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A note on the history of gravity tunnels

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Galileo's *Dialogues*[1] from 1630/32 offer a unique glimpse into the peripatetic doctrine of his days in which he so roguishly (as Einstein put it) and perseveringly confronted the Copernican world system. Apart from being thought-provoking and entertaining, the book also introduced original and recapitulated ancient thought experiments. The regularly repeating fascination with the gravity tunnel, discussed recently in many fine articles in this journal (e.g., Refs. 2–4 and references therein), is one of the many examples I found explicitly discussed by the three debaters in the *Dialogues*. It has been pointed out in one of the several comments[5] on Cooper's paper,[2] which now appears to be considered a classic in this specific context, that references including textbooks going back to the late 19th century were missing.

However, the magnitude of the missing historical dimension to this venerable thought experiment seems not to have been addressed in this journal yet although one will find it well-acknowledged in the academic literature on the history of science, especially the work of the mathematician Andrew J. Simoson.[6–9] The hypothetical Earth-piercing tunnel has been considered at least as early as the second century AD by Plutarch[6] and later by prominent figures (apart from Galileo) such as Tartaglia,[10] Oresme,[11] Maupertuis, Voltaire, Euler,[6–8] Hooke and Newton,[12] and Sherlock Holmes' author Doyle.[9] Returning to Galileo, he in fact conceived of the experiment under the assumption of constant and uniform acceleration, i.e., the surprisingly well-performing[3] approximation of constant gravity. Using his numbers, I find it likely that he must have arrived at a transit time of about 54 min although he did not explicitly state the time.[13]

It further seems that the connection to the deflection problem of a freely falling object on Earth (e.g., Refs. 14 and 15) is rarely if ever mentioned. This interesting connection first appeared in the letters between Hooke and Newton[7,12] and corresponds to lifting the assumption of constraining tunnel walls (or lifting the constraint of considering a path connecting the poles as a special pair of antipodes only). An object falling freely and starting from an arbitrary point would rather describe an ellipse missing the center of the earth (as pointed out by Newton in his *Principia*). Such a trajectory describes a peculiar precessing motion[16] if observed in the rotating coordinate system of Earth, as described by A. J. Simoson.[7]

My hope would be that future research on gravity tunnels in this journal may benefit from a greater awareness for Simoson's work (published in mathematical journals) and a recognition of the long history of the thought experiment.

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[1]*Dialogue Concerning the Two Chief World Systems*, translated by S. Drake (University of California Press, Berkeley, 1953), p. 227.
[2]P. W. Cooper, "Through the Earth in forty minutes," Am. J. Phys. **34**(8), 68–70 (1966).
[3]A. R. Klotz, "The gravity tunnel in a non-uniform Earth," Am. J. Phys. **83**(3), 231–237 (2015).
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[5]P. G. Kirmser, "An example of the need for adequate references," Am. J. Phys. **34**(8), 701 (1966).
[6]A. J. Simoson, "The gravity of hades," Math. Mag. **75**(5), 335–350 (2002).
[7]A. J. Simoson, "Falling down a hole through the Earth," Math. Mag. **77**(3), 171–189 (2004).
[8]A. J. Simoson, *Voltaire's Riddle, Micromégas and the Measure of All Things* (The Mathematical Association of America Inc., Washington, DC, 2010), Chaps. VII, VIII.
[9]A. J. Simoson, "Sliding along a chord through a rotating Earth," Am. Math. Mon. **113**(10), 922–928 (2006).
[10]D. Boccaletti, *Galileo and the Equations of Motion* (Springer International Publishing, Cham, 2016), p. 47.
[11]K. Ierodiakonou and S. Roux, *Thought Experiments in Methodological and Historical Contexts* (Koninklijke Brill NV, Danvers, MA, 2011), pp. 107–110.
[12]R. D. Purrington, *The First Professional Scientist, Hooke and Newton, 1679* (Birkhaüser Verlag AG, Basel, 2009), Chap. 10.
[13]He assumed an object to fall[1] $s_1 = 100$ yards in $t_1 = 5$ s. Galileo implicitly assumes in this context $t_2 = t_1\sqrt{s_2/s_1}$, which together with the earth's radius stated as $R_E = 3500 \times 3000$ yards and the dynamics explicitly described by him yields a transit time of $2t_2 = 54$ min, not too far off of the correct answer of 38 min.[3]
[14]J. M. Potgieter, "An exact solution for the horizontal deflection of a falling object," Am. J. Phys. **51**(3), 257–258 (1983).
[15]R. H. Romer "Foucault, Reich, and the mines of Freiberg," Am. J. Phys. **51**(8), 683 (1983).
[16]A. Koyré, "An unpublished letter of Robert Hooke to Isaac Newton," Isis **43**(4), 312–337 (1952).

