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New phase-lag distances of OH/IR stars

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20 OH/IR stars were monitored 2008-2012 at monthly intervals in the 1612 MHz OH maser line with the Nançay Radio Telescope (NRT). The stars vary with periods between 1.2 and >5 years. The phase-lag between the OH maser lines arising from the front and back sides of the circumstellar shells is used to determine their linear diameters. We find diameters between <1700 and 19000 AU. Combining them with angular diameters available from the literature, distances between 0.5 and 10.6 kpc are obtained for 12 stars. The determination of distances of OH/IR stars in Local Group galaxies will be in reach for the Square Kilometre Array (SKA).

Introduction

OH/IR stars are Asymptotic Giant Branch stars and have optically thick circumstellar dust and gas envelopes (CSE). From these envelopes intense OH maser emission arises. The stars pulsate similarly as Miras, but with much longer periods (Fig. 1). The general understanding is that the OH/IR stars had more massive main-sequence progenitors than the Mira variables. However, because of the uncertain distances of OH/IR stars, the evidence for a mass segregation between Mira and OH/IR stars is concluded from indirect arguments (Habing 1996, Chen et al. 2001).

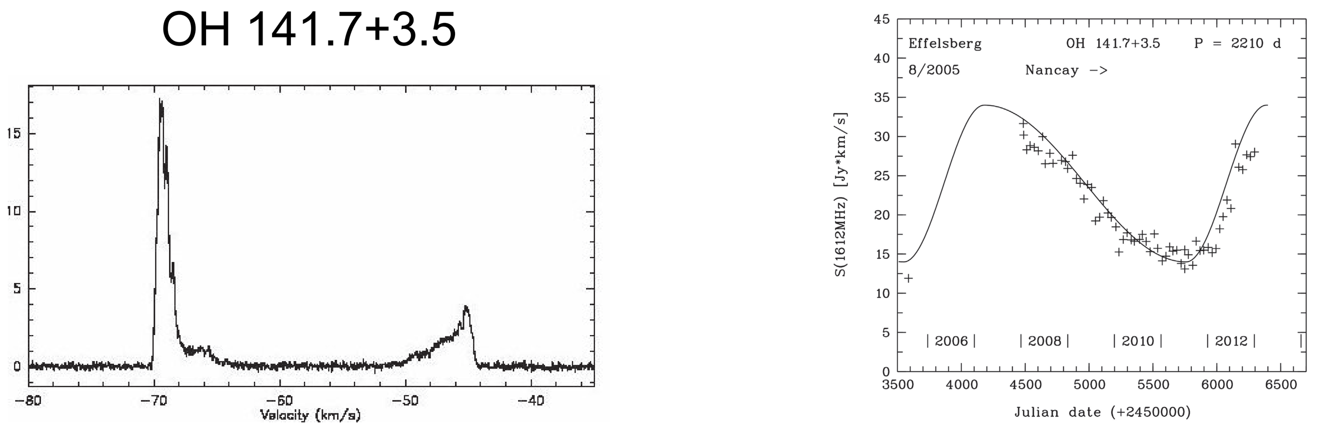

Figure 1:
OH 1612 MHz maser spectrum and and integrated flux variations 2008 – 01/2013 of OH 141.7+3.5 observed with the Nançay Radiotelescope. An additional observation taken in 2005 August with the Effelsberg radiotelescope is included. The observations were fitted using an asymmetric sine curve with a period P ≈ 6 years.

Distances to OH/IR stars are estimated using different techniques, for example using the galactic rotation curve (kinematic distances) or the period-luminosity (PL) relation for Mira variables. Neither technique is very trustworthy because the stars do not follow strictly galactic rotation and the extrapolation of the PL-relation beyond P~450 days is questionable (Whitelock et al. 1991). VLBI astrometry with OH masers was used by Vlemmings & van Langevelde (2007) to derive more reliable distances (errors 5-30%) up to distances of ~2 kpc.

Distance determination using OH maser phase lags

In the 1980s the phase-lag technique was explored by Herman & Habing (1985) to derive distances by combining the linear diameter determined from the phase lag between the two varying OH maser peaks and the angular diameters derived from VLA observations. Their results showed that the majority of their sample of OH/IR stars has distances between 2 and 10 kpc. The accuracy of these distances is however not well determined. Van Langevelde et al. (1990) re-determined the phase lags and hence linear diameters and revised the distances to a much greater extent, than expected from the errors quoted.

The phase lag between the two maser peaks is due to their location on the front and back side of the CSE. Due to the light-travel time through the CSE the observer sees the peak from the back side of the shell responding with a delay τ_0 relative to the peak from the front side. The delays can be as large as 3 months.

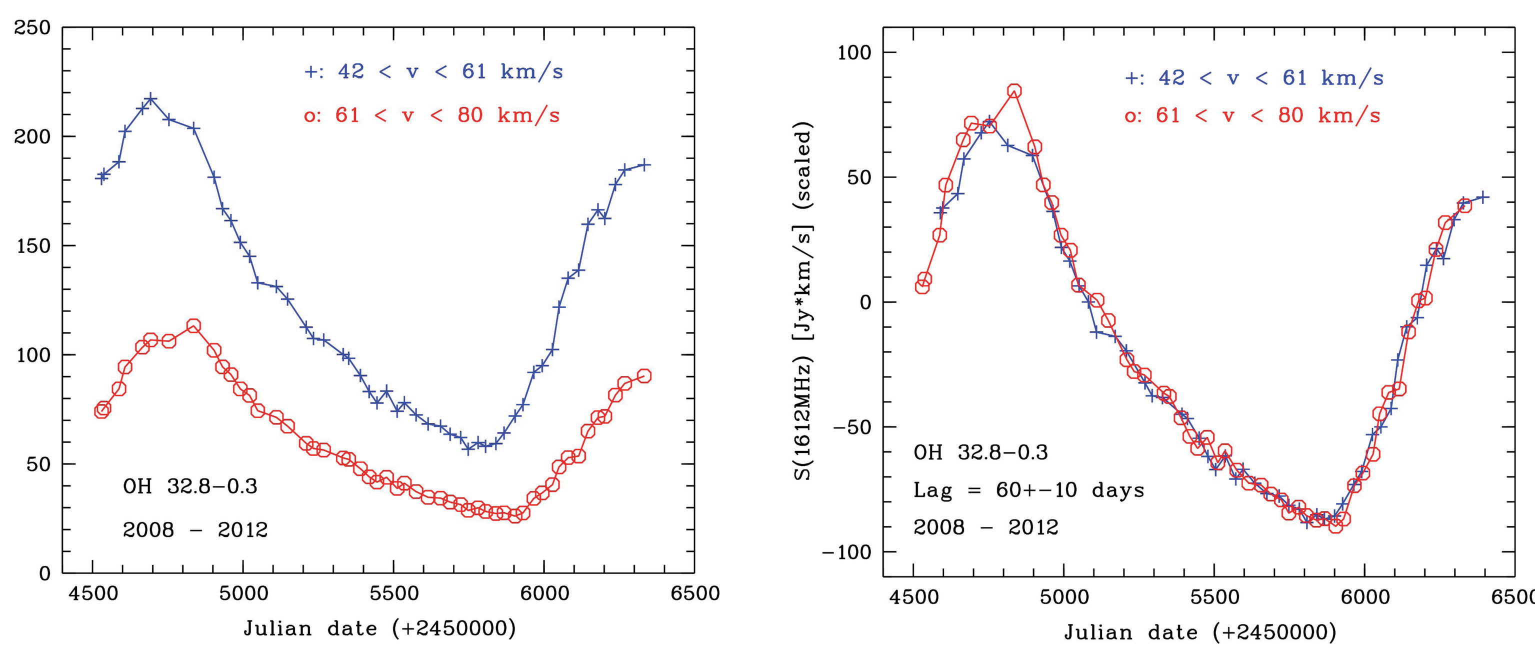

Figure 2:
Determination of the phase lag τ_0 for OH 32.8-0.3 (P=4.63 years). *Left:* Lightcurves of the integrated flux of the blue- and red-shifted maser peaks. *Right:* Match of the processed lightcurves applying a shift of 60 days.

New linear maser shell diameters

The NRT is well suited to measure high-quality OH maser light curves, allowing to apply the phase-lag technique for distance determination on more stars. We therefore monitored the 1612 MHz maser emission of 20 OH/IR stars with the NRT in monthly intervals over a period of five years (2008 - 2012).

The spectra were recorded with a bandwidth of 0.78125 MHz centered on 1612.231 MHz, giving a velocity resolution is 0.035 km/s. Typical integration times are 8 minutes on source, which yield a noise level of ~0.1 Jy and an S/N > 100. The errors in flux density are <5%. For almost all stars a complete variability cycle was covered, only OH 30.1-0.7, OH 141.7+3.5, and OH 16.1-0.3 with P~5.5-6.0 years require additional observations.

For a quick assessment of the phase lags, we analyzed the lightcurves with a simple model. Separate lightcurves were created for the blue and red parts of the spectrum.

It was assumed that the two lightcurves differ only by the mean flux density level and the amplitude. After subtraction of the mean flux and scaling the amplitudes, the two lightcurves were shifted in time until the difference between the lightcurves was minimized. An example of the technique is shown in Fig. 2.

The phase lags found, range between <10 and 110 days yielding linear shell diameters between <1700 and 19000 AU. Due to the simple analysis method the accuracy is only ~20%. The results are given in the Table. Distances to the stars were calculated using angular diameters taken from the literature. Fig. 3 shows the location of the stars in the Milky Way. New interferometric observations have been obtained with the E-VLA and are planned with eMERLIN.

The phase lags compare well (<10%) with the results from van Langevelde et al. (1990) for stars with strong emission in both maser peaks and regular lightcurves (e.g. OH 26.5+0.6). Otherwise larger differences were found, especially for stars with incomplete coverage of the cycle.

While the phase lags and the angular diameters can be detemined with accuracies of ~10%, the accuracy of the distances derived, strongly depends on the underlying assumption that the shells are spherically symmetric and the masers reside in a thin shell with a width $\Delta R << R_{OH}$ (see the discussion by Etoka & Diamond (2010) for OH 26.5+0.6).

Object	P [yrs]	τ_0 [days]	$2R_{OH}$ [10^3 AU]	ϕ [″]	D [kpc]	Object	P [yrs]	τ_0 [days]	$2R_{OH}$ [10^3 AU]	ϕ [″]	D [kpc]
20234-1357	1.16	< 10	< 1.7			OH 32.0-0.5	4.16	65	11.2	1.07	10.6
OH 44.8-2.3	1.47	15	2.6	2.60	1.0	OH 127.8+0.0	4.36	55	9.5	2.69	3.6
IRC +50137	1.74	10	1.7			OH 26.5+0.6	4.36	35	6.0	4.49	1.4
01037+1219	1.78	25	4.3	8.00	0.5	OH 75.3-1.8	4.52	60	10.4		
05131+4530	2.88	30	5.2			OH 32.8-0.3	4.63	60	10.4	2.74	3.8
OH 39.7+1.5	3.45	17	2.9	4.00	0.7	OH 20.7+0.1	4.71	90	15.6	1.65	9.4
OH 55.0+0.7	3.48	50	8.6			OH 104.9+2.4	4.79	35	6.0	2.88	2.1
21554+6204	3.51	30	5.2			OH 30.1-0.7	5.48	60	10.4	2.69	3.9
OH 138.0+7.2	3.86	10	1.7	1.60	1.1	OH 16.1-0.3	6.03	110	19.0		
OH 83.4-0.9	4.11	30	5.2			OH 141.7+3.5	6.05	75	13.0	1.52	8.6

Table: Results of the NRT monitoring program. Listed are object name, period P, phase lag τ_0, linear diameter $2R_{OH}$, angular diameter ϕ, and distance D. Uncertainties in the periods P are < 3% and for the phase lags $\tau_0 \approx 20\%$. The angular diameters of the shell are taken from the literature (Amiri et al. 2012, Baud 1981, Chapman et al. 1984, Herman et al., 1985, Norris et al. 1982, Wolak et al. 2013).

Prospects for research with the SKA

The determination of OH maser shell sizes using the phase-lag technique is distance independent and can therefore be applied also for OH emitting stars in external galaxies. For a shell diameter of 10000 AU the angular diameter at D = 1 Mpc is 10 mas. With peak luminosities applicable to the stronger galactic OH masers of 10^{17} Watt/Hz the expected flux densities are ~1 mJy. The required resolution and sensitivities is in the range of predicted capabilities of the SKA and therefore the phase-lag technique can be used as independent method for extragalactic distance determinations.

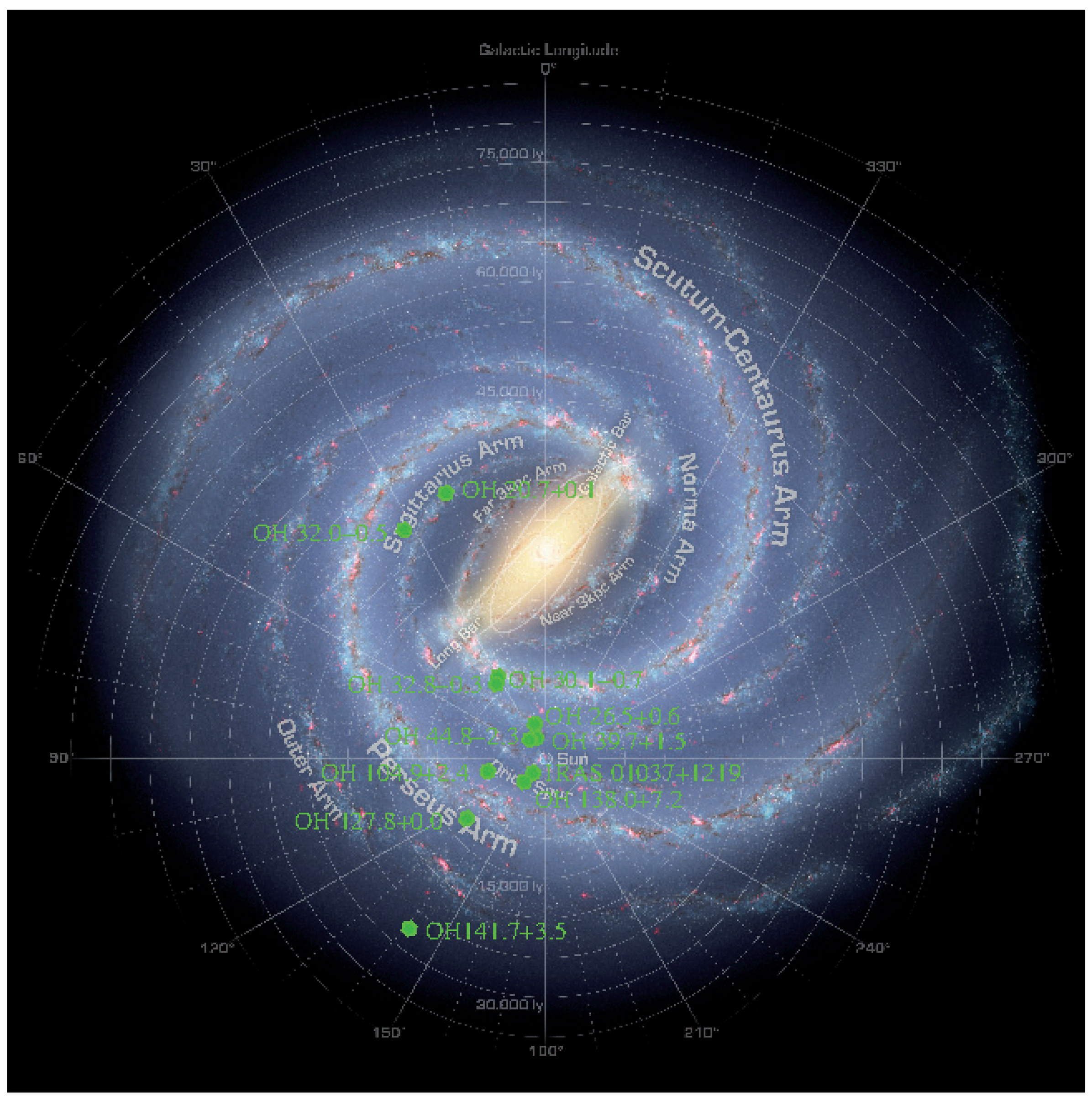

Figure 3
Location of the OH/IR stars with newly determined distances in the Milky Way. (Source of the artists view of the Milky Way Galaxy: NASA/JPL-Caltech/R. Hurt)

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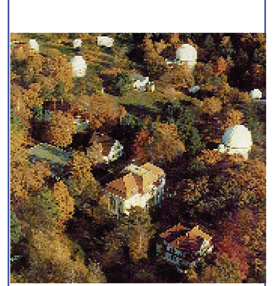

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