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Helge Kragh

Varying Gravity

Dirac's Legacy in Cosmology and Geophysics

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Helge Kragh
Niels Bohr Archive
Niels Bohr Institute
Copenhagen
Denmark

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Preface

The reader will find here a historical investigation of a particular episode in the history of twentieth-century science which principally involves an unorthodox cosmological theory concerning the history of the universe and a no less unorthodox geological theory concerning the history of the Earth. By its very nature, the subject under examination, various early attempts of integrating cosmology and geophysics, is highly interdisciplinary. When Paul Dirac proposed that the gravitational constant decreases over cosmic time, a proposal which dates from the late 1930s, no one thought it would have consequences for geophysics. Nor did anyone think that the Earth might eventually be a testing ground for Dirac's hypothesis. After all, the domain and methods of geophysics were (and still are) very different from those of physical cosmology and at the time the two communities of scientists were entirely separate. As it happened, the audacious gravitation hypothesis was first applied to paleoclimatology in the late 1940s and about a decade later it entered geophysics as an argument for the expanding Earth.

The idea that the Earth has increased in size for at least 500 million years was at the time a fairly popular alternative to the resuscitated theory of continental drift that would soon be merged with mantle convection and sea floor spreading to develop into mainstream plate tectonics. The chief focus of the book is on the interconnection between the two hypotheses, but it also covers in some detail other aspects of varying gravity and the expanding Earth. The subjects gave rise to a considerable literature in physics, astronomy, cosmology, geology and geophysics, much of it of an interdisciplinary nature. Altogether several hundred scientific articles and a few books have been published on these subjects. However, from today's perspective, the efforts were wasted and may seem to have been just much ado about nothing. The currently established view is that the force of gravity, as given by the gravitational constant G, remains constant and that the radius of the Earth has not increased measurably since its formation some 4.5 billion years ago. In spite of this consensus view, there are still scientists cultivating either the varying-gravity hypothesis or the expanding Earth hypothesis—or, in a few cases, both hypotheses. But I largely keep to the historical ground, meaning the period up to about 1980, and only briefly refer to the modern scene.

I came to this subject initially as a result of my earlier studies of Dirac's physical theories and my work on the history of modern cosmology generally. Only at a later stage did I develop an interest in the history of the earth sciences in connection with courses in the history and philosophy of science given to undergraduate geology students at Aarhus University, Denmark. It was only then that I realized how relatively important the varying-gravity hypothesis and expanding Earth models were in the 1960s and 1970s. I recently published a couple of papers on the subject, one in *Physics in Perspective* and another in *History of Geo- and Space Sciences* (see the Bibliography). This book makes use of material from these papers but goes much beyond them. I should also mention that I am not the first to cover the subject. Paul Wesson examined it from a different and more scientific perspective in two valuable books dating from 1978 to 1980. However, Wesson primarily addressed his work to scientists and therefore paid little attention to the rich historical context of his subject.

The book is organized into four chapters of which the first one is rather brief and of an introductory nature, dealing essentially with developments before 1930. Chapter 2 investigates in detail the idea of varying gravity from a cosmological and physical perspective, starting with Dirac in 1937 and ending with the Jordan–Brans–Dicke gravitation theories of the early 1960s. While geophysics plays almost no role at all in this chapter, the expanding Earth is in the centre of Chap. 3 which deals in particular with theories that applied varying gravity as a mechanism for the assumed expansion of the Earth. The fourth chapter carries the story on until the early 1980s, at a time when varying-gravity hypotheses had proliferated but the expanding Earth hypothesis no longer enjoyed recognition from mainstream geophysicists. Although the approach of the book is neither biographical nor prosopographical, of course there are some scientists who appear more frequently than others. They include well-known physicists such as Paul Dirac, Pascual Jordan and Robert Dicke as well as the less well-known Hungarian geophysicist László Egyed. *Varying Gravity* ends with a rather lengthy bibliography which we hope can be useful to historians and scientists who might wish to explore further aspects of this case study.

Copenhagen, Denmark Helge Kragh
August 2015

Contents

List of Figures

List of Tables

Chapter 1
Introductory Issues

Cosmology, the science of the universe at large, is of course very different from geology, a science that in its traditional meaning deals with only a single object in the vast universe, a planet called Earth. Yet the two sciences have interesting and often surprising interconnections that today are cultivated by a growing number of researchers. Both sciences—cosmology and the earth sciences—have changed drastically since the days of the scientific revolution in the seventeenth century, each in its own way and at different paces. In order to evaluate the events that occurred in the post-World War II period it will be useful to survey some of the earlier developments in a broad historical perspective. The survey in this chapter is meant to be an introduction only. It covers various attempts in the period up to the mid-1930s to think about the Earth in a cosmological perspective or otherwise to establish bridges between the science of the universe and that of the Earth. Until varying gravity entered the picture the two sciences had in common only the chronological problem, namely, the age of the Earth as related to the age of the universe.

1.1 The Heavens and the Earth

In the late seventeenth century, geology was often considered in what at the time was seen as a cosmological perspective, such as illustrated by the popularity of speculative "cosmogonies" principally dealing with the origin of the Earth. René Descartes' influential *Principia Philosophiae* from 1644 included a mechanical theory of the origin and evolution of the Earth which he derived from his general vortex theory of the universe. To him, cosmogony (in the sense of geogony, to use an antiquated term) was scarcely distinct from astronomy and cosmology. Other examples of this early tradition include classics such as Thomas Burnet's *The Sacred Theory of the Earth* from 1684, William Whiston's *New Theory of the*

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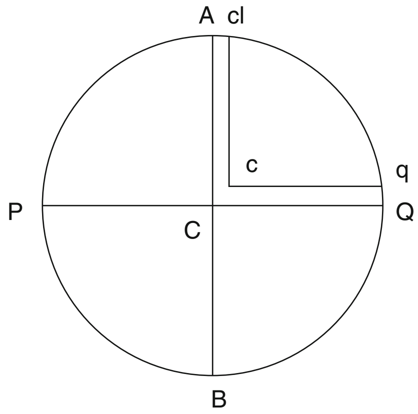

Fig. 1.1 Newton on the shape of the Earth (*Principia*). According to Newton, the proportion of the gravitational force in A from a sphere with radius CA to that in A from the actual Earth would be given by the ratio 126/125.5. From this and a few other arguments he concluded that the Earth was flattened by the ratio 1/230

Earth from 1696, and Leibniz's *Protogaea* published posthumously in 1749.[1] These and other works from the period were as much about God and the Bible as they were about the Earth. They were early examples of the powerful intellectual tradition known as physico-theology or "natural theology" that would dominate much scientific thinking until the beginning of the nineteenth century.

From the same period we have the first example ever of a fundamental physical theory changing the picture of the Earth, namely, Newton's successful prediction of the shape of the Earth based on his new theory of gravitation. Since the theory of gravitation was also the basis for Newtonian cosmology, the case can with some justification be seen as an early instance of the connection between cosmology and the earth sciences. In Book III of his *Philosophiae Naturalis Principia Mathematica* from 1687 Newton argued from mechanical principles that the rotating Earth must have the form of a slightly flattened oblate spheroid (Fig. 1.1). He estimated that the equatorial radius must exceed the polar radius by 1/229th part of the polar radius. The claim was controversial because the shape of the Earth was expected to be a prolate spheroid on the basis of Cartesian natural philosophy. Through the efforts of Pierre-Louis Maupertuis, Alexis-Claude Clairaut and other French scientists in the 1730s, it appeared that geodesic measurements agreed with Newton's prediction at least in a qualitative sense: the Earth was indeed slightly flattened at the poles.[2] The currently known flatness of the Earth is approximately 1 to 300, not far from Newton's value.

In *Principia* Newton also arrived at another result of great geophysical interest, the first scientifically based estimate of the mean density of the Earth. He reasoned as follows:

> In whatever way the planets were formed, at the time when the mass was fluid, all heavier matter made for the centre, away from the water. Accordingly, since the ordinary matter of our earth at its surface is about twice as heavy as water, and a little lower down, in mines, is

[1] See, for example, Laudan (1987) and Oldroyd (1996).

[2] The case is detailed in Greenberg (1995) and Terrall (2002).

> found to be about three or four or even six times heavier than water, it is likely that the total amount of matter in the earth is about five to six times greater than it would be if the whole earth consisted of water.[3]

Although Newton's estimate of a density between 5 and 6 g cm^{-3} was little more than an educated guess, it happened to be correct.

During the next two centuries, geology was transformed into an arch-empirical, inductive science dealing in a much more narrow way than previously with the surface of the Earth and the natural causes for its changes. Yet the cosmological aspects did not vanish completely. What is often regarded as a watershed in the development of geology into a proper science, namely, the uniformitarian methodology introduced by James Hutton and Charles Lyell between the 1790s and the 1830s, was in part of a cosmological nature. According to the uniformitarian credo, geological processes in the past were of the same kind as those observed today and they occurred at about the same rate and intensity as we observe. In his efforts to turn geology into a respectable science, Lyell insisted in his famous *Principles of Geology* (1830–1833) that the past history of the Earth can only be understood in terms of what is presently observed. Lyell explicitly based uniformitarianism on the belief that the laws of nature cannot possibly change in time or space. In the first volume of *Principles* from 1830 he rooted the new geology in "the permanency of the laws of nature," postulating that "their immutable constancy alone can enable us . . . to arrive at the knowledge of general principles in the economy of our terrestrial system." A century later a few physicists would question the immutable constancy of Newton's law of gravitation, the very paradigm of natural law.

Lyell stressed that the new scientific geology was intimately related to the physical sciences but also, and no less importantly, that it was a science of its own which could not be subordinated either physics or other sciences. First and foremost, geology was entirely distinct from the traditional cosmogony dealing with the origin of the world. As Lyell wrote in the very beginning of *Principles*:

> The identification of its [geology's] objects with those of Cosmogony has been the most common and serious source of confusion. The first who endeavoured to draw a clear line of demarcation between these distinct departments, was Hutton, who declared that geology was in no ways concerned "with questions as to the origin of things." . . . We shall attempt in the sequel of this work to demonstrate that geology differs as widely from cosmology, as speculations concerning the creation of man differ from history.[4]

Indeed, strict uniformitarianism was non-directional with respect to the arrow of time and for this reason alone it ruled out cosmogony. On the other hand, it did not follow that Lyell's geology was cosmologically irrelevant. For one thing, it implicitly entailed the notion of an eternal universe.

The uniformitarian principle would much later turn up in cosmological theory, in particular in the steady-state theory of the universe introduced in 1948. There is more than a superficial similarity between the geologists' uniformitarian principle

[3] Cohen (1999), p. 815.

[4] Lyell (1830), p. 4. Available online as http://www.esp.org/books/lyell/principles/facsimile/

and the "perfect cosmological principle" on which steady-state cosmology was founded.[5] The ordinary cosmological principle, which can be traced back long before the Einsteinian revolution in cosmology, states that on a very large scale the universe is spatially uniform, that is, homogeneous and isotropic. According to the perfect cosmological principle, a name due to Thomas Gold, the uniformity is also temporally valid: no era in the history of the universe is distinct from any other era. The perfect cosmological principle may seem to fit with the spirit of relativity theory's space-time symmetry, but what matters is that the principle disagrees with what we know about the universe. Perfect it may be, but wrong it is. In any case, for the large majority of geologists in the nineteenth century, Lyell included, the Earth was more than enough to deal with. They saw no reason to include other celestial bodies and even less to indulge into cosmological speculations.

Cosmology in the fin-de-siècle era remained foreign even to the majority of astronomers, who in the spirit of positivism preferred to ignore questions about the universe as a whole.[6] Works on "cosmogony" were not uncommon, but in most cases they dealt with the origin of the solar system or what the Dutch-British physicist Dirk ter Haar much later called "microcosmogony."[7] Other work from the period dealt with the mysterious spiral nebulae and their relation to the Milky Way. Indeed, terms such as "world" or "cosmos" typically referred to our solar system, usually discussed on the basis of Pierre Simon Laplace's popular nebular hypothesis or some modification of it. The material universe was often identified with the Milky Way, and "with the infinite possibilities beyond, science has no concern," as the Irish astronomer and historian of astronomy Agnes Mary Clerke summarily declared.[8]

Among the very few geologists in the Victorian period who adopted an astronomical perspective on the Earth was the versatile, self-educated Scotsman James Croll. Best known for his astronomical theory of terrestrial climate change, including the ice ages, Croll provided a rare link between the geologists and the astronomers. For example, his astronomically based theory directly influenced Lyell, the leading geologist of his day.[9] In 1885 Croll published a collection of essays under the intriguing title *Discussions on Climate and Cosmology*.[10] However, what he discussed was in reality the influence of astronomical causes on the climate of the Earth, and also subjects such as the age of the Earth, the nature and intensity of the Sun's heat, and the nature of the nebulae. He had nothing to say about cosmology in

[5] On the perfect cosmological principle and its history, see Balashov (1994) and Kragh (1996), pp. 182–183. See also Toulmin (1962) for an interesting case of a late-eighteenth-century geological author adopting a version of the perfect cosmological principle. More about the steady-state theory of the universe follows in Sect. 4.1.

[6] Merleau-Ponty (1983), Kragh (2008), pp. 152–157.

[7] ter Haar (1950), p. 132.

[8] Clerke (1890), p. 368. Of course, cosmology was not absent from pre-Einstein astronomy. For reviews, see North (1965) and Kragh (2007b).

[9] Fleming (2005).

[10] Croll (1885).

the wider sense of the term, the science of the universe in its totality. Indeed, the term "cosmology" only appeared in the book's title and not at all in the text.

Four years later Croll published another book in which he developed a cosmogonical impact theory that differed from the standard Laplace picture by assuming an initial state of dark bodies colliding at high velocities. His theory not only contradicted the nebular hypothesis but also the widely accepted Helmholtz–Kelvin gravitational theory of the origin of the Sun's heat. According to this theory the Sun was composed of compressible gases that through progressive contraction generated the heat and light that poured into space. "Are the facts of geology reconcilable with the theory?" Croll asked, referring to the theory of Kelvin (William Thomson) and Hermann von Helmholtz. He concluded that this was not the case.[11] At the end of his book he briefly considered the cosmological consequences of his own impact theory, which "on purely scientific grounds" led to an absolute beginning of the evolutionary universe. According to Croll, it followed that the universe would continue its evolution forever, whereas the thermal equilibrium state known as the "heat death" would never occur.

The heat death (*Wärmetod* in German) was perhaps the only truly cosmological phenomenon which entered both astronomy and the earth sciences in the period 1880–1920. The much-discussed problem was claimed to be a strict consequence of the second law of thermodynamics as stated in different versions by Kelvin and Rudolf Clausius in the mid-nineteenth century. According to the second law the entropy of the universe would continue to increase, eventually leading to an irreversible cessation of all physical processes—a dead universe including of course a dead Earth. Moreover, it apparently followed that the universe must have had a beginning in time corresponding to some minimum entropy.[12] Charles Darwin was among the naturalists of the Victorian era who worried about the relationship between biological evolution and the cosmic increase in entropy. He found it "intolerable" that the Sun and the planets would one day be doomed to annihilation.[13]

The twin problems of evolution and entropy were occasionally considered within the research tradition known as "cosmical physics," an interdisciplinary branch of science flourishing in the period from about 1890 to 1915 but with roots back to Alexander von Humboldt's influential *Kosmos* published in five volumes between 1845 and 1862. Cosmical physics, comprising elements of geophysics, meteorology and solar-terrestrial physics (including magnetic storms and the aurora borealis), was an ambitious attempt at synthetizing those parts of astronomy and the earth sciences that could be understood on the basis of the

[11] Croll (1889), p. 37.

[12] See Kragh (2008) for details and sources concerning the "entropic creation" argument.

[13] In his autobiography published in 1887, five years after his death, Darwin referred to "the view now held by most physicists, namely, that the sun with all the planets will in time grow too cold for life." He further reflected on "the mystery of the beginning of all things" but decided that it was "insoluble by us." Quoted in Kragh (2008), p. 108. The autobiography is available online at http://darwin-online.org.uk

laws of physics. A few of the cosmical physicists, including the Austrian meteorologist Wilhelm Trabert, the Swedish physical chemist Svante Arrhenius, and the Norwegian physicist Kristian Birkeland, adopted a cosmological perspective. For example, contrary to mainstream geophysics Birkeland maintained that magnetic storms and geomagnetism generally were influenced by magnetic disturbances in space, an idea which he related to his electromagnetic conception of the universe.[14]

In his massive *Lehrbuch der kosmischen Physik* (Textbook of Cosmical Physics) of 1903 as well as in his more popular *Worlds in the Making* of 1908, Arrhenius included chapters on cosmology and cosmogony. His own cosmological theory pictured an infinite stellar universe without a beginning or an end in time. The dispersive effects of the second law were kept in check by postulating an exchange of matter between stars and nebulae in the form of collisions, not unlike what Croll had suggested. The contractive effects of gravity on a cosmic scale were likewise kept in check by the expansive force of radiation pressure. Arrhenius' theory was to some extent inspired by geophysics in so far that it relied on the stellar radiation pressure that he inferred from the aurora borealis.

While Arrhenius was not a geologist, the American Thomas Chamberlin was professor of geology at the University of Chicago, the founder of the prestigious *Journal of Geology*, and the author (together with Rollin D. Salisbury) of a widely acclaimed textbook in geology. Together with his Chicago colleague, the astronomer Forest Ray Moulton, he developed a strong alternative to the nebular hypothesis of the formation of the Earth.[15] Interestingly, his dissatisfaction with the generally accepted nebular hypothesis was originally rooted in its geological rather than astronomical consequences. A specialist in glacial geology, Chamberlin was inspired to his "planetesimal theory" by considerations of the causes of glaciation and climatic change. In a book published in 1916 he related how his studies of glacial deposits in Wisconsin led him to the field of cosmogony. It occurred to him that the Laplace theory—"this theory of a simple decline from a fiery origin to a frigid end"—did not agree with the established record of glaciation in the past:

> When the inquiry was pressed still farther back, and support for the postulate of a molten globe was sought in the crust itself, it was not forthcoming. . . . But one further step remained—to examine the cosmogonic postulates themselves. Could the earth ever have had the vast hot atmosphere postulated? Was the earth's gravity sufficient to hold so vast and vaporous an envelope at such high temperatures and in such an intense state of molecular activity as the old mode of genesis assigned? Was the gaseo-molten genesis a reality? Thus I was already across the pass that leads from the land of rocks into a realm of cosmogonic bogs and fens. . . . Strangely enough, the cold trail of the ice invasion had led by this long and devious path into the nebulous field of genesis.[16]

[14] Birkeland's cosmological ideas, sometimes taken to be anticipations of modern "plasma cosmology," are dealt with in Kragh (2013).

[15] Brush (1996c), pp. 22–67, Fleming (2000).

[16] Quoted in MacMillan (1929), p. 4. As the Chicago astronomer William MacMillan remarked in his obituary of Chamberlin, the cosmogonical Chamberlin–Moulton hypothesis "furnished a foundation for the geologists, which is in harmony with the evidences of their own science."

The planetesimal theory that Chamberlin developed together with Moulton was for a period highly regarded not only by geologists but also by American astronomers. For example, in 1914 Vesto Melvin Slipher at the Lowell Observatory studied nebular spectra in order to test the Chamberlin–Moulton theory. This was only two years after he had detected the first nebular redshifts, a discovery that would have a revolutionary effect on cosmology.

1.2 Cosmology, Cosmogony, and Geology

Chamberlin was not the only professional geologist to consider connections between cosmology (or cosmogony) and the earth sciences. "The age of the earth may indeed claim an importance outside the geological science," wrote the prominent Irish geologist and physicist John Joly in a book of 1909. "For is it not the clue to the chronological scale of our solar system and—for want of better—even of our universe?"[17] To Joly, the common element that connected the Earth and the universe was radioactivity. The young British geologist and geophysicist Arthur Holmes published in 1913 the first edition of his classic *The Age of the Earth* in which he argued strongly for the use of radioactive methods in geochronology. Inspired by Arrhenius he broadened the scope to include also the time-scale of the universe as a whole. Estimating the oldest rocks to have an age about 1.7 billion years, he contrasted the finite age of the Earth with the supposedly infinite age of the universe. Holmes subscribed at the time to an eternal, ever-evolving cyclic universe of a kind similar to the one Arrhenius had advocated:

> If the development of the universe be everywhere towards equalisation of temperature implied by the laws of thermodynamics, the question arises—why in the abundance of time past, has this melancholy state not already overtaken us? . . . In the universe nothing is lost, and perhaps its perfect mechanism is the solitary and only possible example of perpetual motion. In its cyclic development we may find the secret of its eternity and discover that the dismal theory of thermal extinction is, after all, but a limited truth.[18]

The death of heat was ruled out by fiat. As we shall see in Sect. 3.5, this was not the last time that Holmes would use his geological expertise to deal with the universe at large.

The ideas of Arrhenius, Chamberlin, Joly, and Holmes were interesting but did little to strengthen the relationship between cosmology and the earth sciences except on a rhetorical level. In so far that a connection between the Earth and the heavens was admitted, still in the 1920s it was the more traditional one between geology and astronomy focusing on the Earth as a planet. At the time cosmology had changed dramatically as a result of new observations and, not least, the new models of the universe founded on Einstein's general theory of relativity. The

[17] Joly (1909), p. 212.

[18] Holmes (1913), p. 121.

famous astronomer Arthur Eddington was a specialist in Einstein's mathematically abstruse theory, including its cosmological aspects. Still, when he gave an address on the astronomy-geology relationship to the venerable Geological Society of London in 1922, he had nothing to say about cosmology in either its old or new meaning. Perhaps in consideration of his audience he chose to cover more traditional subjects such as the origin of the solar system, the age of the Earth, the Earth–Moon system, and the source of the Sun's heat.[19]

In his address Eddington also referred to the existence of radioactive minerals in the crust of the Earth. The presence of uranium and thorium, he said, indicated a "winding-up process [that] must have occurred under physical conditions vastly different from those in which we now observe only a running-down." Rather than locating the winding-up to a primordial state of the universe, he referred to "the intense heat in the interior of the stars." Eddington reasoned that the irreversible decay of radioactive bodies might function as an arrow of time in a sense similar to the entropic arrow of time. Arguments of this kind had been in the air for some time, but without attracting much interest among physicists, chemists and geologists.[20] It was only after the discovery of the expanding universe that the idea of a radioactive arrow of time became cosmologically significant.

To the Belgian pioneer cosmologist Georges Lemaître, a former student of Eddington, the idea suggested a universe of finite age that had come into existence in a radioactive inferno a period of time ago comparable to the half-lives of uranium and thorium. The argument from radioactive decay played an important role in the process that in 1931 led him to the hypothesis of an explosive universe originating in a "primeval atom," later referred to as the big-bang universe. As Lemaître recalled,

> The idea of this [primeval atom] hypothesis arose when it was noticed that natural radioactivity is a physical process which disappears gradually and which can, therefore, be expected to have been more important in earlier times. If it were not for a few elements of average lifetimes comparable to T_H [the Hubble time of the order 10^9 years], natural radioactivity would be completely extinct now. It might be thought, therefore, that radioactive elements did exist which are actually transformed into stable elements.[21]

The age of the Earth, a classic problem of geology, became of cosmological importance with the recognition in the early 1930s that most cosmological models based on the theory of general relativity resulted in an age of the universe less than two billion years.[22] For the class of so-called Friedmann models with zero

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[19] Eddington (1923).

[20] See Kragh (2007a) for the early use of radioactive decay as a cosmic clock and generally the role of radioactivity in astrophysics and cosmology in the period between 1910 and the early 1930s.

[21] Lemaître (1949), p. 452.

[22] On the notorious time-scale problem, see Kragh (1996), pp. 73–79 and Brush (2001). The problem could be avoided if a positive cosmological constant was admitted, but this was a solution that few astronomers and physicists found appealing. In the period from about 1930 to the 1990s it was generally believed that $\Lambda = 0$.