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# Hypothetical Gravity Control and Implications for Spacecraft Propulsion[1]

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## Abstract

**A scientific analysis of the conditions under which gravity could be controlled and the implications that an hypothetical manipulation of gravity would have for known schemes of space propulsion have been the scope of a recent study carried out for the European Space Agency. The underlying fundamental physical principles of known theories of gravity were analysed and shown that even if gravity could be modified it would bring somewhat modest gains in terms of launching of spacecraft and no breakthrough for space propulsion.**

Putative control of gravity is a topic repeatedly discussed in scientific publications, experiments and even patents. Aiming to critically assess the existing literature and to reach a set of recommendations for future activity, the European Space Agency (ESA) has ordered the authors a scientific study. This study comprised a scientific report of about 140 pages, a database containing about 150 key papers on the subject, as well as information on 38 scientifically active individuals in the research of new space propulsion schemes and its underlying fundamental physical principles [1].

On quite broad terms, we understand by *gravity control* any scheme to alter the effective strength of the gravitational coupling to matter or that can lead, through the intervention of

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other forces, to a change in the local gravity force. For achieving this goal, at least one of the following conditions must be fulfilled:

**1)** Existence of a new fundamental interaction of Nature so to alter the effective strength of the gravitational coupling to matter. This implies in violations of the Weak Equivalence Principle.

**2)** Existence of net forces due to the interplay between gravity and electrostatic forces in shielded experimental configurations, as found in the well-known Schiff-Barnhill effect [2].

**3)** Analogous effect for magnetic fields in quantum materials involving the gravitomagnetic field [3].

**4)** Physically altering the properties of the vacuum so to change the relative strength of the known fundamental interactions of Nature.

In order to critically examine the existing proposals and to consider lines of research that could lead to yet unknown phenomena, a survey on the state of the art of the following topics has been carried out:

- General Relativity
- Einstein Equivalence Principle: Weak Equivalence Principle, Local Lorentz Invariance, Local Position Invariance
- New Interactions of Nature
- String/M-Theory
- Gravitoelectromagnetism in Quantum Materials
- "Vacuum Engineering"
- Gravity-Controlled Propulsion

The conclusions of our survey can be summarized as follows:

- Schemes involving heterodox concepts such as *negative masses*, *negative energy densities*, *Mach's principle, warp drive*, etc, contradict well tested conventional physical theories and cannot so far be seriously considered.
- Gravitational anomalies related to shielding effects (claimed to be observed during total eclipses), reduction of weight due to rotation of quantum materials and amplification of gravitomagnetic fields are almost entirely ruled out. Experimental examination of claims

that have not yet been ruled out is recommended through specifically designed experiments aimed to measure the gravitomagnetic properties of rotating quantum materials [1].

- The Weak Equivalence Principle holds with great accuracy, actually in 5 parts in $10^{13}$ [4] (see [5] for an extensive review) and expected violations, such as the one emerging in certain string theory schemes [6], are far too small, 1 part in $10^{18}$, to lead to any workable scheme to control gravity. The same can be stated about Lorentz (see eg. [7]) and CPT symmetries [8].

- A new interaction of Nature arising from the exchange of a new intermediate massive boson is ruled out for ranges in the interval $10^{-4}\ m \lesssim \lambda \lesssim 10^{13}\ m$ [9]. Submillimeter range new interactions have been recently very much discussed in the context of braneworld scenarios with large extra dimensions [10], but arise also from assuming the new particle account for vacuum energy density in the Universe [11, 12]. Interestingly, this range has recently became accessible to experimental verification [13]. A new interaction of Nature a thousand times weaker than gravity with a range of about $\lambda \simeq 200\ A.U. = 3.5 \times 10^{13}\ m$ has been suggested as a solution to the inferred Pioneer 10/11 anomalous acceleration [14].

- Local Position Invariance is rather poorly established in comparison to the Weak Equivalence Principle and Local Lorentz Invariance. Clock experiments at the International Space Station are recommended as they represent the most promising way to further improve the level of accuracy of this symmetry [15].

- Schemes to alter vacuum properties and the relative strength of the known fundamental interactions of Nature are beyond current theoretical knowledge and out of reach of forseeable technological developments [1].

As far as propulsion is concerned, we have shown that if via an hypothetical scheme gravity could be modified then, fairly independently from the underlying *modus operandi*, the following conclusions can be reached [1]:

- If modifications of local gravity were through any scheme that would decrease the inertial mass of a spacecraft then thrust would be lost as the propellant mass would decrease as well.

- If modifications of gravity were achieved through a scheme that would affect the gravitational mass its impact will depend on the relative gravity contribution in comparison with the other components of the so-called $\Delta v$ requirement. For instance, to reach a Low Earth

Orbit the gain would be rather modest. For a Geosynchronous Orbit however, the gain would be more important, but really significant only through a drastic "shielding" of the gravitational mass ($> 95\%$).

- Wire-like gravitomagnetic field assisted propulsion schemes lead to irrelevant thrust as compared to conventional devices such as deployable booms or electrodynamical tethers.
- Control of gravity would bring a somewhat modest gain in terms of launching of spacecraft and no breakthrough for propulsion in general.

In the light of these conclusions we have suggested a set of recommendations to reflect our view that emphasis in what concerns the subject of gravity control should be focussed on microgravity, manned space flight and fundamental physics. In concrete terms we have strongly recommended that ESA's fundamental physics programme is extended so to emcompass:

**1)** Searches for violations of the Weak Equivalence Principle for antiparticles and charged particles at the International Space Station (ISS). Furthermore, that the ISS is used as a platform to vigorously pursue clock comparison experiments.

**2)** Studies of possible new phenomena involving the gravitomagnetic field in quantum materials.

**3)** Analyses of tracking data of existing and forthcoming missions as well as implementing means for endowing future generation of spacecraft with instrumentation to reliably reconstruct their energy production and dissipation history.

Concerning the last point we have pointed out that a most promising strategy to confirm the existence of anomalous acceleration experienced by the Pioneer 10/11 spacecraft would involve a dedicated mission - provisionally named Sputnik 5 mission [1]. Interestingly, this view has also been recently advocated by the team that has firstly identified this anomaly [16].

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