radio Frequencies

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Abstract. In this paper I discuss two examples of the science that can be done with high-resolution spectroscopy at low radio frequencies.

1. Kinematics of Faint Dwarf Irregular Galaxies

Interest in the kinematics of faint dwarf galaxies has been rekindled by numerical simulations of galaxy formation in hierarchical structure formation models which predict that galaxy halos should have cuspy (the so called "NFW" halos) central density distributions (Navarro, Frenk, & White 1996). Dwarf galaxies, which are generally dark matter dominated, even in their inner parts, are best suited for testing these galaxy formation models. While one might *a priori* assume that the ideal sample would be one composed of the faintest gas rich galaxies, it turns out that it is unclear whether the faintest dwarf irregular galaxies are rotationally supported or not. For example, in a study of nine faint dwarf galaxies Lo et al. (1993) found that only two galaxies showed ordered velocity fields, the remaining galaxies all had chaotic velocity fields. In fact, it has been suggested that normal rotation is seen only in dwarfs brighter than $M_B \sim -14$, and that by $M_B \sim -13$ one begins to find systems with misaligned axis, and other kinematical peculiarities. However, most of the earlier studies of dwarf irregular galaxies were done using relatively coarse velocity resolution (~ 6 km s^{-1}), which would make it difficult to discern the large scale patterns, if any, in the velocity fields of these galaxies.

To check whether dwarf irregular galaxies do indeed have systematic large scale velocity fields, we have made deep, high velocity resolution (~ 1.6 km s^{-1}) observations of a sample of dwarf irregular galaxies. We find that none of the galaxies in our sample have chaotic velocity fields, and that in some of them, the velocity field can be well modeled as arising from a rotating gas disk. Figure 1a shows the velocity field of Camelopardalis B ($M_B \sim -10.9$). As can be seen, the HI in the galaxy has a regular velocity field, consistent with rotational motion. Further, the implied kinematical major axis is well aligned with the major axis of both the HI flux distribution as well as that of the optical emission. Camelopardalis B is the faintest known galaxy with such relatively well behaved kinematics.

The rotation curve derived from the velocity field shows an (inclination corrected) rotation velocity of only ~ 7 km s^{-1} – the high velocity resolution of our observations was hence critical to measuring the rotation curve. Further, the peak rotational velocity is comparable to the random velocity of the gas.

https://doi.org/10.1017/S1539299600017263 Published online by Cambridge University Press

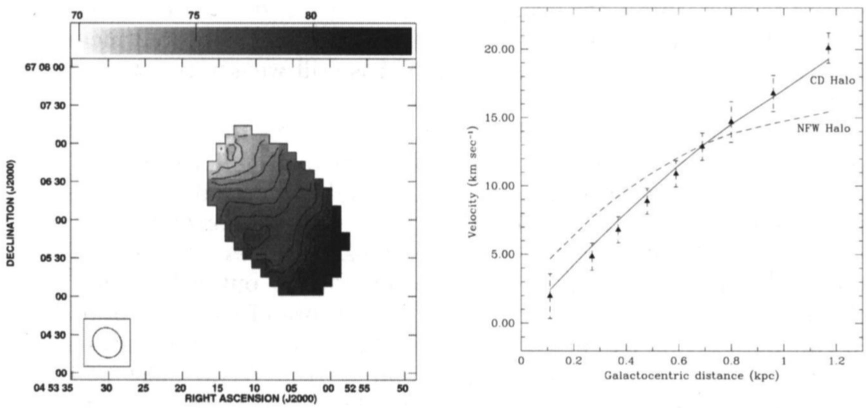

Figure 1. (a) Velocity field of Camelopardalis B. (b) Mass models fit to the asymmetric drift corrected rotation curve.

After correcting the observed rotation velocities for random motions, we find a corrected peak rotation velocity of $\sim$ 20 km s^{-1}. We fit mass models to the corrected rotation curve (Fig. 1b) and find a good fit for a constant density halo with a density of $\rho_0 \sim 12\ M_\odot\ pc^{-3}$, while an NFW halo model provides a poor fit to the rotation curve, regardless of the assumed mass to light ratio of the stellar disk.

2. Absorption from the Galactic WNM

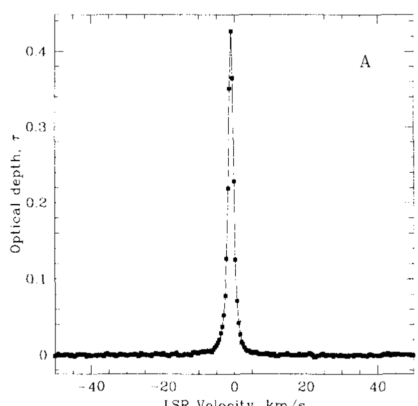

Figure 2. 0.4 km s^{-1} resolution absorption spectrum toward PKS 1814−637 (solid points), along with the 3-Gaussian fit (solid line).

Temperature measurements of HI clouds are usually carried out by comparing the 21 cm optical depth in a given direction (obtained through 21 cm absorption studies toward background continuum sources) with the emission

https://doi.org/10.1017/S1539299600017263 Published online by Cambridge University Press

brightness temperature from nearby directions. This yields the "spin temperature", T_s. While the temperature of the CNM is reasonably well measured by such methods, the temperature of the WNM is still weakly constrained due to the difficulties in detecting it in absorption.

A serious problem with such emission/absorption studies is that the HI emission spectra are affected by stray radiation, non-uniformity of HI clouds across the beam, self-absorption, etc. These make it very difficult to estimate the spin temperature of the WNM in the standard absorption/emission searches. Conversely, HI absorption studies toward compact sources trace narrow lines of sight through the intervening clouds. When carried out using long baseline interferometers one gets an uncontaminated measure of the absorption profile, which can be then be examined for WNM features. The drawbacks are that (1) the WNM optical depth is very low, and (2) the WNM must be searched for in the midst of strong CNM absorption features. The second issue can be mitigated by choosing lines of sight with simple CNM structure and using high velocity resolution observations to model the deep narrow CNM features and subtract them out.

Figure 2 shows a 0.4 km s^{-1} resolution ATCA absorption spectrum toward the source PKS 1814−637. The profile is dominated by a single deep narrow asymmetric component, but there is in addition a shallow broad absorption component. The parameters derived from fitting multiple Guassians to the absorption are shown in Table 1. As can be seen, the broad component is consistent with arising from the WNM. Interestingly, the kinetic temperature of this component places it in the thermally unstable range.

Table 1. Multi-Gaussian fit Parameters for the absorption spectra.

Source	Component	FWHM (km/s)	T_k K	N_{HI} $\times 10^{20}$cm^{-2}
	1	1.43 ± 0.01	44.6 ± 0.7	0.38 ± 0.01
PKS 1814−637	2	3.37 ± 0.06	248 ± 10	1.77 ± 0.15
	3	12.0 ± 0.5	3127 ± 300	7.2 ± 1.7

Acknowledgments I am grateful to Drs. Ayesha Begum and Nissim Kanekar for permission to use material from joint work.

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