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No fundamental-mode pulsation in R Leonis?

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ABSTRACT

We present new and precise angular diameter measurements of the long-period variable R Leonis at 833 and 903 nm. Our inferred photospheric diameter (38 ± 2.5 mas) and stellar effective temperature (2459 ± 150 K) are both in good agreement with recent determinations made at the same variability phase in the near-infrared. Assuming a parallax of 8.3 mas, we derive a stellar radius of 495 $R_{\odot}$. This far exceeds the range of theoretical predictions for fundamental-mode pulsation (200 ± 50 $R_{\odot}$), and thus requires that R Leonis pulsates in the first- or a higher overtone mode. The expected availability of high-quality parallax measurements from the *Hipparcos* satellite and state-of-the-art ground-based instruments suggests that similar mode identification will be possible for a dozen or more nearby Mira-type variables.

Key words: stars: fundamental parameters – stars: individual: R Leonis – stars: late-type – stars: oscillations – stars: variables: other.

1 INTRODUCTION

Ground-based high-resolution interferometric imaging has the potential to revolutionize our understanding of cool stars, particularly Mira variables. Existing 4-m-class telescopes can now routinely provide optical and near-infrared images at resolutions measured in tens of mas, a level at which it begins to be possible to resolve the stellar disc. Application of the non-redundant masking (NRM) method (Haniff et al. 1987; Nakajima et al. 1989) has been particularly successful: results for the M supergiant α Orionis have uncovered rapidly varying surface inhomogeneities (Buscher et al. 1990; Wilson et al. 1991), while a similar application of the method to the long-period variable *o* Ceti (Haniff et al. 1992; Wilson et al. 1992) has revealed unambiguous distortions of the photosphere from spherical symmetry, confirming the results of speckle interferometric studies (Karovska, Nisenson & Papaliolios 1991).

As well as identifying stellar and circumstellar distortions, such interferometric observations also provide accurate stellar diameter estimates. This is of particular interest for Mira variables, where the variation of apparent diameter with wavelength permits investigation of the complex atmospheric structure of such stars (Labeyrie et al. 1977; Bonneau et al. 1982; Scholz & Takeda 1987; Bessell et al. 1989). Angular diameter measurements are also valuable for studying the pulsational properties of these sources and, if combined with an accurate distance estimate, can determine their mode of pulsation unambiguously – see e.g. Hughes (1993). Ever since the first mode identification for old disc Miras (Wood 1975), this has remained a contentious issue. Effective temperatures inferred from infrared photometry, together with luminosities derived from the empirically determined period–luminosity relationship, suggest that these variables pulsate in the first overtone (Robertson & Feast 1981; Glass & Feast 1982). This is also confirmed by studies of metal-rich Miras and semi-regular variables in globular clusters (Whitelock 1986; Perl & Tuchman 1990). However, dynamical models of Mira atmospheres, which predict shock-front speeds in good agreement with observed CO velocities, have in the past suggested fundamental-mode pulsation (Hill & Willson 1979; Willson 1983), although more recently Tuchman (1991) has developed an alternative dynamical model which favours overtone pulsation.

Previous attempts to resolve this question using stellar diameter measurements have been complicated for two main reasons. First, the complex atmospheric structure of Miras means that the transformation from an observed 'intensity' diameter (Baschek, Scholz & Wehrse 1991) to a stellar photospheric diameter is far from straightforward. Secondly, most distance estimates to nearby Miras are far too inaccurate to be of use in this context for converting angular measures to linear measures of stellar diameter. Until recently, the most accurate trigonometric parallax of a Mira variable was for *o* Ceti, $0''.013 \pm 0''.005$ (Jenkins 1952). If R_* is the stellar radius derived using this parallax, then radii lying within one standard deviation of this value (i.e. from $0.6R_*$ to $2.3R_*$) comfortably span a range encompassing a number of possible pulsation modes. The recently determined trigonometric parallax of R Leonis ($0''.0083 \pm 0''.0010$) (Gatewood 1992) obtained using the Allegheny Multichannel Astrometric Photometer thus represents a significant breakthrough.

In this paper we present high-precision narrow-band angular diameter measurements of R Leonis obtained using the NRM method. By combining these with a set of recent model photospheres (Scholz, personal communication), which have been developed in combination with the unpublished self-excited pulsation models of Wood (1990a), we have derived the photospheric angular diameter and effective temperature of the star. Furthermore, in combination with its new trigonometric parallax, we have ruled out fundamental-mode pulsation in this long-period variable.

2 OBSERVATIONS AND DATA REDUCTION

Interferometric NRM observations of R Leonis were obtained at the Ground-based High Resolution Imaging Laboratory (GHRIL) of the William Herschel Telescope (WHT) on the night of 1992 January 20 (JD 244 8641). The optical set-up was similar to that used in previous high-resolution NRM imaging experiments (Buscher et al. 1990; Wilson et al. 1992), and utilized a linear non-redundant pupil mask comprising four subapertures of effective diameter 32 cm. This gave six equi-spaced baselines up to a maximum of 3.8 m. One-dimensional speckle images were recorded using an exposure time of 17 ms. In order to study the two-dimensional structure of the target, data were collected with the mask aligned at six different position angles with respect to the star. Observations at each position angle were interleaved with those of an unresolved reference star, α Leonis (HR 3982), which served to calibrate the transfer function of the telescope/atmosphere combination. Approximately 2500 short-exposure images were secured at each position angle for the source and calibrator star respectively.

The observations were made through two filters, the first centred on 833 nm with a bandwidth (FWHM) of 41 nm and the second centred on 902 nm with a bandwidth (FWHM) of 50 nm. The angular resolutions of the imaging system corresponded to 45 and 49 mas at these two central wavelengths. The rapidly varying opacity of the stellar atmosphere with wavelength for cool stars like R Leonis means that both of these filters isolate continuum windows 'contaminated' with atomic and molecular absorption features. In view of the relatively narrow filter bandwidths, their long central wavelengths, and the small zenith distances experienced during the observations ($\simeq 20°$), no atmospheric dispersion correction system was employed. We expect the residual dispersion, after calibration with the point source data, to be smaller than 5 mas. At the epoch of the observations the visual variability phase of R Leonis was 0.26.

Analysis of the data followed closely the procedures described in Haniff et al. (1987) and Buscher et al. (1990). First the visibility amplitudes and bispectra sampled by the non-redundant pupil mask were accumulated and averaged over the ensembles of short-exposure images obtained at each position angle. To improve the signal-to-noise ratios of these averages, only the best 10 per cent of the data were used. The primary effect of this procedure was to discard those speckle images in which either telescopic or atmospheric fluctuations had reduced the contrast of the interferometric signal within individual short-exposure images. Subsequently, the averaged visibility amplitudes and bispectra were corrected for photon and readout noise biases, and the source data calibrated with similar data obtained on the unresolved reference star. As in previous experiments, the scale and orientation of the detector, as well as the reliability of our mapping procedures, were assessed by observing and mapping a number of close binary systems with well-known orbits. From these data we estimate the errors in the scale and orientation of our final images to be 1.5 per cent and $0\overset{\circ}{.}5$ respectively.

3 RESULTS

For the purposes of investigating the effective temperature and mode of pulsation of R Leonis, we need to estimate the mean photospheric stellar diameter from our interferometric data. Because the mapping from our primary observables (quasi-monochromatic Fourier spectra and bispectra) to estimates of angular diameter is rather lengthy, though straightforward in principle, we have outlined the various steps necessary in the following subsections. These are, in turn,

(i) examination of the raw data for evidence of possible asymmetries in the stellar brightness distribution,

(ii) model-fitting of a suitable parametric model to the Fourier data,

(iii) correction for asymmetries in the stellar brightness distribution,

(iv) correction for atmospheric extension and limb-darkening, and

(v) correction for variability phase effects.

It is interesting to note that previous attempts to infer stellar radii from similar interferometric observations have often ignored a number of these steps.

3.1 Visibility amplitude and closure phase measurement

Prior to any attempts to derive stellar diameter estimates, the calibrated Fourier data were inspected for any evidence for departures of the stellar brightness distribution from circular symmetry. This was assessed in three quite separate ways: by examination of the Fourier data themselves, by model-fitting to the Fourier data, and by inverting the Fourier data to produce diffraction-limited images. The most direct manifestation of such departures is the modulation of visibility amplitude at a fixed baseline with position angle or the presence of non-zero bispectral phases. Such non-zero bispectral phases are indicative of non-centro-symmetric brightness distributions, for example that produced by a feature located away from the centre of an otherwise uniform disc. For R Leonis, the measured bispectral phases were significantly non-zero at 833 nm, and had magnitudes of up to $\sim 20°$ at certain orientations of the pupil mask. However, at 902 nm the evidence for a similar asymmetry was only marginal, and most of the bispectral phases lay in the range $0° \pm 5°$. These values are consistent with the presence of an unresolved feature contributing ~ 10 per cent of the total flux at 833 nm, located some 10 mas from the centre of the stellar disc (as estimated by model-fitting), but contributing less than a few per cent of the total flux at 902 nm.

In order to assess the importance of these departures from circular symmetry, the visibility amplitude and bispectral data were inverted to provide diffraction-limited image reconstructions of R Leonis. A standard radio astronomy VLBI mapping package which employed a maximum entropy algorithm was utilized (Sivia 1987). These images are shown in Figs 1(a) and (b). As expected, the asymmetries are relatively small; at 833 nm the centres of the lowest contour levels are visibly displaced from the peak in the image, but at the longer wavelength any deviation from circular symmetry is difficult to infer from the figure.

With this information as to the two-dimensional brightness distribution of the source, estimates of the stellar diameter at 833 and 902 nm were obtained by fitting models to the visibility amplitude data alone. For the purposes of expediency, we chose to fit the simplest possible models comprising circularly symmetric uniform discs. Although the stellar brightness distribution is not expected to show such uniformity, our measured Fourier data do not extend into the regime beyond the first null of the visibility function where different limb-darkened profiles are most easily distinguished. Furthermore, it appears to be conventional for workers in the field to begin their analyses by fitting uniform-disc models to the data and then to apply appropriate limb-darkening corrections, and so by following a similar procedure we felt that it would be easier to compare our results with those already in the literature.

In order to accommodate the asymmetry known to exist at 833 nm, two approaches were followed. The first of these consisted of fitting a two-component model, comprising a uniform disc and an unresolved point source, to the visibility amplitude and bispectral data. During the fitting, the fluxes of the two components, the diameter of the uniform disc and the position of the unresolved source were allowed to vary freely. The second approach involved the fitting of a uniform-disc model to a subset of the visibility amplitude data obtained by averaging over those position angles for which the closure phases had the largest values. This minimizes the perturbations in the visibility amplitudes of the underlying circularly symmetric disc component; any residual effect will lead to an underestimate of the true disc diameter. The uniform-disc diameters derived by these two methods were 45.2 ± 2 and 44.6 ± 2 mas respectively. In Fig. 2(a) we have plotted the azimuthally averaged subset of the visibility amplitude data at 833 nm, together with the visibility function of the best-fitting uniform-disc model.

For the 902-nm data, the visibility amplitudes were azimuthally averaged prior to model-fitting in order to exploit the known symmetry of the source. Model-fitting to this averaged data set gave a best-fitting uniform-disc model of diameter 43.3 ± 2 mas – the observed data and model visibility function are shown in Fig. 2(b). At both wavelengths the figures suggest that there are systematic deviations of the best-fitting model from the data. At intermediate baselines the model visibilities are somewhat higher than the data, while at the longest baselines the observed visibility amplitudes are greater than those predicted by the model. Fits of Gaussian models were in closer agreement to the measurements, implying, as expected, that the radial brightness profiles are far from uniform.

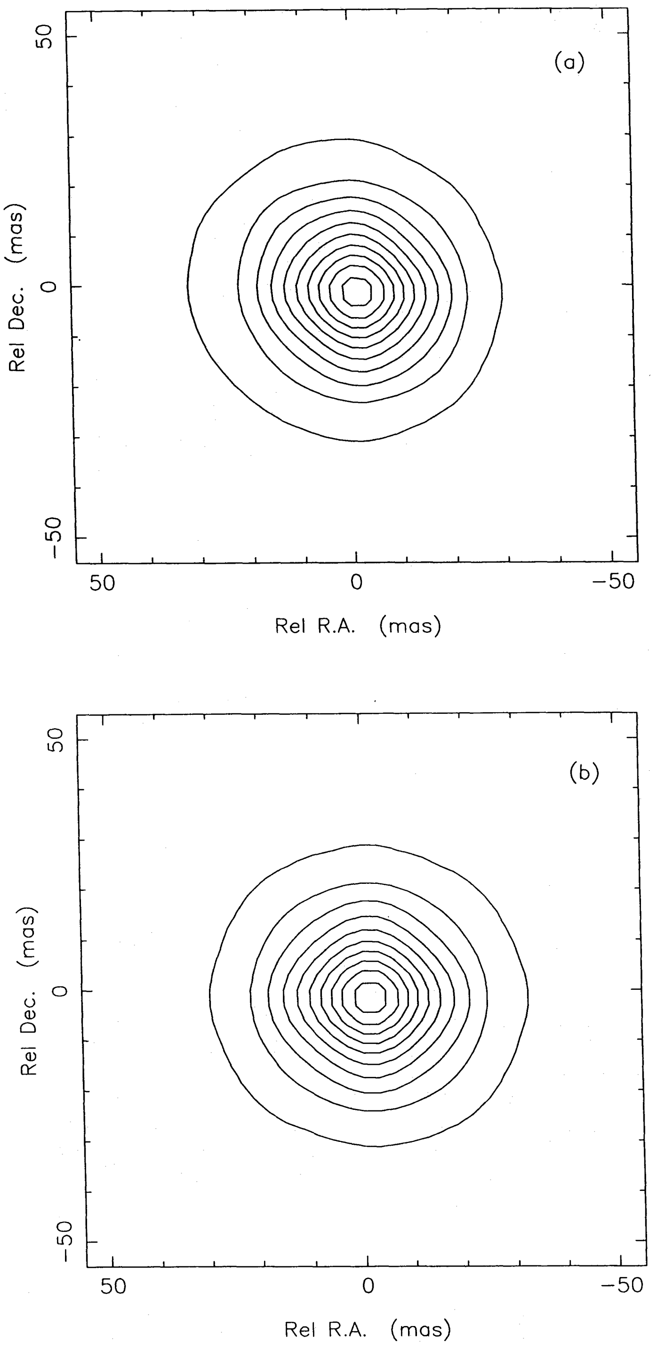

Figure 1. Maximum entropy image reconstructions of R Leonis at 833 nm (a) and 902 nm (b). In each panel the contour levels are plotted from 5 to 95 per cent of the peak intensity in steps of 10 per cent, and the axes are labelled in mas. North is at the top and east to the left.

3.2 Correction for atmospheric extension and limb darkening

Although the diameters derived above by model-fitting to the observed visibility data have relatively small errors, the effects of photospheric extension and limb darkening mean that they will be systematically offset from the 'true' stellar diameter. Indeed, in the context of cool stars such as R Leonis the definition of the stellar diameter is far from straightforward – see e.g. Baschek et al. (1991) for a discussion. For this paper we have chosen to use an optical-depth definition so that the stellar diameter corresponds to the surface at which the Rosseland mean opacity equals unity.

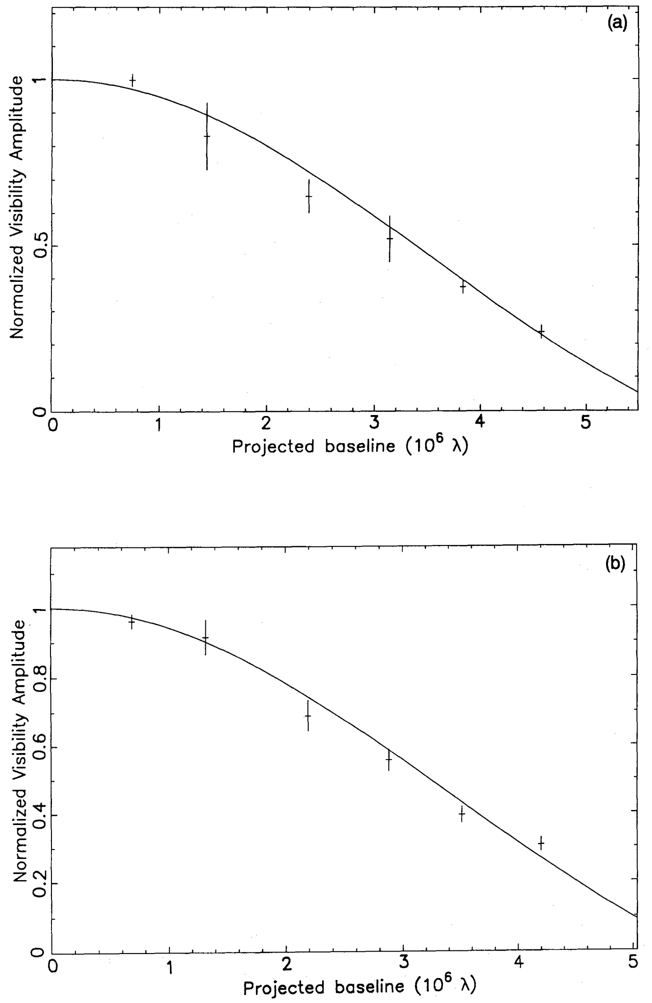

Figure 2. Normalized visibility amplitudes of R Leonis at 833 nm (a) and 902 nm (b). At 833 nm the data plotted are the values averaged over the two orientations of the pupil mask at which the effects of the asymmetry on the stellar disc are minimized, whereas at 902 nm the data have been azimuthally averaged over all position angles. Overplotted on each figure is the visibility function of the best-fitting uniform-disc model: these have diameters of 45 and 43 mas at 833 and 902 nm respectively.

For cool stars, in which molecular opacity in the stellar atmosphere is significant, the effects of photospheric extension and limb darkening tend to act in opposite senses, with photospheric extension leading to an overestimate of the true stellar diameter and limb darkening leading to an underestimate. Most previous studies have tended to address the former of these issues either by the judicious choice of an observing wavelength at which the apparent stellar extent is unaffected by absorption, or by utilizing theoretical models to compute appropriate correction factors to be applied to the fitted uniform-disc diameters. Only recently, with the publication of detailed numerical models (Scholz & Takeda 1987), has it become possible to investigate the variations in apparent angular size due to the expected wavelength-dependent limb darkening across the stellar disc.

To correct our measured uniform-disc diameters, we followed Ridgway et al. (1992) by using theoretical predictions

Table 1. Wavelength-dependent multiplicative scaling factors for conversion of uniform-disc diameters to 'true' photospheric diameters. The model atmospheres from which the factors are derived are parametrized by the effective temperature of the underlying Mira at the radius at which the Rosseland mean opacity equals unity, the variability phase and the mode of pulsation.

Filter λ (nm)	$\Delta\lambda$ (nm)	$T_{\rm eff}$ (K)	Pulsation mode	Variability phase	Scaling factor
833	41	2690	fundamental	0.50	0.86
902	50	2690	fundamental	0.50	0.95
2160	35	2690	fundamental	0.50	1.00
833	41	2332	1st overtone	0.83	0.84
902	50	2332	1st overtone	0.83	0.86
2160	35	2332	1st overtone	0.83	0.94
833	41	2620	1st overtone	0.00	0.80
902	50	2620	1st overtone	0.00	0.84
2160	35	2620	1st overtone	0.00	0.99
833	41	2765	1st overtone	0.10	0.81
902	50	2765	1st overtone	0.10	0.88
2160	35	2765	1st overtone	0.10	1.00
833	41	2608	1st overtone	0.21	0.86
902	50	2608	1st overtone	0.21	0.94
2160	35	2608	1st overtone	0.21	1.01

for the centre-to-limb brightness distribution based on model photospheres. These model brightness distributions were used to compute the conversion factors relating the physical stellar diameter (by which we mean the diameter at which the Rosseland mean opacity equals unity) to the diameter as inferred by fitting a uniform-disc model to visibility amplitude measurements within the first null. The model brightness distributions were computed for the specific filter bandpasses utilized for the observations, and are based on a sequence of recent photospheric models (Scholz, personal communication) that were developed in combination with the self-excited pulsation models of Wood (1990a).

Because of variation of the atmospheric structure with variability phase, this method requires knowledge of the effective temperature of the star under consideration at the time of observations. Di Giacomo et al. (1991) observed R Leonis at a similar phase in its variability cycle in 1990, and inferred an effective temperature of 2450 ± 150 K. Correction factors were computed for a number of Mira models comprising a fundamental pulsator of effective temperature 2690 K and four first-overtone pulsators with effective temperatures in the range 2330 – 2765 K. In keeping with our definition for the stellar radius, the quoted effective temperatures of the models are defined at the radius at which the Rosseland mean opacity equals unity. Fortunately for filters such as ours, which span contaminated continuum windows, the predicted correction factors did not depend strongly on the exact choice of effective temperature, and we have adopted the mean values of the factors given in Table 1 to scale our fitted uniform-disc diameters. Although there is a small systematic difference between the corrections predicted for the fundamental and first-overtone models at 902 nm, it is sufficiently small to be ignored in our subsequent discussion.

After scaling by the mean factors derived from Table 1, the resulting estimates of photospheric diameter at 833 and 902 nm are 37.4 ± 2 and 39.0 ± 3 mas respectively, where the errors now include a contribution due to the scatter in the values given in Table 1. The agreement between these two results gives some estimate of the internal consistency of the data analysis and the level of systematic errors.

3.3 Correction for variability phase effects

An estimate of the magnitude of the expected angular diameter variation with variability phase was derived from near-infrared *JHKL* photometry. Since most of the energy radiated by R Leonis appears in the 1 – 4 μm region, blackbodies were used as interpolation devices to infer the bolometric magnitude of the star (see e.g. Feast et al. 1989). The stellar angular diameter was then computed on the assumption that the blackbody temperature was equivalent to the effective temperature of the star. Using photometry carried out with the 0.75-m reflector at SAAO Sutherland over the period JD 244 2823 to 244 8703, the 'blackbody' diameter was found to vary by no more than ± 5 per cent about its mean value, the maximum diameter occurring towards bolometric maximum. On the other hand, the models of Bessell et al. (1989), which provide an empirical calibration between effective and blackbody temperatures for their extended Mira atmospheres, suggest that the star should be smaller (by ~ 20 per cent) at maximum light than at minimum. Since our observations were taken close to bolometric maximum ($\phi_{\rm bol} = 0.09$), their analysis would place the true time-averaged diameter some 10 per cent greater than the observed value.

In addition, we also utilized the pulsation models described in Section 3.2 to calculate the variation in stellar diameter as a function of visibility phase explicitly for both fundamental and first-overtone pulsations. For both models the predicted diameter at visual phase 0.25 was within 10 per cent of the mean radius. In view of these uncertainties, it seemed prudent not to apply any further explicit corrections to the data for variability phase to obtain a time-averaged estimate. In the following analysis one should bear in mind that such a correction could be as large as 10 per cent.

3.4 Summary

In summary, after correction for the effects of possible asymmetries in the stellar brightness distribution, of atmospheric extension and limb darkening and of variability phase, we have derived values of 37.4 ± 2 and 39.0 ± 3 mas for the photospheric diameter of R Leonis. These values are based on data collected at two different wavelengths (833 and 902 nm respectively), and thus provide two independent estimates for the diameter of the star corresponding to the radius at which the mean Rosseland opacity equals unity.

4 DISCUSSION

4.1 Previous work

Previous determinations of the angular diameter of R Leonis have been summarized by Di Giacomo et al. (1991). Of these, the most reliable measurement is probably their own, recorded at 2.16 μm. Fortuitously, this was secured at a visual phase of 0.25, very similar to the phase of our measurement. Their value for the diameter, 33 ± 1.3 mas, is smaller than our weighted average, 38 ± 2.5 mas, but does not include any correction for limb darkening or photospheric extension. The correction factors for these effects, as derived from the unpublished models of Scholz (see Table 1), are very small, though, and do not alter their result appreciably. However, Di Giacomo et al. state that least-squares fitting of a uniform-disc model to their occultation data leads to diameters in the range 30 – 35 mas. Therefore it seems possible that their quoted error estimate is optimistic and that the small discrepancy between our results can be understood as a measure of the cycle-to-cycle variability of the star, their 2.16-μm measurement being made at a comparable phase to ours but during an earlier cycle.

4.2 Effective temperature

The bolometric magnitude of R Leonis at the epoch of our observations was 0.37, as estimated from blackbody fits to the *JHKL* photometry. We can convert this straightforwardly to an effective temperature using the relation

$$T_{\rm eff} = 2341(F_{\rm bol}/\phi^2)^{1/4}, \tag{1}$$

where $F_{\rm bol}$ is the apparent bolometric flux in units of 10^{-8} erg cm^{-2} s^{-1} and ϕ is the apparent angular diameter in mas. This gives a value of 2459 ± 150 K, where we have added in quadrature an additional uncertainty of 10 per cent to our diameter estimate to accommodate possible systematic errors in our modelling of the stellar atmosphere. Our value for $T_{\rm eff}$ is almost identical to that derived by Di Giacomo et al. (1991) on the basis of their uncorrected near-infrared diameter measurement, and is also very close to the blackbody temperature of the star at this epoch ($T_{\rm bb} \simeq 2500$ K). However, the predictions of the model photospheres of Bessell et al. (1989) suggest that the good agreement between $T_{\rm bb}$ and $T_{\rm eff}$ is simply a consequence of the insensitivity of $T_{\rm bb}$ to $T_{\rm eff}$ at these low temperatures. Fortunately, their conclusion as to the inadequacy of blackbody fitting for determination of the effective temperatures of Mira variables does not extend to the determination of bolometric fluxes, for which such an approach is more than adequate.

4.3 Pulsational models

The pulsational properties of long-period variables were examined in detail by Fox & Wood (1982), and have more recently been summarized by Wood (1990a). One useful diagnostic for determination of the pulsation mode is the pulsation constant, Q, given by

$$Q = P(M/{\rm M}_\odot)^{1/2}(R/{\rm R}_\odot)^{-3/2}, \tag{2}$$

where P is the period in days, and M and R the stellar mass and radius respectively. An alternative parametrization for

Table 2. Predicted stellar diameters for R Leonis based on the parametrization given in equation (3). R_0 and R_1 refer to the fundamental and first-overtone predictions. The values in brackets are the mean values of R_0 and R_1 for the 1-$M_\odot$ models used to correct for limb-darkening effects.

$M/M_\odot$	$R_0/R_\odot$	$R_1/R_\odot$
0.50	164	
0.75	198	
1.00	226 (232)	(416)
1.25	250	

fundamental-mode pulsation is given by the following equation (Wood 1990a):

$$\log(P) = -2.07 + 1.94\log(R/R_\odot) - 0.9\log(M/M_\odot), \quad (3)$$

where P is measured in days.

We can use equation (3) together with a photometric period of 314 d derived from recent near-infrared photometry (Whitelock, personal communication) to predict the stellar radius of R Leonis as a function of mass, assuming fundamental-mode pulsation. These predictions are summarized in Table 2, where we also give the stellar radii corresponding to the atmospheric models discussed in Section 3.2, which combine model photospheres with the recent self-excited pulsation models of Wood (1990a). Unfortunately, we have been unable to find an up-to-date parametrization for first-overtone pulsation that is equivalent to equation (3) in the literature. However, the results of Fox & Wood (1982) suggest that, for a star of similar luminosity to R Leonis, first-overtone pulsation should imply a stellar radius of between 300 and 400 $R_\odot$.

By combining our diameter estimate with the trigonometric parallax of Gatewood (1992) we obtain a linear radius for R Leonis of 495 ± 83 $R_\odot$, where the error includes contributions from both our angular diameter estimate and the assumed parallax distance. This distance estimate to R Leonis agrees with independent estimates based on empirical correlations between, for example, colour and absolute luminosity (see e.g. Rowan-Robinson & Harris 1983; Celis 1984) or period and K magnitude (Feast et al. 1989) to within 20 per cent, and so it is unlikely that the true uncertainty in the distance to R Leonis is any larger than the error in the parallax measurement would imply. Unlike previous studies, which have relied upon indirect estimators such as photometric or CO velocity data, our NRM observations provide a direct estimate of R_*, albeit convolved with the effects of limb darkening and photospheric extension. Although the masses of Miras are still uncertain, primarily because of the effects of mass loss, they are expected to be low-mass objects, and a mass of between 0.75 and 1.0 $M_\odot$ seems most likely for R Leonis. In this case, our diameter measurement clearly identifies R Leonis as a first- or higher overtone pulsator.

Despite the potential uncertainties associated with our estimate of R_* and the complexities involved in modelling the dynamical properties of Mira variables, it seems highly unlikely that the hypothesis of fundamental-mode pulsation can be entertained for R Leonis. Even for a worst case, with the stellar distance and angular diameter as small as the errors allow and the maximum permissible mass ($M_* = 1.25$ $M_\odot$), fundamental-mode pulsation would still be ruled out. While this is consistent with many earlier studies (e.g. Wood 1975; Robertson & Feast 1981; Glass & Feast 1982; Whitelock 1986; Perl & Tuchman 1990), it can only add to the current controversy surrounding the pulsational properties of Miras, in particular the discrepancy between the observed and predicted pulsational velocities for overtone pulsators (see e.g. Wood 1990b for a discussion of these matters). However, recent modelling of Mira variables, which includes the effects of convection (Balmforth, Gough & Merryfield 1990), does suggest that fundamental-mode pulsation can be damped by turbulent pressure and that the first-overtone mode will be excited most strongly in these stars.

Although our data appear to have settled the issue as to whether or not fundamental-mode pulsation is occurring in R Leonis, further interferometric observations of similar stars with accurately known distances are required to establish whether or not this is a common phenomenon and to distinguish clearly between first and higher overtones. A dozen or more parallaxes of the required precision are expected from the *Hipparcos* mission – together with time-resolved monochromatic angular diameter measurements, these should provide a first opportunity to address these issues directly, thereby resolving the dispute between proponents of fundamental and overtone pulsations in long-period variables.

5 CONCLUSIONS

We have used high-precision monochromatic diameter estimates, obtained with the NRM method at 833 and 902 nm, to investigate the effective temperature and pulsational properties of the long-period variable R Leonis. Our value for $T_{\rm eff}$ (2459 ± 150 K) is in good agreement with the most recent occultation measurement, obtained at 2.16 μm (Di Giacomo et al. 1991). In combination with the trigonometric parallax of Gatewood (1992) and recent photospheric models (Scholz, personal communication) adapted to the pulsational models of Wood (1990a), we obtain a value of 495 ± 83 $R_\odot$ for the stellar radius, which clearly eliminates the possibility of fundamental-mode pulsation and identifies R Leonis as a first-, or possibly higher, overtone pulsator. This once more highlights the discrepancy between pulsational mode identifications based on sizes and/or effective temperatures and those determined on the basis of dynamical considerations which favour fundamental-mode pulsation. Further high-precision parallax and angular diameter measurements offer the possibility of confirming this result in many nearby Miras, thereby testing current dynamical models of their photospheres and molecular atmospheres.

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