DETECTION OF OH ABSORPTION AGAINST PSR B1718−35

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Received 2007 November 20; accepted 2008 January 7

ABSTRACT

OH absorption against PSR B1718−35 at \((l, b) = 351.688^\circ, +0.671^\circ\) has been discovered at 1665 and 1667 MHz using the Green Bank Telescope. The absorption appears to arise at the interface of an H II region and a molecular cloud that are likely associated with the high-mass star-forming region NGC 6334. Beam dilution is found to be the cause of differences between the opacity of the OH against the Galactic background continuum emission and against the pulsar. The OH cloud is approximately \(3 \times 1.3\) pc and is located behind the H II region.

Subject headings: ISM: clouds — pulsars: individual (PSR B1718−35) — radio lines: ISM

1. INTRODUCTION

H I absorption measurements against pulsars have provided a wealth of information on the structure of the interstellar medium (ISM). They provide one of the best means of obtaining distance estimates to a large number of pulsars (e.g., Frail & Weisberg 1990). Combining the distances with a pulsar’s dispersion measure (DM) allows the average electron density along the line of sight to the pulsar to be determined. This also allows models of the Galactic electron density to be computed (e.g., Cordes & Lazio 2002, 2003). The H I absorption measurements essentially provide the means by which the electron density model and the atomic neutral gas models of the Galaxy are tied together. Comparison of the H I emission when the pulsar is “off” with the H I absorption against the pulsar can provide information on the density and spin temperature of the absorbing H I gas (e.g., Minter et al. 2005). H I absorption measurements against pulsars have been used to search for structure in the neutral atomic gas on very small scales (e.g., Minter et al. 2005; Weisberg & Stanimirovic 2007). These measurements also play an important role in the study of pulsar population statistics, providing the spatial distribution of pulsars throughout the galaxy (e.g., Lorimer et al. 2006).

It is only natural to attempt to extend absorption measurements against pulsars to molecular gas. Since pulsars have steep spectral indices, it is necessary to look for molecules that have transitions at lower frequencies and that have relatively strong line strengths. This makes the \(2\pi_\text{cm} 2\) transitions of the hydroxyl radical (OH) at 1612, 1665, 1667, and 1720 MHz ideal for looking for absorption from molecular material against pulsars.

Previously, only two pulsars have been found that have measurable OH absorption: PSR B1849+00, discovered by Stanimirović et al. (2003) using the Arecibo Radio Telescope, and PSR B1641−45, discovered by Weisberg et al. (2005) using the Parkes Radio Telescope. Both Stanimirović et al. (2003) and Weisberg et al. (2005) observed numerous bright pulsars, 25 in total. In both cases, the OH absorption seen toward the pulsars have unique properties. The OH absorption measured against the pulsars have narrower line widths and deeper absorption (larger opacities) than is observed when the pulsar is “off.” This has been attributed to the presence of small-scale structure in the molecular material along the lines of sight to the pulsars.

There are a large number of pulsars that have not been observed for OH absorption. In this paper, I present observations of 16 pulsars (PSR B1736−31, PSR B1750−24, PSR B1809−176, PSR B1815−14, PSR B1817−13, PSR B0458+46, PSR B1703−40, PSR B1737−30, PSR B1818−04, PSR B1829−08, PSR B1834−10, PSR B1845−01, PSR B2106+44, PSR B2111+46, PSR B1648−42, and PSR B1718−35) used in the search for OH absorption. OH absorption was only detected against PSR B1718−35.

2. OBSERVATIONS AND DATA REDUCTION

The OH absorption measurements were made using the National Radio Astronomy Observatory’s (NRAO) 100 m Green Bank Telescope (GBT). The GBT has an unblocked aperture and a spatial resolution of \(7.4^\prime\) at 1665 MHz. The 1–2 GHz receiver, placed at the focus of the Gregorian optics system, was used for the observations. This receiver has a nominal bandpass of 1100–1752 MHz and dual linear polarization; it had a system temperature on cold sky of 18 K. The NRAO spectral processor, a fast Fourier transform (FFT) spectrometer, was used to simultaneously observe the 1612, 1665, 1667, and 1720 MHz transitions of OH using orthogonal linear polarizations. The spectral processor integration time was approximately 10 s, set to the nearest integer number of pulse periods. The spectral processor’s 32 level sampling provides excellent dynamic range when radio frequency interference (RFI) is present. Most observations used 256 spectral channels per linear polarization per OH transition with a bandwidth of 2.5 MHz, producing a spectral resolution of \(\sim 1.75\) km s\(^{-1}\) per channel. Higher resolution observations were performed for PSR B1718−35, using 256 spectral channels per linear polarization per OH transition with a bandwidth of 0.625 MHz, producing a spectral resolution of \(\sim 0.44\) km s\(^{-1}\) per channel.

The dates and times of the observations are listed in Tables 1 and 2. Table 1 lists the observing dates and times for those pulsars for which OH absorption was not detected. Table 2 lists the dates, times, and bandwidths used for the OH absorption observations toward PSR B1718−35. The pulsar OH absorption data were reduced using the technique outlined in Minter et al. (2008). The data were flagged for instances when RFI was present.

The Galactic coordinates of PSR B1718−35 are \((l, b) = 351.688^\circ, +0.671^\circ\). Since PSR B1718−35 lies in the Galactic plane, where continuum emission is present, a slice at constant Galactic longitude was observed at the longitude of PSR B1718−35. The observations went approximately \(\pm 5^\circ\) out of the Galactic

\(^1\) The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.
plane. These observations allow the Galactic continuum, along with the continuum from a discrete object in front of PSR B1718–35, to be measured. Combined with the pulsar “off” spectra, the opacity of the OH lines can then be calculated. The data were corrected for the opacity difference between the zenith and the low elevation (10°–12°) of the observations. A zenith opacity of $\tau = 0.0103$ at 1666 MHz was used along with an atmospheric temperature of 250 K. The system temperature of ~15 K found near the zenith was then subtracted from the data. The remaining brightness temperature was assumed to represent the continuum along the line of sight toward PSR B1718–35.

3. SOURCE SELECTION

The two previous large searches for OH absorption against pulsars by Stanimirovic et al. (2003) and Weisberg et al. (2005) selected their targets based on the brightness of the pulsars. This yielded a detection rate of 2 out of 25 (8%), which motivated me to look for better selection criteria for pulsars with OH absorption.

3.1. Scattering as a Possible Selection Criterion

Boldyrev & Königl (2006) proposed that the strongest interstellar scattering (ISS) of pulsar signals was not induced by Kolmogorov-like turbulence in the electrons within the ISM, but by refraction at the random interface between ionized and non-ionized gas along the line of sight. In particular, it was predicted that the photodissociation regions (PDRs) at the edges of molecular clouds (MCs) should produce the strongest scattering. Boldyrev & Königl (2006) also suggested that a pulsar’s time broadening would scale as density to the fourth power ($\tau \propto n^4$), so that only the densest PDR along the line of sight will dominate the ISS. This will give the appearance of a single scattering screen toward the pulsar that is consistent with what is observed (e.g., Hill et al. 2005).

Table 3 lists previous attempts to observe OH absorption against pulsars in Table 3. From Table 3, it can be seen that the only OH absorption found (including all possible detections) are along lines of sight that are highly scattered and that have large amounts of CO. The pulsars with nondetections are typically bright pulsars with relatively weak scattering and little CO along their lines of sight. By looking only at bright pulsars, the searches for OH absorption have been biased to lines of sight with little molecular material. If Boldyrev & Königl’s hypothesis is correct, then the OH absorption searches have also been biased, since they tend to be toward weakly scattered pulsars.

I thus created a list of the most highly scattered pulsars that had a measurable amount of CO along their lines of sight. I obtained the scattering values from the Australia Telescope National Facility (ATNF) Pulsar Catalog (Manchester et al. 2005) and the CO information from Dame et al. (1987). I then selected as my source list the pulsars that were outside the declination range of Arecibo, that were viewable with the GBT, and that could reach a limiting OH opacity of $\tau \sim 0.1$ in less than 10 hours. This list included the pulsars PSR B1736–31, PSR B1750–24, PSR B1809–176, PSR B1815–14, PSR B1817–13, and PSR B1718–35, which were observed in 2005 June–October.

3.2. OH Emission as a Selection Criterion

Another approach that I took was to come up with a list of pulsars that had detectable CO emission along their lines of sight. I excluded pulsars in the declination range of Arecibo, pulsars with Galactic latitudes greater than 5°, pulsars that would take more than 30 hr to reach $\tau \sim 0.1$, and pulsars that had been previously observed for OH absorption. There were 85 pulsars that met these criteria. I then observed the OH emission toward these pulsars with the GBT to determine which lines of sight had detectable OH (these results will be presented in a future paper; A. H. Minter 2008, in preparation).

OH was detected on the lines of sight toward 34 of the 85 pulsars. The velocity of the OH emission, along with the DM-derived distance of each pulsar, was used to determine which

| PULSAR | l (deg) | b (deg) | Dates of Observations | Integration Time (hr) |
|--------|-------|--------|----------------------|----------------------|
| PSR B1736–31 | 357.099 | −0.219 | 2005 Jul 31 – Aug 08 | 5.5 |
| PSR B1750–24 | 4.257 | +0.503 | 2005 Aug 25 – Aug 26 | 4.75 |
| PSR B1809–176 | 12.909 | +0.388 | 2005 Aug 06 – Aug 25 | 10.5 |
| PSR B1815–14 | 16.406 | +0.610 | 2005 Jun 09 – Aug 06 | 9.25 |
| PSR B1817–13 | 17.160 | +0.482 | 2005 Jun 01 – Sep 01 | 18.25 |
| PSR B0458+46 | 160.363 | +3.077 | 2006 May 14 – Sep 30 | 36.75 |
| PSR B1703–40 | 345.718 | −0.197 | 2006 Jun 02 – Aug 29 | 6.0 |
| PSR B1737–30 | 358.295 | +0.238 | 2006 Jul 21 – Jul 30 | 3.75 |
| PSR B1818–04 | 25.456 | +4.732 | 2006 May 27 – Oct 31 | 18.75 |
| PSR B1829–08 | 23.272 | +0.298 | 2006 Jul 21 – Jul 27 | 10.25 |
| PSR B1834–10 | 22.263 | −1.415 | 2006 Jun 07 – Jun 29 | 5.75 |
| PSR B1845–01 | 31.339 | +0.039 | 2006 May 08 | 6.0 |
| PSR B2106+44 | 86.909 | −2.012 | 2006 Jun 19 – Jul 25 | 8.25 |
| PSR B2111+46 | 89.003 | −1.266 | 2006 May 15 – May 19 | 5.25 |
| PSR B1648–42 | 342.457 | −0.922 | 2006 May 29 – May 31 | 4.5 |

### TABLE 1

Dates of the Observations for the Pulsars without Detectable OH Absorption with the GBT

| PULSAR | Galactic Coordinates | Dates of Observations | Integration Time |
|--------|----------------------|----------------------|------------------|
| PSR B1736–31 | l: 357.099 b: −0.219 | 2005 Jul 31 – Aug 08 | 5.5 |
| PSR B1750–24 | l: 4.257 b: +0.503 | 2005 Aug 25 – Aug 26 | 4.75 |
| PSR B1809–176 | l: 12.909 b: +0.388 | 2005 Aug 06 – Aug 25 | 10.5 |
| PSR B1815–14 | l: 16.406 b: +0.610 | 2005 Jun 09 – Aug 06 | 9.25 |
| PSR B1817–13 | l: 17.160 b: +0.482 | 2005 Jun 01 – Sep 01 | 18.25 |
| PSR B0458+46 | l: 160.363 b: +3.077 | 2006 May 14 – Sep 30 | 36.75 |
| PSR B1703–40 | l: 345.718 b: −0.197 | 2006 Jun 02 – Aug 29 | 6.0 |
| PSR B1737–30 | l: 358.295 b: +0.238 | 2006 Jul 21 – Jul 30 | 3.75 |
| PSR B1818–04 | l: 25.456 b: +4.732 | 2006 May 27 – Oct 31 | 18.75 |
| PSR B1829–08 | l: 23.272 b: +0.298 | 2006 Jul 21 – Jul 27 | 10.25 |
| PSR B1834–10 | l: 22.263 b: −1.415 | 2006 Jun 07 – Jun 29 | 5.75 |
| PSR B1845–01 | l: 31.339 b: +0.039 | 2006 May 08 | 6.0 |
| PSR B2106+44 | l: 86.909 b: −2.012 | 2006 Jun 19 – Jul 25 | 8.25 |
| PSR B2111+46 | l: 89.003 b: −1.266 | 2006 May 15 – May 19 | 5.25 |
| PSR B1648–42 | l: 342.457 b: −0.922 | 2006 May 29 – May 31 | 4.5 |

### TABLE 2

Dates of Observations Detecting OH Absorption toward PSR B1718–35 with the GBT

| Date | Bandwidth Per Band (MHz) |
|------|--------------------------|
| 2005 Aug 24–29 | 2.5 |
| 2005 Aug 29–31 | 0.625 |
| 2005 Oct 08 | 0.625 |
pulsars could have OH between the Sun and the pulsar. This then led to a search with the GBT for OH absorption against the pulsars PSR B0458+46, PSR B1703–40, PSR B1737–30, PSR B1818–04, PSR B1829–08, PSR B1834–10, PSR B1845–01, PSR B2106+44, PSR B2111+46, and PSR B1648–42.

4. RESULTS

No OH absorption was detected toward PSR B1736–31, PSR B1750–24, PSR B1809–176, PSR B1815–14, PSR B1817–13, PSR B0458+46, PSR B1703–40, PSR B1737–30, PSR B1818–04, PSR B1829–08, PSR B1834–10, PSR B1845–01, PSR B2106+44, PSR B2111+46, or PSR B1648–42. The 1σ upper limits for the opacity for OH absorption toward these pulsars are shown in Table 4. PSR B1750–24 did not have any detectable OH in the pulsar “off” spectra and was thus not observed for a significant amount of time, resulting in its higher opacity limit. OH absorption was only detected against PSR B1718–35.

4.1. PSR B1718–35 OH Absorption Properties

I show the OH absorption spectra against PSR B1718–35 as well as the pulsar “off” OH spectra for the two resolution modes (1.75 and 0.44 km s\(^{-1}\)) in Figures 1 and 2. After initially detecting the OH absorption against PSR B1718–35 in the lower resolution mode, which allowed a large velocity range to be searched, I switched to the higher resolution mode to resolve the narrow absorption lines that were present. The results of Gaussian fits to the OH absorption lines are presented in Table 5. As can be seen from the results in Table 5, the initial wide-bandwidth observations, which had a spectral resolution slightly larger than the true line widths of the spectral lines, are clearly affected by poor spectral resolution.

4.1.1. Column Density of the OH Absorbing Cloud

From the observed opacity of the 1667 MHz absorption against PSR B1718–35, we can estimate the OH column density, \(N_{\text{OH}}\), in the absorbing cloud. Using equation 9.12 of Elitzur (1992), along with \(\tau(1667) = 0.3 \pm 0.003\) and a line width of \(\Delta v = -1.5 \pm 0.2\), the OH column density is given by

\[
N_{\text{OH}} = \frac{(1 \pm 0.1) \times 10^{14}}{T_x(1667)} \text{ cm}^{-2},
\]

where \(T_x(1667)\) is the excitation temperature of the line, which is typically 5–10 K (Elitzur 1992). The observed line width limits the thermal temperature of the OH to \(T < 830 \pm 240\) K, resulting in the limit that \(N_{\text{OH}} > (1.2 \pm 0.1) \times 10^{11} \text{ cm}^{-2}\). From the typical excitation temperatures, the likely column density is of the order \(N_{\text{OH}} \sim 10^{13} \text{ cm}^{-2}\).
between \(10^{14} \leq \frac{N_{\text{OH}}}{\Delta v} \leq 10^{15} \) cm\(^{-2}\) s km\(^{-1}\), the satellite lines at 1612 and 1720 MHz are conjugates, with the 1720 MHz line being in emission and the 1612 MHz line being in absorption (Weisberg et al. 2005). At column densities \(N_{\text{OH}}/\Delta v > 10^{15} \) cm\(^{-2}\) s km\(^{-1}\), the lines remain conjugates, but with the 1612 MHz line being in emission and the 1720 MHz line being in absorption. Both of these cases occur when the region containing the OH is optically thick to infrared photons. As can be seen in the pulsar “off” spectra in Figure 2, the 1612 MHz line is in emission at the velocity where absorption is seen against the pulsar. However, the 1720 MHz line is not detected at a 3 \(\sigma\) limit of 0.08 K. This is significantly less than the 0.25 K that we would expect if the 1720 MHz line exhibited conjugate emission with the 1612 MHz line. This indicates that the OH column

| PULSAR          | 1665 MHz | 1667 MHz | 1612 MHz | 1720 MHz |
|-----------------|----------|----------|----------|----------|
| PSR B1736−31    | 0.07     | 0.06     | 0.08     | 0.1      |
| PSR B1750−24    | 0.2      | 0.2      | 0.2      | 0.4      |
| PSR B1809−176   | 0.06     | 0.06     | 0.06     | 0.10     |
| PSR B1815−14    | 0.03     | 0.03     | 0.03     | 0.04     |
| PSR B1817−13    | 0.04     | 0.05     | 0.04     | 0.09     |
| PSR B0458+46    | 0.06     | 0.06     | 0.06     | 0.07     |
| PSR B1703−40    | 0.07     | 0.08     | 0.07     | 0.1      |
| PSR B1737−30    | 0.1      | 0.1      | 0.1      | 0.1      |
| PSR B1818−04    | 0.05     | 0.05     | 0.04     | 0.04     |
| PSR B1829−08    | 0.2      | 0.2      | 0.2      | 0.7      |
| PSR B1834−10    | 0.08     | 0.08     | 0.07     | 0.09     |
| PSR B1845−01    | 0.04     | 0.04     | 0.03     | 0.07     |
| PSR B2106+44    | 0.09     | 0.1      | 0.1      | 0.1      |
| PSR B2111+46    | 0.04     | 0.04     | 0.04     | 0.05     |
| PSR B1648−42    | 0.06     | 0.06     | 0.05     | 0.07     |

Note.—The GBT L-band receiver has a resonance around 1720 MHz, which causes the sensitivity at this frequency to be compromised, as one polarization does not contribute very much to the signal-to-noise ratio.

![Figure 1](image_url)  
**FIG. 1.—** Observed OH opacities against PSR B1718−35 with 1.75 km s\(^{-1}\) spectral resolution. The left column shows the pulsar “off” spectra, and the right column shows the OH absorption against PSR B1718−35.
density is $N_{\text{OH}} < (6.7 \pm 0.9) \times 10^{13} \text{ cm}^{-2}$ in the OH absorbing cloud toward PSR B1718–35. Using the standard abundance ratio of $N_{\text{OH}}/N_{\text{H}} = 6 \times 10^{-8}$ (Elitzur 1992), the total hydrogen column density in the absorbing cloud is of the order $N_{\text{H}} \sim (1.7–11.1) \times 10^{20} \text{ cm}^{-2}$. The H\textsc{i} absorption against PSR B1718–35 was measured by Weisberg et al. (1995) and is shown in their Figure 1d. At the velocity of the OH absorption, the H\textsc{i} absorption has an opacity $\tau > 2$, and the emission has $T_B \sim 100 \text{ K}$. The assumption that half of the total H\textsc{i} emission comes from the same side of the tangent point\(^2\) as the OH cloud results in an estimated column density $N_{\text{H}} > 1.8 \times 10^{20} \text{ cm}^{-2}$, which is consistent with the column density derived from OH.

\(^2\) The velocity-distance relationship is double valued for the PSR B1718–35 line of sight. Since the Galactic latitude is small ($b = 0.671^\circ$), we can expect that along the line of sight we will encounter equal amounts of gas on the near side and the far side of the tangent point. Thus, the total emission at any velocity will have half of its contribution from the near side and half from the far side of the tangent point.

**TABLE 5**  
**Gaussian Fit Results for the Observed OH Absorption against PSR B1718–35**

| $\nu$ (MHz) | $\Delta \nu$ (MHz) | $\sigma_\nu$ | $\tau$ | $V_{\text{LSR}}$ (km s\(^{-1}\)) | FWHM (km s\(^{-1}\)) |
|-------------|-------------------|--------------|--------|-------------------------------|-----------------|
| 1665        | 2.5               | 0.008        | 0.076 ± 0.009 | −1.5 ± 0.2                   | 3.0 ± 0.4       |
| 1667        | 2.5               | 0.009        | 0.074 ± 0.008 | −2.0 ± 0.2                   | 3.2 ± 0.4       |
| 1612        | 2.5               | 0.01         | 0.042 ± 0.009 | −1.3 ± 0.4                   | 3 ± 1           |
| 1720        | 2.5               | 0.01         | ...         | ...                          | ...            |

Fig. 2.— Same as Fig. 1, but with higher (0.44 km s\(^{-1}\)) spectral resolution data.

**4.1.2. Distance to the OH Cloud**

Weisberg et al. (1995) determined that the H\textsc{i} kinematic distance to PSR B1718–35 is $5.6 \pm 0.6$ kpc. This puts PSR B1718–35 on the near side of the tangent point for its line of sight. The Galactic bar is on the far side of the tangent point for the PSR B1718–35 line of sight and can be ignored in the following discussions.

I show the velocity-distance relationship for the PSR B1718–35 line of sight using the flat rotation curve of Fich et al. (1989) in Figure 3. In determining the distance of the OH cloud from its velocity, a random motion for cold clouds of 7 km s\(^{-1}\) has been used (Dickey & Lockman 1990). This random velocity was used as an error on the distance model, as suggested in Minter et al. (2008). An upper limit of 1.86 kpc is found for the distance to the OH cloud.

The line of sight toward PSR B1718–35 is in the extended halo of radio continuum emission surrounding NGC 6334 (see the figure on page 347 of Altenhoff et al. 1970). Comparing the observed velocity range, $−1.5$ to $−1.9$ km s\(^{-1}\), for the OH absorption against PSR B1718–35 with the CO velocities of Dickel et al. (1977) shows that the OH cloud has the same velocity as NGC 6334B and the extended CO emission to the northeast of NGC 6334 (see Fig. 6 of Dickel et al. 1977). H\textsc{i} regions in and around NGC 6334 have velocities in the range $+1$ to $−7$ km s\(^{-1}\) (Lockman 1989; Quireza et al. 2006). It is thus quite possible that the OH cloud is part of the NGC 6334 giant molecular cloud. If this is the case, then we can place the OH cloud at the distance of NGC 6334, $1.7 \pm 0.3$ kpc (Neckel 1978), which is consistent with the kinematic distance upper limit.
4.2. Continuum Emission toward PSR B1718–35

The observed continuum emission in a “slice” at the constant Galactic longitude of PSR B1718–35 (351.688°) is shown in Figure 4. The total continuum emission toward PSR B1718–35 in the GBT beam is 9.04 ± 0.05 K. A two-component Gaussian fit that can be assumed to approximate the smooth Galactic synchrotron and free-free emission contribution to the continuum emission was made. As can be seen in Figure 4, this approximates the smooth background continuum emission from the Galactic synchrotron and free-free emission reasonably well. This fit then sets the smooth Galactic component emission at 5.8 K and the continuum in front of PSR B1718–35 at 3.51 K. The continuum emission in front of the pulsar comes from three different sources that are slightly blended (this is easily seen in Fig. 5). At a Galactic latitude lower than PSR B1718–35 is the H ii region G351.662+0.518 (Lockman 1989), and at a higher Galactic latitude is the SNR G351.7+0.8 (Green 2006; Whiteoak & Green 1996). Fitting an additional three Gaussians to this emission results in a brightness temperature of 4.1 ± 0.2 K for G351.662+0.518, 4.2 ± 0.2 K for SNR G351.7+0.8, and 2.9 ± 0.2 K for the continuum source in front of PSR B1718–35. Data from the Parkes 6 cm survey of the southern Galactic plane at 5009 MHz (Haynes et al. 1978) show that the continuum source in front of PSR B1718–35 has a flux of 2.3 ± 0.2 K for the PSR B1718–35 line of sight. This then gives a spectral index of −0.21 ± 0.2 (using $S = \nu^\alpha$), which is consistent with the expected H ii region thermal emission spectral index of −0.07.

4.3. Comparing the Pulsar “On” and “Off” OH Absorption Spectra

For the two previous detections of OH absorption against pulsars, the opacity of the absorption has been greater and the line widths have been narrower against the pulsar than against the continuum background (see Stanimirović et al. 2003; Weisberg et al. 2005). Two viable explanations were put forward in Stanimirović et al. (2003): (1) the absorption comes from OH clouds whose angular size is larger than the observed scattering size of the pulsar but smaller than the angular size of the telescope beam; or (2) there are extra OH clouds that are seen in absorption against the continuum background with the larger telescope beam that are not seen along the pulsar’s line of sight. In the former case, if the OH cloud seen in absorption against the pulsar could be spectroscopically isolated in the pulsar “off” spectrum, then the line widths in the two spectra should be the same. The differences in the optical depth of the line could then be used to constrain the size of the cloud. In the latter case, the OH cloud is expected to be built from smaller “cloudlets” (Stanimirović et al. 2003), and we would expect the line widths and the opacities to be different between the pulsar absorption and the continuum background absorption spectra. Of course, both of these scenarios could be operating at the same time.

In Figure 2, we see that the 1665 and 1667 MHz absorption lines at ~1.7 km s⁻¹ have a narrow component and a broad component. Gaussian fits for narrow and broad line width components to the 1667 MHz background continuum absorption spectrum are presented in Table 6. The broad component Gaussian fit is shown in the top panel of Figure 6. Comparing the results in Table 6 and Table 5, we see that the narrow component has the same velocity, and that the line widths agree at the 1 σ level for the pulsar and continuum background cases. In the bottom panel of Figure 6, I show the opacities of the two narrow components and the difference between them. The opacity of the pulsar “off” spectra was determined using an effective continuum strength of 2.1 K (see below), which makes the opacities equal. As can be seen in Figure 6, there is no discernible difference between the narrow component in the pulsar “off” spectrum and the absorption against the pulsar. Thus, only the size of the OH cloud will play a role in any difference between the opacity observed against the background continuum and against the pulsar.

Since we know the opacity of the OH from the absorption against the pencil-thin beam of the pulsar, and since there is
information on the continuum brightness, limits can be determined for the size of the OH absorption cloud. This is done using

\[ e^{-\tau} = \frac{I(\nu)}{f_{\Omega} T_{bg}} + 1 = \frac{I(\nu)}{T_{eff}} + 1, \]

where \( I(\nu) \) is the measured, baseline-subtracted spectrum (Fig. 6, top), and \( f_{\Omega} = \Omega_{OH}/\Omega_{GBT} \) is the size of the OH cloud (\( \Omega_{OH} \)) relative to the size of the telescope beam (\( \Omega_{GBT} \)). \( T_{eff} = f_{\Omega} T_{bg} \) is the effective brightness temperature and corresponds to the OH cloud-size-weighted background brightness temperature averaged over the entire GBT beam. Performing a least-squares, nonlinear fit to the observed narrow line width component results in \( T_{eff} = \)

### Table 6

**Gaussian Fit Results for the Observed 1667 MHz OH Absorption against the Background Continuum Emission (Pulsar “Off” Spectrum)**

| \( \tau \) | \( V_{ls} \) (km s\(^{-1}\)) | FWHM (km s\(^{-1}\)) |
|------------|------------------|------------------|
| 0.30 ± 0.02 | -1.86 ± 0.03     | 1.8 ± 0.1        |
| 0.23 ± 0.02 | -1.91 ± 0.07     | 5.3 ± 0.3        |

**Note.**—The opacities were determined using an effective background continuum emission of 2.1 K.
2.1 ± 0.2 K. Allowing all of the continuum flux to reside behind the OH cloud, $T_{bg} = 8.7 \pm 0.2$ K, where 5.8 K is from the smooth Galactic continuum, and 2.9 K is from the H II region, giving a minimum size for the cloud, assuming that the cloud is spherically symmetric. For this case $f_1 = 0.24 \pm 0.02$. Using the 7.4’ FWHM size of the GBT beam, the minimum OH cloud radius is 0.89’ ± 0.08’, which at a distance of 1.7 kpc corresponds to 0.44 ± 0.04 pc. If the OH cloud is behind the H II region, and assuming that there is little contribution to the Galactic continuum between the Sun and NGC 6334, $f_0 = 0.36 \pm 0.04$, and the size of the OH cloud is 1.3’ ± 0.1’, which corresponds to 0.64 ± 0.06 pc at a distance of 1.7 kpc. These size scales, along with the column densities derived in § 4.1.1, translate into densities of order $n_H \sim 10^{-10} - 100$ cm$^{-3}$ for the OH cloud.

An ellipse with semimajor and semiminor axes of 3’ and 1.8’ roughly covers the area of 8 $\mu$m emission seen in Figure 5. If we assume that the OH cloud size is represented by the 8 $\mu$m dust cloud size, then $f_0 \approx 0.36$. This is the same number derived above assuming that the OH cloud is behind the H II region and in front of most of the Galactic background continuum emission. It seems likely that the OH cloud lies behind the H II region.

From the FWHM line widths in Table 6, the narrow line width component corresponds to a thermal temperature $T < 830 \pm 240$ K. The broad line width component corresponds to a thermal temperature of $T < 10,400 \pm 1200$ K. Since the OH might be expected to be in regions with temperatures in the range 10–100 K, there is obviously a very large turbulent component to the line widths. The two components fit very nicely with the MC-H II region interaction scenario. The narrow line width OH could be in the part of the MC that has not yet interacted with the H II region, while the broad line width component is in the part of the MC interacting with the H II region.

4.4. Energy Input into the Molecular Cloud

If it is assumed that there is an interaction between the MC and an H II region, then we can estimate the amount of energy input into the MC. This is done by comparing the line widths of the narrow and broad components. From the above size ($6’ \times 2.6’$ or $2.9’ \times 1.28$ pc at a distance of 1.7 kpc) and column density estimates ($N_{OH} < 6.7 \times 10^{13}$ cm$^{-2}$), there are $<2.4 \times 10^{21}$ OH particles in the narrow line component of the cloud. An OH line width of 1.5 km s$^{-1}$ corresponds to an energy of $3.2 \times 10^{13}$ ergs for each OH molecule, using $E = 1/2 m v^2$. This gives a total energy of $<7.7 \times 10^{38}$ ergs for all the OH molecules in the narrow line width component. An OH line width of $5.3$ km s$^{-1}$ corresponds to an energy of $4.0 \times 10^{12}$ ergs for each OH molecule in the broad line width component of the OH cloud. The broad line width component has the same characteristics between the 1720 and 1612 MHz lines as does the narrow line width component. We can thus limit the column density of the broad line to $N_{OH} < 1.9 \times 10^{13}$ cm$^{-2}$, which results in a total energy of $<2.1 \times 10^{39}$ ergs for all the OH molecules in the broad line width component. This suggests that a few $\times 10^{39}$ ergs of energy have been input into the broad line width component.

If we assume that the same amount of energy per particle has been added to all molecular species in the broad component of the OH cloud, then a total of a few $\times 10^{46}$ ergs of energy have been deposited into the cloud. SNRs typically involve a release of $\sim 10^{51}$ ergs of energy. A cluster of O and B stars that form H II regions can also output $\sim 10^{51}$ ergs of energy over their lifetimes. So it is not unreasonable to assume that the broad line width component of the OH cloud has interacted with an H II region or SNR.

5. CONCLUSIONS

PSR B1718–35 is only the third pulsar found to have OH absorption. In all three cases the OH absorption arises in the interaction of a MC with a SNR or an H II region. Forty-seven pulsars have been searched for OH absorption. This suggests that OH absorption against pulsars is either quite rare or that the absorption in most MCs is very weak and below the detection capabilities of current telescopes without very deep searches. That all known cases involve a MC that is in the process of being destroyed by a SNR or H II region and that the detection rate is only $\sim 6\%$ implies that OH absorption against pulsars is a rare occurrence.

The detection rate using pulsar brightness is about $\sim 6\%$. I found a detection rate of $17\%$ using scintillation strength for the selection criteria. I also had a detection rate of $0\%$ using detected OH emission that could be between the Sun and the pulsar. Since the PSR B1718–35 OH detection was found in a search of six pulsars based on their strong scattering, and PSR B1718–35 is the seventh most strongly scattered pulsar, some credence can be given to the hypothesis of Boldyrev & Königl (2006), but it by no means provides conclusive proof for their idea that scattering originates in PDRs at the boundaries of H II regions and MCs.

In all likelihood, the continuum object along the line of sight toward PSR B1718–35 is an H II region associated with the NGC 6334 complex. The spectral index of the source is consistent with what is expected for an H II region. The morphology (see Fig. 5) of cold dust surrounding warm dust is not consistent with the source being a SNR. There is some $H_\alpha$ emission associated with the continuum source (see Fig. 5). Unfortunately, the SHASSA survey (Gaustad et al. 2001) does not provide velocity information for the $H_\alpha$. Although this line of sight was observed as part of the WHAM survey (Haffner et al. 2003), the 1$\sigma$ resolution convolves the emission from the H II region toward PSR B1718–35 with other H II regions in NGC 6334. Thus it is not known if the $H_\alpha$ arises at the same velocities as the OH absorption against PSR B1718–35. Hydrogen radio recombination lines or higher spatial resolution $H_\alpha$ with velocity information observations should be performed to confirm that the continuum source is an H II region.

It was found that the OH cloud along the line of sight of PSR B1718–35 is likely behind the H II region. The OH cloud has a broad line width component and a narrow line width component. Only the narrow line width component is seen in absorption against PSR B1718–35. A similar situation of broad and narrow line width components with only the narrow component seen in absorption against the pulsar was observed for PSR B1849+00 (Stanimirović et al. 2003). This is also the case for PSR B1641–45 (Weisberg et al. 2005). The opacity of the OH absorption against PSR B1718–35 and against the continuum background (pulsar “off” spectrum) can be reconciled via consideration of the beam-filling factor of the OH cloud. This should be investigated further for the PSR B1849+00 and PSR B1641–45 OH absorption.

This work is based (in part) on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. The Southern H-Alpha Sky Survey Atlas (SHASSA) is supported by the National Science Foundation.
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