A&A 381, 491–499 (2002)
DOI: 10.1051/0004-6361:20011518

Astronomy & Astrophysics

Nature of OH maser and SiO thermal emission towards carbon star: IRAS 05373–0810 (V1187 Ori)*

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Received 10 September 2001 / Accepted 23 October 2001

Abstract. We present observational evidence that IRAS 05373–0810 is a genuine carbon star with an ISO SWS spectrum closely resembling that of R Scl. Modelling of the spectral energy distribution of IRAS 05373–0810 suggests that the star has luminosity of order of 8000 $L_\odot$ and loses mass at a rate of about $2{-}3 \times 10^{-7}$ $M_\odot\,\mathrm{yr}^{-1}$. The detected OH maser emission at 1612, 1665 and 1667 MHz and SiO thermal emission at 86.85 GHz towards IRAS 05373–0810 is not associated with this source. The available observations imply that these lines, typical for O–rich sources, come from the molecular cloud L 1641 in the Orion star forming region (OH) and, very likely, from the NGC 2149 molecular complex (SiO).

Key words. stars: AGB and post–AGB, carbon, individual: IRAS 05373–0810 – ISM: dust, extinction

1. Introduction

IRAS 05373–0810 (hereafter IRAS 05373) was first detected during the Two–Micron Sky Survey (IRC –10095; Neugebauer & Leighton 1969) and next during the Air Force Geophysical Laboratory Infrared Sky Survey (RAFGL 796; Price & Murdock 1983) at 4, 11 and 20 μm. Already then, on the basis of an objective–prism survey (Hansen & Blanco 1975), the source had been classified as a medium bright late type C–star. Bidelman (1980) also classified this source as a carbon star, presently named CCGCS 1017 in the Stephenson's (1989) catalogue. The IRAS Point Source Catalogue (hereafter PSC) provided fluxes of good quality of 31.99, 8.81 and 2.11 Jy for the 12, 25 and 60 μm bands, respectively. The resulting IRAS colours $\lg(F_{25}/F_{12}) = -0.56$ and $\lg(F_{60}/F_{25}) = -0.62$, locate this source on the border between regions VII and VIa of the IRAS colour–colour diagram (van der Veen & Habing 1988). The PSC fluxes determined by Strom et al. (1989) by measuring one dimensional IRAS co–adds (33.1, 9.59 and 1.95 Jy for the 12, 25 and 60 μm bands, respectively) move IRAS 05373 to the border between regions VII and I. Therefore, at least from statistical point of view, the source seems to be C–rich with no or a little mass loss. The IRAS Low Resolution Spectrum (LRS) between 7 and 23 μm has been also obtained and classified as LRS 42 (Olnon et al. 1986) due to presence of the SiC feature near 11.3 μm. The classification has been confirmed by Kwok et al. (1997) by means of an eye classification scheme developed by Volk & Cohen (1989). These and other observations which will be discussed in the following sections show that carbon–rich nature of the object is well documented.

On the other hand, te Lintel Hekkert (1990) (hereafter tLH) has reported detection of the OH 1612 MHz maser emission towards IRAS 05373. The existence of OH maser emission around a genuine C–rich star (if proven) would suggest that its circumstellar envelope (at least partly) is oxygen rich and that source has a complex circumstellar chemistry, possibly, similar to that in silicate carbon stars where the 9.7 μm silicate emission has been recognized by Little–Marenin (1986) and Willems & de Jong (1986). In some silicate carbon stars water and OH maser emission were also detected (Benson & Little–Marennin 1987; Nakada et al. 1987; Deguchi et al. 1988; Nakada et al. 1988; Little–Marenin et al. 1988; te Lintel Hekkert et al. 1991; Little–Marenin et al. 1994; Engels 1994; Szymczak et al. 2001). The most recent compilation of 22 known and

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[*] Based on observations with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with participation of ISAS and NASA.

suspected silicate carbon stars is presented by Chen et al. (1999a). Note also the discovery of the first extragalactic silicate carbon star (IRAS 04496–6958) in the Large Magellanic Cloud (Trams et al. 1999).

The group of silicate carbon–stars is probably not the only group of C–rich stars showing peculiar chemistry in their shells. For example, Molster et al. (1999) have presented the Infrared Space Observatory (ISO) observations of carbon star IRAS 09425–6040 which possesses at the same time SiC and crystalline silicate features. The presence of crystalline silicates among some other carbon–rich stars is discussed by Waters & Molster (1999). In addition, Lewis (1992) listed a group of stars with $4n$ LRS spectra and OH maser emission detected. Chen et al. (1999b) using the new LRS catalogue of Kwok et al. (1997) have found that for most of them the $4n$ classification is probably not correct and only three sources (IRAS 08304–4313, IRAS 17371–3021 and IRAS 18551+0323) remain as a possible candidates for C–stars with an OH maser emission. Recently, we have performed a cross–correlation between OH satellite line (1612 MHz) maser sources selected from the literature and the LRS catalogue of Kwok et al. (1997) and found 6 more such objects (Chen et al. 1999b; Chen et al. 2001). One of them is IRAS 05373–0810.

This paper is a first of the series in which we will examine available from the literature and new observations obtained by us with the aim to understand the nature and evolutionary status of C–rich stars associated with OH maser emission. In Sect. 2 we describe our observations obtained from the ISO satellite and IRAM 30–m (Spain), Nançay (France) and Toruń (Poland) radio telescopes. In the following Section we discuss the nature of the oxygen–based molecular emissions observed in direction of IRAS 05373. Next we provide estimation of physical parameters for this source as derived from spectral energy distribution modelling and, finally, we present conclusions.

2. Observations

To understand complex nature of IRAS 05373–0810 (C–star with OH maser emission) we have observed the source with ISO (to confirm its C–rich nature and search for possible signatures of the crystalline silicates), the IRAM radio telescope (to investigate chemical contents of the circumstellar envelope) as well as with the Nançay and Toruń radio telescopes (to check the reality and possible variability of the OH maser emission reported by te Lintel Hekkert 1990).

2.1. ISO

The spectroscopic observation was carried out with the SWS spectrometer (de Graauw et al. 1996) of the Infrared Space Observatory satellite on April 1, 1998 with the second fastest speed covering full grating scan from 2.3 to 45 μm (SWS AOT 01, speed 2). The original pipeline version 8.7 (OLP_87) data were corrected for dark current, up–down scan difference, flat–field and flux calibration by using the Observers SWS Interactive Analysis (OSIA) package. The deglitching and averaging across the scans and detectors was done using the ISAP package. The effective spectral resolution for the following analysis is taken to be 500, independently of the spectral band.

The spectrum obtained for band 2 (from 4.08 to 12 μm) is too weak in comparison with band 1 data by about 13% in the case of subbands 2A (4.08–5.30 μm) and 2B (5.30–7.00 μm) but by about 36% for subband 2C (7.0–12.0 μm). Since 4 subbands of the band 1 agree pretty well with each other we have applied the necessary multiplicative factors to subbands of band 2 to make spectrum of IRAS 05373 smooth. The spectrum obtained from the OSIA analysis for band 3A, 3C and 3D (from 12.0 to 27.5 μm) is more noisy and for further analysis some detectors (21 for subband 3A and 25, 28 and 33 for subband 3D) were not taken into consideration. The flux level of subbands 3A, 3C and 3D is too low in comparison with the corrected previously band 2. In addition, there seems to be a small disagreement between sub-band 3C and 3D. In order to get smoother transitions between neighbouring bands multiplicative factors of 1.26 (for sub-bands 3A and 3C) and 1.1 (for sub-band 3D) have been applied. Because the flux calibration of SWS observation has an uncertainty of order of 20–30%, such corrections seem to be reasonable. The data for bands 3E and 4 (from 27.5 to 45.2 μm) are of bad quality and they are not taken into account. From this calibrated ISO spectrum synthetic IRAS photometry flux at 12 μm has been calculated using the ISAP software and it has been found that the simulated ISO flux density at 12 μm (26 Jy) is still about 18% lower than PSC one (31.99 Jy). Note that at the same time, a factor of 1.16 has to be applied to the IRAS LRS spectrum in order to match with the IRAS photometric result at 12 μm. The difference in flux level between SWS and PSC 12 μm data could reflect the level of precision in the calibration of instrument, but it could also be related to variations of the star. The assigned IRAS variability is 4, which means that large amplitude variations have not been detected by IRAS; however, they may still be possible (see e.g. Whitelock et al. 1994). In fact, other photometric data suggest a significant variability (see Sect. 4) of IRAS 05373 which is recognized as a variable star V1187 Ori (Kholopov et al. 1987).

The reliable part of the SWS spectrum of IRAS 05373 (bands 1A–3D), after the flux adjustment described above, is displayed in lower part of Fig. 1 by thick solid line while the overplotted dotted line represents the IRAS LRS spectrum multiplied by factor of 1.16. Filled triangles mark the IRAS PSC fluxes at 12 and 25 μm. The overall agreement between these spectroscopic data is satisfactory. However, still there seems to be some disagreement between ISO SWS data and IRAS photometry at 25 μm. Note that the SWS data above 27.5 microns are not reliable and the synthetic IRAS photometry for the 25 μm band has not been computed nor has normalization to this PSC band been performed. The difference seems to be almost solely related to the shape of spectrum in sub-band

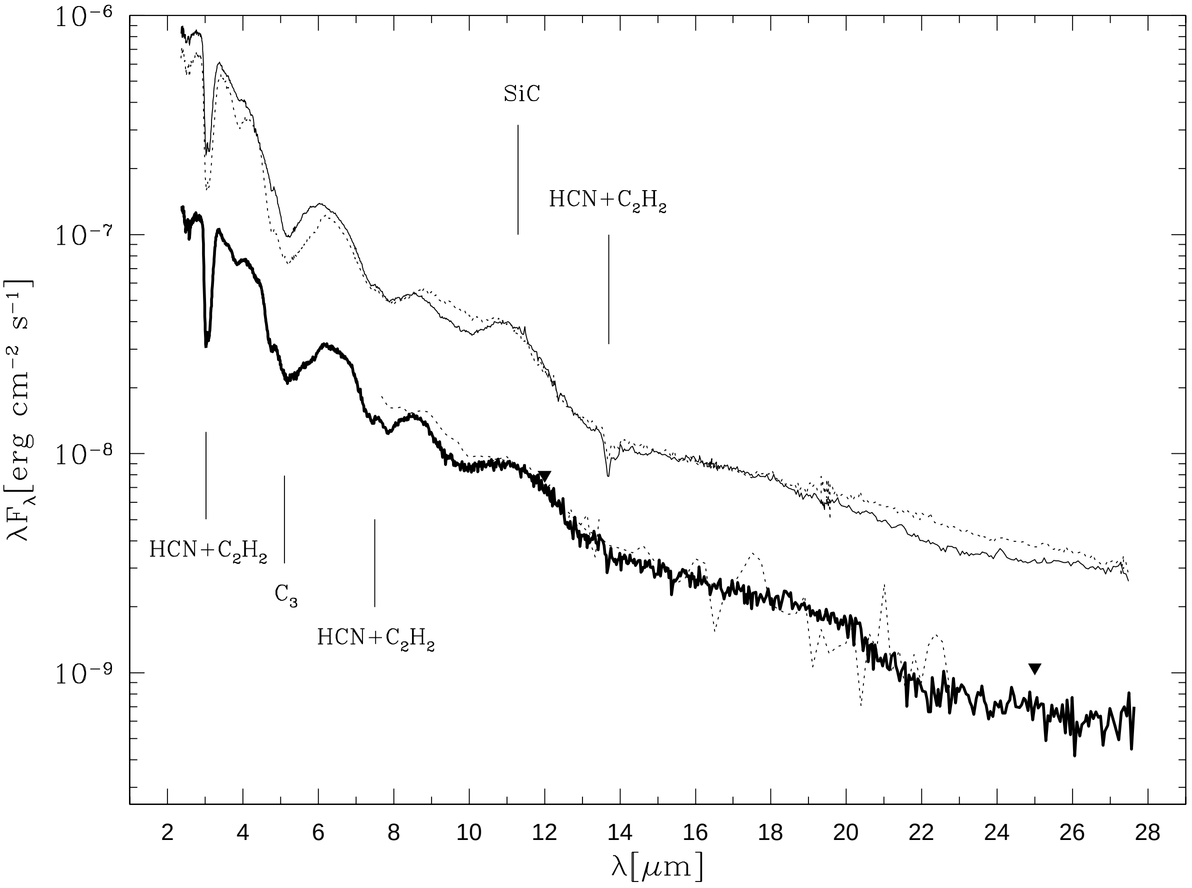

Fig. 1. The ISO SWS 01 spectrum of IRAS 05373–0810 (lower thick solid line) together with the IRAS LRS (lower dotted line) and the IRAS PSC data (filled triangles). The upper lines represent spectra for R Scl (Hron et al. 1998) at visual phases 0.92 and 0.37 (solid and dotted lines, respectively). Positions of some identified C–bearing features are marked by the vertical lines.

3D (19.5–27.5 μm). Note, finally, that with the achieved signal–to–noise ratio it is difficult to recognize possible features at $\lambda > 20\,\mu$m, but it seems that crystalline silicate bands are not present in our spectrum.

The two lines in the upper part of Fig. 1 shows SWS 01 spectrum of well known carbon star R Scl (Hron et al. 1998) taken at visual phase of 0.92 (solid line) and 0.37 (dashed line). The similarity between spectra of R Scl and IRAS 05373 is remarkable. Especially, resemblance between our data and spectrum of R Scl taken at visual phase of 0.92 is striking. Note, that the SWS spectrum of R Scl taken at this phase shows a broad depletion between 18 and 28 μm which disappears at visual phase of 0.37. Similar depletion seems to be present in the SWS spectrum of IRAS 05373 and it is quite possible that such an extended drop in emission is responsible for the mentioned discrepancy between PSC flux at 25 μm and the SWS 01 spectrum of IRAS 05373.

The main C–bearing features are marked by means of the vertical lines and it is clear that all of them appear in the SWS 01 spectra of both stars. A small differences between spectral features could be attributed to slightly different excitation conditions and/or chemical composition of their photospheres. Therefore, the C/O = 1.34 found in R Scl by Lambert et al. (1986) implies similar value of the C/O ratio in IRAS 05373.

2.2. Millimetre and radio observations

Observations of the SiO ($v = 0$) $J = 2 \rightarrow 1$ and $J = 3 \rightarrow 2$, SO $J_N = 6_5 \rightarrow 5_4$, HCN $J = 1 \rightarrow 0$, CS $J = 3 \rightarrow 2$ and $J = 5 \rightarrow 4$ transitions were carried out on May 12 and 14, 1999 with the IRAM 30–m telescope at Pico de Veleta, Spain. Three SIS receivers at 3, 2 and 1.3 mm were used simultaneously and the single sideband system temperatures were 120 K, 360 K and 570 K, respectively. The half power beam widths (HPBW) and the main beam efficiencies were 27″ and 0.77 at 3 mm, 16″ and 0.55 at 2 mm, and 10.5″ and 0.48 at 1.3 mm. The pointing was checked at regular intervals and was found to be accurate within about 3″. The backend consisted of one 256×100 kHz filter bank connected to the 3 mm receiver and two 512×1 MHz filter banks connected to the 2 mm and 1.3 mm receivers. Spectra were taken in wobbler switching mode with the OFF reference symmetric positions 180″ away in azimuth from the ON source position with a wobbling phase time of 2 s. The antenna temperature scale for each spectrum was established by observing

Table 1. Observational results. The peak intensities are the main–beam brightness temperature for the millimetre observations and the antena temperature for the OH maser observations.

	transition	frequency (GHz)	$I_\mathrm{p}(1\sigma)$ (K)	V_p ($\mathrm{km\,s^{-1}}$)	$\int I_\mathrm{p}\mathrm{d}v$ ($\mathrm{K\,km\,s^{-1}}$)
SiO	$J = 2 \rightarrow 1$	86.846891	0.035 (0.007)	9.73	0.059
SiO	$J = 3 \rightarrow 2$	130.268703	(0.011)		
SO	$J_\mathrm{N} = 6_5 \rightarrow 5_4$	219.949391	(0.021)		
HCN	$J = 1 \rightarrow 0$	88.631602	(0.012)		
CS	$J = 3 \rightarrow 2$	146.969049	(0.013)		
CS	$J = 5 \rightarrow 4$	244.935606	(0.022)		
OH		1.667359	0.097 (0.014)	5.66	0.156
OH		1.665402	0.114 (0.015)	5.64	0.210
OH		1.612231	0.081 (0.010)	5.07	0.170

the sky and two loads with different temperatures and was converted into the main beam brightness temperature. The resulting accuracy of the calibration was about 20%, but might be worse for the 1 mm data.

The results of millimetre observations are summarized for the O–bearing molecules at the top and for the C–bearing ones in the middle of Table 1. Frequencies of the observed transitions (in GHz), the line peak intensities together with noise (in K), the peak velocities and the velocity integrated intensities are listed. Weak SiO (2→1) emission ($\sim 5\sigma$) was detected at the local standard of rest velocity (V_LSR) of $9.73\,\mathrm{km\,s^{-1}}$. The observed spectrum (in units of the main–beam brightness temperature) for this transition is shown in the upper panel of Fig. 2. To achieve a better signal to noise ratio the original spectrum has been smoothed over two channels, so the velocity resolution is $0.690\,\mathrm{km\,s^{-1}}$ but rms is about 7 mK only. No emission from SiO (3→2), SO, or from the C-bearing molecules (HCN and CS) was detected.

The OH 18 cm observations were performed with the Nançay radio telescope on April 10 and 11, 1999. The HPBW was $3.5'$ in right ascension by $18'$ in declination. The dual channel receiver was used. The system temperature was about 50 K. The 1024–channel autocorrelation spectrometre was split into 4 banks, each covering a bandwidth of 0.2 MHz, for the three OH lines. The 1612 MHz satellite line was observed in both circular polarizations and the 1665 and 1667 MHz main lines were observed in left and right circular polarization, respectively. The spectra were taken in frequency switching mode with channel spacings of 0.28 and $0.29\,\mathrm{km\,s^{-1}}$ at the main lines and the satellite line, respectively. W 12 was observed to provide the flux density calibration, which was accurate to 10%. OH emission was detected in the all three lines (1667, 1665 and 1612 MHz) at velocities 5.66, 5.64 and $5.07\,\mathrm{km\,s^{-1}}$, respectively which are blue–shifted relative to the SiO feature. The OH observations are summarized at the bottom of Table 1 and the spectra in units of the antenna temperature (hereafter T_A) are shown in the lower panels of Fig. 2.

The OH observations were repeated with the Toruń 32 m radio telescope on March 30, 2000. The dual-channel cooled HEMT receiver had a system temperature of 35 K. The HPBW was $22'$ at 18 cm wavelength. The receiver backend consisted of the 2^{14}–channel digital autocorrelator divided into four banks of 4096 channels. Simultaneous observations of both opposite circular polarizations at 1612 MHz and left and right circular polarizations at 1665 and 1667 MHz, respectively, were performed. The bandwidth of 1 MHz resulted in a velocity range of $180\,\mathrm{km\,s^{-1}}$ and the velocity resolution of $0.08\,\mathrm{km\,s^{-1}}$ after Hanning weighting. Spectra were taken in the position-switching total power mode. The source was observed for 2 hrs and the rms noise in the final spectra was 0.21 Jy. The flux density calibration provided by a few scans on W12 is accurate to about 20%. We detected a single emission features with peak flux density of 0.66, 0.75 and 0.73 Jy and the corresponding velocity of peak emission of 5.77, 5.71 and $5.54\,\mathrm{km\,s^{-1}}$ at 1667, 1665 and 1612 MHz, respectively.

3. Origin of the OH and SiO emission

As it has been mentioned in the Introduction the 1612 MHz OH emission in direction of IRAS 05373–0810 was first detected in April, 1985 with the Dwingeloo 25 m radio telescope (tLH). A double-peaked profile with the blue–shifted feature of 1.94 Jy at $V_\mathrm{LSR} = 4.4\,\mathrm{km\,s^{-1}}$ and the red–shifted one of 0.76 Jy at $V_\mathrm{LSR} = 18.0\,\mathrm{km\,s^{-1}}$ has been reported. The mean rms of the spectrum is about 0.2 Jy (tLH) and indicates that the red–shifted emission was detected on the level of about $4\,\sigma$ only. If this detection was real a probable explanation would be that the observed OH emission came from the circumstellar envelope. Then, the star $V_\mathrm{LSR} = 11.2\,\mathrm{km\,s^{-1}}$ and the expansion velocity of circumstellar shell about $6.8\,\mathrm{km\,s^{-1}}$ could be inferred.

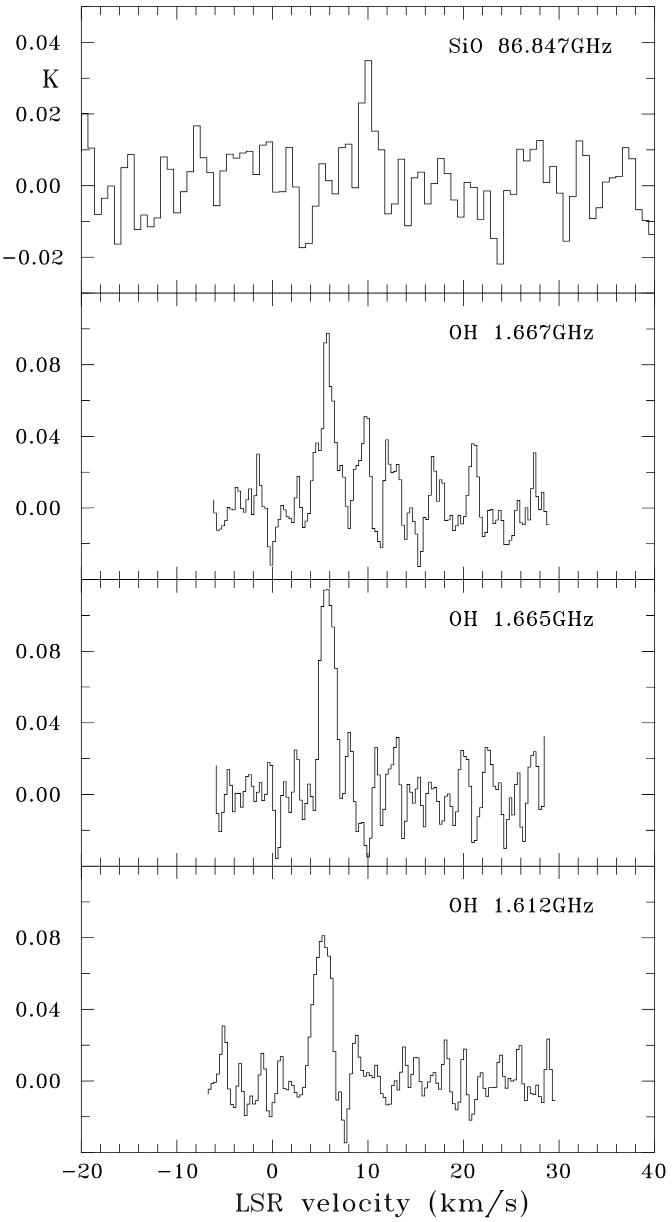

Fig. 2. Millimetre and radio spectra observed towards IRAS 05373–0810. The intensities of SiO and OH lines are given in the main beam brightness temperature and the antenna temperature, respectively.

However, this explanation most likely is not correct. The indirect argument comes from estimation of the OH pumping efficiencies for sources located within beam size (31′) of the Dwingeloo telescope. Besides IRAS 05373 there are 5 more IRAS PSC sources within the antenna beam. Arranged in the order of their distance from IRAS 05373 they are: IRAS 05379–0815, IRAS 05380–0809, IRAS 05382–0805, IRAS 05381–0817 and IRAS 05379–0758, with the closest one being more distant than 10′. Assuming that pumping efficiency can be estimated through the ratio of the OH peak flux density and infrared flux density at 35 μm (Evans & Beckwith 1977; Werner et al. 1980) we can see that none of these sources is able to explain the observed 1612 MHz OH emission in terms of the infrared pumping model which requires at least 4 infrared (35 μm) photons for each maser one. In fact, IRAS 05373 has the largest flux density at 35 μm (5.86 Jy see Chen et al. 2001) but still it is hardly enough to explain the observed blue–shifted component (1.94 Jy) of the OH maser emission towards this source.

The more direct arguments against circumstellar origin of the OH maser emission towards IRAS 05373 come from comparison between measurements obtained with different radio telescopes. In April, 1999 we have detected only one peak of 1612 MHz OH emission at 5.07 km s^{-1} (which could corresponds to the blue–shifted component detected by tLH at 4.4 km s^{-1}) with the Nançay telescope. Inspection of the IRAS PSC catalogue shows that within its beam there are no other IRAS PSC sources. For observations with the Nançay telescope at IRAS 05373 declination the conversion factor from antenna temperature to the flux in Jy is about 1.1 Jy K^{-1}, so the peak flux density at 1612 MHz was about 0.09 Jy. The ratio of beam size between the Dwingeloo and the Nançay radio telescopes is 15.3 and the nonuniformity or even variability of the extended OH maser emission could easily account for the difference in the peak flux density at 1612 MHz of about 22. In March, 2000 we have reobserved IRAS 05373 with the Toruń radio telescope. The beam size ratio between the Toruń and and the Nançay telescopes is 7.7 while OH intensity ratios are 8, 5.8 and 6 for 1612, 1665 and 1667 MHz emission, respectively. Therefore, the differences in intensities of OH emission can be solely explained as a result of beamwidth sizes of different radio telescopes. In consequence, our observations strongly suggest the interstellar origin of the OH emission detected towards IRAS 05373 which is very likely associated with the Orion star–forming region.

In fact, the molecular complex in Orion has been mapped in both OH main lines (1665 and 1667 MHz) by Baud & Wouterloot (1980) with the 25 m Dwingeloo telescope. In direction of IRAS 05373 (l = 212.16° and b = −19.63°) the typical LSR radial velocities of the main lines range from about 4 to 6 km s^{-1} and agree very well with $V_{\rm LSR}$'s for the presently detected maser lines. Similar large scale survey of OH main lines emission from the same region with the same telescope has been performed by Jenniskens & Wouterloot (1990). As it could be inferred from their Fig. 8 values of $V_{\rm LSR}$ for the Orion South molecular cloud are typically around 5 km s^{-1}. Thus, interstellar origin of the OH emission towards IRAS 05373 seems to be well established. However, in disagreement with Table 1 of Jenniskens & Wouterloot (1990) which gives the mean $T_{\rm A}(1665)/T_{\rm A}(1667)$ between 0.71 and 0.87 for galactic longitude of IRAS 05373, our OH observations suggest that the 1665 MHz line is significantly stronger than the 1667 MHz one in direction of this source. It means that local thermodynamical equilibrium (LTE) does not hold for this position inside the Orion South (or more specifically inside the L 1641) cloud. Note finally that in molecular clouds associated with star formation activity, the 1612 MHz masers accompanying the dominant 1665 MHz line are quite rare. Recent survey of 200 sites of the 1665 MHz masers resulted in detection of only 11 counterparts at 1612 MHz (Caswell 1999). Further, the intensity ratio of the 1612 and 1665 MHz lines in molecular clouds is generally small (Cohen 1989) while towards IRAS 05373 intensities of these two lines are comparable.

The presence of peculiar OH maser emission and SiO ($v = 0$) $J = 2 \rightarrow 1$ thermal emission at 86.85 GHz also suggests that these molecular lines come from a source or sources associated with star–forming regions. The recent survey by Codella et al. (1999) has shown that SiO emission is quite frequently related (with detection rate of 52%) to the molecular outflows and others signs of star formation sites. Towards IRAS 05373 the peak velocity of SiO emission ($V_{\rm LSR} = 9.73\,{\rm km\,s^{-1}}$) is red–shifted relative to the OH features ($V_{\rm LSR}$ around $5\,{\rm km\,s^{-1}}$). However, CO (Morgan & Bally 1991) and OH observations (Baud & Wouterloot 1980, Jenniskens & Wouterloot 1990) agree with each other in showing radial velocities concentrated around $5\,{\rm km\,s^{-1}}$ in direction of IRAS 05373 without any component of $V_{\rm LSR}$ close to $10\,{\rm km\,s^{-1}}$. The only exception is Fig. 8 of Jenniskens & Wouterloot (1990), where cloud with a radial velocity of about $10\,{\rm km\,s^{-1}}$ (NGC 2149 which is part of the giant molecular cloud GMC 214–13) extends in longitude up to about the position of IRAS 05373. NGC 2149 is located at Galactic latitude of about $-15°$ and, probably, extends behind the Orion South cloud up to the position of IRAS 05373 ($b = -19.63°$). Probably, the observed SiO thermal emission towards IRAS 05373 comes from the source(s) related to this molecular complex.

4. Spectral energy distribution

IRAS 05373 with estimated distance above 1 kpc (see below) is located behind the Orion South (placed at distance of about 500 pc – Jenniskens & Wouterloot 1990; Morgan & Bally 1991) and, possibly, behind a part of the NGC 2149 molecular cloud (at distance around 800 pc – Jenniskens & Wouterloot 1990). Dust contained in these molecular complexes is responsible for the interstellar extinction towards IRAS 05373. On the basis of maps derived from H I and galaxy counts by Burstein & Heiles (1982) we have derived $E(B-V)$ of about 0.24. Assuming total–to–selective extinction (R) of 3.1 we can estimate the total extinction at V (A_V) to be 0.74. On the other hand, Claussen et al. (1987) have estimated total extinction at $2.2\,\mu$m (A_K) for IRAS 05373 to be 0.05 from which $A_V = 0.47$ could be derived assuming that interstellar extinction follows the Mathis's (1990) law for $R = 3.1$. In addition, independent estimation of the interstellar extinction can be obtained from the ^{13}CO column density using the relation of Bachiller & Cernicharo (1986). Column density, $N(^{13}{\rm CO})$, in direction of IRAS 05373 is $4.1 \times 10^{14}\,{\rm cm^{-2}}$ (Morgan & Bally 1991; Harjunpää & Mattila 1996) so the inferred A_V is in range from about 0.5 up to 1.5 taking into account errors estimated by Bachiller & Cernicharo (1986). From the above analysis it seems that the absolute interstellar extinction in direction of IRAS 05373 is not severe and probably does not exceed 1 magnitude at V.

In Fig. 3 we have plotted available observational data for IRAS 05373. Spectroscopic data shown by the thin solid line represent our ISO observations adjusted in a way described in Sect. 2.1 except of normalisation to the IRAS PSC flux at 12 μm. Photometric data shown in this figure include: IRAS photometry (open squares); the Wyoming infrared photometry (Grasdalen et al. 1983) for 2.3–12.6 μm filter sets (see Gehrz et al. 1974 for the absolute calibration of this photometric system); near–infrared photometry at I, J, H, K, L and M bands from Claussen et al. (1987), Strom et al. (1989), Jones et al. (1990) and Epchtein et al. (1990); and photometry at B, V and R bands from Kholopov et al. (1987), Shevchenko & Yakubov (1992). In addition, the star USNO-A2.0 0750-01509344 ($B = 19.5$, $R = 11.4$) and IRAS 05373 are separated by less than $1''$ and very likely represent the same source. The observed magnitudes at V, J, H, K, L and M bands have been converted to the absolute fluxes using the calibration of Wamsteker (1981) and those at B, R and I bands using values for the Johnson system from Allen (1976). Since IRAS 05373 is a variable source (see Sect. 2.1) only minimum and maximum (if available) photometric fluxes at given band are marked by open circles. Filled circles show maximum fluxes known for given photometric band corrected for interstellar extinction according to the Mathis (1990) law with $A_V = 1$.

In order to estimate physical parameters of IRAS 05373, we have fitted its spectral energy distribution (SED) by radiative transfer modelling. The basic idea of such a model is the solution of the radiation transfer equation through the dusty circumstellar envelope. The central star is assumed to radiate as a blackbody and to lose mass at constant rate with the resulting envelope which expands at constant velocity. Under these assumptions, the frequency–dependent radiative transfer equations are solved under the spherically–symmetric geometry simultaneously with the thermal balance equation for dust (see Szczerba et al. 1997 for more details concerning radiative transfer modelling).

The important parameters that determine the final SED include the properties of the star, the properties of the gas/dust envelope and the (dust) mass loss rate. For simplicity, we have assumed that the only dust component present inside the envelope is amorphous carbon (AC1 from Rouleau & Martin 1991) with dust condensation temperature ($T_{\rm inn}$) of 1500 K and the dust size distribution given by the standard Mathis et al. (1977) model (minimum dust grain size of $0.005\,\mu$m, maximum dust grain size of $0.25\,\mu$m and a power–law index for dust size distribution equal to 3.5). As it can be seen from Fig. 1, the SWS 01 spectra of R Scl and IRAS 05373 are remarkably similar, so the assumption that these stars have similar temperatures seems to be justified. Le Bertre (1997) argued that a blackbody at temperature of 2600 K gives a reasonable approximation to the temperature of R Scl and we have adopted this value as a star temperature, T_*,

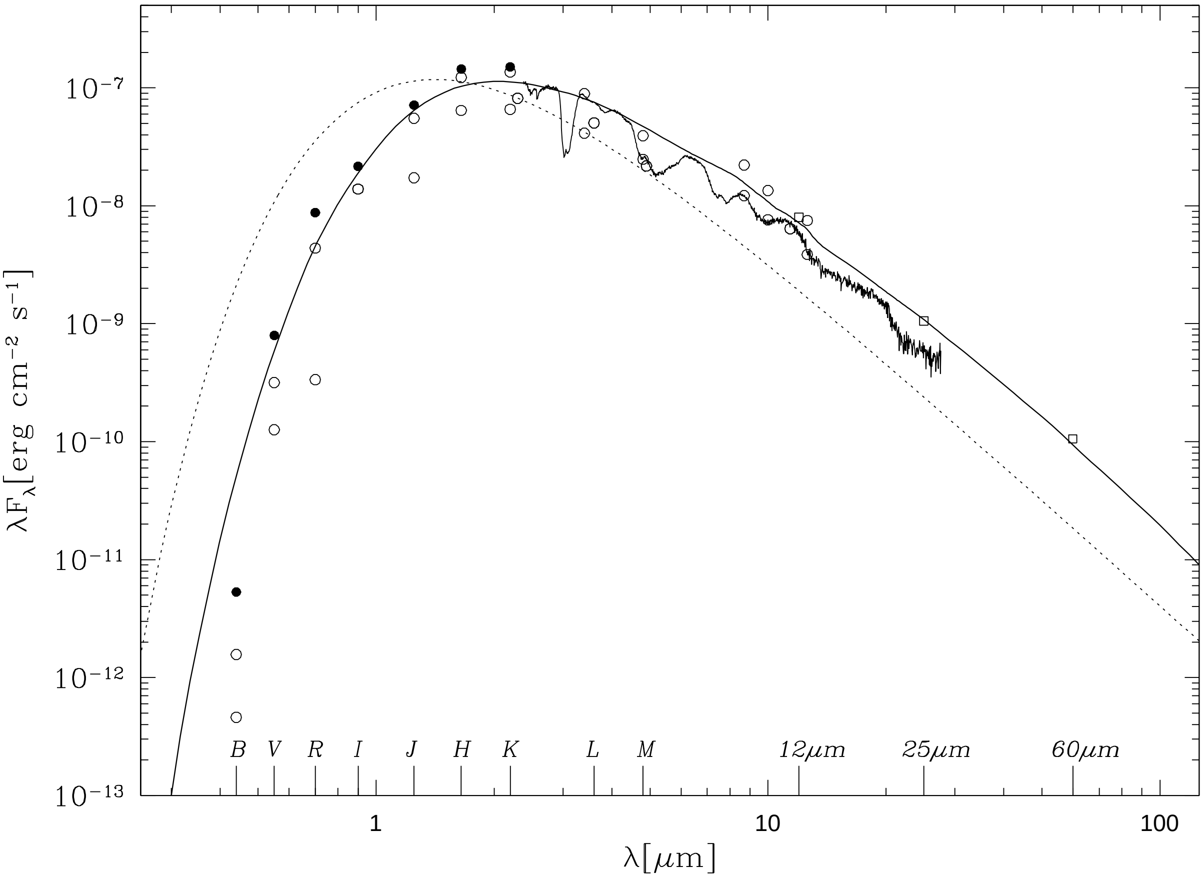

Fig. 3. Spectral energy distribution of IRAS 05373–0810. ISO SWS 01 spectrum (thin solid line), minimum and maximum fluxes at different photometric bands (open circles) except for the IRAS photometry (open squares). Filled circles show maximum fluxes corrected for interstellar extinction assuming the total extinction at $V = 1.0$. For more details concerning observational data shown in the figure see text. The heavy solid line shows the fit to SED from the radiative transfer modelling (see text and Table 2). The thin dotted line represents the input energy distribution of the central star taken to radiate as a blackbody.

Table 2. Parameters for dust model of IRAS 05373–0810.

parameter	value
T_*	2600 K
L_*/D^2	5100 $L_\odot$/kpc^2
$T_{\rm inn}$	1500 K
$R_{\rm inn}/D$	$4''.08 \times 10^{-3}$
$R_{\rm out}/D$	$5''.284$
$\dot{M}_{\rm d}/V_{\rm exp}/D$	$9.88 \times 10^{-11}\ M_\odot\ {\rm yr}^{-1}/({\rm km\,s}^{-1}\ {\rm kpc}^{-1})$
$\tau_{\rm V}$	4.2

for SED modelling of IRAS 05373. Model parameters from fit presented by thick solid line in Fig. 3 are collected in Table 2, where L_* is stellar luminosity, D – distance, $R_{\rm inn}$ and $R_{\rm out}$ – inner and outer radius of gas/dust shell, $\dot{M}_{\rm d}$ – dust mass loss rate, $V_{\rm exp}$ is shell expansion velocity and τ_V its optical depth at V. As it can be seen from Fig. 3 the fit, in spite of its simplicity, reproduce spectral energy distribution of IRAS 05373 fairly well. Discrepancy seen at the shorter wavelenghts (especially B band) will disapear if more realistic input energy distribution from the model atmosphere computations is taken into account.

Claussen et al. (1987) estimated distance to IRAS 05373 (assuming constant luminosity at K band for their sample of carbon stars, $M(K) = -8.1$) to be of 1.43 kpc. On the other hand, Epchtein et al. (1990) obtained 1.1 kpc assuming that all carbon stars have the same absolute bolometric magnitude of -4.9. Let us suppose that distance to IRAS 05373 is 1.2 kpc. Then, from the model parameters presented in Table 2, we have stellar luminosity of about 8000 $L_\odot$ and, assuming in addition that $V_{\rm exp} = 10$ km s^{-1} and dust–to–gas mass ratio is 5.0×10^{-3}, we can estimate gas mass loss rate to be about 2.4×10^{-7} $M_\odot$. This value agree very well with mass loss rate estimated by Claussen et al. (1987) and is in agreement with the low mass loss rate inferred from position of IRAS 05373 on the IRAS colour–colour diagram.

5. Concluding remarks

Sources with mixed chemistry, like silicate carbon stars or [WR] planetary nebulae, are intriguing classes of objects. In spite of the ongoing discussion (e.g. Yamamura et al. 2000; Waters et al. 1998; Cohen et al. 1999) the phenomena responsible for simultaneous appearance of both, oxygen– and carbon–based, features is still poorly understood. Therefore, after selecting a group of carbon stars without signatures of silicate emission but with possibly associated with them OH maser emission at 1612 MHz (Chen et al. 1999b; Chen et al. 2001) we have decided to investigate this group of source in more detail. This paper is first in the series and deals with IRAS 05373–0810 for which we have analysed all available and gathered by us observational data with the aim to understand nature of this source.

We have started with analysis of the ISO SWS 01 observations which were taken by us to check chemical composition of IRAS 05373 and possible presence of crystalline silicate features. Our spectrum showed that IRAS 05373 is a genuine carbon star, and in spite of rather low quality data at longer wavelengths, with no signatures of crystalline silicate bands. In addition, we have found a remarkable similarity between SWS 01 spectra of IRAS 05373 and R Scl. This suggests that chemical compositions of these two stars and physical conditions in their photospheres are fairly similar. Since C/O ratio for R Scl is 1.34 (Lambert et al. 1986) it is unlikely that IRAS 05373 belongs to the group of transition stars between O– and C–rich ones.

Then, we have performed IRAS 05373 observations with the IRAM 30 m radio telescope. Surprisingly, we have detected only thermal SiO $J = 2 \rightarrow 1$ emission at 86.85 GHz towards this source with $V_{\rm LSR}$ of $9.73\,{\rm km\,s^{-1}}$. No detection of any emission from the C–bearing molecules with IRAM does not preclude the presence of C–rich circumstellar material in IRAS 05373–0810 but may be related to its large distance. Analysis of the available observations (especially the LSR velocities) has allowed us to suggest that the observed SiO emission may come from the NGC 2149 molecular complex.

Finally, we have performed OH maser observations with the Nançay radio telescope to check possible variations (and reality) of the two peak 1612 MHz OH feature reported by tLH. Our observations did not confirm presence of two peaks but showed that three OH maser lines (1612, 1665 and 1667 MHz) are present with a single peak which varies in $V_{\rm LSR}$ from 5.07 (1612) up to $5.66\,{\rm km\,s^{-1}}$ (1667 MHz). While, $V_{\rm LSR}$ for 1612 MHz maser line is close to the blue–shifted component reported by tLH ($4.4\,{\rm km\,s^{-1}}$) there is a significant drop in the line flux from 1.94 (Dwingeloo) to 0.09 Jy (Nançay). However, the ratio between beam sizes of these two telescopes is about 15 and an extended OH maser emission could account for the observed drop (a factor of about 22) in 1612 MHz flux. To check this possibility we have reobserved IRAS 05373 with the Toruń radio telescope which have 7.7 times larger beam size than the Nançay telescope. We have found, that the mean intensity of three OH lines measured by the Toruń telesope increased by factor of 6.6 in comparison with the Nançay measurements. Therefore, we concluded that OH maser emission towards IRAS 05373 is not related to this source and is of interstellar origin. From analysis of the available observational data concerning LSR velocities we are convinced that the observed OH emission comes from the molecular cloud L 1641 in the Orion molecular complex.

In conclusion, we can state that IRAS 05373–0810 is a genuine carbon star which is fairly similar to the R Scl (C/O around 1.34) and is located at distance of about 1 kpc behind (at least) two molecular clouds (L 1641 and NGC 2149). From the radiative transfer model for IRAS 05373 spectral energy distribution we found that this source has central star with luminosity around 8000 $L_{\odot}$ and mass lose rate of about 2.4×10^{-7} $M_{\odot}$ assuming that object is at distance of 1.2 kpc.

Acknowledgements. We are grateful to P. Sivagnanam for his help during the Nançay observation, to J. Hron for providing us with reduced by him ISO SWS 01 spectra of R Scl and to S. Deguchi for helpful discussions. This work has been partly supported by grant 2.P03D.024.18p01 of the Polish State Committee for Scientific Research and by the Chinese Academy of Sciences and the NNSF of China. R Sz acknowledges also support from the JSPS Invitation Fellowship Program for Research in Japan and from the Jumelage France–Pologne program.

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