

THE PHARAO/ACES MISSION AND THE ALLAIS EFFECT

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ABSTRACT

Einstein's theory of relativity will be put to the test in a micro-gravitational environment by Atomic Clock Ensemble in Space (ACES), European Space Agency (Esa) mission developed in cooperation with the French Space Agency (CNES). It is scheduled to be installed in 2013 on board the International Space Station (ISS). The space will be studied by a new kind of atomic clock (Pharao) which will yield data accuracy much higher than what is attainable under earth's gravitation. Theoretical physics, metrology and atomic clock design are all starters to benefit from this joint venture. Our wish is that ACES includes the *Allais eclipse effect* in his application domain. This effect is related to an unexplained deviation of the plane of oscillation of the pendulum during solar eclipse. Pharao, called a "cesium fountain clock", would provide a unique way to search a possible variation of the constant G in an eclipse framework. Frequency comparisons between distant clocks both space to-ground and ground-to-ground would allow, during the eclipse time interval, to discover if the gravitational potential and velocity of the ground stations are still constant, if the equivalence principle contains a flaw.

During the total solar eclipse of 30 June 1954, it was observed an abrupt deviation of the oscillation plane of a short paraconical pendulum unaccountable by standard theories. This is essentially what asserted the communications of the experimenter Maurice Allais published from 1957 to 1959 in *Comptes Rendus de l'Académie des Sciences*. Since then, this surprising observation of the Allais effect, considered as heretic by the majority of scientists, among whom some went as far as wanting to prevent its diffusion, did not stop feeding harsh controversies. But it turns out that the discoveries of space research as well as recent developments in measures involving the atomic phase, such as cesium fountain atomic clocks, could provide an indisputable refutation, or confirmation, of this aberrant phenomenon which comes disprove relativity.

WEAK AND STRONG EQUIVALENCE PRINCIPLES

Galileo had discovered that all the objects fell at the same speed and underwent the same acceleration regardless of their mass or composition. He had also shown that the laws of nature were the same in two bodies of reference in uniform rectilinear movement. Einstein extended this "equivalence principle" to all the types of movements. He showed that a blind observer cannot know if he is in a gravitational field or in an elevator accelerating in an empty space of any other mass. So, gravity and acceleration are two sides of the same phenomenon. As long as we consider only the Laws of the mechanics, there are frames of reference in which bodies behave as if the gravity was absent. Einstein then extended this principle and assumed that, in a frame of reference in free-fall, all laws of the physics behave as if gravity was absent. This hypothesis, today now called "Einstein's equivalence principle", is the connection between special relativity and general relativity which Einstein will develop in 1915 [1, 2].

According to Einstein, gravitation is not a force. It is the manifestation of the very structure of spacetime, curved by the presence of matter – or energy – within it. The spacetime is the fabric of the universe, it possesses the three ordinary dimensions of space united with a single temporal dimension to form a four-dimensional spacetime. In the Newtonian conception of an absolute space in three dimensions, a mass as the Sun produces an attractive force that bends the trajectories of planets. In Einstein's theory, a planet undergoes no force, it is free and moves from one point to another according to the shortest path: its trajectory is a geodesic of spacetime curved by the Sun's mass. In fact, Einstein geometrised gravity.

However, for nearly forty years, a race against the clock is on to test the equivalence principle with an accuracy always finer and, consequently, the theory of general relativity, with the hope of detecting a fault and discover a new physics. Test the equivalence principle signifies verifying that the force of gravity is actually the manifestation of a "geometrical" effect related to the curvature of space and time. This basic idea (due to Einstein) ensues directly from the fact that all the bodies are accelerated in the same way in a gravitational field [3].

To understand how Einstein came to a geometrization of gravitation, we must return to the notion of mass which occurs in two different phenomena: gravity and inertia. In the first case, we speak of "gravitational mass", the one that appears in the law of universal gravitation. It measures the strength with which a body attracts or is attracted by other bodies. In fact, there are two types of gravitational masses. It is necessary in any rigor to distinguish the mass which creates the gravitational field, called the *active gravitational mass* (let us say the mass of the Earth M) of the mass on which the field acts, called the *passive gravitational mass* (i.e. mass m_g of a body which would fall into the Earth's gravitational field).

In the second case, we speak about "inertial mass": it measures the resistance of a body to change its state of motion. Within the framework of Newtonian theory, there is no *a priori* reason for the reaction of a body to the gravitational attraction to be identical to its resistance to a change in its motion. But as far back as the time of Newton, experiments suggested that both masses were equivalent. This property has since been repeatedly confirmed experimentally with high precision [4].

Newtonian theory did not care about the distinction between active and passive gravitational mass: these two masses play the same role in the expression of the gravitational force, in agreement with another great Newtonian law, the principle of action and reaction. But the structure of Einstein's theory is different: the active mass curves spacetime, in which a passive mass follows one of the shortest lines (geodesic). Consequently we distinguish the weak equivalence principle, which postulates the equivalence of inertial and passive gravitational mass, and the strong equivalence principle, which postulates the identity of the *three* masses. The latter states that the laws of physics are the same everywhere and all the time, throughout the observable universe, despite any effects of motion or gravity. It is the strong principle which is necessary for the coherence of the theory of general relativity [3, 5].

The equality of inertial and passive gravitational mass, already verified by Newton, is effectively one of the most precise experimental results of current physics: the difference between the values of m_i/m_g for different materials is lower than 1 ten billionth (10^{-10}). It results from the Eötvös experiments at the end of the last century and early twentieth century, who also greatly influenced Einstein in the establishment of the equivalence

principle and the construction of general relativity. Since a few years this type of experiment has been revived with vigour by many teams.

Verification of the strong equivalence principle is more difficult. The same body has to play both active and passive roles, what brings to consider a system of three bodies which comes under astronomy. We can so compare the accelerations of the Earth and the Moon towards the Sun. An experiment of this type became possible since 1969: the ongoing *Lunar Laser Ranging Experiment* measures the distance between the Earth and the Moon using laser ranging. Lasers on Earth are aimed at retroreflectors planted on the Moon during the Apollo program, and the time for the reflected light to return is determined with increasing precision [4]. It was an impressive test to check the strong equivalence principle but there is a drawback: The masses were not tested during a solar or lunar eclipse and a very strong possibility remains that celestial bodies in an eclipse framework behave differently.

THE EQUIVALENCE PRINCIPLE AND THE ALLAIS EFFECT

Maurice Allais, French polymath and 1988 Nobel laureate in economics, worked all his life in physical sciences. His work included groundbreaking experimentation with a paraconical pendulum demonstrating the existence of a new physical field. The comportment of the pendulum during a total eclipse of the Sun on June 30, 1954 gave added reason to suspect a gravitational influence linked to the luni-solar alignment. A sudden variation in the azimuth of the pendulum of a magnitude never observed in any other continuous observation period took place at the start of the eclipse of June 30, 1954. The plane of oscillation was brutally moved from about 13.5 degrees. A similar disturbance with amplitude of about 9 degrees was recorded during the total solar eclipse of October 2, 1959 which was only partial in Paris. In his experimental and theoretical researches, he has highlighted these very significant anomalies (and others) and has demonstrated their existence independently of any pernicious effect. They are totally inexplicable by currently accepted theories. Most scientists today refer to this "eclipse effect" as the Allais effect [6].

So, unless the strong equivalence principle is strictly correct during an eclipse framework, the possibility stays that gravity interacts differently with itself – with the gravitational energy that binds the Sun, the Earth, the Moon together, for example – rather than with other manifestations of energy. Scrutinize this issue should then instigate one of the most interesting experiments in general relativity, all the more as scientists improved the laser-ranging method since Apollo.

In any event, Amar Djema, Internet correspondent, points out that the Atomic Clocks Ensemble in Space, which will be installed in 2013 on board the International Space Station (ISS), could make it possible to verify with great accuracy, during solar and lunar eclipse, if the Allais effect exists. Pharo/Aces is a mission in fundamental physics based on the performances of a new generation of atomic clocks – called "cesium fountain clock" – operated in the microgravity environment of the ISS. Scheduled for launch in the 2014 time frame, ACES will be accommodated on-board the ISS, on the External Payload Facility of the Columbus module. It utilizes a dedicated two-way Micro-Wave Link (MWL) in order to a stable and accurate on-board timescale that can be used for space-to-ground as well as ground-to-ground comparisons of frequency standards. Thanks to the microgravity environment, the linewidth of the atomic resonance will be varied by two orders of magnitude (from 11 Hz to 110 mHz). Performances in the 10^{-16} , 10^{-17} range both for frequency stability

and accuracy are expected. These measurements will search for new physics and new interactions beyond the currently accepted four fundamental interactions.

One of the scientific objectives of the mission is to perform equivalence principle tests. It will be possible to test Local Lorentz Invariance and Local Position Invariance with unprecedented accuracy by doing three types of tests: gravitational red-shift, drift of the fine structure constant and anisotropy of light. Besides these primary objectives, several secondary objectives can be found. For example, if the theory of general relativity is considered as exact, then the measurement of the gravitational redshifts can be used to calculate the gravitational potential differences between diverse clock locations. It is a new type of geodetic measurements using clocks called relativistic geodesy [7, 8].

So far, the data from the ongoing Lunar Laser Ranging Experiment suggest with a high degree of precision that G , the parameter of the gravitational coupling constant, is really a constant. But would it be accredited in a framework of solar or lunar eclipse? During an eclipse of Sun, for example, when the Moon is between the Sun and the Earth, there is often a sudden disturbance, as if the free fall of the Moon around the Earth had wanted to take the tangent of the solar geodesic to go into orbit around the Sun. Although these disturbances seem to be only a temporary broken symmetry (it is already that), they cannot avoid to affect the metric tensor representing the gravitational field of general relativity.

The trend seems to be to test the theory of general relativity in an attempt to find fault with the equivalence principle at a very low level, the order of 10^{-16} , 10^{-17} , even less. A violation of the equivalence principle would constitute a first experimental clue in favour of the current unification theories which try to integrate gravitation in a scheme encompassing the four known forces. These theories (superstring theory for example) anticipate the existence of additional fields to that of general relativity, as far as this last one would not be questioned. In a way, a fifth force which adds to the usual gravitational field [3]. The hope is that this approach will allow watching how G evolves over time and how gravity can explore the possibility of a time beginning. On the other hand, the approach in an eclipse framework of a slight modification of gravity, by the cesium fountain clock or by the laser-moon telemetry, could well be two of the few ways to detect at the macroscopic scale a flaw in of the principle of equivalence, cornerstone of general relativity.

According to Newton's assertion, the Moon and the Earth are accelerated towards the Sun in the same way if they are located in the same position. Is the equality between inertial mass and passive gravitational mass, already well verified by Newton and by the Eötvös experiments, still sticks to during an eclipse framework? The disturbances revealed by the Allais's paraconical pendulum incite to think that the ability of a body to perform an action at a distance on another one could depend on the nature of bodies: if, for example, the Earth and Moon have not the same composition, why should they react the same way with the Sun? It seems that equality between the inertial mass ($F = M_i \times a$) and the gravitational mass (heavy mass), erected into postulate by Newton, then into universal principle by Einstein, is absolutely not obvious at the stage of the eclipse.

Worse for the strong equivalence principle which lays down the identity of the *three* masses. We have seen that M. Allais had detected during two solar eclipses in 1954 and in 1959 an abrupt shift of the plane of oscillation of a paraconical pendulum intended to study the Foucault effect. It seems that when the Sun, the Moon and the Earth are aligned, the Earth and the Moon are not accelerated in an identical way in the Sun's gravitational field. The study of

the movements of celestial bodies in an eclipse framework constitutes a heavenly laboratory which should inform about the way celestial objects intersect between them and on the way the gravity acts with itself. Thus, near and on the line of a solar eclipse, at the tangential point of the spacetime curvatures of the active gravitational masses (Earth for the Moon, Sun for the Earth) there is a set of successive repulsion and attraction which reflects a sudden confusion between the kinds of mass. As if the passive Moon seemed suddenly to take itself for an active planet of the Sun, causing a solar repulsion, then alternates and adds its weight to the Earth which seems to further accelerate towards the Sun. Is the Allais effect an intrinsic violation of a symmetry specifically gravitational which would cause a breach in this property called the universality of free fall?

How to know, considering that M. Allais experiments and their interpretation were not taken seriously by the scientific community? Saxl and Allen (1970) tried a different approach; an increase in the period of a torsion pendulum was reported in 1970, but subsequent attempts to replicate it failed and thus it remains an invalid experiment. Wang *et al.* carried out experiments in 1997 in a remote region of China during a total solar eclipse and in 2001 and 2002 during solar eclipses in Zambia and Australia. Even if there was a possibly related anomalous gravitational effect, they argued that atmospheric motion induced by temperature changes was sufficient to explain the observed anomaly. Eight gravimeters and two pendulums were deployed across six monitoring sites in China for the solar eclipse of July 22, 2009 [9]. Although one of the scientists involved claimed in an interview to have observed an Allais effect, the result has not been published in any mainstream peer-reviewed scientific journal. Various experiments not only with the paraconical pendulum and the Foucault pendulum, but also with the torsion pendulum and the gravimeter have been devoted to observe an Allais effect. The observations are rare and rather contradictory, because of the rarity of such eclipses and for the reason that a rigorous experimental control must be respected. The results of M. Allais have little to do with dubious interpretations from an epidemic of anachronistic pendulums, yo-yo toy versions of the Allais pendulum. The announcement by NASA of the audit of the Allais effect, before and immediately after the eclipse of August 11, 1999, attracted strong media attention, but no thorough analysis of the results was published. Since 1954, fluctuations have been measured during around 20 total solar eclipses, but the results still remain inconclusive. Despairing? Say that these difficulties highlight to what extent the measures of anomalies during eclipses, especially with the pendulums, is a stuttering art.

THE PHARAO/ACES EXPERIENCE AND THE ALLAIS EFFECT

The flash of lucidity of Amar Djema, mentioned above, was precisely to perceive the possibility of obtaining analogical experimental results from cold atom clocks, if not sometimes higher, than those from pendulums. He believes that if a solar eclipse provokes a kind of incidence on a Foucault pendulum, it raises important questions about the nature of these phenomena. But before determining the cause of the Allais effect and potential consequences [10, 11], scientists must first settle the question about whether a pendulum really does act differently during a solar eclipse and if there are gravitational disturbances. In this respect, he propounds two promising suggestions, one concerning the solar eclipse, the other the lunar eclipse:

Since the ultra-stable atomic clocks on-board the International Space Station are compared to a network of ground clocks through a high performance two-way time transfer system, it would be possible to synchronize two atomic clocks on ground using laser cooled atoms (one

witness) with Pharao, and check again the synchronization after the passage of a solar eclipse. A difference in the Earth gravitational potential at this moment could indicate a temporal variation of the fundamental constant G and thus physics beyond the Standard Model.

Another test that he promotes would be the shooting of solitons towards the Moon during a lunar eclipse and, with the measure of the delay by using of a cold clock, a tiny variation in size, and therefore of the Moon's gravity, can be detected. The advantage to use solitons rather than classic pulses lies in the fact that the soliton is a solitary wave that acts like a particle and propagates without distortion in a non-linear and dispersive environment [12]. However, with such level of accuracy, the problem of the thermal and seismic noise has to be studied and considered.

Ultimately, what is the best way to ensure that the Allais effect exists? Obviously, it would be to detect it by the spatial clock Pharao. Atomic fountains which embrace the refinements of the modern technology ask only to get out of the laboratories and to find it. We hold an intriguing anomaly whose presence contradicts the theory of relativity and it becomes urgent to appeal to scientists who are experts in technical ingenuity and who understand the issues – as those that are part of the Pharao/Aces – to perform experiments that will lead to a direct validation of the Allais effect. Or its invalidation, to put an end! If disruptions during eclipses exist and contain unique information about the behavior of gravity, it will be necessary to employ teams well decided to find them – because in astrophysics as elsewhere the devil always hide in the details –, and the resolution of this mystery will involve a new physics. One sure thing, the game is worth the candle.

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