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BEFORE THE SUN IN THE CHURCH

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In John Heilbron's recent book, *The Sun in the Church*,[1] the reader is given an extraordinary amount of information on the extensive use of an interior gnomon (i.e., a meridian line on the floor in the interior of a church with an aperture in the wall) from the fifteenth to the eighteenth century for making solar observations. Heilbron (p. 164) quotes Pope Clement XI (1703), "The grand installations that Gregory prepared for observing the sun by the mathematicians of his age, chiefly Father Egnatius Danti ... are the greatest and most accurate of all instruments for fixing the equinoxes as the Gregorian system decreed". Danti began his work in the 1570s at Santa Maria Novella in Florence, and acknowleged his debt to his Florentine predecessor, Paolo Toscanelli.[2] Indeed, the earliest interior gnomon Heilbron cites (p. 70) is that in Santa Maria del Fiore (Florence), and he properly ascribes it to Toscanelli, whose work is dated 1475 according to an extant archival document found by Howard Saalman.[3] Heilbron (p. 70) also notes that "no piece of writing from Toscanelli has come down to us to indicate why he or Brunelleschi [the architect of the cathedral, d. 1456] wanted to make a *meridiana* in the cathedral". There are some extant astronomical documents in the hand of Toscanelli, bound in a single codex, but they say nothing about this matter and so Heilbron had no reason to mention them.[4] Despite the difficulty in locating sources available to Toscanelli, I had already suggested in 1985 that he was inspired by the Hebrew astronomical treatise of Levi ben Gerson (d. 1344), which was translated into Latin in the author's lifetime.[5]

There are two questions: (1) did Levi ben Gerson construct an interior gnomon?, and (2) is it plausible to suggest that Toscanelli knew about it? I believe the answer is 'yes' to both. In chap. 13 of Levi's *Astronomy*, two methods for finding the local meridian line inside an unspecified building are described. The first is called "approximate" and makes use only of a window facing south. The second is more complicated and involves observations made with a window facing east such that the Sun's rays shortly after sunrise are cast on the west wall of the room. The procedure begins with the determination of the true east–west line, and then a plumb line is dropped to the floor from the (eastern or western) edge of the window facing south. A line perpendicular to the east–west line on the floor that meets the point determined by the plumb line is the meridian.[6] In chap. 15, Levi describes the determination of summer solstice with his meridian line. He indicates that he started to observe the image of the Sun on the floor at noon about 10 days before the solstice and each day thereafter, marking the positions of the images, until it was closest to the south wall. Another method is given for finding the moment of solstice: observe the solar image on the floor at noon some days before the

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solstice, and mark the spot; then note when the image returns to the same spot on the floor at noon on a day subsequent to the solstice (using interpolation to find the moment of the solstice).

Levi tells us that the room in which the observations are made should be at least 40 spans (a span is about 25cm) from the east wall to the west wall, with adjacent walls perpendicular to each other, and the south wall perpendicular to the floor, adding that he had to make adjustments because "a house we prepared for these observations was not built with right angles". He uses as an example a window on the south wall whose top edge was 24 spans above the level of the floor.[7] A room some 10 metres in length, with a ceiling more than 6 metres high, is unlikely for an ordinary household. One possibility is that Levi used a synagogue;[8] and another possible site is a room in the palace of the Prince of Orange. Theoretically, Levi might have used the interior of a church for this purpose but, typically, it would be much larger than the dimensions given here and, in any event, I think it unlikely for him to have done so. That Levi made extensive astronomical observations is not in doubt, for he reports a great number of them, including an observation of summer solstice on 13 June 1334 in Orange.[9] The dimensions of the gnomons of Toscanelli and Danti make Levi's room seem very small, for the aperture made for Toscanelli was more than 90m above the floor, and the aperture for Danti's instrument in Florence was over 20m above the floor. Moreover, the apertures for the Florentine instruments were relatively small, so that each of the churches functioned as a camera obscura. By way of contrast, Levi used as his aperture a window, already in place, that would cast a much larger image (at comparable distances). But in the same treatise Levi fully described the camera obscura and the way to take into account the size of the aperture on the size of the image, and also took these factors into account in using his instrument for observing summer solstice.[10]

We now come to the plausibility of Toscanelli's knowing about Levi's instrument. The evidence, needless to say, is indirect since we have no report whatever from Toscanelli about his gnomon. The first such evidence is that Levi is cited for his astronomical views by George of Trebizond (d. 1472), who was engaged in an acrimonious dispute with Regiomontanus on a number of matters at a time when both of them were in Italy.[11] Regiomontanus (d. 1476) was a member of the same circle in Florence as Toscanelli, and reports on their joint astronomical observations.[12] Moreover, Regiomontanus seems to have owned a copy of a Latin version of Levi's *Tractatus super instrumento astronomiae* (at least such a manuscript was in the *Nachlass* of Bernhard Walther (d. 1504), the patron and colleague of Regiomontanus, and it is most likely that Walther acquired this manuscript from his protégé).[13] There is also the related question of the use of the cross staff (or Jacob's staff) which Levi invented, and this device was used for astronomical observations by Regiomontanus and Walther, among others.[14] The description of this instrument (with a diagonal scale) is included in chaps. 6 and 7 of Levi's *Astronomy*, and it was available in both Latin versions.[15] The long Latin version of Levi's *Astronomy* is preserved in two manuscripts now in the Vatican,

and one of them (MS lat. 3380) was in the library of Fulvio Orsini in the sixteenth century. Indeed, on the basis of this manuscript, Commandino (1558) included a description of Levi's cross staff in his commentary on the dioptra described in Archimedes's *Sandreckoner*.[16] In sum, it is very likely that at least one manuscript of the long Latin version of Levi's *Astronomy* was available in Italy in the fifteenth century. Moreover, a Hebrew manuscript of Levi's *Astronomy* has marginal notes by Mordecai Finzi (d. *c.* 1475), a protégé of the Gonzagas who ruled Mantua at the time;[17] and Pico della Mirandola (d. 1494), who cites Levi three times in his *Disputationes adversus astrologiam*, may have had access to the Hebrew version.[18]

Levi ben Gerson's contribution to early modern European astronomy has long been understood to be restricted to the cross staff, although he invented and improved several other instruments (in addition to his theoretical innovations). It seems appropriate now to add his invention of an interior gnomon (or, at least, the earliest description of it), an instrument that had a major impact on his successors.[19]

Acknowledgments

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REFERENCES

1. J. L. Heibron, *The Sun in the Church: Cathedrals as solar observatories* (Cambridge, Mass., and London, 1999).
2. E. Danti, *La prospettiva di Euclide* (Florence, 1573), 84, cited in T. Settle, "Dating Toscanelli's meridian in Santa Maria del Fiore", *Annali dell'Istituto e Museo di Storia della Scienza di Firenze*, iii (1978), 69–70; and in H. Saalman, *Filippo Brunelleschi: The cupola of Santa Maria del Fiore* (London, 1980), 146. As Heilbron, *op. cit.* (ref. 1), 70f, indicates, Danti wished to make measurements at equinoxes and solstices, whereas Toscanelli's gnomon could have been used only for a few weeks before and after summer solstice.
3. Heilbron, *op. cit.* (ref. 1), 333, n. 42, cites Settle, *op. cit.* (ref. 2), but Settle gives credit to Saalman (not cited by Heilbron) and indicates that Saalman gave him permission to publish a slightly adapted version of the note that had not yet appeared: see Saalman, *op. cit.* (ref. 2), 146–7, 294.
4. See now J. Jervis, *Cometary theory in fiteenth-century Europe* (Wrocław, 1985).
5. B. R. Goldstein, *The astronomy of Levi ben Gerson (1288–1344)* (New York and Berlin, 1985), 14; see also J. L. Mancha, "The Latin translation of Levi ben Gerson's *Astronomy*", in *Studies on Gersonides: A fourteenth-century Jewish philosopher-scientist*, ed. by G. Freudenthal (Leiden, 1992), 21–46. Note that there were two versions of Levi's *Astronomy* in Latin, a short version (extant in six manuscripts) with chaps. 4–11 only, and a long version (extant in four manuscripts) with chaps. 1–103, 106, 109, and 110. The table of contents in Hebrew and in the long Latin version indicates that there were 136 chapters, but a few of them are missing in all the extant manuscripts.
6. Goldstein, *op. cit.* (ref. 5), 86–92, 170–8.
7. Goldstein, *op. cit.* (ref. 5), 95–101, 146. Note that chaps. 13–15 are included in the long Latin version, but not in the short Latin version, of Levi's *Astronomy*.

8. For an estimate of the size of the synagogue in fourteenth-century Orange where Levi lived, see Goldstein, *op. cit.* (ref. 5), 178. There is no information about the synagogue in Orange, but in nearby Cavaillon the old synagogue has the right orientation with windows on the south and east walls, and the appropriate dimensions, approximately. Concerning the old synagogues in Comtat Venaissin, including the one in Cavaillon, we are told, "si leur aspect actuel date essentiellement du XVIII^{e} siècle, leur emplacement et leurs fondations remontent au moyen âge, XIV^{e} ou XV^{e} siècle": R. Molinas, "Les vieilles synagogues d'Avignon et du Comtat Venaissin", *Archives juives*, xvi (1980), 14–26, esp. p. 14.
9. Levi ben Gerson, *Astronomy*, chap. 55 (Paris, Bibliothèque Nationale de France, MS Heb. 724, f. 104a; and MS Heb. 725, f. 79b). See also B. R. Goldstein, "Medieval observations of solar and lunar eclipses", *Archives internationales d'histoire des sciences*, xxix (1979), 101–56; *idem*, "A new set of fourteenth century planetary observations", *Proceedings of the American Philosophical Society*, cxxxii (1988), 371–99; and J. L. Mancha, "Levi ben Gerson's astronomical work: Chronology and Christian context", *Science in context*, x (1997), 471–93, esp. pp. 490–2.
10. Goldstein, *op. cit.* (ref. 5), 48–50, 69–73, 140–4; see also B. R. Goldstein, "Levi ben Gerson: On astronomy and physical experiments", in *Physics, cosmology and astronomy, 1300–1700*, ed. by S. Unguru (Dordrecht, 1991), 75–82. Levi indicates it is best for the aperture to be very small. Although Kepler is usually given credit for the proper understanding of the camera obscura, the same explanation (in an abbreviated form) is given by Levi.
11. Goldstein, *op. cit.* (ref. 5), 11. On the dispute between Regiomontanus and George of Trebizond, see M. H. Shank, "Regiomontanus and homocentric astronomy", *Journal for the history of astronomy*, xxix (1998), 157–66, esp. pp. 161f. As far as I know, Regiomontanus only refers to Levi ben Gerson one time: see Regiomontanus, "Defensio Theonis contra Trapezuntium", in C. T. de Murr, *Notitia trium codium autographorum Iohannis Regiontani in Bibliotheca Christophori Theophili de Murr* (Nuremberg, 1801), 11–12.
12. P. L. Rose, *The Italian renaissance of mathematics* (Geneva, 1975), 30.
13. H. Petz, "Urkundliche Nachrichten über den literarischen Nachlass Regiomontans und B. Walters 1478–1522", *Mitteilungen des Vereins für Geschichte der Stadt Nürnberg*, vii (1888), 237–62, esp. p. 260; and Rose, *op. cit.* (ref. 12), 107. This text is presumably identical with the short Latin version of Levi's *Astronomy*, concerning trigonometry, the cross staff, and the camera obscura, called in the fourteenth century *Tractatus instrumenti astronomie* (Paris, Bibliothèque Nationale de France, MS lat. 7293). In the secondary literature this text is usually cited with the title, *De sinibus, cordis et arcubus, item instrumento reuelatore secretorum*: see J. L. Mancha, "The Provençal version of Levi ben Gerson's tables for eclipses", *Archives internationales d'histoire des sciences*, xlviii (1998), 269–352, esp. p. 270 n. 2.
14. J. Schöner, *Scripta clarissimi mathematici* (Nuremberg, 1544), 34v–60v; see J. J. Roche, "The radius astronomicus in England", *Annals of science*, xxxviii (1981), 1–32, esp. p. 11. Roche, following G. Celoria (*Sulle osservazioni di comete fatte da Paolo dal Pozzo Toscanelli e sui lavori astronomici suoi in generale* (Milan, 1921)), assumed that Toscanelli also used a cross staff for his observations of the comet of 1433, but Jervis, *op. cit.* (ref. 4), 67f, does not accept that claim.
15. Goldstein, *op. cit.* (ref. 5), 51–56, 146–7.
16. Rose, *op. cit.* (ref. 12), 189; Roche, *op. cit.* (ref. 14), 8. I am informed by J. L. Mancha that Vat. lat. 3380 dates from the fifteenth century.
17. Naples, Biblioteca Nazionale, MS Heb. III.F.9. On Finzi, see Y. T. Langermann, "The scientific writings of Mordekhai Finzi", *Italia*, vii (1988), 7–44; repr. in *idem*, *The Jews and the sciences in the Middle Ages* (Aldershot, 1999), Essay IX. See also Goldstein, *op. cit.* (ref. 5), 10, 136; and S. Simonsohn, *History of the Jews in the Duchy of Mantua* (New York, 1977), 601, 640–1, 709.
18. G. Pico della Mirandola, *Disputationes adversus astrologiam*, ed. by E. Garin (Florence, 1952), viii.1, ix.9, and ix.11.

19. T. Settle has informed me, on the basis of a discussion by L. Ximenes (*Del vecchio e nuovo gnomone fiorentino* (Florence, 1757)), that there is some indirect evidence that already about the time of the turn of the millennium the Florentine Baptistry was being used as an "internal gnomon". The internal dimensions are such that a gnomon using the opening of the lantern would function much in the same way as Toscanelli's in Santa Maria del Fiore, that is, for a few weeks on either side of the summer solstice. No meridian line remains but, since the pavement of the Baptistry has been "renewed" so many times, this is inconclusive. In other words, Toscanelli may have depended on a local tradition, rather than on (or in addition to) a text by Levi. Bear in mind, however, that there are very few examples of dated astronomical observations made in Europe in the Middle Ages, and that Levi was exceptional in making over eighty dated (or datable) astronomical observations: for a list, see Mancha, *op. cit.* (ref. 9). Another medieval astronomer, William of Saint-Cloud, made an observation of a solar eclipse on 4 June 1285 with a camera obscura. He suggests making "an aperture in the roof or in a window of a house.... Let the size of the aperture be like that through which wine is drawn in barrels. Once the light of the Sun passes through the aperture, let there be placed at a distance of 20 or 30 feet from the aperture something flat ... in such a way that the light of the Sun falls perpendicularly on the surface of that flat object": see J. L. Mancha, "Pinhole images in William of Saint-Cloud's *Almanach planetarum* (1292)", *Archive for history of exact sciences*, xliii (1992), 275–98, esp. p. 282. Mancha reports that the procedure for casting images of the eclipsed Sun through a small aperture was already described in a twelfth-century Latin text. William of Saint-Cloud also made observations of the solar altitude at summer and winter solstices (presumably in 1290), but no instrument is mentioned (*ibid.*, 283).