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Properties of the Variation of the Infrared Emission of OH/IR Stars I. The K Band Light Curves

Kyung-Won Suh† and Young-Joo Kwon
Department of Astronomy and Space Science, Chungbuk National University Cheongju 361-763, Korea
email: kwsuh@chungbuk.ac.kr

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Abstract

To study properties of the variation of the infrared emission of OH/IR stars, we collect and analyze the infrared observational data in K band for nine OH/IR stars. We use the observational data obtained for about three decades including recent data from the two micron all sky survey (*2MASS*) and the deep near infrared survey of the southern sky (*DENIS*). We use Marquardt-Levenberg algorithm to determine the pulsation period and amplitude for each star and compare them with previous results of infrared and radio investigations.

Keywords: stars: AGB and post-AGB, infrared: stars, stars: oscillations, circumstellar matter, dust, extinction

1. Introduction

The OH/IR stars are generally considered to be the final phase of an oxygen-rich asymptotic giant branch (AGB) star before leaving the red giant branch and rapidly evolving into a planetary nebula. This phase of the Mira variable is characterized by the long period, large amplitude pulsation and dusty stellar winds with high mass-loss rates ($10^{-7} - 10^{-4} M_{\odot}/yr$). Although the OH/IR stars are pulsating, the outer region of the dust shells show constant expansion velocity ($v_{exp} \sim 10 - 30$ km/sec). This implies that almost constant mass loss rate is maintained for a time scale much larger than the pulsation periods (e.g., Herman & Habing 1985a).

OH/IR stars show strong OH line emission at 18 cm and the maximum of their spectral energy distribution lies in the infrared, typically around 10 μm. Herman & Habing (1985b) concluded for their sample of 44 OH/IR stars that 14 % do not vary at all, 11 % have a small amplitude variation and that the remaining 75 % vary with amplitudes comparable to those of the nearby OH Miras. OH/IR stars which show variations vary in a manner simillar to long period Mira variables with periods up to 2000 days. They are considered to be an extension toward older age, longer periods and enhanced mass-loss of the optically known Mira stars. High mass-loss rates of these objects make thicker dust shells around them which absorb almost all optical emission of the central star.

The *2MASS* project (Skrutskie et al. 2006) provides the point source catalog (PSC) that contains fluxes in J, H, and K bands. The *DENIS* (DENIS Consortium 2005) is a deep astronomical survey of the southern sky in two near-infrared bands (J at 1.25 μm and K at 2.16 μm) and one optical band

† corresponding author

Table 1. The sample stars.

OHname	*IRAS* PSC	*G.lat.*	*D[kpc]*
$26.2 - 0.6$	18385-0617	-0.5893	4.1
$26.4 - 1.9$	18437-0643	-1.9346	3.4
$26.5 + 0.6$	18348-0526	+0.6178	1.4
$28.7 - 0.6$	18431-0403	-0.5787	2.8
$30.1 - 0.2$	18445-0238	-0.2322	3.3
$30.7 + 0.4$	18432-0149	+0.4278	5.2
$39.9 + 0.0$	19017+0608	+0.0182	5.6
$45.5 + 0.1$	-	+0.0749	2.5*
$127.8 + 0.0$	01304+6211	-0.0208	1.6

(I at 0.8 μm) simultaneously, conducted by a European consortium, using a one meter telescope (ESO, La Silla). The survey started in 1996 and operations at La Silla have been completed on Sep. 9, 2001.

In this paper, we collect and analyze the infrared observational data in K band for nine OH/IR stars. We make the light curves for the stars and determine the pulsation periods and amplitudes.

2. Sample stars

For this paper, we choose nine OH/IR stars having a range of pulsation periods. New observational data are available since many authors investigated the pulsation properties of the OH/IR stars in 1980s. To complete the light curves in K band (2.2 μm), we have made use of the SIMBAD database, operated at CDS, Strasbourg, France.

For the sample stars, Table 1 lists the name, the $IRAS$ PSC number, the galactic position, and the distance. The galactic positions of stars are based on the SIMBAD. All stars in the list are the OH/IR stars with long periods (500 – 2000 days) of pulsation. The distances refer to Lepine et al. (1995) except for OH $45.5 + 0.1$ (the distance from Nyman et al. 1993).

Table 2 lists the data used for this paper. Although the exact wavelengths for each bandpass used by many authors are slightly different, we use the original data without further reduction. There should be minor uncertainties for the differences. When data points are too far off from the general trend (see section 3), they are not used for determination of the pulsation parameters. The numbers of unused data are marked by parenthesis in Table 2. The earliest data point was obtained on May 3, 1974 for OH 26.5+0.6 (Ney & Merrill 1980).

To obtain the standard flux in W/cm^2 for all the data, we use the zero-magnitude calibrating methods. The zero-magnitude calibrating data are taken from the related references.

3. Light curves

Using the observational data in K band for nine stars (Table 2), we make the light curves. For curve-fitting of the observational data, we have used the Marquardt-Levenberg algorithm to find the coefficients of the independent variables that give the best fit between the sinusoidal equation and the data (e.g., Press et al. 1986). By analyzing the light curves, we determine new pulsation parameters; the period and amplitude. When data points are too far from the general trend, are not used for determination of the pulsation parameters. The unused data points are marked by parenthesis in

Table 2. The K band observations for the sample OH/IR stars.

Reference	26.2-0.6	26.4-1.9	26.5+0.6	28.7-0.6	30.1-0.2	30.7+0.4	39.9+0.0	45.5+0.1	127.8+0.0
Lebofsky et al. (1976)	.	.	.	.	.	.	.	.	1
Evans & Beckwith (1977)	.	.	2	.	3	.	.	4	.
Werner et al. (1980)	.	.	1	.	1	.	.	1	.
Ney & Merrill (1980)	.	.	9	.	.	.	.	1	1
Engels (1982)	10	11(1)	11(1)	10	11	8	10	9	.
Willems & de Jong (1982)	.	1	1(1)	.	.	.	.	.	.
Grasdalen et al. (1983)	.	.	1	.	.	.	.	.	2
Fix & Mutel (1984)	.	1	.	.	.	.	.	.	.
Gehrz et al. (1985)	2	4	.	4	.	3	2	1	2
Persi et al. (1990)	.	.	.	.	.	.	.	.	2
Jones et al. (1990)	.	.	2	.	.	.	.	.	2
Sun et al. (1991)	.	.	.	.	.	.	.	.	1
Noguchi et al. (1993)	.	.	.	.	.	.	.	.	1
Nyman et al. (1993)	1	1	1	1	1	1	1(1)	1	.
Le Bertre (1993)	.	.	13 (2)	.	.	.	.	.	.
Xiong et al. (1994)	.	.	1	.	.	.	.	.	.
Lepine et al. (1995)	.	.	1	.	.	.	.	.	.
Olivier et al. (2001)	.	.	8	.	.	.	.	.	.
2MASS (Cutri et al. 2003)	1	1	1	1	1	1(1)	1	1	1
DENIS	1	1	1	1(1)	.	.	.	.	.
Jimenez-Esteban et al. (2005)	.	.	.	.	.	.	1	.	.
Justtanont et al. (2006)	.	.	.	.	.	.	1	.	.
total number	15	20	53	17	17	13	16	18	13

Table 3. New periods and amplitudes.

Object	Period [days]			Amplitude [mag]			$< m >$ $[mag]$
	This work	Engels (1982)	Radio	This work	Engels (1982)	Radio	This work
26.2-0.6	1192 ± 8.20	1330 ± 50	1181 ± 13	3.16 ± 0.39	3.16	1.05	9.83 ± 0.14
26.4-1.9	491 ± 1.06	540 ± 20	652 ± 26	1.79 ± 0.14	1.78	0.44	7.46 ± 0.06
26.5+0.6	1568 ± 8.53	1630 ± 100	1566 ± 16	3.5 ± 0.24	3.86	1.13	8.37 ± 0.06
28.7-0.6	662 ± 9.55	640 ± 10	627 ± 17	2.0 ± 0.16	1.28	0.83	5.67 ± 0.10
30.1-0.2	929 ± 7.56	970 ± 40	853 ± 21	2.9 ± 0.50	2.81	0.81	6.96 ± 0.13
30.7+0.4	1001 ± 9.93	1140 ± 30	1039 ± 27	2.25 ± 0.32	2.1	0.57	11.41 ± 0.12
39.9+0.0	791 ± 4.66	770 ± 20	823 ± 45	2.36 ± 0.38	2.36	0.8	10.25 ± 0.14
45.5+0.1	696 ± 2.31	720 ± 20	760 ± 31	2.55 ± 0.22	2.26	0.92	7.59 ± 0.07
127.8+0.0	1580 ± 13.64	- -	1994 ± 130	2.95 ± 0.25	-	1.47	7.45 ± 0.15

Table 2 and the light curves (Figures 1-3).

Figures 1 through 3 show the 9 panels of light curves for the nine stars observed for about last 25 years covering various numbers of the pulsation phase cycle. Each panel shows the data points (symbols) and the best fitting sinusoidal curve (a line). The data points unused for the light curve fitting are marked by parenthesis.

Table 3 lists the new pulsation parameters obtained in this paper and the parameters determined by previous authors for the nine stars. The pulsation parameters in the radio band were obtained from the OH maser observations by Herman & Habing (1985b). The standard deviation errors in

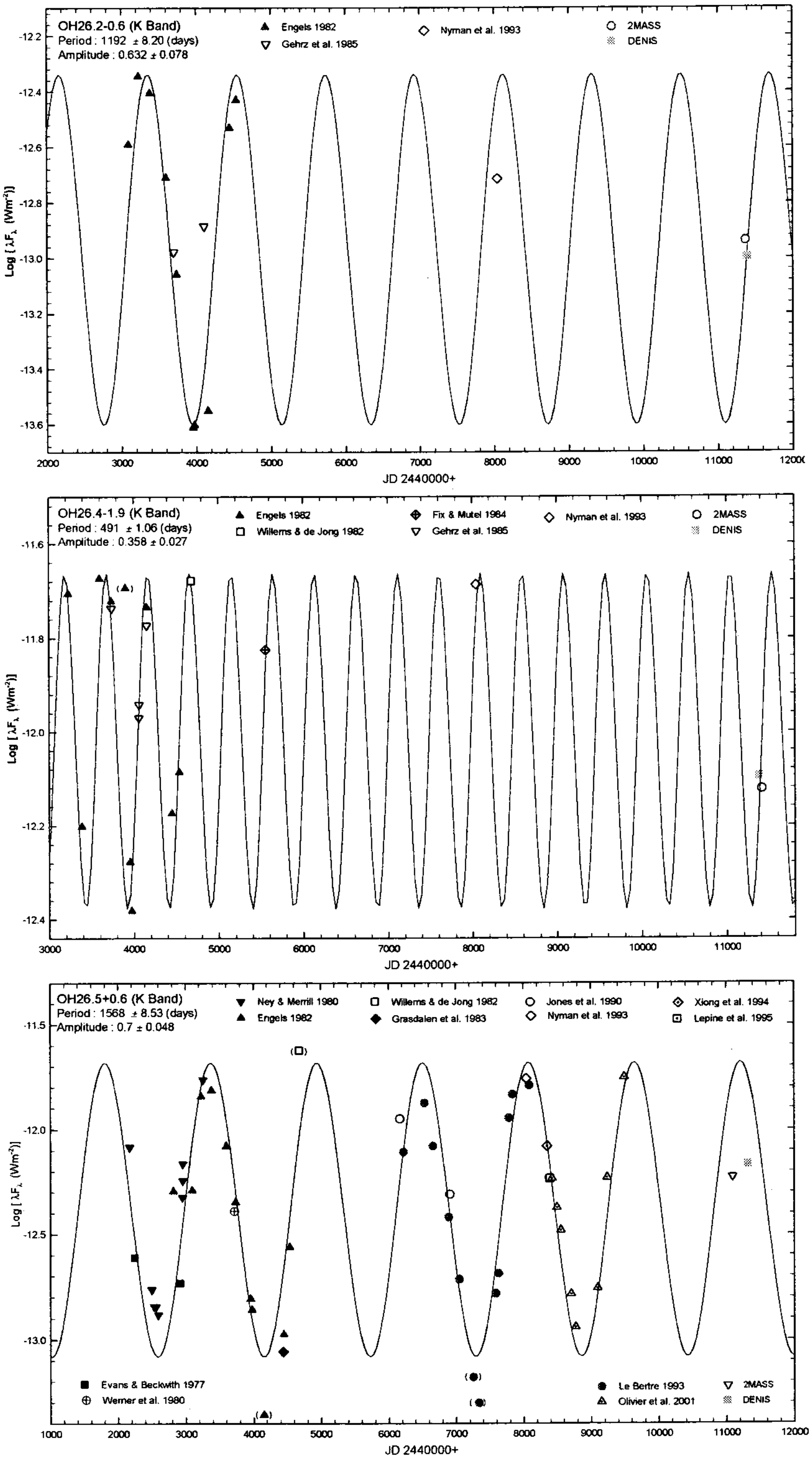

Figure 1. Light curves of OH/IR stars.

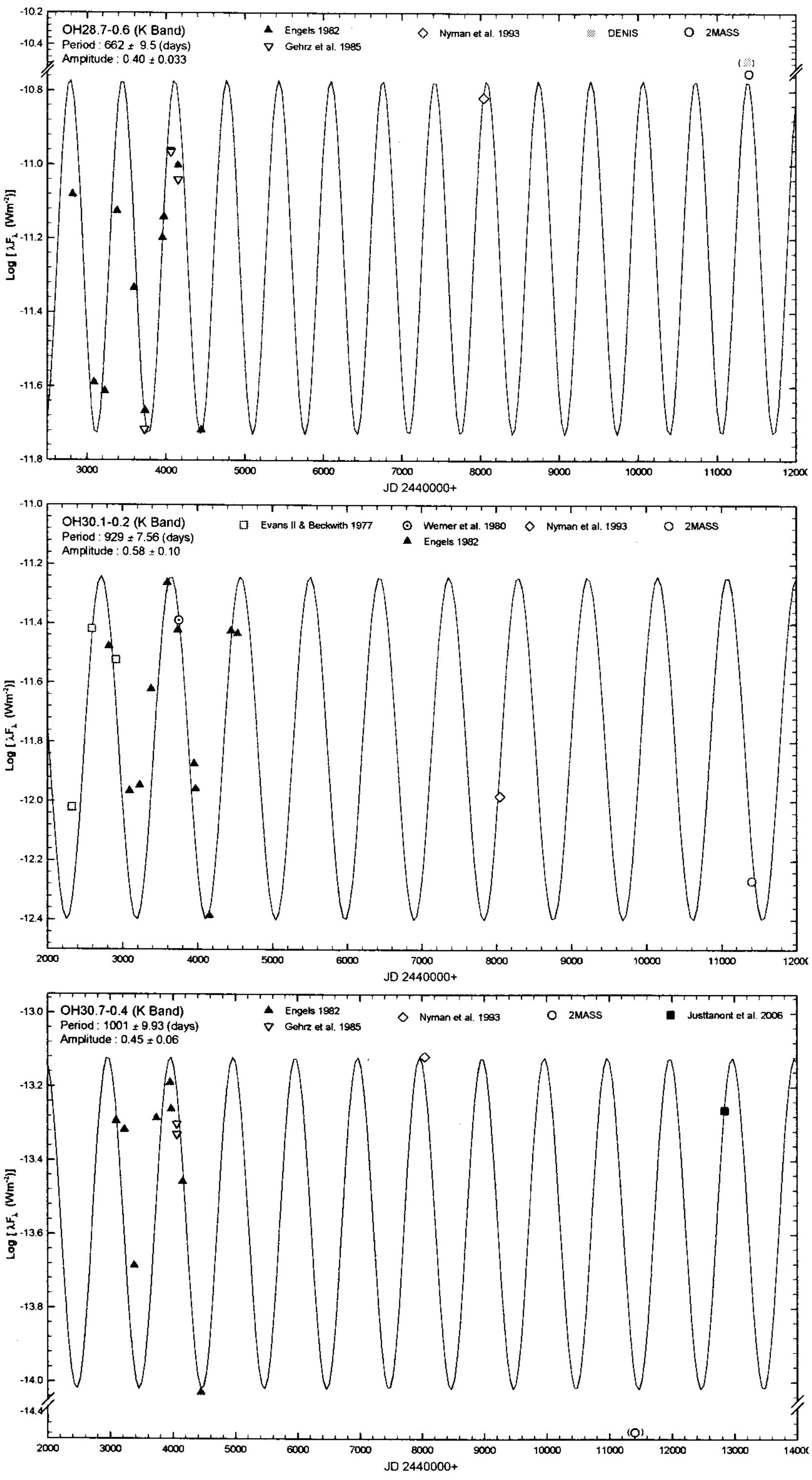

Figure 2. Light curves of OH/IR stars.

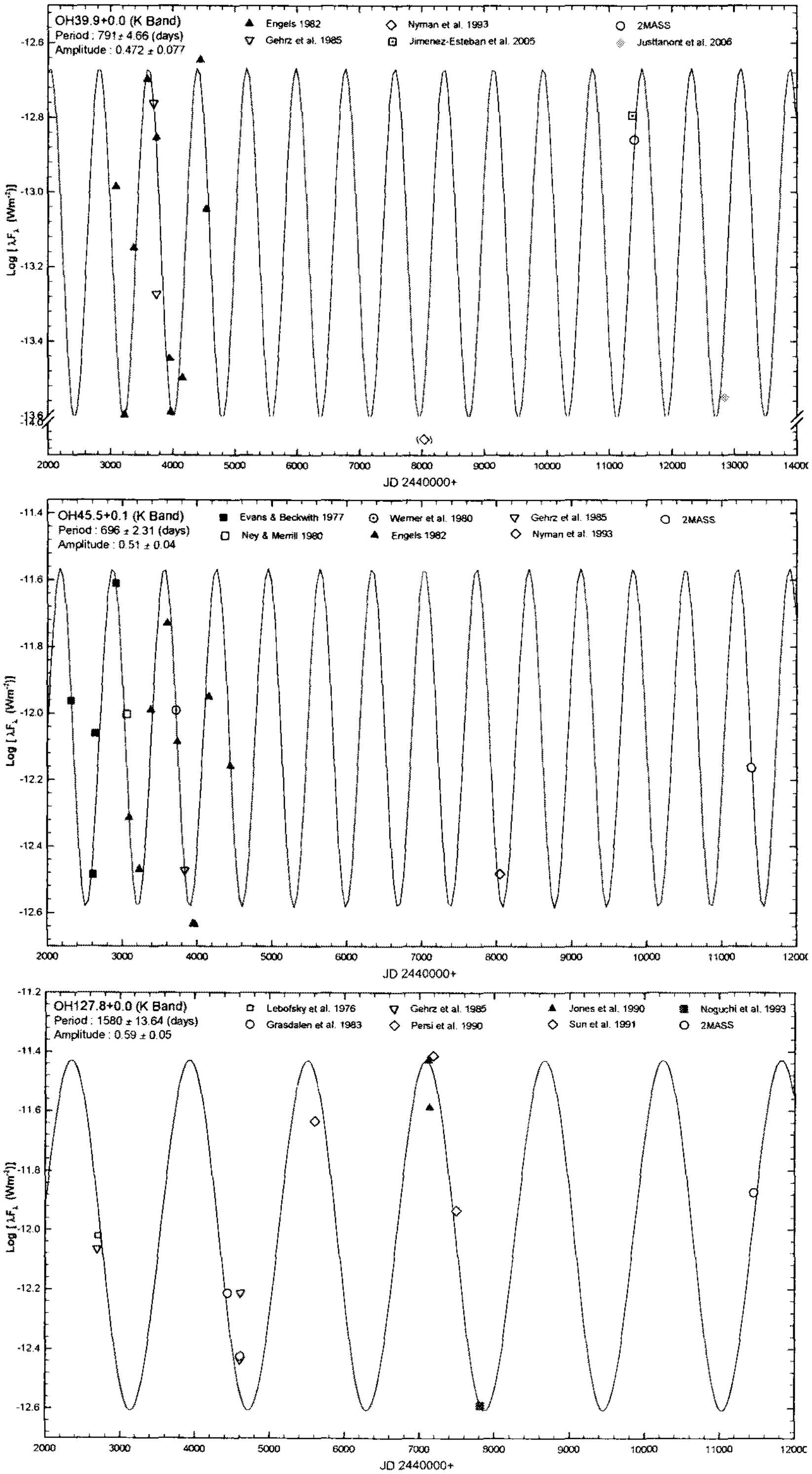

Figure 3. Light curves of OH/IR stars.

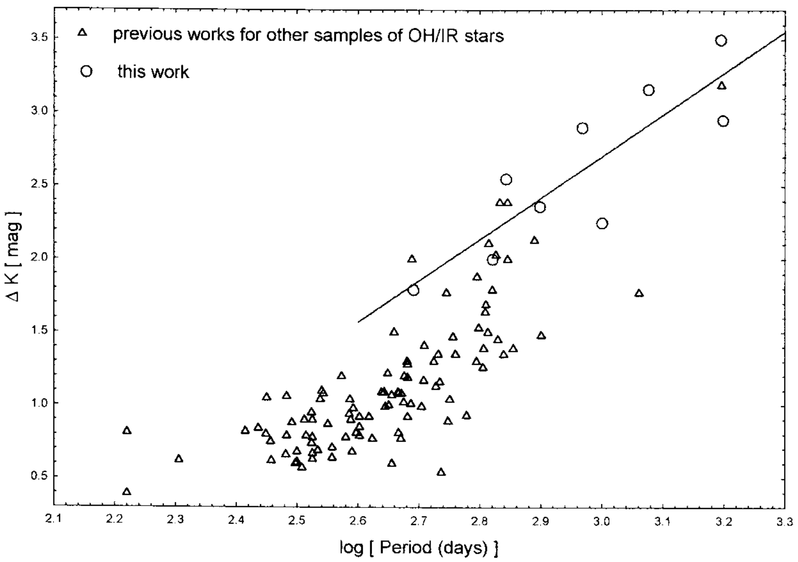

Figure 4. Period-amplitude relationship for OH/IR stars.

this work are smaller than previous work by Engels (1982) because of the increased data points. The mean brightness in magnitude unit ($< m >$ $[mag]$) for each star is also listed in the table.

Figure 4 shows the period-amplitude relationship for OH/IR stars obtained in this paper. The period-amplitude relationship for the nine OH/IR is fairly well fitted to a linear equation (the line in Figure 4). The data points from previous investigations (Engels et al. 1983, Le Bertre 1993, Whitelock et al. 1994, Olivier et al. 2001) of other samples of OH/IR stars are also displayed for comparison. The previous samples of OH/IR stars have generally shorter periods than our sample.

Low mass-loss rate O-rich AGB (LMOA) stars with thin dust envelopes show many molecular lines in NIR bands. The most conspicuous lines are the water vapor absorption at 1.9 and 2.9 μm and CO absorption at 2.3 μm produced in the photosphere and expanded envelope of the central stars. These absorption lines of H_2O and CO make the K band flux fainter for LMOA stars. However, the molecular lines are filled in by the dust emission for the OH/IR stars with thick dust dust envelopes.

4. Conclusions

We have collected and analyzed the infrared observational data in K band for nine OH/IR stars. We use the observation data obtained for about three decades including recent data from the *2MASS* and *DENIS*.

We have determined the pulsation parameters of the nine OH/IR stars. We have used Marquardt-Levenberg algorithm to determine the pulsation period and amplitude for each star and compared them with previous results of infrared and radio investigations. We find the period-amplitude relationship for those stars is fairly well fitted to a linear equation.

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