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HI Absorption in GPS/CSS Sources

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Abstract: Combining our own observations with data from the literature, we consider the incidence of HI absorption in gigahertz peaked spectrum (GPS) and compact steep spectrum (CSS) sources. Here we present our preliminary results, where we find that the smaller GPS sources (<1 kpc) on average have larger HI column densities than the larger CSS sources (>1 kpc). Both a spherical and an axi-symmetric gas distribution, with a radial power law density profile, can be used to explain this anti-correlation between projected linear size and HI column density. Since most detections occur in galaxy classified objects, we argue that if the unified schemes apply to the GPS/CSS sources, a disk distribution for the HI is more likely.

Keywords: galaxies: active — galaxies: ISM — radio lines: galaxies

1 Probing the Gas Content in GPS/CSS Sources

Attempts to study the internal gas properties of GPS/CSS sources have been made in several different wavebands. For instance, optical studies show strong highly excited line emission with large equivalent widths (Gelderman & Whittle 1994), consistent with interactions between the radio source and the interstellar medium. The majority of the small GPS sources are weakly polarised (Stanghellini et al. 1998), suggesting strong depolarisation consistent with a very large central density. Other evidence for a dense environment comes from free–free absorption observations of, for instance, OQ208 (Kameno et al. 2000) and NGC1052 (e.g., Kellermann et al. 1999; Vermeulen et al. 2003a,b). Another example is Marr, Taylor, & Crawford III (2001), who found evidence for free–free absorption in the GPS source 0108+388, consistent with a 100 pc radius disk with an electron density of 500 cm^{-3}. Also in 1946+708 multifrequency continuum studies show indications of free–free absorption concentrated toward the core and inner parts of the counter-jet, again suggesting a disk or torus origin (Peck, Taylor, & Conway 1999). Disk-like kpc-scale distributions of gas have also been found in the optical, and the best example so far is the HST dust disk observed in the GPS source 4C 31.04 (Perlman et al. 2001).

Another way to study the gas content in these sources is by spectral absorption experiments, which are advantageous mainly because the sensitivity is independent of the source redshift. With this method small masses of gas may be probed, although high column densities are required. Using the 21 cm line of atomic hydrogen in absorption it is possible to study the atomic hydrogen (HI) content of GPS/CSS sources. The HI is likely only a fraction of the total gas present, therefore the observations provide lower limits to the total gas mass and density. The strength of GPS/CSS sources at cm wavelengths makes them good targets for such experiments; in addition their small sizes indicate that lines of sight to CSS sources will sample the dense gas confined within the centre of the host galaxy. Similarly the line of sight to a GPS source will trace gas within the narrow-line region.

2 The Sample

In order to increase the statistics of high redshift sources with associated HI absorption, a survey to detect redshifted HI in northern sky sources has been performed using the Westerbork Synthesis Radio Telescope (WSRT). The WSRT is equipped with wide bandwidth UHF receivers (700–1200 MHz), which enables studies of the redshifted $\lambda = 21$ cm line of neutral hydrogen for $0.19 < z < 1.0$. Around 60 GPS/CSS sources have been searched at the WSRT so far, as parts of several different projects with slightly varying goals (R. Vermeulen et al., in preparation). From those sources we select objects which have projected linear sizes <10 kpc, and in addition to our own observations we have included lower redshift GPS/CSS sources from the literature which had available HI absorption data (see Pihlström 2001).

3 Relation between N_{HI} and Linear Size

Including all targets, our preliminary results show a general HI absorption detection rate of 48%. However, if we make the GPS/CSS division at 1 kpc, we find that the GPS sources have a detection rate of 53% as compared to the CSS detection rate of 36%. This could reflect the fact that the more compact sources have a larger part of their continuum emission covered by nuclear gas. This effect has already been suspected due to the high detection rate of HI absorption in nearby GPS/CSS objects (Conway 1996).

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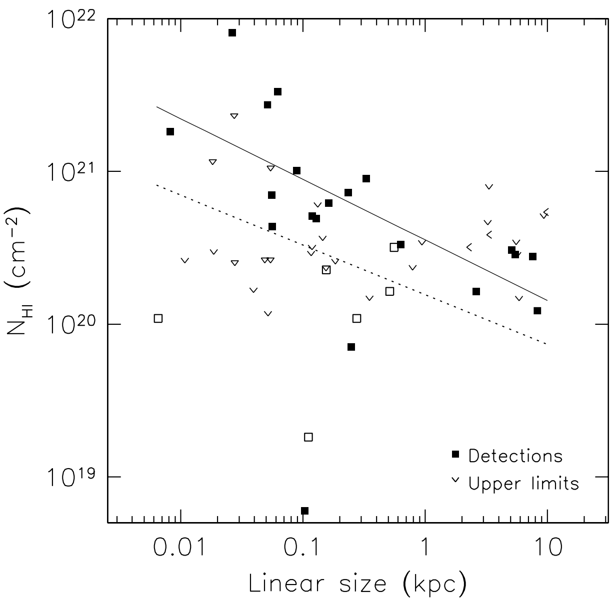

Figure 1 Absorbed HI column density versus projected linear size. Square symbols are detections, while the arrows denote upper limits at the 3σ level. Arrows pointing to the left are points for which we only have upper limits on the source size. Open squares and open triangles indicate preliminary data still being reduced. There is an anti-correlation between the source size and the amount of absorbing gas, confirmed by survival analysis. The least squares fit taking into account the upper limits is shown with the dotted line. This can be compared with a least squares fit to the detections only, plotted with the solid line.

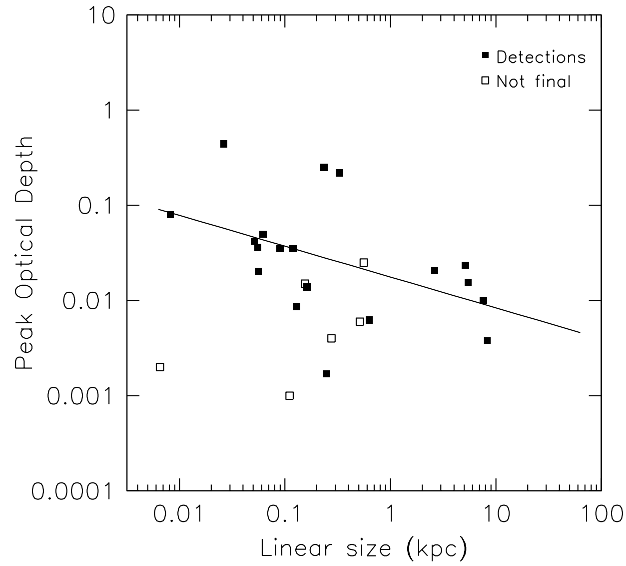

Figure 2 Peak optical depth versus linear size. Filled squares represent HI absorption detections, while open squares are preliminary detections. A clear correlation is found with a probability >95%, which is enough to explain the correlation in Figure 1.

The probable youth of GPS/CSS sources implies the possibility of studying the birth of radio sources, and little is known of the mechanisms triggering the radio activity. It has been suggested that mergers could provide a way to transport gas to the centre of the host galaxies and thus be involved in the onset of the nuclear engine. Indeed, optical observations have shown that many of the GPS/CSS sources are in disturbed or interacting systems (de Vries et al. 2000; O'Dea et al. 1996). If the GPS/CSS sources are young sources resulting from mergers, we expect a gas-rich galactic nucleus. The amount of gas needed to fuel the AGN is probably much smaller than the total gas mass available, thus we do not expect the total gas mass to be systematically different between sources which are all younger than a million years. However, a radial density profile may be reasonable to assume, and then absorption experiments would probe different column densities of gas as the source grows in size (since most of those objects are lobe-dominated). Using results from our HI absorption studies together with results compiled from the literature, we here investigate if the amount of neutral atomic gas shows any systematic variation with source size.

Despite that a few numbers are still tentative (data reduction is still in progress for a number of objects), there appears to be an anti-correlation between the source linear size and the HI column density (Figure 1). A visual inspection suggests that the column densities for sources <1 kpc are larger than for those >1 kpc. The data set contains upper limits both in HI column density, as well as a few points which have upper limits on their size. We therefore investigated the possible slope in Figure 1 using the survival analysis package ASURV, taking into account also the upper limits (Lavalley, Isobe, & Feigelson 1992). A Kendall's Tau test shows that there exists a correlation between the column density and the linear size with a probability >99%, while a Spearman's Rho test shows a correlation with a probability >95%. Linear regression applied with ASURV finds the relationship $N_{\mathrm{H}i} = 10^{20.2} LS^{-0.33}$, where LS is the linear size in kpc. This linear fit is plotted with a dotted line in Figure 1.

An interesting question is whether the population of small sources has larger column densities because the FWHM of the absorption line is wider, or because the line is deeper. Spearman rank tests show no significant correlation between the observed column densities and line widths, while the peak optical depths and linear sizes are correlated with probability >95%. This is shown in Figure 2, where the solid line represents a least square linear fit to the data points. The slope is -0.32, which implies that the slope in Figure 1 mainly depends on a difference in the observed opacity and is not due to differences in the line width.

4 Origin of Absorbing Gas

Our first results show that the column density decreases when the linear size increases, implying a gas density which decreases with radius. Such a density distribution could be either spherical or disk-like. By integrating the column density along the line of sight toward the two lobes, we have investigated some functional forms for the density distribution which may reproduce the observed correlation between linear size and HI optical depth. We have assumed a representative viewing angle of 45°.

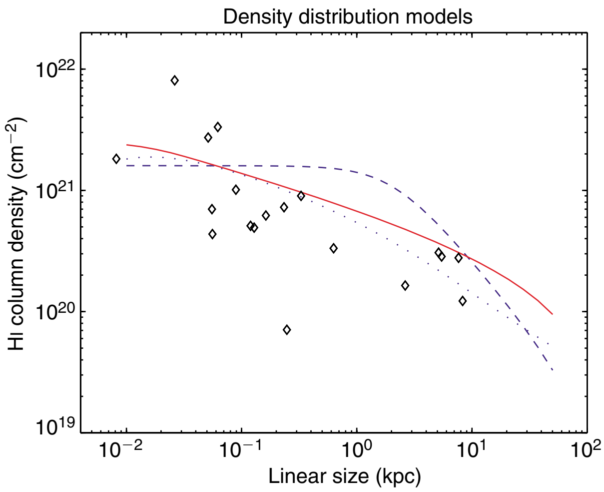

Figure 3 Results of calculating the expected HI column density given different density profiles. The diamonds represent the real data. The spherical King density profile, plotted with a dashed line, cannot reproduce the observed HI column density distribution for any value of β. Instead, a power law drop of the density provides a more similar distribution, with the closest fit for $\beta = 1.25$ and $n_0 = 2.7 \times 10^{-2}$ cm^{-3} (solid line). The dotted line represents a disk distribution; it is possible to find reasonable fits for a large range of opening angles.

Figure 3 shows a spherical and an axi-symmetric (disk-like) distribution, both with a simple power law radial fall-off in density, $n = n_0(r/r_0)^{-\beta}$ ($r_0 = 1$ kpc), and also a King density profile with a cutoff outside 50 kpc, $n = n_0(1 + r^2/r_c^2)$ ($r_c = 1$ kpc). While King profiles cannot provide a good fit, in contrast the power law models can fit the data adequately both for spherical and disk-like geometries. For more details, see Y. Pihlström et al. (in preparation).

In most cases the spatial resolution of present HI data is not enough to determine whether the absorption covers both lobes (consistent with ISM gas) or only one lobe (indicating a disk distribution). To date high resolution HI data exist for a limited number of sources that in all cases indicate HI disks (Conway 1996; Peck & Taylor 1998; Peck et al. 1999), which argue for a disk model. One possibility to distinguish between a disk or a sphere is to look at any possible orientation effects; in general quasars are supposed to be seen at a smaller viewing angle than the radio galaxies. Because of relativistic boosting the core strength is considered to be a good indicator of orientation; Saikia et al. (1995) studied a sample of CSS sources with detected radio cores and found that the degree of core prominence was consistent with those for larger radio sources and also consistent with the unified scheme. Assuming the unified scheme holds for GPS/CSS sources, a spherically symmetric distribution could thus be considered less likely, since we in fact have found that there appears to be a larger detection rate in galaxies (~60%) than in quasars (~25%: Pihlström 2001). We note however that there are indications that the GPS quasars may not be the same type of objects as the GPS galaxies, in which case we cannot use the argument of core prominence to distinguish between a disk or a spherical origin of the gas. Instead, future higher resolution VLBI observations (using the EVN UHF system) will be needed to determine whether disks are the most common cause of the HI absorption also in the higher redshift objects.

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