PSR B1849+00 probes the tiny-scale molecular gas?

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Abstract. In this paper we present and discuss the great difference in OH absorption spectra against PSR B1849+00 and SNR G33.6+0.1 along the same line-of-sight. This finding is important as it clearly demonstrates that statistics of absorbing molecular gas depends on the size of the background source.

Keywords: ISM, molecules, pulsars, supernovae

1. Introduction

Studies of the absorption of signals from background continuum sources by the intervening medium have been a very powerful way of probing the properties of the interstellar medium (ISM). Pulsars are particularly suitable as background sources because of their pulsed radiation which allows us to investigate, in both emission and absorption, almost exactly the same line-of-sight (Weisberg et al. 1995; Koribalski et al. 1995). Another great advantage pulsars have is that their continuum emission subtends over an extremely small solid angle, allowing us to probe needle-thin samples of the ISM.

Motivated by the pulsars’ unique capabilities for studying the ISM, we measured the absorption spectra of several pulsars at the wavelength of the hydroxyl radical (OH), $\lambda = 18$ cm, using the Arecibo telescope. We detected OH absorption against one of our sources – PSR B1849+00. The line-of-sight toward B1849+00 is particularly interesting as it passes right through the Galactic plane ($b = 0^\circ$) and is very close (8 arcmin south) to a nearby supernova remnant (SNR) G33.6+0.1.
2. Observations and Data Processing

OH observations were undertaken with the Arecibo (305 m) radio telescope. The FWHM of the Arecibo telescope beam is approximately $2'.6 \times 3'.0$ at 1.6 GHz. The Caltech Baseband Recorder was used as a fast-sampling backend, simultaneously covering both OH mainlines (at 1665 and 1667 MHz). Two types of spectra of astrophysical interest were formed during the off-line data processing stage: the pulsar absorption spectrum, which depicts the pulsar signal alone (as absorbed by any intervening OH); and the “pulsar–off” spectrum, which registers all emission and absorption lying in the telescope beam during the time that the pulsar signal is not present. The final spectra have velocity resolution of 0.9 km s$^{-1}$. More information about our observations and data processing can be found in Stanimirović et al. (2003).

3. Pulsar and SNR OH Absorption Spectra

Pulsar OH absorption spectra at 1665 and 1667 MHz are shown in Fig. 1 (top two panels). At both frequencies, narrow absorption lines were detected at a velocity of about 102 km s$^{-1}$. The only previous OH absorption detected against a pulsar at 1667 MHz, to our knowledge, was by Slysh (1972). Spectra in Fig. 1 depict the pulsar signal alone as being absorbed by intervening OH. The absorption system shown in Fig. 1, which we label as ‘A’, has higher optical depth than what is typically found towards extragalactic sources (Dickey et al. 1981; Colgan et al. 1989). The ratio of the equivalent widths for the 1665 and 1667 MHz lines is however very close to 5:9 which is expected for thermalized level populations.

The pulsar-off spectra are presented in the same figure (bottom two panels). As the SNR G33.6+0.1 is partially covered by the Arecibo beam absorption features in these spectra are effectively produced against the continuum emission from G33.6+0.1. The absorption features at 102 km s$^{-1}$ differ greatly, in both peak intensity and linewidth, from corresponding features seen in the pulsar absorption spectra at the same velocity. In particular, feature ‘A’ in the 1667 MHz line is almost 15 times wider and 30 times shallower that its corresponding feature in the PSR absorption spectrum.

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1 The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, operated by Cornell University under a cooperative agreement with the National Science Foundation.
Figure 1. Top two panels: Pulsar absorption spectra toward B1849+00 produced against the pulsar continuum emission alone at 1665 and 1667 MHz. Bottom two panels: Pulsar-off spectra toward B1849+00 produced against the continuum emission from G33.6+0.1 at 1665 and 1667 MHz. In addition to the absorption system at 102 km s$^{-1}$, an absorption system at 10 km s$^{-1}$ ('B') and an emission feature at 70 km s$^{-1}$ ('C') are seen.

4. Possible Geometrical Explanations

The pulsar absorption spectra are very deep and narrow, tracing dense molecular gas with $N_{\text{H}} \sim 10^{23}$ cm$^{-2}$, if the OH excitation temperature $T_{\text{ex}} = 10$ K is assumed. However, the most striking observational result is that the pulsar absorption and pulsar-off spectra appear to trace very different absorption features along the same line-of-sight and with the same central velocity of 102 km s$^{-1}$. This result has to account for two additional constraints. First, a large molecular cloud was observed in $^{12}$CO(1-0) in the direction toward the SNR and the PSR by Green & Dewdney (1992). Second, it was suggested that the two objects are interacting with each other (Green 1989; Green & Dewdney 1992). Below we investigate two different geometrical scenarios that can explain the large difference in OH optical depths found against the PSR and the SNR.

(1) An additional molecular cloud could be located in front of the PSR yet behind the SNR. This would be the simplest explanation whereby OH absorption features in the PSR and the pulsar-off spectra originate from two physically unrelated molecular clouds (see Fig. 2, case 1). The sharp and deep absorption lines, seen in the PSR absorption spectra,
are produced by an additional molecular cloud located in front of the PSR yet behind the SNR. On the other hand, broad OH absorption lines in the pulsar-off spectrum are most likely due to the interaction between the SNR with the molecular cloud.

This additional molecular cloud located behind the SNR could be of any size. However, the large-scale $^{12}$CO(1-0) distribution presented in Green & Dewdney (1992) does not show any obvious features that could be associated with this secondary cloud. In addition, we compared the hydrogen column densities derived from OH and $^{12}$CO(1-0) in the PSR direction and found a good agreement. This suggests that, most likely, all OH seen in absorption and CO seen in emission coexist in the same region making the existence of an additional molecular cloud along the line of sight unlikely.

(2) All molecular gas is in front of the SNR and the PSR. An alternative possibility is that the OH absorption features seen in the PSR absorption and pulsar-off spectra originate from the same general molecular cloud located in front of both the PSR and the SNR. This could happen in the case where the PSR absorption is produced by a small clump (‘cloudlet’), while the shallower, broader absorption features against the SNR are caused by an ensemble of ‘cloudlets’ of varying properties (Fig. 2, case 2). More interestingly, the small ‘cloudlet’ could represent a typical building block for the molecular cloud.
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The solid angle subtended by the ‘cloudlet’ intercepts solid angles of both PSR and SNR continuum emission regions, however the pulsar-off spectrum does not appear to have a significant contribution from the ‘cloudlet’. This suggests that the ‘cloudlet’ covers a very small fraction of the SNR and can be used to place an upper limit on its size. By assuming that the molecular cloud is at the distance of 7 kpc, we estimate that the ‘cloudlet’ radius must be $< 1$ pc while its hydrogen volume density is $n > 10^5$ cm$^{-3}$.

5. Discussion

As discussed in the previous section PSR absorption spectra reveal existence of fine spatial structure in the absorbing OH gas on scales $< 1$ pc. Also, all molecular gas seen in absorption is most likely located in front of both the SNR and the PSR. This is a clear demonstration that a pencil-sharp OH absorption sample against the PSR differs dramatically from a large-angle absorption sample against the SNR. The example of B1849+00 and G33.6+0.1 shows that measured optical depths in OH depend heavily on the size of the background source. This OH result is very different from HI absorption findings (Dickey et al. 1979; Dickey et al. 1981; Payne al. 1982) where absorption statistics was compared for a wide range of angular size sources and no significant difference was found. This led to the conclusion that the ‘cloudlet’ model of the interstellar HI, whereby HI clouds are composed of a large number of randomly distributed smaller clumps (or ‘cloudlets’), is not prominent. However, the difference at HI and OH is not totally unexpected: the solid-angle effect is expected to be more pronounced for molecular gas where clumpiness is known to be significant.

We have investigated whether the PSR OH optical depth profiles could be building blocks for the molecular cloud by modeling the SNR optical depth profiles with an ensemble of PSR profiles (see Stanimirovic et al. 2003). It was shown that the ‘cloudlet’ model is not appropriate. A more complex structure of the molecular cloud is required to explain the observed OH line profiles. In order to constrain better molecular cloud geometry detailed OH observations of the whole SNR are crucial. Another open question is whether the line-of-sight toward B1849+00 and G33.6+0.1 is unique or similar examples exist elsewhere in the ISM. We would like to encourage further OH observations towards pulsars to constrain how common this phenomenon may be.
6. Conclusions

We presented here the second ever detection of the OH absorption against a pulsar. Absorption lines were detected against PSR B1849+00 in both OH mainlines. In addition we detected OH absorption against a nearby SNR, G33.6+0.1. The two sets of absorption profiles differ greatly but most likely trace the same molecular cloud located in front of both the SNR and the PSR. This surprising result indirectly points to the existence of small scale (< 1 pc) structure in the absorbing OH gas. Also, it shows that angular size of background sources can influence greatly optical depth measurements in OH. This is opposite to what was found for the HI absorbing gas.

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