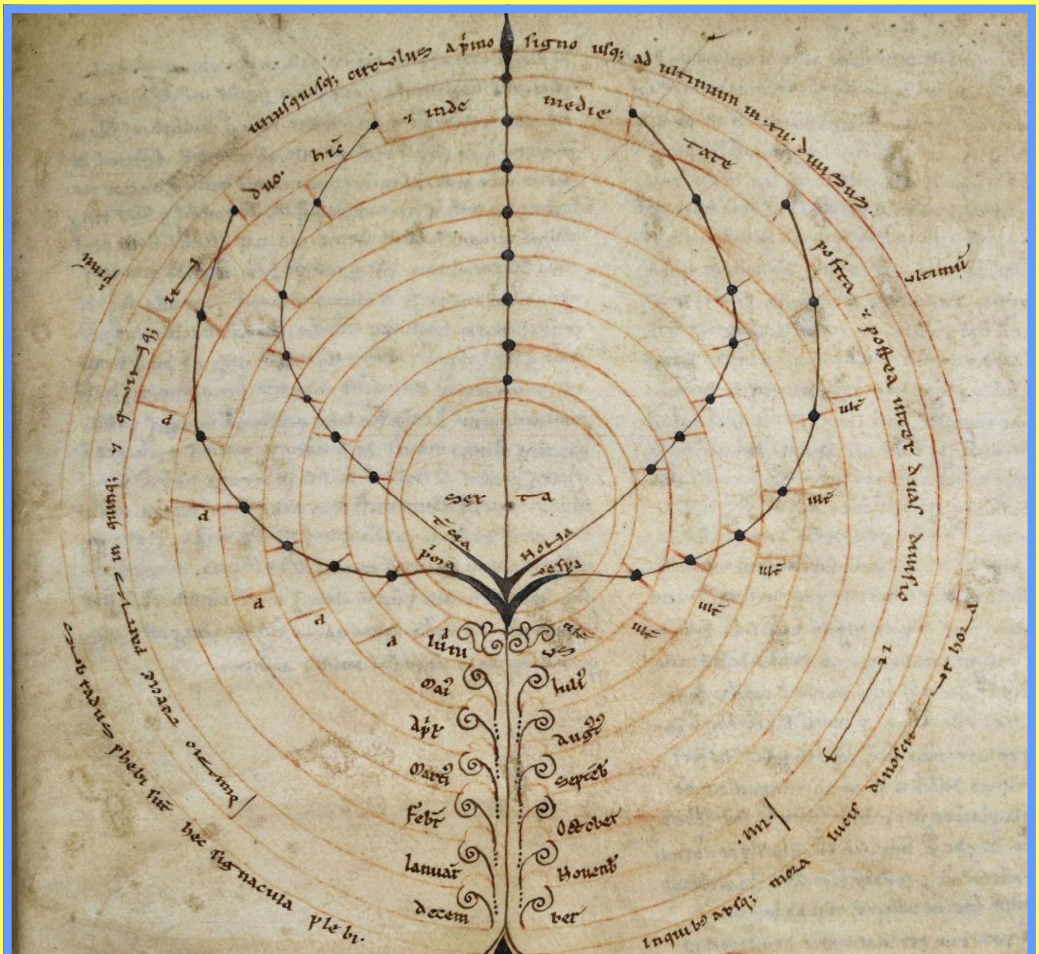
DE CURSU SOLIS

MEDIEVAL AZIMUTHAL SUNDIALS

From the primitive idea to the first structured prototype

Mario Arnaldi



The British Sundial Society

BSS Monograph No. 10

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FOREWORD

More than 15 years ago, when I pointed out in an article that azimuthal sundials were already known by the medieval period, I did not anticipate that I would later be asked to write a foreword for a whole book about that fascinating subject. I have accepted that request with pleasure.

On the one hand, books on medieval sundials are rare. We know almost nothing of how people then thought of sundials and how the instruments were formed and developed. We know some of the people who promoted them, such as Bede Venerabilis ('the venerable Bede') or Hermannus Contractus [Hermann the Lame], but our further knowledge is rather meagre.

On the other hand, Mario Arnaldi became a friend of mine after Edward Martin brought us together in 1994, and I got to know him, the 'scientific artist', and his amiable family personally on a trip to Ravenna in the following year. I discovered a man with an idea – to find more about medieval dials than was currently known, and who was ready to devote his leisure time to that. It is the strong desire to do everything very well which distinguishes him and which is necessary, in the arts as well as in the sciences, to achieve high performance.

The present study is not limited to a simple description of the existing knowledge; it is always the overall picture that Mario has in mind. This is why his work begins with Greek and Roman antiquity and he shows the line which probably has led to the azimuth sundial. The suddenness of its appearance suggests an introduction from outside. In principle, for any sundial, we should always look for an oriental influence, because the Arabic Middle Ages were a high time for gnomonics, in contrast to Latin Europe of the time. But it seems that the azimuthal sundial is a pure invention of the Latin West and was further developed there.

It is true that we have only some scraps of information for this period but Mario shows to us that it is worth assembling them together in a mosaic that gives us more than we had before. Such groundwork is an important eye-opener for the great tradition not only of gnomonics, but for every scientific achievement.

This monograph is valuable to the expert for identifying familiar tools, such as the questions of change and continuity that have been investigated, or the need for a philological scope, because the actual artefacts from the Middle Ages are lost.

It is also valuable to the layman interested in history because it brings material which is new and exciting and which improves our picture of science in the medieval world. But it may also be read independently of time and content because it shows, by an example, the process of thinking and the methods which help to develop new ideas.

Karlheinz Schaldach
Schlüchtern, Germany
October 2012

Introduction and Acknowledgements

For many years I have followed the researches of scholars on this subject. Now, a newly discovered manuscript found in the University Library of Darmstadt (Hessen, Germany) together with consulting other unpublished documents, allows me, finally, to write this monograph. I am indebted to my friend and colleague Karlheinz Schaldach and to John Davis (editor of this monograph) for their great help and encouragement so that today I can write a complete study of this particular subject.

I must also thank the management of the University Library of Darmstadt for allowing me to see the manuscript and for giving permission to make the first publication of the text. John Davis is thanked for obtaining the copies of manuscripts from the British Library, the Paris Bibliothèque National and the Montpellier Bibliothèque Interuniversitaire on which I have made my recent studies. I must also thank him for his work correcting my English and laying out the monograph.

Prof Antonio Saiani of Bologna University and Dr Stefano Pagliaroli of Messina University made useful suggestions and Dr Arianna Borrelli of Wuppertal University, Germany, provided a constructive discussion. I am also grateful to my friend Alessandro Gunella for his help with producing more accurate translations of the Latin texts. Many thanks are due to Andrew James for his careful review of the draft monograph.

I would like to thank all the Libraries and Universities that so kindly let me read their manuscripts or simply supplied copies of them for study. First of all I need to thank the British Library in London for supplying a high-definition colour copy of the manuscript ‘Old Royal 15 B IX’ and giving permission for publishing it on the cover of this monograph. Then I have to thank the University Library of Darmstadt, Germany (Landesbibliothek), the Badische Landesbibliothek of Karlsruhe, Germany, and the Goethe-Universität in Frankfurt am Main, Germany for allowing me to read the text in their manuscripts and to publish them. I also have to thank the Bibliothèque National de France in Paris for supplying copy of mss BnF lat. 7412 and BnF lat. 12117, and Montpellier's Bibliothèque Interuniversitaire, Section de Médicine, for providing a very good copy of Ms. Montpellier, H48. I also should thank the Director of the Herzog August Bibliothek of Wolfenbüttel for letting me publish Fig. 7.

CHAPTER ONE

Beginnings

The first image that comes to mind when we speak about medieval sundials is a vertical semicircle with some radiating lines on it. It is difficult to think of something different, but...

The author lists some medieval manuscripts with instructions for making azimuthal sundials.[1]

Writing today about European azimuthal sundials in the Middle Ages, they look most simplistic or, at least, strange. When we consider medieval gnomonics, we immediately think of a semicircular (or circular) shaped dial showing Canonical or temporal hours, such as the ones that we see on the walls of ancient Romanesque churches. We overlook that in those centuries there existed other kinds of sundials, quite different from the so called 'mass dial'.

The famous 'Canterbury pendant', for instance, was not an isolated example, and the portable cylinder dial (pillar or shepherd's dial) was known since ancient Roman times.[2] Also well known in the Middle Ages were the horary quadrant and the 'schemes' of the shadows (also known as *horologium viatorum*), but we should not forget the universal rectilinear dial which became known thanks to Regiomontanus, or the *Navicula de Venetiis* known in 14th-century England but probably of more ancient origin.[3]

Primitive horizontal sundials were probably the first kind of dial known to our ancestors. Putting a vertical stick in the level ground was the easiest way to see the shadow move around it. This phenomena surely gave the idea of time passing and, consequently, of its reckoning. Tracing a circle around the stick and dividing it into equal parts suddenly generates an approximate time reckoner (see Fig. 1). It was a great idea!

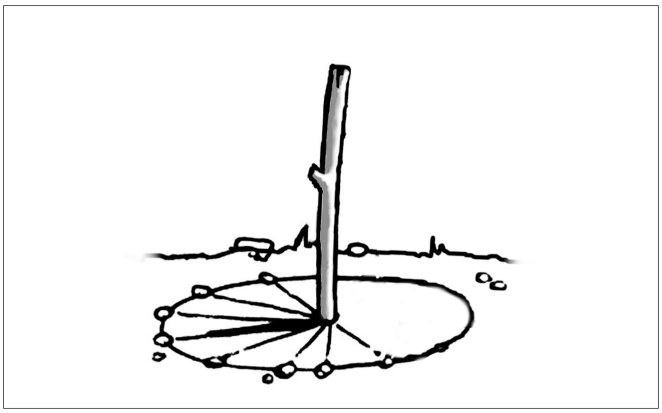

Fig. 1. A vertical stick showing the shadow.

The Greek and Roman Period

Diogenes Laertius (3rd century AD) wrote that Anaximander of Milesius (c. 610 BC – c. 546 BC) was the first to invent the gnomon and this instrument showed the solstices and equinoxes.[4] But it is more credible that he was simply the first to bring the gnomon to Greece from Chaldea where, as Herodotus (5th century BC) wrote, it seems it was already known.[5]

It is not easy to know what kind of instrument Anaximander's 'gnomon' was: it seems that it was not a real sundial but a simple vertical stick erected on a circular plane. Its shadow thus showed the azimuthal directions on a scale of the cardinal points and the solstitial and equinoxtial directions on the horizon.

A similar instrument can also be found in Roman times. Vitruvius (1st century BC), in his book *De Architectura* (i, 6, 5–7), describes a graphic device to find the winds starting from the well-known method for setting out the true North-South direction (today improperly known as 'Hindu circles').

The Roman architect suggests the use of a gnomon[6] (Fig. 2) in the construction of buildings and streets, so that they

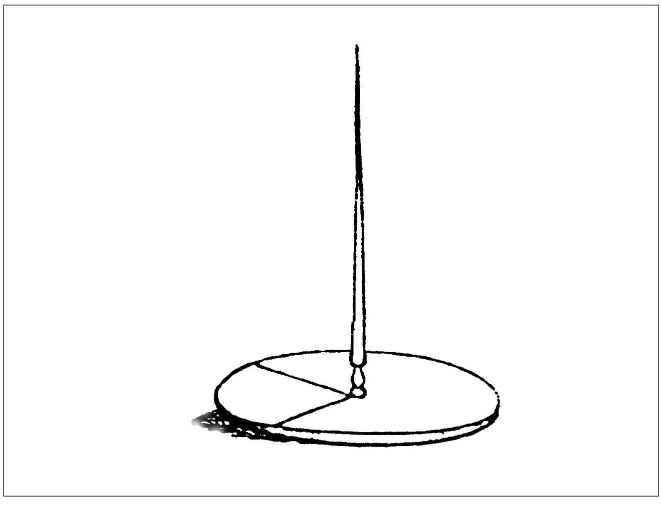

Fig. 2. The Roman gnomon (from 'Dictionnaire des Antiquités Grecques et Romaines').

could be always oriented to the best wind, and he describes it thus:

> "[Given the number of the winds], to find and lay down their situation we proceed as follows: let a marble slab be fixed level in the centre of the space enclosed by the village walls, or let the ground be smoothed and levelled, so that the slab may not be necessary. In the centre of this plane, for the purpose of marking the shadow correctly, a bronze gnomon must be erected (the Greeks called this gnomon σκιαθήρας). The shadow cast by the gnomon is to be marked at about the fifth hour, and the extreme point of the shadow accurately determined. From the central point of the space where the gnomon stands, describe a circle with the radius equal to the length of the shadow just observed. After the sun has passed the meridian, watch the shadow which the gnomon continues to cast till the moment when its extremity again touches the circle just described.
>
> From the two points thus obtained, describe two arcs intersecting each other, and through their intersections, and the centre of the circle, draw a line to its extremity: this line will indicate the north and south points. One-sixteenth part of the circumference of the whole circle is to be set out to the right and left of the north and south points, and drawing lines from the points thus obtained to the centre of the circle, we have one-eighth part of the circumference for the region of the north, and another eighth part for the region of the south. Divide the remainders of the circumference on each side into three equal parts, and the divisions or regions of the eight winds will be then obtained: then let the directions of the streets and lanes be determined by the tendency of the lines which separate the different regions of the winds."[7]

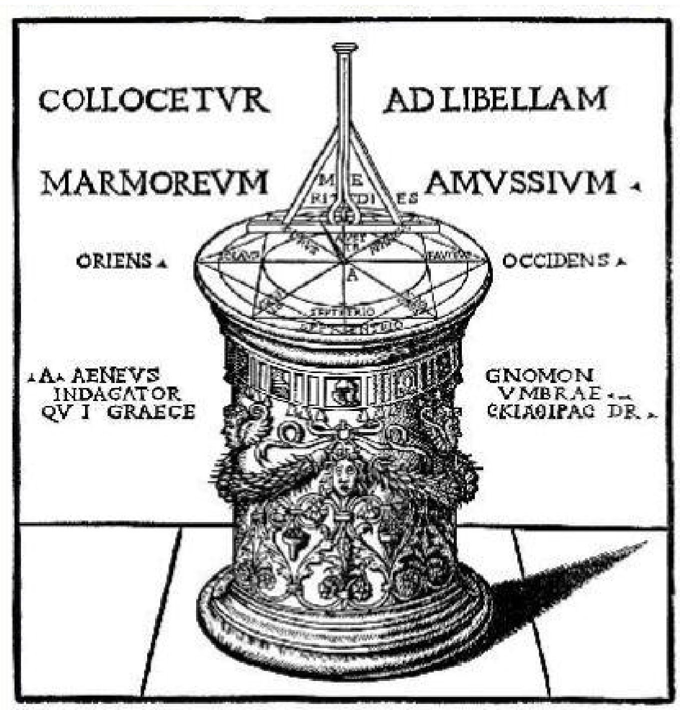

Fig. 3. The gnomon 'indagator umbrae' illustrated in Book I, ch. 6, p. 25v of Vitruvius's 'De Architectura', edited by Cesare Cesariano (1521).

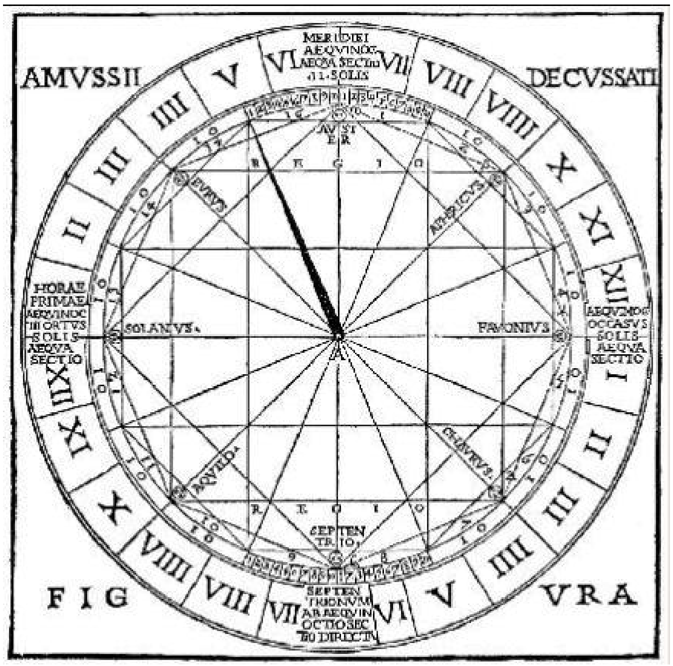

Fig. 4. The diagram of the windrose as illustrated in Book I, ch. 6, p. 25r of Vitruvius's 'De Architectura', edited by Cesare Cesariano (1521).

The resulting diagram from this description illustrates a wind rose but at the same time a compass-like table of the geographical cardinal points showing equinoctial sunrise and sunset, noon and midnight (Fig. 3).

Even today one can see evidence of these diagrams inside museums,[8] ancient buildings[9] and urban developments. Sharon Gibbs, for example, recalls the one along the *Decumanus Maximus* in Ostia Antica, Rome,[10] and Milutin Tadić the one in Ohrid, Macedonia (Fig. 5).[11]

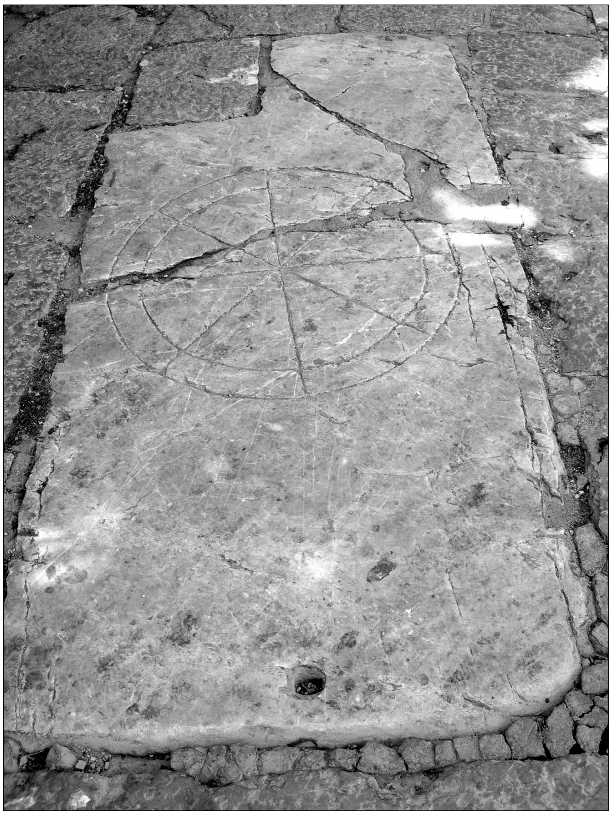

Fig. 5. Ohrid (Macedonia). Diagram.

Pliny (1st century AD) describes the same diagram, but not in an architectural context. He uses it for rural activities. His construction is more empirical than the one illustrated by Vitruvius. Pliny uses the body of the farmer as a gnomon and his shadow as the indicator. He suggests tracing the graphic directly on the ground or on a wooden tablet.

The observer must stand facing North with the sunrise point to his right. When the length of his shadow is at its shortest then it will be midday. At that moment the line traced in that direction will be the North-South line (the meridian, Latin *cardo*). The farmer then should dig a furrow on that line 20 feet long, and divide it in two, finding the centre for tracing a little circle called the '*umbilicus*'. After drawing the perpendicular to the North-South line (*decumanus*), the farmer must draw two other perpendicular furrows which will cross the *umbilicus*, dividing the whole space into 8 equal parts. Pliny states that the *decumanus* is aligned exactly to the equinoctial sunrise and sunset points, while these points move towards North and South in the other months of the year, reaching the diagonal lines at the two solstices.[12]

The purpose of this is to arrange the cultivation of the field most suited to the prevailing winds. Time measurement is not involved, or at least only marginally, but we will see later that the wind rose used in architectural and farm work is most probably the basic drawing for azimuthal medieval sundials.[13]

REFERENCES & NOTES

1. This study has previously been published in three articles written in Italian in *Gnomonica Italiana* (GI), in 2008–2009 and now translated here with some improvements and corrections; see Arnaldi (2008a), Arnaldi (2008b), Arnaldi (2009).
2. Arnaldi : Schaldach (1997).
3. King (2004).
4. Diogenes Laertius: *Lives and Opinions of Eminent Philosophers*, II, 2.
5. Herodotus II, 109.
6. For the original meaning of the word 'gnomon' and its shape, see Gandz (1930–1931): see also *Dictionnaire des antiquiés grecques et romaines*, *s.v.* horologium, p. 256; "*le gnomon consiste essentiallement en une pointe ou stile* (*στοιχειον*) *dressé verticalementsur un plan horizontal. Avec cette appareil, ils* [the ancients] *firent leurs premières observations astronomiques: ils déterminerènt le midi vrai (ombre minima ou maxima de l'année). Plus tard ils arrivèrent à connaître, par la même méthode, les équinoxes, l'obliquité de l'écliptique, et la hauteur du pôle (latitude) pour un lieu déterminé.*"
7. "*Conlocetur ad libellam marmoreum amussium mediis moenibus, aut locus ita expoliatur ad regulam et libellam ut amussium non desideretur, supraque eius loci centrum medium conlocetur aeneus gnomon indagator umbrae, qui graece σκιαθήρας dicitur. Huius antemeridiana circiter hora quinta sumenda est extrema gnomonis umbra et puncto signanda, deinde circino diducto ad punctum quod est gnomonis umbrae longitudinis signum, ex eo a centro circumagenda linea rotundationis. Itemque observanda postmeridiana istius gnomonis crescens umbra, et cum tetigerit circinationis lineam et fecerit parem antemeridianae umbrae postmeridianam, signanda puncto. Ex his duobus signis circino decussatim describendum, et per decussationem et medium centrum linea perducenda ad extremum, ut habeatur meridiana et septentrionalis regio. tum postea sumenda est sexta decima pars circinationis lineae totius rotundationis, centrumque conlocandum in meridiana linea qua tangit circinationem, et signandum dextra ac sinistra in circinatione et meridiana et septentrionali parte. tunc ex signis his quattuor per centrum medium decussatim lineae ab extremis ad extremas circinationes perducendae. Ita austri et septentrionis habebitur octavae partis designatio. Reliquae partes dextra tres ac sinistra tres aequales his distribuendae sunt in tota rotundatione, ut aequales divisiones octo ventorum designatae sint in descriptione. Tum per angulos inter duas ventorum regiones et platearum et angiportorum videntur debere dirigi descriptiones.*"; M. Vitruvius Pollio, *De Architectura libri x,* I, 6, 5–7.
8. Inside the civic museum of Ugento in Puglia, Italy, is a circular calcareous stone with the same diagram and retaining the stub of an iron gnomon in its centre.
9. We find the same drawing on the walls and paving stones of many Romenesque churches.
10. Gibbs (1976), p. 84 and plate 1 at p. 128; Gibbs, though, does not think this slab is related to sundials or astronomy, she thinks it is a gaming-board.
11. Tadić (2002), p. 12.
12. Plinius, *Nat. Hist.*, XVIII, 326–333ss.
13. See the *magnum opus* of Obrist (1997).

CHAPTER TWO

The First Directional Diagrams

The Medieval Period

One often reads that the Venerable Bede was for some reason interested in sundials, but in reality, even if he cites them frequently in his books, it is rare to find a description by him. When Bede writes about *horologia* usually the sentence is related to dates instead of the hours of the day. In the 30th chapter of his *De temporum ratione* he speaks of the Spring Equinox and he writes that it occurs on a precise date that is not, as the old tradition dictates, at *octavo calendarum Aprilium* (8 days to the Calends of April = 25th of March) but at *duodecimo calendarum Aprilium* (12 days to the Calends of April = 21st of March). And this date is not only known by the authority of the Fathers, but also by "*horologica consideratione*" (looking at the *horologium*).[1] What kind of dial can clearly show you a difference of date as fine as 5 days around the Equinox?

After having spoken at length about the different durations of the days at different latitudes ('climates'), Bede gets back to writing about sundials in chapter 38: " ...everyone that does not learn at school, as a child, to understand the signs of the heavens at least learns from the lines of the sundial on the ground what is necessary for his query".[2]

Also in the *Glossae* to the Bede's *De Temporum Ratione*, Pseudo-Byrhtferth seems to write about a sundial of this type.[3]

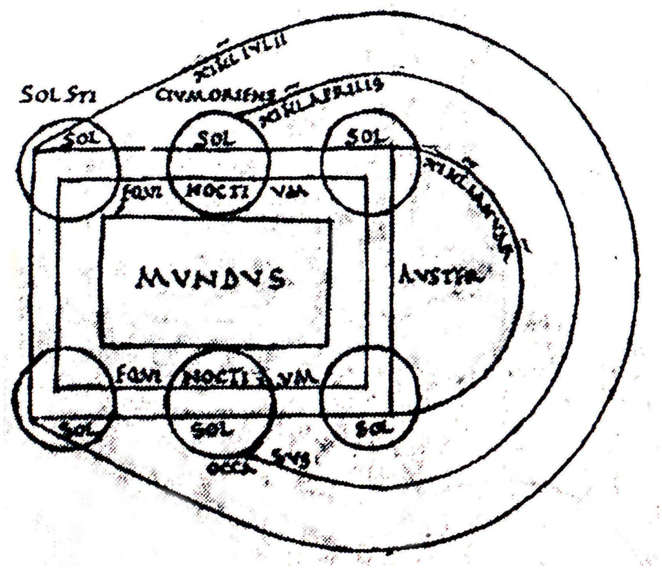

Fig. 6. Diagram of the cursus solis *from ms. Strasbourg, Bibl. Nat. Univ., 326, f. 118v.*

Honorius of Autun also wrote about sundials traced on the ground or laid horizontally on the soil, citing various examples.[4]

Around the 8th and 9th centuries, several manuscripts start to show diagrams illustrating the sun-path for three astronomical occasions of the year: the two Solstices and the Equinoxes. The Earth (the *mundus*), or the plane of the horizon, was represented as a squared or rectangular shape (*Mundus IIII angulos habet* – the Earth has four angles) and around it the curved lines of the sun-paths show the different lengths of the diurnal arcs (Fig. 6).[5]

It is possible that from this simple drawing the first medieval conception for the construction of an horizontal sundial was born, able to show the hours of the day thanks to the different length of the days. It was followed by a second, more developed, diagram where the *Mundus* is rounded and the sun-path arcs no longer touch it (Fig. 7).

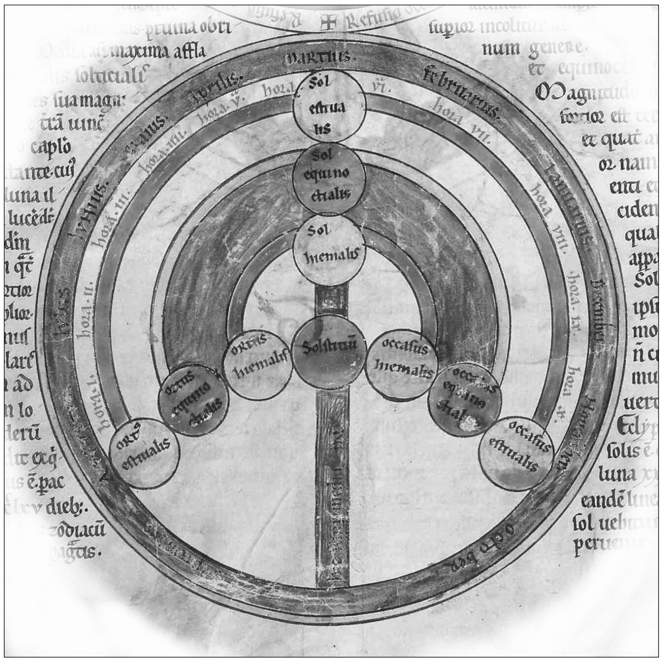

Fig. 7. Diagram of the cursus solis *from the Liber Floridum of Lambertus Onulfus. ms. Herzog August Bibl. Wolfenbuttel, Cod. Guelf. 1 Gud. Lat.*

At the same time, it is easy to see that if those three arcs were divided in 12 portions one obtains a rough sundial based on the position of the Sun on the horizon (azimuth).[6]

This is the case of the drawing given by Isidore of Seville in his *Etymologiarum sive Originum*. In Book iii (sect. *De*

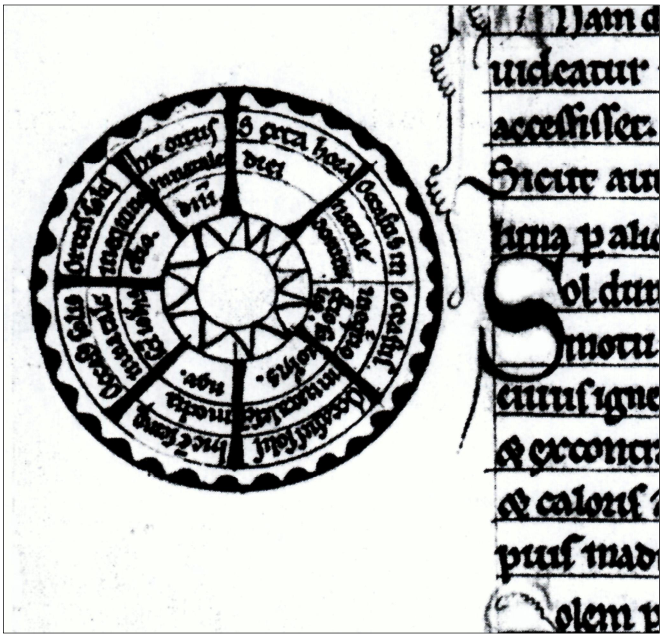

Fig. 8. Diagram of the cursus solis *similar to the one described in the Isidore of Seville's book. The significant points of the sun-path are recorded as:* hic ortus solis in natale Domini *(here is sunrise at Christmas*); sexta hora diei *(sixth hour of the day*); occasus in natale Domini *(sunset at Christmas*); occasus in aequinoctio *(sunset on the Equinox*); occasus solis in natale Iohannis *(sunset on St John's day*); semper media nox *(always midnight*); ortus solis in natale Iohannis *(sunrise on St John's day);* hic ortus solis in aequinoctio *(here is sunrise on the Equinox).*

Astronomia), ch. 5 (*De effectu solis*), it is a circular diagram divided into eight parts that shows the significant sun-path standing points (Fig. 8).[7]

St Willibrord's *Horologium*

Recently, thanks the researches of Barbara Obrist, we know of a widely-copied diagram reproduced in many medieval texts from the first half of the 8th century.[8] The most important and oldest example is the one reproduced in a manuscript compiled in the first years of that century at Echternach and attributed to Saint Willibrord (Northumbria 658 – Echternach 739). The diagram is finally called a dial ("*horologium"*, as written in the manuscript). It had widespread distribution in Carolingian times and later (Fig. 9).

The lines of the '*horologium*' are drawn inside a circle whose radius is divided into 5 equal sections by 4 concentric circles (Figs 9 & 10). The first circle, the central one, represents the *mundus*, the second one describes the diurnal arc of the day of the Winter solstice, the third one reproduces the diurnal arc of the equinoctial days, and the fourth one represents the diurnal arc of the Summer solstice. The amplitudes of those arcs are defined by 8 equi-angular radii (with 45° spacings) radiating from the first central circle. From the second minor circle (Winter solstice) another 4 segments radiate, placed centrally in the 4 segments of the upper semicircle and representing the diurnal part of the dial. These last lines show the moments of Terce and None during the day of the two solstices and are placed exactly halfway on the paths, for those days, from sunrise and noon and between noon and sunset respectively.

In Fig. 9, I have traced faithfully the diagram of the manuscript deleting only the inscriptions unnecessary for the gnomonic use of the *horologium*.[9] In Fig. 10, I reproduce the same diagram in a simplified form for clarity.

The diagram in St Willibrord's manuscript does not seem to be the drawing of a real sundial, complete with its gnomon (none of the known diagrams of the sun-path ever mention the presence of a gnomon). It was simply a geometrical scheme to be traced on the ground (as suggested by Pliny), or to be kept in mind when the monk judged the hour of the day by the Sun's position in the sky (see Fig. 11).

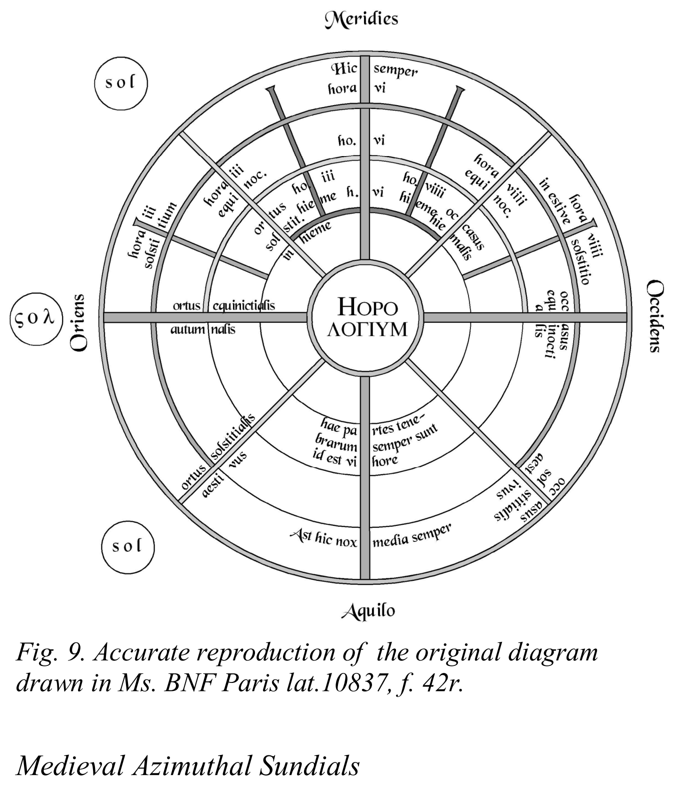

Fig. 9. Accurate reproduction of the original diagram drawn in Ms. BNF Paris lat.10837, f. 42r.

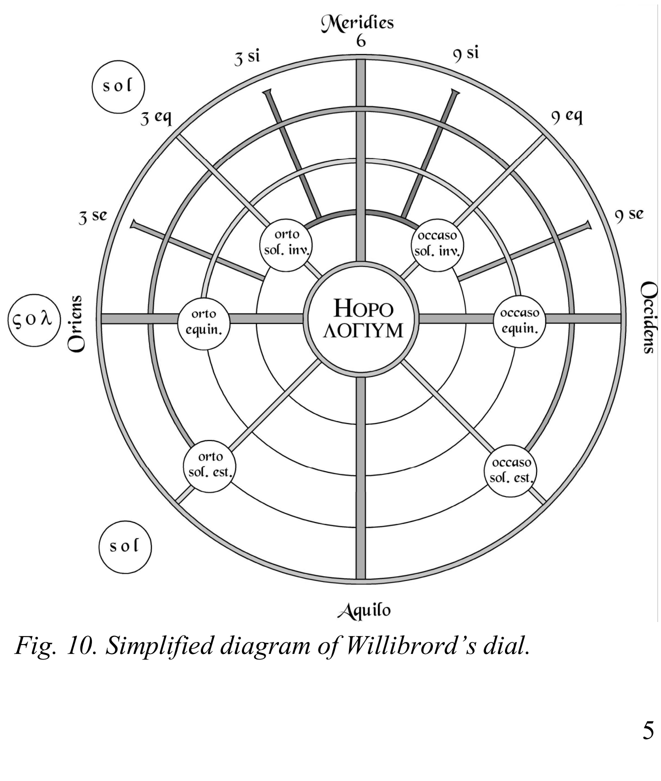

Fig. 10. Simplified diagram of Willibrord's dial.

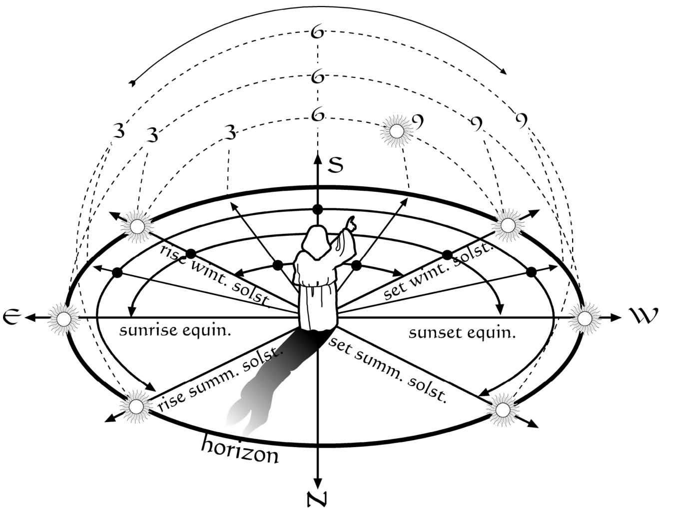

Fig. 11. The use of Willibrord's dial.

Actually, we can see in the drawing that all the hour lines are extended towards the South. A scheme like this cannot work as a sundial which needs the lines towards North. The hour-lines traced in the Willibrord *horologium* are simply azimuthal directions to be read as temporal hours, not as azimuth data.

In order to comprehend this we must remember that in ancient and medieval times it was common to show geographical directions with the typical terminology of time-reckoning. In Pliny, for example, we read that Italy extended towards the South in a direction between the 1st hour of the day at the Winter Solstice and the 6th hour; that is almost halfway between the Winter sunrise and noon.[10] Gregory of Tours, in the 6th century, recommended his monks to rise from their beds when a certain star was in the same region of the sky that during the day was occupied by the Sun at the 5th hour.[11]

We can read many other medieval examples of this method of giving geographical directions, such as in Lobinell's 'History of Britain'.[12]

Of course, given that scheme, the step to convert this diagram to a real sundial (one that worked roughly with the principle of the sun's azimuth), was easy.

The Origin of St Willibrord's Horologium

In order to discover the geographic area where the diagram originated, we need to examine at least three features:

1. The position of the solstitial limits, set exactly at 45 degrees with respect to the cardinal directions.
2. The use of Greek words.
3. The names of the four cardinal points.

It is not easy to establish if the division of the *nychthemeron* into eight segments is an harmonic oversimplification of the diagram or, alternatively, if the regular subdivision is the result of careful calculation. It surely derives from a well-consolidated tradition, both in Greek culture and in the Roman world. Greeks and Romans were used to dividing both day and night into four parts.

As Barbara Obrist has written, Aratus of Soli (3rd century BC) had already split the *nychthemeron* in eight segments.[13] He considered the length of the arc of the Tropic of Cancer as 5/8 long and then assigned the remaining 3/8 to the Tropic of Capricorn.[14] Again, Obrist recalls the Roman tradition, mentioning the astronomer Hyginus (c. 180 AD) who, in his work *Astronomica*, assigned to the climate of Rome (the same as that of Hellespontus) five parts above the horizon for the Summer tropic and three under it.[15]

This means exactly 15 equinoctial hours for the day of the Summer Solstice (M_d) and 9 equinoctial hours for the Winter Solstice (m_d), which are the common values given in antiquity for the climate of the Hellespontus (Greece – Italy).[16]

The diagram of St Willibrord's *horologium*, with its diagonal cross set exactly at 45 degrees to the vertical cross of the North-South and East-West points, clearly identifies the latitude, or more correctly the climate with $M_d = 18^h$ and $m_d = 6^h$, to the region containing Ireland and northerm Britain, places very familiar to Willibrord.[17]

Irish monks were famous in the Middle Age for being skilled in Greek. It seems that Irish and Greek cultures were well connected at this time. For example, we know that the basic computus at Bangor was taught by a Greek monk to Sinnu Moccu Min, and that this computus was the origin of Bede's computistical tradition.[18] So it is common to find Greek words in Irish manuscripts, and particular attention should be paid to the way the names of the four cardinal points were written.

In the diagram of the Parisian manuscript, the four points are designated with Latin words: *Oriens* (East), *Occidens* (West), *Meridies* (noon, South), *Aquilo* (North). Next to these directions are the names in Greek (for clarity they have been omitted from the Figs 9 & 10).

At the South the inscription reads: "*MECEMBPIA* [Mesembria]*, grece, auster, latine. Auster dicitur / ab auriendo aquas unde et crassum aeres / facit, grece nothus quia pestilentiam gignit.*"[19]

At the East we read: "*ANATOAE*" [Anatole] and at the West: "*ΔYCIC*" [Dysis]. At the North we have: "*APKTYC*" [Arctus] and suddenly the wind description: "*Aquilo dicitur eo quod aquas stringat. Est gelidus / ventus et siccus*".[20]

These were some of the names of the twelve goddesses of the hours, daughters of *Kronos*. They may have ruled the months as well and mark the path of the Sun God (*Helios*). *Anatole* (sunrise), *Dysis* (sunset), *Arctos* (the Bear, i.e. the constellation) and *Mesembria* (midday) were interpreted from the ancient Jewish tradition and adopted by the Irish monastic tradition as symbols of the four parts of the world where Adam's descendants spread. The initial letters of each wind-direction actually comprise the name ADAM. These four names were matched to the main Greek winds that were blowing from the four doors of *Harmonia,* (the

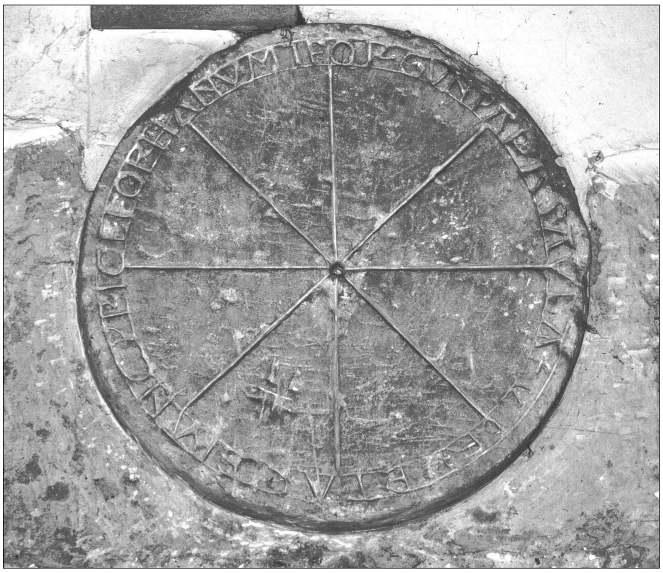

Fig. 12. The stone of Aldbrough, now mounted vertically on the wall as a common medieval sundial. (Photo: Mike Cowham.)

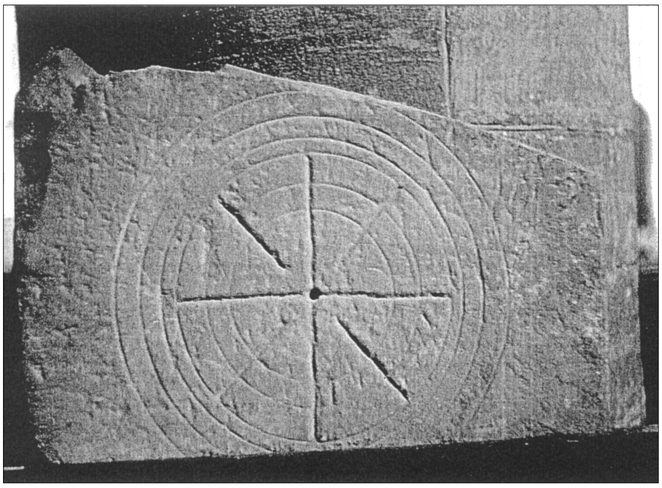

Fig. 13. The Anglo-Saxon sundial at Darlington. (Photo: Mike Cowham.)

sky vault or ‘big house’): the East wind *Euros*, the West *Zephyros*, the South, *Notos* and the North, *Boreas*.[21]

These references to the winds confirm the close bond with the Vitruvian and Plinian traditions. Pliny also is more explicit regarding wind roses attributed to solar directions and he describes the direction of the eight winds in this way: “There are two winds for each quarter of the sky: from the equinoctial rising blows Subsolanus, from the rising of the winter solstice blows Volturnus. (...). From midday comes Auster and from the sunset of the winter solstice comes Africus; (...) Favonius blows from the equinoctial sunset and Corus from the summer solstice sunset. (...) From North comes Septentrio and between this and the rising point of the summer solstice blows Aquilo”.[22]

Sundials and winds were bound together since Roman times but we also have testimony in the medieval period.[23]

New and Brief Descriptions of some Anglo-Saxon Artefacts

The discovery of the so-called ‘Willibrord’s sundial’ gave scholars of the history of gnomonics a key to understanding some rare medieval sundials, thus giving a new insight to their designs. I mean here chiefly the Anglo-Saxon English examples such as the ones at Aldbrough (Fig. 12) and Darlington (Fig. 13).[24]

Of particular interest is the description by Scott & Cowham of the operation of the dial at Coates, Gloucs.[25]

REFERENCES & NOTES

1. Beda venerabilis, *De temporum ratione*, chap. xxx, P.L. Migne, vol. 90, col. 430.
2. “ *...ut qui coeli signis intendere puerili in schola non dedicit, saltem horologii lineis in terra, quae necessaria quaerit apprehendat.*”; *Ibid*., chap. xxxviii, P.L. Migne, col. 468.
3. *Ibid*., chap. xvii, P.L. Migne, col. 381, Bridef. Rames. Glossae “*Partito namque horologio in viginti quatuor spatial...*” (Divide then the sundial in 24 parts....).
4. “*Horologium varietates scire non erit inutile. In concavo enim stante, in terra, in modum pedis, ut mihi videtur: pro varietate dierum, erit et variatio ortuum*” (In my opinion, it will be useful to know the varieties of sundials: the one standing in the concavity, [the one] on the ground, [the one] in the manner of the foot: according to the different day-lengths, and variation the risings); Honorius Augustodunensis, *De solis affectibus seo Affectionibus liber*, cap. 18, P.L. Migne, 172, col. 106D.
5. Obrist (1997), pp. 57–59.
6. Of course the meaning of the Sun’s azimuth at a particular seasonal hour of the day is, here, not fully understood; the division into 12 parts of the diurnal arc does not correspond at all to the same division of the horizontal arc.
7. It is interesting to note that the points of rising and setting of the Sun are given here not as astronomical events but as days in the ecclesiastical calendar “*sequitur figura circularis, quae in medio habet medium [est] mundi, circa autem stationes solis sic inscriptas: hic ortus solis in natale Domini; sexta hora diei; occasus in natale Domini; occasus in aequinoctio; occasus solis in natale Iohannis; semper media nox; ortus solis in natale Iohannis; hic ortus solis in aequinoctio.*”
8. Obrist (2000).
9. For a complete description and the original image of the manuscript, see Obrist (2000).
10. Plinius: *Nat. Hist*., iii, 45; see also *Idem*., vi, 37, 202.
11. “*cum stella in hora diei quinta advenerit, surge.”* (when the star reaches the place of the fifth hour of the day, wake up).
12. See Du Fresne: *Glossarium mediae et infimae latinitatis*, IV, a.v. “Hora nona” and “Hora tertia”, p. 231.
13. Obrist (2000), p. 89.
14. Aratus: *Phaenomena*, lin. 497 seq.
15. Hyginus: *Astronomica*, iv, 2, 2; Obrist (2000), ref. 81.
16. In my articles (Arnaldi (2008a) and Arnaldi (2008b)) I used M for the longest day and m for the shortest one, following the example of Neugebauer. Here I prefer to use M_d and m_d (Maximum day and minimum day) for clarity.
17. The ‘climate’ 18^h / 6^h (the 25th Ptolemeic ‘climate’) refers to a latitude of 58° N, which is part of southern Ireland for Ptolemy (with modern calculations 58.4°).
18. Ó. Cróinín (1982) and Ó. Cróinín (1983).

19. "In the Greek language [they say] MECEMBPIA [Mesembria], *auster* in Latin. Auster is so called from *auriendo* (that accumulates) the clouds (or the rain) and because it makes the air heavy, the Greeks call it bastard, bad, because it carries plague and pestilence."
20. "Aquilone is called the wind that dissipates the clouds. It is a dry and cold wind."
21. See Nonnus (c. iv – v), *Dionysiaca 41, 263 seg*.
22. Plinius, *Nat. Hist.* II, 143; see also Valdameri (2012), expecially pp.25–26 and footnote 23.
23. Recall, for Roman times, the horizontal sundial of Aquileia (Italy) and for the Middle Ages the diagram of the *horologium viatorum* (a shadow scheme) in the manuscript Cologne Ms. 83 II, f. 84r.
24. Arnaldi (2009); Scott & Cowham (2010), pp. 4–6.
25. Scott & Cowham (2010), pp. 6 and 66, but also 71–72.

CHAPTER 3

And finally the sundials (the first medieval Latin insights)

The azimuthal sundials which are the subject of this chapter are a little more sophisticated than Willibrord's Horologium. At the time they were widespread, but, for some unknown reason, today they have been little studied. As we will see, there is a basic error in the rules contained in the manuscripts, but this is not relevant now. I only want to draw attention to this design because it seems to be the real prototype of the correctly-designed azimuthal dials that we know today.

Medieval Azimuthal Sundials

In February or March of the year 989, Gerbert of Aurillac (to become Pope Silvester II in 999) wrote a letter to a certain "brother Adam", probably replying to an enquiry from the monk about gnomonics.[1] In the letter, entitled *Epistola de horologiis duorum climatum ad fratrem Adam* (Letter to Brother Adam on dials for two climates), Gerbert explains how important it is, in making *horologia* (dials) for different climates, to know the length of day-light for the different months of the year.[2]

We already know that the word '*horologium*' does not meant necessarily 'sundial'. That name can be applied to many kinds of horological instrument: the astrolabe, the nocturlabe, the sun dial and the water dial and also the mechanical clock.[3] Nevertheless, the short description in the letter to brother Adam and the instructions written in the manuscript Ripoll 225 were enough for Millàs Vallicrosa,[4] followed by Poulle,[5] and later by Zenner,[6] to conclude that Gerbert was referring to a sundial: more precisely to a kind of azimuthal sundial.

The known manuscripts describing this type of sundial are relatively few and none of them are copies of the others. All of them derive from the same older tradition, but there is no direct parental line between them. Even though there are also two Arabic manuscripts, one from Cataluña and the second from Egypt, scholars – including me – are convinced that the tradition shown by this group of manuscripts came from the Greco-Roman world, and in the Middle Ages the chief author for reference was Martianus Capella.[7]

The Manuscripts

The manuscripts known today are (in chronological order):

1. Ms. Archive of the Crown of Aragon, Ripoll 225, ff. 94r–7r. 10th–11th C (hereafter, simply *RIP*).[8]
2. Ms. Paris BnF lat. 7412, f. 19r. 11th C (hereafter, *PAR*1).[9]
3. Ms Paris BnF lat. 12117, f. 2v. 11th C (hereafter, *PAR*2).[13]
4. Ms. Montpellier, Bibl. Interuniveritaire, Section de Mèdicine H48, f. 3v. 11th C (hereafter, *MON*).[10]
5. Ms. Karlsruhe 504, f. 169v. ca. 1100 (hereafter, simply *KAR*).[11]
6. Ms. Darmstadt cod. 1020, ff. 62v–63v. After 1150 (hereafter, simply *DAR*).[12]
7. Ms. London BM Old Royal 15 B IX, f. 77r. 13th C (hereafter, simply *LON*).[13]

To this list we should add, *in primis*, the cited letter sent by Gerbert to brother Adam (hereafter, simply *GER*).[14]

The Arab manuscripts are:

1. Ms. Florence, Medicea-Laurenziana, Or. 152, ff. 45r-46v. 13th century but probably copied from an older text of the 10th–11th C (hereafter, simply *FIR*).
2. Ms. Dublin Chester Beatty Library, Persian 102, by Najim al-Misri. 14th C (hereafter, simply *DUB*).

Of the two Arab manuscripts I will take only *FIR*, because it is the only one to have a connection with the Latin manuscript tradition.

None of the manuscripts listed above is without gaps and all have passages which are difficult to interpret. Amongst them, *DAR* is the one that gives a more-or-less straight-forward description. The study that follows will be mainly about the English[15] edition with analysis of *DAR,* using *KAR* as a comparison with other testimony in order to find the common roots. But in the appendices I will dedicate space to all the manuscripts with the main interest being *LON* which still has not been studied fully.

Chronology of the Findings

The first edition of a text describing this type of sundial was made in 1931 by Millàs Vallicrosa[16] for the famous manuscript no. 225 of the thousand-year-old monastery of Santa Maria de Ripoll (today kept in the Crown Archive of Aragon). That edition set the starting point for the discovery of a new group of medieval sundials which spread across Christian Europe in the 10th–13th centuries.

The codex is a miscellany of scientific and astronomical texts. Many of the chapters in it are parts of different treatises on the astrolabe directly translated from Arabic originals, almost certainly by Sunifred Llobet of Barcelona. The Ripoll codex also contains some chapters dedicated to the reckoning of time: one of them (ff. 94r – 97r) includes the description of a sundial which Millàs Vallicrosa simply calls 'gnomon' (*RIP*).[17]

The chapter has no figure so Vallicrosa tried to draw one, though we can now easily see, following the description of the text, that it was incorrect. Sixty years later Edward Farré made a new and correct drawing of the dial described in *RIP*.[18]

For more than 30 years after the edition of Millàs Vallicrosa, no new manuscripts were discovered and it is only in the last 20 years that other manuscripts have been found and studied.

In 1962 Marcel Destombre noted the presence of a dial drawing in *PAR2* but did not study it in detail.[19]

In 1996 Josep Casulleras published an edition of a Catalan manuscript copied at the court of Alfonse X and now kept in the Medicea-Laurenziana Library in Florence (*FIR*). The codex is a copy of an original text of the 10th century and contains only one work: the only treatise known today, written in Arabic, about western mechanics.[20] Within that codex, a text describes an azimuthal sundial very similar to those described in the Latin manuscripts listed here. The author gives this type of sundial the name *balāta* which is also used for another kind of Arabic horizontal sundial, very similar to the Latin scratch dials.

In 1999, Armin Zenner published a study of the hypothetical sundial of Gerbert (*GER*) with an interesting contribution on the manuscript kept in the British Library in London (*LON*).[21]

In 2001 François Charette presented his doctorate at the Frankfurt University and then in 2003 he published an edition of an Egyptian manuscript (now kept in the Dublin Library) of the 14th century. One chapter of the book describes an azimuthal sundial (*DUB*).[22]

Pairs of months, after Martianus Capella
June
May – July
April – August
March – September
February – October
January – November
December

Table A

Pairs of months, after *GER* & *RIP*
June – July
May – August
April – September
March – October
February – November
January – December

Table B

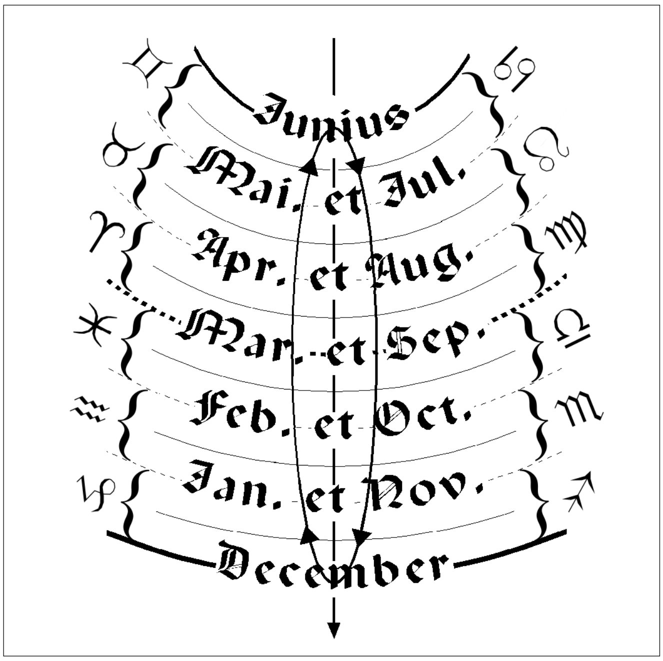

Fig. 14. The version of the calendar used for the sundial described in ms. Karlsruhe 504. This sequence shows evidence of a correlation between the months and the zodiacal signs. The circles mark the midpoints of the months (the 15th day).

Around the year 2005–6 Karlheinz Schaldach started to study ms. Karlsruhe 504 (*KAR*), cited for the first time by Zinner,[23] but he did not publish the results.[24]

In September 2006, I was in the University Library of Darmstadt, Germany, looking for a manuscript of the 12th century. There I had a great surprise in finding two unedited Latin texts. One of them (*DAR*) was the complete description of an azimuthal sundial of the type which is the subject of this study. It is the best-preserved version.

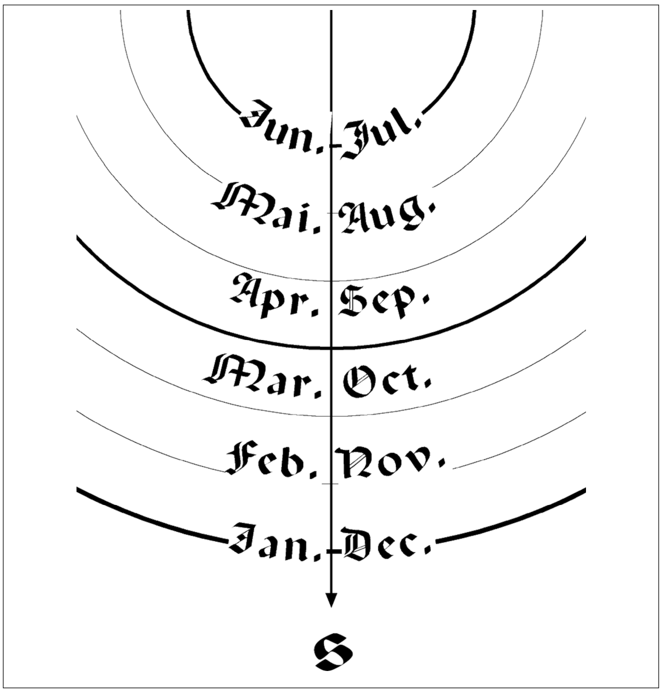

Fig. 15. The version of the calendar with only six concentric circles. The circles mark the whole solar month in one line.

In 2007 David Juste published a book which remembers the presence of the dial in *MON*.[25]

In 2008 Annalisa Borelli published a book in which she records the figure of the dial in *PAR*$_1$.[26]

The Sundial

By following the description in the texts we can start to make the sundial. We must begin by drawing a series of concentric circles with each circle labelled with a pair of months. The number of circles depends on which set of calendar months is used: seven circles if they are set as in Table A (see Fig. 14) and six circles if they are set as in Table B (see Fig. 15).[27] The method in Table B was already known in Roman times[28] and was very common in the Middle Ages in the 'shadow schemes' or in portable sundials such as the Canterbury pendant.[29]

The calendar in *GER* is the same set as the one described in *RIP*.[30] *RIP* and *GER*, in this case, show a good connection. *RIP* says that one can also use also the set of seven circles but the writer of the manuscript does not think it is as good.[31]

RIP, *GER, PAR*$_1$*, PAR*$_2$*, MON* and *LON* give the number of equinoctial hours for each pair of months. The other manuscripts seem satisfied to have the day-length for the three principal circles: two for the Solstices and one, in the centre, for the Equinoxes. To mark the number of equinoctial hours on the sundial we should divide each of these three circles into 24 parts as the hour of the *nycthemeron* (*DAR* uses the wider one,[32] *RIP* the smaller one[33]).

24 invisible rays must be traced from the outer to the inner circle, reaching the centre so that every circle is divided into the same number of parts (Fig. 16).

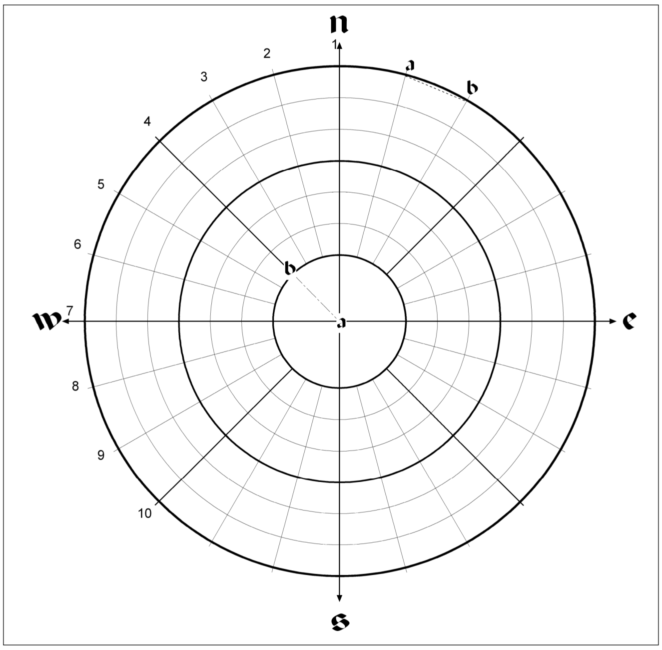

Fig. 16. Drawing of the radial rays following the instructions of ms. Darmstadt 1020.

For each monthly circle we require the length of the daylight, depending on the climate for which the sundial is intended. The hours of the day-length are measured equally to the left and right of the meridian line (for example, 15 hours should be divided into two groups of seven and a half). Of course, to show the temporal hours of the day we must divide this day-length arc into 12 parts. Linking together all the points related to the temporal hours found on each circle, we obtain the hour-lines (curves) of the day.

Usually, for European sundials, not all of the 12 hour-lines were drawn, only the main canonical 'offices': Prime, Terce, Sext, None and Vespers (Fig. 17).[34]

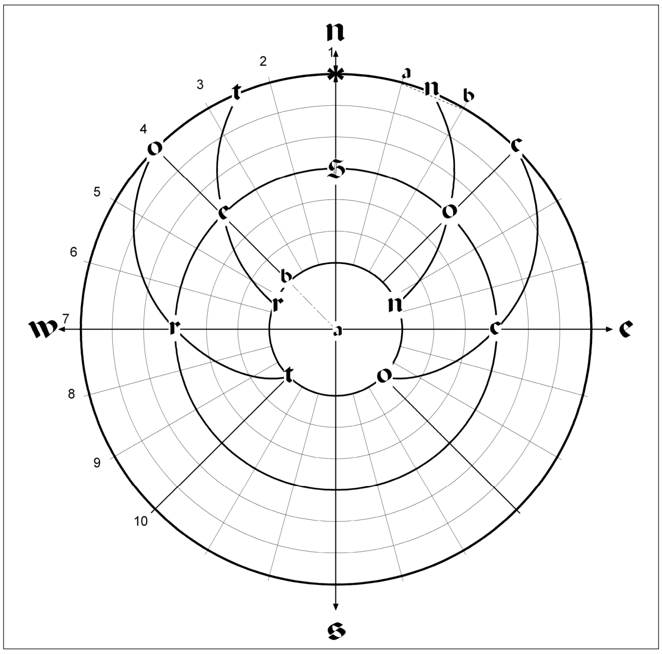

Fig. 17. How to trace the temporal hour-lines following the instruction of ms. Darmstadt 1020. This manuscript shows (as do other mss) how to draw the diurnal canonical hours.

The gnomon is set in the centre of the circles and the hours are shown by its shadow along the date circle for the day.

The reader will surely note that this kind of sundial has a basic error. In this sundial, the 24 sectors that represent the hours of the *nychtemeron* are not real azimuthal values of the equinoctial hours, but simply constant azimuth values, each of 15 degrees.[35] Thus this kind of dial should not be regarded be as a real azimuthal dial as we understand it today. Nevertheless, we are at the start of a good idea, good enough to mark the temporal hours for the period between the 10th and 13th centuries.

The Length of the Days

The ancients were used to defining the latitude of the many places of the world by the length of the daylight at the summer solstice. In late Roman times, Martianus Capella suggested a practical calculation to find the day-length for every month, starting from the longest one, but in medieval times this method was often altered and simplified by different authors.[36]

The group of manuscripts that we are now studying consider essentially only two latitudes (or climates): the one with a longest daylight of 15 hours and the one with a day-length equal to 18 hours.

It is not hard to calculate, for both climates, the maximum and the minimum value of the day-length, which we will call respectively M_d and m_d. The value of M_d gives us also the length of the shorter day m_d, being equal to 24h – M_d. So, for many authors, such as for *DAR*, it is enough to mark a point on the left and the right of the meridian line on the largest circle (winter solstice). These marks will correspond to $m_d/2$, measuring it along the 24 sections made before. On the minor circle (summer solstice) they will mark, on the contrary, the points of $M_d/2$. For the marks on the middle circle (Equinoxes) the values of $M_d/2$ are equal to 6h, no matter what the climate.

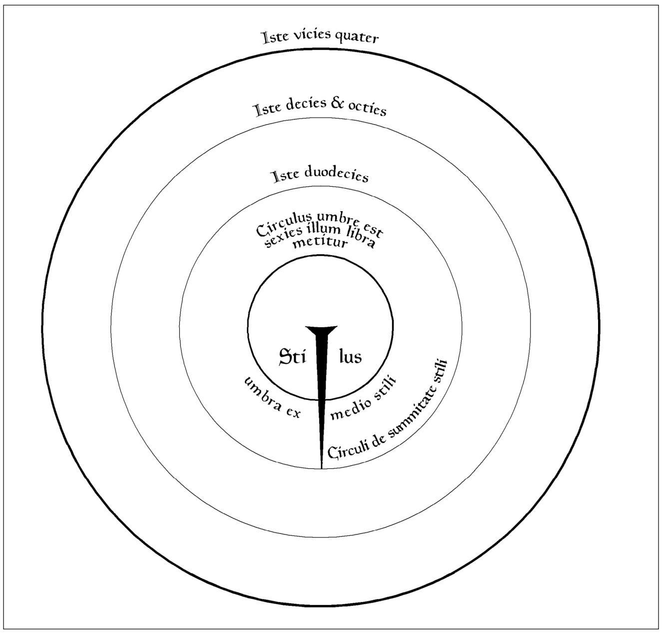

Fig. 19. The drawing at page 71b of codex 901 'fondo' San Marco at the Biblioteca Laurenziana in Florence.

The Gnomon

Almost all the manuscripts explain the construction of the gnomon with much care, but they do not always agree on the appropriate length.

Both *DAR* and *KAR* suggest a style with a length equal to the distance from the centre of the sundial up to equinoctial circle (Fig. 18).[37]

RIP and *FIR*, on the other hand, do not use this definition. For *FIR* the length of the gnomon is equal to the distance from the centre of the dial to outer circle. For *RIP* the gnomon should be as long as required for its shadow to reach the edge of the stone even when shadow is short.[38]

LON, *MON*, PAR_1 and PAR_2 say nothing about it, and the gnomon is not shown in the diagram.

Obviously – as is well known – in an azimuthal sundial the length of the gnomon is immaterial, considering the fact that its fundamental principle is the direction and not the length of the shadow on the horizon. When the shadow of the gnomon touches a hour line crossing the relative date circle, then the hour can be read at the crossing point, whether the shadow crosses the point or it only just reaches it. It is only necessary to have a precise length of the style if the reckoning of hours is made with the tip of the gnomon: this is the case for an equinoctial sundial (of course with temporal hours). Because in *FIR* it is very clear (as also in other manuscripts) that the plane of the dial must be placed horizontally, and given the fact that *FIR*'s author defines the instrument as 'universal', Casulleras's rather unconvincing hypothesis that the original model could have been an equinoctial sundial is wrong.[39]

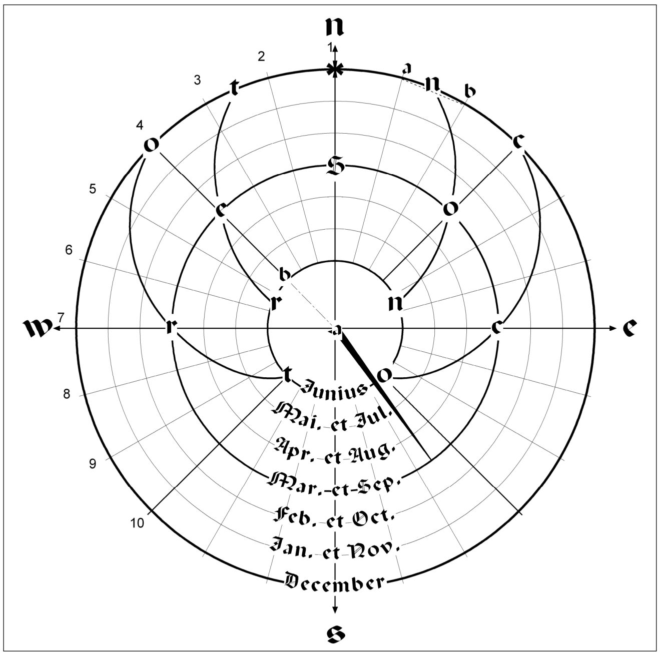

Fig. 18. The azimuthal sundial and its gnomon, following the instructions of ms. Darmstadt 1020.

Maybe the convinction that the gnomon should have that precise length derived from some drawings reproduced already at the end of the 10^{th} century on the basis of the notions described in *De Nuptiis Philologiae et Mercurii di Martanus Capella*, when he is describing Eratosthenes's method for calculating the length of the terrestrial meridian.

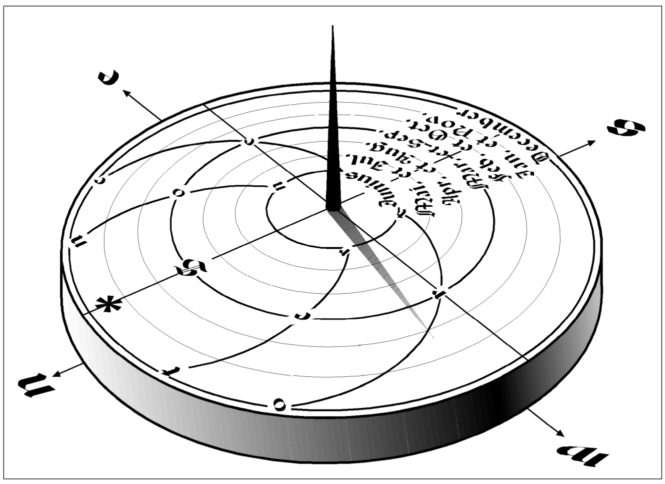

Fig. 20. Graphical reconstruction of the medieval azimuthal sundial descrbed in ms. Darmstadt 1020.

An important note on this is in ms. 901, '*fondo*' St Marco in the Medicea-Laurenziana Library in Florence. On pages 71a and 71b are two drawings that illustrates the Martianus passage; one of them is shown in Fig. 19.[40]

How to Align the Sundial

"You can align this dial by night, putting your eye on the December side (South) toward S mark (North) and find the true North direction using the gnomon apex. So that S will be exactly toward North and the line December perfectly directed to the Pole star and so you will engrave this star also in the slab."[41] (*DAR*, line 34, f. 63r; lines 1-7, f. 63v).

Almost all the manuscripts tell us how to align the dial correctly, but not all suggest the same method. *RIP* suggests the help of an '*oroscope*' (probably an astrolabe or a simple 'gnomon' – now called 'Hindu circles' – as it is described in *FIR*).[42] When the instrument shows the end of the 6th hour then the shadow of the stick in our stone must lie along the meridian line. If it was not possible to have an *oroscope*, then one can align the stone during the night, looking towards the polar star past the tip of the gnomon.

DAR suggests only the nocturnal method described also in *RIP*.

REFERENCES and NOTES

1. Bubnov (1899), pp. 38-41.
2. The climates (Greek: Κλίματα; Latin: Climata) or 'inclination of the heavens' (the ancient Greeks did not consider the latitude as an 'elevation of the pole', but as an 'inclination of the celestial vault'). For a complete description of the climates, see Neugebauer (1975), pp. 725–737.
3. Cf. Poulle (1985), pp. 598-599.
4. Millàs Vallicrosa (1931).
5. Poulle (1985), p. 597: "...et sa lettre à Adam sur deux cadrans solaires,...".
6. Zenner (1999).
7. Martianus Minneus Felix Capella (Carthage, 5th century); author of *The marriage of Mercury and Philology*, a basic work for the study of the seven liberal arts and a great success in the Middle Ages.
8. Full edition and discussion in Appendix B.
9. Full transcription and discussion in Appendix E.
10. Full transcription and discussion in Appendix E.
11. Full edition in Appendix C.
12. Full edition in Appendix D.
13. This manuscript has no text but only brief captions along the lines of the drawing. Full edition in Appendix E.
14. Full edition in Appendix A
15. The first edition of ms. Darmstadt 1020 was made in Italian, together with ms. Karlsruhe 504, in M. Arnaldi, *op. cit.* (chapter 1, ref. 1)
16. Millàs Vallicrosa (1931).
17. Millàs Vallicrosa (1931), pp. 228–230.
18. Farré (1991).
19. Destombre (1962).
20. Casulleras (1996).
21. Zenner (1999).
22. Charette (2003), pp. 166–170, 312–313.
23. Zinner (1979), p. 316.
24. Schaldach did not publish his edition because he was not completely convinced by it. I will propose a corrected version in the Appendix.
25. Juste (2007).
26. Borrelli (2008), pp. 197–203.
27. Zenner describes clearly the difference between those two ways to consider the calendar; see Zenner (1999).
28. Schaldach (2001), pp. 42–43, 117, figs 27, 29, 63.
29. See Arnaldi (2011) and Arnaldi (2012).
30. "*In rotunda et plana equaliter petra circulos eque latitudinis in quibus ut sunt pares queant describi menses xii facies vi*" (On a round and plane stone you will trace 6 circles of constant amplitude, where it is possible to write, because they are in pairs, [the names of] the 12 months of the years), (*RIP*, f. 94r).
31. "*Quod quidem nos minime reprehendimus, sed qualiter stare queat recte nescimus, quia certam dierum vel mensium equiperacionem non videmus sicut superius ullo modo*." (This, actually, we do not want to criticize, but we do not know how to consider it right, because we do not see a way to face directly months and days as, on the contrary, we can see with the method explained above), (*RIP*, f. 96v). Actually, since the hour points are measured on the circles of the 'solar months' nothing changes.
32. "*constitue circulum ad libitum quem secabis in xxiiiior partes, ... duces que radios xxiiiior a minimo ad maximum, per supradictas maximi circuli xxiiiior sectiones*" (make the circle as wide as you like and divide it in 24 parts, … from there trace the 24 lines that go from the little circle to the wider), (*DAR*, lines 4-9)
33. "*His igitur rite peractis, in circulo qui est iunii et iulii ... horis xxti iiiior inceptis, et equaliter designatis, ...*" (So mark 24 equal sections for the 24 hours of the day in the circle designated for June and July), (*RIP*, f. 94v).
34. Only *FIR* explicitly teaches the construction of all the 12 hour lines of the day, but *FIR* is a treatise in Arabic and, notwithstanding that it is about western mechanics, it is delivered from a typical Arabic cultural viewpoint. So, obviously, the author is not interested in Christian canonical hours.
35. That kind of regular subdivision should be counted on the equinoctial circle or at least on the ecliptic – as for the real unequal hours – not on the horizon.
36. See Appendices A and B.
37. "*Gnomo vero, cuius a multis tacita mensura est vel invidia vel inscitia, usque ad medium circulum a centrone* (sic) *pertingere debet, ad cuius umbram totum respicit horologii commodum.*", (*DAR*, lines 31-34); "*Gnomo istius horologii tantae longitudinis erit, quantum est spacii a centro usque ad medium circulum, qui dicitur aequinoctialis*", (*KAR*, f. 169v). Actually, *KAR* looks at the possibility of making a longer gnomon, but this is only for decorative purposes and is not needed for operation. In this case it suggests positioning a marker (with a visible shadow) at the correct position: "*quem etiam si ornatus causa longiorem facere volueris, in loco ubi predictum spacium terminatur, denticulos extantes pro designatione predictae longitudinis ponere curabis*", (*KAR*, f. 129v).
38. In *RIP*, f. 94r we read: "*Erit autem tante longitudinis gnomon iste, ut totam petram queat eius ambire umbra*" (The gnomon will be as long as all the stone can be reached by the shadow), while *FIR*, ff. 45v–46r: 'At this point fix correctly and perpendicularly one gnomon B in the point E [?] (f. 46r) in the middle of the circumference, as long as the ray of the circumference NB (the wider one)'.
39. Following Casulleras's hypothesis, Borrelli also made the same error. Borrelli (2008), pp. 197–203.
40. Leonardi (1956–1957).
41. "*Ad quod ponendum ponas oculum ad lineam Decembris versam ab **S** et diligenter notato polo per ipsum Gnomonem stabili mansione loces. Horologium istud nocte tantum potest*

*statui, **S** ad aquilonem verso, et Decembris linea ad polum rectissime directa, sub eadem etiam stella, fit autem in lapide.*"

42. The term "*oroscopum*" was used also by Johannes Scotus Eriugena (9th century), commenting on a passage of Martianus Capella's book. Martianus was writing about the roundness of the Earth and the difference of the shadow-length with changing climates (latitudes). He used the comparison with hemispherical sundials called "scaphia" (scaphe) – a kind of sundial made of a hemisphere of bronze with a vertical gnomon fitted in the bottom. Martianus also calls the "scaphia" simply "*vasa*" (vases), but he writes the they are also called "*horispica*" (hours watcher) or "*horologia*" (hours meter). Scotus Eriugena read "*oroscopa*" and he writes: "*Oroscopus dicitur horarum visio vel intentio; horologium vero horarum ratio.*" (It is called oroscope the vision or the look of the hours; horologium is said the measure of the hours). Remigius from Auxerre uses the word "*horoscopus*" with the same meaning of "*oroscopus*". So we can understand that in the 9th and 10th centuries the word "*oroscopus*" was used to identify every instrument able to indicate the hours.

CHAPTER 4

Analysis of the Manuscripts

From a careful selection of the most significant passages of the manuscripts described in the previous chapter (and given in the appendices) it is proposed that the original, complete text was composed of six parts. I will define them with the letters: **A**, **B**, **C**, **D**, **E** and **F**.

We will define:

A – the section which shows the basic construction of the dial on the dial plane (the concentric circles and their subdivisions).
B – the section which assigns the pairs of months to the circles.
C – where the number of equinoctial hours for the longest day of each month is determined in order to draw the correct hour lines for the appropriate climate.
D – where the method of drawing the hour lines is given.
E – where the details of the gnomon are explained
F – where the method of aligning the sundial is given.

Each part can be divided into two or three variants. **A**, for example, can be divided into: **A1**, which proposes six circles, and **A2**, with seven circles. **B** is composed of: **B1**, a variant with all the months in pairs, and **B2**, a variant with June and December set singly. **C** is divided into: **C1**, with the longest day 15 equinoctial hours long, **C2**, with the longest day of 18 hours and **C3**, with the longest day 17 equinoctial hours long. **D** contains: **D1**, with the hour lines of 12 temporal hours, and **D2**, where, in contrast, only the canonical hour lines are shown. **E** is made of: **E1**, where the gnomon length is equal to the distance between the centre and the equinoctial circle, and **E2**, where the gnomon length is much longer than that in **E1**. **F** is divided in two parts: **F1** and **F2**, with the former explaining how to align the dial during the day with the latter showing how to align it at night.

The sequence of these parts does not follow the steps which I think are correct, but in each manuscript of this family the differences are more or less evident.

The sequences in the different manuscripts can be represented as follow:

RIP – A[1&2], E[2], B[1], C[1], F[1&2], B[2], D[2].
FIR – A[2], C[1], B[2], D[1], E[2], F[1].
DAR – A[2], D[2], C[2], B[2], E[1], F[1&2].
KAR – E[1&2], A[2], B[2].
PAR₁ & *LON* – do not have discernible sequences that follow a correct line.
PAR₂ – does not have text.
MON – does not have text.

The points of commonality (always and only in the context, never in the text) and differences which are shown in Table C establish two traditions with another analysis given by Table D.

		A		B		C			D		E		F	
		1	2	1	2	1	2	3	1	2	1	2	1	2
989 AD	Gerberto	●		●		●	●							
10th – 11th centuries	Ripoll	●	●	●	●	●			?	●		●	●	●
10th – 11th centuries	Firenze		●		●	●			●			●	●	
11th century	Paris 1		●		●		●			●				
11th century	Paris 2		●		●			●	●	●				
11th century	Montpellier		●		●	?	?	?	●	●				
12th century – ca. 1100	Karlsruhe		●		●						●	●		
12th century – before 1150	Darmstadt		●		●		●			●	●			●
13th century	London		●		●	?	?	?		●				

Table C.

A and B		C			D		E		F	
6 circles	7 circles	15h-max	17h-max	18h-max	12h	H. can.	Short gnomon	Long gnomon	day	night
2	8	3	1	3	3	6	2	3	2	2

Table D.

This kind of sundial was based first and foremost on the idea of 'latitude', understood as 'climate', and its value was given not in degrees but by the length of the longest or shortest day, measured in equinoctial hours.

Table D shows that the most common model uses seven concentric circles and that these dials were usually made for two main climates: M_d = 15h and M_d = 18h, which correspond to the Hellespont (now known as the Dardanelles) and to Ireland or Northern Europe respectively. The most frequent hour lines were those of the canonical hours and the most common gnomon has a length longer than the radius of the equinoctial circle, but there is no agreement on the best time to align the sundial when it is complete.

Origins

We saw in the first chapter dedicated to the prototype sundial of Saint Willibrord that in ancient times this diagram was perhaps not a sundial as we understand it today. It was born in ancient Greek and Roman times. The Willibrord diagram took root in northern Europe (Ireland or North England), probably based on the knowledge of some ancient tradition. Now we need to find the possible sources for this last version of the dial.

Other than *FIR*, there is no single manuscript of this family which uses Arabic words, but the preferred use of the climate of Hellespont (M_d = 15h) suggests a link to Greece and the Mediterranean area. This tradition was passed to the Middle Ages thanks to Roman authors such as Pliny the Elder, Martianus Capella and Macrobius.

To find the original tradition, I see essentially two directions for investigation: the climates and the use of the word *centron* or *centrone*.

In *DAR* we can find both features: the first one is just in the opening passage, where the author cites Ptolemy and the climates, the second one can be found in the use of the word '*centrone*' at line 33 of folio 63r.

Ptolemy and the Seven Climates

Folio 63r of *DAR* starts with the introductory passage: "*Horologium solare facturo vii climata mundi que Ptolomeus rex tot gnomonum constitutionibus invenerat memoriae commendasse non erit inutile*". This short passage refers to Ptolemy, called 'king', and to the seven climates that the author supposes he found with the help of several 'gnomons'. Nowadays we do not write of the Alexandrian astronomer Ptolemy in these terms, because we know that the 'climate bands' were probably established by Hipparchus well before his epoch, and that he was not a king at all.[1]

Manuscript *DAR* has been dated to the first half of the 12th century, but at that time Ptolemy was simply known as an 'important man' from the past, relevant to both astronomy and astrology. Actually, his works had not yet been translated into Latin, and the Greek and Arab versions were not widespread in Christian Europe.

There are essentially two books in which Ptolemy wrote on the climates: the *Almagest*, his most important work, and the *Geography*. So, how it is possible that *DAR* can refer to the Alexandrian astronomer if the first Latin translation of the *Almagest* was not made until 1175[2] and his *Geography* was not known in Europe until the 15th century? Could *DAR* be younger than the 12th century, written in the 13th or even in the 14th century?[3]

Ptolemy was already an unquestioned authority by the 12th century and several ancient authors cited him and his works. Thanks to the books of Pliny, Martianus and Macrobius, and partially that of Gerbert, the climates and their values in equinoctial hours were already known in the 12th century without direct knowledge of the works of Ptolemy.

According to Lindgren,[4] Gerbert's understanding of Ptolemy's works was obviously poor; nevertheless, in chapters 18 and 19 of his *De utilitatibus Astrolabii* the seven climates have the same names and data as given in the Almagest.[5] Where did his knowledge of Ptolemy, even if poor, come from? I still do not know, but we can be certain that knowledge of the climates, and particularly of the seven classical climates, is testified not only by Gerbert but also in other manuscripts[6] and on a Latin astrolabe of the 11th century.

Even though the geographic work of Ptolemy has been cited by Martianus Capella, the only Latin writer that is known for certain to have read Ptolemy's *Geography* was, according to Stahl,[7] Ammianus Marcellinus (4th century). But we must remember that Ammianus, even if he was writing in Latin, was a Greek aristocrat. The Greek astronomical tradition was practically always transmitted to Rome through an intermediary, and thus Varro, who was Pliny's source, surely served in this way.

We know that Severinus Boethius made a translation of Ptolemy's astronomical treatise. Cassiodorus himself testifies to it with great satisfaction.[8] Probably this was the very precious cosmographic book (*Codex cosmographiorum*) that Benedict Biscop, English ecclesiastic and master of the Venerable Bede, carried with him in England in the 7th century after a trip to Rome. It seems, actually, that this marvellous codex, also described by Bede, was brought from the monastery of Vivarium founded at the end of the 6th century by the same Cassiodorus.[9] When Gerbert was abbot of Bobbio, Italy, he asked the arch-bishop of Reims for copy of an astronomical work by Ptolemy, and it seems that this was exactly the translation of Boetius, though we do not know if Gerbert ever received the book.[10]

GER is the only manuscript apart from *DAR* which, describing this kind of sundial, clearly considers the relation of the climates to its construction.[11] The first climate to which *GER* refers is the one which has 18 equinoctial hours at the summer solstice (M_d = 18h : m_d = 6h).[12] Ptolemy put that zone in Ireland and calls it 'South of the little Britain', that is equivalent to a latitude of 58° North.[13] The second climate to which *GER* refers is the one which in the classical period was related to the geographic area called the Hellespont[14] (latitude 40° 56′ N) where the longest day lasts 15 equinoctial hours and the shortest one is 9 hours (M_d = 15h : m_d = 9h). According to the teaching of Martianus Capella,[15] Gerbert proposed two tables with diurnal arcs for each pair of months 'calculated' for these two climates.

Together with Ptolemy and Eratostenes, Martianus was certainly one of Gerbert's major sources. Martianus, for example was cited and praised more than once, both in the letter to brother Adam and in his *De utilitatibus Astrolabii*.[16] Notwithstanding this, Gerbert understood Martianus's lesson in an almost personal way. The method of calculating the length of the days, cited verbatim in the letter to brother Adam, was interpreted incorrectly, or perhaps we should say that it was arranged differently to produce a more suitable result (see Appendix A).[17]

But Martianus Capella's *De nuptiis* consisted of many books, of which Gerbert probably knew only the sixth, dedicated to *Geometry*. Similarly, it is probable that Martianus's text was only partially disseminated in the early Middle Ages; that is, its separate sections were much approximated and interpreted by the commentators.[18]

Nobody knows why exactly seven climates were chosen among the many possible schemes. Scholars have postulated many different hypotheses, but nothing is certain.[19] Maybe this choice results from the sacred meaning that Greeks gave to the number seven, as Macrobius reminds us (5th century).[20]

In effect, all arithmetic subdivisions could be accepted, for example the one suggested by Hipparchus and passed down to us by Strabo (51 BC to between 21–25 AD), and in which the increment ΔM = 0:15h, between one climate and the next, was alternated with ΔM = 0:30h, with one final increment of 1 hour (see Appendix F).

Centrum, Κέντρον and Centrone

A second suggestion that this sundial comes from the distant past or, put another way, that the authors of this family of manuscripts knew the work of Martianus and Macrobius, is the curious latinization of the Greek word κέντρον. Inside *DAR* we find this word at line 33 f. 63r and in *RIP* we read it at f. 94r. The scribe of *DAR* uses the word "*centrone*" instead of *centrum*[21] and the scribe of *RIP* writes "*centron*" with the clear meaning of *centrum* (centre) of the entire sundial and of the concentric circles. The reader can, of course, object that the use of Greek words was common in the Roman scientific and philosophic environment, and that the simple use of a Greek word cannot support such firm conclusions. This is surely true, but the evidence demonstrates that the Greek term *centron* used in place of the more common *centrum* is not as prevalent in the Latin sources as it is in Martianus and Macrobius. The pseudo-Censorinus, for example, in his so-called *fragmentum*,[22] wrote this word twice; Gaio Giulius Iginus used it in his book on astronomy;[23] and St Augustine cites the word *centron* once in his *De civitate Dei*,[24] specifying too the technical use typical of surveyors.[25] This lexical form, in contrast to the named Latin authors, is used much more frequently by two 5th-century writers: Macrobius, (8 times),[26] and Martianus Capella (5 times).[27]

Irish Origin of M_d = 18h as the Favoured Climate

As we have seen, the group of medieval manuscripts that describes azimuthal sundials uses only two favoured climates: M_d = 15h; m_d = 9h and M_d = 18h; m_d = 6h. We now know that this tradition comes from Greece and Rome, but as we have seen in Chapter 2, discussing the division of St Willibrord's sundial, this tradition somehow passed to Northern Europe or, almost certainly, to Ireland. We have also seen that the only author who gives a 'latitude' matched to M_d = 18h is Ptolemy and through him Gerbert uses this climate even if he does not give us a geographic location.

Why, at some point, did M_d = 18h become one of the two most important climates? This probably occurred because around the 9th or the 10th centuries European monks re-placed Martianus Capella's method of finding the day-length with a revised and simpler one, as we have seen in *RIP* and *GER*. Using the *RIP* method we can see that the easiest sequencies are only for M_d = 15h and M_d = 18h.[28] But there could be another reason: a scholarly tradition was born in the Carolingian period with the first teachers of the Palatine school and through them to the formal organization of the seven Liberal Arts of the Trivium and Quadrivium. The name of Martianus Capella again arises in our discussion because his book was one of the most relevant to this project. The medieval fortune of the *De Nuptiis* is well documented by Ilaria Ramelli,[29] who some years ago edited an important edition. At that period the transcriptions of the *De nuptiis* were often limited only to some of the nine books and they were usually commented editions enriched with glossae. There are three main commentators on Martianus: Dunchad (often confused with Martin of Laon), JohnScotos (c. 810 – c. 877) and Remigius of Auxerre (c. 841 – c. 908).[30] All of them were of Irish origin or influenced by Irish culture.[31]

In the same way as Martianus, when defining the longest day, used the value of his native climate (M_d = 14h),[32] and Scotus Eriugena and Remigius used M_d = 18h, the value of their climate.[33]

It is very important not to overlook the great cultural role that these writers had in the scholastic environment of medieval times. The first corpus that commented on Martianus Capella's work was written anonymously in the 9th century. Scholars at first attributed this work to Dunchad, then to Martin of Laon. Ramelli correctly writes that John Scotus Eriugena can be considered the prevailing philosopher of his century. Scotus wrote many philosophical books; outstanding amongst them his 'piece' *De divisione naturae*. He dedicated much of his intellectual work to the comprehension of Martianus's book, so much so that he suffered two sanctions from the Council. The bishop of Troyes accused him of being too dependent on a pagan author.[34]

Also, the commentary on *De Nuptiis* made by Remigius was widely quoted in the Middle Ages, as is demonstrated by the more than seventy manuscript versions produced in the 11th and the 12th centuries. Note that the first printed editions of *De Nuptiis* still has the Remigius notes.

In the cultural environment of the time there was great interest in the many astronomical aspects of the computus, thus keeping Martianus's *De nuptiis*, and Macrobius's *Comment* on the Scipio dream, current as basic sources from which to improve the knowledge of gnomonics. This was fertile ground for understanding the kind of sundial described here.

REFERENCES & NOTES

1. See for example Geminus and Strabo.
2. We know about an anonymous, lost translation of the *Almagest* made in Sicily around the year 1160, but it seems that it was never read outside the island. Cf. Thorndike (1952), pp. 90–91 and footnote 2.
3. Dr Stefano Pagliaroli (Messina University) suspects, on the basis of the calligraphy, that it could have been written in the second half of the 13th century or the beginning of the 14th.
4. Gerbert from Aurillac (alias Herman the lame), *De utilitatibus Astrolabii*, chap. xviii, in PL, Vol. cxliii, curante Migne, Paris, 1844. The book has been always connected with *De mensura astrolabii* by Hermann the Lame and another text dedicated to the construction of a cylindrical portable sundial, and of a quadrant with cursor. While the book *De mensura* was surely written by Hermann, the book *De utilitatibus* that always follows it has been assigned by Bubnov to Gerbert from Aurillac. Bubnov has certified that the manuscripts of *De utilitatibus* came to us 18 times anonymously, twice as Ptolemy's work and seven times under the name of Gerbert; never to Hermann. So it is almost certain that *De utilitatibus* is the lost work on the astrolabe written by Gerbert. See Lindgren (1985), p. 620.
5. Lindgren (1985).
6. See Destombres (1962): Destombres names the 11th century ms Latin 7412, kept in the Bibliothèque Nationale of Paris, in which there is a description of an astrolabe with seven plates (one for each climate). Their data for M_d and locations are identical to the ones described by Gerbert.
7. Stahl (1971), p. 141.
8. We know of this work thanks to Cassiodorus but we do not know which book it was because it has unfortunately been lost; Cassiodorus, *Variae*, I, 45,4; "*Translationibus enim tuis Pythagoras musicus, Ptolemaeus astronomus leguntur Itali...*"
9. Mayvaert (2002), p. 18, n. 46
10. Bubnov (1899), ep. 8.; cf. Lindgren (1985), p. 619, footnote 2.
11. Bubnov (1899), *op. cit.*
12. "*Horologium secundum eos, qui diem maximum habent horarum aequinoctialium xviii*"; Bubnov (1899), op. cit.
13. Ptolemaeus: *Almagestum*, ii, 6; ed. Toomer (1998), p. 88; cf. also Ptolemaeus (1990), tab. ii.
14. Gerbert describes it in the same way: "*Item horologium Hellesponti, ubi dies maximus est horarum aequinoctialium quindecim*".
15. Martianus Capella: *De nuptiis Philologiae et Mercurii*, viii, 878; Ramelli (2004)2. Gerbert declares openly the lesson of Martianus: "*Martianus quippe in astrologia incrementa horarum ita fieri putat:...*", Bubnov (1899), p. 39.
16. "*Sunt enim secundum terrae positionem et discretiones climatum mutanda horologia, de quorum mutationibus Ptolomaeus et Eratosthenes satis lucide tractant. Marcianus quoque non solum de mutationibus climatum, sed etiam de singulorum meridie et altitudine seu horis aequinoctialibus satis expedit.*"; Hermannus Contractus (alias Gerbert from Aurillac), De utilitatibus Astrolabii, chap. xviii, in PL,vol. cxliii, curante Migne, Paris, 1844.
17. Bubnov (1899), op. cit.; see also Poulle (1985), pp. 600–602.
18. Leonardi (1956–1957), p. 43.
19. Cf. Neugebauer (1975), p. 727.
20. Ambrosius Theodosius Macrobius: *Commentariorum in somnium Scipionis*, i.6, 45, ed. J. Willis, BSB B.G. Teubner Verlagsgesellschaft, Bibliotheca Scriptorum Graecorum et Romanorum Teubneriana, Leipzig, 1970, p. 26.
21. "*Gnomo vero ... usque ad medium circulum a centrone pertingere debet*"; (*DAR*, lines 31–33).
22. Pseudo Censorinus, *Fragmentum*, vii,1–2; "*centron est nota circuli medii*".
23. Gaius Iulius Hyginus: *De Astronomia*, i, 2, 6–8.
24. Augustinus, De civitate Dei, xiii, 17; "*intimo terrae medio, quod geometrae centron vocant*".
25. The words of St Augustine reveals the probable origin, as well as the area where it was born and, perhaps, this kind of sundial was used.
26. Macrobius: *Commentarii in Somnium Scipionis*, i, 20,14.1, 22, 4; "*in omni orbe uel sphaera medietas centron vocatur*".
27. Martianus Capella: *De nuptiis...* , viii, 814, 827, 849, 855, 857. For all these quotations, cf. Thesaurus Linguae Latinae (1907), Vol. iii, Lipsiae.
28. For M_d = 15h we have the sequence: 15, 14, 13, 12, 11, 10, 9 and for M_d = 18h we have: 18, 16, 14, 12, 10, 8, 6.
29. Ramelli (2004)2, introduction.
30. For the complete texts of the many commentators on Martianus, see Ramelli (2006).
31. Dunchad, an Irish bishop, was a teacher of astronomy and computus in the monastery of St Rémi at Reims; Martin of Laon, (often confused with Dunchad) was the Irish master of Remigius of Auxerre and a teacher at the Irish colony of Laon; John Scotus Eriugena was the most important philosopher of his century. He left Ireland for France around 840–847 and became a teacher of liberal arts at the Palatine school during the reign of Charles the Bald.
32. Martianus was probably a native of Carthage.
33. Remigius, for example, is explicit ("*Secundum nostrum clima x et viii horas habet diem solsticialis*"); Ramelli (2006), p. 821; see also John Scottus Eriugena, *Annotationes in Marcianum*, Ramelli (2006), p. 499, glossa 259; and also Remigius

Autissiodorensis, *Commentum in Martianum Capellam*, Ramelli (2006), pp. 1338–1339.

34. Ramelli (2006), p. 23.

APPENDICES

Editorial symbols used in the Latin transcriptions and translations

{ }	Braces (curly brackets) contain notes or suggestions of the translator.
< >	Pointed brackets indicate conjectural restorations of the Latin text, when one or more words have dropped out from the text.
[ ]	Square brackets enclose words added by the translator for clarity, but they are not in the Latin text.
/	An oblique indicates a new line (return) in the manuscript.
–	An endash is used where the original text has long spaces between sentences.

APPENDIX A

Transcription, Translation and Discussion of the Letter Written by Gerbert of Aurillac to Brother Adam

Letter of Gerbert to a certain brother Adam, 989 AD.

Epistola de horologiis duorum climatum ad fratrem Adam.

Gerbertus salutem dicit fratri Adae.

Patre meo Ad. inter intelligibilia disposito, tanto curarum pondere affectus sum, ut pene omnium obliviscerer studiorum. Ut vero tui memoriam habere coepi, ne penitus otio torperem et amico absenti aliqua in re satisfacerem, litteris mandavi tibique in pignus amicitae misi quaedam ex astronomicis subtilitatibus collecta, scilicet accessus et recessus solis, non secundum eorum opinionem colligens, qui aequales fieri putant singulis mensibus, sed eorum rationem persequens, qui describunt omnino inequales.

Martianus[1] *quippe in astrologia incrementa horarum ita fieri putat: "Sciendum, inquit, a bruma ita dies accrescere, ut primo mense, duodecima eiusdem temporis, quod additur aestate, accrescat; secundo mense, sexta; tertio, quarta; et quarto mense, alia quarta; quinto, sexta; sexto, duodecima".*[2] *Itaque secundum hanc rationem duorum climatum horologia certis depinxi mensuris, definitas horas singulis mensibus attribuens. Alterum est Hellesponti, ubi dies maximus horarum aequinoctialium est XV, alterum eorum, qui diem maximum habent horarum aequinoctialium XVIII. Hoc autem ideo feci, ut sub omni climate ad veris quantitatem solsticialium dierum ex clepsydris. Quod factu quidem facile est, si furtiva aqua nocturni ac diurni temporis solsticialis seorsum excepta accedat ad divisionem totius summae, que fit XXIIII partium.*

Horologium secundum eos, qui diem maximum habent horarum aequinoctialium XVIII:

Iunius et Iulius	*Die*	*Ho. Xviii*	*Nox*	*Ho. vi*
Maius et Augustus	*Die*	*Ho. xvii*	*Nox*	*Ho. viiii*
Aprilis et September	*Die*	*Ho. Xv*	*Nox*	*Ho. xii*
Martius et October	*Die*	*Ho. Xii*	*Nox*	*Ho. xv*
Februarius et November	*Die*	*Ho. Viiii*	*Nox*	*Ho. xvii*
Ianuarius et December	*Die*	*Ho. Vi*	*Nox*	*Ho. xviii*

Letter to brother Adam about sundials[3] for two climates.

Gerbert greets brother Adam.

After the death of my father Adalberus,[4] I have been so troubled that I forgot almost all my studies. When at last I remembered you, so as not to fall completely into idleness and do something glad to the far away friend, I have written something about astronomical niceties and I sent it to you as a sign of friendship. I have written on the increases and decreases of the sun (read days), not following the theories of those that believe they happen equally every month, but accepting the thesis of those that say they are absolutely unequal.

Martianus [*Capella*], therefore, in his [book on] astrology, writes that the horary increase should be done in this way: "It is to be known that", he writes, "starting from the Winter solstice, [the days] grow in the way that in the first month must be increased the 12th part of that same time that should be added in Summer, likewise in the second month the 6th [part], in the third the 4th, and in the fourth month, again the 4th, in the fifth the 6th and in the sixth the 12th". Therefore, following this criterion I have drawn the dials for the two Climates giving correct measurements for the correct number of hours for every month. The first [sundial] is that one [for the Climate] of Hellespont where the longest day is equal to 15 equinoctial hours, the other one is that one for those [places] that have the longest day equal to 18 equinoctial hours. But I have made all this so that [you understand that] in every Climate the solstitial day-length must be measured with the clepsydra.[5] This is very easy to do, if the sum of the amounts of water flowing out from the clepsydra in the solstitial day-time and night-time, reach the measure of 24 parts.[6]

[These are the data for] the horologium according to those [places] that have a longest day 18 equinoctial hours long:

Months	Day-length hours	Night-length hours
June & July	18	6
May & August	17	9
April & September	15	12
March & October	12	15
February & November	9	17
January & December	6	18

Item horologium Hellesponti, ubi dies maximus est horarum aequinoctialium quindecim:

Iunius et Iulius	*Die*	*Ho. Xv*	*Nox*	*Ho. Viiii*
Maius et Augustus	*Die*	*Ho. xiii s.*	*Nox*	*Ho. x et s*
Aprilis et September	*Die*	*Ho. Xii*	*Nox*	*Ho. xii*
Martius et October	*Die*	*Ho. x s.*	*Nox*	*Ho. xiii s.*
Februarius et November	*Die*	*Ho. viiii s.*	*Nox*	*Ho. xiiii s.*
Ianuarius et December	*Die*	*Ho. viiii*	*Nox*	*Ho. xv*

Likewise [here are the data for] the horologium of the climate of Hellespont, where the longest day has 15 equinoctial hours:

Months	Day-length hours	Night-length hours
June & July	15	9
May & August	13.5	10.5
April & September	12	12
March & October	10.5	13.5
February & November	9.5	14.5
Ianuary & December	9	15

There is a strange statement by Gerbert in which he speaks about Martianus Capella as his first *auctoritas*, as the master who determined the sequence of the horary increments by pairs of months. But in his tables Gerbert does not correctly follow the sequence given by Martianus.

The differences between the Martianus and Gerbert tables can be found in the fact that Gerbert tells us that he used the clepsydra to measure the day-lengths, and also because of the different calendar styles. Martianus uses five pairs of months and two singles (June and December), while Gerbert groups the months together in six pairs (see Appendix G, Table I).

The understanding of Martianus Capella's work by Gerbert does not seem to be either clear or complete, because Martianus cites, in his book *De nuptiis*, eight Climates, whereas Gerbert, in contrast, gives seven (see Appendix F, Tables G and H).[7] In addition, in chapter 18 of the book *De utilitatibus astrolabii*, Gerbert assigns to Martianus the calculation of the diurnal arcs in equinoctial hours and, perhaps confusing him with Ptolemy, assigns to him also the latitudes expressed by degrees.[8]

The Letter

Gerbert's letter says explicitly that the argument is about two *horologia* and I agree with Poulle[9] identification of the subject as a sundial, and with Zenner's[10] belief that it was probably a kind of a medieval azimuthal sundial. Actually, one can object that Adam's request was about two climates and it may be that the dial in question could be a portable one. I do not know any other kind of medieval sundial (fixed or portable), other than azimuthal, that needs knowledge of the day-length to work. I recall that one example of a portable azimuthal sundial has been found in Ireland at Nendrum[11] and this is not the only one.

REFERENCES & NOTES

1. Martianus Capella.
2. Martianus Capella: *De Nuptiis...*, viii, 878; Ramelli (2004)2, p. 627. See also Bubnov (1899), p. 39.
3. I have translated '*Horologium*' as 'sundial' because it is now clear that Gerbert is writing about a sundial. Water clocks also need to know the monthly day-length but the text is too brief to believe that Gerbert is speaking about a water clock. And, on the other hand, it seems that Gerbert was not able to make a complex water clock such as the one described by Vitruvius, because he is writing about the use of a clepsydra that, at least, can be understood as a very simple water clock.
4. Adalberus (or Adalberon), Archbishop of Reims, (spiritual father of Gerbert).
5. This is a strange suggestion, because the day-lengths for every Climate were well-known since Antiquity. The use of a clepsydra to verify the day-length could explain the difference between the Gerbert and Martianus tables.
6. Probably Gerbert is writing about a simple clepsydra and not a water clock, because it seems that he is speaking about hour-mark-levels for measuring hours.
7. Gerbert of Aurillac (sometimes attributed to Hermannus Contractus): *De utilitatibus Astrolabii*, cc. xviii-xix, in PL, Migne, Paris.
8. Martianus, actually, does not distinguish the latitudes by degrees but with day-length hours. It is Ptolemy, on the other hand, that denotes the latitudes with degrees, but of this last author Gerbert, as many of his time, only had approximate knowledge.
9. Poulle (1985).
10. Zenner (1999).
11. See Arnaldi (1999) and Arnaldi (2010), p. 287.

APPENDIX B

Transcription, Translation and Discussion of MS. Ripoll 225

Crown Archives of Aragon, ms. Ripoll 225, ff. 94r–97r – 10th century

In rotunda et plana equaliter petra circulos eque latitudinis in quibus ut sunt pares queant describi menses XII facies VI remanente in medio spacio agnominem centro in ipso firmandum eius ut umbra pateant tocius diei hore. Erit autem tante longitudinis gnomon iste, ut totam petram queat eius ambire umbra.	On a round and plane stone you will trace 6 circles of constant amplitude,[4] where it is possible to write, because they are in pairs, [the names of] the 12 months of the years. In the centre of the last 6th circle, should be fixed a gnomon so that, thanks its shadow, can be shown the hour of the day. This gnomon however will be long enough so that its shadow can always reach to the slab's border's.
Designatis namque VI ut diximus circulis, divides totam per medium petram ut per centron ipsa veniat linea. Dehinc in leva in ipsa videlicet que noctis est parte, et in circulo qui vicinus est centro, mensis designatur iunius, et contra post ipsam lineam que tota dividitur / petra designatur in dextera iulius. In II^{o} autem ciurculo, madius in leva et augustus in dextera. In III^{o} aprilis in leva et september in dextera. In $IIII^{o}$ marcius in leva, et october in dextera. In V^{o} febroarius in leva, et november in dextera. In VI^{o} ianuarius in leva, et december in dextera.	Having done this, divide the stone's plane with a line passing through the centre {this line will be the meridian line}. Then, in the part given for the night-time {the South side of the stone}, inside the circle[5] that is near to the centre, write on the left of the meridian line the month of June, and the right side, will be given to July; inside the 2nd circle you will write May on the left and August on the right; inside the 3rd circle, April on the left and September on the right; inside the 4th one, March on the left and October on the right; inside the 5th, February on the left and November on the right; inside the 6th, January on the left and December on the right.
His igitur rite peractis, in circulo qui est iunii et iulii a medio ipsius linee, que tota dividitur petra, horis XX^{ti} $IIII^{or}$ inceptis, et equaliter designatis, dabis diei horas XV id est ex una parte meridiane linee VII^{em} et mediam, et ex altera parte similiter, et ita fiunt XV, remanentibus ad noctem $VIIII^{em}$. Verum de XV facies equaliter XII ita ut ad meridianam sursum lineam VI una ex parte, / et sex hore veniant ex altera. In madio autem et augusto, sunt hore diei XIIII. Quasquidem per XII dividens, facies sucut superius liquet. In aprilio et septembrio sunt hore diei XIII. De quibus ut diximus superius facies. In marcio et octobrio sunt XII. In febroario et novembrio sunt XI. In ianuario et decembrio sunt X. De X autem quas diximus esse in decembrio horis, nulla tibi sit dubitacio, quoniam absque ulla ambiguitate sunt in inicio eius X et in fine VIIII. Similiter in ianuario, in initio eius sunt VIIII et in fine X. Nulli enim calculatorum ut arbitror dubietas est ulla, de solsticio yemali quod sit XII^{o} kalendarum ianuarii. Et non solum auctoritate paterna, / verum eciam horoloica [sic][1] *consideracione atque oroscopi inspeccione perdocemur, quod XII et XI kalendarum memoratarum sunt ex toto pares. Similiter XIII et X sunt equales. Et ita ab yemali solsticio, id est XII kalendarum ianuarii usque ad estivale solsticium XII kalendarum iulii quot dies vel menses habet sol in sui ascensione vel dierum produccione tot habet eciam in descensione et contraccione. Et per quod gradus ascendit per vi menses cotidie per tot eciam descendit sine dubio per alios viex menses.*	Having done this correctly, you will divide the circle of June and July in 24 equal parts starting from the meridian line.[6] You will give 15 of these parts (hours) for the day,[7] that is, seven and a half each side of the meridian line, that is 15 in total. The remaining 9 will be given to the night. Now, divide the arc of these 15 parts in 12:[8] 6 parts each side of the meridian line. In May and August you will give 14 parts for the day and again this arc must be divided in 12, as before. For April and September include 13 parts, and divide as we did before. March and October will be 12. February and November, 11. January and December, 10. But you must have no doubts of the awarding 10 hours to the diurnal space of December, since the first days of this month have 10 hours and only the last ones have 9 hours. The same happens to the month of January; at its beginning the days have 9 hours but at its end it has 10 hours.[9] Actually, no one single scholar in astronomical computation, as I think, can not doubt that the winter solstice comes at the 12th day before the calends of January {21 of December}.[10] And not only from the authority of the Church Fathers,[11] but also from evidence in sundial and also looking at the 'oroscope' {an astrolabe?}; we see that the 12th and the 11th days before the aforesaid calends[12] are of the same duration. The same happens for the 13th and the 10th day before calends.[13] And going this way from the winter solstice to the summer solstice that is the 12th day before calends of July {21 of June}, the days will be increasing their duration, and then back, they will begin to progressively become shorter. How many degrees every

	day the sun ascends <on the horizon> during six months so many will descend during the other six months.
Ut vero directim sedere ipsa petra queat, die quo volueris eam facere directim sedere, horam in oroscopo pernoctabis (sic)[2] *VI^{tam}, id est quantum sol usque ad medium ascenderit diem. Quo in / vento facies tunc petram ipsamita sedere, ut gnomonis umbra per meridianam sursum veniat lineam. Si autem oroscopum minime habueris, faces ita sedere, ut per medium capitis gnomonis poli stellam videri possis. Sed multo melius est cum oroscopum.*	In order to fix the stone correctly you will detect the 6th hour {midday}, which is the moment when the sun reaches its maximum height, with the help of an 'oroscope'. Having found this the stone will have to be moved until the meridian line coincides with the shadow of the gnomon. If you do not have an 'oroscope' you can arrange the sundial by looking at the star at the pole by means of the tip of the gnomon, although it is much better to do it with the 'oroscope'.
Quidam igitur per VII circulos ipsam petram dividunt, ponentes singillatim penes centrum, in ipso primo circulo cum suis XV diei horis iunium, et in II^o circulo cum horis diei XIIII madium et iulium. In III^o circulo cum horis diei XIII aprilium et augustum. In $IIII^o$ circulo cum horis diei XII marcium et sep / tembrem. In V cum horis XI februarium et octobrium. In VI cum horis X ianuarium et novimbrem. In VII solum cum suis novem diei horis decimbrem ponunt. Quod quidem nos minime reprehedimus, sed qualiter stare queat recte nescimus quia certam dierum vel mensium equiperacionem non videmus sicut superius ullo modo.	Some people used to divide the stone with 7 <concentric> circles, writing inside the first circle near to the centre the name of June alone, with its 15 day-hours; in the 2nd circle, with 14 day-length hour, May and July; the 3rd circle, with 13 hours, April and August; the 4th circle, with 12 hours, March and September; the 5th, with 11 hours, February and October; the 6th, with 10 hours, to January and November; the 7th, with his 9 hours, only to December. This, actually, we do not want criticize, but we do not know how to consider it right, because we do not see a way to face directly months and days as, on the contrary, we can see with the method explained above.
Ut vero ab omnibus facile videri possit ubi I^a et III^a et VI^a et $VIIII^a$ et XII^a sit hora, ab ipsa inferius que noctis est parte, et a circulo qui proprior est centro, atque eciam ab ipsa qua dividitur petra linea, una a leva et altera parte dextera pre / cedit linea. Quarum ipsa que est a leva per omnes progrediens circulos, incidit penes finem spacia prime hore ipsam designando horam. Quod similiter fit in dextera ad demonstrandam horam XII^{am}. De hinc eciam paruissimo ab his interlecto desuper spacio, ab eadem ipsa meridiana linea due oriuntur linee III^{am} in leva, et VIII (sic)[3] *in dextera designantes horam ut supra. De VI autem hora, non est ignorare, quod per omnes circulos vel menses, meridiana respondat linea.*	So actually everyone can easily see where is the 1st, the 3rd, the 6th, the 9th and the 12th hour. From the lower part, that is given to the night, starting from the inner circle and mainly from the meridian line: one is on the left and the other is on the right. And the one that are on the left, extending along the circles, correspond with the end of the spaces of the 1st hour; this happens also to the right with the line of the 12th hour. From here, after a short interval to the meridian line, takes origin other two hour lines: the 3rd on the left and the 9th on the right.[14] One must not forget that the 6th hour is the meridian line that crosses every month circle.

This manuscript was the first to be found and remains the oldest known. The manuscript did not have a drawing of the sundial it described, so Millàs Vallicrosa, who edited it for the first time in 1931, tried to draw one (Fig. 21) by following the description of the text (we now regard it as incorrect). Sixty years later Eduard Farré made a new and better drawing of the dial described in *RIP* (Fig. 22).[15] The text of *RIP*, actually, is insufficiently clear about the hours that must be traced on the sundial. It seems that one must divide every day-arc into 12 hours not in order to show the day hours but only to find and trace the lines of the 1st, 3rd, 6th, 9th and 12th hours, which are canonical times for Prime, Terce, Sexth, None and Vespers. So, following the tradition of the other manuscripts and the *RIP* text, it seems that the drawing of the sundial described in *RIP* should actually be as shown in Fig. 23.

Also, *RIP* uses a different series of values to those suggested by Martianus Cappella, the author rounded all the data for the day-arcs to simplify the sequence. The choice generated a discrepancy between M_d and m_d which he tries to explain in a manner which is, to me, incredible. The reasoning is in these words: "But you must have no doubts of the awarding 10 hours to the diurnal space of December, since the first days of this month have 10 hours and only the last one have 9 hours. The same happens to the month of January; at its beginning the days have 9 hours but at its end it have 10 hours".[16]

Notwithstanding the differences between the calculations of Martianus, Gerbert and *RIP*, the results do not show major differences; there is only an evident contrast at the Winter solstice (see Fig. 25).

REFERENCES & NOTES

1. Surely an error. Read '*horologica*'. This passage is very similar to Bede's *Temporum Ratione*, ch. XXX, "*... et hoc aequinoctium duodecimo Calendarum Aprilium diei veraciter abscribendum, sicut non solum auctoritate paterna, sed et horologica consideration docemur*".
2. Error. Read 'pernotabis'.
3. Incorrect. Read 'viiii'.

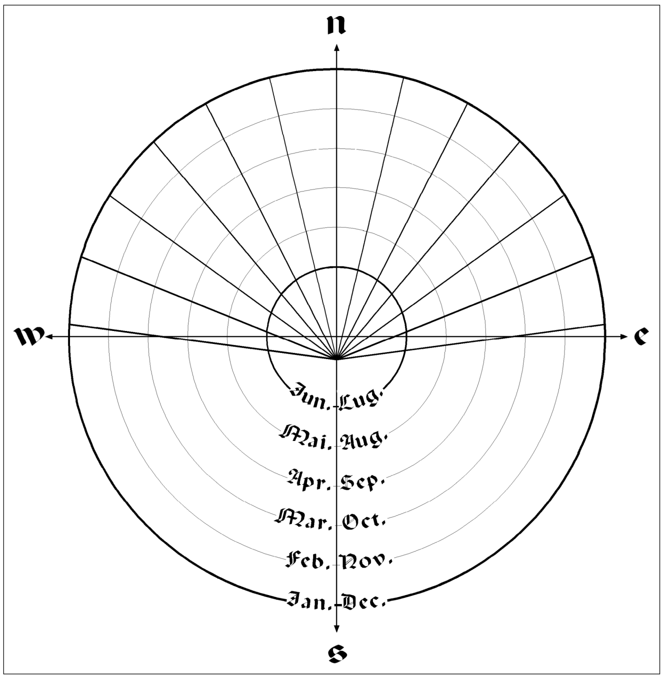

Fig. 21. The sundial drawn by Millàs Vallicrosa.

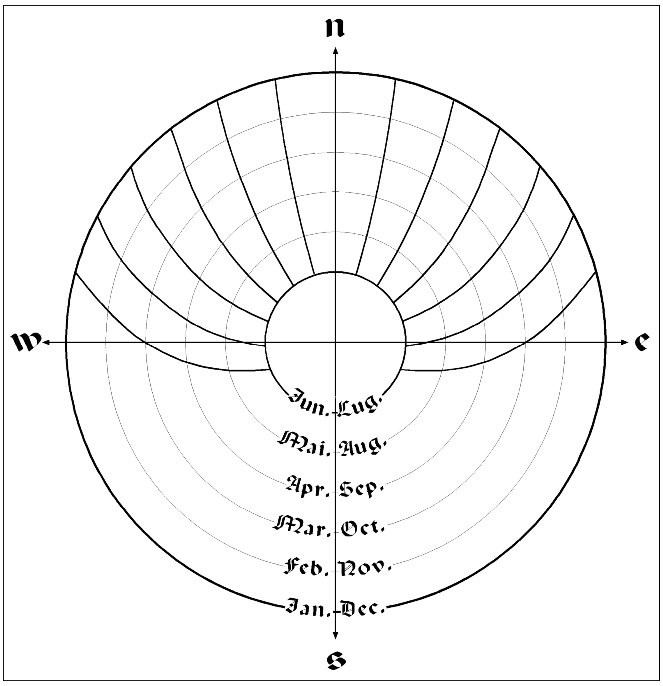

Fig. 22. The sundial drawn by Eduard Farré.

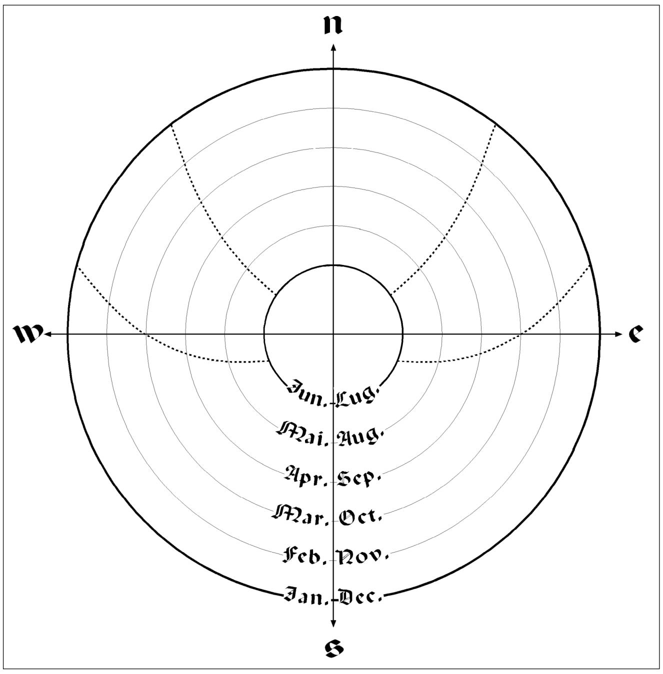

Fig. 23. The sundial as it should be following the RIP text (6 circles).

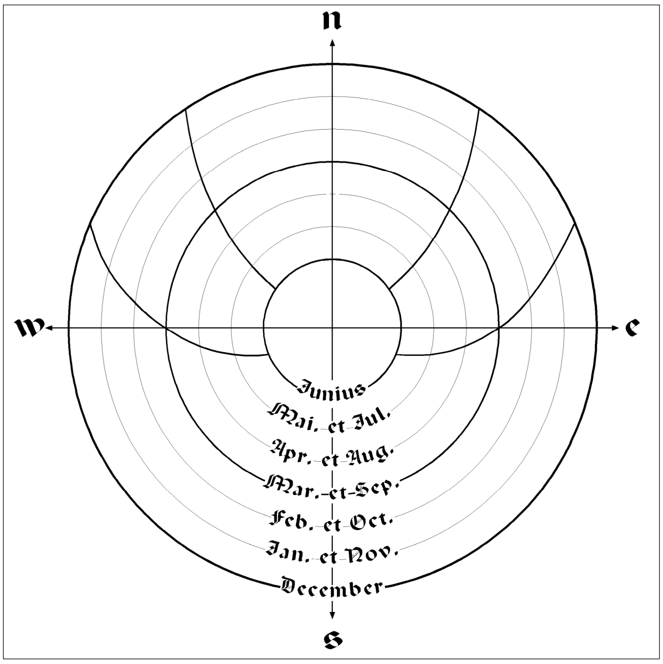

Fig. 24. The sundial as it should be following the RIP text (7 circles).

4. The passage is not clear enough to let us understand that the six circles are concentric, but it will be evident further on.
5. The author here does not mean the circular line but the space between two consecutive concentric circles; a circular ribbon (annulus).
6. These 24 equal parts represent the 24 equinoctial hours of the *nychthemeron*.
7. These are the 15 equinoctial hours referring to the length of the day-light.
8. These are the 12 seasonal (or temporal) hours of the day.
9. This suggests solar months and not calendar months (see Appendix G on the calendar)
10. This statement suggests a tradition older than the date of the manuscript. Solstices, actually, were established at the 12th day before calends by the Council of Nicea (320 AD), to correct the old Julian calendar by moving the Equinoxes. But in the 10th century, the dates of Equinoxes were moved again. So the solstices and almost all the Sun's passages into a new zodiacal sign came on the 15th day before calends. This was recognized by many medieval authors of that epoch, and this why many portable sundials show the passage of the Sun exactly at mid-month.
11. He means the Fathers of the Council of Nicea.
12. The 21st and the 22nd of December.
13. The 20th and the 23rd of December.
14. Here there is surely some error made by the scribe, because the hours (end of the 1st – end of the 12th, then 3rd and 8th) are not symmetrical.

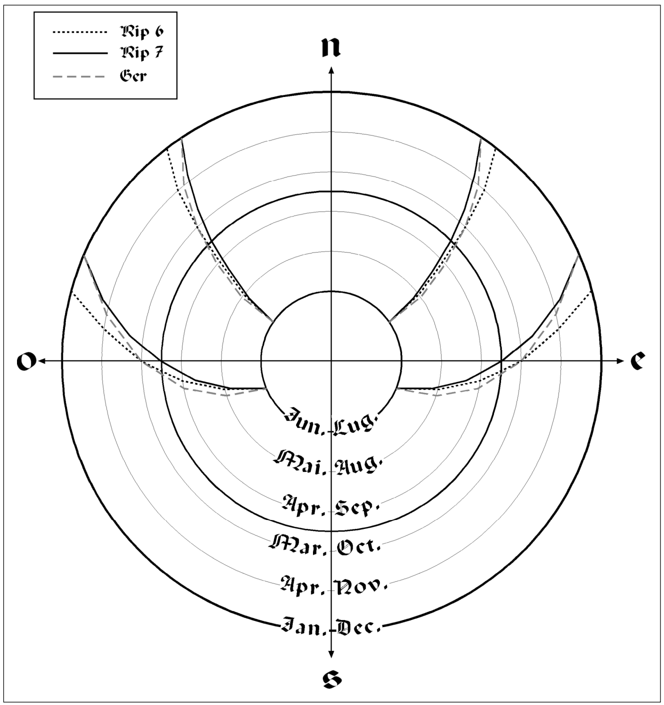

Fig. 25. Comparison of the hour lines made following the G*ER and* R*IP calendars.*

15. Farré (1991).
16. "*De x autem quas diximus esse in decembrio horis, nulla tibi sit dubitacio, quoniam absque ulla ambiguitate sunt in inicio eius x et in fine viiii. Similiter in ianuario, in initio eius sunt viiii et in fine x.*", *RIP*, f. 95r.; Millàs Vallicrosa (1931), p. 319.

APPENDIX C

Transcription, Translation and Discussion of MS. Karlsruhe 504

Ms. Karlsruhe 504

KAR is kept at the Karlsruhe Landesbibliothek, Germany. It is a small parchment codex (200 mm × 144 mm), dated to around the year 1100 and written at the monastery of St Michael in Bamberg (latitude 49° 52′ N) in Bavaria.

The parts referring to sundials are found at ff. 49r–50r with a text titled *Mensura Horologii* (that is, the treatise on the cylinder by Hermann the Lame (Hermannus Contractus)), at f. 88v with two figures of *horologia* (they are simply the quadrant described by Hermann) and at f. 169v (which is the description of our azimuthal sundial) with the title *Mensura cuiusdam horologii*.

Karlsruhe, Badische Landesbibliothek, cod 504, f. 169v. 11th – 12th century.

Mensura cuiusdam horologii	**Rule to draw a certain sundial**
Gnomo istius horologii tantae longitudinis erit, quantum est / spacii a centro usque ad medium circulum, qui dicitur aequinoctialis, / quem etiam si ornatus causa longiorem facere volueris, in loco ubi / predictum spacium terminatur, denticulos extantes pro designa/tione predictae longitudinis ponere curabis, qui ad radium solis / umbram pariant et seriem totius anni in ascensu et / descensu / solis depingant. Dispositio autem mensium talis erit. Lineam, / quae est contra meridiem, in sex aequales partes distribues, et supremam quae minimo circulo, id est solsticio aestivali, est / contigua, in duo aequaliter divides et superiorem medietatem soli / Iunio tribues, infimam vero partem, quae maximo circulo, id est / solsticio hiemali, proxima est, in duo simili modo divides, inferi/oremque medietatem solius Decembris nomine ex utraque parte mediae / lineae inscribes. Deinde spacium quod inter Iunium et Decembrem re/manet in quinque disputes, ubi decem residuos menses tali ordine / dispones. Primo post Iunium spacio maium et Iulium colloca, in / secundo Aprile et Augustum, in tertio Marcium et Septembrem, / in quarto Februarium et Octobrem, in quinto Ianuarium et Novembrem. Sicque fit uti singuli solstitiales menses Iunius scilicet et / December medietatem capiant illius spacii, quod habent duo qui/libet menses alii, insimul autem tantum teneant spacii, quantum / quilibet duo menses alii.	The gnomon of this sundial has a length equal to the distance from the centre to the middle circle, which is called 'equinoctial'; but if, for aesthetic reasons, you wish to make it longer, put an indentation {a nodus} there, to indicate the true length, so that its shadow will be correctly indicated by the sunrays showing the sun path for the whole year.[1] The layout of the months will be in this way: divide the line opposite to midday[2] in six equal parts, and subdivide the upper [section], that is next to the smaller circle (that is, to the summer solstice), in two other equal parts. Give to the month of June alone the upper half, and the lower section, that is next to the wider circle (that is, the winter solstice), divide as before in two equal parts, and in the lower part write only the name of December, part on the right and part on the left of the centre. Then divide the remaining space between June and December into five [sections], where you will dispose the ten remaining months in this order: In the first sector after June write May and July, in the second one April and August, in the third one March and September, in the fourth one February and October, in the fifth one January and November. And so it happens that the single solstitial months, June and December, occupy half of the space required for each pair of months, and together take the same width as that occupied by each pair.

Other than the text on azimuthal sundials, *KAR* has some similarities with *DAR* (which we will see later in Appendix D): both are of a small size suitable for the pocket and with miscellanies of astronomical, computational, musical and mathematical texts. Both have the text on the *horologium viatorum* by Hermann the Lame and the *Micrologus* of Guido of Arezzo. But in spite of this there are only a few textual concordances between the two sundial texts. Basically, there are two points of common agreement:

- the gnomon must have a specific length
- the calendar on the dials has the same layout.

There are no other concordances or discordances between *KAR* and *DAR* simply because *KAR* is unfinished.

The Drawing of the Circles

The *KAR* manuscript is incomplete; it omits the section where the hour line construction should be described. In it we find only the explanations for drawing the monthly circles and the related calendar.

The drawing of the circles in *KAR* is not well explained, nevertheless we can understand that *KAR* uses seven concentric circles. The circles are equi-spaced, but they are made in a complicated manner. First we are told to divide

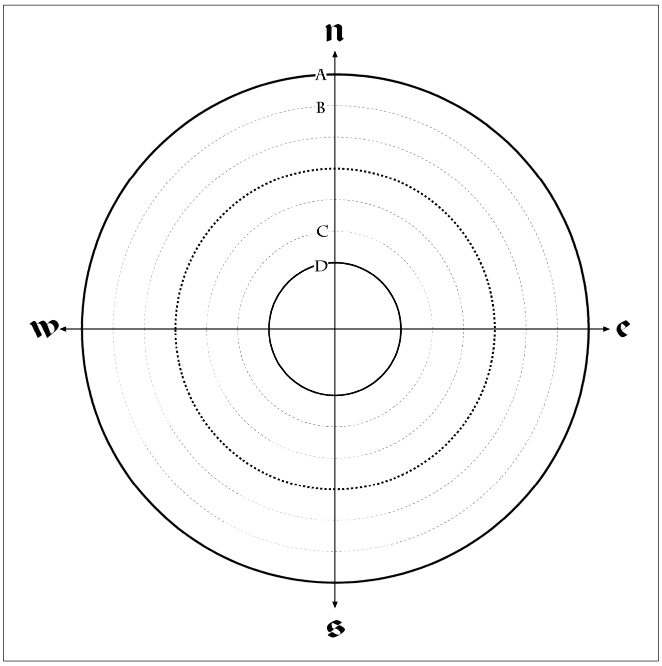

Fig. 26. Construction of the concentric circles following the text of ms. Karlsruhe 504 (first step).

the distance between the smallest and the largest circle into six equal parts, which in Fig. 26 are marked A and D, and then draw the circles.

These circles are drawn to allow the construction of the final circular bands so they are invisible, but they are shown here with dotted lines.

Then the writer tells us to divide the distance between the two extreme circles and the innermost one (AB and CD) in halves, as shown in Fig. 27.

The space between the two innermost halves, just obtained, must be split in 5 equal portions creating 5 concentric bands bordered by two halves (Fig. 28).

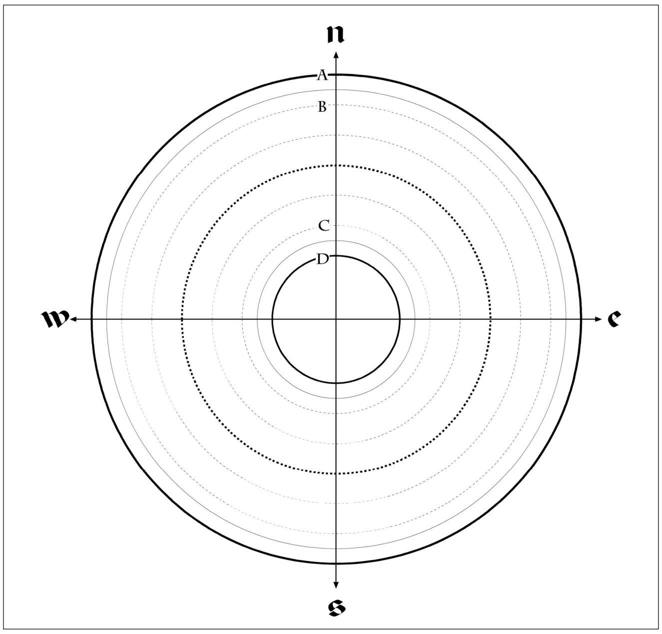

Fig. 27. Construction of the concentric circles following the text of ms. Karlsruhe 504 (second step).

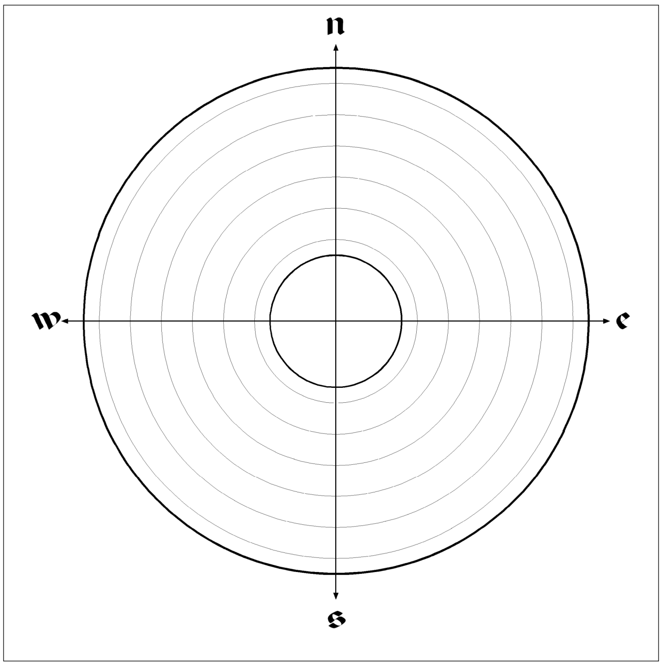

Fig. 28. Construction of the concentric circles following the text of ms. Karlsruhe 504 (third step).

The outer and the inner bands are named with the appropriate solstitial month and the circles between them will carry the names of the other months (Fig. 29).[3]

This kind of division generates 13 circles (8 visible and 5 invisible); Fig. 30 shows that they mark alternately the 'calendar months' (solid lines), this is, from the first to the last day of the month, and the 'Solar months' ('invisible' dotted lines), that is, from the day of the sun's passage into a zodiacal sign until the passage into the next one.[4]

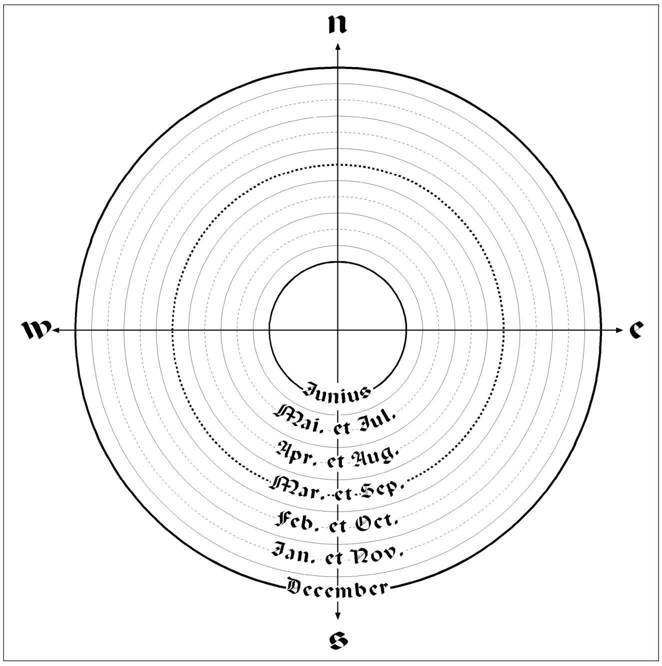

Fig. 29. The calendar settings following the text of ms. Karlsruhe 504 (third step).

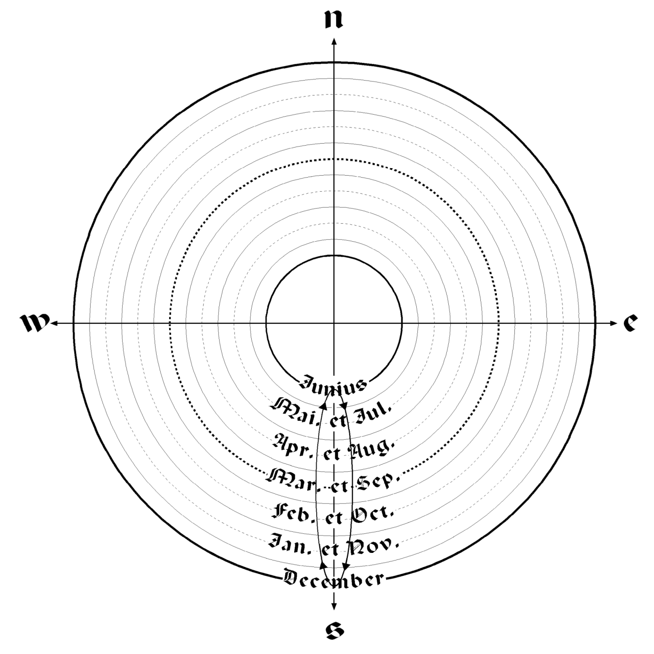

Fig. 30. Visible and invisible circles following the text of ms. Karlsruhe 504.

REFERENCES & NOTES

1. That is, for the days of all lengths.
2. The scribe, omitting the basic explanation about the construction of the concentric circles, forgets to say that the line in question is the diameter of all the circles and passes through the common centre. This line represents the meridian, so the radius opposite to the South (Midday) and directed northwards will be the meridian line, that is the hour line for the sixth temporal hour; the radius directed southwards will be the midnight line and on it there will be written the names of the months.
3. "*uti singuli solstitiales menses Iunius scilicet et December medietatem capiant illius spacii, quod habent duo quilibet menses alii, insimul autem tantum teneant spacii, quantum quilibet duo menses alii*", (*Kar*, lines 20–23).
4. The names of the intervening months do not refer to the beginning of the month but to the day of the passage of the Sun to the next zodiacal sign.

APPENDIX D

Transcription, Translation and Discussion of MS. Darmstadt 1020

DAR has been dated to the beginning of the 12th century. It was mainly written in the monastery of St Jacob at Liège in modern Belgium (latitude 50° 39′ N) by a single hand.[1] At the end of the codex a section can be found with short texts dedicated to describing sundials: one of them is the object of our study and it can be found at ff. 63r–63v. Halfway down f. 63v a section has been left blank, perhaps waiting for an illustration. *DAR* is, together with *RIP* and *FIR*, the most complete text about the construction of this kind of sundial; it lacks only a drawing.

Below is the transcription and translation of the ms.

Ms. Darmstadt, Landesbibliothek, codex 1020, ff. 63r, 63v – 11th-12th century

Mensura horologii	**Rule for making a sundial**
Horologium solare facturo VII clima/ta mundi que Ptolomeus rex tot gnomonum constitutio/nibus invenerat memoriae commendasse non erit inutile./	To whoever intends to make a sundial,[2] it will be helpful to have committed to memory the seven climates of the world that king Ptolemy found with the construction of so many gnomons.[3]
*Orologium igitur facturus constitue circulum ad libi/tum quem secabis in XXIIII^{or} partes, quae XXIIII^{a} pars faci/et minimum. Inter quem et maximum V facies circulos / aeque distantes a se, duces que radios XXIIII^{or} a minimo / ad maximum, per supradictas maximi circuli XXIIII^{or} sec/tiones. In quorum uno ubi eum medius vii circulorum te/tigerit, **S** litteram nota, ad quam totius horologii regu/la pendet et ubi sexta hora totius anni recurrit.*	When you are ready to make this sundial, draw a circle as large as you want that you will divide into 24 parts and one 24th of this circle will give the measure {read “the radius”} of the smaller one. Between the smallest and the largest circles you will trace five circles equidistant between them, and you will conduct 24 radii from the smaller [circle] to the greater one through the above-mentioned 24 sections. In one of those [radii] you will mark the letter **S** at the point where it [the radius] will cross the 7 circles in the middle. From that point the whole sundial delineation depends, and there will be the sixth hour for the whole year.
*A quo / **S** in quarto radio extremi circuli sinistrorsum **O** litteram pone / **S** tamen a te verso. A quo **S** in VII^{mo} radio medii circu/li ponas **R**. Rursumque a supradicta **S** in decimo radio in/fimi circuli ponas **T**. Per quas tres litteras id est **O. R. T.** / arcum duces aptato circino, quem in XC signabis punctos / qui sunt loca tot ortuum solis diversorum euntis et redeuntis, / ad cuius arcus similitudinem dextrorsum pones alium per **O** / interius, **C** medium **C** exterius, qui simili quoquo modo / per suos XC punctos tot solis demonstrat occasus. Rursus si/nistrorsum a predicta **S** inter secundum et tertium radium exterius / pones **T** et in quarto medii **E** et inter V^{tum} et VI^{tum} interius po/nas **R** per quas duces arcum in XC quoque partes distributum ad / designandas tertias anni totius horas. Ad cuius similitudi/nem dextrorsum pones arcum, per **N** interius **O** medium **N** ex/terius, quem etiam XC puncti ad <designandas> tot diversas nonas horas / anni signabunt.*	From the point **S**, towards the left, maintaining the point **S** opposite to you, you set the letter **O** near the fourth radius of the outside circle. From the same point **S**, you will write an **R** near the 7th radius on the median circle. Then still from the aforesaid point **S** you will affix the letter **T** on the tenth radius of the smallest circle.[4] Opening the compass, through these three letters, that are **ORT**, you will trace an arc that you will mark with 90 points, to <represent> all the different points of the sunrise [on the horizon], both in going and return.[5] Equally, towards the right, trace another arc where you will set the letter **O** on the innermost circle, **C** on the middle one and **C** on that towards the outside that similarly through the 90 points shows every sunset point.[6] Returning from the left part, from the aforesaid letter **S** you write **T** between the second and the third ray of the external circle, and in the quarter of the median one writes **E**, and between the 5th and the 6th radius of the innermost circle the letter **R** will be marked,[7] across which make an arc that will also be divided into ninety parts that will point out the third hour for the whole year. In the same way, make an arc towards the right, through the points **N** on the inside circle, **O** on

Et sic minimus circulus solstitialis estivus, Iu/nio deputatus. Secundus, Maio et Iulio. Tertius, Aprili et / Augusto. Quartus, qui equinoctialis est Martio et Septem/ ber. Quintum, Februario et October. Sextus Ianuario et No/vember. Septimus, id est extimus solstitialis hibernus, December. Gno/mo vero, cuius a multis tacita mensura est vel invidia vel insci/tia, usque ad medium circulum a centrone {sic} pertingere debet, / ad cuius umbram totum respicit horologii commodum. Ad quod / ponendum ponas oculum ad lineam Decembris / versam ab ***S*** *et diligenter notato polo per ipsum / Gnomonem stabili mansione loces.*

Quando et quomodo sta/tuatur

Horologium istud nocte tantum potest statui, / ***S*** *ad aquilonem verso, et Decembris linea ad polum / rectissime directa, sub eadem etiam stella, / fit autem in lapide.*

the middle one and **N** on the outermost.[8] This arc will also be divided into 90 points in which the ninth hour falls for all the year.

And so the smallest circle {that is} the summer solstice will be assigned to June. The second to May and July. The third one to April and August. The fourth, that represents the equinoxes, to March and September. The fifth one, to February and October. The sixth to January and November. The seventh one, that is the greatest {that is the winter solstice}, to December. The gnomon, whose size many have left unsaid whether for envy or for ignorance, has to have the same length as from the centre to the median circle. To its shadow the goodness of the whole sundial is submitted. For positioning this dial put your eye on the December line {the meridian line}on the opposite point where **S** is written, and having carefully observed the Pole by the gnomon: you will fix the dial in that position.

When and how [the sundial] is to be set

This dial can be positioned at night only, with **S** toward North, and with the December line {the meridian line} exactly in line with the star at the pole. Mark this on the stone.

The Making of Circles

In *Dar* we read that we should trace seven concentric circles starting, first, from the largest one (representing the winter Solstice) that we may take as large as we like. The 24^{th} part of its circumference gives us the radius of the smallest one (the summer Solstice). From here should be traced the other five circles, simply dividing the space between the large and the small circle into six equal parts. The names of the months are set as in *Kar* (Fig. 31).[9]

What we see here are the same invisible circles as for *Kar*. This means that the calendar is different. In *Kar* the circles show the beginning and the end of every month; in *Dar* they show the passage of the Sun into each Zodiacal sign.

The Hour Lines

The exact method of positioning the hour lines is similar to the one used by *Rip*. The circles must be divided into 24 equal parts by invisible radii. Each section marked by two radii represents one equinoctial hour. Beside the meridian

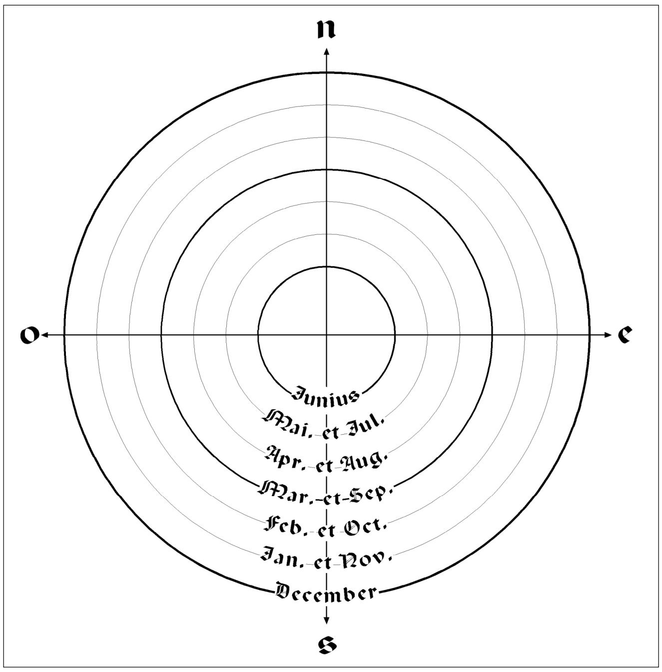

Fig. 31. The seven concentric circles and the calendar following the instructions of ms. Darmstadt 1020.

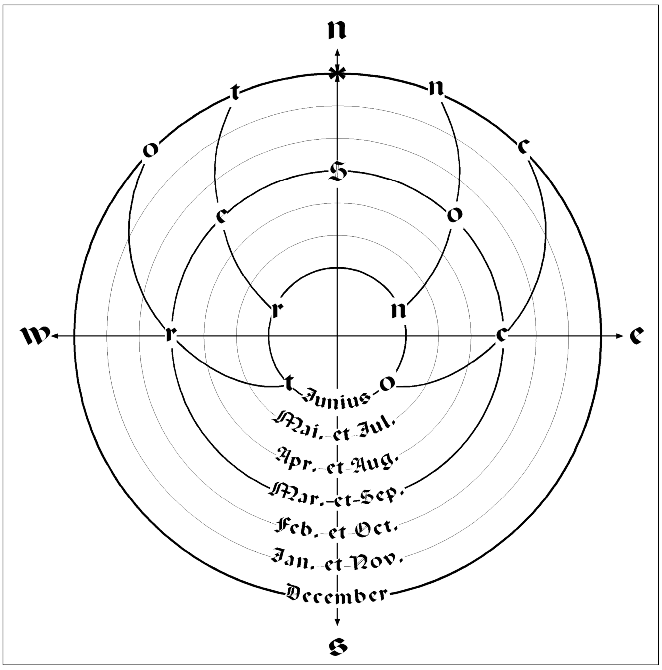

Fig. 32 The hour lines of the azimuthal sundial drawn following the instructions of ms. Darmstadt 1020.

line, one has to count the hours that take place in half a day on the three most significant circles (the largest, the middle and the smallest) and mark the points. Then, joining these points, we draw the hour line.

The hour lines are actually curves; they are drawn as circular arcs by the 'rule of three points'. Not all the hours of the day are shown but only the most important four in the ancient period: Prime, third, sixth, ninth and Vespers. Dividing the day (and night) into four parts was not only a common practice in monastic communities, but, as is attested by Varro, Censorinus and Tertullian, it was a common usage even in Roman civil life.[10] So here they are named, as in *RIP*, not as Canonical hours, but simply as points of the day and seasonal hours.[11] As an aside, knowing that both manuscripts come from monasteries, we can easily suppose that the lines marking sunrise and sunset are the times for Prime and Vespers, as they were traditionally chanted (see Fig. 32).

From the data given by *DAR* for drawing the hour lines, we know that the dial has been calculated for the climate where the longest day is 18 equinoctial hours long.

REFERENCES & NOTES

1. One note written in the 15th century tells us that the book came from the Monastery of St Jacob in Liège and its title was 'Computus of the Abbot Helpericus'; (*Liber monasterii Sti. Jacobi Leodiensis, cuius titulus est Helpericus abbas de compoto (sic)*).
2. As we know, the word *Horologium* had many meanings in the past; in this case we are sure of our translation. *Horologium solare* (sun-clock) unmistakably indicates a sundial.
3. The author means that one should keep in mind the values of M_d and m_d for each of the seven climates in order to be able to make correct sundials for every climate.
4. The letters **O**, **R** and **T** show the construction points of the hour line for sunrise (***ORT****[tus] solis*).
5. That is: from winter to summer and back.
6. The letters **O**, **C** and again **C** show the construction points of the hour line for sunset (***OCC****[asus] solis*).
7. The letters **T**, **E** and **R** indicate the third hour (***TER****[tia]*).
8. The letters **N**, **O** and **N** indicate the ninth hour (***NON****[a]*).
9. "*Orologium igitur facturus constitue circulum ad libitum quem secabis in xxiiiior partes, quae xxiiiia pars faciet minimum. Inter quem et maximum v facies circulos aeque distantes a se, duces que radios xxiiiior a minimo ad maximum, per supradictas maximi circuli xxiiiior sectiones. In quorum uno ubi eum medius vii circulorum...*", (*DAR*, lines 4–9).
10. "*Hoc idem Cosconius in Actionibus scribit praetorem accensum solitum tum esse iubere, ubi ei videbatur horam esse tertiam, inclamare horam tertiam esse, itemque meridiem et horam nonam*", Varro, *De Lin. Lat.*, VI, 9; "*Alii diem quadripartito, sed et noctem similiter dividebant. Idque consuetudo testatur militaris, ubi dicitur vigilia prima, item secunda et tertia et quarta*", Censorinus, *De die nat.*, xxiii, 8–9; *"... tamen tres istas horas* (third, sixth and ninth) *ut insigniores in rebus humanis, quam diem distribuunt, quae negotia distinguunt, quae publice resonant...*",Tertullianus, *De Ieiunio*, x, 3. See also Arnaldi (2011), pp. 165–168.
11. In *RIP* we read: 1st, 3rd, 6th, 9th and 12th hour; in *DAR* we read: ORT[us], TER[tia], S[exta], NON[a] and OCC[asus] (that is: sunrise, 3rd, 6th, 9th and sunset).

APPENDIX E

Transcription, Translation and Discussion of MSS. BnF lat. 7412 (*PAR*$_1$); BM Old Royal 15 B IX (*LON*); BnF lat. 12117 (*PAR*$_2$) and Montpellier H48 (*MON*)

There is a series of manuscripts that I believe should be considered together, simply because they are the only ones I know that show a drawing of the sundial and look to come from a common source. Notwithstanding that, there are significant differences between them, so that they can be divided into two families which I document below.

The common characteristics of the two families are: the tree-like shape of the hour lines, the same monthly calendar, the line of Prime drawn one hour after sunrise and the hour of Vespers traced one hour before sunset.

FIRST FAMILY

This first group of two manuscripts have in common: short explanatory text inserted inside the circles, the names of the hours in full and the calendar written along the trunk (north-south line toward south) of the 'hour-line tree'.

MS. BnF lat. 7412

In 2008 Annalisa Borrelli published in Germany her book *Aspects of the astrolabe: 'architectonica ratio' in tenth- and eleventh-century Europe*. On pages 197–203 she discusses a drawing in the 11th-century manuscript BnF lat. 7412, which she recognizes as a sundial thanks to a verse written along the lower rim of the figure: "*Sub radiis Phebi sunt hec signacula plebi | in quibus absque mora lucis dinoscitur hora.*" (Under the rays of the sun {Phoebus} these are marks for the people | which by means of the shadow instantaneously show the hour). Borrelli, misled by the article of Josep Casulleras on the dial in *FIR*, describes the dial in Ms. BnF lat. 7412 "equatorial".[1]

The drawing shows a dial with 7 concentric circles crossed by a shape similar to a tree that shows the three hour lines of the canonical hours: Prime, Terce, Sixth, None and Vespers (Fig. 33).

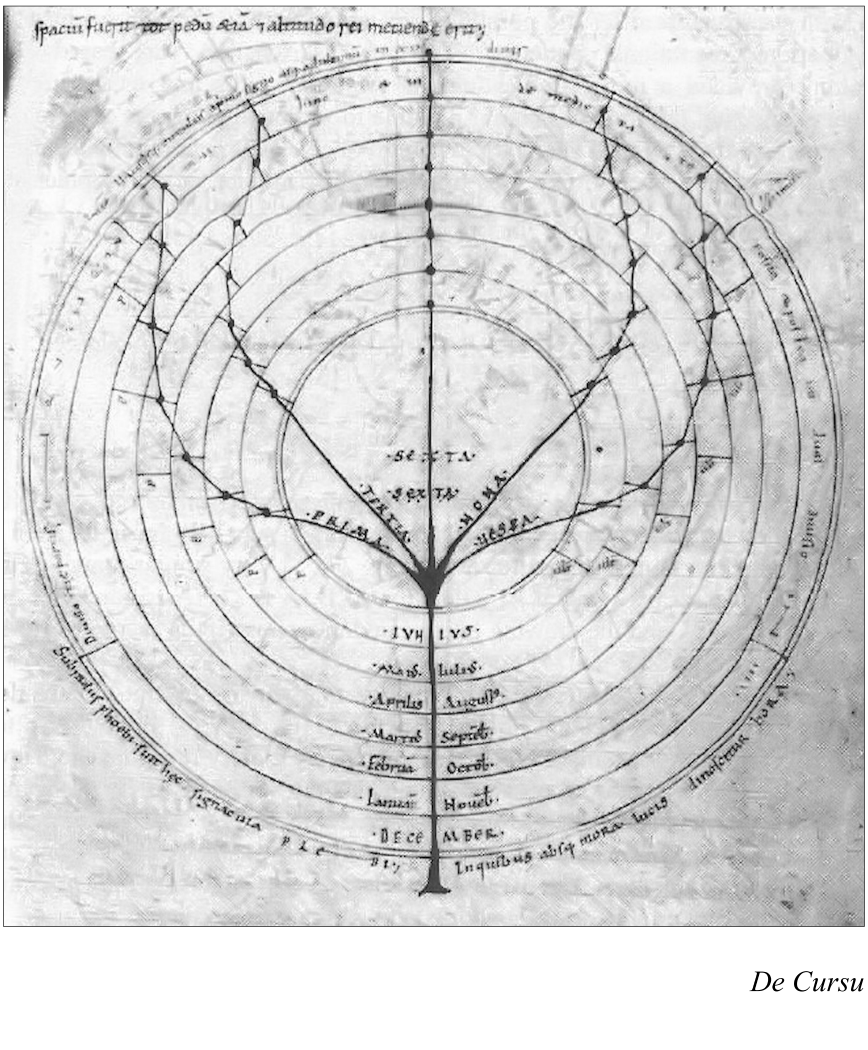

Fig. 33. The drawing of the sundial in ms. BnF lat 7412, f. 19r.

The drawing is at f. 19r but it does not have an accompanying text explanation; nevertheless, some captions inside the figure of the sundial do provide some explanation. The captions are transcribed and translated below.

Ms. BnF, lat. 7412, fol. 19r
(the sign " | " represents the meridian line in the drawing)

1 - Outside the upper part of the largest circle *"primum <signum> – unusquisque circulus a primo | signo usque ad ultimum in xii divisus (est) – ultimum <signum>"*	"first <sign> – Every circle, from the point of the first | sign up to the last one should be divided by 12 – last <sign>"
2 - Outside the lower part of the largest circle *"Sub radiis Phebi sunt hec signacula plebi | in quibus absque mora lucis dinoscitur hora"*	"Under the rays of the sun {Phoebus} these are marks for the people | which by the mean of the shadow instantaneously let recognize the hour"
3 - Inside the circle for December *"Divisio tercie partis in quinque et quinque in duo, hinc et inde | medietate posita et postea inter duas divisio in iiii"*	The third part {of what?} <must be> divided in five, and the fives in two, then put the middle between the extremes and after divide the two halves in 4.
4 - Next to the hour lines *"prima", "tertia", "sex | ta",*[2] *"nona", "vespera"*[4]	"prime", "terce", "six | th", "none", "vespers"
5 - Next to every circle, almost 1 hour before prima *"P[rimum signum]"*	F[irst sign]"
6 - Next to every circle, almost 1 hour after vespera *"Ult[imum signum]"*	"Las[t sign]"
7 - Next to every circle, left and right of the meridian line toward the North *"Iun | ius"* *"Maius | Iulius"* *"Aprilis | Augustus"* *"Martius | September"* *"Februarius | October"* *"Ianuarius | November"* *"Dece | mber"*	"Ju | ne" "May | July" "April | August" "March | September" "February | October" "January | November" "Dece | mber"

Almost all the text inside the drawing is clear enough to be understood, except for sentence no. 3. Translation has not been easy and much is still obscure. It seems that it is explaining a division into 120 parts, but what if the subject of this partition is remains a mystery: the whole circle? All the circles? Only a part of the circle? Something else? I hazard that this division is of the whole external circle simply to provide a finer resolution of the 24 hour-sectors. In this way we obtain hour-sectors partitioned into five, each equal to 2 medieval minutes.[4]

The hour lines are different from those of the other manuscripts. In the drawing we can see the hour lines of *Prima*, *Tertia*, *Sexta*, *Nona* and *Vespera*, but to these lines we should add two others: *p[rimum signum]* and *u[ltimum signum]*. These two lines are invisible in the manuscript and indicated only with short line marks. These represent sunrise and sunset times, as we we are clearly told by sentence no. 1 in the drawing.[5] This is significant because Prime (*Prima*) is not written, as it should be, on the line for the rising sun (as we know time for Prime is sunrise) but at the end of the first temporal hour and Vespers (*Vespera*), on the other hand, is shown at the end of the 11^{th} hour of the day.[6]

We are thus faced not with a traditional disposition of the canonical hours but, as one can see on many medieval sundials, with a shifting of canonical hours of Prime and Vespers, sung one hour after and one hour before the ancient canonical time for them.

A test (Fig. 34) made by simply superimposing the construction lines and adjusting the imperfect drawing, revealed that the dial was made for a climate of M_d = 18h and that it used the RIP formula to draw the hours lines. In other words, increasing every day-length for each pair of months of 1/6 of ΔM (in this case of two units per step: 6, 8, 10, 12, 14, 16 and 18 equinoctial hours).

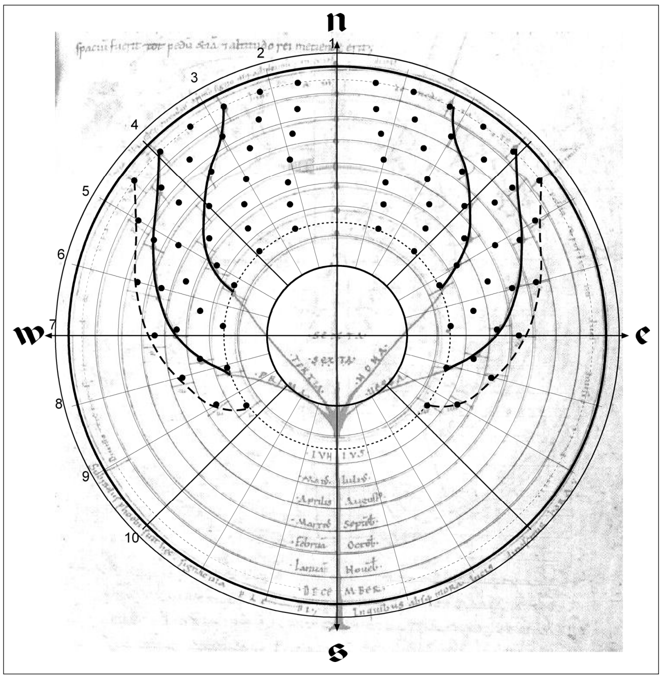

Fig. 34. The drawing of the sundial in ms. BnF lat 7412, f. 19r superimposed by the web of the 24 equinoctial hours. It appears that the dial has been made for the climate M_d = 17h. Primum and Ultimum signum have been traced here with dashed lines. Dots show the position of the 12 hour lines.

MS. BM Old Royal 15 B IX

[Editor's Note: Manuscript LON was given its current designation at a time when the British Library was located within the British Museum, in the Reading Room at Great Russell Street. The British Library is now a totally separate institution, located near St Pancras Station, and the manuscript has been transferred there. Rightly, it should now be designated Brit. Lib. Royal 15 B IX but, because the abbreviation 'BL' is often used for the Bodleian Library, Oxford, which would thus cause confusion, the original designation has been kept.]

Dr Admin Zenner studied this manuscript and wrote his conclusions in 1999.[7] I greatly agree with many of his words but I want add something more to his research.

This is one of only a few Latin manuscripts that shows the figure of the sundial. The drawing is on f. 77r but it does not have a proper text explanation. Nevertheless, on f. 76v we can find three micro texts, or chapters, which Zenner did not consider but which describe the original principle. Further, some captions inside the figure of the sundial give more explanation.

Ms. BM, Old Royal 15 B IX, fol. 76v, rows 7-12

Cum inveniendum in aliquo loco, aliquo tempore qua rite sit oriens*, facto circulo in pulvere plane terre, aut in aliquo plano subiecto medio centro stilus recte figatur. Eius umbra in mane ultra circulum progrediatur; terre ante horam VI notabum circuli locum per quem stili umbra intraverit intra circulum. Deinde similiter in exitu nota per quem locum umbra exierit extra circulum. Post hoc per medium divide spacium quem inter locum primo notatum ingredienda umbra, et locum secundo notatum in egredienda umbra,*[8] *et ubi utriusque loci medietas veniet ibi oriens et contra illam partem esse dicatur.*	**When you want find correctly, for any place and any time, where is the East**, trace a circle in the dust on the ground, or on any suitable plane, fix a stylus at the centre. Its morning shadow progresses beyond that circle; [so] before the sixth hour must be marked the place where the style's shadow enters inside the circle. Then, similarly, mark the place where the shadow exits from the circle. Then, divide the space between the first and the second places that you marked when shadow was passing in and out the circle, and where is the half [of the space between] both signs, there you will find East, and the [second] half is the opposite.[9]

This is discussing the basic function of a gnomon: to find true South. In this case the text is quite different: strangely it suggests how to find the East. Figure 35 shows my reconstruction of the method used.

The text seems to be copied from an ancient text but it presents many errors: wrong words and repeated sentences and words. Surely the scribe was not an expert in the subject he was copying because the description of so simple a construction is totally confused. He did not realize that the mid-point between the two marks is needed to find the meridian line. It seems that he did not even know what a straight line is.

I do not understand why he wanted to find East at all, unless there is connection with maps or church alignments.

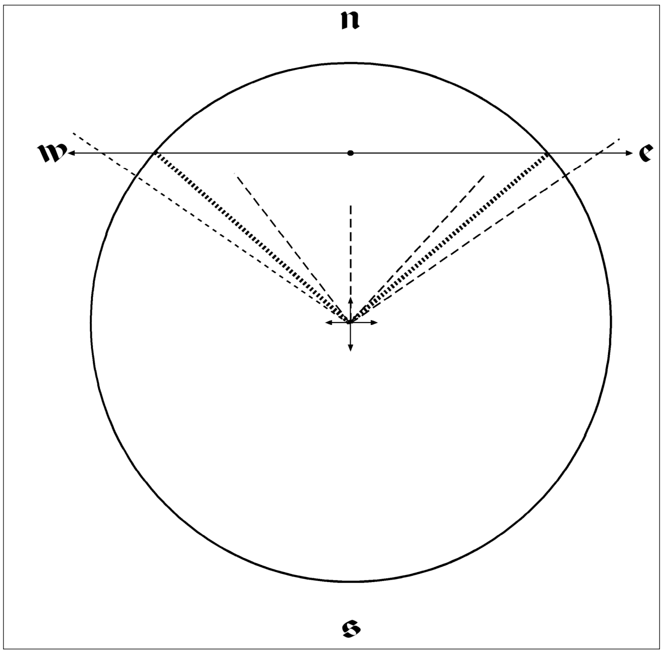

Fig. 35. The unusual way of finding East described in ms. BM, Old Royal 15 B IX.

Then at rows 13-21

***Si autem inveniendum est quo die et quando solsticia vel equinoctia sint**, fac circulum in aliqua planitie, divideque eum equaliter in IIII partes et lineis cancellarim ductis per medium, stilum pone in centro. Deinde, partito circulo in XII, in quibus inscriptis XII lucente sole poterit sic cognosci, in cuius signi fine vel in quo die solsticium vel equinoctium sit, huiusmodi quidem circulo sic preparato, orto sole sapienter perspice si stili umbra super lineam que per medium ducta est cadit, ac in ea die, et in illius signi fine equinoctium esse proferatur quo stili umbra super mediam circuli cadere videatur. Deinde invento quo die equinoctium sit despice quamdiu sol ascenderit, vel descenderit, per eundem circulum.*	**If, however, you wish to find on what day and when solstices or Equinoxes will happen**,[11] trace a circle on some plane surface and divide it equally into 4 portions; and when you have done it by two perpendicular lines that cross in the middle put a style in the centre. Then, having divided the circle in 12 [portions], it will be possible to find in them, by the sunlight, in what end of Sign or in what day the solstice or equinox is. With such a circle so prepared, look carefully, at sunrise [to see] if the stylus shadow falls on the line that has been drawn in the middle [of the circle].[12] On that day and in that end of Sign, when the gnomon shadow is seen to fall along the [line that divides] the circle in the middle, it is to be declared the equinox. Then, after it is found when is the day of the equinox look down constantly the sun to ascend and descend on the same circle.[13]
Post hoc extremo ascensionis vel descensionis termino notato, eo die quo terminus ascendendi vel descendendi occurrit, solsticium esse percia.	After having marked [on the circumference] the extreme points of the [sun's] highest ascent and the lowest descent, that day you can declare as the solstice.
Dicunt ut quidam XV <Kal.> mensium solsticia vel equinoctia esse, quidam xii quidam VIII kalendis. Proinde hoc est comprobandi ratio.	Some say that the solstices or the equinoxes happen at the 15th <day before Calends>, others at the 12th, others again at the 8th day before Calends of the referenced months.[14] So, this the way to verify the correct criterion.

This text teaches how to find the days of the two Equinoxes and the Solstices by looking at the rising and setting points of the sun on the horizon. The division of the circle into 12 parts that represent the zodiacal ring is not needed in this instrument, but its inclusion creates a lot of confusion. Most probably the writer did not understand an astronomical drawing of the zodiac (that runs along the ecliptic circle) with the plane of the horizon. With the method suggested here one can read correctly only two rising points on the horizon: the two equinoxes.

Nevertheless, we know other diagrams with the same misconception: one can be seen in ms. Herzog August Library Wolfenbuttel, Cod. Guelf. 1 Gud. Lat. (Fig. 7, chapter 2 of this work) and another that I know is ms Laon Bibl. Mun. 422, f. 43v, redrawn here in Fig. 36 (overleaf).

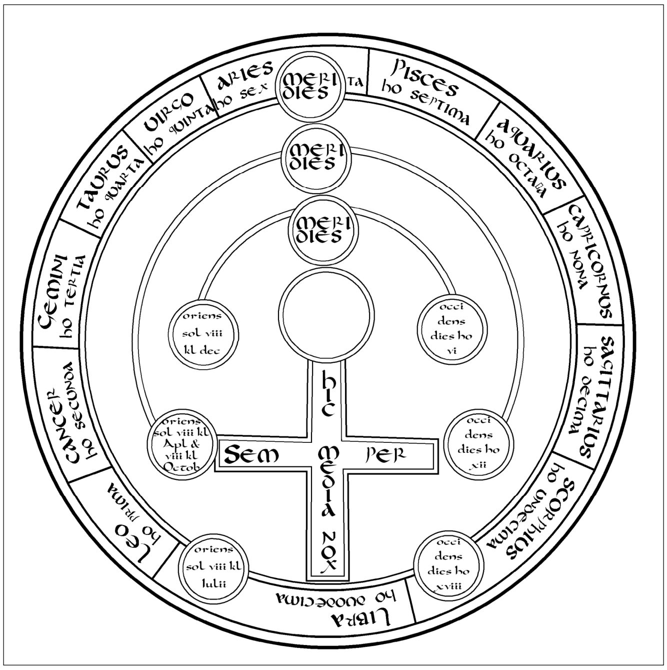

Fig. 36. Copy of the Cursus solis *diagram in ms. Laon Bibl. Mun. 422, fol. 43v.*

And at rows 22-26 of the same folio:

***Qui vult in quolibet loco scire quante sunt diei noctisque hore**, circulum in aliquo plano fixum per* XXIIII *parciatur, in cuius medio stilus fixus <et> summo mane ad ortum solis ponatur. Cuius radius cum apparuerit consideretur in quo circuli loco stilus fecerit umbram. Post vero peracto diei cursu consideretur quo in loco stili umbra descenderit, atque inter ortum et occasum inspecte divisiones: hore diei esse dicantur, relique noctis.*	**If it is wanted to know in any place how many hours are in the day or the night**,[15] let us partition into 24 sections a fixed circle on some plane surface in which a fixed stylus is to be set at the centre <and> early in the morning, at sunrise, is to be noted where on the circumference the shadow of the stylus is pointing. Then, at the end of the day, is to be marked the place where the style shadow ends. So, the sectors between sunrise and sunset will be called the daylight hours; the remaining ones are for the night.

This is similar to the setting of the day-length on the circles of the azimuthal medieval sundials. What makes the difference between this text and those which we know on azimuthal sundials, is that in this case there is no use of tables of the day-length. Everything is found by sight, experimentally.

At f 77r we can see the drawing of the sun-dial (Fig. 37 and on the front cover) which is exactly the same as that of P_{AR_1}, discussed above. but more artistic. Inside the concentric circles we can read the same explanatory text, which does not need to be repeated.

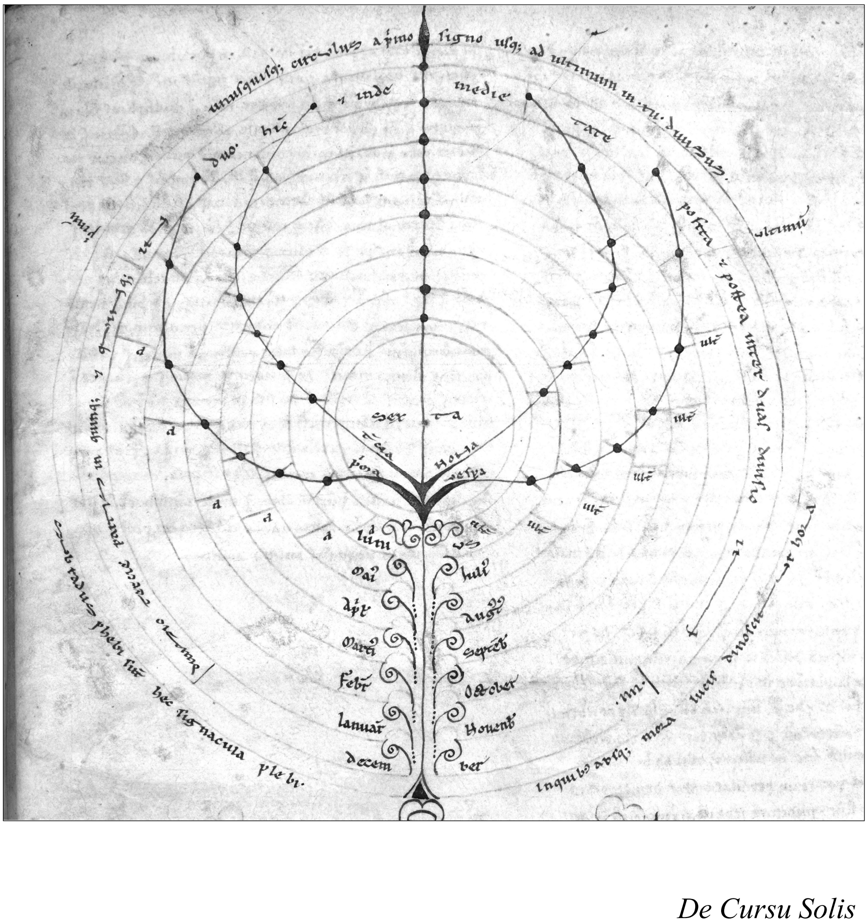

Fig. 37. The drawing of the sundial in ms. BM Old Royal 15 B IX.

As an aside, the drawing presents many geometric problems and incongruities which are displayed in Fig. 38. We can see that the circles are divided into 24 portions as described in lines 22-26, f. 46v, and we notice three things:

1. the carelessness of the medieval artist in drawing the hour lines,
2. the incorrect day-length between the two solstices,
3. the asymmetry of *Terce* and *Nones*.

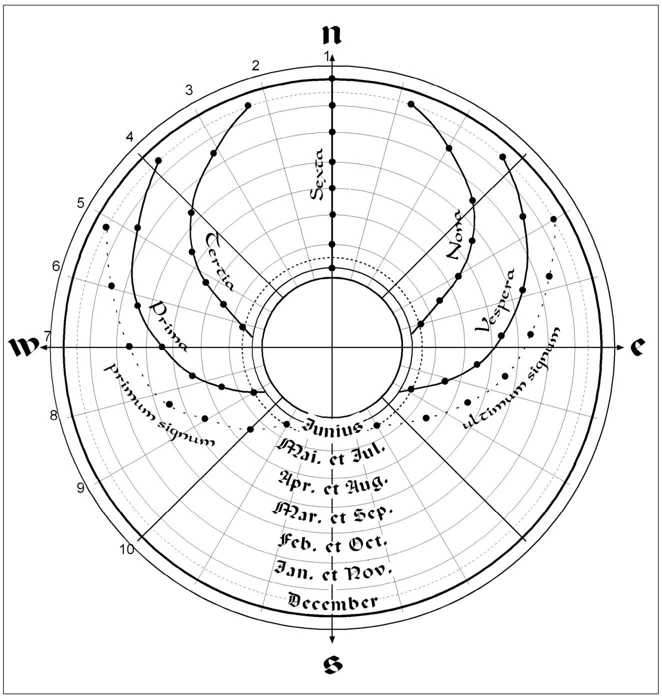

Fig. 38. Reconstruction of the sundial. The 24 radiating lines indicate the inaccuracy of the measurements for the day-arcs.

Zenner was lenient to the medieval artist of the figure: he noted the incorrect values and he rounded them generously. Too lenient in my opinion, because he does not identify a significant error made by the artist, as evidenced by the second problem: the incorrect day-length between the two solstices.

If we count, on the circle of the Winter solstice, the number of sectors between noon and the first sign (*primum signum*) or the last one (*ultimum signum*), we will find four sectors (I will consider sectors rounded to whole numbers or to halves although the original drawing is not very careful). This means that the day-light at Winter solstice lasts 8 hours. So we should expect a Summer solstice day-length equal to 16 hours, but if we count the sectors between the first and the last sign there, we find 10, that is 20 hours, making the *nychthemeron* 28 hours long. This, of course, could not be. So where is the error?

For a moment, forget that an hour is one 12th of the day-length, between the first and the last sign, and suppose that those two signs are not for the sun on the horizon but for the morning and evening twilights points. In this case we will have Prime exactly at sunrise, as it should be, and Vespers at sunset (this is correct too). This can work but, again, if we count the number of sectors at the Winter solstice we read 6 hours and we expect 18 hours for the Summer solstice, but we actually count 16, making the *nychthemeron* 21 hours long. This is also incorrect.

The solution to this problem is not easily found. Certainly, the carelessness of the medieval artist has a great part in it. Nevertheless, the drawing gives us clues, as we will see below. To solve this second problem we should start to find for which latitude, or climate, the dial has been 'calculated'.

We should should discard M_d = 20h because the climate is too far north and not in the common tradition. And we should discard m_d = 6h too, simply because in neither example do we have M_d = 18h. We remain with M_d = 16h and m_d = 8h, but both have been obtained with different methods. Nevertheless, I will take in consideration M_d = 18h too, because Zenner corrected all the errors in the drawing to fit the dial to this last climate.

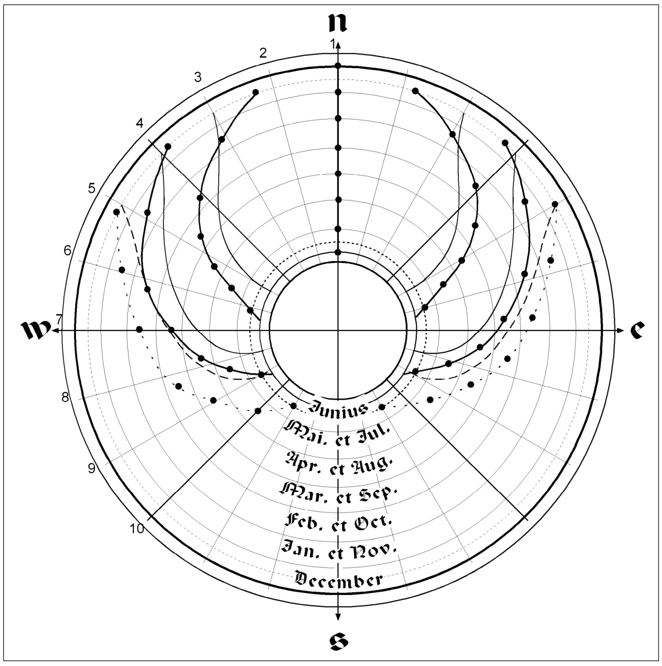

Fig. 39. LON sundial superimposed by curves (in grey) of sunrise and sunset, prime, terce, none, vespers, for a climate with M_d = 16h.

Fig. 39 is an experimental drawing for M_d = 16h, and Fig. 40 is an equivalent drawing for M_d = 18h.[17] As we can see, M_d = 16h does not fit at all with the hour lines in our dial: the curves of the first and the last signs start correctly at the Winter solstice but from the Equinoxes they run almost over the curve of the end of the first hour and the hours of Vespers. Terce and None, similarly to Prime and Vespers, are completely unmatched.

It is no better with M_d = 18h (Fig. 40): the curves of the first and the last signs start, as expected, one hour before the Summer solstice line but suddenly they run to meet the end of the Prime or Vespers curves. Terce and None run near the manuscript's lines but not on the same path, and Prime and Vespers start correctly only to deviate suddenly.

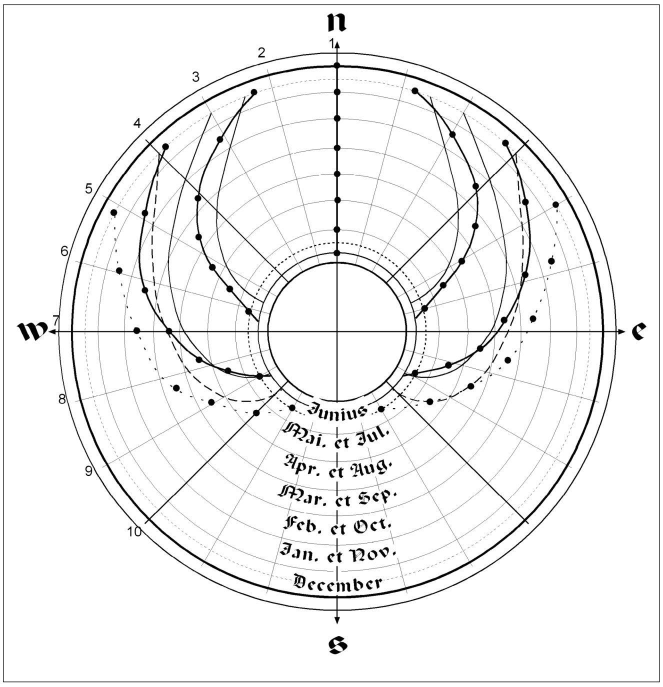

Fig. 40. LON sundial superimposed by curves (in grey) of sunrise and sunset, prime, terce, none, vespers, for a climate with M_d = 18h.

I have calculated the path of the hour curves using (as in the medieval period) the method suggested by Martianus Capella, and I have also tried to use real azimuths for the climates of 16h, 18h and 20h, but in all cases nothing very significant happens. The error remains the same: the day-length for one of the two solstices is longer or shorter than the M_d or the m_d of the climate for the dial.

The design of the dial fits almost perfectly, as we can see in Fig. 41, only if we draw it using the method of *DAR*, that is

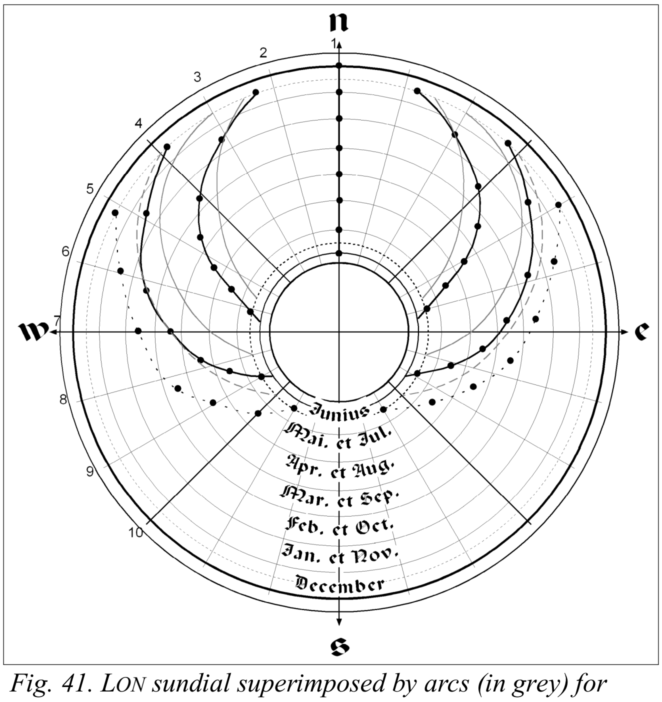

Fig. 41. LON sundial superimposed by arcs (in grey) for sunrise and sunset, Prime (i.e. the end of the first hour), terce, none and Vespers (the end of the eleventh hour), for climate with M_d = 18h. The method for drawing the hour curves is the same as DAR.

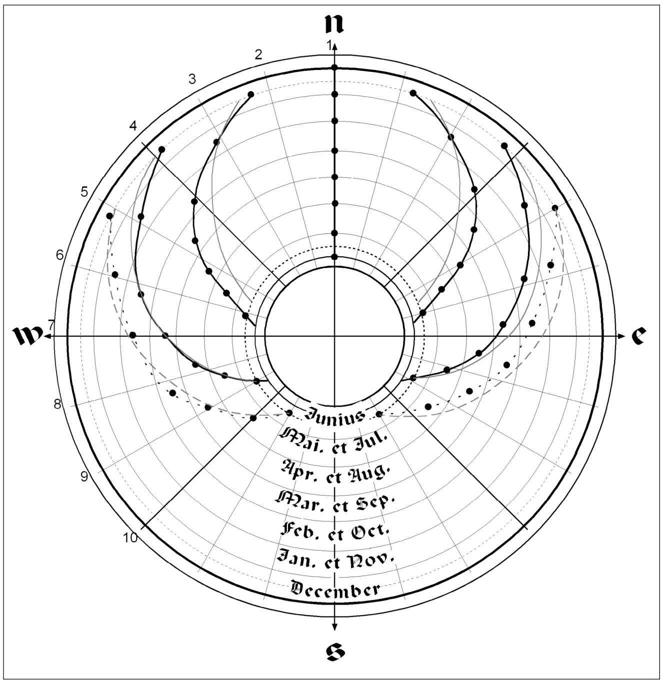

Fig. 42. LON sundial superimposed by arcs (in grey) for morning and evening twilight, sunrise and sunset, terce, none, for the climate with M_d = 18h. The method for drawing the hours curves is the same as DAR.

with arcs passing through the three measured points of Solstices and Equinoxes. Nevertheless, there are still problems with lines of *Primum* and *Ultimum signum* and also with Prime and Vespers.

At this point we can see that it could work correctly only if we understand the curves of *Primum* and *Ultimum signum* not as the instants of sunrise and sunset but as the morning and evening twilight points, so that Prime and Vespers lie exactly at sunrise and sunset (see Fig. 42).

If we accept, as Zenner assumed, that the original drawing was made for a climate with M_d = 18h, then we can also, like him, justify the hour lines becoming wider after Equinox, during the Autumn and Winter, as a movement of the canonical time for prayer. But the manuscript is unclear and this can be only a suggestion.

The overall conclusion of this appendix is that, although the figure in the manuscript is of great interest simply because it is one of the few known in Latin manuscripts, it has so many mistakes, such poor text and is so roughly drawn that it is really hard to make a definitive study of it. After so many tests, my final opinion is that the medieval artist did not know exactly what he was reproducing.

SECOND FAMILY

This group of two manuscripts has in common: the monthly daylight arcs are divided into 12 parts labelled with the zodiacal signs, the names of the hours are written by their initials, the monthly calendar is written on the left next to the daylight arcs and by the specific data "*xv kal. …*".

Ms. BnF lat. 12117

This manuscript offers us an interesting new insight into the history of these sundials. The figure is drawn at f. 2v of the 11th-century manuscript BnF lat. 12117 and even if it does not have any captions inside, like BnF lat. 7412 and BM Old Royal 15 B IX, it demonstrates common elements with the two manuscripts discussed before: the 'tree of the hours', and Prime and Vespers moved one hour after and one hour before the sunrise and sunset.

The drawing (Fig. 43) also has new aspects of interest listed below.

1. First of all we see that each arc of day-length is labelled with the names of six zodiacal Signs.
2. The calendar is the same as many other manuscripts except for June and December, but gives the exact date of the Sun's passage in every zodiacal Sign.
3. The dial is clearly made for a climate of M_d = 17h and this is very uncommon and interesting.

The dial is contained within seven concentric annuli each for a pair of months. Each annulus shows the daytime hours simply by dividing the day-length into 12 portions like bricks. Inside each 2-hour space is the name of the six rising and setting zodiacal signs.[18] The Signs listed are reported in Table E (overleaf).

Each annulus is identified by the name of the reference month, written at the left-hand side, starting just before the Signs-hours sequences. They also show the date of the Sun's passage into every Sign, that is XV Kal. (15th day before Calends of...). This is very interesting because it confirms the manuscript's date and suggests that the drawing of that dial could be a new development by the artist (or the writer). Only around the 9th – 11th centuries did scholars begin to know that the Sun passes into each Sign no longer at XII Kal. but at XV Kal. (see Appendix H for the calendars).[19]

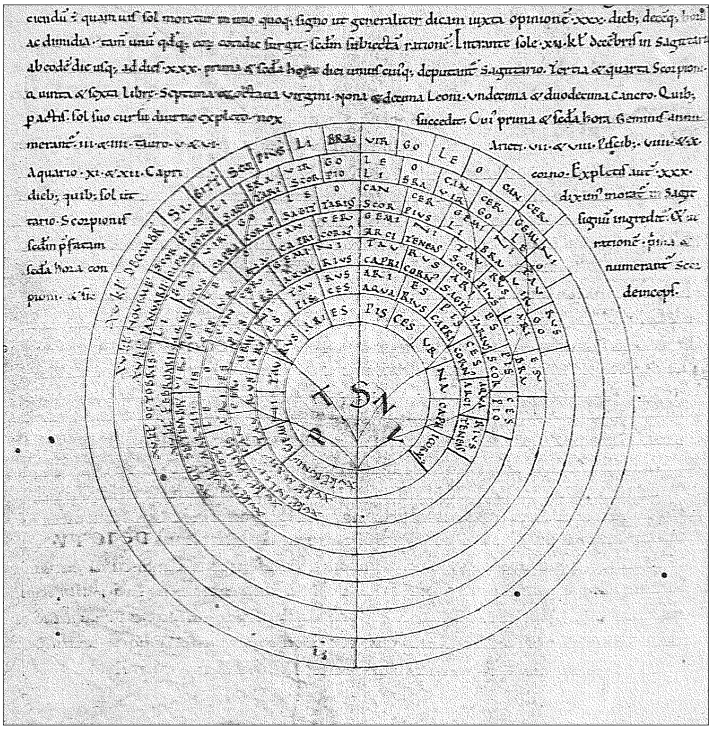

Fig. 43. The drawing of the sundial in ms. BnF lat. 12117, f. 2v.

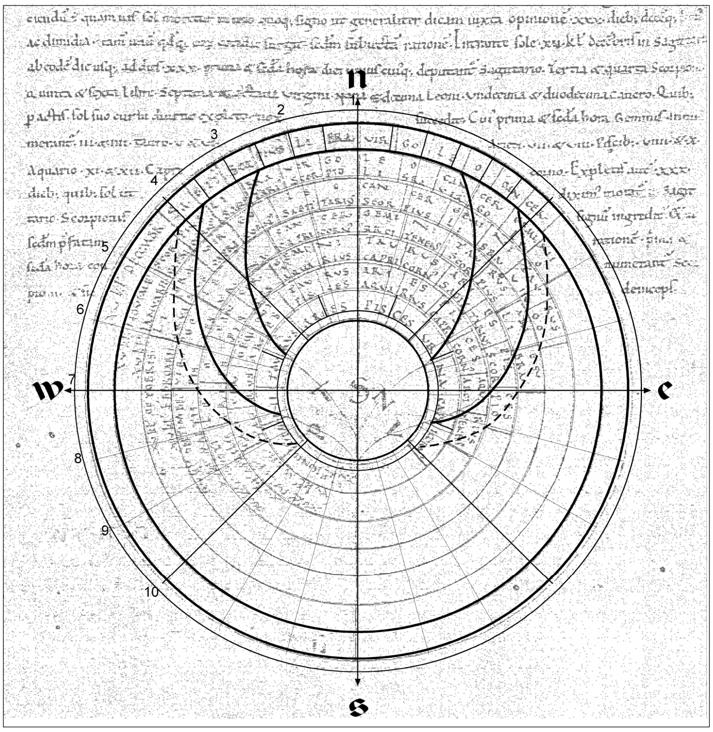

Fig. 44 .The drawing of the sundial in ms. BnF lat 12117, f. 2v superimposed by the web of the 24 equinoctial hours. It appears that the dial has been made for the climate M_d = 18h, for a sundial made with the RIP formula. Primum and Ultimum signum have been drawn here with dashed lines.

Another aspect that makes me believe it is a new development by the writer of the manuscript is visible in Fig. 44. We clearly see that the dial has been drawn for the climate of M_d = 17h, and this is very uncommon in almost all the other manuscripts I discussed previously. We see also that the sequence of increasing values to obtain the next day-length is always a whole number of equal hours. This sequence (Table E) cannot be obtained using the old formula of Martianus Capella nor the Gerbert one nor the *RIP* one. In this case the author created or used a new formula *viz*: 1/10, 1/5, 1/5, 1/5, 1/5, 1/10 for a ΔM = 10h (see Appendix G for the day-length formulas).

Above the dial drawing there is some text that can explain the presence of the zodiacal sign sequences written inside the circles. Here below is the text and its translation.

Ms. BnF Lat. 12117, f. 2v. 11th century.

Sciendum est quantus sol moretur in unoquoque signo ut generaliter dicam iuxta opinionem xxx[ta] diebus decemque horis ac dimidia, tamen unum quod que eorum cotidie surgit secundum subiectam rationem.	One should known how much time the Sun spends inside each [zodiacal] sign. So I will say that, according to a common opinion, it is 30 days, 10 hours and a half. Notwithstanding every Sign rises every day with the following criterion.
Intrante sole xv kal. decembris in Sagittario, ab eodem die usque ad dies xxx[a], prima et secunda hora diei unius cuiusque deputantur Sagittario. Tercia et quarta, scorpioni. Quinta et sexta, Librae. Septima et octava, Virgini. Nona et decima Leoni. Undecima et duodecima, Cancro.	From the 15th day before the Calends of December {the 17 of November}, when the Sun enters Sagittarius, to the 30th day {ca. 18 December} the first and the second hours of each day is given to Sagittarius. Third and 4th to Scorpio, 5th and 6th to Libra, seventh and eighth to Virgo, ninth and tenth to Leo, eleventh and twelfth to Cancer.
Quibus peractis, sol suo cursu diurno expleto, nox succedit. Cuius prima et secunda hora, Geminis adnumerantur; iii[a] et iiii[a], Tauro; v[a] et vi[a], Arieti; vii[a] et viii[a], Piscibus;viiii[a] et x[a], Aquario; xi[a] et xii[a], Capricorno. Expletis autem diebus xxx[a] quibus sol, ut diximum, ut morantur in Sagittario, Scorpionis signum ingreditur. Et ut secundum prefactam rationem prima et secunda hora connumerantur Scorpionem et sic deinceps.	At that point, the daily Sun path is completed and the night begins. The first and the second hours of the night are given to Gemini, the 3rd and 4th to Taurus, the 5th and 6th to Aries, the 7th and 8th to Pisces, the 9th and the 10th to Aquarius, 11th and 12th to Capricorn. After 30 days with the Sun in Sagittarius, the Sun enters the sign of Scorpio and, according to the aforesaid rule, the first and the second hour will be given to Scorpio, and so on.

No mention of the hours or of sundial construction in given in the text. This means that the drawing of the dial has been put there simply to illustrate the sequence of the signs in the concentric circles of the dial. That sequence (Table E) is exactly the same in *MON* as we will see below.

Rising Signs according to *PAR₂* and *MON*												
Zodiacal MONTHS	HOURS and SIGNS											
15 Kal. of...	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
December	Sagittarius		Scorpio		Libra		Virgo		Leo		Cancer	
November January	Scorpio Capricorn		Libra Sagittarius		Virgo Scorpio		Leo Libra		Cancer Virgo		Gemini Leo	
October February	Libra Aquarius		Virgo Capricorn		Leo Sagittarius		Cancer Scorpio		Gemini Libra		Taurus Virgo	
September March	Virgo Pisces		Leo Aquarius		Cancer Capricorn		Gemini Sagittarius		Taurus Scorpio		Aries Libra	
August April	Leo Aries		Cancer Pisces		Gemini Aquarius		Taurus Capricorn		Aries Sagittarius		Pisces Scorpio	
July May	Cancer Taurus		Gemini Aries		Taurus Pisces		Aries Aquarius		Pisces Capricorn		Aquarius Sagittarius	
June	Gemini		Taurus		Aries		Pisces		Aquarius		Capricorn	

Table E

Although this sequence is correct as it stands, it is not the correct form of the calendar for a sundial, as it is used in *MON*.

To fit the rising signs with the correct meaning of the annuli, each month name should correspond to the central point of that inscribed month, that is, the point when the Sun enters the new zodiacal sign.

The wider monthly circle is given to the Winter solstice and the smaller to the Summer solstice, described as "15 *Kal. Decembris*" which is incorrect because that date is 17 November. The month of December, it should be understood, must mean "*15 Kal. Januarii*", that is 18 December, the real Winter solstice for that epoch. And for the same reason "*15 Kal. Junii*" (18 May) must be "*15 Kal. Julii*" that is 17 of June, the real Summer solsticial day for that epoch. And so on for all the other months.

This misunderstanding confused the original author, and others followed the same error without realizing the misleading conception.

The correct sequence should be as in table F.[20]

Correct Rising Signs												
Zodiacal MONTHS	HOURS and SIGNS											
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
December	Capricorn		Sagittarius		Scorpio		Libra		Virgo		Leo	
November	Sagittarius		Scorpio		Libra		Virgo		Leo		Cancer	
January	Aquarius		Capricorn		Sagittarius		Scorpio		Libra		Virgo	
October	Scorpio		Libra		Virgo		Leo		Cancer		Gemini	
February	Pisces		Aquarius		Capricorn		Sagittarius		Scorpio		Libra	
September	Libra		Virgo		Leo		Cancer		Gemini		Taurus	
March	Aries		Pisces		Aquarius		Capricorn		Sagittarius		Scorpio	
August	Virgo		Leo		Cancer		Gemini		Taurus		Aries	
April	Taurus		Aries		Pisces		Aquarius		Capricorn		Sagittarius	
July	Leo		Cancer		Gemini		Taurus		Aries		Pisces	
May	Gemini		Taurus		Aries		Pisces		Aquarius		Capricorn	
June	Cancer		Gemini		Taurus		Aries		Pisces		Aquarius	

Table F

The theory that requires every Sign to rise or set in exactly two temporal hours is not correct, but widely believed in medieval as well as in ancient times.[21] This theory is correct only with real planetary hours that are measured along the ecliptic circle and not along the equinoctial one, as are the equal or the unequal (temporal) hours.

Though the difference between true planetary hours and normal unequal ones is often not explained properly, either in the old literature or in most modern treatises (with the exception of Drecker and those who follow him), the full explanation is not simple and as it is not necessary for the explanation of medieval azimuthal dials it will not be given here.[22]

Ms. Montpellier, H48.

At folio 3v of the 11th-century manuscript H48, kept at the Biblioteque Interuniversitaire (Section de Médicine), Montpellier, France, there is a drawing of an azimuthal sundial identical to the one in PAR$_2$, but incorrectly drawn (Fig. 45).

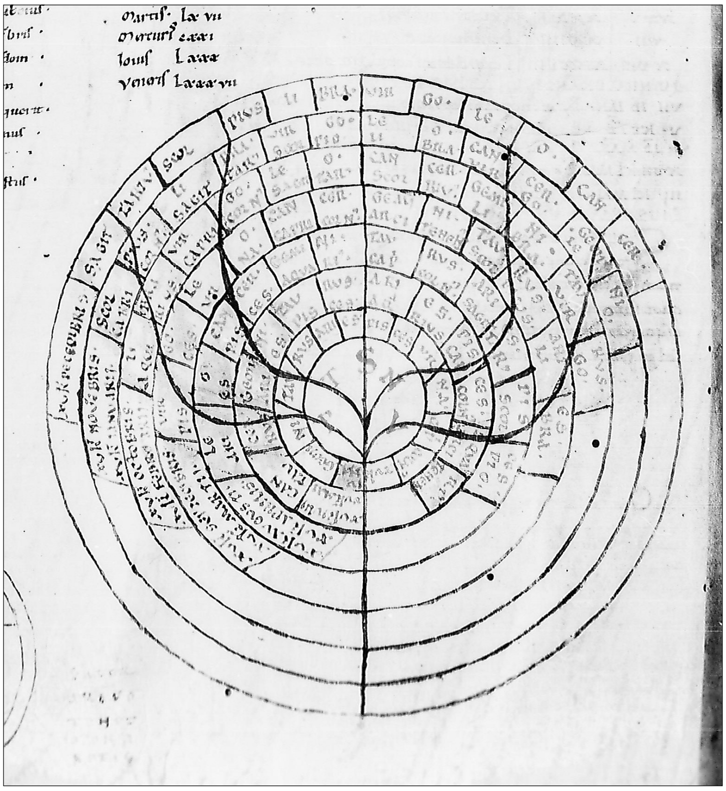

Fig. 45. The drawing of the sundial in ms. Montpellier H48, f. 3v.

Above the diagram there is written the same text that we find in PAR$_2$, but titled *De XII signis quo modo cotidie discurrant* (On the 12 Signs, how they move every day).

At the first sight one can believe that the dial has been made for the climate of M_d = 15h, because the daylight arc for the circle of the Winter solstice is 9 equinoctial hours, but it can be seen that the hour lines run much too wide going toward Summer solstice reaching a daylight arc of 21h (see Fig. 46, overleaf).

We are clearly looking at a bad copy of the same drawing as PAR$_2$ (as LON was of PAR$_1$). Thus it is not worth further effort proving its incorrectness: the discussion of LON will suffice.

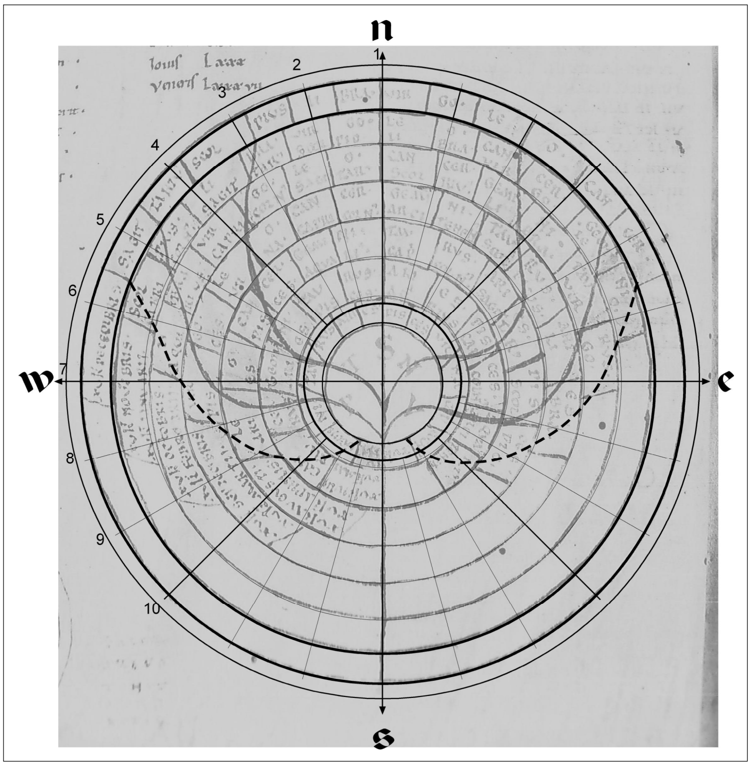

Fig. 46. The drawing of the sundial in ms. Montpellier H48, f. 3v superimposed by the web of the 24 equinoctial hours. It is clear that the dial is wrong.

REFFERENCES

1. I recently had some kind discussion with Dr Borrelli about it, and she agreed with me about the error. She recognized that the drawing represents a dial that works on azimuthal principles.
2. There is a second "*sexta*" just below but it is an error of the scribe (the point under every letter means 'deleted').
3. Borrelli (2008), p. 199 wrongly transcribes "*Messa*" (mass) and not '*Vespera*' (vespers), as one can easily read in Fig. 33.
4. In ancient and medieval times, the hour was divided into more parts than simply two halves. In the Middle Ages, one hour was partitioned into 4 points, 10 minutes, 15 parts, 40 moments, 60 ostentis and 22560 atoms. See Arnaldi (2011), ch. 3.
5. In *DAR* they are referred to as *ORT[us]* and *OCC[asus]*.
6. For the time of prayers (in this case for Vespers) see Arnaldi (2011), ch. 5.
7. Zenner (1999).
8. In *egredienda umbra*: '*egredienda*' is my correction, because the manuscript shows "*ingredienda*" which is incorrect.
9. Here the scribe is not clear at all. My translation is not completely word-by-word, but I have tried to make the sentence more comprehensible than was written.
10. We know that many ancient maps use East as the principal cardinal point, putting East upwards and West at the bottom. Also, many of Willibrord's diagrams show the East at the top and South on the right.
11. This sentence is strange; '*quo die*' (what day) and '*quando*' (when) can have the same meaning, so in this sentence it can be considered a redundant word, but I think that the writer meant: 'on what day [of the month] and when [in the year]', so one can read 'what day and what month'.
12. Of course here the writer forgets to say that the circle must be oriented and that the line in question is the one of the two traced earlier that lies East-West.
13. The writer means here: "With 'ascend' and 'descend' the writer means here: 'the increase and decrease of the sun's declinations on the ecliptic circle, that on the plane are seen as a change of the 'ortive amplitude' degrees, *i.e.* the 'rising amplitude'."
14. For the calendar, see Appendix G.
15. Day-length and night-length, in equal hours.
16. Zenner transcribes as: "*sub radii Phebi surgent hec...*", 'with the sun's rays rises...'; Zenner (1999).
17. I want to remind the reader that here I am not really calculating the hour lines, but just using the geometric method described in the manuscripts. The maximum day-length for each month has been obtained using Martianus Capella's method.
18. Because every day we have six signs above the horizon and six below.
19. *RIP* still uses the late Roman date, 12th day to Calends.
20. For the calendar, see Appendix H, Fig. 52.
21. See the criticism written by Manilius based on this false belief; Manilius, *Astronomica*, III, 235.
22. For details of planetary hours see Arnaldi (2011), pp. 54-63.

APPENDIX F

The Climates

In antiquity, among all the parallel zones of the Earth, there were seven selected bands, or parallels, of the inhabited world: they were called *climata*. These seven strips of land were usually named after some city or region that was the most important to the geography of that area. They were usually distinguished in latitude by the number of equinoctial hours for the longest day, the Summer Solstice.

In his *Geography*, Strabo (1st century BC) gives a list of ten main parallels, selected by Hipparchus and considered as climates.[1] Vitruvius also wrote about climates in the first book of his *De architectura*, and Censorinus (3rd century AD) wrote about them too; both these authors spoke of them in a general way as latitudes.

Geminus (1st century BC), in his *Introduction to the Phenomena*, cites some of the main climates: that of Rhodes (M_d = 14:30h), of Rome and more generally of Greece and the Hellespont (M_d = 15h), of the North Propontis (the Sea of Marmara), Borysthenes (the (mouth of) the Dnieper River) (M_d = 16h), two more northerly with M_d = 17h and 18h,[2] and Alexandria's climate, without giving the value of M_d.[3]

Gaio Plinius Secundus, known as Pliny the Elder (23–79 AD) starts by counting seven climates, but he adds to them other main parallels because (he wrote) they are "of a more recent tradition".[4] Ptolemy (c. 85–165 AD) in his *Almagest* does not write expressly of climates, but he considers seven fundamental parallels which are the classical climates of the Hellenistic tradition.[5] Notwithstanding that the word 'climate' can be read from the maps of his *Cosmographia* or *Geography*,[6] Martianus Capella also speaks of the different parallel zones known with the name of 'climates', but he counts eight.[7]

Regarding the medieval period, I want to consider only the main scholars who have made significant contributions to the diffusion of the geographic and mathematic cultures from the ancient world.

Isidore of Seville (c. 560-636) in his work *Etymologiarum sive Originum*, one of the first encyclopedic works of the Middle Ages, recalls seven main climates;[8] the Venerable Bede (672-735), using the data from Pliny and Isidore, considers eight climates (though he does not allow for the higher latitude of Jarrow),[9] while Gerbert of Aurillac, respecting the Hellenistic tradition, again counts seven (see the comparisons of Tables G and H, overleaf).[10]

In Tables G and H it is possible to compare the different data on climates as they came to us from history: the first column gives the main locality that identifies the climatic belt, column K is the climate name, column M_d shows the length of the day on the Summer Solstice in equinoctial hours, while column m_d gives the day-length of the shortest day for that climate. As can be seen, Ptolemy's data are the same (with a few differences) as those used by Gerbert.

REFERENCES

1. Strabo: *Geographia*, ii.5, 34–42, ed. E.H. Warmington, Loeb Classical Library, 8 vols. London – William Heinemann Ltd, Cambridge, Massachussetts, Harvard University press, 1960–1969, vol. i, pp. 503–517.
2. Geminus: *Introduction to the Phenomena*, vi, 7; Evans : Berggren (2006), p. 162.
3. *ibid*, vii, 19; Evans : Berggren (2006), p. 221.
4. Plinius: *Hist. Nat*., ii, 77, 186; Ivi, vi, 39, 211sq.; Pliny (1956)
5. Ptolemaeus: *Almagestum*, ii,6, ii, 8 sq, ii, 13 sq., ed. Toomer (1998), pp. 82–90, 100–103, 123–129.
6. Ptolemaeus, *Cosmographia*. Tavole della Geografia di Tolomeo, (1990), tav. i
7. Martianus Capella: *De nuptiis...,* vi, 595; viii, 877; Ramelli (2004)2.
8. Isidoro di Siviglia: *Etymologiarum sive Originum libri* xx, iii, 42, ed. Migne, vol., coll.
9. Bede: *De Natura rerum*, c. 47, *De circulis terrae*, coll. 265–273; *De temporum ratione*, chap. 31, *De dispari longitudine dierum et vario statu umbrarum*, c. 32, *Causa inequalitatis dierum eorundem*, c. 33, *Quibus in locis pares sint umbrae vel dies*, coll. 431-450, PL curante J.P. Migne, vol. xc, Paris.
10. Gerbert of Aurillac: *De utilitatibus Astrolabii*, chap. xviii, in PL, vol.cxliii, curante Migne, Paris, 1844, coll. 402–404.

Strabo / Hipparcus 10 parallels		**Pliny** 7 climates + 2 + 3			**Ptolemy** 7 climates			**Martianus Capella** 8 climates			
	M_d		K	M_d		K	M_d		K	M_d	m_d
Meroë	13h	Meroë, Ptolemaides, Red Sea	-Ia	12:30h	Meroë	I	13h	Meroë	I	13h	11h
Syene	13:30h	Syene	-Ib	13:30h	Syene	II	13:30h	Syene	II	13h	10h
Alexandria and Cyrene	14h	Alexandria, pillars of Hercules	I	14h	Low Egypt	III	14h	Alexandria, Cyrene, Africa	III	14h	10h
Sidon and Tyre	14:15h	Sidon, Tyre, Crete	II	14:24h							
Rhodes	14:30h	Rhodes, Cyclades, Syracuse	III	14:32h	Rhodes	IV	14:30h	Rhodes, Peloponnese, Sicily	IV	14h	9h
		Northern Sicily, Gallia Narbonensis	IV	14:40h							
South of Rome – North of Naples	15h	Hellespont, Italy, Armenia, Macedonia	V	15h	Hellespont	V	15h	Rome, Macedonia, Gallia	V	15h	9h
Byzantium	15:15h	Illyricum, Byzantium, Campania, Rome, Etruria	VI	15:07h				Hellespont	VI	15h	8h
Mesopontus	15:30h				Mesopontus	VI	15:30h				
Borysthenes	16h	Borysthenes, Venice, Ravenna, Aquitaine Gallia	VII	15:36h	Borysthenes	VII	16h	Borysthenes, Germany, Britain	VII	16h	8h
North of Maeotian Marshes, South of Riphean Mountains	17h	Tanais, N of Maeotian Marshes, North Germany	+VIIa	16h	Mouth of Tanais [now the River Don]		17h	North Maeotian Marshes, South of Riphean Mountains	VIII	16h	7h
		Hyperborean, Britain	+VIIb	17h	Southern Ireland		18h				
		Riphean Mountains, Thule	+VIIc	6 months							

Table G. Comparison of the climates of some Greek and Roman authors.

Isidore of Seville 7 climates		**Venerable Bede** 8 climates + 2 + 2			**Gerbert of Aurillac** 7 climates		
	K		K	M_d		K	M_d
Meroë	I	Meroë, Ptolemaides, Red Sea	-Ia	12:30h	Meroë	I	13h
Syene	II	Syene	-Ib	13h			
Cathacoras, Africa	III	Red Sea, maritime Africa, pillars of Hercules	I	14h	Alexandria	II	13:30h
		Crete	II	14:24h			
Rhodes	IV	Rhodes, Cyclades, Syracuse	III	14:32h	Dead Sea, Libya	III	14h
		Northern Sicily, Narbonensis Gallia	IV	14:40h	Cyrene, Numidia	IV	14:30h
Hellespont	V	Armenia, Macedonia, Baleares	V	15h	Carthage, Sardinia, Hellespont	V	15h
Mesopontus	VI	Illyricum, Campania, Rome, Etruria	VI	15:07h	Italy, Germany	VI	15:30h
		Venice, Ravenna, transalpine Gallia	VII	15:36h			
Borysthenes	VII	Tanais, Maeotian Marshes, North Germany	VIII	16h	Constantinople, Britain	VII	16h
		Hyperborean, Britain	+VIIIa	17h			
					Unknown zone		18h
		Riphean Mountains, Thule	+VIIIb	6 months			

Table H. Comparison of the climates of some medieval Latin authors.

APPENDIX G

The Day-Length Formulae

We saw in chapters 3 and 4 that the climates M_d = 15h and M_d = 18h had a Greco-Roman origin, but it is important to note that what mainly led us to that conclusion is the linear scheme of increasing values of the daylight hours for the monthly sequence. This linear scheme has Babylonian influences, but we find it as a simple arithmetical progression in ancient Egypt[1] as well. We know linear schemes for M_d = 14h and m_d = 10h, M_d = 15h and m_d = 9h, and also some for M_d = 18h and m_d = 6h.

The Greek tradition for this linear sequence is also found in many other late Roman and early medieval texts.[2] Of course linear arithmetical schemes are only approximations, not the exact data obtained with the later trigonometrical calculation, but here we must recognize practical adjustments for practical purposes.

One of the most known schemes in the medieval period was the one written by Martianus Capella in his *De nuptis Philologiae et Mercurii*. Capella's rule was:

> "Starting from the winter solstice, (the days) grow in such a way that in the first month should be added the 12th part of the same portion of time that is to be added in summer, in the second month should be added the 6th, in the third the 4th, in the fourth again another 4th, in the fifth the 6th and in the sixth month the 12th."

Knowing M_d, that is the number of equinoctial hours of the longest day, we also know m_d, that is its complement of 24.

In other words, with M_d = 15h and the corresponding m_d = 9h, the difference between M_d and m_d (ΔM) is equal to 6h. Now, applying the sequence of the increments given by Martianus (1/12, 1/6, 1/4, 1/4, 1/6, 1/12), we will have a series of monthly M_d as in the following example and that we can see also listed in Table I, Method 1:

December = 9h
January – November = 9h + 1/12 with ΔM = 9:30h
February – October = 9:30h + 1/6 with ΔM = 10:30h
March – September = 10:30h + 1/4 with ΔM = 12h
April – August = 12h + 1/4 with ΔM = 13:30h
May – July = 13:30h + 1/6 with ΔM = 14:30h
June = 14:30h + 1/12 with ΔM = 15h

For a ΔM = 12h, that is M_d = 18h and m_d = 6h, on the other hand, the sequence of the diurnal lengths will be as follows:
December = 6h,
January – November = 6h + 1/12 with ΔM = 7h,
February – October = 7h + 1/6 with ΔM = 9h
March – September = 9h + 1/4 with ΔM = 12h
April – August = 12h + 1/4 with ΔM = 15h
May – July = 15h + 1/6 with ΔM = 17h
June = 17h + 1/12 with ΔM = 18h.

Method 1 (Martianus Capella)			**Method 2 (Gerbert)**			**Method 3 (*RIP*)**		**Method 3 (*PAR₂*)**	**Method 4 (*PAR₁*)**
	M_d = 15h	M_d = 18h		M_d = 15h	M_d = 18h	M_d = 15h		M_d = 18h	M_d = 17h
Jun	15h	18h	Jul – Jan	15h	18h	15h	15h	18h	17h
Jul – May	14:30h	17h	Aug – May	14:30h	17h	14h	14h	16h	16h
Aug – Apr	13:30h	15h	Sept – Apr	13:30h	15h	13h	13h	14h	14h
Sept – Mar	12h	12h	Oct – Mar	12h	12h	12h	12h	12h	12h
Oct – Feb	10:30h	9h	Nov – Feb	10:30h	9h	11h	11h	10h	10h
Nov– Jan	9:30h	7h	Dec– Jan	9h	6h	10h	10h	8h	8h
Dec	9h	6h					9h	6h	7h

Table I

As can be seen, Martianus's sequence appears linear, with a monthly increment of 2 hours, only for a climate with the longest day equal to 18h. The Martianus rule was also cited by Gerbert of Aurillac in his letter to Brother Adam (see Appendix A). Gerbert named Martianus as his main source but he did not use exactly his method; the increase adopted by Gerbert is slightly different, it is: 1/4, 1/4, 1/4, 1/6, 1/12 for the day and 1/12, 1/6, 1/4, 1/4, 1/4 for the night (see Table I, method 2), but he uses a different calendar scale with six circles. Nevertheless, Gerbert also obtained a linear scheme only for the climate with M_d = 18h.

The Martianus formula is the same as that given by Cleomedes in *De motu Circulari Corporum Caelestium* and Pogo demonstrates its Egyptian origin.

RIP also uses a series of values for ΔM revised from those suggested by Martianus Capella. It seems that the *RIP* author knew the original formula for producing the linear sequence of day-length increments for M_d = 15. The sequence of the monthly values of ΔM is always 1/6 of the difference between M_d and m_d. In this way, starting from June-July, we have a sequence of whole equinoctial hours that is 10, 11, 12, 13, 14 and 15. One additional jump of 1/6 is added to pass from 10h to the final 9h (Table I, method 3).

The same method of *RIP* was used by the author of PAR_2 to draw his figure of the sundial made for a climate for M_d = 18h. The sequence of day-length hours is made by an increment of 2h each step, obtaining the sequence: 6, 8, 10, 12, 14, 16 and 18 equinoctial hours. But the *RIP* formula lets us obtain a sequence of whole equinoctial hours only for climates M_d = 15h and M_d = 18h, which is why I am happily surprised to find a new formula in PAR_1.

The drawing in PAR_1 is perfect and, without doubt, it has been traced for the climate with M_d = 17h. This is very unusual in our examples, but offers us another interesting suggestion for analyzing the different methods for calculating the day-length. The sequence of increasing values is now: 1/10, 1/5, 1/5, 1/5, 1/5, 1/10 for a ΔM = 10h, producing a sequence of day-lengths of 7, 8, 10, 12, 14, 16 and 17 whole equinoctial hours (see Table I, method 4). The PAR_1 formula does not give us a very linear scheme, but suggests an effort to make something very close to it.

This suggests that the Martianus Capella's method was not intended as 'universal' in medieval times, because at different climates other than M_d = 15h and M_d = 18h the resulting data were neither integer numbers nor halves. So it appears that medieval diallists found other arithmetic ways to obtain easy mnemonic sequences of day-length hours, or they still knew some ancient tradition or texts that gave simple formulas, probably for every climate.

REFERENCES & NOTES

1. We find this scheme written in a Ramesside papyrus dated about 12th century BC for (strangely) M_d = 18h, using a monthly increment of 2 hours (see Neugebauer & Parker 1960, vol. 1, pp. 119–120). We also can see linear schemes in two Greek papyri dating back to around 300 BC and 180 BC: Papysus Hibeh 27 and the so called 'Eudoxus papyrus'.
2. For linear schemes of the increments for the length of daylight see Neugebauer (1975), vol. 2, pp. 706–709.
3. Cleomede (between 1st century BC and 4th century AD) was a Greek mathematician and astronomer. We know little about him: only his book *De motu Circulari Corporum Caelestium* survives. Scholars still debate his dates.
4. Pogo (1936): the formulae have a strong relationship with the linear diagrams drawn inside the prismatic and cylindrical Egyptians waterclocks.
5. The *RIP* formula was also used to illustrate the lengths of daylight on a vertical Spanish sundial at the Abbey of Santa María de Benevívere at Carrión de los Condes, Palencia. Strangely, the day-length used is M_d = 18h, which is too long for that latitude (the latitude of Carrión de los Condes is appropriate for M_d = 15h). The dial was made for the Abbey founder's grave, Diego (*Didacus*) Martinez, who died in 1176 AD. See Valdés (2002).

APPENDIX H

The Calendar

Many ancient and medieval sundials work as a function of the calendar date. The range of months was usually split into two parts with pairs of months connected by the same value of the Sun's ascension and descension on the celestial equator. There were usually two ways to show the calendar: one, putting all the 12 months into pairs (December and January; November and February; October and March; September and April; August and May; July and June) and the other, leaving the Solstitial months unpaired (December; January and November; February and October; March and September; April and August; May and July; June). It is clear that the choice depends on the astronomical viewpoint we take for our measurements or calculation of the point in time.

Of course both methods take the passage of the Sun into the next zodiacal Sign as month boundaries, but with different concepts. The first considers a scale of 'solar months' (or 'zodiacal months'), that have 30 degrees of the ecliptic circle between two Signs (Fig. 47); the pair of months is actually a pair of Signs.

The second method considers the real 'calendar months', that is, from the first day of one month to the firstday of the next (Fig. 48).

When researching medieval sundials, one should not only bear in mind these two ways of representing the calendar but also should consider the great confusion that existed at that epoch about the date of the Sun's passage in every zodiacal Sign. This confusion produced wide variations in the representation of the calendar.

Astronomically speaking, Solstices and Equinoxes occur at the beginning of their related Signs. Geminus (1^{st} century BC) wrote in his *Introduction to the Phenomena* (or *Introduction to Astronomy*) that Solstices and Equinoxes occur, according to the Greek astronomers, at the first degree of Aries, Cancer, Libra and Capricorn, and also the seasons commenced at those points on the Ecliptic circle.[1] But where in the calendar was the first degree of each Sign?

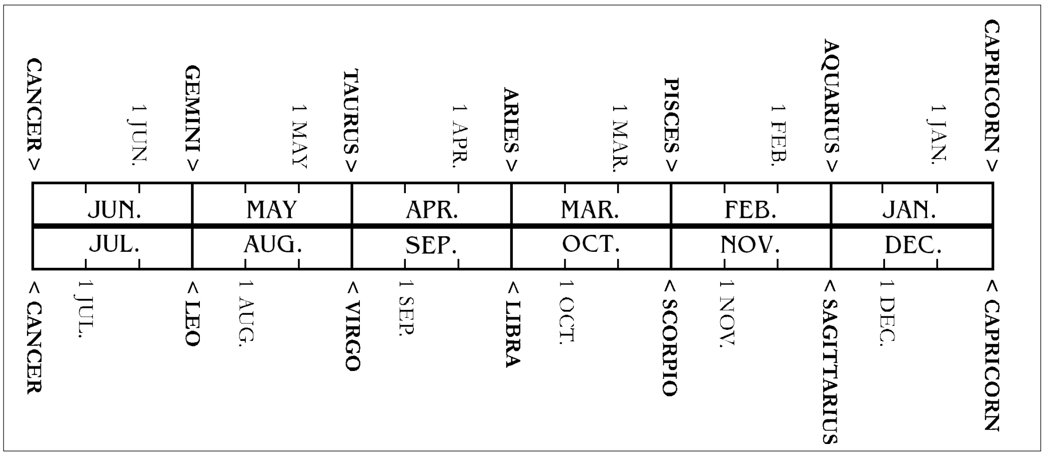

Fig. 47. The 'solar months'.

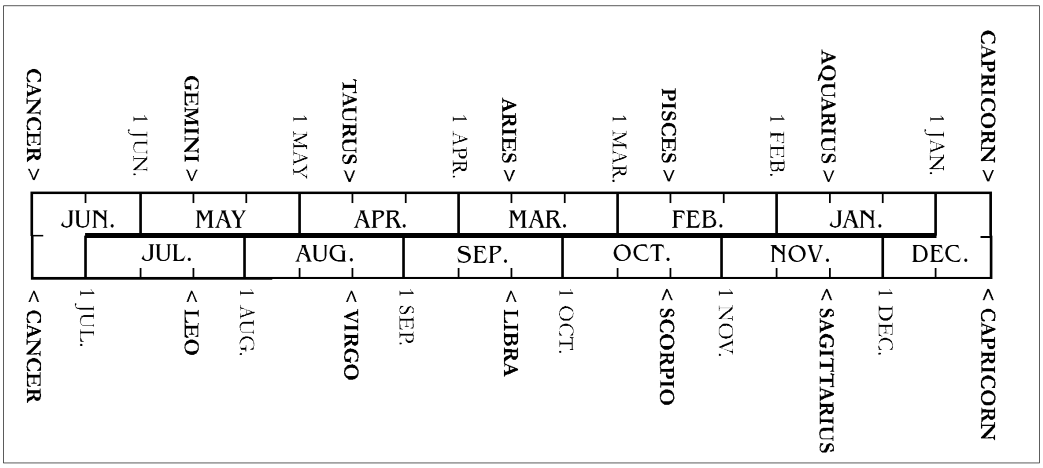

Fig. 48. The 'calendar months'.

In 46 BC, Julius Caesar (with the help of the astronomer Sosigenes of Alexandria), reformed the old calendar and established the Spring Equinox as the 8th day before the Calends of April (25 March), and so consequently Solstices occurred at the 8th day before the Calends of July (24 June) and the 8th day before the Calends of January (25 December). The Autumnal Equinox was on the 8th day before the Calends of October (24 September). The passage of the Sun from Sign to Sign was the 8th day before the Calends of each month. These dates are confirmed not only by many ancient writers, but also by many extant Roman portable sundials. Fig. 49 gives an example and some others are:

- Museum of the History of Science, Oxford (1st – 4th century). Inv. no. 51358.
- Portable sundial found at Crét Chatelard (1st – 4th century). See: Durand & La Noë, 1898.
- Portable sundial found at Rome in 1740 (1st – 4th century). See Baldini, 1741.
- Portable cylinder dial at Amiens (3rd – 4th century). See Hoët-van Couwenberghe & Binet, 2008.

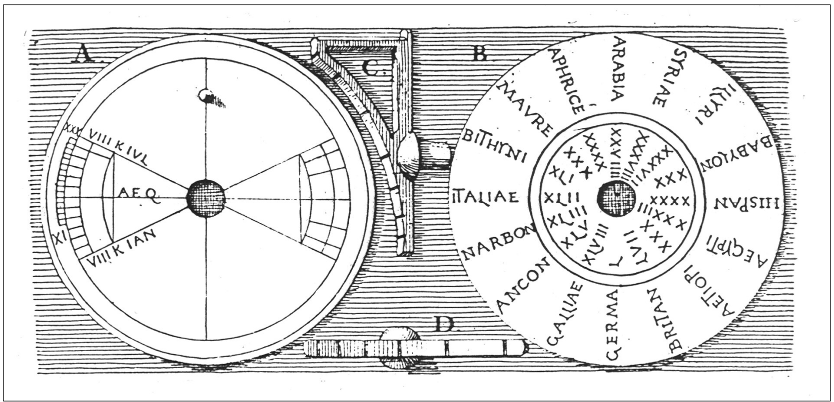

Fig. 49. The portable sundial found near Rome in 1740. From Baldini (1741).

Many books from Roman times were known in the Middle Ages, and many were collected and copied in the Carolingian epoch. Medieval authors trusted ancient authorities such as Pliny, Columella, Martianus Capella, Macrobius etc, so much so that they had no difficulties in accepting the dates of the Equinoxes and Solstices as the 8th day before Calends.

Nevertheless, the Julian calendar was incorrect and the Spring Equinox slowly shifted away from the 8th day before Calends measured in 46 BC (the shift was around 1 day every 128 years) so that in 325 AD the bishops convened at the First Council of Nicaea. After consulting Egyptian experts, they established the correct date of vernal Equinox exactly on 12th day before the Calends of April, that is, in the modern calendar, 21 March.[2] So medieval computists also knew that the true Equinox date had been fixed at Nicaea as 12 days before the Calends of April.

However, the Julian calendar remained inexact and the Spring Equinox again shifted slowly away from 21 March so that, by the 8th century, computus scholars such as the Venerable Bede, realized, with the help of instruments,[3] that the Sun's passage into each Sign occurred around the 15th day before the Calends (between the 15th and the 18th of every month). This began to generate a lot of confusion.[4] Many medieval texts affirm different opinions about the dates of the Solstices and Equinoxes: some accept 8 days before Calends,[5] some 12 days before Calends,[6] and yet others the middle of the months (15 days before Calends).[7] So authors in the Middle Ages faced a very difficult task: "Who is right? Who is wrong? The accepted ancient authorities or the fathers at Nicaea? Or should I trust in my eyes and give credits to the evidence shown by the gnomonic instruments?" The medieval calendar can surely give us a response.

The most well-known calendar used in the Middle Ages is the one compiled by the Venerable Bede and given at the beginning of his *De temporum ratione*. We can easily see that Bede gets much of his astronomical data from an older calendar, probably of Roman origins. At first sight it seems that Bede got his information from Book 18 of Pliny's *Natural History*, but there is proof that Bede did not know this work. There is a high probability that the data were given in the *Cosmographiorum liber* that Benedict Biscop carried from Rome to Northumbria, and afterwards sold to King Aldfrith. We are sure that Bede had the opportunity to study this book because he recalled it in his *Historia Abbatum*, Ch. 15, and also in his *De ratione computi*, Ch. 9.[8] We do not know exactly what it contained because the book is now lost, but it surely included a calendar because Bede gives us some indications about it.[9] Some authors speculate that this book was the famous one kept at the Vivarium monastery, written by Severinus Boetius for Cassiodore. As an aside, it seems that it was a marvellous book.

Bede was so fascinated by this book that he henceforth preferred to disregard the opinion of Isidore of Seville (a great authority for Bede) preferring instead the Roman and Greek auctorities. So, while for Isidore Winter began on 23 November (9 days before the Calends of December), for Bede and the Greco-Romans it began on 7 November (7 days before the Ides of November) and so on: for Isidore Spring starts on 22 February (8 days before the Calends of March) and for Romans on 7 February (7 days before the Ides of February); Summer in Spain on 24 May (9 days before the Calends of June) and at Rome on 9 of May (7 days before the Ides of May); Autumn on 23 August (10 days before the Calends of September) and on 7 August (7 days before the Ides of August).[10] This does not account for the fact that the different latitudes of Italy and Jarrow also change the 'climate'. Nevertheless in Bede's calendar (Table J) we do not find 8 days before Calends as the date for the Sun's passage from Sign to Sign. He keeps 15 days before Calends as the correct date.[11]

<table>
<tr><th colspan="6">BEDE'S CALENDAR</th></tr>
<tr><th>MONTH</th><th>DATE</th><th>EVENT</th><th>SIGN</th><th>GRECO-ROMAN SEASONS</th><th>ISIDORE'S SEASONS</th></tr>
<tr><td>JANUARY</td><td>16 Cal.</td><td>Sun in Aquarius</td><td rowspan="2">AQUARIUS</td><td>WINTER</td><td rowspan="3">WINTER</td></tr>
<tr><td rowspan="3">FEBRUARY</td><td>7 Id.</td><td>Spring begins</td><td rowspan="6">SPRING</td></tr>
<tr><td>14 Cal.</td><td>Sun in Pisces</td><td rowspan="2">PISCES</td></tr>
<tr><td>8 Cal.</td><td>Spring rises</td><td rowspan="6">SPRING</td></tr>
<tr><td rowspan="2">MARCH</td><td>15 Cal.</td><td>Sun in Aries</td><td rowspan="2">ARIES</td></tr>
<tr><td>12 Cal.</td><td>Equinox</td></tr>
<tr><td>APRIL</td><td>15 Cal.</td><td>Sun in Taurus</td><td rowspan="2">TAURUS</td></tr>
<tr><td rowspan="3">MAY</td><td>7 Id.</td><td>Summer begins</td><td rowspan="6">SUMMER</td></tr>
<tr><td>15 Cal.</td><td>Sun in Gemini</td><td rowspan="2">GEMINI</td></tr>
<tr><td>9 Cal.</td><td>Summer rises</td><td rowspan="6">SUMMER</td></tr>
<tr><td rowspan="2">JUNE</td><td>15 Cal.</td><td>Sun in Cancer</td><td rowspan="2">CANCER</td></tr>
<tr><td>12 Cal.</td><td>Solstice</td></tr>
<tr><td>JULY</td><td>15 Cal.</td><td>Sun in Leo</td><td rowspan="2">LEO</td></tr>
<tr><td rowspan="3">AUGUST</td><td>7 Id.</td><td>Autumn begins</td><td rowspan="5">AUTUMN</td></tr>
<tr><td>15 Cal.</td><td>Sun in Virgo</td><td rowspan="2">VIRGO</td></tr>
<tr><td>10 Cal.</td><td>Autumn rises</td><td rowspan="5">AUTUMN</td></tr>
<tr><td>SEPTEMBER</td><td>15 Cal.</td><td>Sun in Libra</td><td>LIBRA</td></tr>
<tr><td>OCTOBER</td><td>15 Cal.</td><td>Sun in Scorpio</td><td rowspan="2">SCORPIO</td></tr>
<tr><td rowspan="3">NOVEMBER</td><td>7 Id.</td><td>Winter begins</td><td rowspan="5">WINTER</td></tr>
<tr><td>17 Cal.</td><td>Sun in Sagittarius</td><td rowspan="2">SAGITTARIUS</td></tr>
<tr><td>9 Cal.</td><td>Winter rises</td><td rowspan="3">WINTER</td></tr>
<tr><td rowspan="2">DECEMBER</td><td>15 Cal.</td><td>Sun in Capricorn</td><td rowspan="2">CAPRICORN</td></tr>
<tr><td>12 Cal.</td><td>Solstice</td></tr>
</table>

Table J. Dates of Solstices, Equinoxes and Seasons in Bede's calendar.

Bede also wrote about the 8 days before the Calends of April as the equinoctial date in Ch. 30 of his *De temporum ratione*. He says that it was an old opinion of some ancient author such as Macrobius or Pliny. But, at the end of a long chapter, he tries to give a reason for both dates: 8 days to the Calends of April should be taken as the ancient astronomical date, and 12 days to the Calends of April is the ecclesiastical Equinox as established by the Nicean Council and should be taken as true for the calculation of Easter.[12]

In other words, the solution to this problem was to justify the differences in some way.

So, trying to 'run with the hare and hunt with the hounds', is perhaps the reason that in medieval calendars (from the 8th to the 10th centuries) we find written "*Ver oritur*" (Spring rises) at 8 days before the Calends of March (22 February), "*Sol in Arietem*" (Sun in Aries) at 15 days before the Calends of April (18 March) and "*Aequinoctium*" (Equinox) at 12 days before the Calends of April (21 of March).

As we can see in Bede's calendar, the starting dates of the seasons are different to what we understand today and it is clear that his calendar is a compromise between old and new calendars and ancient *parapegmata*. The *parapegma* was a kind of calendrical collection of astronomical and meteorological events, mostly used by farmers and common people but really followed in antiquity. The distribution of this kind of calendar was so widespread that people did not care if the events written on a Greek or Egyptian *parapegma* were copied on a Northumbrian calendar.

The calendar on portable sundials is thus very important in dating the masterpiece, or even simply to study it correctly.

On ancient and medieval portable sundials, we meet both kind of measurements: 'solar months' and 'calendar months'. They rarely show explicitly the date of the beginning of every Sign, so we are often forced to discover ourselves which kind of calendar has been used: 8 Cal., 15 Cal. or 12 Cal.

Depending on the method adopted, we have different dates for calculating the hour points on sundials. If the calendar scale is made in 'solar months', the the days involved for calculating the hours can be either the first or the central day of each Sign. Usually it is the second choice.[13]

For the mid-Sign day, see Table K, and also Figs 50 to 55 for the scales of the calendars.

BEGINNING OF SIGNS	DAY IN THE MIDDLE OF SIGNS
15 Cal.	Around the first day of the 'calendar month'
12 Cal.	Around the 5th day of the 'calendar month'
8 Cal.	Around the 10th day of the 'calendar month'

Table K. Midpoint dates in a 'solar month' calendar.

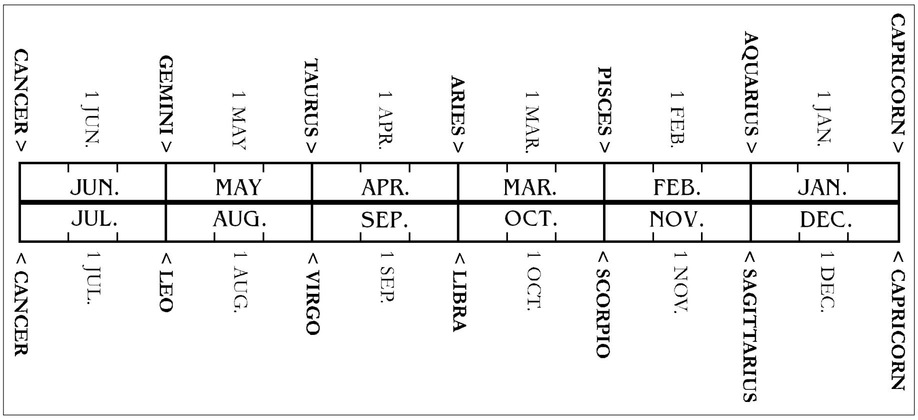

Fig. 50. The 'solar months' with limits at 15 days to Calends.

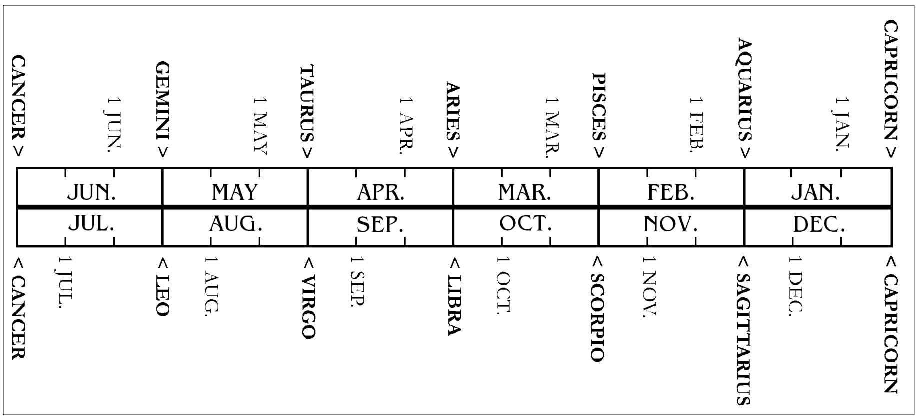

Fig. 51. The 'solar months' with limits at 12 days to Calends.

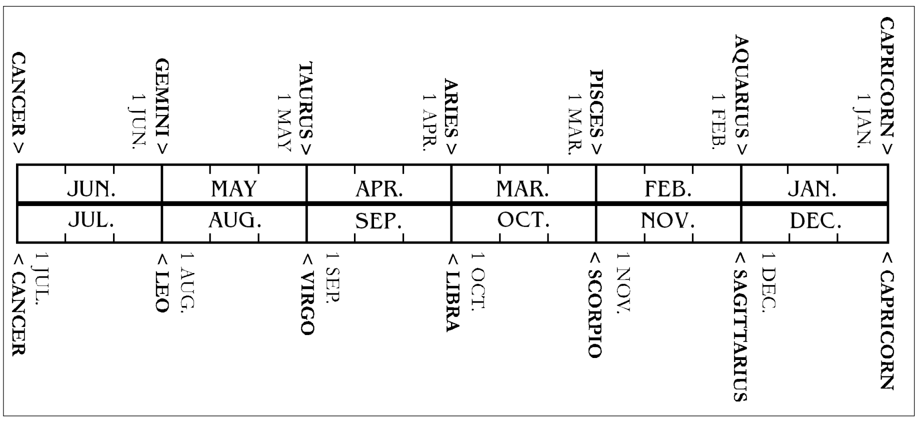

Fig. 52. The 'solar months' with limits at 8 days to Calends.

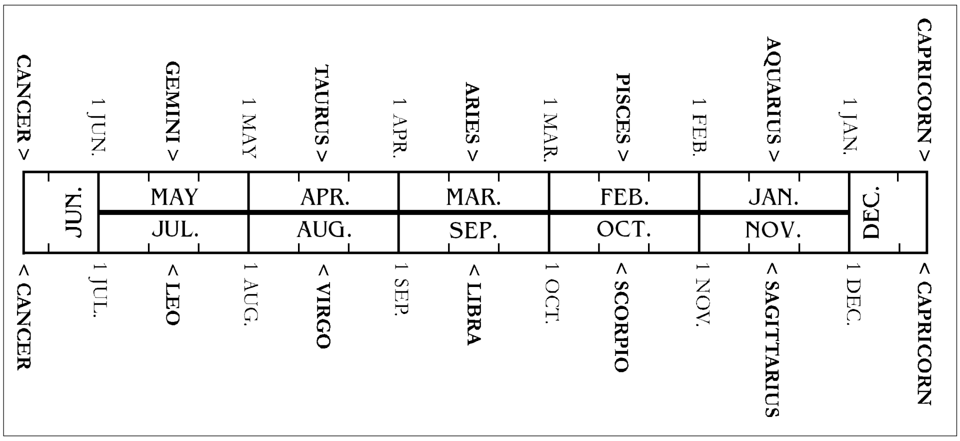

Fig. 53. The 'calendar months' with limits at 15 days to Calends.

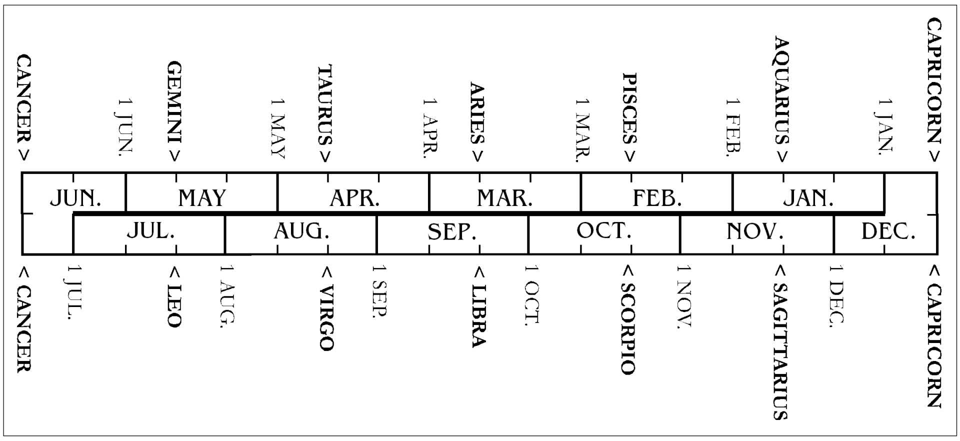

Fig. 54. The ' calendar months' with limits at 12 days to Calends.

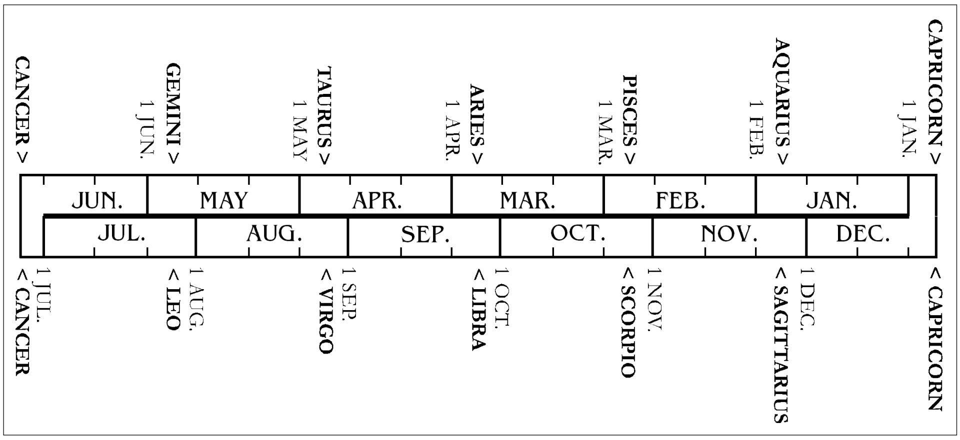

Fig. 55. The ' calendar months' with limits at 8 days to Calends.

With a calendar scale with the sequence in 'calendar months', usually one does not need a mid-month day, because medieval diallists made calculations exactly on the first day of each Sign. That calendar, as can easily be seen in Fig. 48, is symmetrical with the beginning of each zodiacal sign at 15 days before the Calends of the following month.

REFERENCES

1. Evans and Berggren (2006), p. 115–117.
2. This was necessary because of the great controversy that arose in Christian communities between the 2nd and the 4th centuries about Easter Sunday.
3. We can suppose that they arrived at this knowledge with the help of some instrument, probably of the same form as those we are treating here.
4. The shifting of the date of the Equinoxes still went on until the new calendar reform in 1582 by Pope Gregory XIII. At the end of the 15th century the astronomer Johann Mueller (commonly known as Regiomontanus) showed in his *Kalendarium* Equinoxes on 5 Ides of March (11 March) and 18 Cal. of Oct. (14 September), and Solstices on 2 Ides of June (12 June) and 2 Ides of December (12 December); and so on with the other Signs. Regiomontanus: *Kalendarium*, Venetiis.
5. Isidore of Seville (7th cent.), states that the Solstices and Equinoxes occur at 8 days to Calends (Isidore of Sevilla: *Etymologiarum libri* xx, book v, ch. xxxiv, P.L. Migne, 82 and Isidore of Sevilla: *De natura rerum*, ch. viii, P.L. Migne, 83, Paris 1844-1855). The anonymous computistical compilation dated to the 9th century published in P.L. Migne, 129, Paris 1879, considers only 8 days to Calends as main dates.
6. See the *Libellus de mensura horologii* published in Arnaldi (2011) then in Arnaldi (2011b), or Honorius of Autun: *De imagine mundi libri tres*, book ii, ch lxxxiv, P.L. Migne, 172.
7. Bede: *De natura rerum*, ch. xvii. B, and *De temporibus*, ch. vii. A, P.L. Migne, 90, Paris 1862; see also Byrhtferth of Ramsey's *Glossae*, in Bede: *De temporum ratione*, xvi, P.L. Migne, 90, col. 357, Paris 1862. Maurus Rabanus wrote, as Bede, that there are two ways to define the Solstices and Equinoxes: one

on 8 days to Calends and one on 12 days to Calends, and consider this latter one as true for Easter calculation; Maurus Rabanus, *Liber de computo*, ch liii, P.L. Migne, 107.

8. Bede: *De Ratione Computi*, ch. ix. C, P.L. Migne, 90, Paris 1862.
9. Meyvaert (2002)
10. Bede: *De Ratione Computi*,, ch. ix. BC, P.L. Migne, 90, Paris 1862; Isidore of Seville: *De natura rerum*, ch. vii, P.L. Migne, 83, Paris 1844–1855.
11. Bede's calendar provides much data (rise and set of stars and constellations, saints days, Egyptian and Greek months, etc.); I transcribe here only the astronomical data relevant to our topic.
12. For Bede, as we will see later, there remains the conflict between 8 days before Calends and 15 days before Calends.
13. See for example the famous 'Canterbury pendant' (Arnaldi, 2011b and Arnaldi, 2012) or the *LON* drawing (see Appendix E).

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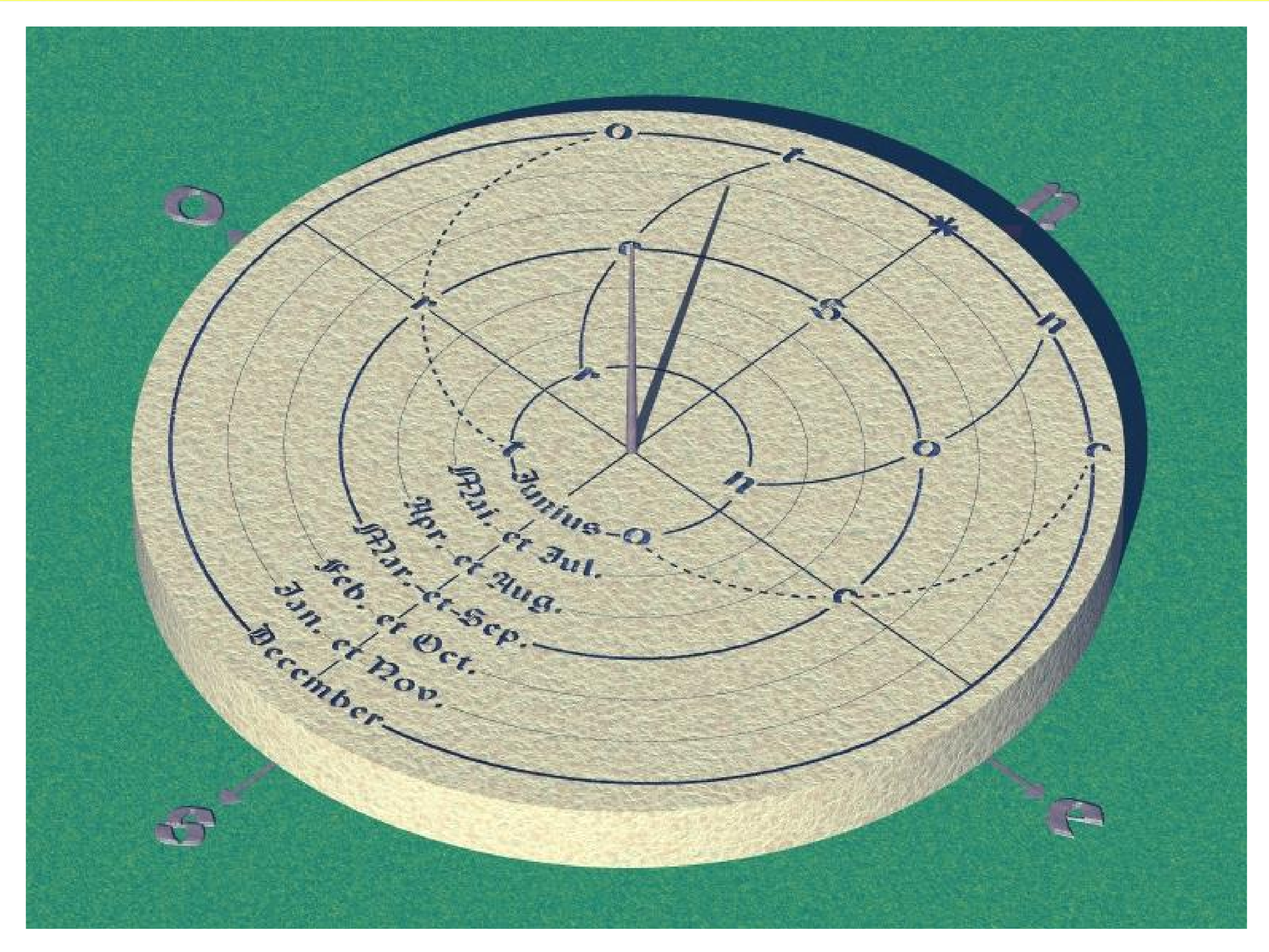

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