Asymptotic Giant Branch Stars
T. Le Bertre, A. Lèbre and C. Waelkens, eds.
I.A.U. Symposium 191, 1999

Long-period Variable Stars Near the Galactic Centre

I.S. Glass

S. A. Astr. Obs., PO Box 9, Observatory, 7935 South Africa

S. Matsumoto

Inst. of Astr., University of Tokyo, Mitaka, Tokyo 181, Japan

B.S. Carter

Carter Observatory, PO Box 2909, Wellington, New Zealand

K. Sekiguchi

Subaru Telescope, NAOJ, 650 N A'ohoku Pl, Hilo, HI 96720, USA

Abstract. A second report on our 4-year survey for long-period variables (LPVs) in the central 24 $\times$ 24 arcmin^2 of the Galactic Bulge is presented. All four seasons of data have now been reduced and $\sim$ 350 variables have been found. Preliminary periods have been obtained for most of them. Fifty-five out of 103 known OH/IR stars in the field have been recovered in the K-band.

1. Introduction

The variable stars of the inner Bulge are of great interest both as population and distance indicators. The easiest of them to identify are the long-period AGB variables, comprising Miras and OH/IR stars. Because of the high extinction in their direction, fields near the Galactic Centre are best observed in the near-infrared, between H (1.6 μm) and L (3.5 μm). At longer wavelengths the photospheric component is swamped by emission from circumstellar and interstellar dust. So far, detailed knowledge of stellar properties near the Centre has largely been confined to the GC Cluster, the nearby "Quintuplet" and the cluster of hot stars near G0.121+0.017.

Surveys for LPVs have been made in the central cluster in the K-band and in the low-obscuration Sgr I and NGC 6522 windows using visible and near-IR photographic techniques. The most recent survey for OH sources near the Galactic Centre has been made by Sjouwerman et al. (1998), who also lists previous work. Some infrared identifications of OH sources and period determinations have been made by Wood, Habing & McGregor (1998). Periods of several OH sources were also found by Blommaert (1998). In addition, Jones et al. (1994) have given the infrared-derived periods of a few Bulge OH/IR stars.

The present programme seeks to uncover the variable star content of the Inner Bulge using infrared techniques. Use is made of a very large-area array of limited sensitivity to study the most luminous part of the late-type stellar population. A first report, containing the findings of the first two seasons' work, was given by Glass et al. (1996).

2. Observations

The observations were made over four southern winters, viz 1994-1997 inclusive. An area of 24 $\times$ 24 arcmin^2, centered near the Galactic Centre, was divided into 25 fields of 300 $\times$ 300 arcsec^2 so that there was an overlap of 15 arcsec between adjacent fields. The PANIC (PtSi Astronomical Near-Infrared Camera), based on a Mitsubishi 1040 $\times$ 1040 PtSi array with pixels of 17 $\times$ 17 μm^2, was used. A complete description of this camera has been given by Glass, Sekiguchi & Nakada (1995).

3. Data-reduction

Standard data-processing involved principally the removal of telescope and sky radiation, amplifier emission and dark current. An empty "sky" frame was constructed by combining groups of five (occasionally three) exposures. First, the five exposures were averaged. The difference between each individual and the average exposure was found and an additive correction was made so that each frame had the same modal pixel value. The median average of the five frames was then found and treated as an empty frame.

The extremely long exposures (usually 10 minutes) necessary because of the low quantum efficiency of the array means that the background level may vary considerably between the first and last of a five-frame series. For this reason, the quality of the "sky" frame was not always perfect and may have led to increased photometric scatter for faint stars when the most crowded fields were reduced.

The coordinates and intensities of the stars were extracted from each exposure using DoPHOT (Schechter, Mateo & Saha 1993). The output of each exposure was called a *sum* file. Further processing depended on the "STAR" suite of programmes written by Dr L.A. Balona (SAAO), whom we thank. Each of the 25 fields was treated separately.

For each field a particular *sum* file was selected as a fiducial one for cross-identification purposes. A new set of files - the *cat* files - on the coordinate system of the fiducial exposure was then created, corresponding to each of the *sum* files, omitting images classified by DoPHOT as non-stellar. This process allowed for translation and rotation of the coordinates and depended on the recognition of at least five bright stars in each frame.

In order to form some idea of the accuracy of the positional measurements, the x and y coordinates of the brightest star ($K \sim 5.8$) and the 200th brightest star ($K \sim 10.8$) in field 1 were extracted from each *cat* file and their standard deviations were calculated. Taking the scale as 3.5 pixels arcsec^{-1} in the x direction and 1.75 pixels arcsec^{-1} in the y direction, the s.d.'s amounted to (s.d.x, s.d.y) = (0.02, 0.02) arcsec for the bright star and (0.09, 0.07) for the faint one.

Thus measurement error does not contribute significantly to the overall error in the position determinations.

The next step was to make a table of photometry for each star, still at this point on the natural systems of the individual exposures. Around 10 to 15 bright stars from the field were compared through all the available *cat* files and used to place the individual exposures on a uniform photometric scale. Because the brightest stars are often variable, the residuals were examined and individual stars were rejected before iterating. After a few iterations, a suitable set of non-variable stars is found, with standard deviations typically around 0.04 mag.

4. Astrometry

Astrometric positions of stars in each of the 25 fields were obtained by reference to stars included within the USNO-A1.0 astrometric catalogue (Monet et al. 1996). The coverage of this catalog is sufficiently dense that many tens of stars are found in each of our fields. Its typical astrometric error is believed to be about 0.25 arcsec. For cross-identification, overlays of USNO-A stars were prepared on the same scale as charts printed out from a DoPHOT *cat* file. Because the USNO stars are often very faint in the K-band, recourse was sometimes necessary to the J-band for guidance in locating the infrared counterparts. The DoPHOT coordinates of the selected stars were then entered into an astrometry programme with RA and Dec (2000) positions from USNO-A. The residuals from the output were examined to eliminate misidentifications (occasionally due to chance correspondences of different visible and infrared objects). Proper motions, crowding and low signal-to noise may also have contributed to the residuals. The final standard errors in the positions were usually estimated to be around 0.5 arcsec, based on the residuals of the local standards from the USNO-A catalogue.

5. Extraction of variable stars

For each field, the light curves of the brightest 200 stars were plotted out and examined by eye. This tedious method was unfortunately necessary because of accidental mis-identifications produced when DoPHOT refused to classify an image as stellar and the cross-identification programme chose a neighbouring faint image instead. This problem occurred once in a few hundred measurements.

Other causes of spurious variability included crowding, such as in the Galactic Centre cluster and the nearby hot star cluster, and proximity to the edge of the array. Crowding was checked for by creating overlays of the variable star positions which matched the scale of the K-image print-outs. Whenever an apparent variable star appeared to be within 40 pixels of the edge in x, or 20 pixels in y, this fact was flagged.

The standard deviations of individual non-variable stars in two of the fields, one crowded and the other less so, were examined as a function of K magnitude (see Fig. 1), after removal of the accidental points referred to. Bright stars have standard deviations around 0.04 mag. but fainter ones have standard deviations that reach 0.1 at $K \sim 10.4$ and 0.2 mag. at ~ 11.4. These figures give an

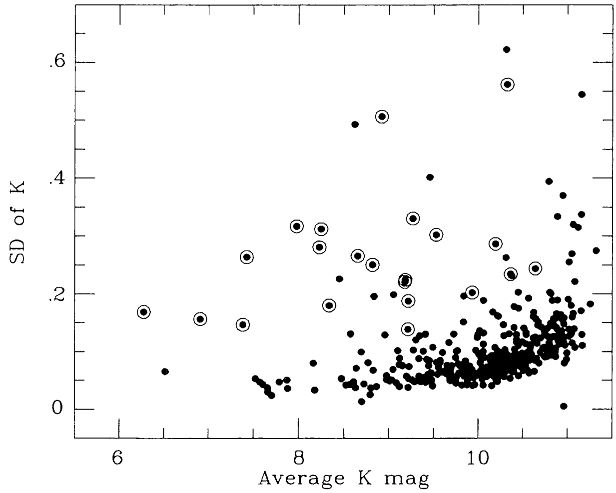

Figure 1. Variability statistics for 400 of the brightest stars in the 5×5 arcmin^2 sub-field no. 13, which contains the "Quintuplet" or AFGL 2004 cluster. Stars believed to be genuine variables are circled. Other high standard deviations are attributable to crowding, proximity to the edges of the array and, at the fainter end, to imperfections in sky-subtraction.

indication of the level at which sinusoidally variable stars of full amplitudes 0.3 and 0.6 mag., of unknown period and with few data points, might be detected.

Periods were determined from power spectra of the data for each star. About 250 of the 350 variables found so far appear to be regular LPVs. However, the present method of analysis may not be optimal, and it is intended to use alternative methods to refine the results.

6. Period Distribution

Fig. 2 shows the period distribution of the LPVs found to date in the overall survey field as well as a similar histogram for the Sgr I Baade's Window, where the extinction is < 0.2 mag. at K. The proportion of longer-period LPVs at first glance appears to be higher in the Centre. However, systematic effects must be guarded against. Firstly, the stars examined so far for variability represent the brightest 200 of each field at K *at a particular time*, and the limiting magnitude will vary from field to field according to the overall numbers of stars. Secondly, if $A_K \sim 3.0$, as it is over much of the survey region, one would expect 200-day Mira variables to appear at about $K = 10.7$ and 600-day variables at about $K = 9.0$, based on their properties in the Sgr I field (Glass et al. 1995). Thus some incompleteness will very probably be present in the census of the shorter-period LPVs. Further analysis will attempt to address this problem.

https://doi.org/10.1017/S0074180900203501 Published online by Cambridge University Press

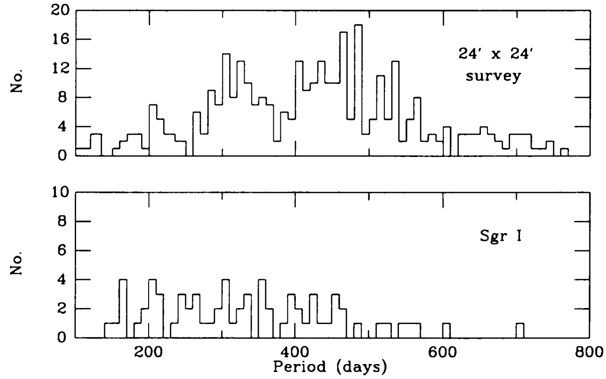

Figure 2. The period distribution of long-period variables *top* in this work and *bottom* in the Sgr I field (Glass et al. 1995).

7. OH/IR Stars

The positions of known OH/IR stars from Sjouwerman et al. (1998) and variables from Wood et al. (1998) were searched specifically if they had not already been located during routine processing. Because the OH/IR star amplitudes are usually very large, it was often possible to find them even if they were faint. Of the ~ 103 OH/IR stars known in the survey area from radio studies, 55 have so far been recovered in our searches. The remainder may be self-obscured by thick dust shells, may be obscured by interstellar matter (which is known to exceed $A_K = 6$ mag. in places (Glass, Catchpole & Whitelock 1987) or may be too crowded for regular DoPHOT analysis, particularly in and around the GC Cluster.

Fig. 3 shows the sources detected in our field as well as known OH/IR sources and variables located by Wood et al. (1998). A small number of the latter were below the faintness limit of this survey. Reference to a K-map of the area (e.g., Glass, Catchpole & Whitelock 1987) shows that detectability is, as expected, reduced in the areas hidden by dense molecular clouds.

References

Blommaert J.A.D.L., van der Veen W.E.C.J., van Langevelde H.J., Habing H.J., Sjouwerman L.O., 1998, A&A 329, 991

Glass I.S., Catchpole R.M., Whitelock P.A., 1987, MNRAS 227, 373

Glass I.S., Matsumoto S., Ono T., Sekiguchi K., 1996, in *The Galactic Center*, Fourth ESO/CTIO Workshop, R. Gredel (ed.), PASP Conf. Series 102, p. 312

Glass I.S., Sekiguchi K., Nakada Y., 1995, in *New Developments in Array Technology and Applications*, A.G. Davis Philip et al. (eds.), IAU Symposium 167, Kluwer, Dordrecht, p. 109

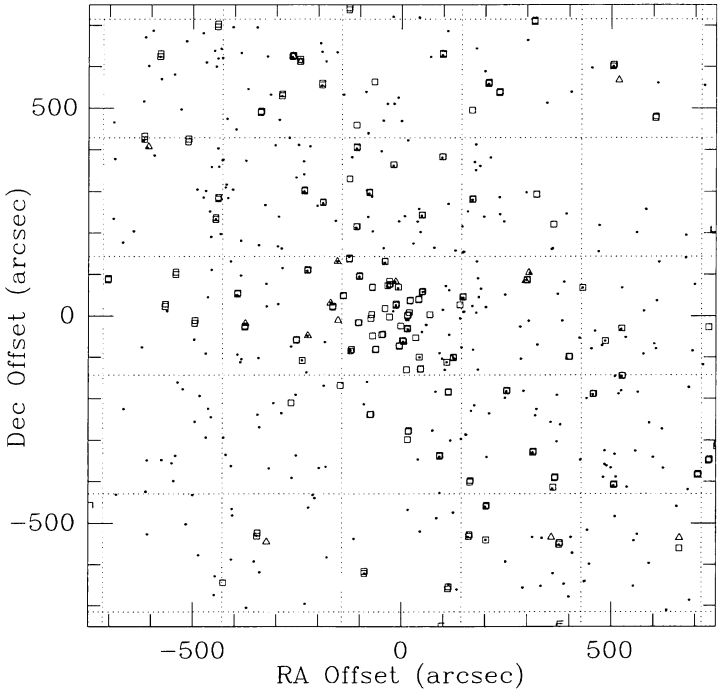

Figure 3. Variables and OH/IR sources. Dots indicate the newly-found variables. Squares are OH/IR stars from Sjouwerman et al. (1998) and triangles are variables found by Wood et al. (1998). The dotted lines indicate the boundaries of the 25 sub-fields.

Glass I.S., Whitelock P.A., Catchpole R.M., Feast M.W., 1995, MNRAS 273, 383

Jones T.J., McGregor P.J., Gehrz R.D., Lawrence G.F., 1994, AJ 107, 1111

Monet D., et al., 1996, *USNO-A1.0: A Catalog of Astrometric Standards*, US Naval Observatory, Washington DC (CD-ROM set)

Schechter P.L., Mateo M., Saha A., 1993, PASP 105, 1342

Sjouwerman L.O., van Langevelde H.J., Winnberg A., Habing H.J., 1998, A&AS 128, 35

Wood P.R., Habing H.J., McGregor P.J., 1998, A&A 336, 925

https://doi.org/10.1017/S0074180900203501 Published online by Cambridge University Press