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The Role of Anomalies in Scientific Research[1]

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Abstract—Anomalies play a key role in science, in calling into question some established belief: an anomaly is an anomaly only with respect to some hypothesis, theory, or belief system. Some anomalies (OK Anomalies) are greeted with interest and investigated vigorously, some (Not-OK Anomalies) are avoided or viewed with suspicion, and others (Sleeping Anomalies) may for some time go unnoticed. In this article, anomalies are viewed from the perspective of scientific inference. This requires that we compare the anomaly with a logically complete set of hypotheses, and that assessments of the evidence for the anomaly, and of its compatibility (or incompatibility) with various hypotheses, be expressed in terms of probabilities. Some anomalies may present a challenge to our "model of reality." (These are normally viewed as "Not-OK.") Identifying our "standard model of reality" makes it possible (and necessary) to identify alternative models so as to form a logically complete set of hypotheses.

Keywords: anomalies—inference—probabilities

The word "anomaly," according to Webster, is derived from the Greek "an" [="not"] and "homalos" [="even"] and signifies a "deviation from the common rule," or "something out of keeping, especially with accepted notions of fitness or order." In referring to an anomaly in science, we think first of the former, manifestly intellectual definition—a result in scientific research that does not conform to expectations based on the prevalent theory. However, members of this Society will be well aware that anomalies also have a sociological import—they may be "out of keeping with accepted notions of fitness or order." Some anomalies may be viewed primarily as intellectual challenges, but other anomalies may be in part a political challenge, in that the weight given to an anomaly depends on the status within the scientific community of the person proposing the anomaly. (Yes, dear reader, there are heresies and heretics in science, as well as in religion [Mellone, 19591.)

Anomalies should be the life-blood of science. Niels Bohr once said that "progress in science is impossible without a paradox," and Richard Feynman (1956) once remarked that "The thing that doesn't fit is the thing that is most interesting." More recently, Jahn and Dunne (1997) have written "... good science, of any topics, cannot turn away from anomalies; they are the most precious resource, however unrefined, for its future growth and refinement."

The first thing to note about "anomaly" is that it is a relative concept, not an absolute concept. A result is an anomaly only with respect to a given theory or hypothesis. In scientific research, it would be an experimental or observational result that is not in accord with current theory. Therein lies its importance. An anomaly provides a test of a theory. As Feynman's remark implies, it is much more important to search for facts that do *not* agree with current theory than to find further facts that do agree with that theory. If a certain fact, which is incompatible with a given theory, can be firmly established, then that theory must be modified or abandoned.

We can consider one or two historical examples. In 1919, Ernest Rutherford gave one of his assistants, E. Marsden, the task of studying the scattering of alpha particles by a gold foil (Whittaker, 1953: 20). According to the prevalent "plum pudding" model, an atom was composed of electrons immersed in a blob of positively charged matter. According to this model, alpha particles should suffer only slight deflection in traveling through gold foil. Rutherford was astonished to find that some alpha particles were backscattered from the foil. He said "It was as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." It took Rutherford over a year to digest the implications of that anomaly. He finally concluded, correctly, that the positive charge in an atom is concentrated in a very small space at the center of the atom.

But not everyone responds to an anomaly in such a direct and productive manner. Roentgen recognized an anomaly when a piece of paper painted with barium platino-cyanide fluoresced when current was passed through an adjacent Crookes tube (Whittaker, 1951: 357). However, that discovery was missed by several physicists. For instance, Frederick Smith, an Oxford physicist, when told by an assistant that photographic plates kept near a Crookes tube were found to be fogged, told his assistant to keep them somewhere else. (Whittaker, 1951: 358). [We may all smile on reading this, but can every one of us be quite certain that he or she is not now failing to recognize an anomaly in his or her research?]

Different anomalies evoke very different responses from the scientific community. I suggest that there are at least three different categories of anomalies: "OK Anomalies," "Not-OK Anomalies," and "Sleeping Anomalies."

An "OK Anomaly" is one that has been discovered by an established scientist, preferably using expensive equipment, and which appears to be an anomaly that scientists can cope with.

A "Not-OK Anomaly" is one that is not obviously resolvable and presents an unwelcome challenge to established scientists, possibly (but not necessarily) because it has been discovered by a non-scientist.

A "Sleeping Anomaly" is one that has not yet been recognized as an anomaly.

As examples of OK anomalies, I cite two from astronomy: (1) Quasars are objects that, when first identified by Maarten Schmidt of the Mount Wilson and Palomar Observatories, were anomalous in that they appeared to be star-like but had redshifts similar to—or larger than—those of typical galaxies (see, for instance, [Shu 1982: 315 et seq.]). Quasars have subsequently been determined to be distant galaxies containing a massive black hole. (2) Pulsars are radio sources that pulse with periods of seconds or less (see, for instance, Shu [1982: p. 131 et seq.]). When discovered in 1967 they were an anomaly since all previously known radio sources were essentially constant or varied only erratically on much longer timescales. Pulsars have subsequently been determined to be rotating neutron stars with very strong magnetic fields.

It is worth noting that claims of both of these astronomical discoveries were made by established astronomers using powerful optical or radio telescopes. The discovery of pulsars led to Nobel Prizes for Professor Anthony Hewish, who was in charge of the research project, and for Professor Martin Ryle, director of the observatory (the Mullard Radio Observatory at Cambridge, England). However, the initial discovery was actually made by Miss Jocelyn Bell, then a research student. It is also interesting to note that the first records of pulsars were kept secret, due initially to the possibility that they may have been emissions from intelligent life forms in other "solar" systems, but later to some other motive—possibly noble, possibly "Nobel."

Both anomalies were viewed as due more to limitations in our astronomical knowledge than to errors in astronomical or physical theory.

A classical example of a Not-OK Anomaly is that of meteorites. These objects fall from the sky and may be discovered by any citizen, educated or not. Moreover, no specialized equipment is necessary. They are now known to enter the atmosphere from outer space, originating in a vast cloud of such objects in the solar system. However, their nature was unknown until the 18th Century, when E. F. F. Chladni published a small book on them in 1794. Twenty-two years earlier, in 1772, French academicians had ruled that these objects could not have fallen from the sky, since there are no stones in the sky to fall. According to Sears (1978), "The scientific community ... made merry over the credulity of people who imagined the stones to have fallen from the heavens." [What are the topics that are genuine, over which present-day scientists make merry?] The authenticity of meteorite falls was established by the distinguished scientist Jean-Batiste Biot, who was sent by the President of the National Institute to investigate a particularly large meteorite fall (over 3,000 stony meteorites) that occurred at L'Aigle on April 25, 1803.

A list of current Not-OK Anomalies contains topics that are generally dismissed as bogus by the scientific community: precognition, telepathy, psychokinesis, reincarnation, "flying saucers," etc., etc. The distinguished English astrophysicist Malcolm Longair (1984) warns young scientists that "it is difficult to be taken very seriously as a scientist if you mix up real science with quasi-scientific pursuits such as spoon-bending, parapsychology, unidentified flying objects, extrasensory perception, etc." However, the list also contains topics studied by scientists with a good track record of scientific research, such as the proposal by Halton Arp that the redshift of quasars may contain a contribution other than the usual cosmological redshift (see, for instance, Arp and Sulentic [1985]), and the proposal by Martin Fleischman that nuclear processes may be influenced by electrochemical processes (Fleischman et al., 1989; see also Storms, 1996).

The close geometrical match between the west coast of Africa and the east coast of South America may be regarded as a "Sleeping Anomaly." Although this fact had been noted by Francis Bacon, Antonio Snider-Pellegrini, Benjamin Franklin and others, it was not generally recognized as a challenge to understanding until Alfred Wegener pointed out, early in the 20th Century, that geologic features of the West African Coast would accurately line up with similar features on the East Coast of South America when the two continents were juxtaposed and proposed an interpretation. Wegener attributed the correspondence to the breakup of one large continent (referred to as "Pangaea") and the progressive separation of the parts by a process he called "continental drift." This proposal was ridiculed for many years. The distinguished geophysicist Sir Harold Jeffreys once remarked to me—with a smile—that there is no force inside the Earth that is strong enough to move continents. Members of one scientific community (in this case, geophysicists) seldom welcome with applause a proposal made by a scientist from another community. (Wegener was a distinguished scientist, but he was a meteorologist, not a geophysicist.) The tide turned when geophysicists found that the magnetic signatures were effectively mirror-imaged on the two sides of the Mid-Atlantic Ridge, showing that it was the spreading center and providing a mechanism for what became the new theory of plate tectonics.

We now know that the scientific community was in error in its response to the challenge of meteorites and to that of continental configurations. Can we be sure that scientists of the 21st century are not making similar errors in their responses to some current phenomena? To pursue this question, we need to give a little thought to the nature of science. Richard Feynman (1956) remarked succinctly that "The essence of science is doubt." Three and a half centuries earlier, Francis Bacon (1603) had written "If a man will begin with certainties, he shall end with doubts; but if he will be content to begin with doubts, he shall end with certainties." These precepts are fully in accord with the rules of scientific inference, as developed by Jeffreys (1973), Good (1950), Jaynes (2004), and others. According to this theory, it is advisable to proceed along the following lines:

We should

1. Think in terms of probabilities, not certainties.
2. Consider a complete set of hypotheses, not a single hypothesis.
3. Examine our initial beliefs, and represent them by "prior probabilities."
4. List the relevant items of evidence, and estimate the credibility of each item.
5. In this way, estimate the "weight of evidence" that each item gives for each hypothesis.
6. Combine the "weights of evidence" with the prior probabilities to arrive at our post-probabilities.

We adopt a logically complete set of hypotheses to be sure that the anomaly can be compatible with one of our considered hypotheses. The epigram "Anything that does happen, can happen" is attributed to the distinguished astronomer and physicist Robert Leighton. Jeffreys (1961) wrote "It is sometimes considered a paradox that the answer depends not only on the observations but on the question; it should be a platitude."

In order to clarify this procedure, it is helpful to consider a simple example. The above procedure need not be restricted to scientific questions. We consider, as an example, the authorship of the "Shakespeare" plays. It is surely an anomaly that the plays show a detailed knowledge of Italy, yet Shakespeare never left England. We may analyze this anomaly as follows, using a procedure based on the principles of scientific inference that have been described elsewhere (Sturrock, 1973, 1994). First, we need a complete and mutually exclusive set of hypotheses. We adopt the following:

H1: The author of the Shakespeare plays was William Shakespeare;
H2: The author of the Shakespeare plays was Edward de Vere, Earl of Oxford;
H3: The author of the Shakespeare plays was somebody else.

We begin by giving these three hypotheses equal prior probabilities:

$$P(H1|Z) = P(H2|Z) = P(H3|Z) = 1/3, \tag{1}$$

where Z denotes "zero-order" or background information. One can usually ignore the term Z, unless one runs into difficulties (such as finding that none of the specified hypotheses is compatible with the evidence), in which case one needs to consider what is really being implied by this term.

We now need one or more "items" that can be part of an interface between data and theory. For present purposes, we adopt just one item, which comprises two exclusive statements:

F1: The author had first-hand knowledge of Italy;
F2: The author did not have first-hand knowledge of Italy

We need to assign probabilities to these statements based on the hypotheses, and based on the relevant evidence (the plays).

We know that Shakespeare had no first-hand knowledge of Italy and that de Vere did. Whether a hypothetical "somebody else" had knowledge of Italy is problematical. Ordinary actors and theater managers would not have had that knowledge. On the other hand, some noblemen and perhaps some merchants may have had extensive stays in Italy. Let us suppose that there is a one percent chance that the unknown author might have had first-hand knowledge of Italy, then

$$\begin{aligned} &P(F1|H1,Z) = 0, && P(F2|H1,Z) = 1; \\ &P(F1|H2,Z) = 1, && P(F2|H2,Z) = 0; \\ &P(F1|H3,Z) = 0.01, && P(F2|H3,Z) = 0.99. \end{aligned} \tag{2}$$

Finally, we need to assess these options on the evidence of the plays. Personally, I find it hard to believe that a playwright who had no first-hand knowledge of Italy would have had the knowledge and motivation to write in such detail about Italy, but I will allow that possibility a chance of one percent:

$$P(F1|plays, Z) = 0.99, \quad P(F2|plays, Z) = 0.01. \tag{3}$$

Then some formal manipulations (Sturrock, 1973, 1994; the relevant equations are reproduced in Appendix **A)** lead to the following post-probabilities that combine our thoughts about the hypotheses and about the relevant evidence:

$$\begin{aligned} \mathrm{P}(\mathrm{H}1|F, \mathrm{Z}) &= 0.005, \\ P(H2|F, \mathrm{Z}) &= 0.980, \\ P(H3|F, Z) &= 0.015. \end{aligned} \tag{4}$$

We see that this item of evidence strongly favors de Vere, and even favors "somebody else" over Shakespeare.

Of course, this is just one piece of evidence, and most people will start out with the presumption that the "Shakespeare" plays were in fact written by Shakespeare. Let us suppose that we start out feeling 99 percent confident that the author was indeed Shakespeare, but allowing 0.5 percent chance that it may have been de Vere and 0.5% chance that it may have been somebody else. Then, if (using the procedure given in the articles just cited) we fold this initial assessment together with the above assessment that was based on the probable familiarity with Italy, we arrive at

$$\begin{aligned} \mathrm{P}(\mathrm{H}1|F, Z) &= 0.074, \\ P(H2|F, Z) &= 0.803, \\ P(H3|F, Z) &= 0.123. \end{aligned} \tag{5}$$

We see that de Vere still comes out ahead, and Shakespeare still comes in last.

We are really interested in the application of these procedures to anomalies in scientific research. Hopefully (but not necessarily) these assessments can be somewhat more objective (or, as Ziman [1978] would say, "consensible") in the realm of science than in the realm of historical literary speculation. However, the merit of this procedure is not so much that it leads to definite answers, as that it will typically lead to definite questions.

I now wish to describe briefly three anomalies that have turned up in my own scientific research in recent years. One of these comes from "mainstream" science, and the other two are from topics that Longair (1984) warns young scientists not to get involved in.

In considering an anomalous experimental result or observation which appears to contravene current theory, we need to be able to estimate the probability that the result could have occurred "by chance" on the basis of that theory. One way to do this is to consider a wide range of similar results so that we can say

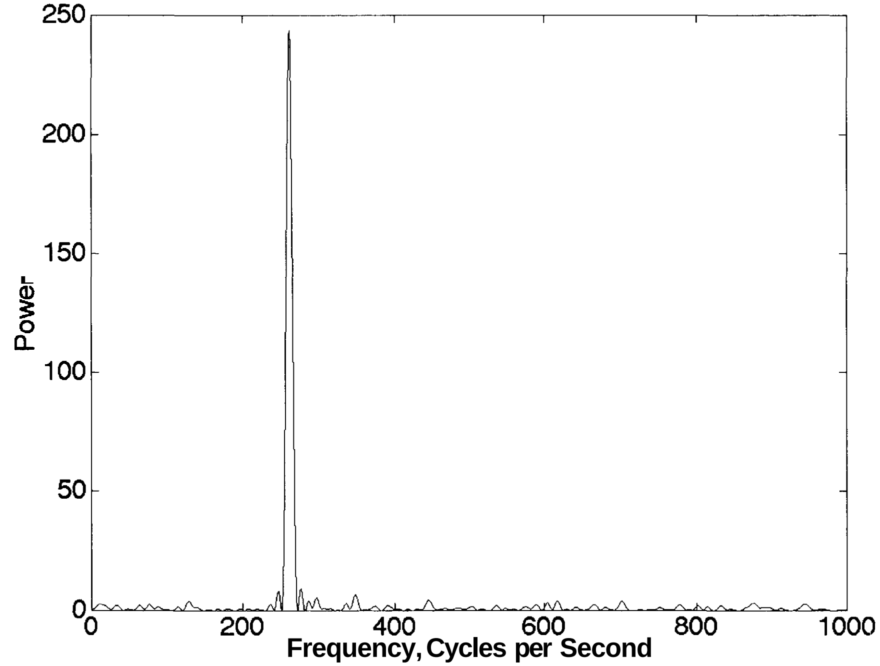

Fig. 1. The power spectrum to be expected from the middle-C note on a piano.

"If this particular result occurred by chance, then many other similar results should also have occurred by chance"—or—"very few similar results would have occurred by chance." That is to say, it is helpful to have some way of "scanning" a wide range of possibilities, of which the result in question is simply a special case.

Indeed, an anomaly in scientific research is typically an unexpected result or observation that follows, or is accompanied by, many results or observations that occur as expected. For instance, in the Rutherford experiment mentioned earlier, for every alpha particle that was backscattered by the gold foil, many more were only slightly deflected. Sometimes the anomalies are associated with particular values of some parameter. In this case, it is obviously helpful to "scan" the result as a function of that parameter.

One scanning procedure that is often helpful is known as "power spectrum analysis." (See, for instance, Jenkins & Watts [1968]). One searches for periodic modulations of a measurement as a function of frequency. If one were to record the sound of middle-C on a piano and then carry out a power-spectrum analysis, one would find a peak in the display corresponding to a frequency of 262 cycles per second, as in Figure 1. There would also be peaks corresponding to "harmonics" of this frequency, at 524 cycles per second, 786 cycles per second, etc. Of course, these patterns are not anomalies; they are expected. However,

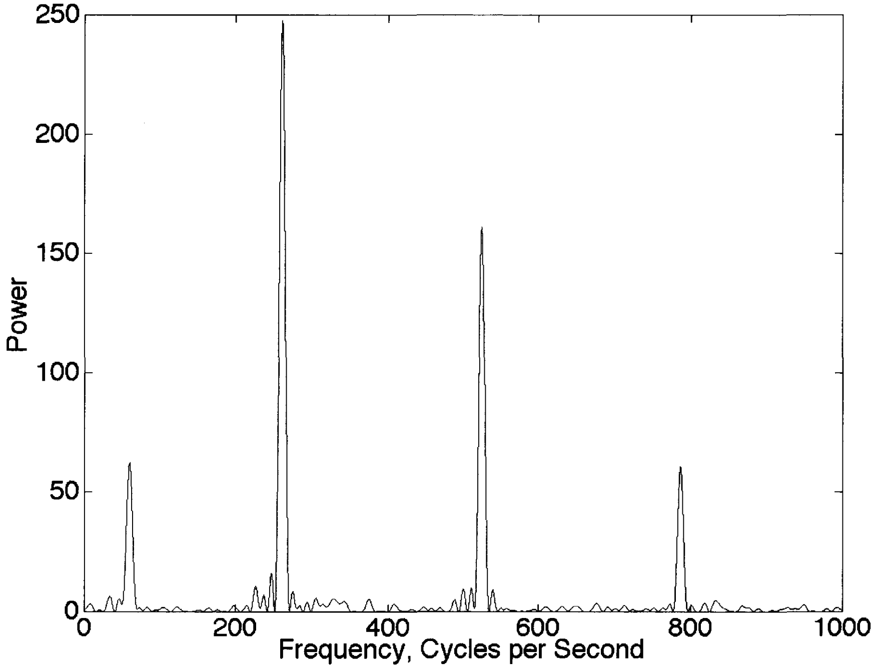

Fig. 2. The power spectrum that might be found, allowing for harmonics and a possible 120-hertz background hum.

one might find one piano in a thousand for which the power spectrum also shows a peak at 120 cycles per second, as in Figure 2. This would be regarded as an anomaly, until one found that the piano contained a piece of electrical equipment, when it would no longer be an anomaly. (The sound produced by 60 cycles per second electrical power is predominantly at 120 cycles per second.) Now suppose that the recording is not that of a musical instrument but the noise of a large room full of chattering people. Then one is likely to obtain a very ragged power spectrum, as in Figure **3.** In this case, it would be an anomaly to find a sharp peak, as in Figure 4. On investigation, one might find that a security alarm had been triggered somewhere in the building. Once that was discovered, the peak would no longer be an anomaly.

This brings me to some of my recent research. I have been studying measurements of the solar neutrino flux. The process producing neutrinos (the thermonuclear conversion of hydrogen into helium, etc.) is generally believed to be constant, and the experimental teams analyze their data on the assumption that the flux is in fact constant. The only expected periodic modulation would be a small variation, with a period of 1 year, due to the fact that the Sun-Earth distance varies in the course of a year. This modulation has been detected.

However, I have been interested in the possibility that the physical pro-

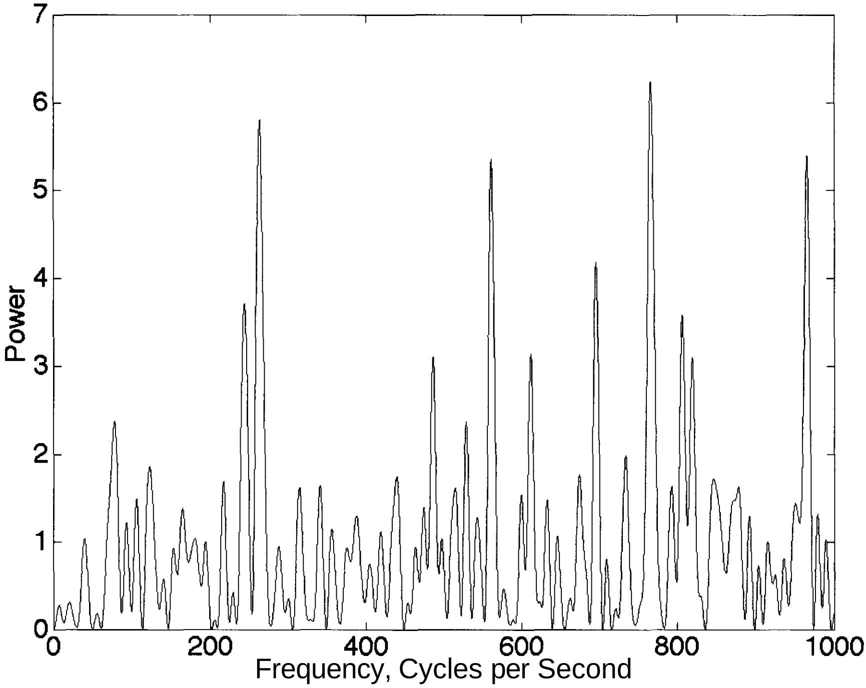

Fig. 3. The power spectrum that might be found from a recording made in a noisy room.

cesses generating the solar neutrino flux may not be spherically symmetric. In this case, one might find fluctuations corresponding to the frequency of solar rotation as seen from Earth—about 13.5 cycles per year, corresponding to a period of 27 days. Many other forms of radiation from the Sun (X-rays, etc.) do vary in this way, since they are influenced by the Sun's magnetic field, which typically has a very complex structure. According to some theories (Chauhan & Pulido, 2005), neutrinos might be influenced by a magnetic field, in which case the measured neutrino flux might be found to vary with a period of about 27 days.

The Super-Kamiokande collaboration has made available an extensive compilation of solar neutrino measurements (Fukuda et al., 2003). My colleagues and I have carried out several power-spectrum analyses of this dataset, the most recent of which (Sturrock & Scargle, 2006) is shown in Figure 5. This does not show a peak at the solar rotation frequency, but neither does the power spectrum of the disk-center magnetic field. One of the main features in the magnetic-field power spectrum is a peak at the second-harmonic of the rotation frequency (three times the rotation frequency) at $39.60 \pm 0.42\ yr^{-1}$. The power spectrum of the solar neutrino data shows a peak in this frequency band, at $39.28\ yr^{-1}$. It shows a stronger peak at $9.43\ yr^{-1}$ which is due, we believe, to a mode of

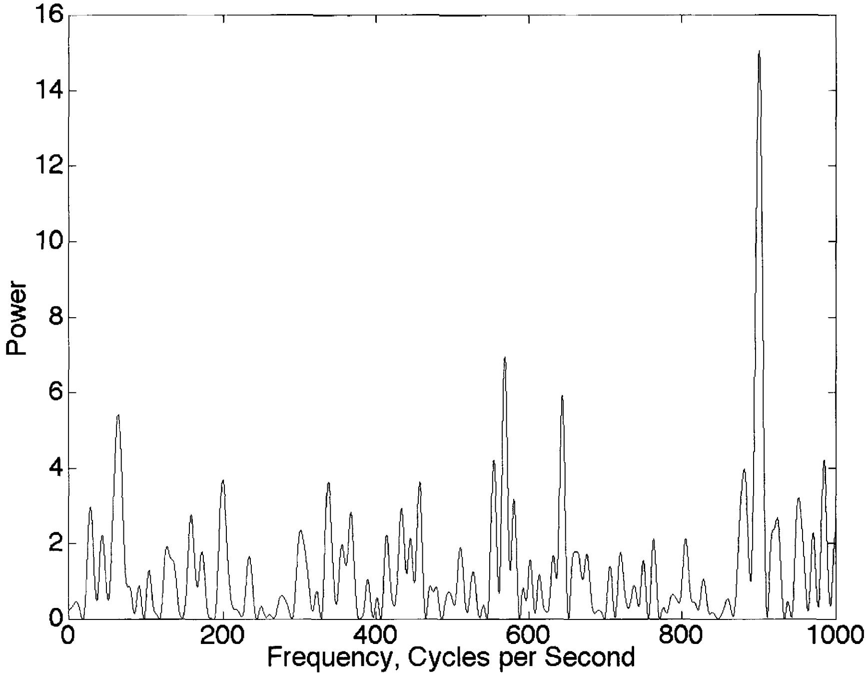

Fig. 4. The power spectrum that might be found from a recording made in a noisy room that shows an anomalous sound at 900 hertz.

internal oscillation of the Sun. These features in the power spectrum of solar neutrino data represent an anomaly since, on the basis of standard neutrino theory, the flux should be constant and the power spectrum featureless.

The next example is closer to the interests of this society. I have carried out an analysis of a catalog of 12,100 UFO reports taken from a catalog compiled by Larry Hatch (Available at: http://www.larryhatch.net; Sturrock, 2003). Figure 6 shows a power spectrum of the events. We see that there is a prominent peak at 1 yr^{-1}, which is not unexpected, since we spend more time outdoors in summer than in winter. Hence this peak does not tell us anything new: it is certainly not "anomalous." However, we can carry out an analysis that is a little more complicated, which searches for evidence of a rotating pattern of modulation. A modulation associated with the location of the stars will show up as a peak with frequency 1 yr^{-1}. A rotation with the same frequency, but in the opposite direction, would show up as a peak with frequency –1 yr^{-1}. The result of this "running-wave" analysis is shown in Figure 7. We see that there are exceedingly strong peaks for forward waves with frequencies 1 yr^{-1} and at 2 yr^{-1}, and only weaker peaks for reverse waves at those frequencies. This result provides very strong evidence for what is called a "local sidereal time" effect: the probability of a UFO event is related to which stars are overhead at the time of the event.

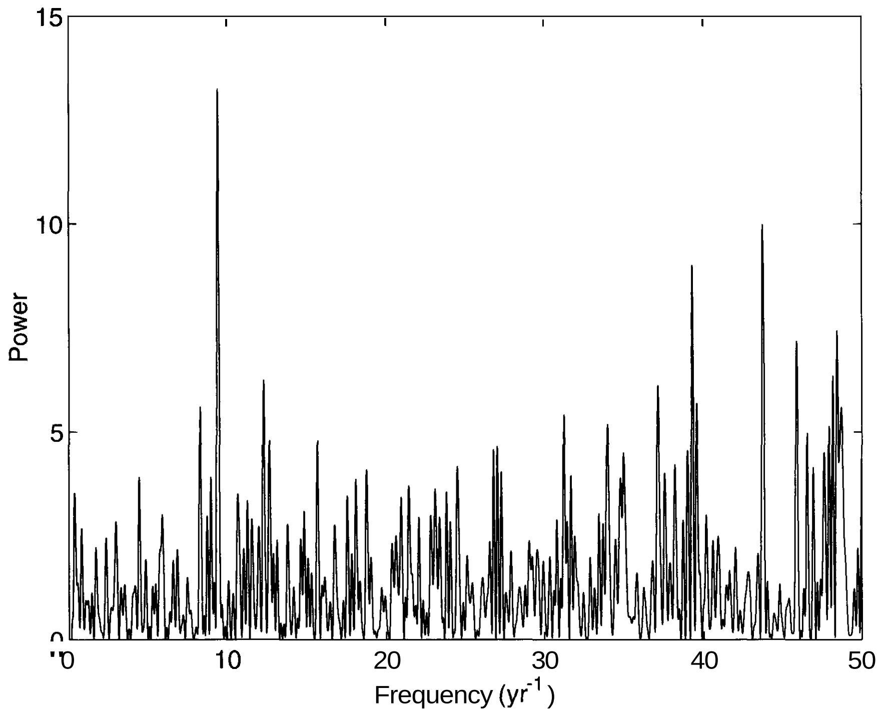

Fig. 5. Power spectrum of Super-Kamiokande solar neutrino data.

Unless one can show that most UFO events are due to misperceptions of certain astronomical objects, in a restricted range of local sidereal time, this comprises an anomaly.

The third example is taken from current research recently carried out in collaboration with James Spottiswoode (Sturrock & Spottiswoode, in press). We have applied the two procedures used in the two previous examples to a catalog of 3,325 free-response anomalous cognition experiments. The results of the simple power-spectrum analysis are shown in Figure 8. The strongest feature in this power spectrum occurs at $v = 24.65\ yr^{-1}$, quite close to twice the synodic lunar frequency ($24.74\ yr^{-1}$). When the data are analyzed in terms of rotating frames, as in our UFO analysis, we obtain the result shown in Figure 9. In this case, the reverse-wave peak is stronger than the forward-wave peak, but this is consistent with an association of the results of the experiments with the position of the moon. Hence this analysis provides quite strong evidence for an anomaly—a lunar effect on anomalous cognition experiments.

There is of course a vast literature of studies of PSI and UFO data, and of many other similarly curious "anomalous phenomena." (See, for instance, *The Sourcebook Project*, available at: http://www.science-frontiers.com/sourcebk.htm). Paul Kurtz (1983; a philosopher) refers to a wide range of such phenomena as

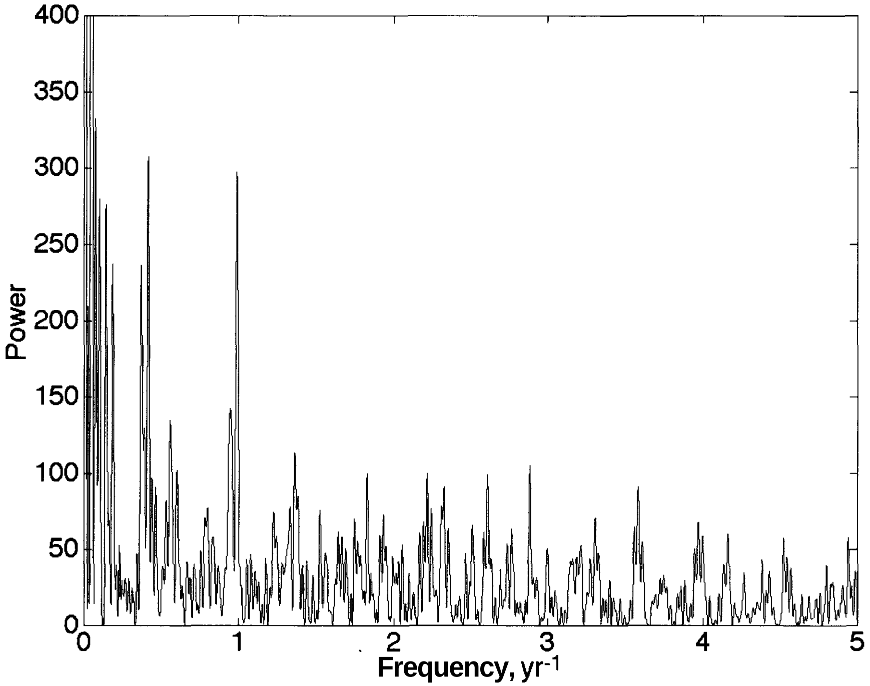

Fig. 6. Power spectrum formed from a catalog of 12,100 UFO events.

"paranormal." He writes "[The term] 'paranormal' ... is applied to anomalous data that supposedly transcend the limits of existing science and are due to unknown or hidden causes. The paranormal world view ... contravenes the model of the universe derived from the physical and behavioral sciences." Kurtz's approach is proto-typical of the self-styled "skeptical" community, which I prefer to refer to as the "pseudo-skeptical" community.

However, practicing scientists do not regard our current scientific knowledge as absolute and immutable. Sagan (1973) wrote "I would like to return to the question of possible new or alternative laws of physics. [Maybe] there are new laws of nature to be found even under familiar circumstances. I think it is a kind of intellectual chauvinism to assume that all the laws of physics have been discovered by the year of our meeting." The Russian physicist Vladimir Ginzburg (1973) wrote "Science of course never ends. There will always be new laws and clarifications. When we say some law of physics is valid, we always bear in mind that it is true within certain limits of applicability." And Edgar Mitchell (1993) wrote "There are no unnatural or supernatural phenomena, only very large gaps in our knowledge of what is natural .... We should strive to fill those gaps of ignorance."

Hence, a major challenge in the study of anomalous phenomena is to identify

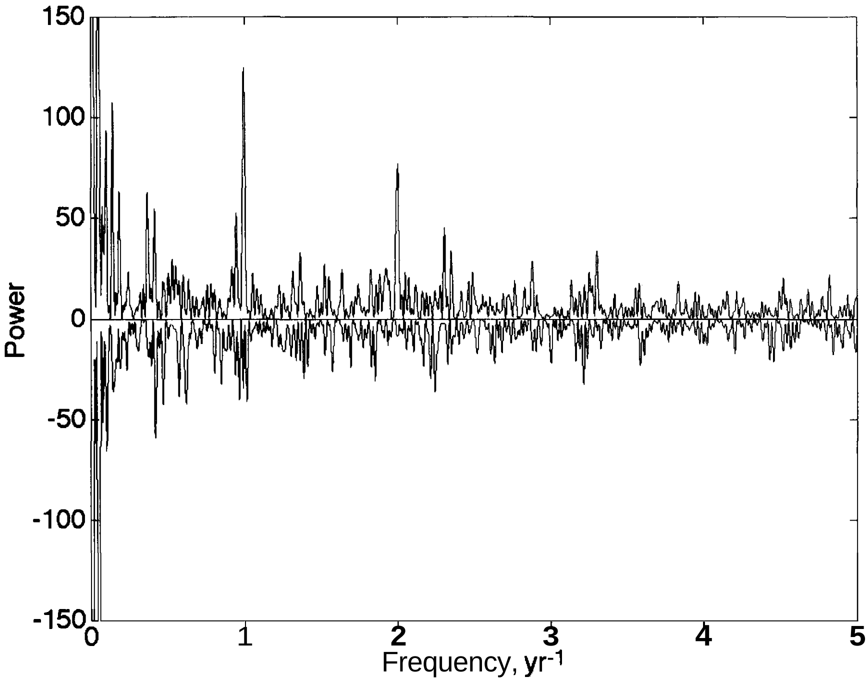

Fig. 7. Running-wave power spectrum formed from a catalog of 12,100 UFO events. Forward waves are shown with positive power and reverse waves with the negative of the power.

the basic assumptions of our current "weltanschauung," "world view," or "model of reality" with which these phenomena are incompatible. This important question could and should be the topic of a major research project. In the present discourse, I look only for a very simple model.

It is my impression that the following three hypotheses form the basis for the usual rejection of evidence for such phenomena:

- Any topic which is incompatible with physical theory, as it is now known, is impossible.
- Consciousness is simply a brain activity.
- No "superior beings" have any influence, or have had any influence, on events and developments on Earth.

I suggest that, if we wish to study such phenomena, we should consider not only these three assumptions, but also the possibility that one or more of these assumptions may be incorrect.

To formalize this procedure, we may introduce the following three pairs of hypotheses:

Ordinary Physics (OP). The world is governed by (and restricted by) laws of physics as they are now known.

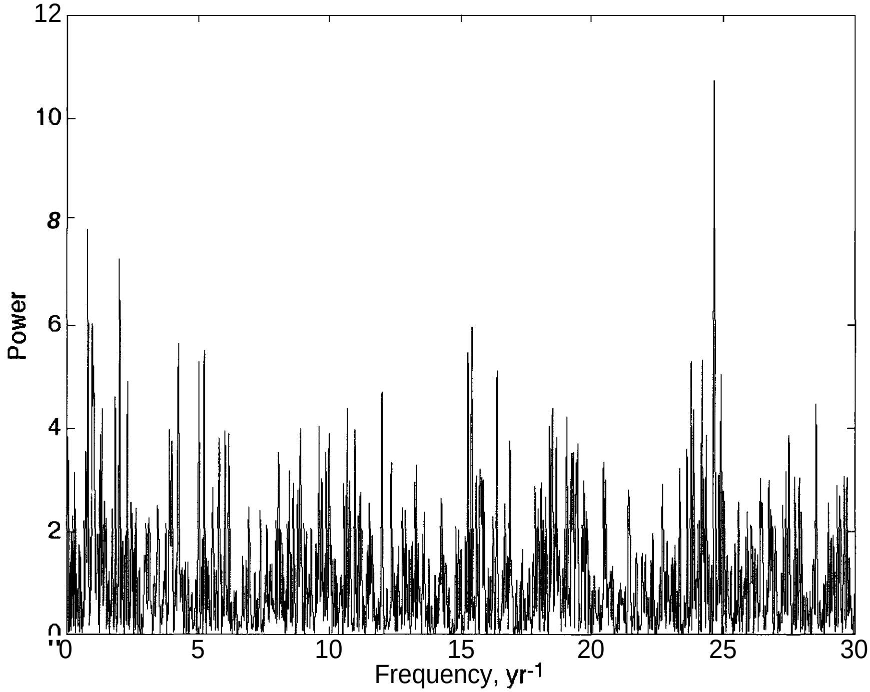

Fig. 8. Power spectrum for the frequency range 0–30 yr^{-1}, formed from Z-values derived from 3,325 free-response anomalous cognition experiments.

Extraordinary Physics (EP). The world is also subject to laws of physics of which we now have no knowledge and which make possible phenomena that are now inconceivable.

Ordinary Consciousness (OC). Consciousness is a brain activity and is therefore localized in time and space.

Extraordinary Consciousness (EC). Consciousness has an existence independent of the brain and is not limited in either time or space.

No Intelligent Intewention (NII). There is not now, and never has been, any intervention by non-human intelligent beings in events and developments on Earth.

Intelligent Intervention (II). There is or has been intervention by non-human intelligent beings in events and developments on Earth.

In terms of this set of options, the "Standard Model of Reality" comprises OP, OC, and NII. In almost all scientific research, the standard model of reality is built into the zero-order information Z. In the current study, it is likely that there are other assumptions built into Z, which are unrecognized and therefore unquestioned. For instance, there may be phenomena which are real, but which cannot be verbalized, for which it would therefore be difficult to enunciate the underlying hypotheses.

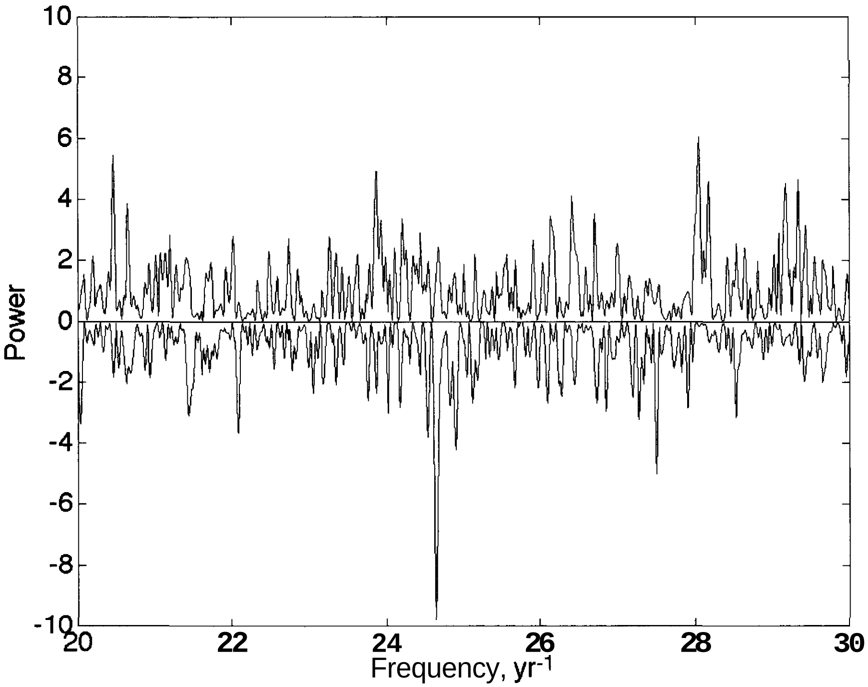

Fig. 9. Running-wave power spectrum for the frequency range 20–30 yr^{-1}, formed from Z-values derived from 3,325 free-response anomalous cognition experiments. Forward waves are shown with positive power and reverse waves with the negative of the power.

Now that we have identified what we regard as the "standard model," we can immediately list seven non-standard models of reality: EP, OC, NII; OP, EC, NII; OP, OC, II; EP, EC, NII; EP, OC, II; OP, EC, II; and EP, EC, II. It is convenient to refer to these as "Model of Reality Version 000," etc., or, briefly, "MOR000," etc. Then the set of models becomes what is outlined in Table 1.

TABLE 1
Models of Reality

MOR000 = {OP, OC, NII}
MOR100 = {EP, OC, NII}
MOR010 = {OP, EC, NII}
MOR001 = {OP, OC, II}
MOR110 = {EP, EC, NII}
MOR101 = {EP, OC, II}
MOR011 = {OP, EC, II}
MOR111 = {EP, EC, II}

Note: MOR = Model Of Reality; OP = Ordinary Physics; OC = Ordinary Consciousness; NII = No Intelligent Intervention; EP = Extraordinary Physics; EC = Extraordinary Consciousness; II = Intelligent Intervention.

If we wish to study anomalous phenomena according to the principles of scientific inference, we should consider all eight of these possible models of reality, not just the standard model.

An important question that now arises is whether we should regard these three choices as independent, or whether the probability of one choice is likely to depend on one or two of the other choices. My own view is that the choice OP/EP will have an important influence on the other two choices. If "extraordinary consciousness" is real, it probably cannot be understood in terms of ordinary physics, so the prior probability that we assign to OC or EC will depend on whether we are associating it with OP or EP. Similarly, one possibility for intelligent intervention is that beings from another "solar system" are visiting or have visited Earth. Travel from other stars seems virtually impossible if we think in terms of ordinary physics, but—for all we know—it may be comparatively easy in terms of some form of extraordinary physics.

If we regard the OC/EC choice and the NII/II choice as independent of each other, then we can proceed to organize the eight prior probabilities as follows: We first assign prior probabilities to OP and EP: $P(OP|Z)$ and $P(EP|Z)$. Note that, in setting these prior probabilities, we should ignore all the experimental and observational results that support OP: since EP must contain OP as a special case, it follows that any result that is consistent with OP will also be consistent with EP.

We next consider the choice OC/EC, but relate the prior probabilities to our choice of OP or EP: $P(OC|OP, Z)$, $P(OC|EP, Z)$, $P(EC|OP, Z)$, $P(EC|EP, Z)$. Based on OP, the probability of OC will be high, and that of EC will be small. Based on EP, the probabilities of OC and EC may be comparable. Similar considerations apply to the choice NII/II.

Based on these assumptions, the prior probabilities for the eight possible models of reality may be listed as follows:

$$P(MOR000) \equiv P(OP,OC,NII) = P(OC|OP,Z) \times P(NII|OP,Z) \times P(OP|Z), \tag{6}$$

$$P(MOR100) \equiv P(EP,OC,NII) = P(OC|EP,Z) \times P(NII|EP,Z) \times P(EP|Z), \tag{7}$$

etc.

The prior probabilities of our eight possible models of reality are formed from combinations of the following ten probabilities: $P(OP|Z)$ and $P(EP|Z)$; $P(OC|OP, Z)$, $P(OC|EP, Z)$, $P(EC|OP, Z)$, and $P(EC|EP, Z)$; and $P(NII|OP, Z)$, $P(NII|EP, Z)$, $P(II|OP, Z)$, and $P(II|EP, Z)$.

However, we are most interested in estimates of $P(EP|Z)$ and of the post probabilities for EC and II, which are given by

$$P(EC|Post,Z) = P(EC|OP,Z) \times P(OP|Z) + P(EC|EP,Z) \times P(EP|Z), \tag{8}$$

and

$$P(II|Post, Z) = P(II|OP, Z) \times P(OP|Z) + P(II|EP, Z) \times P(EP|Z). \qquad (9)$$

In considering our assessment of EP, we should bear in mind that our basic laws of motion and gravity are only 300 years old and that relativity and quantum mechanics are only 100 years old. What is the probability that we have already discovered virtually all of physics? What is the probability that, even if we continue research for the next million years, there will be no further developments as revolutionary as relativity and quantum mechanics? It would be hard to justify a very small value for $P(EP|Z)$. Indeed, it would not be unreasonable to adopt a value larger than 0.5.

On the other hand, most scientists are probably of the opinion that $P(EC|OP, Z)$ and $P(II|OP, Z)$ are small. Hence, the above equations may probably be approximated as

$$P(EC|Post, Z) = P(EC|EP, Z) \times P(EP|Z), \qquad (10)$$

and

$$P(II|Post, Z) = P(II|EP, Z) \times P(EP|Z). \qquad (11)$$

Appendix B lists the prior probability and the two conditional probabilities that need to be assigned in order to arrive at estimates of the probability of the most interesting non-standard models of reality.

The first terms on the right-hand side of these equations represent assessments of very speculative possibilities on the basis of unknown physics. To give these quantities very small or very large values would be an act of faith. It appears that, on the basis of our present knowledge (and ignorance), we cannot assert that extraordinary consciousness and intelligent intervention are either very likely or very unlikely.

The key assessment is the prior probability for EP. If this is considered to be very small, then all the models of reality will be unlikely, except the standard model. However, if the prior probability for EP is thought to be non-negligible, then (since EP is beyond our present comprehension) assessments of the prior probabilities for the four models that involve EP are likely to be non-negligible.

In order to obtain an informed range of estimates of $P(OP|Z)$ and $P(EP|Z)$, it would perhaps be reasonable to consult a number of theoretical physicists, but it is not at all obvious to which intellectual communities one should turn for estimates of $P(OC|OP, Z)$, $P(OC|EP, Z)$, $P(EC|OP, Z)$, and $P(EC|EP, Z)$ or of $P(NII|OP, Z)$, $P(NII|EP, Z)$, $P(II|OP, Z)$, and $P(II|EP, Z)$. However, the assessment of the prior probabilities for the eight possible models of reality is not essential for progress to be made. More important is the *change* in our assessments of the probabilities of these models when we examine the relevant evidence, since scientists should be able to agree on the weight of evidence, even if they differ widely in their prior probabilities. The crucial point is that we will no longer refuse to examine a phenomenon because it appears to contravene the standard model. We will simply estimate the "weight" which each piece of evidence contributes to each of the eight possible models (and any other models that might be proposed) and then keep track of the accumulated weight of evidence for each model of reality.

Note that this approach leads to a different interpretation of the terms "paranormal" and "super-natural." These terms can now simply be interpreted as indicating that certain phenomena are (or appear to be) incompatible with the standard model of reality. It is then an open question, to be investigated, whether these phenomena are compatible with a non-standard model of reality. This interpretation can therefore lead to productive scientific research, whereas the standard approach of the pseudo-skeptical community leads to very little research.

Note

[1] This essay is based on my Dinsdale Lecture presented on June 8, 2006, to the 25th Annual Meeting of the Society for Scientific Exploration in Orem, Utah.

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APPENDIX A

This appendix reproduces equations derived elsewhere (Sturrock, 1973, 1994) and which are used in this essay.

We consider a complete set of hypotheses H_i, i = 1, ..., I and assign them prior probabilities $P(H_1|Z)$, ..., $P(H_I|Z)$, where Z indicates "Zero-order" or background information. For each item of evidence E we introduce a set of statements S_n, n = 1, ..., N and then estimate the probability that each statement follows from each hypothesis, $P(S_n|H_i, Z)$, and from the evidence E, $P(S_n|E, Z)$. Then the posterior probabilities are given by

$$P(H_i|E,Z) = \left[\sum_n \frac{P(S_n|H_i,Z)P(S_n|E,Z)}{\sum_k P(S_n|H_k,Z)P(H_k|Z)}\right]P(H_i|Z). \tag{A.1}$$

If we need to combine results from more than one item of evidence, say E_1, ..., E_A, the result is given by

$$P(H_i|E_1,\ldots,E_A,Z) = \frac{P(H_i|E_1,Z)\ldots P(H_i|E_A,Z)[P(H_i|Z)]^{-(A-1)}}{\sum_j P(H_j|E_1,Z)\ldots P(H_j|E_A,Z)[P(H_j|Z)]^{-(A-1)}}. \tag{A.2}$$

APPENDIX B

This appendix lists the principal prior probabilities that one needs to estimate in order to assign prior probabilities to the most interesting models of reality specified in this essay.

The first estimate one needs to specify is the probability that there is extraordinary physics still to be discovered:

$$P(EP|Z) = \underline{\qquad},$$

where EP indicates Extraordinary Physics and Z indicates "Zero-order" or background information. (Remember that each probability estimate must be larger than zero and less than unity.)

Then, if we ignore the probability that Extraordinary Consciousness (EC) and Intelligent Intervention (II) are compatible with Ordinary Physics (OP), the important estimates to make are

$$P(EC|EP,Z) = \underline{\qquad}$$

and

$$P(II|EP,Z) = \underline{\qquad}$$

Then the post-probabilities, related to the most interesting alternative models of reality, are given to good approximation by

$$P(EP,EC,NII|Z) \approx P(EC|EP,Z)P(EP|Z) = \underline{\qquad} \tag{B.1}$$

$$P(EP,OC,II|Z) \approx P(II|EP,Z)P(EP|Z) = \underline{\qquad} \tag{B.2}$$

$$P(EP,EC,II|Z) \approx P(EC|EP,Z)P(II|EP,Z)P(EP|Z) = \underline{\qquad}, \tag{B.3}$$

where NII indicates No Intelligent Intervention and OC indicates Ordinary Consciousness.