World Journal of Condensed Matter Physics, 2022, 12, 18-26
https://www.scirp.org/journal/wjcmp
ISSN Online: 2160-6927
ISSN Print: 2160-6919

Correlations between the Rotations and Magnetospheres of the Terrestrial Planets and the Sun's Formation in Our Solar System

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How to cite this paper: Cadieu, F.J. (2022) Correlations between the Rotations and Magnetospheres of the Terrestrial Planets and the Sun's Formation in Our Solar System. *World Journal of Condensed Matter Physics*, **12**, 18-26.
https://doi.org/10.4236/wjcmp.2022.122003

Received: April 17, 2022
Accepted: May 28, 2022
Published: May 31, 2022

Abstract

Correlations between the rotations of the terrestrial planets in our solar system and the magnetic field of the Sun have been previously noted. These correlations account for the opposite rotation of Venus as a result of the magnetic field of the Sun being dragged across the conducting core of Venus. Currently, the Sun's magnetic field is not sufficiently strong to account for the proposed correlations. But recently meteorite paleomagnetism measurements have indicated that during the Sun's formation the magnetic field of the Sun was of sufficient strength to have resulted in the observed correlations. Also, dating back to the Sun's formation are measurements showing that the Sun's core rotates four times faster than the Sun's surface. Both the counter rotation of Venus and the initial period of strong Sun magnetic fields are believed to be relics of the time period when the Sun's core to surface differential rotation was established. As a part of these correlations, it was hypothesized that for a terrestrial planet to exhibit a magnetosphere, the average density must be $\geq 5350 \pm 50$ kg/m^3. On this basis, only the Earth and Mercury would have formed initial magnetospheres, while Venus, Mars, and the "Moon" would not have developed magnetospheres. For such correlations to still be present today requires our Sun to have been formed as a sole star and with what might be termed a friendly Jupiter. Otherwise, the observed correlations would have been disrupted over time.

Keywords

Earth, Mercury, Venus, Mars, Magnetic Fields Sun, Early Solar System, Plate Tectonics

1. Introduction

In a recent paper, correlations between the rotation properties of the terrestrial planets in our solar system and the magnetic fields from the rotating Sun were noted [1]. It should be noted that at the present time the Sun rotates about ten times for even one year of Venus traversing around the Sun. One proposed result was that the counter rotation of Venus could be explained by the magnetic breaking action of the Sun's magnetic field acting on the electrically conducting core of Venus. A problem with that explanation was the question of whether the magnetic field from the Sun would be strong enough to influence the rotation of Venus. The magnetic fields from the Sun at the location of the terrestrial planets at the present time do not seem to be strong enough to influence the rotation properties of the terrestrial planets. It was also hypothesized that only terrestrial planets with an average density greater than 5350 ± 50 kg/m^3 would exhibit an initial magnetosphere and magnetic field. On this basis, only Earth and Mercury would have exhibited initial magnetospheres. Venus, Mars, and the Moon would not have exhibited initial magnetospheres. The purpose of this paper is to more fully address whether at some time in the past the magnetic field from the Sun would have been strong enough to influence the rotation of Venus and the other terrestrial planets. Earth, it had been pointed out in an earlier paper, only acquired a sufficiently high average density to acquire a magnetosphere because of the violence of the impact between two bodies that then resulted in the present Earth-Moon system [2]. **Figure 1** illustrates the event that led to the creation of the Earth-Moon system. The dotted line connecting the average densities of Mercury, Venus and Mars shows the expected density variation resulting from the cooler temperatures as a function of the greater distances away from the Sun. The anomalously high density of Earth then resulted from the violence of the event that created the Earth-Moon system. Mars similarly would have to have exhibited a lower electrical conductivity core to allow its rotation to be decoupled from influence from the Sun. At present, the Sun's magnetic field is weak out in the vicinity of the terrestrial planets so the magnetic correlations

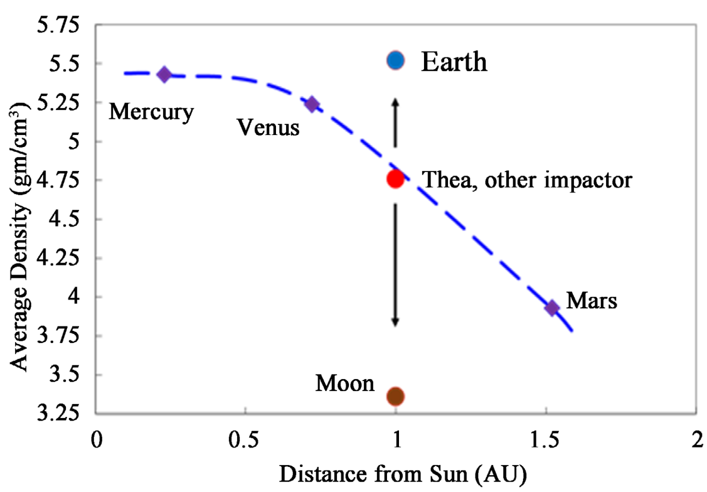

Figure 1. The dotted line shows the variation in the average terrestrial planet density as a function of the distance from the Sun [1]. The anomalous Earth and Moon average densities are also indicated.

as seem to be present must be from some still remaining state when the Sun's magnetic field was sufficiently strong to have established the observed correlations. It is probable that such strong magnetic field interactions only existed during the initial formation of the Sun. Recent paleomagnetic measurements have indicated that a period of strong magnetic fields about the Sun for distances of AU did exist early on during the formation of the Sun [3] [4]. For such effects to still be observable attests to the fact that our solar system formed as a single star system that has a particularly friendly Jupiter. Such behavior has a low probability of being repeated in other low mass star systems.

2. Results and Discussion

The terrestrial planets in our solar system formed in the presence of a thermal gradient with higher temperatures occurring nearer the Sun. The Sun and the planets had a common formation time of 4.6 billion years ago. The Sun comprises 99.9% of the mass in the solar system so that details of the Sun's formation are expected to be important for subsequent time periods. As shown in **Figure 1** the average density of the terrestrial planets Mercury, Venus, and Mars follow a smooth curve with the Earth-Moon system being anomalous because of the violence of the Earth formation process. Terrestrial planets are expected to exhibit gravitational differentiation so that more dense and metallic regions sink to the interior regions. The Earth acquired this anomalously high density as a result of the Earth-Moon formation process.

To have a consistent model for the rotation properties of the different terrestrial planets, it was necessary to postulate that only terrestrial planets with an average density ≥ 5350 ± 50 kg/m^3 would have exhibited an initial magnetosphere. On this basis the Earth and Mercury developed magnetospheres but Venus and Mars never exhibited magnetospheres. Venus exhibited a conducting metallic core so that induced eddy currents were induced because of the relatively rapidly rotating Sun's magnetic field. The small axial tilt angle of Venus provided efficient coupling to the Sun's rotating field. Mars exhibits a relatively large axial tilt angle so that Mars having a relatively low conductivity core allows its rotations to be decoupled from the Sun's field since the lower core conductivity would allow few eddy currents to be generated in the core of Mars. It should be noted that at the present time the Sun still rotates about ten times for one orbital period of Venus. Initially the Sun exhibited a higher angle momentum value and would have been rotating initially faster than at the present time. The Earth's magnetic field except during some brief essential formation period of the Sun appears to be stronger than the Sun's field at a distance of ~AU. These correlations are summarized in **Table 1**. The terrestrial planets interact with the Sun's magnetic field in one of two ways. For terrestrial planets that exhibit a magnetic field of their own, that field usually dominates the effects of the more distant and hence weaker field of the Sun. Terrestrial planets that do not exhibit magnetic fields of their own interact with the Sun's magnetic field to the extent

Table 1. The average density and other key quantities are shown for the terrestrial planets, the moon, and Sun. The Avg. Density, Day Length, Axial Tilt Angle, and Orbital Day Period value are from NASA tables.

Planet	Avg. Density (g/cm^3)	Initial Magnetization	Core Conductivity	Day Length (Siderial Days)	Axial Tilt Angle (˚)	Orbital Days
Earth	5.52	Yes	High	0.9973	23.45	365.26
Mercury	5.43	Yes	High	58.6	0	88
Venus	5.25	No	High	−243	2.64	224.7
Mars	3.93	No	Low	1.026	25.2	686.9
"Moon"	3.37	No	Low			29
"Sun"	1.41	Yes	High	25.4	7.25	

that they have electrically conducting cores or conducting regions.

Recent measurements on remanent magnetizations in meteorite paleomagnetism have provided measurements of the solar nebula magnetic fields during the solar system formation [3] [4]. Quoting from [4]: "Paleomagnetic measurements indicate the presence of fields of 0.54 ± 0.21 G at ~1 to 3 astronomical units (AU) from the Sun and ≥0.06 G at 3 to 7 AU until > 1.22 and >2.51 million years (Ma) after solar system formation, respectively. These intensities are consistent with those predicted to enable typical astronomically observed protostellar accretion rates of $\sim 10^{-8}$ $M_\odot$ $year^{-1}$ suggesting that magnetism played a central role in mass transport in PPDs. Paleomagnetic studies also indicate fields < 0.006 G and <0.003 G in the inner and outer solar system by 3.94 and 4.89 Ma, respectively, consistent with the nebular gas having dispersed by this time. This is similar to the observed lifetimes of extrasolar protoplanetary disks".

In particular, these paleomagnetic studies indicate that there was a time period of several million years for which the solar magnetic field was strong enough to have directly influenced the rotation properties of any electrically conducting bodies at distances of ~AU from the Sun. The paleomagnetic studies also indicated that the solar magnetic fields at such distances were also shown to have become much weaker by about 4 - 5 million years.

Since the initial time period of the Sun's formation is under consideration, the initial luminosity of the Sun is relevant. The Sun's initial luminosity according to Bahcall *et al.* was 0.7 times the present Sun's luminosity [5]. In a previous paper the luminosity of the Sun as a function of time was approximated by a linear approximation [1].

$$L = 0.7 \cdot L_0 + \left(\frac{t(BYr)}{4.6BYr} \right) \cdot 0.3 \cdot L_0 \tag{1}$$

In this equation, L_0 is the present day luminosity of the Sun. This equation is a linear approximation to the detailed modelling of the surface temperature, radii, and luminosity of the Sun plotted as a function of time by Bahcall *et al.* in [5].

The linear approximation agrees with the initial luminosity found in [5] and with the present day luminosity. In [1], the planet surface temperatures for Mercury, Venus, Earth, and Mars were plotted versus absorption length for this initial time period when the Sun's luminosity was 0.7 * L_0. To maintain liquid water on the Earth with an initial luminosity of 0.7 * L_0, a surface temperature of at least 273 K required, an absorption length of about 4 is required versus about 1 for a luminosity of L_0. This indicates that a substantially higher concentration of polyatomic gases, or greenhouse gases, would have been required.

Since the average density of Venus implies that Venus never developed a magnetosphere, the electrically conducting core of Venus directly responded to the rapidly changing magnetic fields from the rotating Sun. The opposite rotation of Venus is then the result of eddy current braking effects due to the strong magnetic field of the Sun during this initial time period being pulled across the conducting core of Venus. The coupling of the rotation of Venus during this period of high initial Sun's magnetic field is shown in **Figure 2**. It should be noted that the resulting motion is independent of the polarity of the Sun's field. Even as the polarity of the Sun's field reverses the forces on Venus still produce the same subsequent rotation of Venus. This can be readily demonstrated by making a model in which Venus is modeled by a brass disk or other conductor. Dragging a magnetic field directed into, or out of, the near edge disk surface results in the same rotation behavior irrespective of the polarity of the magnetic field. The small axial tilt angle of Venus at 2.64˚ provides efficient coupling to the field of the Sun.

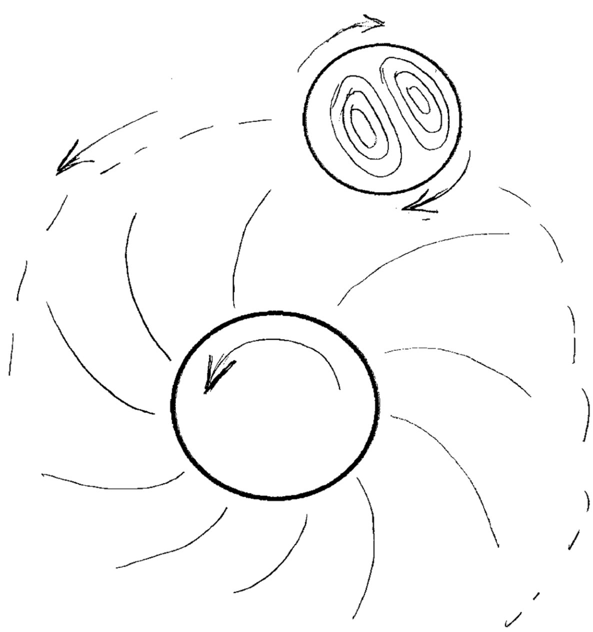

Figure 2. The relatively rapid rotation of the Sun and the nearly redial magnetic field associated with the solar wind are indicated. Eddy currents in Venus that switch directions with the polarity reversing dipolar field of the Sun are indicated. The axial rotation direction of Venus is set by the dragging action of the relatively rapidly rotating Sun on the conducting core of Venus. Note that the response of the eddy currents is independent of whether the Sun's field points into or out of the plane of the figure.

Mars did not respond to the period of high magnetic fields from the Sun it is argued because of the low conductivity of the core of Mars. This allowed the rotations of Mars to be decoupled from the Sun's initially high magnetic field intensity and is consistent with a degree of incomplete differentiation in Mars. The amount of iron oxides and intrinsic red color of the surface of Mars is an indication of this. The axial tilt angle of Mars at 25.2˚ would have provided only weak coupling to any magnetic fields from the Sun. The length of a day on Mars appears to have been largely unchanged since early times in the solar system. Mars never developed a magnetic field rather than having lost some ancient magnetic field. Mercury initially would have had a magnetic field but that magnetosphere was frozen out as the small size of Mercury ensured rapid cooling. Mercury currently does not exhibit plate tectonics but only a contracting single plate crust [6].

It was recently shown by Tarduno *et al.* that by moon rock measurements that the Moon never developed a magnetic field [7]. This result is consistent with the hypothesis for a terrestrial body to manifest an initial magnetosphere since the average density of the Moon at 3370 kg/m^3 is substantially less than the value 5350 ± 50 kg/m^3.

To explore whether the Sun underwent some subsequent period of time in which the Sun's field rose once again to a level that would have been strong enough to have influenced the rotations of the terrestrial planets subsequent to the initial formation it is necessary to examine some aspects of the nebular model. The Nebular model says that the Sun formed when a great swirling cloud of gas and dust became compressed in some region due to some shockwave interaction. Gravity then caused the compressed region to act as a center of rotation with kinetic energy then accumulating as additional mass was drawn to this seed region. Rotational angular momentum increased about this point since rotational symmetry was improbable. For a compact star to be formed requires that a mechanism be present to remove most of the angular momentum from the forming star [8]. As detailed by Larson, it is highly unlikely for a lone low mass star such as our Sun to be formed. It is much more probable that at least two stars allow a much more probable mechanism for transporting angular momentum away from a central point. There is then a low probability for single stars to be formed. Our Sun then represents a relatively improbable case. The increasing kinetic energy of the central region raised the temperature of a core region until some fusion energy release started to limit the further collapse of the forming star. Magnetic field lines developed a dipolar magnetic field aligned principally with the axis of rotation. Infalling material was dragged around by the rotating field. Magnetic field lines then looped into spaced apart regions running through the forming convection zone. These tubules decrease in spacing at higher rotation latitudes because of the smaller circumference leading to flux coupling at higher latitudes where sunspots form with field lines then emanating out from the Sun. If from above the outer surface of the Sun is rotating counterclockwise then the material and forming planets also have a counterclockwise orbital motion.

This supports the convection zone as the principal source of the Sun's magnetic fields. It is then not necessary to change any behavior of the core to have the Sun's magnetic field polarity reverse. This allows the Sun's magnetic field polarity to reverse on the rapid time scale of about every 11 years; at least over the last century. After this initial time period the Sun's magnetic field strength weakened to not more than <0.006 G by 3.94 Ma [4]. Modeling does not show any subsequent time period for which the Sun's magnetic field would have become strong enough again to have affected the terrestrial planet rotation behavior [5]. The initial behavior exhibited by our Sun seems to be unusual and depends on our Sun being a lone star system with a particularly friendly Jupiter to have these relics of the initial star formation process still measurable at the present time. Recent measurements have shown that there was a period in the Sun's formation in which the outer parts of the Sun transitioned to a state in which the outer parts of the Sun rotated at one fourth the rate of the Sun's core [9]. The authors state that this velocity differentiation was a 4.6 BYr old relic from when the Sun formed. To have the outer regions rotating slower than the core regions represents a time period in which the angular momentum of the Sun was rapidly lowered during the time when the Sun's field was of high intensity as measured by the paleomagnetic measurements and then decreasing in magnitude as the outer rotation became stabilized.

At this point, the surrounding material was largely ionized and electrically conducting. This allows efficient coupling to any magnetic fields accompanying the forming star. Solar wind generated emissions of charged particles then transported the angular momentum away from the central star. A spiral generated pattern of magnetic field lines then formed commonly known as the Parker spiral. As the central star formed the transfer of angular momentum and magnetic field levels surrounding the star greatly diminished. Most of the material was drawn into the star region with material in the outer regions condensing in regions hot near the star to lower temperatures farther out. The planets formed outside the star then carried large amounts of angular momentum. In our solar system the orbital angular momentum of the Sun is only about 3% of the total angular momentum of the orbital sum of the planets plus the rotational angular momentum of the Sun. At higher Sun latitudes where the flux lines become closer together so that there is increased magnetic braking so that differential rotation occurs so that the rotation period increases to about 36 days versus about 25 days for the Sun's equatorial region as observed in the present Sun. The initial rotation rate was faster corresponding to a high angular momentum value. Particles emanating from the surface then start to clear the rotating ionized dust from the surrounding material that reduces the angular momentum of the rotating Sun. No period subsequent to the initial formation of the Sun is possible according to Bahcall *et al.* that would have exhibited other than weak dipolar magnetic fields at distances of ~AU from the Sun [5].

3. Conclusion

Table 1 highlights several correlations that have been observed between the terrestrial planet rotations and the dipolar magnetic field of the Sun. If a terrestrial planet exhibits a magnetic field, that field is expected to dominate any field from the distant Sun. Terrestrial planets that do not exhibit a magnetic field can interact with Sun's field proportional to the electrical conductivity of a core region. To obtain a consistent model of behavior, it was necessary to hypothesize that an average density of ≥5350 ± 50 kg/m^3 was necessary for a terrestrial planet, and even the Moon, to exhibit an initial magnetosphere. Venus, Mars, and the Moon would not have ever developed magnetospheres. Venus then having a high conductivity metallic core would be set into counter rotation due to the fairly rapid rotation of the Sun's high initial value magnetic field. Eddy currents in the metallic core of Venus then act to cause the counter rotation of Venus independent of the polarity of the Sun's magnetic field. Mars would then need to exhibit a fairly low conductivity core, so that the rotation of Mars would be independent of the Sun's initial magnetic field. The relatively low electrical conductivity of the Martian core decouples the rotation of Mars from any changes in the Sun's initial magnetic field. It has only been determined recently that during the Sun's formation there was a time period of several million years during which the Sun's magnetic field at ~1 AU was strong enough to have established the observed correlations [3] [4]. This has been established by paleomagnetic measurements. The high angular momentum of the forming Sun was transferred out away from the Sun by an initial high flux of solar wind sweeping out away an initial sheath of charged particles surrounding the Sun. During this initial Sun formation period, there was an initial period of the Sun exhibiting a high magnetic field as required by the paleomagnetic measurements, but also a period of rapid angular momentum transfer out away from the Sun. This is supported by recent reporting that during this initial time period 4.6 BYr ago that the Sun's surface began to rotate 4 times slower than the Sun's core. What is observed now is a leftover relic of this initial formative period 4.6 BYr ago [9]. Identifying the time of this velocity differentiation establishment as the time period when the Sun's magnetic field was high as noted by the paleomagnetic measurements, then the counter rotation of Venus and the core to surface rotation differentiation are both relics of the time when the Sun formed.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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