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GERBERT OF AURILLAC (POPE SYLVESTER II) AS A CLOCKMAKER

Abstract: *The paper analyses three preserved reports, depicting Gerbert of Aurillac (also known as: of Reims, of Ravenna, of Bobbio, and in 999–1003 as Pope Sylvester II) as a clockmaker. The Benedictine monk William of Malmesbury (died around 1143) writes about clocks Gerbert made in Reims in The History of the English Kings and describes them as arte mechanica compositum. The Benedictine Arnold Wion (died around 1610) mentions clocks from Ravenna, where Gerbert allegedly constructed a clepsydra, in The Tree of Life. In his Chronicle, Thietmar of Merseburg (died around 1018) describes a horologium with an observation tube (fistula) from Magdeburg. These three references are analysed from a historical standpoint and especially Williams's and Thietmar's short reports are interpreted as possible references to timekeeping devices – the astrolabe and the nocturlabe.*

Keywords: *Gerbert of Aurillac; clepsydra; astrolabe; nocturlabe*

Gerbert z Aurillacu (papež Sylvester II.) jako konstruktér hodin

Abstrakt: *Studie analyzuje tři dochované zprávy o Gerbertovi z Aurillacu (zvaný také z Remeše, z Ravenny nebo z Bobbia, v letech 999–1003 papež Silvestr II.) jako konstruktérovi hodin. Benediktinský mnich Vilém z Malmesbury (zemřel kolem 1143) v Dějinách anglických králů píše o Gerbertových hodinách vyrobených v Remeši a popisuje je jako arte mechanica compositum. Benediktin Arnold Wion (zemřel kolem 1610) zmiňuje ve Stromu života, že Gerbert v Ravenně sestrojil vodní hodiny. Dětmar z Merseburgu (zemřel 1018) popisuje ve své Kronice horologium s pozorovací trubicí (fistula) z Magdeburgu. Tyto tři reference jsou analyzovány z historického hlediska a zejména Vilémovy a Dětmarovy krátké zprávy jsou interpretovány jako možné odkazy na časoměrné přístroje – astroláb a nokturláb.*

Klíčová slova: *Gerbert z Aurillacu; klepsydra; astroláb; nokturláb*

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1. Introduction

Gerbert of Aurillac has traditionally been associated with a wide range of inventive and practical tools, of which he is supposed to be the propagator, constructor, or creator. This outstanding intellectual of the last third of the 10th century, who became Pope Sylvester II in 999, was deeply interested in the disciplines of the trivium (among others, he created an illustrative aid for practising rhetorical figures[1] and he is considered a progenitor of teaching and commenting on dialectics according to the traditional texts, so-called *logica vetus*[2]). But most importantly, he became famous through his knowledge and interpretation of the quadrivium.

In the field of arithmetic, he is regarded as a key figure responsible for the initial propagation, and originally only sporadic utilisation, of west Arabic numerals (so-called *ghubar*) in the Latin West,[3] or he is perceived as an initiator (inspired by Arabic mathematical knowledge) of a crucial turning point in conducting mathematical operations, since he promoted a calculating tool called abacus (its table form with columns using tokens with

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[1] See Gerbert, "Epistola 92," in *Die Briefsammlung Gerberts von Reims*, ed. Fritz Weigle (Weimar: H. Böhlaus Nachfolger, 1966), 121 (hereafter cited as *Ep.*).
[2] See, for example, John Marenbon, "Medieval Latin Glosses and Commentaries on Aristotelian Logical Texts of the Twelfth and Thirteenth Centuries," in *Glosses and Commentaries on Aristotelian Logical Texts. The Syriac, Arabic and Medieval Latin Traditions*, ed. Charles Burnett (London: The Warburg Institute, 1993), 101, 110, 116, or John Marenbon, "The Latin Tradition of Logic to 1100," in *Handbook of the History of Logic*, volume 2: *Mediaeval and Renaissance Logic*, eds. Dov M. Gabbay and John Woods (Amsterdam: North-Holland, 2008), 40–41. Cf. Richer Remensis, *Historiae* III, 46, ed. Hartmut Hoffmann (Hannover: Hahn, 2000), 193–94.
[3] Cf., e.g., Alain Schärling, *Un portrait de Gerbert d'Aurillac. Inventeur d'un abaque, utilisateur précoce des chiffres arabes, et pape de l'an mil* (Lausanne: Presses polytechniques et universitaires romandes, 2012), 81–86; Menso Folkerts, "The Names and Forms of the Numerals on the Abacus in Gerbert Tradition," in *Gerberto d'Aurillac da abate di Bobbio a papa dell'anno 1000*, ed. Flavio G. Nuvolone (Bobbio: Archivum Bobiense, 2001), 245–65, or Menso Folkerts, "Early Texts on Hindu-Arabic Calculation," *Science in Context* 14, no. 1–2 (2001): 16–18.

symbols of west Arabic numerals).[4] At that time, the abacus was understood as a geometrical tool (*mensa geometricalis*),[5] since, among others, it aided in facilitating land-surveying calculations and Gerbert produced several texts on geometry which are of particular interest as exemplary pieces of a given period.[6] Even in the field of music, Gerbert was active as a theoretician and practical constructer, who was apparently dealing with calculations necessary to reach correct ratios of organ tubes[7] or with the construction of organs itself.[8]

The greatest number of innovation and practical tools attributed to Gerbert is related to astronomy. Gerbert's friend and colleague Richer of Reims describes a quartet of pedagogic tools Gerbert employed: a celestial globe, an observation hemisphere, an armillary sphere with an ecliptic, and an armillary sphere with a horizon, thanks to which it was not only easy to

[4] See, e.g., Nancy M. Brown, *The Abacus and the Cross: The Story of the Pope Who Brought the Light of Science to the Dark Ages* (New York: Basic Books, 2010); Menso Folkerts, "Frühe Darstellungen des Gerbertschen Abakus," in *Itinera mathematica. Studi in onore di Gino Arrighi per il suo 90° compleanno*, eds. Raffaela Franci and Paolo Pagli, and Laura T. Rigatelli (Siena: Università di Siena, 1996), 23–43; Uta Lindgren, *Gerbert von Aurillac und das Quadrivium. Untersuchungen zur Bildung im Zeitalter der Ottonen* (Wiesbaden: Franz Steiner Verlag, 1976), 16–20, or Werner Bergmann, *Innovationen im Quadrivum des 10. und 11. Jahrhunderts. Studien zur Einführung von Astrolab und Abakus im Lateinischen Mittelalter* (Stuttgart: Franz Steiner Verlag, 1985), 176–207.

[5] See Turchillus Compotista, "Reguncule super abacum," ed. E. Narducci, *Bolletino di bibliografia e di storia delle scienze matematiche e fisiche* 15 (1882): 138. Cf. Richer, *Historiae* III, 54, 198.

[6] See Gerbert, "Isagoge Geometricae," in *Gerberti postea Silvestri II papae Opera Mathematica (972–1003)*, ed. Nicolaus Bubnov (Berlin: R. Friedländer & Sohn, 1899), 46–97. Cf., e.g., Hans-Veit Friedrich, "Zur Textgestaltung der Geometrie des Gerbert von Aurillac," *Archivum Latinitatis Medii Aevi* 39 (1973–1974): 113–120, or Kurt Vogel, "L'Aritmetica e la Geometria di Gerberto," in *Gerberto: Scienza, storia e mito*, ed. Michele Tosi (Bobbio: Archivum Bobiense, 1985), 577–96.

[7] See Gerbert, "Rogatus," in *Mensura fistularum. Die Mensurierung der Orgelpfeifen im Mittelalter.* Teil I: *Edition der Texte*, ed. Klaus-Jürgen Sachs (Stuttgart: Musikwissenschaftliche Verlags-Gesellschaft, 1970), 59–81.

[8] Cf., e.g., Anna M. Flusche, *The Life and Legend of Gerbert of Aurillac. The Organbuilder Who Become Pope Sylvester II* (Lewiston: Edwin Mellen Press, 2005), 117–56; Klaus-Jürgen Sachs, "Gerbertus cognomento musicus. Zur musikgeschichtlichen Stellung des Gerbert von Reims (nachmaligen Papstes Silvester II)," *Archiv für Musikwissenschaft* 29, no. 4 (1972): 257–74; Michel Huglo, "Gerbert, théoricien de la musique, vu de l'an 2000," *Cahiers de civilisation médiévale* 43, no. 170 (2000): 143–60, or Frank Hentschel, "Gerbert, organa, and historical thinking," in *Gerbertus qui et Silvester, minima gerbertiana da Piacenza a Lovanio, e altri studi a 1000 anni dalla morte Pontifice (12. V. 1003)*, ed. Flavio G. Nuvolone (Bobbio: Archivum Bobiense, 2002), 53–77.

understand the teachings of astronomy, but also possible to practically verify many theoretical findings by direct observation of the night sky.[9] Apart from these tools, it is clear that Gerbert also focused on some practical aspects of astronomy, namely timekeeping.

In this study I will focus on this specific activity and especially on relating Gerbert's name to clock building. First, the preserved sources mentioning Gerbert as a clock constructor will be introduced, with reference to whether these texts provide a credible report of Gerbert's activity. Then I will focus on the individual types of clocks that were allegedly created by Gerbert in Reims, Ravenna and Magdeburg. Since the sources are not always clear on what type of device is mentioned, apart from the clepsydra, I will also introduce the astrolabe and the nocturlabe while presenting these devices as tools for timekeeping.

2. Gerbert and Clock Construction

Mediaeval and early modern sources contain mentions of at least three different clocks that were allegedly constructed by Gerbert during the 10th century in three different places.[10] The first is *horologium arte mechanica compositum* of Reims mentioned by William of Malmesbury. The written records of the clepsydra (*horologium aquatilis sive clepsidra*), supposed to have been created by Gerbert in Ravenna, are as late as the 16th century. The oldest reference is offered by Thietmar of Merseburg who mentions astronomic clocks Gerbert created and correctly calibrated according to star (*stellae*) observations in Magdeburg.

The clocks in Reims are recorded by the Benedictine monk and historiographer William of Malmesbury (died approx. 1143) who dedicated a portion of the second volume of *The History of English Kings* to a brief introduction of Pope Sylvester II (who is incorrectly called John[11]). Gerbert is presented as a man who lusted for glory (*cupiditas gloriae*) and, therefore, he went to Spain (*Hispania*) in order to study astrology (*astrologia*) and other arts (*artes*) with the Saracens (*Saraceni*).[12] He pursued beneficial

[9] See Richer, *Historiae* III, 50–53, 195, 12–198, 4. Cf. Marek Otisk, "Gerbertův úvod do geocentrické astronomie," *Teorie vědy / Theory of Science* 32, no. 4 (2010): 507–33.

[10] Cf. Stephen C. McCluskey, *Astronomies and Cultures in Early Medieval Europe* (Cambridge: Cambridge University Press, 1998), 176.

[11] William of Malmesbury, *Gesta regum Anglorum / The History of the English Kings* II, 167, 1, ed. Roger A. B. Mynors (Oxford: Clarendon Press, 1998), 278 (hereafter cited as *Gesta*).

[12] Ibid., 167, 1, 280.

(*salubris*) disciplines such as the traditional arts of the quadrivium (*arithmetica, musica, astronomia, geometria*), but also pursued harmful (*noxius*) knowledge.[13] His skills with the astrolabe allegedly surpassed even those of Ptolemy; he allegedly learned to comprehend the motions and positions of stars and derived astrological interpretations from them. Further, he was supposed to have mastered divinatory art and the art of summoning souls of the dead.[14] He concluded his studies by stealing a precious book (*codex totius artis*), during his escape he summoned the devil (*diabolus*), with his help he reached safety and became the devil's vassal (*hominium*).[15]

With the devil's help he became a successful teacher in Gallia and important persons of the contemporary world were among his students, including abbots (e.g., Gerbert's friend and addressee of several letters dealing with scientific issues Constantine of Fleury and Micy[16]), bishops (e.g., another addressee of Gerbert's mathematic letter Adalbold of Utrecht[17]), a king (Robert II, son of Hugh Capet) and an emperor (Otto III).[18] These influential people of the contemporary world were supposed to help Gerbert to secure significant offices of the Church – Robert II was supposedly responsible for Gerbert's appointment as the archbishop of Reims,[19] Otto III was said to have been involved in appointing Gerbert as the archbishop of Ravenna and pope.[20]

[13] Ibid., 167, 2–3, 280.
[14] Ibid., 167, 2, 280.
[15] Ibid., 167, 4–5, 280–82.
[16] Gerbert apparently wrote at least six letters to him, in the form of brief scientific texts dealing with astronomy, music, and arithmetic, at the turn of 970s and 980s. See *Gerberti Opera Mathematica*, 6–35. Several other letters Gerbert sent to Constantine have been preserved. See Gerbert, *Ep.* 86, 114; *Ep.* 142, 168–69; *Ep.* 191, 229–30.
[17] Gerbert, "Ad Adelboldum de causa diversitatis arearum trigoni aequilateri geometrice arithmeticeve expensi," in *Gerberti Opera Mathematica*, 43–45.
[18] William, *Gesta* II, 168, 1, 282–84. For a comprehensive account, see Courtney DeMayo, "The Students of Gerbert of Aurillac's Cathedral School at Reims: An Intellectual Genealogy," *Medieval Prosopography* 27 (2012): 97–117.
[19] Gerbert's struggle to legitimate his archbishop office in Reims (especially 990–95) after the death of Adalbero of Reims (989) resulted in the success of his opponent Arnulf – cf. Claude Carozzi, "Gerbert et le concile de St-Basle," in *Gerberto: Scienza, storia e mito*, ed. Michele Tosi (Bobbio: Archivum Bobiense, 1985), 661–676; Elizabeth Dachowski, *First Among Abbots: The Career of Abbo of Fleury* (Washington: The Catholic University of America Press, 2008), 103–24, or Jason Glenn, *Politics and History in the Tenth Century. The Work and World of Richer of Reims* (Cambridge: Cambridge University Press, 2004), 93–109.
[20] William, *Gesta* II, 169, 2–3, 284. Gerbert was consecrated as Sylvestr II on 2nd April 999 and he stayed in the papal office until his death on 12th May 1003.

In other words, everything that Gerbert pursued turned into a success thanks to the devil's aid. However, William is aware that such stories about the dark origins of successful scholars could have been a mere common people's fabrication (*ficta vulgares*). He supports that with a reference to Boethius who writes in the *Consolation* that he and Philosophy, who taught him, among others, about the orbits of stars (*sidera*), were accused of being protected by the lowest spirits (*praesidia vilissimorum spirituum*).[21] Nonetheless, William does not doubt Gerbert's profanity (*sacrilegium*) which is evidenced by the dreadful circumstances of Gerbert's death.[22]

William's mention of the clocks Gerbert supposedly created is set in this context. It is listed among the proofs of successful and famous acts that Gerbert achieved with the devil's aid: allegedly, it was still possible to see a hydraulic organ (*organa hydraulica*) and mechanically created clocks (*horologium arte mechanica compositum*) in Reims at his time. Even the very circumstances in which William mentions these clocks are reasons for doubt. Although it is true that Gerbert operated in Reims for a long time and he actually became famous as an expert in philosophy and science (the quadrivium), other preserved contemporary reports do not mention such creations in Reims. For instance, Richer of Reims, Gerbert's friend, colleague and possibly even disciple,[23] described Gerbert's stay in Reims in detail and he does not mention anything resembling William's report, while it seems unlikely that he would not have made any record of it, e.g., when he described other aforementioned astronomic tools created by Gerbert. Therefore, William's ascription of the created clock to Gerbert can be regarded as an expression of the chronicler's attempt to show Gerbert's successes and extraordinary achievements as necessarily connected to the influence of tainted powers. To conclude, it is unlikely that his report of Gerbert's clock can be considered credible.

The references to Gerbert's clepsydra in Ravenna do not fare much better. Once again it is true that Gerbert stayed in Ravenna – during the years 998–999 he held the position of archbishop[24] – but his time in Ravenna was fairly short and no sources from his time (or immediately after his death) mention any such device.

[21] William, *Gesta* II, 168, 5–6, 282. Cf. Boethius, *De consolatione Philosophiae* I, 4, 39, ed. Claudio Moreschini (München: K. G. Saur Verlag, 2005), 17.

[22] William, *Gesta* II, 168, 6, 282 or ibid. II, 172, 2, 294.

[23] See, for instance, Glenn, *Politics and History*, 67–70.

[24] For more details, see, e.g., Augusto Vasina, "Gerberto arcivescovo di Ravenna," in *Gerberto: Scienza, storia e mito*, ed. Michele Tosi (Bobbio: Archivum Bobiense, 1985), 255–72.

This report appears at the end of the 16th century when the Benedictine monk Arnold Wion (Vuion, 1554–approx. 1610) dedicated one chapter of his extensive work *Lignum vitae* to archbishop Gerbert, who would later become Pope Sylvester II. His text focuses almost exclusively on relating Gerbert to the construction of clocks and organs. Following the list of several quotations mentioning Gerbert's creations, he reminds the reader that similar devices had been known even earlier,[25] and consequently, he mentions a clepsydra in Ravenna, said to have been created by Gerbert during his time as archbishop.[26]

In the 17th century, the Jesuit Augustin Oldoini (1612–1683) writes in a very similar manner when he complemented the *Vitae et res gestae Pontificum romanorum et S. R. E. Cardinalium* (first published in 1601) of the Dominican scholar Alphonsus Ciacconius (1530–1599). While Ciacconius presents an essentially standard and brief story of Gerbert's life and his intellectual success (even clocks in Magdeburg are not absent) to which he adds narrative passages about Gerbert's pact with the devil,[27] Oldoini includes further information from Gerbert's life and even from the legend surrounding his character. Thus, apart from the clocks and organs from Reims, Ravenna's clepsydra is mentioned as well, with the formulation being nearly identical to the one of Wion.[28]

It is difficult to assume that Gerbert's clock in Ravenna was essentially unknown for six centuries and then suddenly appeared. Thus, none of these reports of a clepsydra can be considered trustworthy.

On the other hand, the case of clocks Gerbert was supposed to create in Magdeburg is different. They are referenced by Thietmar of Merseburg (975–1018), bishop and close friend of Henry II who had been Holy Roman Emperor since the year 1002 after the demise of his cousin Otto III. Thietmar focuses on the deeds of Henry II in his chronicle. At the end of the sixth volume, in one of the many digressions (this one preceded the coronation of the Holy Roman Emperor Henry II by Pope Benedict VIII in 1014), Thietmar briefly lists Benedict's predecessors in the Holy See since Gregory

[25] Arnold Wion, *Lignum vitae, Ornamentum & Decus Ecclesiae* V (Venice: Angelerius, 1595), 741–43.

[26] "Horologii uero aquatici, siue Clopsydrae figura, est Rauennae in Herculis regione, quam ipse idem construxit dum illic esset Archiepiscopus." Ibid., 743.

[27] Alfons Ciaconius and Augustin Oldoinus, *Vitae et res gestae Pontificum romanorum et S. R. E. Cardinalium* (Rome: J. B. Bernabo & J. Lazzarini, 1677), 751A–754D.

[28] "Horologii aquatilis, seu clepsidrae figura est Rauennae in Herculis regione, quam Gerbertus construxit Archiepiscopus tunc Rauennas." Ibid., 756A.

V (pope in 996–999). The only pope he examines more closely is Gerbert and he mentions the illegitimate (*iniustus*) position of archbishop in Reims, his vast education in natural disciplines (*naturales artes*), and an unprecedented knowledge of astronomy (*astrorum cursus*) by which he surpassed (*superare*) all of his contemporaries (*contemporales suos*). Having to leave Reims, he moved to the emperor's court, which was located in Magdeburg at that time.[29] There Gerbert allegedly created clocks (*horologium*) which he correctly calibrated according to the Polar star (*stella*, *dux nautarum*) which he observed through an observation tube (*fistula*).[30] Gerbert's brief biography by Thietmar entirely lacks any reference to the devil's influence and help (the negative legend of Gerbert began to form significantly in later years), only his knowledge of the liberal arts is mentioned.

The credibility of this report is further supported by the fact that in the 990s, after staying in Quedlinburg Abbey and in the Monastery of St. John the Baptist near Magdeburg, Thietmar was a canon of the cathedral chapter of St. Maurice in Magdeburg.[31] He directly experienced Gerbert's stay at the emperor's court in this city during the third quarter of the 990s and it is possible that one of the few details about Sylvester II listed in his chronicle is included because Thietmar witnessed Gerbert's creation himself.

3. Astrolabe

The ascription of creating *arte mechanica compositum* clocks in Reims to Gerbert by William of Malmesbury is doubtful and, above all, it is difficult to determine which device or tool is meant to have been used. Translations and interpretations sometimes mention the designation "mechanical clocks,"[32] i.e., clocks created on a mechanical basis, which is questionable since similar clocks are evidenced since the second half of the 13th century and more likely

[29] For more information on Gerbert's relationship with the Ottonian imperial dynasty, see, e.g., Lindgren, *Gerbert von Aurillac*, 69–94, or Harald Zimmermann, "Gerbert als kaiserlicher Rat," in *Gerberto: Scienza, storia e mito*, ed. Michele Tosi (Bobbio: Archivum Bobiense, 1985), 235–53.

[30] Thietmarus Merseburgensis, *Chronicon* VI, 100, ed. Robert Holtzmann (Berlin: Weidmann, 1935), 393.

[31] Ibid., IV, 16, 151.

[32] See, for example, Gerhard Dohrn-van Rossum, *History of the Hour: Clocks and Modern Temporal Orders* (Chicago: University of Chicago Press, 1996), 55 or David Rollo, *Kiss My Relics: Hermaphroditic Fictions of the Middle Ages* (Chicago: University of Chicago Press, 2011), 70–71.

from the 14th century.[33] Another option is to read William's characteristic of Gerbert's clocks as a description of a method of how the clocks were created, i.e., that they are a piece of craftsmanship and of an applied knowledge of mechanisms.

The latter could be supported by the chronicle of Richer of Reims who mentioned that Gerbert needed a big board to create the calculating tool *abacus* and a fitting tool was provided by a shield-maker (*scutarius*).[34] Similarly, Gerbert employed craftsmanship during the creation of his other astronomical tools – an observation hemisphere and a world globe.[35] It is possibly not a coincidence that similar words are used to describe clocks sent by Caliph Harun al-Rashid to Charlemagne and, from the description of these clocks, it is clear that it pertains to the method of creation and not to the principle of their function (for details, see below).[36] If the mentioned clocks were not mechanical but were created by craftsmanship and knowledge of the necessary arts, then it is possible that the same methods may have been used in the creation of an astrolabe or a nocturlabe.[37] Indeed, even Thietmar's description of Gerbert's clock in Magdeburg, which has been correctly calibrated by an observation tube (*fistula*), makes it possible to interpret it as a clock of this type. If the planisphere astrolabe, i.e., an astronomical tool employing stereographic production to mark the celestial sphere with its circles on a plane and, concurrently, marking the coordinates of horizon, so-called almucantars (see fig. 1), was used, then the said observation tube was an alidade, which was used, e.g., for observing the Sun and bright stars.

This alternative interpretation could be corroborated with the fact that Gerbert is traditionally related to the introduction of astrolabes in the Chris-

[33] Cf., e.g., Lynn Thorndike, "Invention of the Mechanical Clock about 1271 A. D.," *Speculum* 16, no. 2 (1941): 242–243; Abbott Payson Usher, *A History of Mechanical Inventions* (New York: Dover Publications, 1982), 192–96; Donald R. Hill, "Clocks and Watches," in *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*, Volume 1: A–K, ed. Helaine Selin (Berlin: Springer, 2008), 153, or Michael R. Matthews, *Time for Science Education. How Teaching the History and Philosophy of Pendulum Motion Can Contribute to Science Literacy* (Berlin: Springer, 2000), 56–70.

[34] Richer, *Historiae* IV, 54, 198.

[35] Gerbert, *Ep.* 134, 162, 148, 175.

[36] See, for instance, Elly R. Truitt, *Medieval Robots. Mechanism, Magic, Nature, and Art* (Philadelphia: University of Pennsylvania Press, 2015), 146–47.

[37] Cf. Rodney M. Thompson and Michael Winterbottom, *William of Malmesbury, The History of the English Kings: General Introduction and Commentary* (Oxford: Clarendon Press, 1999), 155, or Emmanuel Poulle, "Gerbert horloger," in *Autour de Gerbert d'Aurillac, le pape de l'an mil*, eds. Olivier Guyotjeannin and Emmanuel Poulle (Paris: École des chartes, 1996), 366.

tian Latin West. It was not rare to ascribe the authorship of one of the oldest Latin texts on the astrolabe *De utilitatibus astrolabii* to him, although it is more often assumed today that it was written by one of Gerbert's disciples or colleagues.[38] Authorship notwithstanding, it is clear that Gerbert was more or less involved in a growing interest in the astrolabe, of which other texts were written at the beginning of the 11th century, allowing for its construction and utilisation.

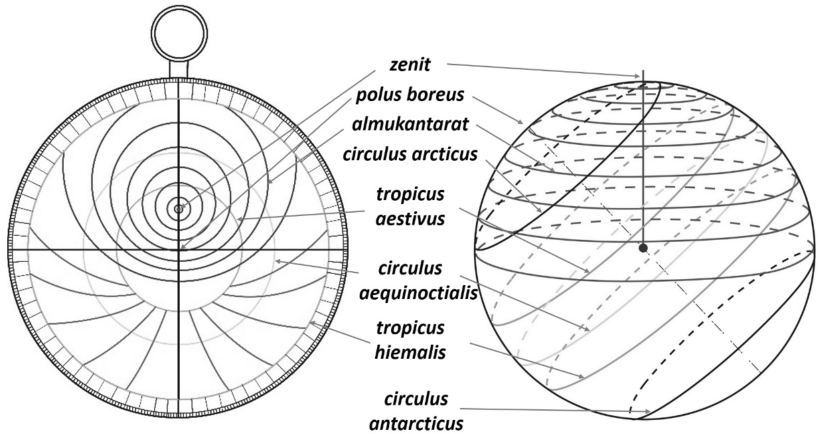

Figure. 1. A celestial sphere with the Earth in its centre and its image on the front side of an astrolabe.

[38] Cf., e.g., Bergmann, *Innovationen im Quadrivum*, 66–174; Arno Borst, *Astrolab und Klosterreform an der Jahrtausendwende* (Heidelberg: Universitätsverlag Carl Winter, 1989); Arno Borst, *The Ordering of Time. From Ancient Computus to the Modern Computer* (Cambridge: Polity Press and Blackwell Publishers, 1993), 54–63; André van de Vyver, "Les plus anciennes traductions latines médiévales (Xe–XIe siècles) de Traités d'Astronomie et d'Astrologie," *Osiris* 1, no. 1 (1936): 658–91; Burkhard Stautz, "Die früheste bekannte Formgebung der Astrolabien," in *Ad radices. Festband zum fünfzigjährigen Bestehen des Instituts für Geschichte der Naturwissenschaften der Johann Wolfgang Goethe-Universität, Frankfurt am Main*, ed. Anton von Gotstedter (Stuttgart: Franz Steiner Verlag, 1994), 315–28, or the monothematic issue "The Oldest Latin Astrolabe," eds. Wesley M. Stevens, Guy Beaujouan, and Anthony J. Turner, special issue, *Physis: Rivista internazionale di storia della scienza* 32 (1995).

In the text of *De utilitatibus astrolabii*, the fact that it is a perfect device for timekeeping is stressed in many places. The very first chapter puts astronomical findings, such as ascending and descending constellations (*ortus et occasus siderum*), stars (*stellae*), or even the Sun (*sol*), in a direct relation to the most precise (*certissima*) method for determining hours, both day and night (*noctes et dies*), natural and artificial (*naturales sive artificiales*), and in a relation to determining the temporal (and geographical) climate (*clima*), which is necessary for timekeeping needs (*horologium*).[39] Similarly, the text mentions that timekeeping via the astrolabe is the most suitable or appropriate (*dignissimum*) method for determining day hours (*diurnae horae*).[40]

This understanding of the astrolabe in *De utilitatibus astrolabii* corresponds to the very content of this work. Essentially, the text mostly focuses on time and on everything related to timekeeping. First (chapter 3), the method of locating the Sun's actual position on the ecliptic is introduced (a degree of the zodiacal constellation) and the way of determining a nadir of the Sun's actual position, i.e., a degree being in direct opposition to the Sun (chapter 4). Then the method of determining day hours according to the altitude (*altitude*) of the Sun (chapter 5) and night hours according to the altitude of stars (chapter 6). The next chapter deals with the marking of the temporal (irregular) hours on the astrolabe disc according to the daily movements of the Sun (chapter 7) and clarifies the difference between regular and irregular hours (*horae aequinoctiales et inaequales*). The former represents 1/24 of the Sun's daily orbit around the Earth, i.e., a shift of the Sun in the sky by 15°, which means that every hour is of the same length (this is the way we define hour today). Its name is derived from the equinox days on which the Sun enters (in the course of its yearly journey) the constellations of Aries (spring equinox) and Libra (autumnal equinox). Since the Sun is just crossing the equator of the celestial sphere, days and nights last the same amount of time – the Sun is over and under the horizon for an equal period. Irregular hours are not of the same length, since the Sun is above (or under) the horizon for a different period of time; however, the presence of the Sun above the horizon is always divided into 12 hours as well as the time of the night, when the Sun is under the horizon, is always 12 hours. During the year, the length of hour changes corresponding to the length of the journey the Sun travels above the horizon – during the summer it may

[39] Gerbert, *De utilitatibus astrolabii* I, 2, in *Gerberti Opera Mathematica*, 115–16.
[40] Ibid., V, 4, 129. An astrolabe is referred as the most certain (*certissimus*) tool for timekeeping also in ibid., VI, 1, 130.

mean, e.g., 19°, i.e., an hour lasts 76 regular minutes, while during the night the Sun travels at 11°, i.e., 44 regular minutes (chapter 8).

Further, the text *De utilitatibus astrolabii* describes the method of determining irregular hours or their parts during the day (chapter 9) or during the night (chapter 10) and then it describes the same for regular hours (chapters 11–13). Further parts of the text are dedicated to the star rise (chapter 14) and to determining other necessary data for finding out the actual time according to the orbits of celestial objects (chapters 15 and 16). Consequently, the stars of constellations and their shapes are introduced, since they are essential to the operation of an astrolabe (chapter 17) and this is accompanied by a detailed description of time and climate zones: their delimitation is determined according to (among others) the length of the equinoctial day, including their geographical descriptions in chapters 18 and 19. The final part of the text focuses on findings important for determining whether noon has already taken place during a given day or not (chapter 20) and then describes a method of timekeeping utilising the back side of an astrolabe (chapter 21). In the last sentence, the author clearly states that an astrolabe (*walzagora, id est plana sphaera*) can serve as a clock (*horologium*) in this way.[41]

This brief overview of the description of the utility of an astrolabe in a text that evidently originated amidst Gerbert's friends, disciples or colleagues implies that the astrolabe was significantly understood especially as a tool for timekeeping. Provided we have placed a disc with inscribed round celestial spheres, including almucantars, corresponding to our actual observing position (i.e., provided that the disc corresponds to the climate we are in), the determination of time using an astrolabe is comparatively simple (see fig. 2):

1. We determine the actual position of the Sun in the ecliptic (e.g., with the help of the back side of an astrolabe where a calendar is located and every day corresponds to degrees in zodiacal constellations).
2. On the *rete*, the front side of the astrolabe, we mark the actual position of the Sun and its nadir.
3. We measure the height of the Sun above the horizon using an alidade (once again on the back side of the astrolabe).
4. We determine whether it is morning or afternoon.
5. On the front side of the astrolabe, we rotate the sign with the actual position of the Sun, marked on the rete, according to the measured ac-

[41] Ibid., XXI, 147.

tual height of the Sun above the horizon to the corresponding degree of almucantars drawn on the front side of the astrolabe (if it is afternoon, we put a mark to the left part of the astrolabe and if it is morning to its right part).

6. The nadir of the Sun will show us the actual time according to the curves of irregular hours on the front side of the astrolabe.

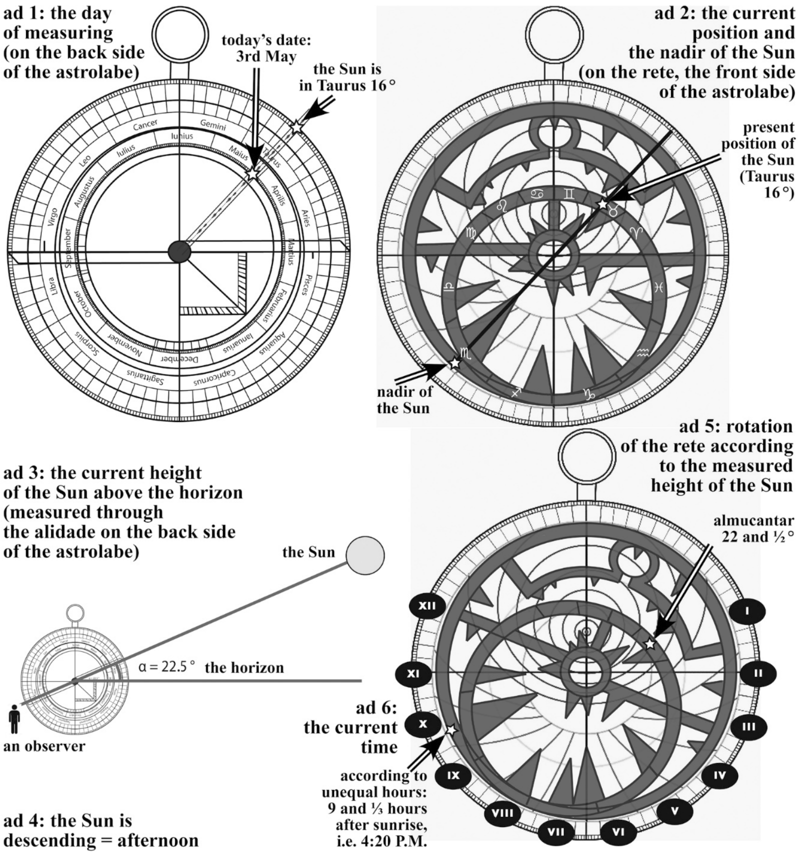

Figure. 2. Determining actual time via the astrolabe.

If we wish to translate this time to regular hours, we can simply count degrees on the edge (*limbus*) of the astrolabe from the noon, or from sunrise, and then divide the result by 15, i.e., the 15° travelled by the Sun in one regular hour, and depending on the starting point of our calculation we arrive at a time expressed in regular hours that has passed since noon or sunrise.

Therefore, one cannot exclude the possibility that certain information concerning the astrolabe as a timekeeping tool could have been presented by Gerbert in Reims. Even though Richer of Reims is silent about Gerbert's Reims astrolabe, at least one passage in Gerbert's correspondence could be interpreted as a reference to timekeeping with the help of an alidade on an astrolabe.[42] If William's mention of Gerbert's clocks in Reims is of any relevance, then it would have entailed an astrolabe that was created with the necessary knowledge of the corresponding art.

4. Clepsydra

Although I have said above that Gerbert probably did not create a clepsydra during his stay in Ravenna, it is beyond doubt that he had knowledge of these clocks. Since Cassiodorus,[43] we know that such clocks were used in the early Middle Ages and that they were known in other places of Europe in Gerbert's time.[44] Even the famous clocks (*horologium*) that were sent by the caliph of Baghdad Harun al-Rashid to Charlemagne in 807 are water timekeeping devices (*clepsidra*).[45] They are, among others, also described as *arte mechanica compositum*, but it is added that they are admirably (*mirifice*) created from brass (*ex auricalcum*).

The clepsydra appears to have been well known during the Carolingian and Ottonian era. Even Gerbert wrote about it in a horological letter to an otherwise unknown brother Adam, in which he explains the time zones

[42] Gerbert, "Regulae de numerorum abaci rationibus," in *Gerberti Opera Mathmetica*, 7–8.
[43] Flavius M. A. Cassiodorus, *Institutiones* I, 30, 5, ed. Roger A. B. Mynors (Oxford: Clarendon Press, 1961), 77–78, or Flavius M. A. Cassiodorus, *Variae* I, 45, ed. Theodor Mommsen (Berlin: Weidmann, 1894), 39–40.
[44] See *Consuetudines Floriacenses antiquiores*, ed. Anselme Davril, in *Consuetudinum saeculi X/XI/XII monumenta non-Cluniacensia*, ed. Kassius Hallinger (Sieburg: F. Schmitt, 1984), 42, or Abbo of Fleury and Ramsey, *Commentary on the Calculus of Victorius of Aquitaine* III, 37, ed. Alison M. Peden (Oxford: The British Academy, 2003), 95. Cf. also Gillian R. Evans and Alison M. Peden, "Natural Science and Liberal Arts in Abbo of Fleury's Commentary on the Calculus of Victorius of Aquitaine," *Viator* 16 (1985): 119–20.
[45] *Annales regni Francorum* 807, ed. Friedrich Kurze (Hannover: Hahn, 1895), 123–24.

and changes in the duration of sunlight during the year on an astronomical basis. He also adds two horological tables for the Hellespont climate and for the climate where the longest day of the year reaches 18 hours.[46] The identification of the proper geographical zone, i.e., latitude, was a key step in the setting of astronomical tools such as the astrolabe, and it was also necessary for translating regular and irregular hours, etc.

In the aforementioned letter to brother Adam, Gerbert introduces practical instructions on how to identify a time zone in which the given individual is located. During solstitial days (*dies solsticiales*), one should precisely measure the volume of water that passes through a clepsydra (*clepsidra*) during the night (*tempus nocturnum*) and during the day (*tempus diurnum*), i.e., from sunset to sunrise and from sunrise to sunset. Both are to be separately captured, and after assessing the ratio should be converted to 24 hours.[47] A specific example follows:

1. During a solstitial night, 5 and ¾ litres pass through the clepsydra.
2. During a solstitial day, 12 and ¼ litres pass through the clepsydra.
3. 18 litres in total pass through the clepsydra over 24 hours, which means that 1 litre = 80 minutes of regular time (i.e., 1 and ⅓ hours).
4. The length of the night is 5 and ¾ · 80 = 460 minutes, i.e., 7 hours and 40 minutes.
5. The length of the day is 12 and ¼ · 80 = 980 minutes, i.e., 16 hours and 20 minutes.
6. The observer is located a little bit further north (approx. 50° northern latitude) of so-called seventh climate,[48] for which it holds (e.g., according to the text of *De utilitatibus astrolabii*) that the longest day in a year is 16 hours and is located at 48° 32′ northern latitude.[49] With the help of tables attached by Gerbert, everybody can easily calculate the length of sunlight during the individual months of the year.

[46] Gerbert, *Ep.* 153, 180–81.
[47] Ibid., 180.
[48] See, e.g., William H. Stahl, *Roman Science. Origins, Development, and Influence to the Later Middle Ages* (Edison: University of Wisconsin Press, 1962), 196–98; Ernst Honigmann, *Die sieben Klimata und die ΠΟΛΕΙΣ ΕΠΙΣΗΜΟΙ. Eine Untersuchung zur Geschichte der Geographie und Astrologie im Altertum und Mittelalter* (Heidelberg: C. Winter Universitätsbuchhandlung, 1929), 183–92.
[49] Gerbert, *De utilitatibus astrolabii* XVIII, 3, 142.

It is clear even from this letter of Gerbert's that he was experienced in using clepsydras and he actively used them for timekeeping. However, it is not justified to believe that he created such a mechanism in Ravenna based on the preserved historical sources.

5. Astronomical Clocks – Nocturlabe

As we have seen, only the horologium in Magdeburg can be considered with some degree of certainty to be Gerbert's creation. Unfortunately, Thietmar's description is very brief and it is therefore very difficult to determine what device it entailed. Essentially, we only know that it was a horologium for whose correct setting Gerbert observed the Polar star by means of an observation tube *(fistula)*.

If we take this fistula to be an alidade, then the tool used was an astrolabe, which is well suited to serve as a timekeeping device. Thietmar's mention of the observation of the night sky (Polar star) could be identified as an attempt to precisely determine the observation area so that the adjustment of the astrolabe disc would have corresponded to the right climate and the astrolabe could have served as a suitable tool for related tasks in Magdeburg.

Another possibility is that it entailed some other alternative tool for night timekeeping. Indeed, such a machine is ascribed to Pacificus of Verona (died during the first half of the 9th century) as well, on whose gravestone (originating from the 12th century[50]) it is written that he had created night clocks (*horologium nocturnum*) never seen before and had devised a method (*argumentum*) of determining time with their help.[51] The epitaph also adds that Pacificus wrote more than two hundred books, including one horological poem about the celestial sphere.[52] Interpretations of this poem and preserved illuminations from contemporary manuscripts provide an idea of how these clocks could have operated.[53]

[50] Cf. Cristina La Rocca, "A Man for All Seasons: Pacificus of Verona and the Creation of a Local Carolingian Past," in *The Uses of the Past in the Early Middle Ages*, eds. Yitzak Hen and Matthew Innes (Cambridge: Cambridge University Press, 2004), 250–57.

[51] *Epitaphium Pacifici archidiaconi*, v. 12–13, ed. Ernest Duemmler (Berlin: Weidmann, 1884), 655.

[52] Ibid., v. 15, 655.

[53] See, e.g., Joachim Wiesenbach, "Pacificus von Verona als Erfinder einer Sternenuhr," in *Science in Western and Eastern Civilization in Carolingian Times*, eds. Paul L. Butzer and Dietrich Lohrmann (Basel: Birkhäuser Verlag, 1993), 229–50.

It consisted of an adjustable observation tube (referred to as fistula in contemporary texts[54]) with a fixed stand and was connected to circular disc (*rota*) on which the lines of hours were inscribed as well as solstitial days (*solstitial*) and equinoctial days (*aequinoctial*) which together formed a cross (*crux Christi*). With the help of the observation tube, the highest star closest to the northern pole of the celestial sphere (*polus*) was found. The celestial sphere (*spera caeli*) goes around (*revolvere*) its axis (*axis*) passing through its poles once per 24 hours (*horae quarter senis*) and the observation tube followed the axis of the world sphere in this way.[55] The location of the machine was fixed as it was adjusted for the given observation place according to the celestial sphere.

From the northern pole to the south, lines can be drawn (*rectae lineae*) which correspond to the hours on the device's disc (the distance between both equinoctial days marked on the disc is 180° which corresponds to twelve hours, i.e., the revolving of the celestial sphere at 15° per one hour). Therefore, due to the daily rotation of the celestial sphere, the stars woven into it (*stellae fixae*) follow bigger or smaller circles (*circuli*) – the closer they are, the shorter (*breviores*) are their orbits. The observer (*curiosus*) must then find the star in the sky according to whose movement he can determine the time (*computatrix*). The northern circumpolar stars are suitable for the northern hemisphere since they can be observed throughout the year. According to an image from the now destroyed manuscript Chartres 214, this could mean star α UMi from the Ursa Minor, i.e., the tail star from the Lesser Bear constellation, i.e., the present Polar star. This star was located at approx. 7° from the northern pole of the celestial sphere in the 9th century and, in contrast to our days, it was not suitable for determining the northern pole.[56] Conversely, its clear visibility and close proximity to the pole allowed for simple night observations of its orbit throughout the year; therefore, it could serve as a suitable time indicator (*computatrix*). The movement of this star in the night sky copies the periphery of the measuring device's disc

[54] See, e.g., Avranches, Bibliothèque Municipale, MS 235, fol. 32v, or manuscript destroyed during the Second World War Chartres, Bibliothèque Municipale, MS 214, fol. 31 or 32. Cf. Henri Michel, "Les tubes optiques avant le téléscope," *Ciel et terre: Bulletin de la société belge d'astronomie, de météorologie et de physique du globe* 70 (1954): 177.

[55] Pacificus, "Spera caeli," ed. Karl Stecker (Berlin: Weidmann, 1923), 692.

[56] Cf. Joachim Wiesenbach, "Der Mönch mit dem Sehohr. Die Bedeutung der Miniatur Codex Sangallensis 18, p. 45," *Schweizerische Zeitschrift für Geschichte* 44, no. 4 (1994): 380–82.

(*volvens*) and the actual position of the star in the sky serves as night hours (*horae noctes*) indicator on the disc (see fig. 3).[57]

Because of the Sun's yearly movements in the ecliptic and, therefore, the uneven beginning and length of night during the year, each rotary disc had to be readjusted daily (rotated for an incomplete 1°).[58] The user of the clocks

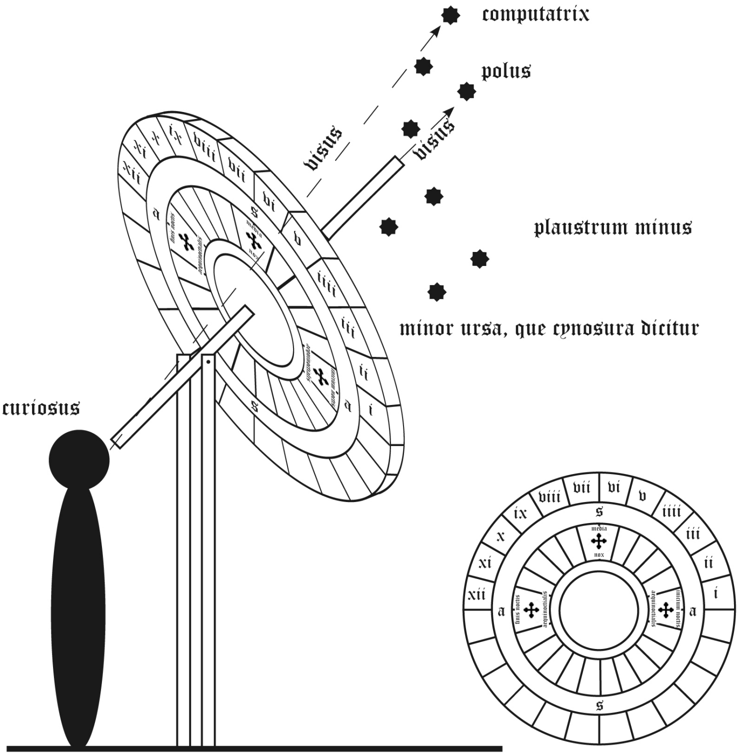

Figure. 3. Possible appearance of clocks ascribed to Pacificus of Verona.

[57] Cf. Costantino Sigismondi, "Gerbert's Acoustical and Astronomical Tubes," *GERBERTVS – International Academic Publication on History of Medieval Science* 3 (2012): 24, or Costantino Sigismondi, "Gerbert of Aurillac: Astronomy and Geometry in Tenth Century Europe," *International Journal of Modern Physics* 23 (2013): 469–71.
[58] See Wiesenbach, "Der Mönch mit dem Sehohr," 383.

had to check the actual rise of the star in order to accurately set the night clock, but he was also able to determine which part of the year is currently underway thanks to the equinoctial and solstitial days. According to the marked lines of the individual hours, time could be determined in regular hours (as implied by an image from St. Gallen, Stiftsbibliothek, Codex Sangallensis 18, 43 [45][59]) or in irregular hours (if concerned about the imperfect nature of the illustrative picture, see an image from Rome, Biblioteca Apostolica Vaticana, MS Vat. lat. 644, fol. 76r[60]).[61]

These clocks could very well correspond to what Thietmar of Merseburg describes as Gerbert's creation in Magdeburg. Gerbert himself, according to the report of Richer of Reims, used an observation tubes (*fistulae*) already in Reims when he created an observation hemisphere. Richer praises its didactic properties while he explains in detail how this hemisphere was created.[62] Gerbert himself wrote about the device and its construction in a letter to his friend and disciple Constantine of Fleury (called *De sphaera*), in which he also mentions observation tubes (*fistulae*) and differentiates them from organ tubes he wrote about as well. While organ tubes (*fistulae organici*) must expand and narrow down, astronomical tubes must be of the same stable diameter (*grossitudo aequalis*) in order to be able to observe the sky accurately through them.[63]

According to Gerbert's letter *De sphaera* and Richer's chronicle, the device utilised multiple tubes that were fixed to the hollow hemisphere, with their location corresponding to the northern and southern pole of the world sphere, both polar circles, both tropics, and the equator.[64] It follows that the tubes passing through the northern and southern poles copied the axis of the celestial sphere, while the other five tubes allowed for night sky observations. Both descriptions suggest that Gerbert built an observation aid in Reims via this method, although it is clear that, with the knowledge of star orbits, the hemisphere could be used for timekeeping as well. Gerbert's *horologium* from Magdeburg could have been similar to Pacificus's night

[59] See *e-codices - Virtual Manuscript Library of Switzerland*, accessed April 15, 2019, https://www.e-codices.unifr.ch/en/csg/0018/43/0/Sequence-235.

[60] See *DigiVatLib - Vatican Library's Digitized Collections*, accessed April 15, 2019, https://digi.vatlib.it/view/MSS_Vat.lat.644.

[61] Cf. Günter Oestmann, "On the History of the Nocturnal," *Bulletin of the Scientific Instrument Society*, no. 69 (2001): 5–6.

[62] Richer, *Historiae* III, 51, 196.

[63] Gerbert, "De sphaera 2," in *Gerberti Opera Mathematica*, 27. Cf. Gerbert, "Rogatus," 59–60.

[64] Richer, *Historiae* III, 51, 196; Gerbert, "De sphaera 2–3," 27–28.

clocks employing an observation hemisphere that he had actively used in Reims. Indeed, if we interpret William's abovementioned description of Gerbert's clocks in Reims as *arte mechanica compositum* as a method used in the creation of the *horologium*, then the observation hemisphere and night clocks could have been merged in the later tradition because both devices required knowledge of the astronomical art for creation. The very fact that William mentions both Gerbert's successes in Reims together – i.e., organs and clocks – could have been motivated by the tubes (*fistulae*) that are called by the same name by Gerbert, but constructed differently – without them neither organs, nor clocks, which Gerbert was supposed to set in Magdeburg, could have functioned.

6. Conclusion

It is beyond doubt that Gerbert dedicated a significant part of his work to timekeeping. His approach to time was influenced by his astronomical observations. It is clear that he was aware of the clepsydra, which he recommends to brother Adam as a tool for determining the geographical latitude (*clima*) in which a given observer is actually located. Therefore, the clepsydra is introduced especially as a tool necessary for obtaining important data for astronomical observation. It was also common during the era that sun clocks were used for timekeeping.

However, for night timekeeping, it was necessary to use other tools. An astrolabe is an obvious choice since it served – as evidenced by the text of *De utilitatibus astrolabii* ascribed (probably incorrectly) to Gerbert – for timekeeping purposes. Since we have no substantial evidence of Gerbert's active use of an astrolabe, we could speculate that he could have attempted to create a modified version of the tool ascribed to Pacificus of Verona – night clocks that require that the timekeeping device is set according to the celestial sphere and its northern pole for correct functioning. This corresponds to the characterisation of Gerbert's *horologium* by Thietmar of Merseburg, whose words – in contrast to other references of clocks constructed by Gerbert – are comparatively reliable.

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