

APIANUS'S *ASTRONOMICUM CAESAREUM* AND ITS LEIPZIG FACSIMILE

OWEN GINGERICH, Smithsonian Astrophysical Observatory and Harvard
College Observatory

The most spectacular contribution of the book-maker's art to sixteenth-century science was without doubt the *Astronomicum Caesareum* of Petrus Apianus. Designed for Charles V and his brother Ferdinand, the volume was in every way a luxurious and princely production. Its pages were large, brilliantly hand-coloured, and filled with ingeniously contrived mechanisms, sometimes with five or even six layers of paper disks, arranged to give planetary positions plus a variety of calendrical and astrological data. Published in 1540 at Apianus's private press in Ingolstadt, the book graphically displayed Ptolemaic astronomy in a fashion fit for a monarch's eyes.

Charles V, who was more than commonly interested in astrology, was appropriately flattered by Apianus's offering, and rewarded the Ingolstadt mathematics professor with 3,000 gold coins and raised him to the rank of hereditary nobility. Other emoluments seldom granted to astronomers followed in turn: the right to appoint notaries, to award the titles of doctor and poet laureate, and to legitimize children born out of wedlock.

Today copies of the *Astronomicum Caesareum* can be found in the major libraries of Europe and America—Munich alone boasts at least nine copies, and Paris at least eight—but it is by no means a common book. It is scarcer than the first edition of Copernicus's *De revolutionibus*, which was published only three years later, and it is considerably rarer than the much-sought 1687 *Principia* of Newton. I know the locations of nearly 70 copies, and I would suppose that about 100 examples have survived. One form of the book is extremely rare, however, a deluxe edition printed on special quality paper (with a cluster-of-grapes watermark). All copies of both editions were hand-coloured at Apianus's press with similar though not identical colouring, but the deluxe edition includes coloured initials throughout and individually gilded stars on the planisphere on folio [B3].

A book as magnificent and as fascinating as the *Astronomicum Caesareum* deserves a wider accessibility, and this has in part been provided by a luxurious and princely facsimile recently produced by Edition Leipzig (and jointly published by McGraw-Hill, New York, 1970; pp. 106, 122; \$550). The multi-colour lithography is a technological *tour de force*—not only all the moving parts but even the stains and apparent wrinkles of the copy in the Landesbibliothek Gotha have been reproduced. I have shown the volume to several book craftsmen, who assure me that the full hand-tooled leather binding alone is worth at least \$75, and knowledgeable librarians inform me that, considering the intricacy of its construction, its cost is in line with other reproductions. With its high price tag, the book will not be found in the private libraries of many astronomers or historians of science, yet as the 750 copies in the facsimile edition find their

way to institutions throughout the world, "Caesar's Astronomy" should be increasingly accessible for study.

And a close study of this masterpiece can be an instructive and challenging experience. Consider, for example, the movable planisphere attached to [B3]. It is one of the earliest printed star maps, although antedated by the woodblock hemispheres of Albrecht Dürer, published in Nuremberg in 1515. The depiction of the constellations owes much to Dürer—for example, the idiosyncratic combination of a viol and a bird for Lyra—but Apianus has added other features such as the hunting dogs that later became the recognized constellation Canes Venatici. (Incidentally, in 1536 Apianus issued a very similar chart as a broadside, possibly printed from the same block but with a somewhat different typography. Does any reader know if the copy reproduced in Basil Brown's *Astronomical atlases, maps and charts* (London, 1932), pp. 13–15, was a uniquely surviving copy? Where is it now?) Apianus's planisphere plays a fundamental role in the book, because the user must set it to find the precessed values for the auges (lines of apsides) of the various planets. An oval trepidation scale on the planisphere is used in conjunction with a precession scale under the chart—a fine pedagogic example of this now-obsolete device from the astronomy of the Middle Ages. The precession, by the way, has the unusual value of $0^{\circ}.7/\text{century}$; perhaps some reader can identify its source.

A few pages further on, [C3], the real fun begins, for here Apianus presents the first of the multi-disk assemblies, a set of volvelles showing the longitudinal motion of Saturn. Apianus has produced not only an extraordinarily beautiful astronomy book, but a precision instrument as well, capable of establishing positions of the Sun, Moon and planets within a degree of their Ptolemaic values.

But alas! Here Edition Leipzig has failed to achieve the 1540 standards. Although their facsimile is a triumph of modern printing technology, the reproduction as issued is by no means a precision instrument. The reason is simple: the volvelles have been put down without insight into the subtlety of Apianus's original design. Thus the idea of non-concentric axes, essential for representing the eccentric motions of the planets, has been disregarded, and a single axis has been forced through the disks. This, in spite of the original Latin instructions and guide marks all faithfully reproduced deep down in the stack of volvelles where they are never seen unless the facsimile is taken apart! Besides this, there are even more conspicuous errors in the facsimile. The assembly of disks found on folio C of the facsimile belongs on F II. The upper disk found on F II belongs on [G5], but the lower disk on F II should go on [G IIIv], and in turn the lower disk on the facsimile's [G IIIv] belongs on [G5].

How the blame should be distributed for these assembly errors is hard to know. Were they in the original example in Gotha? Since that copy was completely taken apart for the reproduction, this is difficult to establish. However, I set out to examine as many other original copies as possible to establish how likely such assembly errors might be. I have now examined over forty copies, and can draw the following conclusions. First, it is virtually impossible to find a copy in a perfect state of preservation, although Oxford's Bodleian copy is remarkably complete. This is especially true with respect to the numerous threads, twelve of which originally carried small seed pearls as sliding indicators.

Second, there are variations in the choice of small central disks supplied; the Gotha example apparently has the correct number of pieces except for one minor modern replacement, but has a nondescript flowered disk in place of one specially printed for folio K III. Third, in a substantial number of copies one or more volvelles have come loose, and this results both in the loss of disks and in mixing their places. A few copies were reassembled or repaired in a bizarre fashion, although invariably with ample indication that repairs had taken place. However, *there was absolutely no evidence that any assembly errors had been made in the original copies* as sent from the printing house in Ingolstadt.

Several pieces of evidence suggest that the workers at Edition Leipzig failed to appreciate the delicacy of their undertaking. When I took a copy of the facsimile apart in order to rectify it, I found holes correctly punched but carefully and erroneously glued together again, and also printed parts erroneously punched out but nevertheless preserved, which could scarcely have been the case in their original prototype. Also, the original Gotha example has the necessary stubs on the planisphere to indicate the auges for the various planets, but the one for Mars and parts of two others have been trimmed away in the facsimile.

Edition Leipzig did have the services of a historian of astronomy, Diedrich Wattenberg of Berlin, who has prepared the interesting supplement volume (in both German and English) entitled "Peter Apianus and his *Astronomicum Caesareum*". Apparently the communication between Wattenberg and Leipzig was not good, because he describes Chapter 17 as having an "instrument" with four disks and two epicycles; in the facsimile no such device is found at Chapter 17 since this is one of the misplaced assemblies.

Edition Leipzig has informed me that they intended to copy the Gotha example as a monument of cultural history, not as a scientific instrument. Nevertheless, their advertisement in this journal has claimed that the "brilliant invention of Apianus' original is perfectly reproduced", and the "volvelles, which he used to calculate positions . . . are perfectly fitted". It is apparent that the publishers have found themselves responsible for an unexpected disaster, and so they will assist owners who want their copies to operate as Apianus intended. The changes can easily be carried out in a few very instructive hours with a knife, manicure scissors, needle and glue. Owners who wish to rectify their facsimiles should write to Edition Leipzig, 701 Leipzig, Postfach 340, for instructions (in both English and German) and for materials.

Equipped with a set of properly-pivoted planetary volvelles, the user of the *Astronomicum Caesareum* can (with a little practice) find after a few minutes the longitude of a planet to within a degree of its Ptolemaic value (although the Ptolemaic theory may lead to errors of several degrees compared to the actual position). This is accomplished by successively setting the three or four large disks and the two epicycle disks of the longitude mechanism. For each planet Apianus gives two examples (in Latin), and similar instructions are given in sixteenth-century German in an accompanying facsimile of an extremely rare German explanatory guide by Apianus. (I have provided English instructions in the first Appendix below.) On the opening following each planetary longitude mechanism is a large circular graph for establishing the latitude; in the original edition this process was facilitated by a small marker pearl sliding on a central



FIG. 1. Apianus, *Astronomicum Caesareum*: folio D4, the device for the Martian latitude.

thread, but in the majority of surviving copies the pearls are lost, and they are lacking from the facsimile as well. (See Figure 1.)

In terms of complexity and finesse the planetary equatoria are the forte of the book, and from an astronomical viewpoint they certainly form the most interesting part. Nevertheless, we must recall the astrological and calendrical motivations for wanting planetary positions in the first place, and these are elaborated in the latter half of Apianus's volume. Included are a variety of simple mechanisms for finding such diverse quantities as the Golden Number (for Easter determination), the hour of conception given the moment of birth, and the critical days in the course of a severe illness.

A shorter "Pars Secunda" follows; though devoid of moving pieces, it bears further witness to Apianus's ingenuity in devising instruments and as a mathematician. Four pages describe the use of the "meteoroscopia planum", a graphical device for solving problems in spherical trigonometry (see J. North, "Werner, Apian, Blagrove and the meteoroscope", *British journal for the history of science*, iii (1966-67), 57-65). Ten more pages present observations of comets. Although Apianus was not the first to point out that comet tails point away from the Sun, his work is apparently the first to illustrate the phenomenon. The final pages describe the construction and use of the torquetum.

The facsimile ends with a magnificent coloured full-page coat of arms, in the form acquired by Apianus after the successful production of the *Astronomicum Caesareum*. (The majority of original copies show the earlier coat of arms on this final page.) The penultimate leaf reproduces a handsome autograph inscription written in what is now the Gotha copy by Tycho Brahe on 14 June 1599: "Coeli enarrant gloriam DEI et opera manuum eius annunciat Firmamentum".

APPENDIX I

In this section I shall give a brief explanation for the use of the lunar and planetary mechanisms in the *Astronomicum Caesareum*. When setting out to find planetary positions with these devices, it is very helpful to be armed with Appendix I of O. Neugebauer's *Exact sciences in Antiquity*. His diagrams are far more useful than Wattenberg's extremely schematic and partially incorrect description that accompanies the facsimile; in fact, one might even suppose that Wattenberg had not worked through the full procedure.

I shall use Apianus's own example for the birth of Charles V (1500 February 23), first for the planet Mars on folio D III (see Figure 2). Facing the Martian volvelles is a table giving at century intervals the mean positions of the epicycle centre (Tabula Medii Motus) and mean positions within the epicycle itself (Tabula Medii Argumenti). With respect to the tables (and implicitly but less obviously on the volvelles themselves) Apianus adopts the mediaeval convention of *complete* dates, and hence we must seek the completed year 1499 rather than 1500.

From the mean motion table we obtain for the century 1400 the value $6^{\circ} 3' 31''$. Index *M* of the largest disk must be set first to this position (Libra $3^{\circ} 31'$); next, find the 99-year position on the periphery of this disk. Using the thread from *A* (mundi) as a marker, advance the index *M* for the 99 years. Finally, again using the thread as a marker, rotate the index *M* for February 23 according to the monthly scale of the largest disk. (This scale is hidden by the disk above it.) Index *M* should now be near Gemini 22° , as shown in Figure 2.

The index *P* of the second disk, the so-called Aux (the modern "line of apsides"),

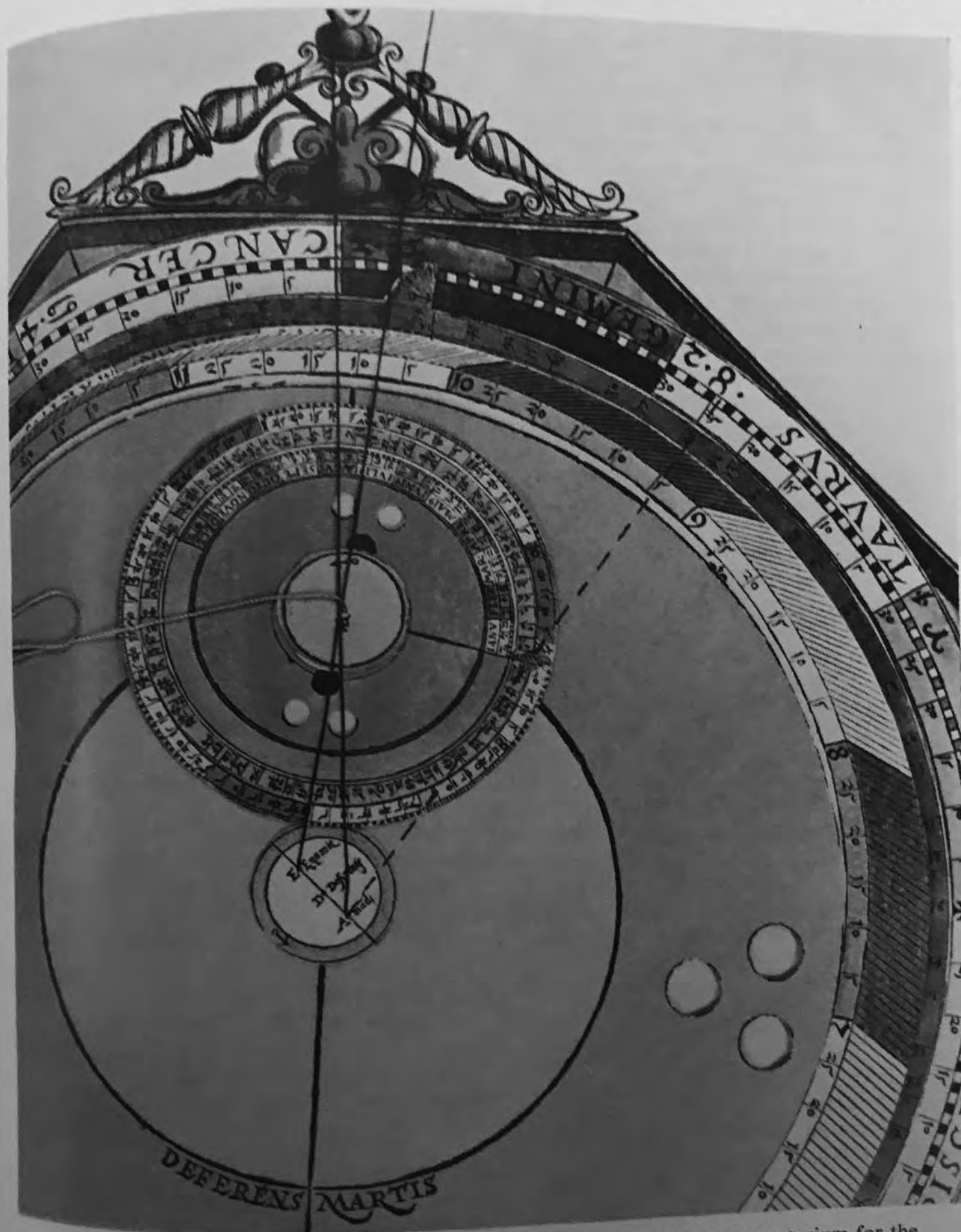


FIG. 2. Apianus, *Astronomicum Caesareum*: detail of folio D III, the equatorium for the Martian longitude, set for the birth of Charles V.

must be set in conjunction with the planisphere on folio [B3] in order to allow for precession. On the planisphere, set the index X to 1500 on the scale concealed under the right edge of the star disk. Extend the thread across the position of 1500 in the trepidation oval on the star disk, and bring the index "Y AUX Communis" to this point. The index for the Aux of Mars on the planisphere should now be at Leo 15° , and this position must be transferred to the Aux disk of the Mars mechanism on D III.

Next, continuing on folio D III, set the mean motion onto the Deferens disk, which carries the epicycle. This must be done with respect to the equant E , which has its own circular angle scale on the Aux disk. The mean motion indicated by index M can be offset into the equantcentric system by following one of the diagonal lines connecting the perimeter and the inner scale of the Aux disk, as shown in the illustration. The reading on the Aux scale, $10^s 8^\circ$, is the mean centre of the epicycle (α in the notation of Neugebauer's Figure 38). Now turn the Deferens disk until the centre of the epicycle coincides with the thread stretched from E to $10^s 8^\circ$ on the Aux scale. Then rotate the lower epicycle disk so that the Φ also coincides with the thread.

The setting of the upper epicycle disk proceeds analogously to the large mean motion disk: first we must set its small tab, rather obscurely labelled Y , at $3^s 15^\circ$ (found from the *Tabula Medii Argumenti* entry for 1400). Then rotate index Y (with the aid of the thread as a marker) to the 99-year position printed on the circumference of the disk. Finally, again rotate index Y for February 23 according to the monthly scale. Index Y is now set at about $8^s 20^\circ$ as shown in Figure 2. This angle is the so-called mean argument or mean anomaly (γ in Neugebauer's notation).

When the thread from A is stretched through the rosette by the Y index to the outer scale, we can find the true geocentric longitude of Mars: Taurus 24° (dotted line added on Figure 2).

In Figure 2 the thread from A stretches through the epicycle centre to display the "equation of the centre", that is, the angle between the two threads, which may be read as about 9° on the larger epicycle circle. The equation of the centre permits the mean argument to be converted into the true argument ($8^s 20^\circ - 9^\circ = 8^s 11^\circ$) and the mean centre to be converted into the true centre ($10^s 8^\circ + 9^\circ = 10^s 17^\circ$). Alternatively, the true centre of the epicycle can be read directly with the aid of the thread from A and the diagonal connecting lines on the Aux disk.

The two "true" quantities provide arguments for the graphical latitude function presented on the following folio of the *Astronomicum Caesareum*. This device is in the form of a polar coordinate graph. The true argument is set on the radial coordinate (originally by means of a pearl sliding on the central thread) and the true centre is set on the angular coordinate. The example above yields a latitude of -2° .

The procedure for positions of Venus and Mercury differs slightly from the superior planets, in that the yearly mean motion within a given century is supplied by an extra table rather than by the calibration of the mean motion disk itself. For Mercury on folio [E4] there is an additional large disk, the "Aux Aequantis", which must be turned equal and opposite to the epicycle according to a reverse scale on the Aux disk.

For a lunar longitude (folio F II; see Figure 3) it is necessary to proceed with some astronomical common sense, especially because Apianus's description is overly terse and marred by several numerical errors.

For the Moon I shall again use Charles V's birth, 1500 February 23, $16^h 20^m$; only the Moon's motion is fast enough for the hours and minutes to make some difference. First, set the mean motion of the Sun with the index M on the largest disk according to the century value in the facing table. The very small correction for the particular year, which arises from the pattern of leap days, is made by adjusting the disk according to the tilt of the appropriately numbered small line on the periphery of the largest disk. For 99 years, in the example this produces a negligible backward rotation of less than a minute of arc. The additional motion for February 23 gives a final



FIG. 3. Apianus, *Astronomicum Caesareum*: folio F II, the mechanism for the lunar longitude, set for the birth of Charles V.

result of $11^{\circ} 12'$ (Pisces 12°); the $9^{\circ} 7'$ erroneously stated by Apianus is not the Sun's mean motion but the Moon's.

Next set the second disk with the Moon's mean motion, starting from the tabular value for 1400, that is, $3^{\circ} 21' 33''$ (as correctly stated in Apianus's German guide but not in the Latin). Then add the increment for 99 years according to the marks on the rim of this disk. The line for the beginning of the month is found inside the year scale, spaced separately on each side of the spiral scale for the days and hours. (Apparently this arrangement confused Apianus's artists, for the first printing was miscoloured and new disks were printed on the other side of the same paper. Thus on most original copies fragments of the falsely coloured print may be found on the under side of this disk.)

The final result of the initial setting plus three incremental rotations is $9^{\circ} 7'$. Note that we must use the *complete* month—in our example, January. Similarly, we would expect to read the day from the scale *before* the number 23, but a special rule applies here. Before the leap day in a leap year the day must be incremented by one; this baffled me at first because although Apianus mentions it briefly at the beginning of the book, he does not repeat it here.

After the second disk has been set according to the example, the Moon's mean elongation from the Sun should read just over 90° on the inner scale of the largest disk. Now measure off 90° in the opposite sense, and set the index of the third disk ("Aux-deferentis-lune") to this point.

The remainder of the procedure is rather analogous to the planetary case. Position the epicycle centre along the thread from *A* to the pointer *P*, but use the thread from the equant *E* through the epicycle centre and beyond to set the larger epicycle disk. (Rotate the Ψ to the farther position from *E* below the thread.) Set the index *Y* of the inner epicycle at $3^{\circ} 10'$, the value for 1400 taken from the "Tabula Medii Argumenti Lunae" on the following page. After three subsequent rotations for years, months, and days, the index *Y* should be at about $6^{\circ} 11'$. A thread extended from *A* through the small lunar symbol to the outermost scale yields the position of the Moon as Capricornus 7° .

The determination of the Moon's latitude from the marvellous dragon volvelle on folio F III is left as an exercise for the reader.

APPENDIX II

F. van Ortro's standard *Bibliographie de l'oeuvre de Pierre Apian* (1901) gives locations of 33 copies of the *Astronomicum Caesareum*, primarily in central Europe; he lists only the British Museum copy in Great Britain, and none in America. A few more copies are listed by S. A. Ionides in "Caesar's Astronomy", *Osiris*, i (1936), 356–389, including his own, which later perished in a fire that destroyed his library. I take this opportunity to list the copies I know about in Great Britain and in America.

Great Britain

1. London, British Museum.
2. London, Royal Astronomical Society.
3. Greenwich, National Maritime Museum.
4. Oxford, Bodleian Library.
5. Oxford, Magdalen College.
6. Oxford, St John's College.
7. Cambridge, Fitzwilliam Museum.
8. Cambridge, Peterhouse.
9. Edinburgh, Royal Observatory, Crawford Library.
10. Edinburgh, National Library of Scotland (in Newbattle Abbey Collection, Dalkeith).

United States

- 1, 2. Cambridge, Harvard University, Houghton Library.
3. New Haven, Yale University.
4. Providence, John Carter Brown Library.
5. Ridgefield, Connecticut, private collection of Harrison Horblit.
6. New York, Metropolitan Museum of Art.
- 7, 8. Washington, D.C., Library of Congress (one copy in the Rosenwald Collection).
9. Chapel Hill, University of North Carolina.
10. Ann Arbor, University of Michigan, William L. Clements Library.
11. San Marino, California, Henry E. Huntington Library.
12. San Juan Capistrano, California, private collection of Robert B. Honeyman, jr.
13. Beverley Hills, California, private collection of Harry Levinson.