

Mach's Principle and the Concept of Mass

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Abstract. Mach's Principle is shown to originate in the electromagnetic force involving vibrating neutral electric dipoles. From the universal electrodynamic force derivation of the forces of inertia and gravity, mass is not a fundamental entity. What was called mass in the past represents a grouping of nearly constant electrodynamic parameters associated with vibrating neutral electric dipoles. The energy of these vibrating neutral electric dipoles is decaying by giving off radiation. The resulting radiation has been identified with the cosmic microwave background radiation which has been found to be distributed throughout the universe in a pattern corresponding to the matter distribution. The value of inertial mass changes with distance from the center of the universe in accordance with Mach's Principle. Local asymmetries also cause inertial mass to change with distance from the center of spiral galaxies, with distance from a star to a planet, and with distance from a planet to a moon. Unlike the Standard Model of Cosmology based on General Relativity Theory and quantum mechanics, the universal electrodynamic force approach does not need to invent dark matter and dark energy to explain the higher than expected constant velocities of the spiral arms of spiral galaxies and the expansion of the universe. These phenomena, for which a halo of dark matter and energy were invented to rescue General Relativity Theory, are explained directly from the universal electrodynamic force law and Mach's Principle. Thus the key assumptions of General Relativity Theory that the universe is homogeneous and isotropic, that gravitational and inertial mass are equivalent, and that dark matter and energy comprise about 95 percent of the universe are shown to be invalid by this work [1].

Introduction. In theoretical physics, especially in inertial and gravitational theories, Mach's Principle is the name given by Einstein to a general principle credited to the physicist and philosopher Ernst Mach. A very general statement of Mach's Principle is

Local physical laws are determined by the large scale structure of the universe [3].

This basic idea also appeared before Mach's time in the writings of George Berkeley [4]. The book **Absolute or Relative Motion?** (1896) by Benedict Friedlander and his brother Immanuel contained ideas similar to Mach's Principle.

In Mach's own words, the principle is expressed as follows:

[The] investigator must feel the need of...knowledge of the immediate connections, say, of the masses of the universe. There will hover before him as an ideal insight into the principles of the whole matter, from which accelerated and inertial motions will result in the same way Mach [5].

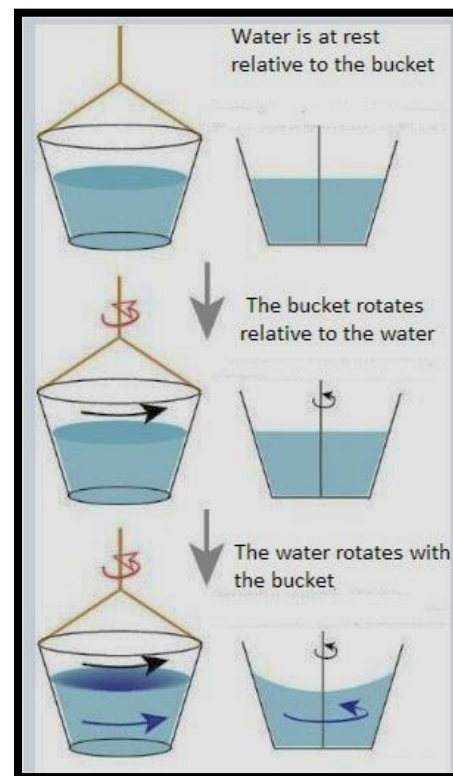
Einstein seemed to view Mach's Principle as something along the lines of "...inertia originates in a kind of interaction between bodies..." Einstein [2].

In some sense Mach's Principle is related to philosophical holism. It appears to require that inertial and gravitational theories should be relational theories depending on relative coordinates. In his book **The Science of Mechanics** [5] Mach criticized Newton's idea of absolute space based on his bucket argument.

In his book **Philosophiae Naturalis Principia Mathematica** [6] (Latin for "Mathematical Principles of Natural Philosophy") Newton tried to demonstrate that one can always decide if one is rotating with respect to absolute space by measuring the apparent forces that arise only when an absolute rotation is performed. If a bucket is filled with water, and made to rotate, initially the water remains still, but then, gradually, the walls of the bucket communicate their motion to the water making it curve and climb up the sides of the bucket, because of the centrifugal forces produced by the rotation. Newton says that this experiment demonstrates that the centrifugal forces arise only when the water is in rotation with respect to the absolute space (represented here by the Earth's reference frame or the distant stars). Alternatively, when the bucket was rotating with respect to the still water no centrifugal forces were produced, thus indicating that the water was still with respect to the absolute space.

Figure 1. Newton's Bucket Experiment

Mach says in his book that the bucket experiment only demonstrates that when the water is in rotation with respect to the bucket no centrifugal forces are produced, and that we cannot know how the water would behave if in the experiment the bucket's walls were greatly increased in depth and width. In Mach's approach the concept of absolute motion should be substituted with a total relativism in which every motion, uniform or accelerated, has sense only in reference to other bodies. Thus one cannot simply say that the water is rotating, but must specify if it is rotating with respect to the vessel or to the Earth or something more massive. Furthermore one should take into account the particular asymmetry that exists in our local reference frame between the small bodies (like buckets) and the bodies like the earth and



distant stars that are overwhelmingly bigger and more massive.

Mach's Principle was never developed into a quantitative physical theory that could explain a kind of interaction by which the stars can have such an effect. Although Einstein was intrigued and inspired by Mach's Principle, his formulation of the principle is not based on some kind of interaction force. However, before completing his development of the General Theory of Relativity, Einstein found an effect which he interpreted as being evidence of Mach's Principle. In a thought experiment Einstein considered a fixed background of the stars for conceptual simplicity and constructed a large spherical shell of mass, and set it spinning in that background. According to Mach's Principle the reference frames in the interior of the mass shell will precess with respect to the fixed background. This effect has been measured and is known as the Lense-Thirring effect. Einstein was so satisfied with this manifestation of Mach's Principle that he wrote a letter to Mach saying,

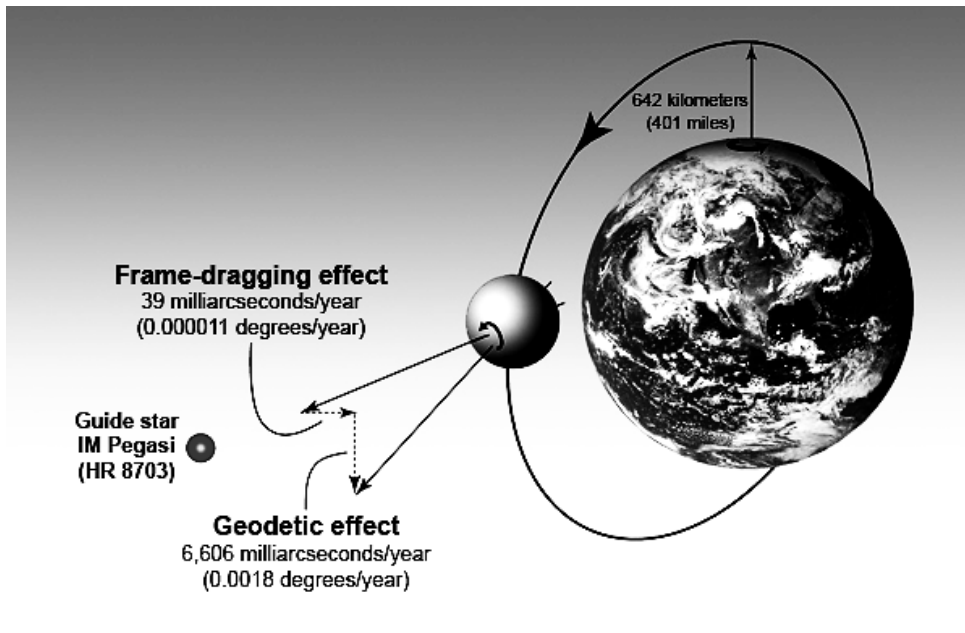
It...turns out that inertia originates in a kind of interaction between bodies, quite in the sense of your considerations on Newton's pail experiment.... If one rotates [a heavy shell of matter] relative to the fixed stars about an axis going through its center, a Coriolis force arises in the interior of the shell; that is, the plane of the Foucault pendulum is dragged around (with a practically unmeasurably small angular velocity) [2].



Figure 2. Lense-Thirring Effect

Another form of the Lense-Thirring effect is the Schiff precession or spin-spin precession known as the Lense-Thirring precession of an orbiting spinning gyroscope. It is caused by the $\mathbf{R} \times (\mathbf{R} \times \mathbf{A})$ effect of the second term of the electrodynamic force of inertia of [1, Equation (8-24)] on a gyroscope orbiting a spinning body. See Figure 3. Two effects— $\mathbf{R} \times (\mathbf{R} \times \mathbf{A})$ (frame-dragging in relativity theory) and the local variations in mass with R [1, Equation (8-11)] (geodetic effect in relativity theory)—were expected to cause a precession (at ninety degree angles with respect to one another) of the gyroscopes aboard the Gravity Probe B satellite. Predicted precessions, given in milliarcseconds (mas), are compared to those measured by Gravity Probe B. The Gravity Probe B was designed by

NASA and Stanford University to measure these two key predictions of Einstein's General Theory of Relativity by monitoring the orientations of ultra-sensitive gyroscopes relative to a distant guide star.



	Measured	Predicted
Geodetic precession (mas)	6602 ± 18	6606
Frame-dragging (mas)	37.2 ± 7.2	39.2

Figure 3. Schiff Spin-Spin Precession and Gravity Probe B[7]

In this paper the concepts of inertial and gravitational mass, as defined by the universal electrodynamic force law, will be developed for the first time into a quantitative theory to support or prove Mach's Principle.

Inertial Mass. The inertial mass m_i of a single vibrating neutral electric dipole consisting of an atomic electron and a nuclear proton was derived to be in **The Universal Force Volume 1** [1, Equation (8-11)]

$$m_i = \left(\frac{2e^2}{3\pi R c^2} \right) \left(\frac{A^2 \omega^2}{c^2} \right) \quad (1)$$

Or in terms of a lump of some element containing N atoms each having Z protons and electrons the more general result is

$$m_i = NZ \left(\frac{2e^2}{3\pi R c^2} \right) \left(\frac{A^2 \omega^2}{c^2} \right) \quad (2)$$

Now this result is different from what one might expect, because it contains the $1/R$ term in it. However, from the perspective of Mach's Principle, it appears to have great significance.

According to Mach's Principle the inertial mass of a lump or piece of matter should depend on the structure and matter distribution of the universe. In [1, Chapter 9] evidence was presented that the universe has a combination of spherical and chiral symmetry with a structure consisting of spherically symmetric toroidal shells with quantized radii following Stanley Dermott's modern version of Bode's Law. If one averages the inertial mass from all the charges in all the atoms of the universe which has spherical symmetry, the inertial mass of a lump of matter on a very large grand scale will have a value depending on the effective average radius R from the center of the universe. This R will be the average distance of all the charges interacting with the vibrating neutral electric dipoles in the inertial lump of mass.

On a more local scale the presence of a massive body nearby can give rise to local asymmetric effects in addition to the grand scale effects. One of these type effects is the Lense-Thirring effect or spin-spin effect. This effect was confirmed by the NASA Gravity Probe B data.

Thus the interaction force that Einstein referred to above that gives rise to the force of inertia is the charge to vibrating neutral electric dipole force. In the next section the interaction force that gives rise to the force of gravity will be considered.

$$\begin{aligned} \vec{F}_G &= - \left(\frac{2}{5\pi} \right) \frac{e^2}{R^2} \left(\frac{A_1^2 \omega_1^2}{c^2} \right) \left(\frac{A_2^2 \omega_2^2}{c^2} \right) \hat{R} = G \frac{m_{g1} m_{g2}}{R^2} \hat{R} \\ &= - \frac{9\pi c^4}{10e^2} \left\{ \frac{2e^2}{3\pi R c^2} \frac{A_1^2 \omega_1^2}{c^2} \right\} \left\{ \frac{2e^2}{3\pi R c^2} \frac{A_2^2 \omega_2^2}{c^2} \right\} \hat{R} = - \frac{9\pi c^4}{10e^2} m_{i1} m_{i2} \hat{R} \quad (3) \end{aligned}$$

Note that the force of gravity has been defined in the past as a $1/R^2$ attractive force using a different definition of mass than the inertial mass. However, if one writes the equation for the force of gravity in terms of the inertial mass as shown in the $\{ \}$ of the second line of Equation (3), one sees that the force of gravity on the grand large scale is a constant attractive force throughout the universe. On the other hand on the local scale where asymmetry exists, the force of gravity empirically appears to be a $1/R^2$ attractive force between two bodies.

In a large spiral galaxy the asymmetric force of gravity dominates near the center of the galaxy, but far out from the center it gets very weak such that the constant force of gravity on the grand scale predominates. Since that force does not diminish with distance, but remains constant except for decaying over time allowing expansion, the velocity v_s of the rotation of the outer spiral arms remains constant beyond the distance that the asymmetric gravitational force dominates.

Local Asymmetry and Grand Symmetry of the Universe. Consider the forces of inertia and gravity for a lump of matter m in the outer spiral arm of a spiral galaxy of mass M_S . There are two terms in the force of inertia. The first term represents the force of inertia due to motion a_s with respect to the center of the spiral galaxy of mass M_S in direction r . The second term represents the force of inertia due to motion a_0 with respect to the center of the universe in direction R . See equation (4).

$$\vec{F}_I = m\vec{a} = ma_s\hat{r} + ma_0\hat{R} \quad (4)$$

where the magnitude of the observed acceleration a when $a_s < a_0$ is

$$a = \sqrt{\vec{a}_s^2 + \vec{a}_0^2} = a_0 \sqrt{1 + \frac{a_s^2}{a_0^2}} = a_0 \left(1 + \frac{1}{2} \frac{a_s^2}{a_0^2} + \dots \right) = a_0 + \frac{1}{2} \frac{a_s^2}{a_0} \quad (5)$$

There are two terms for the force of gravity. The first term represents the force of gravity with respect to the center of the spiral galaxy of mass M_S . The second term represents the force of gravity with respect to the mass of the rest of the universe M_U . See equation (6).

$$\vec{F}_G = -\frac{GmM_S}{r^2}\hat{r} - \frac{GmM_U}{R^2}\hat{R} \quad (6)$$

For stability the forces of inertia must be in equilibrium with the forces of gravity.

$$\vec{F}_I = m \left(a_0 + \frac{1}{2} \frac{a_s^2}{a_0} + \dots \right) = -\vec{F}_G = \frac{GmM_U}{R^2}\hat{R} + \frac{GmM_S}{r^2}\hat{r} \quad (7)$$

Now in equation (7) the first term for the large scale force of inertia is equal to the first term for the large scale force of gravity. Subtracting an equal term from each side of the equation causes it to reduce to

$$m \frac{1}{2} \frac{a_s^2}{a_0} = \frac{GmM_S}{r^2} \quad (8)$$

Solving for the acceleration of the lump of mass m about the center of the spiral galaxy obtain

$$a_s = \frac{\sqrt{2GM_S a_0}}{r} \quad (9)$$

Now using the relationship for the acceleration in terms of the velocity for circular orbits gives

$$a_s = \frac{v_s^2}{r} = \frac{\sqrt{2GM_S a_0}}{r} \quad (10)$$

Solving for v_s obtain

$$v_s = \sqrt[4]{2GM_S a_0} \quad (11)$$

and

$$M_S \propto v_s^4 \quad (12)$$

Note that equation (11) gives a constant value for the velocity when a_s becomes smaller than a_0 . Equation (11) also allows one to calculate a_0 from the observed v_s . Milgrom [9, 10] calculated a value of $a_0 = 6.0 \times 10^{-11} \text{ m/sec}^2$ that fits the spiral rotational velocity as shown in Figure 4. (Note that the picture of the spiral galaxy is not centered at the origin of the graph.)

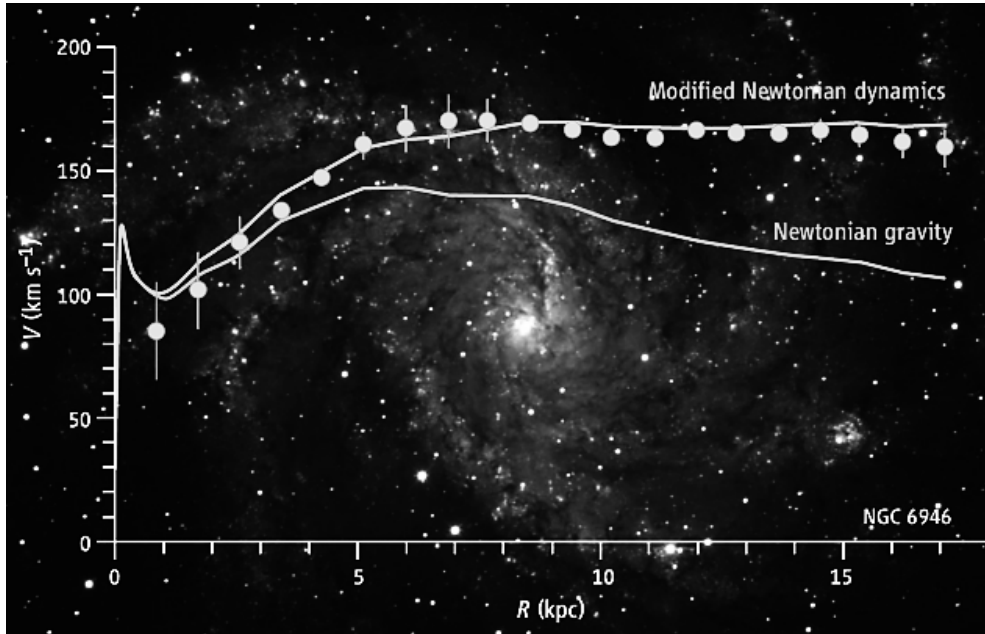


Figure 4. NGC 6946 Spiral Galaxy Graph of Rotational Velocity vs. Distance from Center [8]

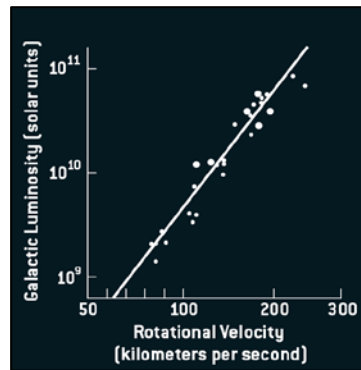


Figure 5. Relationship between Rotational Velocity and Galactic Luminosity and Mass [11]

Equation (12) predicts the Tully-Fisher relationship between the rotation velocity in spiral galaxies and the luminosity as shown in Figure 5[11]. The luminosity is proportional to the spiral galaxy mass M_S in agreement with $M_S \propto V_s^4$.

Since the vibrating neutral electric dipoles included in the mass definitions of Equation (3) are decaying, the constant gravitational force is slowly decaying. This causes the universe to expand on the grand scale. Even on the local asymmetric scale the force of gravity between the moon and the earth is decaying over time. This results in the moon moving further away from the earth in its orbit. The decay rate was probably greater in the past than the present decay rate.

Conclusions. Mach's Principle appears to originate in the electromagnetic force involving vibrating neutral electric dipoles. This force was not noticed by experimenters in the past, because the dipole-dipole force is a $(v/c)^4$ effect that is 10^{-39} weaker than the electrostatic Coulomb force.

When Newton was deriving his force of inertia and force of gravitation, the mass in those equations appeared to be fundamental constants of those apparently different fundamental forces. When Newton was questioned about what mass is, he said toward the end of his life that he did not know. Also Newton said that he did not know what caused the force of inertia or the force of gravity. However, Newton did specify a process to combine the axiomatic scientific method with the empirical scientific method that would decrease the number of independent fundamental forces in the course of scientific investigation and hopefully allow the logic of induction to discover the one universal force and proper set of terms. That has happened in our time as explained in **The Universal Force Volume 1**[1].

Thus from the very successful universal electrodynamic force derivations of the force of inertia and the force of gravity, mass is not a fundamental entity. What was called mass in the past represents a grouping of nearly constant electrodynamic parameters associated with vibrating neutral electric dipoles. The energy of these vibrating neutral electric dipoles is decaying by giving off radiation. The resulting radiation has been identified with the cosmic microwave background radiation. This radiation has been measured and found to be distributed throughout the universe in a pattern corresponding to the matter distribution as shown in Figure 6. This Figure shows the distribution of the red and blue Doppler shifts in the cosmic microwave background radiation about the center of the universe according to the Doppler shift pattern.

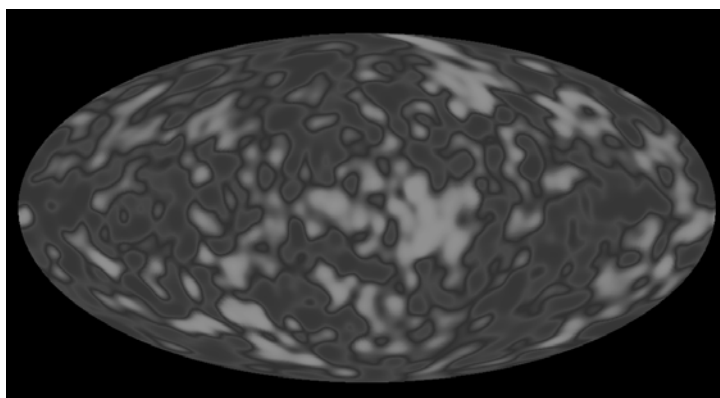


Figure 6. COBE Cosmic Microwave Background Radiation Red & Blue Doppler Shift Data[12]

We now know that what was called mass in the past is not really constant. It is decaying over time. The value of the inertial mass changes universally with distance from the center of the

universe. Local asymmetries also cause mass to change with distance from the center of spiral galaxies, with distance from a star to a planet, and distance from a planet to a moon. Unlike the Standard Model of Cosmology based on General Relativity Theory and quantum mechanics, the universal electrodynamic force approach does not need to invent dark matter and dark energy to explain the higher than expected constant velocities of the spiral arms of spiral galaxies and the expansion of the universe. These phenomena, for which a halo of dark matter and energy were invented, are explained directly from the universal electrodynamic force law which is in agreement with Mach's Principle.

General Relativity Theory assumes that the universe is homogeneous and isotropic. The cosmic microwave data shows that the universe has a center with spherical symmetry invalidating this assumption.

Mach's Principle reveals that Einstein's **Principle of Equivalence** in General Relativity Theory is also invalid, because gravitational and inertial mass are not equal. This can be seen from Einstein's statement of the equivalence principle below.

A little reflection will show that the law of the equality of the inertial and gravitational mass is equivalent to the assertion that the acceleration imparted to a body by a gravitational field is independent of the nature of the body. For Newton's equation of motion in a gravitational field, written out in full, it is:

(Inertial mass) \times (Acceleration) = (Intensity of the gravitational field) \times (Gravitational mass).

It is only when there is numerical equality between the inertial and gravitational mass that the acceleration is independent of the nature of the body [13].

General Relativity Theory's imperfections are further revealed in the necessity to have over 95% of the universe consisting of dark matter and dark energy. Thus a proper understanding of Mach's Principle and the concept of mass allows a simple explanation of many phenomena in terms of a universal electrodynamic force [1].

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