Collaborating on Cosmology with a Medieval Master

Richard G. Bower, Tom C. B. McLeish, Brian K. Tanner, Hannah E. Smithson, Cecilia Panti, Neil Lewis and Giles E. M. Gasper

An unusual research paper in cosmology was published this week [1]. The authors explore the consequences of the interaction between light and matter in the primordial universe, finding that large-scale cosmic structure is very sensitively dependent on the interaction strength. Why is this so very unusual? Mostly because the treatise that inspired this current one appeared (in manuscript form only and in Latin) in 1225, and the current co-authors include Latinists, philologists and medieval historians as well as physicists and cosmologists. The authors also claim that their analysis and computations drew inspiration from the medieval writer, and that the process of formulating a 'mathematical translation' of the text shines new light on the treatise itself. Is such a collaboration across eight centuries of thought really credible?

A scientific response to a thirteenth-century treatise may come as a surprise even to those researchers who know the value of the older literature. Newton's *Principia* and *Optiks* remain extreme mental workouts to the modern reader, and Galileo's *Dialogue* a revelation – but do such conversations with former scientific thinkers really go back further? Coffee-table histories of science maintain that the natural philosophy of the medieval centuries constituted a scientific dead-end of angels and pin-heads, but a deeper examination reveals quite the contrary. Preserved on vellum manuscript, written in coded medieval Latin and enveloped in unfamiliar metaphysics it may be, but the science of the twelfth and thirteenth centuries constitutes a vital stage in the history of thought. Historically, the vast majority of Aristototle's observation-oriented science had just burst afresh onto the European scene, transmitted as part of a long series of cross-cultural translations from Greek to Arabic, to Latin and with both Arabic and Jewish commentary. Great questions arose: *What is colour? What is light? How does the rainbow appear? How was the cosmos formed?* We should also not underestimate the significance, or the imaginative work required to conceive that these questions were, in principle, answerable. Exploring the scientific thought of the 13th century is not, however, a project that scientists today can undertake alone – this is an interdisciplinary project *par excellence*, and the reason for the extraordinary mix of the Durham University based *Ordered Universe* team behind the paper.

The collaboration began when physicist Tom McLeish arrived at Durham University in 2008 as pro-vice-chancellor for research. At his former institution of Leeds, he had often attended seminars in the History and Philosophy of Science group, where historian James Ginther was then working on the extraordinary 13th century English thinker Robert Grosseteste. Of obscure Anglo-Norman origins, Grosseteste ended his career as Bishop of Lincoln. On the intellectual scene he was one of the first to read the newly translated scientific works of Aristotle and their commentaries, attempting to take forward the big questions of what we can know about the natural world (ontology) and how we know it (epistemology).

McLeish was especially impressed by Grosseteste's treatise *On Light* (*De luce*), available in English translation. What struck him first was the critique of classical atomism with which the *De luce* begins: point-like particles cannot generate material extension to a finite volume, however many there are. Light enters as an explanation of the space-filling ability of matter, for it visibly *does* have space-filling properties. It has always been a central task of science to challenge our understanding of the 'obvious', and Grosseteste's recognition that the bulk stability of matter requires subtle explanation was impressive. More intriguing still was his introduction of mathematics as a conceptual tool to illuminate his physics. The treatise explains the emergence of a finite volume from an "infinite multiplication of light" acting on infinitesimal matter – and draws a mathematical analogy to the finite ratio of two infinite sums [Grosseteste claims that (1+2+4+8+…)/(0.5+1+2+4+…) is equal to 2. He does not articulate carefully the idea of limits one needs to make this rigorous, but we know what he means]. The third remarkable ingredient of the *De luce* to modern eyes is its universal canvas: it suggests that the same physics of light and matter that explain the solidity of ordinary objects can also be applied to the cosmos as a whole. Such reflections of a modern scientist became the contents of a tentative seminar at the Durham Institute for Medieval and Early Modern Studies (IMEMS) – "Does this fresh, if undoubtedly naïve, reading from the perspective of science show any promise?" The surprise was that the medievalists, led by historian Giles Gasper, were very enthusiastic, and the collaboration was born. He recruited leading Grosseteste scholars Cecilia Panti [2] at the University of Rome Tor Vergata and Neil Lewis [3] from Georgetown, and the Latinist Greti Dinkova-Bruun at the Pontifical Institute of Mediaeval Studiesin Toronto

Rather than tackle the complex cosmology of the *De luce* right away, the team decided to work up their interdisciplinary skills and to get used to talking across the cultures of sciences and humanities with Grosseteste's much shorter work on colour (just 500 words). It became clear right away that the approach needed expert science, specific to the topic of the treatise in every case. So Hannah Smithson, experimental psychologist and expert in colour perception (then at Durham University and now at the University of Oxford) brought contemporary colour theory to bear on the tightly-worded logic of the *De colore*. A three-dimensional colour space emerged, remarkable because human colour vision does inhabit such a space due to the spectrally-selective photopigments of the three classes of retinal 'cone' cells. Grosseteste's three 'dimensions' are not red, green, blue but the Latin terms *purum, clara, multa*, together with their opposites – *impurum, obscura, pauca*.

Midway through this analysis the team came across a puzzle – everything in *De colore* seemed to have become clear under the new interpretation bar one awkward point. If the 'white corner' of the colour space is described by the combination (*purum, clara, multa*) then the opposite 'black' corner would be (*impurum, obscura, pauca*). Yet at that point the text lists only the first and the last terms – the expected *obscura* is missing. 'Then the medievalists reminded us that the edition we were using [4] was based on an unusually late manuscript; a much earlier one was examined in Madrid by Gasper. It was a good day for the project when, with photographic proof, the presence of the missing *obsura* was confirmed. The interdisciplinary work on the *De colore* came together in a new edition (by Dinkova-Bruun) and commentary on the text [5] and also a paper in the scientific literature [6], a double-strand of publication that has become natural, as the work on computational cosmology illustrates.

With the experience of working for days together around a large table, moving rapidly between Latin word meanings and mathematical structures, and from metaphysical scholastic ideas to the dawning notions of an observational science, the team returned to the material science and the cosmology of the *De luce*. The expert and detailed approach that Smithson had brought to the *De colore* also motivated invitations to solid state physicist Brian Tanner and cosmologist Richard Bower from the Durham Institute of Cosmological Computing. The 'mathematical translation' of the *De colore* had been a relatively straightforward identification of the abstract combinatorial colour cube – the *De luce* was another matter. Over more than a year of round-table meetings and symposia the ideas within the dense writing of the text began to yield to the interdisciplinary examination. An initial explosion of a primordial sort of light (Latin *lux*) expands the universe, according to Grosseteste, into an enormous sphere, thinning matter as it goes (remarkably resonant with the idea of a 'Big Bang' cosmic origin). Then he makes another assumption – strange to our minds but very economic for his cosmology – that matter possesses a minimum possible density at which it becomes 'perfected' into a sort of crystalline form. We would call this a 'phase-transition' today. The perfection first occurs at the thinnest outer edge of the expanding cosmos which then crystallises into the outermost sphere of the medieval cosmos. This perfected matter then re-radiates inward another sort of light (Latin *lumen*) which has the property that it pushes matter by its radiative force, piling it up in front and rarefying behind.

At this point, rather like a sonata returning to the first theme, those finite ratios of infinite sums make a reappearance – but now as a 'quantisation condition' for further perfection of matter. Grosseteste knows that he has to account for the finite number of perfected planetary spheres in the medieval geocentric cosmos, yet has only continuous physics so far as his disposal. But by requiring that the density is 'doubled' in the second sphere and 'tripled' in the third, and so on, he speculated that a nested set of spheres would result. Then in a final impressive stroke of unification, he postulates that, towards the centre of the cosmos, the inwardly-compressed and still un-perfected matter becomes so dense, and the inwardly-radiating *lumen* so weak, that no further perfection-transitions are possible. In one stroke he accounts for the Aristotelian perfection of the super-lunary world and the imperfection of the sub-lunary space of the elements, including the earth. To our knowledge this is the very first worked example that shows that a single set of physical laws might account for the very different apparent structures of the heavens and the earth. A reader cannot help but be reminded of Newton's idea that gravity might unite the falling of objects on earth and the orbit of the moon.

An early result of the work was the clearing-up of a misconception in previous studies. Earlier interpretation has read into the work a series of inward and outward waves of light, one for each sphere. But the detailed approach revealed a single inward propagation of *lumen* that left all the crystalline spheres in its wake. At this point it was natural for the science team to turn this close reading of the text into the mathematics that Grosseteste did not himself possess, but which would be consistent with his careful and linguistically-expressed ideas. They identified six physical 'laws' (including the interaction of light and matter, the critical criteria for perfection, the re-radiation and absorption of *lumen etc.*) that could be given mathematical expression. Among them were ideas implied by the text, though not described explicitly – for example that the spheres possess some opacity to *lumen* that reduces its intensity towards the earth. In differential form the six laws produce a set of field equations that can be computed in three-dimension spherical symmetry albeit with some technical care (the 'snowplough' effect of *lumen* on matter results in a distribution with a 'delta-function' or 'spike' component that needs careful handling). Of course the ancient text leaves some choice of mathematical translation, but this could be accommodated into four dimensionless parameters corresponding to 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. Bower set off computing the space of possible medieval universes as these parameters were varied.

The "Grosseteste Equations" constitute a fascinating alternative physics with very rich solutions. Figure 1 shows a 2-dimensional plot of a medieval cosmos with nine spheres (corresponding to the canonical theory of the time: from the outside in the spheres of the firmament, the fixed stars, Saturn, Jupiter, Mars, the Sun, Venus, Mercury, the Moon). This calculation successfully leaves an unperfected core within the Moon's orbit. It was remarkable to be able to find such a solution, but it appears within only a very narrow region of the parameter space of the whole theory. Most choices of the four parameters gave rise to no spheres at all, or a disordered mess in which spheres at each quantised level of density appeared at more than one radius. Another large region of possible universes contained infinite numbers of spheres accessing unboundedly high densities. The project had unwittingly stumbled upon a whole family of ordered solutions to the novel equation set, within an ocean of disordered ones. The physics of the *De luce* contained within it not just a medieval universe, but a medieval multiverse. Figure 2 shows a three-dimensional slice through the four-dimensional parameter space, indicating how the ordered and finite universes 'nest'. The possible existence of more than one universe was indeed a live issue of the period, and a highly contentious one, though it seems to have been a debate that the Grosseteste had chosen to avoid, however close he came to implying it in his cosmogony.

It might be objected that all this is at best just academic play, and possibly worse, but the value of the project is becoming apparent. For the scientists, it reminds us that the urge to explain the natural world around us, and especially to construct invisible explanatory structures and processes behind apparent phenomena, is much more deeply buried within human culture than we are sometimes allowed to believe. It also gives a longer perspective to our current paradigms. Of course we know now thanks to the telescopic observations from the early seventeenth century onwards, that a geocentric cosmos is untenable, but in 1225 it was clearly the simplest theory consistent with the observations. Grosseteste's project to explore a physical account of its origin, whose processes might be read-off the structures visible in the sky, is an impressive achievement, but also warns us to be aware of the ignorance we still bear in respect of some of our own current cosmological theory. For the humanities scholars as much as for the scientists, it brings a new perspective on arts-science collaboration, the idea of thinking and learning together in new ways, and an appreciation of the intellectual tradition we now call 'science' within the long history of human culture. Perhaps the most exciting current development is the idea to create educational material for schools from the project. The journey from Grosseteste's cosmological ideas to our own is a rich illustration of the slow evolution in our understanding of nature, and of the delight to be found in reaching out into nature with our imagination [7].

Acknowledgement

The Ordered Universe project is funded through a "Science and Culture" network grant from the Arts and Humanities Research Council UK.

References

[1] Bower, Richard G. *et al.* 'A Medieval Multiverse: Mathematical Modelling of the 13th Century Universe of Robert Grosseteste', *PNAS*, (2014)

[2] Panti C (2013) 'Robert Grosseteste's De luce. A Critical Edition' in: *Robert Grosseteste and his Intellectual Milieu, New Editions and Studies*, Eds. J. Flood, J. R. Ginther and J. W. Goering, Papers in Medieval Studies 24, Pontifical Institute for Medieval Studies, Toronto, pp.191-238

[3] Lewis N (2013) 'Robert Grosseteste's De luce. An English Translation' in: *Robert Grosseteste and his Intellectual Milieu, New Editions and Studies*, Eds. J. Flood, J. R. Ginther and J. W. Goering, Papers in Medieval Studies 24, Pontifical Institute for Medieval Studies, Toronto, pp. 239-247

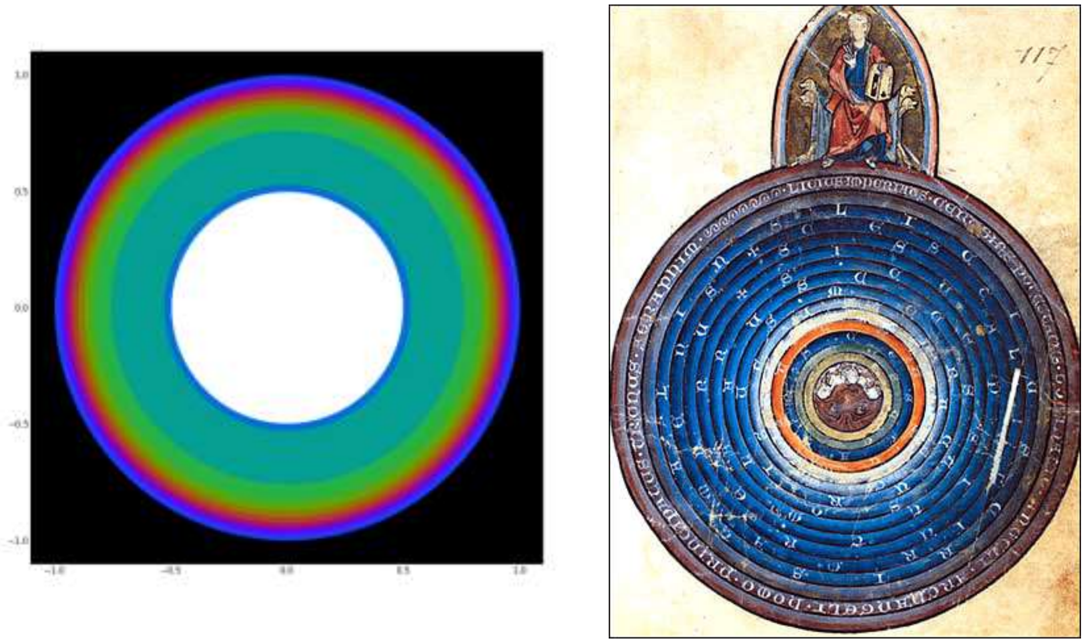
[4] Baur L *Die Philosophischen Werke des Robert Grosseteste, Bischofs von Lincoln* (Münster: Aschendorff, 1912).

[5] Dinkova-Bruun, Greti, Giles E.M. Gasper, Michael Huxtable, Tom C.B. McLeish, Cecilia Panti and Hannah Smithson, *The Dimensions of Colour: Robert Grosseteste's De Colore; Edition, Translation and Interdisciplinary Analysis*, Durham Medieval and Renaissance Texts, Pontifical Institute of Mediaeval Studies, Toronto, 2013.

[6] Smithson H. E. et al., 'A three-dimensional color space from the 13th century', J. Opt. Soc. Am., 29, A346-A352 (2012).

[7] Educational ideas and other material can be found on the Ordered Universe blog at http://ordered-universe.com/

Figures



(a) (b)

Fig. 1.(a) A two-dimensional representation of a convergent simulation of a Grosseteste universe with nine perfected spheres. The central sphere contains imperfect matter as the perfection process stalls as the model starts to generate a tenth sphere. (b) A 13th century representation of the geocentric cosmos from Goussuin of Metz (the red band is the sphere of fire – the first imperfect sphere below that of the Moon).

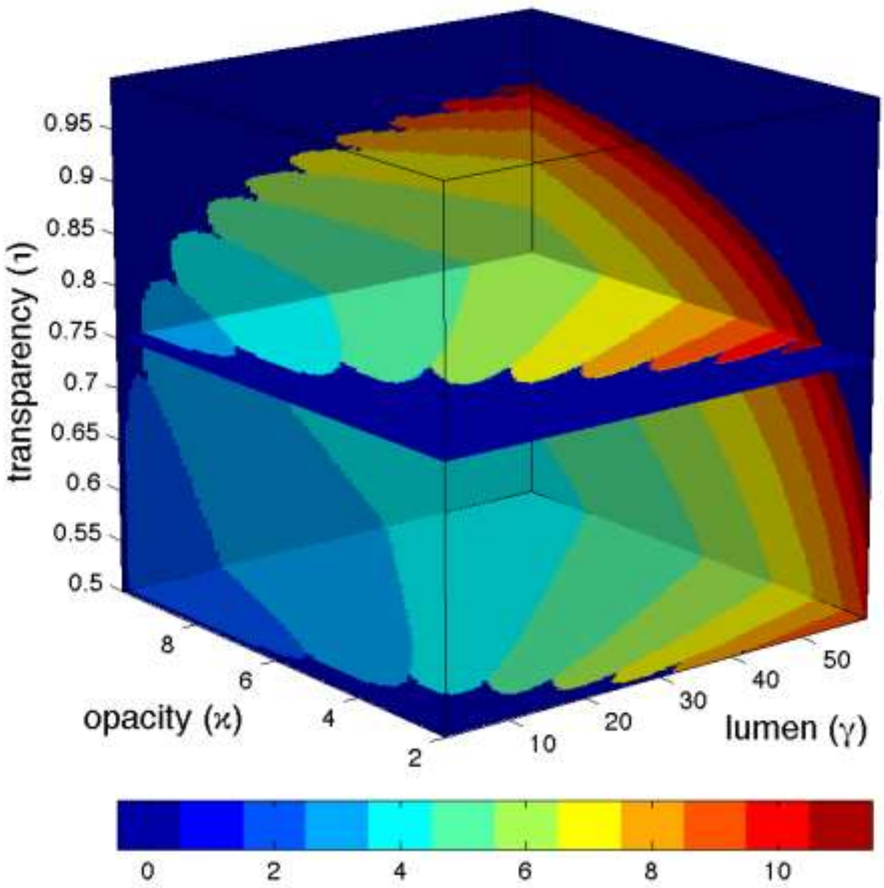


Fig. 2. The "medieval multiverse" showing the regions of stability in opacity κ, *lumen* intensity γ and transparency τ space within which plausible universes exist. The colours correspond to the different numbers of spheres created by the model.