CCD PHOTOMETRY WITH SMALL TELESCOPES

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ABSTRACT. CCD photometry with small telescopes often complements the use of such detectors on larger telescopes and in addition it is ideally suited to projects, such as determining variable star light curves, that require considerable amounts of observing time. Following a discussion of some of the techniques found useful for producing accurate CCD photometry, the results of several projects carried out with the SAAO 1m CCD camera are presented.

1. INTRODUCTION

In the past few years CCD cameras have produced some spectacular results, both in detecting fainter objects than ever seen before and also in allowing accurate photometry, free of systematic errors, to very faint limits. Colour magnitude diagrams of galactic globular clusters, reaching far down the main sequence, is just one example of the type of observation where the use of CCDs have made a major impact by producing results accurate enough to allow detailed comparison with models (eg Harris & Hesser 1984). In general, most of this work has been done with large telescopes in the 4m class.

Concentrating on stellar photometry through broad band filters, I shall attempt to show that a CCD camera system on a 1m class telescope can do valuable astronomy and indeed complement the use of CCDs on larger instruments, much of the work on which tends to be of observ- ations with low S/N on very faint objects. An example of this symbiosis is the colour magnitude diagram for the globular cluster NGC 6752 given by Penny (1984), where the photometric zero-points and the stars to V ≃ 19 were measured using the SAAO 1m telescope while the fainter stars to V ≃ 23 were measured on the AAT.

A 1m telescope plus CCD can do accurate broad-band (B,V,R,I) photometry (few percent or better) down to magnitude ≃ 20 given reason- able seeing with exposure times under 30 minutes. Fainter magnitudes can be reached but require much longer exposure times and/or extremely good seeing, and it is clearly a lot more efficient in these circumstances to use a larger telescope.

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CCD photometry is free from the systematic errors that plague photographic photometry. This is partly due to the inherent linearity of the CCD itself, but is also due to standards and program stars being measured in a similar manner, without the need for sequence extending devices or measurement of standards and program stars by different techniques. The quality of photometry in the magnitude range V = 12 - 20 that can be done with a CCD camera on a small telescope is clearly superior to that achieved either by photoelectric or photographic photometry virtually independent of telescope aperture, provided sufficient attention is paid to the calibration and standardization problems. In some work that has been published the natural CCD photometric system has differed greatly from the standard system to which the photometry was reduced. This is unfortunate since the chances of (poorly determined) errors being introduced are high.

CCD systems on the (few) large telescopes tend to be used to study faint objects, while time allotments are mostly short and almost always difficult to get. For smaller telescopes time allotments are commonly scheduled in units of weeks rather than days; this is of great advantage for instance in the study of variable stars with periods in the fraction of a day - few days range and also means that colour equations can be adequately checked during the course of an observing run. Longer observing runs also mean that the astronomer can come to the telescope with several programs and select the one best suited to the combination of sky transparency, sky brightness and seeing at any given time.

The disadvantage of a CCD system on a small telescope relates mainly to its cost. Over the last few years instruments have become more complex and a larger fraction of the total cost of an installation. CCDs are no exception, particularly if the cost of an autoguider and computer system are included, while the best detectors are expensive. The computer power necessary to cope with large CCDs is considerable, particularly as some degree of on-line reduction is desirable to minimise data storage problems. A powerful computer in the VAX class is required for data reductions however software packages such as DAOPHOT and GRASP (STARLINK) have been widely distributed to astronomical institutions. Olszewski & Aaronson (1985) give an excellent description of the use of DAOPHOT.

2. SOME TECHNICAL ASPECTS

2.1. Pixel scale

CCDs in common use have pixel sizes ranging from 22μ to 30μ. The best seeing at good observing sites is generally about one arc second or a little better and therefore to cover star images with several pixels in order to fully utilize any good seeing requires a pixel size no greater than about 0.5 arc sec which implies a focal length of 10 - 15 metres. As expected, tests have shown that photometric accuracy falls off rapidly as the star images become under sampled. For work that does not require the small pixel size (eg galaxy surface photometry) shorter focal lengths can be used in order to cover a greater area of sky.

2.2. Exposure times

Exposure times are a function of brightness of the object, seeing, CCD readout noise and sky brightness. If integrations are long enough so that sky noise dominates over readout noise then multiple exposures can be made and later summed so that cosmic ray events can easily be recognized, internal photometric errors can be found and the effective dynamic range increased. For a small telescope working at f/10 to f/20 this condition can not always be achieved even with broad band filters and is usually impossible with medium and narrow band filters. The use of CCDs with as low readout noise as possible is therefore even more important for small telescopes than it is for large ones.

2.3. Cleaning CCD frames

This topic has been dealt with in great detail by Djorgovsky(1984). The SAAO practice has been to use the twilight sky for flat fields. The DC bias on each frame is estimated by recording a strip of overscan along with each frame. The preflash (if used) is calibrated by an exposure typically 100 times longer than that applied normally; the preflash is uniform to ± 10 percent across the frame. Subtraction of dark frames and defringing is carried out only if neccessary. The latter is usually only required for I band exposures of 30 minutes or more duration.

2.4. Filters

Duplication of the Johnson UBV and the Kron-Cousins RI systems is possible given that the CCD in use covers the bands (The GEC and Thomson CCDs cover VRI only and the RCA CCDs cover only part of U). Specifications for the UBVRI filters in use at SAAO with the RCA CCD and the resulting colour equations are given in the Table I. The use of methylene blue in the U filter was suggested by Dr D.D. Walker (UCL), while all the filters include WG280 glass to give a total thickness of 7mm.

TABLE I. Filter specifications and colour equations

U: 4mm 28% $CuSO_4$ soln. + 4mm 0.0025% methylene blue soln. + 2mm UG1
B: 2mm GG385 + 1mm BG18 + 1mm BG12 + 2mm KG3
V: 2mm GG495 + 2mm BG18 + 2mm KG3
R: 2mm OG570 + 2mm KG3
I: 3mm RG9

$U-B = 1.002\ (u-b)$ + small non linear term for $U-B < 0.1$
$B-V = 1.090\ (b-v)$
$V-R = 1.030\ (v-r)$
$V-I = 0.975\ (v-i)$
$V = v$

It cannot be over-emphasised enough that great care should be taken

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to use filters that closely match the standard systems and that colour equations should be determined by observing standards with as wide a range of colour as possible. Unless the filters match the standard system the effects of reddening will be unpredictable, and in this context the use of very broad band J and F filters to reach faint stars followed by transforming to B and V requires circumspection.

CCD photometry is of course not restricted to the 'standard' systems; two examples are the use of on-band off-band Hα filters by Holland Ford and co-workers (private communication) to search for novae in M31 while Lynds & O'Neil (1985) have used narrow band filters to measure emission line strengths in NGC 7538.

2.5. Linearity and Stability

The linearity and dynamic range of CCDs are discussed by Djorgovsky (1984) who finds that CCDs are linear over a range of several magnitudes at the 0.1 percent level. With some devices charge transfer efficiency is reduced at low charge levels while non-linearities can occur at the bright end of the range prior to saturation.

The long term stability of the SAAO RCA CCD V magnitude zero-point is shown in Figure 1. The secular fall off in sensitivity can be attributed entirely to the aging of the aluminium coatings on the telescope mirrors. It should be noticed that the zero-point returned to its original value following re-aluminising of the primary mirror. This long term stability is very much greater than that for typical photo-multipliers. The scatter about the steady decline in Figure 1 can be attributed to night to night variations in extinction since the zero-point was calculated using the nominal value K_V = 0.15, and in fact

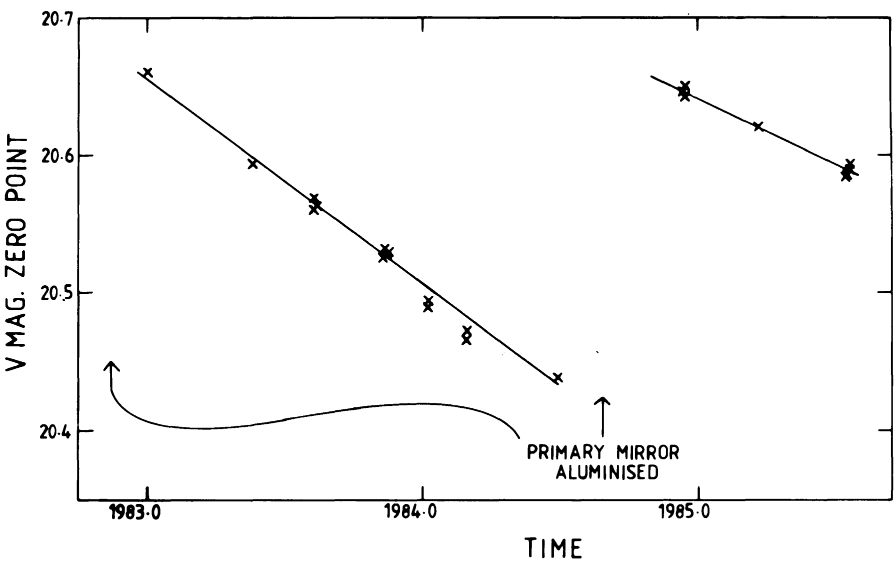

Figure 1. CCD V magnitude zero-point as a function of time.

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the instrumental zero-point is so stable that the extinction changes from night to night can be determined directly by forcing the instrumental zero-point to be constant.

3. ASTRONOMICAL PERFORMANCE

3.1. Standards

In the south the most accurate UBVRI standards are those established by Cousins and co-workers and tabulated by Menzies et al. (1980). More recent measurements with significantly better values for the fainter (mag 8-10) E region stars, particularly in (U-B), are given by Menzies & Laing (1985) and Menzies (private communication). Fainter E region standards have been given by Graham (1982) while equatorial region stars have been measured by Landolt (1973, 1983) and Cousins (1984). Strömgren standards in the E regions are found in Cousins (1985). The great advantage of all these standards is that they are accurate to the few 0.001 mag level and cover a wide range in colour. Exposure times with a 1m telescope average a few seconds. Examples of the quality of photometry achieved on standards are given in Figure 2, in Schild (1983) and in Walker (1984a).

Measuring single bright standards is inefficient both in terms of observing time and in the consumption of magnetic tape; if on line digital aperture photometry were possible then the data storage problem would be alleviated. Techniques such as multiple exposures before read-

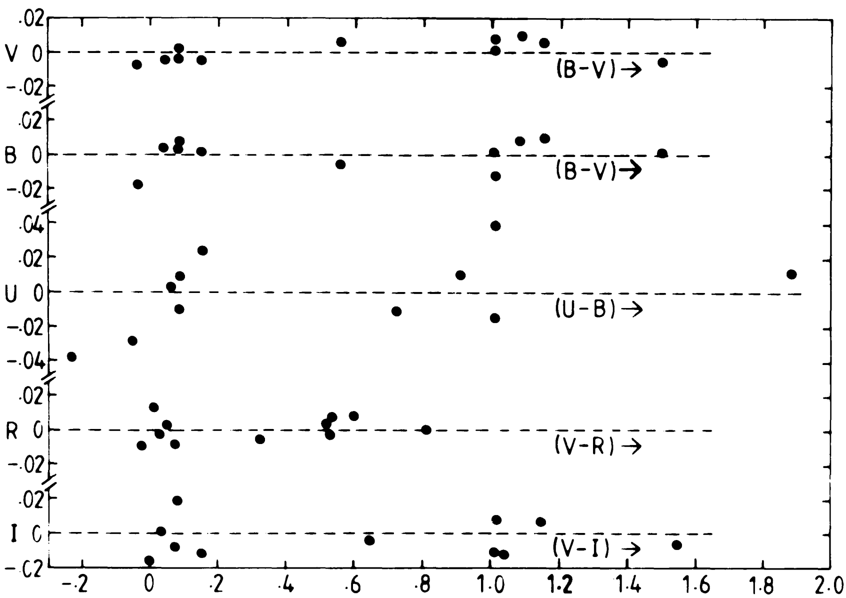

Figure 2. Magnitude residuals as a function of colour, from observations of E region standard stars on July 9 1985.

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out or the defocusing of bright stars are not in general to be recommended since one of the major advantages of the CCD is that the standard star frames and the program star frames can be measured in precisely the same way. Any departure from this must introduce a systematic error at some level.

An alternative to measuring standards singly is to have accurately measured stars in small CCD sized fields with a wide range in colour and a small range in magnitude so that zero-points and colour equations can be determined from only a small number of exposures. Such fields have been set up in the north (Christian et al. 1985, with extensions by Lindsey Davis (KPNO) in progress) but the stars are mostly faint and better suited to large telescopes and in some fields the colour range is limited. The same is generally true of the fields in the south set up by Stobie et al. (1985). A brighter set of stars with a range in B-V from -0.16 to 1.35 have been measured in M67 by Schild (1983), while for Strömgren photometry the accurate work in NGC 3293, 4755 and 6231 by Shobbrook (1983a, 1983b, 1984) is useful.

3.2. Reduction procedure

The following is a brief outline of the reduction procedure necessary in order to measure the brightness of stars on "cleaned" CCD frames (Walker 1984a): (a) Determine colour equations, zero-points and extinction from observations of standard stars, using digital aperture photometry. (b) Measure one or more bright stars on each frame, again using aperture photometry. These will be the local standards. (c) Choose a bright isolated star(s) on each frame and fit a profile to it (Gaussian, Lorentzian, spline etc.). (d) Fit this profile to all the program stars plus the local standards. (e) Find the offset between the aperture photometry and the profile fitting photometry for the local standards. (f) Apply this offset to the program star photometry.

Only steps (c,d,e,f) are necessary once local standards have been set up or if they are already available, in which case observations can be carried out in non-photometric conditions. Given sufficient attention to step (a) above, step (b) will usually limit the accuracy of the procedure at about the 0.01 - 0.02 mag level.

3.3. Faint Star Photometry

For faint star photometry the (internal) errors are not dominated by photon statistics but by the accuracy of the flat fielding, the ability to take account of CCD defects and cosmic ray events, defringing for some spectral bands and the capability of the algorithm used to fit the star profile and the background, especially in the multi-star case.

A field 8 arc min from the centre of the globular cluster ω Centauri has been observed, with BVRI magnitudes being found for 200 stars within a 68 arc sec square area down to V = 23 in order to provide faint calibrating stars for the Space Telescope Wide Field Camera and Planetary Camera. The data can also be used to construct colour magnitude diagrams for the cluster (Figures 3).

Table II gives mean errors as a function of magnitude for the summed

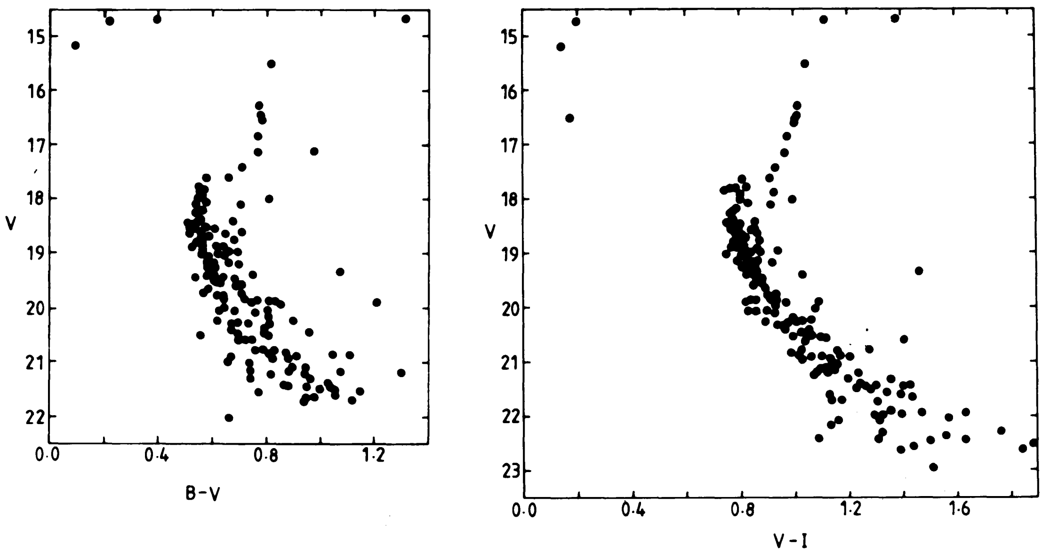

Figure 3. (a) V/(B-V) CM diagram for a field in ω Centauri. (b) V/V-I CM diagram for the same field as in (a).

frames. These were obtained for V by comparing 2500s and 3000s exposures (made on different nights) and a 3000s exposure made two months earlier while for B-V and V-I two successive 2000s exposures were compared. Comparing measurements on repeated (preferably slightly spatially displaced) frames is probably the best way of finding the error as a function of magnitude, although creating artificial stars of known brightness and measuring them along with the program stars has the advantage of also allowing estimates of completion if an automatic star finding program has been used.

The colour spread of the main sequence stars in Figure 3a must be intrinsic, considering the errors in Table II, and indeed is scarcely

Table II. V, B-V and V-I errors as a function of magnitude.

V	σ(V)	σ(B-V)	σ(V-I)
15-18	0.01	0.01	0.01
18-19	0.02	0.01	0.01
19-20	0.03	0.02	0.015
20-21	0.04	0.04	0.02
21-22	0.06	0.06	0.04
22-23	0.08		

less than that found in the photographic study by Cannon & Stewart (1981) even though the photometric errors here are at least a factor of two smaller. This result confirms that of Rodgers & Harding (1983) and is also found in a more extensive study by Dr R. D. Griffiths (Leeds) and co-workers, and shows conclusively that the ω Centauri metallicity variations are primordial. The lack of blanketing in the I band compared to the B band is responsible for the reduced colour spread in Figure 3b.

3.4. Variable Star Light Curves

3.4.1. Cepheids in NGC 1866. NGC 1866, a rich young cluster in the LMC, contains several Cepheid variables all with periods near 3 days. Field Cepheids in the LMC have been used to define the slope of the PL and PLC relation (eg Martin et al. 1978, Caldwell & Coulson 1985). These latter stars almost all have periods longer than the galactic Cepheids in the calibrating clusters and it is important to check whether or not the slope of the PL and PLC relations is the same for both the shorter and longer period stars.

Typical light curves for the NGC 1866 stars are given in Figure 4. The quality of the present results is better than the photographic light curves by Arp & Thackeray (1967) and serve to show that there are significant systematic errors in the photographic photometry. Although analysis of the light curves is not yet complete, it appears that there may be a slight change in slope of the PL and PLC relation for short period Cepheids. This is in the sense of making the LMC closer by ≃ 0.1 mag than if a linear relation is used. There is only a small spread in <B>-<V> colour, in contrast to the spread of 0.2 mag at any given period found by Martin et al. (1979) for stars with periods over 10 days.

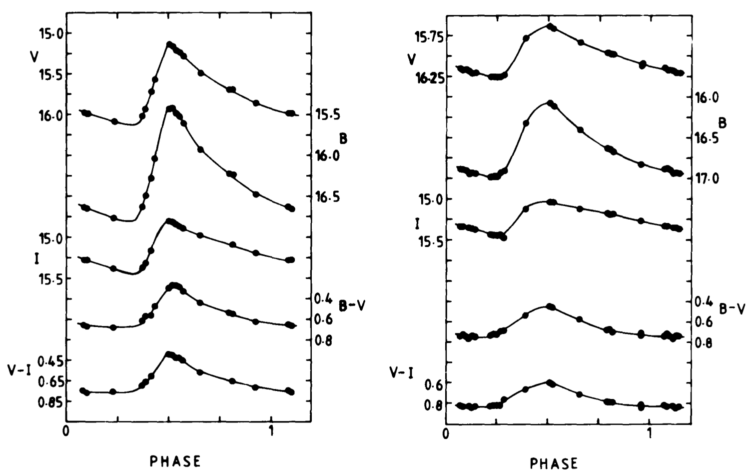

Figure 4. (a) Light curve for the Cepheid NGC 1866f (period 3.439 d), (b) light curve for NGC 1866g (period 3.523 d)

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3.4.2. Light curves of RR Lyrae stars in the NGC 6522 Baade window. The star density of even relatively bright stars in this region is extremely high making any sort of photometry extraordinarily difficult. For the CCD work to be a significant advance in accuracy over other methods requires good seeing when observing and the use of a multi star fitting algorithm when reducing the data. Even so, the light curve quality is poorer than that achieved for stars of similar brightness in less crowded fields. Previous photometry in Baade's window (Gaposchkin 1956, Arp 1965, van den Berg 1971, Hartwick et al. 1972, Blanco 1984) suffers from systematic errors of varying size brought about either by the use of less than ideal techniques when setting up the photometric sequence or by difficulties calibrating the photographic plates used to measure the RR Lyraes.

CCD B and V measurements were made of a standard sequence (Blanco & Blanco 1984) and 13 variable stars in BW; light curves for Baade 118 are shown in Figure 5. The RR Lyrae colours imply that $A_V = 1.78 \pm 0.10$ near NGC 6522, in good agreement with the Mira result (M.W. Feast, private communication) and somewhat larger than usually assumed. A small correction was applied to the Blanco (1984) RR Lyrae magnitudes and hence a value of $R_0 = 8.1 \pm 0.4$ pc was derived, assuming $\langle M_V(RR) \rangle = 0.6$. The results tend to support M_V = constant rather than M_V being a function of [Fe/H] (Walker & Mack 1985).

3.4.3. V84 and V85 ω Centauri. Feast (1985) has plotted <V> as a function of [Fe/H] for the RR Lyrae stars in ω Centauri using the metallicity measurements of Butler et al. (1978) and Freeman & Rodgers (1975). He suggests that the data may indicate that M_V = constant for the metal poor stars but a magnitude-metallicity relation may exist for the more metal rich stars. However the most metal rich star, V84, with [Fe/H] = -0.51, is almost 0.5 mag brighter than the other metal rich stars. CCD photometry of V84 and V85, the latter having [Fe/H] = -1.16,

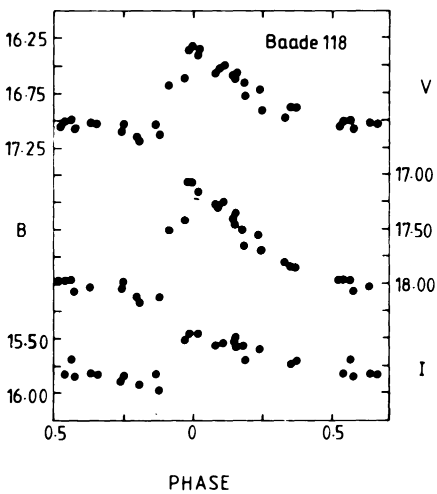

Figure 5. Light curve for the galactic bulge RR Lyrae star Baade 118.

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was made in order to check on the photometry.

The light curves are given in Figure 6; the mean magnitudes are <V> = 14.25 for V84 and <V> = 14.44 for V85. These results confirm the earlier measurements, however V84 has an unusually low amplitude and a possible interpretation of the results is that it is a double star; if the variable component actually has <V> = 14.75 then a light curve is produced with normal amplitude. An alternative explanation, due to Sandage (1981), is that V84 is an overtone pulsator, but it would then be expected to have a sinusoidal light curve with very low amplitude. This is not observed. Spectroscopy of V84 should allow a definite decision to be made as to which postulate is correct since the companion star is expected not to be much fainter than the RR Lyrae and should have constant radial velocity.

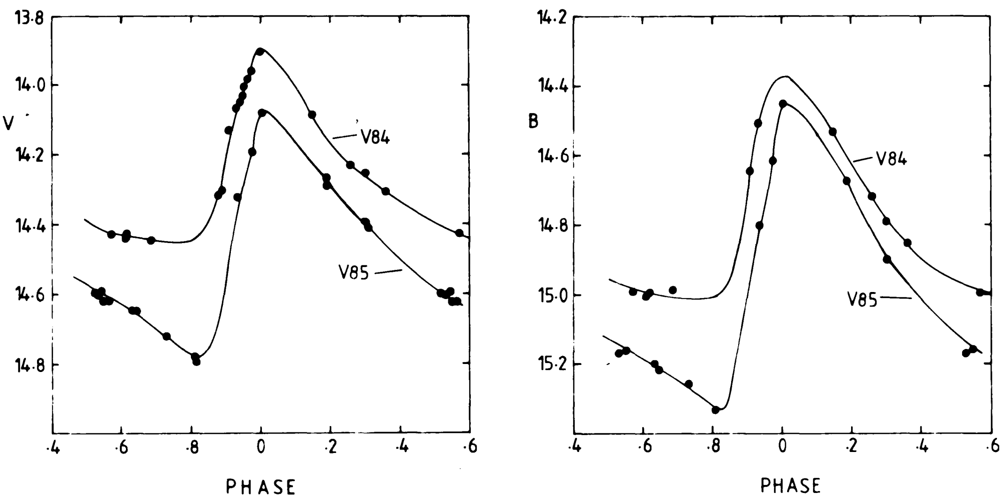

Figure 6. (a) V light curves for V84 and V85 ω Centauri, (b) B light curves for V84 and V85 ω Centauri.

3.5 High Speed Photometry

In normal operation the time resolution of a CCD is limited, by the readout time, to several seconds even if the data is prebinned into "super-pixels". Higher time resolution is possible by slowly reading the CCD out as the integration proceeds (Jacoby et al. 1985). In both cases the advantage of the CCD is that comparison stars are measured simultaneously with the program star and good data can be obtained in non-photometric conditions. In addition, stars with close companions for which normal single channel photometry is difficult can be measured. Data are usually readout noise limited because of the short exposures.

Examples of results achieved by both these methods are given by Walker (1984b) and Jacoby et al. (1985).

3.6 High Resolution Photometry

Studies of the light profiles of globular clusters are being made by P.M. Lugger (Indiana) and collaborators with the KPNO 0.9m telescope and CCD camera in order to search for light spikes at the cluster centres while D.D. Walker (UCL) and collaborators are examining the light profiles of quasars; these are but two examples of the high resolution work that is ideally suited to CCDs. The use of resolution improving techniques such as the maximum entropy method (MEM) are possible with CCD data since all stars on a given frame have the same profile. Therefore any suitably bright star can be used as a profile star, and in addition the errors are quantifiable. Walker & O'Donoghue (1984) used MEM on summed V and I frames of R136 taken in 1 arc sec seeing to achieve a final resolution of 0.4 arc sec (the pixel size) and found 22 stars with V magnitudes between 11.4 and 15.6 within 4.6 arc sec of R136a. The 0.5 arc sec central double R136a$_1$ - a$_2$ (Innes 1927) was also confirmed. The improvement achieved is shown in Figure 7. These results complement the holographic speckle interferometry of the stars within 0.7 arc sec of R136 by Weigelt & Baier (1985) who achieved 0.09 arc sec resolution. Together with the spectroscopy of the surrounding stars by Melnick (1985) and Walborn (1985), the high resolution measurements prove that R136 is merely the highly condensed centre of the very young cluster NGC 2070 and there is no need to postulate the existence of a super massive star at the cluster core.

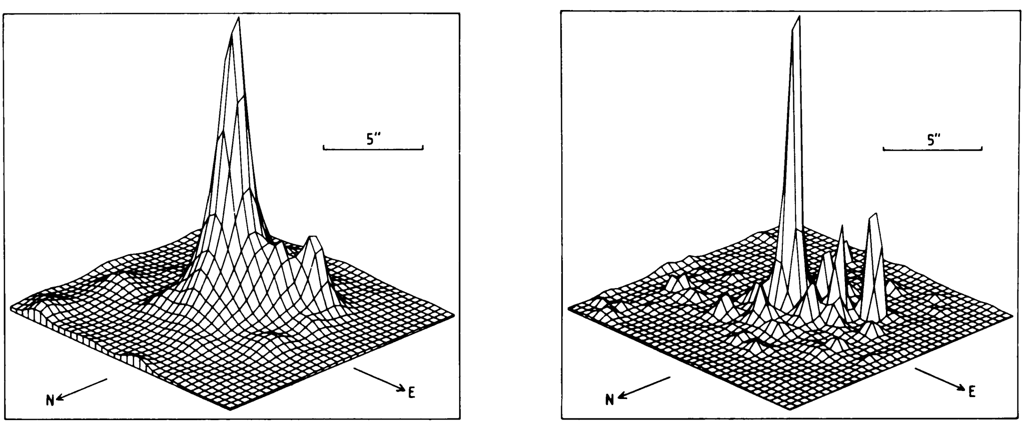

Figure 7. (a) Solid body plot of R136 prior to MEM processing, (b) Solid body plot of R136 after MEM processing, the vertical scale is half that of (a). Total exposure time was 300 seconds through an I filter.

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REFERENCES

Arp, H., 1965. Ap.J., 141, 43.
Arp, H & Thackeray, A.D., 1967. Astrophys. J., 149, 79.
Blanco, B.M., 1984., A.J., 89, 1836.
Blanco, V.M. & Blanco, B.M., 1984. PASP, 96, 603.
Butler, D., Dickens, R.J. & Epps, E., 1978. Ap.J., 225, 148.
Caldwell, J.A.R. & Coulson, I.M., 1985, MNRAS, in press.
Christian, C.A., Adams, M., Barnes, J.V., Butcher, H., Hayes, D.S., Mould, J.R. & Siegel, M., 1985. PASP, 97, 363.
Cousins, A.J., 1984. SAAO Circ., No. 8, p 69.
Cousins, A.J., 1985. MNASSA, 44, 54.
Djorgovski, S., 1984. Proc. NASA/SDSU Workshop on Improvements to Photometry, ed W. Borucki & A. Young, publ. NASA, p152.
Feast, M.W., 1985. Mem. Soc. ast. Ital., 56, 213.
Freeman, K.C. & Rodgers A.W., 1975. Ap.J., 201, L71.
Gaposchkin,S.I., 1956, Variable stars, 11, 268.
Graham, J.A., 1982. PASP, 94, 244.
Harris, W.E. & Hesser, J.E., 1984. IAU Symposium No. 113, ed. J. Goodman & P. Hut, publ. Reidel:Dordrecht, p 81.
Hartwick, F.D.A., Hesser J.E. & Hill, G., 1972. Ap.J., 174, 573.
Innes, R.K.A., 1927. Southern Double Star Catalogue, publ. Union Observatory:Johannesburg.
Jacoby, G., Howell, S. & Junkkarinen, V., 1985. NOAO Newsletter, 2, 16.
Landolt, A.U., 1973. A.J., 78, 959.
Landolt, A.U., 1983. A.J., 88, 439.
Lugger, P.M., Cohn, H. & Grindlay, J.E., 1985. BAAS., 17, 602.
Lynds, B.T. & O'Neil, E.J., 1985. BAAS, 17, 596.
Martin, W., Warren, P.R & Feast, M.W., 1979. MNRAS, 188, 139.
Melnick, J., 1985. A.Ap., in press.
Menzies J.W., Banfield, R.M. & Laing, J.D., 1980. SAAO Circ. No 5, p 149.
Menzies, J.W. & Laing, J.D., 1985. MNRAS, submitted.
Olszewski, E.W. & Aaronson, M., 1985. Steward Obs. preprint no. 589.
Penny, A.J., 1984. Gemini, 12, 1.
Rodgers, A.W. & Harding, P., 1983. PASP., 95, 979.
Sandage, A., 1981. Ap.J., 248, 161.
Schild, R.E., 1983. PASP, 95, 1021.
Shobbrook, R.R., 1983a. MNRAS., 205, 1215.
Shobbrook, R.R., 1983b. MNRAS., 205, 1229.
Shobbrook, R.R., 1984. MNRAS., 206, 273.
Stobie, R.S., Sagar, R., Gilmore, G., 1985. A.Ap.Supp., 60, 503.
van den Bergh, S, 1971. A.J., 76, 1082.
Walborn, N.R., 1986. IAU Symposium No. 116, publ Reidel:Dordrecht,
Walker, A.R., 1984a. MNRAS, 209,83.
Walker, A.R., 1984b. Proc. NASA/SDSU Workshop on Improvements in Photometry, ed W. Borucki & A. Young, publ. NASA, p. 177.
Walker, A.R. & O'Donoghue, D.E., 1984. Astron. Express, 1, 45.
Walker, A.R. & Mack, P., 1985. MNRAS, submitted.
Weigelt, G. & Baier, G., 1985. A. Ap., in press.

DISCUSSION

White: A CCD could be used for lunar occultation observations of bright stars. The light is dispersed along one row. The rest of the rows serve as a buffer. The total observation consists of filling up the CCD buffer with spectra detected on the 'top' row. Clocking down a row at about 100 to 200 Hz would give sufficient time resolution.

Has a Fabry lens been applied to CCD photometry? A stationary, standard, image on the CCD could reduce reduction time by simplification of the algorithm and reduce some sources of systematic errors. As CCD dimensions increase, use of a Fabry lens may be practical for even relatively densely populated star fields.

A.R. Walker: Not that I know of.

Mochnacki: The trailed images you showed on the overhead need not in fact be elongated: Boroson and Shectman, for example, drift scan images over the CCD, reading it out at the same rate as the images drift over the CCD. This takes out a lot of the flat fielding errors.

Jacoby: With regard to scanning a CCD to improve flat fielding, two problems limit the use for photometry. 1) Clouds will affect the sky brightness, so that each row read from the chip will have different sky levels. 2) Any seeing variations affect the profile of each star differently. Both effects complicate photometric reductions.

Schober: A useful technique is to integrate at the telescope on only those stars (5-10) for which you want magnitudes. (You don't read out the whole chip). One can get differential magnitudes with respect to some reference stars. Not so much data has to be stored but good results can be obtained, with an uncertainty of a few thousandths of a magnitude.

A.R. Walker: You need good computing power <u>at</u> the telescope.

Ables: You showed errors in V and B-V photometry. The errors in B-V were equal to and often less than those in V. How did you accomplish this?

A.R. Walker: The contribution of photon statistics to the errors in Table II are only a minor component. It is likely that other sources of error (perhaps flat fielding) systematically affect the magnitudes as a function of position on the frame but have less effect on the colours.

Evans: What is your experience with the seeing at Sutherland?

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Walker: Not often better than 1 arcsec, but usually between 1½ - 2 arcsecs.

Phillips: Have you written your own software or do you use that of others?

A.R. Walker: For the image processing part we are using STARLINK software. Then I use my own photometry program.

Millis: How much more costly in astronomer and computer time is the reduction of CCD photometry in comparison with the reduction of conventional photoelectric photometry?

Walker: For a one week observing run one can expect to take at least this amount of time reducing the data. This lower limit applies to extracting magnitudes of only a few (~5) stars per frame in uncrowded fields. Globular cluster magnitudes would take much longer.