Superflares and the origin of life on Earth

Andrew Sibley

This paper considers the naturalistic view of the early sun at the time when abiogenesis was supposed to be occurring, and early life was, allegedly, evolving on Earth. Theoreticians have, historically, been concerned about answering the faint young sun paradox, but there is growing realisation that the hypothetical early Earth would have faced a very hostile environment from solar superflares, extreme coronal mass ejections, and very harmful radiation storms. While some have tried to turn this to their advantage, the evidence presented is not compelling. This also has a bearing upon the search for extra-terrestrial life. It turns out that the vast majority of star systems are not conducive to hosting Earth-like planets, but most stars are far more variable in their flare output. The sun–Earth system appears to be unique and optimally designed for organic life.

This paper will evaluate naturalistic views of the early sun, and consider the theoretical strength of solar activity at a time when life on Earth was believed to be arising within the evolutionary framework, approximately 3.5 to 4 Ga ago. Increasing evidence from other stars that are similar in size or smaller than the sun, such as red dwarfs, raises serious problems for the naturalistic view. This has a bearing upon naturalistic theories about the origin of life, and it may be noted that in comparison with other stars the sun is in fact unusual in being remarkably stable in its flare output and heat flux.[1]

Naturalistic science holds that the sun has undergone changes in the period since formation, 4.5 Ga. The first claim is that the sun was around 30% dimmer 3.5 to 4 Ga, at a time when life was believed to be arising on Earth. The Luminosity (L) of a star may be determined using Stefan Boltzmann theory if it is treated as a black-body emitter, so that $L = 4\pi R^2\sigma T^4$ (where σ = the Stefan Boltzmann constant, T is temperature, and R the radius of the star).

This lack of heat leads to a problem in that researchers consider that there would have been insufficient irradiance at Earth to allow liquid water to remain stable on the surface: the faint young sun paradox. There are various possible mechanisms raised to get around this, for instance one idea is that the earth was bombarded by asteroids that released greenhouse gases into the atmosphere, or experienced excessive volcanic emissions.[2] Another position is that life arose near deep ocean hot vents.[3] However, there is also a growing understanding that within the naturalistic framework an early Earth would have experienced an extreme space environment from the sun that would have been very harmful to life and the earth system. Although some recent papers have tried to turn this into an advantage, the evidence is not compelling.[4]

Naturalistic theories about the origin of the sun hold that it would have been spinning at a much faster rate than it is today, at a time when abiogenesis was believed to be occurring on Earth (according to naturalism, stars form when giant gas clouds collapse and the concentration of angular momentum leads to a very fast rotating object). The outcome of this excessive spin is that the strength of the sun's magnetic field would also have been much stronger. This is because of differential rotation between the sun's equator and poles, and this feeds into the strength of magnetic fields around sunspot regions. The magnetic field intensity of sunspot regions would have been extremely strong with the possibility of super-strength extreme ultra-violet light (EUV) and X-ray flares (figure 1), more powerful coronal mass ejections (CMEs) (figure 2), and very high energy particle radiation storms. Sunspots form when dynamic forces twist, contort and strengthen magnetic field lines, and greater differential rotation with an early sun would lead to an increase in strength. The theory behind this is referred to as magnetohydrodynamics (from Hannes Alfvén) and basically combines Maxwell's electromagnetic equations with Navier–Stokes equations of fluid dynamics. In CMEs, high tension magnetic fields associated with sunspot regions reconfigure and reconnect with plasma clouds breaking away at very high speeds, sometimes of the order of 2,000 to 3,000 km/s on the present sun. The shock wave ahead of CMEs can also accelerate energetic particles, such as hydrogen ions, to very high energies, even relativistic energies of the region of 500 MeV or more. The release of energy from solar magnetic reconnection is also observed as intense EUV and X-ray emissions. So, given a faster solar rotation speed, these CME emissions, X-ray flares, and radiation storms would have been stronger and thus produced a much bigger impact upon the Earth's atmosphere than at present.

Conditions on the sun and sun-like stars

Studies show that superflares occur on stars that are both slightly larger than our sun and on stars that are smaller, sometimes significantly smaller. One star has been identified that is believed by naturalists to mimic conditions on the early sun. The G5V star Kappa-1 Ceti is a similar size to the sun and about 30 light years away with an estimated age of around 0.5 Ga. From measurements, it rotates at the equator once every 9 days, three times faster than the sun, and has a mass loss in the stellar wind in excess of 50 times greater than Earth's star. The magnetic field strength averages 24 Gauss (G), and peaks at 61G, compared to the sun's 1G. The average dynamic pressure of the current solar wind is dependent upon density and velocity squared: $P = 1.6726e\text{-}6 * \rho * V^2$ (where P is in nano-pascals (nPa), density cm^{-3}, and V is in kms^{-1}). The impact upon the earth's magnetosphere is also related to the north–south component (Bz) of the interplanetary magnetic field (IMF). In the variable solar wind the direction of Bz is important in determining how it interacts with Earth. If it is opposite to the earth's, which occurs in approximately 50% of occasions, then the earth's magnetic field lines open up, recombining with the solar wind and energising the polar cap absorption regions. If conditions on Kappa-1 Ceti were applicable to an early sun spinning at a similar rate, it is estimated that it would compress the earth's magnetopause[5] to 34–48% of the current level.[6]

Another recent paper, by Airapetian and colleagues, suggests that the earth was bombarded by daily superflares, high energy solar proton storms, and CMEs. They suggest that such CMEs would have compressed the magnetopause to one-sixth of its current level (from 9 Earth radii (Re) to 1.5 Re (approximately 9,000 km above ground level) and opened up the earth's atmosphere to harmful radiation. Solar flares they suggest were 1,000 times stronger than those in recent history. Their work argues that the earth experienced events more powerful than the extreme 1859 Carrington event[7] as frequently as one per day for 500 Ma, with levels gradually reducing to present-day levels of activity through prehistory.

However, they also suggest that this radiation led to the formation of nitrous oxides and ammonia, which warmed the planet. These compounds are strong greenhouse gases, and further reactions provided the seed chemicals for life; chemicals such as hydrogen cyanide (although this molecule is highly poisonous to organic life, naturalistic scientists believe it is necessary for abiogenesis to occur). The paper's authors argue that nitrous oxides provide more stable greenhouse gases than CO_2 and CH^4 even though it requires a lot of energy to break molecular nitrogen. Solarflares they think provided sufficient energy. But in response Ramirez questions how these products, produced in the ionosphere, might get down to ground level.[8]

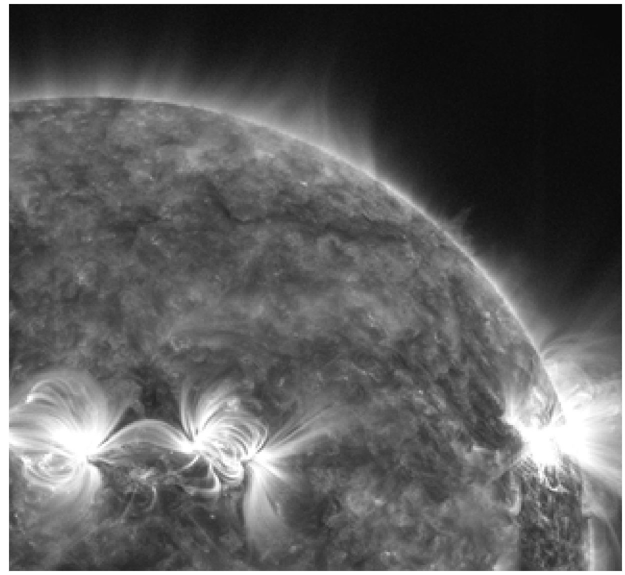

Figure 1. NASA Solar Dynamics Observatory composite image AIA 171 Angstrom (A), 9 Aug 2011 0810 UTC. This shows an X6.9 flare in the right. The magnetic field lines are clearly visible around the sunspot groups.

It also needs to be recognized that very high-energy proton storms in the upper atmosphere may lead to secondary products in the form of harmful neutron radiation at ground level. These events are referred to as ground level events (GLEs). A daily stream of superflares (over 500 Ma) would lead to very harmful radiation levels for organic life, as well as excessive EUV and X-ray radiation. Airapetian acknowledges the problem, but believes that some shielding was possible, although without adequately identifying a solution. He writes:

> "On one hand, our studies suggest that the harsh conditions introduced by intensive radiation from flare and CME activity had a detrimental effect on life … . On the other hand, high levels of steady, intense radiation could have opened a 'window of opportunity' for the origin of life on Earth by setting a stage for prebiotic chemistry it requires."[9]

Naturalists believe the early earth's atmosphere (at 3.5 Ga) consisted of 80% N_2, 20% CO_2 and a small fraction of CH^4. The first life they hold to have been cyanobacteria, organisms that are able to convert the hostile chemistry into free oxygen through photosynthesis. Over the following 3 Ga, naturalists believe that atmospheric oxygen levels rose slowly so that higher organisms could evolve, but much oxygen was reabsorbed into the ocean and land surfaces. These organisms would also have been subject to harmful EUV, X-ray, and neutron radiation on the ocean surface.[10] In the present-day atmosphere stratospheric oxygen and ozone protect against EUV, but this is missing from naturalistic models of the early earth. The susceptibility and importance of ozone in protecting the earth can be seen when it is proposed that

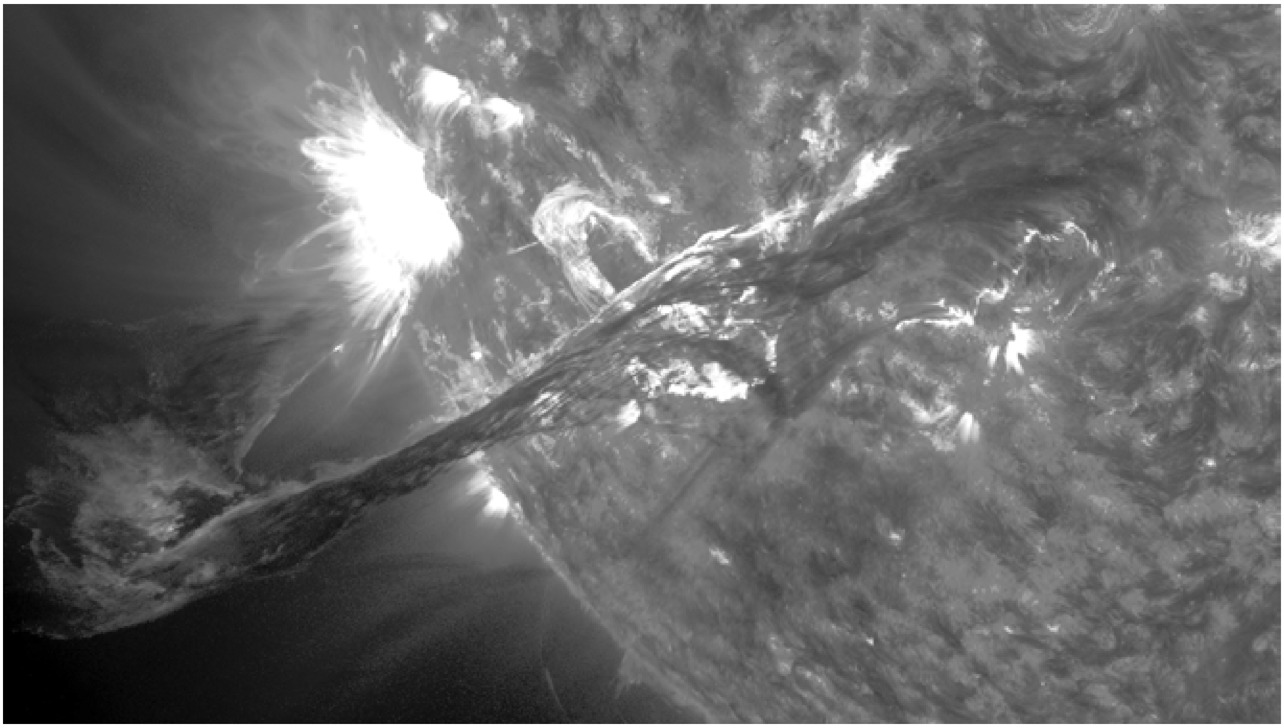

Figure 2. Massive filament eruption / coronal mass ejection from the Sun 31 August 2012 4:36 EDT (USA). This was associated with a C8 flare. Image is NASA SDO AIA 304 A and 171 A.

the 1859 Carrington event enhanced stratospheric nitrous oxides, which in turn lowered ozone concentrations by some 5% for several years. This reduction allowed more harmful UV to pass to ground level.[11]

Such levels of solar activity (as proposed by Airapetian and others) may also harmfully modify and erode the earth's atmosphere. Given a higher dynamic pressure from an early sun and frequent powerful CMEs on a daily basis, severe atmospheric modification might be expected. Although this is not fully quantified at present, superflares, extreme coronal mass ejections, and pressure from the solar wind, with its changeable magnetic field, might be expected to seriously erode the atmosphere of an Earth-like planet over hundreds of millions of years. Further work needs to be carried out to try and quantify this.

An electric wind

There is also increasing evidence that the planets in near sun orbits (Mercury, Venus, Earth, and Mars) are subject to an electric force that impacts upon the ionosphere of each. This is able to denude oxygen and hydrogen if sufficiently strong, whether or not there is a protective magnetic field. Venus and Mars do have very weak magnetic fields and appear to have lost a substantial amount of water as a result of an electric potential drop in the upper atmosphere. The atmosphere of Mars is very tenuous, while that of Venus is at a higher pressure and temperature than Earth, and enriched in CO_2 with smaller amounts of N_2 and SO_2. The ionosphere of these planets is charged as a result of solar EUV and X-ray energy being absorbed by atmospheric molecules, including that of available water and bi-atomic oxygen. Although the Coulomb force seeks to retain balance, highly energized electrons increase the potential difference and lead to loss of these ions to space. The ESA *Venus Express* mission has detected an unexpectedly large ambipolar electric field of the order of 10–12V, sufficient to accelerate ions of oxygen from the atmosphere.[12] Both hydrogen and oxygen ions have been detected downstream from the planet. This electric field is five times greater than the equivalent field strength on Earth and appears to be the major cause of water loss. It is thought that a similar electric field has caused the loss of water on Mars.[12] Although the present Earth has a sufficiently weak electric field that prevents water and oxygen loss to space, it ought to be asked how the strength of an electric field would be modified by stronger ionizing radiation from the sun as well as ionizing polar cap events from a stronger solar wind and faster CMEs. According to naturalism, in the period from 3.5 to 0.5 Ga early life forms were supposed to be leading to an increase in O_2, but at the same time the earth may have been faced with the potential loss to space of free oxygen and water vapour due to a stronger electric force in the ionosphere.

Origin of life on other planets—superflares on brown and red dwarfs

The evidence suggests that the majority of superflares on other stars are formed by a similar mechanism to solar flares on the sun, that is coronal magnetic reconnection in association with star-spot regions involving magnetohydrodynamic forces. Other possibilities that are considered feasible for the observed data are star–star interaction, star–disk interaction and star–planet interaction, but these are less frequent.[13]

Superflares have been detected on stars smaller than the sun, even on stars that may be classified as ultra-cool brown dwarfs. Being so faint, it means that the theoretical habitable zone needs to be much closer to the star than the equivalent habitable zone in the solar system, perhaps even closer than the orbit of Mercury for some star systems. These stars may make up 80% of all stars, and they are believed to be long-lived, potentially lasting for hundreds of billions of years. For these reasons those seeking to find extra-terrestrial life on other planets suggest these small stars provide good candidates. For life to form, there is a need for liquid water, and habitable planets must orbit close in. But being so close a planet would become tidally locked to the star in the same way the moon is locked to the earth. One side of a planet would then experience excess heat, while the other side would be in constant icy cold. Furthermore, such a planet would lose its magnetic field and be more susceptible to the effects of the stellar wind and CMEs. A major part of a planet's magnetic field is believed to be driven by an internal dynamo, and tidal locking severely modifies its rotation and slows the driving magnetic dynamo. But although red dwarfs are small and dim they are not inactive. Many spin at very high speeds, which generates powerful magnetic fields providing very hostile environments for life to form on nearby planets. Some in fact massively exceeding the present-day sun in terms of flare generation and magnetic field strength. It is estimated that at least 40% of these nearby small stars are highly variable in their flare output.[14]

There is an increasing number of examples of powerful, but very small stars. The tiny M8.5V star TVLM 513 is less than one tenth the size of the sun. It is so small and cool that it borders into the transition to ultra-cool brown dwarf stars. It is 35 light-years away, with an estimated naturalistic age of 100–500 Ma.[15] Even so, it has a magnetic field strength several thousand times more powerful that the sun. Part of the reason for this is that it has a rotational period of only 2 hours at the equator, moving at a speed of 60 km/s. The differential speed from poles to equator generates powerful star spots, and from this releases powerful flares in the X-ray spectrum and CMEs.

TVLM 513 was detected by the ground-based ALMA instrument in Chile, but research satellites have also recently detected extremely powerful X-ray flare activity on other nearby M-class dwarf stars using NASA's *Swift* satellite. If such flares occurred on our sun it would make life on Earth impossible. The flares in question were estimated to be up to 10,000 times more powerful than any measured on the sun within the last 50 years, and from a star smaller and normally dimmer than our sun.

Beginning on 23 April 2014 a series of superflares were detected from the M4.0V dwarf binary start system known as DG Canum Venaticorum (DG CVn). This system is about 60 light-years away from Earth, and the two stars orbit about each other at a distance equivalent to three times the sun–Earth distance (3AU), roughly the distance to Ceres in the Asteroid belt. Naturalistic science holds that these stars are young, at 30 Ma old, and rotating at a much faster rate, of the order of one rotation per Earth day. Our sun rotates about once every 25 days at the equator on its own axis (27 days relative to Earth's orbit). With this event the initial Gamma-ray and X-ray flare was estimated to be at level X100,000, about 10,000 times larger than the X45 Solar flare event of November 2003. There were a series of weakening flares over the next few weeks as the star system returned to more normal levels of activity.[16]

Superflares have been detected elsewhere. The M3.5V star EV Lacertae erupted with a massive release in the X-ray spectrum in 25 April 2008, again caused by the enormous strength of its magnetic field, which is perhaps 100 times that of the present sun. This star is about one third the diameter of the sun and rotates once every few days. It lies at a distance of 16 light-years and is estimated to be several hundred million years old by secular science.[17]

Summary

There is growing evidence from satellite and ground-based instruments that dwarf and sun-like stars have the capacity for superflares with much greater stellar magnetic field strengths. Naturalistic theories about the evolution of the sun and inner solar system are beginning to recognize that a hypothetical early Earth would have been faced with a severe space environment from CMEs, energetic particles, EUV and X-ray flares; events much stronger and more frequent than those observed today and over extended periods of time. While scientists have worried about sufficient strength of irradiance from a faint young sun to give liquid water, other factors come into play that are related to magnetohydrodynamics. While naturalists suggest this may help to overcome the faint young sun paradox and provide an explanation for stable liquid surface water, it would also lead to harmful radiation for abiogenesis and evolving organisms.

Given such extreme space weather, the earth system would also be faced with many strong magnetic and dynamic forces in the solar wind. These forces have the potential to erode the atmosphere of inner planets with much stronger conditions, although at present this is not quantified. There are also electric potential forces in the ionosphere of the inner planets that are able to strip the atmosphere of oxygen and water over extended periods of time. Given these factors, it may be noted that it is remarkable that the earth's atmosphere is not like Mars, which does not have much of an atmosphere, or Venus which has very little water and oxygen.

The presence of life on Earth shows that we are in the beneficial Goldilocks position, the right distance from the sun, which is itself remarkably stable in its output of light and heat in comparison with many other stars of similar size. The earth's atmosphere and magnetosphere are also remarkable in their ability to protect life from the harmful space environment and prevent significant loss of water molecules and oxygen to space. The sun and Earth are optimally designed for life.

Evidence from small M-class dwarf stars that form the bulk of stars in the Milky Way suggests that any habitable zone would need to be closer than the earth's orbit, and yet most of these stars also present extreme space environments that would not be conducive to the formation of life. This raises problems for the search for extra-terrestrial life.

References

1. Henry, J. The sun is not an average star, *J. Creation* **17**(3):35–42, 2003.
2. Marchi, S., Black, B.A., Elkins-Tanton, L.T. and Bottke, W.F., Massive impact-induced release of carbon and sulfur gases in the early Earth's atmosphere, *Earth and Planetary Science Letters* **449**:96, 2016; doi:10.1016/j.epsl.2016.05.032, sciencedaily.com/releases/2016/06/160623095610.htm.
3. For instance, Lane, N. and Martin, W.F., The origin of membrane bioenergetics, *Cell* **151**:1406–1416, 2012.
4. Airapetian, V.S., Glocer, A., Gronoff, G., Hébrard, E. and Danchi, W., Prebiotic chemistry and atmospheric warming of early Earth by an active young Sun, *Nature Geoscience* **9**:452–455, 2016; doi:10.1038/ngeo2719, 23 May 2016.
5. Magnetopause is the boundary between the earth's magnetic field and the magnetic field of the solar wind.
6. Nascimento Jr, J.D., Vidotto, A.A., Petit, P. *et al.*, Magnetic field and wind of Kappa Ceti: towards the planetary habitability of the young Sun when life arose on Earth, *Astrophysical Journal Letters*, 12 March 2016.
7. See, for instance, Cliver, E.W. and Svalgaard, L., The 1859 solar–terrestrial disturbance and the current limits of extreme space weather activity, *Solar Physics* **224**:407–422, 2004.
8. Ramirez, R., Atmosphere's solar shock, *Nature Geoscience*, 23 May 2016; doi:10.1038/NGEO2728.
9. Interview in Hadhazy, A., Fierce 'Superflares' from the Sun Zapped an Infant Earth, Astrobiology Magazine, astrobio.net/news-exclusive/fierce-superflares-sun-zapped-infant-earth/, 2 Mar 2015.
10. One way around this for naturalists is to propose that life arose near hydrothermal vents in the deep ocean and obtained energy via chemosynthesis. Michael, S., Hydrothermal Vents Could Explain Chemical Precursors to Life, NASA Astrobiology: Life in the Universe, NASA, 24 June 2014.
11. Thomas, B.C., Jackman, C.H. and Melott, A.L., Modeling atmospheric effects of the September 1859 solar flare, *Geophysical Research Letters* **34**:L06810, 2007, doi:10.1029/2006GL029174.
12. Collinson, G.A., Frahm, R.A., Glocer, A. *et al.*, The electric wind of Venus: A global and persistent 'polar wind' like ambipolar electric field sufficient for the direct escape of heavy ionospheric ions, *Geophysical Research Letters* **43**(11), 16 June 2016. Ambipolar refers to the diffusion by an electric field of positive and negative electric ions in a broadly equal, but opposite, direction.
13. Karoff, C., Knudsen, M.F., De Cat, P. *et al.*, Observational evidence for enhanced magnetic activity of superflare stars, *Nature Communications* 7, Article number: 11058 (2016), doi:10.1038/ncomms11058, published online 24 March 2016.
14. Kowalski, A., Osten, R.A., Sahu, K.C. and Hawley, S.L., An optical flare rate census of galactic bulge dwarf stars, *Bulletin of the American Astronomical Society* **43**, 2011.
15. Williams, P.K.G., Casewell, S.L., Stark, C.R. *et al.*, The first millimeter detection of a non-accreting ultracool dwarf, *The Astrophysical J.* **815**(1):64, 9 December 2015.
16. This was presented by Stephen Drake, an astrophysicist at NASA's Goddard Space Flight Center, Maryland, at an August meeting of the American Astronomical Society, High Energy Astrophysics Division. Reported by Reddy, F., NASA's Swift Mission Observes Mega Flares from a Mini Star, NASA Goddard Space Flight Center, Greenbelt, MD, 29 September 2014, www.nasa.gov/content/goddard/nasas-swift-mission-observes-mega-flares-from-a-mini-star.
17. Naeye, R., The mouse that roared: pipsqueak star unleashes monster flare, NASA Goddard Space Flight Center, Greenbelt, MD, 19 May 2008, nasa.gov/centers/goddard/news/topstory/2008/pipsqueak_star.html.

Andrew Sibley *works as a meteorologist in the UK. He has a B.Sc. (Hons.) and completed an M.Sc. in Environmental Decision Making in 2003 with the Open University, and finished an M.Phil. in theology at a UK university in 2012, which looked at the science and theology of Intelligent Design. He is an occasional speaker and writer with the Creation Science Movement based in Portsmouth, England, and the author of* Restoring the Ethics of Creation.