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# NASA's Pioneer Spacecraft Anomaly, Heat, Dark Matter and a Probable Persuasive Genesis

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## Abstract

An analysis is performed on what is known as the anomaly of NASA's probe spacecraft. It explains why this additional acceleration can hardly be caused by the heat emitted by the electronic equipment of the spacecraft or by the dark matter that the Solar System could contain. Additionally, the correct stellar dynamics are mathematically demonstrated to explain the high speed of stellar rotation directly in galaxies and to show that this dynamics governing galaxies is very different from the dynamics of the Solar System. This also demonstrates the superfluity of postulating the existence of Dark Matter at the galactic level. It is concluded that the anomaly of the Pioneer spacecraft is relatively feasible as a product of an explainable difference between the modeling of the 70s and the real sources of the gravitational field of the Solar System. Therefore, it is claimed that there were sources of gravitational field that were not included in the original modeling because they were unknown at the time. Finally, a particular distribution of the disperse Solar System mass is proposed that could represent the sources of the field that give a plausible explanation for the NASA spacecraft anomaly.

## Keywords

Dark Matter, Pioneers 10 and 11, Galactic Radial Velocity, Gravitation, Radiation Pressure

## 1. Introduction

In the early 1970s, NASA sent Pioneer 10 and 11 spacecraft beyond the Solar System, becoming the first probes to leave it. However, during their flight in the vicinity of Jupiter and Saturn, an irregularity was detected in the position reached by both probes. The spacecraft appeared to have been subject to an additional deceleration of the order of $10^{-10}$ m/s$^2$ that was not taken into account in the flight path calculations, causing them to fall behind by a few meters each day [1]-[9]. By 2003, after approximately 30 years of flight, Pioneer 10 was delayed by thousands of kilometers and was not in the expected location. Various causes have been suggested to explain this anomaly, including the radiation pressure of the spacecraft's own heat, the expansion of the universe, and the presence of Dark Matter in the Solar System [10]-[20]. The latter explanation postulates the existence of Dark Matter at the galactic level to justify the excessive speeds of stars rotating in galaxies [10]-[23]. However, Dark Matter has not been detected inside or outside the Solar System [24]. The concept of Dark Matter was introduced by Fritz Zwicky in the early 1930s and later reincorporated by Vera Rubin in the 60s and 70s to explain the stability of galactic systems and galaxy clusters. Dark Matter is strange because it supposedly interacts only gravitationally and its composition remains unknown after almost 90 years since its postulation [24]-[29].

On the other hand, regarding the possible explanation of the anomaly related to radiation pressure, which is also referred to as the heat model, it is a popular explanation in the scientific community, although not everyone agrees with it [5]. The explanation involving the expansion of the universe has little acceptance and will not be discussed in this study. In this paper, we will elaborate on the heat model explanation [1]-[9]. Even though we accept, without conceding, that there could be an effect caused by the heat dissipation of the spacecraft itself, we will demonstrate that it is unlikely that the anomaly is caused by this, mainly due to the geometry of the heat sources and the ship itself. We will also explain how the postulate of the existence of Dark Matter can be eliminated, and using the appropriate galactic stellar dynamics, this postulate becomes unnecessary. We will show mathematically that the stability of galactic and galaxy clusters is a direct and explainable result when using the correct gravitational dynamics. Additionally, when applying this galactic gravitational dynamics to the Solar System, we find that it is very likely that the Pioneer Spacecraft Anomaly can be explained using purely Newtonian gravitational dynamics with an innovative approach. Finally, this paper aims to clarify that at least an important part of the effect of mass, both at the galactic and Solar System level, is due to the volumetric distribution of field sources. We demonstrate that the distribution of mass itself is a potential factor for modifying the values of the field. In particular, in the Solar System, taking into consideration a possible distribution of masses, the anomaly of NASA's spacecraft can be accounted for with a good margin of reliability.

## 2. A Description of the Ship Anomaly

The Pioneer Anomaly is a small additional acceleration $(8.74 \pm 1.33) \times 10^{-10}$ m/s$^2$ experienced by the Pioneer spacecraft that deviates from the initially modeled gravitational field. The anomaly is directed towards the Sun and Earth and introduces a difference in the trajectory of the spacecraft. The magnitude of the anomaly can be placed between two gravitational field values $7.410 \times 10^{-10}$ - $1.007 \times 10^{-9}$ m/s$^2$, and it has only been detected in some spacecraft like Pioneer, Ulysses, and Galileo. The fact that this acceleration has not been detected in the movement of planets, satellites or comets, suggests that this phenomenon is not universal but circumstantial.

It is possible that the difference between what is calculated and what is measured experimentally has its cause in the original calculation problem. In the 60s and 70s, computers existed but access was limited and difficult, so NASA hired people with mathematical and physics abilities to perform the calculations. Katherine Coleman G. Johnson was one of the Human Calculators who worked for NASA and was known for her ability to check the calculations of satellite trajectories and space flights.

There may be inaccuracies in the calculations of the trajectories of the spacecraft, as well as in the experimental data and its management. The Doppler effect is one way to measure the speed of the spacecraft, but it may not be accurate in some cases. The Pioneer Anomaly does not exist for comets or any massive object that revolves around the Sun because their speed reduces when approaching aphelion and accelerates when approaching perihelion, which is not the case for spacecraft.

## 3. Radiation Pressure, Heat Theory

The theory that the spacecraft's electronic equipment can accelerate the spacecraft itself through heat dissipation is based on the concept of momentum or amount of motion [6] [7]. At first, the idea that a spacecraft could accelerate itself using its own heat seemed improbable, like trying to lift oneself by pulling on one's own shoelaces. This concept of momentum was not always clear, and in the 17th century, Gottfried Leibniz (1646-1716) introduced the concept of "vis viva," which was a product of mass times velocity squared ($mv^2$). In contrast, René Descartes (1596-1650) proposed the concept of "amount of movement" ($mv$), which was a vector quantity. It was not until the 18th century that Jean Le Rond d'Alembert (1717-1783) clarified the distinction between these two concepts.

$$\frac{1}{2}mv^2 = \int \overline{F} \cdot \mathrm{d}\overline{l} \tag{1}$$

Kinetic or potential energy is the effect of an integrated force in space.

$$m\overline{v} = \int \overline{F} \cdot \mathrm{d}t \tag{2}$$

The moment or amount of movement is the effect of a force integrated in time.

In other words, a change in the amount of motion can produce a force or pressure, such as radiation pressure. In this case, the heat waves of the spacecraft and the infrared rays reflecting off a surface change their amount of motion and can produce a force or pressure.

Assuming that the radiation pressure of the heat dissipated by the electronic equipment of the spacecraft itself can accelerate it when reflected on the surface of the parabolic antenna, there are three factors that must be taken into account to analyze this possibility:

1) If the volume of the electronic equipment container were a cube, only about one-sixth of the heat dissipated by the equipment could contribute to anomalous acceleration (See **Figure 1**).

2) Of that sixth part, an important portion of that heat power, emitted by the part closest to the antenna, close to the horizontal axis, does not contribute due to self-reflection between the equipment and the antena (See **Figure 2**).

3) The signal that starts from the antenna dish and travels towards the Earth would accelerate in the opposite direction, away from the Sun and the Earth, instead of towards them (See **Figure 3**).

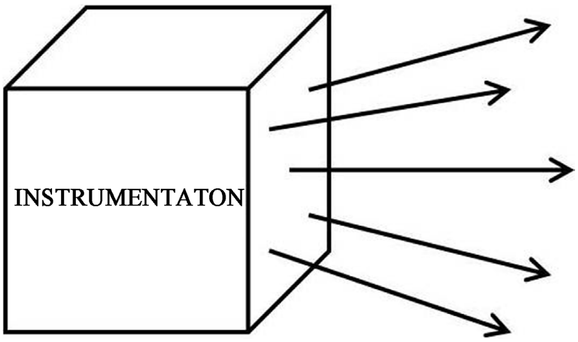

**Figure 1.** If the shape of the container of the electronics of the spacecraft were a cube, the radiation that could, in any case, accelerate the spacecraft itself would be one-sixth of the heat produced by the operation of the equipment.

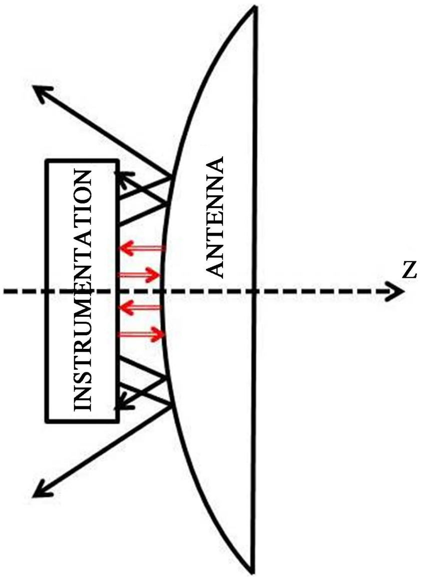

**Figure 2.** A portion of the heat generated by the spacecraft's instrumentation has the potential to accelerate it. However, as shown in the figure, heat radiation directed towards the antenna near the horizontal axis is trapped by multiple reflections on the antenna and the electronic equipment, resulting in no actual acceleration. This reflected radiation is estimated to be approximately 10 W.

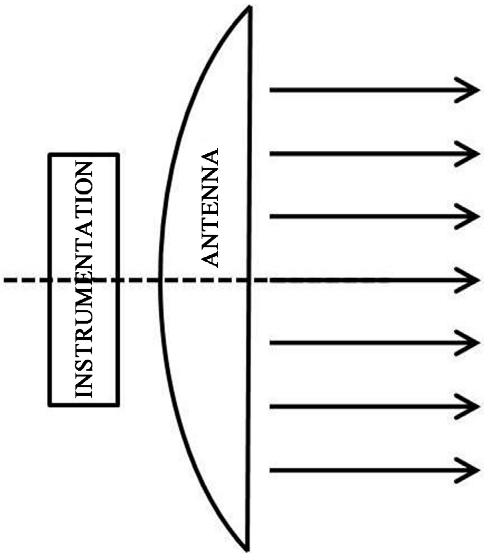

**Figure 3.** In the figure, the arrows represent the energy consumed by the electronic equipment, which transmits the information sent by the probe to Earth. This energy not only does not accelerate the spacecraft towards the anomaly but actually has an antagonistic effect. It accelerates in the opposite direction to the Sun and the Earth.

A schematic representation helps to illustrate each of these contributions more clearly.

a) The receptacle containing the spacecraft's electronic equipment is not a cubic box; rather, it is similar to a low-height hexagonal parallelepiped. Therefore, the radiation power emitted by the electronic equipment towards the antenna is likely greater than the aforementioned one-sixth portion. At the very least, this possibility should be taken into consideration.

The electric power generators in the spacecraft, which are based on plutonium, generate approximately 2000 W and are located 3 meters away from the center of the ship. Of that energy, about 120 W are used for instrumentation [5] [6] [7] [8] [9]. If it is considered that this thermal power is radiated isotropically, in the best-case scenario, only about 20 W, or one-sixth of the heat produced by the equipment, would affect the antenna dish due to the geometry of the instrumentation receptacle. However, for simplicity, it can be assumed that this power is even greater than one-sixth of the heat dissipated, and is approximately 30 W.

b) A significant portion of the radiation that falls on the antenna, with the possibility of accelerating near and around the horizontal axis in **Figure 2**, is reflected and then reflected again indefinitely between the equipment compartment and the antenna. Therefore, this portion of the infrared rays, which is close to the center of the antenna and almost parallel to the horizontal axis, does not cause significant acceleration on the spacecraft. Of the 30 watts, it can be assumed that 10 watts are reflected indefinitely from this central part of the antenna, as shown in **Figure 2**.

The rays that strike the peripheral part of the antenna, at large angles of incidence, bounce off and away from the spacecraft. This part of the radiation is what could potentially cause some acceleration, as shown in **Figure 2**.

c) Assuming that 20 W of the dissipation by the equipment could cause acceleration, we need to consider the radiation emitted by the antenna dish itself when sending the radio signal towards Earth. This signal consumes approximately 8 to 10 W of power. Although this radio signal emitted from the antenna could cause acceleration, it would be in the opposite direction, pushing the spacecraft away from Earth and the Sun.

The schematic analysis presented here shows that any potential acceleration caused by the heat dissipation of the spacecraft's instrumentation would be too small to explain the anomaly. This raises the question: if the heat dissipation is not the cause of the anomaly, then what could be producing the unaccounted acceleration?

## 4. Dark Matter in Gravitational Systems

In the field of scientific research, there are various unexplained phenomena, such as the Pioneer anomaly. These anomalies are irregularities that have not yet been conclusively explained and widely accepted. One such example that has persisted for several decades without a definitive understanding is the existence of Dark Matter, which has been the subject of research and discussion in numerous studies [11] [12] [13] [24] [25].

Zwicky's discovery was later revisited in the 1970s, when astronomers Vera Rubin and Kent Ford studied the rotation curves of galaxies. They found that the outer parts of galaxies were rotating at speeds that could not be explained by the visible matter alone, suggesting the presence of invisible matter or "Dark Matter" [10] [11]. Since then, various experiments and observations have been carried out to try to detect and understand Dark Matter, but its exact nature and properties remain unknown to this day. It is believed that Dark Matter makes up about 25% of the matter in the universe, and its gravitational effects are crucial in shaping the large-scale structure of the universe [12] [13].

Vera Rubin, an astronomer of American origin, among other things, replicated much of Zwicky's results and found no alternative but to associate with the postulate of the existence of some type of strange matter that caused galactic stability [12] [16]. They named it Dark Matter. It was something peculiar because it only manifested its presence through gravitational force. It cannot be seen, emit or reflect light, and cannot be detected by any means other than gravitational interaction. These results of Zwicky and Vera Rubin were given a particular interpretation of Newtonian mechanics [10] [16]. In an article published in 2006 [12], Vera Rubin expressed, "High school students learn that in a gravitationally bound system like our solar system, a planet moves in a closed orbit, such that $MG = v^2 r$ where $M$ is the mass of the sun, $G$ is the gravitational constant, and $v$ and $r$ are the speed of a planet and its distance from the sun. In M31 (Andromeda), the same relationship between mass, velocity, and distance holds" [12].

Here in this paper, we will demonstrate that Vera Rubin's thesis is not accurate. Our argument is that high rotational speeds of stars in galaxies can be explained by employing the correct galactic dynamics.

In summary, the mathematical expression that Vera Rubin claims must hold at the galactic level is derived from the Newtonian potential that describes the speed of planets in the Solar System as

$$v \propto 1/\sqrt{r} \tag{3}$$

The planets in the Solar System have rotational speeds that vary according to Equation (3). Saturn rotates around the sun at a slower speed than Jupiter, and Neptune rotates even slower than Saturn. However, Rubin determined experimentally that at the galactic and galaxy cluster levels, bodies manifest a constant velocity $v$.

$$v = cte \tag{4}$$

That is, a significant number of stars in galaxies exhibit a velocity that does not decrease with distance from the galactic center, but remains approximately constant as expressed in Equation (4) [26] [27]. In addition to mathematically deriving this constancy in stellar rotation speed, we will attempt to explain two crucial observations:

1) The absence of Dark Matter in the Solar System [24].

2) The discovery of galaxies that purportedly lack Dark Matter [29].

To begin developing the appropriate stellar dynamics at the galactic level, we need to refer to the fields and sources that produce them. Similar to classical electrodynamics, it is commonly stated that problems of sources and fields are limited to potential problems [30] [31]. Similarly, in gravitational dynamics, a large number of problems of sources and fields can be limited to potential problems, specifically gravitational potential. Gravitational systems use the same equations as electrodynamics with appropriate changes for the problem, in this case, the gravitational potential. To clarify, in electrodynamics, the electric field is determined by calculating the gradient of the potential. Similarly, in gravitational systems, the gravitational field is determined by calculating the gradient of the Newtonian potential [30] [31] [32].

All mechanics related to the potential problem are encompassed in one of Maxwell's laws, which is known as Gauss's Law for the flux of a field through an arbitrary surface. In the case of the electric field, as shown in **Figure 4**, Gauss's Law is written [30] [31]

$$\epsilon_0 \oint \bar{E} \cdot \mathrm{d}\bar{s} = q \tag{5}$$

To obtain Gauss's Law for the gravitational field, we simply substitute $GM$ for $q/4\pi\epsilon$ in Equation (5). The resulting expression is

$$\oint \bar{g} \cdot \mathrm{d}\bar{s} = 4\pi GM \tag{6}$$

Here $G$ is the gravitational constant, $M$ the mass within the Gaussian surface and $\bar{g}$ is the gravitational field.

Gauss's Law has a wide range of applications when there is symmetry in the problem. For example, in a spherically symmetric problem, the gravitational field can be obtained by extracting it from the integral and integrating the surface to obtain the value of the field multiplied by the area of a sphere.

$$g\oint \mathrm{d}s = g4\pi r^2 = 4\pi GM \tag{7}$$

To apply Gauss's Law in galactic stellar dynamics, some considerations must be taken into account. An important point to note about this expression is that the value of $M$ represents the mass contained within the Gaussian surface. To simplify the mathematical calculations, a galaxy with spherical symmetry will be assumed, and the variables will depend only on the distance to the galactic center, as shown in **Figure 5**.

Therefore the mass within the Gaussian Surface is obtained from the following expression

$$M = \oint \rho \mathrm{d}V = \oint \rho r^2 \mathrm{d}r \sin\theta \mathrm{d}\theta \mathrm{d}\varphi \tag{8}$$

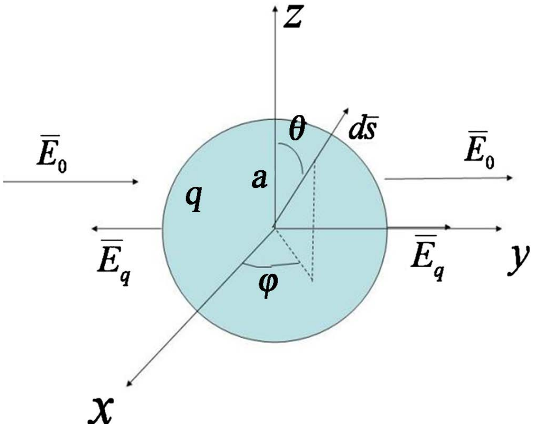

**Figure 4.** In this figure, an arbitrarily shaped Gaussian surface is shown enclosing a charge $q$. The field lines leaving the surface are considered positive and are proportional to the electric charge inside. When the field sources are outside the surface, such as those that produce $E_0$, the net flux across the surface is zero.

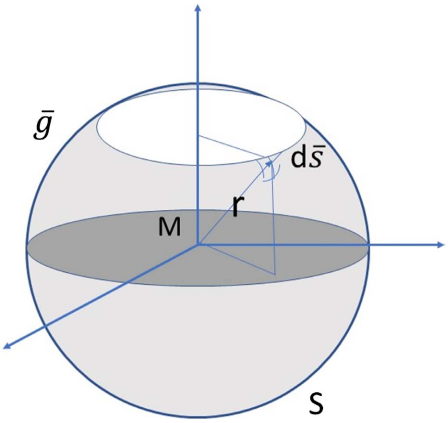

**Figure 5.** A spherical Gaussian surface representing a galaxy is shown. Inside, a mass $M$ acts as the source of the gravitational field, with a distribution $\rho(r)$. With this symmetry, for a given value of $r$, the gravitational field remains constant on the surface.

Here $\mathrm{d}V$ is the differential volume element, expressed in spherical coordinates. From this expression, it can be seen that if the mass density $\rho(r)$ of a spherical galaxy is

$$\rho \propto 1/r^2 \tag{9}$$

With this expression in Equation (8), the mass within the Gaussian surface is proportional to $r$, so Equation (7) becomes:

$$g \propto 1/r \tag{10}$$

To obtain the dynamics of a star revolving around the galactic center at a distance $r$, the gravitational force acting on the star must be equated with the centrifugal force.

$$gm = mv^2/r \tag{11}$$

By virtue of Equation (10), Equation (11) implies that

$$v = cte \tag{12}$$

Which is the speed that Vera Rubin obtained experimentally.

The conclusion is that by using the correct galactic stellar dynamics, the postulate of the existence of Dark Matter is superfluous or unnecessary. Newton's Law of Universal Gravitation, which varies as $1/r^2$ is not valid at the galactic level. In fact, it can have a different mathematical expression that depends on the way in which the mass is distributed within the galaxy. This explains the high rotation speeds observed, as mentioned earlier.

Points 1) and 2) above can be explained by the fact that if a galaxy has a mass distribution similar to that of the Solar System, where the majority of the mass is concentrated at the center, then that galaxy will not contain what has been referred to as Dark Matter [10] [26] [29].

Dark Matter is not required in the Solar System since experimental observations indicate that the planets rotate at a speed that aligns with the predictions of Newton's potential, as given by Equation (3). Therefore, in the Solar System, where Vera Rubin's expression holds, there is no need to introduce Dark Matter.

In a galaxy, the most important part of this description is the way in which the mass of the stars is distributed. That will determine how the gravitational field varies. As will be shown, for the anomaly of the spacecraft, the distribution of the sources of the gravitational field will also be important.

## 5. The Proposed Genesis of the Irregularity

As stated by Vera Rubin in her 2006 paper, is that a planet in the Solar System follows the relationship [12]

$$GM = v^2 r \tag{13}$$

where $M$ represents the mass of the Sun. Therefore, the force acting on a planet of mass $m$ is the force described by Newton's Law of Universal Gravitation.

$$\bar{F} = GMm/r^2\,\hat{u}_r \tag{14}$$

where $\hat{u}_r$ $r$ is a unit vector in the radial direction.

When a spacecraft travels through the Solar System, the force acting on it is expected to have the shape described by Newton's Law of Universal Gravitation, with a certain value for the source of the field, $M$. However, a rigorous calculation must take into account the distribution and influence of all bodies in the Solar System, so $M$ may have several contributions and vary in a particular way. The discovery of the planet Neptune serves as an example of the influence of planetary and satellite mass distribution on gravitational force in the Solar System. Several researchers had noticed irregularities in the orbit of Uranus [33] [34] [35] at the time, leading some to suspect that Newton's theory could be false. Urbain Le Verrier, however, was able to predict the position of Neptune [33] [34] [35] through two years of intense work, and German astronomer Johann Gottfried Galle observed the new planet on the night of September 23-24, 1846. The presence of another mass that modifies the distribution of field sources indicated that the gravitational field on Uranus should be different from the one already calculated and would account for the anomalies of its orbit.

It is reasonable to assume that during the late 1960s, when calculating the trajectory of the Pioneer spacecraft, Vera Rubin's Equation (13) was utilized. However, since this equation is not valid at the galactic level, there could be variations in the gravitational field within the Solar System. In other words, the calculated gravitational field that was included in the modeling for NASA spacecraft hypothetically only accounted for the known sources of gravitational field at that time, in the early 70s. For instance, by that time, the four moons of Jupiter discovered by Galileo Galilei in 1610 were already known, along with nine more moons. As of current knowledge, Jupiter has 92 moons, some of which are very small. The same is true for Saturn, suspected to have more than 100 moons in addition to its rings, and other planets. It is apparent that NASA's calculators could not account for all existing gravitational field sources, indicating that there may be an additional field that was not included in the modeling.

From all of this, it can be concluded that the original model of the gravitational field in the Solar System did not take into account many sources that could have contributed to the Spacecraft Anomaly. The mass of satellites, asteroids, and dwarf planets in the Solar System adds up to a few hundred terrestrial masses. These sources, along with other wandering bodies, dwarf planets such as Ceres, Eris, Sedna, Makemake, Haumea, and other scattered celestial object, if distributed in a certain way, can explain the anomaly. In addition to the dispersed mass that was not taken into account in the original modeling, the genesis of the anomaly depends on the distribution of mass itself, which strongly influences the values of the gravitational field. This has been demonstrated in the case of galactic stellar dynamics. If we go beyond what is currently known about the Solar System and include the Kuiper belt and the Oort cloud, supposedly a spherical structure enclosing everything known about the Solar System up to a distance of more than one light-year, we can consider the Solar System as a "nano galaxy". Therefore, the same gravitational dynamics described above can be applied with some additional considerations to calculate the anomaly. The particular distribution of mass in both the Galaxy and the Solar System is fundamental to obtaining the true mathematical expression for the gravitational field, which determines the stellar dynamics in the galaxy and also the trajectories of spacecraft traveling through the Solar System.

## 6. Numerical Calculation of an Approximation to the Anomaly

For this study, several configurations were tested, including planetary mass distributions and additional dispersed masses. For planetary mass, their positions evolved according to their rotation periods around the Sun. A portion of the dispersed mass was randomly placed in spatial coordinates. In general, there were three main cases considered:

- In the first case, we attempted to include as many sources of gravitational field as our knowledge allowed, including the satellite mass that was not considered in the original modeling. We then compared this field with that of the original model, which could be inferred. The trajectory of the spacecraft was simulated using a parabolic path, and the positions of the planets were evolved based on their rotation period around the Sun during the spacecraft's journey to outer space. Please see **Figure 6** for more details.
- In a second case, we focused on assuming a specific distribution that exclusively included sources of the gravitational field found in the scattered mass of secondary sources such as satellite mass, dwarf planets, and the asteroid and Kuiper belts. We proposed a distribution of dispersed mass with randomly generated positions that varied during the trajectories of the sounding spacecraft. This was an attempt to create a gravitational field that could be considered a significant contributor to the genesis of the anomaly, as shown in **Figure 7**.
- In the third case, we calculated a gravitational field similar to that of the anomaly determined by the sounding ships by considering only a dispersed mass in a random distribution, with a total mass slightly exceeding 100 Earth masses, and varying its positions in time based on geometric and density considerations. The asteroid and Kuiper belts were excluded in this calculation. **Figure 8** illustrates this case.

The first case was helpful in providing insights that there are enough additional sources in the Solar System that can contribute to the gravitational field determined as an anomaly, which means that there were field sources that were not included in the original modeling. **Figure 6** illustrates this.

With the second case, we excluded the sources of the original modeling of spacecraft trajectories that NASA calculators could consider, and instead, we included only the scattered mass and the asteroid and Kuiper belts, which were not originally considered. We were able to obtain a gravitational field that matched the experimental results of the probe ships with good precision. **Figure 7** shows

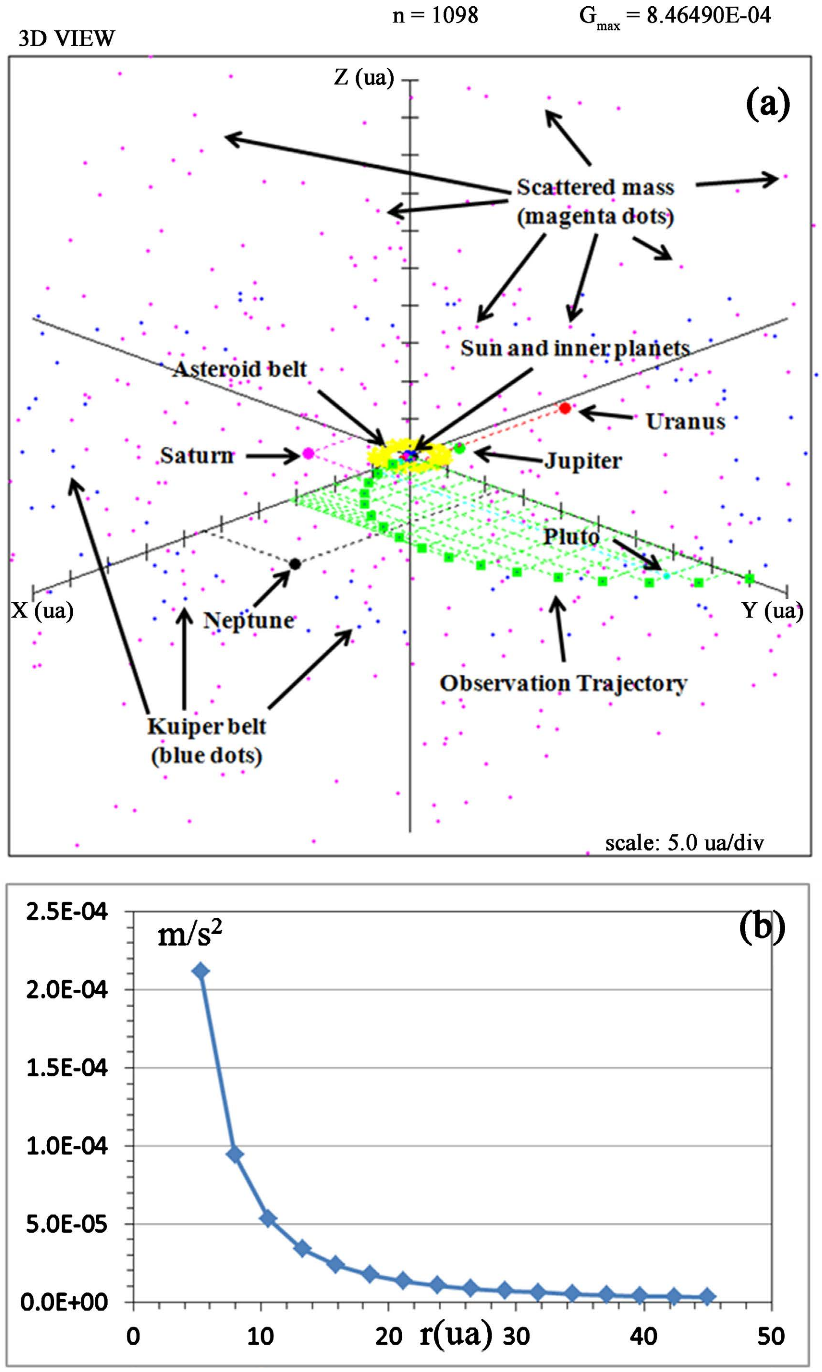

**Figure 6.** The figure presents a 3D view (a) of the initial configuration of the Solar System, which includes the Sun at the origin, the surrounding planets, the asteroid belt, the Kuiper belt, and the scattered mass in the volume occupied by the Solar System. The trajectory that the observation point follows is also shown. Panel (b) displays the variation of the radial component $G_r$ of the gravitational field in m/s$^2$ for this configuration along the observation path in astronomical units.

this result.

Finally, Figure 8 shows the results of the third case, where a random distribution of dispersed mass was considered, excluding the asteroid and Kuiper belts.

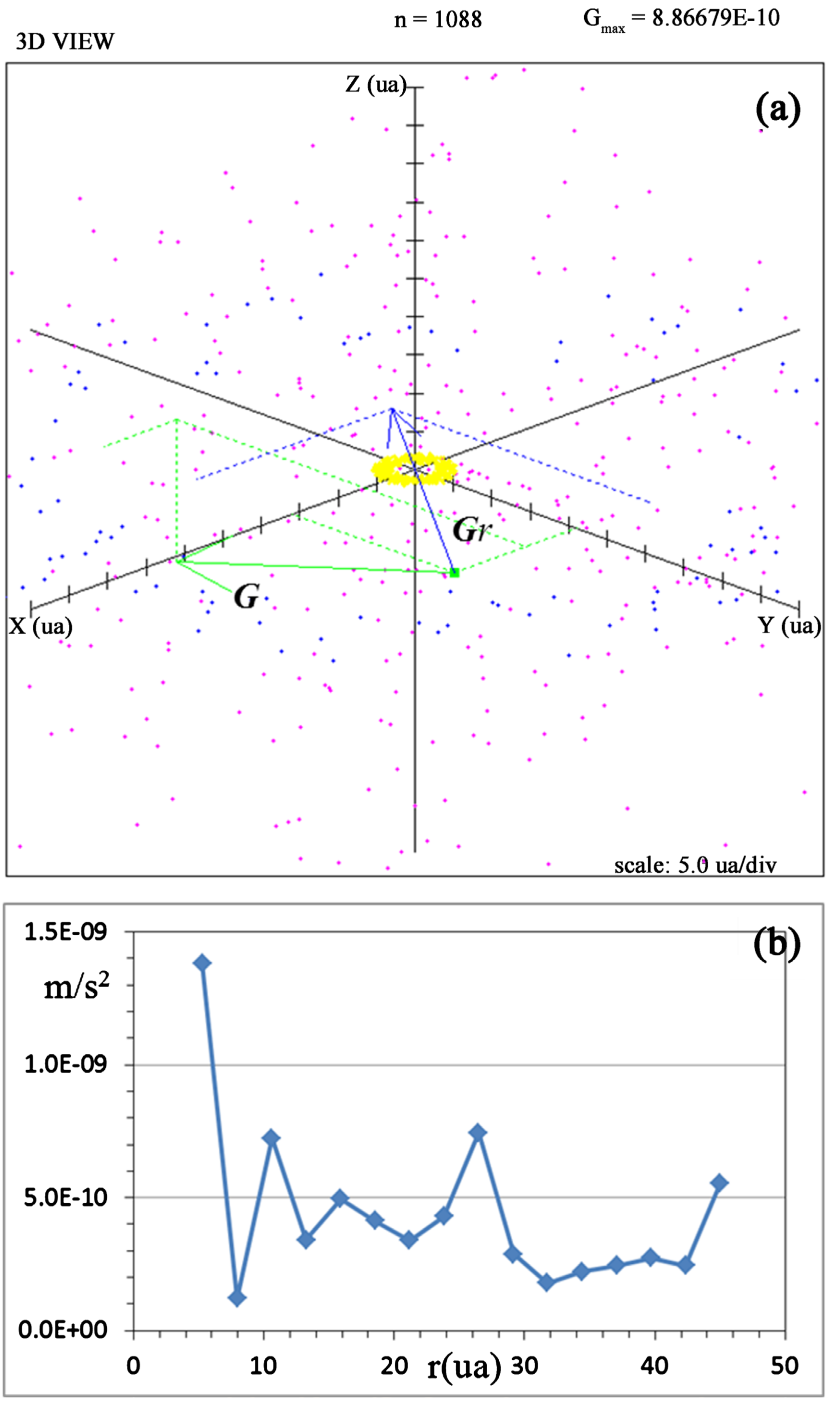

**Figure 7.** In (a) a distribution of the scattered mass, the asteroid belt and the Kuiper belt, is represented at a moment in the temporal evolution, $G = 8.86679 \times 10^{-10}\ \text{m/s}^2$ . (b) Radial gravitational field $G_r$ (m/s$^2$) along the observation path. It is important to note the variation of the field with a frequency similar to the measurement of the pioneer ships reported.

The figure includes a 3D view (a) of the initial configuration of the Solar System with the dispersed mass in the volume occupied by the Solar System. The variation of the radial component of the gravitational field $G_r$ (m/s$^2$) along the observation

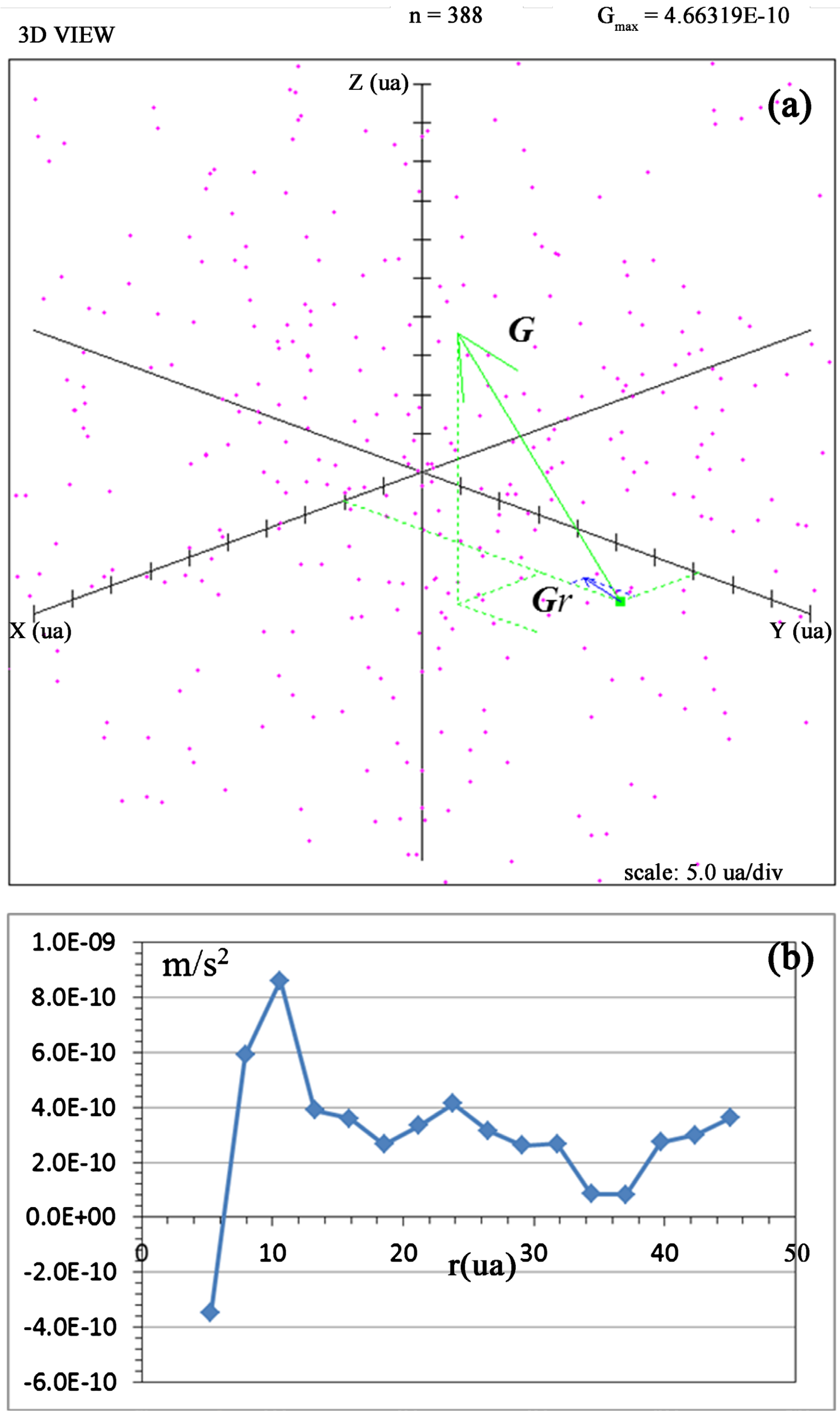

**Figure 8.** (a) Shows a moment in the evolution of the dispersed mass with a gravitational field strength of $G = 4.66319 \times 10^{-10}\ \mathrm{m/s^2}$. (b) Shows the radial component $G_r$ of the gravitational field (in m/s$^2$) along the observation path. The curve represents a good approximation of the gravitational field of the anomaly.

path is shown in (b). It is important to note that this calculation provides a good approximation to the genesis of the gravitational field that is considered an anomaly.

## 7. Comments and Conclusions

Indeed, anomalies or unexpected phenomena are often the source of scientific progress as they force scientists to question their assumptions and seek new explanations. However, it is important to approach these anomalies with a critical and rational mindset, using all available data and scientific methods to try to understand and explain them. It is also important to recognize that scientific understanding is always subject to revision and refinement as new evidence is discovered. By openly discussing and analyzing anomalies, we can continue to deepen our understanding of the natural world and expand the boundaries of scientific knowledge.

Yes, that is a possible explanation for the genesis of the Anomaly. The original modeling of the gravitational field may have neglected or underestimated certain sources of mass and gravitational effects, leading to a mismatch between the predicted and actual gravitational field experienced by the probes. This difference could manifest as an anomaly in the probe trajectories, which is what has been observed and studied in this work. By considering additional sources of mass and refining the modeling of the gravitational field, the calculated field can better match the observed field and provide a more accurate description of the gravitational environment of the Solar System.

Here we aim to clarify some ideas: The Solar System has been found to be a place where Dark Matter does not exist. This is because planetary dynamics follow Newton's gravitational potential with acceptable accuracy. Therefore, this hypothetical foreign matter cannot be responsible for the spacecraft anomaly. In this work, it has been mathematically demonstrated that high speeds of stellar rotation can be explained with the appropriate galactic stellar dynamics. This makes it clear that postulating the existence of Dark Matter is unnecessary. Furthermore, within the structure of the scientific method, it is advisable not to propose the existence of something inexplicable to explain a phenomenon. This would only create an additional problem of explaining the unexplainable on top of the original problem.

The theory of heat, based on the geometry of the spacecraft itself, is not sufficient to explain the radiation pressure that could be affecting the antenna dish of the spacecraft. Three sections of the antenna require analysis: the section closest to the main axis of the antenna, which appears horizontal in **Figure 2** and experiences multiple reflection radiation; the section where heat rays reflect at large angles, which could lead to acceleration; and finally, the section of the antenna that emits the signal that communicates with Earth. This section not only does not accelerate but, on the contrary, produces an effect in the opposite direction to the acceleration of the anomaly.

The NASA computers that were used for modeling in the 1960s and early 1970s were not capable of incorporating unknown sources of gravitational fields into their calculations. Therefore, it is now known that there is enough additional matter to construct a model that approximates the "anomalous" field measured by the spacecraft. This also largely explains why this problem is not observed in the orbits of planets, comets, and other bodies in the Solar System. This is because these bodies do not have an original model that does not coincide with what has been observed.

In the numerical simulation, the field values obtained with the dispersed, distributed mass in a particular way proposed by us are very close to those of the gravitational field interval that defines the anomaly of the NASA spacecraft, $7.410 \times 10^{-10}$ - $1.007 \times 10^{-10}$ m/s$^2$.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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