



Sunspots, Solar Rain, Solar Prominences, Solar Tsunamis, and Sunquakes as Strong Evidence for the Condensed-Matter Nature of the Sun

Jamal S. Shrair



Electronic Engineer and Independent Astrophysics Researcher, Austria

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ABSTRACT

Almost all observations discussed in this work are interpreted as supporting the condensed-matter nature of the Sun. Regrettably, empirical solar data are generally interpreted with the Standard Solar Model (SSM) in mind. Consequently, interpretations of solar features and phenomena are expected to remain compatible with the SSM. For instance, sunspots, granules, and faculae are commonly treated as structures within a gaseous plasma, whereas the present work argues that they are real physical structures formed by condensed crystal lattices. In addition, the Sun's average density (approximately 1.41 g/cm^3), which is comparable to that of Earth's oceans and slightly greater than that of water, is often interpreted within a mathematical model rather than considered as possible evidence for a condensed state. The present work argues that the overall density of the Sun is compatible with a condensed liquid state and that a purely gaseous body would not inherently possess the structural properties required for the observed solar dynamo. Moreover, the continuous solar spectrum is examined in relation to the physical state of solar matter. Dense, opaque matter can produce a continuous spectrum approximating blackbody radiation, whereas isolated low-density gases or plasmas characteristically produce discrete emission lines. Most importantly, this work argues that observed solar-dynamic phenomena such as sunspots, solar prominences, coronal rain, sunquakes, and solar tsunamis cannot be adequately explained without a liquid surface and a solid core.

Keywords: Condensed-matter Sun; Sunspots; Solar prominences; Coronal rain; Solar tsunamis

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INTRODUCTION

Professor Pierre-Marie Robitaille's argument views the Sun as a condensed-matter entity possessing a liquid surface. He outlined 41 distinct lines of evidence, categorized into seven main groups, that he argues refute the SSM (Robitaille, 2004; Robitaille, 2011; Robitaille, 2013a; Robitaille, 2013b). The

present work considers this general condensed-matter interpretation to be substantially correct. High-precision observations of solar oscillations (helioseismology) are interpreted here as indicating a condensed-matter Sun rather than a purely gaseous plasma. In particular, the helioseismic data are argued to show that the internal mass and sound-speed profiles behave according to density bounds more consistent

with condensed matter than with a hot, diffuse gaseous plasma. The author further argues that experimental and theoretical investigations, including attempts to create metallic hydrogen, do not support the extremely high density commonly attributed to hydrogen plasma in the solar core (approximately 150 g/cm³).

However, the present author disagrees with Robitaille's proposed Liquid Metallic Hydrogen Solar Model (LMHSM), because it is argued to conflict with established observations and to fail to account for several fundamental solar features and phenomena. For example, the LMHSM is argued not to reproduce adequately the precise sound waves and p-modes that propagate through the solar interior. Observations of these acoustic waves provide detailed information about the Sun's deep interior, density, and temperature profiles, which the author considers incompatible with a uniform-density liquid-metallic-hydrogen body. Furthermore, the LMHSM is argued not to reproduce mathematically or physically the complex magnetohydrodynamic (MHD) processes associated with the solar cycle, sunspots, solar flares, and coronal mass ejections. The model is also argued not to explain solar neutrinos and high-energy gamma-ray emissions.

However, the author contends that this does not necessarily validate the core nuclear-fusion processes assumed by the mainstream model. Instead, the paper argues that the Sun produces high-energy neutrinos and gamma rays mainly through collisions between galactic cosmic rays and solar material, including the solar surface and atmosphere, rather than as direct by-products of core nuclear fusion ([Helical Universe, 2017](#)).

More importantly, the pressure range above the photosphere is argued to be much greater than assumed in mainstream solar physics, while still remaining far below that required for liquid metallic hydrogen. The author considers inaccurate estimation of photospheric pressure to be a primary reason for the widespread interpretation of the Sun as being composed entirely of gaseous plasma.

The SSM assumes that the pressure above the photosphere is only a small fraction of Earth's atmospheric pressure at sea level, approximately 1/10,000 atm or less. The present work disputes this estimate and argues that it is inconsistent with observational analysis and with the Sun's mass relative to Earth's ([Bahcall et al., 2001](#); [Christensen-Dalsgaard, 2003](#); [Mihalas, 1978](#)).

Furthermore, the Saha equation, which describes the degree of ionization under thermal-equilibrium conditions, is discussed in relation to the solar atmosphere. The author argues that such equilibrium conditions do not exist in the corona and that the equation is therefore applied outside its appropriate physical regime.

The paper also contends that the conventional value is inaccurate by a very large factor. The pressure above the photosphere is not measured directly but is inferred from spectroscopic analysis ([Saha Equation Foundations & Limits, n.d.](#); [allen54.pdf, n.d.](#); [University of Hawaii Stellar Spectra Guidelines, n.d.](#)). The author argues that these spectroscopic methods depend on assumptions of a gaseous-plasma Sun in thermal equilibrium and on endothermic processes in the chromosphere, and therefore considers those assumptions

invalid. Nevertheless, producing liquid metallic hydrogen requires pressures greater than approximately 500 GPa, more than five million times Earth's atmospheric pressure, and the metallic state remains experimentally challenging.

Such pressure is not present above the photosphere. The broader disagreement with the LMHSM and with aspects of mainstream solar interpretation is developed in greater detail elsewhere by the author. The proposed model is presented as experimentally testable through the generation of a self-sustained nuclear-fusion reaction, which the author contrasts with traditional thermonuclear approaches.

The article therefore focuses on dynamic phenomena that are argued to reveal the Sun's condensed-matter nature. These phenomena are classified into two categories: low-intensity and high-intensity dynamic events.

SUNSPOTS

Sunspots were among the earliest phenomena observed on the solar surface and remain among the most important features for understanding solar physics ([Solanki, 2003](#)). Sunspots are directly associated with some of the largest energetic solar events. Specifically, the formation of solar flares, the release of magnetic energy, and the cause of their explosive behavior cannot be fully understood without knowing how active regions form within the Sun's surface layers.

The author argues that, despite the large volume of observational data obtained with modern space- and ground-based instruments, the physical origin of sunspots remains incompletely understood within the current SSM. Hale's discovery of strong magnetic fields in sunspots established the fundamental role of magnetism in their structure ([Hale, 1908](#)). Subsequent theoretical and observational studies have investigated the formation and evolution of sunspots and their relationship to the solar cycle ([Schlichenmaier et al., 2010](#); [Hathaway, 2015](#)).

Nevertheless, the author argues that important questions remain, including why sunspots appear at the solar surface, why they appear dark at visible wavelengths, and why they can be bright in ultraviolet and X-ray observations.

High-resolution observations released on May 19, 2023, from the Daniel K. Inouye Solar Telescope show bright dots within the core of sunspot AR3053. The author interprets such observations as evidence that sunspots should not simply be characterized as uniformly dark or cool structures.

The paper proposes that the dark visible appearance of sunspots is related to high electrical conductivity. In some conductive materials, free electrons and conjugated electronic structures can strongly influence visible-light absorption and reflection ([Lu et al., 2021](#)).

The author further argues that dense solar material within sunspots can interact efficiently with high-energy radiation through photoelectric processes. From this perspective, the conventional explanation that strong magnetic fields lower the sunspot temperature primarily by suppressing convection is challenged. From a thermodynamic perspective, the Sun is treated as a heat engine that converts internal thermal energy into radiant energy emitted from its surface ([Soika, 2021](#)). The governing principles are identified with the laws of thermodynamics, particularly the second law and Carnot's

principle, which are closely related to entropy (Wang, 2017). The author argues that compensatory processes must occur in non-equilibrium active regions, particularly sunspots, as heat is removed from the solar interior. According to the interpretation presented here, the concept of cooler sunspots is therefore inconsistent with the proposed thermodynamic picture. The author further states that magnetic fields do not prohibit heating and estimates, using a Carnot-type approximation, that material ejected from a sunspot may reach temperatures on the order of $T \approx 6,000,000 \text{ K}$. This large temperature contrast is offered as an explanation for the strong ultraviolet and X-ray emission associated with active sunspot regions against the photospheric background.

The original manuscript also emphasizes that the thermal environment around highly energetic sunspot eruptions can become extremely hot, with major flares reaching temperatures of tens of millions of kelvins and, in exceptional cases, approaching about 100 million K . The author uses this contrast to argue that the thermal and magnetic behavior of active regions should not be reduced to the simple description of sunspots as merely 'cool' surface features. Following George E. Hale's discovery of strong magnetic fields in sunspots, researchers increasingly connected sunspot formation with solar magnetism. Historical treatments include the works of Abetti, Cowling, Kiepenheuer, de Jager, Menzel, Bray, and Loughhead, while Solanki later provided an extensive review of sunspot observations and theory (Abetti, 1951; Bray & Loughhead, 1964; Cowling, 1953; de Jager, 1959; Kiepenheuer, 1953; Menzel, 1959).

Many subsequent studies were influenced by Babcock's magnetic model of the solar cycle (Babcock, 1961). The author argues that the Babcock model does not adequately explain several basic sunspot features, including the equatorward drift of sunspot zones, aspects of meridional flow, and diffusive effects of convective motions on the magnetic field. The model is also criticized for its treatment of magnetic flux emergence as fundamentally bipolar. Observations show that isolated single sunspots can also occur, and the author therefore argues that single spots should not be dismissed as insignificant exceptions (Akasofu, 2022). The two images referred to below are presented as examples of isolated single spots without another active feature over a large area of the solar disk. Representative examples are shown in Figure 1.

In addition to the difficulties posed for the RF model, another reason may contribute to the limited attention given to isolated magnetic spots on the solar surface: contemporary physics does not recognize the existence of isolated magnetic monopoles. However, the inability of the RF model to explain single spots is not its only difficulty. The model also does not readily explain the delayed appearance of the following (f-) spot after the preceding (p-) spot, or the imbalance of magnetic flux between the p-spot and f-spot.

Moreover, positive single spots tend to appear in positive unipolar regions, and negative single spots tend to appear in negative unipolar regions, whereas pairs of spots tend to appear at or near the boundary between two unipolar magnetic regions rather than in the middle of a single unipolar region (Akasofu, 2018).

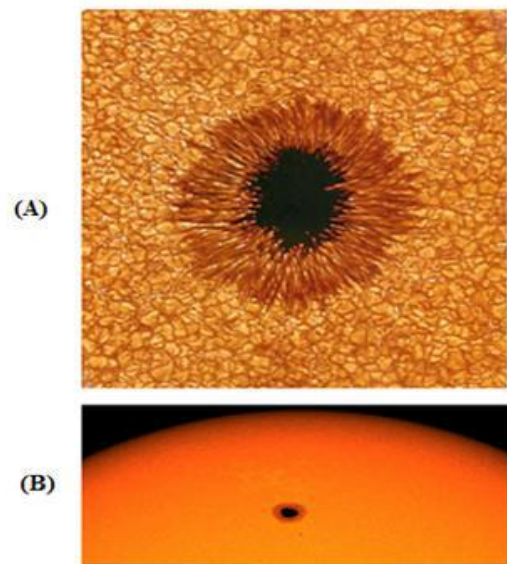


Figure 1. Examples of isolated single sunspots without another nearby active feature. Panels (A) and (B) are different spots. Credit: Big Bear Solar Observatory.

As noted above, current models of sunspot formation and their associated concepts do not, in the author's view, adequately explain the appearance and development of unipolar regions. In the figure on the left, which represents the solar magnetic field during the early phase of a new sunspot cycle, unipolar regions can be seen developing before the appearance of sunspots. The author interprets this as observational evidence that such unipolar magnetic regions are not merely remnants of older active regions. This interpretation is reinforced by the figure on the right, where a pair of unipolar magnetic regions appears without associated sunspots. Despite the introduction of newer dynamo models intended to address features not explained by Babcock's model, the author argues that these models continue to encounter important observational inconsistencies and have not yet yielded a complete physical explanation of the solar cycle.

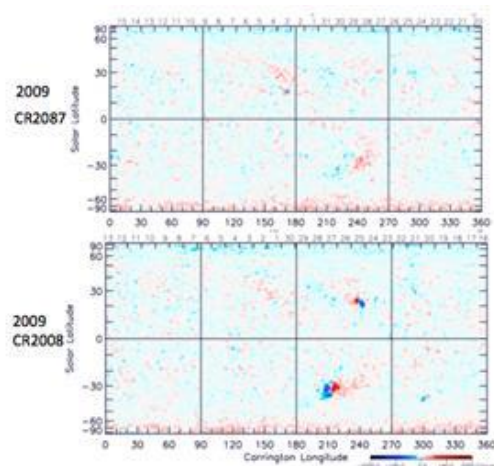


Figure 2. Early-cycle solar magnetic map showing the development of a new unipolar magnetic region before prominent sunspot formation (2009 example).

The early-cycle unipolar-region examples are shown in Figures 2 and 3.

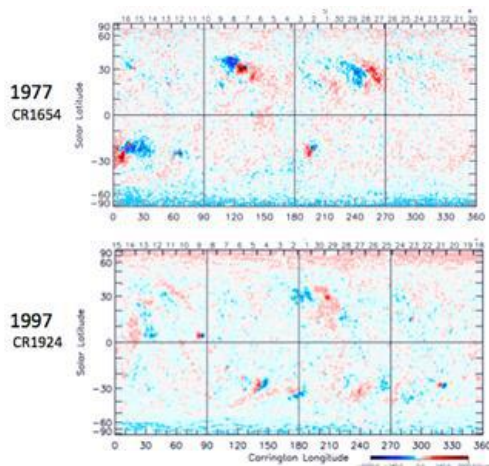


Figure 3. Comparison magnetic maps from earlier solar cycles showing large unipolar magnetic regions and their relationship to active-region development (1977 and 1997 examples).

In addition to the contradictions discussed above between theoretical models and observations, the polarity law of sunspots (Hale's law) is not obeyed in every observed active region. Reversed-polarity, or anti-Hale, sunspot groups are regularly observed. For example, when sunspots in the Sun's northern hemisphere are expected to exhibit a $-/+$ polarity configuration (negative on the left and positive on the right), some groups display the reversed $+/-$ configuration. Systematic analyses confirm the existence of such anti-Hale sunspots (Li, 2018).

The magnetograms from NASA's Solar Dynamics Observatory (SDO) cited in this manuscript illustrate examples such as AR3296 and AR3376, which are presented as violating the expected Hale polarity orientation for Solar Cycle 25 in the northern hemisphere. In these cases, the observed polarity is reversed relative to the conventional hemispheric orientation. The two reversed-polarity examples are shown in Figures 4 and 5.

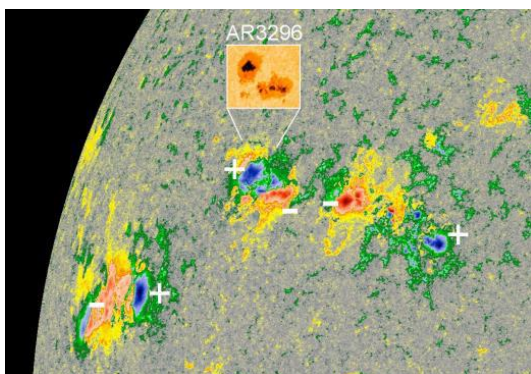


Figure 4. SDO magnetogram highlighting sunspot AR3296 as an example of an anti-Hale or reversed-polarity active region. Credit: NASA/SDO; source noted in the original manuscript: SpaceWeather.com.

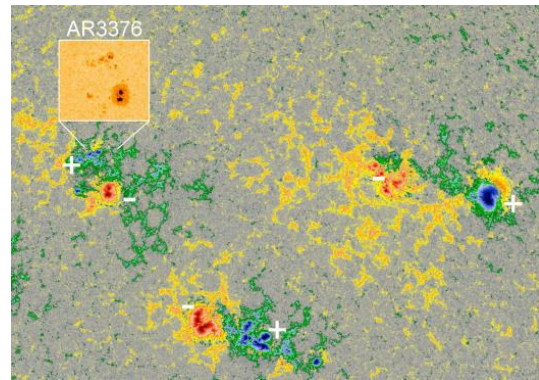


Figure 5. SDO magnetogram highlighting sunspot AR3376 as another reversed-polarity active region relative to the expected Solar Cycle 25 northern-hemisphere orientation. Credit: NASA/SDO; source noted in the original manuscript: SpaceWeather.com.

The author further argues that analyses based on modern spacecraft observations reveal a substantial discrepancy between some conventional flux-emergence models and the actual formation of sunspots. In this interpretation, the deeply rooted flux-tube model is considered inadequate for explaining the full range of observed sunspot behavior. Although increasingly sophisticated imaging and magnetic-field measurements are available, the author maintains that a significant gap remains between theoretical models and observations, largely because proposed alternatives are still constrained by the basic assumptions of the SSM.

The solar cycle itself, including the reversal of magnetic polarity, is also argued here to remain incompletely understood. The author proposes that the modulation of galactic cosmic rays reaching the Sun may contribute importantly to the cycle and that this rate varies on both short and long-time scales. Observational studies do show measurable time lags and relationships among galactic cosmic-ray intensity, sunspot number, and open solar magnetic flux (Koldobskiy et al., 2022). The author interprets these relationships as evidence for an external contribution to the variability of the surface magnetic field from one solar cycle to another.

Long-term sunspot records, extending back to the early seventeenth century, also demonstrate that solar activity varies substantially from cycle to cycle. Episodes of strongly reduced activity, such as the Maunder and Dalton minima, and intervals of enhanced activity provide an important historical record of long-term solar variability (Vaquero, 2007). The author argues that these grand minima and maxima should be considered when assessing models in which the solar cycle is generated exclusively by internal dynamo processes. The long-term observational record is summarized in Figure 6.

In the model proposed in this manuscript, the formation of sunspots depends strongly on the rate of external energy input. During solar maximum, as the magnetic pressure is argued to increase, the number of sunspots also increases. The author proposes that the formation process involves intensified interactions among the plasma atmosphere, the solid interior, and a liquid surface layer, with emerging active regions receiving a relatively high external energy input.

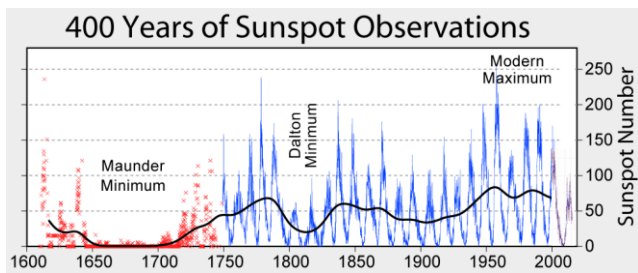


Figure 6. Four centuries of sunspot observations, showing the approximately 11-year cycle together with long-term variations such as the Maunder Minimum, Dalton Minimum, and Modern Maximum. Credit: Robert A. Rohde, *Global Warming Art*; data source noted in the original manuscript: SILSO/World Data Center for the Sunspot Index, Royal Observatory of Belgium.

Consequently, the manuscript proposes that more charged particles become trapped and that a stronger surface magnetic field is induced. External magnetic energy is argued not only to trigger eruptive events, such as solar flares, but also to contribute to the formation of active regions and to the structures and dynamics observed across the solar surface. Granulation covers most of the visible photosphere outside sunspot regions and is closely associated with convection and magnetic structure. General descriptions of solar surface activity and granulation are available from NASA and the UCAR Center for Science Education (NASA, n.d.; UCAR Center for Science Education, n.d.). The present manuscript interprets sunspots as islands of intense magnetic field embedded within a broader fluid surface possessing spatially varying density and moderately strong, inhomogeneous magnetic fields.

Recent research provides strong evidence that the apparently quiet solar photosphere contains substantial unresolved magnetic fields. Trujillo Bueno and colleagues showed, using Hanle-effect diagnostics, that a large amount of magnetic energy is hidden in small-scale fields that cannot be resolved directly in conventional observations (Shchukina & Trujillo Bueno, 2003; Trujillo Bueno et al., 2004; Trujillo Bueno et al., 2006). Their work supports the presence of tangled and spatially unresolved magnetic fields throughout the quiet solar photosphere.

The manuscript also refers to a later study by del Pino Alemán, Trujillo Bueno, Štěpán, and Shchukina, who investigated the small-scale magnetic activity of the quiet Sun using the Hanle effect in the Sr I 4607 Å line. Their three-dimensional radiative-transfer calculations were based on a magneto-convection model with a surface mean magnetic-field strength of approximately 170 G and demonstrated that such unresolved magnetic structure can strongly modify the scattering-polarization signal (del Pino Alemán et al., 2018). The corresponding three-dimensional magnetic model is shown in Figure 7.

The authors of these studies argue that quiet regions, which cover most of the solar disk at any given time, can nevertheless be significantly magnetized. Because the relevant fields are tangled on spatial scales below the resolution of many observations, their presence can be difficult to establish using conventional Zeeman-effect measurements alone.

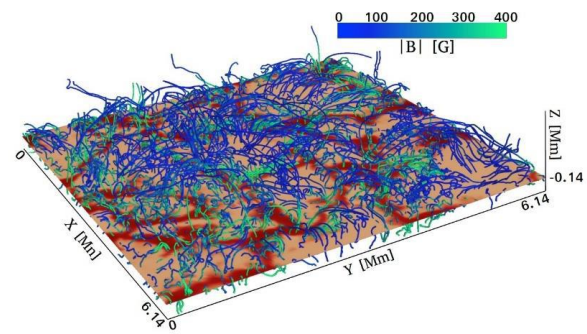


Figure 7. Three-dimensional magneto-convection model of the quiet solar photosphere with a surface mean magnetic-field strength of about 170 G. The original manuscript cites Rempel (2014) and credits del Pino Alemán et al. (2018).

The authors of these studies argue that quiet regions, which cover most of the solar disk at any given time, can nevertheless be significantly magnetized. Because the relevant fields are tangled on spatial scales below the resolution of many observations, their presence can be difficult to establish using conventional Zeeman-effect measurements alone. Hanle-effect diagnostics provide a complementary method by measuring magnetic-field-induced modifications of scattering polarization. Studies using the Sr I 4607 Å line indicate substantial hidden magnetic energy density in the quiet photosphere, with characteristic mean field strengths of order 100 G (Shchukina & Trujillo Bueno, 2003; Trujillo Bueno et al., 2004; Trujillo Bueno et al., 2006).

The manuscript notes that measuring such weak polarization signals requires a compromise between signal-to-noise ratio and spatial and temporal resolution. For this reason, theoretical calculations and magneto-convection models are often used to predict the small-scale polarization signatures expected in lines such as Sr I 460.7 nm. The later study by del Pino Alemán et al. provides a detailed example of this approach (del Pino Alemán et al., 2018). A representative predicted polarization map is shown in Figure 8.

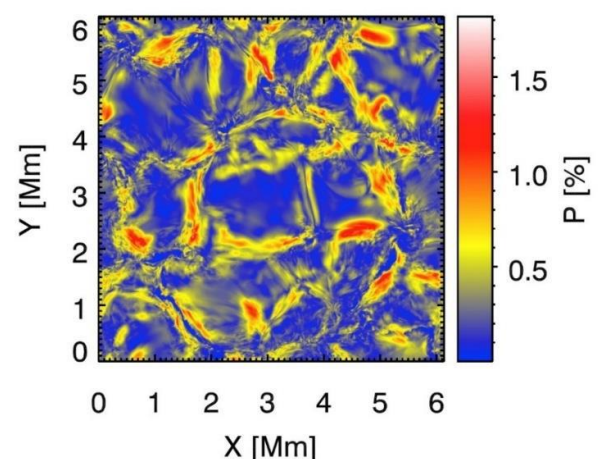


Figure 8. Predicted fractional total-polarization signal of the Sr I 460.7 nm line for a disk-center line of sight in a quiet-Sun photospheric model. Credit: del Pino Alemán et al. (2018).

A further study of the hidden magnetic field of the quiet Sun was carried out by J. C. Trelles Arjona, M. J. Martínez González, and B. Ruiz Cobo. The present author considers their results particularly informative because they allow for a spatially non-uniform hidden magnetic field across the solar surface. Using magnetohydrodynamic simulations together with multiline inversions of intensity profiles in the Zeeman regime, the authors inferred the magnetic-field distribution from 15 spectral lines in the 1.5 μm spectral range and obtained an average quiet-Sun magnetization of approximately 46 G (Trelles Arjona et al., 2021). The inferred spatial distribution of the quiet-Sun magnetic field is shown in Figure 9.

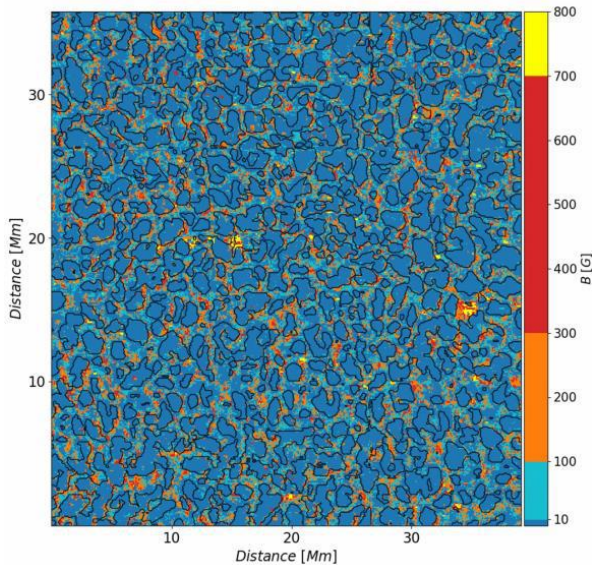


Figure 9. Average magnetic-field strength of the quiet Sun inferred from observational data. Black contours mark the granule/intergranule boundary, and the displayed field-strength scale is clipped at 800 G. Based on Trelles Arjona et al. (2021).

The manuscript interprets this non-homogeneous magnetic distribution as consistent with the broader view that the solar surface contains magnetic fields whose strength and structure vary with convective motion. It further proposes that increases in magnetic pressure, particularly during solar maximum, contribute to the concentration of active regions and the emergence of sunspots. In the model advanced here, this increase in magnetic pressure results from both an external energy supply reaching the solar surface and heat diffusing outward from the interior toward the base of a proposed liquid layer.

The tachocline is interpreted as part of a transition or buffer region involved in transporting this additional heat.

The highly energetic events occurring at the solar surface are then attributed to interactions among the principal solar layers proposed in this model, with excess magnetic energy stored in localized magnetic structures or “bubbles.” These structures are presented as building blocks for transient energetic phenomena such as solar flares and coronal mass ejections. The surface magnetic field is also argued to participate in the release of these events and in the acceleration of ejected

particles. From this perspective, the author considers the conventional treatment of sunspot formation and magnetic reconnection incomplete unless the physical state of the solar surface is reconsidered.

The manuscript further argues that the sharply defined structure and long lifetimes of sunspots are more naturally interpreted in a condensed surface layer than in a freely expanding gaseous medium. Particular attention is given to the Evershed effect, the predominantly horizontal outward flow observed in sunspot penumbrae. The siphon-flow interpretation and subsequent high-resolution observations show that the Evershed flow is highly structured and guided by inclined magnetic fields rather than being an isotropic diffusion process (Montesinos & Thomas, 1998; Ichimoto, 2010). Hinode/SOT observations also reveal fine-scale flow channels, localized upflows and downflows, and apparent twisting motions in penumbral filaments. The manuscript interprets these organized motions as resembling circulation in a magnetically structured fluid. A labeled Hinode/SOT-SP view of this fine structure is shown in Figure 10.

The author also stresses the inverse Evershed effect in the overlying chromosphere, where material can flow inward toward the umbra while the photospheric Evershed flow is directed outward. In the proposed interpretation, these counter-directed flows resemble a large-scale circulation system in a magnetically structured fluid and therefore form part of the broader argument for a physically coherent surface layer.

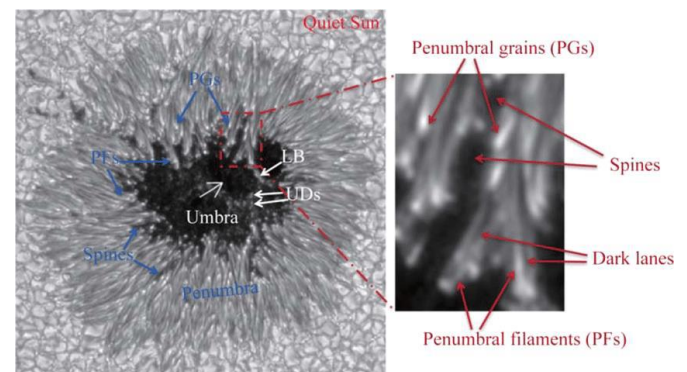


Figure 10. Continuum-intensity image of a sunspot observed with Hinode/SOT-SP, identifying the umbra, umbral dots, penumbral filaments, spines, penumbral grains, dark lanes, and a light bridge. The original manuscript notes reproduction from Tiwari et al. (2015) with ESO permission.

The Daniel K. Inouye Solar Telescope (DKIST) provides exceptionally high-resolution observations of the solar photosphere and sunspot structure. Its instrumentation resolves the umbra, penumbra, fine filaments, and other magnetic features at unprecedented spatial scales (Rimmele et al., 2020).

The present manuscript interprets the clearly resolved internal structure of sunspots as evidence that they should be regarded as physically organized magnetic structures rather than simple optical effects. Representative DKIST views are shown in Figures 11 and 12.

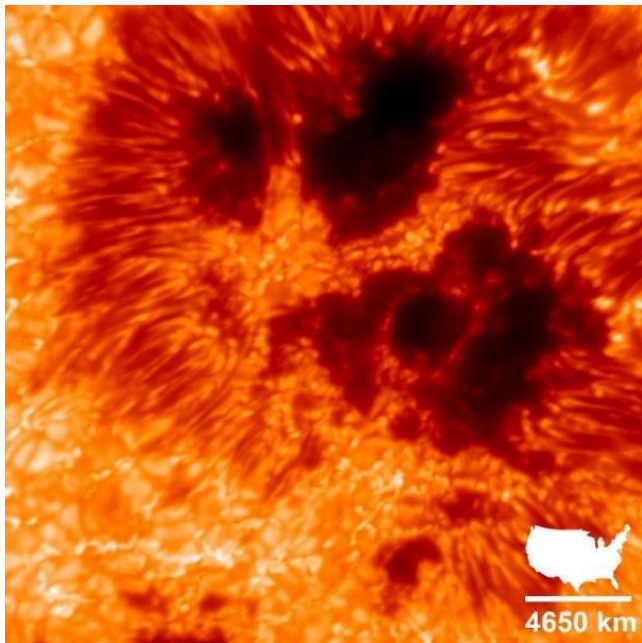


Figure 11. High-resolution DKIST view resolving distinct sunspot zones and fine penumbral structure. Credit: VTF/KIS/NSF/NSO/AURA.

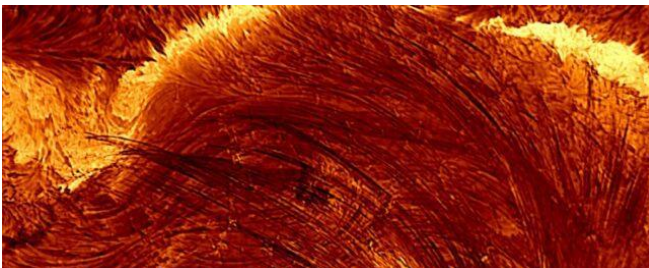


Figure 12. High-resolution image of a solar flare and associated fine magnetic structure. Credit: NSF/NSO/AURA.

GRANULATION

The visible solar surface exhibits a continuously evolving granular pattern. Individual granules are localized convection cells with characteristic horizontal sizes of roughly 1,000–1,500 km and vertical scales of order 100–200 km. High-resolution observations, including those from DKIST, show highly structured bright up flows surrounded by darker intergranular lanes. The present manuscript argues that the distinct boundaries and organized motions of these structures resemble boiling and convective behavior in a dense fluid. Modern DKIST observations and its associated science program provide the observational framework for studying such fine-scale photospheric convection (Rast et al., 2021). A high-resolution example of the granular pattern is shown in Figure 13.

The manuscript also emphasizes the difficulty of describing solar convection using simple one-dimensional or parameterized models that average over granular upflows and downflows. Mesogranulation remains difficult to define as a separate convective scale, whereas supergranulation is a robust observed component of the solar convective spectrum. Helioseismic analysis of approximately 23,000 supergranules

using Solar Dynamics Observatory data found that their vertical flows peak at depths of about 10,000 km and that the observed behavior is not reproduced by conventional mixing-length expectations (Hanson et al., 2024).

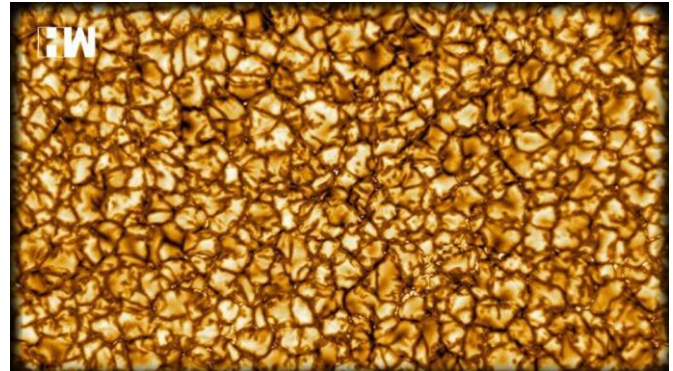


Figure 13. High-resolution view of solar granulation, showing bright granular cells separated by darker intergranular lanes. Credit: NSF/NSO.

The author interprets these results as further motivation for reconsidering simplified descriptions of solar convection.

SOLAR PROMINENCES

Solar prominences are large, cool, dense structures embedded in the much hotter solar corona. Observationally, prominence plasma is substantially cooler and denser than the surrounding coronal material, and prominences may persist for extended periods. Standard prominence physics attributes their support and organization primarily to coronal magnetic fields, with cool material residing in magnetically structured environments such as dipped field lines and flux ropes (Parenti, 2014).

The present manuscript questions whether this conventional plasma description is sufficient to account for the observed longevity, cohesion, and morphology of prominences. A representative limb prominence is shown in Figure 14.

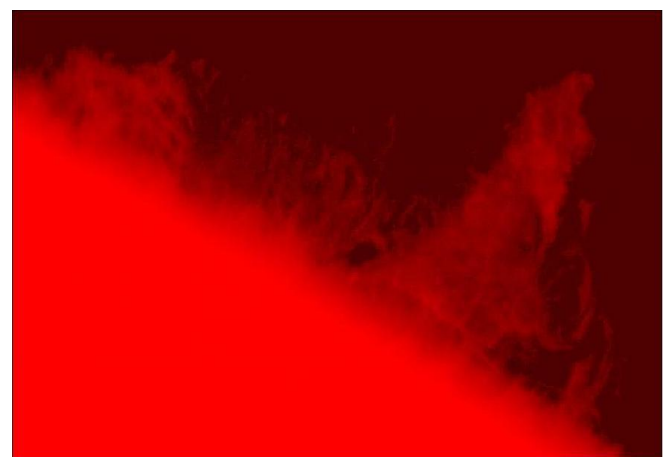


Figure 14. Solar prominence observed above the limb by the Solar Optical Telescope (SOT) aboard Hinode. Credit: Hinode/JAXA/NASA.

The original manuscript gives particular weight to the extreme thermodynamic contrast between prominences and their surroundings. Prominence material is described as roughly 100-1,000 times denser than the surrounding corona, with characteristic temperatures of about 4,300-8,000 K compared with approximately 1-2 million K in the ambient corona.

The author considers the long-term survival of such cool, dense structures in this environment to be a central physical question. Prominences, also called filaments when viewed against the solar disk, are large structures rooted in the lower solar atmosphere and extending into the corona. Modern theoretical models describe their stability and morphology in terms of a complex magnetic “skeleton,” in which magnetic fields support and organize relatively cool prominence material (Gibson, 2018).

The solar magnetic field is strongly structured and varies substantially from active-region photospheric fields to the more extended chromospheric and coronal field (Wiegmann et al., 2014; van Driel-Gesztelyi & Green, 2015).

The manuscript emphasizes this strong spatial non-uniformity and argues that the surface magnetic field should play a dominant role in prominence structure and dynamics.

The author further compares prominence morphology with cohesive, magnetically structured fluids and draws attention to bubbles, plumes, and other sharply defined features observed in quiescent prominences. Such structures are treated in the manuscript as evidence for a more strongly cohesive medium than is assumed in conventional descriptions. The author therefore proposes that prominence bubbles and plumes should be considered in relation to the condensed-matter interpretation developed throughout the paper. Examples of a prominence bubble and associated plumes are shown in Figures 15 and 16.

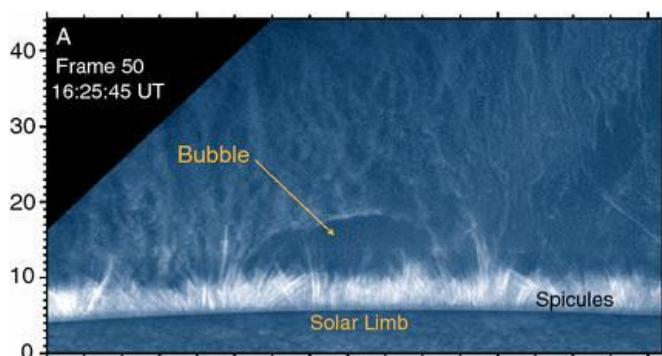


Figure 15. Bubble structure observed in a quiescent solar prominence on 16 August 2007 by Hinode/SOT. The original manuscript states that the image was adapted from Berger et al. (2017).

The author proposes that ejected electrically conductive material can be stabilized by magnetohydrodynamic (MHD) effects. In this interpretation, induced Lorentz forces provide magnetic tension and pressure that oppose disruptive fluid motion and can suppress or reorganize turbulent structures. Related MHD studies examine the stability of conducting media and the role of magnetic forces in turbulent systems (Hnatič et al., 2026).

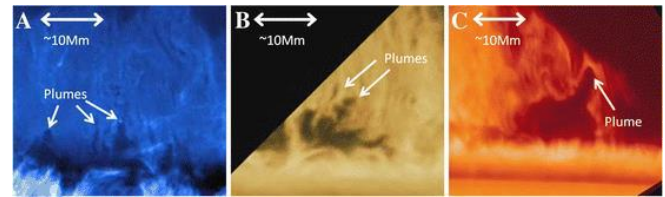


Figure 16. Examples of plumes rising from prominence bubbles in Hinode/SOT observations on 30 November 2006, 8 August 2007, and 22 June 2010. The original manuscript states that the figure was adapted from Hillier et al. (2012a).

The manuscript applies this general physical picture to prominence material, proposing that electromagnetic confinement contributes to the flattened, sheet-like and thread-like morphology frequently observed in prominences.

The manuscript further relates prominence morphology to models in which magnetic topology, heating, condensation, and field-aligned structure determine the evolution of prominence material. Numerical work on prominence formation demonstrates that the adopted coronal-heating prescription can strongly influence the location, morphology, and evolution of condensations within a flux rope (Brughmans et al., 2022).

Reviews of prominence magnetic structure likewise emphasize the central role of magnetic geometry and MHD dynamics in supporting and organizing prominence plasma (Mackay et al., 2010). The original manuscript refers to a SOHO image obtained on July 27, 1999, showing a very large prominence extending far above the solar limb. The author interprets the ordered, flattened appearance of such structures as consistent with magnetic confinement of electrically conductive material. The extraordinary scale of this prominence is illustrated in Figure 17.

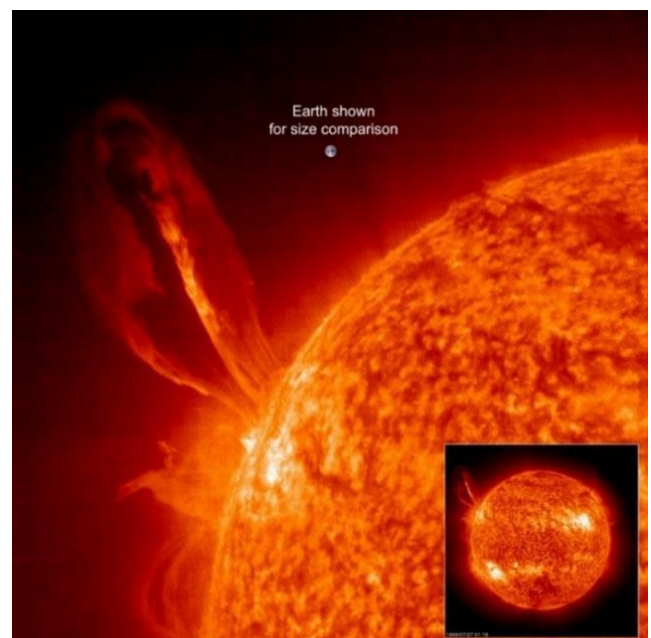


Figure 17. Large solar prominence observed by SOHO on 27 July 1999, with Earth shown for scale. Credit: SOHO (ESA & NASA).

PROMINENCE/FILAMENT INSTABILITY PROBLEMS

The manuscript next discusses several difficulties associated with interpreting prominence dynamics, especially Rayleigh-Taylor-like and Kelvin-Helmholtz-like behavior. One issue concerns the stabilizing effect expected from a predominantly horizontal magnetic field, whereas vertical and rising structures are nevertheless observed.

A second issue involves partial ionization: neutrals do not couple directly to the magnetic field in the same manner as ions, and ion-neutral drift can modify the growth and morphology of instability. Numerical simulations that include partial-ionization effects show that ambipolar diffusion can increase Rayleigh-Taylor instability growth rates and produce measurable ion-neutral drift (Khomenko et al., 2014).

The manuscript also discusses Kelvin-Helmholtz instability and cross-field-looking motions within prominences. High-resolution observations and numerical models show that transverse MHD oscillations can generate Kelvin-Helmholtz vortices, current sheets, turbulence, and heating in prominence structures (Antolin et al., 2015).

Such results demonstrate that fine-scale, apparently complex motions can arise naturally from coupled wave, resonance, and instability processes. Partial ionization introduces further complexity because ions and neutral atoms need not respond identically to magnetic forces. Simulations of prominence Rayleigh-Taylor instability have found faster downward motion of the neutral component relative to the ionized component and significant thermodynamic differences between ideal-MHD and partially ionized cases (Khomenko et al., 2014). The author interprets these effects as evidence that single-fluid descriptions may be insufficient for all prominence conditions.

The thermal origin, condensation, support, and continued replenishment of prominence material remain active research topics. Modern reviews describe several principal formation mechanisms, including injection, levitation, evaporation-condensation, and in-situ condensation, and emphasize that more than one mechanism may operate in different prominence systems (Zhou, 2025). Recent self-consistent numerical simulations likewise model prominence formation and dynamics within magnetized solar-atmospheric systems (Zessner et al., 2026).

The present manuscript interprets the observational and theoretical complexities differently, proposing that prominence material should instead be considered a highly pressurized condensed fluid. The author further proposes that variations in an external magnetic field can disturb the equilibrium of an electrically conductive, highly pressurized fluid and trigger MHD instabilities. In the proposed interpretation, a sudden pressure decrease could drive rapid phase change and expansion. This is presented as an alternative explanation for rapid prominence restructuring, condensation, siphon-like flows, and catastrophic collapse.

FORMATION OF SOLAR PROMINENCES

The manuscript proposes that electromagnetic interactions near active regions can draw highly conductive material

upward from the solar surface through Lorentz-force effects. In conventional prominence modeling, three-dimensional numerical simulations show that prominence material can form through coronal condensation, with continuous chromospheric evaporation supplying mass and establishing circulation between the chromosphere, corona, and prominence (Xia & Keppens, 2016).

The present author interprets the upward transport and subsequent prominence formation within a different condensed-fluid framework. The fate of a prominence—whether it erupts into interplanetary space or remains confined and subsequently falls back—is strongly affected by its magnetic environment. Statistical studies of solar eruptions show that the decay of the overlying strapping field is important for distinguishing confined from ejective events, while the role of helical kink instability is less decisive in many cases (Jing et al., 2018).

Studies of specific active regions also demonstrate that the overlying background magnetic field provides an important constraining force on erupting structures (Nindos et al., 2012). The present manuscript attributes the ultimate driving energy to an external magnetic-energy supply and interprets failed eruptions as cases in which the driving force is insufficient to overcome the overlying field.

POLAR CROWN PROMINENCES (PCPS)

Polar crown prominences are a distinct class of long-lived prominences located at high solar latitudes near the boundary of polar coronal holes. Observational studies show that they can contain vertical threads, dynamic bridges, and complex three-dimensional flows. Detailed analyses of an erupting polar crown prominence have examined its magnetic support and dynamics using SDO and STEREO observations (Su et al., 2015), while other work has investigated the structure and evolution of polar crown prominence/filament systems using SDO, STEREO, and magnetic-field observations (Panesar et al., 2014).

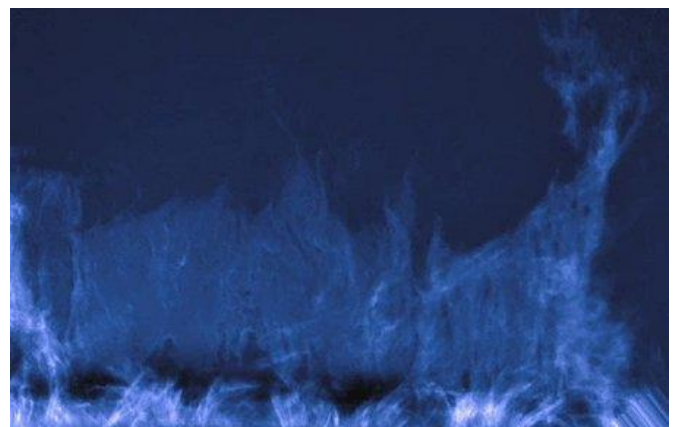


Figure 18. Polar crown prominence observed by Hinode on 30 November 2006, showing vertically structured threads and downflowing material. Source noted in the original manuscript: Dr. Tony Phillips, Science@NASA.

The manuscript notes that Hinode observations revealed dark rising plumes, persistent downflows, and vortical motions

within polar crown prominences. These observations are presented by the author as evidence of fluid-like behavior and as a challenge to simplified static interpretations of prominence plasma. A polar crown prominence displaying this highly structured morphology is shown in Figure 18. The original discussion highlights three observational features reported from Hinode prominence observations: dark tadpole-shaped plumes rising from the prominence base, narrow streams of material falling rapidly downward, and conspicuous swirls or vortices within the prominence body. The author regards the simultaneous presence of rising plumes, rapid downflows, and vortical motion as especially suggestive of a dynamically structured fluid system rather than a simple static plasma configuration. Fast downflows have also been measured during polar crown filament eruptions. Recent observations report plane-of-sky downflow velocities of approximately $92\text{--}144\text{ km s}^{-1}$ during a polar crown filament eruption and discuss possible interpretations involving magnetic-flux-rope geometry and reconnection-related outflows or redirected filament material (Sun et al., 2024). The present manuscript instead interprets these motions as characteristic of dense conductive fluid descending through a magnetized environment.

SOLAR RAIN

Solar rain and solar prominences are closely related phenomena involving comparatively cool, dense material within the much hotter corona. Coronal rain is observed as dense condensations that form in coronal loops and fall toward the solar surface. Observations with SDO/AIA have documented rapid cooling and the subsequent formation and descent of coronal-rain blobs (Vashalomidze et al., 2015). Earlier observations and non-equilibrium simulations likewise demonstrated high-speed coronal rain and showed that catastrophic cooling in loops can generate localized condensations and downflows (Müller et al., 2005).

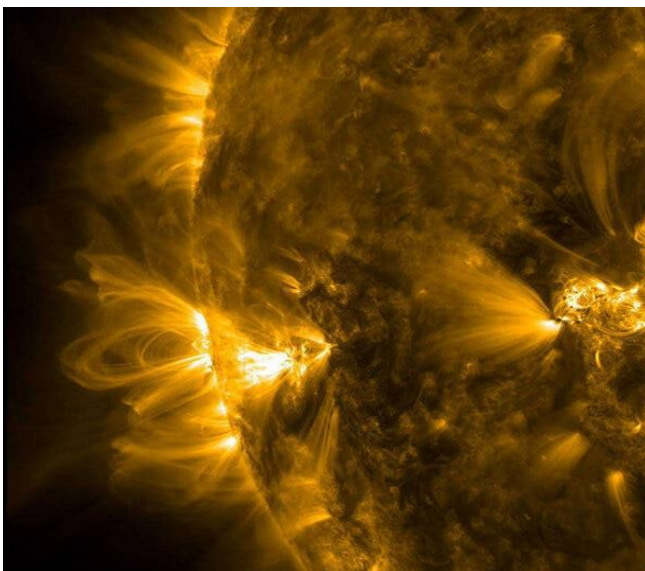


Figure 19. Towering magnetic loops associated with coronal-rain formation in the solar corona. Credit: NASA.

The present manuscript interprets both prominence material and coronal rain as manifestations of the same underlying supercritical-fluid composition, distinguished mainly by magnetic topology, lifetime, and flow geometry. Representative loop and coronal-rain images are shown in Figures 19 and 20.

The manuscript next considers the relation between evaporation, condensation, surface tension, and the physical state of coronal-rain material. Evaporation is a surface process in which molecules with sufficient kinetic energy escape from a liquid into the vapor phase.



Figure 20. Coronal rain descending along a large magnetic loop, with Earth included for scale. Credit: NASA.

At the molecular level, evaporation requires the disruption of intermolecular bonding at the liquid-vapor interface (Nagata et al., 2015). The author therefore argues that surface and interfacial properties are essential to any interpretation in which evaporation contributes to the production of material that later condenses as solar rain.

The paper further emphasizes the role of cohesive forces and surface tension in determining the behavior and geometry of condensed matter. In the author's proposed framework, a supercritical-fluid/plasma boundary would not behave as a conventional liquid-gas interface, but could still contain strong density and electrostatic gradients. The manuscript interprets such gradients as potentially contributing to an effective interfacial confinement.

This is used to support the author's broader argument that the observed droplet-like behavior of coronal rain is more naturally associated with condensed or near-condensed material than with a freely expanding plasma.

The author's original thermodynamic argument is more explicit: the heat required for evaporation is linked to cohesive forces at an interface, and the manuscript writes this qualitatively as $\Delta H_{vap} \propto \gamma$, where γ represents surface tension. It further proposes that a supercritical-fluid/plasma boundary may contain steep density and electrostatic-potential gradients, including double-layer-like structures, that could provide an effective interfacial cohesion even above the conventional critical point.

In conventional solar-physics models, however, coronal rain is explained by rapid radiative cooling and condensation of coronal plasma, often after chromospheric evaporation has supplied material to coronal loops. Recent numerical work demonstrates that time- and space-dependent elemental

abundances can alter radiative losses and can directly facilitate coronal condensations in impulsively heated loops (Benavitz et al., 2025).

The present manuscript disputes this interpretation and instead attributes the rapid cooling mainly to evaporation from an underlying condensed solar medium. The manuscript also compares gravitational and electromagnetic forces in order to argue that charged particles in plasma are influenced far more strongly by electromagnetic interactions than by mutual gravity. A Nobel Prize educational discussion of the four fundamental forces gives an illustrative relative-strength comparison in which the electromagnetic interaction is approximately 10^{36} times stronger than gravity at the elementary-particle scale (Nobel Prize Outreach, n.d.). The author uses this comparison to question explanations in which gravity alone is treated as the principal driver of rapidly descending ionized material. Finally, the manuscript argues that condensation requires overcoming a nucleation barrier before a new condensed phase can form. Classical and modern studies of homogeneous vapor nucleation show that molecules can form clusters in a supersaturated vapor and that sufficiently large clusters can continue to grow into droplets or particles (Wysloulzil & Wölk, 2016).

Thus, homogeneous nucleation can occur without a solid foreign surface, although the process still requires formation of a phase interface and the overcoming of a free-energy barrier. The author nevertheless maintains that the observed splashing, rapid descent, and droplet-like morphology of solar rain are more consistent with the condensed-fluid interpretation proposed in this manuscript.

SUNQUAKES

Sunquakes are presented in this manuscript as important evidence in support of the proposed condensed-matter interpretation of the Sun. Historically, seismic waves associated with flares were generally assumed to be driven by disturbances originating in the flaring atmosphere.

More recent helioseismic analysis, however, has identified compact acoustic sources located approximately 1 Mm beneath the photosphere. Lindsey and colleagues reconstructed three-dimensional acoustic-source structure for the M9.3 flare of July 30, 2011 and reported a component submerged about 1,000 km below the photosphere (Lindsey et al., 2020).

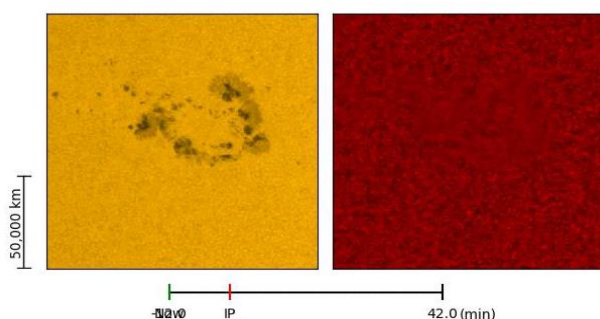


Figure 21. Sunquake observations associated with the 30 July 2011 flare: the active region is shown together with later surface-ripple signatures. Credit: NASA/SDO.

The author emphasizes that this depth is small relative to the solar radius but is nevertheless deeper than previously identified flare-related acoustic sources. The fact that some large flares do not produce strong sunquakes, whereas some smaller events do, is also taken to indicate that the relation between flare magnitude and seismic emission is not straightforward. The observed surface response and the submerged-source geometry are illustrated in Figures 21 and 22.

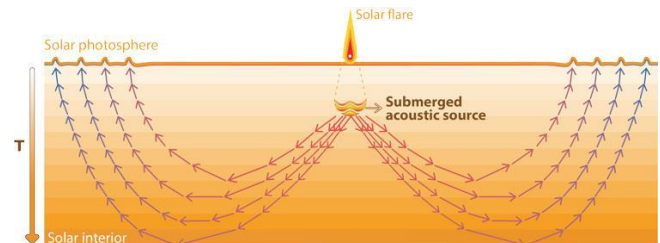


Figure 22. Schematic representation of a submerged acoustic source beneath a solar flare, with acoustic rays refracting back toward the photosphere. Credit: Juan Camilo Buitrago-Casas/UC Berkeley.

The present manuscript interprets sunquakes as localized hydrodynamic explosions beneath the solar surface, in some respects analogous to earthquakes. In this framework, a flare acts as an electromagnetic trigger that rapidly changes local pressure and temperature, initiating mechanical waves in the underlying medium. The author then draws an analogy with solar-wind compression of Earth's magnetosphere and proposes that sufficiently strong external electromagnetic and dynamic pressure can contribute to stress changes in condensed matter.

The cited sunquake study establishes the existence of a submerged acoustic source but does not itself establish the broader terrestrial-seismic mechanism proposed here (Lindsey et al., 2020).

The solar-wind dynamic pressure used in the manuscript is written as $P_D = n_{sw} m_p v_{sw}^2$, where n_{sw} is the solar-wind proton number density, m_p is the proton mass, and v_{sw} is the solar-wind velocity. During strong coronal mass ejections, both density and velocity can increase substantially; because the velocity term is squared, changes in speed can strongly affect the dynamic pressure.

The manuscript further proposes that modulated and unmodulated galactic cosmic rays (GCRs) exert significant electrodynamic pressure on the heliosphere and on the solar body, and extends this idea to terrestrial seismic activity. A large collaboration reported a statistically significant correlation between variations in secondary cosmic-ray detection rates and subsequent global seismic activity, with a periodicity resembling the solar cycle (Homola et al., 2023). The present author interprets this correlation as evidence for a causal cosmic-ray contribution to seismic triggering, while the cited study itself describes the result as a precursor correlation and does not establish the detailed physical mechanism proposed in this manuscript.

Primary cosmic rays consist mainly of charged particles such as protons and atomic nuclei, together with electrons and other

species. They can reach extremely high energies, as illustrated by the well-known 1991 “Oh-My-God” cosmic-ray event, with an observed energy of approximately 3.2×10^{20} eV. The author proposes that cosmic rays exert both approximately isotropic pressure and directed dynamic pressure when streaming relative to a magnetized medium. In the original manuscript, this directed contribution is represented schematically by $P_{dyn} = P_c v_s^2$, where P_c denotes the cosmic-ray pressure contribution and v_s represents the streaming speed relative to the local Alfvénic medium.

The author argues that such pressure may contribute to large-scale heliospheric and solar dynamics. The extreme energy of this event is cited only to demonstrate the energy scale attainable by individual cosmic rays and does not imply propagation faster than the speed of light. The heliospheric context for these interactions is illustrated in Figure 23.

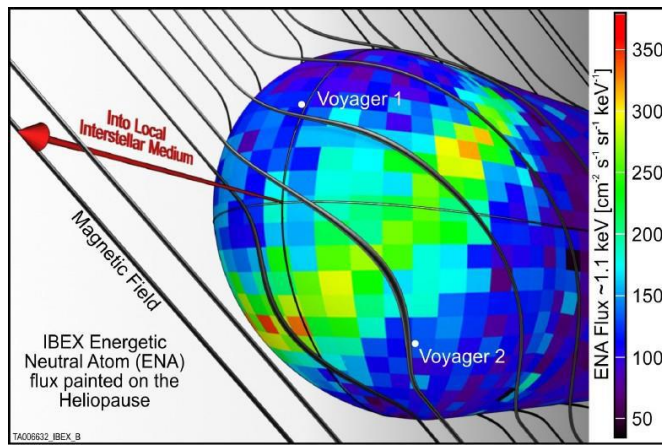


Figure 23. Schematic asymmetric heliosphere with energetic-neutral-atom (ENA) observations and the interstellar magnetic-field geometry. Credit noted in the original manuscript: Adler Planetarium/Southwest Research Institute.

The manuscript argues that cosmic-ray pressure should not be regarded as merely a minor background term in solar atmospheric dynamics.

It notes that the solar corona changes markedly between solar minimum and solar maximum and interprets this variation in relation to changes in the galactic cosmic-ray environment. Cosmic rays interacting with the solar atmosphere are known to produce secondary particles and high-energy emission, and their propagation is strongly affected by the coupled magnetic-field and gas structure of the solar atmosphere (Hudson et al., 2019).

The present manuscript goes beyond this established interaction picture by assigning GCR pressure a dominant role in the large-scale expansion and contraction of the corona. The large solar-cycle change in coronal morphology is shown in Figure 24.

For comparison, the manuscript discusses the Earth's magnetopause, whose location changes with solar-wind conditions. It then extends the analogy to the heliosphere. Reviews of turbulence in the outer heliosphere describe a complex interaction among the solar wind, local interstellar medium, pickup ions, waves, shocks, coherent structures, and turbulence (Fraternal et al., 2022).

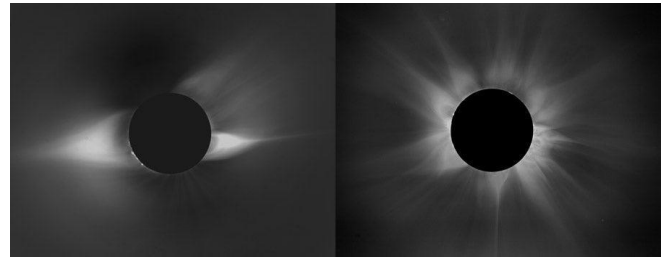


Figure 24. Coronal streamers near solar minimum and solar maximum, illustrating the large solar-cycle change in coronal morphology. Credit: NCAR High Altitude Observatory and Rhodes College.

The author uses these heliospheric variations as part of the proposed external-pressure interpretation of solar activity. The principal magnetospheric regions and solar-wind interaction geometry are shown in Figure 25.

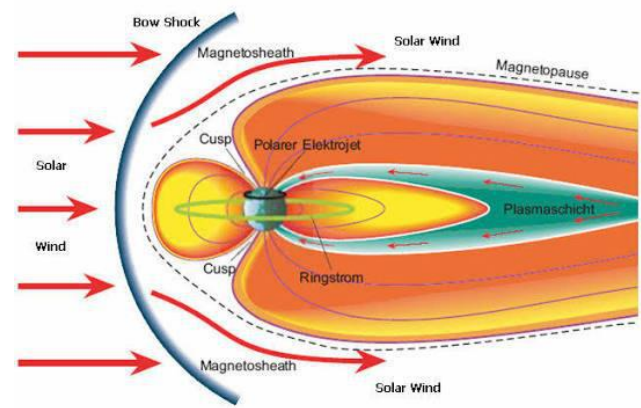


Figure 25. Schematic solar-wind flow around Earth's magnetosphere, showing the bow shock, magnetosheath, magnetopause, plasma regions, and major current systems. Credit noted in the original manuscript: Schlegel (2001).

The manuscript further proposes that the rate of GCRs reaching the solar polar regions is larger during solar minimum and that external electromagnetic-dynamic pressure acts as a trigger for solar eruptions. In this interpretation, fluctuations in incident charged-particle streams provide an external stress that destabilizes active regions and initiates the release of stored energy. The paper then summarizes electromagnetic stress in matter through the Maxwell stress tensor. For vacuum fields, the tensor can be written as

$$T_{ij} = \epsilon_0 \left(E_i E_j - \frac{1}{2} E^2 \delta_{ij} \right) + \left(\frac{1}{\mu_0} \right) \left(B_i B_j - \frac{1}{2} B^2 \delta_{ij} \right) \quad (1)$$

where ϵ_0 and μ_0 are the vacuum permittivity and permeability, E and B are the electric and magnetic fields, and δ_{ij} is the Kronecker delta. The associated magnetic pressure scales as

$$P_m = B^2 / 2\mu_0 \quad (2)$$

The divergence of the Maxwell stress tensor, $\nabla \cdot T$ gives the electromagnetic force per unit volume exerted by the fields. Physically, the diagonal components T_{xx} , T_{yy} , and T_{zz} represent normal electromagnetic stresses or pressure, corresponding to forces acting perpendicular to a surface, whereas the off-diagonal components represent shear stresses acting tangentially along surfaces. In the original reference list, this discussion was linked to a general Maxwell-stress-tensor source (Wikipedia contributors, n.d.-a).

The author applies this formalism to argue that sufficiently strong external electromagnetic stresses can deform condensed matter and may contribute to structural changes, phase transitions, or mechanical failure.

Within the proposed model, sunquakes occur when accumulated electromagnetic and dynamic stresses exceed the structural strength of condensed solar material, releasing elastic energy as mechanical waves. The manuscript therefore argues that a purely gaseous-plasma body would not possess the rigidity required for an earthquake-like brittle-failure process. This is the author's interpretation of the observed submerged acoustic sources, rather than a conclusion established by the helioseismic observations themselves.

SOLAR TSUNAMIS

Large-scale disturbances propagating across the solar atmosphere were historically debated as to whether they represented true waves or apparent motions associated with coronal mass ejections. STEREO observations from separated viewpoints provided important three-dimensional evidence that at least some extreme-ultraviolet disturbances are genuine propagating waves.

Patsourakos and Vourlidas reported the first quadrature observations of an EUV wave with STEREO (Patsourakos & Vourlidas, 2009).

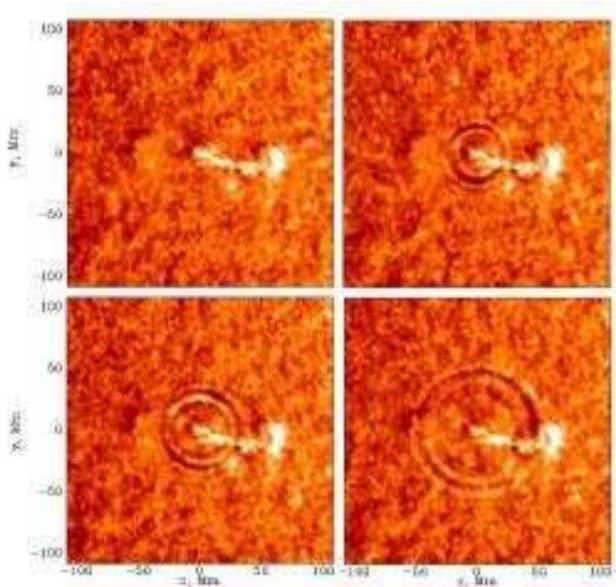


Figure 26. Sequence of a large-scale coronal disturbance observed with SOHO, illustrating the expanding wavefront referred to in the manuscript as a solar tsunami. Credit: SOHO (ESA & NASA).

The present manuscript refers to these large disturbances as “solar tsunamis” and emphasizes their ability to propagate over very large distances and persist for tens of minutes. Representative SOHO and STEREO observations are shown in Figures 26-28.

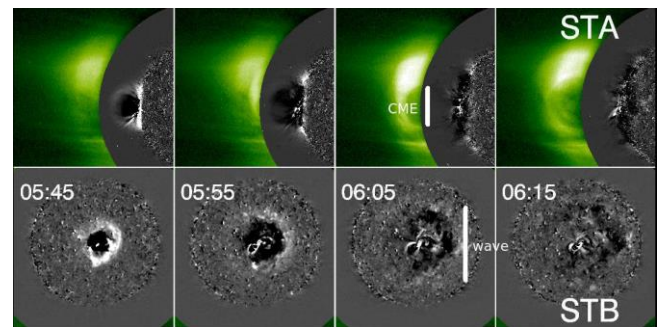


Figure 27. STEREO Ahead and Behind observations of an expanding EUV wave and associated CME geometry. Credit: STEREO/SECCHI.

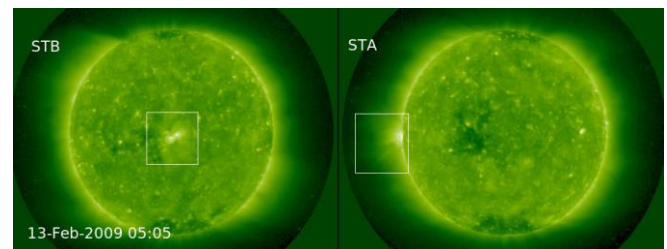


Figure 28. STEREO Ahead and Behind EUVI views from 13 February 2009, when the spacecraft were separated by approximately 90 degrees, providing quadrature observations of the disturbance. Credit: STEREO/SECCHI.

The manuscript compares these solar disturbances with terrestrial tsunamis. On Earth, tsunami generation commonly involves sudden displacement of the ocean by an earthquake, submarine landslide, volcanic process, or another mechanism that moves the seabed or water column. General tsunami overviews describe the propagation of this displaced water as long gravity waves (ScienceDirect Topics, n.d.). Detailed hydrodynamic treatments show how seabed motion transfers energy into tsunami waves and how kinetic and potential energies evolve during propagation (Dutykh & Dias, 2009). The present manuscript uses this terrestrial analogy to argue for the participation of condensed phases in the solar phenomenon.

The manuscript then discusses Moreton waves, which are chromospheric signatures associated with large-scale coronal disturbances. It argues that long-distance propagation and the temporary effects seen in the lower solar atmosphere are difficult to reconcile with a rapidly damped plasma-wave picture. Modern analyses of rare H α Moreton waves emphasize the importance of coronal fast-mode propagation and the magnetic configuration above eruptive regions (Zhong et al., 2025). The present author nevertheless interprets the observed coherence and surface signatures as evidence for a more mechanically substantial disturbance than a conventional

plasma wave. Landau damping is also invoked in the manuscript as a collisionless mechanism by which a plasma wave can exchange energy with resonant particles. The original reference list cited a general explanatory source for this phenomenon (Wikipedia contributors, n.d.-b). On that basis, the author argues that a long-lived, coherent solar tsunami should not be interpreted solely as a conventional plasma oscillation.

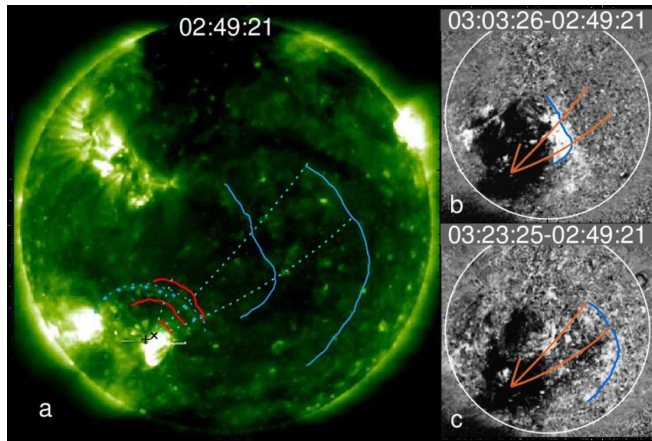


Figure 29. EUV and Moreton-wave fronts in the 24 September 1997 event. The blue and red outlines trace the corresponding propagating fronts. The original manuscript notes that the outlines correspond to Warmuth et al. (2004).

The manuscript emphasizes phenomenological similarities between Moreton/EUV disturbances and terrestrial tsunami propagation, including refraction, reflection, nonlinear steepening, and the possibility of long-lived or spatially redistributed wave energy.

Terrestrial tsunami observations demonstrate that edge-wave trapping and continental-shelf resonance can sustain oscillations for extended periods and can make a tsunami signal appear strongly modified in space and time (Melgar & Ruiz-Angulo, 2018). The present author uses these hydrodynamic analogies to support a condensed-surface interpretation of solar wave phenomena. The corresponding EUV and Moreton-wave fronts are shown in Figure 29.

Moreton and EUV waves can also interact with active regions, coronal holes, filaments, and other large-scale magnetic structures. Multiwavelength studies have documented changes in speed, amplitude, and morphology as solar flare waves propagate through an inhomogeneous solar atmosphere (Warmuth et al., 2004). The manuscript interprets observed reflection-like behavior and filament oscillations as more suggestive of material-surface waves than of purely electromagnetic disturbances.

The original manuscript also draws attention to prominence oscillations following the passage of large-scale solar disturbances. Observations show that prominence material can undergo large-amplitude transverse motions after being disturbed. The author interprets this oscillatory behavior as further evidence of a mechanically responsive, structured medium and uses it as part of the phenomenological comparison between solar-wave interactions and displaced

fluid structures. A representative prominence associated with this discussion is shown in Figure 30.

The author further contrasts this behavior with idealized wave superposition in plasma. Standard plasma-wave theory describes linear waves as superposing as they cross, while nonlinear plasmas can exhibit substantially more complicated interactions. Landau damping and resonant wave-particle interactions provide important collisionless mechanisms by which plasma-wave energy can be transferred to particles (Swanson, 2003). The manuscript argues that the long-distance coherence and apparent interaction of Moreton waves with solar structures remain difficult to reconcile with a simple rapidly damped plasma-wave picture.



Figure 30. Solar prominence used in the original manuscript to illustrate the large-amplitude swaying of prominence material after a disturbance. Image credit noted in the original manuscript: Miguel Claro.

HIGH-FREQUENCY RETROGRADE VORTICITY WAVES ON THE SOLAR SURFACE

Another phenomenon discussed in this manuscript is the high-frequency retrograde (HFR) vorticity-wave family detected on the solar surface.

Hanson, Hanasoge, and Sreenivasan reported equatorially antisymmetric vorticity waves propagating retrograde at approximately three times the phase speed of Rossby-Haurwitz waves of comparable wavenumber (Hanson et al., 2022).

Their discovery showed that the observed frequencies were not reproduced by the conventional hydrodynamic expectations considered in that study. The observed HFR and Rossby-Haurwitz wave signatures are compared in Figure 31.

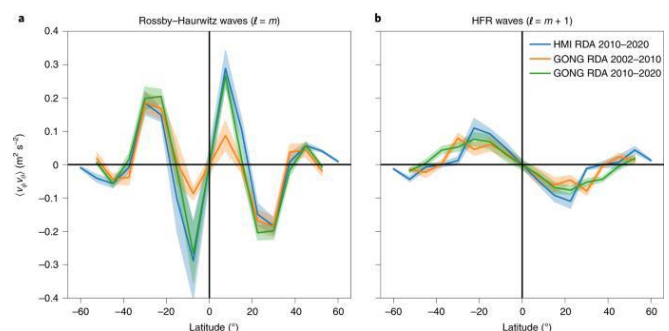


Figure 31. Comparison of Rossby-Haurwitz and high-frequency retrograde (HFR) vorticity-wave signatures as a function of solar latitude. Based on Hanson et al. (2022).

The manuscript interprets this discrepancy as evidence that an important element is missing from the conventional physical description of the solar surface and argues that a dense liquid layer provides a more natural medium for these rapid vorticity motions. In support of this analogy, the author notes that acoustic-wave speeds depend on the stiffness and density of a medium. For a fluid, the sound speed may be expressed as $c = \sqrt{K/\rho}$, where K is the adiabatic bulk modulus and ρ is the mass density. A larger bulk modulus generally increases the propagation speed.

For physical comparison, the original manuscript notes that the speed of sound is about 1,480 m/s in water and about 340 m/s in air under ordinary terrestrial conditions. The author uses this contrast, together with $c = \sqrt{K/\rho}$, to emphasize that wave speed depends on both compressibility (through the bulk modulus K) and density ρ , and argues that a dense, highly pressurized medium can support substantially different wave behavior from a dilute gas. The author also compares HFR vorticity waves with terrestrial Rossby waves because both involve rotating-fluid vorticity and retrograde propagation. This analogy is used to argue that the unexpectedly high solar-wave speeds could reflect the properties of a highly pressurized, dense surface layer rather than a conventional gaseous-plasma medium. This interpretation is the author's proposed explanation and goes beyond the observational conclusion of Hanson et al. (Hanson et al., 2022).

THE SHAPE OF THE SUN

The manuscript finally considers precise measurements of the solar shape. Space-based measurements have shown that the Sun is extremely close to spherical and that its oblateness is remarkably stable over the solar cycle.

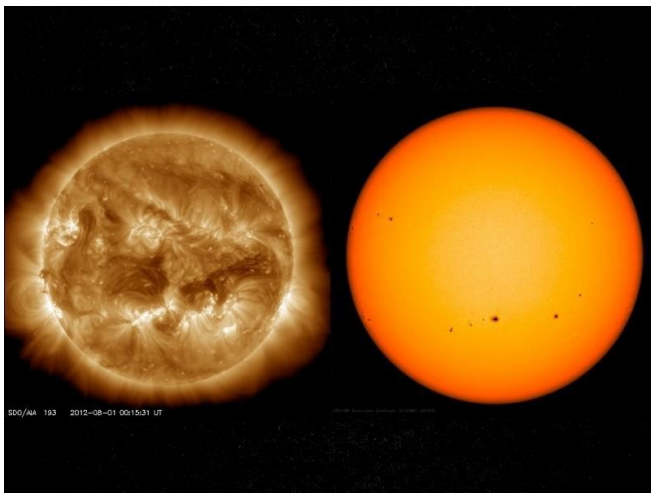


Figure 32. Solar images used to illustrate the exceptionally near-spherical shape of the photospheric disk and its stability relative to changing coronal structure. Credit noted in the original manuscript: NASA/SDO and the AIA, EVE, and HMI science teams.

Kuhn, Bush, Emilio, and Scholl used high-spatial-resolution observations to show that the measured solar oblateness was distinctly constant and almost unaffected by the strong solar-cycle variability observed at the surface (Kuhn et al., 2012).

The visual comparison used in the original manuscript is reproduced in Figure 32.

The measured deviation from a perfect sphere is very small. Kuhn et al. found an oblateness lower than some theoretical expectations and suggested that the discrepancy could be explained by slower differential rotation in the outermost portion of the Sun (Kuhn et al., 2012).

The present manuscript interprets the exceptional stability of the solar shape differently, proposing that a condensed interior, electromagnetic stresses, surface tension, and differential rotation collectively resist large cycle-dependent changes in the visible solar figure.

The original manuscript expresses the smallness of the measured oblateness numerically: the equatorial diameter is stated to be only about 0.0003% larger than the polar diameter. It further illustrates this by noting that, if the Sun were reduced to approximately the size of a basketball, the equatorial diameter would exceed the polar diameter by only about 0.4 μm . The author considers this extraordinary geometric stability to be an important observational constraint on any solar model.

The author contrasts this nearly invariant photospheric shape with the well-known solar-cycle variation of the corona, which becomes more globally distributed around solar maximum and more equatorially concentrated near solar minimum. In the framework proposed here, the differing behavior of the photosphere and corona is taken as additional evidence that the visible solar surface possesses physical properties distinct from those of the overlying atmosphere.

CONCLUSION

This article has examined a broad set of solar observations from a single physical perspective: the possibility that the visible Sun and its subsurface layers should not be treated exclusively as a diffuse gaseous-plasma system.

The central argument developed throughout the manuscript is that the laws of thermodynamics and electromagnetism must remain the primary constraints on any viable solar model. These laws govern the transfer, storage, and conversion of energy in all physical systems, and therefore any interpretation of solar observations must be internally consistent with them. Within this framework, the manuscript has considered several apparently independent phenomena sunspots, hidden quiet-Sun magnetism, granulation, solar prominences, polar crown prominences, coronal rain, sunquakes, solar tsunamis, high-frequency retrograde vorticity waves, and the exceptionally stable shape of the Sun. The author argues that these observations become physically more coherent when the solar surface is interpreted as possessing condensed-matter or strongly fluid-like properties rather than being regarded simply as the visible boundary of a gaseous sphere. In this interpretation, magnetic pressure, Lorentz forces, surface or interfacial tension, density stratification, and the ability of material to store and release mechanical energy are not secondary details; they are essential features of the proposed solar structure.

Sunspots provide one of the principal examples developed in this study. Their sharply organized morphology, strong magnetic fields, long-lived structure, polarity patterns,

association with energetic eruptions, and interaction with surrounding flows are interpreted as evidence for a physically structured surface layer. Likewise, the persistence, cohesion, filamentation, downflows, vortices, bubbles, and Rayleigh-Taylor- and Kelvin-Helmholtz-like behavior observed in prominences are presented as evidence that the material involved has a degree of organization and thermodynamic coherence that, in the author's view, is difficult to reconcile with a simple picture of freely expanding hot plasma. Coronal rain is interpreted in the same context, with emphasis on condensation, droplet formation, interfacial effects, rapid cooling, and the interaction of dense material with magnetic fields.

The seismic and wave phenomena discussed in the later sections extend this argument to the mechanical behavior of the solar body. Sunquakes demonstrate that energetic disturbances can produce acoustic sources beneath the photosphere, while Moreton and EUV disturbances propagate over enormous distances and interact with large-scale solar structures.

High-frequency retrograde vorticity waves travel at speeds that remain difficult to explain within simple hydrodynamic descriptions, and precise measurements show that the photospheric figure of the Sun remains extremely close to spherical despite substantial solar-cycle changes in magnetic activity and coronal structure. Taken together, the author regards these observations as mutually reinforcing evidence that the physical properties of the solar surface and interior deserve to be reconsidered from a condensed-matter and magnetohydrodynamic perspective.

The purpose of this work is therefore not merely to criticize the Standard Solar Model or any particular alternative model. Its more important purpose is to identify a set of observations that can be used to discriminate among competing physical descriptions of the Sun. A useful solar model should explain, within one consistent framework, the Sun's density structure, helioseismic properties, magnetic cycle, sunspot morphology, prominence stability and eruption, coronal rain, subsurface acoustic events, global wave phenomena, and nearly invariant photospheric shape. Where a proposed mechanism depends on assumptions that cannot be directly measured, those assumptions should be stated explicitly and tested against the full range of available observations.

For this reason, the hypothesis advanced here should ultimately be judged by testable predictions rather than by its agreement or disagreement with an established paradigm. The

proposed condensed-matter solar model must be developed quantitatively, with explicit equations of state, pressure and temperature profiles, magnetic-field configurations, energy-transport mechanisms, and predictions that can be compared with helioseismic, spectroscopic, polarimetric, neutrino, and high-energy observations. Laboratory experiments capable of reproducing key thermodynamic and electromagnetic conditions would provide an especially important test. A theory that can make unique, falsifiable predictions about solar structure and energy generation would allow the debate to move from qualitative interpretation to direct experimental and observational discrimination.

The possible implications for fusion research are correspondingly significant. If the physical state and energy-generation mechanism of the Sun differ materially from the assumptions used in conventional thermonuclear descriptions, then a more accurate physical model could suggest alternative experimental pathways. The manuscript therefore proposes that the next stage of this research should be the full quantitative presentation and laboratory testing of the practical solar model referred to in this article.

Demonstrating a self-sustained fusion process under reproducible laboratory conditions would constitute a decisive test of the model and, if successful, could have important consequences for both solar physics and the development of future energy technologies.

This is also the central motivation behind the author's insistence that unconventional interpretations should be judged primarily by quantitative predictions and reproducible tests rather than by whether they conform to an established model. The author maintains that, if a condensed-matter description of the Sun can be translated into a practical laboratory model capable of producing a self-sustained fusion reaction, such a result would provide a decisive experimental test of the physical picture developed in this article.

In summary, the observations reviewed in this work are presented as a cumulative case rather than as isolated anomalies. No single sunspot, prominence, rain event, sunquake, or wave phenomenon can by itself determine the complete physical nature of the Sun. The strength of the argument lies instead in whether one physical framework can explain all of these phenomena simultaneously, quantitatively, and without internal thermodynamic contradiction. The author concludes that a condensed-matter interpretation of the Sun warrants serious quantitative investigation and direct experimental testing.

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