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Letter to the Editor

IRAS 17516-2525: an evolved star or a young stellar object?*

W. E. C. J. van der Veen[1,+], T. R. Geballe[2], H. J. Habing[1], and H. J. van Langevelde[1]

[1] Sterrewacht Leiden, P.O. Box 9513, NL-2300 RA Leiden, The Netherlands
[2] Joint Astronomy Center, 665 Komohana Street, Hilo, HI 96720, USA

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Summary. We report new infrared and radio observations and further analysis of IRAS 17516-2525, whose far-infrared colours suggest that it is a proto-planetary nebula. These include velocity resolved spectroscopy of the Brα line, 6 cm continuum observations, and a search for OH(1612 MHz) emission. In addition we have found a possible optical counterpart for the object. These and previous observations indicate that IRAS 17516-2525 is either an unusual young stellar object or a post-AGB star with a relative high mass loss rate undergoing a rapid transition from the AGB to the planetary nebula phase.

Key words: Planetary nebulae - spectroscopy - stars: circumstellar matter - stars: evolution of

1. Introduction

IRAS 17516-2525 (hereafter IRAS 17516) was selected from the IRAS Point Source Catalogue (IRAS PSC, 1985) on basis of its large F_{25}/F_{12} and F_{60}/F_{25} flux density ratios, which places it in region IV of the two-colour diagram described by Van der Veen and Habing (1988). Sources in this region have large amounts of cold dust, probably due to a preceding phase of heavy mass loss. To study these sources in more detail, near infrared photometry and spectroscopy were carried out for a sample of about 40, mostly unidentified, IRAS sources (Van der Veen et al., 1989). Among them, IRAS 17516 is a unique object. Near infrared photometry in combination with the IRAS photometry shows a bimodal energy distribution with a warm ($\sim 1,000$ K) and a cold (~ 150 K) component (Fig. 1). Near infrared spectroscopy shows the presence of hydrogen recombination lines (Brα, Brγ and Pfγ), indicative of a hot ionized region, and a weak absorption at 3.1 μm ascribed to water ice. Among the 15 objects observed spectroscopically IRAS 17516 is the only source to show both the hydrogen lines and the ice feature. In this paper we present additional observations and discuss the combined data set.

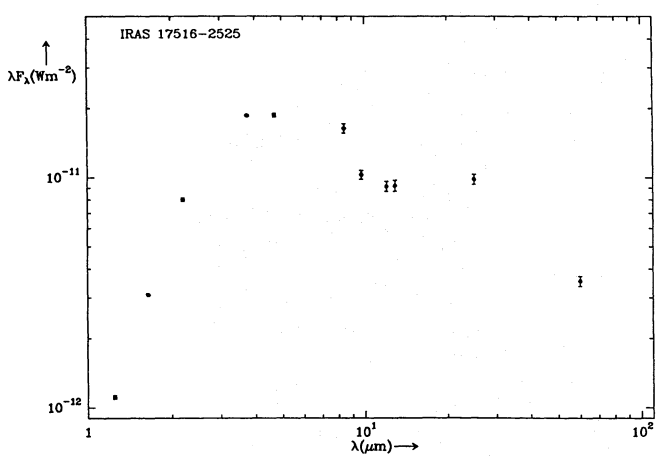

Fig. 1. Spectral distribution of IRAS 17516-2525

* Based on observations collected at the European Southern Observatory (La Silla, Chile), at the United Kingdom Infrared Telescope (Mauna Kea, Hawaii), and at the Very Large Array (Socorro, New Mexico).

+ *Send offprint requests to*: W.E.C.J. van der Veen, Royal Observatory, Blackford Hill, Edinburgh, EH9 3HJ, Scotland, UK

2. Observations and results

2.1. Infrared photometry and spectroscopy

Near infrared photometry of IRAS 17516 was obtained in June 1987 at the 1.0 m ESO telescope at La Silla (Chile); the results, uncorrected for interstellar reddening, are given in Table 1, and plotted along with the IRAS measurements in Fig. 1. The position of the infrared source was measured at 3.7 μm and 8.4 μm with respect to nearby SAO stars, using both this telescope and the ESO 3.6 m telescope, and found to be $\alpha, \delta(1950.0) = 17^h51^m37.4 \pm 0.1^s$, $-25°25'59 \pm 1''$, which is only 4'' from IRAS position. We conclude that the near- and far- infrared emission are both associated with one object.

The infrared photometry yields an integrated flux of $4.4 \pm 0.9\, 10^{-11}\, Wm^{-2}$ and an infrared luminosity of $1,400(D/kpc)^2\, L_\odot$, which should closely

Table 1. Near- and far infrared photometry of IRAS 17516

Band	λ (μm)	mag	F_ν (Jy)	λF_λ Wm^{-2}
J	1.25	8.88(2)		$1.11\ 10^{-12}$
H	1.65	7.00(1)		$3.09\ 10^{-12}$
K	2.20	5.15(2)		$8.00\ 10^{-12}$
L	3.75	2.59(1)		$1.86\ 10^{-11}$
M	4.60	1.81(1)		$1.86\ 10^{-11}$
N_1	8.40	0.18(5)		$1.64\ 10^{-11}$
N_2	9.70	0.11(5)		$1.03\ 10^{-11}$
N_3	12.85	-0.50(6)		$9.21\ 10^{-12}$
IRAS Band 1	12		51.7	$1.29\ 10^{-11}$
IRAS Band 2	25		115.6	$1.39\ 10^{-11}$
IRAS Band 3	60		99.8	$4.99\ 10^{-12}$

Table 2. Intensities of the infrared lines ($10^{-15}\ Wm^{-2}$)

Line	$\lambda(\mu m)$	I_0	I_c
Brγ	2.16	7.8 ± 1.0	20 ± 7
ice	3.10		
Pfγ	3.74	5.0 ± 1.0	7 ± 2
Brα	4.05	10.6 ± 1.0	14 ± 2

I_0: observed
I_c: corrected for interstellar extinction of $A_V = 11 \pm 4$ mag

approximate the bolometric luminosity. The broad band spectrum in Fig. 1 is very similar to that of the bipolar nebula Mz 3 (Van der Veen et al., 1989). Both show a bimodal energy distribution with a warm ($\sim 1,000$ K) and a cold (~ 150 K) component. Mz 3 is a suspected proto-planetary nebula and shows a clear bipolarity on the Schmidt Blue plates (eg. Lopez and Meaburn, 1983). IRAS 17516 has a very weak (~ 22 mag) counterpart on the ESO Blue plate (Section 2.4), but the source is too faint to see any evidence for extended emission.

Nearly simultaneously with the infrared photometry, we obtained infrared grating spectroscopy at UKIRT (Mauna Kea, Hawaii) in the wavelength ranges 2.05-2.50 μm, 2.8-4.1 μm at a resolution of 0.008 μm, using the facility instrument CGS 2. The spectra are shown in Fig. 2; the observed line fluxes are listed in column 3 of Table 2. The presence of the hydrogen recombination lines indicates that IRAS 17516 has an ionized inner region. A weak absorption at 3.1 μm, caused by water ice, and not by C_2H_2 as was previously reported by Van der Veen et al. (1989), is also present. This result indicates that IRAS 17516 has an oxygen-rich shell. Because the source is in a rather crowded region in the sky ($l = 4.0°, b = 0.1°$), no IRAS LRS spectrum (8-21 μm) exists, although its 12 μm flux density (~ 50 Jy) is sufficiently large.

2.2. The Brα line profile

The Brα line was measured again at UKIRT in July 1987, using the CGS 2 in series with a 35 km/s resolution (FWHM) scanning Farby-Perot interferometer. The total integration time at each wavelength was 16 s. From the spectrum (Fig. 3) which is the sum of only two independent spectra, we find that the line has a central (peak) velocity of 0 ± 10 km/s, a FWHM of 50 km/s and a FWZI (Full Width Zero Intensity) of 100 km/s. The line is thus broader than the spectral resolution. The broadening is also too large to be explained by thermal broadening: we must be seeing an expansion or infall of the inner region. The central velocity implies a stellar velocity close to zero. Note that depending on the velocity of the peak emission, which is uncertain due to a small number of samples, the line profile may be asymmetric, with enhanced emission on the blue wing. A possible explanation for such asymmetry is the presence of dust internal to the ionized wind, which suppresses the red wing. If this interpretation is valid, the possibility of infall instead of expansion can be excluded. Another possibility is the presence of a bipolar geometry, where the profile depends on the angle of the flow axis relative to the line of sight and the amount and location of obscuration by a dusty disk.

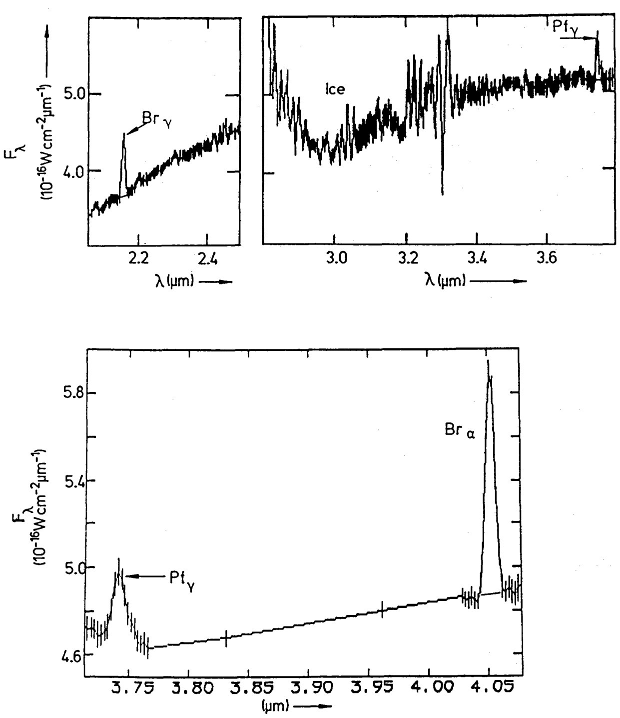

Fig. 2. Near infrared spectrum of IRAS 17516

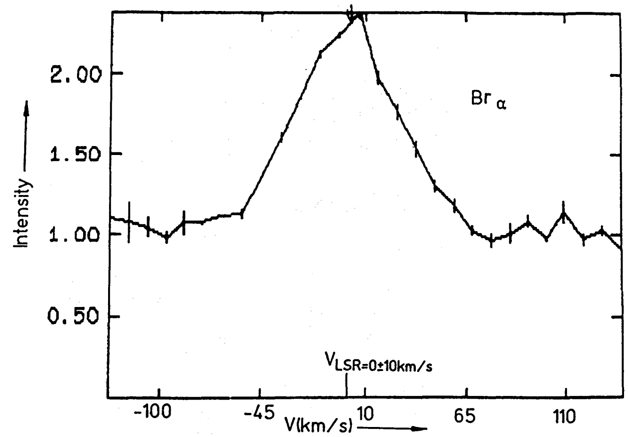

Fig. 3. Brα line profile of IRAS 17516

2.3. Radio observations: OH(1612 MHz) and 6 cm continuum

OH(1612 MHz) observations were made in September 1987 with the VLA, using the B configuration and an integration time of 28 minutes. In contrast to what was reported previously (Van der Veen et al., 1989) we found no OH(1612 MHz) maser brighter than 0.1 Jy, within 1′ of the infrared position, and within 35 km/s from the central velocity of the Brα line; the maser reported before is located at $\alpha, \delta(1950) = 17^h51^m39.4^s, -25°32'51''$ and coincides with OH 3.9+0.0 (Baud et al., 1979).

Radio continuum observations at 6 cm with a resolution of $\sim 1''$ were obtained at the VLA in September 1987, giving an upper limit of 5 mJy.

2.4. Optical counterpart

If an optical counterpart exists, it would have to be a highly reddened object. To search for it we used four plates from the Plate Library of the Royal Observatory Edinburgh: ESO B (~ 385 nm), ESO R (~ 630 nm), SRC I (~ 715 nm) and the United Kingdom Schmidt Telescope Unit (UKSTU) Z (~ 1000 nm). The positions of the stars were determined using 10 nearby reference stars.

We first searched the ESO R plate and found 3 stars within 10″ of the infrared position, indicated as Star 1 (at $\sim 5''$), Star 2 (at $\sim 6''$) and Star 3 (at $\sim 9''$) in Fig. 4. Then we searched the SRC I plate. Where most stars (including Stars 2 and 3) are fainter on the I plate than on the R plate, Star 1 is brighter on the I plate (see Fig. 4).

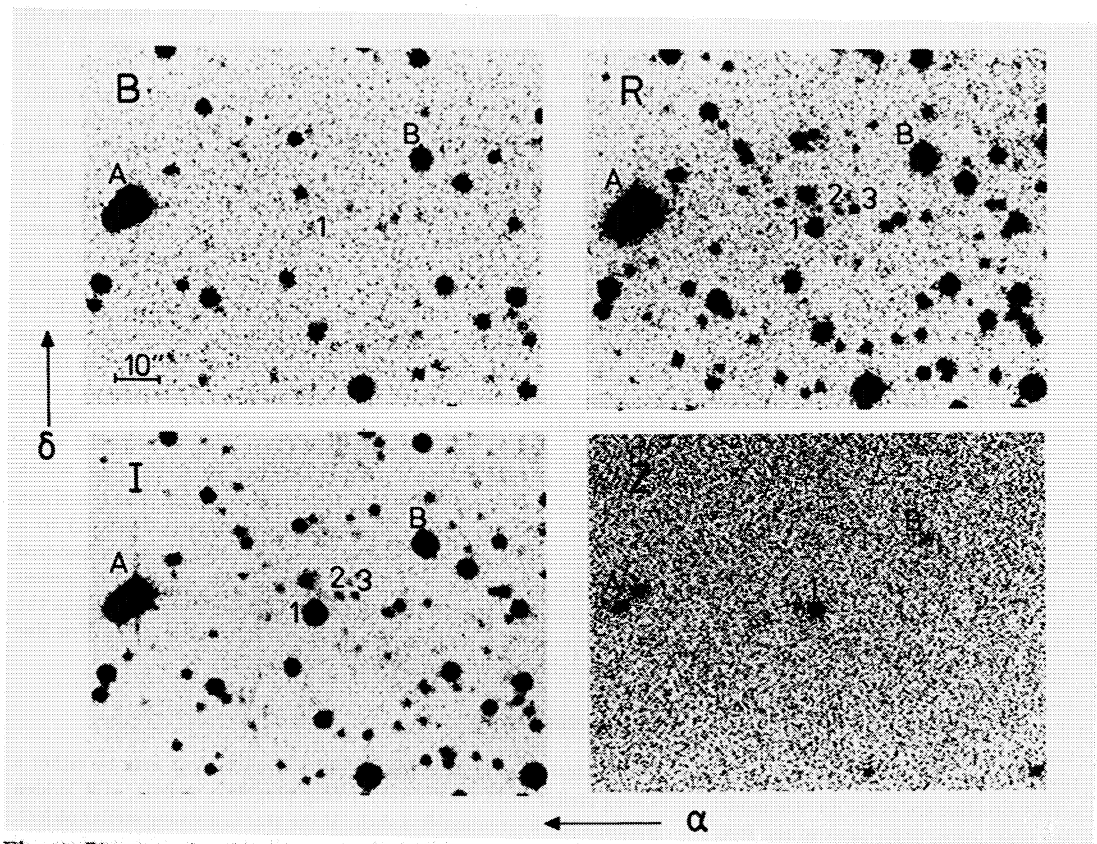

Fig. 4. Pictures taken from the ESO *B* plate, the ESO *R* plate, the SRC *I* plate and the UKSTU *Z* plate

In the ROE plate library we found one UKSTU *Z* plate (plate number Z 7947; exposure time 6 hours). IRAS 17516 is on the edge of this plate and it was not possible to measure accurate positions because of the lack of reference stars surrounding the source. We have used Star *A* and Star *B* (Fig. 4) as a reference and measured the position of the bright source in the centre; its position is identical to the position of Star 1 on the ESO *R* and SRC *I* plates. Stars 2 and 3 are not visible on this *Z* plate, which is the case for most stars that were seen on the *R* and *I* plate.

Finally we searched the ESO *B* plate. Star 1 is visible but very faint ($\sim$ 22 mag); Stars 2 and 3 are not visible. The results of the four plates are summarized in Table 3. Star 1 is clearly the reddest star in the whole field shown in Fig. 4 and it is also closest to the IRAS position ($\sim 2''$) and the infrared position ($\sim 5''$).

Table 3. Positions of possible optical counterparts ($\alpha - 17^h\ 51^m$, $\delta + 25°\ 25'$)

wavelength	IRAS 17516	Star 1	Star 2	Star 3
B(0.4 μm)		37.8 ± 0.1^s $58 \pm 1''$		
R(0.6 μm)		37.8 ± 0.1^s $59 \pm 1''$	37.3 ± 0.1^s $53 \pm 1''$	36.9 ± 0.1^s $54 \pm 1''$
I(0.7 μm)		37.9 ± 0.1^s $58 \pm 1''$	37.4 ± 0.1^s $54 \pm 1''$	37.0 ± 0.1^s $54 \pm 1''$
Z(1.0 μm)		37.8 ± 0.2^s $58 \pm 3''$		
L(3.7 μm)	37.3 ± 0.1^s $59 \pm 1''$			
N1(8.4 μm)	37.4 ± 0.1^s $59 \pm 1''$			
IRAS(12 μm)	37.7^s $59''$			

The difference between optical- and infrared position ($\sim 5''$) seems significant at first sight, although especially the error in the infrared position ($\sim 2''$) might be slightly optimistic. On the other hand, Star 1 is the only 1 μm source visible on the UKSTU *Z*-plate within $40''$ of the infrared position. We tried to estimate its magnitude at 1 μm by comparing it with measured 1.25 μm magnitudes of other stars on the same plate and found $m(1\mu m) = 9 \pm 2$ mag, in good agreement with the $J(1.25\,\mu m)$-magnitude of IRAS 17516: $J = 8.88 \pm 0.02$. Thus we conclude that Star 1 is the optical counterpart of IRAS 17516.

A global inspection of the different plates indicated that IRAS 17516 is not associated with a specific dust cloud. However, the source is close to the galactic centre ($l = 4°, b = 0°$) and many cloud complexes are visible within a few degrees of the source.

3. Discussion

3.1 Extinction

The extinction to the central star in principle can be derived from the ratio of the hydrogen line intensities. The "case B" optically thin relative intensities of these lines (for $T_e = 10^4$ K, $n_e = 10^4$ cm^{-3}) are Brγ/Brα=0.35 and Pfγ/Brα=0.13 (Hummer and Storey, 1987). For reddened optically thin lines we expect smaller line ratios, but from Table 2 we find larger ratios: Brγ/Brα=0.74±0.12 and Pfγ/Brα=0.47±0.10. This can only be explained if the lines are optically thick; thus "case B" does not apply, and we cannot calculate the reddening in this way. However, Alonso-Costa and Kwan (1989) have pointed out that the ratio Pfγ/Brγ is a useful reddening indicator, because it does not vary much with increasing optical depth, even for very optically thick line emission. They have derived a relation that allows the extinction to be determined; using their relation we obtain $A_V = 11 \pm 4$ mag.

3.2 Corrected line intensities, mass loss rates, size of the ionized region

The Brγ, Pfγ and Brα line intensities, corrected for an interstellar visual extinction of 11 ± 4 mag, are listed in column 4 of Table 2. We have used the monochromatic extinction law of Landini et al. (1984) given by $(A_\lambda/A_V) = (0.60/\lambda)^{1.85}$. The extinction corrected line ratios are Brγ/Brα=1.4±0.5 and Pfγ/Brα=0.5±0.2, which is a factor of 4 larger than expected for "case B" (see Section 3.1).

Simon et al. (1983) have shown that in the case of an outflow Brγ/Brα and Pfγ/Brα increase with increasing optical depth, and for a constant outflow velocity, reach asymptotically maximum values of 0.8 and 0.3 for τ(Brα)> 10^3. Larger ratios are found in case of an accelerated outflow. This may be the case for IRAS 17516.

From the extinction-corrected Brα line intensity one can estimate the mass loss rate of the central star. From Simon et al. (1983) we find that

$$\dot{M} \;=\; 2\,10^{-6}\,(\frac{v}{20km/s})^{0.5}\,(D/kpc)^2\,M_\odot/yr, \qquad (1)$$

assuming that the Brα line is optically thick.

The upper limit to the 6 cm continuum flux density of 5 mJy can be compared with the extinction corrected Brα line intensity. Fig. 5 or 7 in Alonso-Costa and Kwan (1989) shows that the observed upper limit to the 6 cm continuum flux is far too low to be explained by the standard (case B) relation between I(Brα) and I_ν(6 cm) when both emissions are optically thin. But even when both emissions are assumed to be optically thick, the ratio of radio continuum to Brα line intensity is much smaller than expected from the standard nebular recombination theory (eg. Simon et al., 1983).

Alonso-Costa and Kwan (1989) have shown that a core-halo model can account for the low 6 cm versus Brα line emission. In this model the line emission is formed in the small core, while most of the free-free radio emission is emitted in the diffuse halo. Comparing our observed values with model calculations of Alonso-Costa and Kwan (1989) shows that the halo must be at least twice as large as the core.

If the 6 cm flux density is optically thick, it can be used to find an upper limit to the size of the ionized region inside the dusty circumstellar shell. Assuming that the ionized region is a sphere of radius R_i that radiates as a black body of temperature $T_e = 10^4\,K$, we find an upper limit to this radius of $(R_i/m) = 10^{13}\,(D/kpc)$. This can be compared with the stellar radius $(R_*/m) = 10^9\,(T_*/30,000K)^{-2}\,(D/kpc)$.

3.3. IRAS 17516: young stellar object versus evolved star

The observations indicate that the IRAS 17516 contains a small ionized region ($R_i \sim 10^{13}$ m) with a high density, as is evidenced by the optically thick hydrogen lines. The low ratio of the 6 cm continuum to the Brα line intensity can be explained if the dense ionized "core" is surrounded by a diffuse "halo" with at least twice the size of the core. Such a physical characteristic is common among luminous young stellar objects (e.g., Alonso-Costa and Kwan, 1989). The expansion velocity as measured in Brα($\sim$ 35 km/s) is much smaller than commonly observed in young stellar objects. The relative weakness of the far-infrared emission is also surprising if it is a young stellar object. Braz and Epchtein (1987) have shown that most young stellar objects are located in a well defined area in the IRAS two-colour diagram: $3.3 < \frac{F_{25}}{F_{12}} < 17$ and $3.3 < \frac{F_{60}}{F_{25}} < 38$. Exceptions, however, do occur, eg. T Tau itself, but the differences are not as large as for IRAS 17516 where we find flux ratios $\frac{F_{25}}{F_{12}} = 2.3$ and $\frac{F_{60}}{F_{25}} = 0.9$; especially its 60 μm flux is far too low for a young stellar object.

Post AGB stars that are becoming planetary nebulae might have a similar appearance as IRAS 17516 for a short time, but such a phase has not previously been observed. Based on its ice band, IRAS 17516 is oxygen-rich, as are many other evolved objects such as the well known source IRAS 0927+1212 (Geballe et al., 1988). Some of these oxygen-rich post AGB stars show 1612 MHz emission as a relic from the preceding AGB mass loss phase (eg. OH 234.8+4.2, te Lintel Hekkert et al., 1988), indicating that they must have left the AGB very recently. The absence of an OH(1612 MHz) maser suggests that IRAS 17516 must have left the AGB much longer ago, and the OH maser has disappeared since then. This, however, would be in conflict with the IRAS colours which place the source close to the end of the evolutionary track for AGB stars (Van der Veen and Habing, 1988). If the 1612 MHz maser disappears, the main line (1665/1667 MHz) maser might still be present (Lewis, 1988). Observations with the Nancay telescope (France) did not show any 1665 or 1667 MHz maser within a few arcmin from infrared position. Perhaps the source, in spite of his oxygen-rich chemistry, has never produced an OH maser. The presence of the H I lines indicates that the central star must be at least 10,000-15,000 K. The combination of a hot central star and its location close to the end of the AGB evolutionary track in the IRAS two-colour diagram (Van der Veen and Habing, 1988) suggest a very short transition time of a few hundred years from AGB to planetary nebula stage. Such fast transition times can only be achieved when the mass loss rate after the AGB is of order of $10^{-6}\,M_\odot/yr$, which would speed up the evolution by a factor of 10 to 20. The transition from stellar temperatures typical for AGB stars ($\sim$3,000 K) to a temperature of 10,000-15,000 K would then take only a few hundred years (Schönberner, 1987). The high mass loss would also prevent the star from moving too far from the AGB evolutionary track in the IRAS two-colour diagram. The strength and width of the Brα line implies such a high mass loss rate (Section 3.2).

4. Conclusions

The evolutionary state of IRAS 17516 is unclear; it may be either a young stellar object, or a very young planetary nebula, still hidden within a thick circumstellar shell. If the star is a young stellar object, its expansion velocity would be unusually low and the weakness of the far-infrared emission would be surprising. If the star is a post AGB star it would be a unique object with an relatively large mass loss rate causing a fast transition from the AGB to the planetary nebula phase.

Although young star and evolved star might look very similar from the outside (circumstellar shell with cold dust), the central stars will certainly look very different. Deep images and spectroscopy of the optical counterpart might help to determine the evolutionary status of IRAS 17516.

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References

Alonso-Costa, J.L., and Kwan, J. 1989, Astrophys. J., Astrophys. J. **338**, 403
Baud, B., Habing, H.J., Matthews, H.E., Winnberg, A.: 1979, Astron. Astrophys. **35**, 179
Braz, M.A., Epchtein, N.: 1987, Astron. Astrophys. **176**, 245
Geballe, T.R., Kim, Y.H., Kracke, R.F., and Noll, K.S.: 1988, Astrophys. J. (Letters) **326**, L65
Hummer, D.G, Storey, P.J.: 1987, Mon. Not. R. astr. Soc. **224**, 801
IRAS, Point Source Catalogue: 1985, US Government Publication Office
Landini, M., Natta, A. Oliva, E., Salinari, P., Moorwood, A.F.M.: 1984, Astron. Astrophys. **134**, 284
Lewis, B.M.: 1988, Astrophys. J. **338**, 234
te Lintel Hekkert, P., Habing, H.J., Caswell, J.L., Norris, R.P., Haynes, R.F.: 1988, Astron. Astrophys. **202**, L19
Lopez, J.A., Meaburn, J.: 1983, Mon. Not. R. astr. Soc. **204**, 203
Simon, M., Felli, M., Cassar, L., Fischer, J., Massi, M.: 1983, Astrophys. J. **226**, 623
Schönberner, D.: 1987, in "Late Stages of Stellar Evolution", eds. S. Kwok and S.R. Pottasch, Dordrecht, Reidel Publ., p. 337
Van der Veen, W.E.C.J., Habing, H.J.: 1988, Astron. Astrophys. **194**, 125
Van der Veen, W.E.C.J., Habing, H.J., Geballe, T.R.: 1989, in "Planetary nebulae", ed. S. Torres Peimbert, Dordrecht, Reidel Publ., p. 446
Van der Veen, W.E.C.J., Habing, H.J., Geballe, T.R.: 1989, Astron. Astrophys., in press.