Sunspots, Solar Rain, Solar Prominences, Solar Tsunamis and Sunquakes are Absolute Evidence Showing the Condensed Matter Nature of the Sun

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Abstract

Almost all observations clearly show the condensed matter nature of the Sun. Regrettably, empirical solar data are always interpreted with the Standard Solar Model (SSM) in mind. Basically, the interpretation of solar features and phenomena must be compatible with the SSM. For instance, sunspots, granules, and faculae are regarded as optical illusions within a gaseous mass, yet they are actually real physical structures formed by condensed crystal lattices. Besides that, the Sun's average density (1.41g /cm^3) —which is comparable to Earth's oceans and slightly denser than water—is ignored or rather deliberately misinterpreted by being considered a mathematical illusion. In fact, not only is the overall density of the Sun perfectly aligned with the condensed liquid state, but pure gases of this composition would also not inherently maintain the observed structural rigidity required for the solar dynamo to operate. Moreover, a continuous solar spectrum cannot be produced by gaseous bodies. That is because a continuous spectrum requires dense, opaque matter (like solids or liquids) in order to emit light across all wavelengths, behaving as a blackbody. In contrast, isolated, low-density gases or plasmas produce distinct, discrete emission lines. Furthermore, and most importantly, it is physically impossible for the observed solar-dynamic phenomena such as sunspots, solar prominences, coronal rain, sunquakes, and solar tsunamis to occur without a liquid surface and a solid core.

Introduction

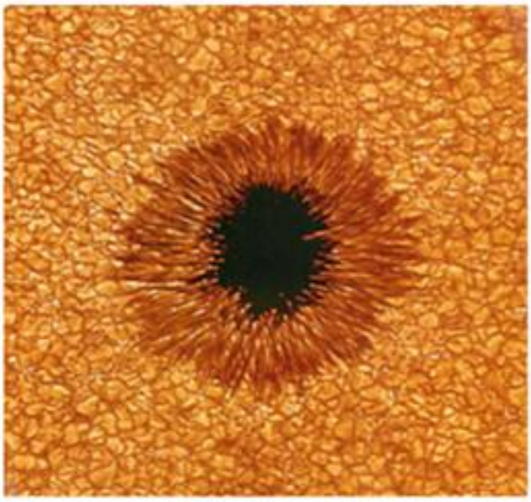
The argument of Professor Pierre-Marie Robitaille, which views the Sun as a condensed matter entity and possesses a liquid surface, is outstanding and generally correct. He outlined 41 distinct lines of evidence—categorized into 7 main groups—that outright refute the SSM (1-4). Undoubtedly, high-precision observations of solar oscillations (helioseismology) clearly show the Sun as a condensed matter rather than a gaseous plasma. Basically, the helioseismic data show that the internal mass and sound-speed profiles behave according to the density bounds of condensed matter, rather than those of a hot, diffuse gaseous plasma. Yet, rather than accepting this empirical evidence, institutional solar physicists are protecting their standard solar model by claiming that the plasma deep inside the Sun behaves differently than predicted from the thermodynamic models developed from experiments and theoretical calculations on Earth. Actually, the opposite is true. Experiments and theoretical calculations—like the attempt to create metallic hydrogen—decisively show that hydrogen plasma inside the Sun's core cannot reach even a fraction of the currently estimated density value (150g/cm^3). However, I disagree with Robitaille's proposed model—the Liquid Metallic Hydrogen Solar Model (LMHSM)—because it conflicts with established observations and fails to account for several fundamental solar features and phenomena. For instance, the LMHSM cannot account for the precise sound waves and p-modes that propagate through the solar interior. Observations of these acoustic waves provide a detailed map of the Sun's deep interior, density, and temperature profiles. These observed profiles are entirely incompatible with a uniform-density liquid metallic hydrogen body. Furthermore, the LMHSM cannot mathematically or physically reproduce the complex magnetohydrodynamic (MHD) processes that drive the solar cycle, sunspots, solar flares, and coronal mass ejections.

Moreover, the model cannot explain solar neutrinos and high-energy gamma-ray emissions, but that does not mean the core nuclear fusion processes assumed by the mainstream model are correct. That is because in reality, the Sun produces high-energy neutrinos and gamma-rays mainly as a result of collision processes between galactic cosmic-rays and solar material (the solar surface and atmosphere), not as direct byproducts of core nuclear fusion processes (5) More importantly, the pressure range above the photosphere is enormous. It is far higher than mainstream solar physics assumes, yet it is still far less than liquid metallic hydrogen requires. Undoubtedly, an inaccurate estimation of the pressure range in the solar photosphere is a primary reason for our misunderstanding of the Sun, specifically the widespread belief that it is composed entirely of gaseous plasma. Essentially, the SSM assumes that the pressure above the photosphere is just a small fraction of the atmospheric pressure experienced on Earth at sea level. Specifically, the pressure above the photosphere is estimated to be approximately 1/10,000 atm or less. Yet, this figure is absolutely wrong based on real observational analysis, and it does not make any sense if one considers the mass of the Sun relative to the Earth's mass (6-8). Furthermore, the Saha equation—which is supposed to describe the degree of ionization—was designed to be used under conditions of thermal equilibrium, and no such state exists in the corona. More fundamentally, this equation is off by a massive factor, around 100 trillion times. Yet, institutional solar physicists are still claiming that the pressure range above the photosphere has been measured and the value is correct. In reality, that is not the case. The pressure value was never measured directly; instead, it was estimated by analyzing spectroscopic lines (9-11). The methods used to analyze the solar spectra are invalid, since they are based on incorrect assumptions, namely, a gaseous-plasma Sun in thermal equilibrium and endothermic reactions in the chromosphere. Nonetheless, achieving liquid metallic hydrogen (LMH) requires pressures higher than 500 GPa, more than 5 million times Earth's atmosphere, and researchers are still not sure if the metallic state can be reached. Certainly, this pressure range does not exist above the photosphere. Furthermore, the complete disagreement with LMHSM and all flaws in the mainstream views are clarified in extensive detail in a comprehensive research manuscript. The manuscript contains an objective interpretation of empirical data that shows decisively the true condensed matter nature of the Sun. Furthermore, and most importantly, the proposed solar model can be verified under laboratory conditions by generating a self-sustained nuclear fusion reaction—something traditional thermonuclear methods cannot achieve.

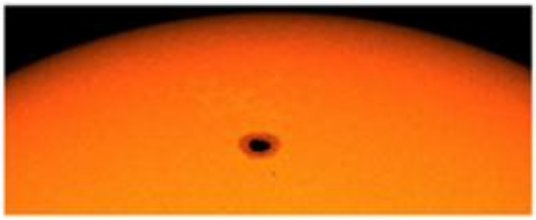
However, there are clear dynamic phenomena that show the Sun's condensed-matter nature. These phenomena can be classified into two categories: low-intensity and high-intensity dynamic events:

Sunspots: sunspots are the first phenomenon observed on the surface of the Sun, and they are one of the most important features when it comes to the basic understanding of solar physics (12). Sunspots are directly related to the largest energetic events. Specifically, the formation of solar flares, the release of their magnetic energy, and the cause of their explosive release can never be understood without knowing how active regions form within the Sun's liquid layer. If one studies deeply the amount of observational data obtained about sunspots by modern space- and land-based instruments, he or she will come to the conclusion that this fundamental solar feature is still a complete mystery under the current SSM. Sadly, even G. E. Hale's important discovery (13) about the exclusive role of magnetism in the formation of sunspots did not alter the fundamental concepts of the SSM or lead to new research paths for studying them. Instead, researchers introduced many theoretical models to bend the observational data on sunspots so they would fit the outdated model. What is more shocking, however, is that even with all the efforts of theoretical physicists (14, 15) true answers about sunspots are still missing. For instance, why do they appear on the surface of the Sun in the first place? Why do they appear dark in the visible region of the spectrum and glow brightly in the ultraviolet and X-ray regions? Actually, the theoretical models multiply the delusion because they were built on the wrong foundations and followed false premises. Solar physicists argue that sunspots are the coolest regions on the solar surface. However, because they form slightly below the upper layer of the photosphere, the idea of cooler sunspots makes no sense—even within the currently accepted gaseous model. Now, look at the images below and see for yourself that sunspots are not as dark as currently assumed. In a May 19th, 2023 press release, the National Science Foundation released new high-resolution images from the Daniel K. Inouye Solar Telescope. They show bright dots speckling the core of sunspot AR3053. https://nso.edu/press-release/new-images-released-by-nsfs-inouye-solar-telescope First of all, the dark appearance of sunspots is due to their high electrical conductivity. High electrical conductivity and a dark appearance often coincide in certain materials because free electrons and dense conjugated structures absorb visible light efficiently rather than reflecting it (16). In the case of sunspots, their dense solar elements absorb high-energy light like X-rays and gamma rays very efficiently. Their large electric charge and many inner electrons create a strong pull. This provides them with a large cross-section for the photoelectric effect, making them very effective at stopping radiation. Nonetheless, the argument regarding cooler sunspots rests on a wrong assumption—specifically, that the strong magnetic field of sunspots lowers their temperature by suppressing convection. Actually, the opposite is true, but this fact cannot be understood without realizing the physical and chemical properties of the liquid layer that makes up the solar surface. Note that, from a thermodynamic perspective, the Sun functions as a heat engine that converts thermal energy into radiant energy emitted from its surface (17). The principal laws governing this engine are the laws of thermodynamics, primarily the second law or, more accurately, Carnot's principle. This principle is a direct consequence of the second law and is controlled by the concept of entropy (18). Since, however, the entropy at the interior of the Sun is decreasing as a result of the removal of generated heat, compensatory processes have to take place in other parts of the solar body in order to maintain the balance. These compensation processes take place in the non-equilibrium and unstable active regions, largely in sunspots. Therefore, the hypothetical notion of cooler sunspots violates an extremely important law that rules all thermal processes occurring on the Sun; moreover, this law does not prohibit heating a substance with a magnetic field. In fact, according to the Carnot approximation, the temperature of material ejected from a sunspot, a region which is ruled by a strong magnetic field, was found to be three orders of magnitude higher than the average temperature of the Sun's surface. Carnot approximation gives a value of $T \sim 6000,000$ K. This huge difference in temperatures is the reason why sunspots shine brightly in the ultraviolet and X-ray regions of the spectrum against the background of the photosphere. Following George E. Hale's discovery that sunspots possess strong magnetic fields, researchers began correlating sunspot formation with magnetism, as seen in the work of Abetti, Cowling, Kiepenheuer, de Jager, Menzel, Bray, and Loughhead. Later on, Solanki provided a lengthy review on the topic. Numerous studies and efforts have gone into the compilation of a coherent sunspot record (19-23). The majority of those studies were based on the proposed model of Babcock or what is known as the RF model, which includes all currently accepted models of sunspot formation (24). In spite of this general acceptance, Babcock's model cannot explain the most basic features of sunspots. It cannot explain why sunspot zones drift toward the equator. It also incorporates a meridional flow that does not agree with modern measurements. And, the model neglects the diffusive effects of the convective motions on the magnetic field. These convective motions were unrecognized when the model was first introduced. Moreover, the Babcock model assumes that the magnetic flux tube always breaks through the solar surface at two points, as a pair of positive and negative spots always forms the basic unit. In fact, that is not true at all; observations clearly and regularly show that the formation of single spots often happens (25). However, since most theoretical models assume that sunspots must always appear as pairs of positive and negative spots, the presence of single, isolated spots (independent spots) is considered an insignificant puzzle and receives no attention. See the two images below. They are remarkable examples of single spots without any other active feature in a large area of the solar disk (NASA's Dynamics Observatory).

(A)

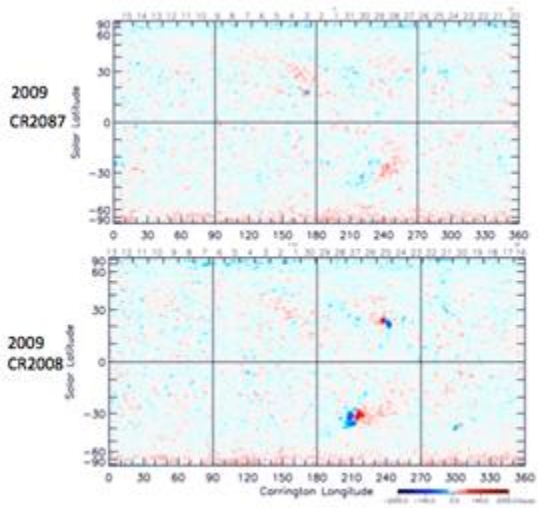


(B)



(A) & (B) are not the same spot (Courtesy of the Big Bear Observatory)

Besides the violation of the RF model, another reason exists to ignore single magnetic spots on the Sun's surface. This is because current physics assumes that a single magnetic monopole does not exist. However, the inability of the RF model to explain the presence of single spots is not the only problem. The model is also unable to explain the delay in the appearance of the f-spot after the p-spot, and the imbalance of the magnetic flux between the p-spot and f-spot. Also, positive single spots tend to appear in a positive unipolar region (and vice versa), and pairs of spots tend to appear at or near the boundary of two unipolar magnetic regions, not in the middle of a unipolar region (26). Obviously, and as has already been mentioned, current models of sunspot formation and their associated concepts do not recognize or explain the appearance of unipolar regions. If one looks at the figure on the left, which represents the solar magnetic field during the early epoch of a new sunspot cycle, it is obvious that unipolar regions are beginning to grow before any sunspots appear. This is clear observational evidence that unipolar magnetic regions are not remnants of the older active regions. This observational evidence becomes clearer in the figure below, on the right. A pair of unipolar magnetic regions appeared without sunspots. Those unipolar magnetic regions cannot possibly be remnants of old active regions. Despite the introduction of new dynamo models meant to explain features that Babcock's model could not, nearly all of these new models still face conflicting observations. Furthermore, these new models, just like Babcock's model, did not contribute to the understanding of the solar cycle, which is one of the oldest and biggest unsolved problems in solar physics.



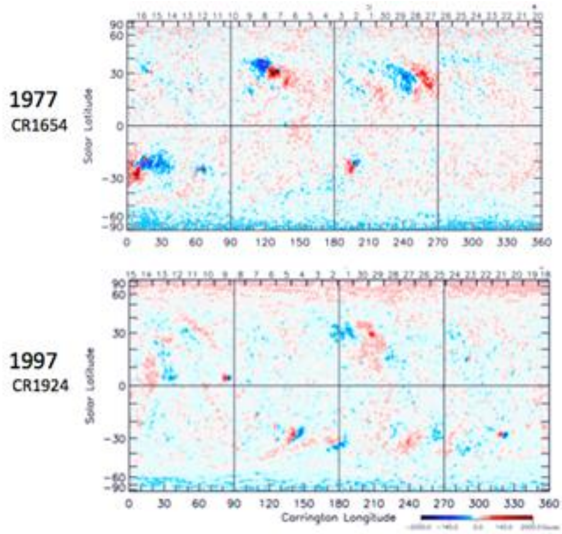
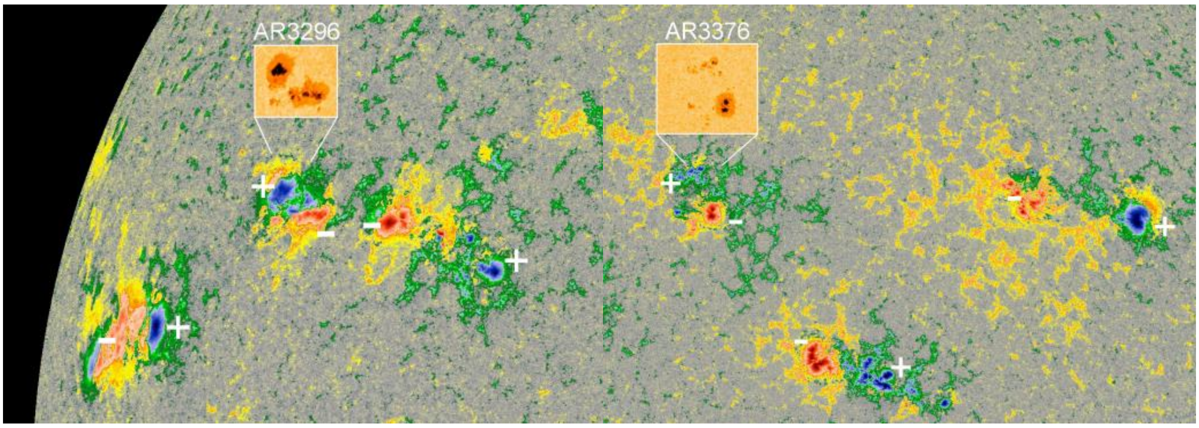


Figure on the left, shows the birth of newly developed unipolar regions during the earliest epoch of the solar cycle. Figure on the right, shows the comparison with the figure on the left, where one can see clearly the growth of unipolar regions during an early epoch of the cycle

Besides the above contradictions between theoretical models and observations, the law of sunspot polarity (Hale's law) is always violated, and reversed polarity is regularly observed. Yet, no explanation is provided for this violation. For instance, when sunspots in the Sun's northern hemisphere should have a -/+ polarity (negative on the left, positive on the right), some spots with a reversed +/- polarity are usually observed, and they are more likely to explode (27).

The magnetogram from NASA's Solar Dynamics Observatory (SDO) shows in the image below how sunspot AR3296 is breaking the Hale's Law. The sunspot's magnetic field is reversed compared to other nearby sunspots in the sun's northern hemisphere. Sunspot AR3376 is also breaking Hale's_Law. According to Hale's Law, Solar Cycle 25 sunspots in the Sun's northern hemisphere should have a-/+ polarity (negative on the left, positive on the right). AR3376 is reversed; its polarity is +/-.

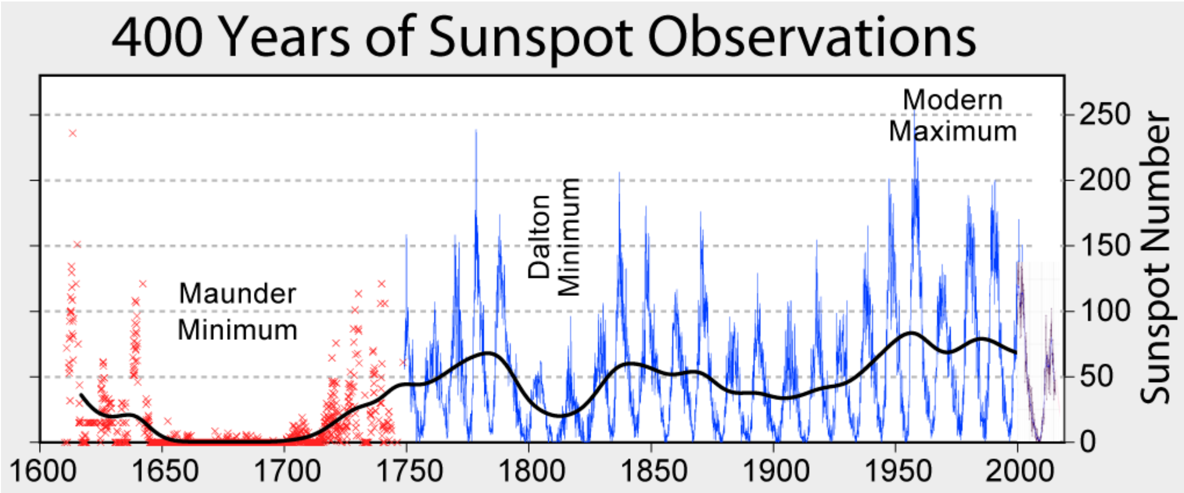


SpaceWeather.com

Nevertheless, analysis of sunspot observations using modern spacecraft data demonstrates that current models are obsolete. The deeply rooted flux model, in particular, is not only incorrect but entirely unrelated to the actual formation of sunspots. Basically, theoreticians are not giving up, in spite of the availability of sufficient data—including those based on advanced imaging and detection devices—that show a large gap between their models and observations. Strictly speaking, solar and theoretical physicists do not accept that their models are obsolete, although the evidence is overwhelming. The reason, of course, is the inability to provide the correct physical model without breaking the SSM.

Surely, the solar cycle process is not understood, including the reversal of magnetic polarity, which is determined – in reality- mainly by the rate of galactic cosmic-rays that reach the Sun. And this rate fluctuates slightly on short time scales and largely on longer time scales. Extensive data show that the intensity of the surface magnetic field varies from one solar cycle to another. In fact, there has never been a solar cycle which is completely identical to another. (28).

Furthermore, the sunspot records which have been monitored since the beginning of the 17th century are clear evidence that the solar cycle does not exclusively depend on the internal processes of the Sun. Over the last 400 years, there have been cycles when the magnetic activity on the surface declined enormously, and others when the activity increased substantially. These cycles, called grand minima and grand maxima, are huge evidence flying in the face of mainstream solar physicists who defend the view of how sunspots form based on the self-powered dynamo theory. See the figure below (29)

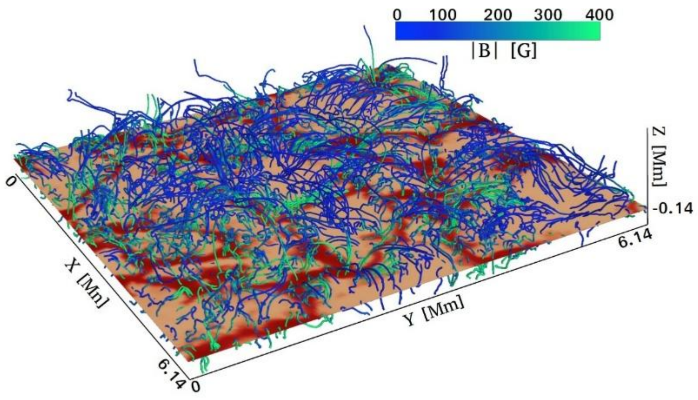


Sunspot activity has been available and are shown here as reported by the Solar Influences Data Analysis Center, World Data Center for the Sunspot Index, at the Royal Observatory of Belgium. These figures are based on an average of measurements from many different observatories around the world. Prior to 1749, sporadic observations of sunspots are available. These were compiled and placed on consistent monthly framework by Hoyt & Schatten (1998a, 1998b).The most prominent feature of this graph is the c. 11 year solar magnetic cycle which is associated with the natural waxing and waning of solar activity. On longer time scales, the sun has shown considerable variability, including the long Maunder Minimum when almost no sunspots were observed, the less severe Dalton Minimum, and increased sunspot activity during the last fifty years, known as the Modern Maximum" Credit: This figure was prepared by Robert A. Rohde and is part of the Global Warming Art projct.

In reality, the formation process of sunspots depends mainly on the rate of the external energy supply. During solar maximum, when the magnetic pressure enters its rising phase, the number of sunspots starts to increase, and the higher the magnetic pressure, the higher the number of sunspots. In other words, the formation process starts as the interactions intensify among the plasma atmosphere, the solid interior, and the liquid layer, where the emerging active regions on the surface receive the highest rate of the external energy supply.

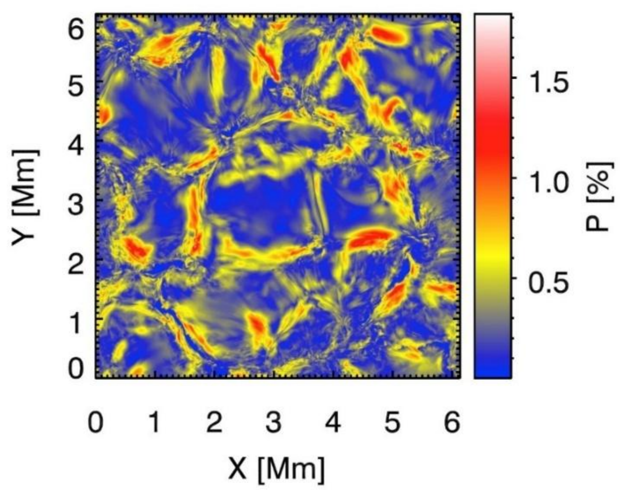
Consequently, more charged particles are trapped, and a stronger surface magnetic field is induced. External magnetic energy not only triggers solar eruptions, like solar flares, but also helps form active regions. This energy contributes to all structures and dynamics observed on the solar surface, including rapid changes in the magnetic field that guide fluid motions to form granulation structures with diverse densities and field strengths. Granulation structures cover the entire solar surface, except for sunspot regions. These regions, however, should be viewed as islands of intense magnetic fields embedded in a vast fluid surface of varying density, possessing moderately strong and inhomogeneous magnetic fields (30).

In fact, recent studies support my assertion that the solar surface as a whole possesses modestly strong and inhomogeneous magnetic fields. Dr. Javier Trujillo Bueno from the Instituto de Astrofísica de Canarias (Spain) is one of the co-authors who helped establish this*:* A novel investigation of the small-scale magnetic activity of the quiet Sun via the Hanle effect in the Sr I 4607 Å line, which was published in Solar and Stellar Astrophysics (astro-ph.SR), stated the following: "At any given time during the solar magnetic activity cycle, most of the solar disk is covered by apparently quiet regions. Yet, such regions are significantly magnetized, although their magnetic fields are elusive to observation."



Conceptual of the magnetic field in a 3D magneto-convection model of the quiet solar photosphere (Rempel 2014; ApJ 789, 132), which has a surface mean field strength of 170 gauss. Credit: Del Pino Alemán et al. (2018)

Actually, the authors presented reasonable arguments for the magnetic fields that permeate quiet regions, even during minimum activity when no sunspots appear on the solar surface. They argued that the magnetic fields covering 99% of the solar surface are very elusive because they are tangled at spatial scales too small for today's telescopes to resolve. However, the authors are certain the fields exist. In their study, they used the Hanle effect, which is the magnetic-field-induced modification of the linear polarization produced by scattering processes in a spectral line. Basically, by using the Hanle effect, they showed that the quiet solar photosphere contains substantial magnetic energy density due to a 'hidden' (unresolved) small-scale magnetic field with a mean strength on the order of 100 gauss (31-33) Note, however, that measuring the Hanle polarization signals with today's telescopes requires sacrificing the spatial and temporal resolution of the observations to increase the signal-to-noise ratio. For this reason, the researchers relied mainly on theoretical calculations and used magneto-convection models of the solar photosphere to predict conspicuous small-scale spatial variations, such as those seen in the image below for the Sr I 460.7 nm line. The complete study is available in the arXiv Research Paper. Anyway, you can read the whole paper at the following link [1806.07293] A novel investigation of the small-scale magnetic activity of the quiet Sun via the Hanle effect in the Sr I 4607 Å line

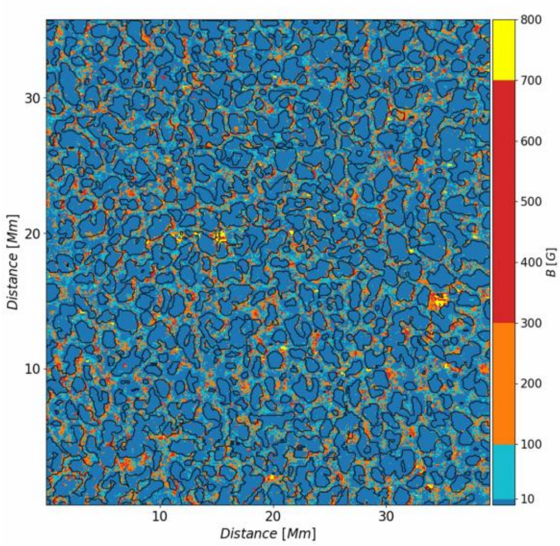


Fractional total polarization signals of the Sr I 460.7 nm line predicted for the disk center line of sight in the model of the quiet solar photosphere / Credit: del Pino Alemán et al. (2018; ApJ).

Another research group came up with an identical research paper about the hidden magnetic field of the quiet Sun. The results of their study are somewhat different from the ones based on the above-mentioned paper.

Nevertheless, I think the results of this study—carried out by J. C. Trelles Arjona, M. J. Martínez González, and B. Ruiz Cobo from the Instituto de Astrofísica de Canarias (IAC) and published on July 5, 2021—are more accurate and more convincing than the results in the previous paper published by Del Pino Alemán et al. (2018).

The authors of *Mapping the Hidden Magnetic Field of the Quiet Sun* are right in saying that the magnetic field strength of the hidden field is not homogeneous on the solar surface, and their method for determining the average magnetic field strength of the hidden quiet Sun is more realistic. See their figure below.



Average magnetic field of the quiet Sun as inferred from the observational data. Black contours display the frontier between granules and inter-granules (i.e. the continuum intensity Ic=1.0). The magnetic field strength color bar has been clipped at 800 G.

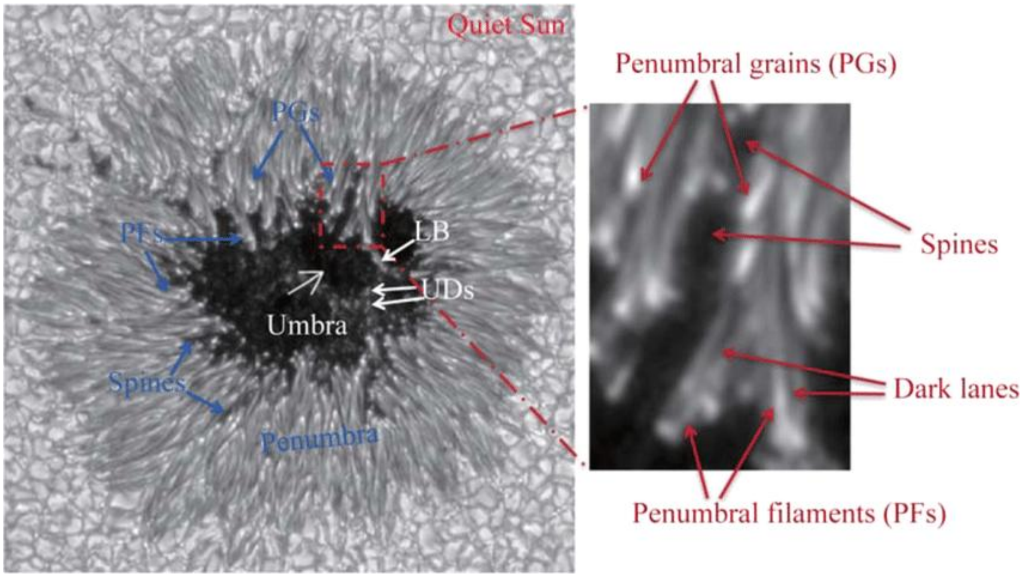
They implemented magnetohydrodynamical simulations to approximate the average strength of magnetic fields in the quiet Sun using multi-line inversions of intensity profiles in the Zeeman regime. They used this technique with 15 spectral lines in the 1.5 µm spectral range. They concluded that the spatial distribution of the hidden field is strongly correlated with convective motion, and that the average magnetization is about 46 G. You can read the whole paper: Mapping the Hidden Magnetic Field of the Quiet Sun https://iopscience.iop.org/article/10.3847/2041-8213/ac0af2

However, the increase in surface tension caused by the increase in magnetic pressure—mainly during the solar maximum—contributes to the intense concentration of active regions and the emergence of sunspots. The increase in the magnetic pressure is caused by both the external energy supply that reaches the surface and the heat diffusion from the interior to the bottom of the liquid layer. The buffer zone, which plays the role of transporting the extra heat from the solid core to the bottom of the liquid layer, is surrounded by what is currently known as the tachocline (T. region). The cyclic speeding up and slowing down of the layers above and below this T. region makes complete sense if you visualize how heat moves from the solid core to the base of the liquid layer.

The highly energetic events that take place on the solar surface result from interactions among the three main layers of the Sun, where extra magnetic energy is stored as magnetic bubbles. These bubbles are the building blocks that generate all types of solar eruptions, like the transient dynamic phenomena of flare explosions and coronal mass ejections. Besides storing energy, the surface magnetic field plays a crucial role in releasing these energetic phenomena and accelerating ejected particles, including non-thermal ones, challenging established models of sunspots and the hypothetical notion of magnetic reconnection. Consequently, the theoretical process leading to the formation of sunspots remains a mystery, one that will persist as long as the liquid nature of the solar surface is unrecognized.

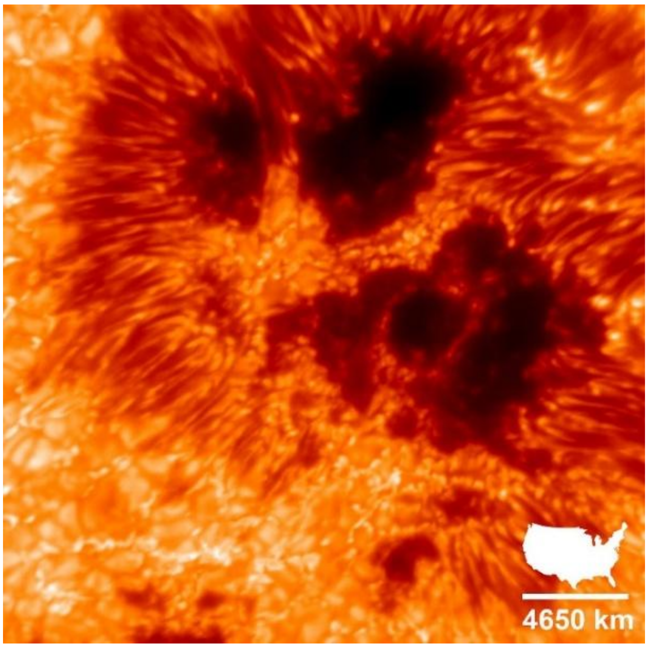
In fact, it is unscientific and irrational in the first place to introduce the assumption that sunspots can be formed in a plasma state. Plasma has no fixed shape or volume, and for these reasons alone, sunspots can never be formed in this state of matter. Sunspots can only be formed in a liquid state, where surface tension plays a very important role in the formation process. Furthermore, sunspots are among the hottest areas of the Sun's surface, as they cause the most energetic activity on the Sun. During a high-energy eruption, the temperature of the area around sunspots reaches millions of degrees. For instance, a very intense solar flare can induce temperatures as high as 100,000,000 K. This temperature is far higher (more than six times higher) than the hypothetical temperature of the solar interior.

So essentially, sunspots exhibit structured, well-defined boundaries and lifetimes. Also, the Evershed effect—the outward horizontal motion of material seen in sunspot penumbrae—displays vortex-like flows rather than isotropic (omnidirectional) gas diffusion. In other words, the outward motion is not isotropic or diffusive. It travels along highly structured, inclined magnetic flux tubes in overturning convection that physically resembles liquid siphon flows. In fact, modern high-resolution observations from the Hinode Solar Optical Telescope and theoretical calculations showed that dynamic behavior exhibits several liquid characteristics (34, 35). Specifically, SOT/Hinode imagery has revealed dynamic twisting and vortex-like behavior within penumbral filaments. The magnetic fields interact with convective material to create whirling, tornado-like dynamics, mimicking liquid vortices. And, while the photosphere experiences radial outflows, the overlying chromosphere often features an inverse Evershed effect. This acts as a counter-Evershed flow, driving material inward toward the sunspot umbra in a large-scale convective loop similar to liquid circulation. See the following links for details. Achievements of Hinode in the first eleven years.pdf , Solar-B / Hinode Mission- eoPortal

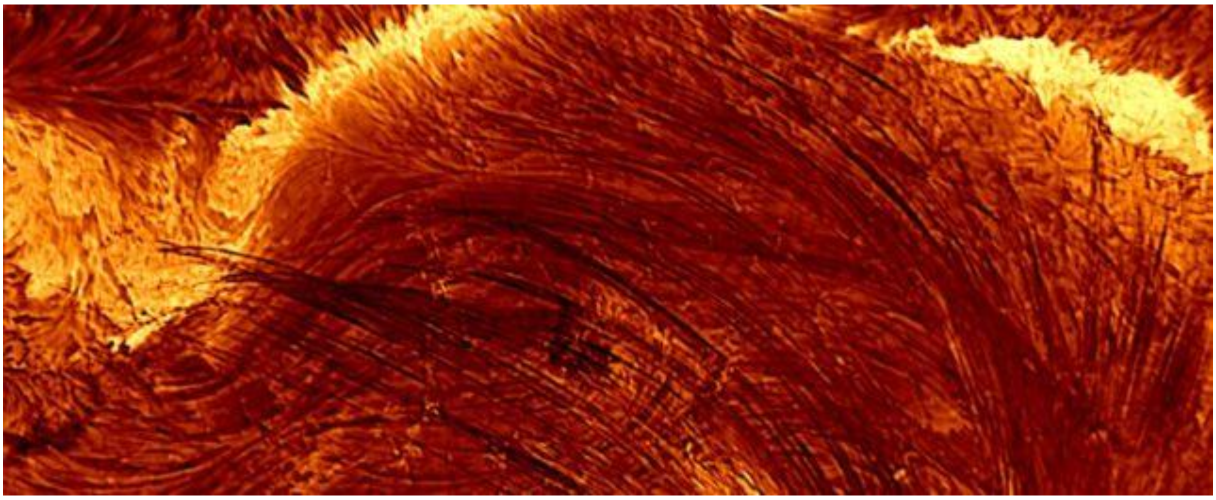


"Continuum intensity image of a sunspot observed by Hinode/SOT-SP [reproduced from Tiwari et al. (2015) by permission of ESO]. Locations of a couple of umbral dots (UDs), penumbral filaments (PFs), spines, penumbral grains (which are actually heads of filaments), and a light bridge (LB) are pointed to by arrows. A larger arrow in the center of the sunspot umbra points to the direction of the solar disk center."

Also, the National Science Foundation's Daniel K. Inouye Solar Telescope (DKIST) provides definitive proof that sunspots are massive, physical magnetic structures rather than optical illusions. Its high-resolution cameras reveal the sunspot's internal features in unprecedented detail, including valleys and hills. Physically speaking, valleys and hills are fundamental features that dictate the topography of a real surface (36).

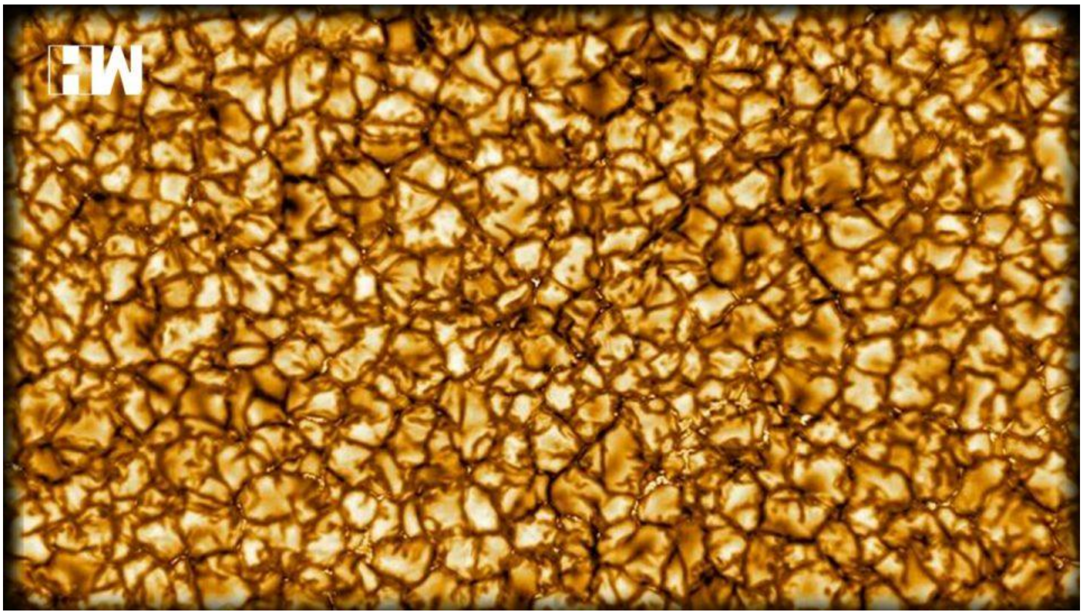


Credit: VTF/KIS/NSF/NSO/AURA/ Largest Imaging Spectro-Polarimeter Achieves First Light at the NSF Daniel K. Inouye Solar Telescope - NSO - National Solar Observatory The images clearly separate a sunspot into distinct physical zones: the dark central umbra, resembles a valley (where the magnetic field is strongest and vertical) and the brighter, filamentary penumbra (where the magnetic field spreads horizontally).



This is the highest resolution at which we've ever seen a solar flare. (NSF/NSO/AURA)

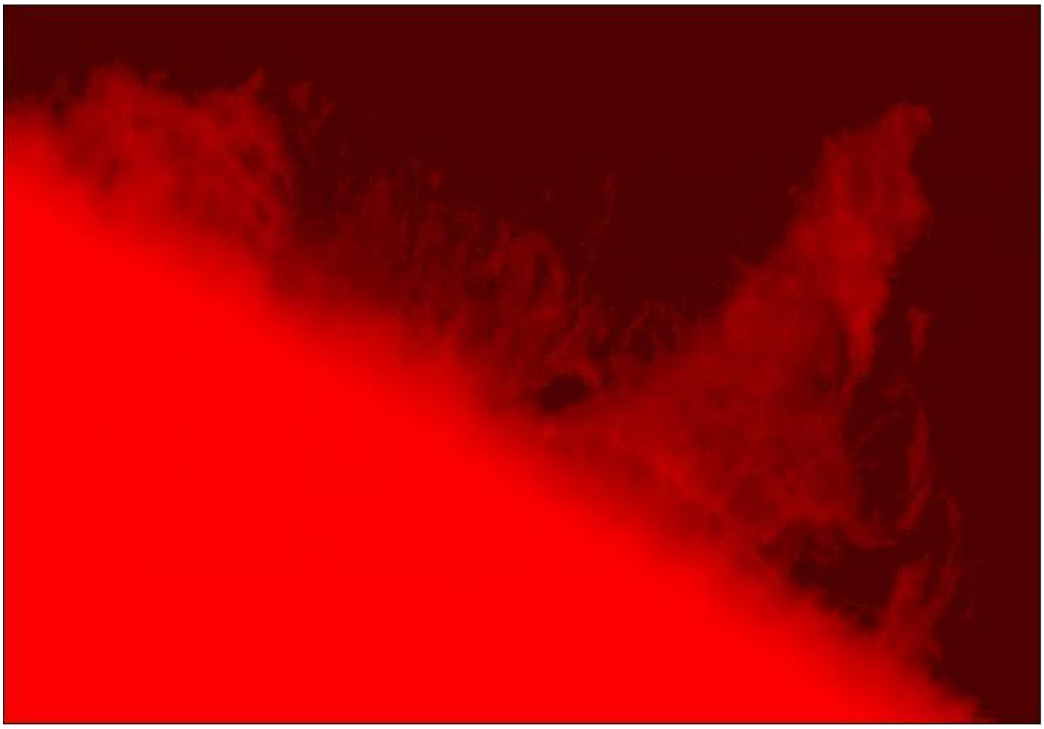
Granulation: The Sun’s surface features a boiling, grainy pattern. These granules are discrete, localized convection cells that maintain structural integrity with distinct borders, strongly resembling liquid boiling rather than the free expansion of a gaseous atmosphere. Namely, granules have real, highly measurable physical dimensions. A typical granule is roughly 1,000 to 1,500 km across and has a depth of about 100 km to 200 km. Indeed, the National Science Foundation's Daniel K. Inouye Solar Telescope, managed by the National Solar Observatory, has shown the Sun's surface to be covered in turbulent, roiling solar material that acts like a dense, boiling liquid rather than boiling plasma. The image below cannot be produced from a plasma, which is a super-heated, ionized gas that lacks both a fixed shape and a fixed volume (37).



This is one of the most detailed pictures of the sun ever released (Image: NSF)

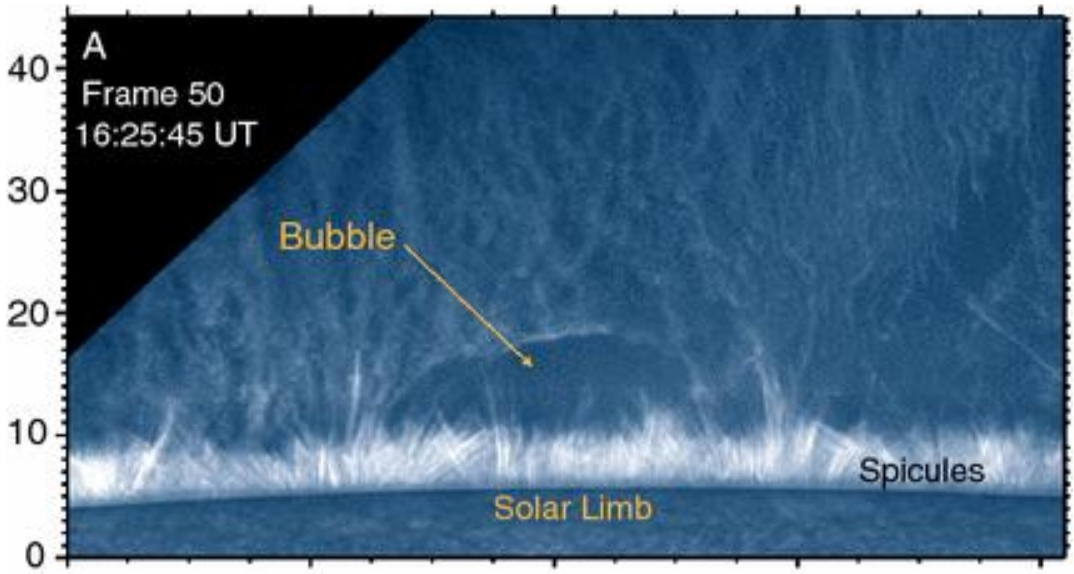
Solar granulation cannot be explained by standard 1D and parameter-based models that average out granular upflows and downflows, while solar mesogranulation remains heavily debated because scientists disagree on whether it is a distinct convective scale or a random statistical result of normal granulation. Typically, standard theories assume a steady-state flow of energy across predictable eddy sizes. In reality, however, granulation is highly quasi-periodic and chaotic, featuring violently exploding granules and persistent downflowing plumes. Observations reveal hot, bright, rising bubbles that are entirely different from the cool, narrow, fast-sinking dark lanes around them. Furthermore, standard convection theory stipulates a smooth, predictable cascade of energy across all sizes. In reality, the Sun skips intermediate scales and exhibits disjointed structures like supergranules. In other words, standard models predict an intermediate hierarchy of convection (mesogranulation). Yet, observations show that the Sun skips these intermediate scales, providing no clear, distinguishable spectral signature between small granules and supergranules. Namely, Helioseismic data from the NASA Solar Dynamics Observatory reveal that supergranules are disjointed and anomalous. Standard models fail to predict them because they lack a clear relation to smaller granules, and descending fluid flows at these scales appear weaker than rising flows (38).

Solar Prominences: It is not only absurd, but also physically impossible that solar prominences - which are supposed to be composed of ionized plasma- can remain stable for weeks or months in the Sun's blistering atmosphere. A solar prominence is roughly 100 to 1,000 times denser than the surrounding corona, with an average temperature ranging between 4,300 and 8,000 K, compared to 1,000,000 to 2,000,000 K for that of the surrounding environment. Nevertheless, based on current consensus, the magnetic fields of the solar corona act as invisible structural shields and supply lines, preventing the cool plasma from evaporating or succumbing to gravity. Solar prominences are supposed to remain stable for weeks, because they reside in magnetic dips or flux ropes (the "cooler plasma" sits in the curved magnetic field lines and the magnetic tension perfectly balances gravity). Furthermore, the surrounding coronal magnetic field forms a thermal shield, insulating the prominence's cool plasma from the high temperature of the corona (39).

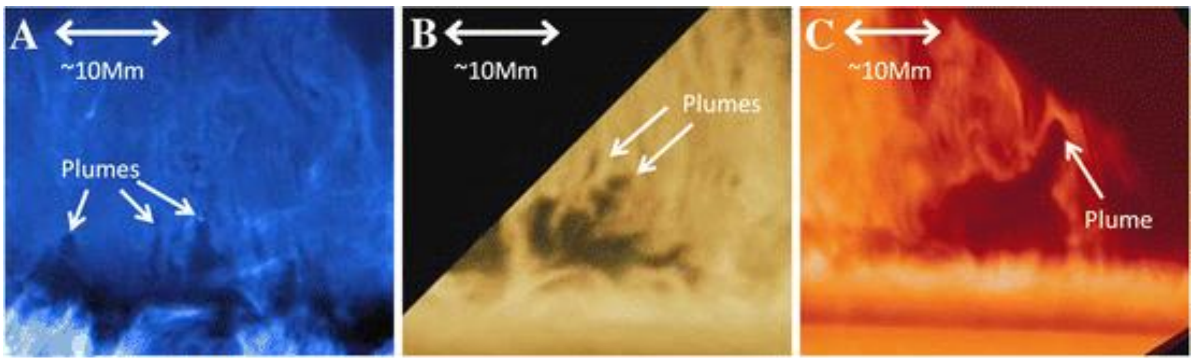


Solar prominence taken from SOT (Solar Optical Telescope) onboard the HINODE satellite showing approx. 150,000 km of the curved edge of the sun (image credit: Hinode JAXA/NASA)

To begin with, it is worth mentioning two things. First, solar prominences (also called filaments when viewed from above against the bright solar disk) are massive, cloud-like structures anchored directly to the Sun's surface (the photosphere) and extending outward into the corona. Secondly, it is well-known that the attraction between electromagnetic fields, in general, depends on the alignment of charges or magnetic poles, not simply on their strength. Yet, in a non-uniform magnetic environment, a stronger field can exert a force on a weaker one. And, in the case of the Sun, the magnetic fields are highly non-uniform, with the field at the solar surface being much stronger than the field in the solar atmosphere (40). The Sun's magnetic field is mainly concentrated at the visible surface (the photosphere), where it can reach 2,000 to 3,000 Gauss in sunspots. As you move outward into the solar atmosphere (the chromosphere and corona), the field spreads out and weakens considerably, typically dropping to 1 to 100 Gauss. Gravity is not the primary downward force acting on dense solar prominences, and it plays no role in their stability, structure, or dynamics. Instead, solar prominences maintain specific shapes and densities that defy standard gas expansion, acting precisely as highly cohesive liquid ropes—similar to a ferrofluid—structured and maintained by magnetic fields. Note that technically speaking, neither a gas nor a traditional thermal plasma can form bubbles, because they are both compressible media that lack a defined surface or volume. Bubbles are pockets of gas enclosed within a liquid or solid (41, 42).



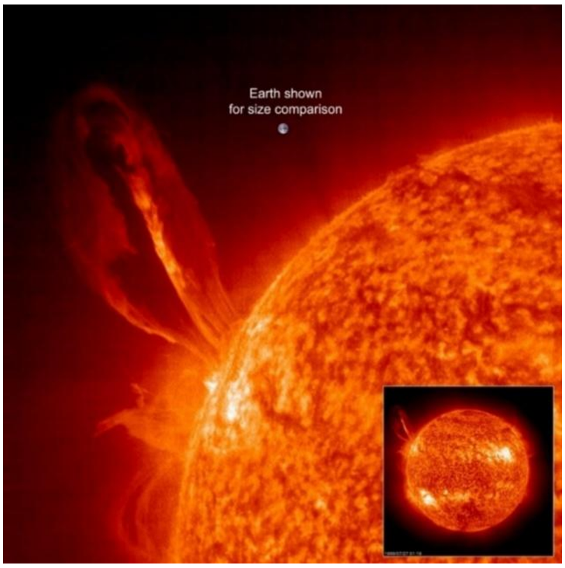
Bubble observed in a quiescent prominence on 16 August 2007 by Hinode SOT. Adapted from Berger et al. (2017)



Different images of multiple plumes developing from bubbles as observed by Hinode SOT. These were observed on (A) 30 November 2006, (B) 8 August 2007 and (C) 22 June 2010. The figure adapted from Hillier et al. (2012a).

The ejected conductive-liquid material, under the influence of a magnetic field, achieves stability due to magnetohydrodynamic (MHD) damping, which suppresses turbulence, Rayleigh-

Plateau instabilities, and vortex shedding. Basically, the induced Lorentz forces act as magnetic tension and pressure, exerting an inward, confining force that squeezes fluidic droplets or coronal loops. More specifically, when conductive loops interact with a magnetic field, the induced electric currents generate their own magnetic fields. The resulting Lorentz force behaves like a taut, invisible rubber band, pulling the boundaries of the structure inward to prevent it from dispersing. In addition to tension, this force acts as pressure, compressing the droplet or the loop (43). Consequently, tension and pressure flatten the shape, offsetting hydrodynamic instabilities and stabilizing the orderly structure against disruptive forces. The flattening of the structure is a direct result of the electromagnetic confinement, which is counteracting internal expansion and surface tension to maintain a highly stable, orderly geometry. In fact, observations show the main body of a solar prominence as flattened or sheet-like. Look to the image below which is a gigantic solar prominence bursts upwards from the Sun's surface. This remarkable image was captured on 27 July 1999 by SOHO, the Solar and Heliospheric Observatory (44). Earth is superimposed for comparison and shows that from top to bottom the loop of prominence extends about 35 times the diameter of our planet into space. To recapitulate, the induced Lorentz forces act on conductive liquids through the interaction of a magnetic field and induced eddy currents. That is because when an electrically conductive liquid moves through a magnetic field, it generates localized eddy currents. This mechanism opposes disruptive forces like surface tension, stabilizing the flow, suppressing morphological instabilities, and ultimately confining the liquid into orderly, elongated shapes. Essentially, the interaction with the primary magnetic field creates Lorentz forces that directly oppose the fluid's disruptive motion. In an electrically conductive fluid, this magnetic field restricts turbulent eddies and streamlines the velocity profile, effectively laminarizing the flow and keeping it orderly even at high velocities. This prevents the composed conductive liquid of the prominence from dispersing and shapes it into vertical sheets or threads. The image below clearly shows a solar prominence maintaining remarkably high-ordered and flattened (sheet-like) structures (45).



Credit: SOHO (ESA & NASA)

In addition, studying the Rayleigh-Taylor instabilities in solar prominences clearly reveals three primary paradoxes—often referred to collectively as the Prominence/Filament Paradox.

The Magnetic Field Contradiction: Classical magnetohydrodynamics (MHD) dictates that a purely horizontal magnetic field strongly stabilizes against vertical instability. Yet, observations persistently show RTI-like dynamics and vertical solar material structures forming in regions with predominantly horizontal fields.

The Partial Ionization Problem: Although solar prominences are considered partially ionized, ideal MHD equations suggest stability. However, taking two-fluid (ion-neutral) interactions into account—where neutral particles are not constrained by magnetic tension—contradicts these baseline models by showing that the instability constantly grows.

Observation vs. Simulation: Standard 2.5D and 3D ideal MHD models assume that RTI plumes and falling fingers undergo mixing, where the most turbulent dynamics and secondary instabilities (like Kelvin-Helmholtz roll-ups) should occur within the cool dense prominence material. Yet, observational data from space-borne instruments (such as SDO/AIA) and ground-based Hα filters show that secondary instabilities are largely concentrated in the hot, surrounding coronal regions rather than in the cool prominence core.

Besides that, Kelvin-Helmholtz Instability (KHI) is a well-documented phenomenon in solar prominences, and empirically speaking, this phenomenon takes place when one fluid moves rapidly past another (or vice versa), driven by velocity differences across the boundary. This quickly causes the fluid to break into a highly turbulent, chaotic mixing layer. On the other hand, the contradiction related to cross-field dynamics and plasma-β is obvious. High-resolution observations (e.g., from the Hinode satellite) reveal the existence of vertical, fine-scale substructures (knots) that undergo impulsive acceleration and cross-field movement. This suggests that cross-field-like behavior occurs regularly even in low-β prominence cores, which ideal-MHD cannot easily account for without incorporating explicitly resolved resistivity or ambipolar diffusion (46).

Furthermore, single-fluid MHD models assume a fully coupled fluid where ions and neutrals move and interact homogeneously during the RTI. However, spectroscopic observations of the Prominence-Corona Transition Region (PCTR) reveal flow decoupling between the ionized and neutral particle populations. In other words, while neutrals do not feel the magnetic field directly, they interact with the ionized fluid through elastic collisions and charge exchange. Observations show them moving and draining faster than the ionized fluid, with temperature discrepancies between the two populations reaching as much as 30 K. The current superficial solution to these discrepancies comes from 3D magnetohydrodynamic (MHD) simulations by modeling the magnetic Rayleigh–Taylor instability (MRTI), yet deep theoretical contradictions still exist. Specifically, the thermal conundrum remained unsolved because the high-temperature environment should rapidly destroy the cold, dense prominence plasma (47).

So, while theoreticians proposed magnetic thermal isolation, they did not identify the precise thermodynamic mechanisms that prevent rapid heat conduction and evaporation. Also, the ab-initio mechanisms driving continuous mass condensation from the chromosphere into the magnetic dips remain unresolved, especially given that prominences contain up to 100 times more mass than the surrounding corona. Furthermore, advanced diagnostics show that prominences exhibit highly multi-thermal and multi-baric behavior, and single-fluid MHD models are unable to fully capture this extreme localized multi-phase state without relying on heavily simplified assumptions. These paradoxes can only be resolved if the real physical nature of prominences is realized. Basically, since a prominence is a highly pressurized liquid, it cannot physically expand. That is because its volume and mass remain fixed, and the liquid's density remains unaffected by the high temperature (48).

However, a persistent external magnetic field can disrupt the confinement of a highly pressurized, electrically conductive liquid. Specifically, in conductive fluids, magnetic and tensile forces couple with the fluid pressure. If the external field is non-uniform or fluctuates, it can trigger MHD turbulence and instabilities (e.g., kink or Rayleigh–Taylor instabilities). This breaks the force-balance equilibrium, causing the confined liquid to rupture or violently escape its boundaries (rapidly expanded). In other words, a persistent external magnetic field would induce a pressure drop in a solar prominence, primarily through MHD effects. The sudden pressure drop forces the prominence to instantly convert a fraction of its own thermal energy into the latent heat of vaporization, causing it to flash into vapor. Before the phase change, the prominence material is virtually incompressible. Once it begins to flash and form bubbles, Rayleigh-Taylor instabilities develop and the mixture becomes compressible. In contrast, a true gas does not undergo a phase change when expanding, as it is already in the gaseous state. Gases are fully compressible from the start; their behavior and flow rates are governed by fundamental gas dynamics, such as the ideal gas law and the Joule-Thomson effect (49). In essence, superheated, highly pressurized liquids share some thermodynamic behaviors with gases, yet during rapid expansion, they are fundamentally distinct. As the liquid leaves its confinement, it experiences a massive, instantaneous drop in pressure, causing it to rapidly flash into a high-speed, two-phase mixture of liquid droplets and vapor. Thus, one can understand the reason for the sudden pressure drops that play a fundamental role in the life cycle of solar prominences. It is additional evidence that these structures are not static clouds of cool plasma, but rather highly dynamic, liquid structures where rapid drops in pressure drive condensation, the creation of siphon flows, and sometimes the catastrophic collapse of the prominence itself.

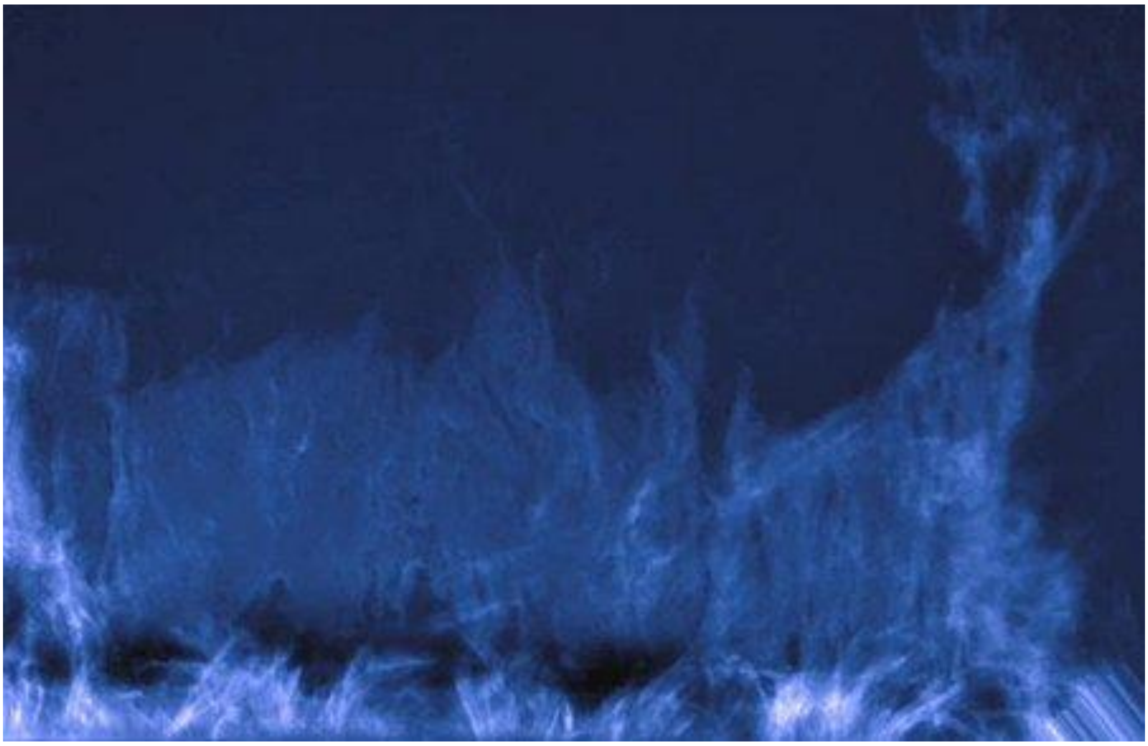
The Formation of Solar Prominence: The electromagnetic interaction on the solar surface, mainly—not exclusively—around active regions, draws the supercritical fluid upward without any physical contact, effectively acting as a straw. This process relies on the Lorentz force (magnetohydrodynamics) and works efficiently because the supercritical fluid is highly conductive. Specifically, since massive electric currents are continuously being generated and passing perpendicular to the surface magnetic field, an electromagnetic interaction is generated that pushes the supercritical fluid upward—**this is how** prominences are formed and extend into the solar atmosphere (50). **Watch the video**: dlmultimedia.esa.int/download/public/videos/2025/11/010/orig-2511_010_AR_EN.mp4

Evidently, solar prominences are condensed, electrically conductive masses that can be considered immense, stable clouds of supercritical fluid hovering above the Sun's surface, with temperatures far lower than their surrounding environment. The fate of a solar prominence—whether it erupts into space or collapses back to the solar surface—is determined primarily by the rate of external energy supply. This external energy that powers the sun is carried out by galactic magnetic fields which are linked to the heliospheric magnetic field. Therefore, if the external energy diminishes rapidly or becomes too weak, the strapping force will fail to create the required torus instability. Consequently, the flux rope loses its acceleration drive, stalls in the corona, and eventually collapses back to the surface (51, 52).

Thus, a weaker eruption is simply the result of a lack of driving force to break through the stronger, overlying magnetic fields of the Sun, causing the burst of energy to fizzle out or remain localized. On the other hand, when the external magnetic field is stronger than the internal one—and that depends on the rate and intensity of the external energy—the structure will break free through the process of magnetic expulsion (not magnetic reconnection), where massive amounts of magnetic energy are released into space. The process of magnetic expulsion, which is responsible for solar eruptions, will be explained in extensive detail in another research article.

Polar Crown Prominences (PCPs): PCPs are a highly distinct subset of quiescent (long-lasting) solar prominences, and they are called plasma waterfalls because they often collapse back downward. However, the term is misleading. Plasma cannot fall like water, since it is highly charged and interacts dynamically with electromagnetic fields. However, while plasma can act, in some sense, like a fluid, it consists of free-moving ions and electrons, and its movement is strongly dictated by magnetic and electric forces rather than by gravity. Standard prominences occur globally and often cluster near low-latitude sunspots, but PCPs strictly circle the Sun's polar crown—which is the boundary between the polar coronal holes and the rest of the Sun. Note also that the large-scale patterns of PCPs show distinct hemispheric differences (often resembling 'right-handed' screws in the north and 'left-handed' screws in the south). Moreover, active-region prominences last merely a few hours and erupt violently. In contrast, PCPs are highly stable and can persist for months. During eruption, they tend to collapse back onto the Sun's surface rather than hurtle entirely into space as coronal mass ejections (53, 54).

Nonetheless, the observed data on polar crown prominences by Japan's Hinode spacecraft puzzled institutional solar physicists. That is because the clear images obtained by the instruments on board the spacecraft are not in line with current scientific models and theories. Here is what Dr. Thomas Berger, former senior research scientist at Lockheed Martin's Advanced Technology Center in Palo Alto, California, had to say: *1. "There are dark tadpole-shaped plumes rising up from the base of the prominence. These have never been seen before and we're not sure what they are." 2. "Narrow streams of plasma at the top of the prominence are constantly falling back to the bottom, much like a waterfall. Mysteriously, the streams plummet faster than ambient magnetic forces seem to allow". 3. "Finally, within the wall itself, there are swirls and vortices" bearing an eerie resemblance to van Gogh's surreal Starry Night.*

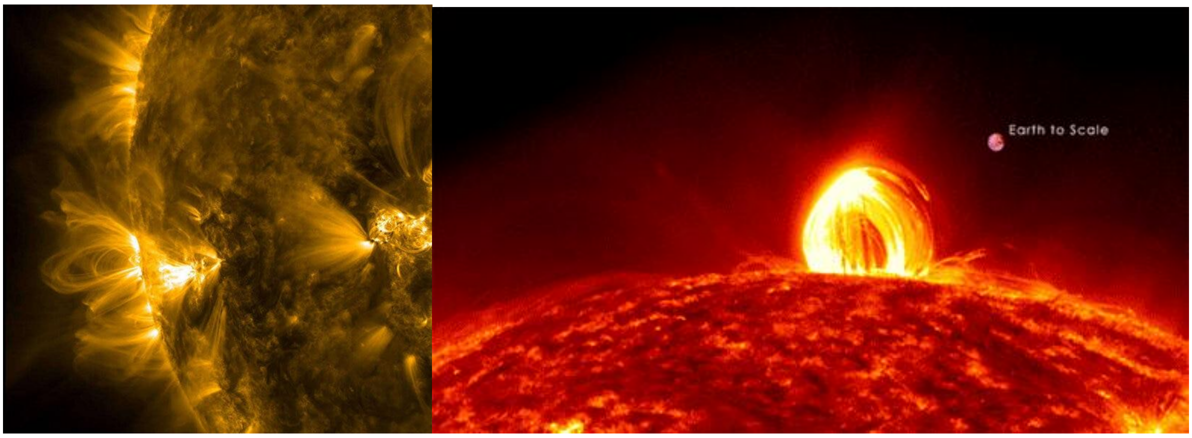


A polar crown prominence recorded by Hinode on Nov. 30, 2006. Source: by Dr. Tony Phillips, Science@NASA

Definitely, these observational data are entirely self-explanatory if the standard solar model is not kept in mind when analyzing them. First, the dark tadpole-shaped plumes are Rayleigh-Taylor instabilities (RTI). RTI typically occurs when a denser, heavier fluid is accelerated into a lighter fluid (e.g., a heavy fluid resting on top of a light one), or when a light fluid accelerates the heavier fluid. It is a phenomenon regularly observed during a solar eruption. Secondly, plummeting is a characteristic associated with falling liquid. A liquid first detaches from a surface or bulk by overcoming surface tension to form a drop and then plummets. Plasma, however, is weightless, highly energetic, and expands rapidly rather than plummeting. And there is no mystery about the plummeting speed, since conductive liquids fall faster through a magnetic field than gaseous plasma. That is because the high density of liquids easily overcomes the magnetic drag, whereas low-density, highly conductive plasma is easily trapped, suspended, or redirected by Lorentz forces (55). In other words, plasma has almost no mass or inertia, and its incredibly high electrical conductivity makes it highly susceptible to electromagnetic forces. A magnetic field can effortlessly trap, levitate, or actuate plasma, significantly slowing its descent. On the other hand, the swirling vortices are rapidly rotating columns of gas descending from above and making contact with a body of liquid. The spinning motion creates a funnel that pulls liquid droplets upward, generating a highly visible twisting vortex, similar to waterspouts. Specifically, a vortex is a specific structure within a swirling flow where the fluid rotates around a distinct central line, often featuring a low-pressure hollow core or downdraft.

Solar Rain: Solar rain and solar prominences are intimately linked phenomena that share the same physical-chemical composition—a supercritical fluid. However, they are fundamentally distinguished by their magnetic topology, lifespan, and flow dynamics. For instance, solar rain falls back to the Sun's surface as massive, droplet-like blobs, while solar prominences are enormous, stable, curtain-like loops that hover in the corona, often with much larger sizes than

Earth itself. When these massive structures lose stability, huge amounts of material crash back down—all at once—toward the Sun's surface at high speeds, creating a striking visual effect (56, 57).

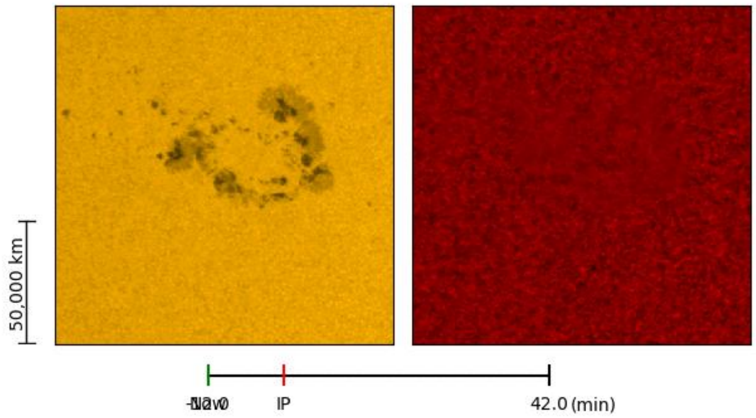


Towering Magnetic Loops and Solar Rain. Credit: NASA

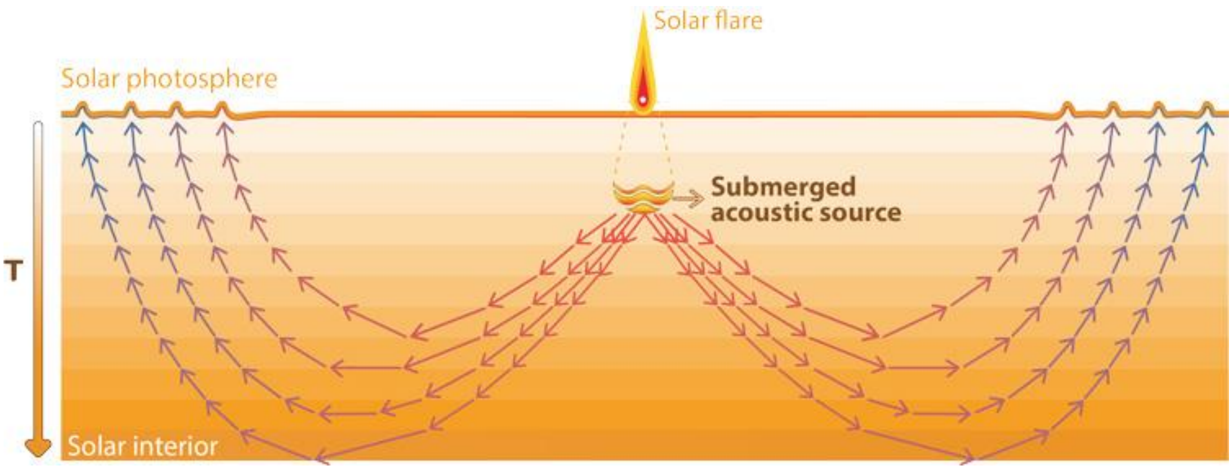
Nevertheless, just like ordinary gases, plasma does not possess a fixed shape or a defined volume, and these are the basic physical reasons why plasma cannot form the shape of a cloud, like the clouds hovering above Earth's surface and covering roughly 67% of it at any given time. Clouds in the Earth's atmosphere maintain distinct shapes because they are not made of gases or plasmas. The molecules and atoms in plasma are broken apart into positively charged ions and free-roaming electrons. Because electrons have negative charges and ions have positive charges, these charged particles repel each other, pushing the plasma outward to expand and fill available space. Moreover, rain cannot happen without evaporation, a surface-level physical change where liquid molecules escape into gas (58). Namely, evaporation occurs when these molecules gain enough kinetic energy to break their cohesive bonds. And due to the fact that surface tension is a direct result of these strong cohesive forces, a liquid with higher surface tension generally requires more thermal energy for molecules to escape into the vapor phase. Keep in mind that the interface between a supercritical fluid (SCF) and a plasma exhibits dynamic interfacial tension rather than classical liquid-gas surface tension. That is because SCFs are above their critical point, meaning that the sharp macroscopic liquid-gas boundary disappears, and when interfaced with an ionized plasma, steep density and potential gradients create electrical double layers. These double layers act as flexible, quasi-spherical membranes and exhibit measurable cohesive surface tension. Furthermore, the energy required to evaporate a liquid—known as the heat of vaporization—is directly linked to its surface tension. The relationship is mathematically bound as: $\Delta H_{vap}\ \alpha\ \gamma$ where γ is the surface tension. Furthermore, the strength of surface tension dictates the shape of a liquid. A lower surface tension makes a liquid spread out more. This increases the total surface area exposed to the air. Since evaporation only happens at the surface, a larger surface area speeds up the overall rate of evaporation. Obviously, surface tension plays a direct and important role in evaporation, but it requires a cohesive liquid or solid state where intermolecular forces draw molecules together. Plasma cannot generate surface tension because it consists of highly energetic, freely moving, and ionized gas particles rather than cohesive molecules. Essentially, the phenomenon of solar rain is physically impossible without a liquid solar surface. However, according to current theory, solar rain occurs through a mechanism involving condensation driven by extreme temperature fluctuations, rather than evaporation. Furthermore, neither evaporation nor condensation are phase transitions of plasma; they are transitions that occur between the liquid and gas states of matter.

Nevertheless, it is assumed that gaseous plasma in the Sun's corona (around 1.0×10^6 K) cools down rapidly, transitioning into a much denser, cooler state, and is pulled by gravity toward the Sun's surface. In other words, since the rain is a condensed plasma, no evaporation is needed, and gravity pulls the dense, cool droplets down through the Sun's magnetic loops, condensing further rather than evaporating. That being said, realistically speaking, coronal rain forms entirely through photospheric-chromospheric evaporation and subsequent cooling cycles. Note that the well-known phenomenon—the catastrophic cooling which precedes solar rain—still remains a mystery in current solar physics, as the solution proposed by researchers at the University of Hawaiʻi Institute for Astronomy is not valid (59). Specifically, evaporation causes extremely rapid cooling because the fastest, most energetic molecules escape into the solar atmosphere as vapor. This process, which absorbs heat from the surrounding environment, lowers the average kinetic energy of the remaining supercritical fluid and the surface it rests on. Gravity cannot be the force that pulls the dense, cool droplets down. Gravity's effect on plasma is very weak—almost negligible—compared to electromagnetism. Electromagnetism is immensely stronger than gravity at the subatomic and particle scales. In plasma, the electromagnetic force between charged particles is about (10^36) times stronger than the gravitational pull between them. Because of this dramatic difference in strength, the behavior of plasma is almost entirely dictated by electric and magnetic fields. In fact, even if we accept for the sake of argument that solar rain does not require evaporation because the plasma is already a gas, that does not eliminate the requirement of a real surface or interface (60). Essentially, condensation requires a real surface or interface to overcome the thermodynamic energy barrier of forming a new phase from vapor. In order for condensation to happen, gas molecules must lose heat and come together. This process requires a surface for them to latch onto, known as a condensation nucleus. Actually, even gas molecules cannot easily condense into liquid droplets spontaneously without something to bind to. Surfaces and interfaces are needed to provide a structural anchor, or nucleation site, for molecules to stick and slow down (61). However, as already mentioned, plasma does not have a definite shape or volume and lacks a distinct physical surface. Also, standard theoretical models suggest that magnetic tension in the Sun's corona should gently suspend the plasma or slow its descent, acting as a magnetic buffer. Observations, however, show splashing and plummeting, where the plummeting speed defies this ambient magnetic braking. Note that splashing is a dynamic physical phenomenon which occurs when a liquid in motion impacts a surface or interacts with another medium that possesses surface tension. So, evidently, the current theory of solar rain lacks fundamental scientific substance and does not reflect the physical reality of the Sun.

Sunquakes: Sunquakes are decisive evidence, showing clearly the condensed matter nature of the Sun. Historically, it was believed that seismic waves were driven directly by the magnetic forces of solar flares exploding in the Sun's outer atmosphere. But recently a research team using NASA's Solar Dynamics Observatory satellite showed sunquakes to be seismically submerged events where acoustic explosions occur beneath the solar surface, just like earthquakes. The team was able to pinpoint the source of the explosion that generated the seismic waves around 1,000 to 1,100 kilometers below the photosphere. This depth is shallow relative to the Sun’s radius of nearly 700,000 kilometers, but deeper than any previously known acoustic source in the Sun. This finding puzzled institutional solar physicists. Although some of them have proposed convective instability and magnetic free energy as sources, these hypothetical ideas fail to explain why acoustic waves emanate from deep within the Sun's hot interior. It is important to note that sunquakes do not simply scale with the overall magnitude of a solar flare; observations show that many large flares do not cause quakes, whereas smaller flares sometimes do.



Movie of a sunquake – the earthquake-like waves that ripple through our star. Left frame shows the active region in visible light (amber) and extreme ultraviolet (red) on July 30, 2011. Right frame shows the ripples on the Sun’s outlying surface up to 42 minutes after the onset of the flare, which is marked by the label “IP” for impulsive flare. Watch: [July 30, 2011 Sunquake- surface ripples]() Credits: NASA/SDO



"Solar flares trigger acoustic waves (sunquakes) that travel downward but, because of increasing temperatures, are bent or refracted back to the surface, where they produce ripples that can be seen from Earth-orbiting observatories. Solar physicists have discovered a sunquake generated by an impulsive explosion 1,000 kilometers below the flare (top), suggesting that the link between sunquakes and flares is not simple. (UC Berkeley cartoon by Juan Camilo Buitrago-Casas)"

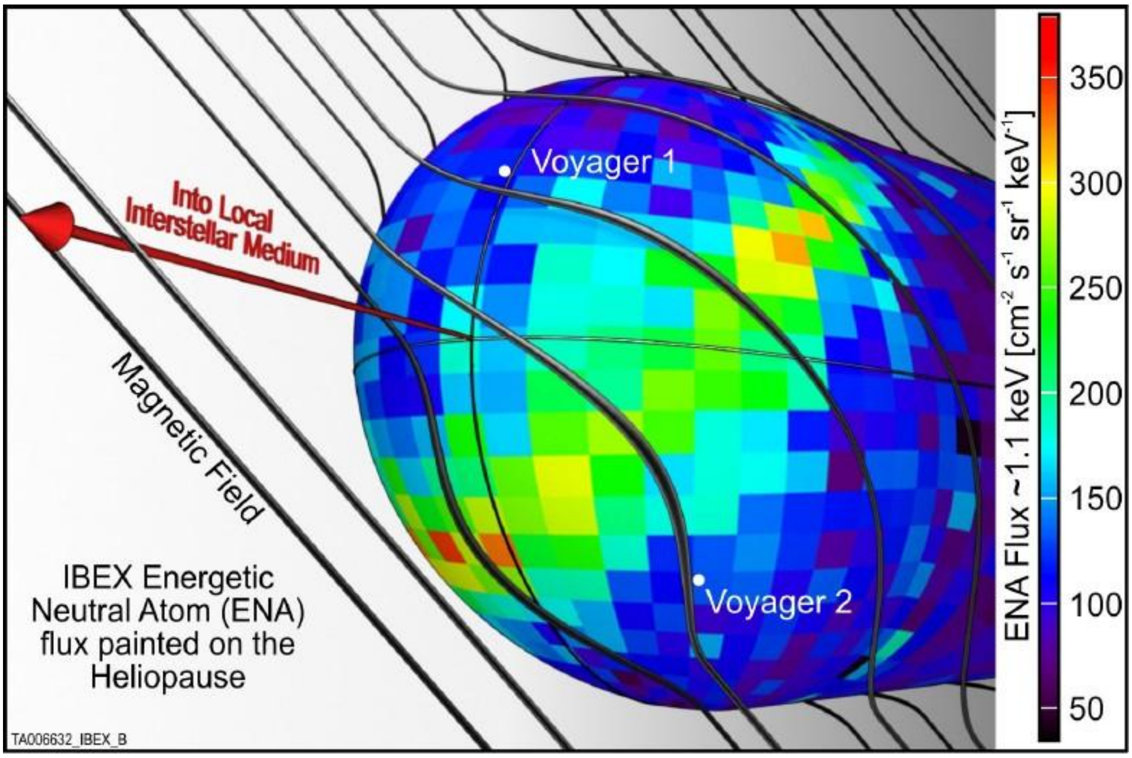
Sunquakes are driven by localized hydrodynamic explosions beneath the Sun's surface, similar to earthquakes. These explosions happen when sudden energy deposits sharply raise internal pressure and temperature, and a solar flare acts as the magnetic trigger. In other words, like earthquakes, sunquakes are triggered by a mix of external electromagnetic pressure and dynamic pressure. During a solar storm, a massive increase in solar wind dynamic pressure heavily compresses Earth's magnetosphere. Sometimes, this pressure becomes immense enough to push the magnetopause inward. Basically, when the protective magnetic shield is compressed to these extreme levels, it causes significant cascading effects on Earth's environment. Ultimately, this massive physical stress on Earth's magnetosphere translates into deep crustal stress along tectonic fault lines, triggering earthquakes and volcanic eruptions (62).

Mathematically, the dynamic pressure exerted by the solar wind on the magnetosphere can be calculated as: $P_D = n_{sw} m_p \, v_{sw}^2$ where n_{sw} is the solar wind proton number density (particles per cubic centimeter), m_p is the mass of a proton and v_{sw} is the velocity of the solar wind (km/s). In the course of severe solar storms (Coronal Mass Ejections), both the density and, most importantly, the velocity can skyrocket from a typical (400 km/s) to well over (800 km/s). Because velocity is squared in the equation, even a modest increase in speed creates a massive spike in pressure.

In case of the Sun, modulated and unmodulated Galactic Cosmic Rays (GCRs)—especially the unmodulated ones—induce significant electro-dynamic pressure on the solar body. Certainly, GCRs do exert a significant amount of dynamic and isotropic pressure on the heliosphere and on the main body of the Sun. Undeniably, if the solar wind can generate huge dynamic pressure, galactic cosmic rays can do the same. Actually, galactic cosmic rays generate a much higher dynamic pressure than solar wind does, even within Earth's atmosphere. Namely, fluctuations in solar and high-energy cosmic radiation—rather than plate tectonics alone—are the primary drivers of seismic and volcanic activity on Earth and other planets in the solar system. High-energy cosmic rays penetrate and charge the ionosphere, inducing fluctuations in the geomagnetic field. These fluctuations induce electromagnetic currents (eddy currents) that heat the rocks in geological fault lines. This heating process reduces the shear resistance and static friction of the rock, triggering fault ruptures. During solar minimum periods, the heliosphere weakens, allowing higher levels of penetrating cosmic radiation. This causes deep-seated earthquakes hundreds of kilometers below the Earth's surface (63).

It is also worth noting that primary cosmic rays are essentially bare atomic nuclei (fully ionized), solitary electrons, protons, and helium nuclei. Because they are stripped of their electron shells, they carry a net electric charge and travel through space, on average, at the speed of light or close to it. Specifically, cosmic particles—such as protons, electrons, and atomic nuclei—do lose energy as they travel across the vast distances of the Universe. The highest energy cosmic ray ever detected is the Oh-My-God particle, observed on October 15, 1991, by the Fly's Eye experiment in Utah, USA. It carried an astounding energy of $\sim 3.2 \times 10^{20}$ eV. Definitely, its energy at the point of origin is far higher, which implies that it covered a great distance travelling with a velocity higher than C.

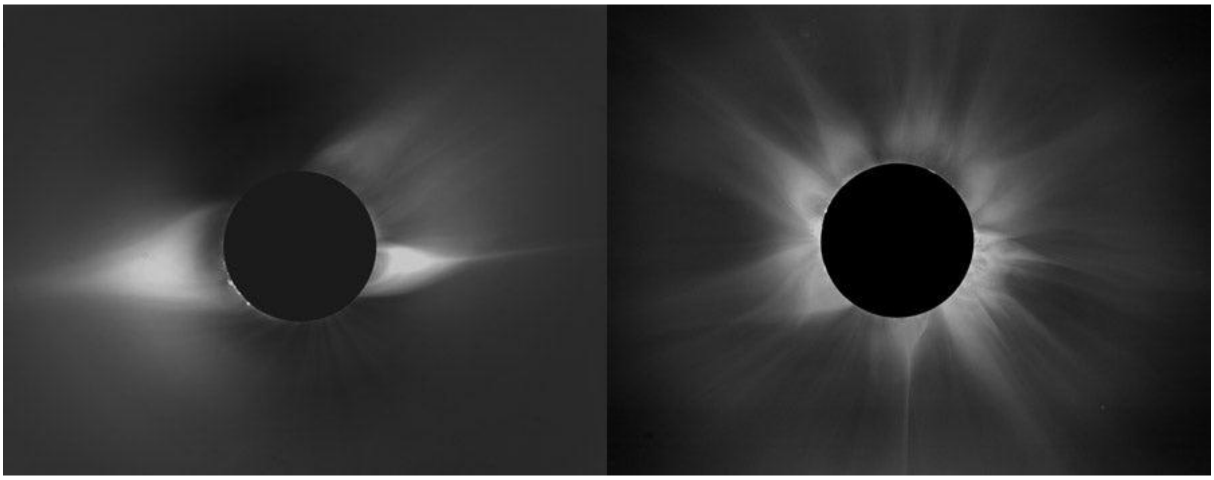
Thus, due to their properties, cosmic rays exert both isotropic pressure (from their random, thermal-like motion) and an anisotropic dynamic pressure when streaming along magnetic field lines. The dynamic pressure (P_{dyn}), which relates to their streaming speed v_s compared to the local Alfven speed v_A is given by $P_{dyn} = P_c v_s^2$. In galaxies, this pressure acts as a crucial driver of cosmic ray-driven galactic winds.



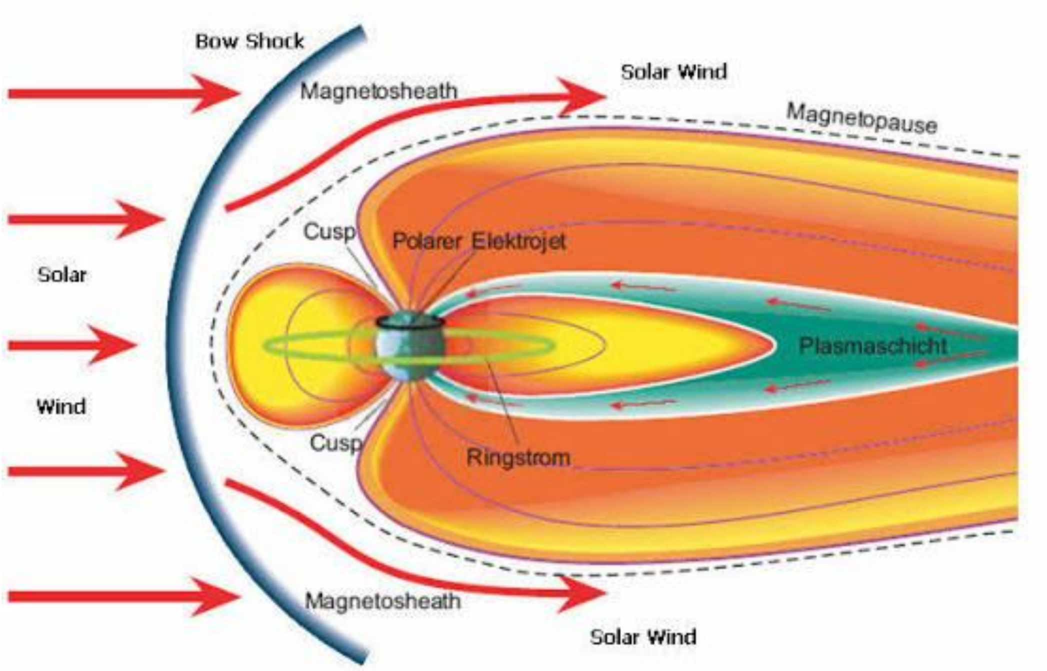
A schematic view of an asymmetric heliosphere together with the directions of the interstellar magnetic field lines. The measured ENA flux at ~ 1.1 keV is superposed on the heliopause with the bright ENA ribbon appears to correlate with where the field is most strongly curved around it. (From the Interstellar Boundary Explorer, IBEX spacecraft's first all-sky maps of the interstellar interaction at the edge of the heliosphere.) See McComas *et al.* (2009) for details. Image credit: Adler Planetarium/Southwest Research Institute.

Apparently, it is not true that the dynamic pressure of cosmic-rays is weak and plays only a minor, background role in the overall dynamics and compression of the Sun's atmosphere. The solar corona drastically changes its shape and size between solar minimum and solar maximum. At solar minimum, it shrinks and flattens into a squashed, "bow-tie" shape, while during solar maximum, it swells and becomes a large, glowing, uniform halo that extends millions of miles into space (64).

The reason for the expansion and contraction mainly has to do with the rate of galactic cosmic rays and their electromagnetic-dynamic pressure. The situation is similar in the case of the Earth. The outer layer of the magnetosphere (the magnetopause) dynamically expands and contracts as the solar wind's dynamic pressure fluctuates. Namely, when the solar wind speeds up or its density spikes (such as during a coronal mass ejection), it exerts higher pressure on the Earth's magnetic field. This compresses the magnetopause inward, bringing the boundary closer to Earth. On the other hand, when the solar wind pressure drops, the internal magnetic pressure of the Earth dominates, and this causes the magnetopause to expand outward (65).



NCAR's High Altitude Observatory and Rhodes College: Streamers in the Sun's corona during a solar eclipse. In the left image, taken in 1994 near solar min, the streamers are mostly absent from the Sun's poles. In the right image, taken near solar max in 1980, streamers sprout from all solar latitudes.



The solar wind flow around the Earth's magnetosphere, its structure due to the solar impact and major plasma regimes and current systems. Courtesy: Schlegel (2001).

Nonetheless, the rate of galactic cosmic rays—which powers the Sun and causes the high temperature of its atmosphere—is higher during solar minimum, when most of them reach the polar regions. The high rate that reaches the polar regions causes these areas to be significantly hotter during solar minimum compared to solar maximum. Actually, all types of solar eruptions which involve interactions of multiple solar layers are triggered by external electromagnetic-dynamic pressure. Fluctuations in bursts of cosmic rays or streams of charged particles exert external magnetic stress on the Sun's active regions. This external pressure acts as the spark that destabilizes the confinement and triggers the explosive release of pressurized stored energy.

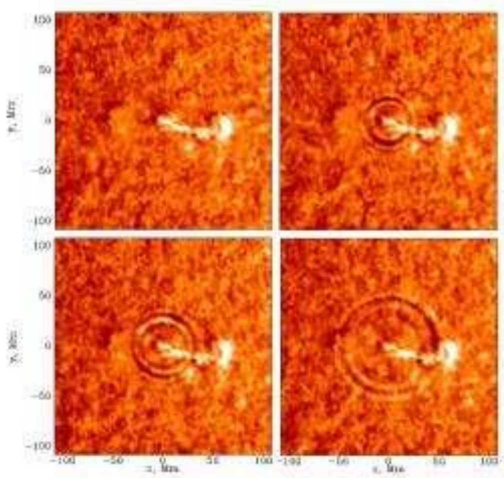
However, it is worth briefly discussing the basic features of radiation pressure, also known as external electromagnetic pressure. It can exert immense forces on condensed matter, frequently reaching gigapascal ranges. In macroscopic terms, these forces are modeled through the Maxwell stress tensor, which calculates how momentum from electric and magnetic fields transfers to a material (66). In systems with strong external fields, this stress can trigger severe deformation and phase transitions by directly acting on the material's electrons and lattice. Mathematically, these forces are governed by key principles:

The Maxwell Tensor represents the momentum flux of the EM field. For isotropic media, the total stress tensor T includes both electric and magnetic field components: $T_{ij} = \epsilon_0 \left(E_i E_j - \frac{1}{2} E^2 \delta_{ij} \right) + \frac{1}{\mu_0} \left(B_i B_j - \frac{1}{2} B^2 \delta_{ij} \right)$. Coupling to Matter: Fields transfer force to materials via polarization, magnetization, and free charge currents. Extreme Magnitudes: The resulting magnetic pressure can be vast, scaling quadratically with the applied magnetic field: $P_m = \frac{B^2}{2\mu_0}$, ε_0 is the vacuum permittivity and μ_0 is the vacuum permeability. E and B are the electric and magnetic fields, and i, j denote spatial coordinates (like x, y, z). δ_{ij} is the Kronecker delta. By finding the divergence of this tensor ($\nabla . T$), you can obtain the force per unit volume exerted by the fields. Physically, the tensor represents the momentum flux density of the electromagnetic field. The diagonal components (T_{xx}, T_{yy}, T_{zz}) represent electromagnetic pressure (pushing outward or inward), while the off-diagonal components represent shear stresses (forces acting tangentially along surfaces).

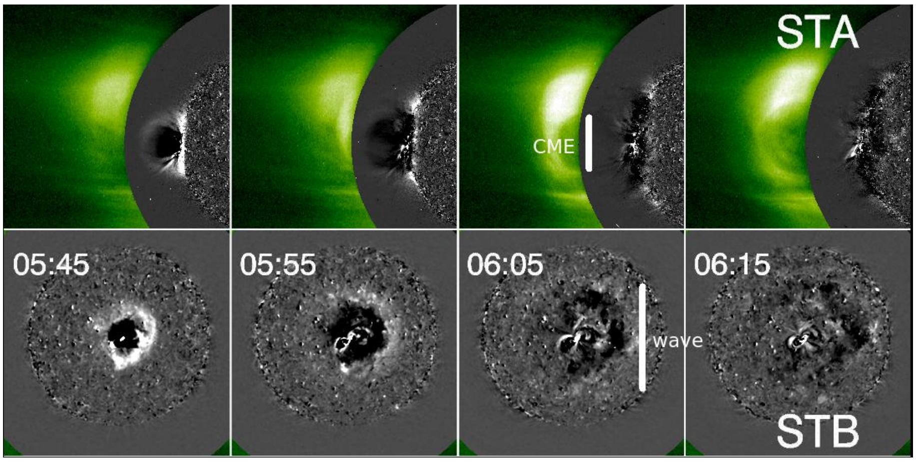
Essentially, cosmic and terrestrial quakes occur when internal stresses in a condensed matter body, which are consequences of electromagnetic and dynamic pressure, accumulate and exceed the material's structural strength, culminating in sudden brittle failure. This releases stored energy, converting elastic strain into the propagating mechanical vibrations known as seismic waves. Therefore, sunquakes according to the standard solar model cannot take place, because a gaseous plasma body cannot undergo sudden brittle failure, as it lacks the rigidity to build up and store the elastic strain energy required for a tectonic-style fault rupture.

(6) Solar Tsunamis: For many years, solar physicists observed towering waves racing across the Sun's surface. The scale of the waves was staggering: they rose up higher than Earth itself and rippled out from a central point in a circular pattern millions of kilometers in circumference. These waves were initially considered shadows, like a trick of the satellite's eye or a kind of optical illusion, but "surely" not real waves. However, in 2009, the twin STEREO spacecraft confirmed that these waves are real by recording the wave from two positions separated by 90 degrees. "It was definitely a wave—not a wave of water, but a giant wave of hot plasma and magnetism," said Spiros Patsourakos of George Mason University, lead author of a paper that reported the finding in *Astrophysical Journal Letters*. But how can a plasma wave last for so long? A plasma wave decays incredibly fast, typically lasting from a few microseconds to milliseconds in most laboratories, or even down to nanoseconds in high-density, laser-generated plasmas. Observations, however, show that a solar tsunami wave typically lasts for

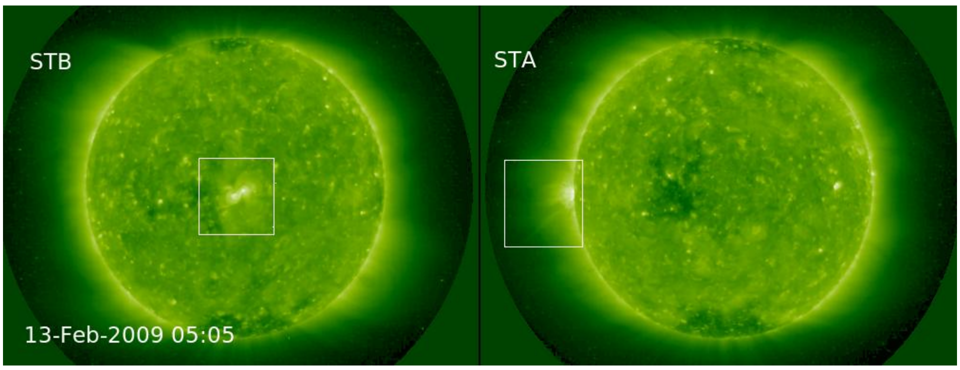
about 30 to 60 minutes. During this time, the massive shock wave races across the Sun's atmosphere, covering a distance of nearly a million kilometers (67).



The first detection of tsunami-like waves on the surface of the Sun was in July 1996 with SOHO. Credit: SOHO (ESA & NASA)



STEREO Ahead ("STA") and Behind ("STB") views of the coronal wave event. The Behind spacecraft views *(bottom)* show the wave expanding over much of the solar hemisphere visible from that spacecraft, while the Ahead spacecraft *(top)* shows the expanding coronal mass ejection (CME) bubble leaving the EUVI field of view (grey difference images) and entering the COR1 field of view (green images). STEREO- Planet identification in STEREO coronagraph images



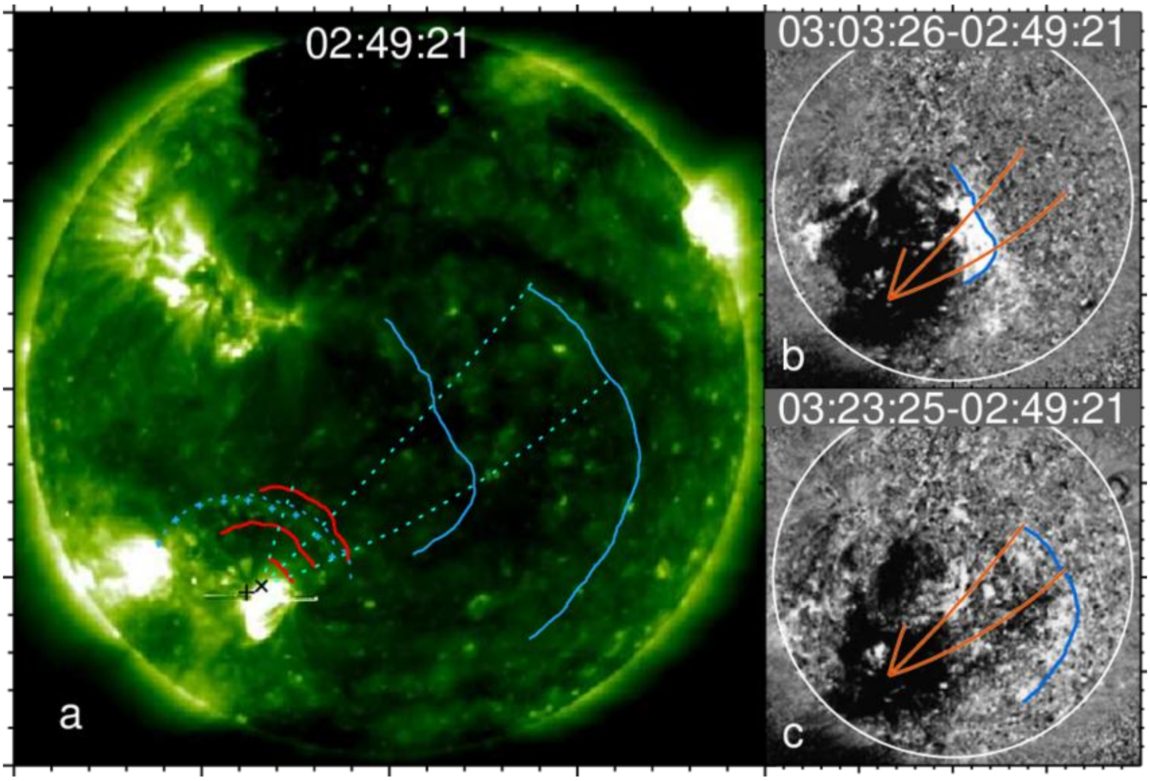
Images of the Sun from the STEREO Behind ("STB") and Ahead ("STA") spacecraft's SECCHI Extreme Ultraviolet Imager (EUVI) instrument, obtained on February 13, 2009, in a spectral line formed at 1.5 million Kelvin. The spacecraft orbit the Sun just inside (Ahead) and outside (Behind) the earth's orbit; in February, they were 90° apart, so Behind was able to observe the boxed active region nearly at disk center, while Ahead saw it on the limb, or edge of the Sun. STEREO- Planet identification in STEREO coronagraph images

A tsunami on Earth requires both solid and liquid states because it is a multi-physics event. The solid tectonic plates shift suddenly along subduction zones or faults on the ocean floor. These solid layers are brittle, store stress over hundreds of years, and their sudden rupture releases a massive amount of energy. This acts like a giant piston, pushing the ocean floor up or down. On the other hand, the liquid state is needed since liquids are incompressible, and when the solid Earth violently shifts, the incompressible liquid water directly above the disturbance cannot be squished out of the way. Instead, the entire water column is forced upward or downward. Gravity then pulls this massive displaced liquid back to its equilibrium level, sending the energy rippling horizontally across the ocean. Obviously, a tsunami cannot happen without the interaction of liquid and solid states (68). In other words, the energy of a tsunami relies entirely on the movement and volume of a liquid, since it is nearly incompressible, and the physical force applied to it transfers energy incredibly efficiently across massive ocean basins. Moreover, the triggers of a tsunami require solid materials, whether they are shifting tectonic plates, collapsing volcanic rock, or a falling chunk of a glacier. Basically, a sudden solid displacement is required to push a massive column of liquid out of equilibrium. In essence, without a large body of liquid to carry the energy, and without a solid trigger to disturb the liquid, a tsunami cannot form (69).

Nevertheless, Moreton waves (solar tsunamis) cannot possibly be considered plasma waves for many reasons. First, plasma waves would not be able to maintain their coherence over long distances. Essentially, over such paths, the frequencies drift apart, causing the wave packet to flatten and lose its spatial form. Plasma waves frequently transfer energy and momentum directly to background particles through a collisionless process known as Landau damping, or via resonant wave-particle interactions. If particles in the plasma travel at the exact same velocity as the wave, they surf the wave's electric field. This extracts energy from the wave and causes it to decay.

Additionally, in warm plasmas, pressure gradients and particle collisions cause the wave's energy to scatter, further disrupting its momentum. In contrast, it is regularly observed that Moreton waves travel swiftly across the solar chromosphere over hundreds of thousands of kilometers without breaking apart. They leave distinct, temporary physical imprints on the lower solar atmosphere (photosphere and lower part of the chromosphere), which are considered the ground tracks or footprints of fast-mode magneto-hydrodynamic (MHD) shock waves (70).

However, how can that be possible? Plasma waves should not leave physical imprints, since they are collective oscillations of charged particles and electromagnetic fields, rather than solid physical projectiles. Essentially, plasma wave oscillations decay rapidly due to Landau damping (71) , causing the wave energy to disperse harmlessly as thermal motion without leaving any lasting structural trace in the medium.



"EUV wave (blue) and Moreton wave in the 24 September 1997 event. a) Non– subtracted EIT 195Å195Å image with the first front (blue crosses). Blue dotted line outlines its foremost edge. Red fronts outline the Moreton wave. White broken lines trace the measurement great circles. Black crosses denote the origins of measurements. b,c) Difference ratio images with blue outlines of EUV wave fronts and red measurement great circles. The outlines correspond to Warmuth et al., 2004a (courtesy A. Warmuth)."

It is crucial to emphasize that Moreton waves share fundamental hydrodynamic and wave-propagation features with liquid waves. In fact, the physical comparison of Moreton waves to terrestrial tsunamis—and liquid surface waves—is highly accurate for several key reasons. To start with, both Moreton waves and tsunamis behave as shallow-liquid gravity waves. They propagate through media where the wavelength is much greater than the depth of the photospheric layer or the ocean depth. And, just as an ocean wave bends around an island or reflects off a coastline, Moreton waves refract as they sweep through varying magnetic field strengths and reflect off dense, highly magnetic active regions on the Sun. Similarly, terrestrial tsunamis and Moreton waves both undergo non-linear steepening. As they travel, the leading edge of the wave can steepen into a shock front. In water, this leads to breaking waves or a bore. In the solar photosphere and the lower part of the chromosphere, this manifests as an abrupt density and temperature front. The other common feature is appearance and disappearance. Some solar tsunamis appear to vanish as they travel across the solar disk, only to reappear much later or at a distance. The same thing happens with tsunamis on Earth (72). They can vanish and later reappear due to continental shelf resonance, wave refraction, and edge waves. These physical processes trap, scatter, and delay wave energy instead of letting it move in a straight line. Also, both tsunamis exhibit distinct fast and slow propagation components.

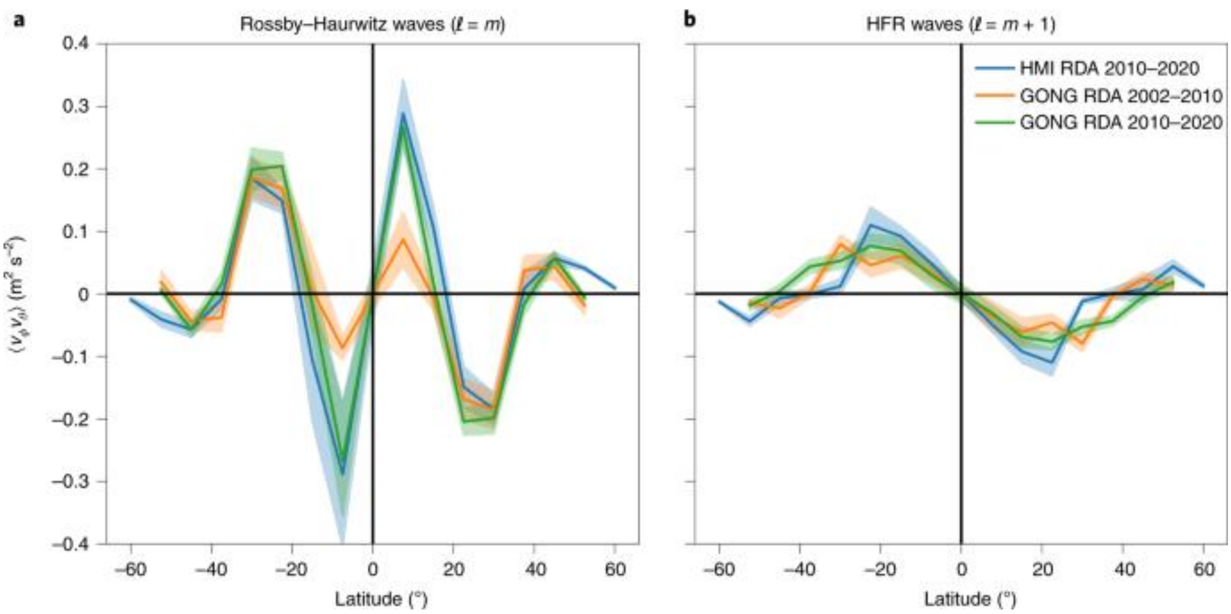
When liquid waves collide, they create complex interference patterns. Moreton waves often interact with co-existing EUV waves and coronal mass ejections (CMEs), resulting in multi-layered wave dynamics in the chromosphere. Furthermore, while liquid waves displace matter in their path, a sweeping Moreton wave goes a step further: it causes solar prominences (filaments) to violently oscillate or temporarily erupt. Yet, based on the principle of wave superposition, plasma waves cannot bounce off like billiard balls when they collide. Explicitly, if two plasma waves collide or cross paths, they do not bounce off one another. Instead, they pass straight through each other. While they are occupying the same space, they temporarily merge to create a combined wave (interference), and then emerge completely unchanged on the other side (73). Observations, however, show Moreton waves behaving like billiard balls bouncing off cushions. When these waves hit coronal holes, they bounce right back, creating chaotic wave patterns. For instance, if a solar tsunami hits a loop of solar prominence, it forces the entire loop to sway back and forth, like it is dancing.

Click on the link and **Watch** the video of the dancing solar prominence: https://vimeo.com/682469968?fl=pl&fe=cm#t=28s

The image was captured by astrophotographer Miguel Claro. He is a professional photographer, author and science communicator based in Lisbon, Portugal, who creates spectacular images of the night sky. A European Southern Observatory Photo Ambassador and member of The World At Night and the official astrophotographer of the Dark Sky Alqueva Reserve, he specializes in astronomical "Skyscapes" that connect both Earth and the night sky.

Definitely, magnetized columns of plasma cannot sway back and forth during a collision due to three primary stabilizing mechanisms: magnetic confinement, line-tying effects, and pressure balance. These forces act instantly to lock the plasma in place or redirect any physical displacement. In contrast, when liquids with different densities and temperatures collide or interact, they do not just mix right away. Instead, the collision generates gravity waves, unstable ripples, and swaying motions at the interface as the system attempts to reach a stable, layered equilibrium (with the denser liquid sinking). Also when the less-dense liquid is forced under or against the denser one, buoyancy pushes it upward. This exchange creates a rhythmic, wave-like sway as the two forces battle for vertical position.

The High-Frequency Retrograde Vorticity Waves on the Solar Surface: The other phenomenon that shows the condensed matter nature of the Sun is the high-frequency retrograde vorticity waves detected on the solar surface. Click the link to see the animation of the equatorial Rossby waves and the recently discovered high-frequency retrograde (HFR) vorticity waves in the Sun (74).



Discovery of high-frequency retrograde vorticity waves in the Sun | Nature Astronomy

The discovery of these waves was announced in March 2022 by researchers at NYU Abu Dhabi's Center for Space Science. The waves travel more rapidly than standard hydrodynamic theory predicts, leaving the astrophysical community shocked and puzzled. Essentially, after analyzing decades of space and ground telescope data, researchers found conclusive evidence that the swirling equatorial waves defy current models of solar hydrodynamics and deep solar interiors.

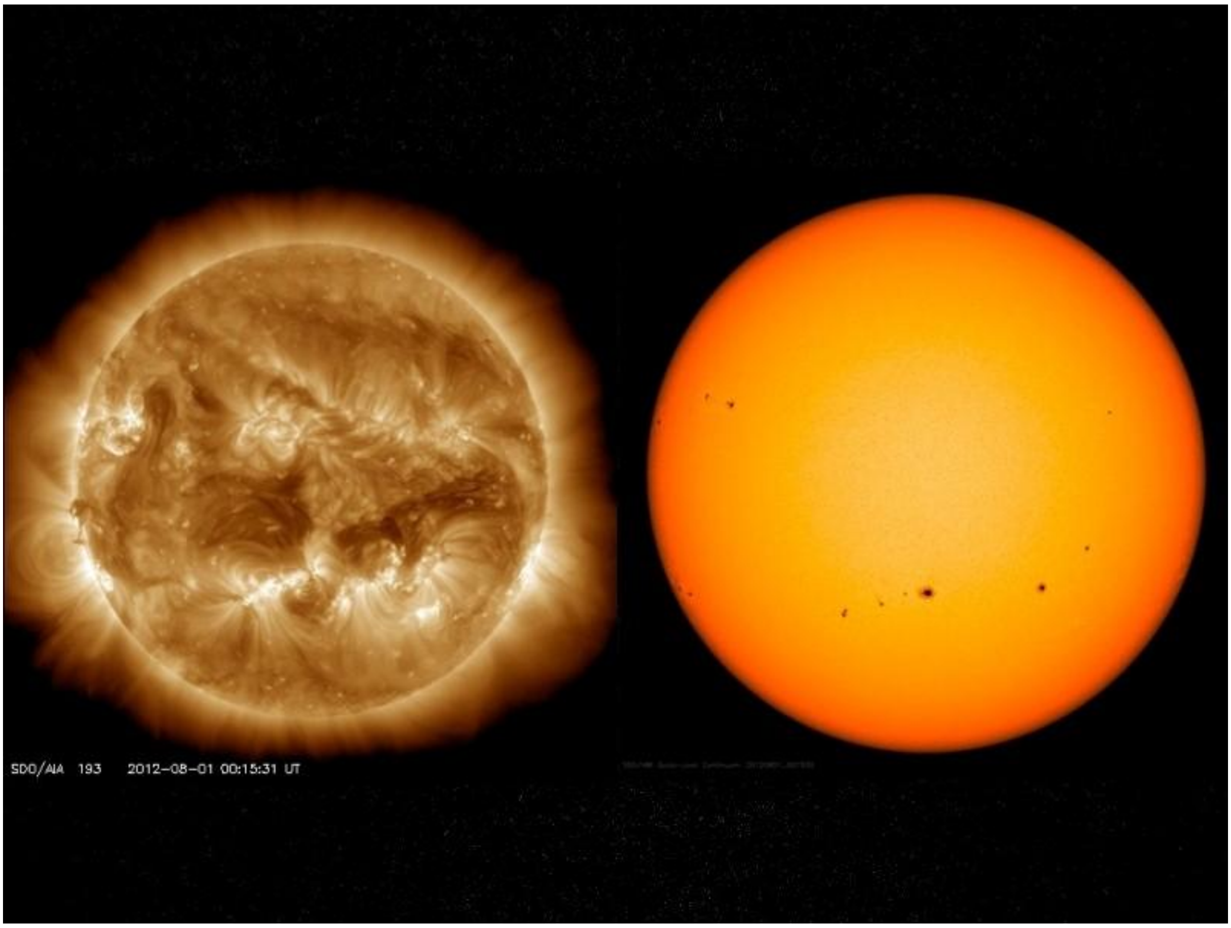
Researchers tested three possible explanations: that the waves were caused by magnetic fields within the Sun; that they came from other ripples in the Sun called gravity waves; or that they are due to compression of plasma. But none of these ideas matches the data. "To find a set of waves that has no current explanation is… exciting and intriguing, because the challenge now remains to explain what they are," said Chris Hanson. And he added, "We are missing an ingredient in our understanding of the Sun. In fact, you are missing fundamental physics facts about the Sun, not just an ingredient. Surely, no real physical model can explain this motion – which is three times faster than allowed within the framework of the standard solar model – without acknowledging a liquid solar surface.

However, it is well-known that acoustic waves travel faster in liquids (like water at ~1,480 m/s) than in gases (like air at ~340 m/s) because liquid molecules are closer together. Furthermore, increasing the external pressure on a liquid compresses it, leading to an increase in its stiffness (bulk modulus), which makes acoustic waves travel even faster. And it should be noted that the speed of sound (c) in a liquid depends on its adiabatic bulk modulus (K, stiffness) and its density (ρ). $c = \sqrt{K/\rho}$.

Higher stiffness makes the wave move faster. The square root puts (K) on the top. c: Speed of the acoustic wave (sound speed) in meters per second (m/s). K: Isentropic or adiabatic bulk modulus of the liquid in Pascals (P_a or N/m^2). It measures how hard it is to compress the liquid. ρ: Mass density of the liquid in kilograms per cubic meter(Kg/m^3). Nonetheless, High-Frequency Retrograde (HFR) vorticity waves are not completely distinct from oceanic Rossby waves. In fact, their similarities are profound, and HFR waves on the solar surface can be considered the Rossby waves of the Sun. Both types of waves propagate retrogradely. Specifically, oceanic Rossby waves — like the Rossby waves of the Sun — also have a retrograde phase velocity, meaning their individual wave patterns propagate westward (backward) relative to the fluid or air they move through.

Furthermore, large-scale Oceanic Rossby waves are fundamentally tied to fluid rotation and vorticity, and a specialized subset known as Vortex Rossby Waves (VRWs) specifically propagate on the radial gradients of intense localized vortices like hurricanes. In addition, one can understand the reason for the difference in speed between Oceanic Rossby waves and HER vorticity waves. The solar surface is highly pressurized and far denser than the oceans on Earth. These are the fundamental reasons for the high speed of the HER vorticity waves on the solar surface compared to oceanic Rossby waves. Evidently, there is no mystery about the speed of the HER vorticity waves if one considers that they are propagating on a highly pressurized, dense liquid surface, not on a gaseous plasma sphere.

The Shape of the Sun: In addition to what has been stated already, data from the Solar Dynamics Observatory (SDO) has provided further evidence showing the condensed matter nature of the Sun. This empirical evidence is related to the shape of the Sun. Note that, the shape of the Sun is extremely important feature, but it has not been accurately determined, despite several decades of photoelectric observations. However, in 2016, researchers used a camera on NASA's Solar Dynamics Observatory, which orbits high above the Earth. The camera is very stable and gets past a lot of the problems of measurement uncertainty that were preventing the precise determination of the shape of the Sun (75).



Courtesy of NASA/SDO and the AIA, EVE, and HMI science teams.

After the obtained data were analyzed with sufficiently high spatial resolution, the shape of the Sun was found to be distinctly constant and completely unaffected by the solar-cycle variability observed on its surface. Basically, the SDO data have shown the shape of the Sun to be almost a perfect sphere. The equatorial diameter was found to be only 0.0003% wider than the polar diameter (a 99.9997% perfect sphere). If the size of the Sun were reduced to that of a basketball, the equatorial diameter would be wider than the polar one by only 0.4 microns. This finding, like all recent findings, was a complete shock to theoreticians who are blindly loyal to the SSM. Namely, the Sun should be slightly flattened since it does not have a real surface. Moreover, because the Sun is supposed to be a ball of gas, its shape must change with the solar cycle. Yet, the shape was found to be remarkably constant and completely unaffected by the solar-cycle variability seen on the surface.

Definitely, this finding makes complete sense and is in full agreement with the physical reality of the Sun. That is because the Sun is not a big ball of gas, and the dominant force on it is not gravity, but rather the electromagnetic force. In other words, the strong magnetic force stiffens the interior and creates an intense surface tension, which prevents the Sun from bulging out at the equator. Besides that, the layers below the surface spin at different rates (differential rotation with depth), and that also contributes to preventing the equator from bulging. On the other hand, if the entire body of the Sun was a gas like its atmosphere, its shape would vary with solar cycle activity. But, as the observations show only the size and shape of the solar corona change significantly during the solar cycle. At solar maximum, the corona is round and bright around the Sun. At solar minimum, it stretches out near the equator and shrinks at the poles. Sun stays nearly spherical, even when it freaks out | Nature

Conclusion

Modern astrophysics is in disarray because, for decades, theoreticians have piled up countless complex theoretical models that lack thermodynamic foundations. However, I think every rational physicist, agrees with me that the laws of thermodynamics, together with the laws of electromagnetism are the core rules of the Universe. They describe how energy, heat, motion and work behave in every physical entity, from the subatomic scales to the cosmological ones. More importantly, no tested experiment has ever broken these laws. Yet, current mainstream astrophysics contradicts them—and not just on grand cosmological scales. More tragically, however, an enormous amount of observational data is routinely misinterpreted in order to protect the theoretical models that were formulated in the 19th and 20th centuries. For instance, although modern observations clearly show that magnetic fields and plasma dynamics profoundly influence cosmic structures, dark energy, black holes, and dark matter are still considered the primary drivers of the cosmos.

On the other hand, the gatekeepers of the scientific press are suppressing any new idea that would bring progress and great prosperity to humanity. The peer-review system and traditional academic publishing are slowing down paradigm-shifting research, or rather, suppressing it altogether. Basically, journals and hired reviewers tend to favor safe, incremental findings that fit existing models. In contrast, revolutionary research faces heavy irrational skepticism, long delays, inconsistent standards, and unfair rejections—especially when money or big investments are at risk, as will be the case with this research article. How can we make real progress with these attitudes and help build a bright future for humanity and all living beings?

Nonetheless, there has never been a greater scientific misunderstanding than the current one regarding the Sun, and there never will be. It is a global failure of the scientific community and acknowledging it requires monumental proof. That is because the complications of this misunderstanding are mind-boggling, as it has been piling up for more than a century. Furthermore, and most importantly, it is extremely hard to convince the global fusion community that the Sun is a condensed matter entity and that the failure to reproduce its primary energy source has nothing to do with technical difficulties, but rather a lack of solar physics. Therefore, the only effective solution—the monumental proof—is to release the scientific details of the practical model that represents the physical reality of the Sun. This model can be used to generate a self-sustained nuclear fusion reaction, providing the correct scientific basis for commercial fusion power.

References:

1- Robitaille, P.-M. (2013). Forty Lines of Evidence for Condensed Matter—The Sun on Trial: Liquid Metallic Hydrogen as a Solar Building Block. *Progress in Physics*, 4, 90–143.

2- Initial Liquid Model: Robitaille, P.-M. (2004). A High Temperature Liquid Plasma Model of the Sun. *arXiv:astro-ph/0410075*.

3- Building Block Hypothesis: Robitaille, P.-M. (2011). Liquid Metallic Hydrogen: A Building Block for the Liquid Sun. *Progress in Physics*, 3, 60–74.
4- Chromospheric and Corona Analysis: Robitaille, P.-M. (2013). The Liquid Metallic Hydrogen Model of the Sun and the Solar Atmosphere VIII. 'Futile' Processes in the Chromosphere. *Progress in Physics*, 3, L35–L40.
5- The solar neutrino problem has not been solved: Journal of Advances in Physics, ISSN 2340-107X, Volume 13, Number 4.
6- Christensen-Dalsgaard, J. (2003). "Solar structure and evolution." *Reports on Progress in Physics*, 66(7), 1079. (Outlines the standard equations for solar interior and photospheric boundary conditions).
7- Bahcall, J. N., Pinsonneault, M. H., & Basu, S. (2001). "Solar Models: Current Epoch and Time Dependences." *The Astrophysical Journal*, 555(2), 990. (Provides standard model pressure, temperature, and density stratifications).
8- Mihalas, D. (1978). *Stellar Atmospheres*. W. H. Freeman and Company. (The classic text detailing hydrostatic equilibrium and gas/radiation pressures in stellar surface layers).
9- Saha Equation Foundations & Limits: Stanford Solar Group IUPAC Gold Book
10- allen54.pdf
11- Photospheric and Chromospheric Pressure Estimates: Atmospheric modeling and spectroscopic line inversions used to determine solar pressures are described in standard stellar atmosphere frameworks outlined by academic resources like University of Hawaii Stellar Spectra Guidelines.
12- Solanki, S. K. (2003). Sunspots: An overview. *The Astronomy and Astrophysics Review*, 11(2–3), 153–286. This paper provides a comprehensive review of empirical knowledge and physical understanding of sunspots over 400 years of study.
13- Hale, G. E. (1908). On the Probable Existence of Magnetic Fields in Sun-spots. *Astrophysical Journal*, 27, 315. The seminal journal reference establishing the magnetic nature of sunspots via the Zeeman effect.
14- Schlichenmaier, R., et al. (2010). Formation of a sunspot in active region 11024. *Astronomy & Astrophysics*, 512, L1. Details the fine-structure emergence and magnetic flux assembly of sunspots on the solar surface.
15- Hathaway, D. H. (2015). The Solar Cycle. *Living Reviews in Solar Physics*, 12(1), 4. Discusses sunspots as the primary tracer of the solar cycle and fundamental dynamo processes.
16- Conjugated Conductive Polymer Materials and its Applications: A Mini-Review, Volume 9 - 2021 https://doi.org/10.3389/fchem.2021.732132
17- Soika AK. Revisiting the nature of dark sunspots: the sun as a heat engine. *Phys Astron Int J*. 2021;5(1):6-9. DOI: 10.15406/paij.2021.05.00228
18- The Second Law: From Carnot to Thomson-Clausius, to the Theory of Exergy, and to the Entropy-Growth Potential Principle by Lin-Shu Wang: *Entropy* 2017, *19*(2), 57; https://doi.org/10.3390/e19020057
19- Abetti, G. (1951). *The Sun*. Faber and Faber, London. Menzel, D. H. (1959). *The Sun*. The Blakiston Company.
20- Cowling, T. G. (1953). *Solar Electrodynamics*. In G. P. Kuiper (Ed.), The Sun (pp. 532–591). University of Chicago Press.
21- Kiepenheuer, K. O. (1953). *Solar Activity*. In G. P. Kuiper (Ed.), The Sun. University of Chicago Press.
22- de Jager, C. (1959). *Structure and Dynamics of the Solar Atmosphere*. In S. Flügge (Ed.), Handbuch der Physik (Vol. 52, pp. 80–362). Springer.
23- Bray, R. J., & Loughhead, R. E. (1964). *Sunspots*. Chapman and Hall, London (or Dover Publications).
24- The Topology of the Sun's Magnetic Field and the 22-Year Cycle, published in the Astrophysical Journal (ApJ, Vol. 133, p. 572, 1961).
25- Single Sunspots, not Pairs of Spots, as the Basic Element of Sunspots: A New Synthesis of Observed Facts: American Journal of Planetary and Space Science. December 1, 2022 (Volume 1, Issue 1).
26- Akasofu SI. Three major paradigms in solar physics. Phys Astron Int J. 2018;2(4):336?339. DOI: 10.15406/paij.2018.02.00107
27- A Systematic Study of Hale and Anti-Hale Sunspot Physical Parameters: The Astrophysical Journal, Volume 867, Issue 2, article id. 89, 16 pp. (2018).
28- Time Lag Between Cosmic-Ray and Solar Variability: Sunspot Numbers and Open Solar Magnetic Flux | Solar Physics | Springer Nature Link Time Lag Between Cosmic-Ray and Solar Variability: Sunspot Numbers

and Open Solar Magnetic Flux. Ergey A. Koldobskiy1,2 ·Riikka Kähkönen1·Bernhard Hofer3·Natalie A. Krivova3· GennadyA.Kovaltsov2,4·Ilya G. Usoskin1
29- Historical sunspot observations: A review: J.M. Vaquero Departamento de Física Aplicada, Universidad de Extremadura, Cáceres, Spain. Historical sunspot observations: A review- ScienceDirect
30- Solar Storms and Flares- NASA Science , The Surface of the Sun | Center for Science Education
31- Trujillo Bueno, J., Shchukina, N., & Asensio Ramos, A. (2004) A substantial amount of hidden magnetic energy in the quiet Sun, Nature, 430, 326–329.
32- Shchukina, N. G., & Trujillo Bueno, J. (2003) The Hanle Effect and the Magnetic Fields of the Quiet Sun, ASP Conference Series, Vol. 286.
33- Trujillo Bueno, J., Asensio Ramos, A., & Shchukina, N. (2006). *Constraints on the Hanle Effect Diagnostics of Quiet Sun Magnetism*, ASP Conference Series, Vol. 358.
34- The Evershed Effect in Sunspots: A Theoretical Explanation: Astrophysics and Space Science, v. 263, Issue 1/4, p. 323-326 (1998). The Evershed Effect in Sunspots: A Theoretical Explanation | Astrophysics and Space Science | Springer Nature Link
35- The Evershed Effect with SOT/Hinode [0903.2605] The Evershed Effect with SOT/Hinode
36- The Daniel K. Inouye Solar Telescope- Observatory Overview: Solar Physics, Volume 295, Issue 12, article id.172. The Daniel K. Inouye Solar Telescope – Observatory Overview | Solar Physics | Springer Nature Link
37- Recent Granulation Tracking and Analysis: Rast, M. P., et al. (2021). Critical Science Plan for the Daniel K. Inouye Solar Telescope (DKIST). *Solar Physics*, 296(70).
38- Hanson, C. S., et al. (2024). Supergranular-scale solar convection not explained by mixing-length theory. Supergranular-scale solar convection not explained by mixing-length theory | Nature Astronomy
39- Living Reviews in Solar Physics, Volume 11, Issue 1, article id. 1, 88 pp.Solar Prominences: Observations | Living Reviews in Solar Physics | Springer Nature Link
40- Solar prominences: theory and models: Solar prominences: theory and models: Fleshing out the magnetic skeleton - PMC, Advanced Space-based Solar Observatory
41- The Magnetic Field in the Solar Atmosphere [1410.4214] The Magnetic Field in the Solar Atmosphere
42- Evolution of Active Regions | Living Reviews in Solar Physics | Springer Nature Link
43- Magnetohydrodynamics in turbulent dynamo regime: the stability problem Magnetohydrodynamics in turbulent dynamo regime: the stability problem
44- The influence of flux rope heating models on solar prominence formation | Astronomy & Astrophysics (A&A)
45- Physics of Solar Prominences: II - Magnetic Structure and Dynamics [1001.1635] Physics of Solar Prominences: II - Magnetic Structure and Dynamics
46- RESONANT ABSORPTION OF TRANSVERSE OSCILLATIONS AND ASSOCIATED HEATING IN A SOLAR PROMINENCE. II. NUMERICAL ASPECTS- IOPscience The Astrophysical Journal, Volume 809, Number 1
47- Rayleigh-Taylor instability in prominences from numerical simulations including partial ionization effects. A&A Volume 565, May 2014
48- The Formation of Solar Prominences: Plasma Origin and Mechanisms
49- Self-consistent numerical simulations for the formation and dynamics of solar prominences Self-consistent numerical simulations for the formation and dynamics of solar prominences | Nature Astronomy
50- Formation and Plasma Circulation of Solar Prominences: The Astrophysical Journal, Volume 823, Issue 1, article id. 22, 9 pp. (2016).
51- Statistical Analysis of Torus and Kink Instabilities in Solar Eruptions: The Astrophysical Journal, Volume 864, Number 2
52- On the Role of the Background Overlying Magnetic Field in Solar Eruptions: The Astrophysical Journal Letters, Volume 748, Issue 1, article id. L6, 6 pp. (2012).
53- MAGNETIC STRUCTURE AND DYNAMICS OF THE ERUPTING SOLAR POLAR CROWN PROMINENCE ON 2012 MARCH 12: The Astrophysical Journal, Volume 807, Number 2
54- On the Structure and Evolution of a Polar Crown Prominence/Filament System | Solar Physics | Springer Nature Link

55- Fast Downflows Observed during a Polar Crown Filament Eruption: The Astrophysical Journal, Volume 974, Number 2
56- Formation and evolution of coronal rain observed by SDO/AIA on February 22, 2012: Astronomy & Astrophysics, Volume 577, id.A136, 8 pp.
57- High-speed coronal rain: Jun 2005. ASTRON ASTROPHYS: D. Müller. Anik De Groof. Viggo H. Hansteen. H. Peter
58- Molecular Mechanism of Water Evaporation | Phys. Rev. Lett.
59- Benavitz, L., & Reep, J. W. (2025). Studies on time-varying elemental composition and rapid coronal rain condensation in flare loops. The Astrophysical Journal, Volume 992, Number 1
60- The Nobel Prize in Physics 1988- NobelPrize.org
61- The experimental science: Overview: Homogeneous nucleation from the vapor phase—The experimental science | The Journal of Chemical Physics | AIP Publishing
62- Submerged Sources of Transient Acoustic Emission from Solar Flares: **The Astrophysical Journal Letters**, **Volume 901**, **Number 1**
63- P. Homola et al, Observation of large scale precursor correlations between cosmic rays and earthquakes with a periodicity similar to the solar cycle, *Journal of Atmospheric and Solar-Terrestrial Physics* (2023). DOI: 10.1016/j.jastp.2023.106068
64- Cosmic-Ray Interactions in the Solar Atmosphere:[1910.01186] Cosmic-Ray Interactions in the Solar Atmosphere
65- Turbulence in Outer Heliosphere/ Space Science Review/Springer Nature. Volume 218, article number 50 (2022)
66- Maxwell stress tensor- Wikipedia
67- Patsourakos, S., & Vourlidas, A. (2009). EUV Wave Observations in the STEREO Era: Coronal Wave or Coronal Mass Ejection-Driven Wave?, *The Astrophysical Journal Letters*, 700(2), L182
68- Tsunami Wave- an overview | ScienceDirect Topics
69- Energy of tsunami waves generated by bottom motion 0808.2861
70- The Magnetic Origin of the Mystery of Rare Hα Moreton Waves- IOPscience
71- Landau damping- Wikipedia
72- Long-Lived Tsunami Edge Waves and Shelf Resonance From the M8.2 Tehuantepec Earthquake. Geophysical Research Letters. First published: 15 November 2018 https://doi.org/10.1029/2018GL080823
73- Swanson, D. G. (2003)- *Plasma Waves* (2nd ed.), Academic Press
74- Discovery of high-frequency retrograde vorticity waves in the Sun | Nature Astronomy
75- The Precise Solar Shape and Its Variability | Science

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