IS THERE A SECULAR TREND IN SOLAR DIAMETER?

Abstract

The concept of a secular trend in solar diameter was introduced in the mid-1800s and was thought to operate on the order of 10^7 yr. By the early 1900s, the solar fusion concept had pushed the possibility of other solar processes into the background, with fusion reactions potentially operable for 10^{10} yr. Eddy and Boornazian revived claims of a secular trend in solar diameter in 1979. The Eddy/Boornazian data, however, do not relate to secular trends in the sun. **Further, solar fusion occurs, making secular diameter change an invalid solar chronometer.** The Eddy/Boornazian results, once claimed as a chronometer, have obscured the existence of other data suggesting a secular diameter trend less than the Eddy/Boornazian rate. Possible implications of such a trend are discussed.

Introduction

In the conventional view of how the sun works, the standard solar model (SSM), the sun has generated fusion energy for billions of years. Though solar fusion occurs, the SSM has uncertainties because the interior of the sun cannot be observed directly. **These unknowns are adjustable parameters in the equations used to work out solar structure and properties.** Nevertheless, the SSM's description of the sun's interior is often regarded as unchallengeable, because of the perception that the SSM's parameters have been evaluated to a high degree of certainty.

Many parameters enter into the SSM. **Fusion reaction rates are 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 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 factor for the *hep* reaction (Bahcall et al., 2001, p. 1002), and the *p-p* reaction cross section (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 modeled (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 this array of parameters and others available for adjustment, the sun could be modeled to evolve over virtually any period. Commonly cited values of SSM parameters, however, are predicated on modeling over 4.6 billion yr (Bahcall, 1989, p. 103; Bahcall et al., 1995, p. 784). **Conventional parameter values are thus dependent on the sun's assumed evolutionary age.**

The SSM also assumes the sun is in hydrostatic equilibrium over a time scale of 10^9 yr. Bahcall (1989, p. 46) labels hydrostatic equilibrium the "first condition" for stellar evolution models. This "first condition" is not as certain as typically assumed (Henry, 2003, pp. 34-39; Henry 2004b, p. 213).

Lack of helioseismic g-modes implies absence of a dense core and a degree of solar homogeneity (Henry, 2003, p. 39). Lack of g-mode detection persists (Phoebus Collaboration, 2001, p. 467; Kumar et al., 1996, p. L83; Wachter, 2003, p. 1199; Antia, 2005, p. 163), despite premature claims of detection (Delache and Scherrer, 1983, p. 651; Thomson et al., 1995, p. 139), and despite the use of g-modes in stellar evolution simulations (Straka et al., 2005, pp. 1075, 1086; Meakin and Arnett, 2006, p. L53). Toulmonde (1997, p. 1177) argues for no long-term solar contraction.

However, **lack of g-modes implies that the sun has the relatively undifferentiated structure of a young star,** not the dense core and segregated structure of the SSM. This makes non-cyclic solar contraction a possibility. It would therefore seem that the sun has the appearance of youth rather than the appearance of age, a conclusion consistent with a recent creation chronology.

The diameter of the sun is about 1.4 x 10^6 km (864,000 mi), ≈ 1920 arc sec, or more precisely 1919.26 ± 0.02 arc-sec (Morrison et al., 1988, p. 421; Brown and Christensen-Dalsgaard, 1998, p. 5; Castellani, et al., 1998, p. 1), where 1° = 3600 arc-sec. The sun's apparent diameter is about the size of the index finger held at arm's length, or half a degree. This is 1/720th of the full 360° circle of the horizon, or twice the 960 arc-sec solar radius.

The SSM Depends on Assuming Old Age of Earth and Sun

Biblically, the sun is thousands of years old, not billions. Over millennia the solar diameter should be virtually constant in the SSM (Bahcall et al., 1995, p. 790). A decreasing solar diameter, or "solar contraction," would power the sun by conversion of the potential energy of infalling gases into heat. **A secular diameter trend means that the sun cannot be in hydrostatic equilibrium and is incompatible with the SSM** (Chandrasekhar, 1939, p. 455):

"The order of the 'age' of the sun [by the] contraction hypothesis is found to conflict with ... evidence ... of a geological nature. ... [T]he geological evidence completely disproves the contraction hypothesis for the sun, and therefore also for the normal stars. We are thus led to seek a different origin for the source of stellar energy."

Chandrasekhar was calling for an acceptance of solar energy sources besides contraction, and for a solar model matching the earth's evolutionary chronology. Over the decades that model developed into the SSM. A.S. Eddington (1929, p. 96) likewise claimed:

"Physical and geological investigations seem to decide definitely that the age of the earth ... is far greater than the [age allowed by solar contraction for] the solar system. It is usual to lay most stress on a determination of the age of the rocks from the uranium-lead ratio . ... The sun, of course, must be very much older than the earth and its rocks."

Clayton (1968, p. 43) and Fix (1999, p. 387) respectively assert:

"This time [for contraction of order 10^7 yr] is much too short for a maximum lifetime of the sun. It is known that the sun has existed over 100 times longer than this, because the age of the earth itself is about 4.6 billion years."

"[There are fossil bearing] rocks 3.5 billion years old ... [T]he Sun has warmed the Earth for at least 3.5 billion years and probably for as long as the Earth has existed."

Though the fusion concept *alone* is age independent, the SSM is not. The SSM is set to have the sun evolve from a zero age on the main sequence to its putative age of 4.6 billion years because that is the earth's conventional age; i.e., "... stellar evolution requires an old universe" (Briegleb, 1993, p. 71). As mentioned above, **SSM parameters are constrained to generate a chronological history of the sun with solar properties attaining their present value over 4.6 billion years.** Harwit (1982, p. 343) emphasizes the importance of the age criterion in the SSM: "Over a period amounting to several aeons [billions of years], a star moves over from the initial zero age main sequence" to its present state. Accommodationist Hugh Ross (1994, p. 107) writes,

"Various measured characteristics of the sun - including its effective temperature, luminosity, spectra, radius, outflow of neutrinos, and mass - all guarantee that the sun [has been] burning by nuclear fusion ... for about 5 billion years."

By naming several observable characteristics, Ross obscures the many unknown parameters the SSM employs. **Interpretation of solar neutrino data also requires assigning values to unknown parameters.** Thus, “confirmation” of the SSM by neutrino oscillations does not close the case for the sun’s conventional age.

The reported detection of neutrino oscillations (Seife, 2001, pp. 2227-2228) has actually increased the difficulty of interpreting neutrino data (Bahcall, 1997, p. 11) rather than making it more straightforward. For example, based on expectations from particle physics, the "mixing angle" involved in solar neutrino detection was once predicted to be small. The value of the mixing angle is unknown *a priori* and is therefore an adjustable parameter. It was found that large mixing angles must be chosen to generate agreement "between observed and predicted neutrino event rates" (Bahcall, 2002, p. 9), i.e., neutrino observations have been brought into line with SSM predictions by an appropriate parameter adjustment (Bahcall, 2002, p. 10).

Bahcall et al. (2002, p. 1) have illustrated the difficulty of appropriate parameter constraint by modeling the sun with 99.95% of its luminosity generated by the CNO bi-cycle. **A parameter set sufficiently flexible to show hydrogen fusion in the sun (the conventional approach), or not, does not confirm either position.** Detection rates of electron neutrinos confirm that solar hydrogen fusion occurs, but the device of "neutrino oscillations" has not confirmed the SSM in its entirety.

Secular Contraction Contradicts the SSM and Conventional Chronology

The earliest notable advocates of solar contraction were Hermann von Helmholtz and William Thompson, Lord Kelvin. **Neither accepted a "tight" biblical chronology or sought to confirm a young solar age via contraction arguments.** Helmholtz proposed the solar contraction concept in 1854, publishing in 1856 "The Interaction of Natural Forces" (Moulton, 1902, p. 62; Birchfield, 1990, p. 54). He assumed the evolutionary model of solar formation still in vogue, that a nebula contracted to form the sun. [Though an existing star can contract, a diffuse nebula cannot (Mulfinger, 1970, pp. 11-12)]. In 1862 Kelvin published "On the Age of the Sun's Heat" (Birchfield, 1990, pp. 54, 241). Like Helmholtz, Kelvin believed that in-falling primordial debris originated solar energy (Kelvin, 1900). He thought solar contraction gave a better solar system age than geologists admitted (Birchfield, 1990, pp. 29-32), but saw the biblical age as too small.

Helmholtz estimated that solar formation required about 20 million yr, as follows. Energy is the product of applied force and distance traversed, and the potential energy released by a falling body is the product of gravitational force and the distance through which it falls. For the sun falling in on itself because of self-gravitation, the sun's mass interacts with its own mass by the law of gravitation, and the amount of potential energy dE released for each incremental decrease in radius dr is

$$dE = \frac{GM^2}{r^2}\,dr \qquad (1)$$

where G is the gravitational constant, and M is solar mass. Assuming that the putative nebula contracted from infinite distance to the present radius of the sun R, and that solar density at any phase of contraction is constant, integrating Equation 1 from $r = \infty$ to $r = R$ gives the potential energy released in the entire contraction process as

$$E = M^2G/R \qquad (2)$$

where R is the solar radius. Starting with Equation 1, we can find the sun's contraction rate, because

$$\frac{dE}{dt} = \frac{GM^2}{r^2}\,\frac{dr}{dt} \qquad (3)$$

Since dE/dt is the solar power or luminosity L, and dr/dt is the contraction velocity v, we have

$$L = \frac{GM^2}{r^2}\quad v \qquad (4)$$

Presently $L = 3.8 \times 10^{26}$ J/s, $r = R = 7 \times 10^8$ m, $M = 2 \times 10^{30}$ kg, and $G = 6.67 \times 10^{-11}$ $N{\cdot}m^2/kg^2$. Solving for the v gives

$$v = \frac{LR^2}{GM^2} \approx 7 \times 10^{-7}\ m/s = 22\ m/yr \qquad (5)$$

Finally, the approximate solar contraction time is

$$E/L \approx 1 \times 10^{15}\ s \approx 30 \times 10^9\ yr \qquad (6)$$

The result in Equation 6 is longer than Helmholtz' 20 million yr estimate because Equation 1 is approximate. A more accurate expression is (Harwit, 1982, p. 307; Benton, 1987, p. 146)

$$E = \frac{3}{5}\frac{M^2G}{R} \qquad (7)$$

By Equation 7, v = 36 m/yr, and the sun's lifetime ≈ 19 million yr, close to Helmholtz' estimate. Helmholtz probably used slightly smaller M and R, values similar to 1.94×10^{30} kg, and 6.92×10^{8} m, and luminosity was thought to be ≈ 3.21×10^{26} J/s, less than the present value (Moulton, 1902, p. 60). (Moulton lists the given value for R; M and L are inferred from other data in Moulton.) With these numbers in Equations 6 and 7, **the sun's lifetime ≈ 22 million years.**

By comparison, the SSM expects the sun's radius to *increase* ≈ 40% over its 10 billion yr main sequence lifetime (Fix, 1999, p. 441). This is an increase of 4 billionths of a percent per year, or ≈ 8×10^{-8} arc-sec per year, since the solar diameter ≈ 1920 arc sec. The cumulative effect of this increase would be unobservable over the entire history of mankind, but nevertheless is accepted as real (Van Till et al., 1988, p. 49):

"As a consequence of changes brought about by thermonuclear fusion, a slow secular increase in stellar size is predicted -- far too slow to observe with present instrumentation, but a secular *increase* nonetheless [emphasis in original]."

On the other hand, Helmholtz contraction is about 36 m or 5×10^{-5} arc-sec of radius contraction per year, too small to be immediately observable, but with a cumulative effect visible over a long period. Over, say, 250 years, the solar diameter decrease by Helmholtz theory would be ≈ 0.025 arc-sec (twice the radius decrease), or ≈ 0.01 arc-sec per century, more than 1000 times the hypothetical increase in the SSM. However, Fix (1999, p. 387) concludes, "If the Sun were actually shrinking at this rate ... it would be very difficult to measure," though he accepts as certain the much smaller (and unobservable) SSM expansion rate.

The Helmholtz' solar time scale puts no constraint on biblical chronology, but the resulting limit on conventional chronology is disastrous. Perhaps this is why creationists frequently have acknowledged the possibility of solar contraction (Benton, 1987, p. 147), claiming that, "It cannot be conclusively stated that the sun is not partly powered by slow gravitational contraction" (Briegleb, 1993, p. 74), and that, "The gross properties of the sun are consistent with both nuclear fusion and gravitational contraction" (Faulkner, 1995, p. 43). Indeed, "most creationists believe that Kelvin-Helmholtz contraction does occur" (Faulkner, 1998, p. 212).

The Eddy-Boornazian Claims Have Been Misunderstand

Eddy and Boornazian (1979, p. 437) published the abstract of a study claiming a decrease in solar diameter of 0.1% or 2 arc-sec per century. The full text was never published (Van Till et al., 1988, p. 180). Van Till et al. (1988, p. 53) conclude:

"Though they did not consider their results ready for formal publication Eddy and Boornazian decided to present their puzzle in a brief talk at a meeting of the American Astronomical Society. In this way the professional scientific community could join them in a critical evaluation of the data and their interpretation." Was Eddy hoping for a more positive response to this announcement than was forthcoming? This can be inferred from Eddy's apparent willingness to accept a "young" sun (Kazmann, 1978, p. 18), a chronological stance open to a Helmholtz contraction time frame.

Some creationists (Akridge, 1980, pp. 1-4; Hanson 1981, 27-29) eagerly exploited the Eddy/Boornazian claim to show that solar evolution did not require the long time of the SSM, and therefore that solar fusion must be absent. This response was faulty, for **questions about the SSM do not rule out solar fusion.** As DeYoung and Rush (1989, p. 51) observed, "The question we are addressing ... is not one of origins but one of operation." Indeed, Eddy and Boornazian (1979, p. 437) doubted that their claimed diameter decrease rate was a secular trend, and much of it was oscillatory (Van Till et al., 1988, p. 51). From 1967-1980 the sun's diameter *increased* slightly (Frolich and Eddy, 1984), confirming that **some of the solar change announced in 1979 was cyclic.**

A common misunderstanding of the Eddy/Boornazian result is that, having been shown to be largely cyclic, it somehow refutes any possibility of secular solar contraction, and anti-creationists have exploited the temporal aspect of the Eddy/Boornazian results for this purpose (Johansson, 2003, p. 18). Another anti-creationist approach is to criticize creationist writings relying on Eddy and Boornazian (Johansson, 1999, pp. 18-20). In dismissing secular solar contraction Johansson mentions only the Eddy/Boornazian figure and creationists (e.g., Akridge, 1980, p. 1) who used it. Van Till et al. (1988, pp. 47-49, 53) follow a similar approach. **However, using the Eddy/Boornazian result to discredit secular solar contraction is invalid, because other studies have produced positive evidence for it.**

Studies Other Than Eddy/Boornazian Have Shown Secular Contraction

This section considers conclusions about secular contraction; cyclic diameter variations are discussed later. Sofia et al. (1979, p. 1306) related changes in the solar constant to solar diameter changes, noting that from 1850-1937 the solar constant decreased ≤ 0.3 percent. This implies that "there is evidence in both the horizontal and vertical directions for a slow systematic [secular] decrease of the observed radius by about 0.2 arc second over this time," a diameter decrease of 0.46 arc-sec per century (Sofia et al., 1979, pp. 1306, 1307).

This result is more than 40 times the Helmholtz diameter contraction rate of 0.01 arc-sec per century. Nevertheless, Van Till et al. (1988, pp. 49-50) minimized this result by comparing it with the Eddy/Boornazian diameter contraction rate of 2 arc-sec per century:

"The sun's diameter did not diminish by more than 0.5 arc second between 1850 and 1937. This value was less than one-fourth the rate proposed by Eddy and Boornazian."

These authors sought to discredit Eddy and Boornazian's results because of the conflict with conventional chronology (Van Till et al., 1988, pp. 59-60, 62):

"Because both geological and radiometric evidence indicated a terrestrial age of billions of years, the gravitational collapse lifetime for the sun - a few tens of millions of years - presented a real puzzle. ... [A] vast array of empirical and theoretical considerations [has] led the professional scientific community to the well-founded *conclusion* (not assumption) that the solar system formed about 4.6 billion years ago [emphasis in original]."

This assessment came after the Eddy/Boornazian data were known to have cyclic components, so Van Till et al. were aiming at a target irrelevant to claims of Sofia et al. (1979, p. 1306).

Shapiro (1980, p. 51) evaluated 23 solar transits of Mercury from 1736-1973 by weighting modern (c. 1950-1973) data to obtain a best-fit secular diameter *increase* of + 0.05 arc-sec per century (Shapiro, 1980, p. 52). Van Till et al. (1988, p. 50) reproduced Shapiro's best-fit diagram, stating, "Shapiro concluded that no significant change in the sun's diameter could be detected."

Both Shapiro and Van Till et al. included in the diagram the much greater Eddy/Boornazian contraction rate, an approach also followed by Lubkin (1980, p. 18) and *Sky and Telescope* (Anonymous, 1980, p. 11), which had the effect of making Shapiro's changes seem insignificant indeed. This assessment was unwarranted. Shapiro acknowledged that if the modern data were not unfavorably weighted, the resulting best fit would be a diameter decrease of 0.11 ± 14 arc-sec per century (Shapiro, 1980, p. 52), about 10 times the Helmholtz rate. Shapiro attempted to justify his weighting of the modern data (Shapiro, 1980, pp. 51, 53) by citing Innes (1925, p. 303), who omitted the "apparently less reliable modern data" to derive a diameter increase of + 0.25 arc-sec per century (Shapiro, 1980, p. 52).

However, the "modern" data omitted in Innes' 1925 study were not the same (c. 1950-1973) data questioned by Shapiro, so the appeal to Innes was irrelevant. Shapiro also noted that Innes attributed his results "to the effects of the use of more powerful optics for observations of the later transits" (Shapiro, 1980, p. 53), not to secular solar diameter increase.

There was little scientific reason for Shapiro's mention of Innes, but possibly a powerful philosophical reason - the desire to discredit data which appeared to confirm secular solar change contra the SSM. Indeed, Shapiro revealed the implicit chronological basis for rejecting the possibility of such contraction (Shapiro, 1980, p. 51):

"The [Eddy/Boornazian rate of solar shrinkage] can clearly not be constant; if it were, the sun ... would have been twice its present diameter 100,000 years ago."

Rejecting the Eddy/Boornazian data because of its temporal aspect is legitimate, but Shapiro's rejection motivated by a defense of evolutionary chronology is fallacious. Shapiro ended his analysis by acknowledging another Mercury transit study (Morrison and Ward, 1975, p. 183) indicating a secular diameter decrease of 0.14 ± 0.08 arc-sec per century, thus confirming Shapiro's unweighted 0.11 arc-sec per century contraction rate.

Dunham et al. (1980, p. 1244) evaluated solar eclipse data from 1715-1979, concluding that "a decrease in the solar radius of 0.34 ± 0.2 arc second was observed," equivalent to a decrease of 0.26 arc-sec per century. Gilliland (1981, p. 1150) corroborated this claim. Further, this conclusion was consistent with the diameter decrease ≤ 0.65 arc-sec over 264 years obtained by Sofia et al. (Dunham et al., 1980, p. 1244). Ribes et al. (1987, p. 53) note that, "An eclipse observation is intrinsically more accurate" for solar diameter measurement than Mercury transit observations.

However, eclipse data also generated the much larger Eddy/Boornazian result. Dunham et al. (1980, p. 1243) explained this discrepancy: "The disagreement was due to the different criteria used by the two groups to select what they considered to be reliable data," indicating that the Eddy/Boornazian result showed a short-term cyclical change in solar diameter, not a secular variation.

Parkinson et al. (1980, p. 548) reached the same conclusion, claiming an 80-year periodicity in solar radius. This claim has stood the test of time as discussed further below. Van Till et al. (1988, p. 51), echoing Parkinson et al. (1980, p. 548), stated that there has been "no secular change over the past 250 years." However, elsewhere co-author F.R. Stephenson wrote concerning this study that, "John H. Parkinson of University College London, Leslie V. Morrison of the Royal Greenwich Observatory and I have calculated that the percentage of decrease [in the solar diameter] is 0.008 ± 0.007 per century" (Stephenson, 1982, p. 172), equivalent to 0.15 arc-sec per century.

Gilliland (1981, pp. 1144, 1154) concluded that there is a 76-year periodicity in solar radius, together with a "secular trend" in radius contraction of 0.1 arc-sec per century in the past 265 yr. Wittman et al. (1991, p. 243) emphasized that Gilliland "presented conclusive evidence for both a cycle-dependence and a long-term [secular] variation of the solar diameter." Gilliland (1981, p. 1150) also responded to the Parkinson et al. (1980, p. 548) assertion of no secular change:

"In the partially justified, but perhaps overzealous, criticism of the early Eddy and Boornazian (1979) claims there is the distinct possibility that much smaller but still fundamentally important . . . secular trends are being inadvertently disclaimed."

Newkirk (1983, p. 460), despite strong advocacy of the SSM, also agreed that "a majority of the analyses indicate a slight [secular] contraction."

Claims of No Secular Contraction Should Be Examined Carefully

In assessing claims that secular contraction does not exist, one should remember the conflict between secular contraction and the SSM prediction. Gilliland (1981, pp. 1144-1145, 1149-1150) wrote:

"[S]tellar evolution theory predicts a *positive*, albeit it indetectably small, secular trend for the solar radius. ... A negative secular trend lasting for solar thermal time scales would present a ... serious problem for astrophysicists ... Since stellar evolution theory predicts a positive secular solar radius change with increasing age (+ 3.3×10^{-6} arc s per century), any negative secular change ... is significant."

Similarly, Noel (2001, p. 697) wrote:

"[A] star like the Sun should have a radius increase not larger than a few parts in 10^{11} per year. ... [S]ome authors [he names Gilliland] claim to have detected significant [secular] variations of the apparent solar radius. ... If these variations are real, they mount a serious challenge to stellar structure theory."

If the SSM is true, there cannot be secular contraction. If secular contraction exists, the SSM is false. An investigator accepting the SSM is in a contradictory position when advocating secular contraction. Unless the SSM is given up, the investigator must eventually characterize secular contraction as insignificant or nonexistent. Parkinson (1983, p. 518) purported to show a reduced secular contraction rate over an earlier study (Parkinson et al., 1981, p. 548), but the reduced rate was not zero.

Likewise, Sofia et al. (1983, p. 522) also claimed no evidence for detectable solar radius change from 1925-1979, but this claim had little bearing on the earlier Sofia et al. (1979, p. 1306) study covering a different period (1850-1937). The two reports of Sofia et al. appear to indicate that changes in solar diameter may occur nonuniformly. The time-weighted average secular decrease in solar diameter between the two reports, using 0.46 arc-sec per century for 1850-1937, and zero for 1925-1979, is 0.31 arc-sec per century, still larger than most of the comparable figures cited above.

Toulmonde (1997, p. 1174) claimed no "sensible secular variation" since the 1600s, echoing Wittman (1980, p. 190) who emphasized alleged difficulties "in the telescope, the observer's eye, or in the observing method" of measurements even in the 1800s.

Toulmonde (1997, pp. 1175, 1176) achieved his results using quantities such as a "personality" factor and lens diffraction as adjustable parameters to correct old observations. These factors seek to adjust for systematic errors among different observers and for the optical properties of old instruments, but such "corrections" have been criticized on several grounds.

There is first the assumption that modern measurements are better than old ones. Noel (2001, p. 698) cites Toulmonde as making this questionable assumption, and points out "that in certain circumstances, visual measurements of the solar radius can be more accurate than those made with photoelectric devices."

Gilliland (1981, p. 1153) emphasized that "personality corrections are arbitrary and subjective; application of different systems of personal equations would yield entirely different results." Finally, O'Dell and van Helden (1987, p. 630) point out that the optical properties of centuries-old instruments cannot be simulated accurately in recent reconstructions and thus cannot be reliably corrected for:

"We question the wisdom of applying corrections derived from telescopes designed and built two centuries after the Picard instruments [of the 1600s]."

Ribes et al. (1987, p. 53) also point out that the "irradiation correction is somewhat uncertain ..." Toulmonde's conclusion that there is no "secular variation" does not appear extremely robust.

Short-Term Solar Radius Studies Do Not Disprove Secular Contraction

Short-term determinations of solar radius have been cited as showing no secular contraction. This is invalid, for Helmholtz contraction happens at too small a rate to measure in intervals less than decades. DeYoung and Rush (1989, p. 49) present a case in which photoelectric determination of solar radius by LaBonte and Howard (1981, p. 907) was used to discredit the Eddy/Boornazian contraction rate, and by extension, the possibility of secular contraction. The LaBonte/Howard study was irrelevant to long-term secular change, because it covered too short a time, < 7 yr. LaBonte and Howard discuss uncertainties and sources of error also discussed by Rosch and Yerle (1983, p. 139), and these imply that secular diameter changes are indetectable over periods less than decades.

Indeed, Laclare et al. (1996, p. 211) analyzed solar diameter measurements from 1975-1994, concluding: "The series of measurements ... is plainly too short to enable the detection of an eventual secular trend" (Laclare et al., 1996, p. 227).

Another photoelectric investigation of solar radius from 1981-1987 concluded that "annual averages of the radius are identical" with an uncertainty of ± 0.026 Mm (Brown and Christensen-Dalsgaard, 1998, p. 1), but the study's 6 yr span was too brief to detect secular change. Using this result, Johansson nevertheless declared "no evidence of [secular] change over time" (Johansson, 2003, p. 19; Johansson, 1999, p. 19).

Solar Cycle Studies Do Not Disprove Secular Contraction

The aforementioned conflict between the SSM and secular contraction perhaps explains why studies of solar cycles have been cited as implying that all solar variation is temporal (e.g., Morrison et al., 1988, p. 421). This objection is invalid, since **cyclic changes can exist alongside a secular trend.** Ribes et al. (1987, pp. 52-55) claimed a solar diameter shrinkage of up to 4 arc-sec since 1669, equivalent to a diameter contraction rate of 1.3 arc-sec per century (Morrison et al., 1988, p. 421), more than 100 times the Helmholtz rate.

Morrison et al. (1988, p. 421) showed that the results of Ribes et al. could not be a secular trend but did not show that smaller secular trend does not exist. The Ribes et al. results may reflect a long-term cyclic change of the same sort proposed by Eddy and Boornazian (1979, p. 437) over about 400 yr (Lubkin, 1979, p. 18). Indeed, "levels of solar activity have been increasing gradually over the past 400 years" (Schatten, 1990, p. 578; Matthews and Venkatesan 1990, p. 600), a fluctuation tied to solar diameter changes as we will now see.

The sun is non-rigid with oscillatory cycles ranging from brief helioseismic phenomena (Henry, 2003, p. 34) to periods possibly as long as centuries (Ribes et al., 1987, p. 54; Wittman et al., 1991, p. 243). Frequently reported cycles include those with periods of about 80 yr (Emilio et al., 2000,

Table I. Solar Secular Contraction Data

Contraction rates are in arc-sec/century. The "Data Type" column lists the type of data used; MT = Mercury transit of the sun; SE = solar eclipse; ST = solar transit. The average secular contraction rate in the diameter is v_{obs}; v_{obs}/v_{theory} is the ratio of the average secular contraction rate compared to the Helmholtz rate of 0.01 arc-sec/century. v_{max} and v_{min} are respectively the upper and lower end of the stated error range.

Investigator(s)	Data Type	v_{obs}	v_{obs}/v_{theory} x 10^{-1}	Error Range v_{max}	Error Range v_{min}
Dunham et al.	SE	0.26	3	0.41	0.11
Gilliland	MT, ST	0.2	2		
Morrison and Ward	MT	0.14	1	0.22	0.06
Parkinson et al.; Stephenson	MT, SE	0.15	2	0.29	0.02
Parkinson[1]		< 0.16	< 2		
Shapiro[2]	MT	0.11	1	0.25	+ 0.03
Sofia et al. (1979)	ST	≤ 0.46	≤ 5		
Sofia et al. (1983 and 1979)[3]		≤ 0.31	≤ 3		
Averages		0.17[4]	2	0.30[5]	0.04

Notes for Table 1:

Note 1. Parkinson (1983, p. 518) showed a reduced upper limit, taken ≤ 0.16 arc-sec per century (Stephenson, 1982, p. 172).
Note 2. Modern data not unfavorably weighted (Shapiro, 1980, p. 52).
Note 3. Time-weighted secular contraction average, with a zero rate for 1925-1979, and 0.31 arc-sec per century for 1850-1937.
Note 4. Averages for v_{obs} and v_{obs}/v_{theory} are for the four entries with error range sets, plus the Gilliland entry.
Note 5. Averages for v_{max} and v_{min} are for the four error range sets.

p. 1007; Gilliland, 1981, pp. 1149, 1153, 1154; Kubo, 1993, p. 828; Laclare et al., 1996, p. 211), 11 yr (Gilliland, 1981, pp. 1152, 1154; Kubo, 1993, 828), and 1000 days (Delache et al., 1985, p. 416; Emilio et al., 2000, p. 1007; Laclare, 1987, p. 451; Laclare et al., 1996, p. 223).

Evidence of temporal solar diameter variation from solar oscillatory f-modes has been contradictory. Antia et al. (2000, p. 459) and Dziembowski et al. (2001, p. 897) inferred "a shrinking sun" during "the rising phase of the [solar] activity cycle," but Antia and Basu (2004, p. 301) re-interpreted the f-mode data to conclude no temporal variation exists.

On the other hand, detected solar diameter oscillations correlate with the solar cycle (Costa et al., 1999, p. L63; Emilio et al., 2000, p. 1007; Laclare, 1987, p. 451; Noel, 1997, p. 825; Noel, 2001, pp. 697, 701), and with solar neutrino flux changes (Laclare, 1987, p. 451; Laclare et al., 1996, pp. 225-226). Further, solar diameter oscillations and the solar cycle are related to the irradiance (Laclare et al., 1996, p. 225; Ulrich and Bertello, 1995, p. 214). These oscillatory cycles coexist with secular diameter change (Gilliland, 1981, p. 1144; Wittman et al., 1991, p. 243).

Secular Contraction Implies a Solar Future Different from the SSM

Table I summarizes the *secular* solar contraction results discussed above; cyclic variations are not included. In Table I, the average minimum contraction rate v_{min} is ≤ 0.04 arc-sec per century, several times the Helmholtz rate. **This figure implies that contraction supplies at a minimum more than enough energy to maintain the sun's luminosity, even without fusion.** If this is so, the sun is accumulating energy within.

The average contraction rate v_{obs} is 0.17 arc-sec per century, corresponding to an average $v_{obs}/v_{theory} \approx 20$. This result implies a contraction rate on the order of 10 times the Helmholtz prediction. **Rather than the 20 million year solar lifetime implied by Helmholtz contraction, this implies a maximum evolutionary solar age of order 10^6 yr.** This age constraint invalidates the 10-billion-year main sequence interval, but is longer than the biblical chronology, so is not a true age indicator. Solar fusion also adds a component to the sun's potential lifetime making impossible an "upper-limit" age determination from solar contraction.

Though the sun appears superficially stable, a contraction rate of order 10 times above the Helmholtz value means that the sun is not in thermal equilibrium, and implies that it could enter an unstable phase in the future due to release of accumulated energy. **If this is the case, the sun appears to be in a degradational collapse mode that will culminate in solar instability.** However, the present contraction rate and observed solar data (as opposed to SSM parameter values) are sufficiently uncertain that it is impossible to estimate a date for this hypothetical instability. The widespread expectation that the sun has a long future period of stability does, however, appear to be less than certain. This expectation is an aspect of the uniformitarian belief that "all things continue as they were from the beginning of the creation" (2 Peter 3:4)

The implication of future instability in a higher-than-Helmholtz rate of contraction suggests that there was a primordial (pre-Fall) equilibrium which was destabilized possibly in connection with the Curse in Genesis. **Perhaps solar contraction was not the energy generation mode which God designed for the sun.** A fusion analog may have operated in the sun before the Fall, but could not have been identical to modern nucleosynthesis theory, since the original creation was not subject to decay, and nucleosynthesis theory ends in star death after extended times.

Though the sun's total irradiance varies by only ± 0.1% over a solar cycle (Bahcall et al., 1995, p. 784), making the sun an unusually stable star (Seife, 1999, p. 15), other sun-like stars are less stable, emitting superflares (SFs) which would extinguish life on earth were they to happen in the sun (Schaefer et al., 2000, p. 1029). It has been proposed that SFs are due to destabilizing forces of giant planets in close orbits, but no such planet has been detected (Rubenstein and Schaefer, 2000, p. 1031). Rubenstein and Schaefer et al. (2000, p. 1028) label such planets "hypothetical," and Rubenstein (2001, p. 45) emphasizes that searching for such planets has yielded "nothing." Newer information (Butler, et al., 2003, pp. 455-466) continues to show that no SF-causing planets have been detected. **Thus the possibility of internal instabilities in these stars cannot be ruled out as a cause of SFs.** Indeed, the denial that such instabilities could occur in the sun is tied to acceptance of the SSM (Emilio et al., 2000, p. 1007):

"[L]uminosity and irradiance changes over solar cycle timescales are quite similar [i.e., the sun's luminosity follows the solar cycle] ... [T]his radiated energy originates from the nuclear conversion of H to He deep in the solar interior. Since energetic photons require nearly a million years to diffuse out of the core region [this is an assumption of the SSM; see Henry (2004a, pp. 251-252)], the emergent luminosity at the core outer boundary is effectively constant on solar cycle timescales. Thus, given the observed luminosity variability at the surface, there must be an intermediate energy reservoir somewhere between the core and the photosphere. Several mechanisms exist for storing energy during a solar cycle (e.g., gravitational or magnetic fields) ..."

Hence instabilities causing luminosity and diameter cycles are believed to lie close to the surface, for the SSM rules out other possibilities. Delache et al. (1985, p. 416) have questioned this assumption: "The physical origin of these variations is found in deep layers of the solar body, possibly in the core for the 1000 days oscillation."

The sun is unusually stable now, but presently unacknowledged instabilities in the interior might be manifested outwardly in time. As mentioned previously, the sun's secular contraction rate may not be constant. "Convective overshooting" associated with such variability may be a plausible mechanism for the "material mixing" in the sun revealed by helioseismology (Gough et al., 1996, p. 1299).

Such variability has in fact been described as a source of potential instability. If happening deeply enough, convective overshooting could affect core fusion reactions, causing the apparent 21.3 day periodicity in solar neutrino flux (Holden, 1996, p. 1663). Though the usual assumption is that neutrino flux periodicity cannot originate from the core, this conclusion actually follows from the assumption of long thermal time scales which in turn is a consequence of assuming high opacity in the SSM (Henry, 2004a, pp. 251-252). With the assumption of a long thermal time scale implied by high opacity, Fix (1999, p. 390) states,

"The energy produced in a single second [in the core] is radiated from the Sun's surface over a period of more than 100,000 years. ... Suppose energy generation were to cease in the core for a day, a year, or even a century, and then resume. By the time the energy flowed to the surface, the temporary absence of energy would be averaged over more than 100,000 years. The resulting drop in solar brightness would be too small to measure."

Using the same argument, Bahcall and Davis (1976, p. 266) rule out the possibility that variability in solar neutrino flux could indicate changes in core activity:

"It is unlikely that variations ... are due to changes in the solar neutrino flux, since solar thermal time scales are tens of thousands of years or longer."

With solar opacity less than the SSM allows, periodicity in solar neutrino flux could be at least partly due to changing fusion reaction rates in the core. There is the possibility "that nuclear burning in the sun's core is not a steady process, as theorists usually imagine, but a cyclic one, like combustion in the cylinders of a gasoline engine" (Holden, 1996, p. 1663). Eddy has commented, "I don't think that such irregularity is a mark of health. I think it's the mark of a shaky, rickety machine" (Bell, 1978, pp. 16-17). **This assessment is consistent with the fact that the sun, and all of creation, is "groaning" (Romans 8:20-22) rather than functioning according to the original design God intended.**

How Would Secular Contraction Affect Solar Temperature and Luminosity?

Suppose the sun contracts at 10 times the Helmholtz rate, generating energy at ≈ 10 times its luminosity, the extra energy accumulating within. This accumulation ≈ 3.8×10^{28} J/s or 1.2×10^{36} J/yr, producing a yearly temperature increase computed as follows. The sun's mass is 2×10^{30} kg. With the average specific heat for solar matter from 10-10,000 times that of water (Kelvin, 1900; Dalrymple, 1994, p. 17), solar internal temperature would increase between 0.014°C and 14°C per yr.

Can heat capacities exceed that of water by powers of ten? Heat capacity increases with temperature, the rate of increase generally being greater the more complex the molecule or atom (Daniels and Alberty, 1966, p. 45; Gordon and McBride, 1999, p. 308). This is true even for monatomic gases, with H departing from ideal-gas heat capacity at ≈ 6800 K, and He at ≈ 12,500 K (Gordon and McBride, 1999, pp. 135, 141).

Heat capacities for plasma species such as H^+ and He^+ do not depart from the ideal-gas value at temperatures below order of 10^4 K (Gordon and McBride, 1999, pp. 137, 143), but more complex plasma species diverge at lower temperatures, and at temperatures of order 10^4 K may have heat capacities several times that of water.

Heavy species are thought to be a small percentage of the sun's mass (Bahcall et al., 1995, p. 785), but at solar interior temperatures for which empirical data are lacking, it is reasonable to expect that heavy monatomic plasma species would collectively produce a heat capacity in Kelvin's proposed range. Heavy species are believed to affect solar interior properties disproportionately (Bahcall et al., 1995, p. 784). By comparison, average specific heat in the SSM's convection zone is said to be ≈ 5 times that of water (Harwit, 1982, p. 328).

Let's assume that the aforementioned temperature rise is detectable immediately at the surface, not a good assumption since this requires a homogeneously mixed sun, but the most conservative we can make. **We now consider the detectable level of temperature increase in the sun since spectroscopic measurements began in the mid-1800s.** Currently, the solar (absolute) luminosity is measured to be 3.844(1 ± 0.004) x 10^{26} J/sec (Bahcall et al., 1995, p. 784). The Stefan-Boltzmann equation relates solar surface temperature to luminosity (Harwit, 1982, p. 132). Solar surface temperature is about 5800 K (Fix, 1999, p. 386). Ignoring the spectral shift with change in temperature, the corresponding range of uncertainty in solar surface temperature is of order 10°C.

It was mentioned earlier that inferred luminosity c. 1900 is 3.21 x 1026 J/sec, slightly below the current value. Accepting this figure at face value, this difference implies a temperature increase in the sun of ~ 290°C over the last century, or ≈ 3°C/yr. That is, **fluctuations in contraction rate causing a temperature rise less than about 10°C could not be detected, and over the past century the temperature rise could not have been > 3°C/yr.**

Since the human eye is sensitive to brightness changes differing by a factor ≥ 2.5 (Harwit, 1982, pp. 508-509), **on the order of a millennium would be required to detect unit magnitude change in the sun's brightness,** assuming the change from $L_\odot$ = 3.21 x 10^{26}J/s to 3.844 x 10^{26}J/s over the last century is real [(3.844 -3.21)/3.84 = 0.164 fractional change per century; 2.5/0.164/century ≈ 15 centuries]. However, the lower $L_\odot$ inferred for c. 1900 may have been based on visual magnitude only, whereas the higher number is an absolute value as noted above.

Nevertheless, it appears that secular contraction at 10 times the Helmholtz rate could be occurring without causing short-term luminosity changes detectable by instruments. **Change noticeable by the unaided eye would be indetectable over less than millennial time scales.**

Secular Contraction May Affect Long-Term Neutrino Flux

Solar neutrino flux is related to solar cycles and oscillatory diameter changes as discussed above. **Secular contraction and long-term neutrino flux changes may also be related.** Neutrino-producing reactions are believed to include the *p-p* reaction, the B-8 reaction, and the CNO bi-cycle (Bahcall et al., 2001, p. 1000), plus other minor contributors. The CNO bi-cycle is thought to be insignificant, producing ≈ 1.5% of expected neutrino flux (Bahcall et al., 2001, p. 1000).

Of the reactions believed to be occurring in the sun, the B-8 reaction is thought to show the strongest dependence of neutrino flux on absolute temperature T, with $\varphi(^8B) \propto T^{25}$, where $\varphi(^8B)$ is the B-8 reaction neutrino flux (Bahcall and Ulmer, 1996, p. 4206; Bahcall, 2002, p. 9), but the B-8 reaction is thought to contribute < 0.01% to the expected neutrino flux (Bahcall et al., 2001, p. 1000). The neutrino flux of the *p-p* reaction is believed to decrease with increasing T, with $\varphi(pp) \propto T^{-1.1}$, where $\varphi(pp)$ is the *p-p* reaction neutrino flux (Bahcall et al., 1996, p. 4205). Thus, if the sun were accumulating energy by contraction, $\varphi(pp)$ should decrease. Since the *p-p* reaction is believed to be the major neutrino contributor (approximately 90%, Bahcall et al., 2001, p. 1000), **overall neutrino flux should slowly decrease with time.**

How might the *p-p* reaction be affected by solar contraction at 10 times the Helmholtz rate? Let's assume that the entire temperature rise due to contraction is restricted to the core where fusion reactions are believed to occur, possibly not a very good assumption since the sun's core may not be well defined (Henry, 2003, p. 35), but which is the most conservative assumption possible. The *p-p* reaction would undergo a corresponding neutrino flux decrease.

The core is conventionally taken to occupy ≈ 1.5% of the sun's volume (Fix, 1999, p. 386). Thus accumulated heat is concentrated in the core by a factor of 100%/1.5% ≈ 70. This factor must be inserted as a multiplier of the computed core temperature increase. Assuming a specific heat 100 times that of water, the core temperature increase is then ≈ 70 x 1.4°C = 95°C. The percent decrease in $\varphi(pp)$ would be ≈ 0.01% per year with a core temperature of 1 x 10^6 K, and ≈ 5 x 10^{-4}% yearly for a 15 x 10^6 K core temperature [100% - 100% x $\{(T_{core} + \Delta T)/T_{core}\}^{-1.1}$]. Time scales of the order of centuries would be required to produce a 1% decrease in *p-p* neutrino flux. **Contraction at 10 times the Helmholtz rate or less would be undetectable by monitoring p-p neutrino flux over any reasonable interval.**

In the B-8 reaction, the dependence of $\varphi(^8B)$ on the twenty-fifth power of temperature means that if the sun warmed, $\varphi(^8B)$ would rise. With the parameter values of the previous paragraph, each year would bring a corresponding increase in $\varphi(^8B)$ of ≈ 0.2% assuming a core temperature of 1 x 10^6 K, and ≈ 0.02% with a core temperature of 15 x 10^6 K [100% x $\{(T_{core} + \Delta T)/T_{core}\}^{25}$ - 100%]. These estimates are upper limits, but assuming the validity of the parameter values employed, **a cumulative rise in $\varphi(^8B)$ might be detectable over several decades if the core temperature of the sun were low.** Such a criterion could serve as confirmation or falsification of (1) lower core temperature than typically assumed, and (2) secular contraction at an enhanced rate.

Conclusions

The sun is powered by fusion; secular gravitational contraction may also occur together with cyclic changes. Secular contraction is not a solar age indicator since it is coupled with fusion to give the sun a longer potential lifetime than the biblical chronology. Gravitational contraction may also have a rate exceeding the Helmholtz rate. This implies neither hydrostatic or thermal equilibrium for the sun. The resulting internal thermal accumulation could lead to future solar instability. Thus the sun (and presumably other stars) are moving on the main sequence at a rate exceeding that predicted by the SSM and stellar evolution. Gravitational contraction seems to be a degradation, possibly initiated by internal stellar changes at the Curse in Genesis. In the initial perfect created state, gravitational contraction may have been absent, with the sun and other stars generating energy over long (essentially eternal) time frames by processes analogous, but not identical, to stellar nucleosynthesis as presumed to be occurring today.

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