The Evolutionary Basis of Eddington's Solar Modelling

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Abstract

In the early 1900s Arthur S. Eddington established the current theoretical basis for the operation of the sun and other stars. Generally, Eddington asserted that main sequence stars generate energy under a condition of hydrostatic equilibrium without contraction. Eddington is one of the more significant solar theorists of the last hundred years. His assumptions are firmly fixed in modern models such that they are often believed to be beyond reasonable doubt, virtually on a par with basic laws of physics. Further, his Quaker background is sometimes emphasized in a manner which obscures the evolutionary presuppositions which he acknowledged as the basis of his theorizing. Scientifically, Eddington is better described not in terms of his Quaker background but as a convinced evolutionist. Evolutionary bias rather than scientific objectivity has been the driving force in stellar modelling since Eddington. Whether conventional solar fusion has been disproved or alternative solar energy sources have been confirmed is not addressed.

Introduction

The concept of nuclear reactions in the sun was developed long before the discovery of fusion, due to the evolutionary need to power the sun for an extremely long time. Even before the proposal of nuclear reactions in the sun, there was a conflict between the long evolutionary age of the earth and the relatively short age for the sun implied by previous solar models. Solar models based on nuclear reactions were seen as a way of resolving this conflict. This historical reality does not in itself invalidate the concept of solar fusion. Further, the common belief that solar fusion has powered the sun for billions of years does not mean that it could not have been doing so for a shorter period.

The conventional solar fusion model (the "standard solar model," or SSM) supposes that, "Nuclear fusion at the centers of stars [like the sun] produces all the energy that emerges from the stars' surfaces" (Goldsmith, 1985, p. 243). Actually there are many SSM's, but they all share the same basic assumptions: (1) that a main sequence star such as the sun is in hydrostatic equilibrium; (2) that the star derives its energy from nuclear fusion reactions; (3) that the star is in thermal equilibrium; (4) that the stellar material is described by an equation of state for gases (Abell et al., 1987, pp. 506–509; Bahcall, 1989, pp. 6–7; Bahcall, 1997, p. 1; Davis, 1994, p. 24; Harwit, 1982, pp. 306–343). Regarding point (1), Bahcall (1989, p. 46) calls hydrostatic equilibrium the "first condition" for stellar evolution models. Each of these assumptions is due directly or indirectly to Eddington.

Eddington's Theorizing Is a Foundation of Modern Astronomy

Eddington provided the basis for much of the conventional theorizing about solar and stellar operation (Eddington, 1926, p. vi; Hartmann, 1991, p. 372; Abell et al., 1987, p. 492). Eddington's theorizing led to Bethe's prediction of fusion in the sun (Bahcall et al., 2002, p. 1), followed by Fowler's modelling of solar/stellar nucleosynthesis (Salpeter, 1999, p. S220), culminating in the famous "B^2FH" paper authored by Burbidge, Burbidge, Fowler, and Hoyle (Burbidge and Hoyle, 1998, p. L1). This paper remains the reference point for nucleosynthesis theory (Wallerstein, 1997, pp. 997–998). Eddington was therefore only one contributor in a lineage of developments in modern solar/stellar evolution theory, though, as history reveals, he was quite an important contributor.

It is possible that if Eddington had never lived, eventually someone else or several others would have devised the same general approach toward solar energy as did Eddington. At any rate, as will be shown below, by Eddington's lifetime Western culture had been "evolutionized" and therefore was ready to receive further evolutionary theorizing by Eddington or others. It will also be shown that notable Christian personalities of Eddington's time had ac-

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cepted evolution, thus illustrating the high level of acceptance of evolution a century ago. Nevertheless, none of what might have been diminishes the significance of what Eddington actually accomplished.

A wide consensus, ultimately based on Eddington's work, has established an evolutionary lifetime for the sun of some 10 billion years, with the sun described as a "middle aged" star having some 5 billion years remaining. There are many parameters in any SSM which can be adjusted to make the sun appear to have a 10 billion year lifetime, while simultaneously attempting to account for observed properties such as luminosity and surface temperature. These parameters include core temperature, the reactions assumed to occur and their dominance, and reaction rates. The difference among SSM's lies largely in the choice of parameters, a situation so flexible that neutrino researcher Raymond Davis (1994, p. 30) has observed "there are many ad hoc elements in the standard model calculations."

Not all of the reactions supposed to be happening in the sun have been observed in the laboratory, nor have their rates and effects been actually measured under solar conditions. Instead, these data are the result of "model calculations" (Wallerstein et al., 1997, p. 1001). At best, conditions for solar reactions are extrapolations from laboratory data (Bahcall, 1989, p. 60; Bahcall et al., 1995, p. 783; Guenther and Demarque, 1996, p. 5). Indeed, one the most basic reaction rates, that for the *p-p* reaction, "is not measurable in the laboratory" (Brun et al., 1998, p. 921). This means that if one cites solar reaction data as virtually certain, there is a misplaced confidence, for the truth is that the reaction parameters have been adjusted so as to make the imaginary 10 billion year life for the sun appear real (Harwit, 1982, pp. 329–332). Any claims that the sun could "evolve" if given enough time are questionable at best, since the possibility of such evolution is derived from reaction parameters adjusted to correspond to the solar core conditions deemed necessary to give a long lifetime. This is circular reasoning. The probability of solar evolution given enough time would appear to be as elusive as the long time scale itself.

Further, there are no generally accepted data (i.e., observations) for internal solar composition, such as core abundance of He. Such figures are model-based. Bahcall writes of "the unknown composition of the deep [solar] interior, where neutrinos are generated" (Bahcall, 1990, p. 56). Christensen-Dalsgaard and Gough (1980, p. 544) write of modelling element abundances in the sun by a "theoretical study" of solar oscillations.

Despite these uncertainties, the SSM is routinely extrapolated to describe how other stars work. Neutrino scientist John Bahcall (1990, p. 56) states,

> The greatest achievement of the solar model is so overwhelming that it is usually overlooked: astronomers use the theory routinely in interpreting observations of the physical and chemical compositions of stars in all sorts of environments, from the solar neighborhood to distant galaxies, without obvious inconsistencies. Any modifications of the solar model, therefore, would have profound implications for astronomy.

Van der Raay (1980, p. 536) concludes: "Clearly if we do not understand our own closest star, the implications on the whole field of cosmology are enormous."

While it is not the purpose of this paper to critique conventional solar/stellar models as such, it is obvious that with modern cosmology riding on solar modelling, which in turn is parametrically adjusted to buttress the evolutionary chronology, there is the definite possibility that defense of the SSM is done for reasons that are chronological as well as data-based. As we will see, the concerns motivating Eddington long ago continue to be reflected in the modern defense of the SSM.

Solar Models Are Built around the Evolutionary Age of the Earth

Ultimately, the only evolutionary reason for believing the sun is old is that the earth is supposed to be old. Thus, the evolutionary belief in an old sun is an extension of the "old earth" doctrine of nineteenth century geological evolution popularized by Charles Lyell. It is a commonplace to claim that the first and only reason for thinking the sun is old is that,

> Geologists have found rocks 3.5 billion years old that contain fossils of marine organisms. These discoveries clearly demonstrate that the Sun has warmed the Earth for at least 3.5 billion years and probably for as long as the Earth has existed (Fix, 1999, p. 387).

In the same vein, astrophysicist Martin Harwit (1982, p. 307) claims,

> The sun must be older than the earth which, as judged from the abundance of the radioactive uranium isotope U^{238} and its decay products, is more than four aeons [billions of years] old. The sun is thought to be of the order of 4.5 ae old.

Similar statements abound (Abell et al., 1987, p. 516; Pasachoff, 1985, p. 154; Snow, 1984, pp. 196–197). John Bahcall (1989, p. 56) repeats this same argument:

> The Sun has been shining for several billion years. Evidence to support this proposition comes from different fields of science [but Bahcall presents only

> one such 'evidence,' as follows]. For example, fossils of primitive organisms have been found on Earth that are more than a billion years old. In addition, the oldest rocks … are of order 3.8 billion years old.

Bahcall (1989, p. 56) concludes that the solar system must be older than this, so "the Sun began to shine … several billion years ago." The sun's age is sometimes said to be based on the presumed age of the oldest meteorites. Bahcall et al. (1995, p. 784) claim that, "The solar age is relatively well determined from meteoritic measurements." However, since conventional meteorite ages are correlated with the alleged age of the oldest ocean sediments on earth (Patterson, 1956, p. 230; Allegre et al., 1995, p. 1445), meteorite ages are actually proxies for the earth's age. Indeed, Brun et al. (1998, p. 918) note that, "The present age [of the sun] is deduced from a study of the age of the earth and solar system formation," with the time of solar system formation being fixed by the presumed age of the oldest meteorites (Bahcall et al., 1995, p. 805), which in turn is based on the supposed age of the earth. Thus the age of the sun, and the resulting commitment to the SSM, are based ultimately on evolutionary beliefs concerning the age of the earth.

This fact was recognized a number of years ago by solar astronomer John Eddy, himself an evolutionist, who observed (Kazmann, 1978, p. 18),

> There is no evidence based solely on solar observations that the sun is 4.5–5 x 10^9 years old. …I suspect that we could live with Bishop Ussher's value for the age of the earth and the sun. I don't think we have much in the way of observational evidence in astronomy to conflict with that.

Rather than the SSM providing an indication that the sun could function for billions of years, the SSM, and all cosmology by extension, derive their chronology from the evolutionary age of the earth.

Eddington Was Born in a Time of Origins Paradigm Shift

By the mid 1800s, some 300 years had passed since the Reformation, and the physical sciences had developed sufficiently to devise a scientific model of the sun's energy generation. This was the gravitational contraction model, the idea that the potential energy of the sun's in-falling gases is converted into heat and light as the sun slowly shrinks. Also known as gravitational collapse or the "shrinking sun" theory, this process would occur at a rate too small to be detectable over intervals less than many decades. This theory was first announced during a public lecture by Hermann von Helmholtz in 1854 and published in 1856 (Moulton, 1902, p. 62; Birchfield, 1990, p. 54).

Helmholtz was not a creationist. Neither was he seeking to show that the sun is young. He assumed an evolutionary model for solar formation that is still in vogue today, that the sun began forming by the gravitational contraction of a nebula. Helmholtz concluded that about 20 million years would be needed for the sun to form this way. Almost from the beginning, there was tension between the evolutionary age of the sun implied by gravitational collapse, and the time claimed for terrestrial evolution. Even in the mid to late 1800s, the earth and its life were thought to be hundreds of millions of years old. Accordingly, investigators sought to make increasingly accurate computations of the sun's age assuming it evolved by gravitational contraction.

George Howard Darwin, son of Charles Darwin, published a study on this topic in 1888 (Moulton, 1902, p. 62). It became increasingly clear that gravitational contraction alone could not provide the age for the sun demanded by geological and biological evolution. This dilemma was part of a larger process in which evolutionists were completing the paradigm shift away from creation toward evolution that had begun with Charles Lyell and Charles Darwin. By the late 1800s, evolutionists were trying to bring chronologies from all scientific disciplines into agreement with the terrestrial chronology devised from Lyell's uniformitarian principles. It was into this context that Eddington was born in 1882.

Defying the evolutionary chronology for the earth, William Thompson, Lord Kelvin, championed the concept of gravitational contraction, believing it provided a more accurate evolutionary age for the solar system than the geologists and biologists were willing to admit. Kelvin was a Christian, but not a biblical creationist. Today he would probably be described as a theistic evolutionist, and he did not have any particular difficulty with an old age for the creation. However, the physical sciences indicated that the earth and the sun could not be as old as was typically demanded, and these were the sciences he trusted (Birchfield, 1990, pp. 29–32). Kelvin's first major paper about solar energy generation was published in 1862 (Birchfield, 1990, pp. 54, 241). Since Helmholtz' original estimate of the sun's evolutionary lifetime was about 20 million yr, any time for stellar change on the order of 10^7 yr became known as Kelvin-Helmholtz (or Helmholtz-Kelvin) time.

A consensus eventually arose that gravitational collapse *on chronological grounds* could not explain all the sun's luminosity. Astronomer Charles Young (1890, p. 154) stated,

> If the sun's heat has been and is still *wholly* due to the contraction of its mass, it cannot have been ra-

> diating heat at the present rate, on the shrinkage hypothesis, for more than 18,000,000 years; and on that hypothesis the solar system in anything like its present condition cannot be much more than as old as that [emphasis in original].

However, Young recognized the evolutionary need for more time, and appended a footnote: "But notice the `if.' It is quite conceivable that the solar system may have received in the past other supplies of heat than that due to the contraction of mass. If so, it may be much older."

It eventually became unfashionable to discuss the age of the sun implied by the Helmholtz theory. Moulton's classic text (1902, pp. 57–61) presents gravitational contraction as the mode of the sun's energy generation, but makes no mention of the possible age of the sun. The age constraint implied by contraction was carefully avoided as theorists cast about for ways to make the sun older. Helmholtz contraction therefore acquired a stigma which has remained to this day. Eddington (1926, p. 295) noted that "the contraction hypothesis was already becoming obsolete" at this time, that "Lord Kelvin's date of the creation of the sun [was] treated with no more respect than Archbishop Ussher's" (Eddington, 1920), and that the sun's 20 million yr life time disagreed with "geological, physical, and biological evidence" (Eddington, 1959, p. 162).

Contradicting these statements, neutrino scientist and anti-creationist Sverker Johansson, writing of the attitude which existed toward gravitational contraction in the early 1900s, has claimed that solar fusion was *not* proposed to give the sun a longer lifetime compatible with terrestrial evolution: "The quest for a new energy source for the sun did *not*, as is commonly believed, stem primarily from a desire to provide sufficient time for biological evolution [emphasis in original]" (Johansson, 1999, p. 3). Johansson then claims that all arguments against gravitational contraction were based on science alone: "The gravitational contraction theory … was abandoned in the early part of the 20th century, for good scientific reasons that had nothing to do with creationism" (Johansson, 1999, p. 18).

On the other hand, Johansson admits that the Helmholtz contraction time scale "was troublesome to many; it was … too short for geologists and biologists, who could see that the earth and its fauna had a far longer history. …Fusion is the only known source of energy that can keep the sun going for billions of years" (Johansson, 1999, p. 3). Thus the claim that solar contraction was rejected for scientific reasons is not true. Even before fusion was accepted as a solar energy source, Eddington emphasized that because of the "demand for an extended time-scale" for the sun, "allowance had to be made for the source [of the sun's energy] being probably subatomic" (Eddington, 1926, p. 295).

The first person to propose a nuclear source of the sun's heat was George Darwin (Darwin, 1903, p. 496). He "suggested that radioactivity, such as produced by radium, might be the source of the sun's heat, and within a week the idea was supported by others who could see this as an explanation for the greater age required by Darwinism" (Taylor, 1987, p. 496). Thus the first proposal of nuclear reactions in the sun was made for reasons of extending the solar chronology, not scientific ones. While the concept of solar nuclear reactions is not inherently evolutionary, the advocacy of this concept has a consistent history of evolutionary activism. But Darwin's idea of fission reactions (as opposed to fusion) powering the sun was soon given up, since it was apparent that even fission could not maintain the sun's luminosity for the required time. Nonetheless, contraction was now firmly rejected despite the absence of any known subatomic solar energy source. This rejection occurred long before fusion reactions were proposed, demonstrating that contraction was not abandoned because of compelling evidence that modern solar theory is accurate, but because of the evolutionary need for a longer chronology.

Eddington Reflected the Evolutionary and Religious Views of His Time

Eddington has been described as "a deeply religious man" (Clausen, 1997) with "strongly held Quaker beliefs" (Encyclopedia Britannica, 2000), a characterization which could lead one to conclude that Eddington's solar theorizing arose from a backdrop of Christian thought, and therefore should be acceptable to biblical creationists. Such a characterization is simplistic, and overlooks the fact that Eddington was first and foremost a thoroughgoing evolutionist whose beliefs on biblical doctrine were not always orthodox. Significantly, Eddington is not listed as a Bible-believing scientist by either Morris (1982) or Barnes (1993).

By Eddington's lifetime, evolutionary ideas had swamped Western culture as if there had never been a widespread belief in creation only a few decades before. In 1894 when Eddington was eleven, it was possible to state accurately that,

> We cannot escape from [evolution]. Its technical phrases have become parts of current common speech. …It does not matter to what sphere of human work we turn, for in all alike we meet with the same mental atmosphere. Are we students of physics or chemistry, we have no sooner mastered the elements of the science than we are plunged into questions which deal with the 'evolution' of the

'atom' or 'molecule' from simpler forms of matter (Iverach, 1894, p. 1).

Since Eddington was schooled in this atmosphere, it is hardly a wonder that he became a convinced evolutionist.

Well known evangelists were also espousing evolutionary beliefs at this time, so completely had evolutionism captured the mind of the Church. Evangelist R.A. Torrey rejected Genesis chapter 1 as a literal creation account, denied that the creation occurred over six ordinary days, and insisted that the evolutionary chronology must be accurate (Torrey, 1907, pp. 19, 29–31, 33–34). Numerous fundamentalists of the time also pressed evolutionary thinking upon the Church. R.A. Torrey in fact led the committee which edited the famous series of twelve volumes setting forth the beliefs which came to be known as fundamentalism (Feinberg, 1990, p. 9). With Torrey in charge, perhaps it is not surprising that though all the contributors to *The Fundamentals* gave lip service to biblical inerrancy, some mildly and others aggressively espoused evolutionary thought and chronology (Feinberg, 1990, pp. 81, 107, 133–134).

Not only the Church but imminent scientists were aggressively urging public acceptance of evolution. Nobel Laureate Robert A. Millikan, who is known today for his "oil drop" method of determining electron charge, sought to integrate his science with Christian faith. However, he supported the secular evolutionary community in questions touching on origins. Millikan claimed that "science" (i.e., evolution) and "religion" were mutually exclusive concepts, that John Wesley had supported evolution before it was fashionable, that Christianity and the Bible were products of the evolution of religion, and that "one of the greatest contributions of science" was the discovery of the "evolutionary process" (Millikan, 1924, pp. 40–41, 48–49, 54–55, 70). He also described those who resisted the entrance of evolutionism into education as "a menace to democracy and civilization" (Millikan, 1924, p. 76), referred to William Jennings Bryan of Scopes trial fame as a "pure dogmatist," opined that a clear victory for creationists at the Scopes trial would have been "the worst set-back to civilization in all history," and ridiculed fundamentalists as having minds that are "closed" and "irrational" (Millikan, 1927, pp. 60, 63, 87). Not surprisingly, he asserted that all the universe was "progressing" through evolution, and that the earth was at least a billion years old (Millikan, 1927, pp. 41, 80).

The ideas of Millikan and Eddington had much in common, not only generally but specifically. Millikan rejoiced with evolutionary astronomers that, because of Eddington's solar modelling, they had been able "to escape their otherwise insuperable [chronological] difficulties encountered because of the sun" (Millikan, 1927, p. 17). Eddington stated that "time" and "nature" were responsible for the upward development of the universe, concluding that "I cannot profess to say whether anything more than this prolific structure-building power of carbon" caused the "beginning" of life (Eddington, 1930, pp. 11, 17, 20). To him, invoking God as Creator is an "attitude [which] is liable to grate a little on the scientific mind," and claimed that most astronomers, "when they are reminded of the psalm `The heavens declare the glory of God'," might "confess to some chafing" because "it is so often rubbed into us" (Eddington, 1930, pp. 23–25).

Interestingly, Eddington justified his "free spirit of inquiry" by an appeal to an inner "voice" or "light" as a rationale for departing from biblical teaching on origins (Eddington, 1930, pp. 24, 26, 41). Such an emphasis on "experience," an "inward Light [sic]" or an "inward way" has been a hallmark of Quakerism in reaction to dead orthodoxy starting with its founder George Fox (Jones, 1924, pp. 11, 13, 22). Unlike George Fox, however, Eddington had a low view of biblical revelation, saying, "I confine myself to the revelation implied in the indwelling of the divine spirit in the mind of man," identifying this spirit as "the self-knowledge of mind" rather than the Holy Spirit (Eddington, 1930, pp. 72, 74). Eddington realized that this position made it possible for him to accept evolutionary doctrine, for he wrote, "Quakerism in dispensing with all creeds holds out a hand to the scientist [i.e., evolutionist]" (Eddington, 1930, p. 89). Thus for Eddington his Quaker background was a vehicle for moving away from orthodoxy.

Indeed, he considered the existence of God "irrelevant to the assurance for which we hunger," claimed that the spiritual world arises "from our own personality," and emphasized "seeking" over religious certainty (Eddington, 1930, pp. 68–70, 82, 88). One hopes that Eddington eventually found "the kind of security we should seek in our relationship with God" (Eddington, 1930, p. 70). On the other hand, his Quakerism produced a certain humility rare among eminent scientists, and Eddington, though driven by his evolutionary beliefs, readily admitted which of his theories he considered to be "speculation" (Eddington, 1920). The combination of his lack of arrogance with his skillful articulation of complex concepts makes Eddington's writings quite accessible, a factor which no doubt aided the acceptance of his stellar theories.

Eddington Defended Evolutionary Chronology by Opposing Contraction

Probably no one was more influential than Eddington in stigmatizing the gravitational contraction theory. As astrono-

mer Lloyd Motz said in an introduction to Eddington's influential *The Internal Constitution of the Stars* (Eddington, 1926, p. vi): "It is to Eddington more than to any other one man that we owe the very rapid development of astrophysics" in modern times. Hartmann (1991, p. 372) opines, "Eddington showed why stars are the way they are," and Hartmann cites Eddington frequently as the starting point for understanding stellar evolution (Hartmann, 1991, pp. 371–378). Abell et al. (1987, p. 492) have similarly summarized Eddington's significance: "Eddington is best known among astronomers for his development of theoretical methods for investigating the internal structure of the sun and stars." Yet as we will see, Eddington never disproved the existence of solar contraction in the sun. He simply rejected it because of the conflict with evolutionary chronology. Eddington (1929, p. 94) was explicit about the long-standing evolutionary animus towards solar contraction:

> In the last century it was shown by Helmholtz and Kelvin that the sun could maintain its heat for a very long time by continually shrinking. …It was assumed that this was the sole resource since no other supply capable of yielding anything like so large an amount was known. But the supply is not unlimited, and on this hypothesis the birth of the sun must be dated not more than 20,000,000 years ago. Even at the time [around 1900] of which I am speaking the time-limit was found to be cramping; but Kelvin assured the geologists and biologists that they must confine their outlines of terrestrial history within this period.

Eddington (1929, p. 94) continues:

> About the beginning of the present century the contraction theory was in the curious position of being generally accepted and generally ignored. Whilst few ventured to dispute the hypothesis, no one seems to have had any hesitation, if it suited him, in carrying back the history of the earth or moon to a time long before the supposed era of the formation of the solar system. Lord Kelvin's date of the creation was treated with no more respect than Archbishop Ussher's.

As previously mentioned, anti-creationist Johansson (1999, p. 18) claims that Eddington disproved gravitational contraction on scientific grounds alone:

> Eddington … showed that the only reasonable conclusion is that stars start out contracting (and shining from gravitational energy), but that they then reach equilibrium along what is now known as the 'main sequence.' Gravitational energy cannot account for that equilibrium; a new energy source is needed. …But even if we didn't know anything about nuclear fusion (or if fusion for some reason didn't work in the sun), Eddington's (1920; 1924) refutation of the gravitational-contraction theory would still remain solid.

This is not true. In fact, Eddington's "scientific proof" that main sequence stars are not contracting was based on the same criterion we have already examined—the belief that the earth must be billions of years old, and that therefore the sun cannot be younger than this. Eddington was quite explicit on this point. In the next several paragraphs, Johansson's claims are interwoven with Eddington's statements, first quoting Eddington to show his true motive for rejecting the possibility of gravitational collapse in main sequence stars:

> The serious consequences of the [contraction] hypothesis become particularly prominent when we consider the diffuse stars of high luminosity; these are prodigal of their energy and squander it a hundred or a thousand times faster than the sun. The economical sun could have subsisted on its contraction energy for 20,000,000 years, but for the high luminosity stars the limit is cut down to 100,000 years. This includes most of the naked-eye stars (Eddington, 1929, pp. 94–95).

Of course, Eddington has here summarized an excellent argument for a young cosmos, assuming that stars generally derive energy by contraction. But he goes on to say, "Dare we believe that [stars] were formed within the last 100,000 years?" (Eddington, 1929, p. 95). Thus he negates the possibility of a young cosmos—and hence contraction—due to a contrary belief about chronology.

Johansson also claims that Eddington made a successful "argument against gravitational contraction, from the frequency stability of variable stars. . ." (Johansson, 1999, p. 19). But Eddington himself reveals his actual motivation for the variable star argument against contraction, and the argument is ultimately not scientific but chronological. Eddington begins by noting that Cepheid variables, if contracting, should show a change in period:

> Does the period show any change? It is doubtful; there is perhaps sufficient evidence for a slight change, but it is not more than 1/200th of the change demanded by the contraction hypothesis. Accepting the pulsation theory, the period should diminish 17 seconds every year—a quantity easily detectable. The actual change is not more than one-tenth of a second per year (Eddington, 1929, pp. 95–96).

At first glance this would appear to be a successful argument against stellar contraction, at least in variable stars. However, there is the possibility of fusion and contraction simultaneously occurring, as Eddington acknowledged: "At

least during the Cepheid phase the stars are drawing on some source of energy other than that provided by contraction" (Eddington, 1929, p. 96). Thus, Eddington admitted that the evidence from Cepheids is not conclusive against contraction, contrary to Johansson's claim. But then Eddington made what can only be considered a staggering statement (though it should not truly surprise us at this point). After marshalling the supposed evidence from the Cepheids against contraction, he concluded with what he believed to be the strongest evidence against contraction:

> On such an important question we should not like to put implicit trust in one argument alone, and we turn to the sister sciences for other and perhaps more conclusive evidence. Physical and geological investigations seem to decide definitely that the age of the earth—reckoned from an epoch which by no means goes back to its beginnings as a planet—is far greater than the Kelvin-Helmholtz age of the solar system. It is usual to lay most stress on a determination of the age of the rocks from the uranium-lead ratio of their contents. …By measuring how much lead occurs with the uranium we can determine how long ago the uranium was deposited. The age of the older rocks is found to be about 1,200 million years; lower estimates have been urged by some authorities, but none low enough to save the contraction hypothesis. The sun, of course, must be very much older than the earth and its rocks (Eddington, 1929, p. 96).

One might think that in his technical opus, *The Internal Constitution of the Stars*, Eddington might have adduced more persuasive theoretical reasons for disallowing contraction, but not so. There we read:

> The energy obtainable from contraction is quite inadequate in view of the great age now attributed to the sun. …Biological, geological, physical and astronomical arguments all lead to the conclusion … that the time-scale given by the contraction hypothesis must somehow be extended (Eddington, 1926, pp. 289, 290).

In short, the earth is old, so the sun must be old. Eddington here at least alludes to a multiplicity of supposed "biological, geological, physical and astronomical" evidences of great evolutionary age. But in the end, the "best" evidence for great age is only geological. Immediately following the last sentence quoted above, he says, "The most direct evidence [for great age] is given by the date of formation of terrestrial rocks…" (Eddington, 1926, p. 290). Thus we see that there really never has been a scientific argument against contraction, even from Eddington, but only the same argument used today, that the sun cannot be younger than the evolutionary age of the earth.

Eddington's Solar Modeling Came from Denying a Young Earth

Contradicting Eddington's statements about upholding a long chronology in solar modelling, Johansson (1999, p. 4) writes as if chronological questions were not a factor in Eddington's theorizing:

> In the early 20th century it was found that a new energy source was needed on astronomical grounds alone. The internal structure of stars had been worked out by Eddington and others (Eddington 1920), well before the discovery of nuclear fusion, and found to be consistent with astronomical observations only if a new energy source was postulated. …And the conditions prevailing inside the sun and other stars (calculated by Eddington (1916; 1917) and others long before Bethe's work) were precisely those in which fusion reactions proceeded at an appropriate rate. Quite coincidentally, it also turned out that the lifetime of a fusion-driven sun is of the same order of magnitude as the age of the earth, solving the geologists' problem.

This statement has several inaccuracies. As has already been shown, it was no coincidence that the sun's age worked out by evolutionists was of the same order as the evolutionary age of the earth. Eddington (1929, pp. 96–97) made this point clearly:

> The sun, of course, must be very much older than the earth and its rocks. We seem to require a time-scale which will allow at least 10,000,000,000 years for the age of the sun; certainly we cannot abate our demands below 1,000,000,000 years. It is necessary to look for a more prolific source of energy [than contraction] to maintain the heat of the sun and stars through this extended period.

Because of this evolutionary requirement, reaction characteristics and other parameters in the SSM are chosen so as to make the sun appear to be as old as the common wisdom says it is.

Another inaccuracy in Johansson's statement above is that "the conditions prevailing inside the sun and other stars … were precisely those in which fusion reactions proceeded at an appropriate rate." In fact Eddington's calculation of the sun's central temperature was 40 million degrees (Eddington, 1929, p. 14), a value so high that even fusion models would predict a far different sun from the real one. Far from predicting conditions suitable for solar fusion, Eddington did not believe that solar fusion was occurring at all. Though aware of the possibility of fusion, he

believed that another process supplied the sun's energy: "On the whole the hypothesis of annihilation of matter seems the more promising [instead of fusion]; and I shall prefer it in the brief discussion of stellar evolution which I propose to give" (Eddington, 1929, p. 94). He was referring to the "annihilation of electrons and protons" (Eddington, 1959, p. 181), and considered the "transmutation" [fusion] of hydrogen to be an "unsatisfactory" hypothesis (Eddington, 1929, p. 102), though later he came to doubt his annihilation scenario.

Finally, it is not true that "the internal structure of stars had been worked out by Eddington and others … and found to be consistent with astronomical observations only if a new energy source was postulated." The internal structure of stars cannot be observed but only modelled: "Descriptions of what lies beneath the sun's fiery surface have been essentially conjecture…" (Bartusiak, 1990, p. 25). Further, solar scientist John Bahcall reportedly looks forward to "knowing the conditions under which [solar] neutrinos were created" (Normille, 1999, p. 1910). In other words, conditions in the solar core are not yet known, despite expressions of confidence to the contrary, as Eddington himself acknowledged: "In any case the composition of the layers bubbling on the outside of the stellar furnaces cannot be taken as a safe guide to the composition within" (Eddington, 1959, p. 137).

It is not true that Eddington had a scientific foundation for his concepts of stellar structure. Eddington's starting point for deriving new concepts of stellar structure was a denial of contraction. As Eddington (1929, pp. 96–97) wrote:

> It is necessary to look for a more prolific source of energy to maintain the heat of the sun and stars through this extended period. We can at once narrow down the field of search. No source of energy is of any avail unless it liberates heat deep in the interior of a star. The crux of the problem is not merely the provision for radiation but the maintenance of the internal heat which keeps the gravitating mass from collapsing. …But the internal heat is continually running away towards the cooler outside and then escaping into space as the sun's radiation. This, or its equivalent, must be put back if the star is to be kept steady—that it is not to contract and evolve at the rate of the Kelvin time-scale.

As is true in solar modelling today, the first principle in Eddington's concept of stellar structure was the assumption of hydrostatic equilibrium. Not only is hydrostatic equilibrium the first principle to which he appealed in his theoretical development, but he invoked the principle repeatedly (Eddington, 1926, pp. 5, 15, 27, 35, 97). Eddington stated that he invoked hydrostatic equilibrium to avoid the possibility that the sun is evolving "at the rate of the Kelvin time-scale" (Eddington, 1929, p. 97). And the reason to avoid the Kelvin time-scale is the one already given by Eddington himself, to insure that the sun is "very much older than the earth and its rocks" (Eddington, 1929, p. 96).

Following from the assumption of hydrostatic equilibrium is the assumption of extremely high core temperature to insure that the resulting inner pressure will prevent the outer layers from collapsing inward. Eddington (1929, pp. 12–13) explained the connection:

> At each point the elasticity of the gas must be just enough to balance the weight of the layers above [i.e., there must be hydrostatic equilibrium]; and since it is the heat which furnishes the elasticity, this requirement settles how much heat the gas must have. And so we must find the degree of heat or temperature at each point. …Evidently we have to assign a temperature such that the sum total of the blows [of atoms of gas in collision] is neither too great nor too small to keep the upper material steadily supported. That in principle is our method of calculating the temperature.

Following from the assumption of high core temperature is the assumption of high opacity, which is necessary to generate an extremely high thermal gradient which will in turn maintain the assumed core temperature. Again, Eddington (1929, p. 28) explained the connection:

> We soon realize that the material of the star must be decidedly opaque. The quantity of radiation in the interior is so great [due to the assumption of extremely high core temperature] that unless it were very severely confined the leakage would be much greater than the amount which we observe coming out of the stars.

Eddington elsewhere makes the same linkage between high core temperature and high opacity (Eddington, 1926, pp. 21, 217). Based on the assumption of high opacity, the description of the staggeringly long time required for electromagnetic radiation to travel from the core to the surface has been told and retold. For example, Fix (1999, p. 390) claims:

> Even though photons travel at the speed of light, the diffusion of radiation from the center of the Sun out to the convection zone is very slow. So many absorptions and reemissions occur that about 170,000 years pass before the energy produced at the Sun's center reaches the surface.

Summarizing the situation, Eddington assumed hydrostatic equilibrium as a denial of gravitational collapse, and

the major features of the SSM follow from it. The evolutionary age of the earth is the basis for the presumed age of the sun, and a long chronology for the sun requires that no significant gravitational collapse be occurring over the sun's main sequence lifetime. Preventing gravitational collapse requires hydrostatic equilibrium, which requires high core temperature, which requires high opacity.

Eddington's concept of stellar structure was no more consistent with astronomical observations than Helmholtz contraction, but was devised primarily for reasons of maintaining an evolutionary chronology. Yet Johansson claims: "That the sun cannot still be in the contraction phase was established already in the 1920's, well before the discovery of fusion" (Johansson, 1999, p. 20). It is indeed true that this conclusion was established before the discovery of fusion, but only because the requirements of evolutionary chronology had trumped the possibility of solar contraction.

Johansson's statements are typical of modern claims, and one must go back to Eddington's writings to understand the chronological assumptions which formed the foundation for his theories of stellar operation. Without doing this, it is easy to accept that there must have been a scientific basis for the establishment of stellar evolution theory. As with Eddington's modelling, modern solar modelling begins with the assumption of great age for the sun (Liebacher et al., 1985, p. 48; Brun et al., 1998, p. 922; Bahcall et al., 2001, pp. 992–993). There is circular reasoning here, however, since Eddington first assumed a process which would give the sun a long lifetime, a consequence of which was high internal temperature and pressure, which in turn would give the sun a long lifetime. This assessment holds despite the "elegant" theoretical system devised for fusion reactions in the sun and other stars (Wallerstein et al., 1997, pp. 995–1084), for Eddington's theoretical framework continues to be the basis of modern solar theory: "[Eddington was responsible for enunciating] the principles that control the structure and evolution of stars … Eddington showed why stars are the way they are" (Harwit, 1991, pp. 71, 72). Thus the biases in Eddington's work influence solar/stellar modelling today.

An overconfidence in the laws of physics as applied in conventional stellar modelling has led to an intellectual arrogance manifested in comments like the following due to Goldsmith (1985, p. 253):

> The power of the human mind, seen both in its analytic ability and in its development of superfast calculating machines, has enabled us to penetrate the interiors of stars and to discover the liberation of kinetic energy [by fusion] within them. We have achieved this success despite the fact that we can see only the *surfaces* of stars [emphasis in original].

This attitude, tantamount to worship of the human mind, is actually a type of religious position, and is the antithesis of the open minded approach required to do productive science.

Eddington's rejection of gravitational contraction caused the contraction concept to be neglected for many decades. The possibility of fusion reactions for the sun was established by Hans Bethe in 1939. It is ironic that, despite the subsequent scientific confirmation of solar fusion, the basic justification for fusion typically continues to be the chronological one, demonstrating that the chronological question remains uppermost in the minds of theorists:

> The problem with explaining the Sun's energy output by gravitational contraction isn't that the Sun couldn't shrink fast enough [an interesting admission], but that it couldn't have been doing so for long enough. …The total amount of energy released would only be enough to keep the sun shining at its present brightness for about 20 million years. …[This] is about 200 times [too short] … (Fix, 1999, p. 387).

In other words, the presumed evolutionary chronology for the sun continues to negate the possibility of gravitational collapse:

> The sun is very luminous and has been shining for billions of years. The enormous amount of energy that the sun has produced since its formation makes it possible to rule out many energy sources, such as … gravitational contraction (Fix, 1999, p. 387).

The core argument against contraction, and ultimately the basic argument for the SSM, has consistently been evolution's need for more time.

Is the SSM Confirmed by "Model Convergence"?

The claim has been made that the conventional solar model must be correct because various SSMs converge on a uniform set of predictions for solar properties (Bahcall and Bethe, 1993, p. 1300; Bahcall and Pinsonneault, 1997, p. 4; Bahcall et al., 1997, pp. 173–174; Bahcall et al., 2001, p. 999). To put such a claim into perspective, astronomers have acknowledged that, apart from chronological considerations, contraction could explain the sun's energy output (Fix, 1999, p. 387), and that there are no data disproving a young age for the sun (Kazmann, 1978, p. 18). Further, we have seen that in conventional solar modelling, the primary solar characteristic consulted (other than directly observable properties such as luminosity, surface temperature, and diameter) is the presumed age of the sun

(Liebacher, 1985, p. 48; Brun et al., 1998, p. 922; Bahcall et al., 2001, p. 991). Apparently the sun could be modelled over a wide range of parameters (e.g., all contraction or all fusion; young or old), but conventional modelling is constrained to a narrow range of parameters (Bahcall et al., 1997, p. 173; Bahcall et al., 2001, p. 991) based on similar assumptions consistent with the assumed evolutionary age (Bahcall et al., 1995, p. 786; Bahcall and Ulmer, 1996, pp. 4202–4203; Basu et al., 2000, pp. 1084, 1099; Bahcall et al., 2001, 998). Indeed, models using parameters within the acceptable range are termed "variant models," but models with parameters outside this range are said to be "deviant" (Bahcall et al., 2001, pp. 999–1000).

It is not generally recognized how flexible the parameters in solar models really are. One of the dominant reactions thought to occur in the sun is the fusion of hydrogen atoms to produce deuterium, a reaction believed to produce many of the sun's neutrinos. This process is thought to be followed by additional reactions to produce helium and additional neutrinos. A reaction sequence called the CNO bi-cycle is thought to be a minor contributor to this process in the sun, producing some 1.5% of the sun's luminosity. However, Bahcall et al. (2002, p. 1) have shown that with appropriate selection of parameters, the CNO bicycle could explain 99.95% of the sun's luminosity. Further, the sun's neutrino flux is also explained by this approach. Indeed, this result was generated to illustrate the difficulty of parameter selection given the possibility of neutrino oscillations en route from the sun to earth (Bahcall, 1997, p. 11). The reason that such a solar model is not considered acceptable is that the reactions of the CNO bi-cycle are thought to have significant rates only at temperatures hotter than those assumed for the sun's core (Groombridge et al., 2002, p. 055802-1), and with a higher temperature, the sun's lifetime would be shorter than that required by the conventional chronology, i.e., the conventional age of the earth.

The CNO bi-cycle itself has an interesting history in the development of the modern SSM. Eddington had no concept of fusion occurring in the sun, and therefore no scenario for solar nucleosynthesis. His model concepts were developed apart from preconceptions about solar nucleosynthesis. It is well known that Hans Bethe in 1939 made a proposal of nucleosynthesis by solar fusion as mentioned earlier. Less well known is the fact that Bethe believed the CNO bi-cycle was the main source of the sun's energy (Bahcall et al., 2002, p. 1). On the other hand, in the 1940s George Gamow and others began developing what has become the modern Big Bang theory. The early belief of Gamow and colleagues was that the primordial fireball was responsible for nucleosysthesis of most elements. The dubious nature of this claim became rapidly apparent to Fred Hoyle and others (Burbidge and Hoyle, 1998, p. L1). Interestingly, Hoyle, as well as Geoffrey Burbidge, maintained a lifelong aversion to Big Bang theory.

Hoyle, together with Geoffrey Burbidge, Margaret Burbidge, and William Fowler, continued efforts through the 1950s to show that stars could account for nucleosynthesis. In the early 1950s they believed that solar-type stars accounted for a significant occurrence of reactions involving heavy elements (i.e., elements beyond He). However, stellar nucleosynthesis theory was encountering problems until 1953 when Hoyle, working with Fowler, successfully predicted a resonance for ^{12}C in the CNO bi-cycle which would allow this sequence to occur under solar conditions (Wallerstein et al., 1997, p. 999; Salpeter, 1999, p. S220). Later, the CNO bi-cycle was recognized as less and less likely to occur in the interior of the sun or in any normal star (Hoyle, 1954, p. 146). Fowler then proposed that C, N, and O reactions happen on the surfaces of stars due to local heating by magnetic fields (Fowler et al., 1955, pp. 167, 180). Subsequent to this, the CNO bi-cycle was ruled out as insignificant in solar-type stars (Caughlin and Fowler, 1962, p. 453). Reactions involving C, N, and O have been postulated for very hot, massive stars (Wagoner et al., 1967, p. 3; Hoffman et al., 2002), or supernovas (Hoyle and Fowler, 1960, p. 565; Arendt, 1999, p. 234). Data for certain resonances and reaction rates of processes involving C, N, and O remain some of the most uncertain quantities in stellar nucleosynthesis theory (Wallerstein et al., 1997, p. 999; Salpeter, 1999, p. S220). Yet reactions involving C, N, and O, and in particular the CNO cycle, are believed to be a key requirement for the stellar nucleosynthesis of other heavier elements (Groombridge et al., 2002, p. 055802-1). Despite Hoyle's successful prediction of the ^{12}C resonance, it is clear that solar/stellar nucleosynthesis theory has not answered basic questions about how the elements came to be. Further, since the sun can be modelled with the CNO bi-cycle accounting for virtually all the luminosity, it is difficult to view Hoyle's successful prediction of ^{12}C resonance as a robust confirmation of the SSM.

As with the reaction parameters for the CNO bi-cycle, many other quantities are treated as parameters in solar modelling, the usual reason being that the actual values are unknown. Previously mentioned is the fact that nuclear reaction rates are generally theoretical and uncertain (Bahcall et al., 1995, p. 783; Guenther and Demarque, 1996, p. 5; Bahcall et al., 2001, p. 1002; Hoffman et al., 2002, p. 1). The following quantities are also treated as adjustable parameters: (1) cross section factors (Bahcall et al., 1995, p. 783; Bahcall and Ulmer, 1996, p. 4203; Hoffman et al., 2002, p. 1), including the cross section fac-

tor for the *hep* reaction (Bahcall et al., 2001, p. 1002) as well as the *p-p* reaction cross section which cannot be measured directly and is therefore theoretical (Brun et al., 1998, p. 921); (2) core temperature (Bahcall and Bethe, 1993, p. 1298); (3) primordial element abundances (Bahcall and Ulmer, 1996, p. 4203), with relative primordial abundances for elements other than He, C, N, O, and Ne being estimated from meteoritic composition (Bahcall, 1997, p. 11), and with primordial He abundance being treated as an unknown which must be modelled (Bahcall et al., 1995, p. 804); (4) Ne abundance, which "cannot be measured directly in the sun" (Bahcall et al., 1995, p. 785); (5) opacities (Guenther and Demarque, 1996, p. 6); (6) adiabatic indices (Basu et al., 2000, p. 1086); (7) density profiles (Basu et al., 2000, p. 1089); (8) equations of state (Basu et al., 2000, p. 1092); and (9) diffusion rates (Bahcall et al., 1995, p. 786). With so many adjustable parameters available, it is little wonder that various models can be made to converge toward virtually any desired set of solar characteristics.

Item 3 in the list above is especially problematic for the biblical creationist, since in the biblical creation account the sun and the other bodies of the solar system were spoken into existence separately rather evolving from a common nebula. Thus there is no Scriptural basis for assuming that the sun has ever had "primordial" elemental abundances supposedly matching those of the meteorites or any other part of the solar system.

In addition, the uncertainty of model predictions is often computed by comparing models with models rather than models with data (Bahcall and Bethe, 1993, p. 1299; Bahcall et al., 1995, pp. 782, 790; Bahcall et al., 2001, pp. 993–994). This has the effect of making model uncertainties appear quite small, given that most researchers will choose model parameters so as to show convergence with existing models rather than "deviance." Investigators working outside the bounds of acceptable parameters may find themselves the object of criticism (Bahcall and Pinsonneault, 1997, p. 10).

It has been noted that the phenomena causing the greatest difficulties for solar models, namely, neutrino fluxes, helioseismic data, and angular momentum data, are generally not considered in framing SSMs (Guenther and Demarque, 1996, p. 2; Brun et al., 1998, p. 913; Bahcall et al., 2001, p. 991). The success of a model in predicting neutrino flux is computed by adjusting parameters such as (1) reaction cross sections in the neutrino detector (Bahcall and Bethe, 1993, p. 1298; Bahcall and Pinsonneault, 1997, p. 10; Bahcall, 2002, p. 6); (2) dependence of neutrino flux on solar core temperature (Bahcall and Pinsonneault, 1997, p. 172); (3) the occurrence of neutrino oscillations (Bahcall et al., 2002, p. 1); and (4) the mixing angle for neutrino interaction in the detector (Bahcall, 2002, p. 10). With such a wide selection of parameters, the agreement between the SNO (Sudbury Neutrino Observatory) results and predictions for neutrino detection have been excellent (Seife, 2001, pp. 2227–2228). Indeed, the resulting agreement has been described as "embarrassingly small" (Bahcall, 2002, p. 5), since normally a deviation too small between predictions and results is taken to indicate some sort of misstep in the method used to obtain it.

The success of a model in matching helioseismic data is computed by comparing model sound speeds in the sun with solar sound speeds inferred from helioseismic oscillations. However, the inversion of sound speeds from helioseismic oscillations requires the use of a "reference solar model," which means that model sound speeds are compared with model sound speeds (Basu et al., 2000, p. 1084), resulting in good agreement between predicted sound speeds (obtained from a SSM) and "observed" sound speeds (obtained via a reference model, also a SSM). This is the basis of claims, for example, that "standard solar models are in remarkable agreement with helioseismological measurements of the Sun" (Basu et al., 1098, p. 1098; Bahcall et al., 1995, p. 782).

In short, model convergence is a result of (1) restricting parameter selection, and (2) restricting model uncertainty computations to comparisons between models. Ironically, among astrophysicists, if not particle physicists, model convergence has been employed as one of the main rationales for accepting neutrino oscillations as real (Bahcall and Bethe, 1993, p. 1299; Bahcall and Pinsonneault, 1997, p. 3–4; Bahcall et al., 2001, p. 999, 1010). Likewise, model convergence in helioseismic sound speeds has also been a basis for accepting neutrino oscillations (Bahcall et al., 2001, p. 991). Among the various considerations taken to imply neutrino oscillations, this type of reasoning would appear to be less than satisfactory.

Conclusions

Since the rise of modern evolution in the 1800s, few if any majority views have escaped its influence. History shows that the present majority view of solar/stellar theory has been shaped by evolutionary bias from the start, particularly by the desire to buttress a long chronology. The theorizing of influential solar astronomer Arthur S. Eddington is an example of this bias.

Rather than being compelled by the laws of physics to reach his conclusions, Eddington selected the laws he wished to invoke so as to sidestep any possibility that the sun and other stars, and therefore the earth, might be young.

He claimed for chronological reasons that the sun must be in hydrostatic equilibrium, and he also insisted that nuclear reactions were the only significant energy source for the sun, again for chronological reasons: "The energy obtainable from contraction is quite inadequate in view of the great age now attributed to the sun" (Eddington, 1926, p. 289); "Unless we choose annihilation of matter [as the energy source], we cut the life of a star so short that there is no time for any significant evolution at all" (Eddington, 1929, p. 112).

Rather than uncritically accepting conventional claims about the operation of the sun and stars, an informed historical perspective would suggest that the biblical creationist ought to tread carefully among such claims, accepting those backed by actual data, while being wary of the evolutionary bias which continues to inform solar/stellar theorizing.

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"…much unnecessary strain is caused by the hasty judgments of the Bible's friends and foes alike. We cannot examine at all thoroughly all the problems growing out of the creation narrative (Gen. 1–3) for example; but, this general statement is true, we believe: If every Bible scholar were careful not to read anything out of the Scripture teachings except what it indubitably teaches and natural scientists were equally careful to claim nothing as scientifically established but what is indubitably true, the tensions between science and Scripture would be reduced to a negligible minimum."

—John H. Gerstner, *A Bible Inerrancy Primer* (Grand Rapids, MI.: Baker, 1965), Pg. 50.

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