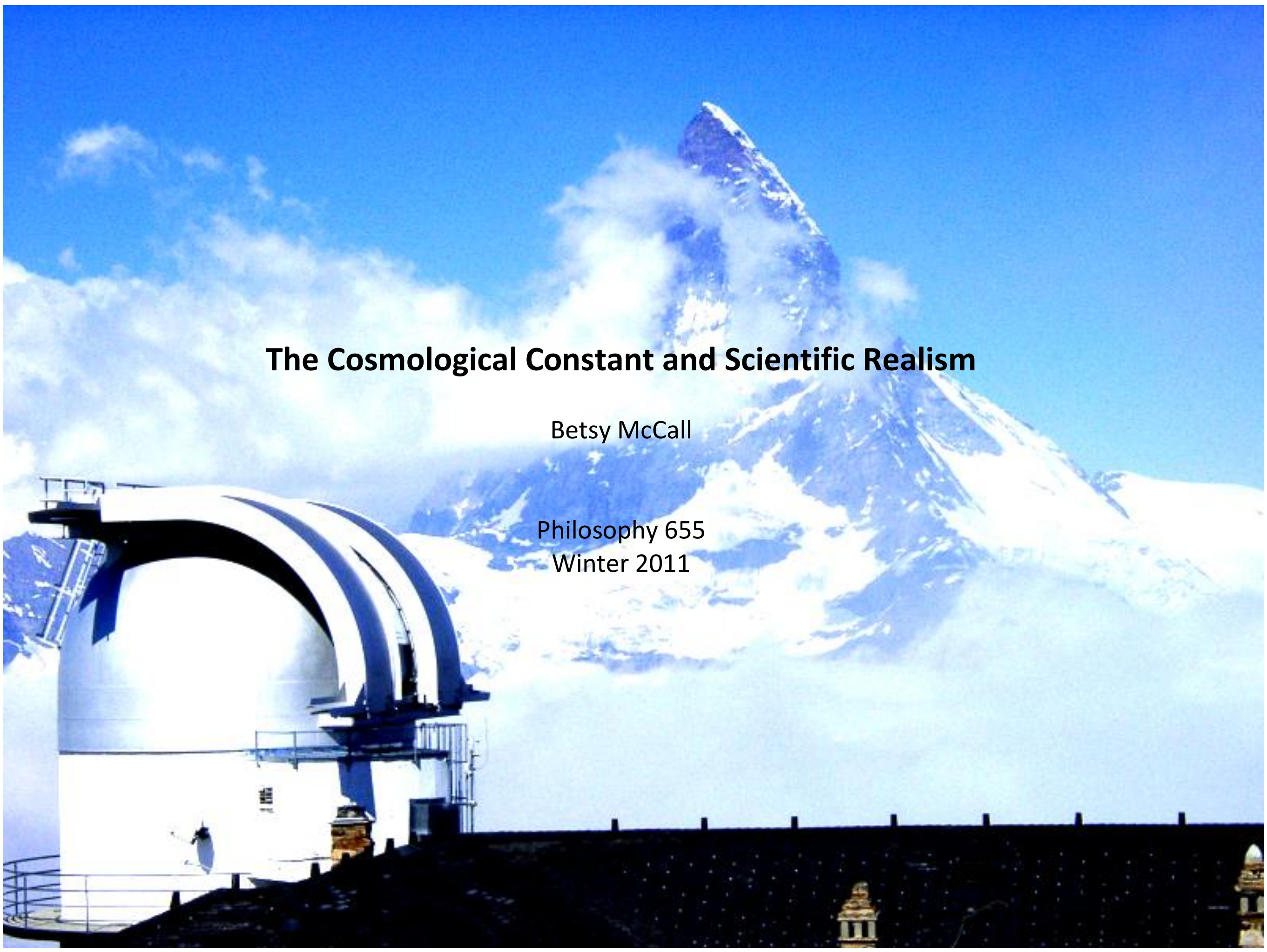

The Cosmological Constant and Scientific Realism

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Scientific realism is the position that we are rationally warranted to believe in the fruits of science, such as scientific theories and their conception of the world. Scientific realism has been under attack for many decades now by several waves of antirealists who would have us undermine, in various ways, our confidence in science. This paper is going to examine a historical episode, one that is still ongoing, concerning the cosmological constant, and the role that scientific realism has played in the debate. I will use this episode to show that antirealist attacks against science cannot account for features of the debate among scientists, nor explain the comings and goings of the cosmological constant itself.

To begin I'd like to briefly consider another episode in the history of science that will be a useful comparison later on.

Heliocentrism vs. Geocentrism

Readers of the literature of realism/antirealism debate will be familiar with only the later stages of the scientific debate between heliocentrists and geocentrists. The Copernican Revolution, of course, was the turning point where geocentrism (that the Earth is the center of the Solar System advocated by Ptolemaic astronomy) was finally overturned by its younger rival, the heliocentrists (that the Sun was the center of the Solar System, advocated by Copernicus). This was a major step forward in the history of astronomy, not only because it also helped lead the way to Newtonian physics, but because it is actually the way that the Solar System works. We can send satellites beyond the solar system and when they look back at us, they don't see a Ptolemaic system, with or without the celestial spheres, they see a heliocentric one.

However, what is not noted in the literature of scientific realism was that Copernicus was at least the third leading astronomer, in the history of Western astronomy, to propose such a heliocentric model. The Ptolemaic model of the solar system was constructed in the early second century of the

Common Era, but the heliocentric model of the solar system was proposed by Aristarchus of Samos in the third century before the Common Era—five centuries before Ptolemaic astronomy took hold (Ryden and Peterson). His model included such details as having all the known planets correctly ordered from the sun; models on the Ptolemaic scheme could not settle on an order for Venus or Mercury, and models including both orders were developed by Ptolemy's successors. Like Ptolemy, who based his model on the philosophy of Aristotle, Aristarchus looked to philosophy for support also, taking the notion of the central fire from Pythagoras, and identifying it with the sun. Nor was Aristarchus a fly-by-night astronomer. He succeeded in measuring distances to the planets geometrically with much better accuracy than previous attempts (Ryden and Peterson). The dominance of Aristotelian physics, which demanded that the Earth be stationary, sealed the fate of Aristarchus' model. It was surely the heliocentric model of Aristarchus that Ptolemy had in mind when noting:

> *"These persons forget however that, while, as far as appearances in the stellar world are concerned, there might perhaps be no objection to this theory in the simple form, yet to judge by the conditions affecting ourselves and those in the air above us such a hypothesis must seem to be quite ridiculous." (as quoted in* (Feyerabend)*).*

Ptolemy's rejection of the heliocentric model was mild compared to that of some of Aristarchus' contemporaries who wanted to charge him with impiety. As any student of Plato know, that charge comes with the death penalty (Heath).

Aristarchus understood the implications of his model, arguing that the stars were much farther away than most ancients believed to explain the unobservability (with the naked eye) of stellar parallax, which suggests that he did not see the model as a mere instrument, but as a realistic picture of how the solar system actually worked.

After the success of the Ptolemaic model, further attempts to revive a heliocentric model were mostly short-lived. Arab astronomers, beginning around the 10th century, proposed and then abandoned a heliocentric model on a number of occasions. The last of these, Ibn Al-Shatir, in the 14th century, developed a mathematical model that was quite similar to the model eventually proposed by

Copernicus (Saliba). There is some speculation that Copernicus may have been influenced by this model since the mathematical techniques employed are nearly identical the ones he used. As it turns out, the Copernican revolution was much longer in coming than most realize.

The Cosmological Constant and the Expanding Universe

The story of the cosmological constant is in many ways very similar to the path travelled by the heliocentric model, though in a much more condensed fashion, taking place over several decades rather than two millennia. The roots of the cosmological constant begin in 1917 when Einstein considered how his theory of general relativity could apply to the structure of the entire universe (Straumann). Without going into the details of the mathematics, the second order differential equations generated by relativity, when solved, allow for the introduction of constants of integration, two of them. One of them is related to the curvature of space, the second, called lambda (Λ) is the famous (or infamous) cosmological constant (Ryden and Peterson).

After Einstein published the relativistic solution to modeling the large-scale universe, it was discovered that the solution was largely derivable from Newtonian mechanics. Indeed, as one physicist put it, it could have been derived from Newtonian mechanics the year after Newton published the *Principia* if someone had thought to try it, although his solution would not have contained the cosmological constant, a product only of relativity (Zel'dovich).

The dominant view of the universe in 1917 was the static model of the universe, one in which the universe had no beginning and no end. As the development of cosmology revealed, this was partly a philosophical stance and partly scientific: science often assume uniformity in the absence of evidence to the contrary, but many astrophysicists felt that a moment of creation was just too much like religion (Straumann). Einstein, himself, was committed to the static model, and there was little data to dissuade him. The data about the recession of galaxies discovered by Edwin Hubble, published in 1929, (Kragh) was not yet available, and most believed the whole universe was just the Milky Way. Einstein's model doesn't depend on the size of the universe, fortunately, just on the density, or in particular, the energy density (Ryden and Peterson).

The solution to the relativist universe was further developed by A.A. Friedman, a physicist working in the Soviet Union, in 1921 (Zel'dovich). His solution was not widely published, but did receive favourable comment from Einstein. When he allowed the value of Λ to be zero, and showed that this led to an expanding universe; however, Friedman considered this to be of only mathematical interest. His expanding model of the universe was rediscovered by Lemaître in 1927 working independently (Kragh). Committed to the static model of the universe, Einstein himself chose a value for Λ that would permit a stable solution that neither expanded, nor contracted. It was not noticed until many years later that Einstein's "stable" solution was discovered to not be so stable; any slight deviation from equilibrium led to rapid expansion or contraction. It was surely this fact, together with the later discovery of galactic redshift that led Einstein (perhaps apocryphally) to call the cosmological constant his greatest scientific blunder (Straumann).

This was not, however, the end of the story. The cosmological constant fell out of favour after Hubble's findings were confirmed and widely accepted, but Hubble's data proved not to be a permanent death knell for Λ. It has been revived several times in an effort to match the predictions of the relativistic model to improving data from galactic redshifts, and more recently, the cosmic background radiation, or differentiate between a universe that will expand forever, or a universe that will eventually collapse; all this depends on the value of Λ (Straumann). An expanding universe predicts, if you run the equation backwards, that at some point the mass in the universe was all concentrated in a single point. A hot "big bang" predicts that the universe should glow faintly in highly redshifted radiation, which was confirmed in the 1960s with the discovery that the sky did indeed glow faintly in microwaves (Ryden and Peterson).

Modeling the big bang and curvature of the universe has led scientists to bring back Λ from the static universe dustbin in the hopes of matching both data, and the wishful thinking of scientists. It is impossible to do the details justice here, but data has been brought to bear on the question from all branches of physics and astronomy, from data on the age of the universe, highly redshifted quasars, quantum mechanical models of nucleosynthesis in the early universe, to measuring the geometrical properties of spacetime. The current model, about which cosmologists have a fairly strong consensus, relies on the cosmological constant being non-zero in the model, and specifically a value that is constant in time, but becomes increasingly important as the volume grows and the densities of matter and radiation decrease. However, rather than stabilizing the universe, Λ combats the force of gravity, acting like a repulsive force. This predicts that the universe is presently in an era where the expansion of the universe is increasing exponentially. Data for this prediction has been found in galaxies with low redshift where we would expect to find the effects of Λ dominating the effects of gravity. Further away, as astronomers look further back in time, the effects of gravity are dominant, and the expansion is measurably slower (Ryden and Peterson).

Astrophysicists are now trying to determine what Λ represents physically. Some proposals for identifying it, such as the zero-point or vacuum energy predicted by quantum mechanics have been proposed, but this will not create a value for Λ large enough to account for observations. For now, then, cosmologists refer to the unknown component of the energy density represented by Λ as “dark energy” (National Aeronautics & Space Administration).

What is the impact of story of the cosmological constant on the question of scientific realism?

One useful comparison may be with some other episodes in the history of science. Consider, for instance, phlogiston. Once abandoned, it was never revived as a credible explanation for what we know now to be oxidization. By contrast, the wave theory of light was preferred for centuries over the particle theory of light, only to have particle behaviour revived in the guise of wave-particle duality. A case that is less clear is the theory of the ether. While generally portrayed in the philosophical literature as a failure of reference (Laudan), Einstein himself suggested that perhaps the term should be revived when it became increasingly clear in the 20th century that the vacuum was not so vacuous, a situation which is only exaggerated by the consideration of what Λ might represent.

These episodes do not suggest that scientists merely lack imagination and so just try to revive old, abandoned theories because they can't think of any alternatives. Rather, it indicates the persistence of truth. Notions of approximate truth are notoriously vague, and precise descriptions of what it means for a scientific theory to be "approximately true" are both hard to come by, and never work in every circumstance the definition (whatever it is) can be applied to. For something as complex as science, it should not be surprising to us that simple models cannot capture all the important details, no more than describing the orbit of any planet as an ellipse, or a falling body as a point mass. Approximations in science come with both qualitative and quantitative features. Physics in particular likes to reduce even the qualitative results to numbers, but the results, despite this, are qualitative. Approximate truth is qualitative; accurate predictions are quantitative. They cannot be separated as intrumentalists would have us do.

Consider what we know so far about the cosmological constant, and the history of the universe. We know that we live in a changing universe. A century ago, we didn't know that. We live in a universe that had a beginning. A century ago, a moment of creation was the tale of the religious, not a matter of science. Today we know that there was indeed a beginning. These were big qualitative changes that shook the foundations of astrophysics when they were first discovered. For seven decades now, science has been trying to piece together the puzzle, and to turn that qualitative data into reliable quantitative results, and in turn, turn that into more qualitative conclusions.

Initially, the data is always quite poor, and we humans really can be lacking in imagination when we begin speculating about new things. Science is conservative and cautious; this is partially intentional, to avoid wild speculation that can't be tested or that goes beyond scientific claims. The data is the only thing that can lead scientists to conclusions that seem bizarre and counterintuitive. It was data that dictated the development of quantum mechanics (Norton), and it is data, despite the best efforts of scientists to talk themselves out of it, that compel them to propose crazy things like dark energy, something they can neither touch nor see, nor even detect with instruments. So far, all they have is data that can't be explained without it, or without overturning almost everything we know about physics.

It is certainly possible to make too much of modern cosmology, and other new scientific theories which increasingly seem so disconnected from our everyday lives. It is sometimes said of Presidents that they need to be out of office for 50 years before their Presidency can be judged fairly by historians. Perhaps philosophers of science also require a waiting period. Trying to judge today whether or not dark energy is to be believed would be a mistake, since so little is known about it. We know so much more about quantum mechanical effects today that was known when Kuhn wrote *The Structure of Scientific Revolutions*.

The result of the Copernican Revolution was quite different than the world ushered in by quantum mechanics. In some ways, we haven't lived with quantum mechanics long enough to make it seem comfortable, and the dark energy predicted by the cosmological constant was only accepted in the last decade of the 20th century. It isn't hard to find cosmologists who are agnostic about the focus of their research, antirealist even, in one way or another, because all they can say is that there is something there that is making the universe expand faster, but we have no idea what. What is needed is more data. With too little data, one can't begin to even form a theory. With qualitative or quantitative expectations in mind, one can begin to interrogate the universe, for only more data can choose between the possible choice, or suggest other alternatives. For being attacked so often by empiricists, scientists still have remarkably a lot in common with them.

The process of science, in the broadest possible strokes and seen with a kind of myopic light, appears almost linear in its progress toward modern science. Look a little more closely, and convergent realism begins to seem implausible with mature sciences latching onto apparently wrong theories and then discarding them. The pessimistic induction suddenly seems plausible, but then look at the details a little closer, the details that come from the literature. Scientific debates are remarkably well documented, and textbook glosses on them rarely do them justice. Change no longer comes only upon the deaths of giants in a field who advocated the old theory. Change in physics and astronomy come so rapidly in the last century that it has become possible to witness several major advances over the course of a single lifetime. But it is always the data, not theory alone, that drives scientists to proclaim they've discovered something true about the world.

The debate over heliocentrism has this character, as does the particle theory of light. These theories made comebacks because conflicting evidence was resolved, in part through reinterpretation of the data, and the collection of new data that made them impossible to deny. The role of the cosmological constant in the debate over the expanding universe does have this character. There is something *right* about these concepts, and that's why they just won't die; they won't die because the data keeps coming back this inescapable conclusion.

A close examination of these episodes will make it difficult to sustain structural realism without also appealing to entity realism. In the case of heliocentrism, it seems difficult to suppose that it is the structure that is being preserved in the debate, when it's the structure itself that is under debate. Similarly, in the case of particles of light, the idea of photons may have been abandoned, but it was these entities that were reconfirmed in quantum mechanics and in wave-particle duality. If we are to have sometimes structural realism and sometimes entity realism, why not just realism?

In the case of the cosmological constant, it's not clear what is being preserved in the adoption, then abandonment, and then re-adoption of the cosmological constant. It's not a matter of entity realism, since cosmologists have next to no idea what Λ represents—some kind of energy density--only that it is now being interpreted correctly enough to make good predictions. But are we to suppose that structural realism appeals to just the mathematical formulae? In the case of the cosmological constant, the differential equations don't require the constant, only allow it, so this is not a feature of the equation in the same way that Fresnel's equations are contained in Maxwell's equations. Solutions to Maxwell's field equations, being differential equations themselves, also produce constants that are solved according to measurable quantities of charge and magnetism. What then is Λ?

That is precisely the question realists, and scientists, want to ask.

Instrumentalists may be ready to trumpet success of their own position with all the talk here of making correct predictions, but the failure of instrumentalism is that it presumes that this is all there is. For one thing, debates over prediction in astronomy often have a different character than debate over prediction in other fields, like particle physics. There is little since in which astronomers can hope to run an experiment to see if their predictions are correct, so they will have to wait thousands or even billions of years to see if nature bears them out. It's difficult to see how an academic exercise of this sort would be of any interest to committed instrumentalists, but this was precisely the reason that Friedman's equation went unnoticed when it was published in 1921, and why Lemaître is considered the father of modern cosmology, because he took seriously the predictions made by well-established physics. (Kragh)

It is too much to expect of scientists, and people in general, that every single one of them will agree on any one philosophical principle, even realism. It is too much to ask of scientists that every theoretical claim they make turn out to be absolutely correct. As Enfield put it "…new theories correct, rather than entail,…" (472) It is through that process of correction and dialogue with the data that scientific theories improve. To determine what is reasonable and unreasonable to believe, philosophers, like scientists, must distinguish between well-supported science like electrons, and poorly supported science, like dark energy, between those parts of science which are unlikely to be overturned easily, and those which are just beginning to find validation. And philosophers also need to recognize that even for the correct scientific theories, the road from pipe dream to accepted science, though rarely a straight line, is not random.

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