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THE OPTICAL AND NEAR-INFRARED COUNTERPART OF IRAS 18476+2054[1]

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RESUMEN

Presentamos aquí, por primera vez, una identificación óptica y infrarroja cercana (NIR) para los orígenes, hasta ahora sin estudiar, IRAS PSC 18476+2054. Fue obtenida la representación directa en $BVRI_{\rm C}iJK_{\rm s}$ y espectroscopia óptica. El complemento óptico se identifica como una estrella variable de la clase Mira —M7 o más gigante o súper gigante— con un exceso en infrarrojo medio (MIR) comparado como Miras "normal" teniendo un período corto. El $V-I_{\rm C}$ es notablemente alto, aunque el $(B-V)$ no da ninguna indicación de una extinción circumestelar llevando a un enrojecimiento. El color $V-[12]$ demuestra un exceso en infrarrojo medio. Las fotonometrias obtenidas aquí y las placas de cielo investigadas nos permiten estimar un período de 145 días y una amplitud baja inusual de $\Delta_V = 2\overset{\rm m}{.}5 \pm 0\overset{\rm m}{.}2$ (para el tipo último de la espectroscopía).

ABSTRACT

We present here, for the first time, an optical and near-infrared (NIR) identification for the previously unstudied IRAS PSC source 18476+2054. Direct imaging in $BVRI_{\rm C}iJK_{\rm s}$ and optical spectroscopy were obtained. The optical counterpart is identified as a variable star of Mira class—M7 or later giant or supergiant—with a mid infrared excess compared to "normal" Miras having such a short period. The $(V–I_{\rm C})$ is remarkably high, although the $(B–V)$ gives no indication for circumstellar extinction driving a reddening. The $V-[12]$ color shows a mid-infrared excess. The photometries obtained here and the sky survey plates allow us to estimate a period of 145 days and an unusually low amplitude for such a late spectroscopic type of $\Delta_V = 2\overset{\rm m}{.}5 \pm 0\overset{\rm m}{.}2$.

Key Words: **INFRARED: STARS — STARS: AGB AND POST-AGB — STARS: INDIVIDUAL (IRAS 18476+2054)**

1. INTRODUCTION

Mira variables are mostly discovered via their high amplitude variations at visual wavelengths. Although they are at the red end of the stellar population, IRAS color diagrams do not separate them from "normal" red giant and supergiant stars. Thus they are normally not discovered via their infrared colors. The IRAS PSC source 18476+2054, having usual stellar IRAS colors, has attracted no attention. Thus it was not included in systematic searches for certain classes of special objects. During test observations in June 2001 with the DENIS survey instrument (Epchtein et al. 1997), the source was picked out as an extremely bright object in the $K_{\rm s}$ band. This raised the suspicion of a possible connection to symbiotic Mira systems (Schmeja & Kimeswenger 2001). In those systems a white dwarf is exciting the wind of

[1]Based on observations collected at the European Southern Observatory, La Silla and the Ibk60cm telescope, Innsbruck, Austria.

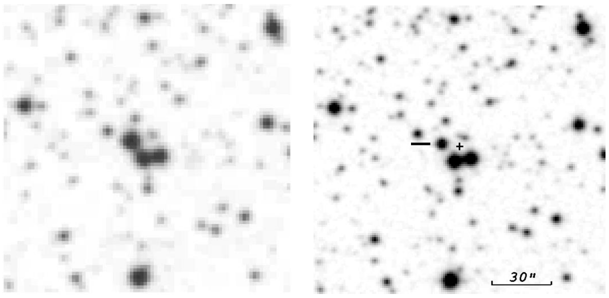

Fig. 1. The red POSS I plate (left) and the red POSS II plate (right). The cross indicates the IRAS PSC position. The target is marked with the bar. The change of brightness is evident.

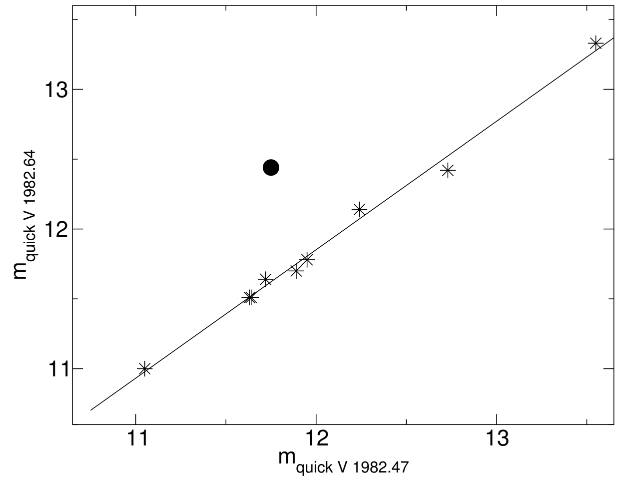

Fig. 2. The photometric change of the target on the sky survey plates (here: quickV blue). The stars around the target give a linear relation. This allows to determine the change of the target (filled circle).

the Mira star and heats the dust to unusual high temperatures (Whitelock 1985; Corradi & Schwarz 1993, 2000). In the 2MASS data base (Cutri et al. 2000) it is given just at the overexposure limit. Follow-up observations at the European Southern Observatory (ESO) in La Silla with the Danish 1.52 m telescope (BVi and spectroscopy) and calibrations on the scanned photographic sky survey plates of the region were performed. $BVRI_{\rm C}$ photometry was obtained from June to October 2001 with the 60 cm telescope owned by the Institute of Astrophysics of the University in Innsbruck (Ibk60cm). They cover 75 percent of a full pulsation. This information about the photometric variability, spanning about 50 years, allowed us to give an estimate of the period and the full amplitude of the variable star. The spectrum is that of a very late-type star, while the near- and mid-infrared characteristics suggest an even "redder" object than a typical Mira. Astrometry on the sky survey plates calibrated with Tycho-2 stars give us the accurate optical coordinates for IRAS 18476+2054 in the ICRS 2000 system:

$$\alpha_{\rm ICRS} = 18^{\rm h}49^{\rm m}50\overset{\rm s}{.}88 \pm 0\overset{\rm s}{.}03,$$
$$\delta_{\rm ICRS} = 20^\circ 58' 07\overset{\prime\prime}{.}6 \pm 0\overset{\prime\prime}{.}2.$$

This is $8\overset{\prime\prime}{.}7$ east and $3\overset{\prime\prime}{.}6$ north of the IRAS PSC coordinates and well within the error ellipse.

2. DATA AND REDUCTION

2.1. *Photometry*

The DENIS observations were performed with the ESO 1 m telescope at La Silla, Chile, which was fully dedicated to the DENIS project. Multiple Gunn-i, J and $K_{\rm s}$ images were retrieved in survey configuration and using $5\overset{\rm m}{.}2$ attenuating filters. The exposure times are fixed in this setup to 9 exposures with 1.1 seconds each and a subsample offset to enhance the spatial resolution, which are combined into one frame by the readout electronics (for details see Epchtein et al. 1997). Five frames with an offset of about $100''$ each to correct for local inhomogeneities and defects on the NICMOS arrays were taken. The definition of the photometric system is given in Fouqué et al. (2000). The observations were obtained in two different photometric nights, and the data were calibrated using the whole set of standards of the survey observations during those runs (Kimeswenger et al. 2003).

Additionally 10 seconds exposures with B, V, and Gunn-i filters were taken at the Danish 1.52 m telescope at ESO/La Silla. For source extraction SExtractor V2 (Bertin & Arnouts 1996) was used. After standard bias subtraction and flat fielding the B and V images were adjusted using the Tycho-2 stars 351091 and 351256 within the same field. The Gunn-i band was calibrated using non-attenuated DENIS frames of the same field. From 2001 June 20 to 2002 June 18 CCD images with the Ibk60cm telescope, using Johnson B, V, R, and $I_{\rm C}$ filters, were taken. The exposure times were 500, 200, 200, and 150 seconds respectively. The frames were calibrated (FLAT, BIAS) in the usual way. As about two-thirds of the nights were not photometric, values were obtained differentially with the other field stars (Kimeswenger 2001; Bacher et al. 2001). Those field stars were calibrated absolutely during two photometric nights using Landolt (1992) standards.

The observational log, the epochs, and parameters of the sky survey plates used, are given in Table 1.

TABLE 1

OBSERVATIONAL LOG AND PARAMETERS OF THE SKY SURVEY PLATES.

Date (UT)	Telescope/Instrument	Band
09.06.2001, 06:50	ESO 1 m/DENIS	iJK_s
15.06.2001, 06:40	ESO D1.52 m/DFOSC	spec.
15.06.2001, 07:00	ESO D1.52 m/DFOSC	BVi
16.06.2001, 05:30	ESO 1 m/DENIS	iJK_s
20.06.2001, 22:40	Ibk60 cm	$BVRI_C$
24.06.2001, 21:35	Ibk60 cm	$BVRI_C$
03.07.2001, 22:10	Ibk60 cm	$BVRI_C$
30.07.2001, 23:00	Ibk60 cm	$BVRI_C$
13.08.2001, 21:00	Ibk60 cm	$BVRI_C$
24.08.2001, 21:00	Ibk60 cm	$BVRI_C$
02.10.2001, 20:30	Ibk60 cm	VR
06.10.2001, 20:30	Ibk60 cm	V
11.10.2001, 20:30	Ibk60 cm	$BVRI_C$
18.06.2002, 21:10	Ibk60 cm	$BVRI_C$
1951.527	POSS I red	
1951.530	POSS I red	
1982.477	quickV	
1982.636	quickV	
1993.489	POSS II red	

The sky survey plates, retrieved as FITS files from the STScI web pages, were calibrated relatively to the two TYCHO-2 stars used also for the DFOSC frames. Figure 1 shows the field on the red POSS I and II plates. Only the ratio of a star on two plates of same filter set was used to study the variability of the object. This ratio is in fact independent from the absolute calibration itself. This ratio is the inclination of the linear fit in Figure 2. The typical rms of those calibrations was about $0\overset{m}{.}06$. The results of the photometry are given in Tables 2 and 3 together with the IRAS flux calibrated according to Cohen et al. (1987). The errors of our photometries at the DENIS instrument, the DFOSC and the Ibk60 cm are about $0\overset{m}{.}05$ in all bands. For the error estimates of the other data two times the RMS were used.

2.2. *Spectroscopy*

The optical follow-up spectroscopy was obtained at the DFOSC instrument attached to the Danish 1.52 m telescope at ESO/La Silla. Spectroscopy with GRISM#4, giving a usable range of 410 to 900 nm, was obtained. The spectra were calibrated relative to the standard star LT7987 (Hamuy et al. 1994). While the S/N (pixel to pixel) was only about 8 at the blue end, from 550 nm on it reached 20 to 50.

TABLE 2

RESULTS OF THE PHOTOMETRY

JD −2452000	B	V	R	i/I_C	J	K_s
069.78				9.01	5.71	4.51
075.78	15.91	14.27		8.97		
076.73				8.98	5.73	4.50
081.44	15.24	13.78	11.59	9.01		
085.40	14.94	13.77	11.51	8.86		
094.38	14.55	13.56	11.38	8.73		
121.46	13.38	12.34	10.59	8.28		
135.38	12.70	11.42	9.86	7.72		
146.38	12.57	11.33	9.78	7.54		
185.35		12.38	10.54			
189.35		12.44				
194.35	13.78	12.65	10.76	8.35		
443.42	15.18	13.84	11.70	9.08		

The spectrum was folded with standard filter curves to test the overall calibration. The synthetic photometry achieved by means of the spectrum corresponds within five percent to the photometry of the night.

3. THE PHOTOMETRIC VARIATION

The photometry with the Danish 1.52 m and the Innsbruck 60 cm allows us to estimate the light curve. For a first period estimate, only the V band data was used independently. The resulting period and phase was used to determine the amplitudes in $BVRI_C$ on those images and then iteratively improve the period. The color change in this period is in good agreement with the typical change in amplitudes at different colors for Mira-like variables (see Hron & Kerschbaum 1994, and references therein). Thus we are able to overlay the photometry of different bands and hence to estimate the complete light curve.

The two red POSS I plates, taken during two consecutive nights, show no variations. This gives us information about the accuracy of the plate calibration used. The red plates of POSS I and POSS II (41.95 years apart) show a variation of about $1\overset{m}{.}2$ (Fig. 2). The two quickV plates taken in 1982 (epoch difference 58 days) have a variation of $1\overset{m}{.}0$. The 2MASS and the DENIS K_s band give only a small shift within the accuracy. In particular, the 2MASS data were slightly overexposed and so this point may give an upper limit only and was not used to optimize the period and the NIR amplitude.

Although the determination of the amplitude is not independent of the estimated period, the pho-

TABLE 3

ARCHIVAL PHOTOMETRY FROM SKY SURVEY PLATES

JD	Band	Magnitude	Error[a]
2450608.5	2MASS J	6.039	0.12[b]
	2MASS $K_{\rm s}$	4.565	0.12[b]
2449167.1	POSS II red	11.5	0.15
2433840.5	POSS I red	10.3	0.15
2445144.7	quickV	11.75	0.12
2445202.8	quickV	12.49	0.12
	IRAS [12]	2.3	0.15
	IRAS [25]	1.6	0.15

[a]2 × RMS error.

[b]2 × RMS value given in the database. As the star is slightly overexposed, larger systematic errors have to be expected.

TABLE 4

FIT PARAMETERS OF THE LIGHT CURVE.

Period $P = 145^{\rm d} \pm 3^{\rm d}$		
Band	$\langle m \rangle$	$\langle \Delta m \rangle$
B	$14\overset{\rm m}{.}2$	$3\overset{\rm m}{.}3$
V	$12\overset{\rm m}{.}5$	$2\overset{\rm m}{.}5$
R	$10\overset{\rm m}{.}7$	$1\overset{\rm m}{.}8$
$i/I_{\rm C}$	$8\overset{\rm m}{.}2$	$1\overset{\rm m}{.}5$
J	$4\overset{\rm m}{.}5$	$1\overset{\rm m}{.}0$
$K_{\rm s}$	$4\overset{\rm m}{.}0$	$0\overset{\rm m}{.}7$

tometry on the sky survey plates allowed us to determine the period rather accurately. The result of such a multicolor fit to all data points, normalized to unity amplitude, is shown in Figure 3. The best fit parameters are given in Table 4. Although those parameters need further verification, they allow us to compare the object to other Mira-like variables.

4. SPECTRAL CLASSIFICATION

The spectrum shown in Figure 4—resolution of 3 Å/pixel—generally has a good S/N even at the blue end. We compared the spectrum of the M5 III star HD 123667 in Serote-Roos, Boisson, & Joly (1996), the latest spectral type for giants in that work, with that of our target. We saw that the star there has much less prominent TiO λ6651 and λ8232 bands. In particular, it shows no VO band at λ7334. Thus IRAS 18476+2054 is of a significantly later type than

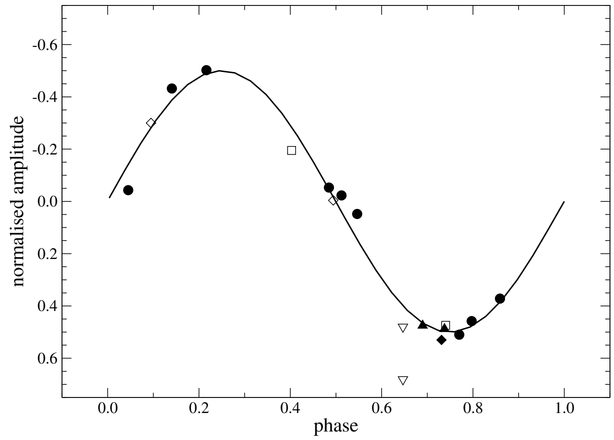

Fig. 3. The pulsation of the star, using the normalized amplitudes (see text) and a period of 145 days. The filled symbols are our observations 2001 June to 2002 June (circles: Ibk60 cm; triangles up: ESO 1 m; filled diamond: Danish 1.52 m). The open symbols give the values from the sky survey plates (POSS red: open squares; quickV: open diamonds) and from the 2MASS survey: open triangles down) shifted by multiples of 145 days each. The 2MASS J images are slightly overexposed. Thus the J-band deviation is not unexpected.

this M5 III star. We selected the criteria of Kirkpatrick, Henry, & McCarthy Jr. (1991). For each spectral feature (left column), we show the original text in italics (middle column) and a description of its strength in our spectrum (right column):

TiO λ6569	*mid to late M stars*	strong
TiO λ6651	*mid to late M stars*	very strong
VO λ7334	*seen only in late M stars*	strong
VO λ7851	*obvious in late M dwarfs*	hardly
CN λ7878	*obvious in supergiants, weaker in giants, not seen in dwarfs*	strong
TiO λ8206	*found in all, strongest in mid M*	weak
TiO λ8432	*prominent in mid to late M*	very strong
VO λ8521	*found only in late M*	weak

Thus we are forced to conclude that this star is of spectral type M7–9 with luminosity class II–I. Finally, we used the indices according to Malyuto, Oestreicher, & Schmidt-Kaler (1997). The values

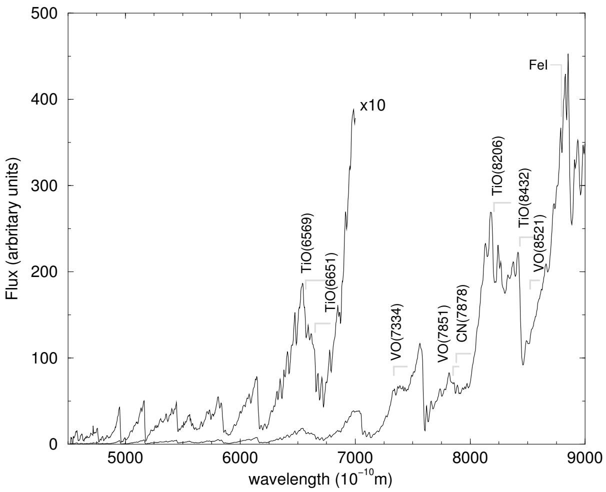

Fig. 4. The optical spectrum of IRAS 18476+2054. The features used for the classification are marked. The blue region was plotted enhanced for clarity.

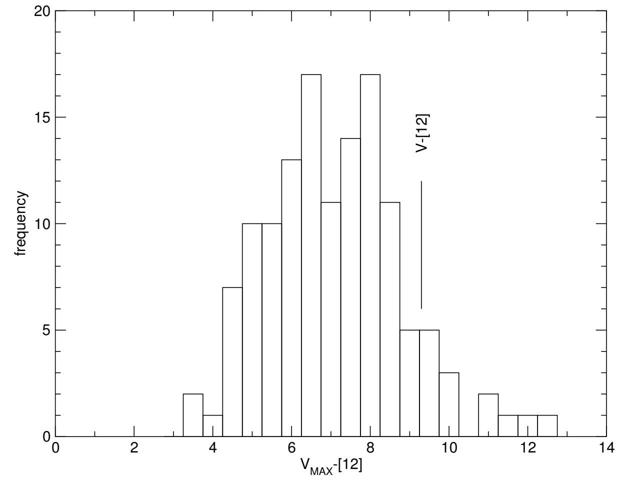

Fig. 5. Frequency distribution of the colors of a sample of Mira-like variables after Feast & Whitelock (2000). The vertical lines mark the positions of IRAS 18476+2054.

$I_{\rm ST} = 2.246$ and $I_{\rm LC} = 1.110$ give us a spectral classification of M8 I in their diagram. Applying the extension to this system by Schmidt-Kaler & Oestreicher (1998), we obtain with $L = 0.221$ a M7–8 II star and $M_{\rm bol} \approx -3.^{\rm m}3$. We thus favor a spectral type of M8. The luminosity class remains somewhat uncertain, but more likely to be II than I. This is supported also by the distance estimate. At the galactic latitude of nearly 10° a M8 I star would be extremely far from the plane.

5. DISCUSSION AND RESULTS

The photometry suggests this object to be a low amplitude Mira-like or SR variable, even though the sky survey plates, the 2MASS data and the current data cover a few epochs only. Using the luminosity calibrator of Schmidt-Kaler & Oestreicher (1998) and the results of the spectroscopy, we achieve M7–8 I–II. Using very conservative estimates of the bolometric corrections and the errors in the determination of the luminosity class we get a distance of 1800 to 3000 pc for this star.

The spectrum places the target among the late Mira-like stars. To classify the object on basis of the photometric properties, we selected from the sample well studied Mira-like stars of Feast & Whitelock (2000) objects having high quality IRAS 12 and 25 μm fluxes (131 out of 177 objects). The NIR colors were taken from Whitelock, Marang, & Feast (2000). $V_{\rm MAX}$ values for those stars were searched in the SIMBAD database. This might be a major source of uncertainty. The color equations between the SAAO system there and DENIS are in fact very small (Carpenter 2001). Thus we are able to compare the results directly. The frequency distribution is given in Figure 5. The $(J-K) = 1.23$ color places IRAS 18476+2054 in the range of the normal Miras, which are concentrated in a narrow band $0.^{\rm m}9 < (J-K) < 1.^{\rm m}8$ with a sharp peak at $1.^{\rm m}3$ in the sample mentioned above. Symbiotic systems have a significantly higher color index of $2.^{\rm m}2 < (J-K) < 5.^{\rm m}0$ (Schmeja & Kimeswenger 2001). The $(V-[12])$ color makes it an outstanding red target, closer to the positions of symbiotic systems or extremely O/Si rich stars with dusty envelopes. This is especially noteworthy, as the period and the amplitude is small compared to very red Miras. While the $(B-V)$ is that of a normal M star (Bessel 1990), the $(V-I)$ is remarkably high. As the first excludes a strong circumstellar shell, the latter is about a factor of three too high. This may also be an indication of an unusual envelope or a companion causing a symbiotic system, although careful inspection of the blue part of the spectrum gives no indication for a blue second star. Further follow-up and especially long term variability studies are of great importance.

Calculations of a circumstellar shell with the dust code NILFISC (Koller & Kimeswenger 2001), which is able to describe transiently heated dust and thus NIR and MIR excess, show that a shell with an excess of small grains is needed to obtain these photometric properties. This clearly needs further investigations at long wavelength (e.g., 10 micron Si-absorption and 20–60 micron excess features of dust grains).

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