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OPTICAL ASTRONOMY AT THE MONASH OBSERVATORY

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I. INTRODUCTION

The optical astronomy group in the Department of Physics, Monash University, consists now of two members of the academic staff together with varying numbers of graduate students (usually 1 or 2) and undergraduate students in the fourth year of a B.Sc. degree (usually 1). We have the occasional assistance of other undergraduate students carrying out minor projects in astronomy. For the first few years of its existence (until about 1975) the group had one staff member, a part-time M.Sc. student and an Honors student.

While we were setting up the observatory almost ab initio we made some mistakes; as we were newcomers to the field this was perhaps only to be expected. We also got some things right. Other people setting out on a similar project may be able to profit from our experiences, so in the account of our work we will try to point out the lessons that we think are to be learned.

II. THE FIRST MONASH TELESCOPE

In the late 1960's (when Monash University was about 8 years old) there was sufficient interest in astronomy among some senior members of staff, particularly Professors Street and Westfold, for the Vice Chancellor to be persuaded to fund the purchase of a 16-inch telescope from the widow of Mr. L. Jeffree, who had not been able to complete the telescope before he died. The telescope was an f/7.35 Newtonian, on a German equatorial mounting, with a falling-weight drive. The tube was of solid wood, with the Newtonian secondary mounted in a steel rotatable turret to maintain access to the Newtonian focus for all positions of the telescope. The 16-inch mirror was of plate glass, purchased by Jeffree from Paris in 1930 or 1931. A photograph of the telescope just before we purchased it is shown in Figure 1.

Workshops in the Departments of Physics and Electrical Engineering upgraded the mirror cell and other mechanical

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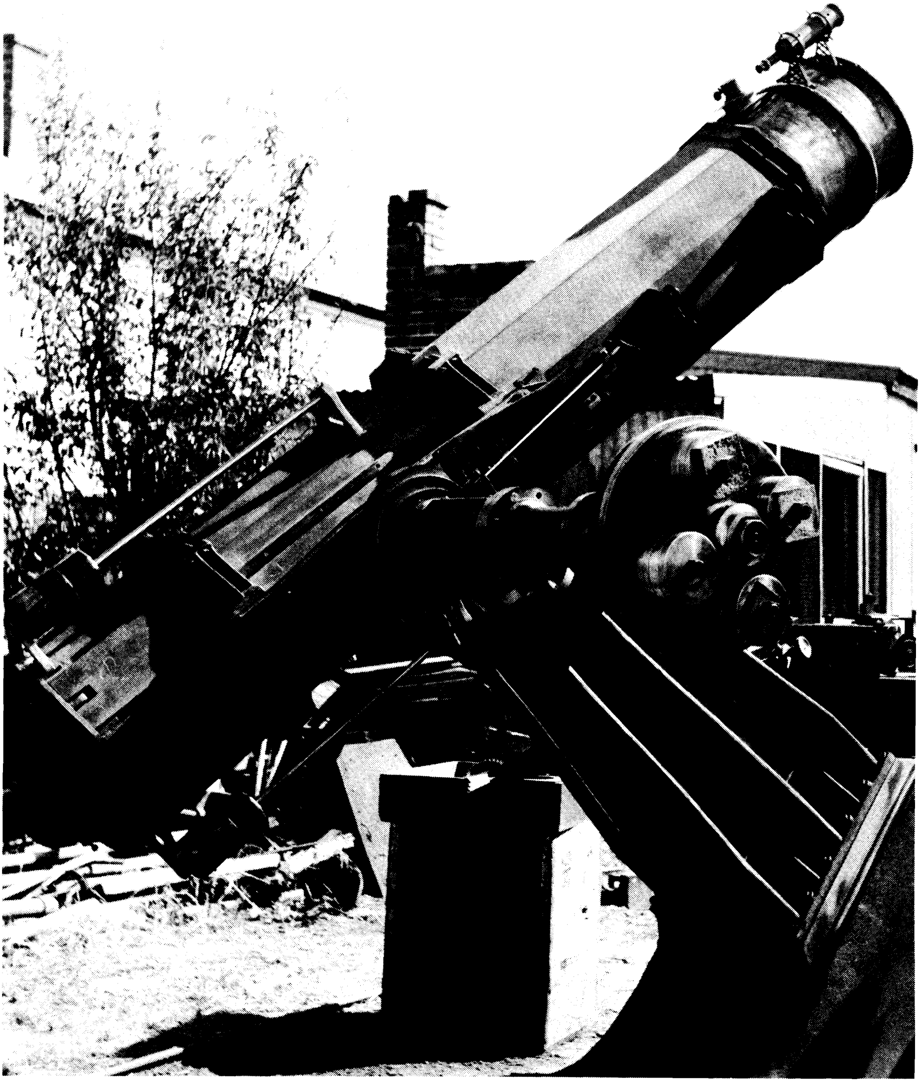

Fig 1. The 16-inch telescope as it was purchased by Monash University.

parts of the telescope, and also made a variable frequency oscillator driving a synchronous motor to replace the falling-weight system. Mr. W.E. James of Melbourne, a well known Australian optical craftsman, figured the primary mirror to $\lambda/8$ precision and also manufactured a secondary flat. When the completed telescope was tested mechanically, a periodic error in the drive of about 8 seconds of an arc was detected. This was traced to the final worm and wheel of the gear train. By a lapping process this periodic error was reduced to a total of about 3 seconds. For subsequent photometric work this residual error has proved to be no problem at all.

An omission at this time, which we have since rectified, was not to have electrically driven slewing and slow motion in declination or slewing in hour angle. We now know that it is very important in photometric work to have electrical slewing and slow motion in both declination and right ascension, and that these motions should be controllable by the observer at the eyepiece.

III. CHOOSING A SITE FOR THE TELESCOPE

Astronomers at the University of Tasmania advised us against our initial plan to set up the telescope on the campus of Monash University, which is in a fairly industrialized suburb about 12 miles from the center of Melbourne, whose population is now some 2.5 million. We were urged to make full use of the potential of the instrument by setting it up at a site further from the city. This advice was heeded, and we finally decided on a position 25 miles east of the University and 40 miles from the city center.

Our criteria for a site were based on meteorological factors (mainly to be above the inversion level on a typical clear night, to avoid fog and other sky pollution), the availability of electrical power, security against vandalism, but above all ease of access from the University. We think that this last point is vital: there is no value in elaborate site-testing for seeing quality and number of clear nights if the site for a small observatory is so remote that observers cannot easily get there. In our case there was a clear choice: we could build the observatory north of Victoria's Great Dividing Range where the rain shadow effect produces 30-60% clear nights, or we could build nearby, not far from the coast, and accept an average of three or four clear nights a month. The first choice would involve 2-3 hours travel each way, the second choice no more than 40 minutes. Unless one can afford to build permanent, comfortable accommodation for observers, who themselves can afford the time to stay for several days at the observatory, then the clear nights at a remote site are attractive but unusable. We have never regretted building only 25 miles from Monash. At a height of 1000 feet we are above the inversion layer on most clear nights; it was worth taking advice from the Bureau of Meteorology on this point. We are close to farm houses, which affords security, particularly as we try to be good neighbours and are on friendly terms with the local community. Finally, we can make use of almost every clear night. For a small group like ours to have 40-50 photometric nights per year to ourselves is quite a luxury.

Incidentally, we have now come across quite a few of Eastern Australia's nocturnal fauna on the drives to and from the observatory. Rabbits, foxes, kangaroos, wombats, opossums, horses and wallabies have all appeared in our headlights at one time or another. On daytime visits we have seen the graceful wedge-tailed eagle soaring overhead. One night the dome resounded to the impacts of suicidal locusts, part of a plague which reached Melbourne that year; in another year it was a plague of Bogong moths, a large variety, which were once a succulent part of the diet of the local aborigines.

The lights and slight smog of Melbourne, some 40 miles to our west, rarely trouble us. To the south, east and north we usually have good dark skies. Extinction coefficients in the V and B bands are typically 0.18 to 0.22 and 0.3 to 0.35 respectively, and although the sky brightness does change quickly at times, we find that rapid cycling between stars largely offsets this problem.

IV. THE OBSERVATORY

Before drawing up a design, we looked at domed observatories housing comparable telescopes in Melbourne and in Tasmania. The lessons we learned were that there should be ample space in the dome and plenty of head room in the ground floor if we decided to have one. We were also warned about the problem of keeping the dome's base circular and horizontal so that it always rotated smoothly.

We opted for a cylindrical building 20 feet in diameter, with two floors. The dome has a fibre glass skin on a steel frame and a substantial steel base. It is rotated by hand and has always moved fairly freely during its 12 year life, but does need occasional adjustment to keep the base horizontal. The walls of the main building are of double brick which provides enough thermal mass to keep the interior cool in the summer when outside temperatures may exceed 100° F. The telescope's base rests on a substantial concrete pier which is founded some 3 feet below ground. Fortunately we were able to consult soil experts in the University's Department of Civil Engineering about building this pier, which has given the telescope essentially vibration-free support. The observing floor is of wood, isolated from the pier, with a trap door for access from the ground floor. To ecable us to bring up bulky equipment the trap door's opening can be extended to 4 feet square. We can handle heavy equipment using a block and tackle atteched to the dome if needed.

The design features (which in retrospect we think that we did right) are the ample space, the many power outlets, the solid support for the telescope, the means of handling heavy equipment and the reasonably reliable dome rotation mechanism. We had to build a large stand on castors, known semi affectionately a "Big Bertha", to give access to the Newtonian focus, which can reach some 12 feet above the floor. The size of the dome lets us manoeuvre this cumbersone stand without much problem. Power outlets seem always to be in demand, for electronics, drive motors, lamps, calculators and computers. One should never underestimate the need for them.

An additional benefit is that the building is well sealed against dust (and agricultural chemical sprays!); all the masonry walls are sealed by painting and the floors are vinyl tiled to minimise airborne dust.

The main thing we did wrong was to make the dome's slit too narrow. Our site is somewhat exposed and windy, so the narrowest usable slit is called for, but at 30 inches for a 16-inch telescope we made ours too small for convenience. We are in the process of widening the slit to 60 inches, at the same time as the 16-inch telescope is being replaced by a new 18-inch. Also, rather than the previous up-and-over mechanism we are fitting slit doors which open sideways.

V. CHOOSING OBSERVING PROGRAMS

Because we were new to astronomy, it took us some time to realize the advantages and limitations of the telescope we had acquired. From experience, the limitations of small light grasp and relatively unsophisticated drive and controls for the telescope are offset by the advantage of being able to dedicate the observatory to a very thorough study of a few stars over a long time. This advantage is not usually available to a large observatory, where because of competition for observing time a particular research group cannot concentrate its efforts in this way. As we shall describe later, our thorough study of one particular star, SX Phe, bore fruit despite the use of only simple techniques. However as some sort of object lesson we shall first describe some of the dead ends we went down.

VI. SPECTROSCOPY AND THE FIRST PHOTOMETER

Our efforts here illustrate the problems of equipment which is unreliable because it is too complex. In the case of the spectrograph there is the additional limitation of only being able to observe the very brightest stars.

We modified the optics of the telescope by adding an ellipsoidal mirror and by making use of the rotatable turret to swing an f/18 beam either into a spectrograph or to a photometer. The initial small light grasp, plus losses at the extra reflections needed to produce this beam, together with the reflections in the spectrograph itself (which was of fairly high dispersion) limited its use to the very brightest stars. It could have done useful work on these, but the problems of keeping all the mirrors in alignment proved insurmountable, partly because of the expansion, shrinking and warping of the telescope's wooden tube as the temperature and humidity changed.

The photometer's main problem was that we employed the system from a domestic refrigerator to cool the photomultiplier. It proved impossible to keep water out of the system, so that the capillary tubes quickly became blocked with ice.

After about a year we dispensed with the f/18 beam and associated instruments altogether, salvaging all of the parts for use in teaching or in subsequent research projects.

VII. PHOTOGRAPHIC PHOTOMETRY AND THE 2ND PHOTOMETER

It was an attractive idea to carry out photographic photometry because we could gather data (albeit of intrinsically low precision) about many stars at once, thus compensating for the relative lack of clear nights at our disposal. We were also advised that several quasars within the range of our telescope were interesting variables, and that a program of photographic photometry was worth while. So we pursued this idea, while at the same time building a photoelectric photometer head with an uncooled 1P21, for use at the Newtonian focus. The photometer is based on the design given in the "Manual for Astronomical Photoelectric Photometry" published by the A.A.V.S.O.

The photographic work never started because a visit by one of us (D. Coates) to the Royal Greenwich Observatory at Herstmonceux in 1975 convinced us that costly improvements were needed in the telescope's tracking and guiding to ensure the perfectly circular images needed for good photographic photometry. Also it was realized that a sufficiently accurate iris photometer to measure the plates would be beyond our resources to buy or make ourselves.

In this way, photoelectric photometry became our sole interest. The uncooled photometer head was completed with a d.c. amplifier, and a chart recorder was purchased. A photograph of the photometer is shown in Figure 2. This was used for some seven years, yielding differential magnitudes to a precision of better than $0\overset{m}{.}007$.

We were ready to work seriously on stars brighter than about the eleventh magnitude.

VIII. STUDIES OF VARIABLE STARS

Influenced by publications such as those of the A.A.V.S.O., and F.B. Wood's "Photoelectric Photometry for Amateurs" we saw the merits of working on variable stars. Observatories like ours had clearly begun to contribute to this field, and we felt that we could do the same. It seemed that we could best follow in detail the behaviour of a small selection of short period variables, preferably ones about which astrophysical questions remained unanswered. By observing short period stars we could perhaps obtain several cycles of the light curve in one night's observing.

The first star of this kind we observed was SX Phe. It is pulsating at its fundamental and first overtone frequencies, with a fundamental period of about 80 minutes. There were (and remain) problems about the nature of this star, in particular about its evolutionary status. From a practical view-point SX Phe is bright and has a large light range, varying between about magnitudes 6.8 and 7.5 in V, so that it is easily measurable. Also, the star passes almost over our zenith and so can be observed through small air masses.

After calibrating our photometer in the usual way, we began observing SX Phe in the B and V bands. We measured a nearby comparison star at intervals of about an hour and also measured the sky background at similar intervals. It soon became clear that this technique, with filter changes every few minutes, was not suitable for determining accurate times of maximum light. After each filter change, the signal recovered slowly, because of the need to use a time constant of several seconds. We did gain useful results, but decided to concentrate on obtaining accurate times of maximum light in order to follow up detailed work done by earlier workers such as E.W. Elst. Subsequent measurements were made in V only, remaining always on SX Phe, with occasional readings of the sky. This enabled us to measure times of maximum light accurate to about 1 minute.

Previous workers had gathered much spectroscopic and photometric data about this star since its variability was discovered by Eggen (1952); in particular we were able to find 267 existing times of maximum light. Our aim was to search for changes in the periods of SX Phe by combining the existing data with those we were accumulating. Attempts by previous workers to find changes in the periods had not been conclusive. We were in fact able to find clear evidence of changes and to calculate quantitative values. This work was published in two papers in Monthly Notices of the Royal Astronomical Society (Coates et al, 1979a and 1982a) and two Information Bulletins on Variable Stars (Coates et al, 1979b and 1980a).

We still cannot decide whether a discrete change in both the fundamental and first overtone periods occurred at about 1960, or if the periods have been changing continuously since the star has been under observation. It may never be possible to reach a final conclusion on this, but we are continuing to measure a few times of maximum light each year to help resolve the problem of how the periods are varying.

As Percy, et al (1978) point out, this sort of project is a good one because with very simple equipment and observing techniques one can obtain results, which though on their own are of little value, when added to the body of data about a pulsating variable, particularly a dwarf Cepheid, do have significance. While we were carrying out the project we learned much about our equipment and about astronomy in general. In between measurements on SX Phe we began to observe other pulsating variables and to refine our observing methods. Soon we were ready to tackle more demanding tasks.

These came with the acquiring of Weiler and Stencel's (1979) list of Southern RS CVn candidates and we were soon organizing ourselves for a program to work through tha beginning with the most likely bright candidates with strong H and K emission. The areas were photographed and the stars identified in Becvar's "Atlas Australis" and suitable finder charts were drawn up. The first observations were towards the end of 1979, but we did not at that time have a proper appreciation of the way comparison stars should be incorporated in the observing sequence, and so although the observations on HD 5303 came at an interesting time, we have never felt free to use them. HD 5303 and HD 174429, observed early in our program have proved to be two of the more interesting stars that we have studied.

Soon afterwards we started to observe known and candidate Ultra Short Period Cepheids (USPC's), and these two programs form most of our observing effort from 1979 to the end of 1983.

Before describing our observing techniques and some of the more significant results we have obtained, we will describe in some detail the equipment for the two telescopes of the Monash Observatory.

IX. EQUIPMENT FOR THE 16-INCH TELESCOPE

The photometer (Figure 2) in use up to recently on the 16-inch telescope was mounted at the Newtonian focus. The field eyepiece of this photometer has a field of view of about 20 arc minutes in diameter. Three apertures are available of approximately 35, 70, and 140 arc seconds diameter. Generally, the 70 arc second aperture was used. U, B and V filters were initially obtained, but problems with the U filter resulted in measurements being made only in B and V for most of the photometer's working life. The photomultiplier tube is an RCA 1P21, used uncooled in a d.c. mode.

At first all of the associated electronics were housed downstairs, with the high tension and signal leads to and from the photometer attached to the telescope tube and running along the side of the concrete pier. The exception was the variable frequency oscillator which drives a synchronous a.c. motor providing tracking at the sidereal rate. This is located upstairs on the mount itself.

Again, until the end of 1982, the only electrically controlled motion (other than tracking) was slow motion in hour angle. All other slow motions and slewing were carried out manually. The slow motion in declination was via a flexible shaft accessible to an observer at the eyepiece. The lack of electrical controls made the instrument somewhat unwieldy and slow to use.

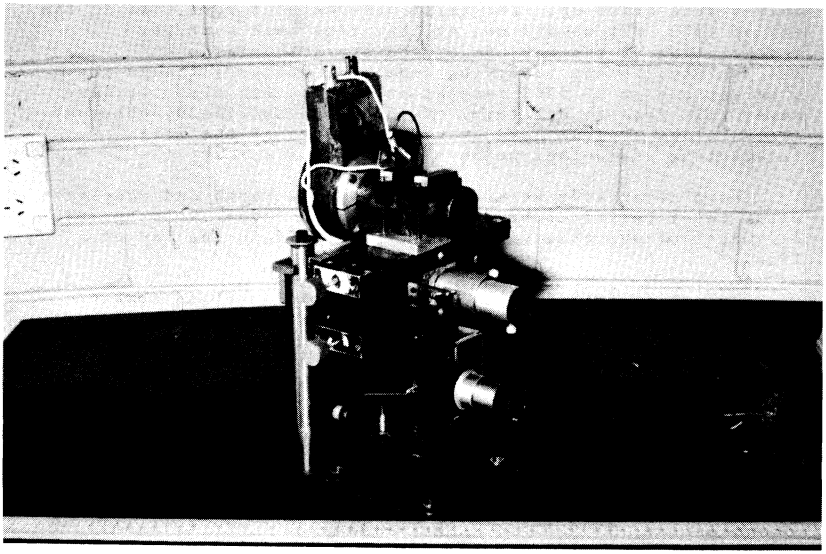

Fig. 2. The second photometer used on the 16-inch. Apertures and filters are carried on slides operated by the knobs at the left. There is a microscope (center) for viewing the star in the aperture, and a field eyepiece below it.

To overcome this problem, small reversible synchronous motors were attached to the R.A. and declination adjustment worms (Moon, 1983). The motors on the R.A. worm provide a "fast" setting speed, while finer setting is achieved by altering the frequency of the drive oscillator described previously. A set of planetary gears was attached to the bevel gears driving the declination adjustment, and two small reversible synchronous motors with appropriate gearboxes now provide "fast" and "slow" setting rates in declination. These motors are controlled by the observer at the eyepiece using a handset with four push buttons (one each for N, S, E and W), and a central toggle switch for selecting "fast" or "slow". Providing motors for the fine controls has made telescope operation much easier and quicker, and it is possible for one person to operate it, although it is more convenient if two are present.

The uncooled 1P21 photomultiplier is run from a high voltage supply at -970 volts. The output current is fed into a d.c. amplifier and integrator. The high voltage supply is a commercial unit, while the d.c. amplifier was built in the Department of Physics Electronics workshop using standard circuits. The gain of the d.c. amplifier is adjustable by selecting one of four feedback resistors.

Until the end of 1982, data logging was by chart recorder only. Voltage to frequency conversion techniques were investigated (particularly for the 10-inch telescope described below), but these were not implemented. The star observed, filter used, chart scale and observing conditions were all noted by hand on the chart.

Towards the end of 1982, a microcomputer-based data logger was installed at the observatory (Innis, 1982). This uses a SYNERTEK SYM-1 microcomputer to record the star, filter, time and voltage for each observation. The star and filter codes are typed in by the observer in response to software prompts. Once the integration is started by the observer, a real time clock is read, then a digital voltmeter is read once a second for a specified time. At the end of the integration the star, filter, time and sum of the readiings is printed on a hardcopy device.

This system is run in parallel with the chart recorder, but after the initial testing the chart is now no longer processed, as the computer print out is much more convenient. The chart is now used as a log of the night's observations, as well as a quick means of detecting clouds, which is easier to pick up on the permanent pen trace than on the fluctuating numerical voltage displayed on the digital voltmeter.

The data logging system is an improvement on the chart alone, but still seems to us to be far from ideal. This is mainly for two reasons. One is that at present all input and output is by a keyboard/printer unit. This means that, unless we wish to produce large quantities of printed output each night, we must limit the number of prompts, status messages and the like produced for each observation. In fact the present system writes only one line of printed output per observation. This in turn immediately places limits on the flexibility of the data collection program, because it is not easy to present the user with a number of options and still keep within the constraints discussed above. The second point is that the software is written in 6502 machine language, which means that it cannot readily be understood or modified by the general user. Also any mathematical task beyond simple addition and subtraction is not really practical.

To overcome these problems we are currently providing a video output using a SYNERTEK Keyboard Terminal Module, and rewriting the software in BASIC, also from SYNERTEK, which will call the machine language routines stored in EPROM to read the real time clock and the digital voltmeter (Figure 3). This should enable considerably more flexible and accessible data collection software to be devised and run.

Even with these changes the SYM system will still be very limited in its applications. However it is only intended for data logging during an observing session. Any numerical calculations required during the night (eg. sidereal time, sec z) are performed using programs read into a TI-59 calculator from magnetic cards. All data reduction and subsequent analysis is performed on the University Burroughs or VAX mainframe computers located on campus, so that the lack of computing power at the observatory itself, while regretted at times, does not present any serious difficulties to us.

A general view of the telescope as it was just prior to decommissioning in January, 1984 appears in Figure 4.

X. THE 10-INCH TELESCOPE

A second-hand 10-inch Newtonian reflector was purchased in 1979 as a teaching instrument. Subsequently a commercial photometer for this telescope was obtained, enabling measurements to be made on the brighter variable stars both for research and teaching of undergraduate students.

The telescope and mount as originally purchased were not of sufficient quality for photoelectric photometry, and a major redesign was undertaken (Moon, 1983). A small shed with a roll-off roof and concrete floor was constructed at the observatory (see Figure 5), known as the "chook house" (Australian for chicken coop), in which the telescope is housed. The original tripod was replaced by a 5 inch diameter steel pipe bent to point at the south celestial pole. This bent pipe is in turn attached to another piece sunk into the concrete floor. At the join there are fine adjustments for precise alignment with the south celestial pole (SCP).

The internal diameter of the original tube was only 10 inches, the same as the diameter of the mirror, thus vignetting occured. A section of strengthened galvanized drainpipe with an internal diameter of 12 inches was used instead. The original primary mirror and cell, and diagonal support were retained, but a new oversize diagonal was purchased and mounted closer to the primary mirror. This was done to enable us to place the aperture plane of the

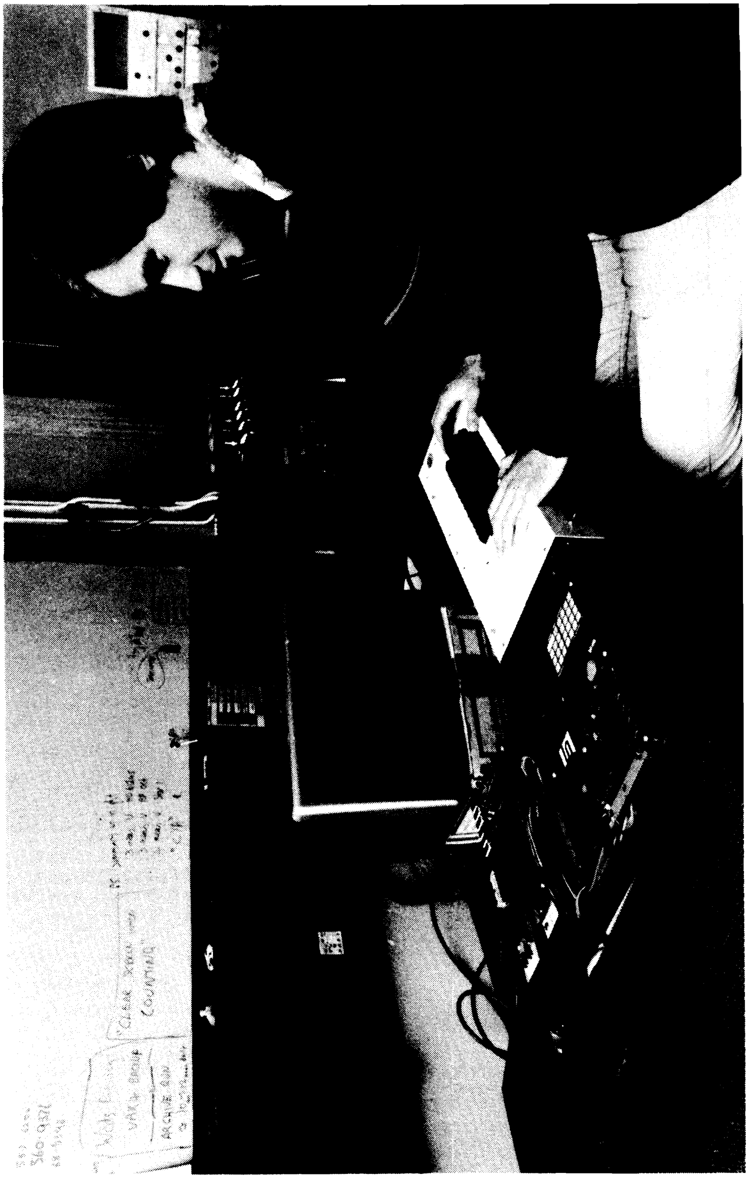

Fig. 3. John Innis with the data logger. The digital voltmeter and the SYM-1 microcomputer are on the left.

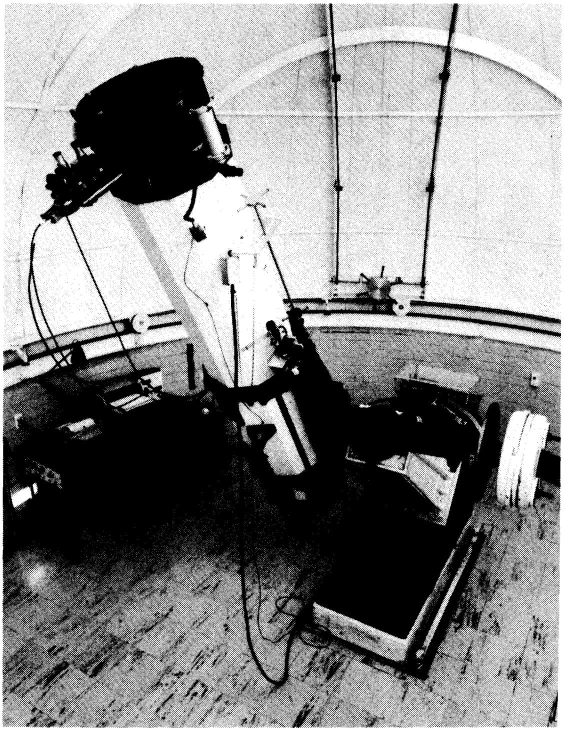

Fig. 4. The 16-inch telescope and photometer just before they were de-commissioned late in 1983. The digital panel meter, printer, chart recorder, and observatory clock are on the bench at left.

Fig. 5. The 10-inch telescope in its shed at the Monash Observatory.

photometer conveniently at the focal plane of the telescope.

The telescope's slow motion controls were originally flexible cables attached to the R.A. and declination worms, and were adjusted manually. However, as on the 16-inch telescope, they could not be reached by an observer at the eyepiece. Small motors were installed to replace these manual adjustments, controlled by a handset similar to that described above for the 16-inch telescope's motor design.

The polar axis was aligned to the SCP approximately at first and then more precisely using a photographic method to determine the pole of the telescope's axis on the celestial sphere. The corrections required in altitude and azimuth were then easily calculated.

The alignment is now satisfactory for photometry, although there is a small residual drift in declination for stars culminating. We can track an equatorial star in a 90 arc second aperture long enough to measure it photometrically. At more southerly declinations (where we normally work) the tracking errors are not as apparent and smaller apertures can be used.

The commercial photometer used with the 10-inch telescope was also fairly extensively modified (Moon, 1983). The unit as supplied did not have an aperture viewer, to check that the star is central and focussed. A reticle with engraved circles to represent the various aperture sizes was provided for the field eyepiece. However, the engraved circles were not optically aligned with the apertures. Adjustment proved difficult to maintain as this was performed using three screws attached to the mounting plate of the flip mirror, all of which were virtually inaccessible when the photometer was mounted on the telescope.

The reticle was not set at the focal plane of the field eyepiece but was cemented into the body of the photometer. This meant that stars could be in focus in the aperture plane and in the eyepiece but that the reticle could be out of focus. The reticle was removed and placed in the focal plane of the eyepiece.

A 10 X pocket microscope was purchased for a few dollars and placed behind the aperture wheel. A small flip mirror was installed so that the apertures could be viewed with this microscope. A 6-V bulb with a rheostat adjustment was positioned to illuminate the front of the aperture, while a microswitch attached to this flip mirror ensures that this lamp is switched off when measurements are made.

The Fabry lens provided was of the wrong focal length and diameter for the focal ratio of the 10-inch telescope. A larger mounting port was made for a suitable Fabry lens.

As supplied, photomultiplier tube housings incorporating a dark slide were attached to the photometer with three screws. This was modified to a quick release "bayonet" fitting of three studs and two suitcase type catches. This bayonet fitting enables tube housings to be replaced in less than a minute. In addition to the side entry housing which came with the unit, an end entry housing was constructed, which will also fit the bayonet mounting.

The original filter wheel had only four positions. This was replaced with a six position wheel, which currently are U, B, V, R, I and clear.

Finally the photometer was mounted on a camera rack and pinion focussing mechanism which could be locked in position when focussed. This mechanism was attached to a plate machined to fit the mounting plate on the 10-inch telescope. The photometer is illustrated in Figure 6.

We chose the roll-off roof shed rather than a dome for the usual reasons of saving money and for ease of construction. However, if we were setting this telescope up again, we would almost certainly place it in a dome. There are several reasons for this, but probably the most significant is observer comfort. Even though the night temperature in Melbourne only very rarely falls below freezing (on one or two nights a year), working a whole night on a 10-inch telescope in the cold and damp is much more fatiguing than a night in the dome on the 16-inch. On the coldest nights one makes frequent trips to the heater in the ground floor of the dome.

We also have heavy dews on many nights. While the dome offers excellent protection for the 16-inch telescope, the roll off roof means the 10-inch telescope, its electronics, and observers are completely exposed. We found the secondary mirror was dewing up continually on these nights, which prevented any useful work being done. To try to overcome this the wire coil from an old rheostat was positioned around the diagonal mirror support. A small current is passed through this coil, which raises the mirror's temperature above the dewpoint. This has performed satisfactorily on even the dampest nights.

The chookhouse has also been adopted as an ideal habitat by many of the local ants, beetles, spiders, bugs and other creepy crawlies. Each observing night brings new delights, from ants' nests in the chart recorder, to earwigs on the eyepiece cross wires, to redback spiders in the high voltage supply. We believe that these spiders are known in other parts of the world as jockey spiders, or black widows. We cannot seem to seal this shed effectively from these intruders. The dome, on the other hand, seems to suffer little from this problem.

Despite these difficulties, worthwhile photometric data can be and is obtained with this telescope. The limiting magnitude in V is about eight, if we wish to measure to our usual precision. Results obatined with this telescope on the star Rho Puppis are discussed below.

XI. OBSERVING TECHNIQUES

When comparison stars were chosen in the RS CVn program

Fig. 6. Terry Moon with the commercial photometer which he modified for the 10-inch. The interchangeable tube housing, locked by luggage clasps, is clearly seen, as are the adapted pocket microscope for viewing the aperture and the focusable camera mount holding the photometer.

we used the lists by Cousins *et al* (1962, 1966) picking stars that had been measured more than once, that were close by the target star in the sky, bright, and of similar color (i.e. G or K type) to the RS CVn candidates.

This last criterion was to reduce errors in estimation of (U-B), and (B-V) although a previous calibration of our photometer had given good transformation equations between instrumental values and the Cousins system. These selection criteria have since proved to have disadvantages in that bright K type stars are quite likely to be long period variable giants; if so, they are of course unsuitable as comparison stars. Over one night's observing the variability of the comparison star may not become apparent. To get over this problem we now prefer ot select G or K main sequence stars as comparisons for the RS CVn's even though these stars tend to be faint.

The pattern adopted in 1980 and subsequently adhered to was to have at least two (and maybe three) comparison stars in the observing sequence, until such time as by mutual comparison between them we felt confident to drop one (or two). It may take several months or longer before we build up this confidence in a particular comparison star.

Having arrived at the observatory with the night's program planned, one observer will open the building to the night air to aid cooling down from day temperatures, retrieve the photometer from its large vacuum can where we store it, (we have found storing it with a dessicant under rough vacuum from a rotary pump sufficient to remove problems of condensation of moisture and leakage currents at the 1P21 photomultiplier tube), and mount it on the telescope. Meanwhile the other observer has obtained the precessed coordinates in declination and local hour angle by using a programmable calculator program fed with star's RA and declination at an epoch, the current date and local standard time.

Both telescopes can be positioned using circles to sufficient precision to place the star in the finder telescope and often within the first eyepiece of the photometer.

We then check the alignment of the finder telescope and can begin the following sequence of observations which we follow for several cycles:

comparison 1 → comparison 2 → comparison 3 (if used) → target star → comparison 1 → etc.
where the measurements for each star take the form:
star, V filter → star, B filter → sky, B filter → sky, V filter.

We always end the cycle with the comparison stars and their respective sky values unless the observing circumstances (e.g. clouds) prevent this. In this way the target star is nearly always bracketed in time by at least two comparison stars.

It is seen that this method of measuring requires more measurements to be made on the comparison stars than on the variable. This is different from the often used "comparison and check" method, in which a number of measurements of the variable are obtained relative to a smaller number of comparison star measurements, while the check star may only be measured on a very few occasions.

We believe that the method we employ has one large advantage over the other. This is that for each measurement of the variable the results yield a magnitude difference between each of the comparison stars as well as a magnitude difference between the variable and all the comparison stars. This allows us to search for variability in the comparison stars (which one hopes is not present), but mort importantly, the scatter in the measured magnitude differences between the comparison stars provides a direct and continuous estimate of the precision of the data obtained on the variable. This is in contrast to measuring a check star once a night, say at the beginning, in which case the photometric quality of the night could only be indirectly determined, from say the extinction graph obtained from the comparison star observations. We also draw attention to our frequent observations of background sky.

The principle disadvantage of the method we employ is that it takes longer to complete a cycle, and hence fewer observations of a given variable star are obtained. We find that it takes between 30 to 40 minutes to complete one cycle in two colors using three comparison stars. For most of our observing this is adequate. If a star needs to be measured more quickly than this, (such as during ingress or egress of a short period eclipsing system) then we may drop a comparison star or two from the cycle.

We have found this procedure to be well suited to our programs at Monash. We can consistently achieve a precision better than 0.007 magnitude r.m.s. (as evidenced by the scatter in our comparison star differences) on most of our observing nights. As our site is only some 1000 feet above sea level, we consider this precision to be very acceptable.

The photometer signal is recorded on a chart which we run at 5mm/minute, the chart paper having 1cm divisions. This speed gives us a convenient way of recording the times of the observations to within a fraction of a minute. As mentioned previously, we have found the chart method useful for giving a visual indication of the seeing conditions as judged by the scatter on the pen trace as the signal is recorded. We usually use a 3 second time constant on the smoothing of our signal. The chart records will show the presence of thin cloud invisible to the naked eye. Before the advent of computerized data logging, the completed chart was "read" by at least two people independently who recorded for each star the signal in volts and the time of the observation. These two records were checked for consistency and any discrepancies bigger than one or two in the third significant figure were checked back against the chart. In this way we guarded against an obvious misreading.

The 16-inch telescope's rotatable turret referred to before was not used but was locked in one of several positions for the night's observing. This sometimes meant an uncomfortable viewing position considering the height above the floor but after several failed attempts we gave up trying to keep the adjustment in line. It was possible to adjust the Newtonian flat such that the whole turret could be rotated and the star would remain visible in the photometer aperture. However after a few days the adjustment was gone. It was almost certainly due to the "solid" wooden tube changing its shape due to temperature and humidity changes.

If any doubt was felt that misalignment may cause vignetting then the star could be tracked in hour angle and also in declination across the biggest of the three apertures, and the chart traced examined to see if it had a sharp cut off as the star left the aperture. Alternatively the star could be variously positioned near the edge of the biggest aperture to check for constancy of signal. For most of our observing we have come into the habit of using the 70 arc second aperture for ease of positioning the star.

XII. DATA REDUCTION AND ANALYSIS

We reduce our photometric data using the standard methods employed for differential photometry. This is done on the University's Burroughs or VAX mainframe computers. The original programs were written by former graduate student Len Halprin. We also have reduction programs written for the Apple II computer, but these are mainly used by the undergraduate astronomy students.

Essentially, all that needs to be entered into these programs are the standard times of the observations, and the signal measured, together with the star co-ordinates and epoch.

The coordinates are precessed to the epoch of the night of the observations. Instrumental magnitudes and air masses are calculated, and the extinction coefficients as determined for the comparison stars for that night are obtained. If the stars have been observed over a reasonable range of air mass, and if the coefficients calculated for the comparison stars are in good agreement, then the average of the extinction coefficients found are used. Otherwise the long term site values of $K_v = 0.22$, and $K_b = 0.33$ are used.

The comparison star instrumental magnitudes are interpolated or, if necessary, extrapolated (but we treat extrapolated results with caution) to the times of observation of the variable. The instrumental magnitudes are corrected for extinction, then the magnitude differences between the variable and the comparison stars, and the differences between the comparison stars themselves, are calculated. The scatter in the measured differences between the comparison indicates the precision in the measurements of the variable, and thus also provides a measure of the photometric quality of the night. A very good night at our site may give an r.m.s. deviation in the comparison star differences as low as 0.002 magnitudes.

Finally, the heliocentric Julian dates of the observations are calculated, and the results printed in tabular form. Transformation to the Johnson system is performed with a programmable calculator afterwards. The typical transformation equations for the 1P21 and Schott filters used on the 16-inch telescope are (e.g. Robinson, 1977; Moon, 1983):

$$V = v + (0.009 \pm 0.006)(B-V) + (\text{constant} \pm 0.005)$$

$$B-V = (0.991 \pm 0.018)(b-v) + (\text{constant} \pm 0.008)$$

Subsequent analysis is of course dependent on the type of star observed, and what aspects of it we are investigating. For example, an eclipsing binary would probably be analyzed with a package such as EBOP (Etzel, 1980), as in the case of HD 5303 described below. However, one of our more frequently used data analysis programs is an internally written discrete Fourier transform package (Halprin, 1983), which is able to search for and identify the dominant frequencies in a given data set. This package is often used to help determine the period of a new variable star, or in a detailed analysis of the frequencies of pulsation of stars of the USPC class, as will be discussed later.

XIII. INVOLVEMENT OF UNDERGRADUATE STUDENTS

As mentioned earlier, we occasionally are assisted by undergraduate students who are working on a project in astronomy. These students are often studying a course in astronomy at second year level. Although the course is introductory (the prescribed text is "University Astronomy" by Pasachoff and Kutner), most of the students are studying physics, chemistry or mathematics in second year, and some have done and astronomy option as part of their final year at school. In our undergraduate course the students have a chance to carry out a project involving some 36 hours over twelve weeks in the second half of the academic year. Naturally we try to match a project to the individual's interests and abilities. We feel that the students gain from the experience of gathering and processing their own data, and are enthused by working in a research environment. We ourselves also gain from the students' assistance.

Among the projects relating to photometry carried out by students have been:
(i) Refinement of the frequencies of pulsation of Delta Scuti. The student (Mark Winsall) took part in observing the star and carried out the computer analysis himself. The results were significant enough to be published in an I.B.V.S. (Number 2238).

(ii) Times of maxima of SX Phe. In 1983, Steven Rawlings measured several times of maximum light and compared the results with those expected from our earlier papers on this topic. When more data gave been taken over the next few years they will all go into a publication.

(iii) Photometry of RS CVn Stars. Salvina Failla took part in several observing sessions and subsequently wrote a good review about photometric techniques and RS CVn stars.

(iv) Computer programs for reduction of photometric data. Robert Stainsby wrote programs for an Apple II which are accurate, well documented, and easy to use.

(v) Fourier analysis of variable star data. A computer program (again for the Apple) was written by Mark Hulme to estimate the pulsation frequencies of USPC's using data taken at the Monash Observatory.

XIV. SOME TYPICAL RESULTS

The following sections outline some of our recent results on a number of stars on our observing programs. Most of the observations have been obtained using the 16-inch telescope at the Monash Observatory, although since 1981 we have also been using the 16 and 24 inch telescopes of the Australian National University at Siding Spring Observatory, some 600 miles to the north of Melbourne at what is one of Australia's best obseving sites. Since 1983 we have also been making spectroscopic observations using the 40-inch at Siding Spring and the 74-inch at Mt. Stromlo, again using the equipment of the Australian National University. These spectroscopic observations are briefly discussed in two of the following sections.

Also included is a section on the star Rho Puppis, based on data obtained with the 10-inch Monash telescope.

XV. RESULTS FOR TWO ULTRA SHORT PERIOD CEPHEIDS

From 1981 to 1983 a project was undertaken to study Ultra Short Period Cepheids (USPC's) which had previously been little observed, and also to search for new stars of this type. The main intention was to define more closely the area in the Hertzsprung-Russell diagram occupied by the USPC's, in order to set precise boundary conditions for the theory. Another idea was to study the variability of particular USPC's in great detail to find the pulsation modes present and to see if each mode's contribution to the light curve remained constant.

This project is probably a little too ambitious for small telescopes at a mediocre site, mainly because you need several long cloudless nights in succession to collect enough data to accurately define the pulsation frequencies of these low amplitude variables. Nevertheless, using the telescopes at our disposal we did make a contribution to this field.

Among the stars studied were δ Scuti, σ Oct, B Oct, BP Oct, and S Eri. The program stars in Octans, near the south celestial pole, are of course observable all the year from the Monash Observatory at 38° S through an essentially constant air mass. Preliminary publications of this work are in I.B.V.S. numbers 2047, 2093, 2145, 2223, 2238, 2383 and 2394, and more complete papers are in preparation. A paper containing a revised list of USPC's has already appeared in Astrophysics and Space Science (Halprin and Moon, 1983).

We will describe here as particular examples the studies made of σ Oct and B Oct since they show, among other things, that it is possible to measure variations with amplitude 0.005 magnitude (total range 0.01 magnitude) using an uncooled 1P21 on a 16-inch telescope.

Sigma Octantis

This A7n star (=HR 7228 = HD 177482) was first recognized as a USPC by McInally and Austin (1978). We observed it in V on July 17 and 19, 1981 using the 16-inch telescope at the Monash Observatory. The comparison star was o Octantis (= DM -89 1 = SAO 258218) which proved constant in light over the two nights. Octantis varied with a period of 0.097 days and a visual light range, V, of 0.025 magnitude. No other period could be detected. These results are similar to those of McInally and Austin, who found a period of 0.100 days and a visual light range of 0.03 magnitude.

Figure 7 shows the data and the reconstructed light curve from Fourier analysis of these data. Our results show that σ Octantis is a δ Scuti star pulsating in the fundamental radial mode only.

B Octantis

This star (= HR 8294 = HR 206553) was also first reported to be a USPC by McInally and Austin (1978).

On the basis of two nights' observations they found a period of 0.064 days and a visual light range of 0.010 magnitude. They also indicated that the light curve was highly variable.

Using the 16-inch telescope at the Monash Observatory B Octantis was observed on July 17 and 19, 1981 in the V band, again with o Octantis as the comparison star. Fourier analysis of the data revealed a period of 0.063 days and a light range of 0.010 magnitude, in excellent agreement with the results of McInally and Austin. However another period of 0.143 days was detected with a visual light range of 0.014 magnitude. Figure 8a shows the data and a light curve reconstructed from the Fourier analysis.

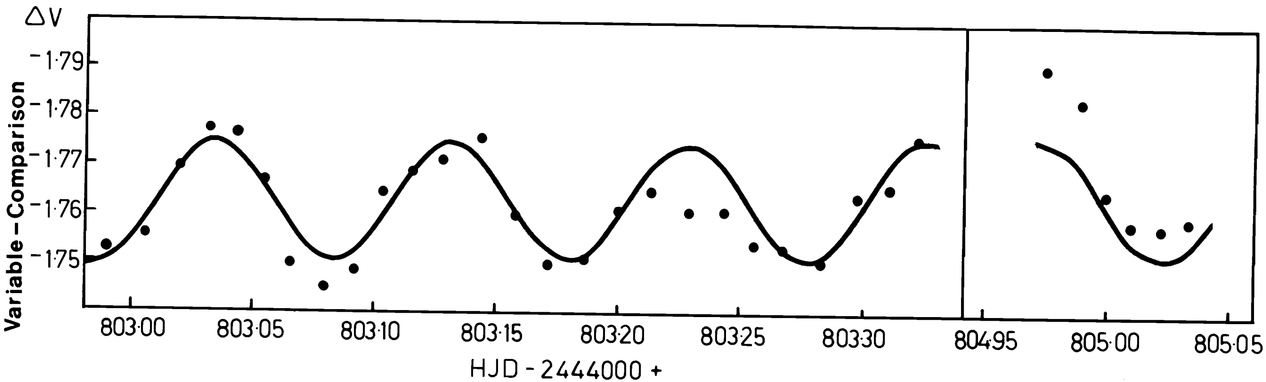

Fig. 7. Data in V for Sigma Octantis taken in July 1981. The solid curve represents the only Fourier component found in the data.

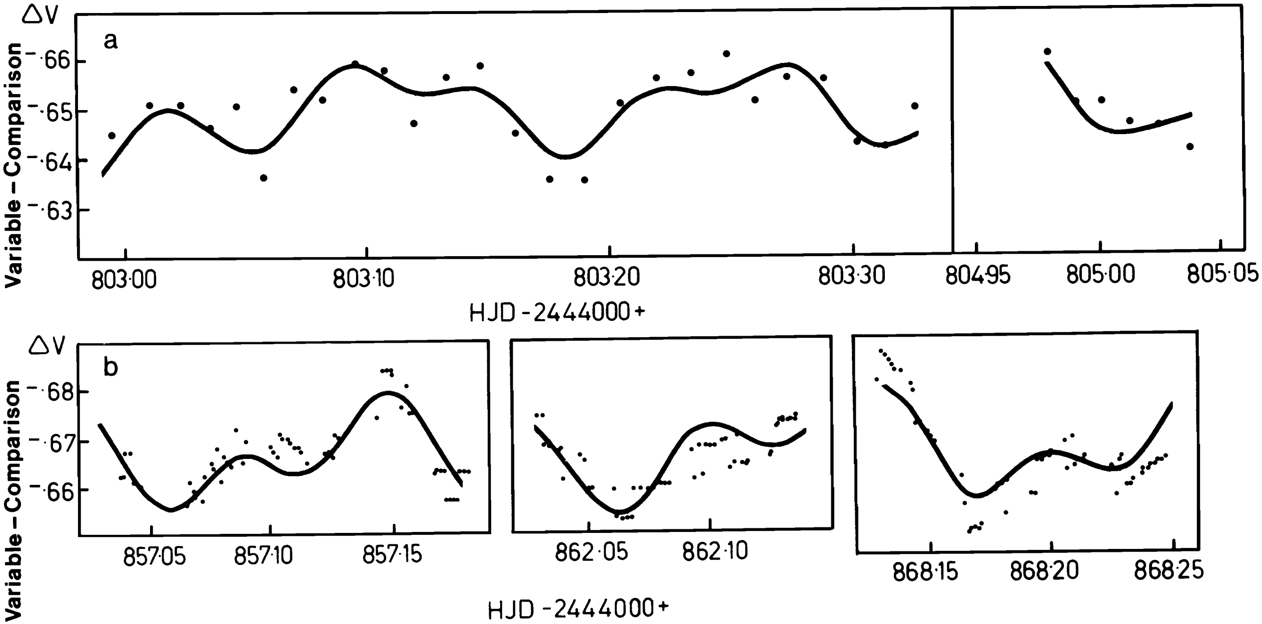

Fig. 8. Data in V and Fourier reconstruction of the light curve for B Octantis.
a: July 1981. b: September 1981.

To check these results B Octantis was re-observed in V relative to o Octantis on September 9, 14 and 20, 1981 using the same equipment. However the observing technique was changed: instead of making alternate measurements on the target and comparison stars, we measured B Octantis continuously, breaking at about half hourly intervals for single 2-minute observations of o Octantis. Fourier analysis of these data revealed the same periods as before. Figure 8b shows the data and the light curves reconstructed from the Fourier analysis.

The interest in these results lies in the fact that the period ratio of 0.44 cannot be attributed to any commonly observed modes of radial pulsation. As pointed out by Breger (1979), the observed period ratios for the radial pulsation in δ Scuti stars are:

$$\frac{P_1}{P_0} = 0.76 \; ; \; \frac{P_2}{P_0} = 0.60 \; ; \; \frac{P_2}{P_1} = 0.81 \; ; \; \frac{P_3}{P_2} = 0.845$$

In I.B.V.S. Number 2047, in which we published this work, we hinted that one of the modes we had observed might be non-radial, although such modes had been confirmed only for a few δ Scuti stars.

Subsequently Tsvetkov (1982) suggested that B Octantis, unusually, may be pulsating in the fourth overtone and fundamental modes of radial pulsation. Petersen (1976) gives a value of 0.438 for the period ratio P4/P0, in good agreement with our measured value of 0.44. It does seem most likely that B Octantis is pulsating in these widely spaced modes, and a project at a good site might be worth while to establish whether mode swapping occurs for this star, so that at times it pulsates in, say, the second overtone rather than the fourth.

Rho Puppis

These results were obtained in order to test for possible period changes since 1963, when the latest photometric light curve was published (Ponsen 1963).

The observations were made with the 10-inch telescope on five nights in April and May of 1983 using ξ Pup as a comparison star. The data were reduced to standard V magnitude differences and are shown in Figure 9 with an epoch of HJD 244543.0 and period 0.14088141 days (from Ponsen 1963). The best fitted times of maximum light from these observations are t max = 2445443.084 $\pm$.004 + 0.14088141E days, which when compared with Ponsen's data gives a period of 0.14088145 $\pm 7 \times 10^{-8}$ days, in excellent agreement with his result of 0.14088141 = 6×10^{-8} days found from 60 years of radial velocity data. We conclude that there is no evidence for frequency change on this highly stable star.

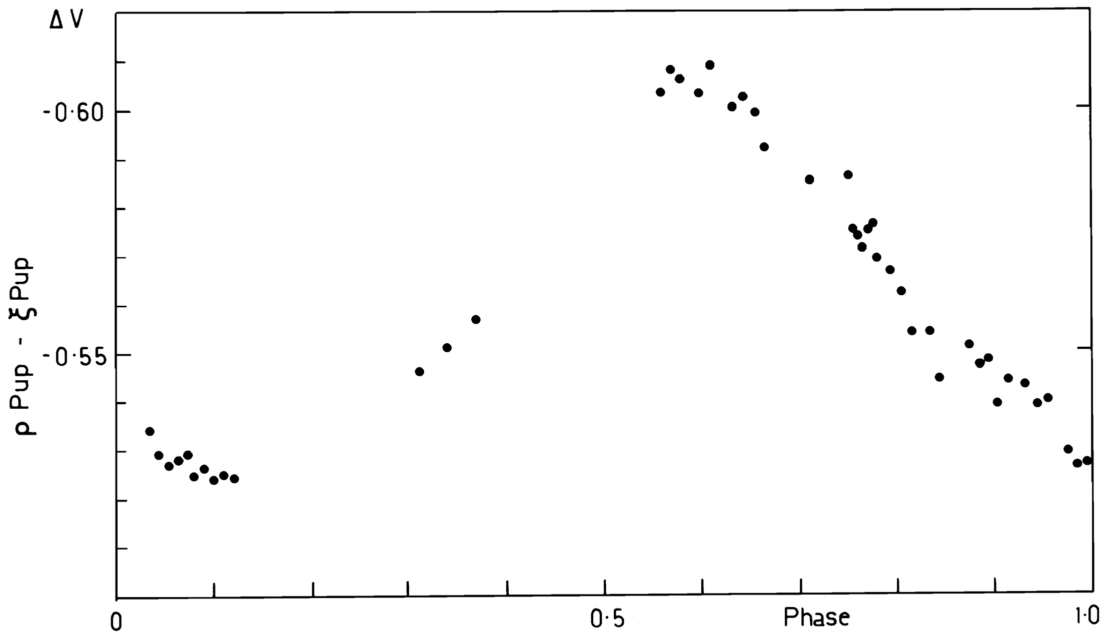

Fig. 9. V data for Rho Puppis taken in April and May 1983. The results are consistent with a constant period over some eighty years.

There are a number of other bright variable stars which would also make suitable projects for telescopes of this size. We expect to make good use of this telescope in the future.

XVI. RESULTS FOR SOME RS CVn STARS

HD 5303

This was one of the earliest of the RS CVn candidate stars to be observed, beginning in late 1979. We were fortunate to catch it in eclipse on our first night and this encouraged us to observe it on every opportunity. The data fit a period of 2.80 days and not the previously published value of 1.84 days obtained spectroscopically. As we acquired a longer span of observations we were able to obtain a more accurate value of the period. The light curve looked like that of a classic eclipsing binary star.

The analysis of the light curve proved difficult for us for two reasons: we were beginners, and it turned out to be not an ordinary eclipsing binary star.

We read through the relevant sections of the book "Photoelectric Photometry for Amateurs" by F.B. Wood and the series of papers by H.N. Russell. We also obtained the set of tables computed by Merrill for such analysis, but none of these worked. The rectification of the out-of-eclipse portion of the curve was only possible by assuming anomalously high stellar reflection coefficients. These coefficients describe the effect of the local heating of the respective facting hemispheres of the two stars of a close binary due to mutual irradiance. Although the energy from one star is absorbed, thermalized, and then re-emitted by the companion star, it is loosely termed a reflection.

Typical values of these reflection coeficients are known from other binary stars and from astrophysical theory. The values we needed to fit the data were very atypical. If sensible values were adopted, then the calculated light at primary eclipse (zero phase) was far greater than the observed light.

P. Etzel kindly supplied us with a copy of the program EBOP (Etzel, 1980) for solving the elements of well detached binary stars. As before, a solution was only possible with peculiar reflection coefficients. In order to reduce the calculated light at zero phase, EBOP wanted to reduce the primary reflection coefficient to zero; but to accommodate the wide range in the wave in the out-of-eclipse data, it wanted to make the secondary reflection coefficient anomalously high.

We finally realized that this was not a normal eclipsing binary star but a RS CVn star with a large spot wave superimposed on the usual eclipse light curve. This spot wave was due to a large dark spot (or spots) on the secondary star on the hemisphere away from the primary (i.e. facing us at zero phase), and this lowered the total light output near zero phase. In this case the spot wave was in phase with the light curve due to the eclipses.

Since the program EBOP was not able to model spot waves, we adopted the following stratagem. We modified the program to enable it to have a negative primary reflection coeffecient. A negative reflection coefficient is physical nonsense. It is simply a mathematical procedure to reduce the overall light of the system at certain phases below the value for a normal binary. This reduction is at its greatest at phase 0.0 and varies smoothly to zero at phase 0.5.

In this way EBOP was able to fit curve "A" (Figure 10) through the data with an r.m.s. scatter of 0.007 magnitude, which was consistent with the general precision of our photometry. In doing this, the other stellar parameters such as luminosities, stellar radii, and orbital inclination were also determined. When we re-ran the program keeping all these fixed but using sensible values for the reflection coefficients, EBOP produced curve "B" (Figure 10) which we assumed was the light curve to be expected from an unspotted star. The difference between curves A and B we attributed to the spot wave. By the use of the radial velocity curve we were able to solve for most of the stellar parameters and determine the components as being G0 V and K2/4 IV, which fits the pattern of other RS CVn systems.

The question of whether this procedure of adopting a negative reflection coefficient introduces any systematic errors of its own, and what must be done if the photometric spot wave is not in phase with the eclipse light curve, were investigated with a computer simulation experiment. (Thompson, 1982).

We have continued to observe HD 5303; our most recent data show a significant change from the 1980-81 results. We are planning to continue our photometry of HD 5303 to discern the nature of this change.

On a few occasions when measuring HD 5303 coming out of primary eclipse we have noticed a peculiar hook-like feature at about 0.08 phase. This may or may not be real; only future careful photometry will resolve this. If the photometric effect is present, it may be due to circumstellar material obscuring the primary at that phase.

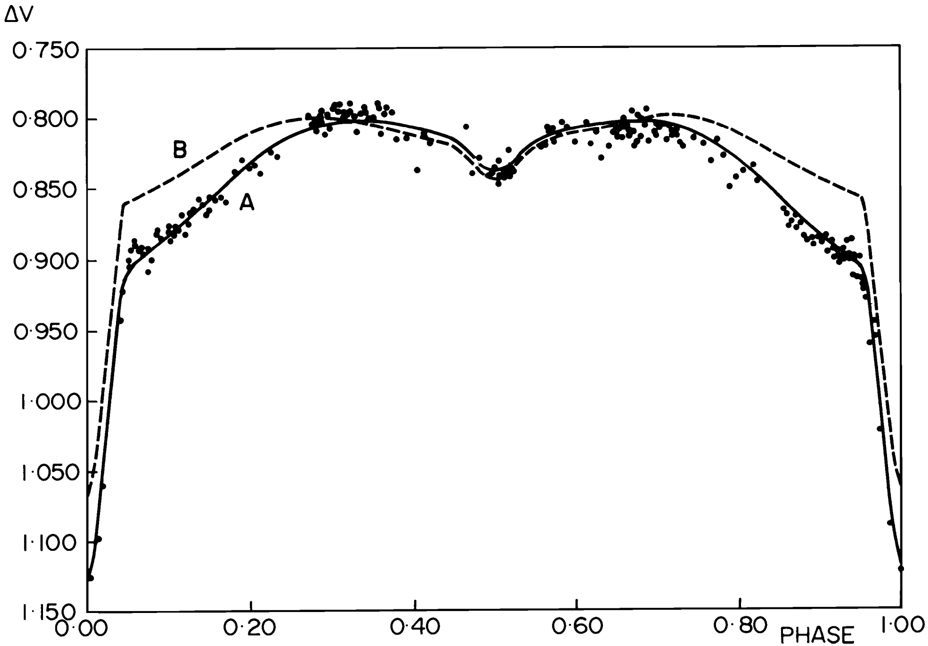

Fig. 10. Light curves for HD 5303. Curve A is the best fit using EBOP with a negative primary reflection coefficient, which models the effects of spots on the secondary, in this case by depressing the binary's light around phase zero. Curve B is the assumed light curve with an un-spotted secondary star.

HD 174429 (PZ Tel)

This star was included in the list of Weiler & Stencel (1979) of southern RS CVn candidates. Stacy et al (1980) reported two radial velocity measurements, which suggested variations of around 50 kms^{-1} in the star's radial velocity on a timescale of about one day.

We first observed this star photometrically at Monash in 1980. Eighty-five V band observations were obtained using 3 comparison stars over nine nights from July to September. From these observations it was found that the star was variable with a range in V of 0.12 magnitude and a period of about 0.943 days. The light curve obtained is shown in Figure 11. It is worthwhile at this stage to bear in mind two points; (i) the fact that the data were collected in just over 2 months, and (ii) there is significant scatter in the light curve around phase 0.1.

We suggested that the star was a non-eclipsing RS CVn system showing a fairly large photometric distortion wave (Coates et al 1980b). The scatter around phase 0.1 was taken as evidence for the variability of the distortion wave, as this is several times bigger than our expected experimental errors.

PZ Tel was not monitored as extensively the following year, 1981. In the observing season April to September, 32 V and 17 B measurements were taken at the Monash Observatory. These data could not by themselves define the light curve.

When the 1981 data were plotted with the same period and epoch as the 1980 data, it was seen that maximum light appeared to have shifted about 0.4 earlier in phase, although other data from 1981 fell more or less on the 1980 light curve. An attempt was made to determine a better period for this star by allowing the 1980 and 1981 maxima to occur at the same phase -however this produced a light curve so scattered that it was decided that the star must be exhibiting real changes in its light curve, and that there was little physical justification for forcing 1980 and 1981 maxima to coincide in phase.

In 1982, PZ Tel was observed on 16 nights between May and October, resulting in 117 V and 73 B measurements. Of these 16 nights, six were at Siding Spring Observatory using the 16-inch telescope. These six nights were from two runs, one in May, the other in August.

The light curve obtained for the entire 1982 season is shown in Figure 12. Our first thought, once most of the data had been collected and reduced, was that this could not possibly be the real behaviour of the star, and that our data must be in error.

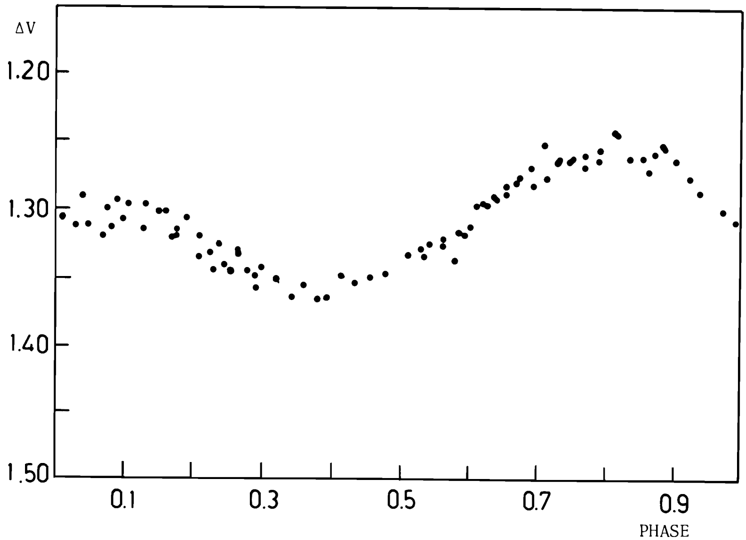

Fig. 11. Light curve for PZ Tel from July to September 1980. Note the scatter around phase 0.1. All light curves for this star use the epoch HJD 2444443 and period 0.943 day.

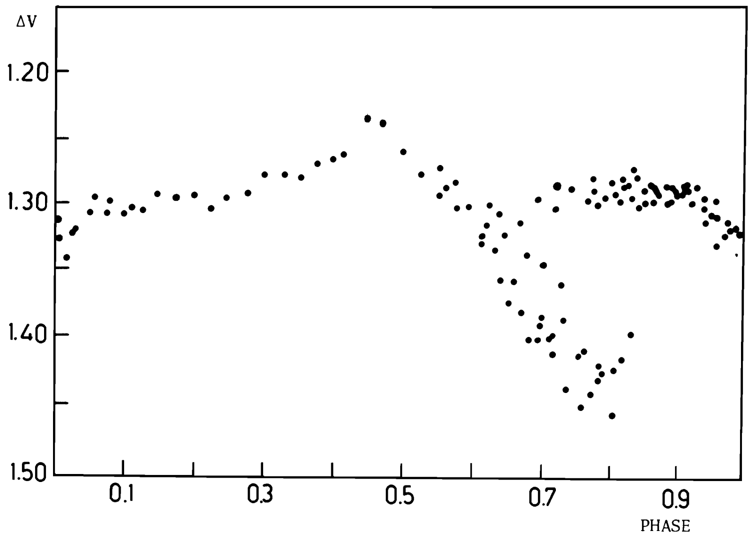

Fig. 12. Data in V for PZ Tel from May to October 1982. The star's behavior has obviously changed significantly during this time.

After much thought (and a little panic!) we concluded that the data were in fact correct, (mainly based on the measured differences between our comparison stars), and that the variations observed were due to the star itself.

The picture becomes a little clearer when the 1982 data are plotted in intervals May to July, and August to October (Figure 13 a and b). In the first part of the season, the light curve was characterized by a deep minimum around phase 0.8. A few months later, this had almost disappeared from the light curve. Maximum light in 1982 was essentially at the same level as measured previously, while the minimum was some 0.1 magnitude below 1980 or 1981. The B-V versus V graph was found to be of negligible gradient with B-V = 0.77 $\pm$0.01.

We now felt sure that we were looking at the distortion wave of an RS CVn system. It also seemed likely that this was a very active RS CVn system indeed. The light curve had altered significantly over a few months; in terms of the "starspot model" this would imply a similarly rapid change in the distribution of spots on the photosphere of this star. These light curves were presented in Coates et al (1982e).

Inspection of the 1982 light curves suggest that the changes are probably not due solely to the shearing of an initially compact spot group (the deep minimum), but likely to be due to the appearance and disappearance of a spot group at essentially the same stellar longitude. This is based on the observation that most of the variations in the light curve are restricted to near phase 0.8. It is thought that if an initially compact group like that which produced the minimum of early in the season was then distributed in longitude so as to remove nearly all trace of this minimum, it should produce a measurable decrease in the star's brightness at all (or most) phases; this was not observed. Indeed, the data taken at photometric phase 0.5 away from this minimum (obtained in September) can be plotted quite well on both of the 1982 light curves which would suggest that the star spots could be highly localized in longitude on the star's photosphere, or at any rate, the variations in the "spottiness" are at times fairly well localized.

From the 1980, 1981 and 1982 data, we knew that PZ Tel has a highly variable, possibly continuously variable, light curve, and that in order to define the light curve at any given epoch, it was necessary to obtain complete phase coverage over no more than 2 or 3 months. We hoped that in 1983 we may have been able to obtain light curves representing the early, middle and late parts of the observing season by an intensive series of photometric observations. In fact, we were only able to determine light curves for the periods May-June, and August-October.

The May-June observations were taken on seven nights in just over one month with the 16-inch Monash telescope. Although only 28 V and 26 B measurements were obtained, fairly good phase coverage resulted. The V and B-V results obtained are shown in Figure 14 a and b (from Innis et al 1983a).

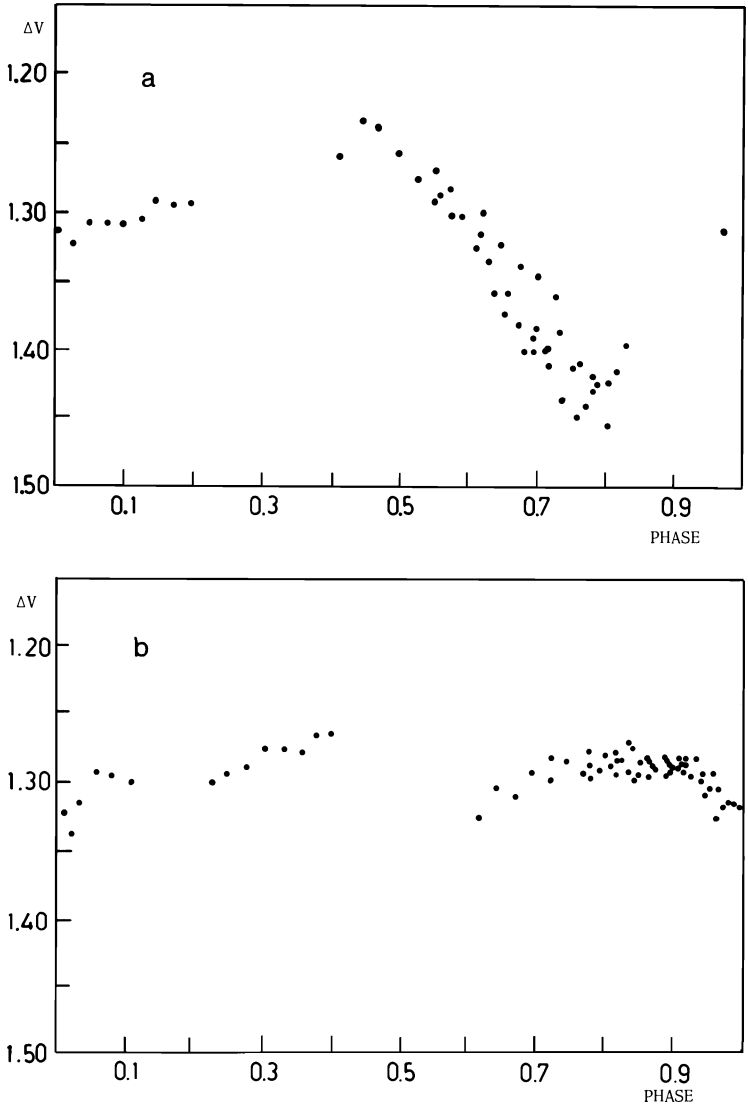

Fig. 13. Data in V for PZ Tel.
a: May to July 1982. b: August to October 1982.

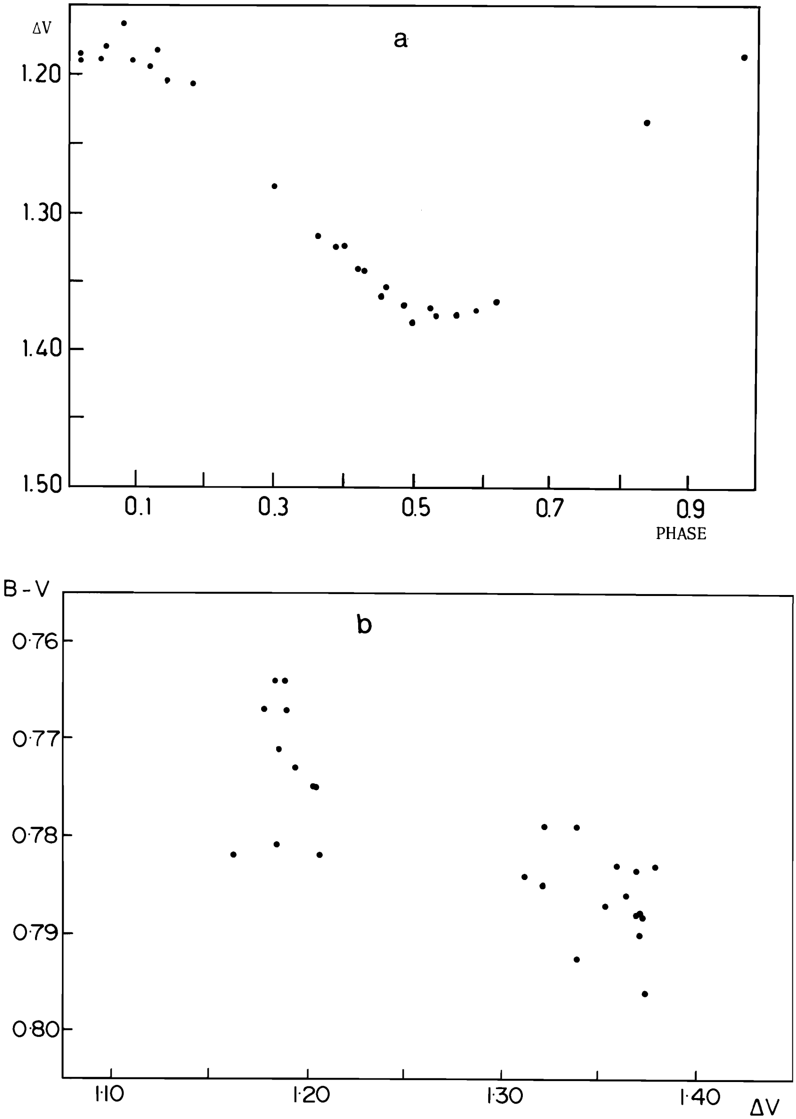

Fig. 14. a: Light curve in V for PZ Tel for May and June 1983.
b: (B-V) versus V for May and June 1983.

The V variations are now sinusoidal again, as in 1980. However, the range in V is about 0.21 magnitude (and thus twice the range of the 1980 data), and the maximum light is some 0.05 magnitude above that of any light curve obtained previously. Once again, we very carefully examined our data to make sure that this was not due to instrumental effects or some other cause, and again we concluded that this must be a real change in the properties of the star.

We also detected a change in (B-V) with photometric phase (B-V was constant in 1982), which is further evidence for a change in the properties of PZ Tel.

Further photometric observations were obtained later in the season on two observing runs with the 24-inch telescope at Siding Spring in August and September 1983, and with the 16-inch Monash telescope in September and October. The V light curve obtained is shown in Figure 15, (at the time of writing this has not been previously published). Once again, as in 1982, the range of the V light curve has decreased from the earlier large range (0.2 magnitude) to a much smaller value (<0.1 magnitude).

These photometric results are extremely interesting; almost tantalizing in some ways, but unfortunately we do not know enough about PZ Tel to be really sure as to what is going on here.

It appears that PZ Tel is going through some cyclical variation, in that the range of photometric variation decreases from around 0.2 to 0.1 magnitudes during an observing season. At least this seems to be the case for the 1982 and 1983 data. The 1980 data would also be consistent with this as it was taken at the end of that season. Of course, we are not in any way suggesting that the photometric variation of PZ Tel is tied in some way to the position of the earth in its orbit about the sun! However, the evidence points to some cycle on this star which seems to have a period near 12 months (or possibly 6 months) which is an unfortunate coincidence, as far as obtaining ground based optical observations is concerned.

We have commenced spectroscopic observations of PZ Tel, and other stars, using the telescopes and detectors of Mount Stromlo and Siding Spring observatories. Spectroscopic data which yield for example radial velocity curves will be of much value in our investigations of this star. Our results so far suggest that PZ Tel is a double lined spectroscopic binary, but this needs confirmation.

Our spectroscopic data also show that the Hα profile of this star is variable, but seemingly not in phase with the photometric variation (Innis <u>et al</u>, 1983c.). We are still considering the meaning of this result. Possibly there is short term flaring at Hα which goes unnoticed in the broadband photometry.

To summarize on PZ Tel: it appears that this star is one of the more active members of the class which show RS CVn behaviour. It has a highly variable, possibly continuously

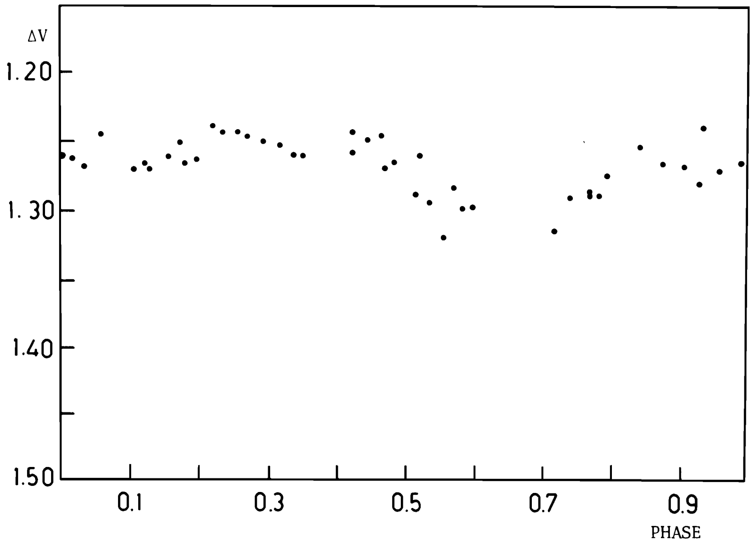

Fig. 15. V data for PZ Tel from August to October 1983.

variable light curve, which suggests a high level of spot formation and decay, or spot redistribution on the stellar photosphere. We are planning to continue our observations, both photometric and spectroscopic, of this star for some seasons to come. We hope that the extensive history of observations of this star will enable us to understand something of the spot cycle behaviour, once some of the basic parameters of PZ Tel have been determined.

HD 196818

This star has been included in several recent lists of stars with Ca II H & K emission, and also appeared in the list of Weiler and Stencel (1979). Hearnshaw (1979) reports very strong H and K emission in six spectra obtained on this object, and notes that the emission is even more intense than in the very active RS CVn star HR 1099 (V711 Tau). He also reports that radial velocity variations may be present. HD 196818 was known to be a variable star, appearing in the Bamberg catalogue as number BV 893.

We commenced photometric observations on this star with B and V measurements in August, 1982, using the 16-inch Monash telescope at Siding Spring Observatory. Again, as is our usual practice, three comparison stars were chosen. Observations were continued with the 16-inch Monash telescope, and by July 1983, we had 65 V and 17 B measurements on this system on fourteen nights.

From these data it was found that the star was varying in V by about 0.3 magnitude. Furthermore, it was found that the brightness changes over a few hours were small compared to the changes observed over a couple of days, so that for a given night's data, two or more adjoining data points were combined to give a mean point, which smoothed the experimental scatter to an extent.

We then searched for possible periodicities in the data using educated guesses and the graphics facility of the microcomputer to plot the data for a given period in a trial and error process. The V data are plotted in Figure 16a using the period of 20.31 days determined by this process.

We also found a large variation in B-V for this star, of some 0.05 magnitude, as can be seen in Figure 16b. Although complete phase coverage in V was not obtained, it seems that the light curve is characterized by an almost linear rise and fall, resembling a saw-tooth wave. The observation that the star is fainter when redder would be consistent with the light variations being due to cooler starspots on the surface of the star. We not that the shape of the light curve and the range of the change in B-V are similar to those of HD 32918, identified by Collier (1982) as a member of the FK Comae class of single rapidly rotating giants. These above results were presented by Innis, et al (1983b).

Further photometry was obtained on HD 196818 after July 1983 using the telescopes at Monash and at Siding Spring. These data (as yet unpublished) show that the light curve has

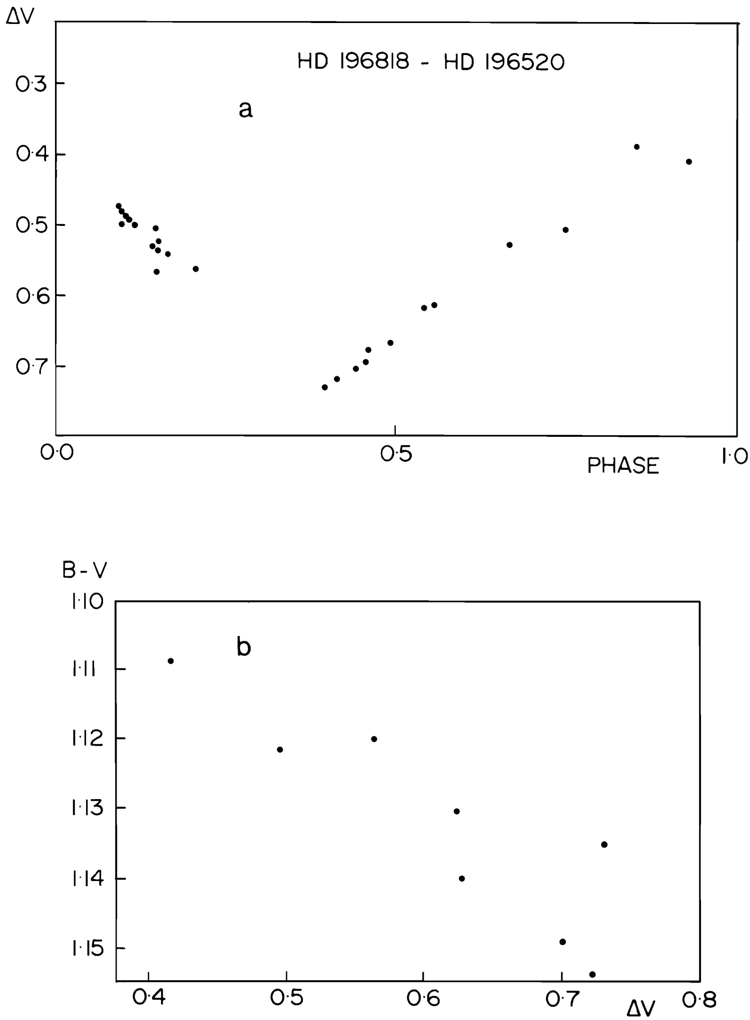

Fig. 16. a: V data for HD 196818 from August 1982 to July 1983. b: (B-V) versus V in this time interval.

changed in both shape and range, minimum light now being some 0.05 magnitude fainter in V.

We have also obtained spectroscopic observations of this star in 1983 and from these data it seems that HD 196818 is a single-lined spectroscopic binary, as its radial velocity shows small but seemingly real changes. As yet, however, the radial velocity data are poorly distributed in phase, and we require further observations. The spectroscopic data also revealed that the Hα profile is variable, being at times in emission (Innis et al, 1983c). We are hoping to gather further data to investigate how the Ha variation relates to the photometric phase.

We are expecting to continue our photometric studies of this star in the coming seasons. As HD 196818 is located within 10 degrees of the South Celestrial Pole, at its lowest it is some 28 degrees above the horizon at the latitude of the Monash Observatory, making it observable almost the year round. This is extremely fortunate, and we hope to be able to make the most of this by obtaining almost continuous photometric coverage of this star. This should be of much value in the understanding of its behavior.

XVIII. FUTURE DIRECTIONS

Improvements in the instrumentation of the observatory have been planned for several years: for instance the idea of acquiring a Cassegrain telescope started in about 1975. Financial problems have limited us to obtaining new equipment a little at a time, but now we are close to seeing everything come together in a new 18-inch Cassegrain and photometric system.

Our motivation for these changes is to make life more comfortable for observers and to make the telescope more easily handled by one person. The secondary spider of the new telescope may be rotated into two possible positions; one forming an f/4 Newtonian arrangement and the other an f/16 Naysmith-like system with a Cassegrainian secondary, and a tertiary flat mounted just above the primary mirror. We will use the latter configuration most often, thus placing the photometer at a convenient height above the floor for most orientations of the telescope. The closeness of this focal plane to the declination axis will also allow quite heavy equipment to be mounted there without the necessity for large counterweights. We intend to use the Newtonian focus (with a corrector lens) for occasional teaching projects, perhaps involving photography. The aluminum telescope tube is considerable lighter than its wooden predecessor and should prove much easier to manoeuver. The tube of the 18-inch was made under contract outside the University, and the mirrors were figured by W.E. James (who produced the original 16-inch mirror). All other parts for the telescope have been made by our Department's very capable workshop.

Other changes to be made include installing a more versatile photometer head with an EMI Gencom thermoelectric cooler, which will accept a range of end-window photomultiplier tubes. We find this type of cooler to be more convenient than those which use dry ice since one does not need to partialy disassemble the photometer at intervals to re-fill with coolant. We are grateful to Mount Stromlo and Siding Spring Observatories (MSSSO) for the loan of a filter box fitted with a 12-position filter wheel and an 8-position aperture wheel. We have already used our cooler as a module compatible with the MSSSO filter boxes on our field trips to the telescopes at Siding Spring Observatory. We will be mostly using an S20 PMT selected for high gain and extended red response, so that we can measure in the R band as well as in UBV. More precise results of astrophysical interest should be obtained in this way. For instance, Vogt (1981) describes an accurate method for calculating the temperatures of star spots from measurements in V and R of a star's spotted and unspotted surfaces. The almost completed telescope and some of the ancillary equipment are shown in Figure 17.

We have purchased a THORN EMI Gencom model C-10 photon counter with an AD-100 amplifier/discriminator to replace the d.c. amplifier and digital panel meter. Two advantages of photon counting lie in being able to measure fainter objects and to start a count immediately after a star is acquired or a filter changed, rather than having to wait for the time constant of a d.c. amplifier to run its course. Our existing SYM microcomputer will be used to log the data from the C-10 as well as to control some of its functions. To keep a record of the quality of the night we will continue to use a chart recorder connected to the analog output of the C-10.

Further ahead, we plan to transfer the digital panel meter to the 10-inch telescope and to buy a simple microcomputer for data logging. The photometer on this telescope already has a side-window S20 PMT installed and calibrated to the standard UBVR system. Even further into the future we are contemplating a two-star photometer for the 18-inch, which should allow precise photometry even through thin clouds as well as permitting observations on fainter objects than we can reach at present.

XIX. CONCLUDING REMARKS

The previous pages contain a description of the establishing and equipping of the Monash Observatory, together with an account of some of the research carried out there. While we are part of a University Department, and thus have access to excellent technical and electronic workshops, we are sure that similar results could be obtained by small colleges or dedicated privately funded individuals. Although our staff members and Honors students frequently are committed to lectures or laboratory classes and so cannot always observe until dawn, our research students are not so committed, and they cheerfully carry out the bulk of the observing. We are grateful to MSSSO for the opportunities to carry out spectroscopy and photometry with the 74-inch at Mount Stromlo and the 16-, 24-, and 40-inch telescopes at Siding Spring. This has provided all of us with valuable training in modern techniques.

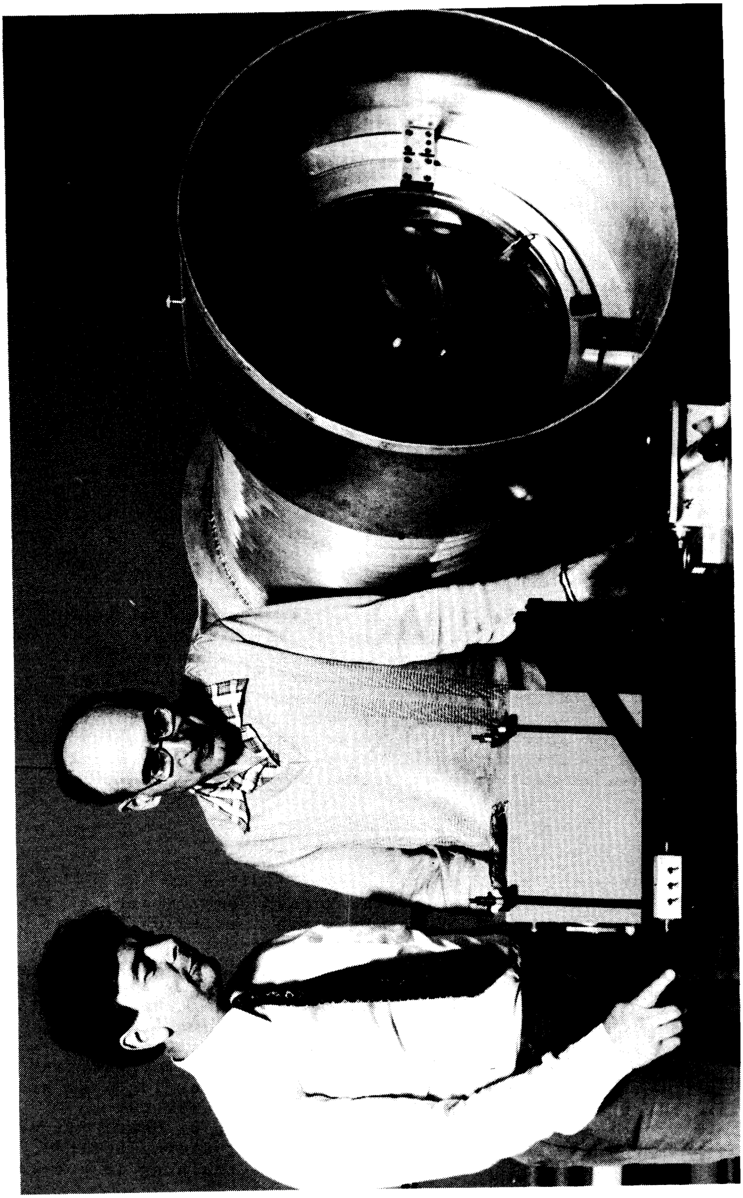

Fig. 17. Keith Thompson (left) and Denis Coates with the almost completed 18-inch telescope. The thermoelectric cooler and A.N.U. filter box are in the foreground.

We expect that work on the RS CVn stars will occupy us for the next few years. There are also one or two aspects of the USPC project to be followed up. The southern sky presents great opportunities: it has still been studied much less than the north. At our observatory, which is one of the most southerly in the world, we foresee enough work for the new 18-inch, its photometer, and data logger, to last for its active life and beyond.

Acknowledgements

We thank Helen Pateras for typing the first draft of this chapter very capably under difficult circumstances. Thanks are also due to Bob Bryant for the photograph in Figure 1, to Steve Morton for all the other photographs, and to Steve McCausland who prepared the line diagrams.

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8

PHOTOELECTRIC PHOTOMETRY IN ESTONIA

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I. PHOTOELECTRIC PHOTOMETRY IN TARTU

The Observatory of Tartu University (Müürsepp and Preem, 1968) was founded in 1808-1811, and is therefore one of the oldest observatories in the European part of the U.S.S.R. Friedrich Georg Wilhelm Struve, the great-grandfather of Otto Struve, began his career here; and the world's largest refractor of that time (a 24 cm, f/4.3 m objective built by Fraunhofer) was obtained on W. Struve's initiative. After World War II the observatory was transferred to the Estonian Academy of Sciences and a new observatory was built 20 km south of Tartu. It was inaugurated in 1964 and named the W. Struve Tartu Astrophysical Observatory.

The first photoelectric observations were by Heino Albo at the old observatory in the town center in 1955. He used a Cassegrain 20cm f/4.2m telescope and a photometer constructed at the workshop of the Leningrad University. It was supplied with a new photomultiplier tube when it was moved to Tartu. Most photometric observations were made by Heino Albo, who for ten years was engaged in the measurement of the close binary stars, Algol and Nova Herculi 1960.

The first instruments applied at the new observatory were a 70 cm Cassegrain telescope for spectroscopy and two identical 48 cm Cassegrains for photoelectric observations (see Figure 1). During 1961-1966 a twin telescope for synchronous photoelectric observations was built (Veismann, 1971). The control and recording console is located in the laboratory building adjacent to one of the domes. The second telescope is mounted in a lightweight, free-standing, plastic dome at a distance of 30m from the first telescope. The design of the complex allows remote control of the telescopes and photometers from the control and recording console. After designing electric drives for the mounts (Veismann and Kyubbar, 1971), the two systems were tested for remote guiding; one with rotating transformers as sensors and the other involving closed circuit television transmission of the images of the setting circles on the mounting. Both methods allowed a guiding accuracy of about 2-5 minutes. Push-button

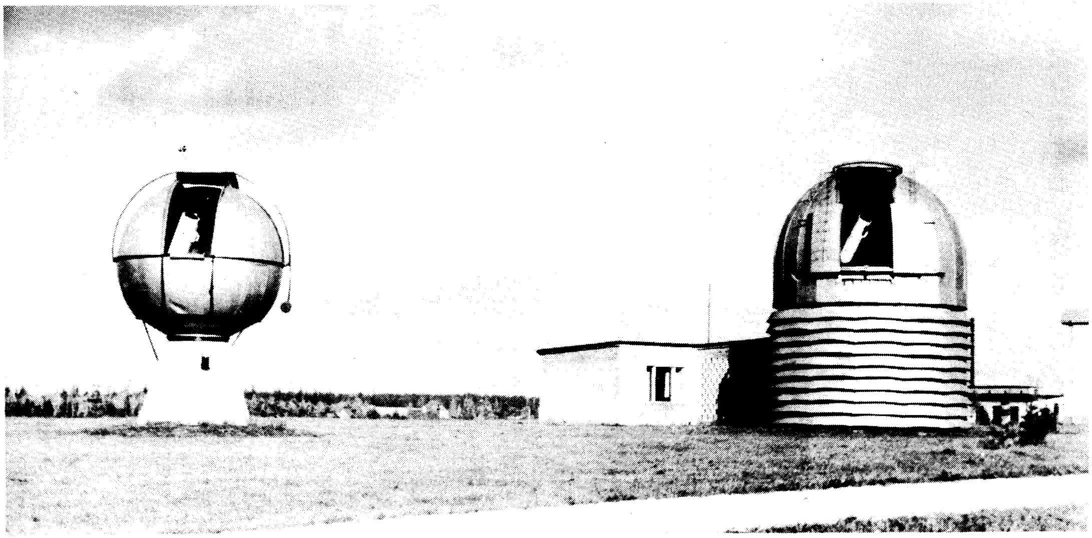

Fig. 1. The domes of the twin telescope.

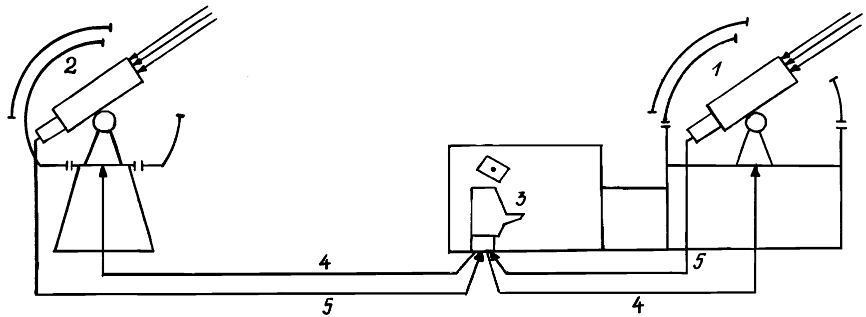

Fig. 2. The configuration diagram of twin telescope:
1 and 2 - telescopes, 3 - control and recording console,
4 - control link, 5 - data link.

switches at the control and recording console provided the changes of UBV filters, diaphragms, and other elements in the optical systems of the photometers, and stepped selectors rotate the ring mounts. The optical systems also include choppers for precise automatic setting and guiding. These electromechanical modulators chop the light beam from a star according to the displacement of the image from the optical axis. The output signals from the photocurrent amplifier are fed through a demodulator to the fine-motion drives of the telescope (photometry is suspended during the guiding operation). EMI 6094B photomultipliers (also FEU-64 and FEU-79), electrometer amplifiers, and line recorders are used. The integration involves 100 or 1000 readings on the extended digital voltmeter scaler, and the results are printed. See Figures 2 and 3.

The twin-telescope complex can be applied for the following purposes: (1) for raising the accuracy of measurements by compensating for the influence of atmospheric instability, (2) for simultaneous measurements of the star in two spectral regions, (3) for investigating the character of atmospheric instability, and in particular the space-time characteristics of low-frequency scintillations, and (4) for conducting independent observing programs with photometric telescopes.

Provisional observations with the twin-telescope complex were begun in 1965. Measurements of star brightness and simultaneous compensation of its ultra low-frequency scintillations using a comparison star at an angular distance up to several degrees have shown that in case of unstable atmospheric conditions the two-channel measurement will ensure a considerable improvement in accuracy. However, the large distance between telescopes and differences between the two photometric channels have reduced our original expectations (as it has been the case with similar telescopes in other observatories around the world).

The two telescopes were used separately (mainly by Heino Albo, Izold Pustylnik, and Leo Sorgsepp) to measure the eclipsing binaries TV Cas, VW Cep, RW Tau, X Tri, and RW Tri. Lauri Luud, together with his colleagues, has observed the symbiotic star CH Cyg for nearly 15 years. In 1970 he initiated an experiment which connected the twin-telescope to the control computer located at 100 m from the photometer in the main building of the observatory (Luud, et. al., 1971).

During 1970 to 1980 scanning spectrometers designed by Seya-Namioka have been constructed and put to the test at the workshops of the observatory (Urgo Ibrus). They were attached to the 70 and 48 cm telescopes for measuring the energy distribution (0.3 to 1 micron) in the spectra of Be and Wolf-Rayet stars, as well as for determining atmospheric extinction.

An infrared photometer with a lead-sulphide photoresistor (2840 1x1, manufactured by Infrared Industries) refrigerated to 195 degrees Kelvin has been designed and built by Mati Pehk and Tonu Tuvikene (1981). The photometer consists of a low-noise preamplifier, a narrow-band synchronous integrator, and

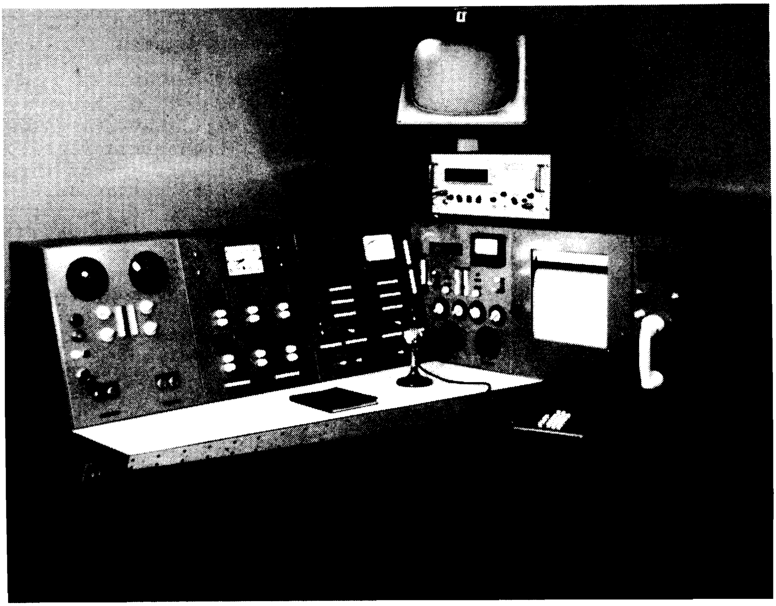

Fig. 3 - The control and recording console of the twin telescope.

a demodulator. The output integrator consists of an integrating voltage-to-frequency converter and a pulse counter. The equipment has high gain stability and an accuracy of +0.05 % in the input range of 0.5 to 5 volts. The conversion rate is 2000 Hz/V.

II. PHOTOELECTRIC PHOTOMETRY IN TALLINN

1). THE BEGINNING

After finishing grammar school in 1911, the well-known astronomer Ernst Öpik founded the VEGA astronomical society in Tallinn and supplied it with a 3-inch refractor. When the society broke up four years later he gave the telescope to Tartu Observatory and asked the authorities to deliver it to any future astronomical society. When a new society was formed in 1954, the VEGA refractor was brought back to Tallinn and set-up in the ex-private observatory of E. Hoeppener. The group of amateurs, led by Charles Villmann, concentrated on variable stars, lunar occultations, and noctilucent clouds. They had tried to construct a photometer during the late 1950's, but could not obtain a photomultiplier tube.

2). A NEW OBSERVATORY

In the search for better observing conditions, the seven-story ruins of the Tower of Glehn (built in 1910 and located 12 km from the town center at the southern boundry of Tallinn) were found to be suitable. This location has a dark sky, and west winds take the smoke from Tallinn in the opposite direction.

Since the group of amateurs could not afford the capitol repairs, the Estonian Academy of Sciences offered a helping hand. So it happened that the main observatory of the Institute of Astrophysics and Atmospheric Physics is situated in the country 20 km from Tartu, while its observation station is in Tallinn. It may be of interest to the reader that from the balcony tower (77 meters above sea level) one can discern the island of Naissaare (Women's Island) and the birth place of the optician Bernhardt Schmidt on its southern coast.

Tallinn Observatory is typical of small photoelectric observatories. We call it the "folk" observatory because in addition to 5 salaried workers (of whom two are theoretists), there are also a group of amateurs. They are mainly involved with photographic photometry of variable stars using the plates of Tartu Observatory. See Figure 4.

3). Photometers

We obtained the first photoelectric photometer in 1968. It was constructed in Tartu Observatory by Enn Mart Maasik, who already had some experience in designing the twin-telescope amplifier. It is a classical UBV photometer using an EMI 9502B, DC amplifier, and an EPP-009 strip chart recording potentiometer. Only in 1979 was the PMT replaced by a new EMI 9502A.

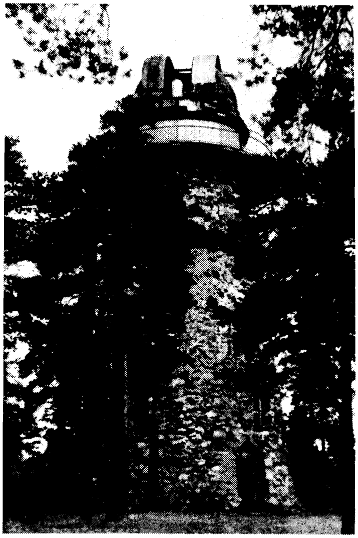

Fig. 4 - Tallinn Observatory.

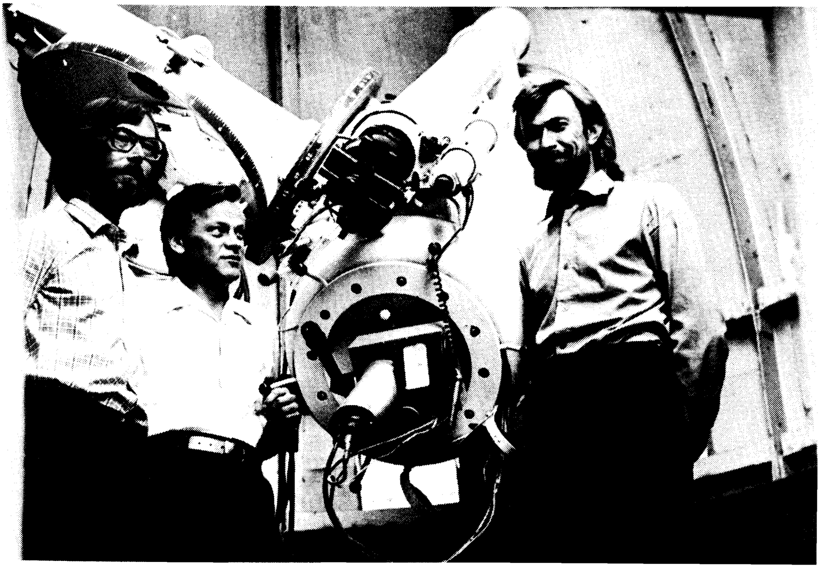

Fig. 5 - Ülo Kestlane, Peep Kalv, 48 cm telescope with the photometer and Voldemar Harvig, designer of the latter.

From 1969 to present there have been three major observers: the author of this chapter, a technician/geologist named Ülo Kestlane, and Voldemar Harvig, who began as a student and is now a professional astronomer. During this time we have had three enthusiastic amateur assistants: Harry Hoyer as an optician and mechanical engineer, and Toomas Aas and Johannes Kalli as specialists in electronics. They are all non-graduates but still they have a great knowledge of this field.

In 1979 our three amateur assistants in co-operation with Voldemar managed to build a new photometer with the multi-alkali Soviet photomultiplier tube FEU-79. The filter wheel has 12 positions, including the mirror of the telescope in the 12th position. The photometer utilizes an iris diaphragm which helps in the centering of the star. Standard diaphragms of 0.5, 1, 1.5, and 2 mm can be used. We used this photometer from 1980 to 1983 to make UBVR and H-alpha observations.

In 1983 these same four men succeeded in constructing another photometer: the so-called "faint-star-photometer". In this photometer the postviewer's flip mirror is replaced by an interference filter. The mirror surface of the interference filter reflects almost the entire light of the star, and thus it is possible to guide it with the main telescope during the entire measuring time. The photometer has three diaphragms which are moved with the help of relays, thus making it possible to measure in turn the brightness of the components of close visual binaries and the sky background. In the present form of the photometer one can measure only in one narrow spectral band which is determined by the interference filter inclined at 45 degrees. See Figure 6.

At this point in time our observatory is not computerized, although for one season we managed to obtain a digital voltmeter, microcomputer, and printer. However, in 1985 we hope to obtain an Electronica-80 computer.

4). OUR EXPERIENCE

There averages about 60 observational nights per year in Tallinn, of which at least half remain clear throughout the night. However, only 10 to 20 are good photometric nights. In some years there are bright polar auroras which extend as far as to the zenith and make it impossible to observe at least half the sky. There are probably even more weak polar auroras which cannot be seen with the naked eye. This is evidenced by the increased and unstable background measurements in the ultraviolet. The town light in the northern determines the 9th to 10th magnitude measurement limit.

III. DESIGNING AN OBSERVATION PROGRAM

At the end of 1968 I designed an observation program which takes into account the bad observing conditions in this location. I choose several objects which require long-time observations (e.g. long-period, semiregular, and irregular variables) which are often overlooked by observers in better

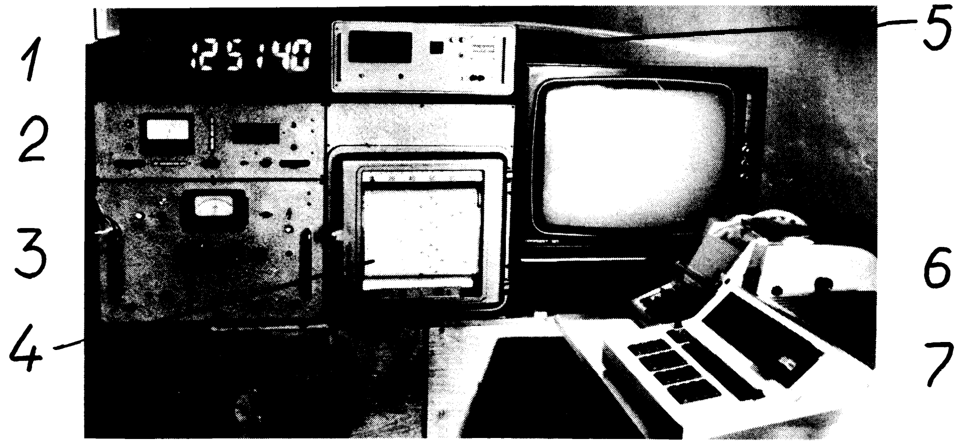

Fig. 6. The electronics of the Tallin Observatory showing: (1) standard time crystal chronopher (designed and built by Toomas Aas), (2) DC amplifier and phone, (3) high voltage power supply, (4) strip chart recorder, (5) printer, (6) microcomputer, (7) interface (not visible in photo).

locations. Being interested in eclipsing binaries, I tried to find binaries with long periods, with components of different spectral types, and with intrinsic variability demonstrated by former visual or photographic observers. If the long-period system has an unusually close binary light curve there exists at least one of the following possibilities: (1) the stars have great masses, (2) the stars have great sizes, or (3) the interaction processes in the double system are very powerful. In all these cases the system is in a short and very fast evolution phase and interesting results are guaranteed.

For this reason RX Cas (P=32 days, period of intrinsic variations = 516 days, small masses), BM Cas (P=197 days, irregular intrinsic variations, great masses), and UU Cnc (P=96 days, irregular intrinsic variations, masses unknown) have been choosen for our observation program. Complete light curves of TW Cnc, AO Cas, GG Cas, V367 Cyg, V448 Cyg, and RY Gem have also been observed. Since 1974 I have also been observing the X-ray binary X Per and the red giant HD 193092. Last year I started observations of BM Cam, WY Gem, and BU Gem. Voldemar has been attached to hot eclipsing binaries. He has obtained full light curves of the systems XZ Cep, AH Cep, CQ Cep, CW Cep, and AO Cas. Ülo has measured the unstable Cepheid RU Cam for a long time. We observe nine Be stars according to the co-operative observation program of the I.A.U.

It is only natural that every observer wants to see the results of his work as quickly as possible. Still, in our opinion it would be nice if every observer included in his program at least one object which is as bizarre and enigmatic as possible, which would be his "own star" which he would observe until the end of his life. While observing such stars there is always "an anticipated unexpectedness", and as to the stellar evolution, a valuable result is almost always guaranteed. One problem with this is that one has to very carefully observe the changes in the color system of the telescope/photometer over the course of time. It would be ideal to share the star with a colleague.

IV. ATMOSPHERIC EXTINCTION

Fine methods have been worked out to determine extinction coefficients and we have nothing to add. Still, I would like to note that if we deal with long-time observations and try to observe as often as possible (as we do in Tallinn), we cannot rely on the determination of the extinction coefficients for every single variable or even for every single night (especially since it is determined from the measurements of the comparison and check star where the differential air mass $\Delta X < 0.1$ and thus the result is very unstable). Special measurements to determine the extinction coefficients take much time and usually cannot be performed, especially if the atmospheric transparancy is unstable. This is why we determine the extinction coefficients very carefully during the nights when we measure standard stars to determine the color system. On other nights we do not even try to measure the extinction coefficient k'' which depends upon the color, so we use an average value which, as pointed out by Hardie

(1962), changes relatively little. We determine the main coefficient k' on every night possible, but here too we often use an average value. The variability of k' practically determines the overall accuracy of our observations. On more than 200 nights we obtained the following results in the V band: k' = 0.008 to 0.44 with a mean value of 0.24, whereas the coefficient of selective extinction changed only as k'' = -0.047 to -0.041 with a mean value -0.043. This is why if we do not succeed in determining the extinction coefficients, we try to observe program stars when $\Delta X < 0.01$ and never when $\Delta X > 0.05$.

V. TIME OF INTEGRATION

If you do not have a computer which is programmed to determine the proper integration time, you must rely upon your own experience taking into consideration the brightness of the star and the sky conditions. I do not generally agree with the wide-spread practice of measuring the sky background for as long as the star (our experience is limited to a strip chart recorder output), as it is more important to move the telescope from the variable to comparison star as quickly as possible, and to measure the background in the least amount of time possible. Usually we will measure a star for 30 seconds in each of 4 filters, and then the sky background for 5 to 10 seconds with the same filters. We will use the same integration time for the star and sky background only when the variable is faint or when we use different gain settings for the variable and comparison stars. Although the stars in our program must be bright enough for our telescope and sky conditions, it often happens that in the ultraviolet the stars turn out to be too faint. Even when the principle minimum of an eclipsing binary coincides with the full moon, I have often measured both the star and sky background with 30 to 60 second integrations with the U filter.

VI. CENTERING THE STAR IN THE DIAPHRAGM

If you have a dark sky and non-illuminated diaphragm, it is difficult to determine if the star is located in the center of the aperture. The most reliable way which we have found to center a star in the diaphragm is with the help of a guider and a photometer output. We use a high magnification eyepiece, and the output of the photometer is kept by us two floors below the telescope in a warm room. A galvanometer which is in parallel with the chart recorder is attached to the head of the photometer. While guiding the star in the middle of the cross-wire we move the telescope in one axis, and by the deflections of the galvanometer we determine the position of the telescope when the star is at both ends of the aperture. With the help of the eyepiece micrometer of the guider we set the ocular exactly parallel with the optical axis of the telescope. We call this process "shaking". One has "to shake" before observing each new variable star.

VII. DUAL-STAR PHOTOMETER

The majority of us work in poor observation locations and therefore must observe when the transparency of the atmosphere is unstable. The only way to improve the accuracy of measurements is to increase the number of readings. Under these conditions a dual-star photometer could be of help. Since it is not possible for us to build a dual-star photometer with two identical channels, we tried to build a simple single-channel dual-star photometer.

The Fabry lens projects upon the PMT photocathode the image of the objective mirror which is uniformly illuminated by the star which is located on the optical axis of the telecope. If we use a large Fabry lens such that it contains the entire field-of-view or exit-pupil of the telescope, all the stars in the field-of-view will illuminate the photocathode, each creating an image of an evenly illuminated mirror in one and the same region of the photocathode. Using three apertures, we let the light of two stars and the sky background pass to the photocathode. With the help of a shutter we can cover the diaphragm is pairs and measure intermittently the variable star, the comparison star, and the sky.

In the focal plane of our reflector the diameter of the field in use is 75 mm, which corresponds to 27' in the sky. Since the loss of light in the Fabry lens is high, we replaced the lens with a mirror. We have a 105 mm diameter, f/160 spherical mirror which provides an acceptable spot of 10 mm on the focal plane. By placing the mirror at an angle of 3 degrees with respect to the optical axis of the telescope, we can reflect the light to the photocathode with the help of a flat mirror. The angle of the Fabry mirror must be at least 20 degrees to avoid the usage of an additional flat mirror. In this case we must deal with the so-called Herschel's asymmetrical optical system in which we notice coma, spherical aberration, and astigmatism. We studied the quality of the image with the help of the Fabry mirror in the photometer model which was attached to the telescope. When we placed the screen which imitates the photocathode at the proper angle, we can angle the Fabry mirror 30 degrees without any noticable image distortion.

One may intuitively think that the quality of the image on the photocathode is not critically important. The main concern is that all of the photons fall on the photocathode and that the position of the image would always be in the same place. As to the latter, the described optical system is very sensitive. The photocathode must be situated exactly in the focus of the Fabry mirror, and if not, the images of two stars will not coincide. However, it is easy the measure the accuracy of the adjustment of the entire system by measuring the sky through all of the apertures.

The shutter may either be in the shape of a revolving disc or a cylinder in which cuts alternately let through the light of the star and the sky. Since the scintillation of the atmosphere does not allow use of very high modulation frequencies, it seems to be more reasonable to move the shutter with two relays. When both are shut there will be the sky signal on the photocathode; when we open one relay the photocahode is illuminated by the light of one star; and when both relays are open, the signal is received from both stars. A computer will easily control the relays, but the most

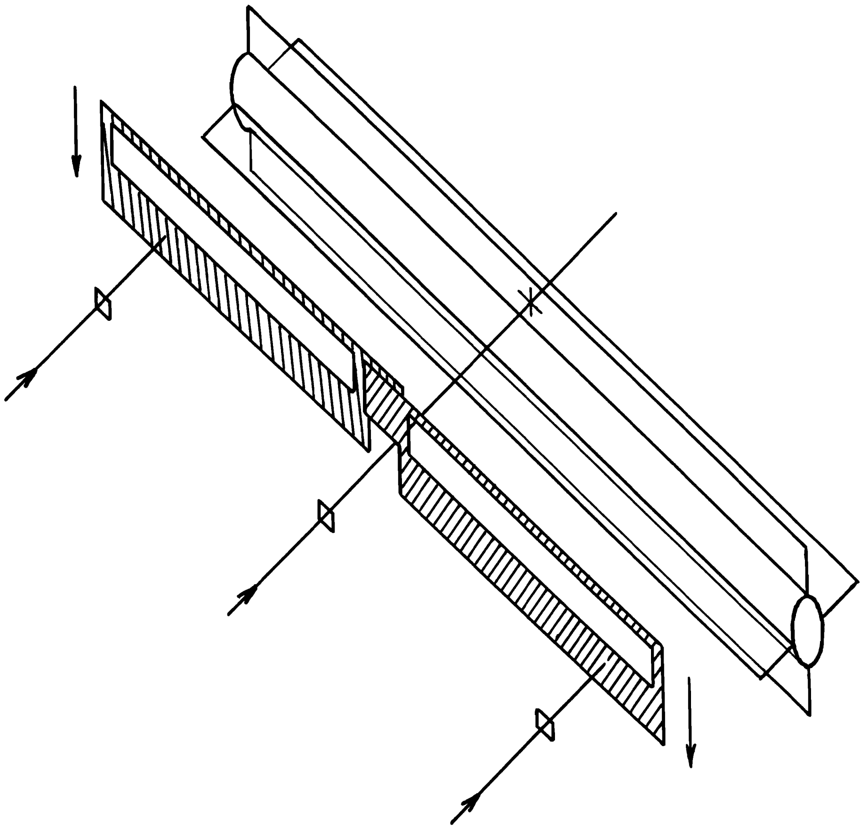

Fig. 7. The DSSC photometer's shutter (controlled by two relays) and filters. Beams through all three diaphragms are seen. The shutter is in the position for the measurement of the sky background.

important thing is that when measuring the stars and sky with different filters, we can use different integration times and the computer will optimize them during the course of the measurements.

In the given optical system it is hard to find a proper place for filters. Since the light paths follow different angles, if the filter were located close to the photocathode there would be a remarkable shift in images due to double refraction. Thus the filters must be placed near the focal plane of the telescope in the shape of long, narrow strips.

The main difficulty in observing with the dual-star photometer is connected with centering both stars precisely in their diaphragms. In the given version we can see the entire field-of-view in the control occular, except for the three diaphragms (the diaphragm of 1 mm in our telescope corresponds to 27" in the sky). By using a reticle with concentric circles, we guide the telescope to a position where the variable and the comparison star are at the same distance from the main optical axis of the telescope. We then turn the photometer over the main optical axis and guide the stars into the diametrical slit. We can control the placement of stars in the slit by using a micrometer screw. We then shift the slider (with wedge-like placed slits) until the stars become invisible, i.e. they are within the parallelogram-shaped diaphragms. For the final centering we use the photometer output and the guider as in the case of the single-star photometer. We can let the light of either one star separately or both stars simultaneously to the photocathode. During the entire measuring procedure we observe that the stars are invisible and do not illuminate the edges of the diaphragms.

It is possible that the photometer which has been describes is only the idée fixe of its author, and could never be put into actual use. Here in Tallinn it is now in the stage of arguing, experimenting, and projecting. It would be very nice to here the opinion of colleagues, and we would be grateful for every piece of advice.

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PHOTOELECTRIC PHOTOMETRY AT VAN VLECK OBSERVATORY

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I. INTRODUCTION

The future of photoelectric photometry is primarily in the hands of astronomers (professionals and advanced amateurs) working with small or medium-sized telescopes often from mediocre sites. At the largest and best-situated observatories, modern detectors like CCD cameras have replaced the once ubiquitous photometer. However, this does not mean that the day of the photometer is over - quite the contrary, the future has never appeared brighter. Frontier astronomical research can be done, and is being done, with a growing number of photometers scattered around the world. The requirements for doing such research are the same as they have always been - a strong desire to do it, a modest investment of capital, careful study and consideration of one's goals, methods, interests and abilities, and lots of hard work. The purpose of this article is to provide some guidance to prospective or active photometrists seeking to do such frontier work, using, as an example, a research program developed primarily by the first author for the 24-inch "Perkin" telescope at Van Vleck Observatory (VVO).

Primarily as a result of the efforts of R.M. Genet, D.S. Hall and other active members of the I.A.P.P.P. there is now a wealth of information and advice available to anyone interested in embarking on a program of photoelectric photometry. Readers of this article will already be aware of the practical guide "Photoelectric Photometry of Variable Stars" by Hall and Genet, as well as compendia on automation techniques ("Microcomputers in Astronomy"), Volume I of "Advances in Photoelectric Photometry", and, of course, the I.A.P.P.P. communications. They may not be aware of, but certainly should read, J.D. Fernie's (1982) article "Photometry Among the Climatically Underpriveleged". Familiarity with the "basics" presented in these sources, as well as a general knowledge of astronomy is assumed in the remainder of this article.

II. EQUIPMENT

The heart of any conventional photometer is the PMT, (see, however I.A.P.P.P. Communication No. 14 on IR and Solid-State Photometry) and a wide variety of choices is now available to the investigator. Selection should be made only after careful consideration of the astronomical problems to which one would like to apply one's efforts, as well as, of course, the size of one's budget. Choosing a tube with extended red sensitivity, for example, can open certain possibilities (e.g. $H\alpha$ line photometry) not otherwise available. At VVO, we use an RCA-C31034A-02 PMT which is the instrumental standard of the Cousin's system (e.g. Bessell, 1979). In the opinion of the present authors, this system, which is well defined both instrumentally, and by standard stars (for equatorial standards see Landolt, 1983), should (and will) supercede the extended Johnson system for routine UBVRI photometry. (See Hall, 1983, and references therein for another opinion and further discussion).

The case for doing R,I photometry, particularly of Mira variables, is made in I.A.P.P.P. Communications No. 14. Let us add, more generally, a plea to consider other alternatives to "just" UBV work, as well, especially for variable stars. If the mechanism of variation of the stars you are observing is not understood, as is the case for T Tauri stars, for example, the best way to constrain it is to obtain, in as much detail as possible, the wavelength dependence of the variations. We found, for example, that even qualitative characteristics of the variability of T Tauri stars are different in UBV than they are in RI (Herbst et al., 1982, 1983). Even if the variation mechanism is established, the details of its workings, can only be learned by as full a wavelength coverage as possible. Since it takes relatively little time to rotate through a few more filters, compared to the set-up time on a star, it also often makes sense to expand one's wavelength coverage purely from an efficiency standpoint.

When considering the choice of filters, we recommend serious thought be given to the use of wide and intermediate band interference filters which can isolate the light of particular spectral lines. Obvious choices would be $H\alpha$ and $H\beta$, but for some stars (eg. those with active chromospheres like RS CVn's and T Tauri's) a filter centered on the K-line of CaII might produce very interesting results. An advantage of $H\alpha$ photometry done, for example, through a wide (150 Å) and intermediate (30Å) band filter is that there is no extinction term to worry about in the "color" reductions (since both filters are centered on the same wavelength), and useful data may be obtained on nights which would otherwise be worthless. $H\alpha$ equivalent widths can be extremely important pieces of information on variable and non-variable stars alike, and it is a shame that more photometric effort is not directed at obtaining them. The inteference filters in use at Van Vleck Observatory were obtained from Spectro-Film, Inc. of Winchester, Massachusetts.

III. AUTOMATION

It is undoubtedly true that the ease with which photometry can now be automated has led to, and will continue to spur, the enormous growth of popularity of the technique in some circles. There are basically three areas in which automation can be applied: data handling, photometer control, and telescope control. At Van Vleck Observatory (VVO), we have adopted the strategem of proceeding with automation in that order, but never shutting down our actual observing just to support the automation process.

The "first-generation" photometer and automated data-handling process at VVO has been described by Herbst (1983). Its primary element is an LSI 11/02 microprocessor which receives the serial-line output from a PAR model 1109 pulse counter, and records it on floppy disk. A problem with floppy disks is that, at present, they do not have sufficient storage to allow one access to all the data that one would normally like to see at once. For example, stars observed on more than one night over a period of several months may be spread over many disks. Floppies also should not be used as an archival storage system. Therefore, we write out data to magnetic tape at the end of each night. If tape is not available, an alternative is to use a hard copy for archival purposes and to reduce the data each night, separating it by object and storing each star's data on its own floppy disk. The advantages of "quick-look" capabilities afforded by automated data handling are well known, and in section III we describe a simple analysis technique which can be used to help observers make on-line decisions about "what to do next".

A modification of our first photometer, implemented last year, was to encode the filter wheel. Four microswitches triggered by protrusions from the shaft of our circular filter wheel provided the four bit code which was communicated through a parallel interface board (DRV 11) to our microprocessor. A commercially available LSI lab software package provides FORTRAN called subroutines which can read/write the input/output registers of the DRV 11. (One must configure one's RT-11 operating system properly to handle this, but instructions for doing so come with the lab package). Anyone with a system similar to ours should be warned that it may be necessry to <u>write</u> zeros to the <u>read only</u> register of the DRV 11 (in order to initialize it) prior to trying to read any externally supplied information. Lack of this knowledge, which is not available in any source we have ever found, caused a two month delay (and much heart-ache!) in placing our filter wheel encoder into operation.

A fully automated photometer for the Perkin telescope is now being bench tested at VVO. We use stepper motors to drive the diaphragm wheel and filter wheel, which also carries a prism for viewing. The design is based on one described by Fried and Mannery in "Microcomputers in Astronomy". We have added a third wheel in front of the other two, which will carry neutral density filters, in order to permit observation of bright stars (eg. Betelgeuse!). We have designed and constructed a stepper motor controller, which communicates with the LSI-11 through a DRV 11 parallel interface board. The controller has a manual mode, as described below, so that observations can be continued even in the event that the computer malfunctions. We turn now to a description of the controller. Anyone interested in obtaining the design, or (possibly) having one built for them by us should contact the authors.

The electronic control for the photometer is designed to accept manual control signals from switches or a 16 bit binary word from a computer. Here is a list and description of all functions of the electronic controller.

Single Step: Lets you advance a filter wheel one step each time you press the manual button or for each pulse the computer gives.

Cycle: Starts a routine of advancing a filter wheel a certain number of steps which is determined by the thumbwheel switch settings or by a BCD code on the computer line.

Initialize: Upon "power up" the unit should be initialized, meaning set to a known location. By activating the Initialize switch or by a computer controlled pulse, each wheel will move until it has reached its home position determined by a microswitch located on each wheel.

Direction: Controls the direction of the filter wheels by use of a toggle switch or computer controlled level.

Motor Select: A rotary switch lets you determine which filter wheel you want to move. The computer input uses a two digit binary number to select the different motors.

Display: The display consists of a series of three, three digit numbers each keeping a running tally of its associated wheel. The motor select determines which display is enabled. The display will count from 000 to 199 with each count being one step of the motor.

Man/Comp: This switch puts the contoller in the manual mode or computer mode. When in the manual mode all computer inputs are disabled and when in computer mode all manual functions are disabled.

Thumbwheel: Lets the operator manually select the number of steps the motor will move with a range of 000 to 199.

The photometer contains three stepper motors each with a resolution of two hundred steps per revolution. The rate of speed of the motors is determined from an oscilator which is set at approximately one hundred steps per second.

The controller for the photometer has manual controls or, through the use of an external connector can be controlled by a computer. Before starting operation the photometer must go through an initialization procedure. By applying an initialization pulse the motors will begin to turn until each has reached its starting position designated by a switch assembly on each wheel. Only one motor will move at a time. To begin normal operation a BCD code is used to determine the number of steps the motor has to travel. A cycle pulse starts the motor moving by enabling the oscillator. The motor will move the number of steps specified by the BCD code applied. A set of counters counts the pulses which correspond to steps of the motor. When the counters have reached the same BCD code that was applied a comparator circuit shuts down the oscillator which stops the motor. The process can be repeated by changing the BCD code if necessary and applying another cycle pulse. The motor can be moved one step at a time for fine tuning by using the single step input. This input has no effect on the cycle length.

The display will keep track of the movement of the motors by counting the pulses applied to the motor. There are three displays each keeping track of one of the motors. The direction is also translated to the display with a forward count for clockwise and a reversal of count for counter clockwise. During initilization the displays are reset to 000 and no other function can take place until this cycle is completed. The controller is equipped with one handshaking signal. This signal is transmitted to the computer upon completion of the initialization procedure and at the end of each normal cycle.

The final stage in the process of automating photometry at VVO is still being planned. If funding can be obtained we would like to mount a low light-level TV camera at the eyepiece of the automated photometer, encode the telescope axes and dome and make operation of the telescope a completely remote, "warm room" affair. Movement of the telescope and dome would still be accomplished by manual operation of control paddles, but from a remote location. If this phase of operation is successful, we might eventually attempt to use the existing drive motors on the telescope axes in a feedback loop with the encoders to place the telescope under computer control. Then completely automated observing will be possible, assuming that the stars on the program are bright enough to allow automated centering using the output of the photon counter. This may be a problem for some of our T Tauri stars, given their faintness, and the brightness of the night sky at VVO. We are considering, for these stars, the possibility of auto-centering on nearby bright stars and then offsetting by the proper amount. Obviously we have much to do, if this automation plan is to succeed, and our cardinal rule remains, "Photons First" ---- if you miss one it's lost forever!

IV. OBSERVING STRATEGY

Fernie (1982) has addressed the question of whether or not accurate photoelectric photometry can be done on a worthwhile number of nights in a mediocre climate (eg. Toronto, which is probably typical of locations in eastern North America). His answer is a resounding "yes", and he discusses some observing strategies for obtaining the best results. At VVO in Middletown, Connecticut, we have, at best, a mediocre climate, and, being located in the middle of the campus of Wesleyan University, an extremely bright sky (V = 18.6 mag/square second on a moonless night, with no snow on the ground) as well. We, nevertheless manage to do photometry on a standard system (UBVRI) of relatively faint stars with a typical dispersion (of a single data point) of 0.02 mag on $\sim$6 or 7 nights per month. Our observing strategy differs from those described by Fernie, and we present it as an alternative which might be useful especially in programs where a particular set of variable stars is monitoired over a long period of time (one or more observing seasons).

Basically, our approach is to do only "differential" photometry, choosing a "comparison" star and "check" star for each program star. If the comparison stars are close enough, one can forget about first order extinction corrections altogether, since the air mass differential will be so small. If possible, choose comparison stars with about the same color as the program star (use the raw-counts from your photometer to estimate colors of a potential comparison star). This will make second order extinction coefficient terms negligible, and reduce any errors arising from poorly determined transformation coefficients. With comparison stars chosen in this manner, transformation to the standard system is simple. For example, for UBV photometry,

$$\Delta V = \Delta v + t_v(B-V)$$
$$\Delta (B-V) = t_{bv} \Delta (b-v)$$
$$\Delta (U-B) = t_{ub} \Delta (u-b)$$

where capital letters denote standard system magnitudes, small letters instrumental system magnitudes, Δ's the difference between program star and comparison star,and t's the transformation coefficients. Transformation coeficients normally change only slowly with time (although possibly with temperature, as well) and may be determined in the standard ways (eg. see Hall and Genet, 1982, or Fernie, 1982) on a couple of excellent nights per year. These nights can also be used to obtain U,B,V magnitudes for the comparison and check stars, so that actual magnitudes can be reported, instead of differential magnitudes. Professional astronomers can also make use of small telescopes at good sites, such as Kitt Peak for this purpoose. As a general practice,we repeat each differential measurement cycle (program, comparison, check) three times. This weeds out accidental errors efficiently. If on-line reductions are available, repeating twice can be sufficient to insure a good measurement.

Another issue worth addressing is the question of how long one must integrate on a particular star in order to achieve a desired accuracy. It is well known that for any count, N, there is associated with it an uncertainty of (at least) $\sqrt{N}$. If we call the sky count, S, and the star plus sky (total) count T, then one can show, with a little algebra, that

$$T = \frac{(1 + S/T)}{(1 - S/T)} \cdot \frac{1}{\delta^2}$$

where δ is the fracional uncertainty in the count for the star alone. For values near 0.01, this is equivalent to the uncertainty of the brightness of the star expressed in magnitudes. For example, if we wish to determine the magnitude of a star to ± 0.01 mag., and the sky count is negligible compared to the star plus sky count ($S/T<<1$), then we require at least $T=1/\delta^2 = 10^4$ counts. Since there may be other sources of error besides the random fluctuations in arrival time of the photons, the value of T calculated should be considered a lower limit to the number of counts one ought to obtain to achieve a desired accuracy.

As a practical matter, we have found it useful at VVO to have, in the dome, a plot of T versus S/T for various values of δ as shown in Figure 1. Having taken a sky reading and a star plus sky reading, it is a simple matter to estimate S/T and, from the plot, T for the desired accuracy. Note that this analysis assumes that equal time will be spent integrating on the star and the sky. Obviously, in the case that T>>S, it is not necessary to do

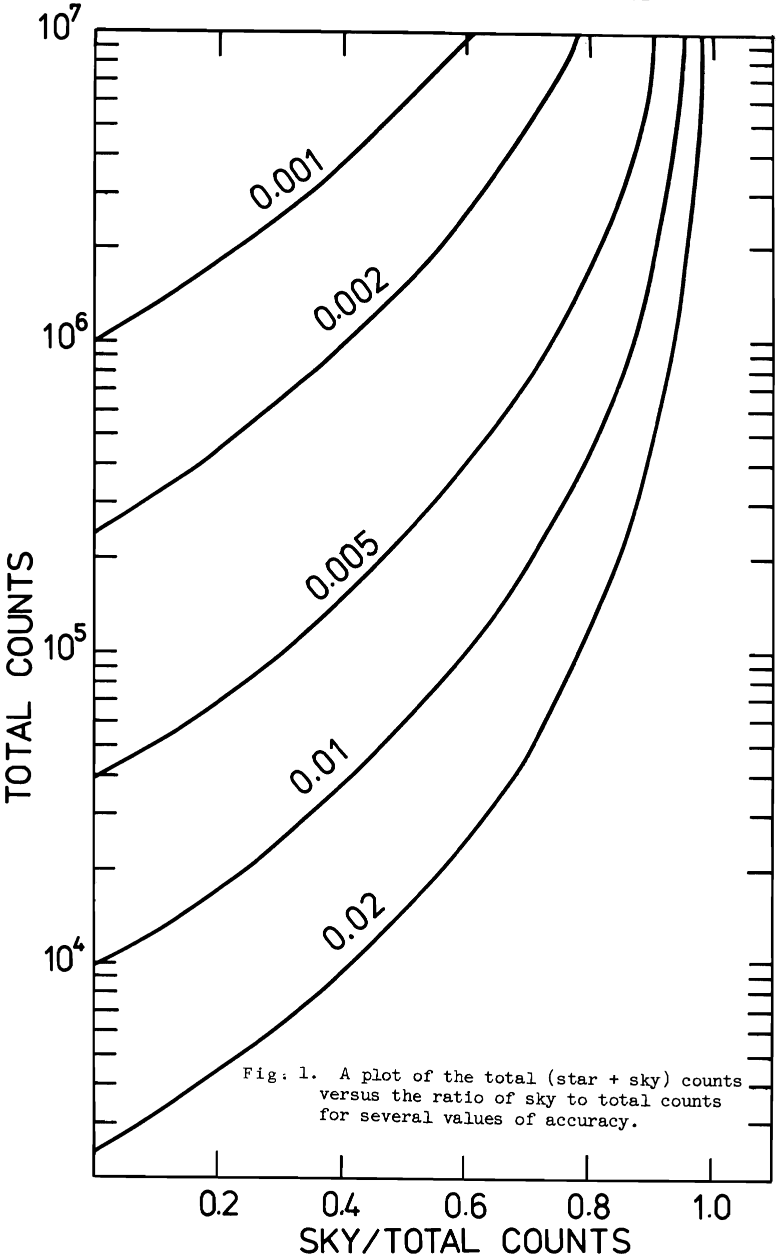

Fig. 1. A plot of the total (star + sky) counts versus the ratio of sky to total counts for several values of accuracy.

so. For a more complete discussion of this question, the reader is reffered to FitzGerald and Shelton's (1982) paper.

V. MONITORING ORION POPULATION VARIABLES RS CVn's AND FLARE STARS

The advanced amateur or professional, whose equipment is sophisticated enough to permit observations to $V \sim 12$ or 13, can make a major contribution to astronomy by concentrating on the irregular variables which make up the Orion Population. These stars have largely been ignored by photometric observers in North America and Europe, although a good deal of work has been carried on in the Soviet Union and East Germany. Western photometrists seem to regard them as too complex and unpredictable to be worth studying. The facts that they are so complex, that their variability can not be characterized in simple ways, and that even the basic mechanism of their variation is not yet understood, are precisely what makes them interesting. A word of caution is in order, however. Light curves in a single color for the irregular variables, such as visual observers obtain, while having some value, are not enough to unlock the secrets of these stars. At least three color photometry, preferably including bands redward of V, is requiured of serious work. Simultaneous Hα photometry has also proven useful.

The best known subset of Orion Population stars is the T Tauri's. They are pre-main sequence stars of about 1 solar mass, and probably have much to tell us about what the early sun and solar system were like. Debate continues to rage over whether their irregular variations are caused primarily by changes in the (dust) envelopes or by phenomena closer to, or in, the stellar photosphere (eg. flares, sunspots, plages,etc.). The Hα and color changes which we have observed for a sample of about 10 stars at VVO lead us to favor the latter hypothesis. However, the sample size needs to be increased, and a larger variety of types of T Tauri stars included before a definitive conclusion can be reached. Anyone contemplating work in this field would do well to read George Herbig's (1962) old, but still useful paper, as well as Cohen and Kuhi's (1979) monumental study. The catalogue of Orion Population stars with emission line spectra compiled by Herbig and Rao (1972) is a useful starting place for choosing potential program stars. Rydgren, Schmeltz, and Vrba (in preparation) are preparing a catalogue of UBVRI and infrared photometry of T Tauri stars to be published by the U.S. Naval Observatory. It should also be a useful starting place for designing an observing program. The interested reader is also encouraged to write to the first author of this article for further information and suggestions concerning a T Tauri star monitoring program.

In many ways the T Tauri stars resemble in their behaviour, the RS CVn stars, a group familiar to all members of the I.A.P.P.P. through the work of D.S. Hall. It is quite conceivable that the underlying cause of variation in the latter group - starspots - is involved in the variations of the former. A characteristic of all magnetic related phenomena on stellar surfaces is its high degree of irregularity and unpredictability. This makes them very difficult to study at major observatories where limited amounts of telescope time are parcelled out to observers months in advance. If one's goal, for example, is to study flare activity on these stars, or possibly related objects such as BY Dra stars, FK Com stars, or traditional flare stars, one must be prepared to spend a lot of time simply waiting for a flare to happen. Smaller observatories, with dedicated instruments, especially if highly automated, should have significant advantages in this kind of work. Conversely, it is studies such as these, involving a large amount of data over an extended period of time, on which they should concentrate their efforts. Once again, we applaud the I.A.P.P.P. for making the information necessary to embark on these programs so readily available to any interested person.

VI. ACKNOWLEDGEMENTS

We would like to publicly thank, once again, Mrs. Richard S. Perkin and the Perkin Fund for their support of our program, as well as Research Corporation and NSF. The new, fully automated photometer, was constructed with the help of a Dudley Award to the first author and Harold L. Nations from the Dudley Observatory, and we are grateful to that organization for their support.

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THE PHOTOELECTRIC PHOTOMETRY OF YUNNAN OBSERVATORY OF THE CHINESE ACADEMY OF SCIENCE

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I. PHOTOMETRIC CONDITIONS AT YUNNAN OBSERVATORY

Yunnan Observatory of the Chinese Academy of Science is situated on Phoenix Hill on the eastern suburbs of Kunming city in the southern China province of Yunnan. It is approximately 2000m above sea level at eastern longitude 104° 46', northern latitude 25° 02'.

The weather conditions can be summed as follows. The average annual temperature is 14.9° C (59° F), and the mean difference of temperature between day and night is 11.1° C. The variation of temperature during one night is within the range of 4.5° C, and the annual average of relative humidity is 71%. About 200 nights each year may be available for photometric and spectral work; 50% of them are suitable for photoelectric photometry and experience has shown that good results can be achieved. Most of the good nights are in the winter and spring seasons. The brightness of the night sky is roughly 20 magnitudes per square arcsec in V band due to the light from the city of Kunming. Although tests have not yet been made systematically, seeing of about 0.7 arcsec can be expected quite frequently. The annual average values of the atmospheric extinction coefficients for UBV system have been determined to be: K_y = 0.167, K_{by} = 0.186, and K_{ub} = 0.267.

There are two Cassegrain telescopes used for photoelectric photometry at Yunnan Observatory, with primary mirrors of 100 cm and 35 cm diameter, and 45' and 25' field of view respectively. The focal lengths are 13.6 m for the 100 cm telescope, and 5 m for the 35 cm one.

II. THE PHOTOMETERS

The integrating photometer system which we designed, has been installed on the 100 cm telescope. It allows us to choose any integration time according to our request. A microcomputer controls the photometer, automatically acquiring and reducing photometric data.

This photometer system is a single-channel one, but two

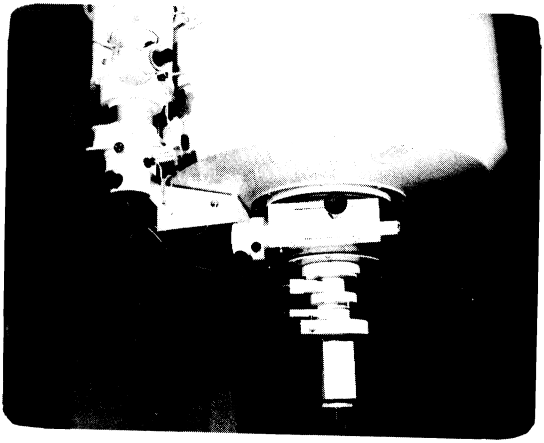


Fig. 1. The 100 cm telescope with its integrating photometer at Yunnan Observatory.

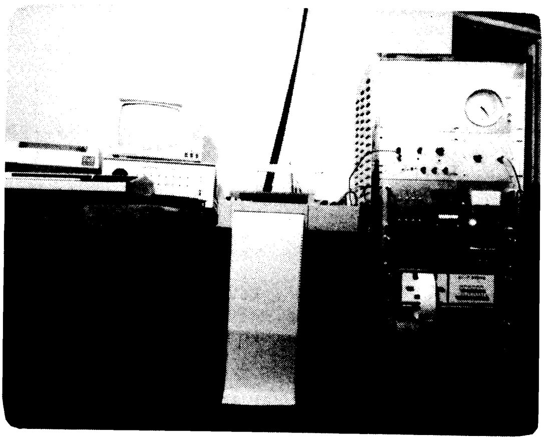


Fig. 2. The integrating photoelectric photometer.

heads are provided for the observer's selection. It also consists of the supporting electronics, the data system, and software. The skeleton drawing of the integration photometer is shown in Figure 3.

1). THE PHOTOMETER HEADS

Two photometer heads with finding and guiding microscopes have been designed for the UBV and the Strömgren four-color systems. Three diaphragms of 0.5, 1.0, and 2.0 mm diameter (corresponding to 8, 16, and 32 arcsec in solid angle respectively for the 100 cm telescope) are available. In the Strömgren system, narrow-band and wide-band filters for the Hβ line are included with the four UBVY filters, and an EMI 6256 photomultiplier is utilized. The other head is very close to Johnson's UBV system, so that observation data obtained with this system can be easily transformed to the standard UBV system.

2). THE SUPPORTING ELECTRONICS

The system is composed of two amplifiers: A high input impedance photoelectric current amplifier with 100% negative feedback, and an integrating amplifier with high open-loop voltage gain. In order to integrate the output voltage of the current amplifier, an RC integration circuit composed of a capacitor in the feedback loop and a resistor in the input circuit is used in the integrating amplifier, and controlled by an accurate relay driven by the timing circuit. In the amplifier, eight sensitive steps are set to match different ranges of input voltage. Therefore, the measurable range of the photometer for bright stars is not limited by the supporting electronics, but by the linearity of the photomultiplier tube. The zero point drift is an annoying problem for D.C. amplifiers; in our case, the zero point drifts of both amplifiers are less than 0.3 mv/hour (output), good enough for differential photometry.

In addition, the supporting electronics also includes the digital clock with five decimal digits and the time-state controller, etc. The clock not only displays time, but also supplies the microcomputer BCD time signal. The controller produces the required interval of time to determine the integration time and signals to select various working modes of the integrating amplifier. The circuit of the controller works in a self-locking mode. If the controller receives another command for starting a new integration during the integrating time, it will not respond, thus proceeding with the original cycle without any interference.

3). THE DATA SYSTEM

The data system consists of the microcomputer system and the interfaces including a digital interface and an analog one. The digital interface is a DI/DO modale board which can receive input data of 48 bits and output data of 8 bits through three-state buffers. The analog interface contains an eight-channel analog switch, a sample-hold amplifier (sample error less than 0.01%), and an A/D converter (ADAD80 12 bits, converting time 25 μs).

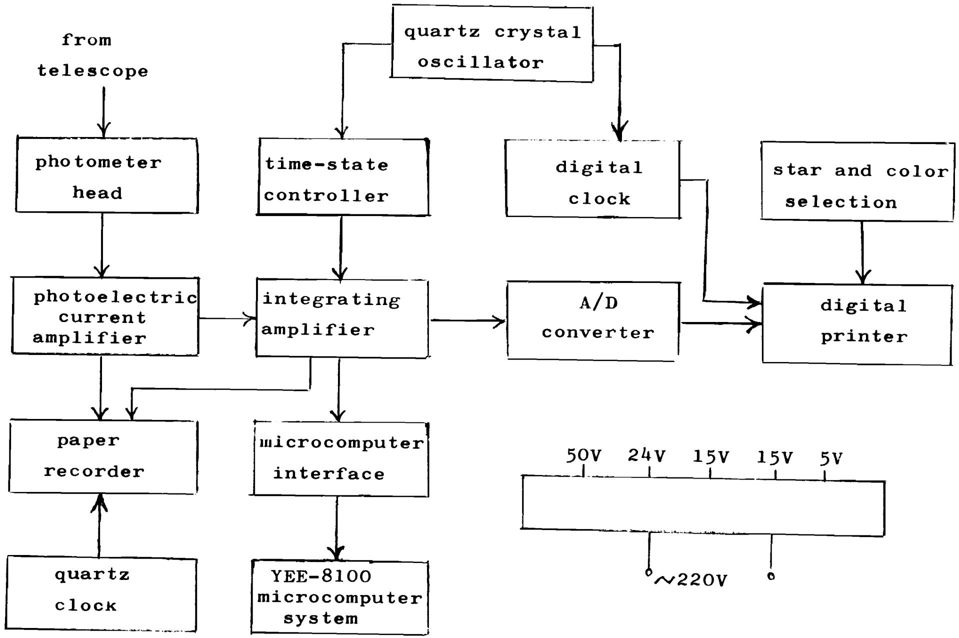


Fig. 3 The skeleton drawing of the integrating photometer

4). SOFTWARE SYSTEM

In addition to the system software of the microcomputer, the DAP program (written in BASIC and assembly language on the Z-80 microcomputer), is used for real-time data acquisition and reduction during observation. The flow chart for the program is shown in Figure 4.

There are nine special keyboard commands in the DAP program. Some of which offer observers the possibility to discover and handle abnormal conditions. They are (1) the data acquisition command, (2) the stop command (for storing the primary data and intermediate information on disk and waiting for the next running without the need for additional man/machine interaction), (3) the list command, (4) the displaying figure command, (5) the replace command (for changing variable star by check star in the observing procedure), (6) the deletion command, (7) the store command (for saving the primary data or the results of real-time data reduction on the disk), (8) the time sequence acquisition command, and (9) the end command.

Furthermore, the capabilities of fault diagnosis and detection/correction are designed in the DAP program. Faults coming from the A/D converter or the integrating control circuit can be automatically detected and displayed on the screen so that observers may decide how to handle them. As a result, real-time mistakes in the data reduction can be modified at once. The problems of storing data on the disk can be handled automatically, and at the same time the observation procedure, data acquisition number, observation accuracy, etc. are displayed on the monitor screen.

There are two auxiliary record systems in addition to the microcomputer: an analog one and a digital printing one. In the event the microcomputer dies, the photometer will still work properly, and two independent sets of observation data can be collected from the analog recorder and the digital printer.

This integrating photoelectric photometer has been used as a routine equipment of the 100 cm telescope since 1981. Another D.C. photoelectric photometer (non-integrating) is mounted on the 35 cm telescope now, but it will be replaced with a new one in two or three months that is similar to the integrating photometer of the 100 cm telescope.

III. PROGRAMS FOR REDUCTION OF PHOTOMETRIC DATA

A set of programs for reduction of photometric data of eclipsing binary stars is written in BASIC at Yunnan Observatory. Results show that the programs are reliable and convenient. These programs include:

(1) Determination of the first-order and color-dependent atmospheric extinction coefficients.

(2) Determination of the transformation coefficients.

(3) The transformation to the international standard UBV system with the following equations:

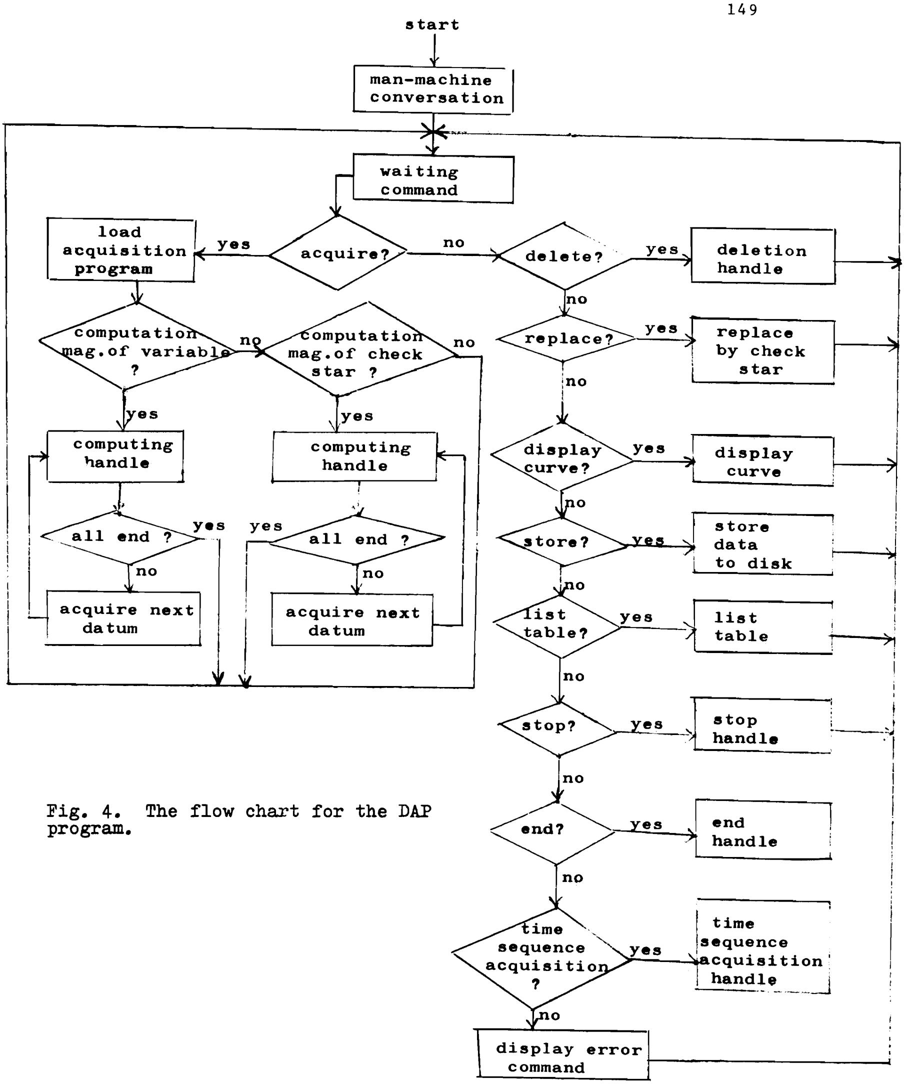


Fig. 4. The flow chart for the DAP program.

$$V = \Delta y - Ky\ \Delta X + A1\ \Delta(B-V)$$

$$\Delta(B-V) = A2\ \Delta(b-y) - A2\ Kby\ \Delta X - A2\ K'by\ \overline{X}(b-y)$$

$$\Delta(U-B) = A3\ \Delta(u-b) - A3\ Kub\ \Delta X - A3\ K'ub\ \overline{X}(u-b)$$

where ΔX and $\Delta \overline{X}$ are air mass difference and mean air mass between the comparison and the variable stars respectively; Δy, $\Delta(b-y)$, $\Delta(u-b)$, ΔV, $\Delta(B-V)$, and $\Delta(U-B)$ are raw and standard differential magnitudes and color indices; Ky, Kby, Kub, K'by, K'ub are first-order and color-dependent atmospheric extinction coefficients; A1, A2, and A3 are the transformation coefficients.

(4) Calculation of the accuracy of the observations.
(5) Heliocentric correction of time.
(6) Determination of the epoch of minimum light of an eclipsing binary star with one of the following methods:

(a) the Kwee and van Woerden method
(b) the quadratic fit method
(c) the cubic fit method

(7)Determination of the period and analysis of the period change.
(8) Ordering the observations according to their phases and combining the observations into normal points.

These programs can be used to reduce photometric data of an eclipsing binary star on the microcomputer. For further interpretation of an eclipsing binary star (for example the various analyses of the light curves), a larger computer is required. We have a copy of the Wilson-Devinney program and a copy of the Wood program in FORTRAN, which help us determine orbital elements of an eclipsing binary system.

IV. ECLIPSING BINARY STAR RESEARCH

Since the first photoelectric observations were carried out at Yunnan Observatory in 1980, we have spent much time establishing the Yunnan Observatory's instrumental UBV color system and uvby color system and their transformations to standard systems. We have also devoted time to measure atmospheric extinction coefficients and the darkness of the night sky at Yunnan Observatory. Our research is devoted to observation and interpretation of eclipsing binary stars. So far, more than 10 eclipsing binary stars have been systematically observed and the results are gratifing. Detailed studies are devoted to UZ Leo, R CMa, WX Cnc, ZZ Aur, Ax Vir, ER Ori, and FG Hya.

UZ Leo is a W UMa-type eclipsing system with a period of 0.618 days. Two epoches of minimum light were measured in 1980 and 1981. The period variation in the system was studied. After combining our data with data from others, we discovered that its period suddenly increased by 0.72 seconds in 1949 and again suddenly increased by 0.59 seconds in 1966.

R CMa is a well-known Algol-type eclipsing system which has been studied by many astronomers. They found that its 1.1359435 day period once had a sudden decrease in 1914. We observed it in 1981. Combining the times of minimum light measured by other observers with ours on the O-C diagram of the period change, we noticed that the accumulated effect had caused a quasi-sinusoidal period. Since there is no evidence of apsidal rotation in the system, it is supposed that the quasi-sinusoidal period variation may be attributed to a third body in the system, whose mass function may be $f(m) = 0.024M_{\odot}$.

WX Cnc is an Algol-type eclipsing binary star with a period of 1.22458 days which had not yet been observed photoelectrically by 1981, when we observed it. The light curves in B and V band are shown in Figure 5.

Since the secondary eclipse of the light curves are deep enough for solving the light curves, four solutions have been obtained with the Russell-Merrill method using the primary and secondary eclipses of the light curves in B and V band. All of them are very consistent within possible errors.

ZZ Aur is a β Lyra type eclipsing binary star with a period of 0.601216 days. We observed it in the B and V band in 1981 and obtained light curved which were solved with the Russell-Merrill and Wilson-Devilley methods. The results are listed in Table 1. The system is found to be a semi-detached system with low mass component filling its Roche surface. The radius of the massive component is fairly close to the Roche surface and its size is larger than that of its contact component. This configuration and the theoretical light curves according to the parameters in Table 1 are graphed in Figure 6.

AX Vir is a β Lyra type eclipsing binary star with a period of 0.7025268 days, and it was observed in 1982. The light curve obtained in V band was analysed with the Russell-Merrill and Wilson-Devinney methods. The results are shown in Table 1 and in Figure 5. It is a semi-detached binary star similar to ZZ Aur.

ER Ori is a very interesting eclipsing binary star studied by many astronomers. We observed it in B and V band from December 10, 1980 to January 9, 1981. The light curves were analysed with three different models of the Wilson-Devinney program (contact, semi-detached, and detached models), the solutions being almost the same within probable error. So it is believed that ER Ori is a typical marginal contact system, but the overly large radii of the components relative to their masses show that the system may be evolved, in contradiction with the W-subtype or the marginal contact state as mentioned above. The parameters in Table 1 are those calculated with contact model. The theoretical light curves and configuration are shown in Figure 7.

FG Hya is a W UMa-type binary star undergoing a complete eclipse. The interval of the complete eclipse is a tenth of the period and the eclipse is so shallow that no reliable elements could be previously determined. We observed this

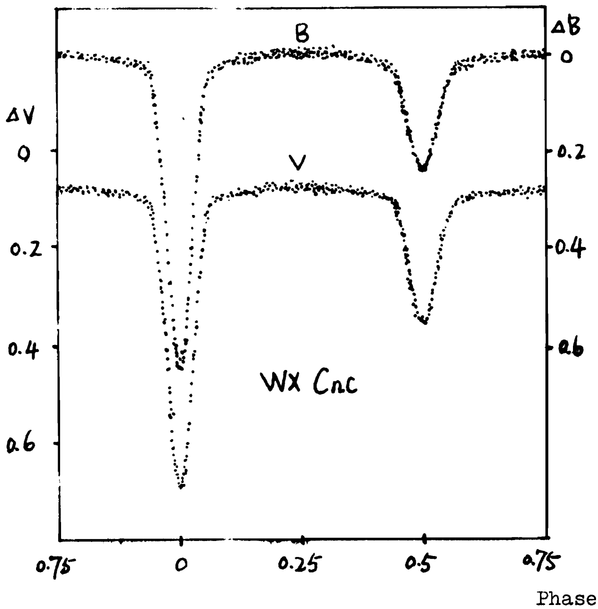


Fig. 5. The light curves of WX Cnc. The setting and rising branches are slightly asymmetric.

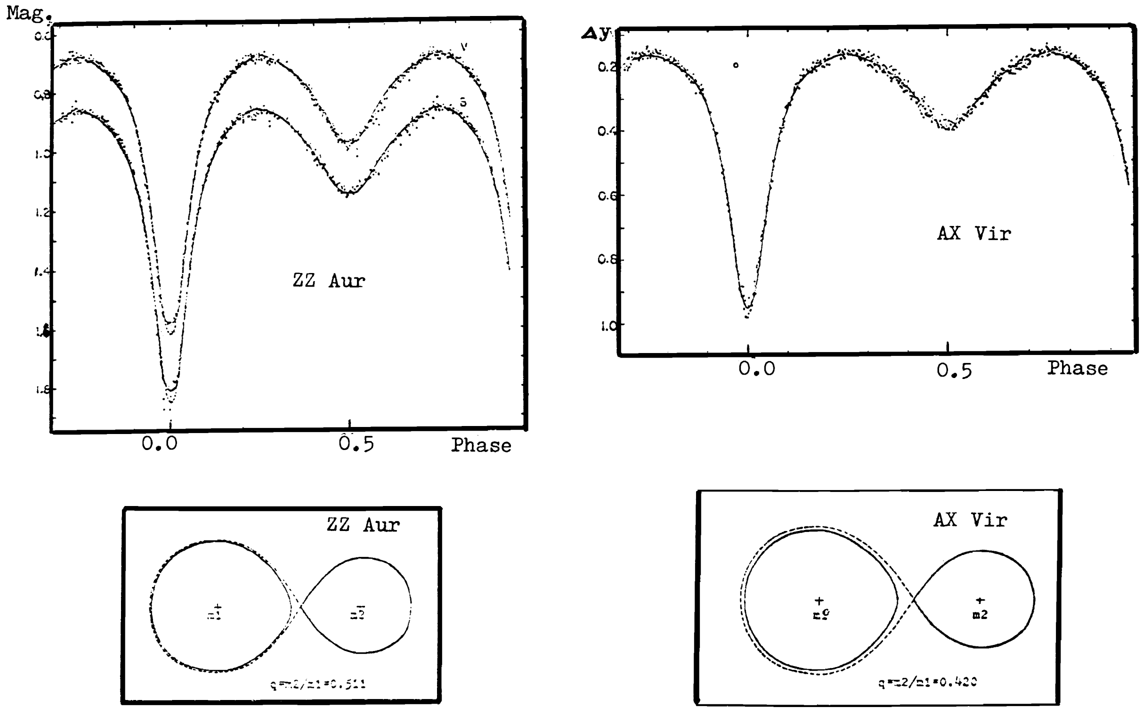


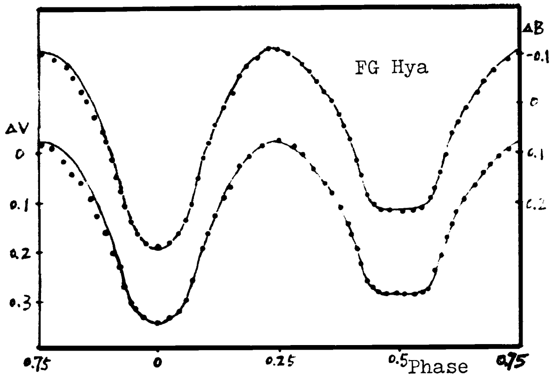
Fig. 6. Observations of ZZ Aur and AX Vir, and their theoretical light curves and the configurations which correspond to the parameters in Table 1. In the diagram of ZZ Aur the dashed light curves represent the results without the third light source.

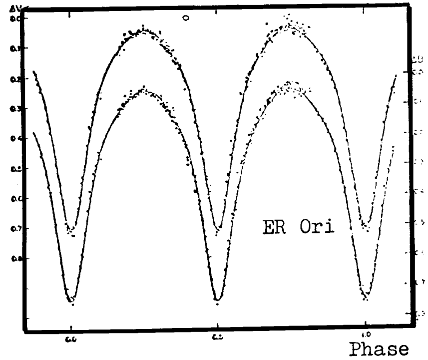
system in 1981 and in 1982. The light curves obtained are asymmetric, in particular the setting branch of primary minimum is lower than that of the theoretical light curves. But our light curves do not show that the maxima following secondary eclipse are higher than those following primary eclipse, as suggested by L. Twigg when he analysed the light curves observed by L. Binnendijk in 1961 to 1962. Our solutions obtained with the Wilson-Devinney program are listed in Table 1. The theoretical light curves fit to the observations combined into normal points which are shown in Figure 7, where the configuration is graphed. It is an over-contact system with the over-contact degree of 52.8%.

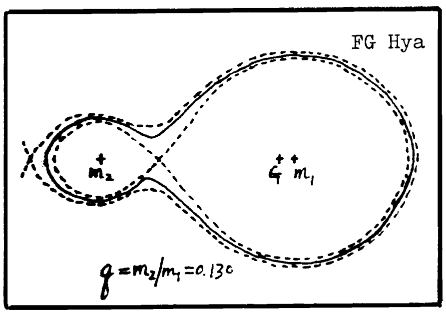
Table 1 Photometric solutions of four systems

elements	ZZ Aur	AX Vir	ER Ori	FG Hya
L1/(L1 L2) V.	0.9134 0.0004	0.9342 0.0002	0.3929 0.0008	0.8676
L1/(L1 L2) B.	0.9383 0.0003	....	0.3970 0.0009	0.8706
X1 V.	0.52#	0.45#	0.582 0.014	0.64#
X1 B.	0.62#	......	0.743 0.015	0.78#
X2 V.	0.52#	0.45#	....	0.64#
X2 B.	0.62#	......	....	0.78#
i	89.65 0.24	82.56 0.27	80.579 0.068	88.00
q m2/m1	0.5105 0.0025	0.4199 0.0036	1.6267 0.0021	0.1296
A1	1.00#	1.00#	0.50 0.02	0.50#
A2	0.63 0.05	0.54 0.03	....	0.50#
g1	1.000#	1.000#	0.547 0.021	0.50#
g2	0.89 0.05	0.68 0.03	....	0.50#
T1 (K)	8200#	9600#	5800#	5980#
T2 (K)	5405 22	5624 29	5775 4	5827
Ω1	2.9202 0.0035	2.8152 0.0074	4.7264 0.0033	2.0018
Ω2	2.8959 0.0035	2.7184 0.0071	4.7265 0.0033	2.0018
r1 (pole)	0.4084 0.0006	0.4119 0.0012	0.3148 0.0003	0.5298
r2 (pole)	0.3012 0.0006	0.2860 0.0013	0.3956 0.0003	0.2195
r1 (point)	0.5129 0.0025	0.4916 0.0033	0.4126 0.0019	......
r2 (point)	0.3944 0.0036	0.3765 0.0083	0.4993 0.0015	......
r1 (side)	0.4319 0.0007	0.4348 0.0015	0.3284 0.0004	0.5892
r2 (side)	0.3138 0.0007	0.2978 0.0016	0.4173 0.0004	0.2300
r1 (back)	0.4590 0.0009	0.4570 0.0019	0.3600 0.0005	0.6131
r2 (back)	0.3461 0.0011	0.3301 0.0024	0.4461 0.0005	0.2795
Ω(inn.)##	2.8959	2.7184	4.7264	2.0476
Ω(out.)##	....	....	4.1303	1.9633
% over-con.	....	....	0	52.8

Assumed; ## Theoretical Value







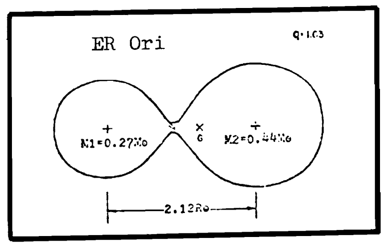


Fig. 7. Observations of ER Ori and FG Hya and their theoretical light curves and the configurations which correspond to the parameters in Table 1. In the diagram of FG Hya, the dots show the normal points.

11

THE GENEVA PHOTOMETRY

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I. THE GENEVA CATALOG

The Geneva photometric catalogue contains 14633 stars in its most recent edition (Rufener, 1981), and 23200 stars in the latest version (1984) available at the Geneva Observatory. This corresponds to more than 150000 individual measurements made with the set of seven passbands $UBVB_1B_2V_1G$, and collected during observations made in both hemispheres. This observational material represents about 20000 hours of recording at the telescope.

The contents of the catalogue are subdivided into four parts. The first part gives, for each star, the bibliographical information necessary for its identification. This consists of the DM number of the star when it figures in one of the Durchmusterung catalogues (BD, CoD, CpD) as well as of its HD number when it is also present in the Henry Draper spectroscopic catalogue. We also give the Bayer and Flamsteed designations and the serial number in the Bright Star Catalogue (BS). A special column is reserved for particular designations related to cluster membership. The second part gives the six independent colour indices; these are the magnitudes measured in each passband and from which the magnitude obtained in band B has been subtracted (colours normalized relatively to B). These data are accompanied by the number of good measurements used for these estimates and the mean standard deviation obtained during the computation of their mean values. The third part gives the corresponding values of some of the simpler to interpret colour combinations. Particularly the combinations $d = (U-B_1) - 1.430(B_1-B_2)$; $\Delta=(U-B_2) - 0.832(B_2-G)$ $g = (B_1-B_2) - 1.375(V_1-G)$; $m_2 = (B_1-B_2) - 0.457(B_2-V_1)$ which are practically independent of the reddening due to interstellar matter. The fourth part gives the V magnitude, with the number of good measurements used to define it and the corresponding standard deviation. Whenever possible,we quote the spectral type given in the literature and we provide a remark if the star is a visual binary not separated during the measurement, a spectroscopic binary,or is known to be a variable. A facsimile of the first page is shown in fig.1.

II. THE ORIGIN OF GENEVA PHOTOMETRY

The Geneva Observatory photoelectric photometry was defined in 1960. Following the results of the spectrophotometry of Chalonge (1958), M. Golay and F. Rufener chose seven filters which were meant to give a more detailed description of the spectral energy distribution than those of the UBV system, which had been created a few years earlier.

The decision to use coloured glass filters, instead of wide interferential filters, was taken at that time because of the inhomogeneities of transparency of the currently available interferential filters and of the difficulty in obtaining such filters with reproducible passbands. The definition of the passbands (fig.2) was strongly conditioned by the photoelectric response of the best,then available , photocathode (Sb-Cs cathode). In spite of the technical difficulties at that time and the shortcomings of the observational means we had access to, our ambition was to attain the highest possible precision. Indeed, to be able to take advantage of the information contained in several passbands, it was necessary for the relative accuracy of the measurements to be better than that already attained in the UBV system. We

PAGE 1

NAME	BS	HD	DM	COORD. 1900	L2	B2	MEMBERSHIP	P	SIG	U	V	B1	B2	V1	G	B1-B2	B2-V1	V1-G	d	DEL	g	m2	Q	SIG	MV	SP-TYPE	REM
			+44.04548	0 .0 45 14	115	-16		1	0	2.487	-.877	1.459	1.052	-.055	-.052	.407	1.107	-.003	.446	.516	.411	-.099	1	0	9.989	(DM2E)	
	1	3	+44.04550	0 .0 44 40	114	-17		2	5	1.590	.859	.883	1.457	1.560	2.037	-.574	-.103	-.477	1.528	.616	.073	-.527	2	1	6.702	A1VN	D
	2	6	-1.04525	0 .0 -1 -4	98	-61		2	3	2.231	-.423	1.370	1.104	.355	.529	.266	.749	-.174	.481	.649	.502	-.076	2	2	6.313	(G9)	
		26	+7.05128	0 .2 8 14	104	-52		2	6	1.644	-.343	1.257	1.183	.434	.643	.074	.749	-.209	.281	.012	.358	-.268	2	6	8.217	K0IIIP	
33 PSC	3	28	-6.06357	0 .2 -6-16	94	-66		1	2	2.082	-.344	1.326	1.136	.435	.615	.190	.701	-.180	.484	.513	.434	-.130	1	6	4.621	K1III	
		38	+45.04408	0 .3 45 16	115	-16		6	11	2.402	-.831	1.461	1.013	.011	-.022	.448	1.002	.033	.300	.528	.403	-.010	4	8	8.213	(DK6+M0)	D
		39	+33.04832	0 .3 33 33	112	-28		1	5	1.266	.358	1.002	1.361	1.089	1.416	-.359	.272	-.327	.777	-.049	.085	-.483	1	2	7.843	(F8)	D
		50	-30.19827	0 .3 -30-51	13	-79	SA 140 230	2	5	1.417	.616	.966	1.414	1.343	1.741	-.448	.071	-.398	1.092	.275	.092	-.480	2	7	9.698	(A5)	
		55	-68.03597	0 .3 -68-23	309	-49		3	5	2.046	-.381	1.394	1.092	.419	.488	.302	.673	-.069	.220	.451	.396	-.006	3	10	8.473	K5V	
			-30.19829	0 .4 -30-26	15	-80	SA 140 231	1	0	1.208	.276	.996	1.349	1.035	1.348	-.353	.314	-.313	.717	-.142	.072	-.496	1	0	11.241	(F7)	
		73	+42.04831	0 .5 42 50	114	-19		2	3	.308	1.178	.778	1.616	1.868	2.410	-.838	-.252	-.542	.728	-.647	-.103	-.723	1	3	8.472	B1.5IV	D
86 PEG	4	87	+12.05063	0 .6 12 51	106	-48		2	2	1.813	-.162	1.223	1.192	.594	.835	.031	.598	-.241	.546	.324	.358	-.242	2	15	5.546	(GG5)	
		91	-30.19834	0 .6 -30-31	14	-80	SA 140 234	2	5	1.341	.565	.969	1.409	1.285	1.673	-.440	.124	-.388	1.001	.152	.087	-.497	2	0	9.902	(A5)	
			-30.19837	0 .8 -30-38	14	-80	SA 140 239	2	4	1.268	.317	1.025	1.346	1.048	1.370	-.321	.298	-.322	.702	-.058	.116	-.457	2	4	10.539	(F7)	
		108	+62.02363	0 .9 63 7	118	1		2	3	.391	.776	.823	1.540	1.496	1.904	-.717	.044	-.408	.593	-.846	-.163	-.737	2	0	7.355	O8FP	
	5	123	+57.02865	0 1.0 57 53	117	-4		3	6	1.444	.114	1.117	1.283	.871	1.145	-.166	.412	-.274	.564	.046	.206	-.354	3	12	5.979	(DG4)	D
			-29.18963	0 1.1 -29 -2	23	-80	SA 140 247	3	6	1.253	.343	1.015	1.368	1.077	1.415	-.353	.291	-.338	.743	-.076	.106	-.486	3	2	10.086	(F9)	
		141	-29.18964	0 1.1 -29-43	19	-80	SA 140 248	3	5	1.328	1.004	.863	1.530	1.704	2.213	-.667	-.174	-.509	1.419	.366	.024	-.587	3	10	7.689	A0VN	
	6	142	-49.14337	0 1.1 -49-38	322	-66		5	2	1.305	.342	1.027	1.349	1.070	1.406	-.322	.279	-.336	.738	.003	.134	-.450	3	5	5.692	G1IV	D
10 CAS	7	144	+63.02107	0 1.2 63 37	118	2		3	2	1.250	.987	.840	1.540	1.690	2.174	-.700	-.150	-.484	1.411	.237	-.043	-.631	2	10	5.549	B9III	
			-30.19840	0 1.2 -30-39	14	-80	SA 140 252	1	0	1.325	.189	1.069	1.271	.909	1.282	-.202	.362	-.373	.545	.063	.304	-.367	1	0	11.687	---	
	8	166	+28.04704	0 1.4 28 29	111	-33		28	7	1.525	.023	1.155	1.247	.783	1.036	-.092	.464	-.253	.502	.102	.251	-.304	22	24	6.100	K0V	VR
		174	+84.00546	0 1.5 84 51	122	23		1	0	1.549	.640	.977	1.423	1.359	1.785	-.446	.064	-.426	1.210	.427	.132	-.475	0	0	8.189	(A3)	
			-31.00001	0 1.5 -31-13	10	-80	SA 140 260	1	0	1.339	.145	1.054	1.315	.855	1.187	-.261	.460	-.332	.658	-.082	.190	-.471	1	0	11.112	(G4)	
			-31.00002	0 1.6 -31 -6	11	-80	SA 140 262	1	0	1.312	.390	1.007	1.394	1.141	1.491	-.387	.253	-.350	.858	-.001	.088	-.503	1	0	11.144	(F9)	
		202	-21.06537	0 1.7 -21-38	61	-78		2	6	1.227	.247	1.033	1.332	.987	1.292	-.299	.345	-.305	.622	-.138	.115	-.457	2	12	9.862	(G5)	
	9	203	-23.00004	0 1.7 -23-40	52	-79		2	5	1.292	.501	.984	1.398	1.227	1.595	-.414	.171	-.368	.900	.058	.085	-.492	3	9	6.170	A7V	
		208	-4.06025	0 1.8 -4-11	97	-64		2	4	1.242	.259	1.037	1.336	.991	1.314	-.299	.345	-.323	.633	-.112	.139	-.457	2	7	8.227	(G0)	
			-31.00004	0 1.8 -30-53	12	-80	SA 140 263	1	0	1.274	.516	.974	1.358	1.232	1.590	-.384	.126	-.358	.849	.109	.102	-.442	1	0	10.844	(F8)	
		212	-31.00006	0 1.8 -31-10	11	-80	SA 140 264	2	4	1.257	.494	.992	1.395	1.216	1.586	-.403	.179	-.370	.841	.021	.099	-.485	1	1	10.207	(A9)	
			-31.00007	0 1.9 -30-55	12	-80	SA 140 266	1	0	1.293	.200	1.083	1.338	.926	1.249	-.255	.412	-.323	.575	-.119	.183	-.443	1	0	11.709	(G6)	
		235	-31.00010	0 2.0 -31 -8	11	-80	SA 140 269	3	3	1.501	.895	.904	1.489	1.592	2.080	-.585	-.103	-.488	1.434	.504	.077	-.538	3	15	8.641	A1VN	
	10	256	-18.06428	0 2.2 -17-57	74	-76		3	3	1.597	.801	.914	1.469	1.504	1.952	-.555	-.035	-.448	1.477	.530	.053	-.539	3	7	6.188	A6VN	
		259	-42.00003	0 2.2 -42-27	332	-73		2	3	1.267	.228	1.048	1.332	.968	1.272	-.284	.364	-.304	.625	-.115	.129	-.450	3	6	8.221	(G0)	
		268	-26.00008	0 2.3 -25-55	41	-80		3	4	1.240	.407	.987	1.381	1.141	1.488	-.394	.240	-.347	.816	-.052	.077	-.504	3	3	7.043	(F5)	
		280	+33.00003	0 2.4 33 47	113	-28		3	6	1.841	-.218	1.246	1.185	.563	.765	.061	.622	-.202	.508	.307	.335	-.223	3	10	8.178	(G5)	
		283	-24.00008	0 2.4 -24-23	49	-80		4	4	1.516	-.022	1.181	1.236	.735	.963	-.055	.501	-.228	.414	.053	.254	-.284	4	8	8.693	K3V	
			-30.00006	0 2.5 -30-51	12	-80	SA 140 282	1	4	1.225	.433	.985	1.394	1.174	1.516	-.409	.220	-.342	.825	-.067	.055	-.510	2	0	10.545	(F8)	
	12	319	-23.00013	0 2.7 -23 -4	56	-79		1	2	1.571	.788	.929	1.459	1.494	1.954	-.530	-.035	-.460	1.400	.524	.094	-.514	2	1	5.912	(A3)	D
			-29.00012	0 2.9 -29-23	20	-80	SA 140 291	2	7	1.258	.330	1.007	1.359	1.064	1.402	-.352	.295	-.338	.754	-.065	.107	-.487	2	6	11.212	(G)	
			-30.00009	0 2.9 -30-41	13	-80	SA 140 293	1	0	1.628	-.090	1.189	1.189	.685	.931	.000	.504	-.246	.439	.224	.334	-.230	1	0	10.280	(G0)	
		343	-30.00010	0 3.0 -30-36	13	-80	SA 140 292	2	5	1.403	.602	.957	1.408	1.325	1.722	-.451	.083	-.397	1.091	.256	.088	-.489	2	4	9.738	(A2)	
	13	344	-34.00017	0 3.0 -34 -6	356	-79		2	4	2.258	-.469	1.381	1.098	.318	.487	.283	.780	-.169	.472	.652	.512	-.073	1	1	5.658	(GK1)	
	14	352	-3.00003	0 3.1 -2-60	98	-63		2	4	2.318	-.768	1.433	1.070	.047	.101	.363	1.023	-.054	.366	.442	.436	-.105	2	32	6.131	(K2)	B
ALF AND	15	358	+28.00004	0 3.2 28 32	112	-33		4	7	.880	1.089	.848	1.573	1.800	2.311	-.725	-.227	-.511	1.069	-.079	-.032	-.621	3	1	2.079	B9P	VR
	16	360	-9.00005	0 3.2 -9-23	92	-69		2	2	2.031	-.333	1.313	1.148	.441	.636	.165	.707	-.195	.482	.457	.430	-.158	2	10	5.987	(G8)	
	17	400	+35.00008	0 3.5 36 4	113	-25		1	3	1.243	.352	1.014	1.370	1.095	1.434	-.356	.275	-.339	.738	-.074	.104	-.482	1	13	6.218	(F4)	
	18	402	-18.00003	0 3.5 -18 -8	75	-76		3	3	3.232	-1.159	1.683	.978	-.333	-.311	.713	1.303	-.022	.529	1.196	.743	.118	3	37	6.010	(M1)	
		416	+36.00004	0 3.7 36 38	114	-25		3	8	1.455	.548	.992	1.382	1.276	1.659	-.390	.106	-.383	1.021	.303	.130	-.438	2	9	8.692	(A5)	
	19	417	+24.00003	0 3.7 24 54	111	-36		3	4	1.936	-.270	1.273	1.168	.497	.706	.105	.671	-.209	.513	.384	.389	-.202	3	7	6.254	K0III	

Fig. 1 Facsimile of the first page in the third Catalogue of stars measured in the Geneva Observatory photometric system (Rufener, 1981).

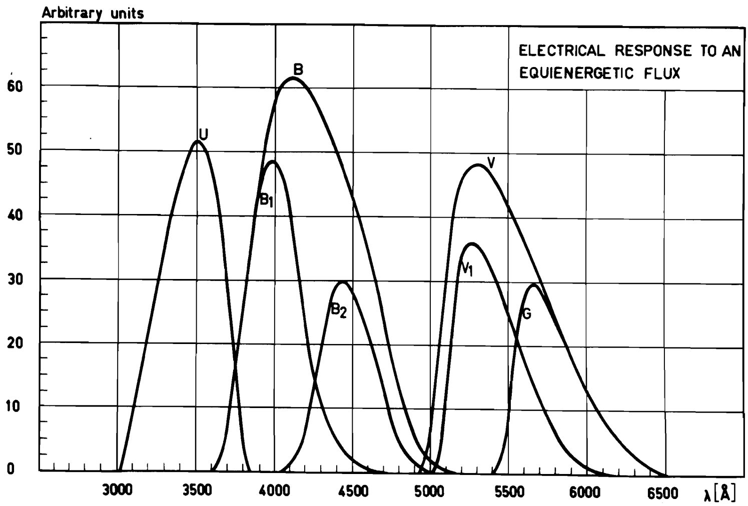

Fig. 2 Response functions of the seven passbands of the Geneva photometry. The units are proportional to the number of photons per second obtained for an equienergetic incident flux. This figure is based on table 2 of Rufener and Maeder (1971), using Code's calibration.

could then hope to detect the small differences in the energy distribution which are not due to the temperature of the source alone. We easily understand that, to reach such a goal, it does not suffice to just ascertain the precise measurement of the photoelectric current delivered by the photomultiplier. One must also strive to attain the greatest stability of the system, i.e. the best possible conservation of the definition of the passbands. This must go together with the development of efficient procedures for reducing the ground-based observations to their values outside the atmosphere, while insuring at the same time their long-term homogeneity. These aims incited me to take a certain number of precautions which I have assembled in three categories.

III. "HARDWARE" PRECAUTIONS

To stabilize the spectral response of a photometer, it is essential to regulate the temperatures of the photomultiplier (PM) and the filters, since these components present variations of chromatic sensitivity which are directly correlated with variations of temperature. These properties have been described by A.T. Young (1974). Generally, the cut-off wavelength of an optical filter is displaced redward with increasing temperature by the order of $\Delta\lambda \cong 2\Delta T$ (λ in Ångstroms and ΔT in $^{\circ}K$). The cathode of a PM, on the other hand increases its red sensitivity with increasing temperature while its blue sensitivity tends to decrease. This requirement concerning the stabilization of the temperatures, which we apply in Geneva, is often neglected elsewhere in favor of just lowering as far as possible the temperature of the PM. This ensures a reduction of the PM's dark current, but sometimes tends to increase the instability of its temperature. Both conditions must be satisfied: A low temperature and a regulation of that temperature around the PM ; the temperature also has to be regulated at the level of the filters. It is often useful to take advantage of these regulated conditions to locate sensitive elements of the measurement system. Another necessary precaution is the shielding of the PM against magnetic and electric fields which can vary in intensity and direction. These variations cause drifts of gain and spectral response. One must be very careful to assure the best possible linearity of the measurement system, particularly concerning an excellent stability of the voltage applied to the PM. If photon counting is used as a means of analysis of the photo-electric current, one must meticulously control its in-sensitivity to external interference. All these precautions are easier to list than to put into practice. Concerning this last point, I would like to emphasize the advantage inherent in subdividing the exposure time necessary to record the sufficient total number of pulses into a large number of small elementary exposures. This sub-division of the integration time allows a real-time appli-cation of statistical criteria. The significance and efficiency of this method which has been applied for 8 years in Geneva is described by Bartholdi et.al. (1984).

IV. REDUCTION OUTSIDE THE ATMOSPHERE

The organization of the measurements in view of enabling the correction of atmospheric absorption is an important subject which can greatly contribute to the accuracy of their values reduced to outside the at-mosphere. We have given up the simplistic model of the Bouguer line in favour of a somewhat more realistic model. Moreover, the effects due to the displacement of the "effective" wavelength relatively to the atmospheric absorption, which are quite appreciable in the case of a wide band filtering the light of stars with very different temperatures, have been corrected in an original manner with a systematic application to all filters. It is now necessary to discuss some details before presenting these methods. Let us consider a passband described by the following characteristics (fig.3):

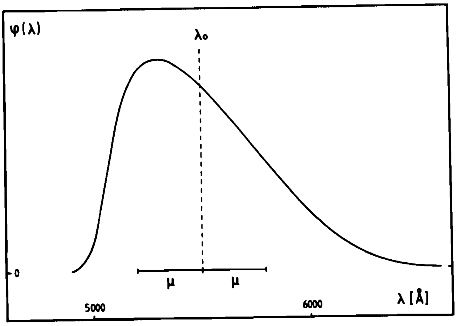

Fig. 3 The spectral response of a typical passband (the V filter of Geneva photometry in this case) with its mean wavelength λ_o and the estimator μ of its half-width.

λ_o its mean wavelength

$$\lambda_o = \int \lambda \phi(\lambda) d\lambda \Big/ \int \phi(\lambda) d\lambda$$

μ an estimator of its half-width, so that

$$\mu^2 = \int (\lambda - \lambda_o)^2 \phi(\lambda) d\lambda \Big/ \int \phi(\lambda) d\lambda$$

Φ the brightness of the passband expressed in magnitudes

$$\Phi = -2.5 \log \int \phi(\lambda) d\lambda$$

By adopting the theoretical approaches proposed by B. Strömgren (1937), I. King (1952) and F. Rufener (1964), we obtain a formulation which describes the apparent magnitude measured at ground-level (m_z) by means of terms which contain the above mentioned passband characteristics, the properties of the mean extinction of the observatory site and the energy distribution of the source

$$m_z = \underbrace{m_o(\lambda_o) - 0.543\mu^2 \frac{E''(\lambda_o)}{E(\lambda_o)} + \phi}_{m_o}$$

$$+ k(\lambda_o)F_z \left[1 + \frac{n_{\lambda_o}(n_{\lambda_o}+1)}{2}\left(\frac{\mu}{\lambda_o}\right)^2 - n_{\lambda_o}\frac{\mu^2}{\lambda_o}\frac{E'(\lambda_o)}{E(\lambda_o)}\right] \qquad (1)$$

$$- 0.46\, n_{\lambda_o}^2 \left(\frac{\mu}{\lambda_o}\right)^2 k^2(\lambda_o)F_z^2$$

Formula (1) retains the principal terms of a series development ; it shows how the width of the passband (μ) intervenes and complicates the classical Bouguer formula.We now give the definitions of each of the factors involved.

m_z: The heterochromatic magnitude measured at ground-level. This is the magnitude for the passband considered, which depends on the crossed air mass F_z along the line of sight.

m_o: The same magnitude reduced to outside the atmosphere.

$m_o(\lambda_o)$: The monochromatic magnitude at the mean wavelength λ_o, reduced to outside the atmosphere.

$E(\lambda_o)$: The spectral energy distribution of the observed star and its first ($E'(\lambda)$) and second ($E''(\lambda)$) derivatives. The values at the mean wavelength λ_o are considered. We verify the following relation for the ratio $E'(\lambda_o)/E(\lambda_o)$:

$$\frac{E'(\lambda_o)}{E(\lambda_o)} = \frac{1}{1.086\lambda_o}\left(\frac{dm(\lambda)}{d^1/\lambda}\right)_{\lambda_o} = \frac{1}{1.086\lambda_o}\;\frac{C^o_{1-2} - \phi_1+\phi_2}{1/\lambda_1 - 1/\lambda_2}$$

where $m(\lambda) = -2.5 \log E(\lambda)$; $\lambda_1 < \lambda_o < \lambda_2$
and C^o_{1-2} is a colour index with $C^o_{1-2}=m(\lambda_1)-m(\lambda_2)$

$k(\lambda_o)$: The value at λ_o of the atmospheric extinction law of the site.

n_{λ_o} : The value at λ_o of the ratio $-\dfrac{\Delta \log k(\lambda)}{\Delta \log \lambda}$

(if n is constant, we have $k(\lambda) = a\lambda^{-n}$).

F_z: The air mass along the line of sight during the observation. It is defined as the number of times one has, along the line of sight, the quantity of air seen in the direction of the zenith. This number is equal, in the first approximation, to sec z where z is the angle between the line of sight and the zenith.

We see that a good knowledge of the passbands of the photometer, of the mean extinction at the observatory site and of the energy distribution of the star observed (i.e. of an appropriate colour index) allow a numerical estimate of the factors in formula (1). We can therefore calculate numerically for each filter the terms α, β and γ which are used here to simplify the expression of formula (1).

$$m_z = m_o + k(\lambda_o)F_z\left[1+\alpha_{\lambda_o} + \beta_{\lambda_o}C^o_{1-2}\right] + \gamma_{\lambda_o}F_z^2 \qquad (2)$$

This relation replaces the Bouguer line. If we consider the passband to have a negligible width we will have $\mu = o$ and, of course, $\alpha=\beta=\gamma = o$. Relation (2) is then reduced to the classical Bouguer line

$$m_z = m_o + k(\lambda_o)F_z \qquad (3)$$

It is customary to use the Bouguer line (3) to determine the atmospheric extinction $k(\lambda_o)$ corresponding to the observations in the passband λ_o. During the night, several measurements of the ground-level magnitude (m_{zi}) of the star are made while its air mass changes significantly (F_{zi}). The application of a linear regression optimized by least squares allows the extinction value $k(\lambda_o)$ and the magnitude of the star outside the atmosphere (m_o) to be computed. This method implicitly relies on three hypotheses: The stability of the photometer, the stability of the star and the stability of the absorption properties together with the isotropy of the atmosphere during the whole night (at least 5 to 7 hours !). According to our experience, the technical precautions described above, together with the choice of a "good" star, enable the first two of these hypotheses to be satisfied. On the other hand, it is rare that the third one is also satisfied.

To illustrate the inconveniences which can result from a slowly variable extinction we present, in fig.4, an example of what can happen when the atmospheric extinction decreases during the time necessary to observe two extinction stars ; the one ascending (M), the other descending (D). We assume that the extinction, if not constant, varies but slowly and isotropically in the whole solid angle considered. This hypothesis is less demanding than that of Bouguer, an. is reasonable when the sky is clear and the variations of extinction result mainly from drifts of atmospheric pressure, from the slow evolution of the vertical distribution of the aerosols and from the nocturnal evolution of the states of equilibrium between absorption and emission in the atomic and molecular bands of the night sky. For the demonstration in fig. 4, we have chosen a slowly decreasing extinction

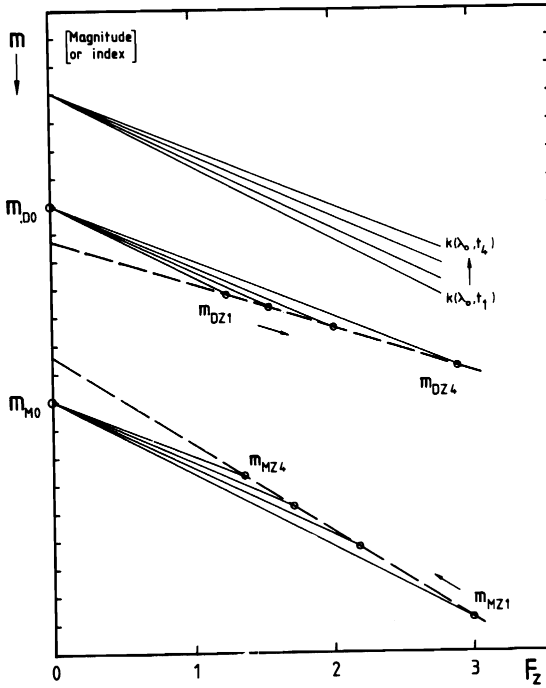

Fig. 4 Simulation of a night with variable extinction. The adopted decreasing values (0.260, 0.240, 0.220, 0.200) of the instantaneous extinction coefficient are shown at the top of the figure. The m_{Mo} and m_{Do} correspond to the true values outside the atmosphere of the stars M and D (these can be unknown). The real observations made at the times t_i would be close to the synthetic values m_{Mzi} and m_{Dzi} represented here by open circles. The two Bouguer lines which one would be tempted to adopt are represented by the broken lines. The M+D method described in the text allows to determine the values m_{Mo} and m_{Do} and the i values $k(\lambda, t_i)$. The tick marks of the ordinate scale correspond to 0.1 mag.

and have initially fixed the $k(\lambda_o, t_i)$ values at the times t_i ; distributed over the whole night. At these given times, we simulate consecutive (quasi-simultaneous) observations of each star M and D (m_{Mzi} and m_{Dzi}). Fig. 4 reveals what is observed at ground-level for the stars M and D whose magnitudes outside the atmosphere (m_{Mo} and m_{Do}) are assumed to be constant. If these simultaneous observations were to be treated by Bouguer's method, we would get two different estimates of the extinction coefficient, both wrong, with the one smaller and the other larger than the true extinction values.

By adopting the hypothesis of a slowly varying isotropic extinction, formula (2) becomes time-dependent with extinction taking the form $k(\lambda_o, t)$. We assume that the terms α, β and γ remain constant and are estimated by a mean extinction ($\bar{k}(\lambda)$). We use relation (2) in the following form

$$m'_z = m_o + k(\lambda_o, t)F'_z$$

with
$$m'_z = m_z - \gamma_{\lambda_o} F_z^2 \qquad (4)$$

$$F'_z = F_z(1+\alpha_{\lambda_o} + \beta_{\lambda_o} C^o_{1-2})$$

Each observation is thus corrected for the band width effects. The "M and D" method proposed by Rufener (1964) consists in obtaining several (n) pairs of observations of two stars, the one called M (ascending) and the other D (descending). We then have two series

$$m'_{Mzi} = m_{Mo} + k(\lambda_o, t_i)F'_{Mzi}$$

$$(5)$$

$$m'_{Dzi} = m_{Do} + k(\lambda_o, t_i)F'_{Dzi}$$

$$i=1,\ldots\ldots n$$

Following the hypothesis that the atmospheric extinction $k(\lambda_o, t_i)$ is the same for the measurements of the stars M and D made at the time t_i, we can eliminate $k(\lambda_o, t_i)$ and treat the system of n relations by least squares

$$\frac{m'_{Mzi} - m_{Mo}}{F'_{Mzi}} = \frac{m'_{Dzi} - m_{Do}}{F'_{Dzi}} \qquad (6)$$

when $n>2$, usually 4 or 5, the system (6) determines by least squares m_{Mo} and m_{Do} which are the magnitudes outside the atmosphere of the stars M and D. We then compute the individual $k(\lambda_o, t_i)$ values which are interpolated for the reduction of the other observations of the night to outside the atmosphere. This M and D method enables the atmospheric extinction to be measured even if it varies slowly during the night. The only assumption is that when a variation takes place, it occurs isotropically, and that the whole solid angle in which the observations are made is affected by the variation of transparency. The effects of fig. 4 are avoided by the M and D method which allows, under such circumstances, a true determination of m_{Mo} and m_{Do}, whereas an application of the Bouguer method to the same data would lead to false results. This M and D method has been applied at Geneva Observatory for more than twenty years whenever extinction measurements have been made. These values are then used for the reduction outside the atmosphere of our program stars observed through any air mass. When extinction is not measured, we adopt a mean value. We then conduct our observations at constant air mass ($\bar{F}_z$). Relation (2) becomes, in this case

$$m_z = m_o + \left(\bar{k}(\lambda_o) + \Delta k\right)\bar{F}_z \left[1 + \alpha_{\lambda_o} + \beta_{\lambda_o} C^o_{1-2}\right] + \gamma_{\lambda_o} \bar{F}_z^2$$

The unknown deviation (Δk) from the mean extinction ($\bar{k}(\lambda_o)$) which characterizes the observational conditions of the night occurs only as a multiple of $\bar{F}_z$, which is the air mass chosen for that night. The deviations $\Delta k\bar{F}_z$ during the night can then be estimated with the aid of a sufficiently large sample of standard stars. Even if Δk varies a little, it is easy to compensate this variation by smoothing over the Δk values and thus obtain precise magnitudes.

V. CORRELATION WITH THE STANDARD AND AVERAGING

The last important precaution concerns the correlation with the standard and the progressive establishment of a "super-standard". We recall here that a photometric standard is a set of frequently measured and inter-compared stars which define the photometric system. The passbands have to be calibrated and described for this system (fig.2, Rufener & Maeder, 1970). Generally, this standard system has physically existed for a certain time. One can show that in the favourable case where the passbands of the natural system (the system in which the observations are presently made) differ very little from the passbands which characterize the standard, it is legitimate to use the linear relation proposed by Rufener (1968). This allows one to transform the colour indices (normalized magnitudes C^n_{1-2}) obtained in the natural system into standardized colour indices (C^s_{1-2}):

$$C^s_{1-2} = aC^n_{1-2} + b$$

The factors a and b are given by

$$a = \varepsilon\left(1 + \frac{\Delta\lambda}{\lambda_2 - \lambda_1}\right) = \frac{\lambda_2\lambda_1\,(\lambda^s_2 - \lambda^s_1)}{\lambda^s_2\lambda^s_1\,(\lambda_2 - \lambda_1)}$$

$$b = \Delta\Phi + \left(\Phi_1 - \Phi_2\right)\left[1-\varepsilon- \frac{\Delta\lambda\ \varepsilon}{\lambda_2-\lambda_1}\right]-\Delta k_{1-2}\bar{F}_z\varepsilon\left(1+ \frac{\Delta\lambda}{\lambda_2-\lambda_1}\right)$$

$$\cong \Delta\Phi - \Delta k_{1-2}\ \bar{F}_z$$

with $\varepsilon = \dfrac{\lambda_1\lambda_2}{\lambda_1^S\lambda_2^S}$

$$\Delta\lambda = (\lambda_2^S - \lambda_1^S)-(\lambda_2 - \lambda_1)$$

$$\Delta\Phi = (\Phi_1^S - \Phi_2^S)-(\Phi_1-\Phi_2)$$

We notice that the slope of the correlation is completely dependent on the drift of the mean wavelengths of the passbands. On the other hand, the zero ordinate is a complicated term which contains as factors the relative differences in gain of the photometer ($\Delta\Phi$), the error on the atmospheric extinction (Δk_{1-2}), the mean air mass and, again, the variations of the mean wavelength.This type of correlation has to be established each night for the reduction of each colour index by reobserving a sufficient number of standard stars. Meticulous practice and careful reductions allow one to insure a critical supervision of the correlation. Any incidents due to temperature control, cleaning of the telescope's mirrors, variations of transparency during constant air mass observations are detected and, as far as possible, corrected. This procedure allows one to estimate the quality of the observations and enables their weighting. Finally, when we proceed to a computation of the data collected for each star after a large number of observing nights, we are often surprised by the discordant nature of the measurements of a given star. We then have to examine whether the origin of the discrepancy can be identified (wrong identification, abnormal sky backgrounds, presence of a nearby star in the diaphragm, technical incident during the measurement, etc...). If none of these conditions can be retained, we attribute to the star a weighted mean of the good measurements with a corresponding standard deviation which qualifies the degree of convergence of the observations. It is only then that a catalogue is produced and that the interpretation of the colours and magnitudes begins. The acuteness and sensitivity as well as the reliability of the subsequent deductions are completely dependent of the care which has been taken to maintain the greatest possible homogeneity of the measurements and of the numerical treatments described above. Each stage is important. We try in Geneva to be as meticulous and systematic as possible. The final reduction and evaluation of the measurements of more than 4000 nights have all been made by the author. The observations, the examination of the measurements and the large number of computations have been carried out with the help of my colleagues and a small number of devoted collaborators. Four increasingly improved photometers have been used since 1960. A fifth instrument is presently being developed ; it will be more sensitive and will insure a more accurate treatment of the sky background. The observations in the northern hemisphere have been made with several telescopes at different sites (Saint-Michel l'Observatoire, in the Haute-Provence, 650 m (France) ; Jungfraujoch, 3600 m (Switzerland) ; Gornergrat, 3100 m (Switzerland) ; Izañia, 2400 m (Canary islands) ; Calar Alto, 2400 m (Spain)). All the observations in the southern hemisphere have been made at the La Silla Observatory, 2400 m (Chile). The Geneva Observatory has set up there a 70 cm telescope which is devoted to Geneva photometry. Fig. 5 shows this instrument which is equipped with the photometer described by Burnet and Rufener (1979).

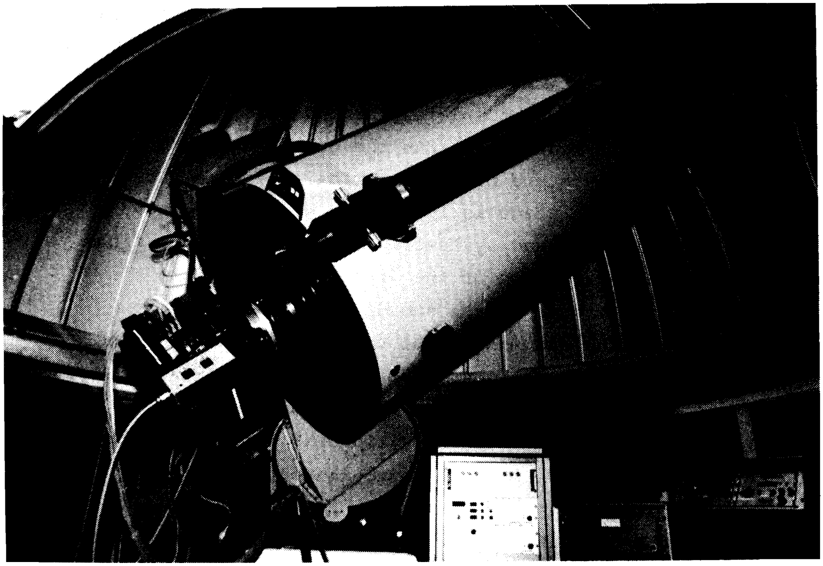

Fig. 5 Cassegrain telescope with an aperture of 70 cm, installed by Geneva Observatory, at La Silla. The La Silla Observatory (2400 m high) is managed by the European Southern Observatory and is situated in Chile at a latitude $\Phi = -29^{\circ}15'$. The photometer installed at the focus is that of Burnet and Rufener (1979).

VI. OBJECTS STUDIED

The already measured stars (~23200) as well as those still to be observed (~8000) all form part of one or several research programs. Some of these have been completed while others are currently being carried out. The observations are "pooled", with only one channel leading to the reduction to the standard. This manner of organizing things favourably influences an intercomparison of stars belonging to different programs ; it also facilitates the optimization of the observing conditions which are influenced by the presence of moon light and by image quality.

The bright stars (BS catalogue) very often allow instrumental gaugings and photometric calibrations based on spectroscopic estimates to be made. This vast program has been undertaken during full-moon periods. A sustained effort has been devoted to the observation of about sixty galactic clusters, so as to have at hand sets of stars having a variety of homogeneous ages and chemical compositions. Several programs concern detailed studies of regions in the HR diagram which are associated with specific problems. For example, the O-type stars and interstellar matter ; the B,A and F stars and questions related with galactic structure ; the G,K and M stars and the analysis of the various stellar populations in the solar neighbourhood. Other programs are oriented towards the study of instabilities associated with rotation, pulsation, or to discontinuous processes such as mass loss. For the latter, particular efforts have been made to monitor B, A and F-type supergiants, B and A stars close to the main sequence such as β Cephei, δ Scuti, and chemically peculiar stars. Many stars showing multiperiodic pulsations have been discovered, as well as several eclipsing binaries.

VII. INTERPRETATION OF THE MEASUREMENTS

It is impossible to give in this paragraph an exhaustive overview of the applications having been based on Geneva photometry. A general review in that sense has been attempted by M. Golay (1980). We will summarize very briefly the main directions of our research. For the O,B and A stars, we use a simple and quasi univocal representation. Cramer and Maeder (1979 (paper 1), 1980 (paper 2)) have introduced the colour-combinations X,Y and Z which are practically independent of interstellar reddening. X is directly correlated with effective temperature, Y with surface gravity, i.e. with absolute luminosity, and Z with spectral peculiarity. This photometric space has been calibrated in terms of MK types, absolute V magnitude, empirically derived effective temperature (paper 1), mean surface magnetic field and model-defined T_{eff} and gravity (paper 2 , see fig. 6), age and mass (North and Cramer , 1981) and intrinsic colours (Cramer, 1982, 1984). We may point out here that our estimate of luminosity is only weakly influenced by emission features which are often present in the hydrogen lines and which affect H_β photometry. The properties of A,F,G and G,K,M stars are deduced by analysing their positions in diagrams which are based on various colour-combinations. The position of a star on a reference sequence, or its deviation from that sequence, enables the interpretation of its physical properties to be made via calibrations, which are themselves established by means of stars for which these properties have been determined by other methods, such as spectroscopy. The deductive process can be systematized by an algorithm. The interpretation can, in some cases, present ambiguities when we have only photometric information at our disposal. Complementary data (spectroscopic or kinematic) can then often serve to lift this ambiguity and allow the desired properties to be determined. These properties are:

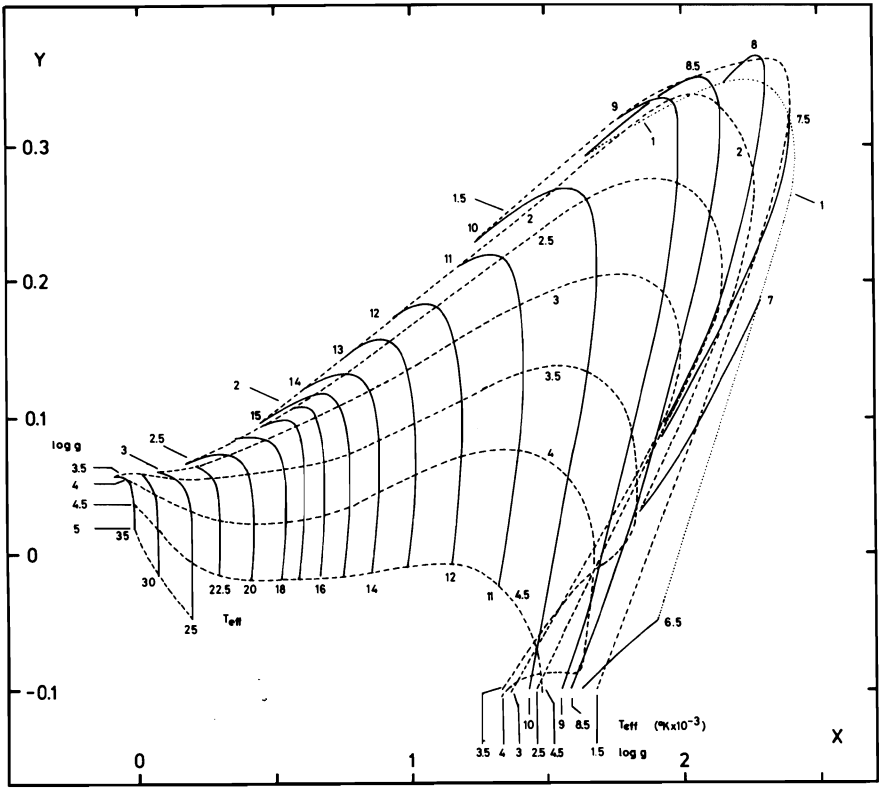

Fig. 6 The X,Y photometric parameter plane.

X=0.3788 + 1.3764 U-1.2162 B1-0.8498 By-0.1554 V1+0.8450 G

Y=-0.8288+0.3235 U-2.3228 B1+2.3363 B2+0.7495 V1-1.0865 G

The lines drawn in this plane correspond to calibrations based on Kurucz's (1979) stellar atmosphere models; full lines are loci of constant effective temperature T_{eff} ; the broken lines are loci of equal gravity (log g). Both parameters X and Y are independent of interstellar reddening, and the figure shows that they are also independent of each other ("orthogonal") over a large range.

- The effective temperature.
- An evaluation of the interstellar reddening along the line of sight.
- The absolute luminosity (therefore also the distance).
- The surface gravity.
- The spectral peculiarity, or the evaluation of the chemical composition.
- Age, or the evolutionary stage.
- Possible binarity .
- The influences of rotation.
- Particular atmospheric features (emission in the hydrogen lines, etc..).

As an n-colour photometry can not estimate more than (n-1) independent quantities, it is certainly not possible to evaluate for each individual star all the properties mentioned above. On the other hand, if we can make a comparative analysis of several samples of stars which have certain properties in common, or which are simply similar to each other (e.g. members of a star cluster), it then becomes possible to detect subtle differences. It is at that level that the precision and the quality of the photometry can be appreciated and judged.

VIII. SOME RESULTS

I find it useful to quote here some interesting and original results,without going into greater detail than giving the main bibliographical references where the various subjects are developed.

- Detection of instability zones in the HR diagram, with an estimation of the amplitudes of the fluctuations (see fig.7, Maeder, 1980).

- Evaluation of a period-luminosity- colour relation for B,A,F - type supergiants (Burki, 1978; Maeder, 1980 and fig. 8).

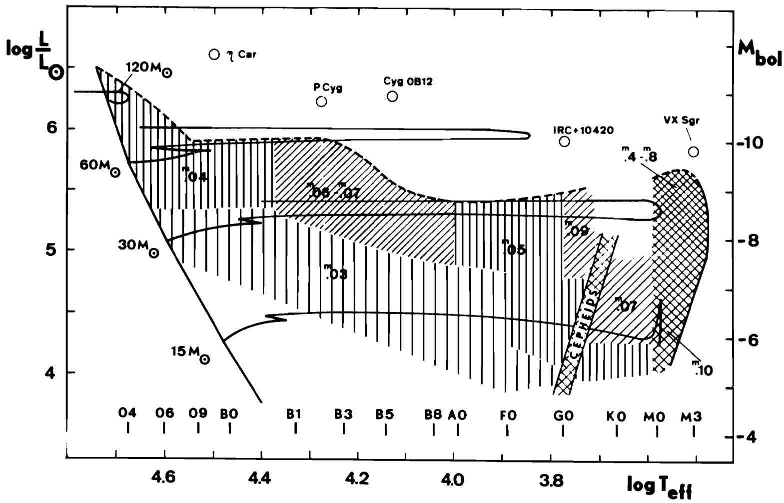

Fig. 7 Distribution of the peak-to-peak amplitudes in the log $L/L_{\odot}$ vs. log T_{eff} diagram. This evaluation results from 2420 measurements collected during 20 years for 327 supergiant stars. Evolutionary tracks with X=0.70 and Z=0.o3 computed by Maeder (1980) with mass loss are indicated. The upper envelope of the hatched area corresponds to the limit of the relatively well populated region of the HR diagram in Humphreys' data (1978).

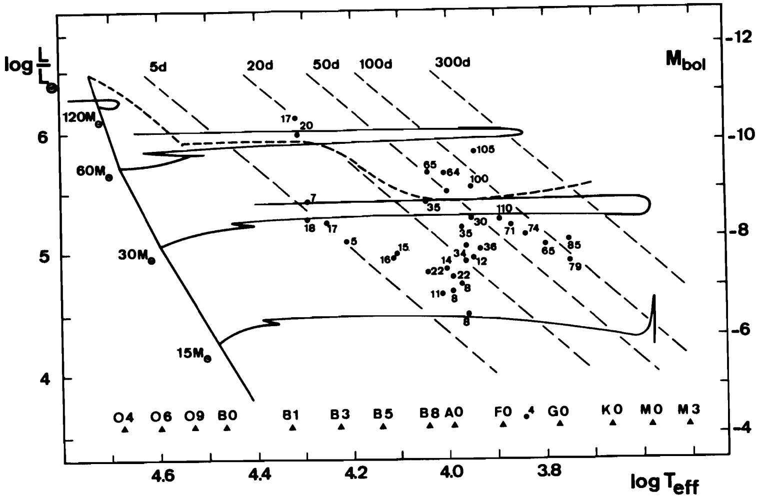

Fig. 8 Distribution of the semiperiods in the HR diagram based on Maeder's models with mass loss and observations collected by Burki (1978).

- Quantitative evaluation of the spectral peculiarities of B and A stars, with an estimate of their surface magnetic field (Cramer and Maeder, 1980 and fig. 9).

- The establishment of a distance scale for 43 galactic clusters (see table I.) directly correlated with the stars having trigonometric parallaxes, by means of the concept of photometric identity (Golay photometric boxes, 1978). Including, in particular, an independent estimate of the distance of the Hyades (Nicolet, 1981).

	present work	Mermilliod, 1981	Becker and Fenkart 1971	others	
NGC 581	11.77 ± 0.47	11.51	11.95	11.94	Moffat, 1972
NGC 457	11.71 ± 0.55	12.13	12.20	12.60	Moffat, 1972
NGC 752	7.830 ± 0.054	7.90	7.90	---	
h Per	11.04 ± 0.41	---	11.47	11.40	Kholopov, 1980
χ Per	11.57 ± 0.42	11.40	11.85	11.40	Kholopov, 1980
IC 1805	11.31 ± 0.61	12.13	12.00	12.60	Moffat, 1972
NGC 1039	8.53 ± 0.12	8.36	8.15	---	
α Per	6.26 ± 0.12	6.14	6.20	5.94 6.1	Kholopov, 1980 Crawford & Barnes, 1974
IC 348	6.81 ± 0.42	7.50	---	7.5 ± 0.15	Strom et al., 1974
Pleiades	5.683 ± 0.048	5.62	5.47	5.64 5.54 5.56	Kholopov, 1980 Crawford, Perry.1976 Turner, 1979
NGC 1502	9.34 ± 0.025	9.46	9.68	---	
NGC 1545	9.05 ± 0.18	---	9.50	---	
Hyades	3.246 ± 0.060	3.19 (by definition)	3.00	3.03 to 3.42 various sources	
NGC 1960	10.30 ± 0.36	10.45	10.51	---	
Orion cl.	8.23 ± 0.16	8.81	8.10	---	
NGC 2168	9.67 ± 0.28	9.79	9.60	---	
NGC 2244	10.86 ± 0.46	---	11.05		
NGC 2264	9.64 ± 0.67	9.54	9.27	9.05	Walker, 1956
NGC 2281	8.502 ± 0.105	8.48	8.38	---	
NGC 2287	8.86 ± 0.18	9.16	9.10	---	
NGC 2422	8.66 ± 0.16	8.29	8.40	---	
NGC 2451	6.69 ± 0.19	6.50	---	---	
NGC 2516	8.151 ± 0.104	8.00	7.88	7.90	Dachs, 1970
NGC 2547	8.22 ± 0.13	7.90	---	7.90	Fernie , 1960
Praesepe	6.166 ± 0.040	6.20	6.00	6.20 6.1 6.05	Kholopov, 1980 Crawford & Barnes,1976 Golay, 1978b
IC 2391	6.020 ± 0.110	5.90	5.93	---	
IC 2602	6.15 ± 0.13	5.87	5.02	---	
NGC 3532	8.296 ± 0.096	8.24	8.10	---	
Coma Ber	4.658 ± 0.114	4.75	4.55	---	
NGC 4755	10.95 ± 0.37	11.33	10.07	9.70	Fenkart & Binggeli,1979
NGC 6025	8.94 ± 0.36	9.61	---	9.40 ± 0.10 9.7 ± 0.1	Feinstein,1971 Kilambi, 1975
NGC 6231	11.04 ± 0.45	10.56	11.24	11.51 11.6	Schild et al.,1969 Garrison & Schild,1979
NGC 6281	8.46 ± 0.22	8.60	---	8.74	Feinstein & Forte,1974
NGC 6405	8.376 ± 0.115	8.32	8.24	8.27 ± 0.20	Vleeming, 1974
IC 4665	7.90 ± 0.22	7.72	7.60	7.5	Crawford & Barnes,1972
NGC 6475	7.152 ± 0.078	7.06	6.83	---	
NGC 6611	12.05 ± 0.70	---	11.13	12.5 ± 0.2	Sagar & Joshi, 1979
NGC 6633	7.47 ± 0.17	7.78	7.61	---	
NGC 6871	11.19 ± 0.52	11.17	10.98	---	
IC 4996	10.84 ± 0.59	---	11.24	---	
NGC 7092	7.46 ± 0.12	7.42	7.08		
NGC 7160	9.53 ± 0.20	9.35	9.17		
NGC 7243	9.83 ± 0.13	9.51	9.62	9.40	Żelwanowa & Schöneich,1971

Table I : This table gives the true distance moduli of 43 galactic clusters obtained by applying the principle of photometric identity (photometric boxes). This principle postulates identical absolute magnitudes for photometrically identical stars. The present original evaluation is based on identities with stars of known parallaxes. The values obtained are compared here with the corresponding moduli obtained by sequence-fitting.

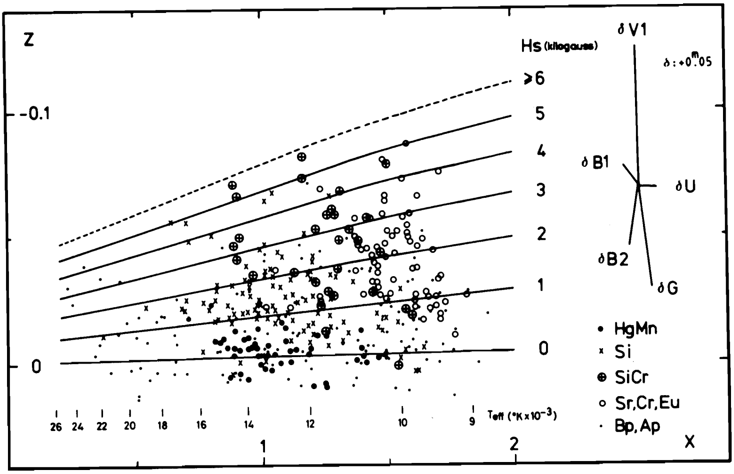

Fig. 9 Calibration of the Z vs.X diagram in terms of the surface magnetic fields Hs. The various classes of peculiarity are indicated as well as the sensitivity of this diagram to variations of $+0^{m}.05$ in each colour. The stars indicated Bp, Ap are those for which no other specification of peculiarity is given.

- Critical analysis of the sample defined by Gliese's catalogue (stars considered to have large parallaxes). Detection of numerous errors concerning the evaluation of distance due to a wrong estimate of luminosity, often resulting from a peculiar chemical composition (Grenon, 1984 and fig. 10).

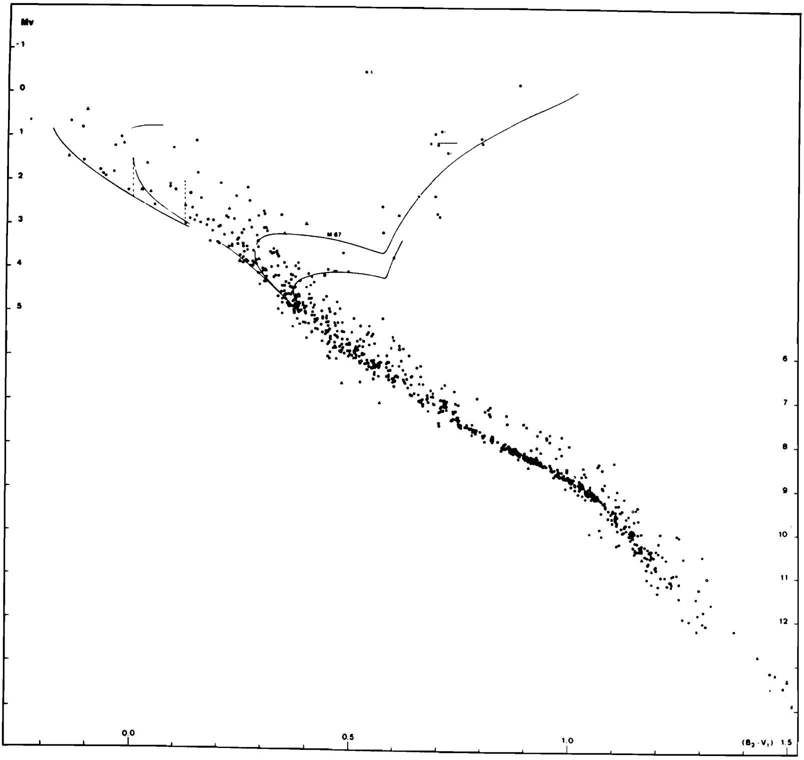

Fig. 10 The HR diagram for stars with photometric $\pi > .045''$. This new HR diagram established with stars of confirmed membership in the local sphere of 22.2 pcs radius is unevenly depopulated with respect to the diagram established with the original Gliese data. In particular the number of stars having masses 1.3 $M_\odot$ is now reduced by a factor of about 2 whereas the number of stars with $M < 0.9\ M_\odot$ has only slightly decreased. This also implies that the rate of stellar formation during the last four million years is twice as low as expected, and the luminosity function is also strongly reduced for stars with $M_V \leqslant 5$.

- Development of a vast observation program of large proper motion stars (objects from Luyten's NLTT catalogue, 1979). This effort is coordinated with the future astrometric program that will be carried out by the HIPPARCOS satellite. We have already discovered a long list of stars having parallaxes >.040" which were unrecognized up to now. This same program has enabled the identification of a large number of population II stars which are crossing the solar neighbourhood (Grenon, to be submitted for publication).

- Contributions to the analysis of instabilities observed for B-type stars. Detection of Be stars and mono- or multiperiodic β Cep stars. Study of the relation between pulsation and binarity (Waelkens and Rufener, 1983).

- Study of the photometric variability of Ap and He- weak stars in clusters and associations (North, 1984).

- Definition of an estimator $\beta(X,Y)$ of the β index in the X,Y diagram of Geneva photometry for O,B, A stars. Together with β this quantity extends the notion of colour index and enables to detect Be stars, to measure the emission feature in H_β , and to examine the line versus continuum consistency of model atmospheres. (Cramer, 1984, submitted for publication, see fig. 11 and 12).

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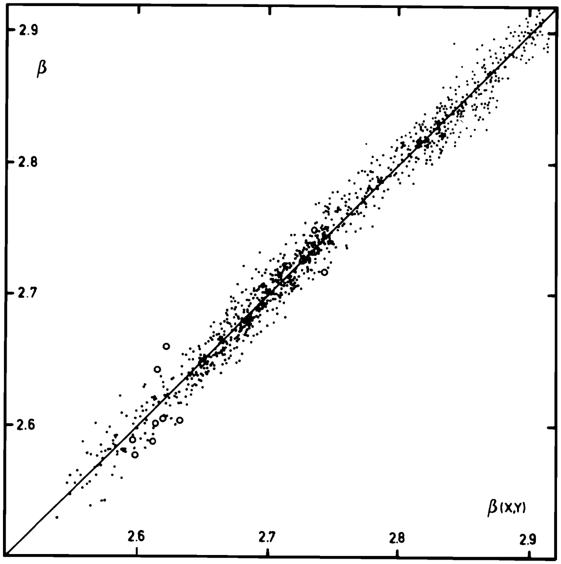

Fig. 11 Correlation between H_{β}- line photometry (β index) and the parameter $\beta\,(X,Y)$ which is a third degree polynomial in X and Y. $\beta\,(X,Y)$ therefore essentially involves measurements of the stellar continuum. This correlation is obtained for stars without emission in the hydrogen lines.

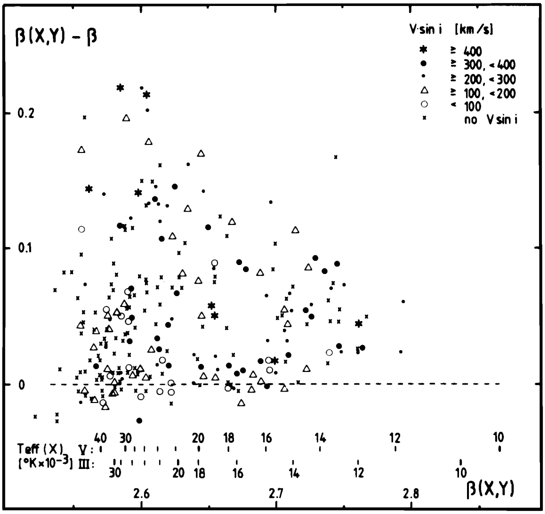

Fig. 12 The pseudo-index β(X,Y) − β allows the photometric detection of emission in the H_β line ; it even enables an estimate of the equivalent width of the emission feature to be made.

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