Chapter 26
Early Photometers at the Royal Observatory, Cape

Ian S. Glass

1 Fabry Photometry

The development of precision photometry at the Cape was very largely due to the efforts of Alan William James Cousins (1903–2001). An electrical engineer by profession but also an accomplished amateur astronomer, Cousins joined the Royal Observatory, Cape of Good Hope, in 1947, developing at first the Fabry methods and later photoelectric photometry. With his technical background and tenacity, he was well placed to introduce the technology required.

While an amateur, Cousins had already been interested in precision photometry, initially in connection with his work on variable stars. This had led him to interact with the astronomers E.G. Williams (1905–1940) and R.O. Redman (1905–1975) at the Radcliffe Observatory in Pretoria. They had been using the Fabry method and inspired him to develop a special film camera using this approach for his work with the 8-in (20 cm) refractor of the Durban Observatory (Cousins, 1943), to which he had access. He was able to achieve a mean magnitude error of ~0.02 mag.

An interest in precision magnitudes had arisen at the Cape from doubts about the accuracy of previous Southern standards set up by Harvard workers in the E-regions, a set of nine fields spaced around the sky at a declination of about −45°. These were needed to calibrate the extensive photographic surveys that were then the main preoccupation of the Observatory. For example, Cousins's work (1943) had found discrepancies of scale and zero point as well as a dependence on colour in the Harvard data.

His interaction with the Cape Observatory began with a 3-week visit in June 1945 (Stoy, 1993a). He was still at this time an engineer at an electricity plant in

I. S. Glass (✉)
South African Astronomical Observatory, Observatory, Cape Town, South Africa
e-mail: isg@saao.ac.za

S. Gullberg, P. Robertson (eds.), *Essays on Astronomical History and Heritage*, Historical & Cultural Astronomy, https://doi.org/10.1007/978-3-031-29493-8_26

Durban. During a "vacation" at the Cape he made experiments to verify that a rotating sector of known geometry could be trusted to reduce the intensity of light in a predictable way for calibration of images on a photographic plate (Cousins & Stoy, 1946). This work impressed the then Her Majesty's Astronomer, J. Jackson (1887–1958), who proposed to Cousins that he should come to work at the Cape should a vacancy arise. In March 1947 this came to pass. At the Cape he was to have access to 13-inch (33 cm) and 24-inch (61 cm) photographic refractors as well as 7-inch (18 cm) and 18-inch (46 cm) visual ones.

2 The Fabry Method as Used at the Cape

The accuracy of conventional photographic photometry was limited mainly by the non-linear response of photographic emulsions, a phenomenon known as "reciprocity failure." Their response to stellar images could only be calibrated over a rather limited range.

In the Fabry method, a focal plane aperture was used to define an area of sky, usually including a star image, whose brightness was to be measured. Behind this, a short-focus lens focused an image of the telescope objective (the exit pupil) onto a photographic plate. In use, a large number of spaced exposures of stars and calibration sources (using a sensitometer) was made on a single plate (see diagram). These could then be measured with a Schilt laboratory photometer that used a photocell and mirror galvanometer (Fig. 26.1). By placing many images on a single

Fig. 26.1 A Lady Computer measuring images with a Schilt microphotometer. On top right is the screen for the reflected beam from the mirror galvanometer that displayed the photocurrent from a detector (SAAO Archives P7963)

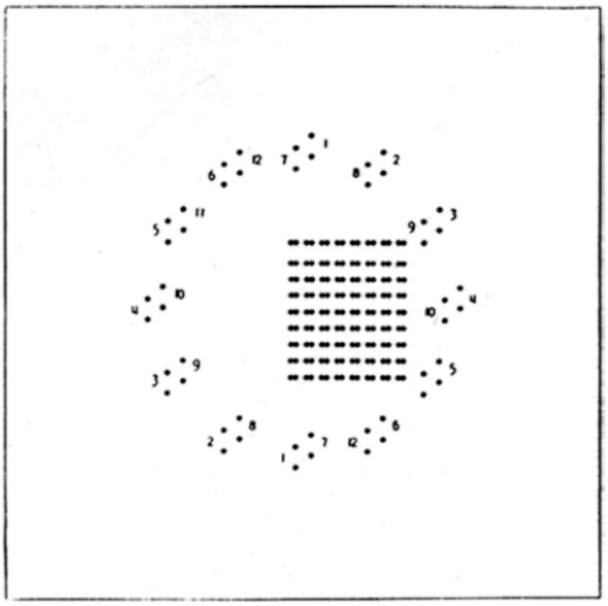


Fig. 26.2 Schematic of a Fabry plate with 216 exposures of individual stars surrounded by multiple images from a standard laboratory source (tube sensitometer). (From Cousins (1950))

plate and encircling them with calibration images the vagaries of photographic plates and the development process could largely be eliminated (Fig. 26.2).

The earliest Fabry photometer(s) at the Cape were constructed ca. 1942 according to Stoy (1993b) but it seems that their serious use dates from the time that Cousins joined the Observatory.

An important innovation was the addition of a high-speed rotating sector before the focal plane. Though several single-factor sectors steps giving reductions of three to five mags were available, a stepped version with precise reductions in half-magnitude steps from 0.5 to 2.5 was generally used (see Fig. 26.3). In this way, the differences in photographic density from one star's image to another could be kept very small and well within the range of validity of the calibration. However, there had been some questioning as to whether rotating sectors really reduced the intensity as predicted and as mentioned, Cousins had carried out a series of precise comparisons in the laboratory, based on the inverse square law (Cousins & Stoy, 1946). His results showed that the sectors could indeed be relied upon as method for fixing the magnitude scale. Before this, photometry had been limited to a range of about three magnitudes, with some degradation at the ends (Cousins, 1953).

In correspondence with A.J. Wesselink (1909–1995), then at the Union Observatory in Johannesburg, Wesselink expressed surprise that the timing of exposures did not affect the error budget of Cousins's Fabry photometry (Wesselink to Cousins, 1950 July 26). In his reply (Cousins to Wesselink, 1948 August 1) he stated that he has "a special electric clock for timing my exposures and estimate the

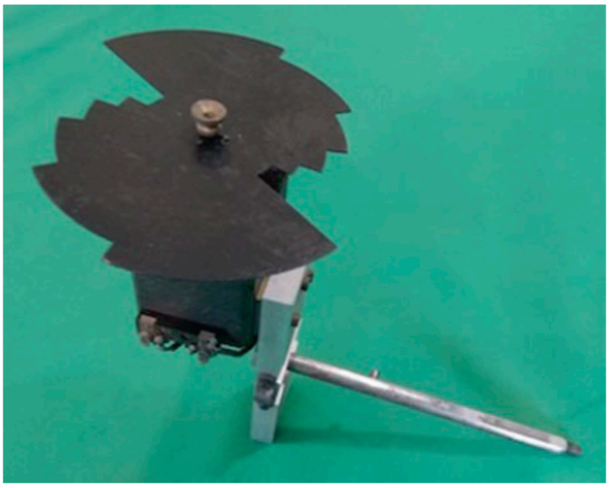


Fig. 26.3 Rotating sector with ½ mag steps. It could be inserted quickly near the optical axis of the telescope and positioned for a particular step by a lever. SAAO Museum Inv. M046, part. (Photo: ISG)

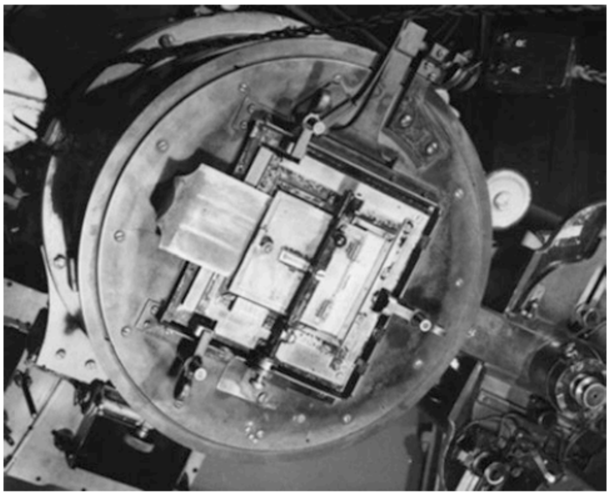


Fig. 26.4 Fabry photometer mounted in place of a plateholder at the focus of the 13-inch refractor. The removable plateholder and dark slide was adjusted in position between exposures. The filter, Fabry lens and aperture were below the plateholder (Cousins, 1953)

probable error of doing so to be a quarter of a second, [out of a minute] but I have not measured it." This is the only mention he makes of his timing which depended on electromagnetic shutters that can be seen on the surviving instruments.

Three "Fabry Photometers" with baseplates about 17.6 cm square, compatible with the holders for the 16 × 16 cm standard glass plates used with the Cape telescopes, still exist (see Figs. 26.4, 26.5, 26.6, and 26.7). Into a baseplate (Fig. 26.5)

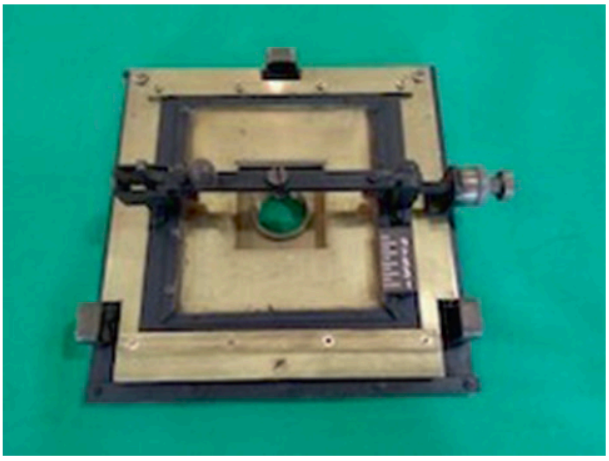


Fig. 26.5 Fabry photometer baseplate without plateholder. The filter, Fabry lens and aperture screwed into the central hole. SAAO Museum Inv. M046, part. (Photo: ISG)

Fig. 26.6 Example of unit containing Fabry lens, aperture and filter that was attached to the rear of the baseplate. SAAO Museum Inv. M046, part. (Photo: ISG)

could be threaded units containing an aperture in the focal plane of the telescope, the Fabry lens of about 8 mm focal length being just below it and, as necessary, a filter just above it (Fig. 26.6). The plateholder with a dark slide was fastened to the baseplate and held down under gentle pressure from a cross-piece. Unfortunately, none of the plateholders survive.

Between exposures, the plateholders were displaced by small amounts across the base using thumbscrews with detents. Each star was usually given two exposures of 1 minute duration. Around the periphery of the plate further exposures were made off the telescope using a tube sensitometer.

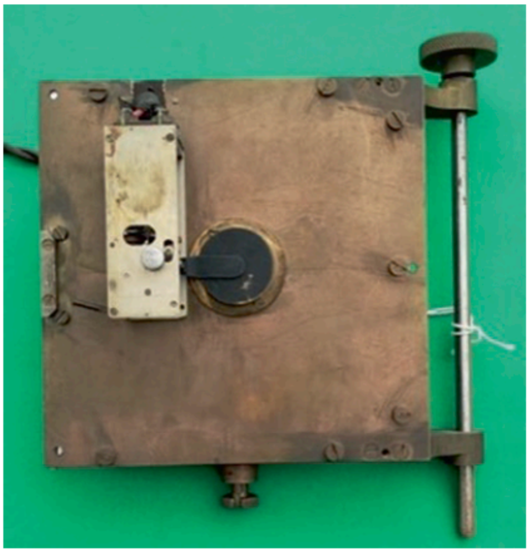


Fig. 26.7 The rear of a plateholder showing the electromechanical shutter, a Fabry lens unit and (in this example) the hinge for swinging the whole photometer out of the way. SAAO Museum Inv. M046, part. (Photo: ISG)

Two bands were observed, "Photographic" and "Photovisual." An important consideration was observing efficiency, 15–20 stars including standards per hour being possible.

The increased precision of the Cape Fabry photometry required the development of new observing techniques, many of which became standard and were used later in photoelectric and CCD photometry. "In each region, two (or sometimes three) stars, usually of spectral type F, were chosen as local standards and used as comparison stars." Programme stars were sandwiched between observations of the standards. This enabled the atmospheric transparency and evenness of the photographic plate to be monitored. In general, observations were kept within 35° of the zenith to minimize atmospheric extinction corrections. The airmass was read from a clinometer attached to the telescope (see Fig. 26.8) with each observation.

The apotheosis of the Fabry method was probably the paper on observations of the (Harvard) E-regions by Cousins (1950). Precise standards for Southern hemisphere photometry of stars in nine of these fields, equally spaced in RA at a declination of −45°, were set up. Pairs of E-regions could be compared at low airmass when equally spaced from the Zenith, the atmospheric extinction being low under these conditions. The observational errors achieved for stars brighter than about eighth mag did not normally exceed 0.007 mag.

Variable atmospheric extinction, sometimes dependent on azimuth, was an issue to be watched out for (Cousins, 1950). The sky above the Royal Observatory was liable to be contaminated by coal smoke from the nearby Salt River shunting yards during NE winds but was quite clear in the prevailing SE conditions.

It is interesting to note that though the constants of the stepped rotating sectors were at first established geometrically with a Hilger measuring machine they had been checked using a laboratory photometer with a photomultiplier and mirror

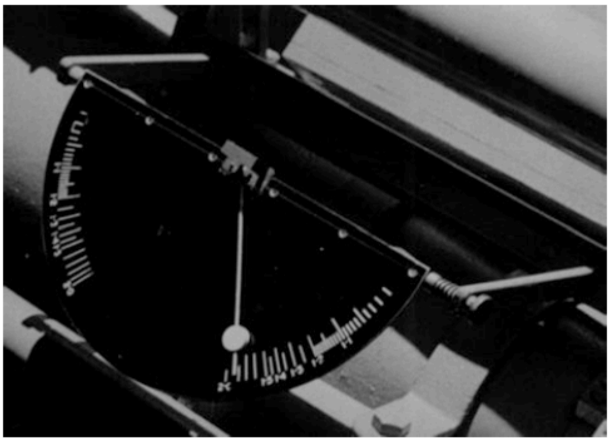


Fig. 26.8 Cousins Airmass Indicator. The axis was mounted parallel to the tube of the telescope and the scale stayed in a vertical plane (SAAO Archives P3571)

galvanometer (mentioned in Cousins, 1950, and in a letter to Wesselink from Cousins 1949, April 3). This setup was also used with a monochromator to obtain filter transmission curves (Annual Report, 1949).[1] In fact, by 1950, photoelectric techniques had become well established at the Cape.

Cousins seems to have been rather reluctant to give up on the Fabry method and remarked at the end of his 1950 paper "… there are those who believe that [photoelectric photometry] has rendered photographic methods obsolete where high precision is desired. This point of view is perhaps too sweeping. There is probably little difference, either in accuracy or in time spent in observation and reduction, between the photoelectric and Fabry methods when used for fundamental magnitude work on the brighter stars …." He did however admit that the photometric quality of an observing night only emerged after the reduction of the data in the Fabry method whereas it was usually obvious from the chart recorder traces when observing photoelectrically.

It was also the case that the Fabry method was unsuitable for use with reflecting telescopes because of the central obscurations that caused a dead spot on the pupil images. This of course meant that the large telescopes could not be used when it was desired to observe faint stars.

In his paper on observations of the E-regions Cousins (1950) listed the sources of the errors in his best Fabry photometry. These are:

- Measuring error
- Error due to background setting
- Intrinsic error (a photographic effect)

[1] The Annual Reports have the full titles "Report for the Year 195× of (His or) Her Majesty's Astronomer at the Cape of Good Hope to the Secretary of the Admiralty." Available at the SAAO Library.

- Error of calibration
- Error of timing exposure

The combination of these came to about 0.01 mag depending on the photographic plates used.

3 Photoelectric Photometry

Although photometric observations with photoelectric methods had been tried since the late nineteenth century (see Hearnshaw, 1996, for a general history), they became much more sensitive when the RCA "squirrel-cage" 931A photomultiplier with a Sb-Cs photocathode became generally available as "surplus" after the Second World War. Ironically, their wartime use had been as broad band "white noise" generators. (The wartime radar jamming unit T–85/APS5 was based on the noise from a dimly-illuminated RCA 931A photomultiplier feeding a broad-band video amplifier that modulated a radio transmitter.) (Fig. 26.9).

The apostle of the new technique was G.E. Kron (1913–2012) who published two influential papers on the subject (Kron, 1946, 1947). The latter paper gives extensive and detailed instructions on the construction of a photometer that he built for the Lick 36-inch telescope. Mechanical and electrical diagrams were included together with photographs of the setup on the telescope and the galvanometer current measuring system.

Cousins (1988) states in an unpublished summary of "Photoelectric Photometry at the Cape" that R.H. Stoy (1910–1994) was responsible for the introduction of

Fig. 26.9 A "Side-View" Photomultiplier, the RCA 931A. Its black base indicates that this example was manufactured early on. As the cathode and anode terminals were close to each other and operated with a potential difference of ca 900 V it was necessary to place the tube in a dessicated container to avoid leakage currents. The cathode and dynode voltages were supplied through a multiwire cable from a separate unit. SAAO Museum Inv. M244. (Photo: ISG)

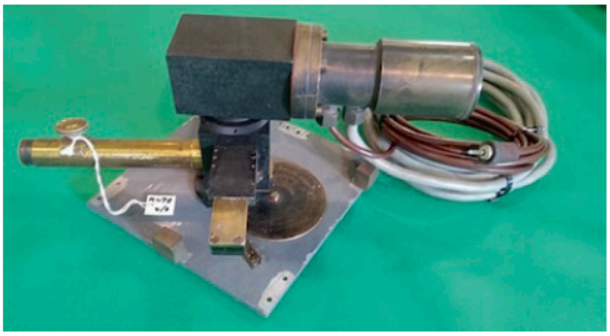


Fig. 26.10 First Cape photoelectric photometer as it exists today and (below, Fig. 26.11) when mounted on the 13-inch Astrographic telescope. SAAO Museum Inv. M098/4. (Photo: ISG)

photoelectric photometry to the Cape following enthusiastic reports he had received on a visit to Europe after the Second World War (1939–1945). He was at that time the Chief Assistant at the Observatory. However, it was clearly Cousins who had the practical knowledge to put the new method into effect.

Detailed drawings and specifications were made available by Kron to other astronomers who wanted to copy his instrument and it is plain that Cousins based much of his first design on this information, such as the separate battery box yielding 90 V per stage and the Leeds & Northrup mirror galvanometer current measuring device (Figs. 26.13 and 26.14).

According to Cousins (1953), during 1948 a "simple type of photometer employing an RCA type 931-A photomultiplier tube was fitted to the 7-inch refractor." The latter telescope is by Merz and dates from 1848. The earliest remaining photographs of this photometer however were taken later and show it mounted on a 17.6 cm square baseplate for attaching to the larger refractors. Some other adaptor must have been used with the 7-inch (see the caption Fig. 26.12 for a detailed description).

On top (as seen in Figs. 26.10 and 26.11) was the side-looking 931A photomultiplier with its dessicator (necessary to prevent electrical leakage between its closely spaced connecting pins). There is a brass viewing microscope and a filter slide with blue and yellow filters. At bottom is a disc with various apertures. The baseplate shown in the photographs matched the plateholders of the Astrographic and McClean telescopes.

Cousins (1953, p. 35) remarked "Tests with this equipment for measuring stellar magnitudes were not encouraging" (!). The sensitivity was improved by increasing the voltage to 1100 and using a more sensitive galvanometer. It should be said that the movements of mirror galvanometers were extremely delicate and were easy to break. Nevertheless, this photometer was put into regular use the following year. Two observers were necessary because of the complexity—one to operate the telescope and photometer and the other to read the galvanometer.

In his thesis, Cousins mentions that tests were done to find out if the photometer was sensitive to orientation. A fluorescent spot (excited by radioactive carbon) was fixed in front of the photometer and deflections were recorded as the telescope was

Fig. 26.11 The first Cape photometer when mounted on the 13-inch Astrographic telescope (SAAO Archives P2964)

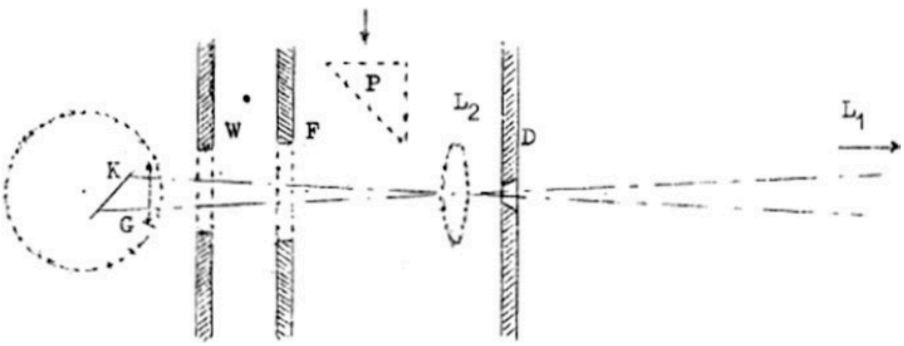


Fig. 26.12 Optical diagram of the first photometer. Starlight entered from the right through the focal plane aperture D and the exit pupil of the telescope was focused by the lens L2 onto the photocathode of the photomutiplier K after passing through the filter F. A retractable prism P was used for viewing the image in the aperture through a microscope. W is the window of the photomultiplier housing (Cousins, 1953, p. 40)

moved. These indicated a small difference of the expected sign and the right order of magnitude (~0.01 mag) when the telescope was reversed.

This photometer was put into regular use for measuring colours of the "Bright Stars" in 1949 but magnitudes were still obtained by the Fabry method.

The use of a new technique involved many small problems that had to be understood and overcome. A number of photometric pioneers visited South Africa during

Fig. 26.13 The separate voltage divider unit used with Cousin's early photoelectric photometers. This provided the correct voltage for each dynode of the photomultiplier. It was normally mounted on the telescope near the photometer. In later instruments the divider resistors were mounted behind the photomultiplier (SAAO Museum Inv. M098/3). (Photo: ISG)

Fig. 26.14 A Mirror galvanometer by Leeds & Northrup. These were the most sensitive type of moving-coil meter and were used to measure photocurrents before the advent of DC amplifiers using valves. A mirror was suspended on a very fine wire or quartz thread that supported the moving coil. It reflected a light beam that projected a dot on a distant scale. SAAO Museum Inv. M120. (Photo: ISG)

these years, becoming lifelong friends, and became useful sources of information as well as sounding boards against which Cousins and Stoy could test their ideas. For example, a tapped battery was used at first to provide the voltages to each dynode of the photomultiplier but cell failures had led to uneven voltages per stage. The solution was to use a chain of resistors across the whole battery to divide the voltages, even though this used more current (Cousins to King, 1950 January 15). Ivan King (1927–2021) was then observing at the Boyden station of Harvard Observatory from early 1950 with a photometer built at Harvard and provided Cousins with the circuit diagram of a regulated 840 V power supply incorporating a voltage doubler and a series of VR105 neon regulator tubes (King to Cousins, 1950 January 23). This is almost identical to the circuit given in Cousins's thesis, Section III, Fig 2.

4 The Advent of Amplifiers

J.B. Irwin (1909–1997) and A.N. Cox (1927–2013) visited the Cape from September 1950 to January 1951 from Kirkwood Observatory in Indiana and brought with them a photometer that had an amplifier and a chart recorder instead of a simple galvanometer.[2] This they used on the Cape 24-inch photographically corrected refractor. The Cape observers were able to try their instrument over several months. It was soon obvious that their recording arrangement was far more convenient than the galvanometer. In fact, Cousins had already been preparing to take this route: Cousins (to King, 1950 February 19) "Our recording milliammeter [chart recorder] has now arrived and the next step will be the construction of a suitable amplifier."

During 1951 much progress was made on the electronics. On 16 April Cousins wrote to Cox that he had an amplifier with a stabilized power unit working. In a letter to King on 2 June he mentioned that it was a compromise between Irwin's design and King's one, as was the power supply. Cox (1951, May 2) pointed out that even the filament power for the amplifier valves had to be regulated and suggested that this could be done with a voltage stabilizing transformer. Linearity over a wide range of photocurrents had to be checked. The circuit given in Cousins's thesis is basically that advocated by Kron but with some additional gain controls. Special care had to be taken over the choice of components such as resistors in order to preserve accuracy and stability and these were difficult to procure locally. Calibrations had to be checked monthly. The Annual Report for 1951 states that in fact two amplifier sets were made, one for each of the two chart recorders mentioned below. These were built by Cousins himself "in his spare time." The first chart recorder—an Evershed & Vignoles recording ammeter (0–2 ma)—was not very satisfactory in that it had a somewhat sticky movement involving a mechanical linkage and its scale was not accurately linear. An automatic rubber hammer tapping device had to be used to keep it moving! (Cousins to Cox 1951, December 21). At least, however, it permitted observers to work without an assistant (Fig. 26.15).

1951, December 21 Cousins to Cox "… we are having trouble with the anode lead with high gains (e.g. with 3×10^{-9} amps. for full scale). The insulation resistance is satisfactory but we get troublesome surges when the cable is moved so that

[2]The correspondence with Cox, Irwin and King is contained in SAAO Archives Box A0251 and that with A.J. Wesselink in Box A0252.

Fig. 26.15 The Evershed & Vignoles chart recorder used at first by Cousins. SAAO Museum Inv. M214. (Photo: ISG)

it is not desirable to touch the telescope until after recording the dark current. The effect is most pronounced when the cable is 'rolled' – either between the palms of the hands or between the foot and the floor. It looks as if a charge was generated or released by such action. Have you ever had this trouble and can it be avoided….?

We are still using the other recorder [Evershed & Vignoles] with an automatic 'tapping device' to keep the pen floating. The pen gave no trouble while your ink lasted but choked immediately we reverted to what the makers supplied! The present ink runs freely but tends to smudge.…" (followed by a P.S. reporting arrival of a Brown Recorder—see below.)

On 1952, February 7, Cousins to Cox: "I have just completed another H.T. power pack, this time following the rather simple Harvard design, and find it quite satisfactory (at any rate in conjunction with a regulating transformer). The E.M.I. tube needs 2,000 volts … We have had so much trouble with batteries that I have no desire to go back to them."

Cousins wrote that Walraven had recommended fixing the amplifier to the telescope to get over the cable problem. However, on 1952, March 28 Cox offered to send Cousins as much coaxial cable as he required. They had had no trouble with their cable. Ultimately, on 12 August, Cousins could report to Cox that the cable had been an improvement.

4.1 *Transfer to the 13-Inch Telescope*

It had become evident early on that the 7-inch telescope was unsuitable for photoelectric work because of the large effect of scintillation when using a small telescope (Cousins, 1953, p. 36).

At the end of 1951 the photometer was transferred to the 13-inch Astrographic telescope. "It at once became apparent that this latter telescope gave appreciably better results. This is, perhaps, on account of its greater aperture and partly because its photographically corrected lens permits the use of a smaller diaphragm with correspondingly reduced sky corrections." In a letter to Walraven (1952, February 6) (T.F. Walraven, 1916–2008) Cousins mentions "Our original photometer and recording milliammeter are now in regular use on the Astrographic (13-inch) telescope."

Quite a lot of correspondence concerned the photomultipliers. They had not been produced with the particular needs of astronomy in mind and the dark current in particular was not predictable from one tube to another. The relative warmth of the weather in South Africa made this a more important consideration than in other countries. Most astronomers had to take potluck in this regard. A later version of the RCA 931A, the 1P21, was usually better. The quantum efficiency of the photocathode also varied from one tube to another and was not uniform across the surface.

Cousins expressed his opinions concerning the various tubes in a letter to Wesselink 1952 February 10, when the latter was already working at Radcliffe Observatory in Pretoria and was responsible for the design of their photometer, then being constructed at Leiden. The Cape had a direct interest since in April 1951 they had become entitled to a share of 74-inch time. Good photomutipliers were so precious that some Leiden astronomers proposed that each observer should bring his own but the Cape people felt that changing tubes was too risky. The Cape only had two 931A tubes with acceptably low dark current and had tried a 1P21 but found it inferior.

The much more sophisticated (potentiometric) Honeywell-Brown recorder had arrived at the end of the year 1951 (Fig. 26.16). With a scale precise to 0.1% this and similar ones acquired afterwards were Cousin's standard recorders for the remainder of his long career. While observing, Cousins would adjust the gain of his amplifier to give as near full scale deflection on the chart as possible so as to take full advantage of its precision. He preferred to use unlined chart paper and read the deflections with a special magnitude ruler (Fig. 26.17).

5 The Second Photometer

In the 1951 Annual report it was stated that a completely new photometer was under construction for the 24-inch telescope. This was of a more rigid design and was more convenient to use. On 1951, October 8 Cousins mentioned to Cox that it was

Fig. 26.16 One of the Honeywell-Brown instruments that were the primary recording medium for all of Cousins later photometry. The scale was accurate to one part in 1000. (Photo: ISG)

Fig. 26.17 Magnitude ruler used by Cousins for reading the Brown recorder charts. To obtain maximum accuracy, the deflection on the chart was kept as high as possible (SAAO Museum Inv. M108)

being constructed by Laurie Brown, the instrument maker of the time, and was closely following the Kirkwood design (Figs. 26.18, 26.19, and 26.20).

1952 January 6 Cousins to Walraven: "Our new photometer is approaching completion in the workshop. The amplifier has been completed and tested and the Brown Recorder has arrived …."

By 1952 February 25 Cousins could mention to Cox that the new photometer was ready for the 24-in refractor (McClean). This was to be the first of three basically similar photometers built at the Cape. But the telescope was being overhauled and could be used only occasionally for much of the time until January 1953.

According to the Annual Report for 1952, the new photometer, when ready, had been transferred to the Astrographic "to replace the old and rather inefficient photometer that was built originally for the Seven-Inch Telescope." Plans were under consideration to build a similar photometer but incorporating a more modern EMI end-window phototube for the 24-inch.

Cousins to Cox 1952 (probably should be 1953), February 1 mentions that "Irwin has sent details for a 'M.I.T.' type amplifier that he claims is much superior to Kron's design. We have had very little trouble with ours… What is the superiority claimed for this M.I.T. circuit?"

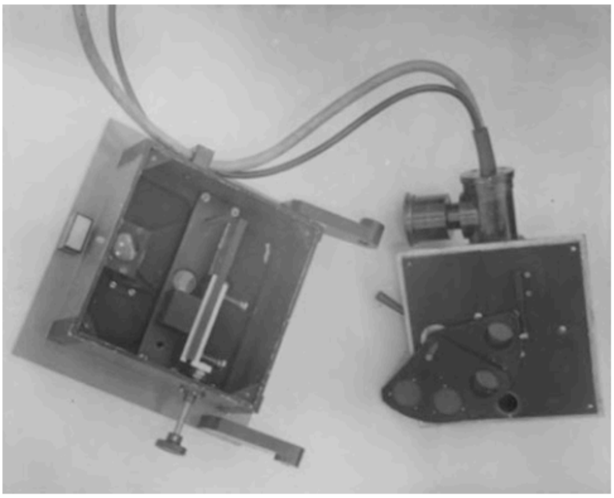


Fig. 26.18 Cousins's second photometer in its original form, shown with the top removed. It contained the same elements as the earlier one but was more rigid and easier to use. The part on the right that has the 931A photomultiplier attached is still in existence, but the base was used as part of the later version with an E.M.I. end-window tube. Attached to the side of the phototube enclosure was a container with dessicant. The base of this instrument was hinged so that it could be swung out, possibly so that a wider-field eyepiece could be used for finding purposes. (From Cousins (1953))

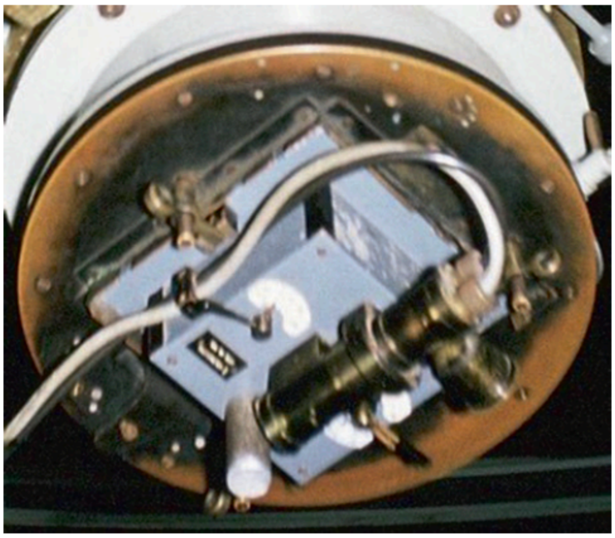


Fig. 26.19 The second photometer photographed on the Astrographic telescope around 1965. It is surprising that it was still in use at this date in view of the superior performance of the EMI end-window tubes. (Photo: Greg Roberts)

Fig. 26.20 The upper part of the first version of the second photometer as it exists today. It was labelled “Photometer II.” The filter and aperture levers were re-used on the next version. SAAO Museum Inv. No. M098/1. (Photo: ISG)

The M.I.T. amplifier mentioned was one published in the *M.I.T. Radiation Laboratory Series* (Valley Jr & Wallman, 1948). (These volumes summarised the huge knowledge of electronics gained during the development of equipment for military purposes in WW II.)

1953 February 16 Irwin to Cousins: “The criticisms of the Kron circuit are: (1) It is not quite linear enough (2) it is not quite stable enough and (3) it does not hold calibration quite well enough. … we are not certain from internal evidence alone that we have the scale any more accurate than .02 or .03 mag. Per 2.5 mags. This of course is not good enough… We now have three M.I.T. amplifiers working; we have no definitive information as yet as to how well they hold calibration but the McDonald folks talk in terms of ten thousandths of a magnitude! Anyway, I’m sold.”

A.D. Code (1923–2009) and J.R. Houck (1940–2015) of the Washburn Observatory (Wisconsin) took over the 24-inch and worked in Pretoria from February to May 1953, using their own equipment.

Cousins to Irwin 1953, March 1: “Code and Haut (sic) have arrived and I did not waste time before comparing notes on amplifiers and other matters of common interest. … I cannot complain of non-linearity troubles with the present amplifiers. The linearity of amplifier and Brown recorder combined is better than the makers claim for the recorder alone…. The fine sensitivity calibration showed a ‘warming up’ error of about $0^{m}.03$ (between 0 and 10) when the feed-back network was composed of carbon resistances of commercial quality. It is appreciably smaller with the amplifier that is fitted with high-stability resistors, the variations amounting to about

$0^m.01$ over a range of 3 magnitudes. The MIT amplifier may be (probably is) better but I cannot really complain about the present ones in this respect…I am sufficiently interested in the new circuit and your and Code's impression of it to contemplate using it for our next amplifier."

5.1 End-Window Photomultipliers

Thoughts must already have been turning to end-window photomutipliers because in the letter to Cox on 7 February 1952 (q.v.) Cousins had mentioned that an EMI tube would require a 2000 V power supply.

During the following year Cousins (to Wesselink 1953, May 6) mentioned the Cape Observatory's activity at the time in making interchangeable housings suitable for both the Cape and Radcliffe (see below) photometers so that they could both use the end-window EMI tube type 5659 (VX5035) with 3/8-inch (9.5 mm) diameter sensitive areas. These photocathodes were flat and allowed for better focusing of the Fabry or pupil image than those of the side-window 931A type that were tilted with respect to the optical axis of the photometer. The responsivity of the photometer would then be less critically dependent on the centering of the star in the aperture.

> I have practically finished building a new power supply—suitable for either a Kron or M.I.T. pattern amplifier and giving up to 2000 V for an E.M.I. tube. Brown [Instrument maker] is building a photometer for the 24-inch ….

1953, November 23 Cousins wrote to James Houck "I have been wiring up a new E.H.T. power supply according to your design and cannot get it to oscillate." This must have been a radio frequency oscillator system feeding a coil and rectifier such as early TV sets made use of and would have been needed to make the high voltages necessary for the end-window phototubes. He went on "Our EMI tube photometer is now working but we are waiting for a second Brown Recorder (due this month) before putting it into regular use."

1953, December 6 Cousins to Wesselink: "We have got our E.M.I. photometer (on the Cape 24-inch) working now. The dark current is very small and produces little noise even at the highest practical sensitivities. …An E.M.I. tube will probably go as faint without refrigeration as a 1P21 will with it …."

The main body of the first end-window photometer was simply that of the side-window version (Fig. 26.18) with a more convenient means for viewing the aperture (Fig. 26.21).

Figures 26.22, 26.23, 26.24, and 26.25 show contemporary photographs of the inner details of a slightly later photometer with the end-window photomultiplier housing. This one has a side extension to accommodate a complete filter wheel rather than a mere segment and also a more convenient periscope for aperture viewing.

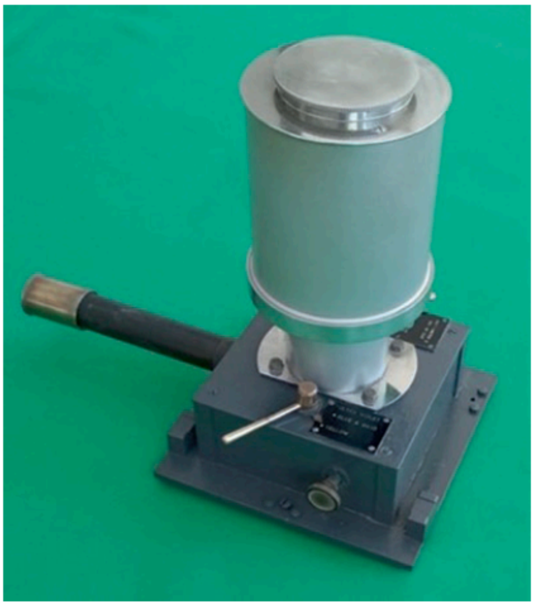
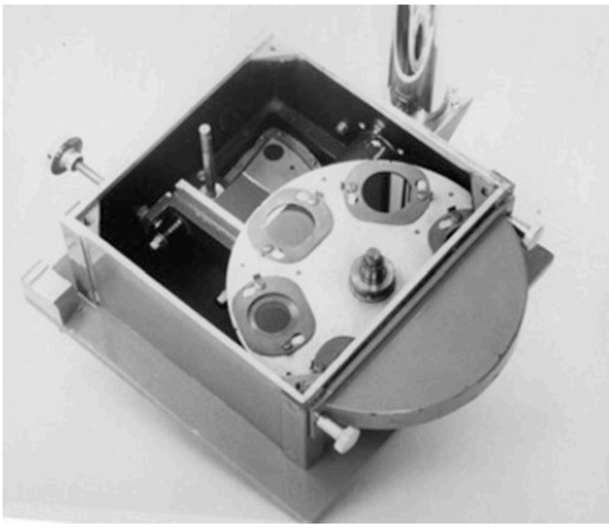


Fig. 26.21 The first of the end-window versions of the photometer, using the lower part of the side-window version. SAAO Museum Inv. M253. (Photo: ISG)



Figs. 26.22 and 26.23 The Cousins photometer (second type, end-window version) shown with and without the filter wheel in place. It was clearly very similar to the first version (see Fig. 26.18). (SAAO photos: P7577, P7578)

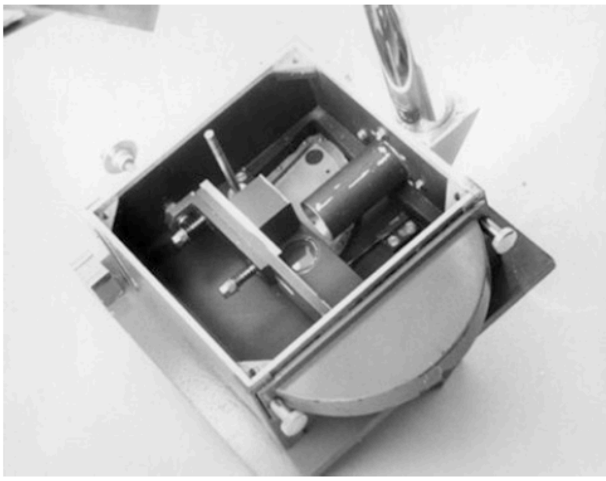


Fig. 26.23 (continued)

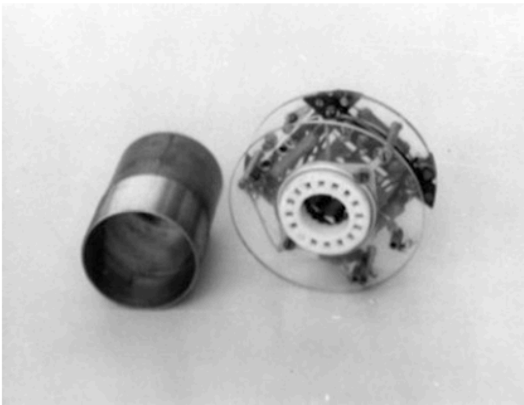


Fig. 26.24 The photomultiplier base and magnetic shield for the end-window EMI photomutipliers installed in place of the RCA 931A tubes. (SAAO photo: P7569)

6 The Leiden Photometer at the Radcliffe Observatory

In parallel with Cousins's activities at the Cape, he was also busy for a few years with a photometer for the Radcliffe Observatory in Pretoria.

In April 1951, the impecunious privately-owned Radcliffe Observatory entered into an agreement with the Admiralty (who then controlled the Royal Observatories) that the Cape would receive 1/3 of the observing time on its 74-inch (1.9 m) telescope in exchange for an income grant. In the same year A.J. Wesselink, formerly of Leiden Observatory, was appointed Chief Assistant at Radcliffe.

Wesselink had already had some experience with photoelectric methods when at the Leiden Southern Station in Johannesburg, but he wrote to Cousins for advice on

Fig. 26.25 A Cousins photometer of the second type, EMI version that made use of the end-window EMI phototubes. Two of these photometers still exist. They continued to be used by Cousins for many years. (SAAO photo: P7581)

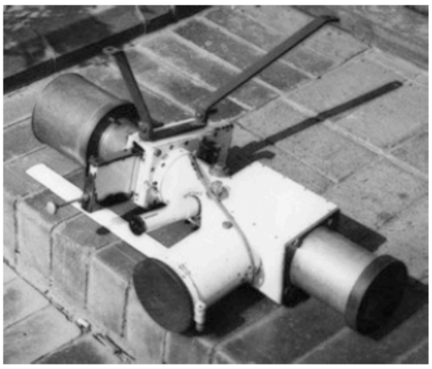


Fig. 26.26 The Leiden photometer supplied to the Radcliffe Observatory. It was attached to the Observatory's prism spectrograph in place of its large "Visitors' eyepiece." The latter was then inserted into the side of the photometer as a field acquisition eyepiece. At the time this photograph was taken, a Cousins-type photomultiplier housing for an EMI tube had already been substituted for the original 931A type and braces had been added to reduce flexure. (Photo: ISG personal collection)

a new photometer to be built at Leiden and sent out to Radcliffe. The Cape was able to offer technical support beyond the meagre capability of Radcliffe. The new photometer was designed to be slid into the large acquisition eyepiece holder of the Radcliffe Cassegrain 2-prism spectrograph to make for easy interchange between photometry and spectroscopy.

The photometer arrived from Leiden in April 1952, but it was not in full operation even a year later. It was originally furnished with a 931A photomultiplier. The Cape astronomers were of course very interested in using it for fainter stars and Cousins took a close interest in developments. He travelled frequently to Radcliffe over the next few years and many of his subsequent letters were dated from there.

In the 1952 Annual Report we find "During the months of June, July and August, the Cape observers made a serious attempt to use this photometer. Though its initial behaviour was very disappointing, there is every indication that it will become a convenient and useful instrument …" On 1952, August 12 Cousins, in a letter to Cox, commented critically on the Leiden design, particularly the electronics, "The new Leiden Cassegrain photometer is a beautiful piece of instrument making but the design is weak from a practical observing point of view. The electronics side was even poorer, and I have had to make a number of changes, particularly to the H.T. (the 'High Tension' or high voltage required for the anodes of the valves) circuit. The amplifier they provided may be very convenient for variable stars and the like but it was useless for setting up scales and I had to get one of our amplifiers sent up from the Cape." This was possible because the 24-inch refractor in Cape Town was still being overhauled and it was not yet needed. The Leiden 931A phototube was also not a particularly good one and Cousins could only go 1 mag fainter with the 74-inch than with Cox's setup on the 24-inch.

During 1953 a new filter carrier and housing for an EMI photomultiplier were made at the Cape for use with this photometer as well as suitable power supplies and amplifiers. These were installed the following year (Fig. 26.26).

1953, September 11 Cousins to Wesselink. Re Code's amplifier. "My plan is to build a complete amplifier—power supply with a H.T. supply for EMI tubes (This would be the EHT or Extra High-Tension unit) before paying you another visit. Our own EMI tube photometer is almost finished and it was intended to duplicate the cell housing for use in Pretoria…

It does not pay to use any but the best components when constructing measuring equipment. The trouble is that one cannot always get what one wants locally and there is often a lot of delay in getting parts from overseas."

1953, December 6 Cousins to Wesselink: "The E.M.I adaptor and 2-inch filter slide (for upgrading the Pretoria photometer) are progressing but are not expected to be ready by January 1. I am therefore planning to use the Cassegrain (i.e., Leiden) photometer as it is (but with a new M.I.T.-type amplifier, now approaching completion) for my next programme…."

1953, December 20 Cousins to Wesselink: "The new amplifier and E.H.T. supply are working but not quite finished. The EMI tube is proving such an advance on the 931-A's we have used in the past that Dr. Stoy is pushing the completion of the unit and I hope to have it to use after all."

1954, February 20 Cousins (at Radcliffe) wrote a summary of the current status of his photometric programme to Cox: "I came up here at the beginning of January with the principal object of initiating a new photometric programme with a new photometer. I had constructed a new amplifier plus the necessary power units following the designs used by Code and Houck. The amplifier has a modified M.I.T.

circuit, with a fine sensitivity 'attenuator' included and a H.F. (television type) step-up designed to give 0.5ma at 2000 volts. The photometer I am using is the Leiden-built Cassegrain photometer with the cell end replaced with a new one containing an E.M.I. photomultiplier cell.

We bought three E.M.I. cells (i.e. photomultiplier tubes) and are using one in a new photometer on the 24-inch at the Cape. Experience with this photometer showed that this cell is about one magnitude better than an unrefrigerated 1P21. Shot noise rather than dark current is the limiting factor. The two tubes I have tried here are more noisy and would benefit from refrigeration (at any rate in the summer months)…

I have very little fault to find with the Cape E.M.I. photometer and was favourably impressed with the performance of the Washburn amplifier and power unit. I am going to change the input circuits of all my amplifiers as the M.I.T. arrangement gives a much higher stability of the coarse sensitivity calibration."

1954, June 2 Cousins to Wesselink mentions a new amplifier and EHT supply to be constructed for Radcliffe. "The components for the amplifier and power pack (including the ([E.]H.T.) have nearly all been ordered now, and some are on hand. We have at last appointed a radio mechanic and he will be starting work in a few days time." This was E.J. Farr, described in the 1954 Annual Report as an "Electronics Mechanic."

1956, December 26 Cousins to Cox: "Photoelectric work goes on steadily. Two photometers are in regular use here and another in Pretoria when I am there and a fourth installation is nearing completion in the workshop. The apparatus is designed for routine rather than specialist use and we are more interested in having it fool-proof as possible rather than aiming at getting spectacular results. There is probably no other observatory where photometry is treated so much as a routine as here."

1957, July 27 Cousins to Irwin: "I have much improved the performance of my Pretoria E.M.I. cell by insulating the supporting sleeve and applying cathode potential to it…."

7 The 18-Inch Reflector

A major improvement to the instrumental armament of the Royal Observatory, Cape, was the arrival of the 18-inch (strictly 49-cm) F/11 Dall-Kirkham Cassegrain reflector during 1955. A new photometer (of the now standard Cousins pattern) was constructed in anticipation, for this telescope. As the new telescope had aluminised mirrors it was going to be possible to make observations in the (now standard) ultraviolet U band. Because of the need to mount the telescope on the former Gill heliometer mount, observing commenced only in 1957. The 7-inch Merz shared the same stand in order to act as a guider.

By this time, no fewer than six DC amplifiers had been constructed and three Honeywell-Brown chart recorders were in service. The M.I.T. design continued to be used for several years and was somewhat improved by Cousins and Wellgate

Fig. 26.27 Photometer labelled "RP3 Photometer VI 1956 L.C.B." (Laurie Brown). Probably the photometer constructed for the 18-inch telescope. SAAO Museum Inv. M127. (Photo: ISG)

(1961). The stability of these amplifiers was always to some extent a problem because of the tendency of the valve characteristics to change slowly. Though the plate (H.T.) and photomultiplier supplies could be provided by conventional regulated power sources, the relatively low-voltage valve heaters had to be supplied from accumulators (lead-acid batteries) as these were independent of mains voltage fluctuations. Only much later on, probably in the late 1960s, did much more stable amplifiers, based on solid-state varactor-bridge op-amps, become available.

For the first time, observations could be made in what had become the standard *U* ultraviolet band, previously not transmitted by the refractors. (The Radcliffe 1.9 m telescope was aluminized for the first time only in 1959, having been silvered up till then.)

A new Cousins-type photometer was constructed for it (Fig. 26.27).

1957, April 25 Cousins to Irwin: "We now have the 18-inch reflector 18-inch (with a new photometer) in operation but have not started on a regular programme with it…. I am afraid photometry is treated as a sort of Cinderella at this 'fundamental' observatory and I have frequently had to re-start programmes with different equipment and consequent wastage of observing time. The 18-inch (on the heliometer mounting) is not as easy a telescope to use as the Astrographic, …but as it has aluminized optics it should now be possible to measure something nearer to Johnson's *U-B*."

In spite of its alleged inconvenience, the 18-inch became Cousins's personal telescope and he continued to work with it almost every evening, well past his retirement in 1972, and into his 90s. For the most part he used the same photometer and

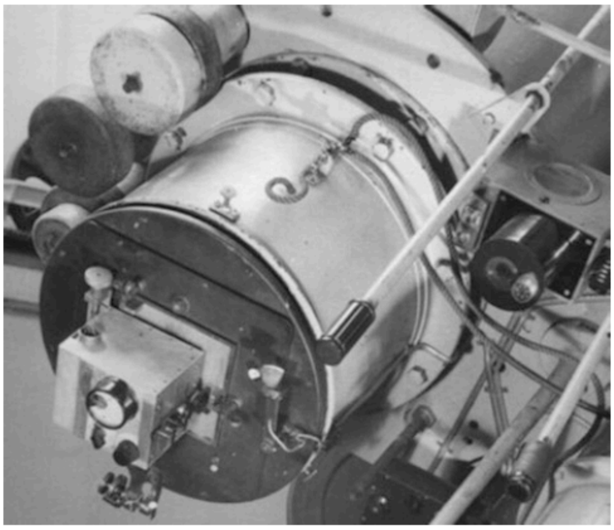


Fig. 26.28 The photometer in this photograph is believed to have been that used for occultation observations by Cousins and Guelke (1953). It no longer exists. Shown here attached to the McClean 24-inch refractor. The early voltage divider (Fig. 26.13) can also be seen. (SAAO photo: P5655)

recording equipment that he had set up over 40 years before, though he was not averse to trying new techniques from time to time and indeed developed the Kron-Cousins *VRI* system using a cooled RCA31034A tube in his retirement. But this goes beyond the period discussed here (see Kilkenny, 1993, 2002 for details of his scientific output and later work).

8 An Occultation Photometer

In the years 1950–1953 Cousins, with the help of R.W. Guelke, Professor of Electrical Engineering at UCT, undertook several observations of occultations of Antares with a time resolution of about 0.01 seconds (Cousins & Guelke, 1953) (Fig. 26.28).

The photometer specially constructed for the occasion no longer exists, but a photograph believed to be of it remains, identified through the printed description of it. The 24-inch McClean telescope was used for this work and guiding was carried out with the 18-inch visual refractor attached to it.

The diaphragm was part of the mounting plate and behind it a metal box contained a 931A photomultiplier with shutter and Fabry lens as well as a single-stage valve pre-amplifier whose circuit was described. The box was hinged so that the star could be centered in the aperture. The knobs on the front of the box adjusted gain and balance according to the deflection on the meter. The signal was recorded on a moving-film camera viewing an oscilloscope.

References

Cousins, A. W. J. (1943). Photovisual magnitudes of Southern stars. *Monthly Notices of the Royal Astronomical Society, 103*, 255.

Cousins, A. W. J. (1950). Magnitudes of bright stars in the E regions observed by the Fabry method. *Monthly Notices of the Royal Astronomical Society, 110*, 531.

Cousins, A. W. J. (1953). *Standard magnitude sequences in the Harvard standard regions at −45° declination*. Doctoral thesis, University of Cape Town, South Africa.

Cousins, A. W. J. (1988). *Photoelectric photometry at the Cape Observatory*. Unpublished manuscript memorandum dated 1988 March 29, South African Astronomical Observatory Archives A0258/3.

Cousins, A. W. J., & Guelke, R. (1953). Photoelectric observations of occultations at the Cape Observatory. *Monthly Notices of the Royal Astronomical Society, 113*, 776.

Cousins, A. W. J., & Stoy, R. H. (1946). On the use of rotating sectors in astronomical photometry. *Monthly Notices of the Royal Astronomical Society, 106*, 286.

Cousins, A. W. J., & Wellgate, G. B. (1961). A direct current amplifier for photoelectric photometry. *Monthly Notes of the Astronomical Society of Southern Africa, 20,* 67. Erratum (1961), 20, 93.

Hearnshaw, J. B. (1996). *The measurement of starlight – Two centuries of astronomical photometry*. Cambridge University Press.

Kilkenny, D. (1993). *Precision photometry: Proceedings of a conference held to Honour A.W.J. Cousins in his 90th year*. South African Astronomical Observatory.

Kilkenny, D. (2002). Alan Cousins (1903–2001): A life in astronomy. In C. Sterken & D. W. Kurtz (Eds.), *Observational aspects of pulsating B and A stars*. Astronomical Society of the Pacific.

Kron, G. E. (1946). Application of the photomultiplier tube to astronomical photoelectric photometry. *Astrophysical Journal, 103*, 326.

Kron, G. E. (1947). The construction and use of a photomultiplier type of photoelectric photometer. *Harvard College Observatory Circular, 451*, 10–29.

Stoy, R. H. (1993a). *Precision photometry: Proceedings of a conference held to Honour A.W.J. Cousins in his 90th year*. South African Astronomical Observatory.

Stoy, R. H. (1993b). Foundation of the E-region standard system at the Cape Observatory. *Monthly Notes of the Astronomical Society of Southern Africa, 52*, 127.

Valley, G. E., Jr., & Wallman, H. (Eds.). (1948). *Vacuum tube amplifiers* (MIT Radiation Laboratory Series) (Vol. 18, p. 480). McGraw-Hill.