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Is the Sun Conscious?

Abstract: *The recent panpsychist turn in philosophy opens the possibility that self-organizing systems at all levels of complexity, including stars and galaxies, might have experience, awareness, or consciousness. The organismic or holistic philosophy of nature points in the same direction. Meanwhile, field theories of consciousness propose that some electromagnetic fields actually are conscious, and that these fields are by their very nature integrative. When applied to the sun, such field theories suggest a possible physical basis for the solar mind, both within the body of the sun itself and also throughout the solar system. If the sun is conscious, it may be concerned with the regulation of its own body and the entire solar system through its electromagnetic activity, including solar flares and coronal mass ejections. It may also communicate with other star systems within the galaxy.*

1. Introduction

Is the sun conscious?

Obviously not, from the point of view of mechanistic materialism or physicalism. The universe is a mechanical system. Nature is non-conscious. Conscious minds are epiphenomena produced by physical activity in brains; or they are identical with the physical activities of brains, just as water and H₂O are identical, but go under different names; or they are illusions produced by brains; or they are nothing more than a folk belief, as yet unenlightened by objective neuroscience (Churchland, 1986). Therefore anyone who supposes that the sun is conscious is making a childish error, projecting anthropomorphic illusions onto inanimate nature. The fact that children often draw the sun with a smiley face shows that this idea is literally childish. The very question is ridiculous.

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In almost all other societies and civilizations, including medieval Europe, the sun and other heavenly bodies were thought to be alive and intelligent. Our ancestors lived in an animistic world. The earth, sun, planets, and stars were living beings. As Plato put it, ‘This world... came to be in very truth a living creature with soul and reason... a single visible living creature, containing within itself all living things whose nature is of the same order’ (Plato, translated by Cornford, 1959). For Plato, and for many philosophers after him, the sun, planets, and stars were ‘visible gods’, endowed with souls and intelligences (Runia, 2008). We still call the planets by the names of ancient gods and goddesses like Mars and Venus, and refer to our planetary home as Mother Earth, or Gaia.

In some cultures the sun was a god: for example, *Sol* in Ancient Rome and *Surya* in India. In others the sun was a goddess: *Amaterasu* in Japan, and *Sunna* among early Germanic tribes. Accordingly, in contemporary Latin-based languages, the sun is masculine, as in French, *le soleil*, and in Germanic languages feminine, as in German, *die Sonne*.

One of the fundamental chants in the Hindu tradition, the *Gayatri* mantra, is an invocation for the divine light of the sun to illuminate our meditation. In S. Radhakrishnan’s translation, ‘We meditate on the adorable glory of the radiant sun; may he inspire our intelligence’ (Radhakrishnan, 1994, p. 229).

This discussion might seem to be purely historical or anthropological if we assume that mechanistic science has triumphed over the archaic worldviews of mythologies and religions. Ever since the seventeenth century, the standard scientific assumption has been that the sun is a non-conscious, inanimate object, like everything else. To see it as conscious is at best poetic.

Nevertheless, despite the dominance of the mechanistic theory, the idea that the sun and other stars might be conscious has never gone away. It is a recurrent theme in science fiction, especially in one of the classics of this genre, Olaf Stapledon’s *Starmaker* (1937), in which stars are conscious beings in a consciousness-permeated universe on a quest for self-discovery. I have taken part in discussions of solar consciousness myself (Fox and Sheldrake, 1996; Sheldrake, McKenna and Abraham, 1998), and several other authors have explored this subject (e.g. Haldane, 1934; Sams, 2009; Harding, 2011).

Greg Matloff, a physicist and pioneer in solar-sail propulsion systems for spacecraft, has opened a new dimension to this discussion with his ‘volitional star hypothesis’ (Matloff, 2015). He suggests an

alternative to the conventional hypothesis of ‘dark matter’. This hypothetical form of matter is by definition invisible. There is no empirical evidence for it, despite many efforts to find it (Bertone and Tait, 2018). I return to a discussion of Matloff’s ideas later.

The question of solar consciousness takes on a new significance in the light of the recent revival of interest in the philosophy of panpsychism. Like traditional animists, panpsychists argue that mind, or experience, or forms of consciousness, or awareness, are aspects of nature at many levels of organization, and are not confined to brains.

2. Panpsychism and the Integration of Information

Much of the recent panpsychist discussion has taken place in the context of the ‘hard problem’ of explaining how and why we have phenomenal experiences that are qualitatively different from physical processes going on in brains and bodies. To avoid the problem of a radical duality, or difference in kind, between minds and matter, panpsychists prefer to think in terms of a difference of degree.

One of the pioneers of modern panpsychism, Galen Strawson, puts the argument as follows: ‘Once upon a time there was relatively unorganized matter, with both experiential and non-experiential fundamental features. It organized into increasingly complex forms, both experiential and non-experiential, by many processes including evolution by natural selection’ (Strawson, 2006). The philosopher Philip Goff makes a similar point: ‘Rather than trying to account for consciousness in terms of non-consciousness, the panpsychist aspires to explain the *complex* consciousness of human and animal brains in terms of *simple* forms of consciousness that are postulated to exist as fundamental aspects of matter’ (Goff, 2019, p. 115).

Strawson and Goff both make it clear that they are not proposing that all physical objects are conscious or aware. Their arguments apply to self-organizing systems like atoms, cells, and living organisms, not to composite structures like stones, tables, and computers. As Goff puts it, panpsychists ‘believe that the fundamental constituents of the physical world are conscious, but they need not believe that every random arrangement of those particles results in a conscious subject. Most panpsychists will deny that your socks are conscious, while asserting that they are ultimately composed of things that are conscious’ (*ibid.*, p. 113).

The integrated information theory of consciousness (IIT), first proposed by Giulio Tononi, enables panpsychism to be conceived of

in terms of integrative processes. Systems such as human brains have a high level of integrated information, quantified in a mathematical quantity called Φ (phi) and are correspondingly highly conscious, with complex and meaningful experiences. Systems of a low Φ have less consciousness with only simple and rudimentary experiences. Systems with zero Φ are not conscious at all.

The details of this theory are helpful in considering the consciousness of the sun later in this article. In this context of IIT, the word ‘information’ has a special meaning: it is about ‘differences that make a difference’ that depend on the amount of information a system has about itself. A system has cause–effect information if its present state has selective past causes and selective future effects within the system (Tononi, 2012). The activity of a brain at a given time depends largely on its preceding states of activity and its future states. The brain is of course influenced by external conditions, including processes in the body and the sensory environment, but its reactions depend to a large degree on the brain itself. By contrast, in a retina, the current state of the retina does not have much effect on determining its past and future states because they mainly depend on the external environment.

According to IIT, as well as having a high level of information about itself, a system has to be able to *integrate* this information to be conscious. Integration depends on the interconnections between the parts of the system and is lost if the system is cut up. Integrated information is irreducible: it cannot be reduced to the information in subsystems that are not interconnected (Tononi and Koch, 2015). The amount of information a system contains about itself also depends on the number of possible states. Brains consist of billions of neurons with many different combinations of firing and not-firing, giving a huge number of possible states. By contrast, a simple photodiode can either be on or off. It contains very little information about itself because it only has two states.

IIT has a further requirement for consciousness called the ‘exclusion postulate’. A conscious system is a maximum of integrated information. It must have more integrated information than its own parts, and also than any bigger system of which it forms part. Thus the brain as a whole must have a higher Φ than any groups of neurons within it, or the molecules and atoms that make up these cells. It must also have a higher Φ than the body as a whole, or the internet, or any other larger system of which it forms a part (*ibid.*).

As summarized by Hedda Mørch, ‘Consciousness, according to IIT, is a matter of balance. On the one hand, it requires complexity and

variation as conditions for higher information. On the other it requires unity and integration — the parts of a conscious system must be more strongly connected to each other than they are to anything else’ (Mørch, 2017).

However, the mathematics of IIT involves so many possible combinations of elements and subsystems that computing Φ for brains is impossible in practice, even with a new streamlined mathematical version of the theory (Kleiner and Tull, 2020). Some calculations show that using the algorithms of IIT to work out Φ for a human brain, containing 86 billion neurons, would take many times longer than the age of the universe. Even to calculate Φ for the 302-neuron brain of a nematode worm would take 5×10^{79} years on a personal computer (Brooks, 2020).

Another strand of panpsychism is rooted in the philosophy of Alfred North Whitehead, who started his career as a mathematician. Whitehead was the first philosopher to recognize the radical implications of quantum physics. He saw that the wave theory of matter destroyed the old idea of material bodies as essentially spatial, existing at points in time, but with no time within them. According to quantum physics, every primordial element of matter is ‘an organized system of vibratory streaming of energy’ (Griffin, 2008). A wave does not exist in an instant — it takes time; its waves connect the past and the future. Whitehead thought of the physical world as made up not of material objects but *events*. An event is a happening or a becoming. It has time within it. All physical objects are processes. Quantum physics shows that there is a minimum time period for events, because everything is vibratory, and no vibration can be instantaneous. The fundamental units of nature, including photons and electrons, are temporal as well as spatial. There is no such thing as ‘nature at an instant’ (*ibid.*).

Perhaps the most original feature of Whitehead’s theory was his view of the connection between mind and body as a relationship in *time*. For Whitehead, mind and matter are related as phases in a process. Time, not space, is the key to their relationship. Reality consists of processes, and one moment informs the next. The distinction between moments requires the experiencer to feel the difference between the moment of now and past or future. Whitehead summed this up in the phrase, ‘Now subject, then object’ (De Quincy, 2008). Experience is always ‘now’, and matter is always ‘ago’. The link from the past to the present is physical causality, as in ordinary physics, and from the present to the past is feeling or, to use Whitehead’s technical term, ‘prehension’, literally meaning seizing or grasping.

Whitehead was not proposing that atoms are conscious in the same way that we are, but rather that they have experiences and feelings (Segall, 2020). Feelings and experiences are more fundamental than human consciousness, and mental events are informed and conditioned by material events. Knowing can happen only because the past streams into the present, forming it and shaping it, and at the same time the subject chooses among the possibilities that help determine its future (De Quincy, 2008).

Whitehead was also one of the principal pioneers of the holistic or organismic philosophy of nature. In this philosophy of organism, atoms are not inert particles of stuff, as in old-style atomism. Rather, as revealed by quantum physics, they are structures of activity, patterns of energetic vibration within fields. In Whitehead's words, 'Biology is the study of the larger organisms, whereas physics is the study of the smaller organisms' (Whitehead, 1925). Whitehead was writing before the recognition of the existence of galaxies beyond our own, and long before evolutionary cosmology, which became orthodox only after 1966 (Singh, 2004). In the light of modern cosmology, physics is also the study of very large organisms, like planets, solar systems, galaxies, and the entire universe. The best-known example of this approach is the Gaia hypothesis, the idea of the earth as a living organism (Harding, 2009).

In the light of the philosophy of organism, everywhere we look in nature, at every level and scale, we find wholes that are made up of parts, which are themselves wholes at a lower level: for example crystals are made up of molecules; molecules of atoms; atoms of nuclei and electrons; atomic nuclei of protons and neutrons, and protons and neutrons of quarks. Or ecosystems are made up of organisms; organisms of organs; organs of tissues; tissues of cells; cells of organelles; organelles of molecules... Or galactic clusters made up of galaxies; galaxies of solar systems; solar systems of stars and planets. Languages have the same kind of organization: sentences made up of phrases; phrases of words; words of syllables; syllables of phonemes (Sheldrake, 2012).

These organized systems are all *nested hierarchies*. At each level, the whole includes the parts. The parts are literally *within* the wholes. At each level the whole is more than the sum of the parts, with properties that cannot be predicted from the study of parts in isolation. Arthur Koestler proposed the term *holon* for such wholes made up of parts that are themselves wholes: 'Every holon has a dual tendency to preserve and assert its individuality as a quasi-autonomous whole; and

to function as an integrated part of an (existing or evolving) larger whole' (Koestler, 1967, p. 385). Koestler saw consciousness as a manifestation of the Integrative Tendency inherent in all holons.

For such nested hierarchies of holons, Koestler proposed the term *holarchy*. At each higher level there was a greater degree of consciousness: 'Since the variety of alternative choices increases with increasing complexity at higher levels, each upward shift is accompanied by the subjective experience of freedom of decision' (*ibid.*, p. 215).

The holistic philosophy of nature, together with different strands of panpsychism, inevitably raises the possibility that the sun and other stars might be conscious.

For the sun to be conscious, it needs to be able to detect what is happening in its own body, and throughout its extended body, the solar system, and to integrate this information. One way in which information can be integrated is through fields, including electrical and magnetic fields, as I now discuss. I then turn to the question of the possible consciousness of the sun in the light of these ideas.

3. Electromagnetic Field Theories of Consciousness

Fields are inherently integrative. They are also holistic by their very nature. Think of the magnetic field of an iron bar magnet. The field emerges from many microscopic magnetic domains within the metal. At the same time, it exerts a top-down influence on these magnetic domains, and sets up three-dimensional patterns of influence beyond its material body. When iron filings are sprinkled around a bar magnet on a horizontal surface, a two-dimensional image of this three-dimensional field appears in the form of curved lines of force. The iron filings do not take up their positions through local, bottom-up interactions; the top-down magnetic field shapes the patterns in which they are arranged.

Gravitational fields also work top-downwards. The universal gravitational field contains everything within the universe and relates all material bodies to everything else. All material bodies affect the gravitational field and are in turn affected by it.

Likewise, electrical fields affect everything within their range of influence that is electrically charged; magnetic fields affect everything that is magnetized or magnetizable. These fields are in turn influenced by electrical charges and magnetic fields. And electrical and magnetic

fields interact. As Michael Faraday showed in his classic investigations, a changing electrical field creates a magnetic field, and a changing magnetic field creates an electrical field. These principles underlie electric motors and dynamos.

Nervous systems in general, and brains in particular, function electromagnetically. The membranes of nerve cells, or neurons, are electrically charged; the inside of the cell is electrically negative relative to the positively charged outside. The resting potentials of nerve-cell membranes are typically around 60 millivolts. When impulses pass along the axons of nerves, which are like the wires of the nervous system, the resting potential is temporarily depolarized. As this wave of depolarization passes along the axon, it changes the ambient electrical and magnetic fields.

Within the brain, large-scale rhythmic patterns of electrical activity emerge from the activities of countless neurons, such as alpha waves (7–15 Hz) associated with wakeful relaxation with closed eyes, theta waves (3–8 Hz) during sleep, and gamma waves (25–140 Hz) associated with large-scale brain activities that may play a role in the formation of unified perceptions. These oscillating electrical fields can be measured through electrodes placed on the skull, as in electroencephalographs (EEG). These electrical waves set up oscillating magnetic fields.

Electrical fields within the brain also affect the activity of neurons themselves. As well as the communication between nerve cells through neurotransmitters released at synapses, neurons are also affected by the electrical activity of nearby neurons through local electrical fields, a process known as ‘ephaptic coupling’ (Su *et al.*, 2012).

Most researchers agree that consciousness is somehow related to the electrical activity of brains. Some go further and propose that brains’ electromagnetic fields actually *are* conscious. In his ‘conscious electromagnetic information field’ (Cemi) hypothesis, JohnJoe McFadden points out that brains both generate electromagnetic fields and are influenced by them. The electromagnetic field affects field-sensitive voltage-gated ion channels in neuronal membranes:

Information in neurons is therefore pooled, integrated and reflected back into neurons through the brain’s em field and its influence on neuron firing patterns... [T]his self-referral loop has physical and dynamic properties that precisely map with consciousness and are most parsimoniously accounted for if the brain’s em field is in fact the physical substrate of consciousness and conscious volition results from

the influence of the brain's em field on neurons that initiate motor actions. (McFadden, 2012)

McFadden also points out that such a field theory would provide a 'natural solution to the binding problem', namely the problem of explaining how different sensory inputs and activities in different regions of the brain are combined together to provide unified experiences.

Likewise, Susan Pockett, a neurophysiologist, argues that some three-dimensional electromagnetic field patterns in brains are conscious: 'conscious experiences may actually be transient spatial patterns of large field potentials: in other words transient spatial patterns of electromagnetism' (Pockett, 2012). She proposes that conscious fields, as opposed to non-conscious fields, exist in a radial direction in the brain, perpendicular to the surface of the cortex, and involve a surface layer of negative charge above two deeper layers of positive charge, separated by a distinct neutral layer (*ibid.*).

There are at least eight other electromagnetic field theories of consciousness (reviewed by Joye, 2019). In addition, the neuroscientist Todd Murphy proposes a primarily magnetic theory of consciousness. Murphy has worked experimentally on the induction of altered states of consciousness through the transcranial magnetic stimulation of brains. He writes:

[C]onsciousness (the brain's magnetic field) is constantly influenced by neural electrical activity through the classically-known relationship between magnetic fields and electrical currents...What we experience in each moment may be the phenomenological correlate of this field's most excited, coherent, or information-rich areas or the regions with the most salient information content... [M]agnetic fields are propagated through the brain significantly faster than neuroelectrical or neurochemical processes. This makes magnetic field communication within the brain the fastest type available. Organisms will respond to threats and opportunities more rapidly if the basis of consciousness were in the brain's magnetic substrate than if it were based on the slower chemical or electrical processes. (Murphy, 2019, p. 650)

Murphy also points out that the magnetic field hypothesis offers a solution to the binding or combination problem. Magnetic fields, like other kinds of fields, are fundamentally integrative.

Thus there is general agreement that the activities of minds are somehow connected to the electromagnetic activity of brains, and some researchers suggest that these fields are not only related to

conscious processes, but actually *are* conscious processes. Might any of these ideas be relevant to the sun?

I first discuss Matloff's hypothesis that some stars adjust their positions within galaxies by controlling the direction of electromagnetically powered jets, and then discuss the electromagnetic fields of the sun.

4. The Volitional Star Hypothesis

Contemporary cosmology and astronomy are based on the hypothesis that the universe contains not only known forms of matter, but also unknown forms of matter called dark matter, the quantity of which greatly exceeds the amount of regular matter. This is the background to Matloff's proposal.

In the 1930s, Fritz Zwicky, a Swiss astrophysicist, studied the movements of galaxies within galactic clusters and realized that the clusters could not be held together by normal gravitation. Galaxies were attracting each other too strongly. The force holding them together seemed to be much greater than the gravitational pull of visible matter could explain (Singh, 2004). Zwicky's results were ignored for decades, but were taken seriously when it became apparent that the orbits of stars within galaxies could not be explained by the gravitational attraction of known kinds of matter. Too much force seemed to be acting upon the stars. Astronomers mapped the gravitational influences and found that apparent sources of gravitation did not correspond to the observable structure of galaxies. Instead, there were clouds of seemingly invisible matter, which they called dark matter, stretching far beyond the fringes of the luminous galaxies, forming vast haloes extending into intergalactic space (*ibid.*).

Dark matter helps to explain the movements of stars within galaxies and the relations between galaxies within galactic clusters, but it does so at a heavy price: nobody knows what it is, and all attempts to detect it experimentally have failed (Bertone and Tait, 2018). A few physicists believe they can get rid of dark matter altogether by modifying the laws of gravitation (Chown, 2014). But galaxies and stars might behave in ways that are not fully explicable in terms of gravitation, with no need to postulate dark matter or to change the laws of gravitation. For a biological analogy, think of cells within a growing embryo. They move of their own accord to take up their appropriate places within the embryo. They do not move under the gravitational influence of invisible dark matter around the embryo.

In his volitional star hypothesis, Matloff suggests that stars adjust their positions within galaxies by firing off electromagnetically powered jets more in one direction than another, steering themselves into their appropriate positions. ‘Stellar volition in a galaxy might be analogous to the tendency of cells in a living organism to self-organize into organs’ (Matloff, 2015, p. 146). He points out that this hypothesis makes several testable predictions. One is that the number of directional jets should increase as the stars’ distance from the galaxy’s centre increases. Another is that the direction of the jets should be aligned opposite to a young star’s galactic trajectory.

The volitional star hypothesis is minimalist, in the sense that moving into the right place in relation to other stars would not necessarily require a high degree of consciousness, perhaps no greater than that of cells within an embryo. On the other hand, volitional movements may be only one manifestation of a much higher degree of consciousness. Humans, for example, make volitional movements in relation to other humans, like forming queues, but there is more to human consciousness than lining-up behaviour.

The philosopher Clément Vidal has proposed a very different view of volitional stars in his stellivore hypothesis. Vidal suggests that some stars may be predators that seek out victims, from which they suck out matter to fuel themselves. They do so in binary star systems in which one of the stars in the pair, the stellivore, accretes matter from the other (Vidal, 2016).

When we look out at the sky, most stars seem to be single points of light, but closer observation reveals that the majority are double or multiple star systems, revolving around each other. Binary star systems have been known since the seventeenth century; in the nineteenth century it was discovered that they have elliptical orbits around each other. Some binary stars are separated by large distances and behave more or less independently. Others are close to each other and interact through the transfer of matter. Sirius, the Dog Star, one of the brightest stars in the sky, is in fact a binary system. Sirius A shines brightly and its much fainter companion, Sirius B, is a white dwarf; they orbit each other every 50 years. These two stars have probably not always been as they are now: Sirius B was more massive to start with, and Sirius A has grown at its expense (Gerbaldi, 1988).

The transfer of mass between binary stars is not controversial; but Vidal’s interpretation of this behaviour is startling:

[T]here are binaries that are moving fast in the galaxy... I have predicted that if stellivores are alive, the motion of such higher velocity

binaries should not be random, but directed towards the nearest star, because it would be looking for the nearest next food source. We could also predict that higher velocity binaries have on average lower-mass companions, meaning that their energy source is almost exhausted, and they need to find and accrete a new star. Such energy-seeking behaviour is already testable with existing data and would constitute fairly intriguing evidence of intelligent behaviour. (Vidal, 2020)

Fortunately, our own sun is a single star, neither threatened by a stellivore, nor a stellivore itself.

5. The Electromagnetic Fields of the Sun

It is a cliché of popular science to say that ‘the human brain is the most complex structure in the universe’ (e.g. BBC, 2014). This claim is unduly self-important in the light of our increasing knowledge of solar physics. The sun is an extraordinarily complex electromagnetic system with effects that permeate the solar system and extend far beyond it through electromagnetic radiation and cosmic rays.

The sun is made up of plasma, hot, electrically charged matter in which atomic nuclei and electrons are separated. Most of the atomic nuclei in the sun are hydrogen nuclei, or in other words protons. The sun rotates on its axis in about 28 days, and as it does so the plasma swirls around with the outer layers moving faster than the inner layers. These movements of electrified plasma create a vast magnetic field, which extends throughout the body of the sun and far beyond it, to the limits of the solar system, and further still. As in the case of the earth, the north and south magnetic poles of the sun are near the rotational poles, but do not exactly coincide with them. The movements of electrical charge inside and beyond the surface of the sun give rise to magnetic fields, and the changing magnetic fields within and beyond the sun give rise to electrical currents in the plasma (Lang, 2001). Moreover, in accordance with the principles of magnetohydrodynamics, the magnetic field lines around the sun become ‘frozen’ into the plasma. The charged particles of the plasma spiral around the field lines, maintaining the magnetism of the lines, and in turn the magnetic field lines keep the electrically charged particles moving around them. Thus magnetic fields control the movements of the plasma and the movements of the plasma control the fields (Green, 2016).

In the layers of the sun beneath the photosphere, the visible surface, complex convection currents of hot plasma make up cellular structures called granulations, of which there are more than a million on the

visible side of sun. In turn, these are contained within much larger structures called super-granulations. All these moving masses of charged particles create electric currents that set up magnetic fields within the global magnetic field that pervades the sun and solar system. In addition, electrically charged spicules project above the photosphere, and these too are electrically charged and set up magnetic fields around them (Lang, 2001).

The entire sun undergoes acoustic vibrations, reverberating like a spherical bell with a wide range of resonant frequencies. These vibrations are influenced by events on the solar surface like solar flares and sunspots. By monitoring and analysing these rhythmic patterns, helioseismologists are able to work out what is happening on the invisible side of the sun through the vibrations that are reflected through the entire solar body. These vibrations of electrically charged plasma set up corresponding vibrations in the sun's electrical and magnetic fields (Green, 2016).

The sun undergoes approximately 11-year cycles of activity. When its activity is greatest, there are many sunspots, from which extraordinarily strong magnetic fields emerge from the sun's interior, loop around above the photosphere, and re-enter the sun through spots of opposite magnetic polarity. Sunspots occur in pairs, and, by convention, the magnetic field lines move outwards from sunspots with a north polarity and inwards through their partner spots with a south polarity. These magnetic fields are so strong that they exclude all the normal convection currents and plasma flows, which is why the sunspots look dark. Around the time of maximum sunspot activity, the global magnetic polarity of the sun reverses, so that the north pole of the sun as a whole becomes the magnetic south pole, and vice versa (Lang, 2001). Thus an entire solar cycle, in which the original polarity is restored, takes about 22 years. (The earth's magnetic poles also undergo reversals, but much less frequently. The last reversal occurred about 780,000 years ago.)

Sometimes these extraordinarily powerful loops of magnetic energy break and re-join, emitting enormous amounts of energy. Large-scale magnetic 'reconnections' create solar flares that shoot out electromagnetic energy and charged particles into the solar system. Some of these electromagnetic events lead to coronal mass ejections in which billions of tons of electrically charged plasma are projected outwards (Green, 2016).

The varying activity in the sun is the main contributor to space weather, and the US National Oceanic and Atmospheric

Administration (NOAA) issues regular space weather forecasts because the sun's activity affects the earth's magnetic field, and influences the northern and southern lights, radio transmissions, and the frequency of lightning. If solar flares or coronal mass ejections are directed towards the earth, they can cause catastrophic outages of electricity systems; long-distance electric transmission lines act as aerials for this electrical energy (Witze, 2016).

If the electromagnetic fields associated with the activities of brains are the principal interface between measurable physical activities and conscious and unconscious minds, then the electromagnetic activity of the sun may well be the principal interface between the physical activity of the sun and the solar mind.

For those who believe that complex electromagnetic fields *are* conscious, as in McFadden's electromagnetic field theory of consciousness, and in Murphy's magnetic field theory, then the sun's consciousness may be none other than the subjective experience of these fields.

In general terms, the sun seems to meet the criteria of IIT for a high Φ , or integrated information. The sun has a high level of information about itself within its electromagnetic fields, and this information is integrated within the global electromagnetic field that pervades the heliosphere. According to IIT, the amount of information a system contains about itself depends on the number of possible states. Brains have many possible states. So does the sun. The mind of the sun, though centred in the sun itself, may integrate information from the entire heliosphere, just as our minds, centred in brains, integrate information from our own bodies and the world around us. And just as the reactions of the brain depend to a large degree on the brain itself, as IIT points out, so the reactions of the sun depend to a large degree on the sun itself. Similar principles may apply to countless other stars and solar systems.

However, actually to calculate the Φ value of the sun is not feasible at present. If current methods would take billions of years to compute Φ for the tiny nervous system of a nematode worm, the vast complexity of the sun would require multiverses of computer time. Nevertheless, IIT helpfully focuses attention on the role of combinations of subsystems in composing integrated information. In the sun, the millions of granulations could be thought of as systems that can be combined into higher-order systems like super-granulations, just as neurons can combine as groups of neurons.

IIT also focuses attention on cause-effect information that counts towards consciousness: the past state of elements constrains the

present state, which in turn constrains future states. There is cause-effect information in the sun. As in the case of the brain, it is an empirical question to what extent the future states of the sun's systems and subsystems are probabilistically affected by the current states.

According to IIT, larger magnitudes of integrated information will be associated with networks with multiple, complex feedback loops and dispersed connections leading to non-local information exchange. Networks that are too regular or simply feed-forward systems will not have much, if any, integrated information. For example, the cerebellum, which in the human brain contains 3.6 times as many neurons as the neocortex, has a repetitive architectural structure; although it may have the capacity to process more information than the neocortex, it is not associated with conscious experience (Oizumi, Albantakis and Tononi, 2014). In relation to the sun, it would be an empirical question as to what extent feedback loops and non-local interactions could generate integrated information. The existence of large spatio-temporal macro-structures such as sunspots or super-granulations suggests that such integrated information is at least possible.

However, whether IIT is applied to brains or to the sun, its bottom-up approach unleashes a combinatorial explosion. The number of possible combinations and interactions of subsystems and systems, like individual neurons and groups of neurons, rapidly becomes intractable. Hence the universe-long computing times. In recent formulations of IIT, Tononi and his colleagues explicitly recognize the need to go beyond the standard reductionist assumption that micro-level causation is all-powerful and underlies macro-levels of organization. As they put it, 'Causal power can be stronger at macro rather than micro levels' (Hoel *et al.*, 2016).

In physical reality, the effects of processes at all levels of organization are integrated into electrical and magnetic fields, which have top-down causal influences both in brains and stars. In its present forms IIT ignores the integrative activities of these fields.

Apart from its computational intractability, one of the key assumptions of IIT is problematic in relation to the sun. The exclusion postulate is a winner-takes-all principle, whereby the highest level of integration is conscious while subsystems within it are not. The solar system is part of the Milky Way galaxy, and therefore if the galaxy became conscious through an integration of information in its component subsystems, then the sun would stop being conscious. And if the universe as a whole became conscious, then all galaxies would lose

their consciousness. In an holistic, panpsychist worldview, this exclusion postulate may need to be revised to allow for multiple levels of consciousness.

The electrical and magnetic fields within and around the sun seem a more promising starting point for a discussion of solar consciousness than IIT in its present forms.

6. How Could the Sun's Mind Work?

In so far as the sun's mind is working habitually, it is probably unconscious, just as we are unconscious of most of our own habitual patterns of activity. According to the general principle of a temporal relationship between minds and matter suggested by Whitehead, discussed above, if the sun is conscious, its conscious mind is likely to be concerned with possible actions and choices among them. Its choices may include an influence on the numbers, locations, and activities of sunspots, the timing and directions of solar flares and coronal mass ejections, and the coordination of granules and supergranules within the surface layers of the sun, as well as the flow patterns within the inner regions of the solar body. All these activities in turn affect the reverberating acoustical vibrations within the body of the sun, which in turn set up rhythmic patterns in its electromagnetic fields.

The sun would be able to sense what is going on throughout the solar system through the electromagnetic field that pervades the heliosphere, which could act as its primary sense-organ. Thus the sun's mind could, in principle, know about all events within the solar system. All these electromagnetic patterns would be integrated into the overall electrical and magnetic fields of the sun. The sun would also be able to sense through its gravitational field the positions and movements of the planets within the solar system, which exert tidal pulls on its body (Stefani, Giesecke and Weiser, 2019).

If the sun's mind is linked to, or even identical with, its electrical and magnetic fields, we can form some estimate of the maximum speed of solar thoughts and perceptions. The sun itself has a diameter of around 1.4 million km (Lang, 2001). The maximum speed at which changes in magnetic and electrical fields can propagate is the speed of light, around 300,000 km per second. Thus the effects of a change in the electrical and magnetic fields on one side of the sun would take at least 4.6 seconds to reach the other. For the sun to sense a change in the outer limit of the heliosphere, the heliopause, would take much

longer. The heliopause, is about 120 astronomical units from the sun, or in other words about 120 times the distance of the earth from the sun (*ibid.*); to travel this distance of about 18 billion km at the speed of light would take about 60,000 seconds or 16.7 hours. Thus, by our standards, solar thoughts and perceptions would be slow.

If the sun is conscious, if it has experiences, feelings, desires, memories, imaginings, and intentions, then what might it be concerned with?

In the first place, the sun is presumably concerned with the regulation and preservation of its own body, the sun itself, and its extended body, the solar system, right out to the heliopause, the plasma membrane that is the frontier between the solar wind spilling out from the sun and the galactic wind blowing through the galaxy, both consisting of charged particles, electric currents, and magnetic fields. Within this electromagnetic boundary, the entire solar system, the heliosphere, is a kind of organism with the sun at its centre. The mind of the sun may be intimately concerned with the modulation of the solar system, influencing it through the intensity of the solar wind, through directional solar flares, and most dramatically through coronal mass ejections pouring billions of tons of charged particles towards anything in their path. The sun may be sensing and influencing what happens in the solar system through its electromagnetic fields.

Secondly, the sun may be aware of its position and interactions with other stars and solar systems in its immediate neighbourhood, and ultimately throughout the entire galaxy. These systems may in turn be part of a galactic mind, like neurons within a galactic brain. They are literally interconnected through the plasma permeating the arms of the galaxy, through which vast electric currents flow, spiralling around enormous magnetic field lines radiating out through the galactic arms that are tens of thousands of light years long. The sun is part of a vastly greater electromagnetic system. Rhythmic patterns of activity in the sun and other stars may enable them to communicate with each other both through electromagnetic radiation, including X-rays, radio waves, and visible light, and through streams of energetic charged particles, including cosmic rays.

At the centre of our galaxy is a supermassive black hole that emits huge amounts of energy, with a galactic wind passing along the spiral arms extending outwards from it (Keeney *et al.*, 2006). The activity levels of this galactic centre change quite rapidly, with several major flares a year (Mossoux *et al.*, 2020). As the sun and other stars rotate around it, they are also influenced by enormous waves in the inter-

stellar gas (Alves *et al.*, 2020). The sun is influenced by the electromagnetic patterns of activity within the galaxy as a whole, which could in turn be closely connected with a galactic mind, perhaps centred in or around the supermassive black hole at the galactic centre. The galactic mind could influence what happens here on earth through its effects on the sun and the solar mind.

Assuming that the galactic mind works in and through electromagnetic fields, then its thoughts and perceptions must be very slow indeed, by our standards. The radius of the Milky Way is about 50,000 light years, so it would take at least this length of time for the galactic centre to perceive what is happening at the periphery, and as long again for it to act on star systems at the edge.

Our galaxy is part of a ‘local group’ that contains more than 50 other galaxies, which may in turn influence the physical and mental activity of our own galaxy. Magnetic filaments connect these galaxies with each other. At an even larger scale, galactic clusters are connected with each other through magnetic filaments hundreds of millions of light years long, which form part of a ‘cosmic web’ of electromagnetic interconnections extending throughout the entire universe (Vacca *et al.*, 2018).

7. Conclusions

We can choose to believe that the entire universe is non-conscious, governed by eternal mathematical laws, and evolving through purposeless and mindless processes. We can think of our own minds as nothing but the physical activity of our brains, and dismiss our experience of making choices as illusory. We can hope that advances in neuroscience will eventually solve the ‘hard problem’ of consciousness mechanistically. In other words, we can put our faith in mechanistic materialism or physicalism.

Panpsychism offers an alternative to this orthodoxy. Human and animal brains may not be the only conscious structures in the universe. Consciousness, awareness, or experience may be present in self-organizing systems at many levels of complexity.

The possibility that the sun is conscious expands the scope of our thinking. We can move beyond familiar debates about the ‘hard problem’, whose primary concern is to explain the emergence of human minds from smaller and less complex systems, and place this discussion within a literally panpsychist context, where ‘pan’ means

‘all’, and ‘all’ includes stars, solar systems, galaxies, the cosmic web and, ultimately, the universe as a whole.

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