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## **Developing asymmetries in AGB stars : occurrence, morphology and polarization of circumstellar Masers**

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Green Bank Telescope Observations  
of the H<sub>2</sub>O masers of evolved stars:  
magnetic field and maser polarization

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## Abstract

Magnetic fields potentially play an important role in shaping the circumstellar envelopes of evolved stars. The measurement of the Zeeman splitting through circular polarization observations of maser species constitutes the most direct way to determine magnetic field strength at various distances to the central evolved stars. H<sub>2</sub>O masers typically occur between 10-100 AU from the star and the circular polarization of the masers is shown to stem from the Zeeman effect. So far significant magnetic field strengths were measured in the H<sub>2</sub>O maser regions of Mira variable stars and supergiant stars as well as in the bipolar outflow of post-AGB objects. We like to extend the previous H<sub>2</sub>O maser circular polarization studies and observe more evolved stars with different mass loss rates using single dish observations in order to be able to probe also the weaker maser sources. The 22 GHz H<sub>2</sub>O maser observations were performed with the Green Bank telescope in full polarization spectral line mode. The Zeeman splitting was measured by cross correlating the right circular polarization and the left circular polarization spectra. We determined the magnetic field strength by applying the Zeeman splitting coefficient to the measured Zeeman splitting. We measured a magnetic field of  $18.9 \pm 3.8$  mG for the H<sub>2</sub>O maser region of the OH/IR star IRAS 19422+3506. The field strength is significantly lower than those measured for Mira variables. For the rest of the sources in our sample we place a  $3\sigma$  upper limit in the range 10-800 mG. Specifically the  $\sim 10$  mG limit on the field of R LMi is significant, considering this is the lowest limit thus far determined in the H<sub>2</sub>O maser region of an evolved star. Additionally, we measure significant variation in the peak flux density of up to two orders of magnitude compared to previous observations. In particular, the appearance of the double peak profile of IRAS 19422+3506 could indicate a bipolar H<sub>2</sub>O maser outflow in this star. Our observations seem to indicate the possible role of magnetic field in shaping the circumstellar envelope of the OH/IR star IRAS 19422+3506. Finally, the H<sub>2</sub>O masers show significant variability in flux density which could imply periodic variation in density and / or the velocity field of the circumstellar envelope.

## 4.1 Introduction

Low mass stars ( $M \sim 8 - 10 M_{\odot}$ ) undergo a period of high mass loss at the end of their evolution while climbing the Asymptotic Giant Branch (AGB). This outflow forms circumstellar envelopes (CSEs), in which several maser species occur at different distances from the central star. Observations indicate that the CSE of AGB stars is generally spherically symmetric (Griffin 2004). However, planetary nebulae (PNe), supposedly formed from the ejected outer envelope of evolved stars, often show elliptical or bipolar morphologies (e.g. Manchado et al. 2000). It is not clear how the spherically symmetric mass loss changes to produce the aspherical PNe. The formation of aspherical PNe has been explained by the interacting stellar wind model (e.g. Balick et al. 1987). In this scenario, a fast wind ( $\sim 1000 \text{ km s}^{-1}$ ) interacts with the older, slow AGB wind. Hubble Space Telescope (HST) observations of a sample of young PNe and proto-PNe revealed collimated jets (Sahai & Trauger 1998, Sahai et al. 2007). The precession of the jets is thought to be responsible for the formation of asymmetric PNe.

Magnetic fields can play an important role in shaping the circumstellar envelope (CSE) of evolved stars and can produce asymmetries during the transition from a spherically symmetric star into an aspherical PNe. They are also possible agents for collimating the jets around these sources (e.g. García-Segura et al. 2005). Polarization observations of different maser species can reveal the strength and morphology of the magnetic field at different regions of the CSEs. In the high temperature and density regime close to the central star (5-10 AU), SiO masers occur. Polarimetric observations of SiO masers indicate field strengths of order 3.5 G, assuming the standard Zeeman interpretation for the observed circular polarization (e.g. Kemball & Diamond 1997, Herpin et al. 2006, Amiri et al. 2011, submitted). However, a non-Zeeman interpretation was introduced by (Wiebe & Watson 1998), according to which the observed circular polarization of the SiO masers can be explained by fields of  $\sim 30 \text{ mG}$ . OH masers occur much further out in the CSEs and probe low temperatures and densities. Polarimetry observations of these masers have revealed large scale magnetic fields with a strength ranging from 0.1 mG to 10 mG (e.g. Etoke & Diamond 2004, Amiri et al. 2010).

$\text{H}_2\text{O}$  masers are found at intermediate distances to the central star (a few hundred AU) and probe a higher density and temperature than the OH masers. The circular polarization of the masers was shown to be due to the Zeeman splitting (e.g. Vlemmings et al. 2002). Therefore, until the uncertainty on the SiO maser polarization interpretation is solved, only  $\text{H}_2\text{O}$  masers can accurately measure the field strength at distances close to the central stars. Recent VLBA polarization observations of  $\text{H}_2\text{O}$  masers revealed significant field strength for Mira variables and supergiants in the range 0.2 G to 4 G (Vlemmings et al. 2002, 2005). In addition, the  $\text{H}_2\text{O}$  maser jet of the proto-PNe W43A was shown to be magnetically collimated with a field strength of 80 mG (Vlemmings et al. 2006).

The origin of strong magnetic fields in the CSE of AGB stars remains a topic of debate. Magnetic fields in AGB stars can be produced by a dynamo. However, one of the arguments against a magnetic dynamo is the slow rotation of the AGB star due to the conservation of angular momentum in combination with the large expansion on the AGB. However, Blackman et al. (2001) showed that a single star model can produce magnetic driven dynamo in the AGB phase. Since magnetic field drains rotational energy, it needs to be reseeded. A binary companion can maintain the differential rotation required during the lifetime of the AGB phase. In the presence of a binary companion, the spiral-in of the companion into the envelope produces rotational energy needed for the generation of the magnetic field (Nordhaus & Blackman 2006).

In order to assess the role of the magnetic field throughout the AGB evolution, polarimetric observations of evolved stars with different mass loss rates are required. So far, significant field strengths are measured for Mira variables and supergiants. However, no systematic studies have been performed to measure the magnetic field strength in the inner parts of the CSE of OH/IR stars. These objects have larger and denser CSEs and much longer periods up to 2000 days compared to those of Mira variables (Herman & Habing 1985b). They are strong 1612 MHz OH maser emitters (Baud et al. 1979). The stars are surrounded by thick dust shells which makes them optically obscured.

In this work, we report the results of our H<sub>2</sub>O maser polarimetric observations of a sample of evolved stars (including Mira variables and OH/IR stars) with the Green Bank telescope. The observations aim to measure the magnetic field strength in the H<sub>2</sub>O maser region of a sample of evolved stars for the first time. Even though the single dish measurements are biased towards underestimating the magnetic field strength due to spectral blending, these observations will probe the overall field strength in stars with individual maser features too weak for VLBI.

The format of this paper is as follows: in Sec. 4.2 we present the observations. The Zeeman splitting theory for H<sub>2</sub>O masers is briefly explained in Sec. 4.3. The results are given in Sec. 4.4. We discuss the interpretation of the observations in Sec. 4.5 and give conclusions in Sec. 4.6.

## 4.2 Observations

We performed the 22 GHz H<sub>2</sub>O maser polarimetric observations of a sample of evolved stars with the Robert C. Byrd Green Bank Telescope (GBT) of the NRAO<sup>1</sup> on 22 April 2010. At 22 GHz the Full Width Half Maximum of the GBT is 30′. The GBT spectrometer was used with a bandwidth of 12.5 MHz and 4096 spectral channels, which provides a channel spacing of 0.04 km s<sup>-1</sup> and a total velocity coverage of 170 km s<sup>-1</sup>. We used the K-band receiver for the frequency range (18-24 GHz). The receiver has two beams, each producing two polarization channels. We observed the sample using a beam switching mode with beam throws of 8′. As a result, one beam was always looking at the source, while the other beam was used for baseline correction. The cycle time of 2 min was sufficient to compensate for atmospheric fluctuations. The total observing time was 6 hours including pointing and focusing observations. The on-source observing time for R LMi, RX Oph, V1416 Aql was 44, 42 and 8 minutes. For IRAS 17230+0113, IRAS 19422+3506 and IRAS 19579+3223 the on-source observing time was 36, 76 and 16 minutes. Although all sources were initially selected based on published observations, to be strong enough for a magnetic field detection, most sources were found to be variable. Sources of which the masers turned out to be weak in real time inspection, were cut short in favor of the stronger masers. The system temperature of the GBT was in the range 35-50 K during the observations. The rms noise in the emission free channels was in the range ~ 8-17 mJy throughout our observations, with the exception of the rms noise of ~50 mJy V1416 Aql due to the short integration time on this source. The GBTIDL<sup>2</sup> software package was used for the data reduction and analysis. Baseline variation due to atmospheric and instrumental effects was determined and subtracted using the spectral channels free of any maser emission.

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<sup>1</sup> The National Radio Astronomy Observatory (NRAO) is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

<sup>2</sup> <http://gbtidl.sourceforge.net>

### 4.3 Zeeman Splitting of H<sub>2</sub>O masers

The ( $6_{16} - 5_{23}$ ) H<sub>2</sub>O maser transition at 22.23508 GHz occurs  $\sim 600$  K above the ground state. This transition consists of six hyperfine components (e.g. Walker 1984). In the presence of an external magnetic field, each hyperfine component will split into 3 groups of lines ( $\sigma^\pm$ ,  $\pi$ ). The  $\pi$  transitions produce emission linearly polarized along the external magnetic field. If the magnetic field has a component parallel to the line of sight, the  $\sigma^\pm$  components appear in the right circular polarization (RCP) and the left circular polarization (LCP) respectively. The RCP and LCP spectra are slightly shifted in frequency with respect to each other. This frequency splitting corresponds to the Zeeman effect. Since the H<sub>2</sub>O molecule is non-paramagnetic, the Zeeman splitting is very small and on the order of  $10^{-3}$  of the maser line width ( $\sim 1$  km s<sup>-1</sup>).

We use the RCP-LCP cross-correlation method introduced by Modjaz et al. (2005) to measure the Zeeman splitting and the magnetic field. This method is able to measure the Zeeman splitting in the case of spectrally blended features of non-paramagnetic molecules, assuming the magnetic field is constant across the spectrum. Cross correlating the RCP and LCP spectra yields the velocity separation ( $q$ ) due to the Zeeman splitting, which is related to the magnetic field strength along the line of sight:

$$B_{\parallel} = \frac{q}{\sqrt{2} A_{F-F'}} \quad (4.1)$$

Where the  $A_{F-F'}$  coefficient depends on the hyperfine component. The value of the coefficient can be determined from the non-LTE analysis which includes consideration of narrowing and re-broadening of the maser line as a result of maser saturation and unequal population of the magnetic sub-levels. This implies  $A_{F-F'} = 0.02$  km s<sup>-1</sup> G<sup>-1</sup> as the merging of the three hyperfine components for H<sub>2</sub>O masers (Vlemmings et al. 2002). The cross-correlation method was shown to be robust against the relative RCP and LCP gain calibration errors. The sensitivity of this method is comparable to the traditional S-curve method, where the Stokes V spectrum is directly used to measure the magnetic field.

#### 4.3.1 Non-Zeeman effects

There are potentially non-Zeeman mechanisms prohibit one to interpret circular polarization as a measure of the magnetic field strength. The first one stems from the competition between the stimulated emission rate ( $R$ ), the Zeeman coefficient rate ( $g\Omega$ ) and the radiative decay rate ( $\Gamma$ ). Following the analysis of (Vlemmings et al. 2002) we rule out the non-Zeeman mechanism proposed by (Nedoluha & Watson 1990), in which the preferred direction of the radiation imposes a circular polarization.

Wiebe & Watson (1998) introduce yet another non-Zeeman effect in which the propagation of a strong linear polarization can create circular polarization if the condition  $g\Omega \gg R \gg \Gamma$  is satisfied. The circular polarization can be generated if the magnetic field orientation changes along the maser propagation direction. The circular polarization produced from this scenario is  $\sim \frac{m_l^2}{4}$  where  $m_l$  indicates the linear polarization fraction. Vlemmings et al. (2002) show that since H<sub>2</sub>O masers do not exhibit significant linear polarization, this effect is also unlikely.

## 4.4 Results

We observed a sample of six evolved stars, including three Mira variables and three OH/IR stars. Fig. 4.1 displays the observed spectra of the H<sub>2</sub>O masers obtained from the observations. These objects were previously observed with the Effelsberg Telescope (Engels & Lewis 1996), and strong H<sub>2</sub>O masers with flux densities in the range 11-160 Jy were measured for these stars. The results of the Zeeman splitting analysis using the RCP-LCP cross correlation method are given in Table 4.1. The table also shows the source name, variability type, position, central LSR velocity, peak flux density.

### 4.4.1 Individual sources

#### 4.4.1.1 R LMi

This source is a Mira variable with a period of 372.19 days (Samus et al. 2009). The H<sub>2</sub>O masers of this source were previously detected by Engels & Lewis (1996) with a maximum flux density of  $\sim 30$  Jy close to the LSR velocity of the star ( $-0.8 \text{ km s}^{-1}$ ). Single dish observations of the SiO and H<sub>2</sub>O masers of this star were performed by Kim et al. (2010), in which they measured peak flux densities of  $\sim 8$  Jy and 112 Jy for H<sub>2</sub>O and SiO masers of this star, respectively. Colomer et al. (2000) performed high resolution observations of the H<sub>2</sub>O masers of this source with the VLA interferometer. Although the distribution of the maser spots suggested the existence of a ring-like structure, they were not able to fit a shell to the distribution of the maser spots.

From the observations, we measured a peak flux density of 17.3 Jy at  $-0.2 \text{ km s}^{-1}$ . Comparison of the spectrum with the previous observations by Engels & Lewis (1996) shows that the overall morphology of the spectrum remains similar between the two observations. However, the peak flux density has decreased by almost a factor of two indicating the strong variability of the masers.

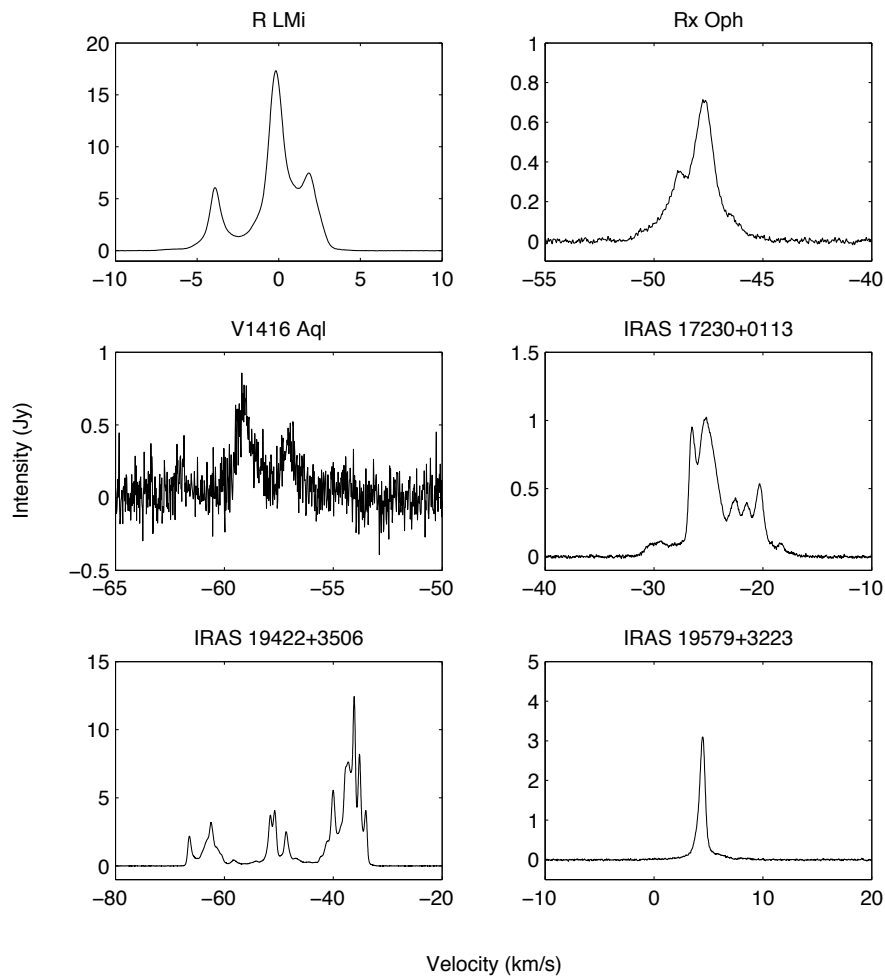
Single dish polarimetric observations of the OH masers of this source revealed a magnetic field of 2.32 mG (Rudnitski et al. 2010). Herpin et al. (2006) performed polarimetric observations of the SiO masers of this source with the IRAS 30m telescope and measured a field strength in the range 0-5.6 G, assuming the standard Zeeman interpretation hypothesis. However, we did not measure a significant magnetic field through cross correlation method, instead we place a  $3\sigma$  upper limit of 10.8 mG for the H<sub>2</sub>O maser region of this star.

#### 4.4.2 RX Oph

This source is a Mira variable with a period of 322.93 days (Samus et al. 2009). The OH masers of this star were previously detected by Lewis (1997). An attempt was made to observe the SiO masers of this object by Nyman et al. (1986), but no detection was reported. Engels & Lewis (1996) observed the H<sub>2</sub>O masers of this star and measured a spectrum with a peak flux density of  $\sim 47$  Jy at  $-47.8 \text{ km s}^{-1}$ . However, the single dish observations of this sources by Shintani et al. (2008) did not result in any detection. Our observations indicate that the H<sub>2</sub>O masers of this source occur close to the stellar velocity ( $-47.8 \text{ km s}^{-1}$ ) with a peak flux density of  $\sim 0.7$  Jy. The observed flux density has decreased by a factor of  $\sim 70$  compared to the previous observations by Engels & Lewis (1996). Furthermore, we did not measure a significant Zeeman splitting through cross correlating the RCP

Table 4.1 – The Zeeman splitting results.

source	Type	R.A. J2000	Dec. J2000	$V_{rad}$ km s <sup>-1</sup>	Peak flux Jy	B mG
R LMi	Mira	09 45 34.28	+34 30 42.77	-0.8	17.3	< 10.8
RX Oph	Mira	16 52 48.2	+05 24 27	-47.8	0.7	< 800
V1416 Aql	Mira	20 07 43.1	+06 03 11	-69.5	0.7	-
IRAS 17230+0113	OH/IR	17 25 36.6	+01 11 05	-24.5	1	< 198
IRAS 19422+3506	OH/IR	19 44 07.0	+35 14 08	-60	12.4	18.9 ± 3.8
IRAS 19579+3223	OH/IR	19 59 51.32	+32 32 09.8	4.1	3	< 98



**Figure 4.1** – The 22 GHz H<sub>2</sub>O maser spectra of a sample of evolved stars obtained from the GBT observations.

and LCP spectra. Instead, we place a  $3\sigma$  upper limit of  $\sim 800$  mG for the H<sub>2</sub>O maser region of this star.

#### 4.4.3 V1416 Aql

This source is known as a Mira variable. The H<sub>2</sub>O masers of this source were previously measured by Engels & Lewis (1996) with a flux density of 120 Jy. However, this source was not detected in single dish monitoring with the VERA telescope (Shintani et al. 2008). Our observations indicate a double peak profile with a maximum flux density of  $\sim 0.7$  Jy for the H<sub>2</sub>O masers of this source, which implies that the flux density is decreased about two orders of magnitude compared to the previous observations by Engels & Lewis (1996). This could indicate that Engels & Lewis (1996) observed this source during a flare. We note that due to the low signal to noise ratio, we were not able to perform the cross correlation method for this star.

#### 4.4.4 IRAS 17230+0113

This object is known as an OH/IR star (Lewis 1997). The 1612 MHz OH masers of this star show a double peak profile (Lewis 1997). Previous 22 GHz H<sub>2</sub>O maser observations of this star indicated multiple peaks close to the stellar velocity with a maximum flux density of  $\sim 12$  Jy. Our observations show similar multiple peaks profile with a maximum flux density of 1 Jy. We note that we did not measure a significant magnetic field by cross-correlating the right and left circular polarization spectra and we only place an upper limit of the magnetic field at  $3\sigma$  of 198 mG for the H<sub>2</sub>O maser region of this star.

#### 4.4.5 IRAS 19422+3506

This source is classified as a high mass loss OH/IR star (e.g. Lewis 1997) and exhibits SiO, OH and H<sub>2</sub>O maser emission (Lewis 1997, Nakashima & Deguchi 2007, Engels & Lewis 1996). H<sub>2</sub>O maser observations of this star showed a single peak profile with a peak flux density of 52 Jy at  $-60.9$  km s<sup>-1</sup> (Engels & Lewis 1996). Later, Nakashima & Deguchi (2007) performed simultaneous SiO and H<sub>2</sub>O maser observations of this star. They measured peak flux densities for SiO and H<sub>2</sub>O masers of 4.2 Jy at  $-48.9$  km s<sup>-1</sup> and  $\sim 9$  Jy at  $-47$  km s<sup>-1</sup>, respectively. Shintani et al. (2008) also observed the H<sub>2</sub>O maser of this star, but no detection was reported.

Our observations (Fig. 4.1) show that the H<sub>2</sub>O masers of this source occur in three emission complexes with a peak flux density of 12.4 Jy. The spectrum shows a double peak profile together with the emission at the center close to the stellar velocity. There is a significant variation in spectral shape and peak flux density between our observations and those observed by Engels & Lewis (1996) and Nakashima & Deguchi (2007), in which only one peak was detected.

We performed cross-correlation for the blue-shifted and red-shifted emission as well as the central emission separately. A magnetic field of  $18.9 \pm 3.8$  mG was measured for the red-shifted region ( $-45$  to  $-35$  km s<sup>-1</sup>). For the emission at the center of the spectrum and the blue-shifted region we did not measure a significant field strength, and the  $3\sigma$  upper limits of 52 mG and 33 mG were determined for these two emission complexes. The field strength of  $18.9 \pm 3.8$  mG is between one and two

orders of magnitude lower than those measured for Mira variables and supergiants (Vlemmings et al. 2005).

#### 4.4.6 IRAS 19579+3223

This star is classified as an OH/IR star (Lewis 1997). The 22 GHz observations of this star by Engels & Lewis (1996) indicated emission with multiple peaks close to the stellar velocity with a maximum flux density of 10.3 Jy. From our observations we measure a spectrum with a single peak with a flux density of  $\sim 3$  Jy at  $4 \text{ km s}^{-1}$ . This implies that the spectrum shows significant variation in spectral shape and the peak flux density.

We did not measure a significant magnetic field strength in the H<sub>2</sub>O maser region of this star. Instead we place an upper limit of  $\sim 98$  mG at  $3\sigma$  level.

### 4.5 Discussion

#### 4.5.1 Magnetic field

The aim of this work is to expand the previous studies to measure the magnetic field strength through circular polarization observations of maser species in the CSEs of evolved stars. Recent observations revealed significant magnetic field strength at different regions of the CSEs. At the inner region of the CSEs, SiO maser polarimetric observations indicate magnetic fields of  $\sim 3.5$  G (Herpin et al. 2006, Kemball & Diamond 1997). Moreover, the polarimetric observations of OH masers which occur at the outer part of the CSEs show field strength in the range 0.1-10 mG (Etoka & Diamond 2004, Amiri et al. 2010). This could imply that a large scale magnetic field is present in the circumstellar environment of evolved stars, something that so far has only been confirmed for the supergiant VX Sgr (Vlemmings et al. 2011).

We performed H<sub>2</sub>O maser polarimetric observations of a sample of evolved stars including Mira variables and OH/IR stars which have higher mass loss rates. The observations show a magnetic field of  $18.9 \pm 3.8$  mG for the red-shifted emission of the OH/IR star IRAS 19422+3506. The measured field is of similar magnitude as the magnetic field in the bipolar H<sub>2</sub>O maser outflow of the post-AGB star W43A (Vlemmings et al. 2006, Amiri et al. 2010). However, the observed field is between one and two orders of magnitude lower than the observed magnetic field of 0.2 to 4 G measured for the H<sub>2</sub>O masers of Mira variables and supergiants (Vlemmings et al. 2002, 2005). Since IRAS 19422+3506 is a high mass loss OH/IR star, the CSE of this object is expected to be larger. Therefore, the lower field measured could imply that the H<sub>2</sub>O masers are located at a larger distance from the central star compared to Mira variables. Polarimetric observations of all other maser species (OH, H<sub>2</sub>O and SiO) are required to determine the magnetic field morphology in the CSE of evolved stars.

For the other sources in our sample we only place upper limits at  $3\sigma$  level in the range 10-800 mG for the magnetic field strength in the H<sub>2</sub>O maser region of the stars. In particular, while for R Lmi field strength of 2.32 mG and 0-5.6 G was measured for the OH and SiO maser regions (Rudnitski et al. 2010, Herpin et al. 2006), we did not measure a significant field strength for the H<sub>2</sub>O masers of this star. However, blending of the maser features will decrease the observed magnetic field

strength with low angular resolution observations (Sarma et al. 2001). Interferometric observations of the H<sub>2</sub>O masers of this star would help us to reveal if R Lmi indeed has a magnetic field strength significantly lower than those of other Miras.

#### 4.5.1.1 The role of the magnetic field in shaping the circumstellar outflow

The role of the magnetic field in forming the aspherical PNe is discussed in the literature (e.g. Pascoli 1987). The interaction of a toroidal magnetic field (due to the stellar rotation) with the fast AGB wind can produce aspherical PNe (e.g. Chevalier & Luo 1994, Garcia-Segura 1997). Alternatively, Matt et al. (2000) propose another mechanism in which the interaction of a slow AGB wind with a dipole magnetic field of a few Gauss produces an equatorial disk. The interaction of the later fast AGB wind with the equatorial disk can produce aspherical, cylindrical PNe (e.g. Icke 1988). Moreover, under the influence of a strong magnetic field, the circumstellar disk can become warped (Lai 2003). The interaction of the fast AGB wind with the warped disk has been shown to produce multi polar PNe (Icke 2003). We are not able to determine the magnetic field morphology in the H<sub>2</sub>O maser region from our single dish observations. However, Vlemmings et al. (2005) suggest a dipole field morphology for the H<sub>2</sub>O maser region of the supergiant VX Sgr, the result which was recently confirmed by the high frequency SiO maser observations of this star (Vlemmings et al. 2011).

#### 4.5.2 Variability

Our observations show that the H<sub>2</sub>O masers of the evolved stars exhibit significant variability in flux density up to two orders of magnitude compared to the previous observations by Engels & Lewis (1996). Moreover, we are not witnessing a significant drift of the line of sight velocities of the maser components which could have indicated radial acceleration between the two observations. H<sub>2</sub>O masers are known to be variable in flux and spectral shape (e.g. Bowers et al. 1993, Engels & Lewis 1996). The flux density may vary by 2 orders of magnitude and occasional flares by up to a factor of 1000 variation in flux are reported (Schwartz et al. 1974). H<sub>2</sub>O masers are located in a region where shock waves driven by stellar pulsation are propagating through the H<sub>2</sub>O maser zone (Rudnitskii & Chuprikov 1990, Shintani et al. 2008). Moreover, the strong variability likely indicate the masers are unsaturated and that they respond exponentially to the variation in excitation conditions in the maser region (Engels & Lewis 1996).

In particular, the H<sub>2</sub>O masers of IRAS 19422+3506 exhibit three emission complexes in the spectrum, in contrast to the single peak profile observed previously by Engels & Lewis (1996). The variation in spectral shape could indicate that we are witnessing a transitional effect in this star. The double peak profile raises the possibility that the outer peaks occur at the tips of a jet that lies not too far to the plane of the sky. The inner components could indicate that the masers occur in the equatorial plane of the circumstellar shell (Walsh et al. 2009). We note that H<sub>2</sub>O maser jets are already observed in several post AGB objects (e.g. Imai et al. 2002, Boboltz & Marvel 2005). In particular, VLBA H<sub>2</sub>O maser observations of W43A revealed a collimated H<sub>2</sub>O maser jet (Imai et al. 2002). Alternatively, the double peak profile may indicate the radial amplification of the masers. Since this object is an OH/IR star, the water maser shell is expected to be larger and located at much larger distances from the central star compared to the location of H<sub>2</sub>O masers in Mira variables. At such large distances, there is a lower velocity gradient which allows the radial amplification of

masers which manifest itself as a double peak profile (Engels & Lewis 1996). Therefore, VLBI observations of this source are required to disentangle the morphology of the H<sub>2</sub>O maser region of this source.

## 4.6 Conclusion

We performed polarimetric observations of the H<sub>2</sub>O masers of a sample of evolved stars including Mira variables and OH/IR stars with the GBT. While, significant field strength of 0.2-4 G was measured previously for Mira variables and supergiants, we only measured a magnetic field of  $18.9 \pm 3.8$  mG for the red-shifted emission of the OH/IR star IRAS 19422+3506. However, this field strength was similar to the field of  $\sim 30$  mG measured for the blue-shifted lobe of the H<sub>2</sub>O maser jet of the post-AGB object W43A. For the rest of the sample we only place upper limits in the range 10-800 mG.

Additionally, our observations show that H<sub>2</sub>O masers show significant variability in flux density up to two orders of magnitude compared to previous observations by Engels & Lewis (1996). This could imply significant variation in density and velocity of the H<sub>2</sub>O maser region of the CSE of these stars.

Follow up monitoring observations of the H<sub>2</sub>O masers of the evolved stars studied in this work are essential to study the variability of the masers in different classes of evolved stars. Furthermore, polarimetric H<sub>2</sub>O maser observations for a larger sample of evolved stars with different mass loss rates are necessary to determine the role of the magnetic field throughout the AGB evolution.

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