BOOKS: HISTORY OF SCIENCE

Cathedrals as Astronomical Instruments

Albert Van Helden

The story of the revolution in astronomy that Nicholas Copernicus began in 1543 is now a well-established narrative: Copernicus put the sun in the center of the planetary orbits. Tycho Brahe provided accurate observations. Kepler made the orbits into ellipses. Galileo discovered new things in the solar system and eloquently argued for the Copernican System. And Newton tied the new astronomy together with the new physics. By this standard account, astronomy and cosmology were dangerous subjects in Italy after the trial of Galileo, and very few contributions to Copernicanism came out of that part of the world. In *The Sun in the Church*, historian John Heilbron argues convincingly that these long-held interpretations are too simplistic and must be revised.

The Sun in the Church
Cathedrals as Solar Observatories
by J. L. Heilbron
Harvard University Press, Cambridge, MA, 1999. 376 pp. $35. ISBN 0-674-85433-0.

Although Heilbron is perhaps best known for his work on 20th-century science, he has also published widely on earlier times. His volume on electricity in the 17th and 18th centuries is a classic, and his new book will surely match it in importance. *The Sun in the Church* is a history of *meridiane* constructed in churches, "reverse" sundials that turned churches into giant pinhole cameras. In the 15th century, the humanist Paolo Del Pozzo Toscanelli installed a short north-south line close to the altar of Florence's great cathedral of Santa Maria del Fiore. Near the summer solstice, the sun's image, projected through a hole in a window in the cathedral's lantern 90 m above the floor, crosses the line. Toscanelli hoped to use this *meridiana* to discover changes in the inclination of Earth's axis. A century later, the Dominican cosmographer Ignatio Danti constructed a small *meridiana* in Florence's Santa Maria Novella and then a bigger one in Bologna's San Petronio. This latter meridian line, after Giovanni Domenico Cassini's improvements in the 1650s, became the central instrument in the reform of precision astronomy during the 17th century.

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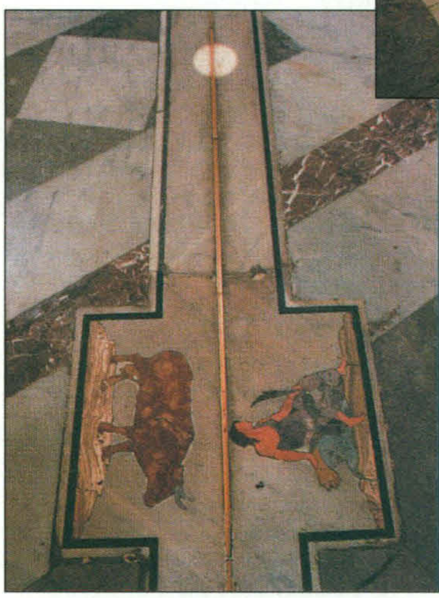
Danti's original aim had been to determine the length of the tropical year to aid in the correction of the calendar. The Gregorian reform of the calendar in 1582 made this measurement less important, although some technical problems with determining the date of Easter still remained. With Cassini, the improved *meridiana* of San Petronio became an instrument to solve practical astronomical problems. The accuracy of tables that predicted the positions of planets had been improved greatly by Kepler's elliptical astronomy. By the middle of the 17th century, when Cassini began his work in Bologna, the great barrier to further precision in position measurements—and therefore predictive tables—lay in the corrections required for refraction and solar parallax. Tycho Brahe had accepted the ancient value of 3 arc min for solar parallax and as a result arrived at different refraction values for the sun and the stars. By his death in 1630, Kepler had reduced solar parallax to about 1 arc min, but the problem with refraction remained. When Cassini tackled the problem, there were different tables of solar refraction for different seasons. He realized that if solar parallax was 12 arc sec or less these different tables collapsed into one. But he also had to correct existing refraction tables when he found that ignoring refraction above altitudes of 45° resulted in a discrepancy of 2 arc min between the heights of the celestial pole measured by direct observation and by means of the *meridiana*. The point is that the San Petronio *meridiana* (with a height over 27 m) allowed measurements accurate to perhaps 15 arc sec.



Solar clock. The sun's image on the *meridiana* in the cathedral of Palermo, which was installed by the priest and astronomer Giuseppe Piazzi in the late 1790s.

Indeed, properly aligned and leveled, meridian lines were the most accurate position-measuring instruments available. Even though measuring arcs equipped with telescopic sights came into use around 1670, these instruments could not compete in accuracy with the best *meridiane* for another century. *Meridiane* were, therefore, central in the determination of fundamental astronomical constants and corrections. For instance, the San Petronio *meridiana*—and others built on its plan—could measure the sun's diameter with sufficient accuracy to show that the eccentricity of the solar orbit (Earth's orbit, to us) needed to be halved from its traditional value. By the 1670s, Cassini had corrected Tycho Brahe's erroneous value for the obliquity of the ecliptic. Cassini's successors went on to determine the variation in the obliquity to the arc second. Their measurements were confirmed by transit theodolites late in the 18th century.

Heilbron tells an important story, one that is not so much neglected as unknown among historians of science. Even in histories of astronomy, there is usually only a passing reference to it. And one looks in vain through standard accounts for a mention of meridian lines and their historical significance. Perhaps that is because the story entails very technical matters. Heilbron's approach is to deal with the basic geometry in the text and to treat the most difficult technical problems in appendices. The discussions of geometry that remain in the text will still drastically slow the reading rate even for those who are not mathematically handicapped, but skipping the technical passages does not take away from the narrative. With wry humor, Heilbron breaks off one such demonstration: "Since the calculation will be obvious to [trigonometers] and tedious for everyone else, it will be enough to give the result."

The book's title is not just an allusion to these wonderful *meridiane*, it also refers to the role of the Catholic Church in technical astronomy. On the one hand, the Church's involvement in, and patronage of, science did not stop with Galileo's condemnation. On the other hand, in its very places of worship devout astronomers made measurements that strengthened the Copernican "hypothesis" and finally made all other astronomical theories simply irrelevant.

BOOKS: ENERGY TECHNOLOGY

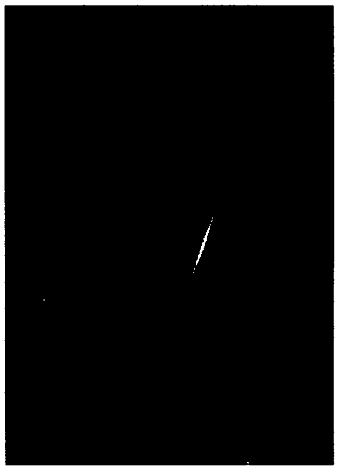
A Bright View, Too Focused

David Faiman

Hans Ziegler, a former German bombing expert, was responsible for the Americans using solar cells aboard their first space satellite. Lloyd Lomer was a U.S. Coast Guard captain who never made it to the rank of admiral because of his crusade for photovoltaics. Bernard Verspieren is a priest who made Mali one of the world's foremost users of photovoltaic water pumps. The sagas of these and other unsung heroes, and anecdotes embracing characters with Runyanesque names like "Available Jones," are chronicled in John Perlin's latest book. Twenty years ago, in *A Golden Thread*, Perlin and co-author Ken Butti provided a delightfully informative history of human efforts to harness the sun's energy (*1*). When Perlin considered writing an updated version, he concluded that although most aspects of solar technologies seemed in decline, photovoltaics (the direct conversion of sunlight into electricity) was a success story begging to be told. Thus solar cells are the focus of his attention in *From Space to Earth*.

**From Space to Earth
The Story of Solar Electricity**
by John Perlin
Aatec, Ann Arbor, MI, 1999. 240 pp. $32. ISBN 0-937948-14-4.

Perlin starts by relating several stories of 19th- and early 20th-century attempts to convert sunlight into electric power, directly or via a thermal intermediate stage. His account is not comprehensive. (When I began to feel somewhat put down by my ignorance of such solar-power pioneers as Willoughby Smith, William Grylls Adams, Richard Evans Day, Charles Fritts, and George M. Minchin, I desperately sought "Becquerel" in Perlin's index. I was greatly relieved to find reference to a footnote that informed me the Frenchman had indeed discovered the photoelectric effect some 40 years before the research efforts discussed in the main text.) And as fascinating and well-written as these and many of the subsequent anecdotes are, the book soon becomes tedious because Perlin laboriously documents attempt after attempt to "market" photovoltaics.



Sunlit flare. Powered by photovoltaics, low-orbiting Iridium communication satellites link solar-powered phone booths around the world.

CREDIT: J. W. YOUNG/JET PROPULSION LABORATORY, NASA

According to its subtitle, the book tells the story of solar electricity, not just photovoltaics. If that is so, it tells a highly partisan one. On the few occasions that the important solar-thermal part of the story is not totally ignored, it is ridiculed by the author. For example, in reference to the solar-thermal water pumps that had been tried out in Africa in the pre-photovoltaic era, Perlin writes: "Each thermal pump required a resident engineer...to make adjustments and repairs. ... Verspieren would have nothing to do with them. And that was smart as none of them ever worked for very long." But only a few pages later, when referring to mechanical problems associated with the first photovoltaic pumps, Perlin observes: "Problems such as these would have spelled doom for Verspieren's solar project had he not built up a stockpile of spare parts, an ultramodern repair facility, and a highly trained staff of African and European technicians."

I am no less enthusiastic about the potential of photovoltaics than the author, but it is important not to let enthusiasm cloud one's judgment of where the true problems lie. Solar-thermal pumps, of the kind originally tried out in Africa, may have had low efficiency (caused by thermodynamics, not poor performance). Nonetheless, similar low–boiling temperature Rankine turbines later powered a 5-megawatt solar demonstration plant at the Dead Sea. This plant, which is not mentioned by Perlin, is the only example to date of solar power generation with built-in night storage.

Perlin, in my opinion, overdoes the use of quotations. Thus most of the copious notes and comments that follow each chapter are of the type "interview with *x*." In a number of cases, the information he presents, often obtained from sales material or personnel, is misleading or even incorrect. For example, when discussing the use of rooftops as mini–solar power stations in the chapter "Solarizing the Electrified," Perlin quotes an executive of a Japanese solar cell producer as saying: "Nobody is even talking about big photovoltaic plants, central power stations anymore." It happens, however, that I am a member of a newly established International Energy Agency photovoltaics working group (Task VIII) set up to study the feasibility of very large photovoltaic power plants. And the coordinators of this working group are mostly Japanese.

The message is clear that photovoltaics are an effective solution for regions in which the implementation of grid electricity would be too expensive, and Perlin need not have emphasized it as frequently as he chose to. In addition, his discussion of the economics of photovoltaics in a utility setting is misleading and possibly confused. Perlin quotes the manager of the Sacramento Municipal Utility District as saying: "This year we installed systems at $5.30 a watt." The author interprets this as "generating electricity at between 16¢ and 18¢ per kilowatt-hour." But "1 watt" of photovoltaic cells can produce at most (that is, in a sunny desert region) about 1.5 kilowatt-hour per year. Thus a $5.30 per watt system would need a trouble-free life of at least 20 years (assuming a zero-interest loan) in order to meet the claimed 16¢ to 18¢ per killowatt-hour value. Furthermore, Perlin tells us in the following chapter that the present price of cells is $5 per peak watt. It is difficult to imagine how the other system components (inverter, wiring, stands, connections, installation) could cost a mere $0.30 "a watt."

Because I enjoyed *A Golden Thread*, I began *From Space to Earth* with great enthusiasm. My enjoyment, however, was soon undermined by Perlin's sales-talk style and his partisan attitude. This book could have been a timely discussion of all the approaches to solar electricity–producing technologies. A hundred years from now a world without solar power will hopefully be as difficult to imagine as a world without electricity is for our generation. But it would be rash to bet that photovoltaics will be the single technology that gets us there.

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