Kronos Vol.IV No.4, Summer 1979

STELLAR THERMONUCLEAR ENERGY: A FALSE TRAIL?

RALPH E. JUERGENS

By now a full generation of highly trained specialists and theorists has devoted its time, its talents, and a substantial share of the world's public and private treasure to a search for the means to produce energy on Earth the way the Sun is said to do it – by fusing together the nuclei of light elements to form heavier ones, and in the process converting mass to energy.

The inspiration for this extended effort rose from the ashes of a world war. As the pall of horror thrown up at Hiroshima and Nagasaki began to clear, atomic scientists looked up at the Sun and imagined it to brighten with promise: There shines the example to be emulated – controlled nuclear fusion – energy unlimited from now till the end of time.

Of course, the violence of the fusion reaction was easily controlled by the Sun. That body was big enough and massive enough to tame the prodigal works, to beat back the fierce radiations, to shift them, sort them, convert them, and delay them until they were winded and docile, and then to release them in forms benevolent to life on Earth. But this need not mean that similar results were beyond the reach of technology.

With the process scaled down to manageable size, why shouldn't controlled fusion become a tool of man? The energy released in the conversion of hydrogen – so abundant in the seas of Earth – to helium – a useful and valuable element – could power the electric generators that man never seemed to have enough of.

Plasma physics became the promised land where all this would come to pass. In a remarkably short time thousands of young people with advanced degrees in plasma physics and electrical engineering were streaming from campuses of higher learning, primed and eager to get on with the business of harnessing fusion energy.

These enthusiasts disappeared into research laboratories and were seldom heard from again. The fusion reaction, so straightforward in theory, refused to be tamed.

Although the uranium-fission bomb of 1945 rather quickly led to a practical, controlled-fission device for the production of energy, the hydrogen-fusion bomb of 1952 led nowhere. The construction of a "clean" reactor based on nuclear fusion is as far away today as it was in the early 1950's.

Always – by analogy with the Sun – controlled fusion has been conceived as a two-part problem: A plasma of heavy hydrogen (deuterium and tritium) must be heated to tens of millions, or even to 100 million degrees, so that its component particles gain the speed and momentum needed to produce fusion when they collide; and this hot plasma must be held together long enough for such collisions to take place.

From the start the solution to the heating problem has been known; driving electric current through the plasma could handle that. So all these years of research have been devoted to devising a non-material container for the plasma – one that would not instantly vaporize at the required temperatures or chill the plasma to the point where fusion could not come about. The non-material of choice has always been the magnetic field, even though every proposal thus far advanced as to how such a field ought to be structured to do the job has brought nothing but frustration.

At every attempt, long before the plasma could be brought to *thermonuclear* temperatures, it always managed to leak out of its magnetic reactor.

This thermonuclear "crisis" was recognized and acknowledged as early as 1960, as was pointed out by Hannes Alfvén on the occasion of his acceptance of the Nobel Prize for Physics in 1970:

". . . As you know, plasma physics has started along two parallel lines. The first one was the hundred-years-old investigations in what was called electrical discharges in gases. This approach was to a high degree experimental and phenomenological, and only very slowly reached some degree of theoretical sophistication. Most theoretical physicists looked down on this field, which was complicated and awkward . . . it was a field which was not at all suited for mathematically elegant theories.

"The other approach came from the highly developed kinetic theory of ordinary gases. It was thought that with a limited amount of work this field could be extended to include also ionized gases. The theories were mathematically elegant and when drawing the consequences of them it was found that it should be possible to produce a very hot plasma and confine it magnetically. This was the starting point of thermonuclear research.

"However, these theories had initially very little contact with experimental plasma physics, and all the awkward and complicated phenomena which had been treated in the study of discharges in gases were simply neglected. The result of this was what has been called the thermonuclear crisis some 10 years ago. It taught us that plasma physics is a very difficult field, which can only be developed by a close cooperation between theory and experiments. . ."

Though Alfvén's words received wide circulation, published as the lead article in *Science* for 4 June 1971, they have been little heeded, and theory continues to lead the way as the search for magnetically contained thermonuclear plasma goes on.

Meanwhile, the same theories have been applied by astrophysicists trying to understand the universe, again leading to much frustration. Alfvén discussed this, too, in his Nobel Address:

"The cosmical plasma physics of today is far less advanced than the thermonuclear research physics. It is to some extent the playground of theoreticians who have never seen a plasma in a laboratory. Many of them still believe in formulas which we know from laboratory experiments to be wrong. The astrophysical correspondence to the thermonuclear crisis [,however,] has not yet come . . . [Nevertheless,] several of the basic concepts on which the theories are founded are not applicable to the condition prevailing in the cosmos. They are 'generally accepted' by most theoreticians, they are developed with the most sophisticated mathematical methods; and it is only the plasma itself which does not 'understand' how beautiful the theories are and absolutely refuses to obey them. . ."

Alfvén's paper, of course, dates from 1970. In the years since then, it appears, a problem has come up that may indeed signal the onset of a thermonuclear crisis in astrophysics to match that in the search for controlled nuclear fusion.

Surprisingly, this problem emerged in connection with the supposed fusion reactions that power our Sun.

The certainty that the Sun generates its prodigious outpourings of energy through thermonuclear reactions deep in its interior has been with us about half a century. But now, suddenly, suspicions are being voiced that this may not be the case after all.

Doubts have been raised by recent findings on several fronts.

Probably the most distressing of these discoveries concerns the sub-atomic particles called *neutrinos,* which ought to be showering down on us from the Sun but apparently aren't. Suppose we let John N. Bahcall and Raymond Davis, Jr., two researchers who have followed this trail for a long time, tell part of the story:

"For the past 15 years we have tried, in collaboration with many colleagues in astronomy, chemistry, and physics, to understand and test the theory of how the sun produces its radiant energy (observed on the earth as sunlight). All of us have been surprised by the results: there is a large, unexplained disagreement between observation and the supposedly well established theory. This discrepancy has led to a crisis in the theory of stellar evolution; many authorities are openly questioning some of the basic principles and approximations in this supposedly dry (and solved) subject.

". . . Most natural scientists believe that we understand the process by which the sun's heat is produced – that is, in thermonuclear reactions that fuse light elements into heavier ones, thus converting mass into energy. However, no one has found an easy way to test the extent of our understanding because the sun's thermonuclear furnace is deep in the interior, where it is hidden by an enormous mass of cooler material. . .

"There is a way to directly and quantitatively test the theory of nuclear energy generation in stars like the sun. Of the particles released by the assumed thermonuclear reactions in the solar interior, only one has the ability to penetrate from the center of the sun to the surface and escape into space: the neutrino. Thus neutrinos offer us a unique possibility of 'looking' into the solar interior. Moreover, the theory of stellar aging by thermonuclear burning is widely used in interpreting many kinds of astronomical information and is a necessary link in establishing such basic data as the ages of the stars and the [cosmic] abundances of the elements. The parameters of the sun (its age, mass, luminosity, and chemical composition) are better known than those of any other star, and it is in the simplest and best understood stage of stellar evolution, the quiescent main sequence stage. Thus an experiment designed to capture neutrinos produced by solar thermonuclear reactions is a crucial one for the theory of stellar evolution . . ." (*Science* 191, 264, 23 January 1976).

In the beginning, neutrino astronomy was hailed as a new branch of science. Confidence ran high that the thermonuclear theory would be fully substantiated. In 1965 the first naturally occurring neutrinos – produced in the bombardment of the Earth's atmosphere by cosmic rays – were detected by F. Reines, co-discoverer of the first man-made neutrino from an atomic reactor. Reines' ingenious detector, located nearly two miles underground in a South African mine to shield out all radiation from the surface except the highly penetrating neutrinos, proved that neutrinos are produced in natural atomic reactions and can be detected.

Davis soon set about the construction of a similar device to search for solar neutrinos. His was built almost a mile from the surface in the Homestake Gold Mine at Lead, South Dakota.

By 1967 the detector was in operation, and the first, terse announcement of results was released: "Solar neutrinos were not detected in the first 48 days of exposure . . ." (*Science News*, September 30, 1967).

A few months later, on the basis of Davis' further inability to capture solar neutrinos, F. J. Dyson of the Institute for Advanced Study at Princeton, New Jersey, reported to the American Physical Society that there was "something fundamentally wrong" with the theory of the Sun ("Doubts Are Cast on Theory of Sun," New York *Times*, February 1, 1968).

But dismay was slow in surfacing. After the first full year of fruitless effort in the search for solar neutrinos, *Science News* commented (July 20, 1968) that "it is a testament to the persistence of the neutrino astronomers and to the strength of their theoretical base that their intensive search for these ghost particles still goes on". Another four years were to pass, the "intensive search" continuing without interruption, before V. Trimble and Reines, discussing "The Solar Neutrino Problem – A Progress (?) Report," would concede that "The conflict between observation and theoretical prediction of the flux of . . . neutrinos from the sun has advanced from being merely difficult to understand to being impossible to live with" (*Reviews of Modern Physics* 45, 1, January 1973).

At a meeting of the International Astronomical Union in Warsaw late in 1973, W. A. Fowler of the California Institute of Technology reported that the status of the theory had gone from bad to worse. Instead of detecting about one neutrino per day, as previously estimated – and this only ten percent of the predicted number, the experimenters were recording only about one per month, and even this one might well be of extraneous origin. Actually, "the number of [solar] neutrinos reaching the earth . . . may even be essentially zero" (*Scientific American*, January 1974, p. 50).

Trimble and Reines, in their review article of 1973, remarked that "The critical problem is to determine whether the discrepancy is due to faulty astronomy, faulty physics, or faulty chemistry". It seems likely, however, that the true "fault" for the present predicament of solar physics will be found to lie not in astronomy, not in physics, and not in chemistry, but in certain fundamental assumptions upon which all research into the workings of the Sun and the stars has been built.

The null result of the solar-neutrino experiments, which still go on, has been a fact of astrophysical life for more than a decade. The theory that prompted this research has been scrutinized, modified, fine-tuned, and polished, but the discrepancy remains. At the very least, therefore, it can be said that neutrino astronomy, by failing to find neutrinos coming from the Sun, has raised serious doubt as to the validity of the "conventional wisdom" (Bahcall and Davis) concerning stellar-energy production.

And some other recent observations raise the same kind of doubt.

Early in 1975, H. A. Hill of the University of Arizona reported that he and several colleagues had found the Sun to be oscillating in brightness with variable cycles lasting from a few minutes to nearly one hour. Hill suggested that the oscillations might be due to mechanical waves (similar to sound waves) delivering energy from the core of the Sun to the surface in as little as 25 minutes. This is to be compared with something like 30 million years for radiant energy, continually obstructed by the high opacity of solar gases, to make the same trip.

Hill reasoned that if energy is being brought to the surface by such waves, perhaps the Sun's core is cooler than supposed and, particularly, too cool for neutrino-producing reactions to take place.

But there remained the possibility that mechanical waves might be produced as a result of the more-or-less routine violence that characterizes the atmosphere of the Sun. So Hill's findings, by themselves, provoked little alarm over the health of the thermonuclear theory.

However, in the British journal *Nature* for January 15, 1976, pulsations of another kind were reported independently by research teams from the Soviet Union and Britain. And this "new" effect, apparently a regular expansion and contraction of the Sun with a period of 2 hours and 40 minutes, strikes another blow at the accepted theory of the Sun.

A. B. Severny, V. A. Kotov, and T. T. Tsap of the Crimean Astrophysical Observatory observed the Sun's magnetic fields and were surprised to find evidence of a periodic rise and fall of the entire solar surface. The amplitude of the oscillations was about 10 kilometers.

According to the investigators, "the simplest interpretation is that we observed purely radial pulsations. The most striking fact is that the observed period of 2 h 40 min is almost precisely the same as . . . if the sun were to be an homogeneous sphere". This is equivalent to saying that the Sun pulsates as if, like a balloon, its gases were of uniform density throughout its body. Such a condition, of course, differs radically from almost any solar model one can imagine, for gravity could be expected to increase the density enormously toward the center.

The Soviet team suggested two possible explanations for its findings: "The first alternative is that nuclear . . . reactions are not responsible for energy production in the Sun. Such a conclusion, although rather extravagant, is quite consistent with the observed absence of appreciable neutrino flux from the Sun . . ." The second possibility is that the pulsations are not purely radial motions, but are harmonics of a more fundamental gravity wave affecting the Sun. But there seemed to be little enthusiasm for this latter suggestion: "It seems strange, however, that this high harmonic [should be] dominant."

The British observers, J. R. Brookes, G. R. Isaak, and H. B. van der Raay, of the University of Birmingham, discovered the same radial pulsation of the Sun quite independently and by an entirely different technique based on slight shifts in the positions of spectral lines. Like the Soviets, they pointed out that "Current models predict a period of [about] 1 h corresponding to a steep density increase in the solar interior, in marked contrast to the observed . . . period, which is consistent with a nearly homogeneous model of the Sun".

Two University of Cambridge theorists, J. Christensen-Dalsgaard and D. O. Gough, who commented on the newly discovered pulsations in the same issue of *Nature*, emphasized the unlikelihood that any model can be devised for the Sun to accommodate both the observed radial oscillations and the thermonuclear theory.

Nigel Weiss, a *Nature* scientific correspondent, added: "The observers suggest that the [2-hour, 40-minute oscillation] is indeed a fundamental radial pulsation of the Sun. If so, this measurement would upset the established theory of stellar structure and, with it, many astrophysicists."

And the story of upsetting new findings is not yet complete.

The steadiness of the Sun's radiance has been considered a certainty for centuries. And it is remarkably constant, as repeated direct studies have shown. But now it appears that there may be variations of as much as a few percent in solar-energy output – variations that further strain the credibility of the accepted theory of stellar energy.

In 1975, Lowell Observatory astronomer G. W. Lockwood reported (*Science* 190, 560, 7 November 1975) on measurements of the sunlight reflected back toward the Earth from several outer planets of the solar system. Consistently, in observations extending from 1950 to

1966 and renewed in 1972, "Brightness changes of Uranus and Neptune . . . were highly correlated . . .". The most straightforward explanation seemed to be that the changes were due to variations in solar light-emission.

As Lockwood noted, "No reasonable explanation . . . is evident that does not involve the sun, directly or indirectly, as the causative factor". He was careful, however, to mention the possibility that the observed variations in reflected light might be related to actual variations in the Sun's invisible radiation or in the solar wind, with resultant effects on the reflecting powers of the planetary atmospheres. He noted that "Such a large variation in visible output, if real, would be unique for solar-type stars".

But the implications of the more obvious explanation did not go un-noted. *Science News* commented (July 19, 1975, p. 37): "If the variability is confirmed, solar physicists will have to build it into their models, and these models are in enough trouble already predicting things [neutrinos] that can't be found, that they don't need this shock."

Yet another shock was still to come, this one at least as damaging as any that had gone before. It was reported in late February, 1976, to the annual meeting of the American Association for the Advancement of Science by J. A. Eddy of High Altitude Observatory at Boulder, Colorado. When he finished reading his paper, a colleague is reported (*Science News,* March 6, 1976) to have remarked to the assembled audience: "Maybe we've heard a turning point in the history of science."

Eddy's was a work of historical research, and what he found was that an old idea – that the Sun has not always behaved as it does now – may indeed be correct.

Kendrick Frazier's *Science News* account of the meeting would be hard to improve on:

"The current dogma is that the sun is steady, dependable, constant. In this view, its well-known 11-year sunspot cycle is the manifestation of a smoothly running, well-ordered machine, clicking with regularity like astrophysical clockwork. It is a *comfortable view,* the sun being of some importance to us all here on earth.

"Now an astronomer with a historical bent has delved back through past observational records and, by making numerous independent cross checks, resurrected and made a persuasive case for an old hypothesis that the solar cycle and the sun itself have changed in *historic* time. The evidence shows that for a 70-year period from A. D. 1645 to 1715 sunspots were almost totally absent on the surface of the sun. Solar activity was at a near-zero level, a true and strange anomaly. . .

"Eddy's conclusions imply that the often-discussed 11-year solar cycle is of far less importance and concern than are longer term variations – the overall 'envelope' of solar activity. That patterns of solar activity have varied over historic time is interesting enough in itself. But beyond that, Eddy believes that the long-term fluctuations may be due to changes in the solar constant, the total radiative output of the sun. Such an idea is of fundamental importance. Whether the solar constant may vary, once considered improbable, is now being much debated. . ." [emphasis added].

So the Sun fails to emit neutrinos in detectable numbers, it pulsates as if gravity were of little influence on its internal structure, it radiates less steadily than was long supposed, and even its "cycles" of surface activity apparently are not rhythmical at all. Each of these recent discoveries, in its own way, calls into question the assumption that thermonuclear fusion is the source of solar energy. What are we to think, then, of man's efforts to simulate merely hypothetical conditions in the core of the Sun and thus achieve controlled fusion?

Could it be that the search for *thermo*nuclear energy is a false trail that has been followed all these years with no real hope of success?

If the Sun and the stars indeed succeed in fusing lighter elements to form heavier ones, are the relevant activities carried out more or less in plain sight – in their atmospheres?*

Flagstaff, Arizona
Spring 1976

---

* Some years ago, R. Shapiro and F. Ward reported (*J. Atmos. Sci.* 19, 506-508, 1962) that, of the basis of their power spectral analyses, relative sunspot numbers vary with a period of 25.7 months. Providing the above citation, Kunitomo Sakurai of Kanagawa University in Yokohama has recently suggested (*Nature* 278, 146, 8 March 1979) a correlation between solar neutrino production and the activity responsible for sunspots. The flux of neutrinos, while inexplicably low, seems to vary with a similar period (he arrives at 25.3 months).

Although Sakurai favors an explanation for both phenomena in terms of "some unknown process . . . in the interior of the Sun . . . [with motions penetrating] into the region where the thermonuclear fusion is taking place . . .", it would seem more straightforward to seek a cause of sunspotting and a source of neutrinos (too few, in any case, to be coming from postulated thermonuclear fires in the interior) much closer to the visible surface of the Sun (see following article).

Space does not permit elaboration here. I would simply call attention to the following: 1) The synodic period of Mars with respect to Earth is 780 days, or 25.7 months; 2) if the Sun is fired electrically from the outside, one would expect electrically charged planets orbiting through its current-carrying atmosphere (its electrical "discharge" – a misleading term) to behave somewhat like "grids" in a vacuum tube, which is to say, to interfere with the flow of current to varying degrees as their relative positions change with time; 3) the most pronounced depression of relative sunspot numbers in Sakurai's Fig. 3 coincides very well with Mars' favorable opposition of August 10, 1971, when Mars was closer to Earth and to the Sun simultaneously than it will be again until 1986 or so. Of course, Mars and Earth are not alone in the inner solar system, but it may be significant that the orbitings of these slowest-moving inner planets seem to produce a signal discernible above the noise raised by Venus and Mercury.

Ralph E. Juergens, June 1979

* * * * *

EDITOR'S NOTE (LMG):

At the present writing, those solar problems noted above remain unresolved. "The continued negative results of a careful experiment to detect neutrinos from the sun has led to a deepening scientific crisis. If, as astronomers confidently believe, the sun generates its energy by the proton-proton chain of reactions in which hydrogen is converted into helium, then neutrinos should be liberated in great numbers deep within the sun. Neutrinos are massless, uncharged subatomic particles that travel at the speed of light, and interact so weakly with matter that they can pass virtually unchecked through the sun and reach the earth" (*Sky and Telescope,* November, 1976, p. 324).

An Earth-based experiment designed to catch solar neutrinos has shown "that only 0.13 argon-37 atom was being formed per day, close enough to the cosmic-ray background rate of 0.09 atom per day to raise the possibility that no solar neutrinos were being detected at all!. . . The neutrino counts are low enough to cause doubts that thermonuclear fusion is in fact the sun's energy source" (*S & T, Ibid.).*

According to one author, writing in the February 1977 *Analog* (p. 31), "If even *low*-energy neutrinos are not being emitted from the solar furnace, something is very, very wrong with our Sun. Is it possible that our Sun will *not* peacefully continue evolving as a main-sequence star, until it reaches the Red Giant stage? Maybe our Sun is not, after all, 'an ordinary star'."

And the article concludes: "Perhaps the most frightening speculation along these lines is that our Sun might have had an accident: it may have run into a quite small black hole in the very recent past, which is sitting on the core, gobbling up mass from the surrounding gases and regurgitating energy. Radiation pressure keeps more than just a little bit of matter at a time from falling into the hole, but eventually, say, 150 million years, the Sun will be eaten up from within by this cancer? Nightmares, anyone?" (*Analog, Ibid.*).

In April 1978, Kendrick Frazier reiterated the astrophysical dilemma posed by the Sun's perplexing behavior. "In the 1970s studies of the sun have shown it to be filled with enigma and unanticipated possible variations. . . . New mysteries have arisen. The lack of the expected number of neutrinos reaching earth from the sun's interior has thrown theories about basic stellar processes into confusion. The picture of a regular, constant sun, apart from the long-known 11-year cycle, has been dramatically assaulted from flanks at opposite time scales. . . .

"If the confirmation of coronal holes in the 1970's solved one long-discussed problem about the sun, the mystery of the missing neutrinos has deepened throughout the decade to become one of the major unsolved scientific problems of our time . . . . Only about a fourth of the expected number of solar neutrinos – tiny particles produced in the core of the sun as a byproduct of the fusion reaction – have been monitored by a detector a mile beneath the earth in a gold mine in South Dakota. Something is wrong. . . .

"Astronomers' ideas about the interior structure of the sun may be wrong. If so, our understanding of the evolution of stars may be in error, and that would have far-reaching consequences.

"The apparent neutrino deficit could mean that some of the fusion reactions in the sun's interior have switched off; perhaps it is at heart a variable star. . . .

"The missing solar neutrinos are a genuine and disturbing puzzle" (*Science News*, Vol. 113, April 22, 1978, pp. 252-254).

In the same issue of *Science News*, Dietrick E. Thomsen echoed his colleague's sentiments. "The orb we had once thought so regular turns out to be more and more variable and unpredictable. Perhaps it was inevitable that this should come to pass. Our impression of solar regularity may have depended more on our inner need for a dependable celestial parent – living in the neighborhood of a variable star is a bit of a nervous strain – than it did on the facts.

"One recent contribution to the solar upheaval, which is still highly controversial, but, if correct, extremely important, is that the sun itself has the shakes, oscillations that go deep into its insides. . . . In recent months the evidence that the oscillations are real and belong to the sun has greatly increased . . . this tends to alter our traditional picture of solar steadiness, and it will have, if and when it is widely accepted, profound effects on the theoretical physics of the sun. . . .

"[A] change in the energy transport possibilities will alter the picture of the nuclear reactions that must go on in the interior of the sun to supply the observed flux of energy – especially in the convection zone where heating churns up the solar material. For these reasons the existence of the oscillations may also provide a solution to the solar neutrino problem – why the sun does not produce the flux of neutrinos that would be expected from the thermonuclear reactions that currently accepted theory proposes take place in the sun's interior. . . .

"In the end we may be discovering that we do not live in as quiet a corner of the universe as we may have wished" (*Science News, Ibid.*, p. 253).

By February 1979, scientific concern over solar behavior intensified. As expressed by *Science News* (Vol. 115, February 17, 1979, p. 103) – "If the sun should fall, metaphorically and theoretically, that is, the destruction in astrophysics would far outreach the loss of fish if Skylab were to plunge into Lake Ontario with a thunderous hiss. Astrophysicists' whole basic notion of how stars generate energy would have to be redone.

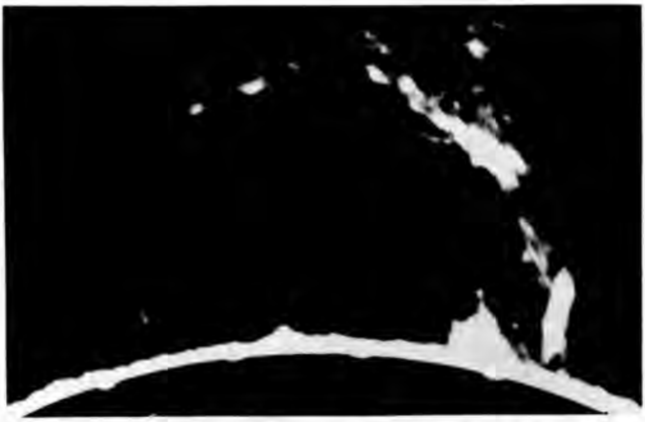
"Such a fall of solar theory seems imminent. An experiment [referred to above] that has been measuring the flux of neutrinos from the sun for the last ten years indicates that something is drastically wrong. Basically, the chain of thermonuclear reactions by which energy is produced in the sun according to the 'standard theory' should produce a certain flux of neutrinos as a byproduct. That flux is not being recorded. If standard solar theory doesn't fall, it seems standard neutrino theory must. The experiment is also based on that, especially the belief that neutrinos are not subject to radioactive decay and therefore all survive the 8-minute journey from the sun. If standard neutrino theory goes, the repercussions in particle physics could take an antitextbook to list. Experiments are being proposed to find out which is wrong."

In the words of one physicist: " 'Looking for neutrinos from the sun's *core* is the first critical and direct test of the theory [which was built on evidence from the surface]. Much to our consternation, the experiment has failed to reassure us that the sun works in the way we thought it did' " (*Science News, Ibid.* – last brackets and emphasis in text).

Possible confirmation that the Sun pulses every 2 hours and 40 minutes has dealt yet another blow to standard solar theory. Again Dietrick E. Thomsen: "That the sun may vibrate to its own beat – possibly to several of its own beats – is a suggestion entered into the debate over solar physics in recent years." That suggestion now gains credence via a report in the February 22, 1979 issue of *Nature* "intended to convince astronomers and physicists that the vibrations are real".

"Such vibrations would proceed from deep inside the sun. They are a fast way of transporting large amounts of energy from the interior to the surface that is not envisioned in present theory. They could upset the thermodynamics of the solar interior and so change expectations about the thermonuclear processes that go on there. They could stir up the material inside the sun, which current theory tends to see as well layered, and that could affect the fusion dynamics. If they come to be generally accepted, they will require a reworking of solar theory, and that carries in its train a reworking of stellar theory generally. These vibrations could reverberate throughout astronomy" (*Science News,* Vol. 115, April 21, 1979, p. 270).*

*[*ADDITIONAL READING: Natural History,* Vol. LXXXV, No. 9, November 1976, "The Turbulent Sun," edited by S. Lindsay, pp. 54-86.]



A Solar Prominance – Courtesy of NASA

28. I. Langmuir, **op. cit.**

29. W. Allis, **op. cit.,** p. 59.

30. J. Eddy, **New Scientist** (21 March 1974), p. 738.

31. H. Zirin (**op. cit.,** p. 262) estimates that at least 90% of all matter in the photosphere is neutral hydrogen.

32. Solar flares are effects that might be expected, were neutral gases suddenly to evolve in quantity and be ejected into the solar discharge.

33. Cf. O. Namba and W. Diemel, **Solar Physics** 7, 167 (1969).

34. R. Juergens, **op. cit.**

35. Cf., e.g., J. J. and G. P. Thomson, **Conduction of Electricity through Gases,** vol. II (1933); Dover Publications (1969), p. 404.

36. Cf. J. Kirk and W. Livingston, **Solar Physics** 3, 510 (1968).

37. Cf. L. Loeb, **Electrical Coronas,** University of California Press (1965), p. 402.

38. Cf. R. Howard and A. Bhatnagar, **Solar Physics** 10, 245 (1969); these authors write of "velocity gradients" inferred from their data, which imply acceleration (by electric fields?).

39. M. Minnaert (**op. cit.,** pp. 163-164) calls attention to the "anomalies" cited here.

40. H. Zirin, **op. cit.,** p. 295.

41. M. Minnaert, **op. cit.,** p. 171.

42. H. Zirin, **op. cit.,** p. 282.

43. **Ibid.,** p. 247.

44. Cf. G. Pneuman, **Sky & Telescope** 39, 148 (March 1970).

45. Skylab observations include a new class of features, *macrospicules,* reaching heights of 35,000 kilometers above the Sun's limb. Cf. **Sky & Telescope,** April 1975.

46. Cf. R. Kopp, **et al., Astronomy & Astrophysics** 44, 299 (1975).

47. Cf. L. Loeb, **op. cit.,** passim.

48. F. Llewellyn-Jones, **The Glow Discharge,** Methuen (1966), p. 70.

49. Cf. P. McIntosh, **op. cit.,** p. 280.

50. Cf. O. Namba and W. Diemel, **op. cit.,** p. 167.

51. M. Altschuler (**Solar Physics** 47, 183-192, 1976) cites evidence "suggest[ing] the possibility that all phenomena of solar activity are manifestations of the rapid ejection and/or gradual removal of electric currents of various sizes from the photosphere".