Journal for Occultation Astronomy

2014–02

FORMERLY OCCULTATION NEWSLETTER

INTERNATIONAL OCCULTATION TIMING ASSOCIATION

The ring of the Centaur

Journal for
Occultation Astronomy

Dear reader,

Observing and measuring the times of disappearance and reappearance during an occultation of a star by a minor planet are now standard tasks. From a positive result we can obtain a chord or even the diameter of the occulting object. A detailed analysis of the recording with a high time-resolution might lead to the determination of the occulted stellar diameter too!

Compared to predictions and results in the 1970s where, e.g. a "European-predicted" occultation occurred in North Africa, the accuracy of star positions is much better now, giving a high percentage of positive results.

Unfortunately this situation seems to be back concerning Trans-Neptunian-Objects (TNO) but this time the problem has changed to the occulting bodies; due to the fact that these objects have been discovered just a few years ago and they are very distant, their orbits are still not that precise! Anyway, whenever an occultation of a TNO has been calculated for your hemisphere you should try to observe it, for its diameter, shape and possible (frozen?) atmosphere are still unknown.

According to the latest predictions, when staying e.g. on the Canary Islands you might have the chance on July 4th to record 2 events within 24 hours: Pluto (to check if it still has a gaseous atmosphere) and Quaoar (to look for its shape, possible atmosphere and moons).

I originally planned to go to the Canary Islands – but after a 3 months' stay in hospital I am still not allowed to travel that distance by 'plane.

I hope somebody else will take up the challenge: In case you are interested please contact Dr. Wolfgang Beisker.

Hans-J. Bode (Editor in chief)

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In this issue:

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Journal for Occultation Astronomy

The Occultation Machine of HM Nautical Almanac Office

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Abstract

In the first half of the 20th century, accurate timings of lunar occultations were of great value in monitoring irregularities in the motion of the Moon and became the standard method of estimating the value of ΔT, the varying difference between Terrestrial Time and Universal Time. Before the invention of programmable electronic computers, the manual generation of predictions was labour intensive, involving many hours of repetitive tasks. This paper describes an ingenious Occultation Machine that simplified the process.

Introduction

A lunar occultation occurs when the Moon passes in front of a star or a planet as seen by an observer on Earth. During the Moon's journey around the Earth, stars (and occasionally, planets) will be seen to disappear at the Moon's eastern (preceding) limb and reappear at its western (following) limb. Because most stars have very small angular diameters and the Moon has no tangible atmosphere, the occultation event will be almost instantaneous. In comparison, occultations of the major planets are relatively long-duration events. An accurate timing of an occultation of a star gives a unique measurement of the position of the Moon against the stellar reference frame.

In 1919 Professor Ernest William Brown published his great treatise on lunar theory, **Tables of the Motion of the Moon,**[1] which led to his call for a worldwide programme of timings of lunar occultations to monitor discrepancies in the observed longitude of the Moon, which were not fully explained by gravitational models. Astronomers were debating whether the cause was a secular acceleration of the Moon or a slowing of the Earth's rate of rotation. An effect of Einstein's new theory of general relativity had been discounted.[2] By the 1930s it was generally accepted that most of the fluctuations were caused by the irregular rotation of the Earth.[3]

J. D. McNeile and the BAA occultations programme

Members of the British Astronomical Association (BAA) took part in the programme and in the 1920s and 1930s its Computing Section undertook the laborious task of manually computing predictions of lunar occultations for a number of locations in the UK and the (then) British Empire.[4],[5] At this time a computer was a person with numeracy skills, not an electronic device. They had an aptitude for working diligently and conscientiously through numerous arithmetical steps, often with reference to tables of logarithms, sometimes aided by mechanical calculating machines. J. D. McNeile was responsible for the BAA's reductions of lunar occultation observations made in the UK and its Dominions.

Figure 1. James Duncan McNeile. (Courtesy: Wellington College.)

James Duncan McNeile MA, FRAS (Figure 1), was born on 29th April, 1879 in Beckenham, Kent. He was the son of Lt-Col John Magee McNeile R.E.[6] After attending St. Lawrence College[7] in Ramsgate and Gresham's School in Holt, Norfolk, he read mathematics at Sidney Sussex College, Cambridge, where he graduated in 1901 as 24th Wrangler.[8] Shortly afterwards he became Fereday Fellow of St. John's College, Oxford.[9]

From Easter 1904 he was appointed Mathematical and Engineering Master at King William's College on the Isle of Man, teaching mathematics and technology. He left after only a year.

"We regret to hear that Mr McNeile is leaving. The workshops have flourished under his supervision. It is a pity he could not have remained to help in the setting up of the new Metal Shop. He will be missed in the Photographic department and on the Fives Courts, where his keenness was markedly displayed."

Barrovian no. 78 (May 1905)[10]

He received his MA and returned to Gresham's School, to teach mathematics. He left Gresham's in 1909 and for the next 25 years he taught at Wellington College, Berkshire. In 1911 he wrote **A School Calculus** [11] with his older brother, Archibald Magee McNeile, a Mathematical Master at Eton College. James McNeile had been a sickly child, which affected him in his adult years; he was excused military duty and served as House Master during the First World War.[6]

He had a keen interest in astronomical computation,[12] rather than visual observations,[13] although he supervised the use of the 7-inch (18cm) refractor[14],[15] at Wellington College. (The original Imperial measurements of astronomical instruments have been retained throughout this paper; 1-inch equals 2.54cm.) He was one of the volunteer plate measurers of the international Astrographic Catalogue project, assisting the work of Professor Herbert Hall Turner of Oxford University on the star fields allotted to its Observatory, and in 1916 he wrote a short paper with Chief Assistant Frank Arthur Bellamy on Faint stars with large proper motions.[16]

McNeile joined the BAA in 1927 and found his métier in the Computing Section,[6] where he participated in work such as computing ephemerides of comets, although his main role was supervising a small team of members reducing occultation observations; many of the reductions were computed or verified by him.[12] His election to FRAS was published on 10th January, 1930.

He enjoyed playing golf, tennis and Eton Fives (a game of handball), and many of his Christmas holidays found him skiing in Switzerland. In April 1934 he retired from his post as Senior Mathematical Master at Wellington College, intending to devote himself to his passion for computing. In October of that year he succeeded Major Arthur Everard Levin TD, FRAS as Director of the Computing Section, but sadly, only 3 months later, on 5th January, 1935 he died of heart failure, whilst on holiday in Davos. His last contribution had been checking the reductions of the occultation observations for 1933.[6],[12]

The wooden Occultation Machine

McNeile was also a skilled craftsman, and in 1928-29 he designed and built an analogue computer, constructed mainly from wood, to simulate the alignments of the Earth, Moon and an occulted star (Figure 2). It was used to identify those observing stations from which a star would be occulted and hence generate provisional times of disappearances and reappearances, which would otherwise have to be computed by hand.[6] It was possibly inspired by the works of James Ferguson FRS (1710-1776), Scottish astronomer, portrait painter and instrument maker, who constructed numerous mechanical devices to illustrate the movements of the Sun, Moon and planets.[17], [18]

Figure 2. McNeile's wooden Occultation Machine. (Science Museum/Science & Society Picture Library

McNeile's Occultation Machine was based on the Besselian model of an occultation.[6] The German astronomer and mathematician Friedrich Wilhelm Bessel (1784-1846) considered the circumstances of a lunar occultation from the viewpoint of the star. Parallel rays of light from an occulted star will cast a cylindrical shadow of the Moon onto the Earth.[19] The edge of this circular shadow, the size of the Moon, defines where an observer on Earth would see the star disappear (or reappear) at the Moon's limb (Figure 3).

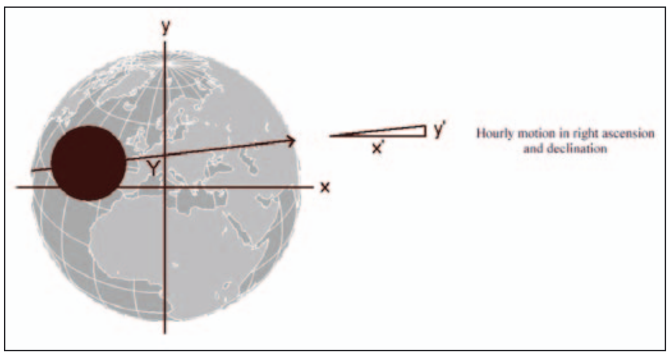


Figure 3. The Besselian model of a lunar occultation, as seen from the occulted star.

The Besselian model visualised the line from the star through the centre of the Earth as a fundamental reference axis, with the Earth as a flat circle on a 2-dimensional fundamental plane perpendicular to this axis. The Moon moves relatively slowly from west to east in its orbit around the Earth and it can take over an hour to pass in front of a star. During the short duration of a stellar conjunction the Moon's path can be regarded as a straight line, so it is sufficient to know its slope projected onto the fundamental plane at the time of the occultation.[19]

The Besselian elements of a lunar occultation are δ, T_0, H, Y, x' and y',[20] where

is the declination of the star.

T_0 is the time, in GMT (as used then), of geocentric conjunction of the Moon and the star, when they have the same right ascension.

H is the Hour Angle of the star, from the meridian of Greenwich.

Y is the intersection of the Moon's path with the y-axis, north or south of the centre of the Earth, measured in the fundamental plane.

x' and y' define the slope of the Moon's orbit at time T_0, with respect to the fundamental plane, where

x' is the hourly motion in right ascension.

y' is the hourly motion in declination.

The values of Y, x' and y' are given in Earth radii.

McNeile's Occultation Machine (Figure 2) utilised a 12-inch (30 cm) Philips terrestrial globe to represent the Earth, which could be rotated about its polar axis. Abbreviated names of observing stations were written on small paper discs glued onto its surface (Figure 4). A paper

Figure 4. Observing stations were indicated by paper discs. (Science Museum / Science & Society Picture Library)

scale divided into hourly and 10 minute intervals, for setting the Hour Angle of a star from the Greenwich meridian, was glued around its equator (Figure 2).

In front of the globe was a lamp that simulated the star, with a 4-inch (10cm) diameter condenser lens that projected a horizontal circle of light onto the Earth globe, to scale with the circular shadow of the Moon cast by an occulted star onto the Earth's surface. On the assumption that the radius of the Moon is 0.2725 that of Earth, as measured at the Earth's equator, the lens was stopped down to an aperture of 12 x 0.2725 = 3.27 inches (8.3 cm).[21]

Setting up the wooden Occultation Machine

Using the Besselian elements, the operator configured the Moon lens and Earth globe to replicate the circumstances of the conjunction of a star with the Moon. The Occultation Machine would then indicate if the star was likely to be occulted from one or more observing stations marked on its globe.

Because the beam from the star lamp and Moon lens was fixed in the horizontal plane, the 12-inch (30 cm) globe representing the Earth was tilted forwards or backwards to set its equator to the angle , the declination of the selected star, with reference to a scale on the right hand side of the Machine (Figure 5).[22]

Figure 5. The Machine's declination axis scale. (Science Museum / Science & Society Picture Library)

The Earth globe was then rotated on its polar axis until its equatorial scale was set to the value of H, the Hour Angle of the star at Greenwich.[22] The correct hemisphere of the Earth globe was now facing the star lamp and Moon lens at the time of conjunction (Figure 2).

The lamp and lens housing was moved up or down in its support frame, until it matched the value of Y, above or below the Earth's centre.[22] A ruled scale at the front of the Machine, graduated in hours and minutes, was aligned with the Moon lens, to mark T_0, the time of geocentric conjunction (Figure 2).[22]

The Machine had now been prepared for a prediction run.

Operating the wooden Occultation Machine

After configuring the Machine to the Besselian elements of a stellar conjunction, the operator had to rotate the Earth globe then separately move the Moon assembly to emulate the motions of the Earth and Moon as seen from the occulted star, making it slow and cumbersome to use.[23]

The lamp and lens assembly traversed from left to right at the slope of the Moon's orbit, and the circle of light projected by the Moon lens passed across the rotating Earth globe. If the illuminated circle touched an observing station the operator noted the predicted time of the occultation (the offset from T_0), given by the time marker and scale at the front of the Machine, and then estimated the Position Angle of the star measured from the north point of the Moon, indicated by markers on the Moon lens. This gave the angle around the Moon's limb where it would disappear or reappear and assisted the observer in correctly identifying the star.

Members of the BAA's Computing Section used this Machine to generate predictions with an accuracy of about 2 or 3 minutes,[24] which they refined by numerical methods. It was in use for about 6 years, until responsibility for predicting lunar occultations was transferred to His Majesty's Nautical Almanac Office (HMNAO) and it was replaced by a new Machine.[21]

L. J. Comrie and the metal Occultation Machine

Leslie John Comrie (Figure 6) was Superintendent of HMNAO from 1930 to 1936. He was born in Pukekohe, New Zealand in 1893, studied at Auckland University College where he founded their astronomical society, and graduated in 1916 with BA and MA degrees in Chemistry. Despite his increasing deafness he served with the New Zealand Expeditionary Force in France in the First World War, where in 1918 he suffered the loss of his left leg.[25] Whilst convalescing in England he became particularly interested in mechanical calculators and how they could be applied to computational astronomy.[26],[27]

Figure 6. Dr Leslie John Comrie FRS.

Comrie took an Isaac Newton post-graduate studentship at St John's College, Cambridge in 1920 and in the same year he helped to form the BAA's Computing Section, being appointed its first Director.[27] The popular **The Companion to The Observatory** ceased publication, but was superseded, in 1922, by the first BAA **Handbook,** edited by Comrie[26] who handed over the Directorship of the Section to Major A. E. Levin.

In 1923 Comrie received his PhD from St John's for his thesis on **Planetary occultation prediction and observation and the phenomena of Saturn's satellites. [27]** He travelled to the USA and taught as an Assistant Professor, initially at Swarthmore College, Philadelphia and later at Northwestern University, Illinois,[26] lecturing in Numerical Analysis. Comrie returned to England, where he joined the staff of HMNAO in October 1925, being appointed its Deputy Superintendent only four months later. He continued his investigations into using commercial mechanical devices to automate astronomical calculations.[25] At that time "… the **Nautical Almanac** was computed by retired Cornish clergymen with long white beards, using dog-eared 7-figure logarithm tables."[28]

Comrie became Superintendent of HMNAO in August 1930[29] (on the retirement of Dr Philip Herbert Cowell) and during his tenure he implemented a thorough reorganisation and modernisation of its methods, so that tables of logarithms were replaced by the new technology of Brunsviga mechanical calculators (Figure 7), Hollerith punched card machines and National accounting machines.[26],[27],[30]

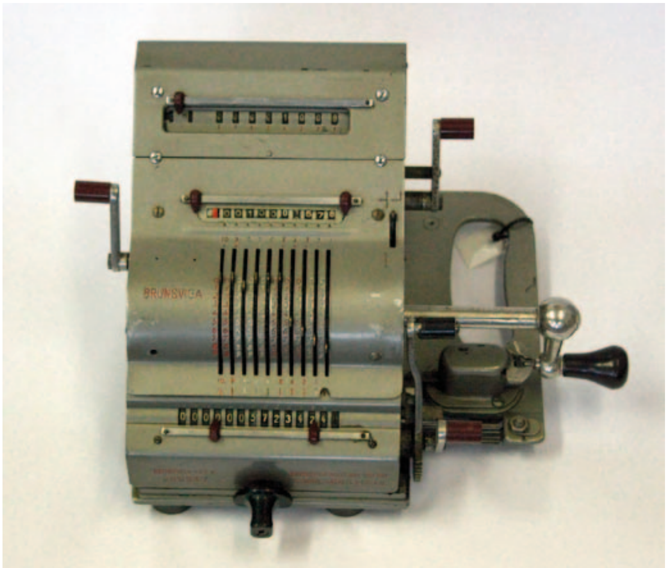


Figure 7. A Brunsviga hand-crank calculator, similar to the type introduced by Leslie Comrie to HMNAO. (Courtesy: The National Museum of Computing, http://www.tnmoc.org/)

From 1935 HMNAO was to undertake the onerous task of calculating and publishing worldwide predictions of lunar occultations, including coordinating the receipt of observers' timings and reductions. Comrie recognised the benefits of McNeile's Occultation Machine and it was lent to HMNAO for evaluation in computing the predictions for 1932 and 1933.[6],[31],[32],[33]. He then requested approval for a new, improved model to be constructed in metal.[24] ,[32]

After a lengthy correspondence between Comrie, the Astronomers Royal and the Hydrographer of the Navy, debating the justification for spending the 'excessive' sum of £150 on a new Machine,[34] approval for the expenditure of £115 was finally granted in July 1933. It was to be designed and constructed in the Royal Observatory engineering workshop at Greenwich[35] by Leading Joiner A.C.S. Wescott.[36] (The Astronomer Royal, H. Spencer Jones, commented that an instrument making firm would charge at least double that amount).[34] The general duties of Wescott and his colleagues were to maintain and repair the telescopes and ancillary equipment at the Royal Greenwich Observatory (RGO) and to assist in new developments.[37],[38]

The Admiralty challenged the overtime payments to Wescott authorised by the Astronomer Royal, who replied that the new device was a major improvement on McNeile's rudimentary model and the work had to be done outside of normal working hours because of workshop duties. Wescott's construction of the Machine included design work, technical drawings, patterns, purchasing materials, machining, travelling and foundry visits.[39]

The metal Occultation Machine (Figure 8) was completed in June 1934 at a total cost of £155 17s 0d [£155.85] and tests confirmed that it performed to its design specifications, predicting events to within 30 seconds of the computed times.[40][41],[42]

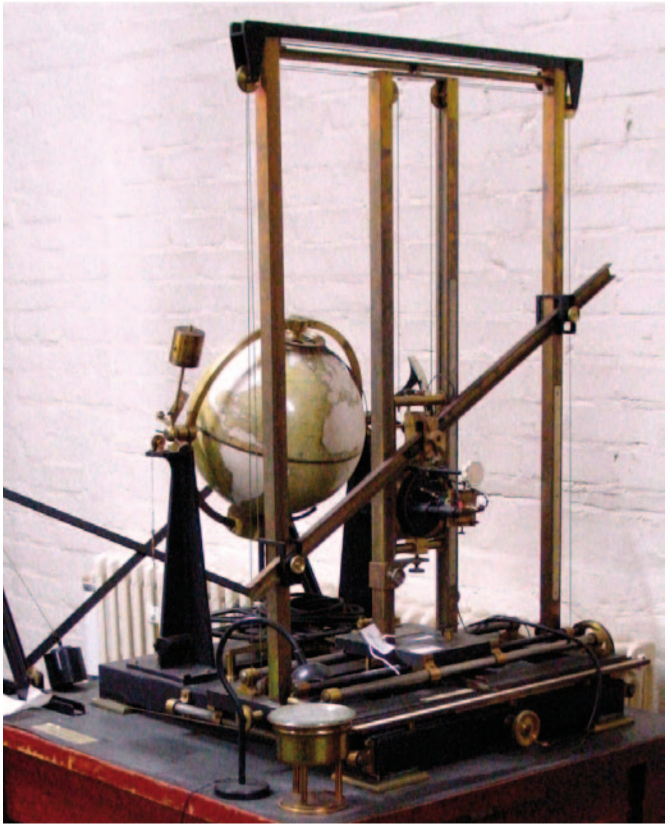
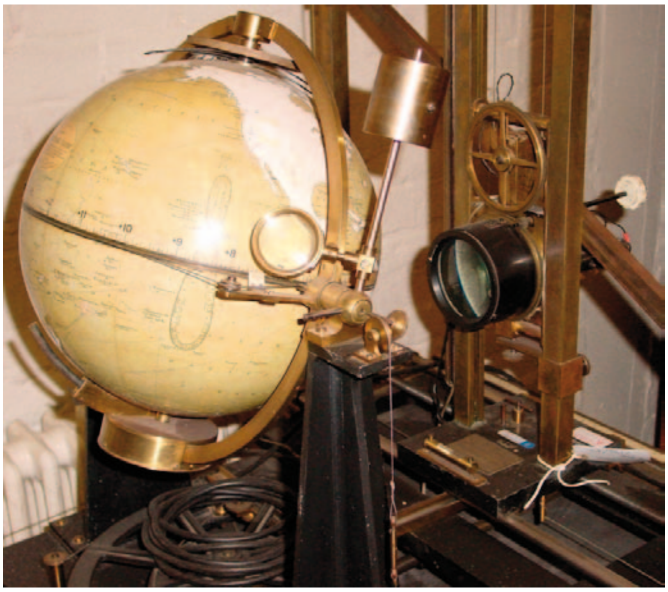


Figure 8. Wescott's metal Occultation Machine.
(Courtesy of the National Maritime Museum, Greenwich, London.)

Arthur Charles Stanley Wescott joined the RGO staff in June 1914. He was employed as a joiner and progressed to the position of workshop foreman engineer.[43] On 1st June 1953 he was awarded an MBE in the Queen's Coronation Birthday Honours List. [44] He retired on 30th June 1956, after 42 years' service at the RGO. [43]

Following the same fundamental design as McNeile's wooden model, but incorporating a number of functional improvements, Wescott's metal Machine also had a 12-inch (30 cm) diameter globe to simulate the Earth.[45] A small car headlamp and 4-inch (10cm) condenser lens represented the star and the Moon's 'shadow'. These were mounted on a diagonal crossbar which was set to the inclination of the Moon's orbit at the time of the conjunction (Figures 8 and 9.). [21]



(Figure 9.) The Earth globe and Moon lens assembly. (Courtesy of the National Maritime Museum, Greenwich, London.)

Setting up the metal Occultation Machine

The US Nautical Almanac Office (US Naval Observatory, Washington D.C.) computed an annual 'Region of Occulted Stars', then by checking against the new **Zodiacal Catalog[46]** produced a table of stars to magnitude 6.5 that could be occulted by the Moon, which included the Besselian elements for each lunar conjunction throughout the year. They were published in the **American Ephemeris and Nautical Almanac.** HMNAO[47] extended the list to magnitude 7.5 and, using the new Occultation Machine, generated predictions for up to 60 observing stations around the world.[48] These were prepared 2 or 3 years in advance.

Working from the Besselian elements, the operator configured the Occultation Machine to ascertain the provisional times of any disappearance(s) or reappearance(s) at one or more observing stations.

Figure 10. The declination scale and the twilight wires. (Courtesy of the National Maritime Museum, Greenwich, London.)

As with McNeile's wooden Machine, the Earth globe was tilted on its bearing to set it to the value of δ, the declination of the star (Figure 10).

The globe was then rotated until the scale around its equator matched the star's Hour Angle, H (Figure 9).[22],[49] (This method was also used to mark observing stations on the globe, by setting the latitude and longitude of a station on the scales, then replacing the lamp and lens with a stylus.)[50]

The vertical support struts of the Moon lens ride on a horizontal pivot arm in the base of the chassis (Figure 9). The Machine was initialised to the time of conjunction, T_0, by turning the operating handle on the right hand side of the base (Figure 8) until the pointer on the pivot arm moved to a zero scale marker at the front of the machine. The adjacent moveable ruled time scale was then slid to the left or right to set T_0 (in minutes and tenths of a minute) against the pivot arm pointer (Figure 11).[22],[49]

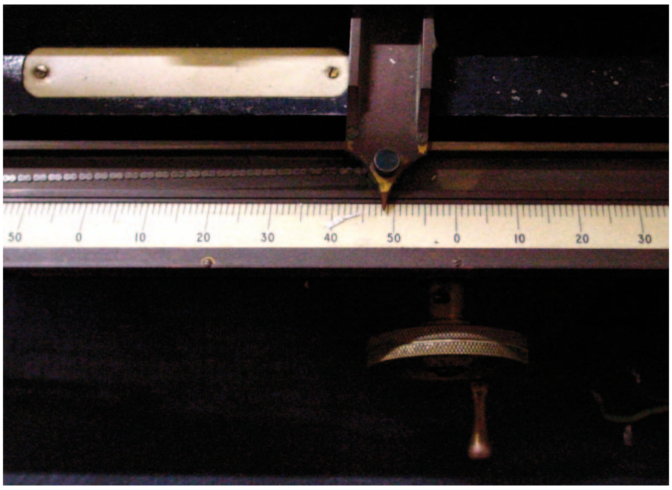


Figure 11. Time scale and pointer, and the x′ wheel. (Courtesy of the National Maritime Museum, Greenwich, London.)

The hourly motion in right ascension, x′, was set on a scale in the baseplate of the unit by turning another wheel at the front of the Machine (Figures 8 and 11). This moved the Moon lens (on its support frame on the pivot arm) nearer to or further away from the Earth globe; the nearer the globe the slower the lateral movement in x′, and vice versa.[22],[49]

The slope of the Moon's orbit was set by tilting the crossbar carrying the star lamp and Moon lens to the values of x′ on a scale on the left of the Machine, and y′ on a scale on the right-hand support strut (Figures 8 and 9). A clamp was temporarily released to move the tilted crossbar up or down, until the Moon lens assembly matched the value of Y, above or below the centre of the Earth globe, measured against a scale on the right-hand strut.[22],[49] The weight of the Moon was balanced by counterweights within the vertical support struts.[21]

The Machine had now been configured. The sliding uprights carrying the crossbar assembly were then moved to the far left, the starting position for a prediction run.[49],[51]

Operating the metal Occultation Machine

The Machine was located behind a curtain in a darkened part of a room, such that the only light available for the operator to read the scales came from that emitted by the star lamp.[52]

Wescott solved the problem of synchronising the movements of the Moon assembly and the Earth globe with a clever system of interlinked wires and pulleys. As the operator slowly turned the handle (Figure 8), the disc of light from the Moon lens moved from left to right, passing over the Earth globe, which was simultaneously rotated by a friction wire around its equator (Figure 9). For each hour measured by the time pointer and scale at the front of the Machine, the Earth globe rotated through 1 hour 0.2 minutes, to simulate the star's movement in sidereal time.[22] If the edge of the disc of light touched one of the observing locations marked on the globe, the time of disappearance or reappearance of the star, to a precision of 0.1 minute, was read by the operator from the time scale (Figure 11). The Position Angle of the occulted star was measured, to a precision of 1°, from 10° markers around the edge of the Moon lens, that were projected onto the Earth globe.[50] (Gordon Taylor, President of the BAA from 1968-1970 and Director of the Computing Section from 1974-2009, once broke a tooth on the back of the Moon carriage, but his claim for industrial injury compensation was turned down![52])

A second person, on the other side of the curtain, would write the time and Position Angle of the event, called out by the operator,[52] onto preprinted forms that contained the names of the observing stations.[53] A **Remarks** column was used to note any of the following conditions:-

B - timing uncertain because the observing station was obstructed by a band wire

G - grazing or short-duration occultation

L - low altitude star

S – twilight (A set of **Sun and Altitude Tables** had been prepared for each station.)[50],[53],[54]

These special circumstances were further investigated by the human computer when generating the predictions for publication in the **Nautical Almanac.**

The setup procedure involved a number of steps, but a proficient operator could configure the Machine in less than 2 minutes and it would not take much longer to complete a run if the circle of light did not pass over any observing stations. However, if the track moved across Europe the operator and assistant might have to measure and record numerous immersion and / or emersion times and Position Angles.[50]

It is quite fitting that McNeile was the first person to use the new Machine and within a month he had recorded the provisional times and Position Angles of all events for the year 1937, observable from 40 stations around the world. He was working on the computational corrections until his fateful holiday in Switzerland.[6] In January 1935 Harold W. P. Richards succeeded McNeile as Director of the BAA Computing Section[55] until Major A. E. Levin resumed as Director, a year later.[56],[57] Richards supervised HMNAO's occultation programme during the 1930s, which was later managed by Miss Flora M. McBain.[58]

Processing and publishing the results

The Machine often confirmed that the Moon's shadow would not pass over any of the globe's observing stations or that an event was unsuitable for observation, saving time and expense doing unnecessary computations and the resultant waste of observing time. Up to half of the conjunctions were rejected during this process. For example, the prediction run for the year 1941 examined 2511 stars, 1241 were rejected and 7999 preliminary times were logged for numerical processing [59], mostly performed by non-HMNAO staff at 'piece work' rates. [24] Some calculations were sent for checking to a farmer in the West Country, who was very proficient at the task.[60]

The following selection criteria were also applied: - [61],[62]

No predictions were computed for events within 24 hours of New Moon or Full Moon.

Only bright stars were considered for events at the sunlit limb or for grazing occultations.

Daylight occultations of bright stars and planets were checked for observability.

The star had to be at least 10º above the horizon.

Events occurring during civil and nautical twilight [63] were reviewed using the **Sun and Altitude Tables. [50]**

The Machine was a triumph of mechanical engineering. Its provisional timings of occultation events were usually accurate to 1 minute, which were then refined by numerical methods to an accuracy of about 0.1 to 0.3 minutes.[64]

In its first years of use the number of stations increased six fold.[65] The annual predictions for about 60 standard stations, such as Greenwich and Edinburgh, were published in the **Nautical Almanac.** They included longitude and latitude coefficients **a** and **b,** which could be used to compute the time of the occultation at another location up to about 500km from a standard station. A more accurate prediction could be obtained if the observer was between 2 standard stations. The coefficients were also used in the method of 'linking', where neighbouring standard stations were used to crosscheck their predicted times.[66] The times of events at a small number of standard stations, including the corresponding values of **a** and **b,** and a description of how to use them in the prediction formulae, are still published in the Lunar Occultations section of the **BAA Handbook. [67]**

Comrie's brilliant organisational and technical innovations had revolutionised HMNAO, but he had become very unpopular with the Admiralty, following his constant requests for extra staff and using staff to undertake non-HMNAO work, which led to him being suspended on 19th August 1936 and his excellent Deputy, Donald Harry Sadler, was immediately appointed Acting Superintendent, then Superintendent in 1937.[68]

Sadler and Richards included a detailed description of Wescott's Occultation Machine in **The prediction and reduction of occultations as a Supplement to the Nautical Almanac for 1938. [69]** Sadler later mentioned that there were some inaccuracies in the document, because he wasn't familiar with all of the procedures, but he didn't elaborate on them.[58]

Professor E. W. Brown and Dirk Brouwer of Yale University collated and analysed worldwide timings of lunar occultations, including those made by BAA members, and published annual reports on variations in the longitude of the Moon.[70] Brouwer continued the work after Brown died in 1938 and Miss McBain of HMNAO maintained the annual summary of the reductions, containing the observed deviations of the Moon from its mean tabular longitude and latitude.[71]

HMNAO ceased publishing reduction elements in the 1943 **Nautical Almanac,** (intended for mathematically competent observers to reduce their own observations) and they offered to reduce and analyse all worldwide observations of occultations, which created a significant workload for the staff. They also stopped computing predictions for observatories in 'enemy and occupied countries' because of the difficulties in communicating with them, until hostilities ceased after the Second World War.[72]

The **Nautical Almanac** for 1960 no longer included worldwide occultation predictions. From this year onwards HMNAO distributed predictions to any astronomical journal that wished to publish them, e.g. the BAA **Handbook** and **Sky and Telescope. [73]**

Machine enhancements

In addition to occasional repairs to its mechanical components, Wescott's metal Occultation Machine underwent an extensive series of improvements during its long working life; many of them were suggested by HMNAO and RGO staff.

In the summer of 1944 George W. Rickett of the Chronometer Department replaced the linear time scale with an old chronometer (Figure 12), so that timings could be read from its clock face.[74]

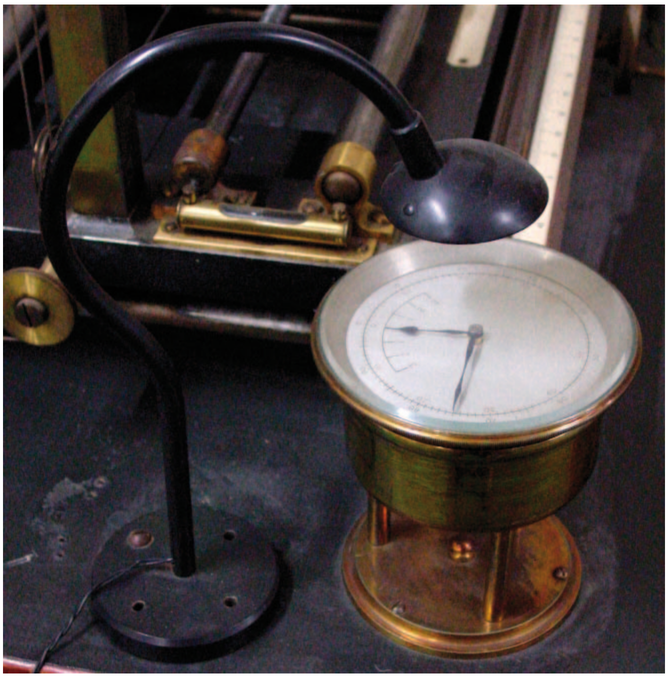


Figure 12. Occultation prediction chronometer. (Courtesy of the National Maritime Museum, Greenwich, London)

That autumn, Walter A. Scott of the Navigation Section, an expert on the Machine, suggested adding a geared wheel to the rim of the Moon lens to improve the measurement of the Position Angle of the occultation. [75] The modification was delayed because the Chronometer Department was being relocated, but a year later Rickett recommended a precision engineering company that could make the gearing.[76] The barrel of the Moon lens was linked via a pinion to a brass wheel that was graduated in degree intervals. By aligning a pointer on the Moon lens with the occultation, its Position Angle could be read to a precision of 1° (Figures 9 and 13).

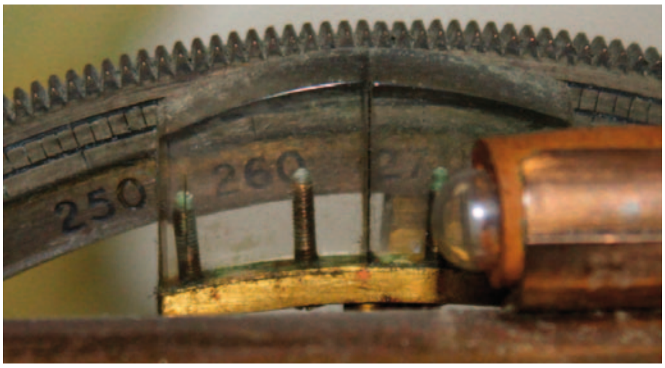


Figure 13. Position Angle scale and lamp. (Courtesy of the National Maritime Museum, Greenwich, London.)

During a major post-war overhaul of the Machine that commenced in late 1950, HMNAO Superintendent Sadler proposed a number of modifications to improve its accuracy, but they had to be completed by February 1951, in time for the prediction runs for 1954.[77],[78],[79] The work included suspending a framework of wires above the Earth globe, to delineate local sunrise, sunset, and civil and nautical twilight.[80] This was constructed by Wescott, who used a strong gauge of wire for stability (Figure 10). The operator would then check the magnitude of the star against the sky brightness indicated by the wires, to decide if an observation was feasible.[52] This eliminated the need to refer to the **Sun and Altitude Tables** and having to recalculate the **Tables** when new stations were added to the programme.

A vertical band wire was removed from the front of the Earth globe, because it was obstructing some observing stations and causing timing inaccuracies. The Hour Angle magnifying lens was moved to the side of the Earth globe, to make it easier to read (Figure 9). A knurled wheel was added to the polar axis of the Earth globe (Figures 8, 9 and 10) to make it easier to rotate by hand when setting the value of H.

After discussions with Sadler, Dudley Stewart Perfect of the Time Department in Abinger, Surrey suggested major modifications to the Machine to simplify setting the parameters of the Moon's orbit, which were implemented by Wescott.[81] To assist in setting up the inclination of the Moon crossbar, a bright lamp and parabolic reflector were installed about 2 metres from the Machine to cast the shadow of the crossbar onto a projection board about 1 metre away on the far wall of the room.[49],[78],[82] A similar arrangement was proposed for setting the declination axis.[78]

The star and Moon assembly was redesigned by Dr Perfect, replacing the condenser lens with a parabolic reflector to eliminate colour fringes and to give a sharper edge to the Moon 'shadow'. It was constructed by the National Physical Laboratory (NPL)[83] and completed by February 1951, at a cost of £78 19s 3d [£78.96].[84] Sadler felt that the NPL had not kept exactly to Dr Perfect's design and that it was inferior to Wescott's craftsmanship. Wescott had to add extra counterweights to support the new heavier Moon unit, making it ready for use in April 1951.[85]

Following a request that autumn from Miss McBain, [86] Rickett modified the chronometer to show the time difference from T_0 instead of displaying GMT, and he engraved its dial to indicate a time interval of +/- 3 hours for its 'hour' hand, with additional markings of 1/100ths of an hour for its 'minute' hand.[87]

The land surfaces on the Earth globe were painted white[78] and numbered observing locations were marked in black ink (Figure 14). For example, Edinburgh, Scotland was station 26.

Figure 14. Land areas on the Earth globe were painted white and observing stations were identified by numbers or letters. (Courtesy of the National Maritime Museum, Greenwich, London.)

During the 1950s radio astronomers were detecting numerous radio sources, but they were unable to determine their celestial coordinates with great accuracy because of the relatively low resolution of the radio telescopes, hence any optical counterparts were difficult to confirm. Researchers at Jodrell Bank, Cheshire employed the 250-foot (76m) diameter dish, linked with smaller radio telescopes, to show that some of these objects were 'radio stars'. Astronomers in California also used this technique of radio interferometry to reveal that the coordinates coincided with blue stars. IAU Commission 40 approved a list of 37 radio sources to be added to the occultations programme.[88] Analysis of the results from a number of lunar occultations of a radio source would give a more accurate position for the object.

HMNAO staff applied the locations of radio telescope observatories to the Occultation Machine's Earth globe, indicated by letters of the alphabet, marked and encircled in red ink, to distinguish them from visual stations. For example, Jodrell Bank was letter 'J' (Figure 14) and Parkes, New South Wales, Australia was letter 'Y'. When generating predictions for radio telescope observatories the celestial position of a target object was taken from a reference catalogue such as the **Third Cambridge Catalogue of Radio Sources (3C),** and then four additional occultation predictions were made, N, S, E and W of this position, to cater for the uncertainty in the size and location of the source.[52],[89] Following a request in September 1961,[90] two small lamps were installed, to illuminate the chronometer dial (Figure 12) and the Position Angle scale (Figure 13). The chronometer lamp was on a swivel pedestal that could be swung over the clock face.

The end of an era

In the summer of 1959 HMNAO acquired an ICT 1201 computer. One of its tasks was to predict lunar occultations, replacing the need for laborious manual calculations, but the Occultation Machine was still employed for preparing the lists of possible events, then detailed predictions were generated by the electronic computer.[91] During 1966 the ICT 1201 was replaced by a model 1909, which gradually took over all aspects of the occultations programme, phasing out the Occultation Machine. This was led by Leslie Morrison, supervised by Mrs Sadler (née McBain).[92]

In 1981 HMNAO's responsibility for the prediction of lunar occultations was transferred to the U.S. Naval Observatory (USNO), and the collation and reduction of observations were to be done by the International Lunar Occultation Centre (ILOC) in the Hydrological Department in Tokyo, Japan.[93]

The BAA Computing Section's Microprocessor Users' Group was formed in 1983 to support members using personal computers, such as Andrew Elliott, who was writing his own occultation prediction programs with a target accuracy of 2s.[94] Section Director Gordon Taylor contributed occultation software, that ran under MS-DOS, to the Program and Database Library.[95],[96]

In 1992 ILOC took over the task of generating worldwide occultation predictions from the USNO. ILOC closed in March 2009, but since 1st September 2008 the International Occultation Timing Association (IOTA) has coordinated the receipt of observations from around the world, which are archived in the **VizieR** databases of the Centre de Données astronomiques de Strasbourg.[93]

Lunar occultation observers can now use software packages such as Lunar Occultation Workbench[97] or Occult[98] to generate their own predictions on a home computer. In contrast to the sterling efforts of the human computers of the early 20th century, a year's events (including grazes) can be listed within a minute. The software can also be used to submit observations to the coordinating body and make a preliminary reduction of the data.

Achievements and legacy

Collectively, the wooden and metal Occultation Machines were in use for about 40 years. Without the Machines, HMNAO's occultations programme would have been prohibitively expensive, because of the high labour costs of manual computation.[24]

The analysis of lunar occultation observations predicted by these ingenious devices improved our knowledge of variations in the Moon's longitude, confirming that the discrepancies studied by Professor E. W. Brown **et al [2], [3]** were due to a secular acceleration of the Moon and a slowing in the rate of rotation of the Earth, caused by tidal friction,[99] as well as other small variations, geophysical in origin. This led to the introduction of a number of time standards,[100] including Ephemeris Time (now known as Terrestrial Time) a uniform time standard for astronomical ephemerides and observations (regulated by atomic clocks), and Universal Time (civil time, determined by the erratic rotation of the Earth). The varying difference between Terrestrial Time and Universal Time is denoted by the term ΔT[101] and is determined by observations. Leap seconds were introduced in 1972, to keep Coordinated Universal Time (UTC) within 0.9s of UT1 (Earth's rotation measured with reference to quasars).[102]

Leslie Morrison carried out detailed analyses of HMNAO's archive of lunar occultations to study long-term changes in the length of the day.[103] Using historical observations of eclipses and occultations he collaborated with Professor F. Richard Stephenson (University of Durham) on a number of important papers on secular variations in ΔT.[104],[105]

The Occultation Machine was used to predict the track of the corpuscular eclipse of 1940 October 1. The Moon lens was stopped down to an aperture of just over 1-inch (2.5cm) to simulate the circumstances of the solar wind interacting with ionised layers in the Earth's atmosphere during a total solar eclipse. It was assumed that particles would travel with a velocity of 1000 miles per second (1600 km/s), taking slightly more than a day to reach the Earth. The Machine provided an outline of the corpuscular eclipse track, and the times of the start and end of totality at a number of locations that were specially added to its Earth globe for this event.[106],[107],[108]

Graham Appleby collected reports of stars that were seen to fade as they were occulted by the Moon. Photoelectric observations of occultations of red giant stars resulted in measurements of their angular diameters.[109] A stepped disappearance or reappearance could indicate that the star had more than one component. Observation of non-instantaneous occultations has led to the discovery and confirmation of close binary and multiple stars.

The metal Machine played a key role in the identification of the first quasar.[52] Cyril Hazard and colleagues used the 210-foot (64m) Parkes radio telescope in New South Wales, Australia to monitor the signals from 3C 273 in Virgo, which was predicted to undergo a series of lunar occultations during 1962.[89],[110] Bill Nicholson of HMNAO calculated the profiles of the lunar limb at the times of the observations (from Chester B. Watts' newly published charts),[111] which were used to accurately determine the right ascension and declination of this binary radio source. Using the great 200-inch (5m) reflector at Mt Palomar, California, Maarten Schmidt photographed the 13th magnitude star-like optical counterpart and obtained a spectrum indicating an object with a high redshift, which confirmed its extragalactic nature.[52],[89],[112]

The lunar occultation technique could only be applied to radio sources near the ecliptic, but it was used to identify more quasars and to investigate their size and structure. Morrison extended the programme to include predictions of lunar occultations of X-ray sources, observable by rocket-bourne detectors.[52],[91],[113]

Lunar occultation datasets are used to correct systematic errors in the star catalogues based upon the Hipparcos satellite data and to define the International Celestial Reference Frame.[114], The right ascension of the quasar 3C 273B is traditionally the zero point of the International Celestial Reference System for Very Long Baseline Interferometry.[115]

The field of occultation astronomy is indebted to J. D. McNeile, L. J. Comrie, A. C. S. Wescott and their many colleagues at HMNAO, the RGO and USNO for their significant contributions to our knowledge of the celestial mechanics of the Earth-Moon system, variations in the length of the day and ΔT, distant quasars and the fundamental stellar reference frame.

Where are the Occultation Machines now?

It was the wish of J. D. McNeile that his wooden Occultation Machine remained with HMNAO, but he never put this in writing, so when he died his brothers agreed, in 1937, for it to be donated to the Science Museum.[116] It resides in their Small and Medium Objects store in London.

Wescott's metal Occultation Machine was donated to the National Maritime Museum by the Science and Engineering Research Council (SERC) in 1988.[43] It is stored in their archives near Greenwich, London.

Acknowledgements

This paper developed from a discussion with the late Andrew Elliott during planning ESOP XXIX in York and a conversation with Dr Wolfgang Beisker at ESOP XXX in Berlin, who asked me about an 'Occultation Machine' described by Gordon Taylor in his presentation to ESOP XVI in Cambridge in 1997. Gordon worked at HMNAO from May 1949 until August 1984, during which he used Wescott's Machine for a number of years.[60] He was the longest-serving Director of the BAA Computing Section (1974-2009).

Sheridan Williams, the current Director, helped me to get in touch with Gordon, which led to most fruitful discussions about his recollections of using Wescott's Machine, its applications and its contributions to astronomy. Mrs Mavis Wayman, (a colleague of Gordon's at HMNAO), provided useful information about the occultation selection criteria and Dr Harry Ford supplied an early photograph of the metal Machine. Sheridan is also thanked for supplying a photograph of the Brunsviga calculator at the National Museum of Computing.

The author's grateful thanks go to Rory Cook and Rebecca Storr (Science Museum) and Dr Richard Dunn (Senior Curator of the History of Science and Technology, National Maritime Museum) who supplied copies of some early documents on the Machines and helped me to inspect and photograph the Machines in their stores. Richard also generously provided additional photographs of Wescott's Machine and a character reference to enable me to visit Cambridge University Library (CUL). I would like to thank Sophia Brothers (Science & Society Picture Library, Science Museum) and Emma Lefley (Picture Librarian, National Maritime Museum) for permission to reproduce my photographs in this paper.

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Quotations from the RGO Archives are by permission of the Science and Technology Facilities Council and the Syndics of Cambridge University Library.

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This research made extensive use of the comprehensive Personal Histories of Drs Sadler (HMNAO) and Wilkins (RGO), NASA's Astrophysics Data System, URANIA – the USNO Online Catalog, and the BAA Journals on DVD and on the BAA website.

References and notes

The Cambridge University Library RGO Archives are referred to by their classmarks, e.g. RGO 08/101.

Some of Dr Sadler's handwritten letters are difficult to read. By photographing them and using image processing software to stretch them vertically 3:1 the author found them much easier to decipher.

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4 http://britastro.org/computing/history.html

5 Wilkins G.A., 'A Personal History of the Royal Greenwich Observatory at Herstmonceux Castle – Volume 1' http://www.lib.cam.ac.uk/deptserv/manuscripts/RGO_history/ p. 37

6 Comrie L. J., 'Obituary: James Duncan McNeile.', **J. Brit. Astron. Assoc.,** 45(5), 208-210 (1935)

7 Founded in 1879 as South Eastern College.

8 Cambridge Alumni Database http://venn.lib.cam.ac.uk/Documents/acad/enter.html

9 St. John's Oxford is the sister college of Sidney Sussex Cambridge.

10 **The Barrovian** is a magazine produced for Old Boys of

King William's College, Isle of Man. Courtesy: Mike Hoy, Archivist, King William's College, Isle of Man., **pers. comm,.** 2012 February 8

11 McNeile A. M. & McNeile J. D., **A School Calculus,** London (1911)

12 Sadler D. H., 'Obituary Notice: James Duncan McNeile', **MNRAS,** 96, 296-297 (1936)

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6th April, 1933. The author has been unable to find a record of the observation by McNeile and it is not included in his Computing Section report: McNeile J. D., 'Lunar occultations observed
during 1933', **J. Brit. Astron. Assoc.,** 45(3), 104-113 (1935)

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Saunder passed away in 1912 and **J. Brit, Astron. Assoc., 23(5)** 162 (1913) announced 'The late Mr. Saunder's Instruments... refractor of 7-inch aperture, by Troughton and Simms... for sale by auction'. However, after a visit to Wellington College, John Wrigley, in 'Meeting Reports', **J. Brit. Astron. Assoc.,** 99(5) 269 (1989) reported that its 7-inch Troughton & Simms refractor '...was bought for Wellington College in 1907'. The author is in discussion with Chris Potter and the Archivist of Wellington College to confirm the previous owner of their refractor.

15 The dome rotates on cannon balls! Tim Haymes, **pers. comm.,** 2011 November 18

16 Bellamy F. A. & McNeile J. D., 'Tenth Note on the Number of Faint Stars with Large Proper Motions. Zones +25°, +27°, and +29°', **MNRAS,** 76, 538-542 (1916)

17 Baldwin R., **Globes,** National Maritime Museum, London (1992) p. 11

18 Smith, Elder & Co., **Dictionary of National Biography – Ferguson, James (1710-1776),** London (1885-1900)

19 Sadler D. H. & Richards H. W. P., **The Prediction and Reduction of Occultations. Supplement to The Nautical Almanac for 1938,** HMSO, London (1937) p. 4

20 Boyd Brydon H., 'Occultations: Their prediction, observation and reduction', **JRASC,** 38, pp. 274-275 (1944)

21 Sadler & Richards, **op. cit.** (ref. 19), p. 9

22 **ibid.,** p. 10

23 Spencer Jones H., Letter to the Hydrographer of the Navy, 1934 February 10 RGO 08/101
The author has been unable to locate a detailed operational guide to McNeile's wooden Machine. Any information would be gratefully appreciated.

24 Sadler D. H., 'A Personal History of H.M. Nautical Almanac Office.'
http://astro.ukho.gov.uk/nao/history/dhs_gaw/index.html p. 26

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27 http://janus.lib.cam.ac.uk/db/
'Papers of Leslie John Comrie' GBR/0180/RGO 46

28 Tee G. J., "New Zealand and the Pioneers of Early Computing", **New Zealand Journal of Computing,** 1, No. 2 (1989)

29 Admiralty, Letter of appointment of L. J. Comrie, 1930 July 24 RGO 8/24

30 Comrie L. J., 'The application of the Hollerith tabulating machine to Brown's tables of the Moon'. **MNRAS,** 92, 694–707 (1932)

31 Sadler, (ref. 24), says that Comrie purchased it for HMNAO.

32 Comrie L. J., NAO Report to the Hydrographer of the Navy, 1930 September 17 RGO 8/24

33 Comrie L. J., Letter to Sir Frank Dyson (Astronomer Royal), 1930 September 3. RGO 8/24
Comrie comments about his NAO Report to the Hydrographer of the Navy, writing: 'You will note that I have deleted the suggestion of a gratuity being paid to Mr. McNeile.'

34 Correspondence between L. J. Comrie, Sir Frank Dyson (Astronomer Royal), his successor Harold Spencer Jones, and the Hydrographer of the Navy, 1930 September to 1933 June RGO 8/24 and 08/101
In a report to the Hydrographer, 1932 October 3, p. 16, Comrie requested the purchase of commercial calculating machines and the construction of a new Occultation Machine for HMNAO, writing '…the methods of a generation ago may be compared with digging up Piccadilly with a hand pick.' RGO 08/101

35 Hydrographer, Letter to H. Spencer Jones, 1933 July 15 RGO 08/101

36 A brass plate on the Machine reads "Constructed by A.C.S. Wescott Royal Observatory Greenwich. S.E.10. 1934". In his Personal History, Sadler, (ref. 24), incorrectly refers to him as 'Westcott'. Wilkins uses the correct spelling in ref. 5, incorrectly in ref. 42 and both spellings in ref. 44.

37 Wilkins, **op. cit.** (ref. 5), p. 72

38 They constructed the Astronomical Clock in York Minster, which was designed by Dr Robert d'Escourt Atkinson (Chief Assistant to the Astronomer Royal) and unveiled by the Duke of Edinburgh on 1st November, 1955.

Booklet, **'The Astronomical Clock – a memorial to fallen airmen 1939-1945',** Dean and Chapter, York Minster.

39 Correspondence between H. Spencer Jones and the Hydrographer of the Navy, 1933 July to 1934 July. RGO 08/101

The Admiralty remarked that as a Leading Joiner, A. C. S. Wescott should only be paid overtime at 2s 3d [11p] per hour, not 2s 6d [12.5p] as approved by Spencer Jones. The overpayments were recovered by weekly deductions, although Wescott did receive additional payments for materials and travelling expenses. RGO 08/101

40 Spencer Jones H., Letter to the Hydrographer, 1934 June 14 RGO 08/101

41 Hydrographer, Letter to H. Spencer Jones, 1934 July 11 RGO 08/101

42 In a presentation to the U.S. Naval Observatory on its 150th anniversary, Wilkins commented that Wescott constructed the Machine in his own time at a cost of £100. Wilkins, G. A., 'The history of H.M. Nautical Almanac Office',

Proceedings: Nautical Almanac Office sesquicentennial symposium, U.S. Naval Observatory, March 3-4, 1999. Washington, D.C. U.S. Naval Observatory, 1999, p.59

43 Richard Dunn (National Maritime Museum), **pers. comm.,** 2012 January 19

44 Wilkins G.A., 'A Personal History of the Royal Greenwich Observatory at Herstmonceux Castle – Volume 2' http://www.lib.cam.ac.uk/deptserv/manuscripts/RGO_history/ p. 59

45 In a letter to the Hydrographer (Edgell) dated 1933 June 20, H. Spencer Jones said he did not recommend commercially available globes. He estimated the cost of the new Machine to be £125 if supplied with a metal globe or £110 if a wooden globe was provided. RGO 08/101

Both of the wooden and metal Machines currently have a 12-inch (30cm) diameter Philips terrestrial globe, but Sadler & Richards (ref. 21), say that the metal Machine's original globe was constructed from 1-inch (2.5cm) layers of wood, accurately turned on a lathe into a spherical shape, onto which was pasted a commercial map.

46 Robertson J., 'Catalog Of 3539 Zodiacal Stars For The Equinox 1950.0.', **Astronomical Papers of the United States Naval Observatory,** V.10 Part 2, Washington (1940)

47 Wilkins, **op. cit.** (ref. 42), p. 57, says that the regal prefix 'HM' was first used in 1904, in the Preface to the

Nautical Almanac for 1907. Its origin is uncertain, but perhaps it was added to distinguish between the British and American offices. There has been a lot of collaboration between HMNAO and the US NAO during the past 100 years, including the unification of their almanacs.

48 Sadler & Richards, **op. cit.** (ref. 19), p. 3

49 Richard Dunn (National Maritime Museum), HMNAO note: - 'To use Occultation Machine' **pers. comm.,** 2011 October 25

50 Sadler & Richards, **op. cit.** (ref. 19), p. 12

51 Gordon Taylor, **pers. comm.,** 2011

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53 Sadler & Richards, **op. cit.** (ref. 19), p. 13

54 **ibid.,** p. 14

55 **J. Brit. Astron. Assoc.,** 45(4), 140 (1935)

56 **J. Brit. Astron. Assoc.,** 46(4), 134 (1936)

57 H. W. P. Richards is often inadvertently omitted from the list of Directors of the BAA Computing Section.

58 Sadler, **op. cit.** (ref. 24), p. 46

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74 Sadler D. H., Letter to P. Herbert (Ministry of Supply) 1944 October 5 RGO 16/272/7

75 W. A. Scott, 'Proposal to facilitate the reading of position angle on the occultation machine' 1944 September 10 RGO 16/272/7

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The precision engineering company was 'Philip Thornton, Great Heywood, Stafford… at a provisional estimate of £5.'

77 Sadler D. H., Letter to Dr D. S. Perfect 1950 September 21 RGO 16/272/7

78 Sadler D. H., Letter and memorandum 'Adjustments to Occultation Machine' to A. C. S. Wescott 1950 December 16 RGO 16/272/7

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80 Sadler D. H., Letters and diagrams to Miss F. M. McBain and A. C. S. Wescott 1950 December to 1951 February RGO 16/272/7
Sadler had considered, and then discounted, a bright lamp to replicate the Sun.

81 Sadler, **op. cit.** (ref. 24), p. 110

82 McBain F. M., Notes - 1951 February 8 and 21 RGO 16/272/7

83 Correspondence between Sadler, Perfect, the National Physical Laboratory, the Astronomer Royal, Miss McBain and Wescott 1950 December to 1951 April RGO 16/272/7

84 National Physical Laboratory, Invoice 1951 February 27. RGO 16/272/7
They later admitted overcharging for the work and sent a credit note.

85 Correspondence between Sadler, Perfect, the National Physical Laboratory, Miss McBain and Wescott 1951 February to April RGO 16/272/7

86 She married Donald Sadler on 22nd December 1954. Wilkins, **op. cit.** (ref. 44), p. 63
A number of staff met their partners whilst working at HMNAO and the RGO.

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89 Taylor G. E., 'Presidential Address: 1970: Occultations' **J. Brit. Astron. Assoc.,** 81(1), 20 (1970)

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Hans-Peter Dreesen: Too early…

Last year an experienced occultation observer and solar eclipse chaser passed away at the age of only 74. He recorded a lot of occultation observations and solar eclipse data.

I remember well the time when we left (as a 3-person team) for a solar eclipse in New Guinea, a real adventure – we did not meet man-eaters but everything was the way one could read in the specialised literature…

We shall keep him in mind

Farewell Hans-Peter

A Personal History of the Implementation of GPS Technology for Occultation Observations

by Dave Gault · dave4gee@yahoo.com.au

Introduction

The following is a personal history of my involvement in using GPS technology for the timing of occultation events. Over the years, I have observed many hundreds of total lunar occultations, 41 lunar grazing occultations, and 53 asteroid occultations, all aided by the convenience and accuracy of GPS devices.

No doubt there are other programs and devices that were available at one time or another, however this paper is, as the title decrees, the personal history of the author.

KIWI-PC

My interest was sparked on June 17th 2002, when Geoff Hitchcox (a.k.a. Kiwi Geoff) of Christchurch New Zealand, advised the IOTAoccultations[1] yahoo group (see message #2362) that a cheap (second hand) Trimble Sv6 GPS receiver could be purchased for $25 and it would be suitable for use with his KIWI – Precision Timestamp Utility[2]. Geoff also advised that the Australian Shortwave Time and Frequency station radio VNG was to close. Well here was a fix to a serious problem, so I purchased one of the Sv6 GPS receivers even though I knew little about electronics.

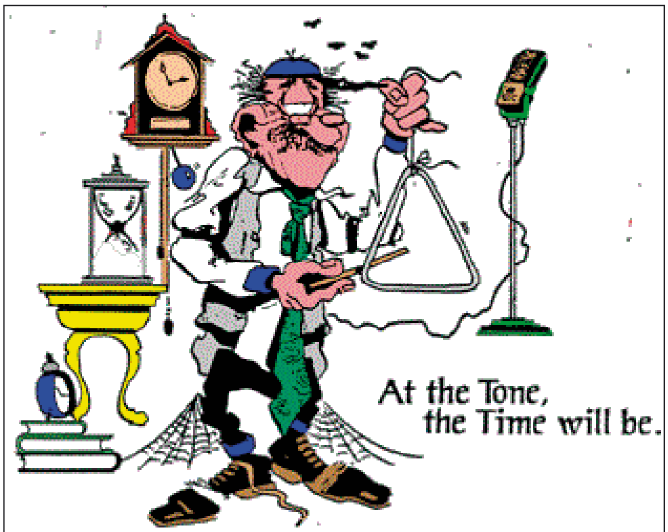


Fig. 1

So began a long and continuous association with the program known as KIWI-PC, which is characterised in my mind by the cartoon, Fig. 1, that is a feature of Geoff's old geocities website.

In due course the Sv6 arrived and over the next three months, and with lots of help from Geoff, I managed to learn which end of a hot soldering iron not to hold (har-har-ouch) and to get the GPS and program working on an old 286 PC tower. Eventually I made it portable by using an old Toshiba 386 laptop built into my old school case.

I visually observed many lunar occultation events and a couple of grazes with KIWI-PC as the UT source, and these were all by way of pressing the momentary switch to trigger a timestamp when the event occurred.

The KIWI-PC coded beep format:

- beginning of the minute	= long beep
- 10th, 20th, 30th, 40th and 50th seconds	= short beep
- 55th, 56th. 57th and 58th second	= brief beep
- 59th second	= silent (no beep)
- the minute code	= double beep
- the hour code	= triple beep

Fig. 2

In about 2003 I became interested in video observations and purchased a PC-164C video camera. For video-based observations KIWI-PC is useful because it produces a clear and coded audio beep that can be recorded with the signal from the PC-164C, and during the course of a minute of recording, the precise time can be determined from the audio track alone – see The KIWI-PC coded beep format diagram Fig 2. I have a YouTube video[3] of KIWI-PC in action as the time source used for a 2004 occultation by the asteroid 16 Psyche. I have many other YouTube videos that concern KIWI-PC that may be of interest and these can be seen by visiting my YouTube channel[4].

The DOS program KIWI-Precision Timestamp Utility (its correct name) is still freely available to this day and is highly recommended for anybody who, like me, is a self-confessed time-nutter, and wishes to have precision Universal Time on the cheap.

KIWI-OSD

On the 26th June 2004 Geoff announced on the IOTAoccultations yahoo group[1] that he was working on a new project to be called KIWI-OSD. That was to be a Video Time Inserter, and on 12th August 2004 he announced (see message 8915) that he had essentially completed the design and had a working prototype that he was happy with.

Geoff entered negotiations with various people with the aim of producing quantities of KIWI-OSD for sale, and eventually Vince Sempronio of PFD Systems became the manufacturer. It is my understanding that Vince did not have the microprocessor code for KIWI-OSD and he would

Fig. 3a

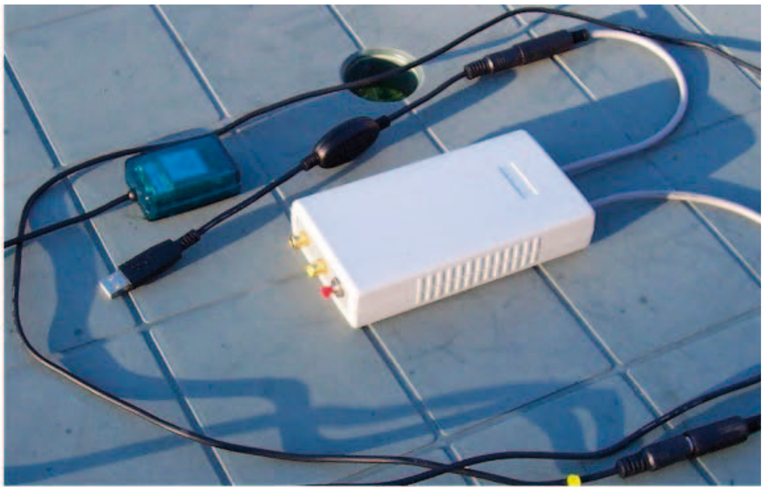


Fig. 3b

send batches of chips off to Geoff for programming. Production versions of KIWI-OSD became available in 2005.

Meanwhile, in November 2004, Geoff kindly sent me KIWI-OSD prototype #0001. This device had a hand wired board (see Fig.3a) that was discarded during development, and once the design was established, #0001 was brought up to the current standard.

It used a Deluo GPS that was first considered for the project, but was superseded by the Garmin 18 GPS. My only job was to house the hand-wired board in a suitable case (see Fig. 3b). KIWI-OSD#0001 still works to this day. From November 2004 onwards, I used this device for testing, by comparison with KIWI-PC and occultation observations, and many of the photos used by Geoff in his KIWI-OSD web pages[5&6] were produced by myself.

Over the next four years many KIWI-OSDs were produced and sold, possibly over 2000 devices by my guesstimate. Most were used for timing occultation events, but many were put to other uses: the timing of thunderstorm sprites, the timing of re-entry of space missions and even for time recording of medical videos. Personally, I had three production KIWI-OSDs, one for my home observatory, one for my mobile observing rig, and a spare. Prototype #0001 was not used after about mid-2006 due to its fragile and unique nature.

Sadly and with little notice to the timing community, in 2009 Geoff withdrew the manufacturing rights for KIWI-OSD to PFD Systems and so the production-flow of the most popular Video Time Inserter ceased. This left the observers, in particular new observers, of the International Occultation Timing Association without a device they could purchase.

IOTA-VTI

In 2010 Tony Barry attended a meeting of The Western Sydney Amateur Astronomy Group[7] (WSAAG) where I gave a lecture on observing occultation events, and all the videos I showed had timestamps by KIWI-OSD. Tony asked where this device could be purchased and I told him that it was no longer available. Unknown to me at the time, Tony had had previous experience working with video inserting devices in his capacity as a Biomedical Technician at an R&D lab affiliated with a

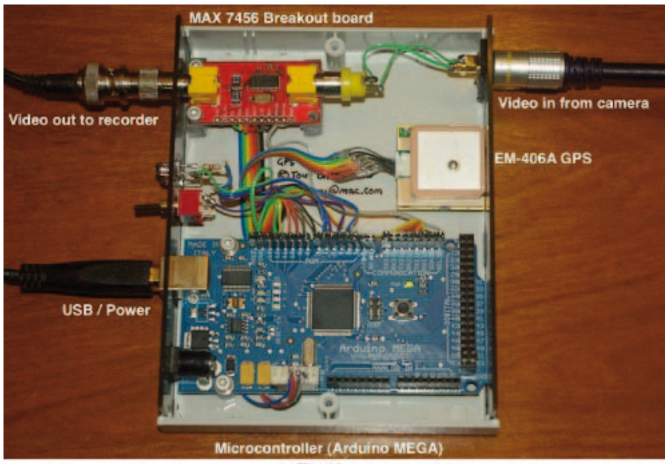


Fig. 4

local base-hospital. After researching the problem and desiring a Video Time Inserter of his own, and seeing he had some expertise, he decided to develop a device for his own use.

In October 2010 Tony contacted me to the see if I could aid him to test his new device. This device used two off the shelf boards, and an internal GPS (see Fig. 4) and microprocessor code loaded into the main board.

Over the next four months we were able to improve the design that became known as GPS-VTI, with the aim of presenting this as an open-source design that anybody, who knew which end of hot soldering iron to hold, could make.

I presented this concept, on Tony's behalf, to the December 2010 IOTA-AGM.

In early 2011 I convinced Tony that, while an open-source product was OK, most observers were not interested in producing their own device, regardless of how simple it was to make. Around this time Tony credited me with equal development status, although I hasten to add that 99.9% of the design was done by Tony. After a lot of discussion we decided that neither of us desired to take the project into production.

So the next step was to find a manufacturer and eventually Walt Morgan stepped forward to set up Video Timers[8]. Together with Sandy Bumgar-

Fig. 5

ner they were to develop for small scale production, the hand made GPS-VTI into the device now known as IOTA-VTI. (see Fig.5)

However we quickly realised that to produce on-going manufacturing security – to prevent untimely withdrawal of manufacturing rights similar to that which occurred to KIWI-OSD -Tony and I decided to set up a secure licensing agreement between, a) Tony and Dave (the developers) and IOTA (the organisation responsible for the occultation observations; b) IOTA and Video Timers (the manufacturer); and c) Video Timers and the end user. Dave Herald aided in securing the appropriate structure of all licence agreements.

I hope IOTA-VTI continues to be produced, sold and used for many years to come.

ADVS

Tony, Dave and Hristo Pavlov thought that interlaced scan analogue video could possibly be bettered in a number of criteria by progressive scan digital video, and at Easter 2011 we met at Hristo's home to discuss where to next. Together, we three formed the unofficially named "Working Group on Scientific Video Astronomy" and started on the Astronomical Digital Video System (ADVS) journey.

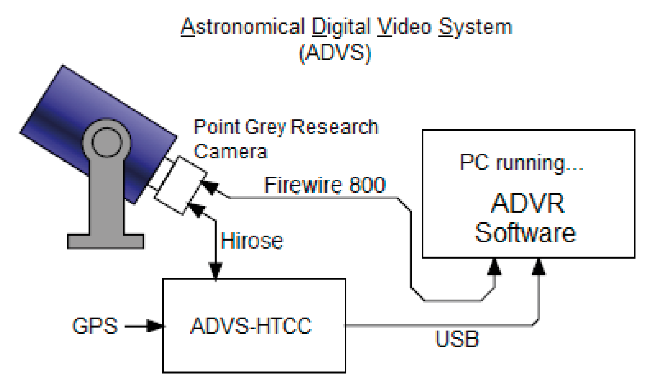


Fig. 6

Hristo was to look after the PC application that became known as ADVR (R for Recorder). Tony was to look after the hardware device that became known as Hardware Timer and Camera Controller (HTCC). Dave was to look after Quality Assurance - that the timestamps the system produced were accurate.

By July 2012 we had a working system that recorded files in a new and unique file format (.adv) that was designed for the intended purpose.

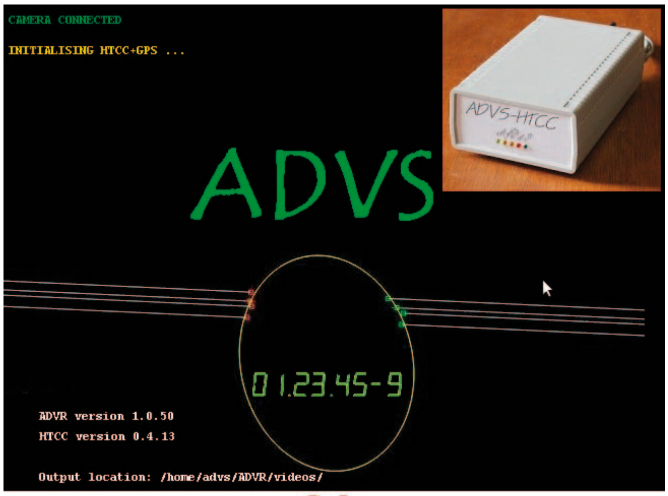


Fig. 7

Hristo developed a version of Tangra that could read and make use of the full bit depth the Point Grey cameras are capable of (Grasshopper Express = 14bit video) and to use high-level logic to process each video frame to ensure the embedded time stamp of the video frame was consistent with its neighbours.

ADVS[9] is currently being beta tested by a number of observers.

Shown in Fig. 7 is the ADVR startup screen as well as (inset) the HTCC device.

GPS-ABC

Recognising that visual observations can be valid observations, provided that a good timebase is available, Tony and Dave decided that another device could be developed and made available to visual observers.

The device was to be stand-alone and not require a computer to operate. The observer need only have a battery of sufficient capacity, and a good GPS reception, and the device would obtain a GPS fix and start beeping. The device has similar GPS almanac processes to the IOTA-VTI and provided the Almanac-OK (A-OK) LED is lit, the times are guaranteed.

GPS-ABC is released under a Berkeley 3-clause licence and information can be found on Dave's website[10].

The device can be procured using a number of methods, from totally home-made by the user, to fully finished ready to go devices made by Dave. You can make your own hand-wired device (Fig. 8a), or go for a PCB version (Fig. 8b).

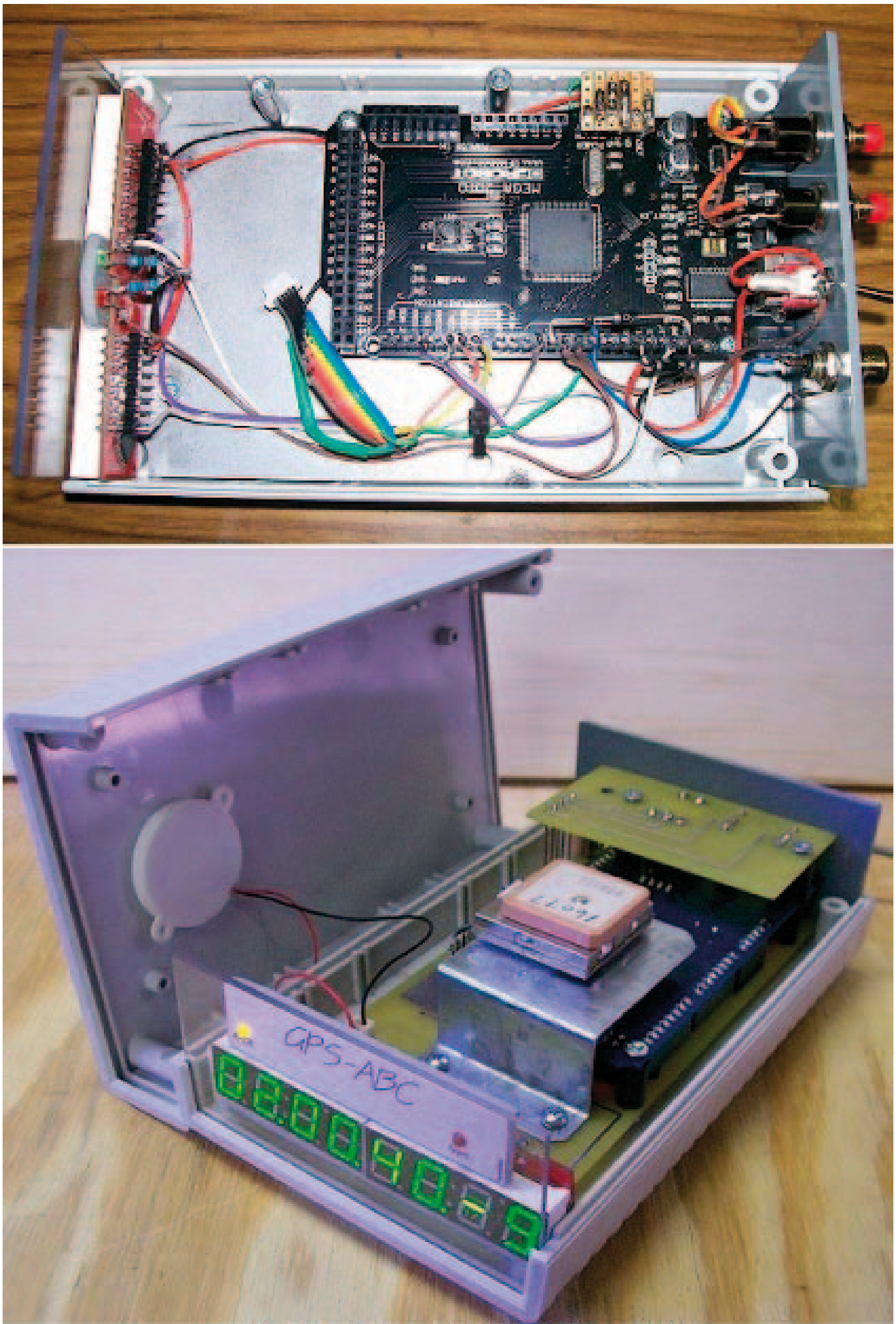


Fig. 8a (upper) Fig. 8b (lower)

The cost is based on how much or how little Dave has to do to aid your procurement.

An excellent video that features GPS-ABC can be found on YouTube[11].

Dave Gault
15th February 2014
Kuriwa Observatory (E28)
The Blue Mountains
Australia

Notes:

1) https://groups.yahoo.com/neo/groups/IOTAoccultations (Requires prior Yahoo registration)

2) http://www.oocities.org/kiwi_36_nz/kiwi/kiwi.htm

3) http://www.youtube.com/watch?v=LTppV1JfXAE

4) http://www.youtube.com/user/dave4gee

5) https://sites.google.com/site/kiwiosd/

6) https://sites.google.com/site/kiwiosd/example

7) http://wsaag.org/

8) http://videotimers.com/home.html

9) http://www.kuriwaobservatory.com/

10) http://www.kuriwaobservatory.com/GPS-ABC.html

11) http://www.youtube.com/watch?v=EzHMYUPeb7o

Journal for
Occultation Astronomy

Ring in the new...

JOSEPH A. BURNS · joseph.burns@cornell.edu

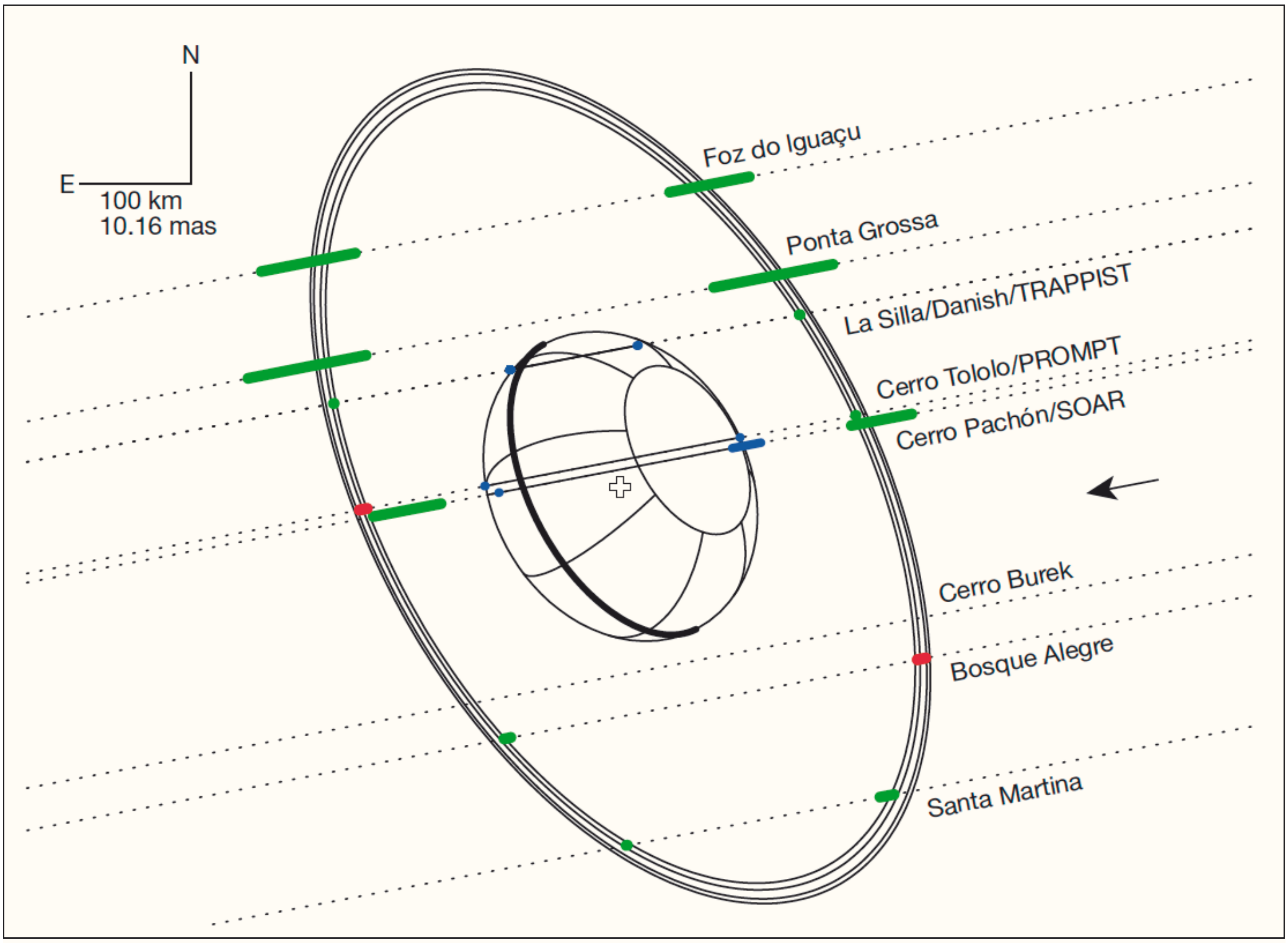
Abstract.

Two dense rings have been detected encircling a minor planet that resides beyond Saturn.

Figure Caption. As a solar-system body transits in front of – and blocks or occults – a star, the star will blink off for an interval that depends on the length of the chord across the body. Two dark rings were detected in such a stellar occultation to surround Chariklo, a ~125 km (= R_{Ch}) minor planet. The inner ring C1R, centered at 391 km (3.1 R_{Ch}), is ~ 7 km across and extinguishes ~ 40 % of the star's light. A clear ~ 9 km gap separates it from a ~ 3 km wide outer ring (C2R) at 405 km (3.3 R_{Ch}) that removes ~ 5 % of the starlight. The ring masses correspond to those of a km sized body (C1R) and half that (C2R), insignificant compared to Chariklo. Here, dotted lines show the star's track as viewed from several separate observatories, including La Silla (solid line). The dashed line indicates the star's path seen from another observatory where the transit did not occur.

To date, rings have been only known to surround the four giant planets, notably Saturn[1]. Now, continuing nature's excellent track record of upending the firm beliefs of planetary theorists, a fully developed ring system has been detected surrounding the Centaur (10199) Chariklo. Centaurs are relatively small, icy interlopers from the distant reaches of the solar system; they travel along short-lived, moderately elliptical orbits in the region of the giant planets. As reported of the current issue, this discovery occurred when F. Braga-Ribas and colleagues[2] stationed an armada of small telescopes in western South America to watch as the enigmatic Chariklo crossed in front of a star (see figure). Astronomers employ such stellar occultations just as a motorist gauges an obstacle's location and silhouette on a dimly lit highway by watching background lights flicker as the obstacle passes before them. Here an international team sought to use this technique to refine Chariklo's size and determine its shape during a predicted occultation. But they – and we – got much more.

Chariklo's rings are not the first discovered by occultation. Although planetary experts[3] had maintained for decades that special circum-



Chariklo ring system

The dotted lines are the trajectories of the star relative to Chariklo in the plane of the sky, as observed from eight sites (Supplementary Information), the arrow indicating the direction of motion. The green segments represent the locations of ring C1R observe dat each station (1suncertainty). For clarity, we have not plotted the detections made at the TRAPPIST and 0.275-m telescopes (at LaSilla and Bosque Alegre, respectively) because they have larger error bars than their local counterparts, and would supersede the corresponding green segments. Two ringe vents occurred during camera read out times (red segments) at Bosque Alegre and Cerro Tololo, and also provide constraints on the ring orbit. The ring events are only marginally detected at Cerro Burek, but the signal-to-noise ratio is not sufficient to put further constraints on the ring orbit and equivalent width. An elliptical fit to the green and red segments (excluding, because of timing problems (Supplementary Information), the SOA Reventsat Cerro Pacho´n) provides the centre of the rings (open cross), as well as their sizes, open in gangle and orientation. Chariklo's limb has been fitted to the two chords' extremities (blue segments) obtained at La Silla and Cerro Tololo, assuming that the centres of Chariklo and the rings, as well as their position angles, coincide. This is expected if Chariklo is a spheroid, with a circularring orbiting in the equatorial plane.

stances led Saturn, alone among all planets, to sport rings, a complex ring system was detected nestled within a few radii of Uranus during an occultation in 1977[4],5. In the following decade, occultations probed Neptune's surroundings, and measured ring-like signatures but only one-tenth of the time. Eventually the realization struck that the hit-and-miss nature of these signatures could be explained if Neptune's rings were restricted to localized arcs covering ~10 % ofthe circumference[6]; Voyager 2 images confirmed this unexpected morphology in 1989.

This is not the first time that Chariklo has surprised observers. Following its discovery in 1997, Chariklo's brightness systematically and mysteriously dropped by 40 % and its strong water-ice signature gradually faded[7], only to have these trends reverse, starting in 2008. The identification of Chariklo's rings now allows these puzzling changes to be understood: they occur as the rings (with 15 % of Chariklo's surface area but three times its reflectivity) become edge-on when viewed from Earth. Like so many baffling observations in science, the answer is obvious once its explanation is known.

Of the four planetary ring systems, Uranus' rings provide the closest analog to Chariklo's pair. Its dozen or so isolated, coal-black ringsmost only a few kilometers wide with crisp edges and sometimes slightly variable widths-are separated by clear gaps. "Shepherd satellites" were hypothesized[8] to pry open lanes and to confine the edges of the Uranian rings. In this mechanism, higher-order gravitational perturbations of moons generate repulsive torques on nearby disks of orbiting material. To be effective at their task, the shepherds need masses comparable to that of the ringlet that they herd, i.e., to be perhaps a few kilometers in radius, or too small to be visible through a ground-based telescope. When Voyager images subsequently spied two tiny moons riding herd on Saturn's F-ring, another pair guiding particles in Uranus' ε-ring, and also the small moon Pan amidst Saturn's Encke gap, this clever mechanism was enshrined as fact. It is now routinely called upon to explain openings and confined rings in all sorts of astrophysical disks, even protoplanetary nebulae.

Naturally then, Braga-Ribas and his co-authors hypothesize that hidden small shepherd satellites account for the gap between Chariklo's rings as well as CiR's crisp peripheries. But a dirty secret of planetary rings should be exposed: following exhaustive searches by Cassini imaging scientists since 2004, it is certain that none of the numerous gaps in Saturn's Cassini Division and C-ring harbor any shepherds of the requisite size.

Perhaps the physics missing in our attempted explanations of such ring features as gaps will be revealed by investigations of Chariklo's much simpler system. Its rings extend a mere 0.003 the dimensions of Saturn's; indeed its entire retinue could slip – with much room to spare – through the largest gaps at the outer and inner edges of Saturn's rings. Circular orbital speeds in the rings scale with size, too, and are tens of m/sec for Chariklo's ring particles. Relative speeds between ring particles should produce a thickened ring, unlike Saturn's. Exploring this toy model of Saturn's rings would permit us to investigate ring dynamics in a previously unimagined regime.

How might such a diminutive ring system have formed? Given Chariklo's relatively small mass, it seems improbable that its rings formed contemporaneously in the processes that gave birth to the minor body itself. A more likely scenario is similar to the origin of Earth's Moon[10], where a nearly catastrophic collision lofts much impact ejecta into orbit. Alternatively, disks of orbiting material can be produced through tidal fragmentation or rotational fission of weakly bound rubble piles. Whatever its cause} as this disk spreads a few R_{Ch} out, the largest shards may then shepherd the remaining disk material. An even better model involves the gentle disruption of a pre-existing satellite of Chariklo. About five percent of Centaurs and TransNeptunian Objects have small companions, possibly obtained by threebody capture[11]. At Chariklo's ring distances, orbital speeds are low but many impact fragments depart slowly, implying that a tube offragments encases the satellite}s orbit[12].

The detection of rings ab out Chariklo will startle many planetary theorists. But so it has always been in planetary exploration: theoretical ideas rarely generate searches that lead to discovery – rather discoveries such as this prompt us to new understandings.

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IOTA's Mission

The International Occultation Timing Association, Inc. was established to encourage and facilitate the observation of occultations and eclipses. It provides predictions for grazing occultations of stars by the Moon and predictions for occultations of stars by asteroids and planets, information on observing equipment and techniques, and reports to the members of observations made.

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