Menchaca comments: The account by Bogdan C. Maglich on unpublished details of the Chephren pyramid experiment by Luis Alvarez and coworkers[1] provides fascinating insight into this pioneering application of high-energy physics to archaeology. The method used by Alvarez involves finding statistically significant differences between measured and simulated muon flows in a given direction. The necessary ignorance of a detailed density distribution inside the investigated volume requires an approximation. As Maglich implies, both we and the Alvarez group assumed that the internal pyramid density is constant. Also, we are aware[2] of the limitations introduced, not only by uncertainties related to the internal density distribution, but also by uncertainties about the external shape description, among other factors.

In Teotihuacan we assume that the mean composition and density distribution are similar to those found inside a 200-meter-long horizontal tunnel excavated near the base of the Pyramid of the Sun last century. We sampled the pyramid filling along that tunnel. The study reveals that the Mexican monument, although fairly uniform, is more heterogeneous than the Egyptian pyramid seems to be as judged by the limestone walls of the tunnel leading to the Belzoni chamber, where the Alvarez team located its muon detector. The measured mean density in Teotihuacan turns out to be appreciably smaller than the density of rock. As Maglich correctly suggests, we do consider the conditions in which stony walls of a hypothetical hidden cavity would result in a compensated mean density that would cancel the sought-for signal. This and other considerations helped determine the limitations of our experiment.[2]

In contrast with the Chephren case, archaeological excavations in the Pyramid of the Sun provide excellent calibration references. Finally, in the Egyptian case, we tend to agree with the private response Maglich says he received from Alvarez concerning the unlikely possibility that a cavity having a granite ceiling would result in mean density compensation in all directions. That would be particularly unlikely with internal structures as large and intricate as those found in the Cheops pyramid.

References

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2. R. Alfaro et al., *Rev. Mex. Fis.* **49**(S4), 54 (2003).

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Rømer and the Finite Speed of Light

Ole Rømer's 1676 demonstration that light propagates at a finite speed must have been a revelation to the members of the French Royal Academy of Science. A young and brilliant Danish "postdoc" at the Paris Observatory, Rømer had unexpectedly answered a long-standing fundamental question. Before his discovery, the likes of René Descartes and Johannes Kepler had claimed that light was an instantaneous phenomenon, and all attempts to prove otherwise had failed.

Isaac Newton and especially Christiaan Huygens welcomed Rømer's result; Huygens found it encouraging in the development of his wave theory of light. There were also a few ardent opponents, such as Robert Hooke and Rømer's observatory colleague Jean Cassini.

What value of the speed of light did Rømer actually report? I found 16 references, spanning the years 1694–2003, that give values from 200 000 to 350 000 km/s. Such a range can hardly be attributed to mistakes in the conversion of measurement units.

None of the sources I found quoted an original paper or proceedings. The present French Academy of Sciences led me to proceedings of a 1976 conference marking the tricentennial of Rømer's discovery.[1] Those proceedings include a copy of his only publication about the speed of light.[2] The sole message of that concise and tantalizing paper is that the speed of light is finite, though incredibly large. Rømer did not mention any specific value.

The first paragraph of Rømer's paper states the question: Is light propagation an instantaneous phenomenon or does it take time? The next paragraph gives observations of Jupiter's innermost moon (the one we now call Io) to show that light covers a distance like Earth's diameter, "about 3000 lieues" (one lieue = 4.448 km), in less than one second. Rømer's reasoning was as follows: If light has a finite speed, then when Earth is approaching Jupiter, Io's period should appear shortened. Half a year later, when Earth and Jupiter move apart, the moon's period should appear to be longer. Io's actual period is about 42.5 hours, during which time Earth traverses "at least 210 Earth diameters." The two periods therefore, according to Rømer, should differ by "nearly half a quarter of an hour." But he did not observe a difference.

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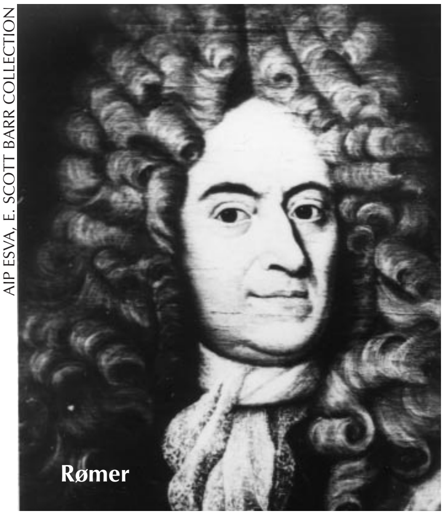

Rømer

However, Rømer wrote, that does not mean that light travel does not take time. Comparing the time lapse of 40 successive periods of Earth's nearing Jupiter with 40 periods while Earth is receding, he observed a perceptible difference. Therefore, he stated, light should traverse the diameter of Earth's orbit around the Sun in 22 minutes. This retardation of light showed up in all of the observations Rømer had done at the Paris observatory since 1668.

With a good sense of dramatic timing, Rømer played his ace in the next paragraph, where he illustrated the effect of the proposed retardation of light. In early September, he had predicted that Io's emerging from Jupiter's shadow on 9 November would be 10 minutes late with respect to a timetable he had made up from August observations. The prediction appeared to be correct, which convinced academy members that Rømer's idea about a finite speed of light was correct.

The final paragraph of his paper explains that none of the reasons normally used to account for irregularities in the period of a moon or planet can explain the observed deviations in the period of Jupiter's innermost moon.

At best, the paper provides data to establish a lower limit on the speed of light. Rømer says that