the radio MINITRACK satellite system. This error is still being perpetrated today, on the Internet-WIKI, for example. The Satellite Applications Centre (SAC) of the CSIR at Hartebeesthoek still had a MOTS camera as recent as last year.

ANNALS OF THE INTERNATIONAL GEOPHYSICAL YEAR Vol VI Parts 1-V 1958 and Volume XII Part II 1961.

BULLETIN FOR VISUAL OBSERVERS OF SATELLITES, published by SAO 1956 -1958.

Semi-Annual reports of the SATELLITE-TRACKING AND EARTH-DYNAMICS RESEARCH PROGRAM as well as Semi-Annual reports on the OPTICAL TRACKING OF SATELLITES – both prepared by SAO as part of the NASA grant for operating the BNCs. ☆

The Astrographic Telescope of the Royal Observatory, Cape

I.S. Glass, South African Astronomical Observatory

Introduction

The first photographically produced catalogue of stars, the *Cape Photographic Durchmusterung* (CPD), was the brainchild of David Gill, Her Majesty's Astronomer at the Cape in the years 1879-1907. It covered the whole sky south of 19 degrees south declination and included 454 875 stars. The CPD camera made use of a standard Dallmeyer portrait lens of 6 inches aperture and 54 inches focus, giving it a field of 6 degrees square.

Even while the CPD was progressing, the first international astronomical conference – the Astrographic Congress – was held in Paris in 1887 under the leadership of Admiral Mouchez, director of the Paris Observatory, and David Gill. Its aim was to promote a project called the *Carte du Ciel* ('Map of the Sky').

The *Carte du Ciel* and its telescopes

The *Carte du Ciel* was to be a much more ambitious sky survey than the CPD, involving as it did twelve observatories, each equipped with photographic refractors having the same aperture (13 in or 33 cm), field (2 degrees square) and focal length (3.43 m). Each participating observatory was assigned to cover a particular declination zone, the Cape's being -40° to -52°. Each photographic telescope was to have a guide telescope with an aperture of 10 inches (25.4 cm) diameter rigidly fixed to it.

Half of the Astrographic telescopes were made by the Grubb Company in Dublin. The others were mostly made in France where the brothers Henry had shown what was possible. Gill and Grubb corresponded extensively, covering all aspects of the design. The optics were something new for Grubb as, unlike the case for typical visual refractors where only the on-axis performance and achromatism had to be good, the new telescopes had the extra requirement of a large field. Grubb had difficulty in achieving good performance over the whole field. This is reflected in the fact that his lens designs for the early telescopes differed from those of the later ones (see Grubb, 1891).

Another requirement of photographic telescopes was that their drives should be extremely precise and steady so that guiding should not have to be done too often during the long exposures. To achieve this, Grubb used governor-controlled clockwork motors of a very heavy design. He also devised a scheme for synchronising the drive to the observatory time service by means of a phase-locked loop. Three contactor wheels on the final drive shaft were used to make comparisons with pulses generated by a pendulum swinging through a blob of mercury. Planetary gears could be engaged by electromagnets to speed up or slow down the drive as required (see Grubb 1888).

The RA drive was otherwise of typical Grubb design, making use of a precisely cut sector of a wormwheel instead of a complete wheel. This meant that the telescope had to be stopped every few hours; the sector was then unclamped from the polar axle and re-wound. The justification was that the declination axis could be much shorter than a large wormwheel would allow. The telescope was therefore less prone to oscillate or shake in the wind.

Construction

The construction of the telescope was sanctioned 30 Aug 1888 following the ap-

Fig. 1. (left) The pendulum that controlled the drive. Its tip passed through a blob of mercury to generate precise time pulses (see text).

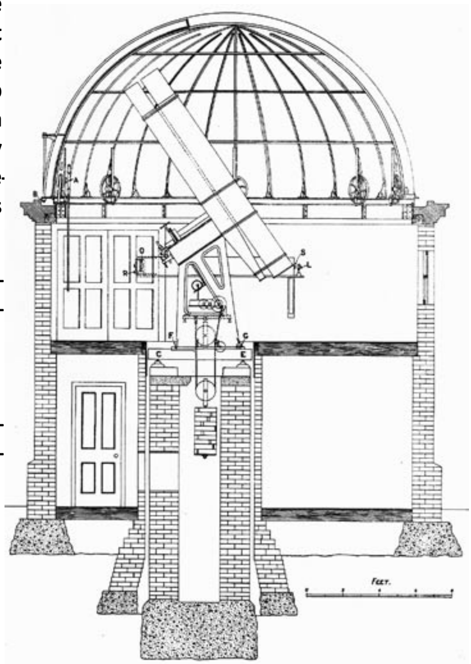

Fig.2. (right) Section of the Astrographic building and dome in Cape Town. The horizontal apparatus for imposing reseaus on the plates can be seen just behind the telescope at the level of the bottoms of the tubes.

plication of some political pressure and in the face of passive opposition from the then Astronomer Royal in England, William Christie (see Glass, 1997).

The building, shown in Fig. 2, contained downstairs a computing room, a developing room and a store room. Upstairs, there was a dark nook for handling plates and imposing a 'reseau' on them by projection. These reseaus were believed to improve the accuracy with which star positions could be measured but were later abandoned.

Fig. 3. The completed Astrographic telescope photographed around 1900. The large circular object inside the pier contained the governor for the clockwork motor.

The mechanical parts arrived in the Cape on 11 June 1890 and the objective of the guide telescope a few weeks later. Gill had to shorten the tube by about 3 cm to get it to focus! The photographic objective arrived later and was mounted by 12 August. Gill was unhappy with both lenses and returned them to Dublin for further figuring in January 1891. It was also necessary to alter the plateholder arrangements, to provide springs to keep the lenses centred in their cells and to make other small improvements. Grubb worked on the lenses until September 1891. He blamed their initial defects on sabotage!

The photographic lens as finally received still shows a slight elongation of images situated near the plate corners and the focal plane is slightly curved, requiring that focusing be done 4 or 5 cm from the plate centre for best overall results.

The Period of Astrometric Programmes

Only on 29 July 1892 did Gill begin the programme for which the telescope was designed. The Cape Zone required 1 632 plates, which were taken in duplicate. The publication of the Cape Astrographic Zone (CAZ) catalogue was achieved in 1923 under Gill's successor, S.S. Hough. It contained 20 843 stars of CPD mag 9.0 and brighter.

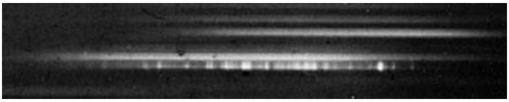

Fig. 4. One of several spectra taken in 1897 by McClean with his objective prism attached to the Astrographic Refractor in Cape Town. This is one of the earliest photographic spectra of the unusual massive interacting binary η Carinae (Photo courtesy of M. Kaye, Norman Lockyer Observatory, Exeter, UK).

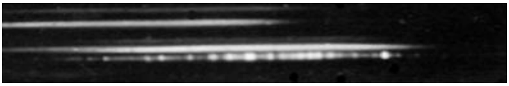

Fig. 5. Another spectrum of η Car taken in 1899 by Gill using the McClean 24-inch telescope and objective prism. The bright line on the right is Hβ. Shorter wavelengths are to the left (See Gill 1900).

Several other, smaller, programmes were conducted, sometimes simultaneously with the CAZ. One of the most interesting early applications of the telescope was during a visit in 1897 by Frank McClean, the famous English amateur who donated the McClean telescope. He mounted a 12-inch objective prism of 20 degrees angle in front of the photographic objective and made a spectrographic survey of all southern stars brighter than mag 3.5. In the course of this he discovered that oxygen is present in certain types of stars (McClean 1897). An example of a spectrum of η Carinae is shown in Fig. 4.

A series of photographs of Jupiter's satellites was taken in 1902-1905 for Willem De Sitter (later a famous cosmologist who suggested the possibility of an expanding universe based on his solution of Einstein's equations of General Relativity).

In 1910 the photoheliograph was mounted on the side of the Astrographic. The use of this telescope twice daily to take photographs of the Sun cannot have been good for nighttime work because of the heating that must have occurred.

From about 1917 Wood of the Union Observatory repeated the CAZ survey. The images were blinked against the first series by R.T.A. Innes.

Other early projects included selected areas for deeper study, polar areas, comets, variable stars and parallax plates. The latter were taken around 1917 by J.G.E.G. Voûte, a Dutch volunteer who was working at the Cape and played a large part in determining the distance of Proxima Centauri, the nearest star, then recently discovered by R.T.A. Innes at the Union Observatory in Johannesburg.

The Cape Astrographic Zone was re-photographed on a number of occasions to look for proper motions. The earliest of these programmes seems to have been started in 1917 by H.E. Wood of the Union Observatory in Johannesburg, with the participation of J.K.E. Halm, Chief Assistant of the Royal Observatory. These were blinked by Innes against the original plates to find stars of large proper motion.

S.S. Hough died in 1923 after a long battle with cancer and was succeeded by Harold Spencer Jones who brought new energy to the Observatory.

Fig. 6. The 12-inch diameter objective prism of 20° angle used by F. McClean with the Astrographic Telescope during his work on Oxygen in stars in 1897. This prism is owned today by the Norman Lockyer Observatory in Exeter, UK (Photo courtesy of M. Kaye).

In the 1920s the main programme was a systematic repetition of the CAZ programme. Spencer Jones initiated this even before he had arrived at the Cape. It was completed only in 1928. The smaller programmes in the 1920s included the usual transient phenomena such as comets and novas. Some Kapteyn `Selected Areas' were observed for magnitudes and proper motions. These were parts of the sky selected for in-depth studies too intense to be extended to the whole sky. Kapteyn himself was a noted Dutch astronomer based in Groningen who had worked with Gill and was co-author of the CPD catalogue. The products were uniform series of photographic magnitudes and proper motions for the original 20 843 stars of the CAZ, published in 1936, and for 20 554 fainter ones published in 1941.

A programme on the Solar parallax (distance) through triangulation of Mars was carried out during the opposition of that planet in 1924. This was when Mars was on the opposite side of the earth from the Sun and thus at its nearest. This telescope was also used for the Eros programme of 1931 when that minor planet was also in opposition.

In 1929 the photoheliograph was removed and placed on a mount in the NW dome, where it still is. Some other overhauling of the telescope was also carried out.

After 1929 a camera known as the Wide Angle Lens (WAL), of 6 inches diameter and 80 inches focal length, with a field of 25 square degrees, was mounted and used to take plates for the Cape Photographic Catalogue (CPC50). This programme complemented the CAZ by photographing the parts of the southern sky south of -30° not already covered and also complemented the AGK2 project being carried out in the northern hemisphere. Over 68 000 stars were listed, with proper motions, magnitudes, colours and spectral types by the time it was finished in 1968.

The Photometric Period

The Royal Observatory became interested in precision measurement of the brightness of stars by means of photography during the Second World War, partly in collaboration with R. Redman who was then at the

Radcliffe Observatory in Pretoria. The technique they used was `Fabry Photometry'. Conventional photographic photometry depended on measuring the diameters of star images but Fabry photometry involved spreading out the starlight evenly by means of a lens placed close to the image and focusing the objective of the telescope onto the photographic plate. The density of the image on the photographic plate was afterwards measured with a microdensitometer. This gave a considerable improvement in accuracy, to the 1% to 3% level. Though now completely obsolete, Fabry photometry was in use until about 1951.

The Fabry photometer was the most frequently used accessory from about 1944. One of the aims was to obtain accurate comparison stars around the sky in the so-called 'E-Regions' which were conveniently high in the sky at our latitude. The later Nobel prizewinner Allan Cormack participated in this work in early 1945 as a vacation student!

By 1952 a photoelectric photometer was mounted on the Astrographic, though plates continued to be taken and the twin photometric lenses were also in use. The photometer probably used a RCA 931A photomultiplier. In 1962 this photometer was reconstructed to make use of an E.M.I. end-window photomultiplier.

R.V. Willstrop used the Astrographic to mount a narrow-band photometer around 1957 and again in 1967 used a 10-channel photometer.

A Markowitz dual-rate Moon Camera was used during the International Geophysical year 1957-8 as part of an international effort to re-define time in terms of the earth's orbital properties.

In the 1960s the telescope continued to be used for a variety of programmes, principally photometric ones. The 18-inch reflector that came into service in 1957 and the 40-inch telescope in 1964 caused some diminution of interest in the Astrographic since they as aluminised reflectors were much more suitable for U-band (ultraviolet) measurements than a refractor. This decade saw the completion of a programme to measure the southern stars of the *Bright Star Catalog* (referred to as HR stars).

During the next 25 years the use of the telescope declined. Only occasional programmes were mentioned in the Annual Reports. A programme of proper motions of the Sco OB1 Association is mentioned as having been conducted for Leiden in 1981. Otherwise, occasional photographs of comets were taken. An interesting use was to repeat a plate of the 30 Dor region of the Large Magellanic Cloud, showing SN1987A, the brightest supernova since the start of the 17th century.

Later history of telescope

In 1933 a system was installed to rewind the drive weight automatically.

In 1942, during the Second World War, this dome, with the others, was painted

Fig. 7. The Astrographic building and dome (May 2012), just after repainting and exterior renovation.

dark green, presumably to make the Royal Observatory less of a landmark for possible bombing raids. In 1945 it was re-painted with aluminium paint.

In 1950, the panels of the dome were replaced with Masonite

In 1952 the Wide Angle Lens was moved to the McClean telescope, where it still is, though now called the 'Old Astrometric Camera'. Twin photometric cameras (5-inch, F/7) were mounted in its place and stayed there until moved to the Multiple Refractor Mount (MRM) around 1964.

In 1952 it had become clear that the frequent re-setting of the telescope for photometry (every few minutes) had caused a lot of wear. The two-colour PE measurements were made with 4 min between stars of which 2 min were taken up by recording. In 1954 the weight-driven drive clock was removed and replaced by a synchronous electric motor. However, the planetary gearing system used for guiding and set speeds was retained. The telescope was rewired and the 10-inch guider serviced. In 1957 it was overhauled at Simonstown Dockyard and roller bearings were fitted to the Dec and RA axes.

In 1995 the Astrographic tubes were removed and a 16-inch Parkes F/5 Newtonian was placed on the mount. This was used by Shigeru Matsumoto, a student of the University of Tokyo, with the `PANIC' PtSi infrared camera for a survey of the Galactic Bulge in the J and H infrared bands.

Now, in 2012, this venerable telescope has had the algae cleaned off its dome and the outside of the building re-painted. The Dent clock that once stood inside has been removed for safekeeping but the pendulum apparatus of the original phase-locked loop is still in place.

It is hoped that the currently unused Parkes telescope can be removed and the Astrographic tubes replaced in the near future while there are still people around who can remember how they were taken off!

Sources and References

Annual Reports of the Royal Observatory, Cape of Good Hope

Gill, Sir D., 1900. The spectrum of η Argus, Mon. Not. R. Astr. Soc., **61,** 66-68 + 1 plate.

Gill, Sir D., 1913. *A History and Description of the Royal Observatory, Cape of Good Hope*. HMSO, London.

Glass, I.S., 1997. *Victorian Telescope Makers, the Letters of Thomas and Howard Grubb.* Institute of Physics Publishing, Bristol and Philadelphia.

Grubb, H., 1888. New Arrangements of Electrical Control for Driving Clocks of Equatorials. *Mon. Not. R Astr. Soc.,* **48**, 352-356.

Grubb, H., 1891. The Construction of Telescope Object-Glasses for the International Photographic Survey of the Heavens, *Trans R. Dublin Soc.,* **4**, 475-480.

Laing, J.D., 1970. *The Royal Observatory, Cape of Good Hope 1820-1970. A Sesquicentennial Offering,* Royal Observatory, Cape of Good Hope.

Stoy, R.H., letter to I.S. Glass 9 Feb 1992.

McClean, F., 1897. Comparison of Oxygen with the extra Lines in the Spectra in the Helium Stars, β Crucis, &c.; ..., *Proc. Roy. Soc. London*, **62**, 417-423.

Warner, B., 1979. *Astronomers at the Royal Observatory, Cape of Good Hope.* Balkema, Cape Town and Rotterdam. ☆

Geared to turn photons into paper

Willie Koorts

When visiting the Sutherland Observatory you are astounded by the sheer number of domes and hosted experiments populating the plateau today. The three domes present during the official opening of the Observatory on 15 March 1973 have since grown to 20. Although the number of hosted experiments have only increased from two to six, they got much more sophisticated. This article gives and overview of the facilities on the Sutherland hilltop today.

If we start with the three original domes which housed the 0.5-m (20-inch), 0.75-m