The Hewitt Camera Archive at Crayford

J. J. Howarth

The Hewitt Camera Archive is a collection of approximately 11,000 Schmidt camera plates made by various professional bodies in the UK and in Australia during the past 30 years. The purpose was to track artificial satellites, but background stars are also recorded to a high positional accuracy. Following the transfer of the Royal Greenwich Observatory from Herstmonceux, to Cambridge the Archive and a Zeiss plate measuring machine have been transferred into the keeping of Crayford Manor House Astronomical Society. The Zeiss has been reassembled and the plates have been fully indexed. The Archive and the plate measuring machine will be made available to the astronomical community.

Background

The Hewitt Camera was conceived and designed in the late 1950s by Joseph Hewitt (1912–1975), a physicist and optical analyst who worked at the Royal Radar Establishment (RRE), Malvern. The original purpose was to track the Blue Streak Missile but, when this was cancelled, it was decided to use the Hewitt design to track satellites for geodetic analysis. Two Schmidt cameras of this design (referred to simply as 'Hewitts') were built by Grubb Parsons, under contract to RRE, and these became operational in 1962 at two sites: Sheriff's Lench, near Evesham – later called the 'Malvern' site – and Lye Vallets (between Leominster and Hereford).

An interesting feature of these observatories, and of later constructions, was the double-skinned run-off hut which protected the camera. Sensors monitored the temperature inside and out and, as evening approached, the interior was automatically cooled to the outside temperature. Observing could thus begin without delay as soon as the hut was rolled back.

A diagram of the main components of the Hewitt is shown in Figure 1. The design yields a high light grasp and a very large field of view.

The cameras had a spherical focusing mirror of 864 mm (34 inches) diameter and a focal length of 680 mm. The correcting plate was placed 1062 mm from the front surface of the mirror, at or near its centre of curvature. The diameter of the correcting plate was 630 mm and, as this is the true aperture of the system, it would give a focal ratio of f/1 in round figures. A field flattening lens with a diameter of 156 mm was placed over the photographic plate, and just in front of the focal plane, convex side facing towards the mirror. The lens was used to obviate the need to bend the photographic plate to the curved focal plane of the classical Schmidt design. The system was arranged to produce a circular focal plane diameter of approximately 100 mm on the photographic plate, and this gave a field of 10 degrees.

Thus the Hewitt had the properties needed to photograph with high precision a significant part of the satellite's trajectory, together with enough bright background stars to give reliable positional references.

The Lye Vallets camera was moved to the Royal Observatory Edinburgh (ROE) at Earlyburn in 1964, where it remained operational until the cancellation of the ROE satellite project in 1975, when the camera was put into storage. At about this time the project was taken over by the Ordnance Survey.

In 1978 the Science and Engineering Research Council sponsored a team from Aston University to take over the running of the cameras and the analysis of the plates. The decision was then taken to recommission the ROE camera at Siding Spring Mountain, near Coonabarabran in New South Wales. Here it operated from 1982 until 1990, providing results to complement those obtained in the UK.

The Malvern camera was never as much travelled as its twin. However, in 1982, when it was decided to close Sheriff's Lench owing to leasing and safety problems, a space was found for it at the Royal Greenwich Observatory (RGO), Herstmonceux. This location also enabled it to share resources and expertise with the Satellite Laser Ranger System. After a brief commissioning period, during which time it was overhauled and realuminised, its productivity continued unabated.

At the closure of the RGO site at Herstmonceux in 1990, it was decided that no further plates should be taken, either in the UK or in Australia, and that the Archive should be closed. The RGO approached the BAA to ask if it would be prepared to act as curators. The BAA agreed, and, following discussion, Crayford Manor House Astronomical Society (CMHAS) consented to be custodians of the plates, records and measuring equipment. This marked the beginning of the project that is to be described.

Aim of the project

The aim of this project is to make the Hewitt Camera Archive at Crayford accessible as an historical resource to assist amateur and professional astronomers. Their studies might include astrometry, orbital dynamics, variable stars and geodetics. The project will include the recommissioning of a Carl Zeiss Jena plate measuring machine, and will involve familiarisation with its use and construction, in order to assist would-be users of the Archive.

Acquisition and description

The archive was delivered to Crayford in the early spring of 1990 and, a few weeks afterwards, the Zeiss plate measuring machine and its air-conditioning equipment were collected from Herstmonceux. A total of about 7,200 plates had originated in England, about 3,900 having been taken from late 1965 till March 1982, mostly at Sheriff's Lench, and 3,300 after the camera had been moved to Herstmonceux, beginning December 1982 and continuing until February 1990.

A further 3,700 plates were sent from Siding Spring Observatory, Australia, dating from late 1982 till January 1990. A small number (about 100) came from the Royal Observatory Edinburgh (dated 1969–1971), making about 11,000 plates in all.

In addition, a large quantity of documentation was acquired, including Trails Data Sheets, which gave details of the times and dates of the photographs, and the satellites and star fields shown on them.

Reference system

The documentation and the photographs themselves were referenced by a code of numbers and letters, e.g. 1355A17. The first set of digits – 1355 – identifies the observing session, and was incremented by one at the start of each night that observations were made. The letter following was either A for Malvern or Herstmonceux or B for Siding Spring or Edinburgh. The trailing numerals (17 in the example) identified the particular plate. As many as 30 could be taken in one night. Following the move to Herstmonceux the sequence continued uninterrupted; thus 1A1 to 1246A1 refer to Malvern plates and 1247A1 to 1753A2 refer to Herstmonceux plates. Both Siding Spring and Edinburgh plates appear to have used the same numbering system (starting from one) and the same letter; since the plates are stored separately no conflict should arise.

Photographic details

All the plates are negatives – that is, the stars are dark images on a transparent background. Each exposure is circular of diameter about 100 mm. This covers an angular diameter of about 10 degrees, amounting to a solid angle of approximately 80 square degrees. Prior to June 1978 the images were each recorded on a glass plate, measuring about 200 × 150 × 6 mm, and weighing approximately 450 g. After this date (Malvern serial numbers 1102 onwards and all Herstmonceux and Siding Spring plates), a thin plastic film was used instead. The film was also 200 × 150 mm, and is just as easily handled and measured as the glass plate, but is much lighter and easier to store.

As the Schmidt cameras did not track, the star images are significantly trailed. Moreover, in order to time the satellite accurately, a rotating shutter was employed. The image of a satellite, which would otherwise have been a continuous line across the plate, actually appears as a series of dashes. The end of any one of these dashes would have defined precisely where the satellite was at the instant when the light was interrupted. Hence the star images are also dashed. For

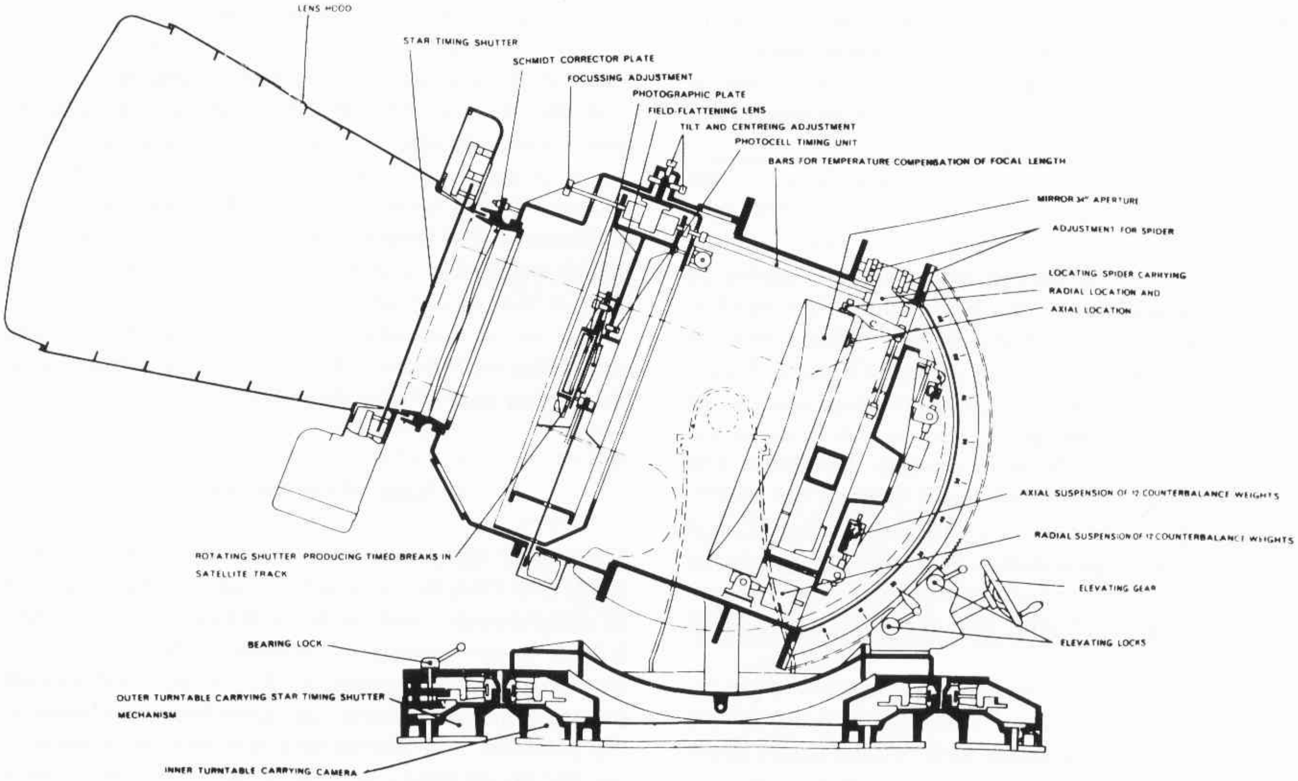

Figure 1. Diagram of 34-inch (864-mm) Schmidt camera (courtesy of RGO).

astrometry, however, this will present no problem, provided the same end of the same dash is used when measuring all the stars of interest.

Limiting magnitude

The magnitude of the faintest stars recorded will naturally depend on exposure time, light from the Moon, cloud and many other factors. Stars of magnitude 11 are generally visible and, in some cases, objects fainter than magnitude 13 are recorded. The print of plate 1336A13 (Figure 2) shows many stars fainter than magnitude 10, and the plate itself shows still fainter objects.

Distribution of plate parameters

The distribution of the plates over time is presented in Figures 3 and 4. Figure 3 is a histogram which shows, for UK and Australian plates separately, the numbers of photographs taken each year. Figure 4 shows the numbers taken in each month of the year, and this reflects differing night lengths, weather conditions and, perhaps, seasonal preference for satellite launch. No adjustment has been made for the numbers of days in each calendar month. Figure 5 shows, again for the UK and Australian plates separately, a histogram of their distribution according to altitude above the horizon. The altitude divisions are all 10°, from 0 (horizon) to 90 (zenith).

One would expect there to be fewer exposures near the zenith, simply because the solid angle subtended between successive divisions of altitude decreases as the altitude increases, and this is seen. Also, below 20° altitude the number of plates falls off dramatically. This, too, is to be expected since observation of artificial satellites, in common with most other sky objects, becomes increasingly difficult near the horizon.

Figure 6 shows scatter diagrams of (a) all UK and (b) all Australian plates. The vertical scale has been calculated so that equal areas of the diagram represent equal solid angles in the sky. Thus the density of the dots reflects the true density of the plate centres. The same information is shown in a different form in Table 1: the numbers of plates whose centres lie in various ranges of RA and Dec. have been found and adjusted to give estimates of the numbers of plates that will show any fixed object in that region.

Work that was planned

In order to fulfil the aim of this project, it was decided to do the following:

(1) Assemble the plates in serial number order and store them in an accessible place. The series from England, Scotland and Australia would be kept separate. The system adopted should facilitate their quick selection and their correct replacement.

(2) Install the air-conditioning plant, to provide a stable environment for both the plates and the measuring machine. The need for such an environ-

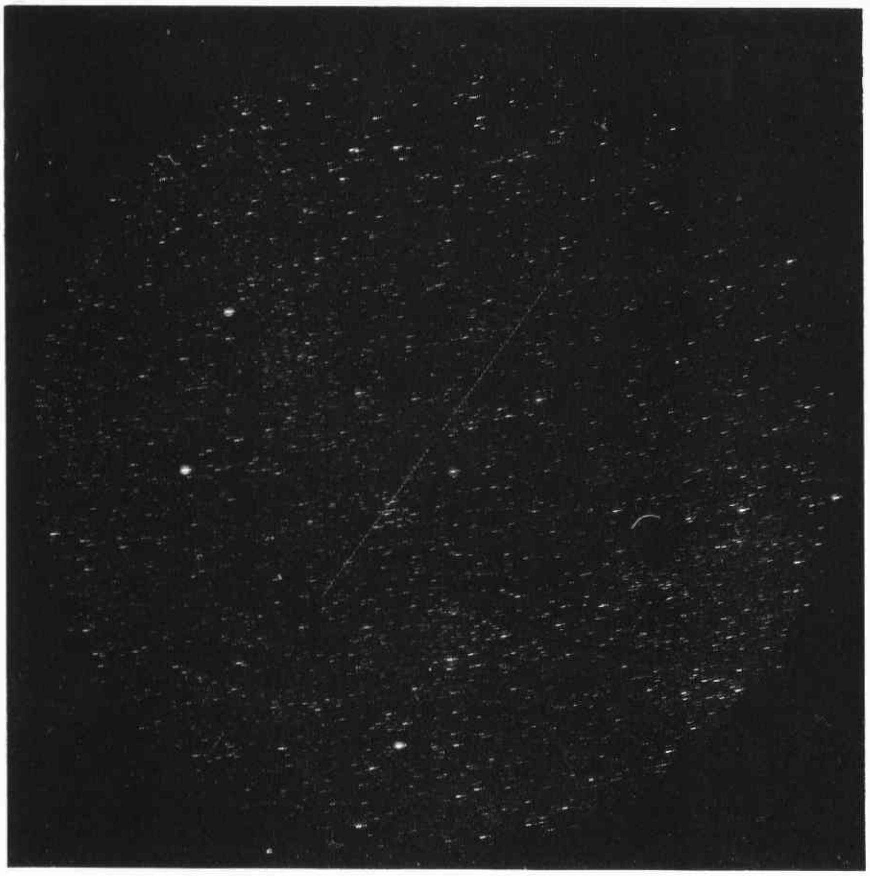

Figure 2. Contact print of Plate 1336A13, taken 13/8/83, 0131 UT, RGO Herstmonceux, Sat. No. 7003402, centre at RA 21h 27m, Dec 48.9° (1950); M39 is about 1° SE of centre (north is at the top).

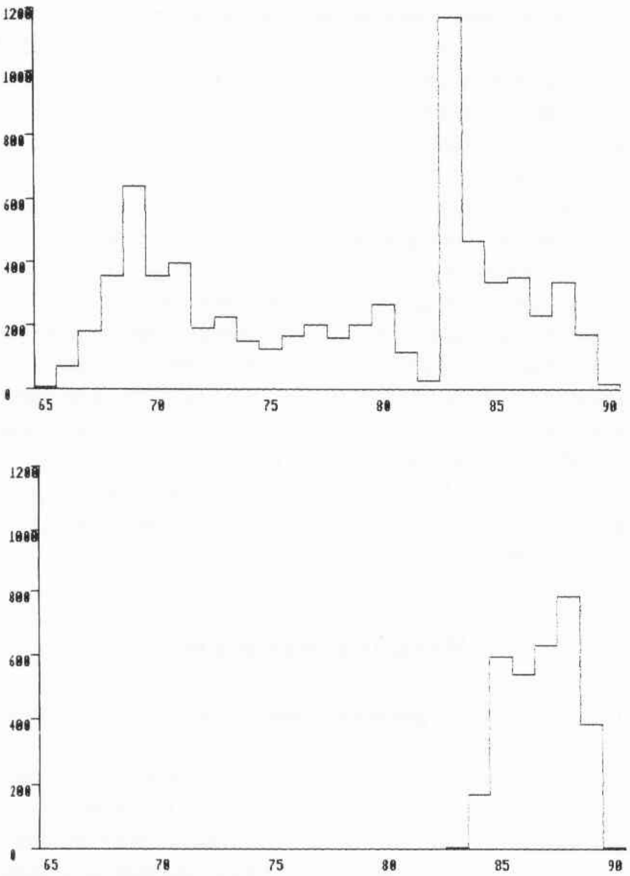

Figure 3. Histogram of total numbers of plates taken versus year in (top) UK and (bottom) Australia.

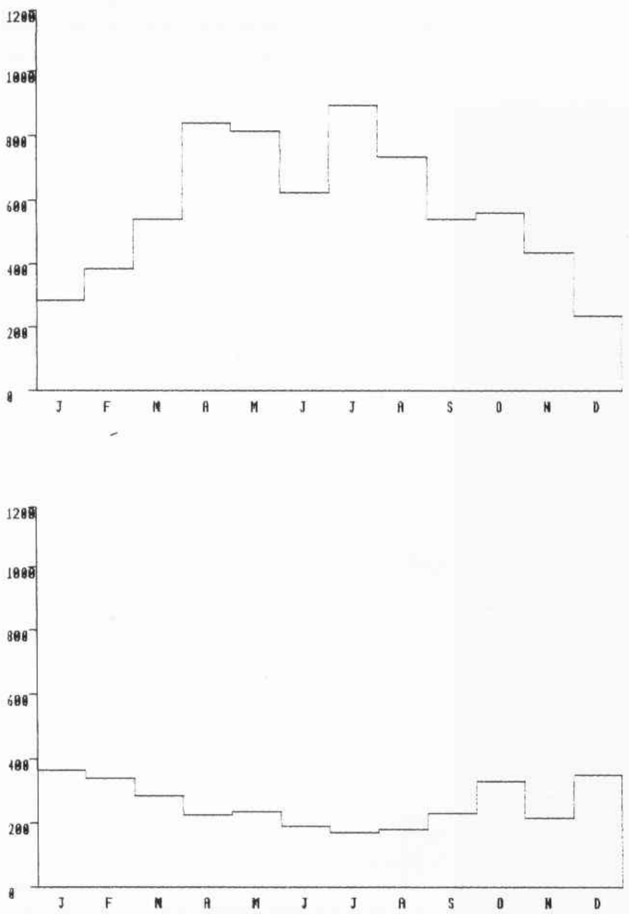

Figure 4. Histogram of total numbers of plates taken versus calendar month in UK (top) and Australia (bottom).

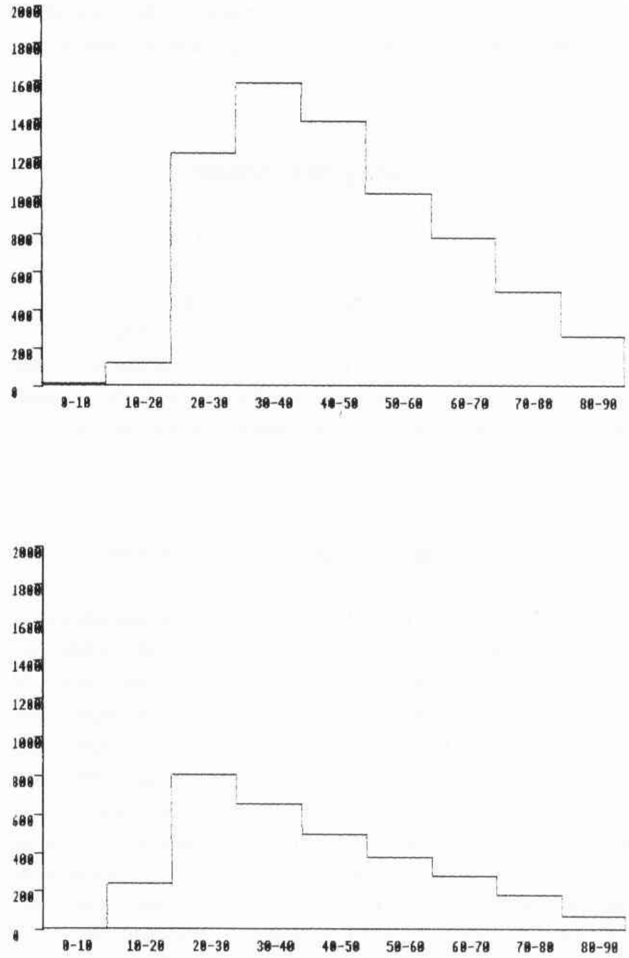

Figure 5. Histogram of total numbers of plates taken versus altitude above horizon in UK (top) and Australia (bottom).

ment is made clear in the Zeiss literature[1] and confirmed from experience at the RGO.

(3) Construct a computerised index of all plates, including details of the satellite, the RA and Dec. of the plate centres, time and plate serial number.

(4) Recommission the Zeiss plate measuring machine, and provide ancillaries such as working space, a light table and a personal computer with display and storage, all in close proximity to the archive and sharing its controlled environment.

The progress to date with these items is described below.

Practical use of the Archive

The first stage in using the Archive will involve the selection, from the 11,000 available, of those plates containing the objects of interest. This might be done by studying a printed copy of the index – particularly if only a short span of time is involved. More generally, however, the computerised version of the index will be used, described in Appendix 1. If several projects are running concurrently it will be advantageous to record which plates have been removed for which project, and the computer will provide an automatic and effortless way of doing this.

Having found the plates it will be necessary to extract data from them. Although the plates could, for some applications, be scanned directly by eye, the high concentration of detail they contain suggests a more refined technique. It is therefore anticipated that the plate measuring machine will nearly always be needed, whether positions or magnitudes are wanted. Procedures for making these measurements are summarised in Appendix 2, though the instructions from Carl Zeiss Jena should be consulted for full details. It is vitally important that the user should identify the stars in the field correctly, including those to be used as references or comparisons. Accurate charts and a catalogue of stars down to magnitude 8 or fainter should be to hand. Details of proper motions must be included. A catalogue such as the SAO is suitable,[2] and a copy of it will be available.

The raw measurements may now be processed to give reduced positions of the objects of interest (if only magnitude estimation is required then this stage can be left out). The procedures for plate reduction are summarised, along with some of the supporting theory, in Appendix 3. The method is based on procedures described in Reference 3.

Current state of the work

At the time of writing this report, 1 January 1992, the status of the work is as follows:

(1) All the plates have been sorted by serial number and stored in the archive room close to the plate measuring machine and the light table.

(2) The air-conditioning plant has been fixed in place, and it remains to connect it to the existing power supply, to pressurise the heat exchange system and to commission the apparatus.

(3) The first version of the computerised index has been produced. We were helped by the existence of a computer index to most of the southern plates, compiled at Siding Spring. The information for the remaining plates was extracted, for the most part, from the Trials Data Sheets. The arduous task of transcribing details onto microcomputer was carried out by Society Members.

Most of the earlier sheets did not give the RA and Dec. of the centre of the field but, since altitude and azimuth were provided, these were transcribed instead and later converted automatically to RA and Dec. It was decided to refer all celestial coordinates to the fixed epoch, 1950.0. This was, in fact, the epoch that had been chosen for the southern index. Satellites are recorded by their 7-digit international designation, and these are cross-referenced to their familiar names and numbers when required (e.g. 6305302 = Explorer 19 Rocket).

(4) The Zeiss plate measuring machine has been reassembled, and it is hoped to commission it shortly, and to test its performance by reducing again some of the Hewitt plates. The BAA has kindly loaned us an IBM compatible Olivetti M24 Personal Computer, on which have been installed the index and the software to access it, along with a version of the SAO Catalog.

Plans for the future

It remains to be seen just how the logistics of using the archive will evolve, but the procedure will be kept as flexible and informal as possible. A typical scenario might be that an amateur or professional astronomer will approach the BAA and, if it appears that the project might benefit from use of the Archive, the request will be passed to CMHAS. At a mutually agreeable time, the user will be shown the Archive, and, if necessary, will receive instruction in its use. Several visits may be required. It is anticipated that many of the research projects will be carried out by Crayford members, either wholly or in collaboration.

From time to time there will need to be reissues of the index, as inconsistencies come to light, or as improvements suggest themselves. Ultimately the only way to check the index is to verify by eye that each plate contains the field that is recorded in the index; if it does not, the true field should be determined and the entry amended. The time scale for such a procedure is very long and, for an amateur society like ours, can only be handled as an on-going process. It is expected eventually to include in the index-searching software a facility to find Sun-orbiting objects. This will enable searches to be done for asteroids and comets, and will permit the Archive to be used in the historical determination of their orbital and rotation periods.

Still in the realm of software, it is hoped ultimately to be able to integrate the index searching, the plate reduction and the star catalogue. In this way the user at the Zeiss will be able to call up a computer generated image of his star field for comparison with the plate. Stars can then be identified and their details fetched automatically from the catalogue. These data can then be transferred to the plate reduction software. In this way much of the burden on the user to look up and transfer data from one medium to another will be removed, and with it many of the possibilities for error.

Conclusions

In summary, it can be said that the project has proven to be feasible, if somewhat arduous, and that the aim stated earlier is attainable. Most of the main tasks are well on the way to completion, and many of them have been successfully accomplished already. It was originally intended to get the archive working by spring 1992, and the work is currently on schedule. It is accepted, however, that the application of the archive will continually suggest improvements, and the future way in which it develops will depend to a great extent on the user.

Current interest in the project suggests there will be no lack of demand.

Acknowledgements

Thanks are due to the Officers of the BAA and to the staff of the RGO for their encouragement and cooperation. It is pleasant, too, to be able to acknowledge the unstinting effort of the members of CMHAS in carrying out this project, particularly Rita Whiting and Valerie Stoneham for the many Monday evenings they sacrificed to the transcription of the index.

Address: Crayford Manor House Astronomical Society, Crayford Manor House, Mayplace Road East, Crayford, Kent DA1 4HB.

References

1 'Carl Zeiss Jena Coordinate Measuring Instrument 30 cm × 30 cm' (English translation of instructions), Carl Zeiss Scientific Instruments Ltd.

2 *Smithsonian Astrophysical Observatory Star Catalog*, SAO, K. L. Haramundanis, 1966.

3 *Positional Astronomy*, D. McNally, Muller Educational, 1974.

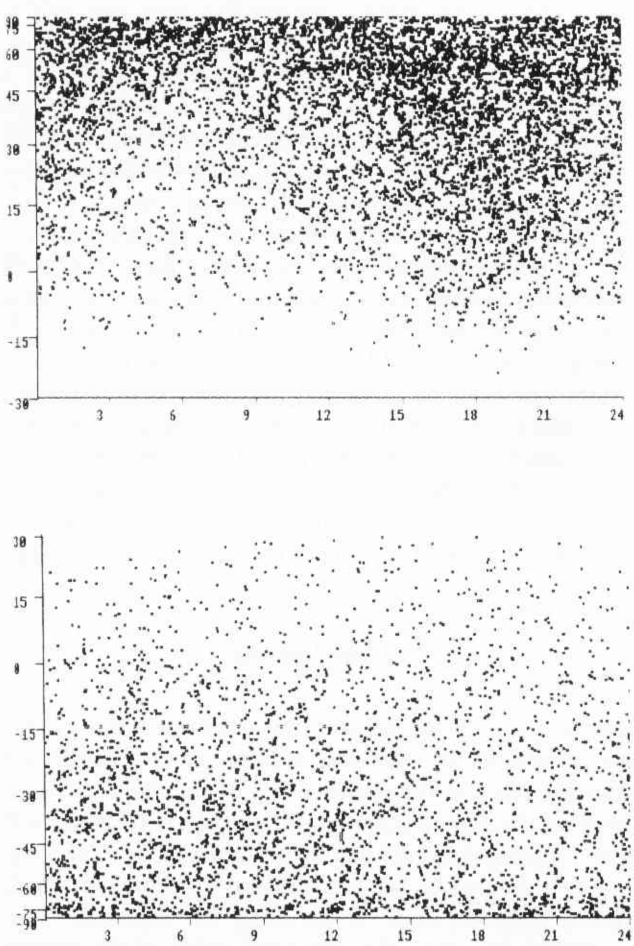

Figure 6. Positions of centres of plates for (a) UK, (b) Australia, in RA (horizontal) and Dec. (vertical) (1950). The vertical scale has been calculated to give constant solid angle per unit of plotted area.

Table 1. Estimated number of plates containing a particular object.

Dec. of object (deg)	*Right Ascension of object (hours)* 0–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24
(a) UK Plates								
+80 to +90					42			
+70 to +80	40	47	45	47	53	40	47	51
+60 to +70	45	50	43	39	46	45	46	42
+50 to +60	36	38	26	36	44	58	50	41
+40 to +50	31	22	18	24	35	42	40	39
+30 to +40	27	12	14	17	24	35	36	27
+20 to +30	18	7	10	12	23	29	34	24
+10 to +20	12	7	8	11	16	24	27	20
0 to +10	9	4	5	6	9	16	21	12
−10 to 0	4	4	2	3	4	11	10	6
−20 to −10	2	1	0	0	2	3	3	2
−90 to −20					none			
(b) Australian Plates								
+40 to +90					none			
+30 to +40	0	0	0	1	1	1	0	0
+20 to +30	1	1	2	3	3	1	2	1
+10 to +20	2	3	3	1	2	3	3	2
0 to +10	3	4	3	3	3	4	4	3
−10 to 0	5	8	8	6	5	5	5	6
−20 to −10	8	11	7	9	6	7	5	6
−30 to −20	14	12	10	10	9	8	6	7
−40 to −30	14	15	16	13	14	9	6	8
−50 to −40	12	15	16	16	8	9	10	10
−60 to −50	17	15	17	16	13	10	7	6
−70 to −60	16	14	10	13	14	12	14	15
−80 to −70	29	24	21	26	22	20	20	22
−90 to −80					22			

4 *Sky Catalogue 2000 Vol. 2*, A. Hirshfeld and R. W. Sinnott (eds), Cambridge University Press and Sky Publishing Corporation, 1985.

5 'Concerning a Zeiss Coordinate Measuring Instrument', A. Koenig, *Astronomische Nachrichten*, **246**, pp. 237–252.

6 *Plate reading, using the Carl Zeiss Jena Coordinate Measuring Instrument*, D. J. C. Chapple, Earth Satellite Research Unit, University of Aston, Birmingham, July 1980.

Received 26 October 1991; accepted in revised form 4 January 1992

Appendix 1
Use of the Index

The computerised index can be used in two different ways. The first is to search for all plates that feature a given fixed object and the second is to search for all plates that feature given satellites.

If the first way is selected the user is then asked to state the RA and Dec. (R_I, D_I) of the object of interest, and the epoch at which these coordinates apply. The user will also be able to specify the assumed radius, r, in degrees, of each plate. This will normally be 5° but different values may be used to suit the circumstances. The computer will first convert the given celestial coordinates (R_I, D_I) to coordinates (R_E, D_E) at 1950.0, the epoch of the index. Then for each of the plates in the index the computer will determine whether the point (R_E, D_E) is included – that is, whether the point lies within r degrees of its centre. The algorithm used is: the plate will be flagged if, and only if,

$$\cos D \cos D_E \cos (R - R_E) + \sin D \sin D_E > \cos r,$$

where (R, D) are the celestial coordinates of the centre of the plate, obtained from the index.

Table 2. Results of search for plates containing R Scuti.

Hewitt Camera Archive – position scan using north and south data.
Epoch: 2000.0 RA = 18h 47.5m. Dec. = −5.7 deg.
Radius = 5.00 deg.

Plate Ref	Satell Number	Date yy-mm-dd	Time hh-mm	Plate Centre RA (1950) Dec HH MM.M DD.D
North				
247A1	6605601	67 9 22	20 51	18 34.0 −2.8
250A1	6000901	67 10 4	19 23	18 43.8 −3.0
440A3	6800201	69 7 17	0 0	18 48.9 −7.3
441A6	6800201	69 7 18	0 19	18 33.1 −3.2
491A1	6501104	69 10 31	18 29	18 37.0 −2.4
949A1	7302701	75 10 9	19 44	18 35.6 −4.6
1120A2	6505306	79 6 25	22 36	18 43.0 −1.1
1190A1	7202301	80 10 9	18 42	19 4.4 −5.2
1284A7	7507202	83 5 23	0 6	18 53.1 −1.0
1321A3	7009901	83 7 27	22 20	18 55.4 −4.0
1471A3	6807001	84 6 30	1 34	18 48.8 −8.5
1522A3	7705701	85 8 19	21 26	18 39.1 −7.6
1528A2	6710402	85 9 10	19 59	18 58.1 −2.5
1545A5	8203301	85 11 12	18 39	18 56.9 −2.9
1635A3	7705701	87 9 7	20 6	18 39.6 −8.9
1637A2	7705701	87 9 24	20 16	18 57.5 −2.8
South				
300B01	6804002	85 7 27	8 15	19 0.6 −4.8
668B01	7705701	87 11 5	9 48	18 49.6 −1.8
742B08	7101601	88 3 27	18 36	18 37.6 −6.8
784B04	7101601	88 7 13	9 32	18 37.8 −7.3

Matches found = 20. Date of scan 10/08/1991.

A value for r of more than 5° may be required if the user wishes to be certain of including all possible plates, even marginal ones. A value for r of less than 5° may be used to ensure that the object is close to the centre of each plate that is flagged.

The user also has the option of scanning only the northern or southern parts of the index. In practice both indexes can be scanned in about 5 minutes (even when using a PC without an arithmetic coprocessor). The result of scanning the index for the variable star R Scuti (RA 18h 47.5m, Dec. −5 42′, epoch 2000.0)[4] is shown in Table 2, and is broadly in agreement with the estimated number of plates (see Table 1).

If the second method of search is selected, the user will be invited to enter the 7-digit designation codes for all the satellites of interest. Only those plates containing one or more of these satellites will then be flagged.

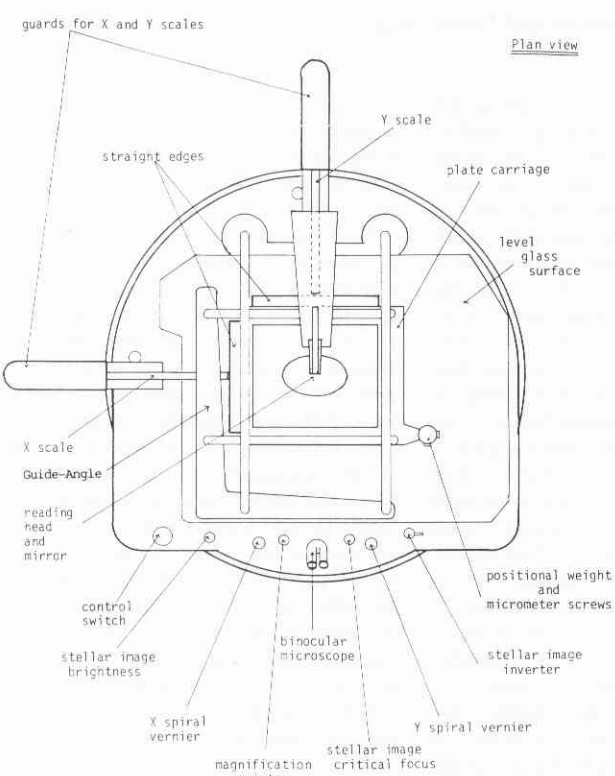

Figure 7. Diagram of Carl Zeiss Jena plate measuring instrument (adapted from Chapple[6]).

Appendix 2
Description and use of the plate measuring machine

The plate measuring machine was built by the firm Carl Zeiss of Jena, Germany. The instrument has a diameter of 1.05 metres and rests on a massive metal table. The height of the binocular viewing microscope is approximately 1 metre above the floor. The whole apparatus, including the table, weighs about 500 kg.

The photographic plate is placed in a carrier which can move freely across the horizontal base plate. It is prevented from rotating about a vertical axis by a double pantograph mechanism (see Figure 7); two parallel struts link the carrier to the L-shaped guide-angle, and two further struts link the guide-angle to the securing points on the base plate. The carrier is also connected to two mutually perpendicular straight edges that each press against precision sliding scales (one in the x direction, and one in the y), and each scale moves against a pointer. The pointers are fixed relative to the base.

A complex optical system enables the user to view, through the binocular microscope, both the star field on the plate and the two scales with their pointers. In operation, the user moves the carrier (and hence the plate) about, with the aid of fine screw adjusters, until a fixed viewing reticle coincides with the object of interest. Since both scales are set against their respective straight edges, the scales will move by exactly the same amount that the plate does. Thus the position of the object can be read off directly from the scales. Because the scales are at right angles to the straight edges, and situated in the plane of the photograph, any geometrical misalignments in either the scales or in the base will have minimal effect. This is in accordance with the Comparator Principle of Ernst Abbe, one of the founders of Zeiss Jena.

The scales are calibrated to 3 significant figures, so can be read directly to 10^{-3} metre. A further 4 significant figures are obtained with the aid of an ingenious spiral vernier micrometer, which allows measurements to 10^{-7} metre (0.1 micron) to be made in both x and y directions. Separate verniers are provided for each axis, and the optical system enables the user to view either the star field or the measuring scales at the turn of a knob.

A facility also exists within the Zeiss to help the user estimate stellar magnitude. A series of images of comparison stars, of known magnitude, must first be arranged on a transparent strip. A mechanism then allows the strip to be moved across the star field. The user estimates the magnitude by eye, rather as one would deduce the magnitude of a variable star observationally.

The design and calibration of the plate measuring machine mean that most errors will be eliminated. However any systematic errors which get into the raw plate measurements should be substantially cancelled out in the plate reduction process which follows.

Further details concerning the theory of the plate measuring machine are given in Reference 5, and, concerning its use, in Reference 6.

Appendix 3
Plate reduction

Once the position of an interesting object on the plate has been measured it would, in principle, be possible to convert that position directly to RA and Dec. In practice, however, most of the geometrical details that we need to do this are not known: these include the exact position and orientation of the plate in the camera, the focal length of the camera, the exact position and orientation of the plate in the measuring machine and non-orthogonality of the machine's straight edges and scales. In order to determine the combined contribution from these unknowns, we must select reference stars, whose positions may be found in a catalogue, and measure the plate positions of these also.

The procedure is first to convert the celestial coordinates of the reference stars to the epoch of the plate, allowing too for the proper motions. The celestial coordinates of the centre of the plate are estimated as closely as possible: RA = A_0, Dec. = D_0. Given the celestial coordinates of reference star number i, (A_i, D_i), it is now possible to calculate the position of the reference star in rectangular equatorial coordinates, with the origin at the centre of the plate. In this coordinate system, z points from Earth to the point in the sky at the centre of the plate, x points eastwards from that point along the line of constant declination, and y points northwards along the line of constant RA.

Then

$$x_i = \cos D_i \sin (A_i - A_0);$$

$$y_i = -\cos D_i \sin D_0 \cos (A_i - A_0) + \sin D_i \cos D_0;$$

$$z_i = \cos D_i \cos D_0 \cos (A_i - A_0) + \sin D_i \sin D_0;$$

if the vector is normalised so that it has unit length.

The projective relationship that exists between the rectangular equatorial coordinates (x, y, z) and the measured plate coordinates (p, q) can be represented, to first order, by

$$x - p = ax + by + c; \; y - q = dx + ey + f;$$

where a, b, c, d, e, f define the precise orientation and origin of the star field on the plate, and are referred to as the 'plate constants'. The plate constants can be determined by a technique such as least-squares fitting, using the measured positions of the reference stars. Strictly, only three reference stars are required to determine the six plate constants, though in practice at least four are always used, as these can then provide a cross-check on the reduction process. If the residual error coefficient from the least-squares fit is too large, then the plate must be remeasured.

In addition to the geometrical uncertainties mentioned, the plate constants will subsume a number of other unknowns: errors in the estimation of A_0 and D_0, differential atmospheric refraction across the plate and the differential aberration of light. Once the plate constants have been deduced, the contributions from each of these effects individually are no longer important.

Using inverted versions of the formulae above, the measured position of the object of interest can be converted firstly into rectangular equatorial coordinates then into RA and Dec. at the equinox of the date, and the determination is complete.

Assuming the plate measurements are good, such a technique will generally yield results to a precision of better than 1 arc second. If higher precision is requried, or if the image is particularly distorted in some respect, the evaluation of higher order plate constants might be considered,

$$\text{e.g. } x - p = ax + by + c + gx^2 + hxy + jy^2;$$

$$y - q = dx + ey + f + kx^2 + lxy + my^2;$$

in which case at least seven reference stars would be used, to allow a cross-check as before.

The finding of Jupiter V (continued from page 323)

and behaviour. Nevertheless his claim was challenged, if briefly, as noted in *Nature* of 27 October 1892, the idea being that Barnard was influenced by knowledge of alleged earlier sightings of a fifth Jovian moon by Scheiner (1612), Fontana (1630), de Rheita (1643), John Winthrop (1664) and de Gasparis (1865). We do not doubt the authenticity of those reports, yet it is obvious they could not, indeed do not relate to the delicate object discovered in 1892.

As to naming the satellite, Barnard wrote: 'I . . . defer any suggestions as to a name until a later paper. It should certainly not disturb the present harmony existing in the Roman numerals already applied to the satellites. It is so wholly different from any of the other moons in physical aspect, that it ought, in a sense, to be considered independent of them, and simply called, say, the fifth satellite, with a suitable mythological name.' Today Jupiter V is also known as Amalthea.

Jupiter V moves inside the orbit of Io, some 181 300 km from Jupiter. It is an irregular, dark reddish moon about 150 km across, and 270 km in length, with its longer axis pointing at Jupiter. It was the first jovian satellite to be found since 1610, a fact that had a profound effect on some elements of the scientific community, as W. F. Denning observed in *Nature*, 22 September 1892: 'The fact that Jupiter possessed four satellites has become familiar to every schoolboy. Few people therefore could have imagined that the statement would ever be controverted or rendered untenable by new discoveries . . . The four satellites were so bright and so palpably visible in small telescopes that it was scarcely thought possible that another existed small enough to remain unseen.' This throwback to pre-Newtonian thought was as astonishing as it was consolidated by the further statement that: '. . . there was a significant agreement in the relatively increasing numbers of satellites surrounding the planets Mars, Jupiter and Saturn. Mars was known to have two satellites, Jupiter four, and Saturn eight, the number doubling itself with each step outward from the Sun, and it was considered probable that the harmony of the series would not be disturbed.' What, one wonders, would be the reaction to the latest findings?

For Barnard, former portrait-photographer of Nashville, a man of parts in a nineteenth-century pattern, virtually self-taught in science, already well-known for his comet discoveries, the finding of Jupiter V was a triumph in a long and useful career. That same year he notched up another first, the photographic discovery of a comet, which but for Max Wolf's successful photographic search for asteroids begun in 1891, would have been the first photographic disclosure of a new celestial object. No matter. Jupiter V affirmed his skill and vigilance, and signalled his eminence among observers, qualities French scientists recognized by awarding him the Lalande Gold Medal of the French Academy of Sciences (1892), the Arago Gold Medal (1893) and the Janssen Gold Medal (1900).