# Dante's insight into galilean invariance

The poet's vividly imagined flight unwittingly captures a physical law of motion.

In 1632, Galileo described his experience of motion aboard a large ship[1,2] and exposed in detail the invariance principle, which was then rightly named after him. I suggest that more than three centuries earlier, in *The Divine Comedy*, his fellow countryman Dante Alighieri intuitively grasped what Galileo was later to establish as one of the pillars of modern science.

*The Divine Comedy* narrates Dante's journey through the hereafter. A remarkable feature of this masterpiece is the vividness of the narration: it is a work of fiction brought to life by the realistic detail. One part deals with Dante's descent from the seventh to the eighth circle, recounted in canto XVII of the *Inferno*. Up to this point, the pilgrim Dante had travelled on foot and occasionally by other means (for example, on Phlegyas' boat, in canto VIII, and on the back of the centaur Nessus, in canto XII).

However, the steepness of the bank between the two circles makes descent possible only by flying — in this case on the back of the monster Geryon. Dante himself reminds us that he is not the first, mythologically speaking, to have flown: Phaeton and Icarus had done it before him. But he is probably one of the first to describe the actual sensation of flying, which he does with an accuracy that is evidence of his extraordinary imagination, as noted by several commentators[3].

Sitting on Geryon's back, Dante describes the initial motion of the infernal monster by comparing it to "a little vessel [that] shoves from shore". Geryon then turns and leaves the circle rim, causing Dante to lose his points of visual reference: "I perceived myself / On all sides in the air, and saw extinguished / The sight of everything but of the monster". Then (lines 115–117, written around 1310 and translated by Henry Longfellow in 1867 (ref. 4)): "Onward he goeth, swimming slowly, slowly / Wheels and descends, but I perceive it only / By wind upon my face and from below."

These three lines are a typical example of Dante's ability to summarize several concepts and to describe complex situations in simple statements of a few words. In spite of its apparent simplicity, the tercet reveals some remarkable physical intuition. First, the observer Dante can imagine himself in a frame that a contemporary physicist would define, with fair approximation, as inertial. Although the monster is wheeling, its motion occurs "slowly, slowly" while obeying Virgil's command "Now, Geryon, bestir thyself; / The circles large, and the descent be little". So the flight path corresponds to a wide, slowly sinking spiral and is travelled

**Flight of fancy: Gustave Doré's vision of Geryon, who helps Virgil and Dante along their way.**

smoothly ("swimming"), or, a physicist would say, almost uniformly.

At the bottom, the monster sets the poet down close to the wall, so the flight path may be assumed to have a diameter similar to that of the cylindrical "abyss". This was estimated by, among others, Galileo[5] to be 35 Italian miles wide, or about 60 km: this value relies on two precise indications, given in canto XXIX, line 9 and canto XXX, lines 86–87, respectively (which also suggest that Dante was aware of the approximation $\pi \approx 22/7$).

A contemporary physicist could show that, given such dimensions and whatever the speed, the fictitious centrifugal force experienced by the passenger would be much smaller than the surface force due to the apparent wind: no such force is mentioned in the text. Although such a derivation would have been beyond the knowledge of physics in the Middle Ages, Dante did understand how his motion occurred seemingly in a straight line: he indicates its direction, by decomposing the vector describing the apparent wind in terms of its horizontal ("upon my face") and vertical ("from below") components.

Now comes the crucial point. With regard to the motion experienced on the flying monster, in the original tercet Dante says "*ma non me ne accorgo*": he is not aware (or, more accurately, he imagines that he is not aware) of anything but the apparent wind. Dante asserts that, aside from the effect of the wind, his sensation of flying was not dissimilar from being at rest. From a physical point of view, this 'invariance' is in agreement with the concept expressed by Galileo some three hundred years later. In Galileo's work, the invariance is explicitly related to observations and experimental results. But sitting on the monster's back, Dante could not do much better than rely on and consider his own sensory perceptions.

It is difficult to argue that this descriptive accuracy is accidental. Dante intentionally devised a journey, setting up different scenes and situations to express his message directly or allegorically. His imagined experience of flight is the core of this part of the narration, with the entire scene and landscape being created as a stage for its description. In this instance he seems to avoid allegory, perhaps to allow for a more factual, physical interpretation of the text.

Dante intuitively grasped the concept of invariance but, unlike Galileo, he did not pursue this idea any further. Still, it seems that he was well ahead of his time with regard to the views about the laws of nature held in the Middle Ages.

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**Competing financial interests:** declared none.

Anthropology

## The earliest toothless hominin skull

The site of Dmanisi in the Eurasian republic of Georgia has yielded striking hominin, faunal and archaeological material as evidence for the presence of early *Homo* outside Africa 1.77 million years ago, documenting an important episode in human evolution. Here we describe a beautifully preserved skull and jawbone from a Dmanisi hominin of this period who had lost all but one tooth several years before death. This specimen not only represents the earliest case of severe masticatory impairment in the hominin fossil record to be discovered so far, but also

raises questions about alternative subsistence strategies in early *Homo*.

The cranium and its associated mandible (specimens D3444 and D3900, respectively) were recovered during the 2002–04 field seasons. The skull is similar in its overall morphology (for details, see supplementary information) to the Dmanisi individuals described earlier[1,2], except that it is edentulous (Fig. 1a–e). All the maxillary teeth were lost before death, as evinced by the complete resorption of the tooth sockets and extensive remodelling of the alveolar process. In the mandibula all sockets, except those for the canine teeth, have been resorbed and only the left canine persisted at the time of death. The mandibular body has been resorbed down to the level of the mental foramen, and the projection of the symphyseal region is likely to be the result of remodelling following loss of the incisors.

Applying clinical comparative standards[3], the advanced alveolar bone atrophy indicates substantial tooth loss several years before death as a result of ageing and/or pathology. This is also demonstrated in Fig. 1f, in which a computer tomography scan is compared with those of a juvenile and an adult Dmanisi skull with dentition[1,2].

We are not aware of any other fossil hominin that displays such extensive tooth loss and remodelling (the subsequent mid-Pleistocene Bau de l'Aubésier[4] and La Chapelle-aux-Saints[5] specimens had a more intact dentition at the time of death). Recorded instances of wild, non-human primates showing comparable masticatory impairment are also extremely rare[6]. Because no apes live today in a temperate environment similar to that at Dmanisi, the behavioural implications of the new specimen can only be considered within the context of the biocultural data preserved at the site.

D3444 and D3900 were recovered from stratum B1 in block 2 (see supplementary information), which also contained stone artefacts and eight animal bones with stone-tool cut and percussion marks indicative of carcass processing and meat-eating, as found at other Pliocene hominin sites[7,8]. Meat may have been key to the success of these hominins living at high latitudes[9], especially in winter, and the consumption of soft tissues such as bone marrow or brain may have increased the chances of survival of individuals with masticatory impairment.

The D3444/D3900 individual apparently survived for a lengthy period without consuming foods that required heavy chewing, possibly by eating soft plant and animal foods and/or by virtue of help from other individuals, which must have exceeded that capable of being offered by non-human primates. The edentulous Dmanisi specimen raises interesting questions regarding social structure, life history and subsistence strategies of early *Homo* that warrant further investigation.

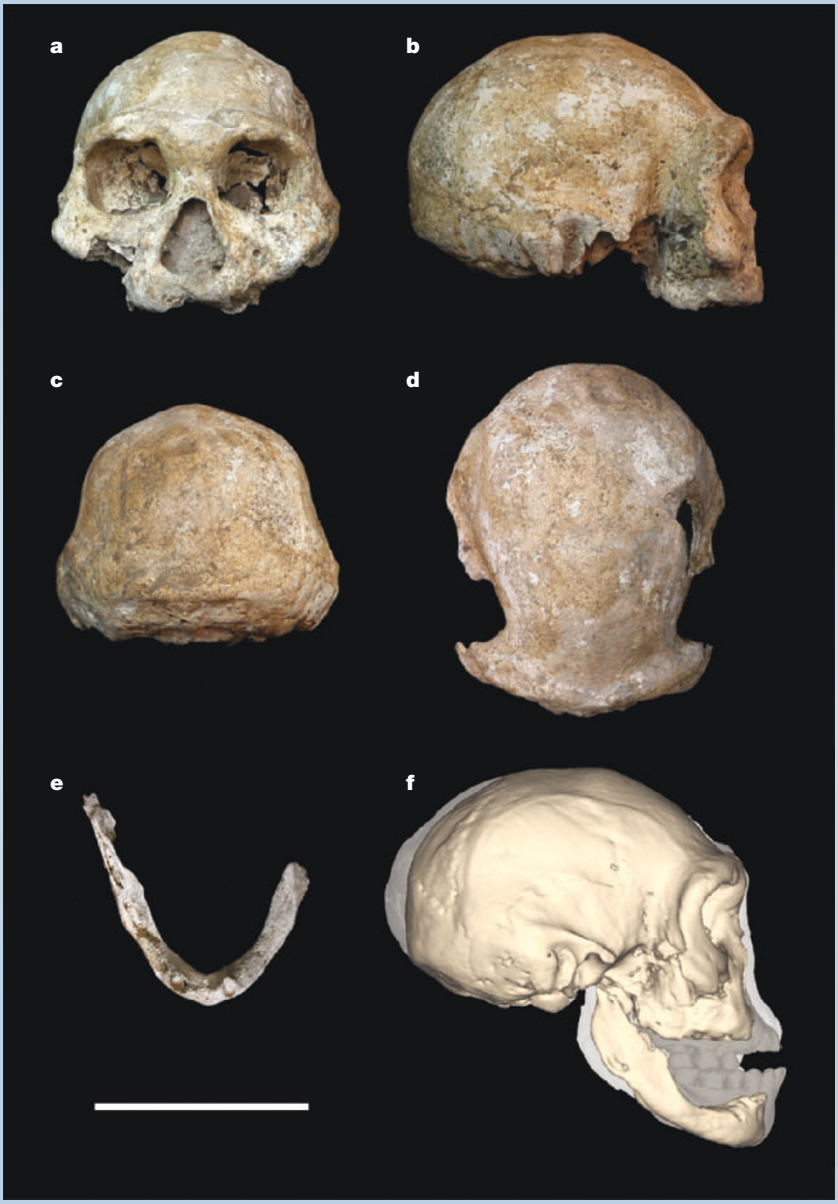


**Figure 1** Edentulous hominin skull from Dmanisi, Georgia. **a–d,** Cranium specimen D3444 (**a**, frontal; **b**, right lateral; **c**, posterior; **d**, superior views). **e,** Mandible specimen D3900. **f,** Comparative computer-tomography-based lateral views of skull D3444/D3900 (coloured), the juvenile skull D2700/D2735 (light grey), and cranium D2282 with articulated mandible D211 (dark grey) (for details of D2700 and D2282, see supplementary information). Scale bar, 10 cm.

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**Supplementary information** accompanies this communication on *Nature*'s website.
**Competing financial interests**: declared none.