

COMMENT

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A thirteenth-century depiction of the geocentric cosmos.

A medieval multiverse

Ideas in a thirteenth-century treatise on the nature of matter still resonate today, say **Tom C. B. McLeish** and colleagues.

Earlier this year we submitted an unusual paper¹ to a scientific journal. What is unusual about it is not the topic — computations of how interactions between light and matter in the primordial Universe affected large-scale cosmic structures — but what inspired it. The paper draws on ideas in a medieval manuscript by the thirteenth-century English scholar Robert Grosseteste.

De Luce (*On Light*), written in 1225 in Latin and dense with mathematical thinking, explores the nature of matter and the cosmos. Four centuries before Isaac Newton proposed gravity and seven centuries before the Big Bang theory, Grosseteste describes the birth of the Universe in an explosion and the crystallization of matter to form stars and planets in a set of nested spheres around Earth.

To our knowledge, *De Luce* is the first attempt to describe the heavens and Earth using a single set of physical laws. Implying, probably unrealized by its author, a family of ordered universes in an ocean of disordered ones, the physics resembles the modern 'multiverse' concept.

Grosseteste's treatise was translated and interpreted by us as part of an interdisciplinary project led by Durham University, UK, that includes Latinists, philologists, medieval historians, physicists and cosmologists (see ordered-universe.com). Our experience shows how science and humanities scholars working together can gain fresh perspectives in both fields. And Grosseteste's thesis demonstrates how advanced natural philosophy was in the thirteenth century — it was no dark age.

EARLY INSIGHTS

Many coffee-table histories of science maintain that the natural philosophy of the medieval centuries constituted a scientific dead end — burrowing ever deeper into alchemy and astrology. A closer examination reveals a more nuanced story. Preserved on vellum manuscripts, written in coded medieval Latin and enveloped in unfamiliar metaphysics it may be, but the science of the twelfth and thirteenth centuries constitutes a crucial stage in the history of thought.

By the late twelfth century, Aristotle's observation-oriented science had burst afresh onto the European scene, transmitted in a long series of cross-cultural translations from Greek to Arabic to Latin. Great ▶

► questions arose in the minds of scholars such as Grosseteste, Averroes (in Cordoba) and Gerard of Cremona (in Toledo). What is colour? What is light? How does the rainbow appear? How was the cosmos formed? We should not underestimate the imaginative work needed to conceive that these questions were, in principle, answerable.

Grosseteste (c.1175–1253) rose from obscure Anglo-Norman origins to become a respected theologian and Bishop of Lincoln. He was one of the first in northern Europe to read the newly translated scientific works of Aristotle, attempting to take forward the big questions of what we can know about the natural world (ontology) and how we know it (epistemology). The late thirteenth-century philosopher Roger Bacon called him “the greatest mathematician” of his time. Grosseteste’s work on optical physics influenced mathematicians and natural philosophers for generations, notably in Oxford during the fourteenth century and in Prague during the fifteenth.

Exploring the scientific thought of the thirteenth century is inherently interdisciplinary, requiring knowledge of Latin, history and philosophy, as well as of mathematics and science. Our collaboration at Durham began in 2008, following a seminar on Grosseteste by one of us, Tom McLeish, a physicist who had become interested in the thirteenth-century thinkers after hearing talks at Leeds University, UK, by historian James Ginther of Saint Louis University in Missouri.

Intrigued, medieval scholars at Durham, including Giles Gasper, recruited other Grosseteste specialists, including Cecilia Panti at the University of Rome Tor Vergata, Neil Lewis at Georgetown University in Washington DC, and the Latinist Greti Dinkova-Bruun at the Pontifical Institute of Mediaeval Studies in Toronto, Canada. Before tackling *De Luce*, we honed our skills^{2,3} on two simpler short works by Grosseteste: *De Colore*, on colour theory, and *De Iríde*, on the rainbow, aided by colour psychophysicist Hannah Smithson at the University of Oxford, UK, and Durham optical physicist Brian Tanner.

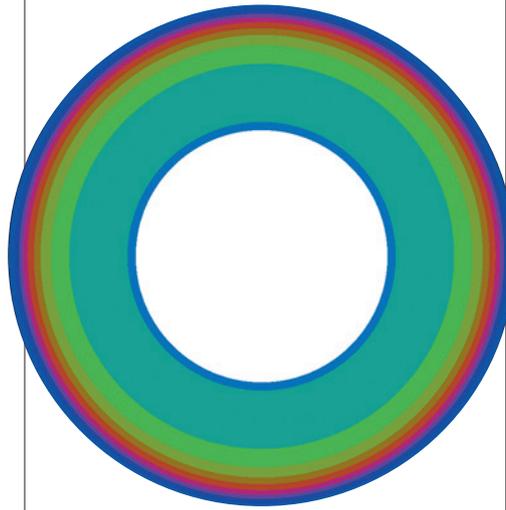
LIGHT WORK

Grosseteste’s *De Luce*, available in English since the 1940s, opens by addressing a problem with classical atomism: why, if atoms are point-like, do materials have volume? Light is discussed as a medium for filling space. Grosseteste’s recognition that matter’s bulk and bulk stability requires subtle explanation was impressive. Even more intriguing was his use of mathematics to illuminate his physics.

A finite volume, he writes, emerges from an “infinite multiplication of light” acting on infinitesimal matter. He draws an analogy to the finite ratio of two infinite sums, claiming

that $(1 + 2 + 4 + 8 + \dots)/(0.5 + 1 + 2 + 4 + \dots)$ is equal to 2. He does not articulate carefully the idea of the limits one needs to make this rigorous, but we know what he means — simultaneously adding to both numerator and denominator keeps the ratio finite.

The third remarkable ingredient of *De Luce* to modern eyes is its universal canvas: it suggests that the same physics of light and matter that explains the solidity of ordinary objects can be applied to the cosmos as a whole. An initial explosion of



A simulation of Robert Grosseteste’s nine-sphere universe.

a primordial sort of light, *lux*, according to Grosseteste, expands the Universe into an enormous sphere, thinning matter as it goes. This sounds, to a twenty-first-century reader, like the Big Bang.

Then Grosseteste makes an assumption: matter possesses a minimum density at which it becomes ‘perfected’ into a sort of crystalline form. Today, we would call this a phase transition. The perfection occurs first at the thinnest outer edge of the cosmos, which crystallizes into the outermost sphere of the medieval cosmos. This perfect matter radiates inward another sort of light, *lumen*, which is able to push matter by its radiative force, piling it up in front and rarefying it behind. An analogous process in today’s physics is the inward propagation of shock waves in a supernova explosion.

Like a sonata returning to its theme, that finite ratio of infinite sums reappears, this time as a ‘quantization condition’ — a rule that permits only discrete solutions such as the energy levels in atoms — that limits matter to a finite number of spheres. Grosseteste needed to account for nine perfect spheres in the medieval geocentric cosmos: the ‘firmament’, the fixed stars, Saturn, Jupiter, Mars, the Sun, Venus, Mercury and the Moon. By requiring that the density is doubled in the second sphere and tripled in the third, and so on, a nested set of spheres results.

In an impressive final stroke of unification, he postulates that towards the centre of the cosmos, the remaining unperfected matter becomes so dense and the inwardly radiating *lumen* so weak, that no further perfection transitions are possible. He thus accounts for the Aristotelian distinction between the perfect heavens and the imperfect Earth and atmosphere.

MODERN TOOLS

To our knowledge, *De Luce* is the first worked example showing that a single set of physical laws might account for the very different structures of the heavens and Earth, hundreds of years before Newton’s 1687 appeal to gravity to unite the falling of objects on Earth with the orbiting of the Moon. Our translation has also cleared up a misconception in some previous studies that the light in Grosseteste’s treatise travelled both inwards and outwards.

To explore the consequences of the physics in the treatise further, and to urge a closer and more careful reading of the text, the science team turned to modern tools. *De Luce* is remarkably precise in its formulation of physics — had Grosseteste had access to the mathematics of calculus and the computing power we have today, it would have been natural to apply them.

We identified six physical ‘laws’ in the manuscript, including the interaction of light and matter, the critical criteria for perfection, and the re-radiation and absorption of *lumen*. We wrote down these laws mathematically, including modern concepts such as opacity, which were consistent with the text although not described explicitly in it. Then we computed the resulting equations, expressed in differential form, in three-dimensional spherical symmetry.

To assess the range of possible solutions to these novel equations, and out of curiosity, Durham cosmologist Richard Bower then computed the space of possible medieval universes by varying the values of four parameters: the gradient of the initial ‘Big Bang’ matter distribution, the coupling strength of light and matter, the opacity of impure matter and the transparency of the perfected spheres.

A rich set of solutions emerged. A narrow set of parameters did indeed produce the series of celestial perfected spheres and, within the Moon’s orbit, a further four spheres corresponding to fire, air, water and earth — as the medieval world view demanded. But most choices of the four parameters yielded no spheres, or a disordered mess of hundreds of concentric spheres with no radial pattern to their densities. Other possible model universes contained infinite numbers of spheres, some with unbounded density. The project had unwittingly stumbled on a medieval multiverse.

The possible existence of more than one

universe was indeed a live issue of the period, and a highly contentious one — appearing, for example, in the Papal edict of 1277 that banned a list of scientific teachings. But it was a debate that Grosseteste apparently chose to avoid. None of his surviving treatises discusses the possibility of other forms of universe, however close he came to implying it in his cosmogony.

Of course we know now, thanks to telescope observations from the early seventeenth century onwards, that a geocentric cosmos is untenable. But in 1225, it was the simplest theory consistent with the observations. Grosseteste's effort to give a physical account of its origin is an impressive achievement, but it also reminds us of the limitations of our own current cosmological theory, with its reliance on intangible factors such as 'dark matter' and 'dark energy'.

SCIENTIFIC VALUE

The translation of *De Luce* is an exemplar of the importance of collaborations between the arts and sciences, of thinking and learning together in new ways, and a reminder that the intellectual tradition we now call science has a long and rich history.

Both the scientists and the humanities scholars in our collaboration found working together enriching and transformational; it forced us to engage with different ideas and problems. There were challenges:

getting used to each other's methodologies and approaches took time and patience. And our expectations changed. At the start of the project we had hoped for a sharper understanding of the text; we were surprised when new science emerged as well.

What next for the collaboration? The Durham-led team has examined three of Grosseteste's science works in detail so far. There are at least another ten to explore, including a work on the origin of sounds (*De Generatione Sonorum*). The scientific writings of Grosseteste's immediate predecessors, Alfred of Sareshull and Alexander Neckham, and his successors, including Bacon, could hold similar insights into the evolution of ideas.

Funding for such interdisciplinary work, however, remains a problem. In the United Kingdom, none of the scientific research councils offered grants for such a project. In the end, we were funded by the Arts and Humanities Research Council. The US granting system is similarly biased. The European Research Council and philanthropic sources, such as the Wellcome Trust, do fund science-arts projects, but in our experience it is easier to obtain funding for science and social science collaborations than for science and humanities partnerships.

Because projects such as ours can be of significant scientific and cultural value, scientific granting agencies should consider funding

arts and sciences projects or partnering with arts and humanities councils to translate other early scientific works, for example.

The eight-century journey from Grosseteste's cosmological ideas to our own offers a rich illustration of the slow evolution in our understanding, and of the delight to be found in reaching out into nature with our imagination. ■

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The art of science advice to government

Peter Gluckman, New Zealand's chief science adviser, offers his ten principles for building trust, influence, engagement and independence.

In 2009, I was appointed as the first science adviser to the Prime Minister of New Zealand. The week I was appointed coincided with the government announcement that the New Zealand food industry would not be required to add folate to flour-based products to help to prevent neural-tube defects in newborns, despite an earlier agreement to do so. As it happens, this is an area of my own scientific expertise and, before my appointment, I had advised the government that folate supplementation should occur. But various groups had stirred considerable public concern on the matter, about health risks and about medicalizing the food supply.

Thus, in my first media interview as science adviser I was asked how I felt about my advice not being heeded. I pointed out that despite strong scientific evidence to support folate supplementation, a democratic government could not easily ignore overwhelming public concern about the food supply. The failure here was not political; rather, it was the lack of sustained and effective public engagement by the medical-science community on the role of folate in the diet. As a result, the intervention did not get the social licence necessary to proceed.

Five years on, I am still in the post. I have come to understand that the primary functions and greatest challenges for a

science adviser are providing advice not on straightforward scientific matters, but instead on issues that have the hallmarks of what has been called post-normal science¹. These issues are urgent and of high public and political concern; the people involved hold strong positions based on their values, and the science is complex, incomplete and uncertain. Diverse meanings and understandings of risks and trade-offs dominate.

Examples include the eradication of exogenous pests in New Zealand's unique ecosystems, offshore oil prospecting, legalization of recreational psychotropic drugs, water quality, family violence, obesity, teenage morbidity and suicide, the ageing ▶