# Near-Infrared Photometry of Carbon Stars ${ }^{\star}$ 

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Received date; accepted date


#### Abstract

Near-infrared, $J H K L$, photometry of 239 Galactic carbon-rich variable stars is presented and discussed. From these and published data the stars were classified as Mira or non-Mira variables and amplitudes and pulsation periods, ranging from 222 to 948 days for the Miras, were determined for most of them. A comparison of the colour and period relations with those of similar stars in the Large Magellanic Cloud indicates minor differences, which may be the consequence of sample selection effects. Apparent bolometric magnitudes were determined by combining the mean $J H K L$ fluxes with mid-infrared photometry from IRAS and MSX. Then, using the Mira period luminosity relation to set the absolute magnitudes, distances were determined - to greater accuracy than has hitherto been possible for this type of star. Bolometric corrections to the $K$ magnitude were calculated and prescriptions derived for calculating these from various colours. Mass-loss rates were also calculated and compared to values in the literature.

Approximately one third of the C-rich Miras and an unknown fraction of the non-Miras exhibit apparently random obscuration events that are reminiscent of the phenomena exhibited by the hydrogen deficient RCB stars. The underlying cause of this is unclear, but it may be that mass loss, and consequently dust formation, is very easily triggered from these very extended atmospheres.


Key words: stars: individual: EV Eri, R Lep, R Vol, IRAS09164-5349, IRAS101365743, IRAS16406-1406 - stars: variable: other - dust, extinction - infrared: stars - stars: carbon - stars: AGB and post-AGB - stars: distances.

## 1 INTRODUCTION

Intrinsic carbon stars are produced when asymptotic giant branch (AGB) stars experience sufficient dredge-up to change their surface carbon to oxygen ratios from $\mathrm{C} / \mathrm{O}<1$ to $\mathrm{C} / \mathrm{O}>1$. Exactly how and when this occurs depend on the initial mass and the abundances of the star in question, but the details remain controversial. It has been known for a long while that the majority of the C stars in the Magellanic Clouds were low mass objects (e.g. Iben 1981), but it has only recently been possible to model the production of C stars among relatively low mass stars (e.g. Stancliffe et al. 2005).

In attempting to find an appropriate group of local C stars to study it is natural to examine the large amplitude

[^0]variables. First, the amplitude of their variability identifies them as AGB stars and therefore one can be reasonably certain that their carbon enrichment is intrinsic rather than the result of binary mass transfer. Secondly, observations of extragalactic C Miras suggest that they obey a well defined period luminosity relation (Feast et al. 1989, Whitelock et al. 2003) and it should therefore be possible to establish their distances, provided their periods and apparent luminosities can be measured.

This particular project arose from the requirement to identify a significant local population of Galactic C stars with distances and radial velocities which could be used for kinematic studies. From these it should be possible to gain insight into the nature, in particular the ages and masses, of the local C star population which will be invaluable for comparison with theory and with similar populations in Local Group galaxies (e.g. Menzies et al. 2002).

In this paper, the first of three, we discuss infrared pho-
tometry of C variables observable from the southern hemisphere. Subsequent papers will deal with radial velocities and northern C-rich Miras (Menzies et al. 2006, Paper II) and the kinematics of the full sample (Feast et al. 2006, Paper III).

## 2 SOURCE SELECTION

Much of the $J H K L$ photometry reported here comes from two specific programmes; first, stars selected from the catalogue of Aaronson et al. (1989) and secondly, stars selected from the IRAS Point Source Catalogue (IRAS Science Team 1985), henceforth referred to as the 'Aaronson' and 'IRAS' samples, respectively. The stars from each group were monitored for several years to determine their pulsation periods and to establish the characteristics of their variability. These data were supplemented by observations of C stars that had been obtained from SAAO over the years as part of other programmes. In general stars were selected to be south of declination $+30^{\circ}$ for ease of monitoring from Sutherland.

Aaronson et al. (1989) published velocities and JHK photometry for C stars. The stars selected for monitoring were chosen on the basis of their colours $\left((H-K)_{0}>0.8\right)$ (using a very rough estimate of the reddening correction) or their $K$ variability as potential Mira variables which could be used to establish the kinematic properties of the C Miras (the colour criterion may have resulted in the omission of some C Miras, but the objective was to find stars with a high probability of being $C$ Miras rather than to be complete). These stars are identified with an ' A ' in column 10 (G) of Table 1 Data are reported here for 60 such stars, including three which are probably not C stars.

The IRAS sample was selected from the Point Source Catalogue (PSC) using the following 3 criteria: spectral types 4 n , indicating SiC features in the LRS spectra; 25 to 12 $\mu$ m flux ratio, $\mathrm{F}_{25} / \mathrm{F}_{12}>0.4 ; 12 \mu \mathrm{~m}$ flux, $F_{12}>40 \mathrm{Jy}$. The flux ratio criterion was intended to isolate stars with dust shells; while the limit to the $12 \mu \mathrm{~m}$ flux was intended to ensure that the stars would be observable, at least at $K$ and $L$, on the 0.75 m at Sutherland. Note that the spectral-type criterion will have resulted in the omission of C Miras without SiC shells, but again the objective was to find stars with a high probability of being C-rich Miras rather than to be complete. Some of the stars selected in this way were already being observed as part of other programmes; nevertheless, they will be identified as part of the 'IRAS' sample for the purpose of the discussion below. These stars are identified with an ' I ' in column $10(\mathrm{G})$ of Table $\square$ Data are presented for 96 such IRAS sources, including five which are unlikely to be C stars.

A further 32 C-stars with IRAS photometry have $\mathrm{F}_{25} / \mathrm{F}_{12}>0.4$, but with $F_{12}<40$. These were not chosen on the basis of their IRAS characteristics but are identified here with an ' i ' in column $10(\mathrm{G})$ as an interesting group to compare with their brighter counterparts. Five of the stars selected in this way are probably not C stars.

A number of sources from the Aaronson and IRAS samples were identified by the selection criteria mentioned above, but observations proved impossible because of severe crowding.

There are only two stars in common between the Aaron-
son and the IRAS samples, although another 8 are found in the faint IRAS sample. This might suggest that the fainter IRAS sources are not simply more distant but that they actually have thinner shells than their brighter counterparts.

The names of the C stars are listed in Table in one of the forms recognizable by the SIMBAD data base, with preference being given to a variable star designation (from Samus et al. 2004, henceforth GCVS) where one exists. IRAS names are also listed, and are used throughout this paper without the 'IRAS' prefix. The C numbers listed in the table are from the updated version of Stephenson's Catalogue of Galactic Carbon Stars (Alksnis et al. 2001). Most of the coordinates were taken from Cutri et al. (2003, henceforth 2MASS).

At the end of Table 18 stars are listed which were observed as part of the programme, but which are either peculiar in some way or are probably not bona fide C stars. Peculiarities include transitional objects, i.e. SC stars.

## 3 INFRARED PHOTOMETRY

The detailed SAAO photometry is reported in Table 3 for the first star only, the full dataset of photometry is available electronically. The table gives times of the observations as Julian Date (JD) followed by the JHKL mags measured for that date. It is organized in order of right ascension with the dubious C stars (the 18 listed at the end of Table 1) mixed among the definite ones. Where measurements were not made, usually at $J$ or $L$ because the star was too faint, the column is left blank. Most of the $J H K L$ measurements were made with the MkII infrared photometer on the 0.75m telescope at SAAO, Sutherland. They are on the current SAAO system as defined by Carter (1990). A few measurements were made on the SAAO $1.9-\mathrm{m}$ and these have been transformed to the SAAO system ${ }^{1}$. These are marked ' 1.9 m ' in the last column of the table.

The post-1979 photometry is accurate to better than $\pm 0.03 \mathrm{mag}$ at $J H K$, and to better than $\pm 0.05 \mathrm{mag}$ at $L$; observations with $J>13.0$, measured using the 1.9 m telescope, or $J>10.4$ measured using the 0.75 m , are good to $\pm 0.06$ at $J$. Measurements marked with a colon are accurate to better than 0.1 mag. Some older (pre-1979) measurements were reported by Catchpole et al. (1979). The measurements listed here differ slightly from those in Catchpole et al., because they have been corrected to Carter's improved values for the standard stars. These measurements are slightly less accurate than the more modern values, but see Catchpole et al. for details.

[^1]Table 1: Stars observed in this survey.

| name | IRAS | RA |  |  | Dec |  |  | MSX | G | C comment |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Equinox 2000 |  |  |  |  |  |  |  |  |  |
| R Scl | 01246-3248 | 1 | 26 | 58 | -32 | 32 | 36 |  | I | 234 |  |
| YY Tri | $02152+2822$ | 2 | 18 | 6 | +28 | 36 | 45 |  | I | 6028 |  |
| R For | 02270-2619 | 2 | 29 | 15 | -26 | 5 | 56 |  |  | 361 |  |
| EV Eri | 04067-0922 | 4 | 9 | 6 | -9 | 14 | 12 |  | i | 6070 |  |
| [TI98]0418+0122 | $04188+0122$ | 4 | 21 | 27 | +1 | 29 | 14 |  |  | 6075 |  |
| V718 Tau | $04284+1732$ | 4 | 31 | 22 | +17 | 39 | 10 |  |  | 714 |  |
| TT Tau | $04483+2826$ | 4 | 51 | 31 | +28 | 31 | 37 |  |  | 794 |  |
| R Lep | 04573-1452 | 4 | 59 | 36 | -14 | 48 | 23 |  |  | 833 |  |
| TU Tau | $05421+2424$ | 5 | 45 | 14 | +24 | 25 | 12 | X |  | 1038 |  |
| Y Tau | $05426+2040$ | 5 | 45 | 39 | $+20$ | 41 | 42 |  |  | 1042 |  |
| QS Ori | $05428+1215$ | 5 | 45 | 37 | +12 | 16 | 15 |  |  | 395 |  |
| 05418-3224 | 05418-3224 | 5 | 43 | 43 | -32 | 23 | 29 |  | I | 1045 |  |
| V1259 Ori | $06012+0726$ | 6 | 4 | 00 | $+7$ | 25 | 52 |  | I | 6113 |  |
| 06088+1909 | $06088+1909$ | 6 | 11 | 48 | +19 | 8 | 20 | X | I | 1187 | 1 |
| BN Mon | $06192+0722$ | 6 | 21 | 58 | + 7 | 20 | 58 | X |  | 1246 |  |
| ZZ Gem | $06209+2503$ | 6 | 24 | 01 | +25 | 1 | 53 |  |  | 1251 |  |
| V617 Mon | $06210+0831$ | 6 | 23 | 48 | +8 | 29 | 51 | X |  | 1254 |  |
| V636 Mon | 06226-0905 | 6 | 25 | 1 | -9 | 7 | 16 |  |  | 6146 |  |
| V477 Mon | $06268+0849$ | 6 | 29 | 35 | $+8$ | 47 | 16 | X | I | 1287 |  |
| CR Gem | $06315+1606$ | 6 | 34 | 24 | +16 | 4 | 30 | X | i | 1309 |  |
| GM CMa | 06391-2213 | 6 | 41 | 15 | -22 | 16 | 43 |  | i | 1357 |  |
| V503 Mon | $06422+0953$ | 6 | 44 | 57 | +9 | 50 | 48 | X |  | 1377 |  |
| RT Gem | $06436+1840$ | 6 | 46 | 35 | +18 | 36 | 54 |  |  | 1389 |  |
| 06487+0551 | $06487+0551$ | 6 | 51 | 24 | + 5 | 47 | 34 | X | I | 1430 |  |
| CG Mon | $06487+0517$ | 6 | 51 | 27 | + 5 | 13 | 23 | X |  | 1431 |  |
| CL Mon | $06529+0626$ | 6 | 55 | 37 | + 6 | 22 | 43 |  |  | 1465 |  |
| 06531-0216 | 06531-0216 | 6 | 55 | 40 | - 2 | 20 | 16 | X |  | 1471 |  |
| NP Pup | 06528-4218 | 6 | 54 | 27 | -42 | 21 | 56 |  |  | 1478 |  |
| 06564+0342 | 06564+0342 | 6 | 59 | 6 | + 3 | 37 | 56 | X | I | 1494 |  |
| W CMa | 07057-1150 | 7 | 8 | 3 | -11 | 55 | 24 | X | i | 1565 |  |
| 07080-0106 | 07080-0106 | 7 | 10 | 35 | -1 | 11 | 26 |  | I | 1580 |  |
| VX Gem | 07099+1441 | 7 | 12 | 49 | +14 | 36 | 4 |  |  | 1595 |  |
| 07097-1011 | 07097-1011 | 7 | 12 | 8 | -10 | 16 | 39 | X | A | 1597 |  |
| R Vol | 07065-7256 | 7 | 5 | 36 | -73 | 0 | 52 |  |  | 1599 |  |
| HX CMa | 07098-2012 | 7 | 12 | 4 | -20 | 17 | 23 |  | I | 1601 |  |
| 07136-1512 | 07136-1512 | 7 | 15 | 57 | -15 | 18 | 08 | X | A | 1630 |  |
| 07161-0111 | 07161-0111 | 7 | 18 | 39 | -1 | 16 | 52 |  | I | 1642 |  |
| 07217-1246 | 07217-1246 | 7 | 24 | 3 | -12 | 52 | 28 | X | AI | 1696 |  |
| 07220-2324 | 07220-2324 | 7 | 24 | 7 | -23 | 30 | 46 |  | I | 1699 |  |
| 07223-1553 | 07223-1553 | 7 | 24 | 35 | -15 | 59 | 52 | X | A | 1701 |  |
| 07293-1832 | 07293-1832 | 7 | 31 | 31 | -18 | 39 | 4 | X | A | 1751 |  |
| 07319-1940 | 07319-1940 | 7 | 34 | 6 | -19 | 46 | 56 | X | A | 1775 |  |
| [W71b]W007-02 | 07348-1926 | 7 | 37 | 2 | -19 | 32 | 54 | X | A | 1798 |  |
| 07373-4021 | 07373-4021 | 7 | 39 | 4 | -40 | 28 | 47 |  |  | 1825 |  |
| [W71b]W008-03 |  | 7 | 40 | 55 | -26 | 1 | 31 | X | A | 1831 |  |
| V471 Pup | 07390-2618 | 7 | 41 | 6 | -26 | 25 | 19 | X | A | 1834 |  |
| [ABC89]Pup 3 | 07403-2943 | 7 | 42 | 17 | -29 | 51 | 4 | X | Ai | 1847 |  |
| [ABC89]Pup 17 |  | 7 | 49 | 32 | -27 | 23 | 36 | X | A | 1897 |  |
| 07454-7112 | 07454-7112 | 7 | 45 | 2 | -71 | 19 | 46 |  | 1 | 1901 |  |
| [ABC89]Pup 21 | 07506-2819 | 7 | 52 | 43 | -28 | 26 | 52 | X | A | 1924 |  |
| V831 Mon | 07551-0032 | 7 | 57 | 43 | -0 | 41 | 6 |  |  | 1960 |  |
| 07576-4054 | 07576-4054 | 7 | 59 | 24 | -41 | 3 | 16 |  | I | 1992 |  |
| 07582-1933 | 07582-1933 | 8 | 0 | 25 | -19 | 42 | 11 |  | I | 1993 |  |
| V509 Pup | 08004-3023 | 8 | 2 | 26 | -30 | 32 | 16 | X | A | 2010 |  |
| [ABC89]Pup 38 | 08010-2626 | 8 | 3 | 7 | -26 | 34 | 31 | X | A | 6268 |  |
| FF Pup | 08014-2356 | 8 | 3 | 35 | -24 | 4 | 35 |  |  | 2022 |  |
| [ABC89]Pup 42 | 08029-2942 | 8 | 4 | 58 | -29 | 51 | 26 | X | A | 2043 |  |
| Continued on Next | Page... |  |  |  |  |  |  |  |  |  |  |


| name | IRAS | RA |  |  | Dec |  |  | MSX | G | C | comment |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Equinox 2000 |  |  |  |  |  |  |  |  |  |
| V518 Pup | 08045-1524 | 8 | 6 | 51 | -15 | 33 | 23 |  | I | 2056 |  |
| 08050-2838 | 08050-2838 | 8 | 7 | 6 | -28 | 47 | 40 | X | I | 2062 |  |
| RU Pup | 08053-2246 | 8 | 7 | 30 | -22 | 54 | 45 |  |  | 2064 |  |
| FK Pup | 08073-3608 | 8 | 9 | 11 | -36 | 17 | 7 | X |  | 2086 |  |
| 08074-3615 | 08074-3615 | 8 | 9 | 20 | -36 | 24 | 27 | X | I | 6267 |  |
| [ABC89]Ppx19 | 08080-3259 | 8 | 10 | 2 | -33 | 8 | 29 | X | A | 2091 |  |
| [W71b]021-05 | 08083-3145 | 8 | 10 | 18 | -31 | 54 | 22 | X | A | 2095 |  |
| [ABC89]Ppx22 | 08085-3351 | 8 | 10 | 29 | -34 | 0 | 36 | X | A | 2099 |  |
| V346 Pup | 08088-3243 | 8 | 10 | 49 | -32 | 52 | 6 | X | AI | 2101 |  |
| [W71b]026-01 | 08160-3822 | 8 | 17 | 52 | -38 | 32 | 16 | X | A | 2146 |  |
| RY Hya | 08174+0255 | 8 | 20 | 6 | +2 | 45 | 56 |  |  | 2150 |  |
| [ABC89]Ppx40 | 08197-3447 | 8 | 21 | 41 | -34 | 57 | 24 | X | A | 2173 |  |
| [W71b]029-02 | 08233-4110 | 8 | 25 | 10 | -41 | 20 | 2 | X | A | 2203 |  |
| [W71b]029-04 | 08266-4110 | 8 | 28 | 26 | -41 | 20 | 43 | X | A | 2224 |  |
| 08340-3357 | 08340-3357 | 8 | 36 | 3 | -34 | 7 | 34 |  | I | 2260 |  |
| R Pyx | 08434-2801 | 8 | 45 | 31 | -28 | 12 | 3 |  |  | 2326 |  |
| UW Pyx | 08450-3407 | 8 | 47 | 00 | -34 | 18 | 59 |  |  | 2334 |  |
| T Cnc | 08538+2002 | 8 | 56 | 40 | +19 | 50 | 57 |  |  | 2384 |  |
| 08535-4724 | 08535-4724 | 8 | 55 | 11 | -47 | 35 | 56 | X | I | 2389 |  |
| 08534-5055 | 08534-5055 | 8 | 55 | 2 | -51 | 7 | 20 | X | I | 2390 |  |
| IQ Hya | 09112-2311 | 9 | 13 | 32 | -23 | 23 | 31 |  |  | 2450 |  |
| CQ Pyx | 09116-2439 | 9 | 13 | 54 | -24 | 51 | 25 |  | I | 6325 |  |
| 09164-5349 | 09164-5349 | 9 | 18 | 2 | -54 | 2 | 27 | X | I | 2473 |  |
| 09176-5147 | 09176-5147 | 9 | 19 | 17 | -52 | 0 | 28 | X | I | 2476 |  |
| [ABC89]Vel19 |  | 9 | 26 | 19 | -52 | 6 | 4 | X | A | 2508 |  |
| [W71b]046-02 | 09249-4909 | 9 | 26 | 45 | -49 | 22 | 25 | X | A | 2512 |  |
| [ABC89]Vel44 | 09331-5010 | 9 | 34 | 57 | -50 | 24 | 30 | X | A | 2563 |  |
| 09433-6233 | 09433-6233 | 9 | 44 | 41 | -62 | 47 | 32 |  | I | 6339 |  |
| CW Leo | $09452+1330$ | 9 | 47 | 57 | +13 | 16 | 43 |  | I | 2619 |  |
| W Sex | 09484-0147 | 9 | 50 | 58 | -2 | 1 | 43 |  |  | 2635 |  |
| 09484-6242 | 09484-6242 | 9 | 49 | 49 | -62 | 56 | 9 |  |  | 2645 |  |
| 09513-5324 | 09513-5324 | 9 | 53 | 7 | -53 | 38 | 54 | X | I | 2653 |  |
| 09529-5506 | 09529-5506 | 9 | 54 | 41 | -55 | 20 | 16 | X | I | 2660 |  |
| 09533-6021 | 09533-6021 | 9 | 54 | 52 | -60 | 35 | 26 |  | i | 2663 |  |
| 09521-7508 | 09521-7508 | 9 | 52 | 30 | -75 | 22 | 28 |  | I | 2664 |  |
| 09586-6150 | 09586-6150 | 10 | 0 | 9 | -62 | 5 | 19 |  | i | 6344 |  |
| 10019-6156 | 10019-6156 | 10 | 3 | 29 | -62 | 10 | 37 |  |  | 2691 |  |
| 10023-5946 | 10023-5946 | 10 | 3 | 58 | -60 | 0 | 37 | X |  | 2692 |  |
| 10026-5849 | 10026-5849 | 10 | 4 | 20 | -59 | 4 | 0 | X |  | 6347 |  |
| 10052-5906 | 10052-5906 | 10 | 6 | 57 | -59 | 21 | 25 | X |  | 2703 |  |
| 10098-5742 | 10098-5742 | 10 | 11 | 35 | -57 | 57 | 53 | X | i | 6352 |  |
| 10109-5958 | 10109-5958 | 10 | 12 | 40 | -60 | 13 | 30 | X |  | 2720 |  |
| RW LMi | 10131+3049 | 10 | 16 | 2 | +30 | 34 | 19 |  |  | 2724 |  |
| 10130-5703 | 10130-5703 | 10 | 14 | 49 | -57 | 18 | 45 | X | 1 |  |  |
| 10136-5743 | 10136-5743 | 10 | 15 | 27 | -57 | 58 | 11 | X |  | 2729 |  |
| 10145-6046 | 10145-6046 | 10 | 16 | 13 | -61 | 1 | 43 |  |  | 2734 |  |
| 10149-5919 | 10149-5919 | 10 | 16 | 43 | -59 | 34 | 52 | X |  | 2735 |  |
| 10151-6008 | 10151-6008 | 10 | 16 | 50 | -60 | 23 | 55 | X | i | 6354 |  |
| 10175-5957 | 10175-5957 | 10 | 19 | 17 | -60 | 12 | 52 | X |  | 2745 |  |
| 10199-5801 | 10199-5801 | 10 | 21 | 44 | -58 | 16 | 35 | X | i | 6363 |  |
| 10220-5858 | 10220-5858 | 10 | 23 | 49 | -59 | 13 | 54 | X |  | 6366 |  |
| CPD-58 2175 | 10231-5823 | 10 | 24 | 58 | -58 | 39 | 17 | X | 1 | 2760 |  |
| CZ Hya | 10249-2517 | 10 | 27 | 18 | -25 | 32 | 56 |  |  | 2764 |  |
| [ABC89]Car5 |  | 10 | 29 | 44 | -62 | 28 | 29 |  | A | 2776 |  |
| [ABC89]Car11 |  | 10 | 32 | 22 | -60 | 42 | 29 | X | A | 2784 |  |
| TV Vel | 10324-5358 | 10 | 34 | 28 | -54 | 14 | 28 |  |  | 2790 |  |
| U Ant | 10329-3918 | 10 | 35 | 13 | -39 | 33 | 45 |  |  | 2793 |  |
| [ABC89]Car28 |  | 10 | 37 | 9 | -60 | 59 | 34 | X | A | 6391 |  |
| [ABC89]Car32 | 10366-5950 | 10 | 38 | 29 | -60 | 5 | 57 | X | A | 2817 |  |
| Continued on | Page |  |  |  |  |  |  |  |  |  |  |


| name | IRAS | RA |  |  | Dec |  |  | MSX | G | C | comment |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | quin | $\times 200$ |  |  |  |  |  |  |
| FU Car | 10390-5907 | 10 | 41 | 0 | -59 | 23 | 13 | X | Ai | 2832 |  |
| [ABC89]Car54 | 10442-5809 | 10 | 46 | 16 | -58 | 25 | 21 | X | A | 2850 |  |
| [ABC89]Car59 |  | 10 | 48 | 30 | -60 | 11 | 32 | X | A | 2862 |  |
| V Hya | 10491-2059 | 10 | 51 | 37 | -21 | 15 | 00 |  | I | 2877 |  |
| [ABC89]Car73 | 10509-6036 | 10 | 52 | 55 | -60 | 52 | 10 | X | A | 6426 |  |
| [ABC89]Car81 |  | 10 | 54 | 27 | -60 | 19 | 50 | X | A | 2897 |  |
| [ABC89]Car84 |  | 10 | 56 | 45 | -60 | 3 | 37 | X | A | 2907 |  |
| [ABC89]Car87 | 10558-6203 | 10 | 57 | 47 | -62 | 19 | 16 | X | A | 2911 |  |
| [ABC89]Car93 |  | 10 | 59 | 5 | -60 | 31 | 49 |  | A | 2917 |  |
| [ABC89]Car105 | 11009-6117 | 11 | 3 | 1 | -61 | 33 | 28 | X | Ai | 2941 |  |
| 11145-6534 | 11145-6534 | 11 | 16 | 39 | -65 | 50 | 56 |  | I | 2987 |  |
| [W65] c1 |  | 11 | 20 | 34 | -59 | 30 | 51 | X |  | 2997 |  |
| [W65] c2 |  | 11 | 22 | 5 | -59 | 38 | 45 | X | A | 3003 |  |
| [W65] c13 | 11299-6103 | 11 | 32 | 19 | -61 | 20 | 34 | X | A | 3051 |  |
| [TI98]1130-1020 | 11308-1020 | 11 | 33 | 25 | -10 | 36 | 59 |  |  | 3052 |  |
| 11318-7256 | 11318-7256 | 11 | 33 | 58 | -73 | 13 | 19 |  |  | 3062 |  |
| [ABC89]Cen3 |  | 11 | 35 | 54 | -60 | 33 | 41 | X | A | 3068 |  |
| [ABC89]Cen4 | 11339-6012 | 11 | 36 | 17 | -60 | 29 | 18 | X | A | 3071 |  |
| 11463-6320 | 11463-6320 | 11 | 48 | 48 | -63 | 37 | 28 | X | I | 6455 |  |
| [ABC89]Cen32 | 11468-5950 | 11 | 49 | 21 | -60 | 7 | 5 | X | Ai | 3108 |  |
| [ABC89]Cen43 | 11510-6046 | 11 | 53 | 31 | -61 | 3 | 33 | X | A | 3120 |  |
| [ABC89]Cen60 | 11556-6357 | 11 | 58 | 8 | -64 | 14 | 54 | X | A | 3139 |  |
| [ABC89]Cen78 |  | 12 | 4 | 10 | -62 | 42 | 26 | X | A | 6464 |  |
| CF Cru | 12023-6230 | 12 | 4 | 55 | -62 | 47 | 39 | X | A | 3165 |  |
| [ABC89]Cen97 | 12100-6122 | 12 | 12 | 44 | -61 | 39 | 01 | X | A | 6473 |  |
| 12194-6007 | 12194-6007 | 12 | 22 | 10 | -60 | 24 | 15 | X | I | 3220 |  |
| SS Vir | 12226+0102 | 12 | 25 | 14 | + 0 | 46 | 11 |  |  | 3236 |  |
| 12298-5754 | 12298-5754 | 12 | 32 | 41 | -58 | 11 | 29 | X | I | 3251 |  |
| CGCS3268 | 12374-5706 | 12 | 40 | 15 | -57 | 22 | 46 |  | A | 3268 |  |
| 12394-4338 | 12394-4338 | 12 | 42 | 10 | -43 | 55 | 03 |  | I | 3275 |  |
| 12421-6217 | 12421-6217 | 12 | 45 | 7 | -62 | 33 | 38 | X | I | 6489 |  |
| RU Vir | $12447+0425$ | 12 | 47 | 18 | + 4 | 8 | 41 |  |  | 3286 |  |
| V Cru | 12536-5737 | 12 | 56 | 36 | -57 | 53 | 57 | X |  | 3310 |  |
| 12540-6845 | 12540-6845 | 12 | 57 | 16 | -69 | 1 | 51 |  | I | 3311 |  |
| [ABC89]Cru17 | 13022-6400 | 13 | 5 | 26 | -64 | 16 | 11 | X | Ai | 3327 |  |
| [ABC89]Cir1 | 13342-6232 | 13 | 37 | 44 | -62 | 48 | 28 | X | Ai | 3410 |  |
| 13343-5807 | 13343-5807 | 13 | 37 | 41 | -58 | 23 | 10 | X | I | 3411 |  |
| 13477-6532 | 13477-6532 | 13 | 51 | 29 | -65 | 46 | 56 | X | I | 3439 |  |
| 13482-6716 | 13482-6716 | 13 | 52 | 4 | -67 | 30 | 56 |  | I | 3441 |  |
| 13509-6348 | 13509-6348 | 13 | 54 | 34 | -64 | 3 | 23 | X | I | 3446 |  |
| [ABC89]Cir18 |  | 13 | 55 | 26 | -59 | 22 | 24 | X | A | 6547 |  |
| [ABC89]Cir26 | 14004-6047 | 14 | 4 | 5 | -61 | 01 | 50 | X | Ai | 6549 |  |
| [ABC89] Cir27 | 14010-5927 | 14 | 4 | 33 | -59 | 41 | 22 | X | Ai | 3470 |  |
| [W71b]093-02 | 14192-6327 | 14 | 23 | 8 | -63 | 41 | 9 | X | A | 3487 |  |
| 14395-5656 | 14395-5656 | 14 | 43 | 14 | -57 | 8 | 45 | X | A | 3523 |  |
| 14404-6320 | 14404-6320 | 14 | 44 | 26 | -63 | 33 | 28 | X | I | 3525 |  |
| 14443-5708 | 14443-5708 | 14 | 48 | 4 | -57 | 20 | 37 | X | I | 6565 |  |
| 15082-4808 | 15082-4808 | 15 | 11 | 41 | -48 | 19 | 59 |  | I | 3570 |  |
| 15084-5702 | 15084-5702 | 15 | 12 | 15 | -57 | 13 | 28 | X | I | 6572 |  |
| II Lup | 15194-5115 | 15 | 23 | 5 | -51 | 25 | 59 | X | I | 3592 |  |
| 15261-5702 | 15261-5702 | 15 | 30 | 2 | -57 | 12 | 46 | X | I |  |  |
| 15471-5644 | 15471-5644 | 15 | 51 | 6 | -56 | 53 | 24 | X | I | 6600 |  |
| CGCS3660 |  | 16 | 2 | 44 | -41 | 21 | 32 |  |  | 3660 |  |
| 16079-4812 | 16079-4812 | 16 | 11 | 34 | -48 | 19 | 51 | X | I | 3670 |  |
| NP Her | $16150+2558$ | 16 | 17 | 9 | +25 | 51 | 02 |  |  | 3679 |  |
| 16171-4759 | 16171-4759 | 16 | 20 | 50 | -48 | 6 | 53 | X | I | 3681 |  |
| V Oph | 16239-1218 | 16 | 26 | 44 | -12 | 25 | 36 |  |  | 3698 |  |
| SU Sco | 16374-3217 | 16 | 40 | 39 | -32 | 22 | 48 |  |  | 3720 |  |
| CGCS3721 | 16387-5401 | 16 | 42 | 45 | -54 | 7 | 10 |  |  | 3721 |  |

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| name | IRAS | RA |  |  | Dec |  |  | MSX | G | C | comment |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Equinox 2000 |  |  |  |  |  |  |  |  |  |  |
| 16406-1406 | 16406-1406 | 16 | 43 | 27 | -14 | 12 | 00 |  | i |  |  |
| 16538-4633 | 16538-4633 | 16 | 57 | 32 | -46 | 37 | 47 | X | I | 3747 |  |
| 16545-4214 | 16545-4214 | 16 | 58 | 6 | -42 | 19 | 24 | X | I | 3748 |  |
| T Ara | 16584-5459 | 17 | 2 | 33 | -55 | 4 | 16 |  | i | 3756 | 2 |
| V901 Sco | 16595-3239 | 17 | 2 | 46 | -32 | 43 | 31 | X |  | 3762 |  |
| 17047-2848 | 17047-2848 | 17 | 7 | 56 | -28 | 52 | 06 |  | I | 3772 |  |
| V2548 Oph | 17049-2440 | 17 | 7 | 58 | -24 | 44 | 31 |  | I | 6661 |  |
| SZ Ara | 17065-6153 | 17 | 11 | 7 | -61 | 57 | 15 |  |  | 3774 |  |
| V617 Sco | 17103-3551 | 17 | 13 | 41 | -35 | 55 | 21 | X | I | 3786 |  |
| 17105-3746 | 17105-3746 | 17 | 13 | 59 | -37 | 50 | 8 | X | I | 6670 | 3 |
| 17130-3907 | 17130-3907 | 17 | 16 | 33 | -39 | 10 | 46 | X | I | 3794 |  |
| 17209-3318 | 17209-3318 | 17 | 24 | 15 | -33 | 21 | 20 | X | I | 6674 | 4 |
| 17217-3916 | 17217-3916 | 17 | 25 | 13 | -39 | 19 | 22 | X | I | 3823 |  |
| 17222-2328 | 17222-2328 | 17 | 25 | 18 | -23 | 30 | 46 |  | I | 3825 |  |
| V833 Her | $17297+1747$ | 17 | 31 | 55 | +17 | 45 | 21 |  | I | 6677 |  |
| V Pav | 17389-5742 | 17 | 43 | 19 | -57 | 43 | 26 |  |  | 3861 |  |
| 17446-4048 | 17446-4048 | 17 | 48 | 12 | -40 | 49 | 36 |  | I | 6685 |  |
| 17446-7809 | 17446-7809 | 17 | 52 | 35 | -78 | 10 | 42 |  | I | 6687 |  |
| 17463-4007 | 17463-4007 | 17 | 49 | 50 | -40 | 7 | 58 |  |  |  | 5 |
| V348 Sco | 17478-4315 | 17 | 51 | 30 | -43 | 16 | 23 |  | i | 3886 |  |
| 17581-1744 | 17581-1744 | 18 | 1 | 6 | -17 | 44 | 23 | X | I | 3925 |  |
| 18036-2344 | 18036-2344 | 18 | 6 | 42 | -23 | 44 | 22 | X | I | 6709 |  |
| FX Ser | 18040-0941 | 18 | 6 | 50 | -9 | 41 | 16 |  | I | 6711 |  |
| V1280 Sgr | 18073-2652 | 18 | 10 | 28 | -26 | 51 | 58 | X |  | 3960 |  |
| 18119-2244 | 18119-2244 | 18 | 15 | 1 | -22 | 43 | 58 | X | I | 6729 |  |
| 18147-2215 | 18147-2215 | 18 | 17 | 43 | -22 | 14 | 39 | X | I | 6733 |  |
| V5104 Sgr | 18194-2708 | 18 | 22 | 35 | -27 | 6 | 29 |  |  | 6738 |  |
| V2548 Sgr | 18234-2206 | 18 | 26 | 29 | -22 | 4 | 15 | X | I | 4007 |  |
| 18239-0655 | 18239-0655 | 18 | 26 | 39 | -6 | 54 | 4 | X | I | 6743 |  |
| 18244-0815 | 18244-0815 | 18 | 27 | 7 | -8 | 13 | 10 | X | i |  |  |
| V1076 Her | $18240+2326$ | 18 | 25 | 6 | +23 | 28 | 47 |  | I |  |  |
| 18248-0839 | 18248-0839 | 18 | 27 | 34 | -8 | 37 | 23 | X | I | 4014 |  |
| 18269-1257 | 18269-1257 | 18 | 29 | 47 | -12 | 54 | 58 | X | I | 4024 |  |
| 18320-0352 | 18320-0352 | 18 | 34 | 40 | - 3 | 50 | 14 | X | I | 6750 |  |
| V627 Oph | $18321+0910$ | 18 | 34 | 34 | +9 | 12 | 42 |  |  | 4045 |  |
| 18367-0452 | 18367-0452 | 18 | 39 | 22 | -4 | 48 | 45 | X | I | 6754 | 3 |
| V1417 Aql | 18398-0220 | 18 | 42 | 25 | -2 | 17 | 27 | X | I | 4077 |  |
| 18400-0704 | 18400-0704 | 18 | 42 | 45 | - 7 | 1 | 10 | X | i | 6757 |  |
| V821 Her | $18397+1738$ | 18 | 41 | 55 | +17 | 41 | 8 |  | I | 4078 |  |
| 18424+0346 | $18424+0346$ | 18 | 44 | 59 | $+3$ | 49 | 35 | X | I | 4093 |  |
| V874 Aql |  | 18 | 45 | 41 | +9 | 38 | 39 |  |  | 4099 |  |
| V2045 Sgr | 18463-1706 | 18 | 49 | 15 | -17 | 3 | 25 |  |  | 4117 |  |
| S Sct | 18476-0758 | 18 | 50 | 20 | -7 | 54 | 28 | X |  | 4121 |  |
| $18475+0926$ | $18475+0926$ | 18 | 49 | 55 | +9 | 30 | 07 | X | I | 6761 |  |
| AI Sct | 18481-0647 | 18 | 50 | 52 | -6 | 44 | 23 | X |  | 4124 |  |
| V1418 Aql | $19008+0726$ | 19 | 3 | 18 | + 7 | 30 | 45 | X | I | 4162 |  |
| $19029+2017$ | $19029+2017$ | 19 | 5 | 7 | +20 | 22 | 4 |  | 1 | 6767 |  |
| 19068+0544 | $19068+0544$ | 19 | 9 | 16 | $+5$ | 49 | 10 | X | I | 6772 |  |
| V1420 Aql | 19175-0807 | 19 | 20 | 18 | -8 | 2 | 12 |  | I | 6780 |  |
| V374 Aql | 19276-0056 | 19 | 30 | 15 | - 0 | 50 | 9 |  | I | 4301 |  |
| V1965 Cyg | $19321+2757$ | 19 | 34 | 10 | +28 | 4 | 8 | X | I | 4347 |  |
| $19358+0917$ | $19358+0917$ | 19 | 38 | 13 | +9 | 24 | 9 |  | I | 4378 |  |
| $19455+0920$ | $19455+0920$ | 19 | 47 | 56 | +9 | 28 | 9 |  | I | 4475 |  |
| R Cap | 20084-1425 | 20 | 11 | 18 | -14 | 16 | 3 |  |  | 4701 |  |
| RT Cap | 20141-2128 | 20 | 17 | 7 | -21 | 19 | 4 |  |  | 4774 |  |
| BD Vul | $20351+2618$ | 20 | 37 | 18 | +26 | 29 | 13 |  |  | 4915 |  |
| V442 Vul | $20570+2714$ | 20 | 59 | 10 | $+27$ | 26 | 39 |  | I | 5063 |  |
| RV Aqr | 21032-0024 | 21 | 5 | 52 | - 0 | 12 | 42 |  |  | 5120 |  |
| Y Pav | 21197-6956 | 21 | 24 | 17 | -69 | 44 | 2 |  |  | 5239 |  |

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| name | IRAS | RA |  |  | Dec |  |  | MSX | G | C | comment |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | quin | $\times 2000$ |  |  |  |  |  |  |
| [TI98]2223+2548 | 22239+2548 | 22 | 26 | 19 | +26 | 3 | 38 |  |  |  |  |
| [TI98]2259+1249 | $22592+1249$ | 23 | 1 | 47 | +13 | 5 | 14 |  |  |  |  |
| LL Peg | 23166+1655 | 23 | 19 | 13 | +17 | 11 | 33 |  | I | 6913 |  |
| RU Aqr | 23217-1735 | 23 | 24 | 24 | -17 | 19 | 9 |  | i |  |  |
| IZ Peg | 23257+1038 | 23 | 28 | 17 | +10 | 54 | 37 |  | 1 | 6916 |  |
| CS stars, peculiar and uncertain C stars |  |  |  |  |  |  |  |  |  |  |  |
| R Ori | $04562+0803$ | 4 | 58 | 59 | + 8 | 7 | 49 |  |  | 828 | 6 |
| R CMi | 07059+1006 | 7 | 8 | 42 | +10 | 1 | 26 |  |  | 1561 | 6 |
| 08276-5125 | 08276-5125 | 8 | 29 | 8 | -51 | 35 | 5 |  | i |  | C? |
| 08439-2734 | 08439-2734 | 8 | 46 | 6 | -27 | 45 | 49 |  | I | 2329 | 7 |
| UX Pyx | 09075-2758 | 9 | 9 | 41 | -28 | 10 | 21 |  | i |  | 8 |
| MU Vel | 09450-4716 | 9 | 46 | 54 | -47 | 29 | 51 |  | i |  | C? |
| 10226-5229 | 10226-5229 | 10 | 24 | 34 | -52 | 43 | 29 |  | I |  | C? |
| [ABC89]Car10 | 10293-5912 | 10 | 31 | 9 | -59 | 28 | 16 | X | Ai | 6382 | 9 |
| TU Car | 10331-6027 | 10 | 34 | 55 | -60 | 42 | 35 | X | A | 2795 | 10 |
| V354 Cen |  | 11 | 50 | 59 | -47 | 55 | 21 |  |  |  | C? |
| [ABC89]Cen50 | 11529-6350 | 11 | 55 | 29 | -64 | 7 | 23 | X | A |  | 9 |
| BH Cru | 12135-5600 | 12 | 16 | 16 | -56 | 17 | 7 |  |  |  | 6 |
| TT Cen | 13163-6031 | 13 | 19 | 34 | -60 | 46 | 44 | X | i | 3367 | 6 |
| RV Cen | 13343-5613 | 13 | 37 | 35 | -56 | 28 | 33 |  |  | 3412 | 11 |
| 16316-5026 | 16316-5026 | 16 | 35 | 30 | -50 | 32 | 10 |  | I |  | 8 |
| VX Aql | 18575-0139 | 19 | 0 | 9 | - 1 | 34 | 56 | X |  |  | 6 |
| 18595-3947 | 18595-3947 | 19 | 3 | 2 | -39 | 42 | 56 |  | I |  | 12 |
| V1293 Aql | 19306+0455 | 19 | 33 | 6 | $+5$ | 1 | 45 |  | I |  | 13 |

Notes:

1. Complex flattened circumstellar shell (Richichi et al. 1998).
2. Super lithium rich star (Catchpole \& Feast 1976).
3. No 2MASS photometry; image blended.
4. C star $35^{\prime \prime}$ east of $\mathrm{OH} 353.81+1.45$; IRAS probably blend of two.
5. 17463-4007 is the only known cool C star in the Bulge as noted from an objective prism survey by S. Hughes (private communication).
6. SC star (Keenan \& Boeshaar 1980).
7. SC star (Lloyd Evans 1991).
8. SIMBAD quotes spectral type other than C.
9. S star (Lloyd Evans \& Catchpole 1989).
10. Not a C star (Aaronson et al. 1989).
11. C star with silicate shell (Skinner et al. 1990).
12. Not a C star (Chen et al. 2003).
13. Not a C star, e.g. Groenewegen (1994) and references therein.

C? These have been suggested as C rich on the basis of their infrared colours or IRAS spectra, but the evidence is inconclusive.

Table 2: Near-infrared data.

| Name | $J$ | $H$ | $K$ | $L$ <br> $(\mathrm{mag})$ | $\Delta J$ | $\Delta H$ | $\Delta K$ | $\Delta L$ | $\mathrm{P}_{K}$ | $\mathrm{P}_{l i t}$ | Var | no. |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| (day) |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| R Scl | 2.02 | 0.66 | -0.08 | -0.73 | 0.86 | 0.64 | 0.36 | 0.28 | 375 | 363 | 20 | 157 |
| YY Tri |  | 9.82 | 6.81 | 3.06 |  | 1.80 | 1.74 | 1.40 | 624 |  | 10 | 74 |
| R For | 4.08 | 2.41 | 1.21 | -0.07 | 1.10 | 0.92 | 0.66 | 0.58 | 385 | 389 | $11^{\dagger}$ | 100 |
| EV Eri | 5.55 | 4.30 | 3.60 | 3.00 |  |  |  |  | 226 |  | $21^{\dagger}$ | 59 |
| [TI98]0418+0122 | 9.23 | 7.36 | 6.01 | 4.53 | 1.64 | 1.42 | 1.08 | 0.78 | 422 |  | 10 | 31 |
| V718 Tau | 5.92 | 4.07 | 2.84 | 1.63 | 1.46 | 1.18 | 0.78 | 0.80 | 388 | 405 | $13^{*}$ | 14 |
| TT Tau | 2.78 | 1.45 | 0.97 | 0.54 |  |  |  |  |  | 166 | 20 | 1 |
| R Lep | 2.49 | 1.03 | 0.07 | -0.94 | 0.94 | 0.78 | 0.52 | 0.50 | 438 | 427 | $11^{\dagger}$ | 71 |
| Continued on Next Page... |  |  |  |  |  |  |  |  |  |  |  |  |


| Name | $J$ | H | K | $L$ | $\Delta J$ | $\Delta H$ | $\Delta K$ | $\Delta L$ | $\mathrm{P}_{K}$ | $\mathrm{P}_{l i t}$ | Var | no. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| TU Tau | 3.62 | 2.25 | 1.68 | 1.09 |  |  |  |  |  | 190: | 20 | 1 |
| Y Tau | 2.13 | 0.83 | 0.27 | -0.29 |  |  |  |  |  | 242 | 20 | 6 |
| QS Ori | 6.40 | 4.82 | 3.80 | 2.73 | 1.58 | 1.44 | 1.02 | 1.00 | 483 | 476 | 10 | 12 |
| 05418-3224 | 9.15 | 6.68 | 4.86 | 2.75 | 1.70 | 1.56 | 1.36 | 1.30 | 483 |  | 11:* | 15 |
| V1259 Ori |  | 11.29 | 7.73 | 3.44 |  |  |  |  |  | 696 | 10 | 2 |
| 06088+1909 | 8.57 | 6.07 | 4.26 | 2.25 | 1.38 | 1.20 | 1.00 | 0.86 | 493 |  | 10 | 13 |
| BN Mon | 4.44 | 2.99 | 2.24 | 1.59 |  |  |  |  |  | 600: | 20 | 3 |
| ZZ Gem | 5.41 | 4.02 | 3.21 | 2.60 | >0.8 | $>0.6$ | $>0.4$ | >0.2 | 316: | 317 | 10 | 9 |
| V617 Mon | 7.24 | 5.45 | 4.17 | 2.83 | 0.88 | 0.84 | 0.72 | 0.62 | 444 | 375: | $14^{*}$ | 13 |
| V636 Mon | 5.01 | 3.13 | 1.82 | 0.41 | 1.62 | 1.26 | 0.86 | 0.56 | 543 |  | 10 | 15 |
| V477 Mon | 8.87 | 6.45 | 4.55 | 2.26 | 1.66 | 1.48 | 1.22 | 0.96 | 619 | 820: | 10 | 12 |
| CR Gem | 3.36 | 1.91 | 1.38 | 0.92 |  |  |  |  |  | 250 | 20 | 1 |
| GM CMa | 4.52 | 3.10 | 2.22 | 1.39 | 0.76 | 0.54 | 0.30 | 0.22 | 403 |  | 21 | 94 |
| V503 Mon | 8.11 | 6.59 | 5.69 | 4.9: | 0.60 | 0.40 | 0.16 | 0.16 | 357 | 355 | 20 | 11 |
| RT Gem | 6.51 | 5.21 | 4.62 | 4.21 | 0.76 | 0.74 | 0.58 | 0.72 | 350 | 350 | 10 | 9 |
| $06487+0551$ | 9.14 | 6.58 | 4.62 | 2.24 | 1.34 | 1.20 | 1.02 | 0.74 | 536 |  | 10 | 12 |
| CG Mon | 5.33 | 3.96 | 3.30 | 2.75 | 0.82 | 0.74 | 0.60 | 0.70 | 424 | 419 | 10 | 9 |
| CL Mon | 4.78 | 3.06 | 1.88 | 0.59 | 1.28 | 1.02 | 0.74 | 0.52 | 511 | 497 | 10 | 10 |
| 06531-0216 | 6.95 | 4.89 | 3.35 | 1.61 | 1.32 | 1.18 | 0.98 | 0.64 | 595: |  | $14^{*}$ | 13 |
| NP Pup | 2.49 | 1.38 | 1.03 | 0.64 |  |  |  |  |  |  | 20 | 3 |
| 06564+0342 | 10.26 | 7.59 | 5.43 | 2.84 | 1.50 | 1.32 | 1.16 | 1.02 | 584 |  | 10 | 12 |
| W CMa | 2.59 | 1.40 | 0.96 | 0.50 |  |  |  |  |  |  | 20 | 13 |
| 07080-0106 | 11.5 | 8.68 | 6.23 | 3.49 |  | 2.54 | 1.60 | 1.04 | 594 |  | 10 | 12 |
| VX Gem | 4.96 | 3.74 | 3.13 | 2.78 | 1.14 | 1.06 | 0.66 | 0.78 | 391 | 379 | 10 | 9 |
| 07097-1011 | 8.91 | 7.04 | 5.92 | 4.95 | 0.50 | 0.36 | 0.22 | 0.24 | 437 |  | 20 | 13 |
| R Vol | 5.08 | 3.14 | 1.71 | 0.08 | 1.46 | 1.26 | 0.98 | 0.80 | 452 | 454 | $11^{\dagger}$ | 88 |
| HX CMa | 7.92 | 5.46 | 3.62 | 1.42 |  |  |  |  |  | 725 | 10 | 1 |
| 07136-1512 | 8.12 | 6.50 | 5.57 | 4.74 | 0.36 | 0.28 | 0.16 | 0.10 | 486: |  | 20 | 12 |
| 07161-0111 | 7.40 | 5.26 | 3.58 | 1.64 |  |  |  |  |  |  | 23 | 12 |
| 07217-1246 | 8.88 | 6.32 | 4.30 | 1.91 | 1.42 | 1.32 | 1.12 | 0.88 | 620: |  | 10 | 12 |
| 07220-2324 | 9.51 | 6.80 | 4.77 | 2.46 | 1.58 | 1.24 | 1.06 | 0.88 | 560 |  | 10 | 13 |
| 07223-1553 | 7.98 | 6.23 | 5.23 | 4.38 | 0.56 | 0.44 | 0.24 | 0.18 | 457 |  | 20 | 13 |
| 07293-1832 | 8.80 | 6.99 | 6.02 | 5.17 |  |  |  |  |  |  | 20 | 12 |
| 07319-1940 | 7.91 | 6.36 | 5.64 | 4.99 |  |  |  |  |  |  | 20 | 6 |
| [W71b]007-02 | 7.85 | 6.08 | 4.93 | 3.79 | 1.12 | 0.94 | 0.70 | 0.40 | 460: |  | 13 | 15 |
| 07373-4021 | 5.39 | 3.52 | 2.23 | 0.77 | 1.40 | 1.20 | 0.90 | 0.78 | 459 | 471 | 13 | 15 |
| [W71b]008-03 | 9.50 | 8.01 | 7.30 |  |  |  |  |  |  |  | 20 | 6 |
| V471 Pup | 7.08 | 5.78 | 5.13 | 4.63 | 1.04 | 0.98 | 0.76 | 0.92 | 390 |  | 10 | 16 |
| [ABC89]Pup3 | 7.79 | 6.31 | 5.37 | 4.61 | 0.24 | 0.22 | 0.10 |  | 309 |  | 20 | 9 |
| [ABC89]Pup17 | 9.42 | 7.86 | 7.12 | 6.54 |  |  |  |  |  |  | 20 | 6 |
| 07454-7112 | 8.03 | 5.08 | 2.82 | 0.07 | 2.08 | 1.98 | 1.72 | 1.46 | 511 |  | 10 | 11 |
| [ABC89]Pup21 | 9.27 | 7.55 | 6.38 | 5.34 |  |  |  |  |  |  | 23 | 17 |
| V831 Mon | 6.53 | 4.99 | 3.89 | 2.76 | 1.38 | 1.04 | 0.74 | 0.58 | 331 | 319 | 10 | 13 |
| 07576-4054 |  | 9.29 | 6.62 | 3.39 |  | 1.98 | 1.80 | 1.40 | 519 |  | 10 | 16 |
| 07582-1933 | 10.70 | 7.74 | 5.39 | 2.69 | 1.84 | 1.82 | 1.62 | 1.42 | 541 |  | 10 | 14 |
| V509 Pup | 5.95 | 4.48 | 3.72 | 3.01 |  |  |  |  |  |  | 20 | 8 |
| [ABC89]Pup38 | 10.65 | 8.79 | 7.43 | 6.06 | 1.26 | 1.08 | 0.88 | 1.00 | 431 |  | 10 | 15 |
| FF Pup | 6.64 | 5.38 | 4.69 | 4.00 | 1.10 | 1.16 | 0.94 | 1.06 | 431 | 436 | 10 | 8 |
| [ABC89]Pup42 | 8.52 | 6.97 | 6.16 | 5.45 | 0.28 | 0.22 | 0.14 | 0.06 | 199 |  | 20 | 15 |
| V518 Pup | 6.96 | 4.90 | 3.52 | 2.07 | 1.06 | 0.94 | 0.76 | 0.80 | 228 | 448 | 13 | 13 |
| 08050-2838 | 10.40 | 7.28 | 5.08 | 2.57 | 2.10 | 1.80 | 1.48 | 1.26 | 555 |  | 13 | 11 |
| RU Pup | 3.65 | 2.52 | 2.04 | 1.48 |  |  |  |  |  | 425 | 20 | 2 |
| FK Pup | 3.55 | 2.16 | 1.46 | 0.78 |  |  |  |  |  | 502 | 20 | 2 |
| 08074-3615 |  | 13.13 | 9.09 | 4.50 |  | 2.14 | 1.74 | 1.46 | 832 |  | 10 | 13 |
| [ABC89]Ppx19 | 9.98 | 7.77 | 6.11 | 4.23 | 1.78 | 1.30 | 0.88 | 0.46 | 474 |  | 13 | 16 |
| [W71b]021-05 | 6.66 | 5.19 | 4.40 | 3.71 |  |  |  |  |  |  | 20: | 4 |
| [ABC89]Ppx22 | 6.59 | 5.10 | 4.34 | 3.62 |  |  |  |  |  |  | 20: | 4 |
| V346 Pup | 8.67 | 5.92 | 3.75 | 1.16 | 1.78 | 1.60 | 1.38 | 1.14 | 568 | 571 | 10 | 51 |

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| Name | $J$ | H | K | $L$ | $\Delta J$ | $\Delta H$ | $\Delta K$ | $\Delta L$ | $\mathrm{P}_{K}$ | $\mathrm{P}_{l i t}$ | Var | no. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| [W71b]026-01 | 8.27 | 6.51 | 5.58 | 4.72 |  |  |  |  |  |  | 20: | 4 |
| RY Hya | 4.36 | 2.98 | 2.24 | 1.46 | 0.46 | 0.30 | 0.14 | 0.12 | 516 | 529 | 20 | 61 |
| [ABC89]Ppx40 | 7.68 | 6.15 | 5.36 | 4.73 | 1.20 | 1.04 | 0.74 | 0.78 | 428 | 439 | 10 | 13 |
| [W71b]029-02 | 9.48 | 7.28 | 5.63 | 3.86 | 1.06 | 0.92 | 0.72 | 0.52 | 470 |  | 10 | 19 |
| [W71b]029-04 | 8.62 | 6.80 | 5.82 | 5.01 |  |  |  |  |  |  | 20: | 4 |
| 08340-3357 | 11.29 | 8.14 | 5.61 | 2.56 | 2.32 | 1.56 | 1.46 | 1.16 | 590 |  | 10 | 18 |
| R Pyx | 4.55 | 3.28 | 2.53 | 1.81 | $>0.74$ | $>0.46$ | $>0.22$ | $>0.34$ | 369 | 365 | 13 | 11 |
| UW Pyx | 4.87 | 3.46 | 2.68 | 1.85 |  |  |  |  |  | 423 | 10 | 5 |
| T Cnc | 3.21 | 1.81 | 1.07 | 0.43 |  |  |  |  |  | 482 | 20 | 1 |
| 08535-4724 |  | 10.78 | 7.58 | 4.05 |  | 1.84 | 1.72 | 1.54 | 570: |  | 13 | 14 |
| 08534-5055 |  | 11.96 | 8.50 | 4.55 |  | 2.56 | 1.92 | 1.60 | 703 |  | 10 | 15 |
| IQ Hya | 5.68 | 4.06 | 2.89 | 1.64 | 1.14 | 0.94 | 0.70 | 0.68 | 382 | 397 | 10 | 15 |
| CQ Pyx |  | 9.31 | 5.98 | 2.09 |  | 1.84 | 1.82 | 1.48 | 659 |  | 10 | 33 |
| 09164-5349 | 4.14 | 2.73 | 2.11 | 1.40 |  |  |  |  |  |  | $25^{\dagger}$ | 12 |
| 09176-5147 | 11.57 | 8.59 | 6.31 | 3.63 | 1.50 | 1.54 | 1.36 | 1.02 | 431: |  | 13 | 16 |
| [ABC89] Vel19 | 10.11 | 7.98 | 6.75 | 5.64 |  |  |  |  |  |  | 21 | 20 |
| [W71b]046-02 | 9.03 | 7.27 | 6.38 | 5.78 | 1.00 | 0.76 | 0.40 | 0.34 | 265 |  | 10 | 15 |
| [ABC89] Vel44 | 8.02 | 6.25 | 5.15 | 4.09 | 0.74 | 0.60 | 0.40 | 0.32 | 413 |  | 10 | 16 |
| 09433-6233 | 11.33 | 8.94 | 7.18 | 5.17 | 1.06 | 1.10 | 1.10 | 1.10 | 590: |  | 13 | 12 |
| CW Leo | 7.34 | 4.04 | 1.19 | $-2.54$ | 2.06 | 2.14 | 2.06 | 1.74 | 651 | 630 | 10 | 37 |
| W Sex | 5.11 | 3.95 | 3.49 | 3.06 | 0.32 | 0.26 | 0.16 | 0.12 | 195 | 134 | 20 | 17 |
| 09484-6242 | 7.63 | 6.27 | 5.56 | 4.89 | 0.06 | 0.10 | 0.08 | 0.06 | 244: |  | 20 | 7 |
| 09513-5324 | 10.92 | 7.60 | 5.07 | 2.04 | 1.92 | 1.70 | 1.54 | 1.30 | 630 |  | 10 | 12 |
| 09529-5506 | 10.66 | 7.91 | 5.82 | 3.11 | 2.56 | 2.08 | 1.72 | 1.50 | 688: |  | 10 | 8 |
| 09533-6021 | 12.78 | 9.54 | 7.03 | 4.04 | 1.96 | 1.90 | 1.72 | 1.38 | 714 |  | 10 | 12 |
| 09521-7508 | 8.11 | 5.36 | 3.22 | 0.70 | 1.98 | 1.96 | 1.74 | 1.28 | 539 |  | 10 | 9 |
| 09586-6150 |  | 12.02 | 9.19 | 5.90 |  | 1.78 | 1.68 | 1.38 | 506 |  | 10 | 11 |
| 10019-6156 | 7.87 | 6.55 | 5.99 | 5.49 |  |  |  |  |  |  | 20 | 7 |
| 10023-5946 | 6.94 | 5.53 | 4.90 | 4.20 | 0.32 | 0.26 | 0.18 | 0.12 | 571: |  | 20 | 11 |
| 10026-5849 | 9.80 | 7.49 | 5.90 | 4.22 | 1.04 | 0.94 | 0.68 | 0.52 | 531 |  | 13 | 10 |
| 10052-5906 |  | 7.46 | 6.47 | 5.67 | 0.52 | 0.38 | 0.20 | 0.10 | 448 |  | 20 | 12 |
| 10098-5742 |  | 10.29 | 7.55 | 4.24 |  | 1.38 | 1.26 | 1.16 | 585 |  | 10 | 14 |
| 10109-5958 | 7.26 | 5.49 | 4.27 | 3.03 | 0.78 | 0.70 | 0.58 | 0.50 | 423: |  | 13 | 11 |
| RW LMi | 6.18 | 3.43 | 1.32 | -1.21 | 1.86 | 1.72 | 1.50 | 1.28 | 617 | 640 | 10 | 14 |
| 10130-5703 | 6.30 | 4.07 | 3.07 | 2.23 |  |  |  |  |  |  | 20 | 5 |
| 10136-5743 | 8.33 | 6.40 | 5.23 | 3.94 |  |  |  |  |  |  | $15:{ }^{\dagger}$ | 13 |
| 10145-6046 | 5.78 | 4.35 | 3.65 | 2.97 |  |  |  |  |  |  | 20 | 11 |
| 10149-5919 | 6.68 | 5.18 | 4.53 | 3.90 |  |  |  |  |  |  | 20 | 6 |
| 10151-6008 | 9.28 | 7.86 | 7.21 | 6.51 |  |  |  |  |  |  | 20 | 6 |
| 10175-5957 | 8.28 | 6.61 | 5.66 | 4.86 |  |  |  |  |  |  | 20 | 12 |
| 10199-5801 | 11.81 | 8.51 | 6.20 | 3.52 | 1.66 | 1.56 | 1.28 | 1.02 | 675 |  | 10 | 14 |
| 10220-5858 | 8.54 | 6.62 | 5.39 | 4.20 | 0.86 | 0.64 | 0.42 | 0.32 | 585: |  | 10 | 11 |
| CPD-58 2175 | 12.33 | 9.39 | 7.14 | 4.54 | 1.74 | 1.58 | 1.42 | 1.22 | 548 |  | 10 | 10 |
| CZ Hya | 4.73 | 3.32 | 2.39 | 1.38 | 1.42 | 1.30 | 0.96 | 0.92 | 444 | 442 | 10 | 12 |
| [ABC89]Car5 | 9.76 | 8.28 | 7.53 | 6.83 | 0.20 | 0.20 | 0.14 |  | 168 |  | 20 | 12 |
| [ABC89]Car11 | 8.50 | 6.99 | 6.17 | 5.41 |  |  |  |  |  |  | 20: | 4 |
| TV Vel | 5.08 | 3.82 | 3.24 | 2.74 | 0.60 | 0.54 | 0.40 | 0.40 | 404 | 365 | 10 | 14 |
| U Ant | 1.24 | 0.01 | -0.49 | -1.11 |  |  |  |  |  |  | 20 | 25 |
| [ABC89]Car28 | 8.95 | 7.29 | 6.36 | 5.47 | 0.56 | 0.42 | 0.24 | 0.20 | 495 |  | 20 | 16 |
| [ABC89]Car32 | 7.67 | 5.85 | 4.84 | 3.90 |  |  |  |  |  |  | 20 | 15 |
| FU Car | 6.41 | 4.81 | 3.85 | 2.89 | 0.70 | 0.58 | 0.32 | 0.28 | 431: | 365: | 20 | 13 |
| [ABC89]Car54 | 6.98 | 5.16 | 4.26 | 3.44 | 0.22 | 0.22 |  |  | 232: |  | 20 | 6 |
| [ABC89]Car59 | 7.22 | 5.56 | 4.62 | 3.78 |  |  |  |  |  |  | 20: | 4 |
| V Hya | 1.78 | 0.29 | -0.70 | $-1.86$ | $>0.52$ | $>0.42$ | $>0.30$ | $>0.28$ | 532 | 531 | $22^{\dagger}$ | 75 |
| [ABC89]Car73 | 10.69 | 8.10 | 6.34 | 4.41 | 1.88 | 1.32 | 1.06 | 0.84 | 483 |  | 10 | 14 |
| [ABC89]Car81 | 9.12 | 7.28 | 6.28 | 5.46 |  |  |  |  |  |  | 20: | 3 |
| [ABC89]Car84 | 8.07 | 6.37 | 5.34 | 4.25 | 1.00 | 0.80 | 0.52 | 0.46 | 501 |  | 10 | 15 |
| [ABC89]Car87 | 8.66 | 7.10 | 6.12 | 5.43 | 1.08 | 0.88 | 0.52 | 0.38 | 473 |  | 10 | 9 |


| Name | $J$ | H | K | $L$ | $\Delta J$ | $\Delta H$ | $\Delta K$ | $\Delta L$ | $\mathrm{P}_{K}$ | $\mathrm{P}_{l i t}$ | Var | no. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| [ABC89]Car93 | 8.64 | 6.64 | 5.54 | 4.56 | 0.72 | 1.06 | 0.86 | 0.44 | 416 |  | 10 | 12 |
| [ABC89]Car105 | 7.32 | 5.47 | 4.24 | 2.91 | 0.90 | 0.70 | 0.46 | 0.34 | 497 |  | 11:* | 15 |
| 11145-6534 | 10.00 | 6.93 | 4.49 | 1.69 | 1.72 | 1.72 | 1.58 | 1.46 | 623 |  | 10 | 12 |
| [W65] c1 | 9.16 | 7.59 | 6.81 |  |  |  |  |  |  |  | 20 | 8 |
| [W65] c2 | 8.03 | 6.70 | 6.26 |  |  |  |  |  |  |  | $24^{*}$ | 8 |
| [W65] c13 | 8.68 | 6.92 | 5.85 | 4.91 | 0.96 | 0.74 | 0.44 | 0.34 | 395 |  | 10 | 14 |
| [TI98]1130-1020 | 7.82 | 5.68 | 4.04 | 2.20 | 1.38 | 1.24 | 1.12 | 0.94 | 443 |  | 10 | 20 |
| 11318-7256 | 4.01 | 2.13 | 0.85 | -0.66 | 1.38 | 1.14 | 0.90 | 0.68 | 526 | 535 | 10 | 9 |
| [ABC89]Cen3 | 9.63 | 7.87 | 7.00 |  |  |  |  |  |  |  | 20: | 5 |
| [ABC89]Cen4 | 7.12 | 5.53 | 4.68 | 3.83 | 0.76 | 0.68 | 0.46 | 0.44 | 514 |  | 10 | 16 |
| 11463-6320 | 10.39 | 7.50 | 5.44 | 2.99 | 2.02 | 2.06 | 1.80 | 1.60 | 615 |  | 10 | 14 |
| [ABC89]Cen32 | 8.95 | 6.67 | 5.05 | 3.28 | 1.14 | 1.04 | 0.84 | 0.70 | 652 |  | 10 | 14 |
| [ABC89]Cen43 | 9.16 | 7.18 | 5.82 | 4.41 | 1.36 | 1.10 | 0.78 | 0.50 | 535 |  | 10 | 13 |
| [ABC89]Cen60 | 8.66 | 6.84 | 5.71 | 4.56 | 1.02 | 0.86 | 0.60 | 0.68 | 414 |  | 10 | 13 |
| [ABC89]Cen78 | 9.39 | 7.51 | 6.48 | 5.65 | 0.54 | 0.34 | 0.20 |  | 401 |  | 20 | 13 |
| CF Cru | 8.91 | 7.14 | 6.21 |  | 0.72 | 0.62 | 0.42 |  | 430 |  | 10 | 15 |
| [ABC89]Cen97 | 10.3 | 7.90 | 6.57 | 5.27 | 2.12 | 1.32 | 0.80 | 0.46 |  |  | 23 | 14 |
| 12194-6007 | 9.59 | 7.00 | 4.96 | 2.57 | 1.66 | 1.54 | 1.26 | 0.94 | 627 |  | 10 | 12 |
| SS Vir | 2.93 | 1.56 | 0.75 | 0.01 | 0.92 | 0.68 | 0.36 | 0.20 | 359 | 364 | 20 | 55 |
| 12298-5754 | 9.28 | 6.65 | 4.40 | 1.70 | 1.56 | 1.66 | 1.54 | 1.24 | 580 |  | 10 | 10 |
| CGCS3268 | 5.63 | 4.28 | 3.43 | 2.78 |  |  |  |  |  | 396 | 10 | 1 |
| 12394-4338 | 7.49 | 4.89 | 2.91 | 0.72 | 1.68 | 1.62 | 1.30 | 1.24 | 551 |  | $14^{*}$ | 12 |
| 12421-6217 |  |  | 8.47 | 4.50 |  |  | 2.40 | 2.02 | 806 |  | 10 | 8 |
| RU Vir | 4.86 | 3.09 | 1.80 | 0.29 | 1.40 | 1.24 | 0.98 | 0.90 | 444 | 433 | 10 | 46 |
| V Cru | 4.71 | 3.46 | 2.88 | 2.45 | 0.76 | 0.68 | 0.50 | 0.64 | 380 | 376 | 10 | 96 |
| 12540-6845 | 8.20 | 5.52 | 3.52 | 1.15 | 2.04 | 1.78 | 1.56 | 1.30 | 586 |  | 10 | 10 |
| [ABC89]Cru17 | 10.16 | 8.39 | 7.45 | 6.15 |  |  |  |  |  |  | 20 : | 1 |
| [ABC89]Cir1 | 7.91 | 5.95 | 4.85 | 3.56 |  |  |  |  |  |  | 25 | 11 |
| 13343-5807 | 9.75 | 7.04 | 4.98 | 2.57 | 1.86 | 1.88 | 1.62 | 1.42 | 556 |  | 10 | 13 |
| 13477-6532 |  | 9.67 | 6.62 | 2.78 |  | 1.46 | 1.68 | 1.36 | 690 |  | 10 | 13 |
| 13482-6716 | 8.47 | 5.79 | 3.78 | 1.49 | 1.66 | 1.66 | 1.44 | 1.18 | 500 |  | 10 | 12 |
| 13509-6348 |  |  | 5.12 | 2.72 |  | 1.70 | 1.46 | 1.36 | 678 |  | 10 | 16 |
| [ABC89]Cir18 | 10.04 | 8.27 | 7.33 | 6.5 |  |  |  |  |  |  | 20 | 13 |
| [ABC89]Cir26 | 9.13 | 6.71 | 5.12 | 3.36 | 1.74 | 1.36 | 0.96 | 0.74 | 495 |  | 10 | 15 |
| [ABC89]Cir27 | 9.50 | 7.12 | 5.27 | 3.10 | 1.18 | 1.22 | 1.02 | 0.84 | 538 |  | $13^{*}$ | 12 |
| [W71b]093-02 | 10.5 | 8.67 | 7.41 |  |  |  |  |  |  |  | 10 : | 4 |
| 14395-5656 | 9.15 | 7.21 | 6.01 | 4.73 | 0.86 | 0.66 | 0.44 | 0.28 | 488 |  | 10 | 11 |
| 14404-6320 |  | 11.46 | 8.32 | 4.39 |  | 2.08 | 2.18 | 1.70 | 643 |  | 10 | 9 |
| 14443-5708 |  | 12.77 | 8.93 | 4.94 |  | 2.98 | 2.16 | 1.80 | 723 |  | 10 | 8 |
| 15082-4808 | 10.00 | 7.00 | 4.36 | 0.86 | 1.76 | 1.68 | 1.64 | 1.48 | 632 |  | 10 | 13 |
| 15084-5702 |  | 10.85 | 7.33 | 3.37 |  | 2.38 | 2.36 | 1.94 | 948 |  | 10 | 10 |
| II Lup | 5.92 | 3.58 | 1.79 | -0.33 | 1.04 | 0.92 | 0.82 | 0.88 | 576 | 580 | $11^{\dagger}$ | 28 |
| 15261-5702 |  | 8.45 | 5.96 | 3.07 |  | 2.34 | 2.02 | 1.40 | 716 |  | 10 | 15 |
| 15471-5644 |  |  |  | 7.78 |  |  |  |  |  |  | $10^{*}$ | 1 |
| CGCS3660 | 6.82 | 5.67 | 5.38 | 5.19 |  |  |  |  |  |  | 20: | 2 |
| 16079-4812 |  | 10.24 | 6.85 | 2.88 |  | 2.02 | 2.32 | 1.96 | 710 |  | 10 | 12 |
| NP Her | 5.79 | 4.36 | 3.50 | 2.79 |  |  |  |  |  | 448 | 10 | 1 |
| 16171-4759 | 9.58 | 6.89 | 4.89 | 2.70 | 1.26 | 1.28 | 1.06 | 0.86 | 560 |  | 13 | 14 |
| V Oph | 3.65 | 2.35 | 1.61 | 0.99 | 1.20 | 0.86 | 0.48 | 0.38 | 294 | 297 | 10 | 11 |
| SU Sco | 3.08 | 1.77 | 1.11 | 0.56 |  |  |  |  |  | 414: | 20 | 5 |
| CGCS3721 | 6.56 | 5.08 | 4.12 | 3.28 |  |  |  |  |  | 353 | 10 | 1 |
| 16406-1406 |  | 11.79 | 8.74 | 5.10 |  |  |  |  |  |  | $15:^{\dagger}$ | 28 |
| 16538-4633 | 8.84 | 6.07 | 4.27 | 2.30 | 1.18 | 1.04 | 0.84 | 0.72 | 527 |  | 13 | 12 |
| 16545-4214 | 7.14 | 4.50 | 2.52 | 0.38 | 1.62 | 1.68 | 1.46 | 1.28 | 534 |  | 10 | 12 |
| T Ara | 4.53 | 3.27 | 2.77 | 2.27 | 0.20 | 0.12 | 0.10 | 0.08 | 327 |  | 20 | 13 |
| V901 Sco | 5.52 | 4.01 | 3.18 | 2.38 | 0.70 | 0.58 | 0.38 | 0.34 | 439: |  | 20 | 10 |
| 17047-2848 | 9.45 | 7.09 | 5.36 | 3.28 | 1.88 | 1.74 | 1.52 | 1.38 | 531 |  | 10 | 12 |
| V2548 Oph |  | 8.48 | 5.61 | 1.98 |  | 2.08 | 2.06 | 1.80 | 747 |  | 10 | 40 |
| Continued on Next Page... |  |  |  |  |  |  |  |  |  |  |  |  |


| Name | $J$ | H | K | $L$ | $\Delta J$ | $\Delta H$ | $\Delta K$ | $\Delta L$ | $\mathrm{P}_{K}$ | $\mathrm{P}_{\text {lit }}$ | Var | no. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| SZ Ara | 6.16 | 5.00 | 4.45 | 4.06 | 0.94 | 0.68 | 0.44 | 0.42 | 222 | 220 | 10 | 8 |
| V617 Sco | 4.67 | 3.15 | 2.17 | 1.23 | 1.42 | 1.48 | 1.14 | 1.04 |  | 524 | 10 | 6 |
| 17105-3746 | 9.74 | 7.16 | 5.14 | 2.60 | 1.98 | 2.18 | 2.10 | 1.82 | 568 |  | 10 | 10 |
| 17130-3907 | 8.92 | 6.15 | 4.23 | 2.09 | 2.32 | 1.82 | 1.36 | 1.18 | 628 |  | 13 | 14 |
| 17209-3318E | 12.63 | 9.04 | 6.24 | 3.18 |  |  |  |  |  |  | 10 | 4 |
| 17217-3916 |  | 9.30 | 6.42 | 3.14 |  | 1.90 | 1.94 | 1.60 | 630 |  | 10 | 11 |
| 17222-2328 | 9.67 | 6.66 | 4.60 | 2.30 | 1.88 | 1.74 | 1.58 | 1.48 | 603 |  | 13 | 9 |
| V833 Her | 9.58 | 6.66 | 4.19 | 1.00 | 2.36 | 2.80 | 2.72 | 2.10 | 540 |  | 13 | 13 |
| V Pav | 2.08 | 0.76 | 0.19 | -0.39 |  |  |  |  | 437 | 225 | 20 | 69 |
| 17446-7809 | 7.22 | 4.69 | 2.72 | 0.55 |  |  |  |  |  |  | 10 | 4 |
| 17446-4048 | 8.15 | 5.54 | 3.60 | 1.47 | 1.34 | 1.24 | 1.10 | 1.18 | 545 |  | $13^{*}$ | 12 |
| 17463-4007 | 10.04 | 8.37 | 7.22 | 5.92 | 1.58 | 1.32 | 0.98 | 0.90 | 399 |  | 10 | 14 |
| V348 Sco | 7.09 | 6.11 | 5.66 |  | 0.26 | 0.30 | 0.26 | 0.12 |  | 274 | 20 | 6 |
| 17581-1744 | 8.26 | 5.77 | 4.03 | 2.12 | 1.70 | 1.40 | 1.08 | 0.94 | 628 |  | 10 | 8 |
| 18036-2344 | 10.71 | 7.37 | 4.93 | 2.17 | 2.66 | 2.78 | 2.22 | 1.96 | 664 |  | $13^{*}$ | 9 |
| FX Ser | 7.03 | 4.45 | 2.59 | 0.54 | 1.70 | 1.54 | 1.28 | 1.02 | 519 |  | 10 | 26 |
| V1280 Sgr | 5.33 | 3.58 | 2.39 | 1.02 | 1.10 | 1.02 | 0.78 | 0.70 | 532 | 523 | 13 | 57 |
| 18119-2244 |  | 8.39 | 5.60 | 2.65 |  | 2.24 | 1.82 | 1.56 | 611 |  | 10 | 12 |
| 18147-2215 |  | 9.92 | 6.50 | 2.91 |  |  |  |  |  |  | 10 | 5 |
| V5104 Sgr | 9.05 | 5.87 | 3.52 | 0.78 | 1.80 | 1.72 | 1.52 | 1.34 | 655 |  | 10 | 44 |
| V2548 Sgr | 4.47 | 2.96 | 2.11 | 1.22 |  |  |  |  |  | 159 | 23 | 11 |
| 18239-0655 | 10.31 | 7.23 | 4.64 | 1.69 | 1.58 | 1.48 | 1.44 | 1.24 | 635 |  | 10 | 9 |
| 18244-0815 | 11.4 | 8.58 | 5.97 | 3.27 |  |  |  |  |  |  | 10 | 6 |
| V1076 Her |  | 9.14 | 5.84 | 1.95 |  | 2.20 | 1.98 | 1.62 | 609 |  | 10 | 12 |
| 18248-0839 | 12.8 | 9.14 | 6.13 | 2.88 |  |  | 2.04 | 2.04 | 659: |  | 10 | 7 |
| 18269-1257 | 13.1 | 8.98 | 5.85 | 2.53 |  |  |  |  |  |  | $10^{*}$ | 5 |
| 18320-0352 |  | 11.61 | 8.31 | 4.45 |  |  |  |  |  |  | 10 | 4 |
| V627 Oph | 7.90 | 5.97 | 4.66 | 3.17 |  |  |  |  |  | 452 | 10 | 3 |
| 18367-0452 |  | 10.47 | 7.11 | 3.17 |  |  |  |  |  |  | 10: | 2 |
| V1417 Aql | 6.23 | 3.78 | 1.96 | -0.08 | 1.30 | 1.10 | 0.92 | 0.72 | 617 |  | 13 | 25 |
| 18400-0704 |  |  | 8.28 | 4.64 |  |  |  |  |  |  | 10 | 3 |
| V821 Her | 5.98 | 3.68 | 1.85 | -0.25 | 1.88 | 1.78 | 1.52 | 1.22 | 524 | 511 | 10 | 15 |
| 18424+0346 | 9.73 | 6.99 | 4.87 | 2.48 |  |  |  |  |  |  | 10 | 6 |
| V874 Aql | 8.71 | 7.61 | 7.22 | 6.79 |  |  |  |  |  | 145 | 10 | 3 |
| V2045 Sgr | 6.21 | 4.50 | 3.46 | 2.42 |  |  |  |  |  | 451 | 10 | 7 |
| S Sct | 2.43 | 1.13 | 0.57 | 0.05 |  |  |  |  |  | 148 | 20 | 16 |
| 18475+0926 |  |  | 5.91 | 2.36 |  |  |  |  |  |  | 10 | 3 |
| AI Sct | 6.12 | 4.50 | 3.48 | 2.63 |  |  |  |  |  | 408 | 10 | 5 |
| V1418 Aql | 8.29 | 5.44 | 3.14 | 0.47 | 2.02 | 1.74 | 1.42 | 1.08 | 562 | 577 | 10 | 20 |
| $19029+2017$ | 8.17 | 5.68 | 3.87 | 1.86 |  |  |  |  |  |  | 10 | 5 |
| 19068+0544 | 8.01 | 5.41 | 3.75 | 2.07 |  |  |  |  |  |  | 10 | 7 |
| V1420 Aql | 5.94 | 3.68 | 2.08 | 0.06 | 1.68 | 1.44 | 1.22 | 1.18 | 694 | 676 | 12 | 18 |
| V374 Aql | 4.91 | 3.30 | 2.29 | 1.26 |  |  |  |  |  | 456 | 20 | 8 |
| V1965 Cyg | 7.64 | 5.00 | 2.95 | 0.55 | 2.52 | 2.08 | 1.68 | 1.26 | 577 | 625 | 13 | 11 |
| $19358+0917$ |  | 11.91 | 8.36 | 4.46 |  |  |  |  |  |  | 10: | 1 |
| $19455+0920$ | 12.1 | 9.32 | 6.73 | 3.5 |  |  |  |  |  |  | 10 | 5 |
| R Cap | 5.31 | 3.94 | 3.05 | 2.09 | 1.42 | 1.18 | 0.86 | 0.96 | 349 | 345 | 10 | 15 |
| RT Cap | 2.48 | 1.15 | 0.54 | -0.06 | 0.30 | 0.24 | 0.14 | 0.10 | 359 | 393 | 20 | 23 |
| BD Vul | 5.84 | 4.30 | 3.37 | 2.63 |  |  |  |  |  | 430 | 10 | 4 |
| V442 Vul | 9.78 | 6.84 | 4.22 | 1.14 | 2.14 | 2.28 | 2.02 | 1.56 | 661 |  | 10 | 12 |
| RV Aqr | 4.68 | 2.75 | 1.39 | -0.13 | 1.58 | 1.32 | 1.04 | 0.94 | 433 | 454 | 10 | 7 |
| Y Pav | 1.89 | 0.69 | 0.26 | -0.08 |  |  |  |  |  | 233 | 20 | 2 |
| [TI98]2259+1249 | 6.97 | 5.78 | 5.24 | 4.90 | 0.78 | 0.74 | 0.54 | 0.68 | 306 | 294 | 10 | 36 |
| LL Peg |  |  | 10.50 | 4.27 |  |  |  |  |  | 696 | 10 | 7 |
| RU Aqr | 3.10 | 2.08 | 1.78 | 1.51 |  |  |  |  |  | 69 | 20 | 1 |
| IZ Peg |  | 10.26 | 7.09 | 3.04 |  | 1.98 | 1.94 | 1.56 | 486 | 486 | 10 | 103 |
| [TI98]2223+2548 | 7.19 | 5.56 | 4.35 | 3.06 | 1.40 | 1.18 | 0.90 | 0.80 | 343 |  | 10 | 16 |

Continued on Next Page...

| Name | $J$ | H | K | $L$ | $\Delta J$ | $\Delta H$ | $\Delta K$ | $\Delta L$ | $\mathrm{P}_{K}$ | $\mathrm{P}_{\text {lit }}$ | Var | no. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| CS stars, peculiar and uncertain C stars |  |  |  |  |  |  |  |  |  |  |  |  |
| R Ori | 5.82 | 4.70 | 4.15 | 3.76 | 0.92 | 1.00 | 0.78 | 0.96 | 381 | 377 |  | 14 |
| R CMi | 4.03 | 2.97 | 2.48 | 2.22 | 0.88 | 0.82 | 0.86 | 0.74 | 335 | 338 |  | 12 |
| 08276-5125 |  |  | 11.69 | 6.63 |  |  |  |  |  |  |  | 1 |
| 08439-2734 | 6.56 | 4.85 | 3.79 | 2.40 | 1.66 | 1.52 | 1.28 | 1.26 | 475 |  |  | 14 |
| UX Pyx | 3.93 | 2.91 | 2.59 | 2.26 |  |  |  |  |  | 423 |  | 1 |
| MU Vel |  |  | 9.49 | 5.30 |  | 1.54 | 1.56 | 1.48 | 597 |  |  | 33 |
| 10226-5229 | 8.89 | 6.25 | 4.56 | 2.60 | 2.98 | 2.32 | 1.86 | 1.50 | 756 |  |  | 10 |
| [ABC89]Car10 | 7.00 | 5.59 | 4.99 | 4.37 | 1.14 | 1.00 | 0.88 | 0.88 | 397 |  |  | 15 |
| TU Car | 7.16 | 6.07 | 5.52 | 4.92 | 0.78 | 0.86 | 0.74 | 0.58 | 254 | 258 |  | 10 |
| V354 Cen | 9.22 | 8.33 | 8.04 | 7.6 | 0.38 | 0.32 | 0.18 |  | 150: | 150 |  | 11 |
| [ABC89]Cen50 | 9.73 | 7.54 | 6.01 | 4.34 | 0.92 | 0.82 | 0.70 | 0.60 | 512 |  |  | 12 |
| BH Cru | 3.21 | 2.03 | 1.56 | 1.23 | 0.62 | 0.66 | 0.58 | 0.64 | 491 | 421 |  | 46 |
| BH Cru | 3.15 | 1.98 | 1.40 | 1.01 | 0.72 | 0.70 | 0.50 | 0.64 | 524 | 421 |  | 36 |
| TT Cen | 4.35 | 2.99 | 2.43 | 1.91 | $>0.72$ | $>0.76$ | $>0.68$ | $>0.80$ | 448 | 462 |  | 89 |
| RV Cen | 3.33 | 2.08 | 1.47 | 1.00 | 0.68 | 0.56 | 0.36 | 0.46 | 447 | 446 |  | 87 |
| 16316-5026 | 4.28 | 2.56 | 1.82 | 1.00 | 1.48 | 0.96 | 0.84 | 0.74 | 565 |  |  | 13 |
| VX Aql | 4.90 | 3.59 | 3.06 | 2.41 |  |  |  |  |  | 604 |  | 2 |
| 18595-3947 | 3.30 | 1.52 | 0.51 | -0.69 | 2.02 | 1.50 | 1.10 | 0.98 | 449 |  |  | 22 |
| V1293 Aql | 2.10 | 1.11 | 0.83 | 0.59 |  |  |  |  |  |  |  | 5 |

$\dagger$ These stars are discussed in the section 11 on long term trends.
*These are stars for which the second parameter of the variable type depends on the combination of our observations and photometry from other sources. V718 Tau Epchtein et al. (1990) and 2MASS data obtained before and after SAAO observations, at phases which are similar to our faintest measurements (i.e. not in the gap) suggest that it has been much fainter ( $K=3.94$, 3.88 respectively, $\Delta K \sim 0.7$ ) and redder, than the faintest SAAO measurements. 05418-3224 An observation by Epchtein et al. (1990) predating ours is 3 and 5 mag brighter at $K$ and $J$ respectively. 2MASS photometry contemporaneous with ours and Fouqué et al. (1992) measurements predating ours are within the range shown in our light curve. We therefore class this star as showing obscuration events, but note that the evidence is very limited. V617 Mon Although Noguchi et al. (1981) present measures distinctly different from ours, a comparison with 2 MASS suggests they actually observed $\mathrm{BD}+08^{\circ} 1312$, an M star about one arcmin away from V617 Mon. 06531-0216 Note that the 2MASS ( $K=4.45$ ) and Epchtein et al. (1990) ( $K=2.89$ ) observations do not agree with the phasing of the SAAO data. The period must therefore be regarded as uncertain. [ABC89]Car105 The Aaronson et al. (1989) observation ( $K=5.41$ ), which predates the SAAO photometry, is much fainter than our minimum ( $K=4.48$ ). This may indicate an obscuration event. [W65] c2 While the 2MASS, the 1985 Aaronson et al. (1989) and the SAAO observations differ by less than 0.1 mag at $K$, the 1988 Aaronson et al. photometry is considerably fainter ( $J=9.14, K=7.21$ ). 12394-4338 The Fouqué et al. (1992) observation ( $J=8.55, K=4.48$ ) is significantly fainter at $K$, but not at $J$, than the SAAO minimum $(J=8.60, K=3.74)$, while the 2MASS and Epchtein et al. (1990) observations are comparable to those listed here. [ABC89]Cir27 The Aaronson et al. (1989) measurement $(K=3.87)$ is significantly brighter than the SAAO maximum ( $K=4.57$ ) and may indicate that the source was obscured during the SAAO observations. 15471-5644 Too crowded for measurement at $J H K$, but 2MASS has $K=14.8$ and Groenewegen et al. (1993) have $K=11.4, L=4.6$, so it is certainly a large amplitude variable. 17446-4048 The Fouqué et al. (1992) measurement ( $K=4.81$ ) is significantly fainter than the SAAO minimum ( $K=4.21$ ) and may indicate the star was being obscured at the time the observation was made. 2MASS is also faint ( $K=4.65$ ). 18036-2344 The Guglielmo et al. (1993) measurement ( $K=6.53$ ) is significantly fainter than the SAAO minimum $(K=5.81)$ and may indicate that the star was in an obscuration phase. 18269-1257 2MASS has $K=8.02$ on JD 2450937, so all our observations are near maximum and $P \sim 700$ days.

Some of the photometry discussed in the present paper has already been published by Whitelock et al. (1994, 1995, 1997, 2000), Olivier et al. (2001), Feast et al. (1985, 2003), Groenewegen et al. (1998) or by Lloyd Evans (1997). All of these data are included in the electronic table for ease of reference. A small number of measurements were made at SAAO as part of other programmes by T. Lloyd Evans and/or by S. Bagnulo and I. Short. These are used in the means quoted and in the diagrams, but the basic data will be published elsewhere. Individual observations of some objects also appeared in other papers without dates (e.g. Gaylard \& Whitelock 1988; Gaylard et al. 1989); these measurements are included in the present tabulation.

### 3.1 IRAS and MSX data

Because energy distributions of C stars typically peak between 3 and $10 \mu \mathrm{~m}$, a measure of the energy output beyond the $L$ band is important for estimating their bolometric flux. Following earlier work (e.g. Whitelock et al. 2000, 2003) we use the IRAS 12 and 25 fluxes and, where possible, supplement these with data from the MSX survey (Egan et al. 2003) using the $A-(8.28 \mu \mathrm{~m}), C-(12.13 \mu \mathrm{~m})$ and $D$ ( $14.65 \mu \mathrm{~m}$ ) bands.

IRAS photometry was taken preferentially from the IRAS Faint Source Catalogue (FSC Moshir et al. 1989) or from the PSC (IRAS Science Team 1989). The IRAS fluxes for CW Leo were taken from the PSC rather than the FSC as these were more consistent with comparable values from the literature (Gezari, Pitts \& Schmitz 1997). The IRAS photometry was colour corrected using the prescription from the IRAS explanatory supplement for the purpose of calculating bolometric magnitudes only. For the discussion of colours etc. the raw magnitudes were used.

There are 18 stars which have no IRAS fluxes, but 13 of these have been measured in the MSX $A$-band. The remaining 5 sources all have $K-L<1.0$ and the long wavelength fluxes will not make a significant contribution to their bolometric magnitude (in fact one of them, V354 Cen, is probably not a C star and only two, V874 Aql and [ABC]Car93, are classed as C Miras).

The MSX data were extracted from the complete MSX6C catalogue in the Galactic Plane $\left(|b| \leqslant 6^{\circ}\right)$ and the high latitude, $|b|>6^{\circ}$, subsections only. A few of our sources have detections in the low reliability sources ([ABC89]Car5) and singleton source (extracted from a single scan but with good fluxes: Y Tau, CL Mon, 070800106, 07220-2324, FF Pup, 08340-3357, MU Vel, 095336021, 10145-6046, TV Vel, 11145-6534) sections of the catalogue, but a close examination suggested these were unreliable, e.g. some singleton sources showed unphysical colours.

The very bright sources appear to be saturated in the MSX- $A$ band, which is more sensitive than any of the others, as can be seen in the plot of $A-C$ against $C$ (Fig. 11. The four very bright stars are II Lup, V1417 Aql, V1418 Aql and V1965 Cyg. Their MSX- $A$ magnitudes are inconsistent with other MSX and IRAS magnitudes, although this is not clear from the flags provided with the catalogue. It appears that among this type of object anything brighter than 270 Jy at $C$ will be saturated at $A$.

Note also from Fig. 1 the difference in the $A-C$ colours of stars, particularly Miras, that are brighter and fainter

Table 3. Individual $J H K L$ Observations (Full table available electronically).

| $\begin{gathered} \text { JD } \\ \text { (day) } \end{gathered}$ | (mag) |  |  |  | Tel. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| R Scl |  |  |  |  |  |
| 2443123.5 | 1.75 | 0.60 | -0.03 | -0.62 |  |
| 2443405.5 | 2.04 | 0.76 | 0.01 | -0.54 |  |
| 2444187.2 | 1.87 | 0.61 | -0.04 | -0.67 |  |
| 2446265.8 | 2.17 | 0.74 | -0.05 | -0.79 |  |
| 2446300.5 | 2.44 | 0.95 | 0.09 | -0.74 |  |
| 2446303.5 | 2.53 | 1.03 | 0.13 | -0.61 |  |
| 2446334.5 | 2.55 | 1.07 | 0.15 | -0.64 |  |
| 2446356.5 | 2.55 | 1.06 | 0.13 | -0.65 |  |
| 2446373.5 | 2.46 | 0.98 | 0.10 | -0.70 |  |
| 2446391.2 | 2.43 | 0.96 | 0.10 | -0.69 |  |
| 2446640.5 | 2.02 | 0.62 | -0.14 | -0.83 |  |
| 2446655.5 | 2.15 | 0.71 | -0.09 | -0.80 |  |
| 2446662.5 | 2.18 | 0.75 | -0.07 | -0.84 |  |
| 2446690.5 | 2.40 | 0.91 | 0.02 | -0.76 |  |
| 2446695.5 | 2.44 | 0.97 | 0.08 | -0.68 |  |
| 2446712.5 | 2.53 | 1.02 | 0.11 | -0.67 |  |
| 2446741.5 | 2.54 | 1.04 | 0.13 | -0.63 |  |
| 2446749.5 | 2.50 | 1.00 | 0.11 | -0.62 |  |
| 2446754.2 | 2.45 | 0.98 | 0.09 | -0.67 |  |
| 2446775.2 | 2.31 | 0.88 | 0.05 | -0.62 |  |
| 2446782.2 | 2.26 | 0.85 | 0.03 | -0.64 |  |
| 2446805.2 | 2.14 | 0.77 | 0.02 | -0.56 |  |
| 2446984.8 | 1.61 | 0.33 | -0.28 | -0.90 |  |
| 2447014.5 | 1.80 | 0.44 | -0.26 | -0.94 |  |
| 2447056.5 | 2.15 | 0.69 | -0.13 | -0.88 |  |
| 2447073.5 | 2.28 | 0.79 | -0.09 | -0.84 |  |
| 2447113.5 | 2.32 | 0.86 | -0.03 | -0.74 |  |
| 2447144.2 | 2.19 | 0.75 | -0.07 | -0.79 |  |
| 2447176.2 | 2.07 | 0.67 | -0.07 | -0.65 |  |
| 2447191.2 | 2.03 | 0.67 | -0.08 | -0.66 |  |
| 2447364.8 | 1.62 | 0.32 | -0.35 | -0.98 |  |
| 2447379.5 | 1.70 | 0.36 | -0.31 | -1.03 |  |
| 2447394.5 | 1.73 | 0.41 | -0.32 | -1.01 |  |
| 2447427.5 | 2.02 | 0.61 | -0.19 | -0.94 |  |
| 2447447.5 | 2.16 | 0.73 | -0.12 | -0.89 |  |
| 2447497.2 | 2.36 | 0.92 | 0.01 | -0.69 |  |
| 2447512.2 | 2.30 | 0.88 | 0.01 | -0.73 |  |
| 2447534.2 | 2.19 | 0.80 | -0.04 | -0.72 |  |
| 2447732.8 | 1.56 | 0.27 | -0.35 | -0.93 |  |
| 2447745.5 | 1.55 | 0.25 | -0.38 | -1.03 |  |
| 2447761.5 | 1.57 | 0.26 | -0.39 | -1.01 |  |
| 2447779.5 | 1.74 | 0.38 | -0.31 | -1.01 |  |
| 2447805.5 | 2.03 | 0.61 | -0.18 | -0.88 |  |
| 2447816.5 | 2.14 | 0.74 | -0.09 | -0.88 |  |
| 2447821.5 | 2.21 | 0.78 | -0.06 | -0.84 |  |
| 2447841.5 | 2.42 | 0.96 | 0.05 | -0.77 |  |
| 2447873.5 | 2.54 | 1.11 | 0.16 | -0.61 |  |
| 2448073.8 | 1.98 | 0.65 | -0.05 | -0.68 |  |
| 2448077.8 | 1.96 | 0.64 | -0.05 | -0.73 |  |
| 2448109.8 | 1.91 | 0.55 | -0.14 | -0.74 |  |
| 2448141.8 | 2.00 | 0.61 | -0.12 | -0.77 |  |
| 2448172.5 | 2.13 | 0.70 | -0.08 | -0.78 |  |
| 2448211.2 | 2.43 | 0.96 | 0.08 | -0.67 |  |
| 2448224.5 | 2.50 | 1.03 | 0.11 | -0.69 |  |
| 2448252.2 | 2.53 | 1.06 | 0.14 | -0.61 |  |
| 2448280.2 | 2.41 | 0.97 | 0.10 | -0.58 |  |
| 2448492.5 | 1.76 | 0.46 | -0.19 | -0.87 |  |
| 2448519.5 | 1.92 | 0.55 | -0.16 | -0.85 |  |
| 2448873.5 | 1.82 | 0.47 | -0.22 | -0.88 |  |
| 2448900.5 | 2.03 | 0.62 | -0.15 | -0.87 |  |

Table 3. continued...

| $\begin{gathered} \text { JD } \\ \text { (day) } \end{gathered}$ | $J$ |  | $\begin{gathered} K \\ \mathrm{ag}) \end{gathered}$ | $L$ | Tel. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2448933.5 | 2.29 | 0.81 | -0.04 | -0.82 |  |
| 2448960.2 | 2.41 | 0.92 | 0.04 | -0.75 |  |
| 2448990.2 | 2.42 | 0.94 | 0.04 | -0.73 |  |
| 2449000.2 | 2.41 | 0.94 | 0.04 | -0.70 |  |
| 2449022.2 | 2.26 | 0.86 | 0.02 | -0.65 |  |
| 2449146.8 | 1.83 | 0.56 | -0.08 | -0.65 |  |
| 2449204.8 | 1.61 | 0.35 | -0.27 | -0.84 |  |
| 2449212.8 | 1.62 | 0.35 | -0.28 | -0.86 |  |
| 2449271.5 | 1.63 | 0.35 | -0.28 | -0.87 |  |
| 2449223.5 | 1.65 | 0.35 | -0.28 | -0.88 |  |
| 2449236.5 | 1.67 | 0.37 | -0.29 | -0.85 |  |
| 2449263.5 | 1.85 | 0.48 | -0.24 | -0.92 |  |
| 2449282.5 | 2.01 | 0.60 | -0.18 | -0.88 |  |
| 2449289.5 | 2.09 | 0.65 | -0.15 | -0.92 |  |
| 2449296.2 | 2.14 | 0.69 | -0.14 | -0.86 |  |
| 2449346.2 | 2.37 | 0.90 | 0.01 | -0.76 |  |
| 2449497.8 | 1.73 | 0.47 | -0.16 | -0.69 |  |
| 2449518.8 | 1.68 | 0.44 | -0.17 | -0.70 |  |
| 2449581.5 | 1.46 | 0.24 | -0.34 | -0.90 |  |
| 2449614.5 | 1.64 | 0.34 | -0.29 | -0.95 |  |
| 2449637.5 | 1.88 | 0.50 | -0.22 | -0.89 |  |
| 2449642.5 | 1.93 | 0.56 | -0.19 | -0.96 |  |
| 2449668.5 | 2.33 | 0.89 | 0.03 | -0.78 |  |
| 2449672.5 | 2.37 | 0.92 | 0.04 | -0.72 |  |
| 2449709.2 | 2.57 | 1.11 | 0.16 | -0.62 |  |
| 2449728.2 | 2.53 | 1.09 | 0.16 | -0.64 |  |
| 2449772.2 | 2.25 | 0.85 | 0.03 | -0.65 |  |
| 2449941.8 | 1.71 | 0.43 | -0.16 | -0.70 |  |
| 2449975.5 | 1.84 | 0.51 | -0.18 | -0.83 |  |
| 2449986.5 | 1.95 | 0.58 | -0.12 | -0.73 |  |
| 2450019.5 | 2.25 | 0.83 | 0.00 | -0.72 |  |
| 2450029.2 | 2.34 | 0.90 | 0.04 | -0.66 |  |
| 2450052.5 | 2.52 | 1.04 | 0.13 | -0.61 |  |
| 2450057.2 | 2.54 | 1.08 | 0.15 | -0.64 |  |
| 2450062.2 | 2.55 | 1.09 | 0.15 | -0.65 |  |
| 2450082.5 | 2.59 | 1.13 | 0.18 | -0.62 |  |
| 2450109.2 | 2.50 | 1.03 | 0.14 | -0.59 |  |
| 2450144.2 | 2.24 | 0.84 | 0.04 | -0.55 |  |
| 2450260.8 | 1.81 | 0.55 | -0.07 | -0.60 |  |
| 2450274.5 | 1.69 | 0.45 | -0.14 | -0.66 |  |
| 2450299.5 | 1.48 | 0.28 | -0.27 | -0.82 |  |
| 2450317.5 | 1.43 | 0.24 | -0.30 | -0.84 |  |
| 2450362.5 | 1.73 | 0.42 | -0.25 | -0.88 |  |
| 2450398.2 | 2.19 | 0.76 | -0.07 | -0.80 |  |
| 2450414.5 | 2.37 | 0.91 | 0.03 | -0.71 |  |
| 2450420.5 | 2.43 | 0.96 | 0.06 | -0.69 |  |
| 2450437.2 | 2.55 | 1.05 | 0.14 | -0.70 |  |
| 2450469.2 | 2.52 | 1.04 | 0.10 | -0.66 |  |
| 2450471.2 | 2.50 | 1.01 | 0.08 | -0.64 |  |
| 2450503.2 | 2.25 | 0.83 | -0.02 | -0.69 |  |
| 2450681.5 | 1.61 | 0.35 | -0.26 | -0.77 |  |
| 2450712.5 | 1.67 | 0.38 | -0.27 | -0.83 |  |
| 2450721.5 | 1.73 | 0.42 | -0.26 | -0.82 |  |
| 2450753.5 | 2.03 | 0.63 | -0.13 | -0.80 |  |
| 2450792.2 | 2.33 | 0.87 | 0.00 | -0.76 |  |
| 2450830.2 | 2.40 | 0.92 | 0.02 | -0.71 |  |
| 2451025.2 | 1.64 | 0.40 | -0.20 | $-0.76$ |  |
| 2451052.2 | 1.56 | 0.34 | -0.26 | -0.79 |  |
| 2451115.5 | 1.87 | 0.50 | -0.20 | -0.86 |  |
| 2451154.2 | 2.26 | 0.82 | -0.01 | -0.82 |  |
| 2451186.2 | 2.49 | 1.01 | 0.10 | -0.69 |  |
| 2451417.5 | 1.61 | 0.38 | -0.22 | -0.75 |  |
| 2451481.5 | 1.64 | 0.31 | -0.33 | -0.95 |  |

Table 3. continued...

| $\begin{gathered} \text { JD } \\ \text { (day) } \end{gathered}$ | (mag) |  |  |  | Tel. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2451502.5 | 1.75 | 0.38 | $-0.31$ | -0.94 |  |
| 2451575.2 | 2.33 | 0.86 | -0.04 | -0.78 |  |
| 2451600.2 | 2.39 | 0.91 | 0.01 | -0.71 |  |
| 2451738.8 | 1.80 | 0.54 | -0.09 | -0.70 |  |
| 2451743.8 | 1.76 | 0.51 | -0.11 | -0.68 |  |
| 2451782.5 | 1.55 | 0.33 | -0.24 | -0.83 |  |
| 2451785.5 | 1.58 | 0.33 | -0.25 | -0.87 |  |
| 2451859.5 | 1.75 | 0.41 | -0.27 | -0.98 |  |
| 2451869.5 | 1.81 | 0.46 | -0.25 | -0.93 |  |
| 2451881.2 | 1.89 | 0.52 | -0.20 | -0.94 |  |
| 2451809.5 | 1.57 | 0.29 | -0.31 | -0.90 |  |
| 2451831.5 | 1.62 | 0.32 | -0.31 | -0.91 |  |
| 2451929.2 | 2.26 | 0.81 | -0.04 | -0.79 |  |
| 2452182.5 | 1.57 | 0.30 | -0.28 | -0.87 |  |
| 2452208.5 | 1.55 | 0.26 | -0.35 | -1.00 |  |
| 2452226.2 | 1.63 | 0.32 | -0.34 | -0.98 |  |
| 2452241.2 | 1.72 | 0.38 | -0.30 | -0.95 |  |
| 2452257.2 | 1.88 | 0.50 | -0.25 | -0.94 |  |
| 2452285.2 | 2.14 | 0.71 | -0.09 | -0.86 |  |
| 2452321.2 | 2.45 | 0.98 | 0.06 | -0.68 |  |
| 2452529.5 | 1.76 | 0.49 | -0.15 | -0.78 |  |
| 2452572.5 | 1.69 | 0.38 | -0.27 | -0.88 |  |
| 2452602.2 | 1.75 | 0.43 | -0.26 | -0.89 |  |
| 2452691.2 | 2.32 | 0.87 | -0.01 | -0.75 |  |
| 2452888.5 | 1.64 | 0.39 | -0.23 | -0.81 |  |
| 2452932.5 | 1.61 | 0.37 | -0.28 | -0.89 |  |
| 2452960.5 | 1.69 | 0.38 | -0.28 | -0.96 |  |

Some of these observation of R Scl were published by Lloyd Evans (1997) and by Whitelock et al. $(1995,1997)$.
than $C \sim 1$ mag. This occurs because the bright Miras are intrinsically different from the faint ones - the stars with large colour indexes, i.e. the "red" stars, are all relatively bright. There are various selection effects contributing to this, but critically we would have been unable to perform $J H K$ photometry of faint red stars. A similar dichotomy is seen in the IRAS data, in that most of the Miras with [12] $>0$ have $[12-25]<0.5$ and those with [12] $<0$ have $[12-25]>0.5$. There are, however, some notable faint nonMiras with $[12-25]>1$ : EV Eri (see Section 11), 101516008, [ABC89]Cru17 and [ABC89]Cir1.

Figs. [2] \& [3] illustrate the types of two-colour diagram which are frequently used to distinguish between O- and Crich stars (e.g. Ortiz et al. 2005) using IRAS and MSX data respectively. The solid line on both figures is the blackbody locus, while the dashed line provides a rough division between C- and O-rich stars, which in the case of the MSX figure has been copied directly from Ortiz et al. The division is far from being a precise one and stars close to the line must be regarded as having uncertain chemical type unless spectroscopic information is available. Nevertheless, most of the programme stars fall in the region you would have expected given their C-rich nature. A similar separation can be achieved using slightly different combinations of colours, as was discussed, e.g., by Guglielmo et al. (1993).

In the MSX diagram the four peculiar non-Miras lying above the upper line are: 09164-5349 (see Section 11), [ABC89]Cir1, V2548 Sgr and [ABC89]Cru17, the latter being the only point well away from the line (NB the differ-


Figure 1. The MSX $A-C$ colour as a function of the MSX- $C$ magnitude. Symbols: crosses: well observed Miras without obvious peculiarities; open crosses: other Miras; open circles: well observed small amplitude variables without obvious peculiarities; close circles: other non-Miras. The four sources with large $A-C$ colours are saturated in the $A$ band. Note the difference between the typical $A-C$ colour for the stars brighter and fainter than $C \sim 1$, particularly the Miras.
ences between Miras and non-Miras and between 'peculiar' and 'normal' relate to the variability characteristics and are described in Section 4.2). The normal non-Mira above the line is [ABC89]Pup3. The stars in a comparable position on the IRAS diagram are these same peculiar non-Miras plus EV Eri and 10151-6008, while the normal non-Miras are R Scl (which has a detached dust shell, Bujarrabal \& Cernicharo 1994) and T Ara (which is super lithium rich, Feast 1954).

## 4 PULSATION CHARACTERISTICS

### 4.1 Pulsation Periods

Periods $\left(\mathrm{P}_{K}\right)$ were determined from a Fourier transform of the $K$ light curve for all of the stars with SAAO nearinfrared observations on 8 or more dates; these are listed in Table 2 Where a pulsation period has been published elsewhere it is listed in column $11\left(\mathrm{P}_{\text {lit }}\right)$ of Table 2 These are taken from the following sources, in order of preference: GCVS, Le Bertre (1992), Jones et al. (1990), Hipparcos (ESA 1997) or Pojmański (2002). Figure 4 shows our period plotted against the value from the literature. The agreement is generally better than 5 percent and a brief discussion of the exceptional cases follows:

V477 Mon The original period is from Maffei (1966) who indicated it as " M ? $\mathrm{P}=820:$ : days". The near-infrared observations are not consistent with this value and we use the newly determined 619 days which provides a very good fit to these data.


Figure 2. Combined IRAS near-infrared two-colour diagram; symbols as in Fig. 1 The solid line is the blackbody locus while the dashed line roughly separates C- from O-rich stars. Note that sources selected according to the IRAS selection criterion described in Section 2 will only find sources with $[12-25]>0.565$. Symbols are the same as in Fig. 1


Figure 3. Combined MSX near-infrared two-colour diagram; symbols and lines as in Fig. 2

V1965 Cyg The original period is from Jones et al. (1990) (who incorrectly associates AFGL 2417 with V1129 Cyg) and there is evidence for rather erratic behavior in both their and our light curves. Analyzing the two data sets together (using only the 6 observations actually listed in their paper) suggests a period of 617 days.

BH Cru This is known to have a lengthening period (Bateson et al. 1988; Walker et al. 1995; Zijlstra et al. 2004)


Figure 4. Periods, $\mathrm{P}_{K}$, derived from data discussed here plotted against those from the literature, $\mathrm{P}_{\mathrm{lit}}$; Symbols: crosses are Mira C-stars (outstanding points represent V477 Mon and V518 Pup), open circles are non-Mira C stars; solid squares are various peculiar sources including non-C stars, SC stars and C-stars with silicate shells (the two outstanding points represent BH Cru, which has a variable period, at different times).
and our data, which were obtained in two batches with a gap in the middle, suggests a change from 491 to 524 days, between 1984/9 and 1997/2004.

V617 Mon The GCVS period is 375 : days with which the near-infrared observations are not consistent. We use the newly determined 444 days which provides a very good fit to our data.

FU Car The GCVS variability type and period of M: and $\mathrm{P}=365$ : days respectively, come from Luyten (1927) who records FU Car's variability along with that of another star and notes "The available plates are insufficient for a determination of the light curves, but the possibility is indicated that both variables have a period of nearly one year, and a range of at least two magnitudes". This is consistent with our determination of 431 days and our assertion that it is not a Mira.

TV Vel GCVS records this as variability type M with $\mathrm{P}=365$ days and no indication of any uncertainty. There is no clear source for the period. We also classify TV Vel as a Mira, but it is certainly a border-line case. Our data are inconsistent with the 365 day period.

W Sex The difference between the GCVS period of 134 days and the Hipparcos period of 200 days was noted by Whitelock et al. (2000). Our newly determined period of 195 days is consistent with the Hipparcos value. It is not a Mira.

RT Cap This is not a Mira and the GCVS period of 393 days is inconsistent with the 359 days derived here.

V518 Pup The 448 day period comes from the ASAS database of Pojmański (2002) who also classifies it as a Mira. The 228 day period derived from the IR data is inconsistent with the ASAS data. While 228 days is the best fit to the
infrared photometry, 448 days is also a possible solution. In this case 448 days would be preferred and is in fact the value we adopt, but the Mira classification must be regarded as uncertain.

Figs. A-1 and A-2 in the appendix, illustrate for Miras and other variables, respectively, the $K$ light curves plotted as a function of phase for the stars with sufficient data to determine a period.

From this it can be seen that the accuracy of the derived periods and amplitudes varies considerably from one star to the next, depending on the number of observations, their distribution in time and the stability of the light curve over the sampling interval. Most of the illustrations show the $K$ magnitude phased at the period determined from the $K$ data. Where satisfactory periods could not be determined from our data they are shown phased at the GCVS period. For 10220-5858 a period of 585: days is given, but 290: is also possible. Although we use the 585 day period in the following discussion the blue colours and low amplitude would fit better with the shorter period.

### 4.2 Variability Class

In view of the fact that we wish to use the Mira PeriodLuminosity (PL) relation to estimate the distance to the C-stars it is vital that we decide if particular stars can be classed as Miras or not. According to the classical GCVS definition Miras have characteristic late-type emission spectra (Ce in the cases we are discussing) and $V$ light amplitudes greater than 2.5 mag. Their periodicity is well pronounced, and periods lie in the range from 80 to 1000 days. For many of the stars of interest very little is known about the $V$ magnitude and we must make the best estimate we can from other sources of information. Unfortunately the distinction between Miras and other types of long period variable is not as clearcut for C-rich stars as it is for O-rich ones, where the JHKL colours of Miras and non-Miras are distinctly different (e.g. Whitelock et al. 1995).

Where there are sufficient observations we determine if a star is a Mira or not on the basis of the SAAO infrared photometry; if it is clearly periodic and has a peak-to-peak $K$ amplitude over 0.4 mag we call it a Mira and assign it to class 1 n . If the variations are not periodic or are less than 0.4 mag at $K$ we assign it to class 2 n , and call it a nonMira. If there are insufficient data to do this we use the GCVS or ASAS classification if there is one. Otherwise, if our $K$ magnitudes differ from published values (Aaronson, 2MASS ...) by 0.4 mag or more we assign it to class 1 n else to class 2 n . Stars classified in this last way are labeled with a colon after the classification in Table 2 as they are clearly less certain than the others. There are 74 class 2 n and 165 class 1 n in the table.

The assignment of the second digit, or sub-class, of the variability classification is described in Table 4 The sub-class to which a variable is assigned obviously depends strongly on how many observations we have, e.g. many objects of type 13 would probably be classed as type 11 given more data. There is actually only one star, V1420 Aql, catalogued as type 12, which is illustrated in the last panel of Fig. A-1 although there are several marginal cases, e.g. [ABC89]Cir27, as can be seen from the illustrated light curves. Even with V1420 Aql there is some uncertainty in

Table 4. Second parameter, $n$, of the variability type 1 n or 2 n .

```
n description of light curve
    sinusoidal and reasonably repeatable
    evidence of obscuration events or a long term trend
    for pronounced second peak in light curve (Miras only)
    for erratic behavior, includes large amplitude non-Miras
    inconsistent with other published photometry
    star with peculiarities described in text
```

its period and if it is plotted at the other period given in Table 2 ( 676 days from Le Bertre 1992) then the second peak is less pronounced.

Our classification agrees reasonably well with the GCVS for most of the 102 stars in common and we briefly discuss the 10 differences here. We classify the following stars as Miras whereas the GCVS provided the classification given in parenthesis after the name: V471 Pup (SR:), V518 Pup (SR: also Mira in ASAS), UW Pyx (Lb: also Mira in ASAS), RW LMi (SRa), CF Cru (Lb), FX Ser (Lb:). The ASAS classification, based on optical data, is relevant as they have many more observations than we do and can do a better job with classifying visually bright variables. However, we agree with the GCVS classification of V374 Aql (SR) rather than the M: assigned by ASAS. The following were classed as Miras in the GCVS: FU Car, V354 Cen, V348 Sco and V503 Mon, but are classed as non-Miras here, because their $K$ amplitudes are much less than expected from Miras.

The Mira nature of $10220-5858$ is uncertain, it has a low amplitude and small $K-[12]$ for its period and limited data suggest an erratic light curve.

A number of authors have noted that the IRAS colours of [ABC89]Cir1 are those expected for a silicate shell (e.g. Chen et al. 1993 and references therein) and it has been investigated on this basis. We note that it has a slightly larger $K-L$ than normal non-Miras.

Of the 57 C stars in the Aaronson sample, 26 are Miras, and periods in the range 265 to 652 days have been determined for 24 of them, while the other 31 are erratic or low amplitude variables.

Of the 93 C-stars in the IRAS sample, 86 are Miras and periods ranging from 431 to 948 days were determined for 69 of them, while the other 7 are low amplitude or erratic variables. Of the 26 C-stars in the faint IRAS sample 12 are Miras, and periods in the range 495 to 714 days were determined for 10 of them, while the other 14 are erratic or low amplitude variables.

### 4.3 Mean Magnitudes and Amplitudes

Table 2 gives the Fourier-mean magnitudes and amplitudes for all of the stars discussed here. These were derived by fitting first order sine curves to the light curves, and the peak-to-peak amplitudes of those curves are also tabulated. The number of points used in the fit is listed in the last column. This may be less than the full number of observations available, as it is for stars showing obscuration events where we have excluded cycles showing heavy obscuration (see section 11). This is somewhat subjective and the results dependent on how well any particular light curve is covered.

The pulsation amplitude generally decreases with increasing wavelength, although there are a few examples of $\Delta J<\Delta H$. Where the source is faint at $J$ a low amplitude may indicate contamination of the $J$ flux by another source in the aperture; there are, however, examples, e.g. CW Leo, where the measured amplitudes are definitely a true reflection of the C star variations. Fig. 5 shows the dependence of pulsation amplitude on colour. Although there is a great deal of scatter, the amplitude and colour are clearly correlated. While there will be several effects contributing to this dependence, the primary one will be the amplitude's direct or indirect dependence on temperature fluctuations of the star. We also anticipate a correlation between the stellar pulsation amplitude, as measured by $\Delta K$, and the massloss rate, as measured by $K-[12]$ which is proportional to the optical depth of the shell (see section 6 and Whitelock, Pottasch \& Feast (1987). It is not possible to separate the effects of temperature fluctuations and pulsation amplitude changes with the available information.

The peaks of the energy distributions for these stars is at wavelengths over $2.5 \mu \mathrm{~m}$ (the combined effect of low temperature and thick circumstellar dust shells), therefore at $J$ and $H$ and usually also at $K$ and $L$, we are sampling the Wien part of the energy distribution which is extremely sensitive to temperature fluctuations. The cooler the star the larger the flux changes at $J H K L$ that will be caused by small changes of the stellar temperature. Molecular opacity fluctuations in the $J H K L$ bands, also in response to temperature changes of the star, will serve to magnify the amplitude dependence on stellar temperature. Thus to a first approximation we might expect the $J H K L$ amplitudes to tell us more about the temperature of the C star, and changes in its temperature around the pulsation cycle, than about the bolometric amplitude of the pulsations themselves. The colours that we discuss here, including $K-[12]$, are much more strongly influenced by reddening of the circumstellar shell than they are by the temperature of the underlying star (see Section 6). Nevertheless, the cooler stars will tend to have the thicker dust shells, so we still understand the correlation in Fig. 5 to be very considerably a consequence of fluctuations in the stellar temperature, but with a good deal of scatter as the thickness of the shell is not a simple function of the temperature of the star.

## 5 MIRA PERIOD-LUMINOSITY RELATION

The existence of a PL relationship for Mira variables was discussed in detail by Feast et al. (1989) for O- and C-rich Miras in the LMC. Subsequently Whitelock et al. (2003) discussed the PL relation for longer-period, thick-shelled Miras also in the LMC, including photometry from IRAS and ISO. The studies by Feast et al. and by Whitelock et al. encompassed stars with multiple near-IR observations and therefore well defined mean magnitudes. Groenewegen \& Whitelock (1996) used data for spectroscopically confirmed C stars only, but included those with single observations to provide a larger sample of LMC stars. All of these papers found rather similar bolometric PL relations for the C stars.

Here we combine the data from Feast et al. (1989) and Whitelock et al. (2003) to derive a PL relation for the C stars that covers the period range of interest for the Galac-


Figure 5. For the Miras, $K-[12]$ colour as a function of the pulsation amplitude at $K, \Delta K$. Symbols as in Fig. 1
tic C stars under discussion. We omit four stars classed by Whitelock et al. as C-rich: WBP14 for which the data were uncertain; 04496-6958 and SHV 05210-6904, which lie above the PL relation (Whitelock et al. suggested that this may be the result of extra energy from hot bottom burning, although that conclusion is controversial for a carbon star and more detailed studies are required to investigate these luminous stars); 05128-6455 which Matsuura et al. (2005) have shown to be O-rich. Thus we have 38 C-rich Miras which are illustrated in a PL diagram (Fig. 6), for which a least squares fit gives:
$M_{b o l}=-2.54 \log P+1.87, \quad(\sigma=0.17)$
assuming that the distance modulus of the LMC is 18.50 mag. This is close to the relationships given in the various references cited above and is what we use in Section 9 to derive distances. Some of the 0.17 mag dispersion will be introduced by the limited temporal coverage of IRAS (the satellite did not observe long enough to provide mean magnitudes for these long period stars).

This PL is distinctly different from that derived for Orich Miras (Feast et al. 1989; Whitelock et al. 2003). Due to the differences in slope the relations, which are close at short periods, diverge at long period. At a period of 500 days the C-Miras are 27 percent fainter than their O-rich counterparts at the same period. Part of this difference may be due to the different energy distributions of the O- and C-rich stars which can lead to different systematic errors affecting the estimates of total luminosity (e.g. the strong water features which are present in O-rich, but not C-rich Miras). However, the large differences at long periods suggest that there may be real luminosity differences between the two types of Mira at a given period.

The PL relationship is revisited in Paper III of this series, where the kinematics of the Galactic C Miras are used to derive a zero-point.


Figure 6. The PL relation for C-rich Miras in the LMC. The crosses and circles represent stars from Feast et al. (1989) and from Whitelock et al. (2003), respectively. The straight line is the locus given by equation 1

## 6 INFRARED COLOURS

In the following analysis we compare various data on Galactic C-rich Miras with comparable measurements of LMC objects. The LMC samples are taken from Feast et al. (1989) (with updated periods from Glass \& Lloyd Evans (2003)) and Whitelock et al. (2003). Note that the Feast et al. stars, which were optically selected, do not have $L$ or IRAS observations; many of the Whitelock et al. sample, which were selected from IRAS sources, do not have $J$ measurements; thus not all the stars appear in all the diagrams. Two bright LMC C stars with distinctly blue colours for their period are always distinguished in the illustrations. These stars, which also lie above the bolometric period-luminosity relation, are thought to be undergoing hot bottom burning (Whitelock et al. 2003).

Figs. 7 and 9 illustrate the colours prior to correction for reddening. The stars illustrated here are those with 10 and 20 classifications in Table 2 and with at least 9 observations contributing to the mean. Thus they represent well-characterized normal Miras and non-Miras as far as it is possible to define them.

It is clear that the Miras spread to much redder colours than the non-Miras as one might expect given their higher mass-loss rates and resultant circumstellar shells. At the blue extreme the non-Miras and Miras follow slightly different loci in the two-colour diagrams, but the differences are subtle and it is not possible to distinguish between individuals in the two groups simply on the basis of their colours. This is in marked contrast to the situation for O-rich stars (e.g. Whitelock et al. 1995).

The lines illustrated in these two figures represent a maximum likelihood fit to the Mira data and are given in equations 7 and 8 which are discussed later.

The reddening-corrected colours for the Miras only are illustrated in Figs. 8 and 10 where they are compared to the colours of Miras in the LMC (the derivation of the reddening corrections is given in Section 9 below). The colours of the Miras with peculiarities (class $1 \mathrm{n}, \mathrm{n}=1,5$ ), which are il-


Figure 7. A two-colour diagram comparing Miras (crosses) having known periods, with non-Miras (open circles); stars from both groups are well observed (at least 9 measurements) and lack obvious peculiarities. The locus for the Miras, given in equation 7 is illustrated as is a reddening vector for $A_{V}=10 \mathrm{mag}$.


Figure 8. As Fig. 7 but after correcting for interstellar extinction as described in section 9 and showing only the Miras, but including those with peculiarities (open crosses). The filled circles are the LMC Miras, with the two large open circles representing LMC stars suspected of undergoing hot bottom burning.
lustrated as open crosses, do not differ significantly from the class 10 Miras. The loci illustrated in the two figures were fitted by maximum likelihood to the class 10 objects only:
$(H-K)_{0}=-0.549+1.002(J-H)_{0}, \quad(\sigma=0.010)$,
$(K-L)_{0}=-0.252+1.295(H-K)_{0}, \quad(\sigma=0.014)$,
Note that the $J$ values for some of the faint LMC sources


Figure 9. As Fig. 7 but for alternative colours. The locus described by equation 8 is shown.


Figure 10. As Fig. 9 but after correcting for interstellar extinction as described in section 9 and showing only the Miras; the symbols are as in Fig. 8
in Fig. 8 are uncertain by up to 0.2 mag , as are the $H$ values for the faintest LMC sources in Fig 10 There appears to be a small shift between the LMC and the Galactic $J H K$ colours in that $(J-H)$ for the LMC sources is on average $\leqslant 0.1 \mathrm{mag}$ less for the LMC stars than for the Galactic ones at the same $(K-L)$. Cohen et al. (1981) discuss a colour difference between Galactic and LMC C-stars in the same sense, but few of their sample are Miras and their stars are in the colour range $0.4<(H-K)_{0}<0.8$. For $(H-K)_{0}<0.8$ we find that LMC and Galactic C-rich Miras occupy the same part of the two-colour diagram. This diagram is obviously rather sensitive to reddening corrections and to errors in transfor-


Figure 11. Period $(H-K)$ colour relationship for Galactic (crosses) and LMC (closed circles) C stars. The open crosses represent Galactic Miras with 1n ( $\mathrm{n}>1$ ) classifications. The two LMC points with circles around them are luminous Miras thought to be undergoing hot bottom burning. The locus described by equation 4 is shown.


Figure 12. Period $(K-L)$ colour relationship with symbols as in Fig 11 The locus described by equation 5 is shown.
mation between different photometric systems, which tend to be largest for $J$.

The Galactic $(H-K)_{0}$ and $(K-L)_{0}$ period-colour relationships are compared to those for Miras in the LMC in Figs. 11 and 12 There is no obvious difference between the class 10 and class $1 \mathrm{n}(\mathrm{n}>1)$ Miras. There appear to be differences between the distributions of LMC and Galactic Miras in these figures, but there is a great deal of overlap between the two samples and the differences could plausibly


Figure 13. $K-[12]$ as a function of period for all of the Miras (class 1n) discussed here, compared with C stars from the LMC (closed circles) C stars. The two LMC points with rings around them are luminous Miras thought to be undergoing hot bottom burning. The locus described by equation 6 is shown.
be attributed to the very different selection effects in the Galactic and LMC samples. In particular it is possible that we would have been unable to measure the $H$ flux for any LMC Miras with extremely red colours ( $H-K>2.8$ ). It is also likely that our selection criteria for the Aaronson and for the IRAS samples would have excluded most short period Miras. The relatively blue $(H-K)$ and $(K-L)$ colours of the Galactic Miras, compared to the LMC ones, with periods less than 500 days is notable.

Although neither $H-K$ nor $K-L$ shows a linear dependence on period there is certainly a trend to larger colours at longer period. The least-squares fit to the Galactic data in Figs. 11 and 12 (omitting the points at the shortest period, SZ Ara, in both figures and the one with the largest $K-L$, LL Peg, in Fig. [12) gives the following relationships:
$(H-K)_{0}=-15.69+6.412 \log P \quad(\sigma=0.48)$,
and
$(K-L)_{0}=-20.56+8.300 \log P \quad(\sigma=0.61)$.
Fig. 13]shows $K-[12]$ as a function of period and compares it to LMC data. The straight line is a least squares fit to the Galactic data, which yields:
$K_{0}-[12]=-43.0+17.7 \log P \quad(\sigma=1.5)$
$K-[12]$ is a very good indicator of the optical depth of the dust shell and hence of the dust mass-loss rate (e.g. Whitelock et al. 1994). There has been some discussion in the literature of differences in mass-loss rates between the Magellanic Clouds and the Galaxy. Such differences might be expected if Magellanic Cloud Miras have lower metallicity than their Galactic counterparts and therefore form dust with lower efficiency. If, however, the pulsation period of the Mira is a function of its metallicity, as it is for Orich Miras (Feast \& Whitelock 2000), differences between


Figure 14. As Fig. 13 but showing only stars from the IRAS sample (asterisks), the faint IRAS sample (crosses) and the Aaronson sample (open crosses); note that four of the Aaronson sample are also faint IRAS sources. The line is equation 6
the two systems will be more subtle. A recent analysis by van Loon (2006) suggests that, while the situation is very complex, there is no evidence for a mass-loss rate dependence on metallicity. The differences seen in Fig. 13] seem to be relatively minor and may be due to selection effects in the various samples rather than to fundamental properties of the two galaxies.

The very large effect of selection criteria is well illustrated by Fig. 14 which shows only the Galactic C stars, but distinguished according to the original sample from which they were drawn. Note that there is almost no overlap between the bright IRAS selected stars, most of which have $K-[12] \geqslant 5 \mathrm{mag}$, and the optically selected Aaronson sample which all have $K-[12] \leqslant 5 \mathrm{mag}$. It is clear that the C Miras show a large range of colour at a given period and that selection criteria will determine how this range is sampled.

## 7 APPARENT BOLOMETRIC MAGNITUDES

The bolometric magnitude was calculated by spline fitting to the $J H K L, 12$ and $25 \mu \mathrm{~m}$ flux as a function of frequency, as described in Section 6 of Whitelock et al. (1994) and/or by spline fitting to $J H K L$ MSX- $A$ flux in the same way.

Some preliminary tests were done to compare the results of using spline fits to $J H K L$ and MSX- $A,-C$ and $-D$ fluxes with those on $J H K L$ and MSX- $A$. This because there were only 67 stars with the full data set. These tests indicated that a small colour correction was necessary if the integrations using only MSX- $A$ were to give the same result as the full dataset. Thus the bolometric magnitudes derived by spline fitting $J H K L$ and MSX- $A$ were corrected by $0.0119-0.0148 \times(K-L)$; its largest effect is to change the bolometric magnitude by only -0.055 mag .

There were 91 Miras with both MSX- $A$ and IRAS data and the mean difference in the bolometric magnitudes de-
rived from the two sets (IRAS-MSX) was $-0.02 \pm 0.03 \mathrm{mag}$, with extreme values of -0.73 and +0.35 . The corrections with the largest absolute values were always for the redder sources, as the mid-infrared is less important for the bluer sources.

Where there is no value for $J$ (24 stars), $H$ ( 3 stars) or $L$ ( 1 star) an estimate is made from one of the following relations, for the purpose of calculating the bolometric magnitude:
$(H-K)=-0.642+1.011(J-H)$,
$(H-K)=+0.233+0.769(K-L)$.
These loci are illustrated in Figs. 7 and 9 If the $12 \mu \mathrm{~m}$ flux has been measured, but the $25 \mu \mathrm{~m}$ flux has not, the colour corrected [25] is estimated from:
$([12]-[25])_{c c}=0.0337+0.109(K-[12])$.
Because it is only for very red stars that $J$ or $H$ were not measured, and only for blue ones that [25] was not measured, these estimates do not compromise the quality of the final bolometric magnitude. The $L$ flux is much more important, but only one Mira with a known period, CF Cru, does not have a measured value for $L$, which is estimated from $H$ via equation 8 above.

Given that we chose to reject the faint cycles for the very well observed stars we examine briefly the difference it would make to the bolometric magnitudes if we used faint rather than bright cycles, assuming that the cause of the change is line of site obscuration and that the IRAS and/or MSX fluxes remain constant. R For would go from $m_{b o l}=4.54$ to 4.97 , R Lep from $m_{b o l}=3.52$ to 4.13 and II Lup from $m_{b o l}=3.89$ to 4.07 , the size of the change being strongly dependent on the relative contributions to the total flux from $J H K L$ and from the mid-infrared.

## 8 BOLOMETRIC CORRECTIONS

The main interest in bolometric corrections is their use when limited data are available. With this in mind we provide, in Table 5 the coefficients of the best fit least squares fourth order polynomials to the bolometric correction at $K, \mathrm{BC}_{K}$ as a function of the colour $(x-y)$ :
$B C_{K}=c_{0}+c_{1}(x-y)+c_{2}(x-y)^{2}+c_{3}(x-y)^{3}+c_{4}(x-y)^{4}$,
for a variety of colours. The table also includes the maximum (max) and minimum (min) values of the colour for which the fit was determined (this type of fit should not be extrapolated), the error ( $\sigma$ ) associated with an individual observation and the number of stars used in the fit (No).

Two examples of these fits are shown in Fig. 15 for $(J-K)_{0}$ and $K_{0}-[12]$. It is clearly possible to derive an accurate bolometric correction if observations in widely separated bands, such as $K$ and [12], are available. In practice it will often only be possible to use something like $(J-K)$ when dealing with photometry from e.g. the 2MASS survey or typical measurements that are now being done on extragalactic C stars with large telescopes.

The curves listed in Table 5 provide excellent fits to the LMC C-star bolometric corrections discussed by Whitelock et al. (2003) and illustrated in their fig. 13, although

Table 5. Coefficients for calculating the bolometric correction as a function of colour according to equation 10.

|  | $(J-K)_{0}$ | $(H-K)_{0}$ | $(K-L)_{0}$ | $(K-[12])_{0}$ | $(K-A)_{0}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $c_{0}$ | 0.972 | 2.360 | 3.228 | 2.801 | 3.130 |
| $c_{1}$ | 2.9292 | 3.1729 | 0.8720 | 0.7101 | 0.4807 |
| $c_{2}$ | -1.1144 | -2.5747 | -0.7042 | -0.1958 | -0.1655 |
| $c_{3}$ | 0.1595 | 0.5462 | 0.06350 | 0.01032 | 0.002241 |
| $c_{4}$ | $-9.568910^{-3}$ | -0.043014 | $-1.634110^{-3}$ | $-2.205410^{-4}$ | $-2.240510^{-4}$ |
| $\max$ | 6.5 | 4.0 | 6.2 | 14 | 10 |
| $\min$ | 1.5 | 0.5 | 0.3 | 1.2 | 0.5 |
| $\sigma$ | 0.23 | 0.27 | 0.17 | 0.11 | 0.13 |
| No. | 123 | 142 | 144 | 144 | 70 |

the LMC data do show more scatter because the stars are fainter. There is no evidence of any difference between C stars in the Galaxy and the LMC in respect of the bolometric corrections as a function of colour.

The lack of scatter in Fig. [15]is largely a consequence of the way the bolometric magnitudes are calculated. Thus, for example, if we examine II Lup during a bright cycle ( $\bar{K}=$ 1.79 mag ) we derive $K-[12]=5.92$ and $B C_{K}=2.15$, while during a faint cycle ( $\bar{K}=3.0 \mathrm{mag}$ ) we obtain $K-[12]=7.12$ and $B C_{K}=1.2$; both of these points fit on the curve in Fig. 15 The bolometric magnitude derived from these data, $m_{\text {bol }}=0.48$ and 0.52 , are not very different because the $J H K L$ flux is only a small part of the total. In contrast, for R Lep we obtain $K-[12]=2.81$ and $B C_{K}=3.47$ when it is bright ( $\bar{K}=0.07 \mathrm{mag}$ ) and $K-[12]=3.54$ and $B C_{K}=3.36$ when it is faint ( $\bar{K}=0.8 \mathrm{mag}$ ). Again the points fall close to the curve in Fig. 15 but the resulting bolometric magnitudes, $m_{b o l}=3.52$ and 4.13, differ considerably because the $J H K L$ flux is a major contributor to the total.

Fig. 15 also shows a comparison with the bolometric correction derived by Guandalini et al. (2005) for a slightly different colour ( $K-[12.5]$ ). The two relations differ by at most 0.19 mag in the region in which there are many points, $3<K-[12]<4$, and this difference goes up to 0.36 mag at $K-[12]=14$.

## 9 INTERSTELLAR REDDENING AND DISTANCES

We assume that the Galactic C-rich Miras obey the LMC bolometric PL relation as discussed above (Section 5). Thus a first estimate can be made of the distance to the star by comparing the measured and absolute bolometric magnitudes. The extinction is then estimated using the Drimmel et al. (2003) three dimensional Galactic extinction model, including the rescaling factors that correct the dust column density to account for small scale structure seen in the DIRBE data, but not described explicitly by the model. The measured mean JHKL magnitudes are corrected for extinction following the reddening law given by Glass (1999) and the bolometric flux is recalculated. This process of calculating distance, extinction and bolometric magnitude is then iterated as necessary, typically two to five times, until the distance modulus changes by less than 0.01 mag. The extinction values, $A_{V}$, derived in this way are listed in Table 6


Figure 15. The bolometric correction at $K$ as a function of (top) $(J-K)_{0}$ and (bottom) $K_{0}-[12]$. The curves are fourth order polynomials with the parameters given in Table5 The lower figure also shows LMC values (solid circles) from Whitelock et al. (2003). The dashed curve is the relation for $K-$ [12.5] from Guandalini et al. (2005) fig. 5.

They range up to $A_{V} \sim 5.8$ and therefore have a significant effect on the $J H K L$ colours and on the derived distances.

We have 70 stars in common with those of Groenewegen et al. (2002) for which the derived distances can be compared. Groenewegen et al. calculate distances either from the PL relation of Groenewegen \& Whitelock (1996), for stars with known periods longer than 390 days, or from the $12 \mu \mathrm{~m}$ flux, with a bolometric correction that depends on the 25 to $12 \mu \mathrm{~m}$ flux ratio, for the others. The statistical agreement is good, with the average distance calculated by Groenewegen et al. for the 70 stars in common being only 8 percent larger than our value.

Table 6: Derived data for Miras with pulsation periods.

| name | $\begin{array}{r} \text { dist } \\ (\mathrm{kpc}) \end{array}$ | $A_{V}$ | $m_{\text {bol }}$ | $(J-H)_{0}$ | $\begin{array}{r} \hline(H-K)_{0} \\ (\mathrm{mag}) \end{array}$ | $(K-L){ }_{0}$ | $K_{0}-[12]$ | $K_{0}$ | $\begin{gathered} \log \dot{M} \\ \left(\mathrm{M}_{\odot} \mathrm{yr}^{-1}\right) \end{gathered}$ | $\begin{gathered} \mathrm{BC}_{K} \\ (\mathrm{mag}) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| YY Tri | 2.25 | 0.24 | 6.53 |  | 2.99 | 3.74 | 8.43 | 6.79 | -4.45 | -0.26 |
| R For | 0.70 | 0.04 | 4.54 | 1.67 | 1.20 | 1.28 | 3.62 | 1.21 | -5.87 | 3.33 |
| [TI98]0418+0122 | 6.42 | 0.37 | 9.24 | 1.83 | 1.33 | 1.46 | 3.61 | 5.98 | $-5.73$ | 3.26 |
| V718 Tau | 1.46 | 1.35 | 6.12 | 1.70 | 1.15 | 1.15 | 3.42 | 2.72 | -5.85 | 3.41 |
| R Lep | 0.47 | 0.25 | 3.52 | 1.43 | 0.94 | 1.00 | 2.81 | 0.05 | -6.03 | 3.47 |
| QS Ori | 2.65 | 0.69 | 7.17 | 1.50 | 0.98 | 1.04 | 3.08 | 3.74 | -5.89 | 3.43 |
| 05418-3224 | 2.73 | 0.04 | 7.24 | 2.47 | 1.82 | 2.11 | 5.49 | 4.86 | -5.19 | 2.38 |
| 06088+1909 | 2.37 | 1.18 | 6.91 | 2.37 | 1.74 | 1.96 | 4.98 | 4.15 | -5.08 | 2.76 |
| ZZ Gem | 1.76 | 0.61 | 6.75 | 1.32 | 0.77 | 0.58 | 1.85 | 3.15 | -6.65 | 3.60 |
| V617 Mon | 2.94 | 1.01 | 7.48 | 1.68 | 1.22 | 1.29 | 3.05 | 4.08 | -5.96 | 3.41 |
| V636 Mon | 1.09 | 0.45 | 5.11 | 1.83 | 1.28 | 1.39 | 3.39 | 1.78 | $-5.76$ | 3.34 |
| V477 Mon | 2.61 | 1.01 | 6.86 | 2.31 | 1.84 | 2.24 | 5.12 | 4.46 | -4.83 | 2.40 |
| RT Gem | 3.43 | 0.54 | 8.08 | 1.24 | 0.56 | 0.39 | 1.44 | 4.57 |  | 3.51 |
| $06487+0551$ | 2.40 | 0.80 | 6.84 | 2.47 | 1.91 | 2.34 | 5.47 | 4.55 | $-5.36$ | 2.29 |
| CG Mon | 1.99 | 0.75 | 6.69 | 1.29 | 0.61 | 0.52 | 1.53 | 3.23 |  | 3.46 |
| CL Mon | 1.11 | 0.47 | 5.22 | 1.67 | 1.15 | 1.27 | 3.34 | 1.84 | $-5.85$ | 3.38 |
| 06531-0216 | 2.01 | 0.86 | 6.35 | 1.97 | 1.49 | 1.70 | 3.86 | 3.27 |  | 3.07 |
| 06564+0342 | 2.99 | 0.83 | 7.24 | 2.58 | 2.11 | 2.55 | 5.84 | 5.35 | -5.27 | 1.89 |
| 07080-0106 | 3.76 | 0.16 | 7.70 | 2.80 | 2.44 | 2.73 | 6.63 | 6.22 | -4.71 | 1.48 |
| VX Gem | 1.88 | 0.03 | 6.66 | 1.22 | 0.61 | 0.35 | 1.92 | 3.13 | -6.54 | 3.53 |
| R Vol | 0.88 | 0.49 | 4.84 | 1.89 | 1.40 | 1.61 | 3.83 | 1.67 | -5.70 | 3.18 |
| HX CMa | 1.68 | 0.74 | 5.73 | 2.38 | 1.79 | 2.17 | 5.81 | 3.55 | -4.90 | 2.18 |
| 07217-1246 | 2.18 | 0.84 | 6.47 | 2.47 | 1.97 | 2.35 | 5.64 | 4.22 | -4.98 | 2.24 |
| 07220-2324 | 2.75 | 1.13 | 7.09 | 2.59 | 1.96 | 2.26 | 5.22 | 4.67 | -5.22 | 2.42 |
| [W71b]007-02 | 4.34 | 1.33 | 8.29 | 1.62 | 1.07 | 1.08 | 2.85 | 4.81 |  | 3.49 |
| 07373-4021 | 1.09 | 0.54 | 5.30 | 1.81 | 1.26 | 1.44 | 4.21 | 2.18 | -5.51 | 3.12 |
| V471 Pup | 4.17 | 1.43 | 8.39 | 1.14 | 0.56 | 0.44 | 1.85 | 5.00 |  | 3.39 |
| 07454-7112 | 0.83 | 0.45 | 4.60 | 2.90 | 2.23 | 2.73 | 6.08 | 2.78 | -5.14 | 1.82 |
| V831 Mon | 2.33 | 0.09 | 7.31 | 1.53 | 1.09 | 1.13 | 3.29 | 3.88 | -6.05 | 3.43 |
| 07576-4054 | 2.86 | 1.25 | 7.26 |  | 2.59 | 3.17 | 7.45 | 6.51 | -5.18 | 0.75 |
| 07582-1933 | 2.49 | 0.44 | 6.91 | 2.91 | 2.32 | 2.68 | 6.51 | 5.35 | -5.02 | 1.56 |
| [ABC89]Pup38 | 12.30 | 0.98 | 10.63 | 1.75 | 1.30 | 1.33 | 3.75 | 7.34 |  | 3.29 |
| FF Pup | 3.77 | 0.58 | 8.06 | 1.20 | 0.65 | 0.66 | 2.65 | 4.64 |  | 3.42 |
| V518 Pup | 2.03 | 0.10 | 6.67 | 2.05 | 1.37 | 1.45 | 4.08 | 3.51 | -5.68 | 3.16 |
| 08050-2838 | 2.63 | 0.97 | 7.01 | 3.01 | 2.14 | 2.47 | 6.04 | 4.99 | -5.10 | 2.01 |
| 08074-3615 | 2.40 | 1.52 | 6.37 |  | 3.94 | 4.52 | 10.80 | 8.95 | -4.32 | -2.59 |
| [ABC89]Ppx19 | 5.89 | 2.19 | 8.93 | 1.97 | 1.52 | 1.78 | 4.12 | 5.91 |  | 3.01 |
| V346 Pup | 1.36 | 0.88 | 5.57 | 2.65 | 2.11 | 2.55 | 6.40 | 3.67 | -4.85 | 1.90 |
| [ABC89]Ppx40 | 5.13 | 1.54 | 8.74 | 1.36 | 0.69 | 0.56 | 1.71 | 5.22 |  | 3.52 |
| [W71b]029-02 | 4.88 | 3.04 | 8.53 | 1.87 | 1.46 | 1.63 | 3.41 | 5.35 |  | 3.17 |
| 08340-3357 | 2.26 | 0.83 | 6.60 | 3.06 | 2.48 | 3.01 | 7.17 | 5.53 | -4.84 | 1.07 |
| R Pyx | 1.35 | 0.38 | 6.00 | 1.23 | 0.73 | 0.70 | 2.07 | 2.50 | -6.38 | 3.50 |
| UW Pyx | 1.50 | 0.67 | 6.11 | 1.34 | 0.74 | 0.80 | 2.36 | 2.62 | -6.28 | 3.49 |
| 08535-4724 | 3.51 | 4.53 | 7.64 |  | 2.91 | 3.33 | 8.07 | 7.17 | -4.53 | 0.47 |
| 08534-5055 | 4.29 | 2.20 | 7.90 |  | 3.32 | 3.85 | 9.22 | 8.30 | -4.24 | -0.40 |
| IQ Hya | 1.55 | 0.53 | 6.26 | 1.56 | 1.14 | 1.23 | 3.10 | 2.84 | -6.05 | 3.42 |
| CQ Pyx | 1.14 | 0.49 | 4.99 |  | 3.30 | 3.87 | 9.30 | 5.94 | -4.76 | -0.94 |
| 09176-5147 | 3.17 | 3.64 | 7.69 | 2.58 | 2.05 | 2.52 | 6.49 | 5.98 | -4.77 | 1.71 |
| [W71b]046-02 | 5.12 | 5.63 | 9.26 | 1.15 | 0.54 | 0.35 | 1.37 | 5.87 |  | 3.40 |
| [ABC89]Vel44 | 4.18 | 3.34 | 8.33 | 1.41 | 0.89 | 0.91 | 2.46 | 4.85 |  | 3.48 |
| 09433-6233 | 8.66 | 0.90 | 9.60 | 2.29 | 1.70 | 1.97 | 5.31 | 7.10 | -5.02 | 2.50 |
| CW Leo | 0.14 | 0.07 | 0.40 | 3.29 | 2.85 | 3.73 | 9.25 | 1.18 | -4.65 | -0.78 |
| 09513-5324 | 1.79 | 1.87 | 6.05 | 3.12 | 2.41 | 2.95 | 6.75 | 4.90 | -4.82 | 1.15 |
| 09529-5506 | 2.80 | 1.82 | 6.90 | 2.55 | 1.98 | 2.63 | 6.87 | 5.65 | -4.69 | 1.25 |
| 09533-6021 | 4.81 | 1.48 | 8.03 | 3.08 | 2.42 | 2.92 | 6.97 | 6.90 | -4.74 | 1.14 |
| 09521-7508 | 1.12 | 0.72 | 5.19 | 2.67 | 2.09 | 2.49 | 5.83 | 3.15 | -5.19 | 2.03 |
| 09586-6150 | 9.13 | 1.03 | 9.80 |  | 2.77 | 3.24 | 7.46 | 9.10 | -4.75 | 0.71 |

Continued on Next Page...

| name | $\begin{array}{r} \text { dist } \\ (\mathrm{kpc}) \end{array}$ | $A_{V}$ | $m_{\text {bol }}$ | $(J-H)_{0}$ | $\begin{array}{r} \hline(H-K)_{0} \\ (\mathrm{mag}) \end{array}$ | $(K-L)_{0}$ | $K_{0}-[12]$ | $K_{0}$ | $\begin{gathered} \log M \\ \left(M_{\odot} y r^{-1}\right) \\ \hline \end{gathered}$ | $\begin{array}{r} \mathrm{BC}_{K} \\ (\mathrm{mag}) \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 10026-5849 | 5.68 | 4.73 | 8.72 | 1.79 | 1.29 | 1.47 | 3.71 | 5.47 |  | 3.25 |
| 10098-5742 | 3.91 | 3.54 | 7.81 |  | 2.52 | 3.15 | 7.55 | 7.23 |  | 0.58 |
| 10109-5958 | 2.95 | 1.70 | 7.55 | 1.58 | 1.11 | 1.16 | 3.05 | 4.12 |  | 3.43 |
| RW LMi | 0.46 | 0.09 | 3.10 | 2.74 | 2.10 | 2.53 | 6.35 | 1.31 | -4.94 | 1.78 |
| 10199-5801 | 4.39 | 4.33 | 7.90 | 2.83 | 2.04 | 2.49 | 5.82 | 5.81 | -4.10 | 2.09 |
| 10220-5858 | 5.45 | 3.73 | 8.52 | 1.51 | 1.00 | 1.02 | 2.67 | 5.05 |  | 3.47 |
| CPD-58 2175 | 5.76 | 4.53 | 8.72 | 2.45 | 1.96 | 2.40 | 6.04 | 6.73 |  | 1.99 |
| CZ Hya | 1.35 | 0.13 | 5.80 | 1.40 | 0.92 | 1.00 | 3.05 | 2.38 | -6.06 | 3.42 |
| TV Vel | 1.84 | 1.08 | 6.57 | 1.14 | 0.51 | 0.45 | 1.53 | 3.14 |  | 3.43 |
| [ABC89]Car73 | 6.05 | 4.52 | 8.97 | 2.10 | 1.48 | 1.73 | 3.83 | 5.93 |  | 3.04 |
| [ABC89]Car84 | 4.54 | 4.45 | 8.30 | 1.21 | 0.75 | 0.89 |  | 4.93 |  | 3.36 |
| [ABC89]Car87 | 7.09 | 3.46 | 9.33 | 1.18 | 0.76 | 0.53 | 1.28 | 5.81 |  | 3.53 |
| [ABC89]Car105 | 2.95 | 2.57 | 7.37 | 1.57 | 1.07 | 1.21 | 3.15 | 4.01 |  | 3.36 |
| 11145-6534 | 1.73 | 1.51 | 5.96 | 2.91 | 2.34 | 2.73 | 6.37 | 4.35 | -4.82 | 1.61 |
| [W65] c13 | 5.38 | 4.53 | 8.93 | 1.27 | 0.78 | 0.74 | 1.86 | 5.44 |  | 3.49 |
| [TI98]1130-1020 | 2.16 | 0.09 | 6.82 | 2.13 | 1.63 | 1.84 | 4.82 | 4.03 | $-5.56$ | 2.79 |
| 11318-7256 | 0.66 | 0.56 | 4.07 | 1.82 | 1.24 | 1.48 | 3.47 | 0.80 | -5.66 | 3.27 |
| [ABC89]Cen4 | 4.00 | 1.68 | 8.00 | 1.41 | 0.74 | 0.77 | 2.49 | 4.53 |  | 3.47 |
| 11463-6320 | 3.13 | 2.77 | 7.27 | 2.59 | 1.89 | 2.33 | 5.56 | 5.19 | -4.84 | 2.08 |
| [ABC89]Cen32 | 4.40 | 2.58 | 7.94 | 2.00 | 1.46 | 1.65 | 3.75 | 4.82 | -5.45 | 3.12 |
| [ABC89]Cen43 | 6.06 | 3.93 | 8.85 | 1.55 | 1.11 | 1.23 | 2.77 | 5.46 |  | 3.39 |
| [ABC89]Cen60 | 5.25 | 3.50 | 8.82 | 1.44 | 0.91 | 0.99 | 2.85 | 5.39 |  | 3.43 |
| CF Cru | 5.88 | 5.80 | 9.03 | 1.14 | 0.56 |  | 1.79 | 5.68 |  | 3.35 |
| 12194-6007 | 2.84 | 2.21 | 7.04 | 2.35 | 1.90 | 2.29 | 5.44 | 4.76 | -5.21 | 2.28 |
| 12298-5754 | 1.85 | 1.58 | 6.19 | 2.46 | 2.15 | 2.63 | 6.00 | 4.26 | -4.86 | 1.93 |
| CGCS3268 | 2.05 | 1.36 | 6.83 | 1.20 | 0.76 | 0.59 | 2.39 | 3.31 |  | 3.52 |
| 12394-4338 | 1.33 | 0.34 | 5.53 | 2.56 | 1.96 | 2.17 | 4.76 | 2.88 | -5.41 | 2.65 |
| 12421-6217 | 4.87 | 5.42 | 8.03 |  |  | 3.73 | 8.76 | 7.98 | -4.24 | 0.06 |
| RU Vir | 0.91 | 0.08 | 4.94 | 1.76 | 1.28 | 1.51 | 4.08 | 1.79 | -5.69 | 3.15 |
| V Cru | 1.47 | 0.98 | 6.16 | 1.14 | 0.52 | 0.39 | 1.49 | 2.79 |  | 3.37 |
| 12540-6845 | 1.37 | 0.65 | 5.52 | 2.61 | 1.96 | 2.34 | 5.89 | 3.46 | -4.71 | 2.06 |
| 13343-5807 | 2.40 | 1.94 | 6.82 | 2.50 | 1.94 | 2.32 | 5.66 | 4.80 | -5.14 | 2.01 |
| 13477-6532 | 2.32 | 1.36 | 6.49 |  | 2.96 | 3.78 | 8.24 | 6.50 | -4.52 | -0.01 |
| 13482-6716 | 1.70 | 0.87 | 6.17 | 2.59 | 1.96 | 2.25 | 5.17 | 3.70 | -5.20 | 2.47 |
| 13509-6348 | 2.98 | 2.30 | 7.06 |  |  | 2.30 | 5.89 | 4.91 | -5.16 | 2.15 |
| [ABC89]Cir26 | 3.81 | 4.11 | 7.93 | 1.97 | 1.33 | 1.58 | 3.53 | 4.75 |  | 3.18 |
| [ABC89]Cir27 | 3.57 | 4.14 | 7.70 | 1.93 | 1.59 | 1.98 | 4.50 | 4.89 | $-5.35$ | 2.80 |
| 14395-5656 | 6.58 | 3.41 | 9.13 | 1.57 | 0.99 | 1.13 | 2.71 | 5.70 |  | 3.43 |
| 14404-6320 | 3.62 | 2.55 | 7.53 |  | 2.98 | 3.82 | 8.83 | 8.09 | -4.75 | -0.55 |
| 14443-5708 | 5.17 | 3.43 | 8.27 |  | 3.62 | 3.84 | 9.08 | 8.62 | -4.15 | -0.35 |
| 15082-4808 | 0.95 | 0.60 | 4.65 | 2.93 | 2.60 | 3.47 | 7.92 | 4.31 | -4.67 | 0.35 |
| 15084-5702 | 3.48 | 3.58 | 7.05 |  | 3.29 | 3.80 | 8.36 | 7.00 | -4.10 | 0.04 |
| II Lup | 0.64 | 0.48 | 3.89 | 2.29 | 1.76 | 2.10 | 5.92 | 1.75 | -4.82 | 2.15 |
| 15261-5702 | 3.31 | 1.51 | 7.23 |  | 2.40 | 2.82 | 6.44 | 5.82 | -4.72 | 1.41 |
| 16079-4812 | 2.13 | 3.36 | 6.28 |  | 3.18 | 3.82 | 8.36 | 6.54 | -4.69 | -0.26 |
| NP Her | 2.44 | 0.17 | 7.07 | 1.41 | 0.85 | 0.70 | 2.22 | 3.48 | -6.37 | 3.59 |
| 16171-4759 | 2.84 | 2.70 | 7.16 | 2.40 | 1.83 | 2.07 | 5.35 | 4.64 |  | 2.52 |
| V Oph | 0.78 | 0.90 | 5.06 | 1.20 | 0.68 | 0.58 | 1.55 | 1.53 | $-6.95$ | 3.53 |
| CGCS3721 | 2.71 | 1.29 | 7.56 | 1.34 | 0.88 | 0.78 | 2.24 | 4.00 |  | 3.56 |
| 16538-4633 | 2.42 | 2.57 | 6.88 | 2.49 | 1.64 | 1.85 | 4.65 | 4.04 | -4.67 | 2.84 |
| 16545-4214 | 1.03 | 0.75 | 5.01 | 2.56 | 1.93 | 2.11 | 5.23 | 2.45 | -5.02 | 2.56 |
| 17047-2848 | 3.22 | 1.31 | 7.49 | 2.22 | 1.65 | 2.02 | 5.62 | 5.24 | -5.07 | 2.25 |
| V2548 Oph | 1.09 | 0.87 | 4.75 |  | 2.82 | 3.59 | 9.15 | 5.53 | -4.47 | -0.78 |
| SZ Ara | 2.44 | 0.47 | 7.84 | 1.11 | 0.52 | 0.37 | 1.40 | 4.41 | -6.48 | 3.44 |
| V617 Sco | 1.29 | 1.19 | 5.52 | 1.39 | 0.91 | 0.89 | 2.88 | 2.06 |  | 3.46 |
| 17105-3746 | 2.73 | 3.20 | 7.07 | 2.23 | 1.82 | 2.40 | 5.81 | 4.85 | -4.75 | 2.22 |
| 17130-3907 | 2.24 | 1.62 | 6.52 | 2.59 | 1.82 | 2.07 | 5.13 | 4.08 | -4.90 | 2.44 |
| 17217-3916 | 2.88 | 2.03 | 7.10 |  | 2.75 | 3.19 | 7.60 | 6.24 |  | 0.86 |
| 17222-2328 | 2.64 | 2.58 | 6.92 | 2.73 | 1.90 | 2.18 | 4.84 | 4.37 | -5.14 | 2.55 |

Continued on Next Page. . .
$\left.\begin{array}{lrrrrcrrrrr}\hline \text { name } & \begin{array}{r}\text { dist } \\ (\mathrm{kpc})\end{array} & A_{V} & m_{\text {bol }} & (J-H)_{0} & \begin{array}{c}(H-K)_{0} \\ (\mathrm{mag})\end{array} & & (K-L)_{0} & K_{0}-[12] & K_{0} & \begin{array}{c}\log M^{\prime} \\ \left(M_{\odot} y r^{-1}\right)\end{array}\end{array} \begin{array}{r}\mathrm{BC}_{K} \\ (\mathrm{mag})\end{array}\right]$

There are, however, some individually large differences and some systematic trends. For the bluer sources ( $K-$ $[12]<6)$ our distances tend to be smaller because the apparent bolometric flux we derive is larger and there is a clear trend with colour. The Groenewegen et al. results for the 34 stars with $K-[12]<5.9$ are 24 percent more distant than we find. The most extreme case is R Cap (200841425), $K-[12]=2.85$, for which we find 1.52 kpc while Groenewegen et al. get 3.45 kpc (Le Bertre et al. (2001) got 1.33 kpc ; see below). The main source of this difference is in the apparent bolometric magnitudes, which differ by 1.25 mag, although the absolute magnitudes also differ in such a way as to increase the difference in derived distance. Our results suggest that Groenewegen et al. systematically underestimated the contribution from $H K L$ to the total flux, thereby underestimating the apparent bolometric flux for blue sources. This will have had very little effect on the red sources that make up the bulk of their C-star sample.

For the redder sources our distances tend to be slightly larger than the Groenewegen et al. ones, but there is no systematic trend with colour for stars with $K-[12]>6$ and the effect is not large. For the 36 stars with $K-[12]>$ 5.9 Groenewegen et al. get distances 6.5 percent less than ours. The most extreme examples are RW LMi, $K-[12]=$ 6.35 , for which we and Groenewegen get 0.32 and 0.46 kpc respectively, and 08534-5055, $K-[12]=9.22$, for which the distances are 3.10 and 4.29 respectively. For RW LMi the difference is entirely in the apparent bolometric magnitude and for $08534-5055$ it is largely so.

Le Bertre et al. (2001) calculate distances using a [2.20$3.77] \mu \mathrm{m}$ dependent bolometric correction to the [2.20] mag, applied to observations obtained with the Japanese IRTS. For this purpose they assume $M_{b o l}=-5.01 \mathrm{mag}$ for all their sources (this is the bolometric magnitude we would associate with a Mira with a period of 530 days) indicating a factor of 1.8 uncertainty for the distances of individual sources owing to this latter assumption. They have only 3 sources in common with us, R Cap, HX CMa and 11318-7256, for which they estimate distances 9 to 30 percent smaller than we do.

CW Leo is a very well studied, thick-shelled, C star for which numerous distance estimates, in the range 0.11 to 0.17 kpc , have been made. It is also one of the few stars for which a geometric distance, of 0.145 kpc , has been measured using the dust outflow speed combined with the proper motion of the shell (Tuthill et al. 2000). This value is in good agreement with our estimate of 0.14 kpc .

Guandalini et al. (2005) tabulate distances (their tables 1 and 2) for various C stars including some Miras. For the four stars in common in their table 1 (which they describe as having "astrometric, or reliable, distance estimates") their distances are, in the mean, 7 percent larger than ours. For the 8 stars listed in both our Table 5 and in their table 2, the mean difference is zero. The distances in table 1 of Guandalini et al. (2005), which are described as "astrometric" are taken from Bergeat \& Chevallier (2005) and are based on a procedure of Knapik et al. (1998) who corrected the Hipparcos parallaxes by a semi-empirical statistical method of their own. Contrary to a standard Lutz-Kelker type approach to this problem, which would have resulted in negative corrections to the parallaxes and absolute magnitudes, both positive and negative corrections result from their method. They do not discuss the uncertainties in the corrections applied.

However, it is clear from table 1 of Bergeat et al. (1998) that these corrections are often large. Knapik et al. (1998) also say (their section 5), ": individual values [of the corrections] may occasionally be wrong and a few such cases were detected from data at hand...... In such cases the catalogue value can be kept if positive or the star is abandoned".

So far as C-Miras are concerned, the possibility of using Hipparcos parallaxes to calibrate the zero-point of the $\mathrm{PL}(K)$ relation was investigated by Whitelock \& Feast (2000). A definitive result was not obtained due primarily to the small number of C-Miras with parallaxes of significant weight. It may be possible to re-investigate this matter when the revision of the Hipparcos catalogue is completed (see van Leeuwen 2005, van Leeuwen \& Fantino 2005).

The distances tabulated here probably represent the best currently available for carbon Miras, particularly for those where the light curve has been well characterized over many cycles. Noting the discussion in the last paragraph of Section 7 there is a potential problem in calculating accurate apparent bolometric luminosities during obscuration events (see also Section 11). If we had made $J H K L$ observations of a C star with a thin dust shell (where most of the bolometric flux is emitted at near-infrared wavelengths) only during an obscuration event, then we would have underestimated its luminosity and overestimated its distance. It also remains possible that we have failed to identify a small number of bright hot-bottom-burning stars for which we will have underestimated the distances.

## 10 MASS-LOSS RATES

Mass-loss rates can be derived for many of these stars using the expression given by Jura (1987):
$\dot{M}=1.7 \times 10^{-7} v_{15} d_{k p c}^{2} L_{4}^{-1 / 2} F_{\nu, 60} \bar{\lambda}_{10}^{1 / 2} \mathrm{M}_{\odot} \mathrm{yr}^{-1}$,
where $v_{15}$ is the outflow velocity in units of $15 \mathrm{~km} \mathrm{~s}^{-1}, d$ is the distance in kpc, $L_{4}$ is the luminosity in units of $10^{4} \mathrm{~L}_{\odot}$, $F_{\nu, 60}$ is the flux from the dust at $60 \mu \mathrm{~m}$ and $\bar{\lambda}$ is the mean wavelength of the light emerging from the star and its shell in units of $10 \mu \mathrm{~m}$. Note that this equation assumes a constant dust-to-gas ratio. The results are given in Table 6

For the outflow velocity $\left(v_{15}\right)$ we use the expansion velocities tabulated by Groenewegen et al. (2002) while noting that those authors, in their own calculation of mass loss add an additional drift velocity (of the order of 2 or $3 \mathrm{~km} \mathrm{~s}^{-1}$ ) to their expansion velocities to determine the outflow velocity. For the stars in our sample which have no measured expansion velocity we assume $19 \mathrm{~km} \mathrm{~s}^{-1}$, this being the mean for the 68 stars in our sample which have all the other parameters necessary to calculate $\dot{M}$. We find that $\bar{\lambda}$ varies from 0.23 to 1.42 , i.e. it is generally somewhat larger than the 0.3 assumed by Groenewegen et al. particularly for the very red stars which constitute the bulk of their sample.

For $F_{\nu, 60}$ we use the IRAS flux at $60 \mu \mathrm{~m}$, and where there is no IRAS flux at this wavelength we do not attempt to calculate mass-loss rates. Note that this approach will result in an overestimate of the mass-loss rate if the shell is very thin and a significant fraction of the $60 \mu \mathrm{~m}$ flux actually originates from the underlying star. We can estimate the effect by assuming the stars radiate as blackbodies at the temperatures given by Bergeat et al. (2002) and using
the $K$ mag given in Table 6 to estimate the stellar contribution to the measured $60 \mu \mathrm{~m}$ flux. Bergeat et al. tabulate temperatures for 4 of the 5 stars (none for R Cap) listed with $\log \dot{M}<-6.4 \mathrm{M}_{\odot} \mathrm{yr}^{-1}$ in Table 6 For V Oph, ZZ Gem, VX Gem and SZ Ara the stellar contribution to the $60 \mu \mathrm{~m}$ flux will be approximately $39,32,23$ and 12 percent, respectively. For these 5 stars (including R Cap, where the contribution from the star is estimated at 20 percent) the mass-loss rates given in the table have been adjusted by the amount indicated; for all the others the effect will be negligible.

For very close stars the $60 \mu \mathrm{~m}$ flux will have been spatially resolved and therefore not entirely included in the IRAS PSC estimate. In which case the mass-loss rates would be underestimated. The 3 stars with distances under 500 pc are the only ones where the extended nature of the source is likely to be significant; these are CW Leo, R Lep and RW LMi. Two of these stars (CW Leo and R Lep) were examined by Young, Phillips \& Knapp (1993) who found extended contributions from both, amounting to about 10 percent of the PSC flux. The mass-loss values tabulated for these three stars have therefore been increased by 10 percent. For all the other stars the effect will probably be insignificant, but certainly less than 10 percent.

A number of authors have calculated mass-loss rates for C-rich Miras and the results differ quite significantly from one paper to another. There are many factors which contribute to these differences, but uncertainty in the distance, which appears squared in equation 11 is always a major factor. This aspect has already been discussed in Section 9

Whitelock et al. (1987) showed that mass-loss rates of relatively thin shelled O-rich Miras depended on their pulsation amplitudes, providing strong support for the role of pulsation in driving mass loss. While it would be very interesting to do a similar exercise for the C Miras under discussion, it is unfortunately not practical. As shown in Fig. [5and discussed in Section 4.3 the $J H K L$ amplitudes tell us little about the pulsation amplitude of the star. Ideally we should measure the bolometric amplitude, but this must await monitoring at mid-infrared wavelengths.

Fig. 16]shows how the mass-loss rates depend on colour. The line is a polynomial fit to the Galactic C Miras:

$$
\begin{array}{r}
\log \dot{M}=-7.668+0.7305(K-[12]) \\
-5.398 \times 10^{-2}(K-[12])^{2}+1.343 \times 10^{-3}(K-[12])^{3} \tag{12}
\end{array}
$$

The LMC Miras discussed by Whitelock et al. (2003) are shown for comparison. The two groups follow the same trend and the slight displacement of the LMC points with respect to the Galactic ones should not be seen as significant in view of the different assumptions that went into the mass-loss rate calculations (see van Loon et al. 1999 for the LMC data). The relationship is also qualitatively similar to that found for O-rich stars (Whitelock et al. 1994 fig. 21) and covers the transition from an optically thin dust shell, $K-[12]<5$, to optically thick one $K-[12]>7$.

## 11 LONG TERM TRENDS, OBSCURATION EVENTS AND THE RCB PHENOMENON

The very extended atmospheres of Miras are intrinsically unstable and all their light curves show some level of vari-


Figure 16. Mass-loss rate as a function of $K-[12]$ colour, for Galactic C Miras (crosses) and LMC C Miras (closed circles, van Loon et al. 1999), the line is equation 12
ability from one cycle to another. However, some Miras show much greater variability (typically around $\Delta K \sim 1 \mathrm{mag}$ on top of the normal pulsation), which can be understood as the result of dramatically changing obscuration from dust. Detailed descriptions have been given for R For (Whitelock et al. 1997) and II Lup (Feast et al. 2003) where the obscurations are attributed to the ejection of dust puffs in our line of sight. It is clear from these references that the dust ejection cannot be in the form of a spherically symmetric shell. A similar phenomenon has been noted in the photographic red magnitudes of northern C stars, measured over a period of 30 years (Alksnis 2003).

These obscuration events in C-rich Miras are phenomenologically similar to those observed in the H -deficient RCB C stars. The RCB stars are characterized by apparently random declines in brightness of 7 mag or more in visual light. The brightness variations are a consequence of the ejection of puffs of material at random times and in essentially random directions (e.g. Feast 1996). C-rich dust condensing in these puffs of material is responsible for the observed extinction. There is as yet no consensus on the evolutionary status of, or the mechanism for mass-loss from, RCB stars.

As discussed by Feast et al. (2003) there are differences in the details of obscuration events in Miras and RCB stars, but these are to be expected given the differences in the sizes, outflow velocities and temperatures of the stars involved.

In this section we look at the additional information provided on this phenomenon by the data presented here. The frequency of occurrence is obviously important; we see clear obscuration events in 5 out of 18 Miras for which we have at least 25 observations. This should probably be regarded as a lower limit as some of those with photometry over a limited time may eventually show obscuration events if observed for long enough. We therefore estimate the fraction of C-rich Miras exhibiting obscuration events at very roughly one third. Furthermore, we demonstrated above (see Figs. [8] to 13) that there is no difference in the infrared properties of the Miras in which obscuration events have been observed and those in which they have not. It is therefore


Figure 17. EV Eri at $K$; note the obscuration event at around JD 2450700.
possible that all Miras will be seen to do this if monitored for long enough.

Although, as we discuss below, the phenomenon is also observed among non-Miras, the statistics for this group are not reliable. Our primary interest in this work has been the Miras and we generally stopped observing other stars when we had sufficient observations to establish that they were not large amplitude variables.

In the following some individual examples are briefly discussed. Given in brackets after each star name is the variability type (M or SR) and the number of SAAO nearinfrared observations that are available. Although more data are presented here we do not reconsider the behaviour of $\mathbf{R}$ For (M 209) or II Lup (M 264) mentioned at the start of this section.

EV Eri (SR 92) was discussed by Whitelock et al. (1997) who estimated its period at 228 days, not significantly different from the 226 days derived here from a slightly larger dataset. Since then it has undergone an obscuration phase (Fig. [17) similar to those shown by the Miras R For (Whitelock et al. 1997) and R Lep (see below and Fig. 18. At its dimmest EV Eri was fainter than usual by $\Delta J \sim 1.1$, $\Delta H \sim 0.9, \Delta K \sim 0.8$ and $\Delta L \sim 0.7$ mag. Gigoyan et al. (1998) classified it as C-type ( R or N ) on an objective prism spectrum and identify it with CGCS611 (Ste85-21), presumably incorrectly as the coordinates differ significantly (EV Eri: 0409 07.48-09 14 12.0; CGCS611: 0403 39.20-09 13 17.3 (Equinox 2000)). In view of the similarity of the light curve of EV Eri to those of RCB stars it would be interesting to see what a higher resolution spectrum revealed. As discussed above this star shows IRAS colours (see Fig. 2 where $K-[12]=2.14$ and $[12]-[25]=1.02)$ that are unusual among non-Mira C-rich variables. RCB stars show an excess at near-infrared wavelengths (e.g. Feast et al. 1997; Feast 1997).

R Lep (M 154) was discussed by Whitelock et al. (1997). The light curve from the larger dataset is illustrated in the top part of Fig. 18 while the bottom part shows the $K$ curve after removing the 438 day periodic term (modelled as a sine curve plus its harmonic). The smoothness of this residual is a measure of the regularity of the underlying 438 day pulsation. An analysis of data from the AAVSO archive gives a period of 436 days and shows an earlier deep minimum around JD 2443700 in addition to the one illustrated here.
$\mathbf{R}$ Vol (M 88). There is little to add to the discussion by Whitelock et al. (1997), but to note that R Vol is brighter now, at $J H K$ and $L$ than it has ever been in the 24 years we


Figure 18. (top) R Lep at $K$. (bottom) $R$ Lep at $K$ after removal of the 438 day pulsations.
have been observing it. The most recent maximum recorded by the AAVSO, around JD 2453000, is the brightest in almost 100 years. The star may be emerging from a prolonged obscuration event.

09164-5349 (SR 14) has a rather remarkable light curve, illustrated in Fig. 19 which was typical of a very low amplitude SR variable for more than 1000 days before it started a slow decline, changing in brightness by $\Delta K>2.0$ mag and $\Delta J>3.5 \mathrm{mag}$ over the next 800 days. Epchtein et al. (1990) reported $J H K L M$ photometry from January 1986 , i.e. almost 10 years before our first observations, at the same bright quiescent level as our early measurements with $K=2.14$. Because of its unusual IRAS colours (e.g. it lies above the dashed line which separates most O - and C-rich stars in Fig. 22 09176-5147 has been identified by various authors as a potential C star with silicate dust shell (e.g. Chen et al. 1993) although no evidence was found for anything other than a normal C-rich shell. The colour changes during the fading event suggest an increase in dust absorption. This particular object differs from most others showing dust obscuration events in that it does not show evidence for pulsation or other types of large amplitude variability. Groenewegen et al. (2002) did not detect CO emission.

If 09164-5349 is indeed exhibiting the same type of obscuration event as the other stars discussed in this section it is particularly important because its existence proves that the phenomenon is not necessarily associated with large amplitude pulsation (10136-5743 and 16406-1406 may not be pulsating, but that is not proved beyond any doubt).

10136-5743 (M: 13) has a large amplitude, $\Delta K>1$ mag, but is not obviously periodic (Fig. 19), although a period of the order of 1000 days is possible if the light curve is erratic. There has been very little published on this object beyond confirmation that it is a carbon star. It may be similar to 16406-1406.

16406-1406 (M: 28) is one of the most peculiar stars in the survey. It is also one of the few objects for which we have no spectroscopic evidence for its C-type classification, and this must therefore be regarded as uncertain.


Figure 19. 09176-5147, 10136-5743 and 16406-1406 at $K$; the \# in the bottom plot is an observation from 2MASS.

There has been very little published about it. Kwok et al. (1997) describe the IRAS spectrum as type-F, i.e. showing a featureless continuum. It is very red $3.3<K-L<4.0$, and has large amplitude variations, $\Delta K>1.5 \mathrm{mag}$, with no evidence for periodicity unless it is with a period of about 1800 days and very erratic. Its colours, e.g. $K-[12]=8.62$ and $[12-25]=0.89$, are certainly typical of a C star with a moderately thick shell. It is in the Galactic Centre quadrant, but well out of the Galactic plane ( $\ell=4.1, b=20.2$ ).
$16406-1406$ has similarities to $10136-5743$. It is also possible that it is like R For and that the periodicity has been totally disrupted by an obscuration event. In Table 2 we tentatively classified it as a Mira because of its large amplitude variability, but the light curve of Fig. 19 does not suggest Mira-like periodicity.

In summary, these obscuration events occur in very roughly one third of C-rich Miras and in an unknown fraction of other C-rich variable stars. It is possible that they are related to the RCB phenomenon as discussed above and it would certainly be worth making a more detailed study of the abundances and other properties of these stars. It is also possible that these stars are in binary systems with low level interactions. It may even be that the RCB-like mass loss is triggered by binary-related effects. Although obscuration events are not seen among solitary O-rich Miras they are very common among symbiotic Miras (Whitelock 1987), where they are thought to be a consequence of binary star interaction. It is also worth noting that the well studied C-
rich binary SR variable V Hya shows colour changes (e.g. Olivier et al. 2001) which are modulated at its orbital period but which otherwise look very similar to the obscuration phenomenon under discussion. At the same time we do have enough data to be certain that the obscuration events in R For are not periodic (Whitelock et al. 1997).

Finally we note that Woitke \& Niccolini's (2005) results offer at least a partial explanation of the obscuration events. In their model for dust driven winds in AGB stars, instabilities (hydrodynamical, radiative or thermal) allow the occasional formation of dust clouds close to the star in temporarily shielded areas; these clouds are then accelerated outward by radiation pressure. At the same time, but elsewhere, thinner dust-free matter falls back towards the star. In this way a turbulent and dynamical environment is created close to the star, which can be expected to produce the strongly inhomogeneous dust distribution which we observe in the C stars discussed here.

## ACKNOWLEDGMENTS

We thank the following people for their contribution to the SAAO observations reported here: Brian Carter, Robin Catchpole, Ian Glass, Dave Laney, Lerothodi Leeuw, Karen Pollard, Greg Roberts, Jonathan Spencer-Jones, Garry Van Vuren, Hartmut Winkler and Albert Zijlstra. We are grateful to Tom Lloyd Evans, Steven Bagnulo and Ian Short for allowing us to use their data in advance of publication. We also thank Luis Balona for the use of his STAR Fourier analysis package and John Menzies for a critical reading of the manuscript. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. We acknowledge with thanks the variable star observations from the AAVSO International Database contributed by observers worldwide and used in this research. We are grateful to the referee, Jacco van Loon for some helpful suggestions.

## REFERENCES

Aaronson M., Blanco V. M., Cook K. H., Schechter P. L., 1989, ApJS, 70, 637
Alksnis A., 2003, Baltic Astron., 12, 595
Alksnis A., Balklavs A., Dzervitis U., Eglitis I., Paupers O., Pundure I., 2001, Balt. A., 10, 1
Bujarrabal V., Cernicharo J., 1994, A\&A, 288, 551
Bateson F., McIntosh R., Venimore C. W., 1988, RASNZ Publ. Var. Star Sec., 15, 70
Bergeat J., Knapik A., Rutily B., 1998, A\&A, 332, L53
Bergeat J., Knapik A., Rutily B., 2002, A\&A, 390, 967
Bergeat J., Chevallier L., 2005, A\&A, 429, 235
Carter B. S., 1990, MNRAS, 242, 1
Catchpole R. M., Feast M. W., 1976, MNRAS, 175, 501
Catchpole R. M., Robertson B. S. C., Lloyd Evans T. H. H., Feast M. W., Glass I. S., Carter B. S., 1979, SAAO Circ., 1, 61

Chen P.-S., Lou E.-R., Li J.-Q., 1993, Acta Astron. Sinica, 34, 92
Chen P. S., Zhang P., Fu H. W., 2003, New Astron., 8, 719
Cutri R. M., 2003, "The 2MASS All-Sky Catalog of Point Sources", IPAC/CIT (2MASS)
Cohen J. G., Frogel J. A., Persson S. E., Elias J. H., 1981, ApJ, 249, 481
Drimmel R., Cabrera-Levers A., López-Corredoira M., 2003, A\& A, 409, 205

Egan M. P., Price S. D., Kraemer K. E., Mizuno D. R., Carey S. J., Wright C. O., Engelke C. W., Cohen M., Gugliotti G. M., 2003, Air Force Research Laboratory Technical Report AFRL-VS-TR-2003-1589
Epchtein N., Le Bertre T., Lépine J. R. D., 1990, A\&A, 82, 104
ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200
Feast M. W., 1954, Mem. Soc. R. Sci. Liège, 14, 413
Feast M. W., 1996, in: S. Jeffrey, U. Heber (eds.), Hydrogen Defficient Stars and Related Objects, ASP Conf. Ser. 96, p. 3
Feast M. W., 1997, MNRAS, 285, 339
Feast M. W., Whitelock P. A., 2000, in: F. Matteucci, F. Giovannelli (eds.) The Evolution of the Milky Way: stars versus clusters, Kluwer Academic Publishers, Dordrecht, ISBN 0-7923-6679-4, p. 229
Feast M. W., Whitelock P. A., Catchpole R. M., Roberts G., Carter B. S., 1985, MNRAS, 215, 63P
Feast M. W., Glass I. S., Whitelock P. A., Catchpole R. M., 1989, MNRAS, 241, 375
Feast M. W., Carter M. S., Roberts G., Marang F., Catchpole R. M., 1997, MNRAS, 285, 317

Feast M. W., Whitelock P. A., Marang F. 2003, MNRAS, 346, 878
Feast M. W., Whitelock P. A., Menzies J. W., 2006, MNRAS, submitted (Paper III)
Fouqué P., Le Bertre T., Epchtein N., Guglielmo F., Kerschbaum F., 1992, A\&AS, 93, 151

Gaylard M. J., Whitelock P. A., 1988, MNRAS, 235, 123
Gaylard M. J., West M. E., Whitelock P. A., Cohen R. J., 1989, MNRAS, 236, 247
Gezari D. Y., Pitts P. S., Schmitz M., 1997, Catalog of Infrared Observations, Edition 4, unpublished 1997
Gigoyan K. S., Hambaryan V. V., Azzopardi M., 1998, Astrophys., 41, 356
Glass I. S., 1999, Handbook of Infrared Photometry, CUP
Glass I. S., Lloyd Evans T., 2003, MNRAS, 343, 67
Groenewegen M. A. T., 1994, A\&A, 290, 207
Groenewegen M. A. T., Whitelock P. A., 1996, MNRAS, 281, 1347
Groenewegen M. A. T., de Jong T., Baas F., 1993, A\&AS, 101, 513
Groenewegen M. A. T., Whitelock P. A., Smith C. H., Kerschbaum F., 1998, MNRAS, 293, 18
Groenewegen M. A. T., Sevenster M., Spoon H. W. W., Pérez I., 2002, A\&A, 390, 511
Guandalini R., Busso M., Ciprini S., Silvestro G., Persi P., 2005, astro-ph/0509739
Guglielmo F., Epchtein N., Le Bertre T., Fouqué P., Hron J., Kerschbaum F., Lépine J. R. D., 1993, A\&AS, 99, 31
Iben I., Jr, 1981, ApJ, 246, 278
IRAS Science Team, 1988, Explanatory Supplement to the IRAS Point Source Catalogue
Jones T. J., Bryja C. O., Gehrz R. D., Harrison T. E., Johnson J. J., Klebe D. I., Lawrence G. F., 1990, ApJS, 74, 785

Jura M., 1987, ApJ, 313, 743
Keenan P. C., Boeshaar P. C., 1980, ApJS, 43, 379
Knapik A., Bergeat J., Rutily B., 1998, A\&A, 334, 545
Kwok S., Volk K., Bidelman W. P., 1997, ApJS, 112, 557
Le Bertre T., 1992, A\&AS, 94, 377
Le Bertre T., Matsuura M., Winters J. M., Murakami, H., Yamamura I., Freund M., Tanaka M., 2001, A\&A, 376, 997
Lloyd Evans T., 1991, MNRAS, 249, 409
Lloyd Evans T., 1997, MNRAS, 286, 839
Lloyd Evans T., Catchpole R. M., 1989, MNRAS, 237, 219
Luyten W. J., 1927, HB No.842, 9
Maffei P., 1966, Mem. Soc. Ast. It., 37, 475
Matsuura M., Zijlstra A. A., van Loon J. Th., Yamamura I., Markwick A. J., Whitelock P. A., Woods P. M., Marshall J. R., Feast M. W., Waters L. B. F. M., 2005, A\&A, 436, 691

Menzies J., Feast M., Tanabé T., Whitelock P., Nakada Y., 2002, MNRAS, 335, 923
Menzies J. W., Feast M. W, Whitelock P. A., 2006, MNRAS, submitted (Paper II)
Moshir M. et al. 1989, IRAS Faint Source Catalog, Version 2, Infrared Processing and Analysis Centre
Noguchi K., Kawara K., Kobayashi Y., Okuda H., Sato S., Oishi M., 1981, PASJ, 33, 373

Olivier E. A., Whitelock P. A., Marang F., 2001, MNRAS, 326, 490
Ortiz R., Lorenz-Martins S., Maciel W. J., Rangel E. M., 2005, A\&A, 431, 565
Pojmański G., 2002, Acta. Astron., 52, 397 (www.astrouw.edu.pl/~gp/asas/asas.html)
Richichi A., Stecklum B., Herbst T. M., Lagage P.-O., Thamm E., 1998, A\&A,334, 585

Samus N.N., Durlevich O.V., et al., 2004, "Combined General Catalog of Variable Stars" (GCVS4.2, 2004 Ed.) Moscow, Institute of Astronomy of Russian Academy of Sciences (GCVS)
Skinner C. J., Griffin I., Whitmore B., 1990, MNRAS, 243, 78
Stancliffe R. J., Izzard, R. G., Tout C. A., 2005, MNRAS, 356, L1
Tuthill P. G., Monnier J. D., Danchi W. C., Lopez B., 2000, ApJ, 243, 284
van Leeuwen F., Fantino E., 2005, A\&A, 439, 791
van Leeuwen F., 2005, A\&A, 439, 805
van Loon J. Th., 2006, in: (eds.) Lamers, Langer, Nugis \& Annuk, Stellar Evolution at Low Metallicity: Mass Loss, Explosions, Cosmology, ASP, in press astro-ph/0512326
van Loon J. Th., Groenewegen M. A. T., de Koter A., Trams N. R., Waters L. B. F. M., Zijlstra A. A., Whitelock P. A., Loup C., 1999, A\&A, 351, 559

Walker W. S. G., Ives F. V., Williams H. O., 1995, Southern Stars, 36, 123
Whitelock P. A., 1987, PASP, 99, 573
Whitelock P. A., Feast M. W., 2000, MNRAS, 319, 759
Whitelock P. A., Pottasch, S. R., Feast, M. W., 1987, in: (eds.) S. Kwok \& S. R. Pottasch, Late Stages of Stellar Evolution, Reidel, Dordrecht, p. 269
Whitelock P. A., Menzies J.W., Feast M.W., Marang F., Carter B., Roberts G., Catchpole R. M., Chapman J., 1994, MNRAS, 267, 711
Whitelock P. A., Menzies J.W., Feast M.W., Catchpole R.M., Marang F., Carter B., 1995, MNRAS, 276, 219
Whitelock P. A., Feast M.W., Marang F., Overbeek M.D. 1997, MNRAS, 288, 512
Whitelock P. A., Marang F., Feast M. W. 2000, MNRAS, 319, 728
Whitelock P. A., Feast M. W., van Loon, J. Th., Zijlstra, A. A., 2003, MNRAS, 342, 86
Woitke P., Niccolini G., 2005, A\&A, 433, 1101
Young K., Phillips T. G., Knapp G. R., 1993, ApJS, 86, 517
Zijlstra A. A., Bedding T. R., Markwick A. J., Loidl-Gautschy R., Tabur, V., Alexander K. D., Jacob, A. P., Kiss L. L., Price A., Matsuura M., Mattei J. A., 2004, MNRAS, 352, 325


Figure A-1. $K$ light curves for the Mira variables; each point is plotted twice to emphasize the periodicity.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves. The curve for V833 Her extends beyond the range shown here.


Figure A-1. continued $K$ Mira light curves.


Figure A-1. continued $K$ Mira light curves.


Figure A-2. $K$ light curves for semi-regular variables on the same scale as the Miras.


Figure A-2. continued $K$ SR light curves.


Figure A-2. continued $K$ SR light curves.


[^0]:    * This paper is based on observations made at the South African Astronomical Observatory.
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[^1]:    ${ }^{1}$ Transformation from the $1.9-\mathrm{m}$ natural system to the SAAO system defined by Carter (1990) assumes $K_{1.9}=K$ and ( $J-$ $H)_{1.9}=0.95(J-H)$ or $(J-K)_{1.9}=0.955(J-K)$.

