A New Look at the Astronomy and Geometry of Stonehenge

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Abstract. Recent authoritative work by Ruggles on whether there were significant astronomical and calendrical alignments built into Stonehenge in the third millennium BCE has concluded that the evidence for accurate alignments is minimal and that there is none for sophisticated astronomical practices, nor for any kind of calendar. Whether sophisticated geometry was used in designing the site is not discussed. I will review the relevant evidence – previously discussed by Hawkins, Thom and Atkinson – in the light of both Atkinson's accurate on-site surveys in 1978 and Hawkins' photogrammetric survey. It will be argued that these data allow us to infer that important lunar and solar alignments were built into the rectangular formation of the Station Stones, and into the main axis of the site. Moreover, geometrical constructions – and the use of at least one standard length unit – have been postulated for the Station Stones and the sarsen circle these ideas too are investigated. It seems that these two aspects of prehistoric intellectual skills – astronomy and the calendar, and geometry – are closely interwoven at this site, and that this emerging picture has broad implications for our understanding of Neolithic society.

This paper enquires whether Stonehenge – one of the most famous prehistoric sacred sites in Europe – was built in a more sophisticated way, and for more sophisticated purposes, than those usually suggested in archaeological textbooks. Was it laid out according to advanced geometrical principles and with the aid of skilled surveying? Were sight lines built into it which pointed at the risings and settings of the sun and moon at important stages in their calendars? Or is it a primitive structure remarkable mainly for the size and weight of its component standing stones, their skilful dressing and shaping, and for the ingenuity and effort which must have been involved in raising them into their final positions?[1] These questions are seldom asked in modern British archaeology. A recent comprehensive review and analysis of all the archaeological work ever done at the site, prepared for English Heritage about fifteen years

1 R.J.C. Atkinson, *Stonehenge*, (Harmondsworth: Penguin, 1961).

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ago, says not a single word about the site's possible geometrical properties and astronomical capabilities, apart from some comments on the main axis of the site.[2] Indeed, so great was the authors' lack of interest in – perhaps lack of awareness of – the possibilities of studying Stonehenge from a geometrical and astronomical point of view that they appear to have had no knowledge of two very accurate plans of the site which have been made within the last thirty-five years.[3] Instead, they relied on the old Office of Works plan of 1919 as the basis for their new maps and plans.[4] By contrast, Chippindale's detailed assessment of the site deals fairly with its possibly more esoteric aspects.[5] Since this paper was written, reports on recent excavations at Stonehenge have been published, namely those of the Riverside Project (by Parker Pearson *et al.*) and Tim Darvill *et al.*, which have further revised the understanding of the sequence of developments at Stonehenge.[6] Further work should address the arguments in this paper in relation to the findings and interpretation of recent excavations.

The Astronomy of Stonehenge: Modern studies

Recent attempts to discover whether Stonehenge was designed to perform any astronomical functions really started in 1965 with the publication of *Stonehenge Decoded* by Gerald Hawkins – an English astronomer working in America. With the help of an early computer he claimed to have discovered many indications of rising and setting points of the sun

2 R.M. Cleal et al., *Stonehenge in its landscape* (London: English Heritage, 1995.

3 One is a ground survey by Alexander Thom now in the National Monuments Record in Edinburgh (L. Ferguson, 'A catalogue of the Alexander Thom archive held at the National Monuments Record of Scotland', in C.L.N. Ruggles (ed.), *Records in Stone: papers in memory of Alexander Thom* (Cambridge: Cambridge University Press,1988). The other is a photogrammetric plan, prepared from air photographs by Hunting Surveys for G.S. Hawkins in the early 1970s (G.S. Hawkins, *Beyond Stonehenge* (London: Harper & Row, 1973), Figure 3 in Appendix). The author does not know the whereabouts of the original.

4 This appears as a fold-out at the end of R.S. Newall's booklet *Stonehenge, Wiltshire* (London: HMSO, 1959).

5 C. Chippindale, *Stonehenge Complete* (London: Thames & Hudson, 1994).

6 Mike Parker Pearson and the Stonehenge Riverside Project, *Stonehenge-A New Understanding: Solving the Mysteries of the Greatest Stone Age Monument* (New York: The Experiment, LLC, 2011, 2013); Tim Darvill et al., 'Stonehenge remodelled', *Antiquity* 86 (334) (2012): pp. 1021-1040.

and moon at important times in the calendar. In other words, there were pairs of artificial features – standing stones, gaps between stones, stone holes and so on – which lined up quite convincingly on these solar and lunar events; the assumption was made that these had been deliberately arranged by the prehistoric designers and builders. The book was ill-received by a sceptical archaeological profession which was not accustomed to thinking about this aspect of the past.

Two years later Alexander Thom – a retired Scottish professor of engineering at Oxford –described the results of his accurate surveys of scores of standing stones and stone circles throughout Britain.[7] Thom found abundant evidence of deliberate solar and lunar alignments of the kind suggested by Hawkins, including many which were miles long and therefore potentially quite accurate. Stonehenge – architecturally our most elaborate stone circle – was not dealt with but was surveyed in the early 1970s and an analysis of its geometry and astronomy appeared in a later book.[8] Thom's work was new in several ways, not least because it seemed to show that sophisticated geometrical and astronomical knowledge could have been intertwined. This book, at least at first, was given a more respectful hearing than Hawkins'.[9]

The Stonehenge Sequence

The site (Figure 1) has a very long history which is usually divided into three main Phases (not shown in the drawings). In outline, and omitting some details, Phase 1 dates to around 3100 BCE and consists of the surrounding bank and ditch with the ring of Aubrey holes just inside the bank. The outlying Heel stone probably also belongs to this period and it will be argued later that the Station Stones do, as well. Phase II consisted of the addition of a number of timber settings but the most spectacular changes came in Phase III, when standing stones were erected on the site. At first – in Phase III.1 at about 2600 BCE – the settings were of bluestones brought from Wales and another major addition to the site at this time was the Avenue (Figure 2). This consists of two parallel ditches forming what looks like a straight ceremonial way running northeast from the site. The Heel stone stands alone on this roadway a few yards in front of the site, but the hole for a vanished companion stone has been found.

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7 A. Thom, *Megalithic Sites in Britain* (Oxford: Oxford University Press, 1967).

8 A. Thom and A.S. Thom, *Megalithic Remains in Britain and Brittany* (Oxford: Oxford University Press, 1978).

9 R.J.C. Atkinson, Review of A.Thom, *Megalithic Sites in Britain* in *Antiquity*, Vol. 52 (1968), pp. 77-78.

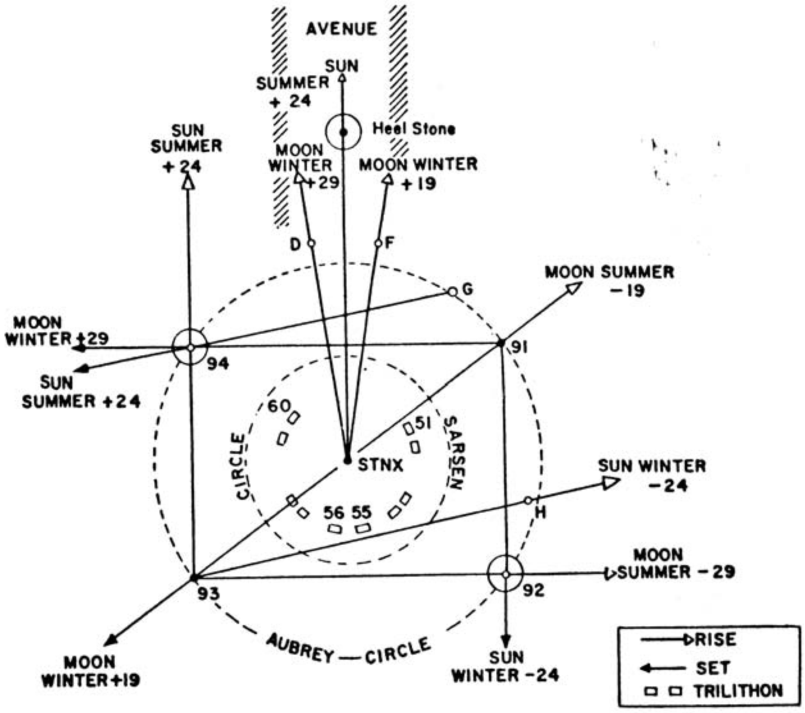

Fig. 1. Schematic plan of Stonehenge

Figure 1: Plan of the astronomical alignments detected in Stonehenge by G.S. Hawkins, but omitting those using the archways in the Sarsen Circle. The figures next to the arrowheads represent the declination, or astronomical latitude, of the body concerned. The Station Stones 91, 92, 93 and 94 are marked and the lettered positions are various post-holes and stone-holes.

In Phase III.2 – dating from about 2600-2400 BCE – the huge sarsen stone structure which dominates the site today was put up. These included the outer lintelled ring and the inner horseshoe of five tall lintelled archways, or trilithons. These settings have a clear axis of symmetry which is aligned northeast to southwest on midsummer sunrise and, in the opposite direction, on midwinter sunset. The four sarsen standing stones known as the Station stones – which form a rectangle surrounding the sarsen circle – are usually assigned to this period but there is no definite evidence of their age.

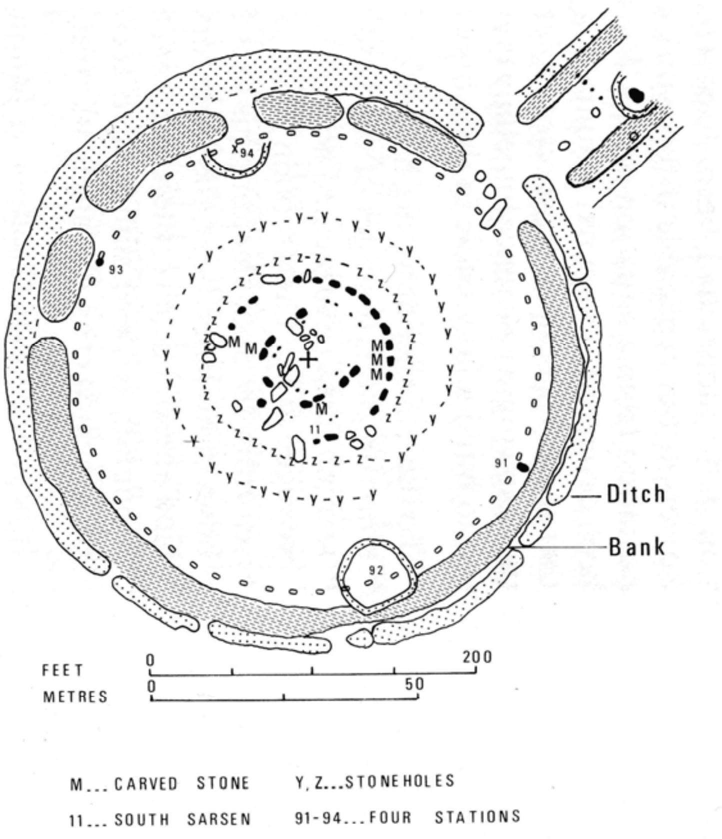

Figure 2: Plan of the main features of Stonehenge in Phases 1 – III[10]

Possible Prehistoric Astronomical Alignments

It has been known probably for centuries that the midsummer sun rises over the Heel stone when viewed from the centre of the sarsen circle; this is the best-known astronomical feature of Stonehenge. However Hawkins does seem to have been the first to point out in detail that, not only were there probably other solar alignments built into the site but, that moon alignments could also have played an important part in prehistoric astronomical practices there. His diagram (Figure 1) shows the most

[10] In H.A.W. Burl, *Stone Circles of the British Isles*, (New Haven: Yale University Press, 1979.

important of his supposed sight-lines; moonrises and moonsets were thought to be marked by the long and short sides of the Station Stone rectangle, and by several other artificial elements on the site, particularly the gaps between the stones of the sarsen circle as viewed from the centre of the site.[11]

What lunar and solar 'targets' might have been recorded by prehistoric Britons? The sun's rising position on the horizon fluctuates from northeast (midsummer) to southeast (midwinter) and back again once in a year; sunsets do the same of course, but from northwest to southwest and back again. The difficulty for naked eye observers is that, on either side of the extremes (the midsummer and midwinter solstices) the position changes extremely slowly for about a week; one of Thom's original ideas was that very long alignments (using notches on the horizon) could have pinpointed these, perhaps to the exact day.

More controversial is the possible existence in ancient times of a solar calendar based entirely on the sun's movements.[12] This was constructed by dividing the year beyond the natural split into halves which are created by the sun's rising position slowing down, stopping and reversing twice, at midsummer and midwinter. The difficulty in marking these subdivisions is that, between the solstices, the sun is moving along the horizon in one direction, so there are no natural clues to the dates of any subdivisions required; they have to be established by counting the days in the year and sub-dividing. Thus each half-year was divided into quarters of about 92 or 93 days (giving the equinoxes around March 21st and September 21st), and then into eighths – periods of 45 or 46 days. These give the four 'Quarter Day' dates halfway between the solstices and the equinoxes; it is particularly interesting that these four dates – around February 2nd, May 2nd, August 2nd and November 2nd – coincide closely with the four ancient Celtic festivals of Imbolc, Beltane, Lughnasadh and Samhain. There is some evidence from the standing stone alignments that the year was further divided into sixteenths, giving 'long weeks' of 21 or 22 days. Because the year is slightly less than 365.25 days long, these subdivisions cannot be exact numbers of days; the calendar alignments therefore tend to point at their average position on the horizon.

The position of moonrise (and moonset) also fluctuates along the same arc of the horizon as the sun, but much faster and over a monthly

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11 Hawkins, *Stonehenge Decoded*, Figure 14.

12 Thom, *Megalithic Sites*, chap. 9.

period; shorter alignment markers to keep track of it are therefore possible. However the lunar extremes themselves – better called 'standstills' than 'lunar solstices' – fluctuate on either side of the solstice positions over a period of 18.61 years, so the moon can sometimes rise monthly well *outside* the solar limits. It can go beyond midsummer sunrise position to the north, and correspondingly to the south of the midwinter position (the two major standstills); but 9.3 years later it will rise monthly well *inside* these solar limits (the two minor standstills) and will therefore be much lower in the sky. There are, therefore, two lunar standstills to mark instead of one, and a total of eight possible extreme lunar risings and settings instead of four for the sun. Hawkins believed that six of these moon positions were marked at Stonehenge, mainly by the Station Stones (Figure 1).

There is another very small fluctuation in these extreme positions, knowledge of which could have led to the prediction of eclipses and which is therefore highly controversial. It is not discussed here but new evidence bearing on the phenomenon is found elsewhere.[13] It is important to state at this point that no-one now claims that there are any accurate astronomical *alignments* at Stonehenge: that is, long sight-lines capable of pinpointing individual days in the year and therefore of practical use in time-keeping. The horizon is too close for that and lacks suitable notches and peaks. Any plausible indicated lines would be *orientations*: pairs of artificial features which point at the rising or setting of celestial objects on days already known. They would thus have been a *record of existing knowledge* rather than observing instruments trying to establish something new.

Another general comment needs to be made. The author now believes that the evidence favours a working hypothesis which argues that prehistoric British astronomical practices were intimately bound up with the geometric and metrological knowledge of the time, to such an extent that the two branches of knowledge are really inseparable. This is not a popular view. Alexander Thom's inferences about the geometry underlying stone circles, and his concept of the standard unit of length then used – the megalithic yard (MY) of 0.829m – have, if possible, been even more completely ignored than his astronomical inferences.

Clive Ruggles is one of our foremost authorities on British prehistoric astronomy and he finds no plausible astronomical lines at

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13 T. Gough, 'Precise Lunar Alignments: Real or Chance? New Data from Argyll' (paper presented at INSAP VII, Bath, UK, 25-28 October, 2010, Bath UK).

Stonehenge apart from the well-known phenomenon of the main axis being directed towards midsummer sunrise and midwinter sunset.[14] Alignments towards the equinoxes – those dates in the spring and autumn which are halfway between midwinter and midsummer – are ruled out as improbable *a priori* and no other possibilities are discussed.[15] He accepts that elements of the architecture of the sarsen circle and trilithons were almost certainly orientated on the midsummer sunrise. The foam reconstruction of the same view (made for a TV programme) shows well how the pair of outlying stones – the Heel stone and its vanished companion – framed the first appearance of the sun on June 21st early in the third millennium BCE.[16]

Ruggles argues that midwinter was also important at Stonehenge and 'Foamhenge' again showed clearly how.[17] When looking into the centre of the site *from* a specific point to the north-east, the setting midwinter sun would have shone through the small space between the underside of the lintel of the central and tallest trilithon and the tops of the lintels of the sarsen circle below and beyond it. However, no other lunar or solar sight lines are discussed and – except for an expressed scepticism that the five trilithons were laid out round an ellipse (an idea of the Thoms) – the possibility that geometrical designs are incorporated in the site is not mentioned.[18]

Is it reasonable to dismiss by implication all these other design elements? Any evidence that sophisticated geometry underpins the design of the site surely needs to be addressed; if it did, we can be more confident that geometry and astronomy were intertwined, and that there may, therefore, be more astronomy in the site than Ruggles allows. The Station Stone rectangle is the key; here, if anywhere on the site, geometry and astronomy are combined at a high level.

14 C.L.N. Ruggles, 'Astronomy and Stonehenge', in B. Cunliffe and C. Renfrew (eds.), *Science and Stonehenge* (Oxford: The British Academy, 1997), pp. 203-30; C.L.N. Ruggles, 'Interpreting Solstitial alignments in Late Neolithic Wessex', *Archaeoastronomy*, Vol. 20 (2006), pp. 1-27.

15 Ruggles, 'Astronomy', p. 208.

16 Ruggles, 'Solstitial alignments', Figure 1b; W.M.F. Petrie and G.S. Hawkins, *Stonehenge: Plans, Description, and Theories with an update by Gerald S.Hawkins* (London: Histories and Mysteries of Man,1989), Figure on p. 65.

17 Ruggles, 'Solstitial alignments', Figure 3.

18 Thom and Thom, *Megalithic Remains*, Figure 11.5.

Stonehenge Geometry

Precisely drawn circles.

In the 1870s William M. Flinders Petrie was the first to survey the site with real accuracy and the first to discover that the inner, dressed faces of the sarsen ring form a true circle 97.33 ft in diameter (by 'true circle' is meant one laid out with a compass – probably a central peg, a rope attached to it and a marker peg at the chosen distance – the radius – from the first peg).[19] In the 1960s Richard Atkinson gave the same figure, though it is not clear if he had done his own survey or was quoting Petrie. Petrie realised that this length was very close to 100 'Roman' feet of 11.68 inches (0.296m); there are a number of examples carved in stone of this foot length – which was used in earlier times in Greece. These interesting metrological inferences have subsequently been largely overlooked, mainly because the use of standardised foot lengths seemed implausible in a British prehistoric context. However, the geometrical structure and astronomical capabilities of the sarsen circle are not discussed further here because these stones were not originally on the site. It seems more important to try to discover what the *original* builders were trying to do in geometrical and astronomical terms – or, indeed, if they were trying to do anything of the kind – when laying out the Phase 1 site. In other words, was the position and design of Phase 1 Stonehenge determined for such abstruse reasons as geometry and astronomy? If they were, our understanding of the site and its later history would be transformed.

Pythagorean triangles.

So far we have only talked about circles laid out on the ground accurately with a peg-and-string 'compass' and quite possibly (though not necessarily) with a radius (the length of the string) in whole numbers of some standard unit of length. Now, triangles have to be considered – particularly the triangles with one right-angled corner known as 'Pythagorean' after the ancient Greek philosopher who defined them. Pythagoras showed that – whatever the lengths of the sides – the sum of the squares on the two shorter sides of a right-angled triangle is equal to the square on the longest side – the hypotenuse. There are a few right-angled triangles in which the three sides feature whole numbers of any length unit –

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19 W.M.F. Petrie, *Stonehenge: Plans, Description, and Theories* (London: Edward Standard, 1880), p. 23.

the so-called ‘perfect’ Pythagorean triangles – and these seem to have been of particular interest to the stone circle builders. The best-known of these is the one with sides in the proportion of 3, 4 and 5 but the most important one in the present context has sides in the ratio of 5, 12 and 13.[20]

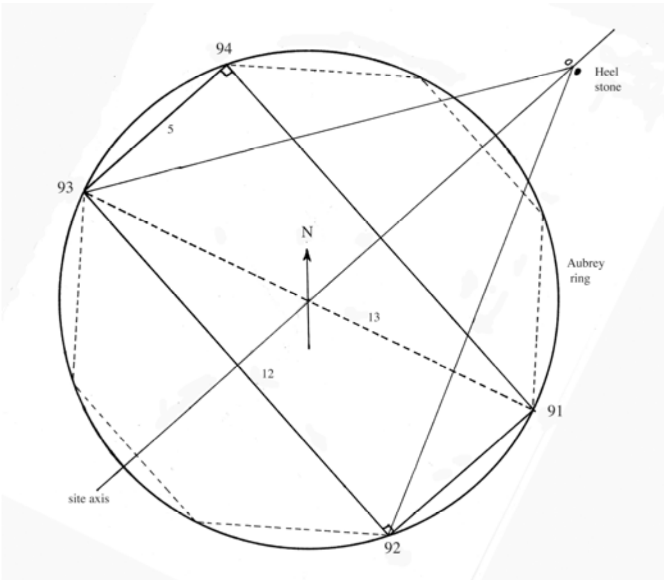

Figure 3: Possible geometrical principles underlying Stonehenge I (which is assumed here to include the four Station Stones and the Heel stone as well as the Aubrey holes). The 5:12:13 Pythagorean triangle fits exactly eight times into the Aubrey hole circle. It is also a fundamental part of the Station Stone rectangle itself and of Aubrey circle construction; another 5:12:13 triangle seems to connect the Heel stone to the site axis and to one long side of the Rectangle.

When considering the geometry of the Station Stones and the Aubrey Holes at Stonehenge one simple geometrical fact has to be taken into account (Figure 3). If the diameter of a circle is taken to be the longest side of a triangle, then any two lines drawn from its ends to a point on the circumference will make a right angle – a

20 The reader can check the correctness of Pythagoras’ theorem by confirming that 9 + 16 = 25 and that 25 + 144 = 169.

Pythagorean triangle, in fact. If the diameter of the circle is 13 units long, then lines of 12 and 5 units can be drawn to a point on the circumference. Of course the other 'perfect' Pythagorean triangles can also be drawn within a circle, and with their corners touching it; but the 5:12:13 triangle has an additional unique property. Its shortest side (5 units) will fit exactly eight times round the circumference, so that eight, non-overlapping such triangles form an octagon (Figure 3). This remarkable geometrical fact could provide a key to understanding the origins of Stonehenge.

The geometry of the Aubrey holes

The ring of Aubrey holes is just within the bank (Figure 2) and some seem originally to have held wooden posts (or even bluestones according to some recent evidence). This feature is firmly dated to Phase 1 of Stonehenge – at about 3100 BCE – and it was carefully surveyed by Richard Atkinson and Alexander Thom in 1973.[21] The centres of the 56 holes mark a circle with a radius of 140.8 feet, or 42.92m. [22] So the circle on which the pits were to be placed was very probably marked out on the turf first with a peg-and-cord 'compass'. It has been observed that Aubrey Holes 56, 7 and 28, and every other similar set of three, also form Pythagorean triangles with sides in the proportion of 5, 12 and 13, and with the hypotenuse as the diameter.[23] As we saw, only a multiple of 8 holes will show this property of the design and, 56 being 7 times 8, this may be one of than additional reason for there being 56 Aubrey holes. It is evident that the Aubrey circle was designed by people who knew about the peculiar properties of the 5:12:13 Pythagorean triangle in relation to a

21 Thom and Thom, *Megalithic Remains*, p. 146.

22 The standard deviation is ± 0.08 feet, or 0.96 inches. This means that there are 68 chances in a hundred that the circle as laid out by the prehistoric designers had a radius within 1 inch on either side of the calculated one, and about 96 chances in a hundred – almost a certainty – that the original radius was within two inches (actually 1.92 inches) of the calculated one.

23 In 1971 the author received a letter from the late R.S. Newall, in response to an enquiry about his 1959 booklet on Stonehenge which pointed this out. He also mentioned in it (several years before Dibble's 1976 Note) that the Station Stone rectangle is composed of two triangles of similar proportions, that stones 92, 93 and the Heel stone also form two similar, larger triangles and that the Heel stone stands at the mean of the two winter extremes of moonset (see J.H. Robinson, 'Sunrise and Moonrise at Stonehenge', *Nature*, Vol. 225, No. 5239 (March 1970): pp. 1236-37).

circle, described above. Perhaps the positions of the pits were laid out by placing every seventh one on the angles of the octagon described earlier and then interpolating the rest.

The geometry of the Station Stone rectangle

As was mentioned earlier this rectangle of once-standing sarsen stones (two of which have vanished) formed a vital element in Hawkins' hypotheses about the astronomical orientations built into Stonehenge (the stones are numbered 91, 92, 93 and 94 – Figure 4). He claimed that the long sides marked the rising and setting positions of the moon at the major standstill and that the diagonal of 91/93 marked those at the minor standstill. This claim dramatically increases the sophistication of the astronomical knowledge assumed for the designers of the site. Unfortunately there is no direct evidence for the place of the Rectangle within the site sequence, or any independent evidence for its age from radiocarbon dates. However, it probably predates the sarsen stone settings of Phase 3 because it would have been hard to set out accurately with the sarsen stones in position. One could also assume it to be of earlier construction because the two surviving stones are not dressed or shaped in any way: like the Heel stone but unlike most of the others in the sarsen settings of Phase III. Although it is usually assigned to Phase III.1 this timing is accepted as uncertain.[24] It will be argued here that the Station Stone Rectangle was established as a geometrical figure in Phase 1, though the four stones may have replaced original posts at a later date.

The geometry of the Station Stone Rectangle and of the circle of Aubrey pits were surely interlinked (Figure 3). If the rectangle itself is a genuine 'perfect' Pythagorean triangle then the sides must have been measured out using a standard unit of length; such triangles do not come about by accident. This unit could have been the 'megalithic yard' (MY) – a standardised unit of 0.829m (2.72 ft) derived statistically by Thom from his analyses of the geometry underlying scores of stone circles throughout Britain. In this case – as Table 1 in the Appendix shows – the sides of the two 5:12:13 triangles are very close to 40, 96 and 104 MY respectively. Likewise the diameter of the Aubrey circle – independently assessed – is also close to 104 MY; the Station Stones and sockets fall almost exactly on the circumference of that circle, the diameter of which must therefore be the same as the diagonals of the Rectangle. It does look

24 Cleal *et al.*, *Stonehenge landscape*, p. 378.

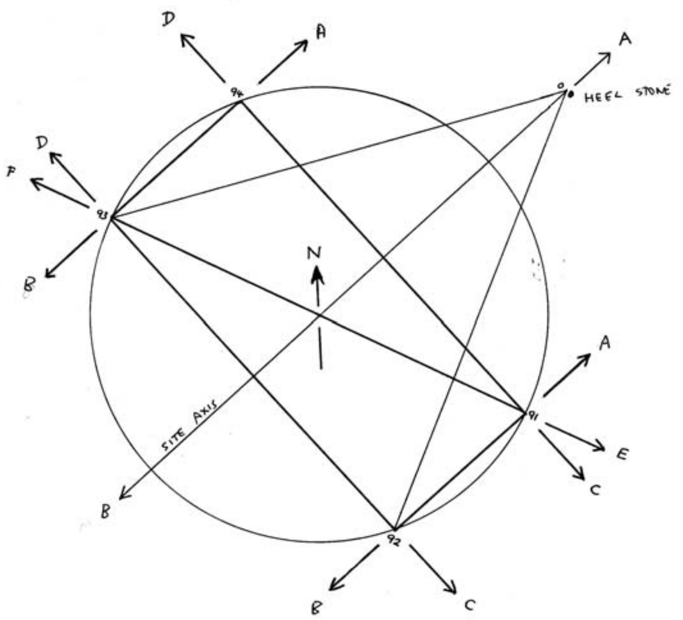

Figure 4: the astronomical capabilities of the geometrical figure formed by the Station Stone rectangle and the Aubrey Holes at the latitude of Stonehenge. 'A' = midsummer sunrise, 'B' = midwinter sunset, 'C' = minor standstill moonrise, 'D' = major standstill moonset, 'E' = Quarter Day sunrises on Feb 2nd and Nov. 2nd, and 'F' = Quarter Day sunsets on May 2nd and August 2nd.

as if the Aubrey circle and the Station Stone Rectangle were set out as a single geometrical construction, and this must have been in Phase 1, at the beginning of the site's history.

A few years ago Stonehenge was re-examined by Ranieri for possible geometrical qualities using the most accurate available plans in the English Heritage report.[25] Two of the several new inferences made are of particular interest to this essay. The first is one result of a statistical analysis of the various measurements collected, which showed that a unit

25 M. Ranieri, 'Geometry at Stonehenge', *Archaeoastronomy*, Vol. 17 (2002-03): pp. 81-93.

of length of 0.665m – or two of these making 1.33m – could have been used. Ranieri thought this was probably of little general importance but was evidently unaware that these lengths are multiples of the Drusian or ‘Northern’ foot of 0.333m which survived in England into Saxon times when it was used in the dimensions of some religious buildings.[26] It is intriguing that this unit fits the ‘ideal’ dimensions of the Station Stone Rectangle slightly better than does the megalithic yard (see Table in Appendix). The sides of the Station Stones triangle then become 100, 240 and 260 Drusian feet.

The second new inference was that the point on the main axis of the site, where it passes through the gap between the Heel stone and its vanished companion on its northwest side, appears to be connected geometrically to the Station Stone Rectangle (Figure 3). If the line between stone 92 and 93 is regarded as the base of two opposed right-angled triangles – the upright sides of which are the site axis (Figure 3), and the apices of which are at the Heel stone point just mentioned – then these too are in the proportions of 5, 12 and 13. Here, however, the megalithic yard does not work (see Table in the Appendix) because two sides of the triangle have to be in fractions, namely 48, 115.2 and 124.8. In terms of the Drusian foot, however, they are 120, 288 and 312, which supports the idea that this was the unit of measure used in early Stonehenge. The large triangles form a huge arrowhead pointing to the northeast and surely reinforce the idea that the midsummer sunrise was the main item of astronomical interest to the builders in about 3100 BCE – at least in terms of something spectacularly visible to the population at large.

Stonehenge Astronomy

What was the point of all this elaborate geometry? The fact that the Rectangle is set out with its *short* sides parallel to the main site axis – towards midsummer sunrise and midwinter sunset – surely means that geometry and astronomy are intertwined here. The new rising positions indicated by the *long* sides still support Hawkins’ hypothesis that the moon at its ‘major standstill’ was being recorded (Figure 2) – rising

26 Such as the old minster at Winchester; see B. Kjolbye-Biddle, ‘The 7th century minster at Winchester interpreted’, in L.A.S. Butler and R.K. Morris (eds.), *The Anglo-Saxon church: papers on history, architecture and archaeology in honour of Dr. H.M. Taylor* (London: Council for British Archaeology Research Report 60, 1986), pp. 196-209).

position approximately in the southeast and setting in the northwest. [27] The two sides are not quite parallel; it may be that both the first appearance of the rising lunar disc and the point at which it ceased to touch the horizon were being marked separately.

However, thanks to Atkinson's latest survey we now have better information about the orientation of diagonal 93-91 and this no longer supports Hawkins's idea that it indicates the risings and settings of the moon at the 'minor standstill' (Figure 2). The diagonal 93 to 91 actually points slightly too far north for this rising moon but does indicate sunrise on two of the Quarter Days of the prehistoric solar calendar (Figure 5) – at the beginning of February and the beginning of November, respectively.[28] The opposite direction marks *sunset* on the other two Quarter Days, at the beginning of May and of August.

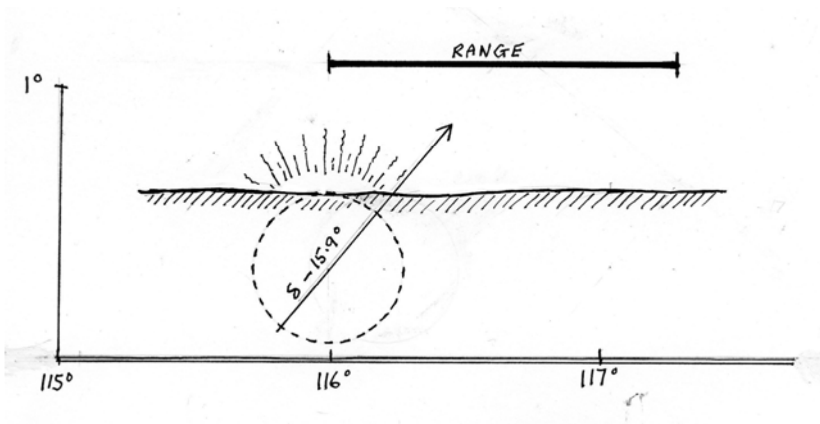

Figure 5: the Sun rising on the part of the SE horizon at Stonehenge indicated by the diagonal 93 to 91 of the Station Stone Rectangle. The 'range' is the span of horizon in which sunrises marking the two Quarter Days (early February and early November) can occur (Thom 1967, Figure 9.2).

27 Computed from Atkinson's new survey; see R.J.C. Atkinson, 'Some new measurements on Stonehenge', *Nature*, Vol. 275 (7 Sep 1978): pp. 50-2. The results are explained in more detail in E.W. MacKie, 'The prehistoric solar calendar: an out of fashion idea revisited with new evidence', *Time and Mind*, Vol. 2.1 (March 2009): pp. 9-46.

28 Thom, *Megalithic Sites*, Figure 5.1.

Thus the four basic 'eighths' of the year (halfway between the solstices and the equinoxes) were marked by the Rectangle; this strongly supports the reality of the prehistoric solar calendar, which has often been doubted. It also makes the marriage between geometry and astronomy in Phase 1 even more remarkable. Of course if the diagonal 93/91 was intended as a useful reminder of approaching Quarter Day dates, it must have been set up in either Phase 1 or 2. In Phase 3 the sarsen stone circles would have completely hidden stone 91 from 93.[29]

As noted earlier, the 56 Aubrey holes could simply be a result of the peculiar geometry of that circle, and of the way the 5:12:13 rectangle fits into it. However the number probably also has astronomical significance. As Hawkins pointed out many years ago it is close to three of the moon's 18.61 year standstill cycles, totalling 55.83 years.[30] In practical terms of whole years the cycles would have worked well with two of 19 and one of 18. With some of the standstills being recorded in the Station Stone Rectangle, this explanation for the number of Aubrey holes seems highly plausible.

Conclusions

We may summarise the facts and conclusions discussed and ask whether it is likely that they can be explained as coincidences. First there are the geometrical and astronomical facts:

- A right-angled triangle can always be formed on the diameter of a circle by straight lines running from each end to a point on the circumference.
- When a 5:12:13 rectangle – composed of two such triangles – is drawn in this way the short side fits exactly eight times along the circumference. Multiples of eight of these triangles can subdivide the circle exactly.
- This is the only one of the 'perfect' Pythagorean triangles which has this property.
- The Aubrey circle has 56 holes, a multiple of eight, and three cycles of the moon from one major standstill to the next take 55.83 years. Two cycles of nineteen years and one of eighteen (total 56) will keep track of this lunar cycle for many years.

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29 Cleal *et al*., *Stonehenge*, Plan 1 at the back.
30 Hawkins, *Stonehenge Decoded*, 140ff.

- The Station Stone Rectangle (with proportions of 5 and 12) has its corners almost exactly on the Aubrey ring.
- At the latitude of Stonehenge (51.18° N) the long sides of the Station Stone Rectangle can be made to point at the minor standstill moonrise in one direction and at the major standstill moonset in the other.
- In this case the short sides simultaneously point at midsummer sunrise in the northeast and midwinter sunset in the southwest.
- The diagonal 93/91 also points simultaneously to sunrise on the two Quarter Days – in early February and early November – and to sunset on the other two – in early May and early August.
- Only over a fairly narrow band of latitudes about 100km wide would the lunar standstills and the solstitial suns rise and set at right angles to one another; this suggests that the site could have been chosen for astronomical reasons. If the right-angle mentioned is defined by a rectangle with sides in the proportion of 5 and 12 instead of any old rectangle, one diagonal will also point at Quarter Day sunrises and sunsets. It may be that the range of latitudes where all three of these phenomena are possible is even narrower.
- All these points strongly imply that Phase 1 of Stonehenge included the geometrical construction shown in Figure 3 and that the Station Stones as well as the Heel stone and its vanished companion were all part of it. This implies that 5000 years ago understanding of the solar calendar and the intricate movements of the moon over its 18.61-year cycle were already well understood and that the new circular site on Salisbury plan was designed to record this basic data in an ingenious design based on Pythagorean triangles.

To us geometry is simply a branch of mathematics; but to the priests and wise men of Wiltshire in the late fourth millennium BCE these geometrical and metrological discoveries must surely have seemed like an amazing insight into the nature of the universe and into the minds of their gods. Perhaps, and because these remarkable phenomena only took place there, the latitude of Stonehenge at 51.18° N was a sacred one, and that is why the famous site was placed there. Something similar seems to have been found at the ancient site at Ringlemere in Kent on the same latitude, and the remarkable bronze and gold Nebra 'sky disc' was found on a ceremonial top of the Mittelberg at almost exactly the same latitude in eastern Germany.[31] No geometry has yet been found on the Mittelberg but conspicuous distant mountains visible from the hilltop mark the summer solstice sunset, and also sunset on the Quarter Days of May Day (local Walpürgisnacht) and inevitably also at the harvest festival, Lammas or Lunasda in the Anglo-Saxon and Celtic traditions. Perhaps we may expect more significant Neolithic ritual sites to be found on this latitude, preferably also with some indication of the importance of the 5:12:13 Pythagorean triangle.

31 E. MacKie, 'Prehistoric solar calendar', Figure 14; Hammond, John, 'Gold Cups and Ring Ditches: Cosmology, Astronomy and Sacred Geometry at the Time of Stonehenge' (paper presented at the INSAPVII conference, Bath, October 2010).

APPENDIX

This Table compares the surveyed distances at Stonehenge with their 'ideal' equivalents in megalithic yards of 0.829m and in Drusian feet of 0.333m, assuming that the suggested Pythagorean geometry is correct.[32] In almost every case the Drusian foot is closer to the actual measurements on the ground.

	metres	*Meg Yards* (.829m)	*Drusian ft* (0.333m)	*Meg. Rods* (2.5 MY or 6.80m)
Aubrey Holes				
Diameter (Thom)	86.44	**104** (86.22m)	**260** (86.58m)	--
do. (Hawkins)	86.87	**104** (86.22m)	**260** (86.58m)	
Circumf. (Thom)	271.56	-	-	**131** (271.50m)
do. (Hawkins)	272.90	-	-	**131** (271.50m)
Station Stones				
91-92 (Atkinson)	34.17	**40** (33.16m)	**100** (33.30m)	-
93-94 (Atkinson)	32.70	**40** (33.16m)	**100** (33.30m)	-
do. (Ranieri)	33.23	**40** (33.16m)	**100** (33.30m)	-
92-93 (Atkinson)	79.93	**96** (79.58m)	**240** (79.92m)	-
do. (Ranieri)	79.78	**96** (79.58m)	**240** (79.92m)	-
91-94 (Atkinson)	80.26	**96** (79.58m)	**240** (79.92m)	-
do. (Ranieri)	79.75	**96** (79.58m)	**240** (79.92m)	-
Diagonals				
93-91 (Atkinson)	86.66	**104** (86.22m)	**260** (86.58m)	-
92-94 (Ranieri)	86.44	**104** (86.22m)	**260** (86.58m)	-
Larger triangle				
α to Heel (Ranieri)	95.97	**115.2** (95.50m)	**288** (95.90m)	-
93 to α (Ranieri)	39.89	**48** (39.79m)	**120** (39.96)	-
do. (Atkinson)	39.97	**48** (39.79m)	**120** (39.96)	-
				-
92 to Heel stone (Thom)	104.00	**124.8** (103.50m)	**312** (103.9m)	-
93 to Heel (Thom)	105.25	**124.8** (103.50m)	**312** (103.9m)	-

32 Under 'Larger triangle' α is the mid-point between stones 92 and 93 and marks the two '5' sides of the pair of 5:12:13 right-angled triangles based on Stones 92 and 93 and with their apices at the Heel stone. The dimensions marked 'Thom' are measured from the 1:250 general plan, no. DC 4708/c in the National Monuments Record in Edinburgh (Ferguson 1988, p. 53); those marked 'Hawkins' are from his photogrammetric plan (Hawkins 1973, p. 59, Pl. 15: 1989, p. 52 and map at end).