Low Frequency Spectroscopy

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1. Introduction

The most commonly observed spectral lines at low radio frequencies ($\lesssim$ 1.6 GHz) are the HI 21cm and OH 18cm transitions. Apart from radio recombination lines, only a handful of other lines have been detected at these frequencies. These include CH_3OH, CH_2CN and CH_3CHO, low frequency transitions of which have so far been detected only in our own galaxy. In this article, we describe recent results obtained from radio spectroscopy at low frequencies, in the Galactic CH_3CHO and redshifted HI and OH lines, primarily with the Giant Metrewave Radio Telescope (GMRT).

2. HI 21cm absorption studies of high redshift galaxies

Damped Lyman-α systems (DLAs), the highest HI column density absorbers seen in QSO spectra, are believed to arise in the precursors of present-day galaxies (e.g. [1]). Despite their importance in the context of galactic evolution, the typical size and structure of DLAs (as well as physical conditions in them) have long been issues of much controversy (e.g. [2, 3]). If the QSO behind the DLA is radio-loud, absorption studies in the redshifted 21cm line provide a new dimension in our understanding of the absorbers, probing the kinematics, temperature and distribution of the absorbing gas.

2.1 The spin temperature

In the case of a radio-loud background quasar illuminating a DLA, the 21cm optical depth can be combined with the total HI column density (obtained from the Lyman-α profile) to yield the spin temperature T_s of the absorbing gas (e.g. [4]). Earlier 21cm studies have found T_s values in DLAs to be significantly higher than those seen in the Milky Way or local spirals (e.g. [5]); however, the small size of the sample made it very difficult to detect any clear trends. Further, hardly any absorbers of the sample were at low redshifts, $z < 1.6$. We have used the GMRT to carry out deep searches for 21cm absorption in 25 DLAs, with $0.09 \lesssim z \lesssim 3.4$ (see [4] and references therein); this has resulted in the detection of absorption in ten systems (with $0.09 < z < 3.4$) and fairly stringent upper limits on the 21cm optical depth in the other cases. We find, in general, that high redshift absorbers have high spin temperatures ($\gtrsim$ 1000 K), significantly larger than those typical of the Galaxy or Andromeda ($T_s \lesssim 300$ K). On the other hand, both high and low spin temperature absorbers are detected at low redshifts ($z < 1$). Interestingly enough, *all* low z DLAs with low spin temperatures ($T_s \lesssim 350$ K) are identified as arising in luminous $L \sim L_\star$ galaxies ([4]); conversely, $z < 1$ DLAs with $T_s \gtrsim 1000$ K are found to be associated with low luminosity dwarf or low surface brightness (LSB) systems.

In a multi-phase medium, the observed spin temperature is the column-density-weighted harmonic mean of the spin temperatures of different HI phases along the line of sight; it thus contains information about the relative fractions of gas in the CNM and WNM, besides their actual temperatures. The harmonic mean also implies that T_s is biased towards cold gas; for example, a line of sight with half of the HI at 100 K and the other half at 10^4 K would have $T_s \sim 200$ K. Similarly, T_s is only ~ 1000 K even if 90 % of the HI is at 10^4 K and the rest at ~ 100 K. Higher T_s values are thus to be expected in smaller systems like dwarf galaxies whose low metallicities and pressures are not conducive to the formation of the CNM ([6]). Current samples of 21cm absorbers are still of modest size (~ 30), the next generation of radio telescopes like the Square Kilometre Array should allow the detection of literally hundreds of such systems in blind surveys ([7]). A particular advantage of such blind surveys, is that radio absorption-selected samples are far less biased towards the brightest galaxies, or against dusty absorbers.

2.2 HI 21cm mapping studies

A particularly unique and exciting application of radio absorption spectroscopy is the direct measurement of the physical sizes of the redshifted absorbing galaxies, their kinematics and gas distributions. This cannot be done in the optical or ultraviolet bands because the background QSO is unresolved at these wavelengths. However, radio emission from quasars and radio galaxies often extends to hundreds of kilo-parsecs, far larger than the telescope synthesized beam. One can thus attempt to image the HI 21cm absorption against this extended continuum and to thus directly determine the size and nature of the absorber. We have used the GMRT to obtain such spatially resolved images of 21cm absorption at $z \sim 0.437$ towards the radio galaxy 3C196. The two main components of the 21cm profile were shown to arise from absorption in two arms of a large barred spiral, against the S-W hotspot and the eastern lobe of 3C196, as originally argued by Briggs et al. [9]. 21cm absorption was detected out to a radius of ~ 70 kpc, far beyond the extent of the optical galaxy (as is common in local spiral disks). Similarly, we have also mapped the 21cm absorption from the $z \sim 0.395$ DLA towards PKS 1229−021 ([8]), showing that the absorber has a physical size larger than ~ 30 kpc. These observations have only now become possible due to the combination of high sensitivity, excellent frequency coverage and long interferometric baselines at the GMRT. Prospects with next generation telescopes are truly exciting ([7]).

OH at high redshift

The small covering factor of molecular gas in galaxies implies that molecular absorption systems are quite rare. Only four cosmologically distant systems are known to show absorption in radio bands, detected through the strong CO and HCO^+ lines in the redshift range $0.25 - 0.9$ (e.g. [10, 11]). While these lines arise due to rotational transitions at high frequencies ($\gtrsim 100$ GHz), one of the most abundant molecules in the interstellar medium, OH, has four spectral lines at ~ 1.6 GHz. We have detected the two strongest transitions of this quadruplet (the "main" lines), in absorption, from the above four high-redshift absorption systems ([12, 13, 14]). We find, interestingly, that the linear correlation between OH and HCO^+ column densities found in molecular clouds in the Milky Way ([15]) persists out to $z \sim 1$. It has been suggested ([15, 16]) that OH is a possible tracer of molecular hydrogen, with $N_{\rm H_2}/N_{\rm OH} \approx 10^7$ over a variety of physical conditions. We have used this relationship to estimate $N_{\rm H_2}$ in the above four absorbers and find that the resulting column densities are more consistent with the observed visual extinction than those obtained from the CO line ([13]).

Next, it can be shown that the frequencies of the four OH 18cm transitions have different dependences on three fundamental "constants", the fine structure constant α, the proton gyro-magnetic ratio g_p and the electron-proton mass ratio μ. Comparisons between the measured redshifted line frequencies can hence be used to estimate changes in combinations of the above three constants with cosmological time ([18, 19]). This is very interesting as all the lines arise in a single species and one can thus test whether the different transitions arise from a single gas cloud or whether intrinsic velocity offsets between the lines might affect the measurement. Similarly, one can constrain changes in a different combination of α, μ and g_p by comparing OH and HI 21cm redshifts from a single absorber. We have applied these techniques to our best current OH and HI spectra, in the $z \sim 0.685$ absorbers towards B0218+357 and find results consistent with no evolution in the above constants. Even more interesting, we have detected the weak 18cm "satellite" lines from the $z \sim 0.25$ source PKS1413+135, with the 1720 MHz line in emission and the 1612 MHz line in exactly conjugate absorption ([19]). The conjugate behaviour ensures that the two lines arise from the same gas (so that intrinsic velocity offsets are not an issue) and allows us to place strong constraints on any evolution in the above constants over the redshift range $0 < z < 0.247$ ([19]).

Widespread organic molecules in the Galaxy

While the strongest lines from complex organic molecules in the interstellar medium arise in the millimetre regime, it is very difficult to probe the spatial structure and extent of these species through observations at these frequencies. This is because single-dish mm-wave telescopes have fairly poor spatial resolution, while, conversely, present millimetre arrays have very poor UV coverage. Complex species have long been believed to be confined to hot molecular cloud cores, compact regions of size ~ 0.1 pc. Recently, however, there have been indications that some large organic molecules are more wide-spread in the Sgr B2 cloud than was hitherto believed (e.g. [20]); however, no direct evidence was available. We have used the GMRT to map 1065 MHz line emission from the $1_{11} \rightarrow 1_{10}$ rotational transition of acetaldehyde (CH_3CHO) in the molecular cloud complex Sgr B2and directly demonstrate that this molecule is widespread in the cloud, over a region two orders of magnitude larger than the size of typical hot cores ([21]). Our observations are unique in that they have a high spatial resolution ($\sim 4''$), while still being sensitive to large-scale emission. The line emission is confined to regions with radio continuum emission and correlates well (in both position and velocity) with formaldehyde absorption towards this continuum; this is consistent with earlier single dish results suggesting that it is likely to be weakly mased. Our observations also suggest that grain mantle destruction by shocks plays an important role in the observed gas phase abundance of CH_3CHO in Sgr B2.

In summary, low frequency radio spectroscopic studies provide an important complement to information from other wavebands in understanding the nature of the interstellar medium and galactic and cosmological evolution. The recent commissioning or upgrade of telescopes such as the GMRT, the GBT and the WSRT has resulted in a dramatic improvement in radio spectroscopic instrumentation and make this an exciting time in the field.

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