BURNETT, D. Graham /
SOLOMON, Jonathan D.

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Masters of the Universe

Models are good to think, not just good to make and show. It is perhaps some indication of the power of the model as a deep and (un)dead metaphor that the ubiquitous term "theory" traces its etymology back to the Greek word for a "model of the planetary system." In this sense every aspiration to systematic rationality may secrete a cosmology, and every effort at abstraction (a leaving-of-the-world-behind) may well be dogged by the (ever-so-worldly) wax and paste and wire and paper contraptions with which early star gazers tried to imagine themselves as gods. To follow up on these ideas, 306090 met with D. Graham Burnett, a historian of science at Princeton University, who has written on geography, astronomy, and cartography; he currently directs the Program in History of Science at Princeton, and serves on the Executive Committee of the Center for Architecture, Urbanism, and Infrastructure at the School of Architecture.

Jonathan D. Solomon: I am hoping that we can cover two things in the course of this conversation, Graham. The first is the history of the scientific model itself as an apparatus or device. Out of what desires did it evolve, to what uses was it put, and perhaps most importantly: when seen historically, what effects did it have? Second, I want to explore with you—if possible—the proper and improper uses of a model, from a perspective that might be useful for architects. Are models rightly thought of as conclusions, or as points of departure? Can a model—be it mathematical, philosophical, mechanical—ever be taken "too far"? Architects fret over these questions. So let's start by talking about a type of model that is fraught in this way—if not downright dangerous: comprehensive models, models that attempt to reveal the universe in totality. How do they work? What is at stake?

D. Graham Burnett: One of my first research projects in the history and philosophy of science was an investigation of the "cosmogonic" (i.e., "cosmos-generating") experiments of Robert Fludd, a late sixteenth-early seventeenth-century natural philosopher. He was also an alchemist, and he tinkered a bit with natural magic. Fludd argued that his "experiments"—they were little mechanical and hydraulic devices, really—would afford evidence on the question of the origin of the universe. To give one example, Fludd directs the reader to cook up various mixtures of water and wine in interesting ways, and then to permit this goo to settle. Fludd asserts that the resulting layers of scum can be correlated with the original division of elements during the genesis of the Earth and the heavens. Some of his other devices are pneumatic or steam-driven contraptions that he alleges will, under certain kinds of manipulation, give the investigator evidence on how the initial motion of the universe took shape.

I was interested in the epistemological status of these experimental devices—I think it is certainly fair to call them "models." In other words, I wanted to understand how Fludd thought they worked: what kind of knowledge did they help produce? How?

Were they, for instance, analogical devices—devices that facilitated thinking by providing the user with an assemblage of elements and relations that were intended to be juxtaposed with some other assemblage of elements and relations? "Aha, the goo forms five layers; well, that is *just like* the five layers of the primordial elements!" If this is how they worked, how far could the analogies be pushed? "Hey, this goo settles out in layers of different thickness; I bet those ratios are *just like* the quantitative ratios that governed the original deposition of matter out of the formless abyss at the creation!"

You could want the models to work this way—and think they did—without committing yourself to the higher-stakes game of arguing that you are watching, in the bottle of goo, the *actual process* and/or *actual substance* of that original cosmic formation. In other words, "X is *like* Y" is a very different proposition from "X *is* Y." Did Fludd think that the five layers of goo *were* (in some form) the *very stuff* of the five primordial elements? Did he think you were watching in that jar the operation of the *very same forces* that originally organized all the matter in the universe?

The short answer is, I think, "yes, sometimes," though this was not how those devices had been interpreted before (suffice it to say that the full story here is complex—but irrelevant for our purposes). The larger force of this claim can be generalized: on the one hand, models can create a situation in which you may reason *analogically* about the nature of things; but on the other hand they can cause to be made manifest—and hence allow for the revealing, touching, tweaking, or accessing of—*the actual forces and stuff at issue*.

In this latter case the language of analogy is no longer going to suffice, because analogies are the juxtaposition of ontologically discrete referents. It's essential that the domains at issue be different, since the intellectual volatilities of an analogy lie precisely in the discreteness of the elements that are being juxtaposed. You can't do analogies when you are likening X and X. Something else is happening: you are, somehow, "breaking through" to the nature of things.

When was Fludd doing which thing with his models? When were they predicated on analogies and when were they predicated on an underlying ontological continuity? This is the sixty-four thousand dollar question. And indeed I would argue that what makes modeling so powerful is precisely the slipperiness of this distinction. The move from "as" to "is" can happen fast, can happen for only a moment, can subsequently be denied—it is in this instability, this indeterminacy, that models ultimately do their real work.

JDS: Interesting. Is this process affected, in your view, by the character of the models themselves? By what they are made out of, by how well they work? I press these questions because I think there has been, lately, a real perception among architects that the work models can do has been so augmented by the evolution of new computational tools as to have been fundamentally transformed.

Maybe you could speak a little more about models as actual devices. When did it became possible, technologically, to build mechanical models that accurately imitated or predicted the behavior of a natural system, and what was the effect of such devices on the way people understood the systems being modeled?

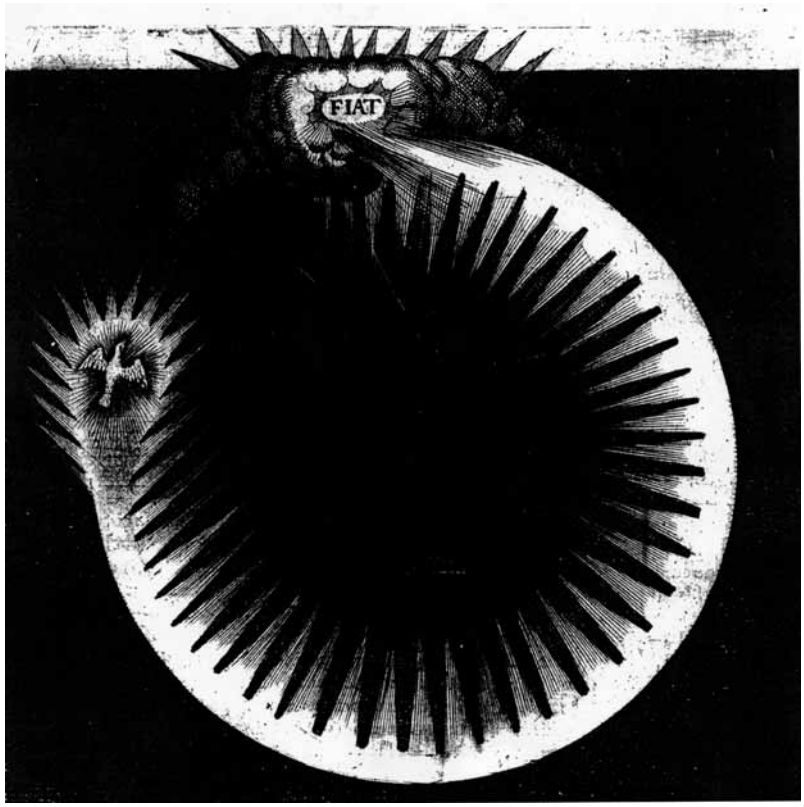
DGB: Different historians would answer this question in different ways, but looking at the Renaissance and the early modern period (say, 1350-1700) it is hard to overlook the rise of mechanistic explanations of the natural world. It is awfully tempting to link this story to the history of the clock, the most fundamental model of natural processes that would have been familiar to people in Europe in this era.

We don't immediately think of a clock as a model, but it is. What's it a model of? It's a model of the relationship between the Sun and the Earth—some doo-dad in the clock swings around once in the same amount of time that the Sun and the Earth go through one complete diurnal cycle. You don't need to have a Copernican account of celestial dynamics to have the model be "right" as a representation of this relationship. Upshot: in endeavoring to model the relationship between the heavens and the Earth, people build what were the most sophisticated mechanical devices that exited up to that time. In the fifteenth century you're already well along with weight driven clocks, and new escapements, and by the sixteenth century you have pretty fancy spring driven clocks as well. There's a complicated and interesting story (one that crosses between the history of science and the history of technology) that can be told about the efforts to develop techniques for regularizing the patterned bits of the clock's cycle, for making many exactly equal beats, those discrete units of time. For instance, the integration of the pendulum into timekeepers marked a very important jump in precision and accuracy.

JDS: I'm hooked. How so?

DGB: There is little sense rehearsing the technical story here (it can be found in lots of places, including David Landes' *Revolution*). For our purposes what is key is to consider what all this clockwork-clockwork has to do with the larger emergent idea of the "clockwork-universe." It is a primo example of the sort of slippage I was talking about before.

As early as the late fourteenth century, you see mechanical clockwork devices that model the heavens pretty successfully. They've been elaborated to the point that they can show much more than just the patterned interaction of Earth and Sun—wheels and dials indicate the positions of the known planets and the zodiacal constellations. These showy devices are like a whole astronomical almanac set to music and animated. And somewhere in there a mess of thinking folks go from having built a clockwork model of the visible features of celestial dynamics to reasoning that the celestial dynamics themselves may well be a big clockwork. Well,



The separation of light from formless darkness at the creation. Robert Fludd, Utriusque Cosmi Historia*, 1617.*

wait… A clockwork universe? No, no—*you* built the clock *of* the universe. And now you are telling me that you see the cosmos as itself an enslaved mechanical contraption? As dead matter driven by a motive force? As an assemblage possibly designed at some point by some remote and indifferent deity, but then set in motion and abandoned in the same way that a clock is set in motion by a clockmaker who then goes home for supper? This is the story that is going to be told by the eighteenth century about the origin and nature of the universe.

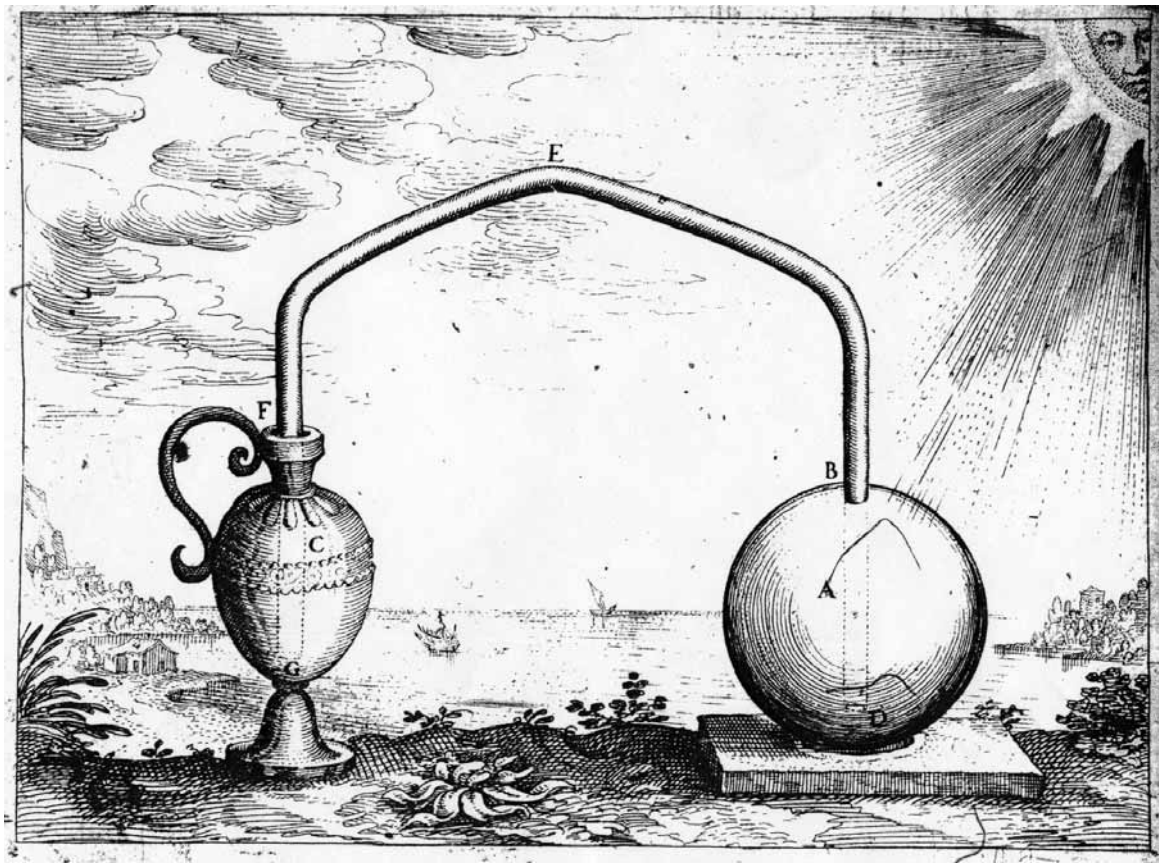
You can see how it's a product of a bizarre kind of conflation. We could sit here for a bit and think how often it is you start out with a model as an analogy—as an effort to stimulate analogical reasoning (or reify it)—and you wind up having decided that the thing you set out to model is *nothing more or less* than the thing you've just built as a model. It's a charged, and by no means frictionless, and by no means costless slippage in the way our thinking with models and about models moves.

JDS: Is this sort of slippage good or bad? I got the sense before that the you were putting forward the slide from the metaphorical to the ontologically continuous—from "as" to "is"—as a momentary looseness in the model that, when properly managed, allowed for a generative or creative process to unfold. But here, this sort of slippage in the model's use would seem to stake out far more dangerous territory. Suddenly the model is there not as a way to think but as a thought, not as a tool, but as a discovery, a demonstration, or even an explanation.

DGB: We have an interdisciplinary faculty workshop running this year here at Princeton on the subject of "explanation"—mathematicians, physicists, biologists, anthropologists, etc.—and so, naturally, I have never been as confused about the whole business of "explaining" as I am right now. If we go back to our simple example of a clock, we can certainly say that a clock does *in fact* "model" the relationship between the sun and the earth, but can we say it "explains" it? No. I don't think so. In fact only if you permit that notorious slide from "as" to "is" do you begin to think it might have explanatory value. My watch doesn't *explain* the relationship between the sun and the earth, it just permits a modest predictive capacity where their relations are concerned. Which is very nice, but you'd have to be out of your mind—as indeed the entire eighteenth century, and perhaps everyone who has called himself a rationalist since Descartes has been out of his mind—to think that…

JDS: The energy, information, or process that are actually moving through that model…

DGB: … are those that drive the heavens. That's when you're off to the races with a clockwork universe and some clockmaker God who set this whole thing in



Above and opposite: Vessels for demonstrating different forces and configurations of matter under various conditions. Robert Fludd, Utriusque Cosmi Historia*, 1617.*

motion and then retired to sit by the fire. It's a product of convincing yourself that the model has explanatory value, when in fact you have no grounds for making any such suggestion.

JDS: Let's turn for a moment to the Borges story, *On Exactitude in Science*. My understanding of that story is that a model of the world replaces the world—the map of the empire is achieved at a scale of 1:1, so that the map/model is no longer *analogous* to the world, it *is* the world. If we look at this story itself as a model, it implies that models need to back away from such totality.

DGB: Yes, delicious, a wonderful point, since the story itself is presented as a fragment—and thus disavows totalizing ambitions in its actual form, as well as in its apparent *morale*. I love *Del Rigor de la Ciencia*. I confess I've never thought of it in the context of modeling in part because I've never been entirely at ease applying a language of modeling to cartography. I remain more comfortable with models as dynamical or kinetic propositions.

JDS: Is a map closer to a diagram? I don't suppose you have a working definition for me of the difference between the two?

DGB: No, I'm afraid not. An email used to circulate among historians of cartography that featured something like 500 different definitions of the word "map"—drawn from different historical periods and languages. What a pain! To me the Borges vignette has always been understood most congenially as an exercise in post-colonial critique. That is, it's a story of the perils of "seeing like a state," to use James Scott's formulation. All knowledge-making programs with totalizing ambitions ultimately unmake themselves. They unmake themselves because they forget that knowledge is a process of leaving the world behind. Knowledge *is* abstraction (this is a secular way of saying what Catholics mean by original sin). For this reason, the totalizing programs of so many rationalist projects boldly pontificate the conditions of their own impossibility, and they are prevented from being called to account only by the simple (the blessed!) recalcitrance of the world around them. That is, they can't achieve their much-vaunted goals—and that's what permits them to survive.

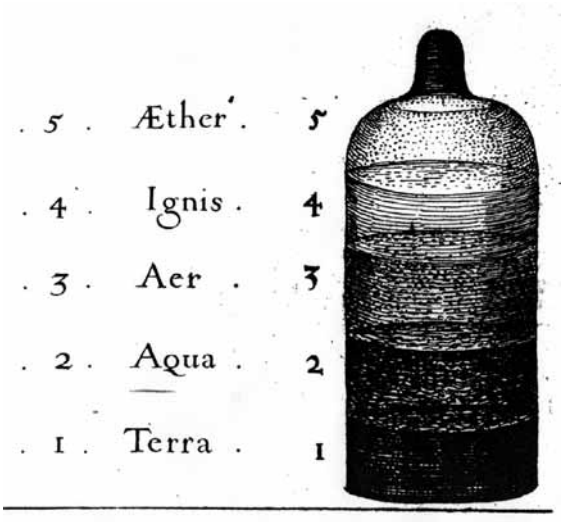
JDS: Totalizing as a practice would seem to be very much a partner to modeling. You mention James Scott's book. Scott also speaks about the danger of legibility, in which models both philosophical and technological would seem to be complicit.

DGB: Borges' vision of the western barbarians holing up their sheep in yurts that are cut from the fabric of this universal map (which was so obviously the megalomaniacal fantasy of some remote imperial overlord) has always felt to me like a wonderful and flippant rejoinder to the totalizing hysterias of colonial regimes. *Voilà*—behold the flotsam and jetsam of your rationalizing programs, which had looked so promising when laid out on that wonderfully even surface of a table in some negotiating room in a metropolitan capital. The image of that table I borrow from Paul Carter, for whom that clean surface stands as a kind of altar on which the material specificity of the world has been again and again sacrificed: the table is well polished, but there is blood all over the floor.

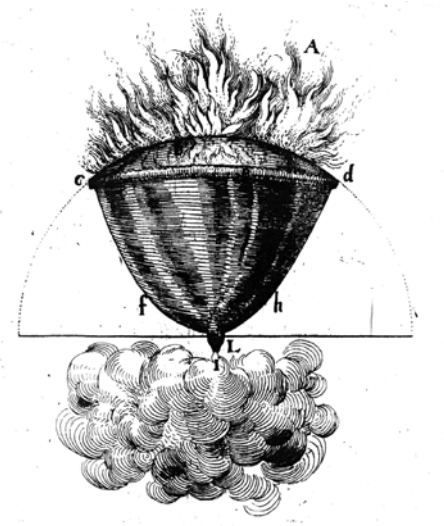
In another way (also very Carter-esque) the Borges story plays on the relationship between representation and enactment—I think it can be read as ultimately a parable about mimesis. It reminds us that mimesis is dependent on certain kinds of scalar transformations: when those scalar transformations are subverted, representation itself becomes impossible; when you are at 1:1 you're in the realm of *methexis*—you're walking what you know, not making pictures.

But to go back to what I said before, the map-as-model has always been a little less immediate for me because maps don't move. It's like what DeLillo says about pornography in *Running Dog*: It's got to move!

JDS: Maybe we could move the discussion to moving maps? My world was rocked this past year by Google Earth, a model unlike anything I had ever experienced in terms of its depth, its breadth, and its "smooth" scalability both graphically and with respect to the data it can



Robert Fludd, Utriusque Cosmi Historia*, 1617.*



Robert Fludd, Utriusque Cosmi Historia*, 1617.*

present. Can you connect this contemporary model to a lineage of devices that represent the universe?

DGB: Once upon a time I did a lot of research on maps that do move, on kinetic globes and animated cartographies and so forth. In the end it all went nowhere. But I did it because it felt to me there was something special about mobilizing cartographic material dynamically.

Depending on your definition of a map (ack—that annoying problem again!) you might take something like an Orrery as an example of a dynamic cartography. They are in some sense the clockwork universe realized, because they are driven by clockwork mechanisms, but instead of having the clock merely represent the relationship of the Sun to the Earth by means of a dial or a indicating hand, an Orrery is going to go ahead and represent that relationship spatially, in a system that pretends to correspond point-by-point, in time, with the actual solar system.

On the other hand, you can build one of those big fancy clocks we were talking about before, which is going to set in motion wheels representing the dynamics of all the planets that are visible from earth with the naked eye in the night sky. That is effectively a kind of mini-planetarium. It's the same information that's presented in an Orrery. Only the perspective is different. You see mobilized a set of ratios that are depicted in polar coordinates. The indicator wheels don't have to be homocentric. There's no effort to organize all this information in some spatial domain that is construed as analogous to the spatial domain in which the planets are situated.

JDS: It's the human's-eye-view, not the God's-eye-view?

DGB: Yes, maybe. We see all the same stuff at work in this fancy clock that we could see in an Orrery, and yet the Orrery is emphatically the God's eye view. You've pushed the clockmaker God right out of the universe, and then you've figured a device by which you can occupy His seat, by rebuilding the planetarium in such a way that you stand in relation to it as God would stand to the clockwork universe. It's worth dwelling on this issue of subjectivity. With the astronomical clock you are really much closer to an animation of a mathematical register or ledger. What you've done is set into a wrought iron frame all the pages of the notebook in which you did the calculations for the celestial positions. So you stand in relation to such a device much more like the reader of a book. You can sort of turn the pages, look from side to side, and see dynamic renderings of the same set of calculations you could do with pencil and paper if you were a medieval astronomer or a caster of horoscopes.

JDS: But these are all analogical models, in the sense we used earlier. Neither demonstrates any of the "ontological continuity" you said made models really powerful.

DGB: The weird thing is, if you have a weight driven clock, the forces that are driving that model *are* in fact the same forces that drive the heavens: gravity. The falling weight is what's driving the mechanism of the clock, and the perpetual "falling" of all the stuff in the universe is what's moving the planets. Now as it happens, people got interested in the notion of a clockwork universe long before Newton spelled out the way that a falling body on the earth is a manifestation of the same phenomenon that drives the planets as they spin around each other. That didn't happen until the *Principia*, 1687. But something like the clockwork universe was accessible to Dante,

The Earth as seen by Google. Image courtesy Google Earth™ mapping service.

for God's sake! So here's a queer situation where the analogical form of reasoning affords you access to an unexpected ontological continuity, one that was embedded in the model from the outset. Another way of putting it, still more extravagant, might be: Would Newton have reached his conclusions about the unity of the laws of motion in the super- and sub-lunary domains had he not already been mobilizing a notion of the clockwork universe and been familiar with astronomical clocks? I think an actual Newton scholar would call this an asinine question. But it is an odd thing to consider… There is an actual Newton scholar upstairs. Should we go ask him?

JDS: No, let's save him for our next issue, since I have a question for you: You seem obsessed by this idea of ontological continuity; are models that display this feature better than the "merely" analogical kind? Better in the sense of more fruitful, conducing to novel insights and creative findings?

DGB: I am sort of making this up as I go along here, and I am suddenly pained by the sense of that huge fat literature out there on these difficult topics (another colleague of mine—this one downstairs—has a book coming out later this year, *Science Without Laws: Model Systems, Cases, Exemplary Narratives*, that will be very useful to anyone who wants to dig in on these problems). But, hell, let's not let ourselves get bogged down. It's like Nietzsche says: big problems are like a cold bath; you've got to jump in and then get out fast.

So with that in mind, I guess I'd say that ultimately much of the creative work that happens when using a model derives not from the model's positing an underlying ontological continuity, but rather from its capacity to fudge that nettlesome issue. In other words, the generative power of models lies in the degree to which they afford opportunities to be equivocal about questions of identity, to elide or blur the extent to which you are positing an underlying continuity of force or matter (a homology of substrate), and the extent to which you are reasoning analogically. And every time you permit a trepidation between those very different fundamental claims ("as" and "is"), every time you allow for an oscillation between the referents, important thinking happens. That's how ideas change.

Not to suggest that all truths lie in etymology, but I believe the origin of the English word "model" comes to us through French from the Latin *modulus*. "Modulus," tellingly, turns out to be an auto-antonymic; i.e., it means itself and its opposite. *Modulus* can mean a "fake," just as it can mean an "ideal or original." Right there in that equivocation is what it means to think with models.

JDS: When an architect takes on a scientific model, say a model of cellular dynamics from biology, or a model of viscous flow from physics, and—

DGB: Are you asking me if all architects are bullshitters? Excellent question! For sure! But the good news is that, on the account I have just given, genius is just a particular kind of misunderstanding. To the extent that you guys take things from other disciplines, utterly pervert them, misuse them, and deploy them in ways that are generative—you are doing crucial voodoo.

JDS: But if the purpose of models is to be generative—and if, like metaphors, models are just a special kind of lie—then models are only *there* to be perverted, right?

DGB: I love the idea. Since I've argued that the power of thinking with models lies in the occasions they afford for rapid and obscure oscillation between "as thinking" and "is thinking," I find quite felicitous the notion that it is the confidence men who, in the end, press our thinking most effectively. That is, those who dive in and don't fully understand, those who fake, those who forge (another auto-antonymic there…), those who just might be putting us on. How could it be otherwise? It's exactly when we aren't sure whether our interlocutor is speaking literally or poetically that the interesting stuff starts happening.

This feels right to me. Most features of erudition are certainly more fun, probably more interesting, and possibly more useful when deployed by those who have really no idea what they're talking about.

But don't tell anyone I said so…

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Jonathan D. Solomon *is an editor of 306090.*

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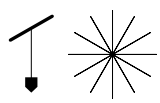
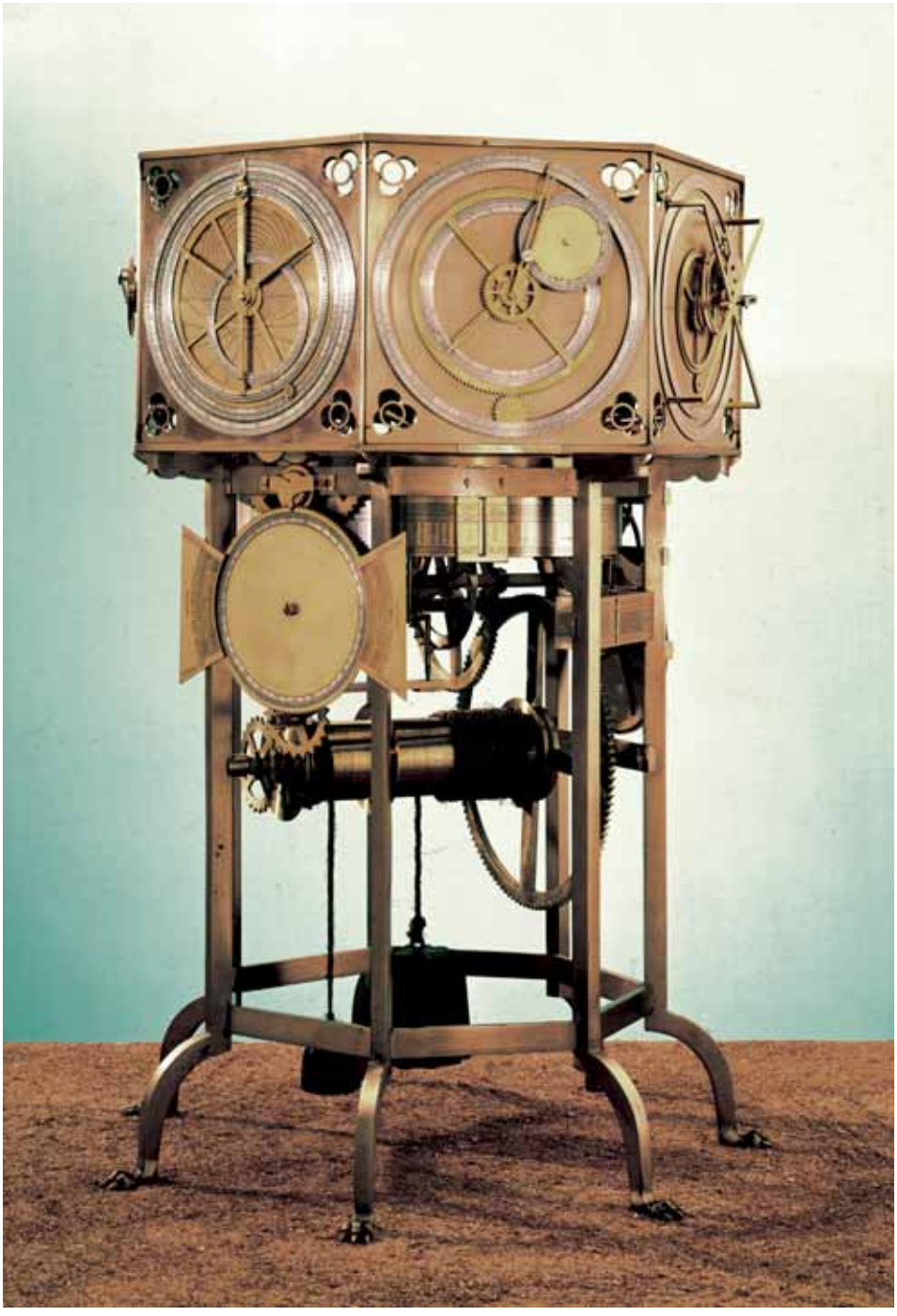


Hand-cranked orrery, showing the movements of Mercury, Venus, and the Earth around the Sun, and the Moon around the Earth. Printed, colored, and varnished dial; brass wheels and gears, Sun and Moon; ivory planets. Built by famed London instrument makers, William and Samuel Jones, 1794. The orrery demonstrates astronomical phenomena related to the diurnal rotation of the earth, the annual revolution of the earth around the sun, and monthly revolution of the moon around the earth, such as the reasons for day and night, seasons, and eclipses. The dial has calendar, zodiac names, symbols, and figures, and related calibrations in the outer concentric circles; tables of data relating to the planets (Mercury through Saturn) occupy the center area. Image courtesy Historic Maps Collection, Department of Rare Books and Special Collections, Princeton University Library.



De Dondi's Astrarium*, 1364. Reconstruction by Thwaites and Reed Ltd. Giovanni de Dondi (1318-1389), a scientific polymath of the Middle Ages, designed and constructed this remarkable and complex clock in Mantua, Italy, between 1348 and 1364. Although the original clock was lost during the sacking of Mantua in 1630, de Dondi left detailed plans which have survived, enabling this reconstruction. Besides the usual solar mean time, de Dondi's clock was the first to show sidereal—or star—time as well as the motions of the sun, moon, and the five then known planets (Venus, Mars, Saturn, Mercury and Jupiter), according to a Ptolemaic conception of the solar system (with the earth at the centre and the sun and planets rotating around it). Image courtesy Science Museum/Science & Society Picture Library.*