Mass-Losing Semiregular Variable Stars in Baade’s Windows

C. Alard$^{1,12}$, J.A.D.L. Blommaert$^2$, C. Cesarsky$^3$, N. Epehstein$^4$, M. Felli$^5$, P. Fouque$^6$, S. Ganesh$^7$, R. Genzel$^8$, G. Gilmore$^9$, I.S. Glass$^{10}$, H. Habing$^{11}$, A. Omont$^{12}$, M. Perault$^{13}$, S. Price$^{14}$, A. Robin$^{15}$, M. Schultheis$^{12}$, G. Simon$^1$, J.Th. van Loon$^9$, (The ISOGAL Collaboration)

C. Alcock$^{16,30}$, R.A. Allsman$^{17}$, D.R. Alves$^{18}$, T.S. Axelrod$^{19}$, A.C. Becker$^{20}$, D.P. Bennett$^{21,30}$, K.H. Cook$^{16,30}$, A.J. Drake$^{16}$, K.C. Freeman$^{19}$, M. Geha$^{22}$, K. Griest$^{23,30}$, M.J. Lehner$^{24}$, S.L. Marshall$^{16}$, D. Minniti$^{25}$, C. Nelson$^{26}$, B.A. Peterson$^{19}$, P. Popowski$^{16}$, M.R. Pratt$^{27}$, P.J. Quinn$^3$, W. Sutherland$^{28,30}$, A.B. Tomaney$^{26}$, T. Vandehende$^{23}$, D.L. Welch$^{29}$ (The MACHO Collaboration)
ABSTRACT

By cross-correlating the results of two recent large-scale surveys, the general properties of a well defined sample of semi-regular variable stars have been determined. ISOGAL mid-infrared photometry (7 and 15 µm) and MACHO $V$ and $R$ lightcurves are assembled for approximately 300 stars in the Baade’s Windows of low extinction towards the Galactic bulge. These stars are mainly giants of late M spectral type, evolving along the asymptotic giant branch (AGB). They are found to possess a wide and continuous distribution of pulsation periods and to obey an approximate log period – bolometric magnitude ($\log P - M_{\text{bol}}$) relation or set of such relations.

Approximate mass-loss rates $\dot{M}$ in the range of $\sim 1 \times 10^{-8}$ to $5 \times 10^{-7} M_\odot$ year$^{-1}$ are derived from ISOGAL mid-infrared photometry and models of stellar spectra adjusted for the presence of optically-thin circumstellar silicate dust. Mass-loss rates depend on luminosity and pulsation period. Some stars lose mass as rapidly as short-period Miras but do not show Mira-like amplitudes. A period of 70 days or longer is a necessary but not a sufficient condition for mass loss to occur.

For AGB stars in the mass-loss ranges that we observe, the functional dependence of mass-loss rate on temperature and luminosity can be expressed as $\dot{M} \propto T^\alpha L^\beta$, where $\alpha = -8.80^{+0.96}_{-0.24}$ and $\beta = +1.74^{+0.16}_{-0.24}$, in agreement with recent theoretical predictions.

If we include our mass-loss rates with a sample of extreme mass-losing AGB stars in the Large Magellanic Cloud, and ignore $T$ as a variable, we get the general result for AGB stars that

$$\dot{M} \propto L^{2.7},$$

valid for AGB stars with $10^{-8} < \dot{M} < 10^{-4} M_\odot$ yr$^{-1}$. 
1. Introduction

One of the most complex and least understood phases of stellar evolution is the asymptotic giant branch (AGB; Iben & Renzini 1983). AGB evolution is regulated by very high rates of mass loss (Bowen & Willson 1991; Vassiliadis & Wood 1993).

The current theory of mass loss from red giants invokes a combination of two physical processes: stellar pulsation and radiation pressure on dust grains (see reviews by Morris 1987; Gail, Kuntz & Ulmschneider 1990; Lafon & Berruyer 1991; Habing 1996). The association of mass loss with pulsation is due to the fact that mass-losing red giants are often variable stars, such as Miras, and the mass-loss rates of Miras are observed to be correlated with their pulsation periods (de Gioia-Eastwood et al. 1981; Whitelock et al. 1994, 1995). Stellar pulsation is theoretically linked to mass loss through the propagation of periodic shocks (Wood 1979; Willson & Hill 1979). The shocks are nearly isothermal, and thus responsible by themselves for very low mass-loss rates (Bowen 1988). However, they also extend the outer-atmospheres of red giants, increasing the gas density at the dust condensation radius. Dust therefore forms efficiently, and radiation pressure accelerates the dust grains (Hoyle & Wickramasinghe 1962). The accelerated dust grains are momentum-coupled to the gas, which drives mass loss at high rates (Gilman 1972; Kwok 1975). The standard theory of mass loss has evolved to include sophisticated treatments of time-dependent hydrodynamics, grain condensation, and radiative transfer (e.g. Fleischer, Gauger & Sedlmayr 1992; Arndt, Fleischer & Sedlmayr 1997).

The standard theory of mass loss in red giants may not be appropriate for all AGB stars. While the majority are variable (e.g. Alcock et al. 2000), most do not show the large-amplitude, long-period pulsations characteristic of Miras. Instead, most AGB variable stars are classified as semiregulars (SRs). The classical requirement for a Mira is that it shows an optical pulsation amplitude $\Delta V > 2.5$ mag, while the semiregulars are defined as having pulsation amplitudes smaller than this. Stars with visual amplitudes around the dividing level occur relatively infrequently (Payne-Gaposchkin, 1951). The optical pulsation amplitudes of current model AGB stars with periodic shocks as prescribed by the theory of mass loss are typical of the pulsation amplitudes of Miras, but not of semiregulars. Another characteristic feature of Miras is periodic Balmer-line emission, believed to arise from shocks (Willson 1976). The theoretical velocity changes across the periodic shocks are in agreement with those inferred from the Balmer-line emission of Miras (Fleischer, Gauger & Sedlmayr 1992). Although data are scarce, many SRs do not exhibit periodic Balmer-line emission. In addition, near-infrared spectra of SRs do not show line-doubling as Miras often do, a characteristic of shocks (Hinkle, Lebzelter, & Scharlach 1997). Thus the pulsations induced in the standard theory of mass loss are probably too strong to be appropriate for semiregulars.

Up till now, detailed knowledge of the properties of the SR variables has been limited to relatively small numbers of bright objects, mainly situated in the solar neighborhood at unknown distances (e.g. Jura & Kleinmann 1992; Kahane & Jura 1994; Kerschbaum, Olofsson
However, the picture is undergoing rapid change thanks to the gravitational lensing experiments like MACHO and OGLE, and the astrometric satellite Hipparcos, which have obtained frequent photometric measurements of large samples of SRs at known distances, and over long periods of time. These relatively new databases cover well-defined samples and can reveal variations with amplitudes as small as a few hundredths of a magnitude, well beyond the capabilities of earlier photographic work. We mention Alves et al. (1998), Minniti et al. (1998), Wood et al. (1999), and Glass et al. (2000) who have discussed MACHO observations of SRs in the LMC and Galactic Bulge. Koen & Laney (2000), Bedding & Zijlstra (1998), and others have discussed SRs observed by Hipparcos in the solar neighborhood.

At the same time, the ISOCAM camera of the Infrared Space Observatory (ISO)\textsuperscript{31} pointed, observatory-style satellite has enabled mid-infrared photometric surveys to be carried out with much greater sensitivity and spatial resolution than, for example, was possible with IRAS, which suffered severely from crowding of sources near the Galactic plane. In particular, in the Baade’s Windows of low extinction in the inner part of the Galactic bulge, the ISOGAL Collaboration has detected 1193 stars in the ISOCAM 7$\mu$m or 15$\mu$m bands in two fields of $15 \times 15$ arcmin\textsuperscript{2} (Glass et al. 1999). As a result, it is now evident that there is a continuous sequence of increasing mass-loss from mid- to late-type M-giant stars on the AGB, ending with the Miras and other long-period, large-amplitude variables.

In order to advance our theories of AGB stellar evolution, and in particular, advance our understanding of mass loss, we have undertaken a new study of AGB stars in the Galactic bulge. We have combined two types of observations ideally suited to investigate issues of AGB star mass loss: optical-band lightcurves from the MACHO Project and mid-infrared photometry from the ISOGAL Collaboration. Our dataset is the first large sample of mass-losing AGB variable stars whose pulsation and mass-loss rates are well-characterized, and whose distances, and thus energetics, are also known.

2. Data

2.1. ISOGAL

The ISOGAL Survey\textsuperscript{32} is a multi-wavelength infrared survey of the inner Galaxy at high resolution (Omont et al. 2000). It made use of the ISOCAM camera (Cesarsky et al. 1996) on the ISO satellite to survey numerous sample fields in visually-obscured regions along the Galactic plane and towards the center of the Galaxy in order to study topics such as Galactic structure,

\textsuperscript{31}ISO is a European Space Agency (ESA) project with instruments funded by member states (especially the PI countries: France, Germany, the Netherlands, and the United Kingdom) and with the participation of ISAS and NASA.

\textsuperscript{32}This is paper no. 10 in a refereed journal based on data from the ISOGAL Survey.
the red giant population, interstellar extinction and other matters.

2.1.1. **ISOGAL observations**

The survey comprises mainly exposures in the LW2 (5.5–8 µm) and LW3 (12–18 µm) broad-band filters of ISOCAM. Each pixel subtended 6 × 6 arcsec$^2$ on the sky. The detector arrays had 32 × 32 pixels. Large areas could be imaged by combining individual images obtained during raster scans. The data that we describe were obtained from two areas located in the Baade’s Windows, each covering 15 × 15 arcmin$^2$ in ℓ, b. Exposures were made on two occasions, about a year apart (see Glass et al. 1999). On the first occasion, observations were obtained only with the LW2 filter; on the second, both filters were used. The centres of the fields were at ℓ = +1.03°, b = −3.83°, which includes the globular cluster NGC 6522, and at ℓ = +1.37°, b = −2.63°, known as the SgrI field. The Baade’s Window fields were included because, although they are near the galactic centre, they are sufficiently unobscured (with visual extinction $A_V \sim 1.5 – 1.8$ mag) to be observable at visual wavelengths and have been the subject of numerous previous investigations. Thus they can be regarded as fiducial fields for the analysis of more heavily obscured areas.

2.1.2. **Photometric properties**

ISOGAL has identified 1193 sources from these fields at either or both of the 7- and 15-micron passbands. In the fields SgrI and NGC 6522, there are 696 and 497 sources, respectively. Of these, 182 and 287 were detected at both wavelengths. The methods used for reducing the photometry, taking account of various difficulties produced by the responses of the detectors and the crowded nature of the fields, have been described by Glass et al. (1999). The flux calibrations of the 7 µm and 15 µm bands were set for a spectrum with $F_{\lambda} \propto \lambda^{-1}$ and should be correct at wavelengths 6.7 and 14.3 µm respectively. Conversion from magnitudes follows the relations

$$[7] = 12.38 - 2.5 \log F_{LW2} (\text{mJy})$$

and

$$[15] = 10.79 - 2.5 \log F_{LW3} (\text{mJy}),$$

where the zero points have been set to obtain zero mag for a Vega model flux at the isophotal wavelengths given above.

Only sources with fluxes greater than 5 mJy in either or both filters were accepted for the final catalogue. These limits correspond to $[7] = 10.64$ and $[15] = 8.99$. The rms dispersion of the ISOGAL photometry is 0.14–0.2 mag, except at the faint end, where it rises to $\sim 0.4$ mag (see Glass et al. 1999; Ganesh et al. in preparation). With 35–45 pixels per source, observations in these fields are seen to be close to the confusion limit.
As in Glass et al. (1999), we have not applied extinction corrections to the ISOGAL data. The absorption in the ISOGAL bands is believed to be less than 0.05 mag, though the precise character of the interstellar extinction curve in this wavelength region is not well-determined.

2.1.3. Astrometric calibration

The extracted source positions were set systematically by reference to the Deep Near-Infrared Survey (DENIS) positions for the same area. The DENIS survey has an internal astrometric accuracy of order 0.5″ (see Omont et al. 1999) and is ultimately referred to the USNO-A2.0 astrometric catalogue, which has a rms absolute accuracy of 1 arcsec. The rms dispersions of the differences between the ISOGAL and the DENIS positions are (0.6, 0.7) and (0.9, 0.8) arcsec in (R.A., Dec) for NGC 6522 and Sgr I, respectively.

2.1.4. ISOGAL color-magnitude diagram

Figure 1 shows the color-magnitude diagram (CMD) for 182 and 287 stars detected at both wavelengths in NGC 6522 and Sgr I fields, respectively. The objects in the Baade’s Windows are almost exclusively from the Bulge, and are therefore at a nearly constant distance from the Sun, with a distribution governed by the thickness of the Bulge. The minimum photometric scatter due to line-of-sight effects can be expected to be similar to that derived from the period–K luminosity plot for Miras in the Sgr I field (Glass et al. 1995), viz 0.35 mag, since the intrinsic scatter in the relationship is known to be ≤ 0.13 mag from Magellanic Cloud studies (Glass et al. 1987). There is a continuous progression of [15] mag, and therefore dust output, with [7]–[15] color and late spectral type (Glass et al. 1999). The sequence stretches from the top of the Red Giant Branch (RGB), located in the bottom left corner of the diagram, to the Mira variables, which are generally, but not exclusively, the most luminous dust emitters. Mira-type large-amplitude variability is thus seen not to be a necessary condition for mass-loss in M-stars, as was previously believed.

The objects which approach the Miras in dust emission are close to them in K-mag also (Frogel & Whitford 1987; Glass et al. 1999), indicating that they have similar bolometric mags. Spectral types are available for all the M-giants in part of the ISOGAL NGC 6522 field (Blanco 1986), as well as for late-type M-giants in the whole field (Blanco, McCarthy & Blanco 1984). It is evident from figure 12 of Glass et al. (1999) that only M5 giants or later types are detectable at 15μm, i.e., it is only these objects that have observable dust shells. Mira and SR variables of C-type are entirely absent from these fields.

A group of stars with luminosities similar to Miras, marked by crosses in Figure 1, were examined by T. Lloyd Evans on the photographic plate material that was used for finding most of the known Miras in the Baade’s Window fields (Lloyd Evans 1976). Little additional evidence was
found for photometric variability, ruling out the notion that they may have been overlooked as Miras, but not excluding the possibility that they could be SR variables of much lower amplitude. It therefore became of interest to see if a modern photoelectric survey would reveal anything more.

2.2. MACHO

The MACHO Project had dedicated use of the 50-inch Great Melbourne Telescope located at the Mount Stromlo Observatory in Australia from January, 1992 to January, 2000. A system of corrective optics installed at the prime focus gave a focal reduction to $f/3.9$ and a $1^\circ$ field of view. A dichroic beam-splitter enabled simultaneous blue and red imaging. The MACHO filters were non-standard, with the blue filter running from $\sim 4500 - 6300$ Å and the red filter from $\sim 6300 - 7600$ Å (see Alcock et al. 1999). At both the red and blue foci, a mosaic of four $2048 \times 2048$ Loral charge coupled devices (CCDs) were mounted, yielding an 0.52 square degree imaged area.

Approximately 45 square degrees of the Galactic bulge were observed every few nights, with exceptions for weather and the southern summers. Photometry was handled by a special purpose crowded-field, PSF-fitting code called SoDOPHOT, which is described by Alcock et al. (1999). At the time of this work, the MACHO photometry database contained a time-series of $\sim 1000$ two-color photometric measurements spanning $\sim 6$ years for most Galactic bulge fields. Most of the stars of interest here are quite bright, and thus the typical error on each photometric measurement is about $\pm 0.02$ mag.

Following Alcock et al. (1999), the MACHO instrumental photometry have been calibrated to the standard Kron-Cousins system using:

$$ V = v + 23.699 - 0.1804 \,(v - r) $$

$$ R = r + 23.412 + 0.1825 \,(v - r) $$

where $v$ and $r$ are instrumental magnitudes, and $V$ and $R$ are on the Kron-Cousins standard system. The color coefficients are averages of the values determined for different CCDs in the MACHO focal plane, corrected for airmass. These calibration formulae are estimated to have an overall absolute accuracy of $\pm 0.10$ mag in $V$ or $R$, and $\pm 0.04$ mag in $(V - R)$. For the purposes of calibration, we assumed $(v - r) = 0.5$ mag for all stars without instrumental colors in the database; the systematic error may be larger for these stars. The systematic calibration error may also be larger for stars with colors of $(V - R) > 1.2$ mag (see Alcock et al. 1999).

Astrometry for the MACHO database was derived independently for each field using the Guide Star Catalog. Astrometric offsets of order $\sim 1''$ between MACHO fields (as determined from common stars in field overlap regions) are typically found, which gives an indication of the overall astrometric accuracy to be expected.
3. Matching MACHO & ISO GAL Sources

In our initial reconnaissance of the MACHO photometry database, we overplotted MACHO “tiles” on the spatial distribution of ISO GAL sources (tiles are a defined region of the sky in the MACHO database, each approximately a few arcminutes square). In this manner, we identified 54 tiles that overlapped (or nearly overlapped) ISO GAL sources. Unique starlists were extracted from the MACHO photometry database for these tiles, which totaled just over \(3 \times 10^5\) stars. We estimate that 91\% and 88\% of the areas of the ISO GAL SGR I and NGC 6522 fields, respectively, are included in the MACHO photometry database. This estimate accounts for gaps in MACHO sky coverage between fields and CCDs, but not for area lost to CCD defects or saturated pixels. The latter probably accounts for no more than ~5\% of the field area.

A blind spatial matching of the ISO GAL sources with such a large number of MACHO stars would have certainly resulted in numerous chance coincidences. Therefore, we decided to apply a “reasonable” cut in the optical color-magnitude diagram before attempting to cross-correlate sources. We considered only MACHO stars with \(V > 13.5 + 4.67(V - R)\) as possible counterparts to the ISO GAL sources. This cut was chosen to include the red clump, very red faint stars, and very bright blue stars. It excluded most faint main sequence stars, but may have also excluded some relatively blue AGB stars located behind the Galactic bulge. After applying this cut, approximately \(4 \times 10^4\) MACHO stars remained.

For each of the 1193 ISO GAL sources, the angular distance to each MACHO star was calculated, and the closest positional match was recorded if lying within 3 arcseconds. In an initial matching trial, median offsets in \(\alpha\) and \(\delta\) were calculated using a subset of matches that included only MACHO stars with colors \((V - R) > 1.5\) mag, which were considered very likely matches. The offsets for each field, in the sense of ISO – MACHO, and in units of arcseconds, are: \((\Delta \alpha, \Delta \delta) = (1.4, 0.7)\), and \((0.8, 0.6)\) for ISO GAL fields SGR I and NGC 6522, respectively. A second and final matching trial proceeded as the first, except that the offsets were applied.

Figure 2 shows the final distribution of angular separations for matches in ISO GAL fields SGR I and NGC 6522. In order to provide some estimate of the number of spurious matches, we repeated the matching procedure described above, except that we applied an arbitrary (~15 arcsec) shift to each MACHO starlist. The result of this control matching trial is also shown in Figure 2 (shaded histograms). The total number of matches are 518 and 386 in ISO GAL fields SGR I and NGC 6522, while the probabilities for a spurious match are 7\% and 3\%, respectively. The details of the matching criteria described above do not affect the main results of this work.

The total number of matches (904) represents 76\% of the 1193 ISO GAL sources, which compares to the estimated ~90\% overlapping area between the MACHO and ISO GAL fields. This discrepancy (~165 stars) is probably too large to attribute to CCD defects in the MACHO images, which would tend to lower the percentage of overlapping area (~5\%). It would also seem too large to attribute to saturation in the MACHO data \((V_{SAT} \sim 11\); although this is certainly case for some known Miras, as discussed below). It is unlikely that this represents a significant
population of self-obscured AGB stars, since there aren’t that many very bright ISOGAL sources. It is possible that the ISOGAL sources without optical counterparts are not real, but are instead low signal-to-noise, false detections. However, a combination of all of the above effects is perhaps the most likely explanation. A detailed accounting of each ISOGAL source is beyond the scope of this work. We are confident that we have correctly matched a large number of ISOGAL sources with MACHO stars, and will proceed with an analysis of this dataset.

332 stars of the 904 MACHO and ISOGAL matches have complete sets of $V$, $R$, [7], and [15] mags. They are listed in Table 1. In Figure 3, we plot all 904 sources, distinguishing those with four-color photometry. The four-color sources are seen to deviate in the direction of higher $V - R$ and/or fainter $V$ from the others, apart from the small group of stars near $V \sim 17$, $V - R \sim 0.9$, which coincide with the red giant clump. This can be an effect of either or both of photospheric temperature and reddening due to circumstellar material. Those located near the clump are consistent with chance matches.

For the remainder of this work, we restrict our analyses to the subset of 332 matches with four-color photometry.

4. Pulsation characteristics

4.1. Periodicity

Most of our sample (305 out of 332, or 92%) show quite well-defined periodic or quasi-periodic variations of moderate amplitude superimposed on irregular longer-term fluctuations, which do not, with a few exceptions, appear periodic on the overall time scale of our observations. Of the remaining 27 stars, 26 were frequently saturated in the MACHO image data and thus have unusable light curves. The remaining object is an eclipsing binary. There are 14 known Miras in these fields and they are discussed separately below. The SRs outnumber the Miras by about 20:1.

4.2. Semiregular Variables

All 332 $R$-band light curves were plotted and examined. Approximate periods were first estimated by eye and later made more precise by Fourier analysis. The seasonality of the observations led to the presence of confusing noise at low frequencies as well as aliases. Stars with estimated values of $\log P < 2.2$ were analysed separately from those with longer periods.

The $\log P < 2.2$ stars (280) were Fourier analysed season by season and their amplitude periodograms were then summed. The component with highest amplitude with $\log P < 2.2$ was taken to be the most characteristic or relevant one, even if other periods sometimes had almost equal amplitudes.
The remaining 25 of the 305 periodic or quasi-periodic variables, i.e., those with estimated 
log \( P \geq 2.2 \), were also Fourier analysed, but using the information derived by eye from the light 
curves to assist in the interpretation.

It is traditional to divide the SR variable giants, whether having M-, C-, or S-type spectra, 
into subtypes SRa and SRb, according to their variability characteristics. The SRa types show 
persistent periodicity in the range 35–1200 days, though with amplitudes less than Miras (defined 
to have minimum amplitude >2.5 mag at \( V \)) and variability in amplitude and light-curve shapes. 
The SRb stars have much more poorly expressed periodicity in the range (20–2300) days, with 
slow, irregular changes, or even periods of constancy. Usually, however, a mean period can be 
assigned to them.

About 3/4 of our variables can be classified as SRa and most of the remainder as SRb. 
However, this classification scheme can only be regarded as subjective. The SRb types occur 
predominantly among the longer-period objects.

Figure 4 (a) – (d) shows examples of the different types of variables.

4.3. Mira Variables

Of the fourteen Miras known from previous work (Lloyd Evans, 1976; Glass et al. 1995), six 
have good to recognizable Mira light curves (Table 2). Five were completely missing from the 
overall list of 332 identifications because they were saturated in the MACHO template images 
for these fields and thus do not appear at all in the MACHO photometry database (Alcock et 
al. 1999). The remaining three were misidentified and do appear amongst the 332, but as matches 
to nearby faint stars. The Miras themselves were saturated in the MACHO images. Two of the 
resulting three ‘wrong’ light curves exhibit irregular flare-like spikes which presumably arise from 
occasional seeing-related contamination from the true Mira counterparts.

The periods determined by MACHO are based on much more comprehensive light curves than 
either those of Lloyd Evans (1976) or Glass et al. (1995). It is therefore interesting to compare 
these values in order to have some check on the error arising from uncertain \( P \) values when 
Determining \( P - L \) relations. The differences may be due to observational error or to intrinsic 
irregularities in the Mira light curves (Fig 4a). For the 6 stars in common with Lloyd Evans 
(1975) we find \( \Delta P / P_{\text{MACHO}} = 7 \pm 5\% \) and for the 4 stars in common with Glass et al. (1995) we 
get \( \Delta P / P_{\text{MACHO}} = 9 \pm 9\% \). Since the scatter of the LMC Miras around their \( K, \log P \) relation is 
around 13\%, it is clear that errors arising from uncertain or poorly determined periods contribute 
significantly to the overall scatter in the relationship, besides those associated with finding the 
mean values of \( K \).
4.4. Period-Luminosity Relations for Semiregulars and Miras

Fig 5a shows the log $P$, [7] diagram for our sample. As we will see, the 7$\mu$m mag is, like the $K$, closely related to $M_{bol}$ for these stars. We have superimposed a line equivalent to that which fits local SR variables having photometric and astrometric data from Hipparcos, as suggested by Bedding and Zijlstra (1998). To transform from their empirical $M_K$ relation to one involving [7], we made use of 51 late-type non-Mira stars in the NGC 6522 Baade’s Window having $K_0$ (de-reddened) values by Frogel & Whitford (1987) and also 7$\mu$m mags from ISOGAL, finding that [7] = 1.04 $K_0$ – 0.20 (s.d. 0.26). (For reference, using Frogel & Whitford’s (1987) bolometric magnitudes corrected for the difference in assumed distance moduli, we also found $M_{bol} = 0.75 [7]_{obs} – 9.25$ (s.d. = 0.21) for the same sample. The distance modulus of the Baade’s Windows was taken to be 14.7 in our work and 14.2 by Frogel & Whitford). The Bedding and Zijlstra (1998) line then has the form

$$[7] = -1.85 \log P + 11.27. \quad (5)$$

The Bedding & Zijlstra (1998) line runs fairly centrally through, or perhaps 0.1 to 0.2 mag above, the distribution of Baade’s Window points. It is about 0.8 mag above that originally found for globular cluster variables with periods in the range $0 \leq \log P \leq 2.8$ by Whitelock (1986).

Fig 5a also includes an empirical log $P$, [7] fit for the Miras, excluding TLE 57 (a possible SR):

$$[7] = (-6.9 ± 1.4) \log P + (23.5 ± 3.4), \quad (6)$$

with s.d. 0.4. Unlike the case for the SR variables, the 7$\mu$m flux from a Mira is likely to include a substantial component arising from dust as well as normal photospheric emission. It is therefore no longer a simple measure of bolometric output, particularly at longer periods.

The $K$ emission of Miras is little contaminated by dust and is thus more representative of bolometric output. Accordingly, in order to facilitate a more direct comparison with other work, in Fig 5b we have transformed the [7] mags of the SRs to $K_0$ and plotted a log $P$, $M_K$ diagram, with the Bedding and Zijlstra (1998) line and the same authors’ transformation of the Whitelock (1986) fit (its exact position is dependent on the distance scale used).

Fig 5c shows the log $P$, $M_{bol}$ diagram, where we have transformed the [7] mags of the SRs to $M_{bol}$ using the relationship given above. The Miras and their $P – L$ relation from Glass et al. (1995) are shown, as is the (linear) $P$, $M_{bol}$ relation given by Whitelock (1986) for Galactic globular clusters.

The shallow sequence of SRs relative to the Miras in these diagrams (Figs 5a,b,c) may reflect an evolutionary sequence. Evolutionary tracks of this kind, though covering a much reduced period range ($1.8 < \log P < 2.8$), were predicted by Vassiliadis & Wood (1993). Alves et al. (1998) have also projected theoretical evolutionary tracks onto the PL diagram, extending the sequences to the lower luminosities and shorter periods appropriate for SRs. The Alves et al. (1998) PL sequences are based on accurate analytic approximations to the grid of Vassiliadis & Wood (1993).
AGB models and are thus properly comparable to the latter authors’ PL sequences. The absolute luminosities of the evolutionary PL sequences depend on initial mass and metallicity. Alves et al. (1998) showed that SRs in the clusters 47 Tuc and NGC 1783, which have similar metallicities but different initial masses, support the relative luminosities predicted by the theoretical PL sequences. Therefore, the overall luminosity of the SRs in Fig. 5a,b,c may indicate the characteristic age and metallicity of the AGB population.

When a star moves up along one of the nearly parallel evolutionary sequences in the PL diagram, it eventually reaches the Mira line at a unique position. For Galactic globular clusters, this occurs at the relatively short period of about 200 days, in accordance with the known period distribution of the Miras that they contain. The solar neighbourhood line intersects the Miras at about 460 days. The period distribution of local Miras is unknown at present, but long periods are common and this figure may be reasonable. The census of Miras in the Sgr I Baade’s Window is complete (Glass et al. 1995) and their average period is 346 days, in accord with the distributions in Fig. 5a,b,c. This period is much longer than the typical 200 days found for Miras in Galactic globulars and is consistent with the SRs in Baade’s Window lying above the Whitelock (1986) PL sequence.

It is known that the scatter of the Miras in the Sgr I Baade’s Window around the log $P$, $K_0$ relation is $\sim 0.35$ mag (Glass et al. 1995). Most of this is attributed to the distribution of the Miras along the line of sight, i.e., the finite thickness of the Bulge, though some of it may be caused by the patchy nature of the interstellar extinction. The scatter of the SR variables in Fig. 5a is not much greater, implying that the spread of evolutionary tracks cannot be very wide.

As can be seen from Fig. 6 (upper panel), there is no conspicuous clumping in numbers at any given period of the semiregular variables in our sample. There is however a gap visible in Fig. 5a,b,c between the Mira region and the semi-regular variables similar to that noted by Wood & Sebo (1996) and Wood (2000) in the case of the Large Magellanic Cloud. This gap corresponds, however, to the period range where aliasing is severe due to the seasonality of the MACHO data, and may in part be an artefact. Wood & Sebo (1996) and Wood (2000) interpret the Mira sequence as being one of fundamental mode pulsators and suggest that the semi-regulars pulsate in higher modes. First overtone pulsators are expected to lie on a parallel sequence about $\Delta \log P \sim 0.35$ to the left of the fundamental, and higher modes should lie at progressively smaller intervals to the left of these. The sequences arising from the higher modes, although clearly seen in the LMC, are not expected to be separated from each other as clearly in our Baade’s windows data because of greater observational error and a range of distances. The necessity that the short-period end of the semi-regular M-giants must pulsate in very high modes has also been discussed by Koen & Laney (2000). This interpretation is not incompatible with the evolutionary picture previously discussed.
4.5. Amplitudes

Because the short-period variability of the SRs is often modulated by apparently irregular long-period trends, eye-estimates of the envelope of the $R$-band variations were made for each star, accurate to about 20% or 0.05 mag, whichever is greater. None exceeded $\Delta R \sim 1$ mag, whereas the five Miras with adequate data (Fig. 4a) each showed $\Delta R \sim 4$ mag.

Three stars with short periods around 50 – 60 days also showed long periods around 400 days (one or two other short-period stars are also suspected to have long periods close to a year, but their interpretation is confused by the annual nature of the observations). They have amplitudes of 0.1 – 0.2 mag in the short periods and 0.5 mag in the long (see Fig. 4d), but have luminosities appropriate to SRs rather than Miras. Similar stars are found in the LMC MACHO data (see Alves et al. 1998; Wood et al. 1999), covering short periods of 50 – 100 days and long periods of 250 – 1000 days. Wood et al. find long to short period ratios in the range 5 – 13.

Figure 6 shows a histogram of the average amplitude of variability as well as the period distribution. There is a very clear trend towards smaller amplitudes at shorter periods (see also Minniti et al. 1998). The shorter period groups may have been influenced by selection effects, in the sense that very small amplitude variables may not have been detected.

5. Discussion of mass-loss rates

In non-Mira M-giant stars, the flux entering the $7\mu m$ ISOCAM LW2 filter arises primarily from photospheric emission and does not include a large dust contribution. The $15\mu m$ LW3 filter, on the other hand, overlaps with the silicate dust emission features at 10 and $18\mu m$ and is strongly affected by dust, when present. Only when the dust is optically thick, such as in long-period Miras and OH/IR sources, is the $7\mu m$ band likely to be strongly affected. The $K_0$ and $[7]$ mags of the SRs and Miras previously discussed in §4.4 are consistent with this scenario.

5.1. Spectral Energy Distributions

Here we model the spectral energy distributions (SEDs) for the small subset of our sample also identified by Frogel & Whitford (1987). These stars allow us to calibrate mass-loss rates based upon the observed 15 $\mu m$ flux excess using model SEDs. We also attempt an initial characterization of how mass-loss rates depend on fundamental stellar parameters such as luminosity and effective temperature in order to compare with recent theoretical predictions. This is the first time that dust sensitive mid-infrared photometry has been assembled for a sample of SRs (and Miras) whose distances and thus energetics are known. We compare pulsational properties of the sample with mass-loss rates calibrated here in §5.4.
First, we assembled $J_0$ and $K_0$ photometry (see also Table 2) and SED-integrated bolometric magnitudes for 26 stars (1 Mira from Table 1 and 25 SRs from Table 2) from Frogel & Whitford (1987). The bolometric magnitudes were adjusted by $-0.5$ mag to account for a distance modulus of 14.7 mag as discussed previously. The ISOGAL running number (BW), the MACHO identifier, the star name by Frogel & Whitford (1987) and the adjusted values of $M_{\text{bol}}$ are listed in the first four columns of Table 3, respectively. The $V$ and $R$ magnitudes were dereddened by adopting a visual extinction of $A_V = 1.5$ mag and taking $A_R/A_V = 0.75$. Optical and near-infrared fluxes were calculated using the zero points from Bessell, Castelli, & Plez (1998). The mid-infrared fluxes were calculated from Eqns. (1) & (2) of this paper. Errors associated with absolute flux calibration and dereddening are negligible for the purposes of this work.

Stellar effective temperatures in column (5) of Table 3 were calculated from the dereddened $(V - K)_0$ color, where we employed the calibration of Bessell, Castelli, & Plez (1998). These temperatures are assumed to represent an accurate, relative effective temperature scale. It is noted that systematic uncertainty in the temperature scale at the $\pm 100$ K level or less will not affect our conclusions (e.g., see §5.2).

For our SED modeling, we assembled the “corrected” model spectra of Lejeune, Cuisinier, & Buser (1997) with solar [Fe/H], $\log g$ of either 0.28 or 0.00, and effective temperatures of 2500, 2800, 3000, 3200, 3350, 3500, 3750, and 4000 K. This was the finest temperature grid available. This corrected spectral library, by definition, yields synthetic optical and near-infrared broadband colors consistent with the $(V - K)_0$ color-temperature calibration adopted above. We caution that these model spectra are for static stars and do not take account of photospheric extension arising from variability (e.g., Bessell et al. 1989).

The Lejeune et al. (1997) model spectra were input as $\lambda, F_{\nu}$ files into the radiative transfer code, DUSTY (Ivezić, Nenkova, & Elitzur 1999). DUSTY solves the radiative transfer problem of an AGB star enshrouded in dust, including a self-consistent solution for the density structure in the wind-driven dust shell. We adopted the faster-running analytic approximation for the wind-driven dust density structure, which is an option in DUSTY. We chose 100% warm silicate for the grain composition (Ivezić et al. 1999). The grain size distribution was a truncated power-law ($q = -3.5$, $a_1 = 0.005$ $\mu$m and $a_2 = 0.25$ $\mu$m; Ivezić et al. 1999; see also Mathis, Rumpl, & Nordsieck 1977). The temperature at the dust shell’s inner-boundary was fixed to be 1000 K, which is supported by observations (Reid & Menten 1997). We ran a total of $\sim 200$ model SEDs with DUSTY using the 8 different Lejeune et al. (1997) model spectra as inputs and allowing for a wide range of mass-loss rates. DUSTY reports the mass-loss rate ($\dot{M}_{\text{L4}}$) and the expansion velocity ($V_{\exp}$) normalized to a luminosity $L = 10^4 L_\odot$. The true mass-loss rate ($\dot{M}$) scales in proportion to $L^{3/4}$ and $(r_{gd}\rho_s)^{1/2}$, where $r_{gd}$ is the gas-to-dust ratio and $\rho_s$ is the dust grain bulk density. The expansion velocity scales as $L^{1/4}$ and $(r_{gd}\rho_s)^{1/2}$. For these latter parameters, the default values from DUSTY are employed: $r_{gd} = 200$ and $\rho_s = 3$ g cm$^{-3}$. This corresponds to an absorption coefficient at 60 $\mu$m of $\chi_{60} = 70$ cm$^2$ g$^{-1}$. For all stars, we assume that $r_{gd}$, $\rho_s$, the grain size distribution, the dust composition, and the temperature at the inner-boundary are the
same. These simplifying assumptions are sufficient to establish a plausible, relative calibration of the mass-loss rates in our sample.

Each model SED from DUSTY is fit to the observed, dereddeded flux data in the $\log(\lambda F_{\lambda})$ versus $\log(\lambda)$ plane, allowing for one zeropoint constraint. The SED fits yield both the luminosity and temperature. The best-fit input model spectrum temperature ($T_{\text{MOD}}$) and the mass-loss rate normalized to $L = 10^4 L_\odot$ ($\dot{M}_{L4}$) are listed in columns (6) & (7) of Table 3, respectively. The true mass-loss rate ($\dot{M}$), which is rescaled for each known stellar luminosity by a factor of $(L/10^4 L_\odot)^{3/4}$, is listed in column (8) of Table 3. Finally, the expansion velocity corrected for a factor of $(L/10^4 L_\odot)^{1/4}$ is listed in column (9) of Table 3.

We find reasonable agreement between the $(V - K)_0$ color temperatures and those indicated by the best-fit model SEDs. However, the former are preferred because of the poor temperature resolution of the grid of model spectra. We also checked that the stellar luminosities derived from our SED fits agree with those taken from Frogel & Whitford (1987). The agreement is fair in most cases. However, in a few instances of fitting the SEDs of stars with high mass-loss rates, we obtain luminosities lower than those given by Frogel & Whitford (1987). In these cases, our statistical best-fit model SED (which gives equal weight to all flux data) underestimates the near-infrared flux (near the peak of $\lambda F_{\lambda}$) and overestimates the mid-infrared data. Fortunately, while this affects the luminosities so obtained, the mass-loss rates themselves are not underestimated at a level which is important in this work. In summary, we adopt the distance modulus-adjusted, SED-integrated Frogel & Whitford (1987) luminosities, the Bessell, Castelli, & Plez (1998) $(V - K)_0$ color temperatures, and the SED-fit mass-loss rates in our subsequent analyses.

Figure 7 shows four example SEDs (filled circles) and their best-fit DUSTY SEDs (solid lines). Each input spectrum is shown as a dotted line. We plot $\log(\lambda F_{\lambda})$ versus $\log(\lambda)$.

### 5.2. Mass-loss rate, effective temperature, and luminosity

Our data, as presented in Table 3, can be used to obtain observational constraints on the dependence of mass-loss rate on effective temperature and luminosity for the first time. We assumed that the relationship should be of the form: $\dot{M} \propto T^\alpha L^\beta$. Adopting a factor of two uncertainty for each true mass-loss rate, a chi-squared minimization yields the power-law exponents:

$$\alpha = -8.80^{+0.96}_{-0.24} \quad \beta = +1.74^{+0.16}_{-0.24}$$

(7)

Theoretical studies of mass-loss for C-rich long-period variables (not yet extended to O-rich or M-type variables) suggests that their mass-loss rates are mainly governed by stellar photospheric temperature, followed by mass and luminosity, and are relatively independent of amplitude of variation, C over-abundance, and pulsational period (Arndt, Fleischer & Sedlmayr 1997). They
obtain
\[ \dot{M} \propto T_{\text{eff}}^{-8.26} L^{1.53}. \]  
which is in good agreement with our observations.

5.3. Dust-based mass-loss rates from 15 \( \mu \)m photometry

Table 3 includes the excess of 15 \( \mu \)m flux based on a Rayleigh-Jeans extrapolation of the 7 \( \mu \)m flux \((x[15]\text{ in mJy})\) for each star. We can calibrate this quantity in terms of the true mass-loss rate, as given by the DUSTY models, yielding
\[ \log \dot{M} = 0.78(\pm 0.08) \cdot \log(x[15]) - 7.88(\pm 0.11), \]  
with a s.d. = 0.30 dex. This formula should be valid for SRs having observed 15\( \mu \)m excesses from 3 to 130 mJy, giving mass-loss rates from \( 1 \times 10^{-8} \) to \( 5 \times 10^{-7} \) \( M_\odot \) yr\(^{-1}\).

As previously explained, determination of the 15\( \mu \)m continuum by Rayleigh-Jeans extrapolation of the 7\( \mu \)m flux will not be correct for objects whose dust shells become optically thick at shorter wavelengths than is usually the case for SRs. Thus, in particular, we do not expect long-period Miras to follow the empirical relationship given.

It is instructive to compare our values with those given by the Jura (1987) formula for the mass-loss from an AGB star:
\[ \dot{M} = 1.7 \times 10^{-7} \left( \frac{150}{\chi_{60}} \right) v_{15} R_{kpc}^2 L^{-1/2}_4 F_{\nu,60} \lambda_{10}^{1/2} M_\odot \text{yr}^{-1}, \]  
where \( v_{15} \) is the gas outflow velocity in units of 15 km s\(^{-1}\), determined from CO observations, \( R \) is the distance to the star in kpc, \( L_4 \) is the stellar luminosity in units of \( 10^4 \) \( L_\odot \), \( F_{\nu,60} \) is the flux from the object at 60\( \mu \)m in Jy, \( \lambda_{10} \) is the mean wavelength of light emerging from the star in units of 10\( \mu \)m, and \( \chi_{60} \) is the dust absorption coefficient in units of cm\(^2\) g\(^{-1}\). We adopt \( R \sim 8.7 \) kpc, \( L_4 = 0.3 \), \((M_\text{bol} = -4.04)\) and \( \lambda_{10} = 0.1 \) from the bolometric magnitude of a 200-day Mira (Glass et al. 1995). To relate the given 15\( \mu \)m flux to the 60\( \mu \)m flux required, we take the relation by Jura (1986), intended for carbon stars (but see also the values of \( Q_{\text{abs}} \) for astronomical silicate grains; Draine & Lee 1984), namely \( F_{\nu} \propto \nu^{1.54} \). As noted above, our DUSTY models employ \( \chi_{60} = 70 \) cm\(^2\) g\(^{-1}\). Finally, we adopt the mean expansion velocity of those listed in Table 3, or 16 km s\(^{-1}\); this compares to 8 km sec\(^{-1}\), the average value determined for semi-regular variables by Kerschbaum, Olofsson & Hron (1996). If the excess 15\( \mu \)m flux is 100 mJy, we obtain \( \dot{M} = 2 \times 10^{-7} \) \( M_\odot \) yr\(^{-1}\). This is within a factor of two of the mass-loss rate expected from our calibration, \( 4 \times 10^{-7} \) \( M_\odot \) yr\(^{-1}\) for a similar 15\( \mu \)m flux excess. Thus our mass-loss rate calibration and Jura’s well-known calibration yield similar results.
5.4. Mass-loss rate and Pulsation Periods

The part of the 15\,\mu m flux emitted by dust ($x[15]$) for the whole sample of SRs has been estimated by subtracting the photospheric flux which was taken to be a Rayleigh-Jeans tail fitted to the 7\,\mu m measurements. The latter were assumed to be completely free of dust emission. Figure 8 shows this quantity $x[15]$ as a function of log period. Although the same procedure has been applied to the Miras, which are also included in Fig. 8, it becomes unreliable with increasing period because the assumption that the 7\,\mu m flux is free of a dust component progressively ceases to be valid.

It is evident from Fig. 8 that the mass-loss rates of the longer-period SRs overlap those of the short-period Miras and clearly do not depend on the presence of large-amplitude pulsation. The lack of measurable mass-loss for stars with periods $P < 60$ days accords with the finding of Kerschbaum, Olofsson & Hron (1996, see below) that CO radio emission is not detected for $0 < P < 75$ days. Similarly, though stars with periods in the range $75 < P < 175$ days may show dust emission, as they may also show CO emission, this does not constitute a sufficient condition.

5.5. CO-based information

As noted above, the period-dependent behavior of the quantity $x[15]$ for SRs in the Galactic bulge is consistent with that of CO detections for SRs found in the solar neighborhood. It is therefore of interest to briefly recall the CO-based information.

Kahane & Jura (1994) found CO emission from 11 SRs with measured periods (typically 100-160 days) and brighter than $K = 0$. They determined mass-loss rates of $1-1.5 \times 10^{-7} \, M_\odot \, \text{yr}^{-1}$, which they compared to calculations based on the dust mass-loss rates derived from IRAS 60\,\mu m fluxes. Similar dust-to-gas ratios, CO line ratios, outflow velocities and mass-loss rates were found as for Miras with $300 \leq P \leq 400$ days period, leading to the speculation that this group of SRs were overtone pulsators corresponding to the Miras which pulsate in the fundamental mode. Kerschbaum, Olofsson and Hron (1996) extended their sample to another group of SRas and SRbs, selected on the basis of their 60\,\mu m fluxes. The Kerschbaum & Hron (1992) blue SRVs were not detected, whereas the red ones and the Miras had a 50\% detection rate. Those with periods below 75 days were not seen, nor were those with $175 \leq P \leq 325$ days. Those with $75 \leq P \leq 175$ had a high detection rate. A CO study by Young (1995) of nearby Miras with optically thin dust shells showed that only stars of type later than M5.5 could be detected, the rate becoming 100\% only for M7 and later types. The mass-loss rate was found to be correlated with far-IR luminosity but not color, and also with CO outflow velocity. Similar mass-loss rates were found for M6.5–M8 types (comparable to the rates for semiregular variables found by other workers).
5.6. Mass-loss rates as a function of luminosity only

We have seen that mass-loss in SRs can be expressed as a function of $T$ and $L$. High luminosities and long periods in LPVs are associated with low temperatures, which are not independent variables but are connected by evolutionary tracks.

Figure 9 shows $M_{\text{bol}}$ plotted against the mass-loss rates from Table 3 of our work together with those derived for dust-enshrouded O- and C-rich AGB stars in the LMC by van Loon et al. (1999). There is a striking continuity between the rates exhibited by the low-luminosity semi-regular variables and those found amongst the extreme AGB-tip variables, both C-type and M-type, in the LMC, in spite of the differences in metallicities between the samples. We have derived a linear fit between $\log \dot{M}$ and $M_{\text{bol}}$. Because the distribution of errors between these quantities is uncertain, we have solved first assuming that all the errors are in $M_{\text{bol}}$ and second assuming that they are in $\dot{M}$. Both fits are shown and the average slope is given by the solid line, whose form is

$$\dot{M} \propto -1.09 M_{\text{bol}},$$

i.e., we find that

$$\dot{M} \propto L^{2.7},$$

in the range $10^{-8} < \dot{M} < 10^{-4} M_{\odot} \text{ yr}^{-1}$.

6. Conclusions

1. Almost all non-Miras in our sample detected in the four MACHO and ISO colors show semi-regular variability.

2. The SRs outnumber Miras by 20:1 in our sample.

3. We see no preferred periods in 10-200 day range, but a gap exists between the distributions of SRs and Miras which may be explicable in terms of pulsation modes.

4. The Galactic bulge SRs possess a $P - L$ distribution similar to that of the solar neighbourhood SRs observed by Hipparcos. They can probably be regarded as lying on a series of $P - L$ relations with slopes equal to that observed in globular clusters, but with luminosity levels appropriate to higher metallicities and initial masses.

5. The amplitudes of the SRs increase with period, reaching about 0.3 mag at 100 days.

6. Mass loss depends on luminosity and period, but does not require large Mira-like amplitudes, even though the mass-loss levels reach those of the shorter-period Miras.

7. A minimum period of about 70d is required for, but does not guarantee, detectable mass loss, in agreement with conclusions based on CO observations.
8. The mass-loss rate for semi-regular variables depends on temperature and luminosity approximately according to $\dot{M} \propto T^{-8.8} L^{1.7}$.

9. The observed mass-loss rates in SRs range from $1 \times 10^{-8} M_\odot \text{yr}^{-1}$ to $5 \times 10^{-7} M_\odot \text{yr}^{-1}$.

10. Taking into account the work of van Loon et al. (1999) concerning extreme mass-losing AGB stars in the LMC, we find the general result that $\dot{M} \propto L^{2.7}$ in the range $10^{-8} < \dot{M} < 10^{-4} M_\odot \text{yr}^{-1}$.

Note that in this work we have discussed only those stars which were detected in both MACHO and both ISOGAL bands. A preliminary examination of the light curves of the stars seen by ISOGAL only at 7$\mu$m indicates that most of them are also SRs, but presumably with mass-loss rates too low for 15$\mu$m detection.

D.R.A. acknowledges support of this work from a NASA grant administered by the American Astronomical Society. D.R.A. also thanks the South Africa Astronomical Observatory for his appointment to the Visiting Astronomer Program, and acknowledges their financial support of his visit.

I.S.G. thanks the Institute of Astronomy, University of Cambridge, and the Institut d’Astrophysique, Paris, for their hospitality and support during part of this work, under PPARC and CNRS grants, respectively.

We thank M. Groenwegen for useful comments on an early version of this paper.

The MACHO Collaboration thanks the skilled support by the technical staff at MSSSO. Work at LLNL was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract No. W7405-ENG-48. Work at CfPA was supported by NSF AST-8809616 and AST-9120005. Work at MSSSO was supported by the Australian Dept. of Industry, Technology and Regional Development. W.J.S. thanks PPARC Advanced Fellowship, K.G. thanks DOE OJI, Sloan, and Cottrell awards, C.W.S. thanks Sloan and Seaver Foundations. D.M. is supported by Fondecyt 1990440.
REFERENCES

Alcock, C. et al. 1999, PASP, 111, 1539
Alcock, C. et al. 2000, AJ, 119, 2194
Alves, D. et al. 1998, proc. of IAU JD 24, “Pulsating Stars: Recent Developments in Theory and Observation”, eds. D. Sasselov & M. Takeuti (Tokyo: Universal Academy Press)
Arndt, T.U., Fleischer, A.J., & Sedlmayr, E. 1997, A&A, 327, 614
Bedding, T.R. & Zijlstra, A.A. 1998, ApJ, 506, L47
Bessell, M.S., Brett, J.M., Scholz, M., & Wood, P.R. 1989, A&A, 213, 209
Bessell, M.S., Castelli, F., & Plez, B. 1998, A&A, 333, 231
Blanco, V.M. 1986, AJ, 91, 290
Blanco, V.M., McCarthy, M.F., & Blanco, B. 1984, AJ, 89, 636
Bowen, G.H. 1988, ApJ, 329, 299
Bowen, G.H. & Willson, L.A. 1991, ApJ, 329, L53
Cesarsky, C.J. et al. 1996, A&A, 315, L32
de Gioia-Eastwood, K., Hackwell, J.A., Grasdalen, G.L., & Gehrz, R.D. 1981, ApJ, 245, L53
Draine, B.T. & Lee, H.M. 1984, ApJ, 285, 89
Fleischer, A.J., Gauger, A., & Sedlmayr, E. 1992, A&A, 266, 321
Frogel, J.A. & Whitford, A.E. 1987, ApJ, 320, 199
Gail, H.-P., Cuntz, M., & Ulmschneider, P. 1990, A&A, 234, 359
Gilman, R.C. 1972, ApJ, 178 423
Glass, I.S., Alves, D., & the ISOGAL & MACHO teams, 2000, in ISO Surveys of a Dusty Universe, D. Lemke, M. Stickel, & K. Wilke (eds.), Lecture Notes in Physics Series, Springer-Verlag, in press
Glass, I.S., Catchpole, R.M., Feast, M.W., Whitelock, P.A., & Reid, I.N., 1987, in Late Stages of Stellar Evolution, S. Kwok & S.R. Pottasch (eds.), Reidel Dordrecht
Glass, I.S., Whitelock, P.A., Catchpole, R.M., & Feast, M.W. 1995, MNRAS, 273, 383
Glass, I.S., Ganesh, S., Alard, C., Blommaert, J.A.D.L., Gilmore, G., Lloyd Evans, T., Omont, A., Schultheis, M., & Simon, G. 1999, MNRAS, 308, 127
Habing, H.J., 1996, A&A Review, 7, 97
Hinkle, K.H., Lebzelter, T., & Scharlach, W.W.G. 1997, AJ, 114, 2686
Hoyle, F. & Wickramasinghe, N.C. 1962, MNRAS, 124, 417
Iben, I. & Renzini, A. 1983 ARA&A, 21, 271
Ivecić, Z., Nenkova, M., & Elitzur, M. 1999, User Manual for Dusty, preprint (astro-ph/9910475)
Jura, M., 1986, ApJ, 303, 327
Jura, M., 1987, ApJ, 313, 743
Jura, M. & Kleinman, S. 1992, ApJS, 83, 329
Kahane, C. & Jura, M. 1994, A&A, 290, 183
Kerschbaum, F. & Hron, J. 1992, A&A, 263, 97
Kerschbaum, F., Olofsson, H., & Hron, J. 1996, A&A, 311, 273
Koen, C. & Laney, C.D. 2000, MNRAS, 311, 638
Kwok, S. 1975, ApJ, 198, 583
Lafon, J.P.-J. & Berruyer, N. 1991, A&AR, 2, 249
Lejeune, T., Cuisinier, F., & Buser R. 1997, A&AS, 125, 229
Lloyd Evans, T. 1976, MNRAS, 174, 169
Mathis J.S., Rumpl W., & Nordsieck, K.H., 1977, ApJ, 217, 425
Mennessier et al., 2000, in preparation
Minniti, D. et al 1998 proc. of IAU JD 24, “Pulsating Stars: Recent Developments in Theory and Observation”, eds. D. Sasselov & M. Takeuti (Tokyo: Universal Academy Press)
Morris, M. 1987, PASP, 99, 1115
Omont, A. et al. 1999, A&A, 348, 755
Omont, A. et al. & the ISOGAL Collaboration, 2000, in ISO Surveys of a Dusty Universe, D. Lemke, M. Stickel, & K. Wilke (eds.), Lecture Notes in Physics Series, Springer-Verlag, in press
Payne-Gaposchkin, C. 1951, in Astrophysics, J.A. Hynek (ed.), McGraw-Hill, New York
Reid, M.J. & Menten, K.M. 1997, ApJ, 476, 327
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
Vassiliadis, E. & Wood, P. 1993, ApJ, 413, 641
Whitelock, P.A. 1986, MNRAS, 219, 525
Whitelock, P.A. et al. 1994, MNRAS, 267, 711
Whitelock, P., Menzies, J., Feast, M., Catchpole, R., Marang, F., & Carter, B. 1995, MNRAS, 276, 219
Willson, L.A. 1976, ApJ, 205, 172
Willson, L.A. & Hill, S.J., 1979, ApJ, 228, 854
Winters, J.M., Fleischer, A.J., Gauger, A., & Sedlmayr, E. 1994, A&A, 288, 255
Wood, P.R. 1979, ApJ, 227, 220
Wood, P.R. 2000, Publ. Astr. Soc. Austr., 18, 18
Wood, P.R. et al. 1999, proc. of IAU Symposium 191 “Asymptotic Giant Branch Stars”, p. 151
Wood, P.R. & Sebo, K.M., 1996, MNRAS, 282, 958
Young, K. 1995, ApJ, 445, 872
Fig. 1.— Combined ISOCAM color-magnitude diagram for the $15 \times 15$ arcmin$^2$ fields in the NGC 6522 and Sgr I windows. Note the characteristic sequence of increasing 15$\mu$m flux, representative of mass-loss, with $[7] - [15]$ color. The heavy dots represent Mira variables and the crosses are bright stars that were examined unsuccessfully for variability in the pre-MACHO data. The top of the red giant branch (RGB) is around $[15] \sim 8$. The objects brighter than this level are asymptotic-giant-branch (AGB) stars, except for a few foreground objects. Representative error bars are shown at each end of the sequence.
Fig. 2.— The distribution of $\delta S$ (the angular distance between ISOGAL and MACHO source coordinates in arcseconds) for the final match lists. Example distributions of spurious matches are also shown (shaded histograms).
Fig. 3.— The optical CMD for MACHO+ISO GAL sources in the SGR I and NGC 6522 fields. 904 matched sources with MACHO $V$ and $R$ colors are shown as open circles. Sources with four colors ($V$, $R$, [7], and [15]), are shown with bold filled circles. The $V,(V - R)$ cut described in §3 is shown as a solid line. The four-color sources lie mostly in the reddest areas of the AGB. Some sources are foreground stars, and some are possible spurious matches (i.e., near the red clump at $V \sim 17$, $V - R \sim 0.9$).
Fig. 4.— (a) Left: MACHO $R$ light curves (mag vs. day) for five Miras. Right: Same, folded according to period (mag vs. phase).
Fig. 4.— (b) Left: MACHO $R$ light curves (mag vs. day) for five variables classified SRa. Right: Same, folded according to period (mag vs. phase).
Fig. 4.— (c) Left: MACHO $R$ light curves (mag vs. day) for five variables classified SRb. Right: same, folded according to period (mag vs. phase).
Fig. 4.— (d) Left: MACHO $R$ light curves (mag vs. day) of two double-period variables (upper panels) and three large-amplitude SRas (bottom panels). Right: same, folded according to period shown (mag vs. phase).
Fig. 5.— (a) The $[\text{mag}] - \log P$ diagram ([mag] in mags, P in days) for cross-identified objects. The open circles are the main periods identified. Open triangles are separately identified long periods and solid triangles are Mira (large-amplitude) variables, some of which were saturated in the MACHO data. Periods for these cases were taken from Glass et al. (1995). The dashed line is an empirical period-luminosity relation derived for semiregular variables in the solar neighbourhood from Hipparcos and other data by Bedding & Zijlstra (1998). The solid line is an empirical fit to the Mira data (see text).
Fig. 5.— (b) Similar to Fig 5a but for $K$, $\log P$. The solid line is a fit to Mira data for the whole Sgr I field, taken from Glass et al. (1995). (See Fig. 5c for the distribution of Miras in a similar version of this diagram.) The dotted line is from Bedding & Zijlstra (1998), representing semi-regular variables in the solar neighbourhood with known periods and distances from Hipparcos. The dashed line is the relation for globular cluster variables from Whitelock (1986) as transformed by Bedding & Zijlstra (1998).
Fig. 5.— (c) Similar to Fig 5b but for $M_{bol}$, $\log P$. Miras (dark dots) and their $P-L$ relation (solid line) for the entire SgrI field, have been taken from Glass et al. (1995). The dashed line is the observed relation for galactic globular clusters, taken from Whitelock (1986).
Fig. 6.— Lower: Histogram of mean amplitudes of all variables for log(period) groups, excluding the Miras. Standard deviations are also shown. Upper: Numbers of variables in each log $P$ box.
Fig. 7.— Examples of observational data for four stars (filled circles) and best-fit model spectral energy distributions (SEDs; \( \lambda F_{\lambda} \) in erg s\(^{-1}\) cm\(^{-2}\) and \( \lambda \) in Å) including circumstellar dust (solid lines; modeled with “DUSTY”). Each input spectrum without circumstellar dust is shown as a dotted line (same units as the DUSTY model SEDs). The zero-point (C) is arbitrary and there is a vertical offset of 3 dex between each star.
Fig. 8.— Excess 15µm flux, an indication of mass-loss, beyond what is expected by assuming a Rayleigh-Jeans photospheric energy distribution fitted to the 7µm fluxes, shown plotted against log P. Symbols are as in Fig. 5a. Having a period P > 70 days appears to be a necessary, but not a sufficient condition, for significant mass-loss.
Fig. 9.— $\dot{M}$ in units of $M_\odot\text{yr}^{-1}$ plotted against $M_{\text{bol}}$ for our sample of Baade’s Window SRs (open squares) and a sample of extreme mass-losing AGB stars in the LMC, from van Loon et al. (1999). The LMC C-type stars are shown as solid dots and M-type stars as open circles. The crosses are M supergiants. The solid line is a linear fit and the dotted lines give an indication of the errors in the slope (see text).
Table 1. Summarized Photometry of Sources

| ISOGALP | BW | MACHO | V | R | J0 | K0 | [7] | [15] | Amp. | log PE | notes |
|---------|----|--------|---|---|----|----|-----|-----|------|-------|-------|
| J175840.5–290348 | 54 | 113 18155 17 | 14.92 | 13.47 | 8.61 | 8.07 | 0.2 | 1.891 |
| J175840.9–290827 | 57 | 113 18154 52 | 16.81 | 15.16 | 8.46 | 8.37 | 0.2 | 1.738 |
| J175841.8–290352 | 61 | 113 18155 68 | 17.49 | 15.38 | 6.86 | 5.41 | 0.3 | 2.093 |
| J175842.1–290650 | 65 | 113 18155 18 | 15.90 | 13.92 | 7.12 | 6.73 | 0.25 | 2.019 |
| J175842.4–290515 | 67 | 113 18155 251 | 19.06 | 16.65 | 8.04 | 7.07 | 0.4 | 2.048 |
| J175842.6–290240 | 68 | 113 18156 31 | 15.72 | 14.01 | 7.93 | 7.82 | 0.15 | 1.490 |
| J175842.6–291029 | 69 | 113 18154 179 | 18.30 | 16.10 | 7.44 | 6.59 | 0.3 | 1.891 |
| J175842.7–290340 | 70 | 113 18156 252 | 18.69 | 16.31 | 8.59 | 8.07 | 0.25 | 1.594 |
| J175842.9–290845 | 72 | 113 18154 65 | 17.25 | 15.11 | 7.58 | 7.00 | 0.3 | 1.871 |
| J175843.4–291012 | 74 | 113 18154 51 | 17.09 | 15.21 | 8.62 | 8.56 | 0.1 | 1.433 |
| J175843.9–290325 | 77 | 113 18156 21 | 14.87 | 13.41 | 8.58 | 8.59 | 0.2 | 1.672 |
| J175843.9–290712 | 78 | 113 18155 43 | 17.65 | 15.69 | 6.33 | 5.28 | 4.0 | 2.468: Mira |
| J175844.6–290234 | 82 | 113 18156 38 | 15.68 | 14.05 | 8.55 | 8.28 | 0.12 | 1.301 |
| J175845.6–290357 | 87 | 113 18155 118 | 17.64 | 15.75 | 8.29 | 8.17 | 0.15 | 1.560 |
| J175845.9–290326 | 88 | 113 18154 48 | 16.17 | 14.43 | 8.80 | 8.64 | 0.12 | 1.574 |
| J175846.0–291033 | 89 | 113 18154 84 | 17.32 | 15.43 | 8.95 | 8.87 | 0.1 | 1.574 |
| J175846.0–290748 | 90 | 113 18154 108 | 17.68 | 15.65 | 8.67 | 8.61 | 0.15 | 1.396 |
| J175846.2–290310 | 93 | 113 18156 75 | 17.15 | 15.08 | 8.14 | 8.12 | 0.35 | 1.753 |
| J175846.9–290722 | 99 | 113 18155 402 | 18.08 | 16.87 | 8.11 | 7.96 | 0.1 | 1.490 |
| J175846.9–290332 | 100 | 113 18156 76 | 16.99 | 15.10 | 8.60 | 8.68 | 0.15 | 1.490 |
| J175847.2–290711 | 104 | 113 18155 159 | 18.20 | 16.02 | 7.83 | 7.35 | 0.1 | 1.834 |
| J175847.5–290157 | 108 | 113 18156 54 | 16.47 | 14.66 | 8.54 | 8.37 | 0.15 | 1.768 |
| J175847.8–290943 | 111 | 113 18154 23 | 15.78 | 14.24 | 9.29 | 8.79 | 0.1 | 1.980 |
| J175848.0–291003 | 112 | 113 18154 20 | 16.17 | 14.06 | 7.33 | 7.26 | 0.3 | 2.342: |
| J175848.2–290127 | 113 | 113 18156 279 | 18.74 | 16.39 | 7.72 | 6.52 | 0.3 | 2.145 |
| J175848.7–290743 | 117 | 113 18154 80 | 17.98 | 15.60 | 7.48 | 6.58 | 0.3 | 1.993 |
| J175849.2–291120 | 121 | 113 18154 26 | 16.53 | 14.64 | 8.02 | 6.74 | 0.5 | 2.581: dp(0.15,1.756) |
| J175849.3–290528 | 124 | 113 18285 146 | 16.97 | 15.14 | 8.68 | 8.85 | 0.1 | 1.298 |
| J175849.5–291012 | 126 | 113 18284 606 | 18.98 | 16.65 | 8.41 | 7.47 | 1.0 | 2.344: |
Table 1—Continued

| ISOGALP$^A$ | BW$^B$ | MACHO$^C$ | $V^D$ | $R^D$ | $J_0$ | $K_0$ | [7] | [15] | Amp. | log $P^E$ | notes$^F$ |
|-------------|--------|-----------|------|------|------|------|-----|-----|-----|--------|--------|
| J175850.2−290633 | 128    | 113 18285 55 | 14.93 | 13.61 |      |      | 8.52 | 8.40 | 0.1  | 2.145  |         |
| J175850.3−290455 | 129    | 113 18285 115 | 17.45 | 15.15 |      |      | 7.47 | 6.57 | 0.5  | 2.063  |         |
| J175850.6−291015 | 134    | 113 18284 413 | 18.14 | 16.01 |      |      | 7.64 | 6.53 | 0.5  | 2.094  |         |
| J175850.7−290314 | 135    | 113 18286 81 | 16.66 | 14.73 |      |      | 8.14 | 7.94 | 0.15 | 1.478  |         |
| J175850.9−290106 | 136    | 113 18286 615 | 18.61 | 16.70 |      |      | 7.54 | 5.51 | 0.35 | 2.158: |         |
| J175851.2−290721 | 139    | 113 18285 35 | 15.02 | 13.40 |      |      | 7.60 | 6.99 | 0.4  | 1.852  |         |
| J175851.2−290206 | 140    | 113 18286 592 | 17.25 | 16.24 |      |      | 8.64 | 8.50 | 0.1  | 1.523  |         |
| J175851.6−290315 | 141    | 113 18286 54 | 15.69 | 14.15 |      |      | 8.15 | 8.20 | 0.08 | 1.185  |         |
| J175852.0−290524 | 143    | 113 18285 523 | 17.15 | 16.14 |      |      | 8.17 | 7.16 | 0.1  | 1.980  |         |
| J175853.3−290422 | 154    | 113 18285 314 | 17.69 | 15.74 |      |      | 8.57 | 8.35 | 0.3  | 1.523  |         |
| J175853.3−290831 | 155    | 113 18284 79 | 15.92 | 14.28 |      |      | 8.61 | 7.86 | 0.1  | 1.560  |         |
| J175853.6−285938 | 157    | 113 18287 1926 | 16.55 | 14.59 |      |      | 7.93 | 7.99 | 0.15 | 1.448  |         |
| J175854.2−290351 | 162    | 113 18285 61 | 15.70 | 14.13 |      |      | 8.74 | 8.50 | 0.1  | 1.390  |         |
| J175854.2−290523 | 163    | 113 18285 390 | 18.00 | 15.90 |      |      | 8.55 | 7.90 | 0.6  | 2.048  |         |
| J175854.5−291031 | 164    | 113 18284 188 | 17.89 | 15.62 |      |      | 7.51 | 6.63 | 0.4  | 1.922  |         |
| J175854.5−290323 | 165    | 113 18286 189 | 17.51 | 15.49 |      |      | 8.85 | 8.67 | 0.2  | 1.409  |         |
| J175854.8−285831 | 167    | 113 18287 1897 | 14.43 | 12.74 |      |      | 6.84 | 6.94 | 0.25 | 1.403  |         |
| J175854.9−290118 | 168    | 113 18286 24 | 9.71: | 9.40: |      |      | 7.46 | 7.76 |      |        |         |
| J175855.1−290037 | 169    | 113 18286 42 | 15.16 | 13.59 |      |      | 8.21 | 8.57 | 0.2  | 1.718  |         |
| J175855.1−290627 | 170    | 113 18285 564 | 17.79 | 16.21 |      |      | 6.99 | 5.53 | 0.15 | 2.127  |         |
| J175855.5−285808 | 172    | 113 18287 1899 | 14.33 | 13.13 |      |      | 8.94 | 8.61 | 0.1  | 1.240  |         |
| J175855.7−291208 | 174    | 113 18283 170 | 17.40 | 15.37 |      |      | 7.86 | 7.67 | 0.25 | 1.615  |         |
| J175855.7−290707 | 176    | 113 18285 138 | 17.08 | 15.11 |      |      | 8.00 | 7.73 | 0.2  | 1.672  |         |
| J175856.1−285943 | 183    | 113 18286 33 | 13.51: | 12.24: |      |      | 8.80 | 8.37 |      |        |         |
| J175856.4−290050 | 187    | 113 18286 454 | 19.08 | 16.46 |      |      | 6.73 | 5.37 | 0.3  | 2.299: |         |
| J175856.7−290559 | 190    | 113 18285 133 | 16.93 | 15.07 |      |      | 8.68 | 8.37 | 0.15 | 1.448  |         |
| J175856.9−290339 | 194    | 113 18286 166 | 17.34 | 15.40 |      |      | 8.32 | 8.20 | 0.2  | 1.746  |         |
| J175857.0−290445 | 197    | 113 18285 148 | 17.39 | 15.17 |      |      | 7.62 | 7.14 | 0.3  | 1.649  |         |
| J175857.1−290804 | 198    | 113 18284 189 | 16.93 | 15.23 |      |      | 8.91 | 8.80 | 0.1  | 1.324  |         |
Table 1—Continued

| ISOGALP<sup>A</sup> | BW<sup>B</sup> | MACHO<sup>C</sup> | V<sup>D</sup> | R<sup>D</sup> | J₀  | K₀  | [7] | [15] | Amp. | log P<sup>E</sup> | notes<sup>F</sup> |
|---------------------|---------------|-------------------|---------------|---------------|-----|-----|-----|-----|------|----------------|----------------|
| J175857.4−291215    | 200           | 113               | 18283 439    | 16.97         | 15.88|    | 7.20| 6.11| 0.12 | 2.006         |                |
| J175857.5−290537    | 202           | 113               | 18285 41     | 14.81         | 13.43|    | 8.57| 8.73| 0.1  | 1.993         |                |
| J175857.6−290632    | 204           | 113               | 18285 39     | 14.78         | 13.41|    | 8.65| 8.60| 0.5  | 1.776         |                |
| J175858.1−291114    | 206           | 113               | 18286 193    | 17.73         | 15.75|    | 6.65| 5.34| 0.4  | 2.512         |                |
| J175858.0−290349    | 208           | 113               | 18285 420    | 18.28         | 16.17|    | 8.46| 7.84| 0.6  | 2.365         |                |
| J175858.4−285636    | 214           | 113               | 18287 41     | 15.38:        | 13.89:|    | 8.40| 7.35|      |                |                |
| J175858.5−291135    | 218           | 113               | 18284 54     | 14.91         | 13.61|    | 9.01| 8.81| 0.1  | 1.303         |                |
| J175858.5−290845    | 219           | 113               | 18284 274    | 17.66         | 15.71|    | 8.47| 8.25| 0.25 | 1.560         |                |
| J175858.6−290722    | 220           | 113               | 18285 65     | 15.96         | 14.23|    | 8.59| 8.47| 0.2  | 1.691         |                |
| J175900.0−285813    | 234           | 113               | 18287 1906   | 15.10         | 13.74|    | 8.43| 7.69| 0.1  | 1.229         |                |
| J175900.2−290556    | 235           | 113               | 18285 156    | 16.68         | 15.12|    | 9.27| 8.97| 0.1  | 1.214         |                |
| J175900.2−291111    | 236           | 113               | 18284 59     | 16.23         | 14.50|    | 7.85| 7.44| 0.10 | 2.164         |                |
| J175900.7−290305    | 242           | 113               | 18286 103    | 16.90         | 14.95|    | 8.58| 8.47| 0.15 | 1.426         |                |
| J175900.9−290952    | 244           | 113               | 18284 834    | 18.74         | 16.67|    | 8.28| 7.13| 0.4  | 1.912         |                |
| J175900.9−291238    | 245           | 113               | 18283 201    | 17.26         | 15.40|    | 8.35| 8.19| 0.2  | 1.560         |                |
| J175901.1−285821    | 247           | 113               | 18287 2391   | 17.48         | 16.56|    | 5.96| 4.46|      |                | Mira-nil; sat  |
| J175901.2−290910    | 249           | 113               | 18284 285    | 17.59         | 15.61|    | 8.94| 8.87| 0.2  | 1.396         |                |
| J175901.2−290518    | 250           | 113               | 18285 296    | 17.89         | 15.83|    | 8.07| 7.29| 0.15 | 1.800         |                |
| J175901.4−290802    | 252           | 113               | 18284 491    | 18.34         | 16.21|    | 7.98| 7.03| 0.3  | 1.922         |                |
| J175902.0−290531    | 258           | 113               | 18285 157    | 17.17         | 15.22|    | 8.23| 8.50| 0.2  | 1.555         |                |
| J175902.1−290625    | 261           | 113               | 18285 134    | 17.36         | 15.36|    | 7.55| 6.60| 0.3  | 1.922         |                |
| J175903.0−290137    | 266           | 113               | 18286 150    | 16.48         | 15.07|    | 9.86| 8.09| 0.25 | 1.523         |                |
| J175903.0−290842    | 267           | 113               | 18284 474    | 17.17         | 16.15|    | 8.39| 8.32| 0.2  | 1.183         |                |
| J175903.2−291205    | 270           | 113               | 18283 48     | 15.45         | 13.94|    | 8.51| 8.51| 0.15 | 1.637         |                |
| J175903.5−290603    | 273           | 113               | 18285 150    | 17.19         | 15.30|    | 7.96| 7.55| 0.08 | 1.792         |                |
| J175903.5−290830    | 274           | 113               | 18284 39     | 13.51:        | 12.49:|    | 8.63| 8.66|      |                |                |
| J175903.7−285919    | 277           | 113               | 18287 1968   | 16.56         | 15.07|    | 8.77| 8.79| 0.15 | 1.444         |                |
| J175903.8−291126    | 278           | 113               | 18284 36     | 13.38:        | 12.00:|    | 8.27| 8.41|      |                |                |
| J175904.0−290922    | 282           | 113               | 18284 37     | 13.57:        | 12.45:|    | 8.38| 8.43|      |                |                |
| ISOGALP$^A$ | BW$^B$ | MACHO$^C$ | $V^D$ | $R^D$ | $J_0$ | $K_0$ | [7] | [15] | Amp. | log $P^E$ | notes$^F$ |
|-------------|--------|---------|------|------|------|------|-----|-----|-------|----------|---------|
| J175904.2—291103 | 288 | 113 18284 192 | 17.59 | 15.39 | 8.32 | 8.05 | 0.5 | 2.063 |
| J175904.7—290745 | 291 | 113 18284 284 | 16.92 | 15.43 | 7.02 | 5.65 | 0.3 | 2.103 |
| J175905.2—290708 | 294 | 113 18285 47 | 14.95 | 13.53 | 8.64 | 8.81 | 0.1 | 1.339 |
| J175905.6—285833 | 299 | 113 18287 2109 | 18.47 | 16.36 | 7.95 | 6.86 | 0.3 | 1.901 |
| J175905.6—290545 | 302 | 113 18285 44 | 14.65 | 13.37 | 8.85 | 8.72 | 0.1 | 1.273 |
| J175905.6—290235 | 303 | 113 18286 399 | 18.48 | 16.15 | 7.08 | 6.01 | 0.3 | 1.980 |
| J175905.7—291128 | 304 | 113 18284 389 | 18.34 | 16.38 | 8.84 | 8.74 | 0.5 | 1.303 |
| J175905.8—291105 | 308 | 113 18284 66 | 15.45 | 14.03 | 8.13 | 8.09 | 0.1 | 1.704 |
| J175906.0—290620 | 311 | 113 18285 45 | 15.21 | 13.71 | 8.46 | 8.55 | 0.3 | 1.776 |
| J175906.0—290732 | 312 | 113 18285 60 | 14.32 | 13.70 | 8.73 | 8.63 | 0.06 | 1.409 |
| J175906.5—290527 | 317 | 113 18285 107 | 16.59 | 14.87 | 8.04 | 8.04 | 0.15 | 1.459 |
| J175907.2—291259 | 326 | 113 18283 37 | 14.66 | 13.28 | 8.25 | 7.93 | 0.4 | 1.980 |
| J175907.3—291241 | 327 | 113 18283 141 | 16.97 | 15.12 | 8.63 | 8.58 | 0.15 | 1.470 |
| J175907.3—291024 | 328 | 113 18284 57 | 16.01 | 14.02 | 7.24 | 6.68 | 0.6 | 2.145 |
| J175908.1—285827 | 336 | 113 18417 2005 | 16.99 | 15.07 | 8.43 | 8.22 | 0.25 | 1.486 |
| J175908.3—290856 | 338 | 113 18414 98 | 17.19 | 15.01 | 7.46 | 6.40 | 0.6 | 2.084 |
| J175908.3—290729 | 339 | 113 18415 36 | 14.89 | 13.42 | 8.43 | 8.33 | 0.2 | 1.555 |
| J175908.6—291250 | 343 | 113 18413 45 | 15.73 | 14.08 | 8.25 | 8.11 | 0.1 | 1.216 |
| J175908.7—291345 | 345 | 113 18413 2532 | 19.05 | 18.12 | 7.86 | 7.73 | 0.35 | 1.968 |
| J175909.3—290423 | 350 | 113 18415 116 | 16.72 | 15.05 | 8.93 | 8.85 | 0.15 | 1.365 |
| J175909.5—290825 | 352 | 113 18414 49 | 16.09 | 14.23 | 7.48 | 7.31 | 0.2 | 1.615 |
| J175909.6—285800 | 353 | 113 18417 1984 | 15.90 | 14.36 | 8.98 | 8.83 | 0.1 | 1.383 |
| J175910.1—290936 | 357 | 113 18414 26 | 11.85: 11.00: | 8.72 | 8.77 |
| J175910.1—291358 | 358 | 113 18413 59 | 16.34 | 14.49 | 8.32 | 7.72 | 0.35 | 1.746 |
| J175910.5—290129 | 363 | 113 18416 198 | 19.83 | 16.44 | 4.87 | 3.37 | 2.672: Mira; few |
| J175910.6—290457 | 365 | 113 18415 117 | 17.54 | 15.25 | 7.24 | 6.45 | 0.4 | 2.145 |
| J175910.7—290035 | 370 | 113 18416 80 | 15.99 | 14.24 | 7.99 | 7.81 | 0.2 | 1.724 |
| J175910.9—290708 | 372 | 113 18415 43 | 15.37 | 13.87 | 8.15 | 8.07 | 0.25 | 1.637 |
| J175910.9—285747 | 373 | 113 18417 1968 | 15.66 | 14.00 | 8.45 | 8.47 | 0.2 | also long per |
Table 1—Continued

| ISOGALP<sup>A</sup> | BW<sup>B</sup> | MACHO<sup>C</sup> | V<sup>D</sup> | R<sup>D</sup> | J<sub>0</sub> | K<sub>0</sub> | [7] | [15] | Amp. | log P<sup>E</sup> | notes<sup>F</sup> |
|---------------------|---------------|------------------|-------------|-----------|-----------|-----------|-----|-----|-----|-------------|----------------|
| J175911.1—290315    | 375           | 113 18146 597    | 18.27       | 16.50     | 6.71      | 5.34      | 0.5 | 2.201: |     |             |                |
| J175911.1—291401    | 376           | 113 18143 410    | 18.35       | 16.25     | 7.87      | 6.95      | 0.35 | 2.110 |     |             |                |
| J175911.3—290114    | 380           | 113 18146 29     | 10.04:      | 9.64:     | 7.51      | 7.19      |     |       |     |             |                |
| J175912.4—291357    | 388           | 113 18143 60     | 15.98       | 14.27     | 8.21      | 8.37      | 0.1 | 1.448 |     |             |                |
| J175912.7—290608    | 392           | 113 18141 112    | 16.94       | 15.02     | 8.48      | 8.50      | 0.25 | 1.490 |     |             |                |
| J175913.2—290901    | 395           | 113 18144 198    | 17.78       | 15.62     | 7.81      | 7.15      | 0.25 | 1.852 |     |             |                |
| J175913.5—291409    | 399           | 113 18143 125    | 16.92       | 15.00     | 8.45      | 8.35      | 0.15 | 1.416 |     |             |                |
| J175913.6—285812    | 400           | 113 18147 1956   | 14.18       | 12.62     | 7.36      | 7.10      | 0.4 | 1.980 |     |             |                |
| J175913.7—285852    | 402           | 113 18147 1965   | 19.49       | 16.44     | 6.96      | 5.75      | 4.0 | 2.487: | Mira |             |                |
| J175913.8—290703    | 403           | 113 18145 100    | 16.78       | 14.98     | 8.78      | 8.32      | 0.15 | 1.514 |     |             |                |
| J175914.0—290950    | 405           | 113 18144 551    | 18.27       | 16.28     | 7.14      | 5.58      | 0.3 | 2.063 |     |             |                |
| J175914.0—290815    | 406           | 113 18144 137    | 17.03       | 15.12     | 8.75      | 8.95      | 0.15 | 1.356 |     |             |                |
| J175914.1—290241    | 407           | 113 18146 337    | 18.02       | 15.98     | 8.00      | 7.16      | 0.35 | 1.852 |     |             |                |
| J175914.4—291335    | 410           | 113 18143 19     | 13.03:      | 11.80:    | 7.21      | 6.80      |     |       |     |             |                |
| J175914.6—290853    | 412           | 113 18144 39     | 14.12       | 13.54     | 8.80      | 8.62      | 0.1 | 1.433 |     |             |                |
| J175914.8—291129    | 416           | 113 18144 338    | 18.13       | 15.86     | 7.40      | 6.41      | 0.4 | 1.970 |     |             |                |
| J175915.5—290134    | 421           | 113 18146 1364   | 18.05       | 17.60     | 6.80      | 6.07      | 0.4 | 1.159  | few |             |                |
| J175915.5—290533    | 422           | 113 18145 74     | 17.16       | 14.86     | 7.60      | 6.80      | 0.5 | 1.901 |     |             |                |
| J175915.9—290824    | 425           | 113 18144 177    | 17.42       | 15.33     | 7.87      | 7.78      | 0.2 | 1.816 |     |             |                |
| J175915.9—290839    | 426           | 113 18144 61     | 16.16       | 14.25     | 7.64      | 7.59      | 0.25 | 1.724 |     |             |                |
| J175916.0—290408    | 427           | 113 18145 71     | 16.36       | 14.56     | 8.66      | 8.53      | 0.15 | 1.738 |     |             |                |
| J175916.4—290805    | 431           | 113 18144 211    | 17.35       | 15.31     | 7.57      | 6.75      | 0.25 | 1.808 |     |             |                |
| J175916.8—290011    | 434           | 113 18146 28     | 9.75:       | 9.42:     | 7.24      | 7.38      |     |       |     |             |                |
| J175916.9—290225    | 435           | 113 18146 138    | 16.08       | 14.83     | 9.16      | 8.73      | 0.05 | 1.163 |     |             |                |
| J175917.0—290502    | 439           | 113 18145 39     | 14.43       | 13.27     | 9.04      | 8.85      | 0.2 | 1.753 |     |             |                |
| J175917.4—290643    | 442           | 113 18145 24     | 13.36:      | 12.04:    | 7.76      | 7.76      |     |       |     |             |                |
| J175917.4—291048    | 444           | 113 18145 56     | 16.55       | 14.43     | 7.58      | 6.93      | 0.7 | 2.185: |     |             |                |
| J175917.9—290806    | 447           | 113 18144 290    | 18.22       | 15.92     | 7.53      | 6.48      | 0.3 | 1.945 |     |             |                |
| J175918.2—291434    | 452           | 113 18143 20     | 13.42:      | 11.98:    | 6.66      | 6.50      |     |       |     |             |                |
Table 1—Continued

| ISOGALP<sup>A</sup> | BW<sup>B</sup> | MACHO<sup>C</sup> | \(V^D\) | \(R^D\) | \(J_0\) | \(K_0\) | \([7]\) | \([15]\) | Amp. | \(\log P^E\) | notes<sup>F</sup> |
|---------------------|----------------|-------------------|--------|--------|------|------|-----|-----|-----|---------|----------|
| J175918.2−290123    | 453            | 113 18416 40      | 14.36  | 12.64  | 6.07 | 5.83 | 0.45 | 1.579|
| J175918.5−291302    | 454            | 113 18413 33      | 14.96  | 13.70  | 8.65 | 8.81 | 0.1  | 2.145|
| J175918.5−290505    | 455            | 113 18415 73      | 16.73  | 14.58  | 7.29 | 6.58 | 0.8  | 2.124|
| J175918.5−290608    | 457            | 113 18415 415     | 18.73  | 16.34  | 7.32 | 5.77 | 0.4  | 2.097|
| J175918.6−290046    | 458            | 113 18416 49      | 14.75  | 13.44  | 8.75 | 8.74 | 0.15 | 1.399|
| J175918.9−290548    | 463            | 113 18415 62      | 15.76  | 14.30  | 8.94 | 8.64 | 0.08 | 1.209|
| J175919.6−290452    | 467            | 113 18415 26      | 14.17  | 12.95  | 8.50 | 8.42 | 0.15 | 1.776|
| J175919.8−291247    | 469            | 113 18413 56      | 15.65  | 14.15  | 8.77 | 8.80 | 0.15 | 1.448|
| J175920.1−291416    | 471            | 113 18413 670     | 17.93  | 17.37  | 8.48 | 8.42 | 1.0  | 1.834|
| J175920.6−290953    | 477            | 113 18414 1489    | 19.00  | 17.78  | 9.06 | 8.10 | 0.9  | 2.078|
| J175920.7−291506    | 478            | 113 18413 167     | 17.45  | 15.34  | 7.37 | 7.07 | 0.25 | 1.834|
| J175921.8−290841    | 486            | 113 18414 97      | 16.75  | 14.84  | 8.35 | 8.39 | 0.35 | 1.717|
| J175921.9−291058    | 487            | 113 18414 96      | 16.78  | 14.86  | 7.88 | 7.79 | 0.25 | 1.654|
| J175922.0−291229    | 488            | 113 18413 21      | 14.65  | 12.84  | 6.46 | 6.03 | 0.35 | 1.816|
| J175922.0−290547    | 490            | 113 18415 83      | 16.56  | 14.69  | 8.32 | 8.15 | 0.35 | 1.724|
| J175922.1−291157    | 492            | 113 18413 1433    | 18.66  | 17.49  | 8.82 | 8.11 | 0.4  | 1.944|
| J175922.5−291133    | 500            | 113 18414 95      | 16.57  | 14.76  | 8.80 | 8.68 | 0.25 | 1.792|
| J175923.2−290820    | 506            | 113 18414 34      | 14.71  | 13.34  | 8.54 | 8.31 | 0.3  | 1.871|
| J175923.3−290902    | 510            | 113 18414 27      | 12.33  | 10.78  | 8.22 | 8.19 |       |       |
| J175923.4−290216    | 511            | 113 18416 290     | 16.67  | 15.56  | 6.37 | 5.39 |       |       |
| J175923.5−291451    | 512            | 113 18413 317     | 18.33  | 16.08  | 8.00 | 7.44 | 1.0  | 2.117|
| J175923.7−291236    | 514            | 113 18413 1776    | 18.94  | 17.04  | 6.83 | 5.64 | 4    | 2.405|
| J175923.8−290952    | 516            | 113 18414 93      | 16.70  | 14.94  | 8.85 | 8.84 | 0.2  | 1.490|
| J175924.4−291358    | 522            | 113 18413 31      | 15.54  | 13.60  | 7.24 | 6.21 | 0.4  | 1.896|
| J175924.6−291237    | 524            | 113 18413 206     | 18.40  | 15.88  | 7.47 | 6.15 | 0.5  | 2.020|
| J175925.3−290336    | 529            | 113 18416 521     | 18.40  | 16.43  | 7.13 | 5.70 | 0.25 | 2.110|
| J175925.7−290036    | 533            | 113 18416 58      | 15.20  | 13.78  | 8.96 | 8.77 | 0.15 | 1.594|
| J175926.1−290612    | 536            | 113 18545 1157    | 18.47  | 17.06  | 8.20 | 7.90 | 0.25 | 1.791|
| J175926.4−290707    | 540            | 113 18545 19      | 15.14  | 13.34  | 7.03 | 5.84 | 0.35 | 1.718|
Table 1—Continued

| ISOGALP<sup>A</sup>  | BW<sup>B</sup> | MACHO<sup>C</sup> | V<sup>D</sup> | R<sup>D</sup> | J<sub>0</sub> | K<sub>0</sub> | [7] | [15] | Amp. | log P<sup>E</sup> | notes<sup>F</sup> |
|----------------------|----------------|------------------|--------------|-------------|-----------|-----------|-----|-----|------|----------------|-----------------|
| J175926.5—290218     | 541            | 113 18546 277    | 17.34        | 15.46       | 7.34      | 5.60      | 0.2  |         | 1.891 |                  |                 |
| J175926.9—290345     | 545            | 113 18545 273    | 16.87        | 15.63       | 9.18      | 8.62      | 0.06 | 1.205 |        |                  |                 |
| J175927.4—290310     | 550            | 113 18546 982    | 19.17        | 17.80       | 7.46      | 5.91      |      |        | 1.191 | eclip bin        |                 |
| J175927.9—291332     | 553            | 113 18543 48     | 16.14        | 14.41       | 8.39      | 8.23      | 0.1  | 1.191 |        |                  |                 |
| J175927.9—290530     | 556            | 113 18545 233    | 17.92        | 15.71       | 7.46      | 6.61      | 0.3  | 1.861 |        |                  |                 |
| J175927.9—291038     | 559            | 113 18544 65     | 16.85        | 14.85       | 7.76      | 7.62      | 0.3  | 1.615 |        |                  |                 |
| J175928.0—290118     | 561            | 113 18546 36     | 14.49        | 13.18       | 8.38      | 8.19      | 0.1  | 1.760 |        |                  |                 |
| J175929.7—290926     | 575            | 113 18544 13     | 13.76        | 12.64       | 8.46      | 8.37      | 0.2  | 2.164 |        |                  | sat?             |
| J175930.7—290950     | 581            | 113 18544 12     | 11.80        | 11.60       | 6.88      | 6.83      | 0.3  |        |        |                  |                 |
| J175931.1—290858     | 585            | 113 18544 399    | 18.04        | 16.13       | 7.05      | 5.67      | 0.3  | 2.083 |        |                  |                 |
| J175932.1—290857     | 595            | 113 18544 26     | 15.51        | 13.90       | 8.32      | 7.67      | 0.3  | 2.020 |        |                  |                 |
| J175932.4—290802     | 598            | 113 18544 474    | 16.90        | 16.07       | 7.99      | 7.91      | 0.1  | 1.311 |        |                  |                 |
| J175934.0—290727     | 611            | 113 18545 927    | 17.38        | 16.53       | 8.64      | 8.57      | 0.06 | 1.110 |        |                  |                 |
| J175935.0—291110     | 619            | 113 18544 255    | 16.54        | 15.64       | 8.26      | 7.64      | 0.08 | 1.154 |        |                  |                 |
| J175935.2—290506     | 623            | 113 18545 81     | 14.79        | 14.34       | 8.56      | 8.74      | 0.05 | 1.980 |        |                  |                 |
| J175936.1—290916     | 626            | 113 18544 21     | 15.60        | 13.61       | 6.96      | 6.75      | 0.4  | 2.145 |        |                  |                 |
| J175936.3—290516     | 628            | 113 18545 740    | 17.36        | 16.38       | 8.30      | 7.64      | 0.1  | 1.079 |        |                  |                 |
| J175937.0—290835     | 633            | 113 18544 131    | 17.46        | 15.48       | 7.44      | 6.56      | 0.6  | 2.110 |        |                  |                 |
| J175937.1—290253     | 634            | 113 18546 458    | 16.78        | 16.04       | 8.34      | 8.32      | 0.05 | 1.753 |        |                  |                 |
| J175937.8—290925     | 639            | 113 18544 36     | 15.60        | 14.18       | 8.81      | 8.74      | 0.25 | 1.283 |        |                  |                 |
| J175938.3—290129     | 644            | 113 18546 279    | 16.68        | 15.66       | 7.92      | 7.34      | 0.06 | 2.020 |        |                  |                 |
| J175939.3—290915     | 655            | 113 18544 61     | 16.72        | 14.69       | 8.58      | 8.39      | 0.2  | 1.649 |        |                  |                 |
| J175940.9—290737     | 661            | 113 18545 532    | 17.03        | 16.10       | 8.41      | 8.36      | 0.06 | 1.968 |        |                  |                 |
| J175941.9—290458     | 667            | 113 18545 33     | 13.95        | 13.49       | 8.25      | 8.28      | 0.03 | 1.039 |        |                  |                 |
| J175943.4—290735     | 672            | 113 18545 228    | 16.25        | 15.34       | 7.88      | 7.03      | 0.05 | 1.451 |        |                  |                 |
| J175947.0—290357     | 687            | 113 18675 756    | 17.17        | 16.31       | 7.65      | 7.02      | 0.25 | 1.079 |        |                  |                 |
| J175948.2—290350     | 689            | 113 18675 1135   | 17.62        | 16.70       | 7.05      | 6.37      | 0.15 | 2.033 |        |                  |                  |
| J180232.1—300201     | 6              | 119 19831 41     | 14.85        | 13.71       | 8.63      | 8.56      | 0.06 | 1.213 |        |                  |                 |
| J180233.9—300232     | 8              | 119 19831 110    | 16.14        | 14.99       | 9.94      | 8.89      | 0.05 | 1.386 |        |                  |                 |
| ISOGALP<sup>A</sup> | BW<sup>B</sup> | MACHO<sup>C</sup> | V<sup>D</sup> | R<sup>D</sup> | J<sub>0</sub> | K<sub>0</sub> | [7] | [15] | Amp. | log P<sup>E</sup> | notes<sup>F</sup> |
|-------------------|-------------|-----------------|-----------|-----------|-------|--------|-----|-----|-----|-----------|-----------------|
| J180235.2−295855  | 14          | 119 19832 2797  | 14.75     | 12.73     | 6.50  | 5.78   | 0.1 | 1.951 |
| J180236.1−300216  | 17          | 119 19831 173   | 17.54     | 15.62     | 8.99  | 8.50   | 0.2 | 1.422 |
| J180236.6−295752  | 19          | 119 19832 2843  | 16.95     | 15.03     | 7.81  | 7.54   | 0.2 | 1.455 few |
| J180238.0−295933  | 22          | 119 19832 2832  | 16.54     | 14.78     | 8.80  | 8.76   | 0.15 | 1.625 |
| J180238.7−295954  | 24          | 119 19831 471   | 18.18     | 16.59     | 7.75  | 6.25   | 0.35 | 2.075 |
| J180239.4−295918  | 25          | 119 19832 2808  | 15.22     | 13.80     | 8.93  | 8.78   | 0.1  | 1.361 |
| J180239.4−295636  | 26          | 119 19832 18    | 11.96     | 10.35:    | 7.46  | 7.16   |      |      |
| J180240.2−295821  | 27          | 119 19832 2805  | 15.40     | 13.87     | 7.96  | 7.78   | 0.15 | 1.625 |
| J180240.6−300053  | 28          | 119 19831 75    | 16.51     | 14.67     | 8.16  | 8.02   | 0.15 | 1.433 |
| J180241.0−295902  | 31          | 119 19832 2872  | 17.83     | 15.80     | 8.80  | 8.43   | 0.2  | 2.060 |
| J180241.7−295753  | 35          | 119 19832 2804  | 15.38     | 13.83     | 8.54  | 8.27   | 0.2  | 1.716 few |
| J180241.8−295957  | 36          | 119 19831 139   | 17.40     | 15.52     | 8.25  | 7.91   | 0.3  | 1.990 |
| J180242.1−295937  | 38          | 119 19832 2794  | 12.25     | 11.25:    | 8.28  | 8.19   |      |      |
| J180242.9−300335  | 41          | 119 19831 494   | 19.06     | 16.88     | 7.48  | 5.86   | 0.5  | 2.106 |
| J180243.5−295615  | 45          | 119 19832 45    | 16.88     | 15.02     | 8.36  | 8.25   | 0.25 | 1.625 |
| J180245.1−295813  | 53          | 119 19832 2824  | 16.01     | 14.52     | 9.28  | 8.99   | 0.1  | 1.256 |
| J180245.4−295536  | 57          | 119 19833 45    | 14.57     | 13.51     | 8.40  | 8.25   | 0.5  | 1.249 |
| J180245.6−300328  | 60          | 119 19831 49    | 15.62     | 14.14     | 8.99  | 8.86   | 0.06 | 1.703 |
| J180245.8−300111  | 61          | 119 19831 299   | 18.22     | 16.22     | 7.58  | 6.00   | 0.35 | 2.060 BMB3 7 |
| J180248.4−300309  | 70          | 119 19961 106   | 17.46     | 15.40     | 8.12  | 7.69   | 0.3  | 1.759 |
| J180249.0−295430  | 76          | 119 19963 151   | 17.75     | 15.65     | 8.00  | 7.02   | 0.4  | 1.899 |
| J180249.5−295852  | 79          | 119 19962 2779  | 16.22     | 14.63     | 8.53  | 8.06   | 0.3  | 1.798 BMB6 6 |
| J180251.1−300326  | 83          | 119 19961 18    | 12.74:    | 12.47:    | 8.31  | 8.25   |      |      |
| J180251.2−300013  | 85          | 119 19961 64    | 17.30     | 15.14     | 7.49  | 6.61   | 0.7  | 1.943 BMB7 7 |
| J180251.8−300246  | 88          | 119 19961 132   | 17.41     | 15.32     | 8.11  | 7.65   | 0.25 | 1.767 |
| J180252.4−300239  | 90          | 119 19961 163   | 17.80     | 15.70     | 8.57  | 7.87   | 0.3  | 2.060 BMB12 6 |
| J180252.7−295459  | 92          | 119 19963 178   | 17.78     | 15.76     | 9.64  | 8.47   | 8.72 | 8.65 | 0.2  | 1.555 BMB11 7; few |
| J180252.9−300106  | 94          | 119 19961 146   | 18.05     | 15.92     | 8.36  | 7.63   | 0.4  | 2.004 BMB10 6.5 |
| J180253.0−300249  | 96          | 119 19961 162   | 17.60     | 15.53     | 7.51  | 6.66   | 0.3  | 1.920 |
| ISOGALP\(^A\) | BW\(^B\) | MACHO\(^C\) | \(V^D\) | \(R^D\) | \(J_0\) | \(K_0\) | [7] | [15] | Amp. | \(\log P^E\) | notes\(^F\) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J180253.8--295425 | 102 | 119 19963 60 | 16.10 | 14.48 | 8.25 | 8.16 | 0.15 | 1.554 | BMB15 6 |
| J180254.1--300048 | 103 | 119 19961 84 | 17.03 | 14.89 | 7.65 | 6.65 | 0.5 | 1.899 | BMB12 6 |
| J180256.1--295534 | 110 | 119 19963 138 | 18.08 | 15.73 | 6.71 | 5.77 | 0.5 | 2.447: |
| J180256.7--295705 | 114 | 119 19962 23 | 15.11 | 13.63 | 8.47 | 8.14 | 0.5 | 1.869 |
| J180256.9--295548 | 118 | 119 19962 99 | 16.79 | 15.71 | 7.63 | 7.32 | 0.15 | 1.444 BMB20/21 6/6.5 |
| J180257.2--295201 | 121 | 119 19963 67 | 16.07 | 14.54 | 9.24 | 8.75 | 0.1 | 1.631 |
| J180257.4--300351 | 126 | 119 19960 22 | 13.97 | 12.77 | 8.27 | 7.69 | 0.1 | 1.625 |
| J180257.6--295124 | 128 | 119 19964 19 | 13.07 | 12.25: | 6.80 | 6.32 |
| J180258.1--295049 | 131 | 119 19964 25 | 14.47 | 13.17 | 8.36 | 8.14 | 0.15 | 1.365 |
| J180258.4--300311 | 135 | 119 19961 108 | 17.20 | 15.26 | 8.38 | 8.49 | 0.2 | 1.767 |
| J180258.8--295426 | 136 | 119 19963 30 | 15.29 | 13.77 | 8.23 | 6.95 | 0.5 | 2.581: dp(0.2,1.869) |
| J180258.9--295221 | 138 | 119 19963 32 | 14.86 | 13.57 | 8.88 | 8.77 | 0.08 | 1.554 |
| J180258.9--300108 | 139 | 119 19961 71 | 16.64 | 14.87 | 8.70 | 8.56 | 0.25 | 1.554 BMB27 6.5 |
| J180259.0--295757 | 140 | 119 19962 2777 | 16.28 | 14.45 | 8.01 | 7.40 | 0.3 | 2.004 |
| J180259.6--300253 | 147 | 119 19961 176 | 17.71 | 15.64 | 8.47 | 7.23 | 7.03 | 5.28 | 0.4 | 2.371: BMB28 7 |
| J180300.2--295514 | 152 | 119 19963 15 | 12.27: | 10.84: | 7.81 | 7.55 |
| J180300.6--295018 | 156 | 119 19964 22 | 14.40 | 12.93 | 8.27 | 7.63 | 0.05 | 1.919 |
| J180301.1--300142 | 162 | 119 19961 20 | 15.33 | 13.07 | 6.36 | 5.51 | 0.1 | 2.004 |
| J180301.7--295959 | 166 | 119 19961 155 | 17.58 | 15.63 | 8.31 | 8.09 | 0.25 | 1.527 BMB35 6.5 |
| J180301.7--295053 | 167 | 119 19964 38 | 14.62 | 13.59 | 9.02 | 8.60 | 0.1 | 1.103 |
| J180302.6--295645 | 172 | 119 19962 28 | 16.30 | 14.43 | 7.96 | 7.44 | 0.6 | 2.091 BMB37 6 |
| J180303.2--295515 | 179 | 119 19963 20 | 14.24 | 12.83 | 8.48 | 8.60 | 0.06 | 1.823 |
| J180303.8--300242 | 183 | 119 19961 130 | 17.25 | 15.31 | 8.50 | 7.88 | 0.5 | 1.850 BMB36 6.5 |
| J180304.0--295135 | 184 | 119 19964 79 | 16.35 | 14.71 | 9.03 | 8.55 | 0.2 | 2.090 BMB44 6.5 |
| J180304.6--300405 | 187 | 119 19960 39 | 15.53 | 14.15 | 8.60 | 8.32 | 0.2 | 1.645 |
| J180304.9--295258 | 189 | 119 20093 2040 | 17.18 | 15.29 | 8.43 | 8.31 | 0.15 | 1.573 |
| J180305.2--295516 | 192 | 119 20093 2054 | 17.71 | 15.51 | 8.35 | 7.00 | 6.86 | 5.52 | 0.3 | 2.060 BMB46 7 |
| J180305.4--295033 | 194 | 119 20094 1986 | 13.75 | 12.58 | 8.06 | 7.68 | 0.05 | 1.204 |
| J180305.9--295345 | 197 | 119 20093 2027 | 16.37 | 14.78 | 9.09 | 8.48 | 0.4 | 1.824 |
| ISOGALP<sup>A</sup> | BW<sup>B</sup> | MACHO<sup>C</sup> | V<sup>D</sup> | R<sup>D</sup> | Jₗ | Kₗ | Amp. | log P<sup>E</sup> | notes<sup>F</sup> |
|----------------------|-------------|----------------|--------|--------|-----|-----|------|-------------|-------------|
| J180305.9−300508     | 198         | 119 20090 51   | 16.70  | 14.91  | 8.87| 8.83| 0.2  | 1.370       |             |
| J180306.3−295204     | 205         | 119 20093 2179| 18.38  | 16.42  | 7.40| 5.75| 0.2  | 2.142       |             |
| J180306.3−295141     | 206         | 119 20094 2053| 17.29  | 15.29  | 7.82| 6.75| 0.4  | 1.910 BMB50 7 |
| J180306.7−300136     | 207         | 119 20091 8   | 12.47  | 11.02  | 8.62| 8.62|      |             |             |
| J180307.0−300633     | 211         | 119 20090 106 | 18.04  | 16.00  | 7.93| 7.09| 0.2  | 1.888 BMB45 7 |
| J180307.1−300519     | 213         | 119 20090 118 | 18.26  | 16.08  | 8.60| 7.55| 0.4  | 1.866 BMB49 6.5 |
| J180307.4−300255     | 215         | 119 20091 11  | 14.60  | 13.29  | 8.45| 8.31| 0.25 | 1.609       |             |
| J180307.8−300452     | 217         | 119 20090 26  | 15.15  | 13.88  | 9.16| 8.82| 0.05 | 2.075       |             |
| J180308.2−300330     | 221         | 119 20091 95  | 17.23  | 15.64  | 8.22| 7.71| 0.2  | 1.966 BMB53 6.5 |
| J180308.5−300525     | 224         | 119 20090 355 | 18.97  | 16.68  | 8.41| 6.94| 6.32 | 4.82 4.0 2.531: Mira; BMB54 7 |             |
| J180308.8−295202     | 226         | 119 20093 2095 | 18.17 | 16.02 | 7.83| 6.43| 0.3  | 1.991 BMB59 6.5 |
| J180308.9−300551     | 227         | 119 20090 43  | 16.06  | 14.64  | 9.45| 8.75| 0.1  | 1.292       |             |
| J180309.3−295241     | 231         | 119 20093 1994 | 15.15 | 13.71 | 8.04| 7.97| 0.2  | 1.631       |             |
| J180309.4−300241     | 234         | 119 20091 13  | 14.55  | 13.45  | 8.86| 8.83| 0.1  | 1.292       |             |
| J180310.0−300138     | 236         | 119 20091 27  | 15.95  | 14.51  | 8.66| 8.45| 0.1  | 1.473 BMB58 6 |             |
| J180310.6−295619     | 240         | 119 20092 756 | 15.85  | 14.66  | 9.30| 8.49| 0.15 | 1.079       |             |
| J180311.2−295312     | 242         | 119 20093 1991| 14.41  | 13.01  | 8.09| 7.79| 0.6  | 1.850       |             |
| J180311.9−295900     | 248         | 119 20092 2338| 13.89  | 12.74  | 9.09| 8.73| 0.05 | 1.598       |             |
| J180312.5−300429     | 254         | 119 20090 55  | 17.48  | 15.23  | 7.04| 5.98| 0.4  | 1.954 BMB54 7 |             |
| J180313.4−300056     | 256         | 119 20091 153 | 19.23  | 16.41  | 7.38| 6.35| 0.7  | 2.346 BMB67 8 |             |
| J180313.9−295620     | 259         | 119 20092 748 | 15.93  | 14.16  | 8.02| 7.36| 0.4  | 1.876       |             |
| J180317.9−300230     | 292         | 119 20091 3890| 17.02  | 15.29  | 8.86| 8.58| 0.3  | 2.060 BMB79 6.5 |             |
| J180318.1−300309     | 294         | 119 20091 3853| 16.03  | 14.51  | 10.10| 9.09| 9.30 | 8.85 0.1 1.943 BMB84 6 |             |
| J180318.4−295346     | 299         | 119 20093 55  | 17.57  | 15.81  | 8.64| 7.29| 7.15 | 5.29 0.2 1.879 BMB86 9; long per? |             |
| J180320.1−295935     | 313         | 119 20092 4026| 15.32  | 13.83  | 8.64| 8.35| 0.1  | 1.088 BMB89 5 |             |
| J180320.3−295432     | 317         | 119 20093 31  | 16.36  | 14.79  | 9.41| 8.37| 8.62| 8.57 0.1 1.389 BMB91 6.5 |             |
| J180320.8−300451     | 319         | 119 20090 3751| 17.29  | 15.42  | 9.12| 8.66| 0.15 | 1.396       |             |
| J180322.3−300255     | 333         | 119 20091 3839| 14.88  | 13.22  | 8.23| 7.18| 7.43| 7.08 0.25 1.710 BMB93 6 |             |
| J180323.4−300838     | 339         | 119 20219 52  | 16.97  | 14.97  | 7.58| 6.20| 1.0  | 2.091       |             |
Table 1—Continued

| ISOGALP\(^A\) | BW\(^B\) | MACHO\(^C\) | \(V^D\) | \(R^D\) | \(J_0\) | \(K_0\) | [7] | [15] | Amp. | \(\log P^E\) | notes\(^F\) |
|----------------|--------|-----------|------|------|------|------|-----|------|------|----------|---------|
| J180323.9−295410 | 346    | 119 20223 112 | 17.18 | 15.15 | 8.08 | 6.92 | 0.35 | 1.943 | BMB103 6.5 |
| J180323.9−300004 | 347    | 119 20221 80  | 15.73 | 14.33 | 10.04 | 9.04 | 9.14 | 8.74 | 0.5    | 2.602;  B28 5; dp(0.1,1.7) |
| J180324.0−295925 | 350    | 119 20222 2570 | 17.59 | 15.57 | 8.16 | 7.97 | 0.3  | 1.790 | BMB101 6.5 |
| J180324.5−300414 | 354    | 119 20200 61  | 16.18 | 14.41 | 9.32 | 8.27 | 8.71 | 8.83 | 0.1    | 1.518; BMB99 6.5 |
| J180325.1−300849 | 357    | 119 20219 54  | 15.13 | 14.14 | 9.22 | 8.56 | 0.03 | 1.370 |
| J180325.3−300645 | 360    | 119 20220 54  | 16.22 | 14.37 | 8.43 | 8.56 | 0.4  | 1.790 | BMB102 6.5 |
| J180325.3−295947 | 361    | 119 20221 104 | 16.79 | 14.70 | 9.36 | 8.29 | 8.51 | 8.46 | 0.15   | 1.573; BMB106 6 |
| J180325.8−295847 | 365    | 119 20226 2546 | 16.83 | 14.84 | 8.54 | 7.51 | 9.04 | 8.74 | 0.5    | 2.060; BMB108 6 |
| J180326.3−295653 | 368    | 119 20220 12  | 13.44 | 12.52 | 8.27 | 8.25 |
| J180326.4−300700 | 370    | 119 20200 395 | 16.98 | 16.02 | 8.91 | 8.38 | 0.15 | 1.455 |
| J180327.3−300102 | 375    | 119 20221 126 | 16.91 | 14.81 | 8.80 | 7.65 | 7.78 | 7.10 | 0.3    | 1.824; BMB114 6.5 |
| J180327.5−302224 | 379    | 119 20221 55  | 15.23 | 13.65 | 9.09 | 8.09 | 8.29 | 8.71 | 0.1    | 1.220; B47 5 |
| J180327.7−300655 | 381    | 119 20200 158 | 16.75 | 15.41 | 9.50 | 8.37 | 0.15 | 2.107 |
| J180328.4−295545 | 382    | 119 20222 81  | 18.30 | 16.02 | 7.25 | 5.54 | 0.1  | 2.030; BMB119 9 |
| J180328.9−300334 | 386    | 119 20221 30  | 12.74 | 11.28 | 8.81 | 8.90 |
| J180329.3−300248 | 387    | 119 20221 45  | 14.16 | 12.97 | 8.61 | 8.72 | 0.35 | 1.767; B54 1 bl? |
| J180329.4−295939 | 389    | 119 20222 2540 | 16.38 | 15.11 | 8.58 | 7.31 | 7.38 | 5.99 | 0.1    | 2.075; BMB120 7 |
| J180329.6−300108 | 394    | 119 20221 108 | 16.51 | 14.63 | 7.92 | 7.25 | 0.5  | 1.943; BMB121 6.5 |
| J180330.0−295821 | 397    | 119 20222 2501 | 14.71 | 13.30 | 8.43 | 8.21 | 0.25 | 1.603; B61 5 |
| J180331.0−295846 | 405    | 119 20222 2498 | 13.16 | 12.08 | 9.40 | 8.49 |
| J180331.1−295908 | 407    | 119 20222 2573 | 17.61 | 15.46 | 9.26 | 8.12 | 8.41 | 7.51 | 0.2    | 1.806; BMB127 7 |
| J180331.2−295333 | 409    | 119 20223 158 | 17.29 | 15.35 | 8.77 | 7.56 | 7.75 | 7.64 | 0.2    | 1.910; BMB136 8 |
| J180331.3−300101 | 410    | 119 20221 39  | 15.02 | 13.10 | 6.71 | 6.33 | 0.2  | 1.625; BMB129 6.5 |
| J180331.6−300043 | 413    | 119 20221 44  | 14.20 | 13.03 | 9.58 | 8.74 | 8.98 | 8.77 | 0.06   | 1.568; B66 3 |
| J180331.9−300608 | 414    | 119 20200 50  | 16.35 | 14.39 | 8.93 | 7.85 | 8.01 | 7.36 | 0.3    | 2.060; BMB128 7 |
| J180331.9−300027 | 415    | 119 20221 56  | 15.35 | 13.65 | 8.81 | 7.79 | 8.17 | 8.13 | 0.25   | 1.638; BMB131 6 |
| J180332.3−300147 | 418    | 119 20221 60  | 15.20 | 13.71 | 8.91 | 8.60 | 0.1  | 2.031; BMB133 6 |
| J180332.3−300444 | 419    | 119 20220 81  | 16.34 | 14.61 | 9.77 | 8.71 | 8.82 | 8.73 | 0.3    | 1.416; BMB133 6 |
| J180333.2−295910 | 425    | 119 20222 2518 | 17.19 | 15.12 | 8.37 | 7.56 | 1.0  | 2.316; BMB140 6.5 |
Table 1—Continued

| ISOGALPA  | BWB  | MACHOC  | VD | RD | J0 | K0 | [7] | [15] | Amp. | log P'E | notesF |
|-----------|------|---------|----|----|----|----|-----|-----|------|--------|--------|
| J180333.4−300523 | 426  | 119 20220 89 | 15.98 | 14.73 | 9.23 | 8.06 | 8.86 | 7.39 | 0.2 | 1.869 | BMB134 7 |
| J180334.1−295957 | 432  | 119 20221 178 | 17.52 | 15.30 | 8.17 | 6.90 | 6.97 | 5.56 | 0.35 | 2.075 | BMB142 8 |
| J180334.2−300104 | 433  | 119 20221 88 | 16.34 | 14.39 | 7.71 | 7.15 | 0.2 | 2.004 | BMB143 6.5 |
| J180334.6−300137 | 437  | 119 20221 100 | 16.48 | 14.57 | 8.36 | 8.35 | 0.2 | 1.760 | BMB146 6; few |
| J180336.9−300148 | 445  | 119 20221 290 | 16.23 | 15.42 | 8.51 | 7.21 | 7.07 | 6.03 | 0.2 | 1.043 | BMB152 9 |
| J180339.1−295826 | 456  | 119 20222 2502 | 14.77 | 13.55 | 9.23 | 8.99 | 0.1 | 1.737 | B101 4 |
| J180340.2−29531 | 459  | 119 20223 43 | 14.75 | 13.35 | 8.04 | 8.24 | 0.2 | 1.473 | |
| J180340.4−295612 | 460  | 119 20222 19 | 15.80 | 14.40 | 9.26 | 8.91 | 0.15 | 1.258 | |
| J180342.9−295606 | 467  | 119 20352 15 | 10.41: | 9.94: | 8.62 | 8.62 |  |  |  |  |  |
| J180345.1−295516 | 473  | 119 20353 289 | 16.73 | 15.77 | 0.44 | 8.91 | 0.05 | 1.412 | |
| J180346.2−295912 | 476  | 119 20352 2239 | 17.60 | 15.41 | 8.20 | 6.87 | 7.00 | 5.21 | 0.3 | 2.075 | BMB179 7 |
| J180348.5−295946 | 483  | 119 20351 63 | 16.77 | 14.60 | 7.79 | 7.09 | 0.25 | 1.850 | BMB186 6.5 |
| J180350.9−295618 | 491  | 119 20352 38 | 18.76 | 16.79 | 7.61 | 6.44 | 6.31 | 5.26 | 4.0 | 2.498: | BMB194 6.5; Mira |

A The full ISOGAL designation is of the form: ISOGALP Jhhmmss.s-ddmmss (2000). P signifies ‘provisional’.

B BW denotes the running number during the analyses of the Sgr I and NGC6522 fields.

C The MACHO 3-digit identifier refers to the field, tile, and the sequence number (see Alcock et al. 1999).

D V and R mags are flux-weighted time-averages. Those marked with “:” are by-eye estimates; these MACHO lightcurves show saturation effects. In these cases, no estimates for Amp. and log P are given.

E Periods are in days. Those marked with “:” are by-eye estimates for some long-period variables as described in the text.

F BMB denotes Blanco McCarthy Blanco (1984), B denotes Blanco (1986), and the following number is the M giant spectral sub−type. Those marked with “Mira” are also listed in Table 1. In some cases we note a second or “double” period using the notation: dp(Amp, log P).
Table 2. Mira variables in the survey area

| Name     | MACHO       | $[7]_{avg}$ | $[15]$ | $K_{avg}$ | Period$^1$ |
|----------|-------------|-------------|--------|-----------|------------|
| NGC 6522 |             |             |        |           |            |
| TLE D9   | missing$^2$ | 4.96        | 3.64   | 5.78      |            |
| TLE228   | missing$^2$ | 6.03        | 5.11   | 6.60      |            |
| TLE403   | 119 20090 355 | 6.32    | 4.82   | 7.00      | 340/335    |
| TLE238   | missing$^2$ | 6.84        | 5.80   | 7.44      |            |
| TLE136   | 119 20352 38 | 6.31        | 5.26   | 6.44      | 315/270    |
| SGR I    |             |             |        |           |            |
| TLE65    | 113 18155 43 | 6.33        | 5.28   | 6.98      | 296/265    |
| TLE79    | 113 18287 2391 | 5.96  | 4.46   | 6.66      | mis-id$^4$ |
| TLE53    | 113 18416 198 | 4.87        | 3.37   | 6.43      | 470/500;$^3$ |
| TLE87    | 113 18417 1965 | 6.96   | 5.75   | 7.29      | 307/315    |
| TLE54    | 113 18416 290 | 6.37        | 5.39   | 7.04      | mis-id$^4$ |
| TLE39    | 113 18413 1776 | 6.83  | 5.64   | 7.80      | 254/235    |
| TLE55    | missing$^2$ | 6.51        | 5.47   | 6.81      | -          |
| TLE57    | missing$^2$ | 7.24        | 6.97   | 8.18      | -          |
| TLE56    | 113 18675 1135 | 7.05 | 6.37   | 7.43      | mis-id$^4$ |

Notes:

$^1$The left period was derived from MACHO data and the right by Lloyd Evans (1976).

$^2$“missing” stars probably appeared constant or non-stellar in the MACHO data due to saturation, and were rejected before the matching stage.

$^3$fragmentary MACHO light curve.

$^4$An apparent MACHO counterpart was mistakenly found during the cross-identification process; the image of the correct star was probably saturated.
Table 3. Spectral Energy Distribution Modeling Results

| BW | MACHO       | FW87 | \( M_{\text{bol}} \) | \( T_{(V-K)} \) | \( T_{\text{mod}} \) | \( \dot{M}_{\text{L4}} \) | \( \dot{M} \) | \( x_{[15]} \) | \( V_{\text{exp}} \) |
|----|-------------|------|-------------------|----------------|-------------------|----------------|-------|--------|-----------|
| 92 | 119 19963 178 | 11   | -3.12            | 3077           | 2500              | 1.0e-7         | 2.3e-8 | 0.79   | 13.6      |
| 147| 119 19961 176 | 28   | -4.35            | 2912           | 3000              | 8.2e-7         | 4.4e-7 | 129.65 | 16.2      |
| 192| 119 20093 2054| 46   | -4.47            | 2882           | 3000              | 8.2e-7         | 4.8e-7 | 92.79  | 16.6      |
| 294| 119 20091 3853| 84   | -2.69            | 3442           | 3500              | 6.8e-8         | 1.2e-8 | 2.23   | 14.4      |
| 299| 119 20093 55  | 86   | -4.18            | 2939           | 3000              | 8.2e-7         | 3.9e-7 | 131.36 | 15.6      |
| 317| 119 20093 31  | 91   | -3.37            | 3273           | 3200              | 5.4e-8         | 1.5e-8 | 0.72   | 15.1      |
| 333| 119 20091 3839| 93   | -4.53            | 3318           | 3350              | 6.3e-8         | 3.8e-8 | 9.51   | 21.3      |
| 347| 119 20221 80 | B28  | -2.84            | 3489           | 3500              | 1.4e-7         | 2.6e-8 | 2.27   | 14.8      |
| 354| 119 20220 61 | 94   | -3.39            | 3286           | 3350              | 6.3e-8         | 1.7e-8 | -0.37  | 16.4      |
| 361| 119 20221 104| 106  | -3.38            | 3197           | 3200              | 1.1e-7         | 3.0e-8 | 0.80   | 15.1      |
| 365| 119 20222 2546| 108 | -4.19            | 3076           | 2500              | 1.9e-7         | 9.1e-8 | 17.36  | 16.3      |
| 375| 119 20221 126| 114  | -3.98            | 3085           | 2500              | 1.9e-7         | 7.9e-8 | 14.74  | 15.5      |
| 379| 119 20221 55 | B47  | -3.69            | 3408           | 3350              | 3.1e-8         | 1.1e-8 | -2.70  | 17.6      |
| 389| 119 20222 2540| 120 | -4.20            | 3113           | 3000              | 4.0e-7         | 1.9e-7 | 61.22  | 16.1      |
| 407| 119 20222 2573| 127 | -3.43            | 3051           | 2500              | 1.9e-7         | 5.4e-8 | 12.01  | 13.7      |
| 409| 119 20223 158| 136  | -3.98            | 3016           | 2500              | 1.9e-7         | 7.9e-8 | 2.58   | 15.5      |
| 413| 119 20221 44 | B66  | -3.38            | 3805           | 3750              | 4.2e-8         | 1.2e-8 | 1.40   | 18.7      |
| 415| 119 20221 56 | B47  | -3.95            | 3339           | 3350              | 6.3e-8         | 2.6e-8 | 0.98   | 18.6      |
| 414| 119 20220 50 | 128  | -3.82            | 3197           | 3200              | 2.1e-7         | 7.8e-8 | 11.26  | 15.6      |
| 419| 119 20220 81 | 133  | -2.95            | 3329           | 3350              | 1.3e-8         | 2.7e-8 | 0.84   | 14.7      |
| 426| 119 20220 89 | 134  | -3.58            | 3284           | 3350              | 2.5e-7         | 7.9e-8 | 17.29  | 15.9      |
| 432| 119 20221 178| 142  | -4.58            | 2894           | 3000              | 8.2e-7         | 5.2e-7 | 91.57  | 17.1      |
| 445| 119 20221 290| 152  | -4.27            | 3120           | 3000              | 4.0e-7         | 2.0e-7 | 50.96  | 16.4      |
| 476| 119 20352 2239| 179 | -4.59            | 2880           | 3000              | 8.2e-7         | 5.2e-7 | 139.46 | 17.1      |
| 491| 119 20352 38 | 194  | -5.06            | 2718           | 3000              | 3.3e-6         | 2.9e-6 | 104.12 | 16.3      |
| 224| 119 20090 355 | TLE403     | -4.51          | 2741           | 3000              | 3.3e-6         | 2.0e-6 | 186.07 | 14.3      |