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Pulsar observations and small-scale structure in interstellar H I

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SUMMARY

If small-scale structure is present in H I clouds, then H I absorption profiles towards pulsars with large proper motions should show changes on a time-scale of a few years. We have compared absorption measurements, made with an interval of about four years, towards two pulsars and find a marginal difference in one of them. If confirmed, this could imply structures on the scale of ~ 1000 AU in H I clouds.

Key words: pulsars: general – interstellar medium: clouds – interstellar medium: structure – radio lines: atomic.

1 INTRODUCTION

Recent VLBI observations of some extragalactic sources at 21 cm by Diamond *et al.* (1989) seem to indicate that H I absorption in the interstellar medium (ISM) changes over small angular scales. This has been interpreted by these investigators as due to the presence of very small-scale (about 25 AU) structures in the H I distribution in the ISM. If the spin temperature of these structures is about 50 K, which is typical of H I clouds, then the measured column density of a few times 10^{19} cm^{-2} implies that the number density in these small-scale structures is about 10^4–10^5 cm^{-3}. The resulting pressure in these structures will be two to three orders of magnitude greater than the average interstellar pressure. If the number of such structures in the ISM is large or comparable to the number of H I clouds, then there are serious difficulties in understanding their formation and maintenance in the ISM. Clearly there is a need for further and possibly independent investigations of the small-scale structure in H I clouds in the ISM. In this note we present an independent method of studying such structures.

2 H I ABSORPTION TOWARDS PULSARS

If H I clouds with sizes of a few tens of AU indeed exist in the ISM, then we should be able to see noticeable changes with time in the H I absorption profiles against pulsars which have large proper motions. For example, a transverse pulsar velocity of 100 km s^{-1} will result in an apparent (mid-way) motion of the ISM of about 10 AU yr^{-1}. Accurate measurements of the proper motion of pulsars with distances up to about 5 kpc (Lyne, Anderson & Salter 1982; Bailes *et al.* 1990; Harrison, Lyne & Anderson 1992) indicate a wide range of space velocities (up to about 1000 km s^{-1}). The expected contribution to the apparent motion of the ISM from galactic rotation is also appreciable for most of the distant pulsars. Therefore comparison of H I absorption measurements made at different epochs in the directions of pulsars should provide an excellent means to investigate the structure in the H I distribution along their lines of sight. [One of us (VR) learnt through private communication that D. A. Frail of NRAO is conducting similar investigations.]

Considering this possibility, we have, as a first step, examined two cases, namely PSR 1557 – 50 and 1154 – 62, for which H I absorption measurements have been published for two epochs separated by about four years. We find a marginal difference (at the 4σ level) in the absorption profile in the case of PSR 1557 – 50, whereas the spectra at the two epochs for PSR 1154 – 62 are essentially consistent with each other within observational errors.

The profiles shown in Figs 1 and 2 are the H I measurements on pulsars 1557 – 50 and 1154 – 62 reported by Ables & Manchester (1976) and Manchester, Wellington & McCulloch (1981). The epochs of these observations are separated by about four years and both the sets of measurements were made with the Parkes telescope and used the same frequency resolution of 33 kHz. This makes the comparison of the spectra easier. The earlier observations, however, were less sensitive and used only a single linearly polarized feed. Before we compare the absorption profiles, it is worth noting that the emission profiles (Figs 1a and 2a) obtained in the two measurements are consistent with each other.

The error bars estimated from the parameters quoted in the above papers are shown along with the absorption

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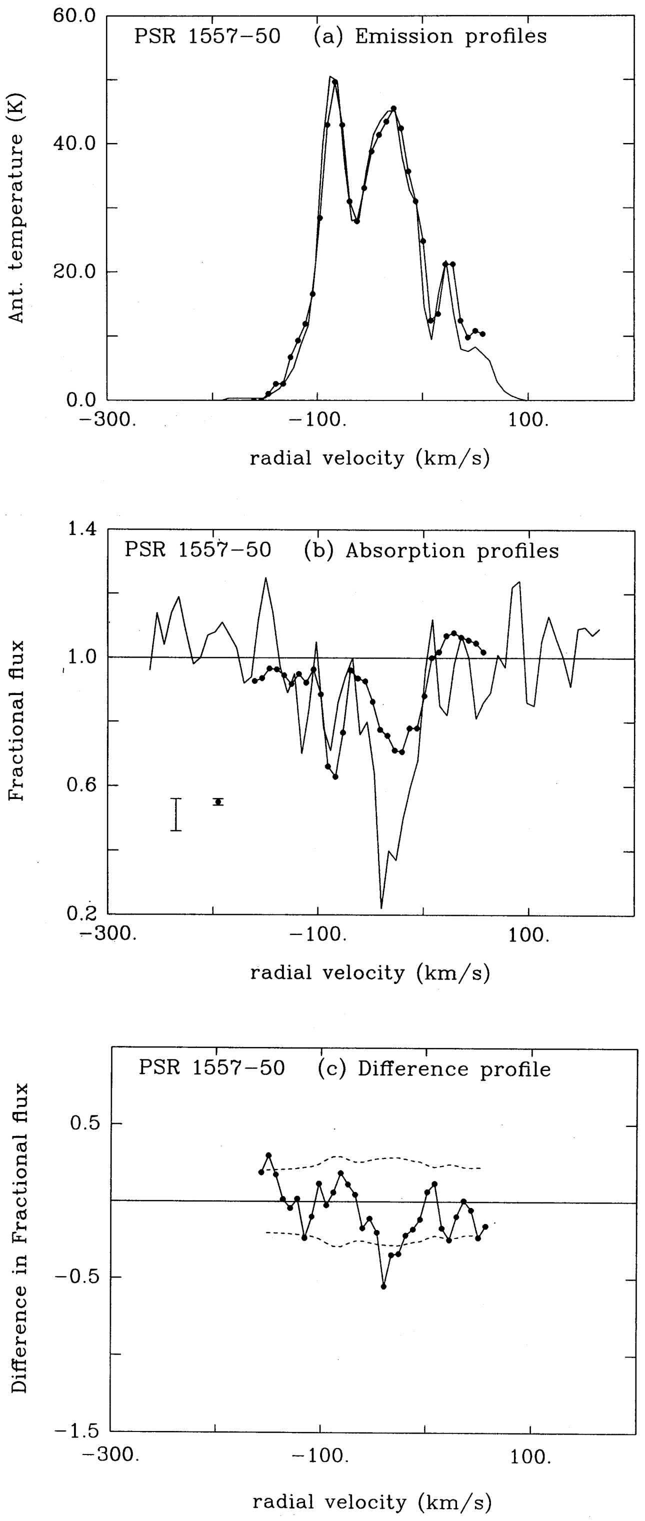

Figure 1. H I absorption and emission measurements at two epochs towards the pulsar PSR 1557 − 50. The profiles in (a) and (b) are taken from Ables & Manchester (1976) (continuous lines) and Manchester *et al.* (1981) (continuous lines with dots). The two vertical bars in (b) represent the rms errors of the two measurements in regions away from line emission. The difference between the two absorption profiles is shown in (c) where a negative value implies deeper absorption at the earlier epoch. The two dashed lines in (c) represent the estimated $\pm 2\sigma$ noise across the difference spectrum. These noise estimates *do* include the effect of the increased noise due to the presence of H I emission.

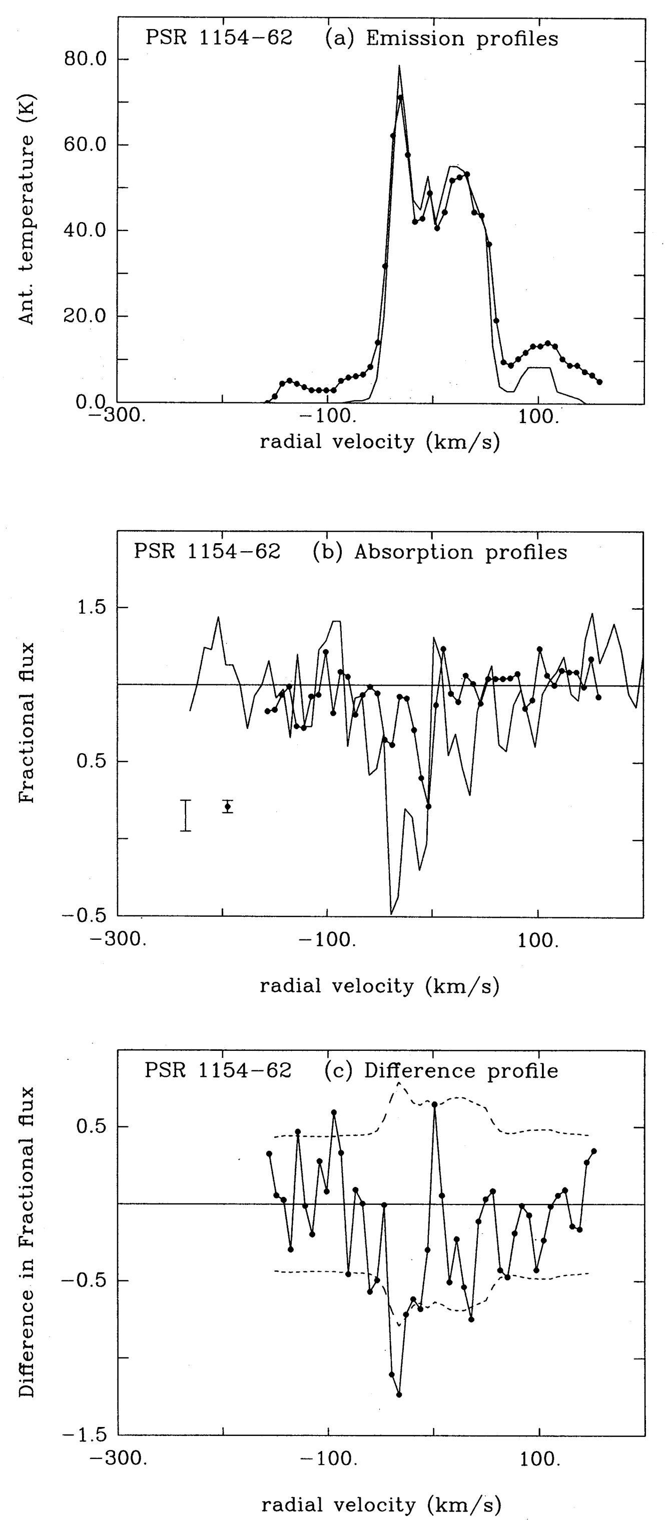

Figure 2. As Fig. 1 for the pulsar PSR 1154 − 62.

profiles. These estimates seem consistent with the variations seen at velocities away from the line features. It should be noted that these errors are strictly valid only in the regions of the spectrum where the H I emission is absent. One important aspect that should be kept in mind while comparing H I absorption features in the galactic plane is that the noise fluctuations in the channels where H I emission is present will be much larger, since in these channels the system noise will have a substantial contribution from H I emission. For example, in the observations by Manchester *et al.* (1981), the system noise (and therefore the rms noise in the spectrum) would become almost double in the central region of the spectrum due to a contribution of 40–50 K from H I emission (Figs 1a and 2a).

2.1 PSR 1557 − 50

The absorption profiles for the two epochs are shown in Fig. 1(b), and they do seem to differ in the depth of absorption in the velocity range -20 to -50 km s^{-1}, whereas the agreement for the -80 km s^{-1} feature is quite good. In Fig. 1(c) we have plotted the difference in the two absorption profiles along with 2σ error estimates for each of the channels. These error estimates also take into account the differences in the system noise in different frequency channels due to the presence of strong H I emission. The differences in the absorption features are generally consistent with the noise fluctuations except at the radial velocity of -40 km s^{-1}, where the difference is at about the 4σ level. This difference retains its significance even after removing a possible first- or second-order baseline fitted to channels where absorption is absent. The difference in the apparent optical depth at -40 km s^{-1} between the two epochs could be $\Delta\tau \sim 1.1^{+1.1}_{-0.6}$ (the errors correspond to 1σ errors in the depths of absorption). The apparent motion of the clouds with respect to this line of sight due to galactic rotation is estimated to be 25 to 50 km s^{-1}. If the proper motion of the pulsar is ignored then the lines of sight at the two epochs are estimated to be separated by 20 to 40 AU. A velocity of 100 km s^{-1} for the pulsar proper motion will increase this separation by about 40 AU in the most favourable case. Assuming a spherical shape for the cloud, a value of 2 for the central optical depth and the pulsar proper motion to be about 100 km s^{-1}, we estimate that the diameter of these clouds would be in the range 100 to 2000 AU. If the column density in a cloud is $\sim 10^{19}$ cm^{-2} and the spin temperature is 50 K, then the number density would be in the range 300 to 6000 cm^{-3}. The cloud would be out of pressure equilibrium with the ISM.

2.2 PSR 1154 − 62

The absorption profiles for this pulsar, shown in Fig. 2(b), are much noisier. Some marginal differences are seen (Fig. 2c) in the velocity range -30 to -40 km s^{-1} and around zero velocity. However, in these regions of the spectrum the estimated errors are quite large because of a significant contribution to the system noise from H I emission. No significance can be attached to the negative peak seen near -30 km s^{-1} in the difference profile (Fig. 2c), since it is precisely at this velocity that the fractional flux in one of the absorption profiles (Fig. 2b) goes below zero because of noise fluctuations. Furthermore, when a second- or third-order baseline is removed from the difference spectrum, no significant difference remains between the two epochs.

3 DISCUSSION AND CONCLUSIONS

The scope of the above comparison is limited mainly by the signal-to-noise ratio of the spectra at the two epochs. The fact that the observations by Ables & Manchester (1976) used only a single linearly polarized feed is not expected to affect their result, since the differential Faraday rotation across the observed band is very small. Some systematic differences in the absorption spectra between the two epochs could result from the fact that the later spectra are measured over a narrower total bandwidth and therefore their baselines are not as well defined as for the earlier spectra. However, this is expected to contribute only a low-order residual baseline in the difference spectra and, as we have already discussed, any possible removal of such low-order baselines does not seem to affect the significance of the apparent difference for PSR 1557 − 50. Such measurements could be affected by diffractive scintillations when the decorrelation bandwidths are comparable to the spectral resolution. In the above two cases we can ignore such effects, since the observing time is much longer than the typical timescale of these scintillations.

Of the two cases that we have examined here, one shows a marginal difference, which, if confirmed, could imply structures on the scale of about 1000 AU. Since the column density of this feature appears to be at least 10^{19} cm^{-2}, the implied number density could pose problems for understanding the maintenance of such structures in the ISM. Clearly there is a need for further studies of this kind which provide an independent method of studying the small-scale structure in H I clouds.

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