The globe and the sundial were symbols of erudition in Roman antiquity. Cicero praised Archimedes as a man close to God because he could construct spheres, and to him horologia were examples by which one could see the work of God in man. Also, on the mosaic of the Roman villa on the Isle of Wight and at the meeting of the philosophers on the mosaic in Naples, the globe and the sundial are the instruments of the scholar. How great must have been the symbolism when both instruments were combined in one! This explains why our object at issue here (Fig. 1) was not damaged and stayed safe from its inception around 100 BC until its consecration to the Argive Heraion in the 2nd century AD.

The Heraion is located just to the west of the main road from Mycenae to Argos, approximately equidistant to both places. The traveller Pausanias, visiting the site in the 2nd century AD, referred to the area as Prosymna (Description of Greece 2.17.1-7). This temple of Hera, daughter of Kronos and wife of Zeus, was the ritual centre of the Argolid and one of the oldest and most famous of Greece, which is also expressed in Homer when he let Hera say (Iliad 4, 50–52): “The three towns I love best are Argos, Sparta and Mycenae of the broad streets”. The sanctuary flourished from the 8th–5th century BC, but continued in importance throughout the Roman period, when baths and a palaestra were added near the site.

But it is not only the symbolic content and its particular location to where it was donated, but also the subtlety with which the globe sundial was manufactured that allows us to say that it is one of the most amazing scientific objects that has survived from antiquity. It does not work with a pointer as most dials do but with a terminator, the boundary of light and shadow, in a way that we can speak of a three-dimensional nomographical procedure. Ptolemaios also used nomograms in his Analemma but the idea cannot have come from him – as the globe is older – or from the French engineer Philbert Maurice d’Ocagne (1862-1938) who is commonly said to have invented nomography in 1884.2

Though the globe is extraordinary, it has until now been described only briefly, from the excavator Carl Blegen in 19393 to Sharon Gibbs in her work from 1976 on Greek and Roman Sundials.4 Blegen himself admitted that he had not understood the system of arcs and lines and that he did not know enough about sundials to perform on it “an intelligent discussion”, as he said. Also, Gibbs gave only measurements and a brief interpretation. So this article represents the first detailed description with analysis results of the data of the dial.

Description

The globe was not found in the Heraion, which lies on a hill, but at the end of a slope a small distance from it, where the stone probably rolled down to. The dedication to Hera is another strong argument that it was originally placed in the Heraion.

It lies now in the apothiki (i.e. depot) of the ephorate of Nafplion, which is not open to the public, but a visitor to the ephorate will be shown a resin copy. It is a solid ball of white marble with a radius of about 268 mm. It carries a dedicatory inscription (inscription A), a labelled point system (inscription B) and three line systems I, II and III, of which only line system II is labelled (inscription C). The surface of the sphere is flattened in the region of the line systems and shows in the other parts traces of a toothed stone chisel.

The globe dial of Prosymna

KARLHEINZ SCHALDACH and ORTWIN FEUSTEL1

Fig. 1. The Prosymna dial. Top view of the globe with line system I, some holes and parts of line system II. Photograph by K. Schaldach.
The sphere is bisected by two great circles. One great circle passes through the zenith, the highest point, and the nadir, the lowest point, where a 10 cm wide by 10 cm deep hole with the remains of a lead filling hints that the sphere was attached to a base of some kind. That circle can be interpreted as a meridian line. Fig. 2 shows a cross-section along the line with some measurements (large numbers) that gives the impression that the important values of the sphere (which were calculated, therefore the small numbers) as ε, the obliquity of the ecliptic, with 23.6° and the latitude φ with 35.7° fit rather well, compared with Ptolemaios, who in his *Syntaxis* gave the climatic zone of Rhodos as 36°, which stood also for the whole of the Peloponnesian.

A second great circle bisects the ball horizontally. On the N-half of the sphere, below the horizontal line, there is the votive inscription which says (inscription A; where | represents the meridian line, which separates the following text):

```
Ἡρῆς ἱροπόλος με θεῆς ἱερῆς Θάλεια
ηλιακῶν ὡρῶν ἄγγελον ἠμερίοις.
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(The priestess of the goddess Hera, Thalia has ordained me, the herald of the sunny hours for the mortals.)

This inscription was cautiously dated by Blegen to the second century AD. The space under the inscription is empty. Only the meridian line leads down to the lowest point of the sphere.

Above the inscription and the horizontal line is the line system I (B after Blegen) that incorporates the zenith and has a shape like that of a hollowed sphere with a hole in the zenith, but the connecting lines between the hour points are made by straight lines. Also, there are small holes marking the intersection of the meridian line with the equatorial line in order to emphasise that spot.

From the zenith, and symmetrical to each other to the opposite side of the globe, there is a radiating point system consisting of two rows of six flat holes with a diameter of 8 mm each, not – as Blegen noted – to hold chopsticks in order that their shadows indicate the hour, but for fastening bronze rod studs. Each of the holes is accompanied by a number with a height of about 8–10 mm (inscription B):

```
ς ἑ ζ ὀ ἑ ἠ ἑ ι ἐ ἑ ι ἑ (6 5 4 3 2 1 12 11 10 9 8 7 6)
```

The holes pass line system II with its seven day lines and 13 hour-lines. The reason that we have more hour-lines than, for instance, a hollow spherical dial is because we need one hour-line for the sunrise and another for the sunset, as in this case we have no stone edge to define the surface for the shadow. The series of holes begin with the holes on the horizontal line, which are marked by a Greek 6, and then climb up to the hole at the zenith which is marked by 12. Fig. 1 shows the sphere with parts of systems I and II and the point system from a bird’s-eye view, while Fig. 3 was photographed from the East.

Line system II looks more elaborated than I, because the lines fit well with the rounding of the stone.

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**Fig. 2.** S stands for the summer line, A for the equinoctial line, W for the winter line, Z for the zenith and C, H and D for the lines of system III. Drawing by K. Schaldach.

**Fig. 3.** View from the east of the globe with parts of line systems II and III as well as holes for the hours six to eleven. Photograph by K. Schaldach.
In the squares formed by the lines are letters which give the following names of the zodiac (inscription C):

<table>
<thead>
<tr>
<th>καρκίνος</th>
<th>δίδυμοι</th>
</tr>
</thead>
<tbody>
<tr>
<td>λέων</td>
<td>ταῦρος</td>
</tr>
<tr>
<td>παρθένος</td>
<td>κριός</td>
</tr>
<tr>
<td>ζυγός</td>
<td>ἱχθῦος</td>
</tr>
<tr>
<td>σκορπίως</td>
<td>ὑδρηχόος</td>
</tr>
<tr>
<td>τοξότης</td>
<td>αἰγόκερος</td>
</tr>
</tbody>
</table>

Cancer   Gemini
Leo       Taurus
Virgo     Aries
Libra     Pisces
Scorpio   Aquarius
Sagittarius Capricorn

Special features are the notation for καρκίνος which crosses the meridian line into the field for Gemini, and the rare variant ὑδρηχόος for ὑδρηχόος. While the first seems to be an error of the stonemason, the variant ὑδρηχόος is not unknown and it therefore indicates neither a particular time nor a special background. A close view of line system II is shown in Fig. 4.

The zodiac is given in the common order, that is, counterclockwise. The solstices and equinoxes are not mentioned in the inscription, but they can easily be added: the summer solstice near the top, the winter solstice at the bottom line of that system.

Line system III, for which there was previously no interpretation, crosses over system II. The horizontal line is part of the system, which is also bisected symmetrically by the meridian line (Fig. 5).

The drawing Fig. 6 provides a flattened surface of the globe with an overview of all the systems and inscriptions. It is not to scale. The top stands for the N, the bottom for the S, the right side for the E and the left for the W side of the sphere.

Blegen said that the labelling of the holes and lines of system II “seem to belong to the end of the second century BC”, while Gibbs does not mention any age. Actually, inscription A is very different from the inscriptions B and C, and Blegen’s dating proposal possible, but we would like to expand it into the first century BC as well.
A problem is that the stigma ζ form of the 6s tends to be more Roman than Hellenistic (Fig. 7). Probably they are later additions as they are slightly larger than the other hour-number letters and their orientations do not seem to be consistent with them. Nevertheless, it is the very first sundial on which the hours were marked by Greek numerals. Then about 200 years after its production, around the middle of the 2nd century AD, the piece was given to the Hera sanctuary as an offering of the priestess Thalia. The poetic expression ἄγγελος ἡλιακῶν ὥρων in the dedicatory inscription has, we believe, no close relationship with the original scientific nature of the device. Also, the word ὥρων together with ἄγγελος are only found in Galen, the prominent physician, surgeon and philosopher of the 2nd century AD (ὅταν δὲ τὴν δευτέραν ὥραν ἄγγείλῃ τὸ ἡλιακὸν ωρολόγιον = If the sundial announces the second hour), another reason for the rather late dating of inscription A.

Review of the Analysis

Both the pattern of the spherical line nets and the kind of indicator (namely using the terminator) mean that, in contrast to the calculation of dials with a gnomon, a totally new way of thinking is required: not using the tip of the sun vector to indicate the time and date but instead the edge of the terminator plane, perpendicular to the sun-vector. Thus it was necessary to find possible solutions not previously used. The mathematical tools and methods required were analytical analysis (column vectors), trigonometry, 4th order curves, and transformation of coordinates by rotation and by orthogonal projection. Using these methods it was possible to derive formulae for calculating the intersection point coordinates between spherical lines as well as the hole positions and the terminator.

Function of the Series of Holes

The 13 holes are arranged on the globe’s south face: one hole is positioned at the globe’s zenith, twelve holes are distributed symmetrically on both sides of the meridian down to the sphere’s east and west points. The two curves branch with the hole positions from the zeroeth to the sixth hour, and from the sixth to the twelfth hour, deviate only slightly from the first vertical – see Fig. 8. The terminator cuts exactly the individual hole positions for every full hour only at the equinoxes. We will see later that in this respect the holes and the line system III are causally related. Of course it is possible to read the temporal hours at the hole positions too, because the scatter range for the terminators for non-zero declination values is negligible in comparison to the circumference of the globe. Fig. 10 shows as an example three terminator lines that run through hole position I.
The typical deviation of measured and calculated values concerning the arcs between the holes is about ±2% for the holes from 1 to 5 and 7 to 11; only the deviations for the remaining hole distances amount to 8.5% and −12.5%.

Functions of Line System I

Line system I consists of two branches of the conchoid of a circle for the solstice lines and a circle for the equinoctial line. Both curves are orthogonal projections from the equinoctial plane onto the northern surface of the sphere. The cuspidal point of the conchoid is at the globe’s zenith; the vertices are positioned at the meridian line. The centre of the equinoctial circle lies on the meridian line and the circle itself runs through the globe’s zenith – Fig. 9. Ten pairs of great circle arcs are arranged between these algebraic curves; their intersection points are related both to the temporal hours and the seasons. The arc pair for the first temporal hour is also shown in Fig. 9. In Fig. 6, two dots are drawn at the intersection of the meridian and equinoctial lines: all equinoctial terminators pass through this point (Fig. 9).

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The typical deviation range along the inner branch of the conchoid is from −1.6% to 1.3%. The deviations along the equinoctial circle are divided in two; there are deviations in the range of only a few percent but also more than 10%. The deviation range for the outer branch of the conchoid is very non-uniform, namely from a few percent up to some 10% as freak values. The deviations for the arc lengths between the declination curves vary in a similar manner.
Fig. 13. View from the south of line system I with five declination lines and part of the hour line for hour 1 as well as line system III with three great circles and two great circle arcs. The terminator at the equinoxes cuts the accompanying intersection points between arcs and great circles of system III and first hour and equinoctial lines of system II. The two arcs intersect with the cross point of meridian and horizon circles.

Functions of Line System II

Line system II is formed by one great circle arc for the equinoxes, six parallel circle arcs according to the zodiacal belt, and twelve temporal hour lines. The hour lines contain a low bend between the summer solstice line and the equinoctial line as well as a considerable bend between the equinoxes and the winter solstice. Figs 10 and 11 show as examples the curves for the temporal hours 1, 6 and 7.

The deviations for the 48 circle arc lengths along the declination lines and the meridian line show the following results: about one third of the measured lengths deviate less than \( \pm 5\% \), about one fifth is within the range \( \pm 5\% \) to \( \pm 10\% \), and about two fifths are within the range \( \pm 10\% \) to \( \pm 20\% \).

The systems I and II can each indicate, in principle, the seasonal dependence of the temporal hours. For each system, there is more than one intersection of the terminator and the current season but the second system allows this ambiguity to be resolved. Additionally, the daily moment of the sun’s culmination (sixth hour) is best read if the terminator touches the relevant intersection point of system I as well as the east and west point at the system II, see Fig. 12.

Function of Line System III

Two great circles arcs – one above and one below the horizon circle – and the horizon circle itself belong to system III; the two great circle arcs intersect at the east and west points, and the angle between them is about equal to the latitude. Ten pairs and two single arcs are inserted between the three great circles. This net does not serve for the continuous indication of an astronomical quantity. Rather, the purpose was clearly to indicate two very important annual events, namely the equinoxes: the terminator cuts simultaneously only at the equinoxes each three intersection points. In Fig. 13 only two visible intersection points are seen because the third one is covered by the terminator on the horizon line. The individual points of these triplets are located along the three great circles; the distance from point to point amounts to one temporal hour at the equinoxes, i.e. one equinoctial hour.

The deviations vary as follows: along the horizon line they are mostly of a few percent, along the lower half circle they are partially in the \( \pm 10\% \) range, along the upper half circle they are unusually high, i.e. up to \( \pm 30\% \) near the meridian line. But this deficiency is not as significant as the fact that the stonemason has probably chiselled by mistake the upper and lower arcs mirror-imaged with respect to the horizon line; comparing Figs 3 and 13 makes this clear. In spite of this handicap it has been still possible to use at least the cross points along the horizon circle, but of course that was not really the intended use of system III.

Final Remarks

One may suggest that this unusual sundial seems to be overcomplicated with three nets of lines and a row of marking studs for indicating the time and season. But there are definitely plausible explanations for this ‘redundancy’. On one hand, systems I and II, as well as system III and the arrangement of marking studs, complement one another in an appropriate manner as described (see Figs 13 and 14).
And on the other hand, the terminator does not offer a sharp boundary line rich in contrast (especially with a hazy sky) and so two readings on different faces improve the evaluation of the relevant values sought.

On the whole, the ingenious concept of the Prosymna globe sundial, and the generally impressively small differences between calculated and measured values, demonstrate the high knowledge and skill of the designer as well as the stonemason who have together created this admirable rare specimen about two thousand years ago.

ACKNOWLEDGEMENTS

We have to thank Christos Piteros and the 4th Ephorate of Prehistoric and Classical Antiquities in Nafplion for allowing us to measure and photograph the globe dial and to publish our results; Klaus Hall (Berlin) for his help with the inscription; and Alexander Jones (New York) for his suggestions on the stigmata.

REFERENCES and NOTES

1. Introduction and description by Karlheinz Schaldach, review of the analysis results by Ortwin Feustel.
2. Nomography continued to be an important procedure in the art of gnomonics as we know from astrolabes, quadrants and the quadratum horarium generale of Regiomontanus, to mention only a few examples.
5. Strictly speaking they are the ends of the hours that are marked.

Sometimes it is claimed that F (digamma) stands for 6 in Greek, which is wrong as there is no example known for that and we have only the form similar to C or like that on the globe which was called stigma in Byzantine times.

6. O. Feustel: “The mathematical analysis of the globe sundial of Prosymna” is expected be published in September 2013 NASS Compendium.
7. Deviation is defined as the difference between a measured and a calculated value divided by the measured value (in percent).
8. \( \theta \) = angle that the \( z \)-axis makes with the direction of sight vector, \( \eta \) = angle that in a right-handed system the \( x \)-axis makes with the projection of the direction of sight vector onto the \( xy \) plane.

Karlheinz Schaldach’s ties with the BSS began in 1994 with a talk at the summer meeting on medieval sundials (abbreviated version in Bull, 96.3). Latterly, his interests turned to the Graeco-Roman sundials on which he has written articles and books. He began to write his first book on the Greek dials when he was lucky to stay in Greece for some years and to get support in his research work by Hermann Kienast, the former scientific director of the German Archaeological Institute in Athens, whose monograph on The Tower of the Winds with a contribution by Karlheinz will be published in the near future. His second book will represent sundials of the Greek islands, many not yet published, as well as the history of Greek gnomonics from its very beginnings until 500 AD. He can be contacted at info@antikesonnenuhren.de

For a biography and portrait of Ortwin Feustel see BSS Bull., 24(ii), (June 2012). He can be contacted at feustel_gnomonik@t-online.de