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# The physics of *Interstellar* – Mission impossible

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## Abstract

The recent Hollywood movie Interstellar (production cost $ 165 million) turned out to be a blockbuster in the U.S. and Europe, and most likely will be so in Asia. The movie story is great. Without doubt, one of its benefits is the renewed enthusiasm in the science of space flight by the public. But alas, it is only Hollywood's science fiction, not science, despite the efforts of the producer. The basic reason is that General Relativity (*GR*) alone does not provide a sufficient basis for the underlying physics. Additional constraints from quantum theory have to be observed, and, when applied, render the existence of wormholes, though allowed by *GR*, completely unphysical. However, despite this negative result, an alternative concept for propellantless propulsion might exist in the form of novel gravity like-fields, which is briefly presented.

## Keywords

Interstellar movie; Physics of traversable wormholes; Causal dynamical triangulation; Non-linear physics; Computer simulation; Novel gravity-like fields.

## INTRODUCTION

The recent Hollywood movie *Interstellar* generated a wave of renewed interest in spaceflight and its underlying science has been widely discussed, for instance in[1,2]. So-called future (i.e., advanced, not based on chemical propulsion) space propulsion systems have been conceptualized since the early 1930s.

For instance, with the advent of Dirac's relativistic quantum field theory in 1928 that postulated the existence of antimatter, *antimatter propulsion* has been proposed and thoroughly investigated as the ultimate propulsion scheme. A simple calculation shows that it is one of the most inefficient ways to fly, apart from the inherent danger of antimatter. At present, about $10^{-9}$ g (1 nanogram) of antimatter per year are being produced in the Large Hadron Collider (LHC) at CERN near Geneva at a cost of $160 million. Suppose a spacecraft of a relatively small mass of 100 t has to be launched from the surface of the *Earth*. At an acceleration of 10 m/s$^2$ let us calculate the kinetic energy of the craft for (nonrelativistic) 100 km/s. This would require about 6 g of antimatter, which at current production cost would amount to $160 million $\times 10^9 \times 6$, slightly above the NASA annual budget. Though physically not infeasible, the efficient and effective technical realization of these advanced concepts belongs to the realm of science fiction. Moreover, entering an alien solar system with a large amount of antimatter would (most likely) be seen as a declaration of war by its inhabitants.

Since the time of the famous *Einstein-Rosen paper*, 1935, wormholes (scientifically known as *Einstein-Rosen bridge*) have become a fashionable subject for space travel. A wormhole is a mathematically admissible solution of the vacuum Einstein field equations, providing some kind of shortcut between two separated spacetime regions. For the mathematical solution, the right hand side in the field equations is set to zero (energy-momentum tensor), which means that neither matter nor energy is present.

The public, blissfully unaware, that current physics does not have even the remotest concept for interstellar travel, simply expects a miracle to occur. Hollywood is providing this miracle in form of the discovery of a wormhole orbiting *Saturn* that will serve as short cut to the stars, in order for mankind to leave an uninhabitable *Earth* (in the movie it is *not* climate change that has ruined the *Earth*). According to the movie script, NASA scientists believe that extra-dimensional beings have created the wormhole to save humanity. The hero then is piloting an experimental spacecraft, termed *Endurance*. So far for the movie, which is great. However, the physics of the movie might not be realistic, because important aspects of quantum physics were not considered. The picture of a warped spacetime (described as *ultrarealistic* by M. Fontez[2]) shows that the propulsion principle in the movie is based on the existence of wormholes, which are mathematical (topological) structures in spacetime that act as a tunnel (shortcut) connecting distant points in spacetime. By contrast, black holes are spacetime singularities that consume all of the mass that comes sufficiently close to them. These (mathematical) singularities occur, since general relativity, in contrast to quantum physics, assumes that spacetime is a continuum at all length scales. The movie uses a wormhole (not a black hole), generated by aliens in the vicinity of *Saturn*, as a means to save desperate humanity.

Apart from the fact that we first would need to go to *Saturn* with current chemical propulsion (fairly hopeless), the wormhole somehow has to be made to be traversable. The main problem, however, is do wormholes exist in the *Universe*? Black holes are a different story, but the nearest black hole might be at the center of our galaxy, that is, it is completely out of reach.

## GENERAL RELATIVITY AND QUANTUM PHYSICS OR THE PHYSICS OF NON-EXISTING WORMHOLES

For those who are following theoretical physics, it came to a major surprise, when recently Ambjørn (Niels Bohr Institute, Denmark), Jurkiewicz (Jagellan University, Poland), Loll (Utrecht University, The Netherlands) et al. published their results based on what they call *CDT* (Causal Dynamical Triangulation), which is a nonpertubative quantum theory of gravitation based on Feynman's path integral approach. Their major step forward is, that no approximate analytic work is done, but the full nonlinear equations are solved by Monte Carlo simulations on a numerical mesh that quasi-organizes itself, representing an evolving spacetime. The aim of their simulations is nothing less, but to generate spacetime (the *Universe*) from first principles, without specifying the number of dimensions or the type of spacetime topology etc. Everything has to come out from Feynman's path.

Their results are *staggering*.

First, when they leave out causality, i.e., if no arrow of time is built in explicitly in their computer simulations (causality is not present in general relativity), nothing will develop. That is, a spacetime lattice cannot evolve, there is just a mess of spacetime points in many dimensions. Hence, the direction of time (directed motion) needs to be built in explicitly as a fundamental principle. This means that the equations of general relativity alone are insufficient as governing physical principle for an enfolding *Universe*.

Second, if one leave's out *Einstein's biggest blunder*, the cosmological constant $\Lambda$, the *Universe* (spacetime) does not evolve either. $\Lambda$ seems to work as some kind of repulsive gravitational force.

Third, the dimension of spacetime depends on the length scale. Above $10^{-34}$ m, spacetime has four dimensions and is smooth, that means, *GR* should be applicable down to this length scale, which is many orders of magnitude smaller than the Compton wavelength of the heaviest known material particle (top quark).

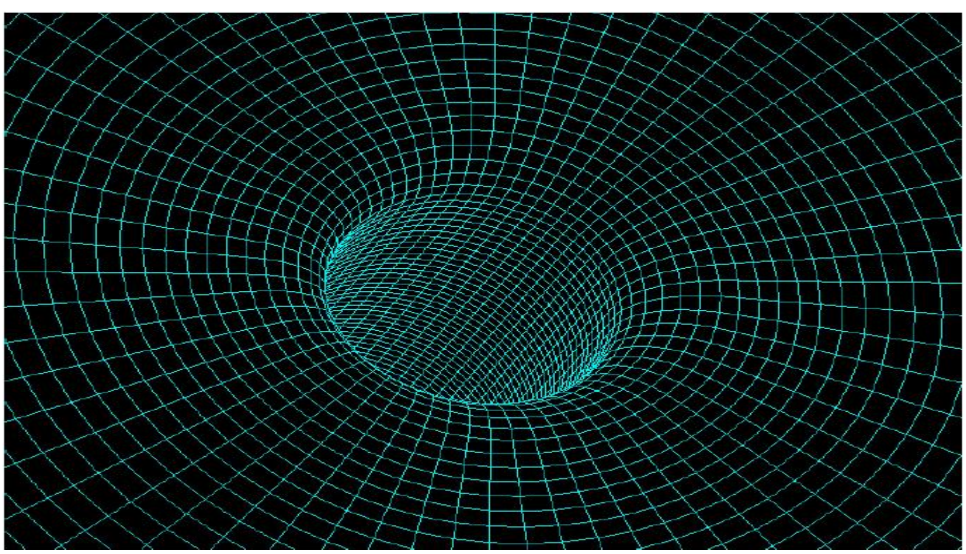

**Figure 1 : The figure (generated by the *GridPro* software package) is meant to depict the entrance of a wormhole. A wormhole has an entrance and an exit, connecting two separate regions in spacetime, acting like a shortcut.**

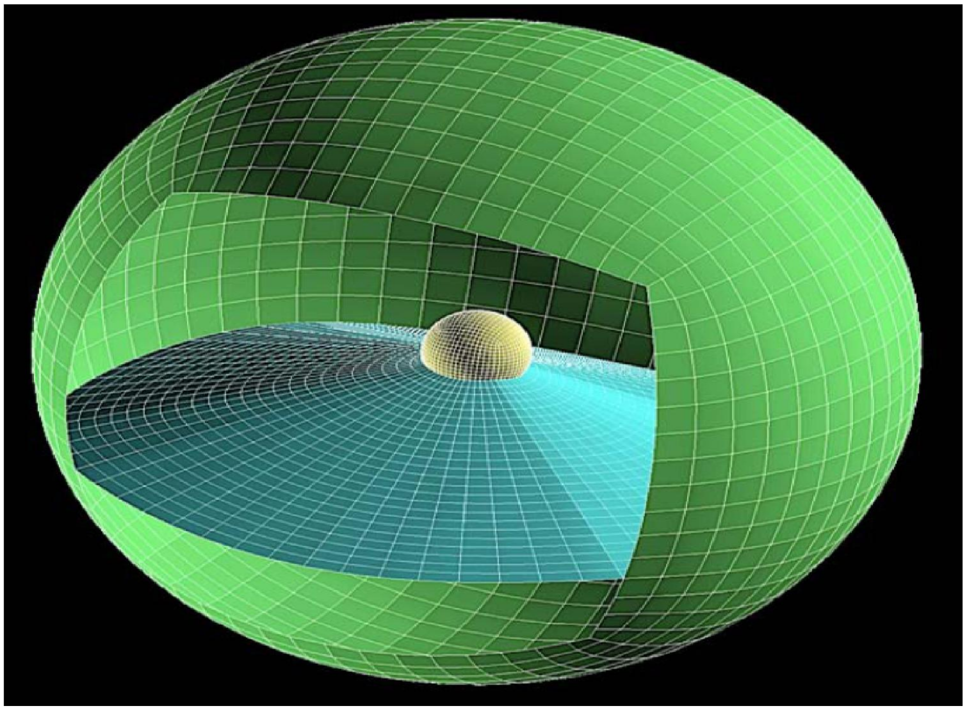

**Figure 2 : The figure (generated by the *GridPro* software package) is meant to depict a sequence of expanding closed spacetime lattices. This is simply an example, because the number of spacetime atoms should increase during expansion. In addition, grid spacing might decrease with expansion and not increase as shown.**

Going further down to the Planck length scale, $10^{-35}$ m, spacetime becomes (fractal) two-dimensional. The grainy (or discrete) nature of spacetime will become apparent at the Planck length scale.

Forth, and now we come to Hollywood: the topology (or simply the shape) of spacetime is a *de Sitter* spacetime. This means, spacetime is curved, even when matter and energy are absent, but its curvature is positive and its topology is simply connected. In other words, there are no wormholes. Hence, space travel based on traversable wormholes or any other similar concept is impossible. That is, these ideas are *no* longer valid, even in science fiction. They are now outside physics.

Of course, there is no doubt that Einstein's field equations allow wormholes, but only as mathematical solutions, which, and this is important, are not realized by *Nature*. This phenomenon is not uncommon and is well known from other areas of nonlinear physics. For instance, the compressible Navier-Stokes (Euler) equations have shock waves as mathematical solutions, both in the form of compression and expansion shocks. However, in real fluid flow, only compression shocks occur. Expansion shocks are unstable, and thus do not exist. Moreover, general relativity is not the only kid on the block. The quantum principle is present from the very beginning of the *Universe*, and manifests itself in form of additional constraints (unknown in general relativity).

Hence, attempts to exclusively use Einstein's field equations as a means for advanced space travel are probably based on incomplete premises and bound to fail. The authors of *CDT*, in their very readable article in *The Self-Organizing Quantum*, Scientific American, July 2008, already recognized: wormholes now seem exceedingly unlikely etc. They conclude that space travel based on wormholes is *not* a realistic option.

## COMPUTER SIMULATION AND THEORETICAL PHYSICS

There is, however, the impression that the groundbreaking results of *CDT* are not fully appreciated by the community of theoretical physicists, because numerical simulation might be considered inelegant.

Furthermore, in practice, many of the currently employed highly complex mathematical procedures like Feynman diagrams, propagators, and renormalization etc. might be superseded by much more realistic computer simulations, requiring much less mathematical skill. The level of physical realism obtained from *CDT* *cannot* be matched by any approximation techniques, regardless of their level of sophistication.

In the same way, today, three-dimensional numerical fluid dynamics simulations have completely replaced analytic solutions of the Navier-Stokes equations, i.e., the numerous ingenious approximate solution techniques (e.g. boundary layer equations, inclined flat plate solution, or hypersonic approximate solutions etc.) of the 1960s (especially for re-entry simulation) must be

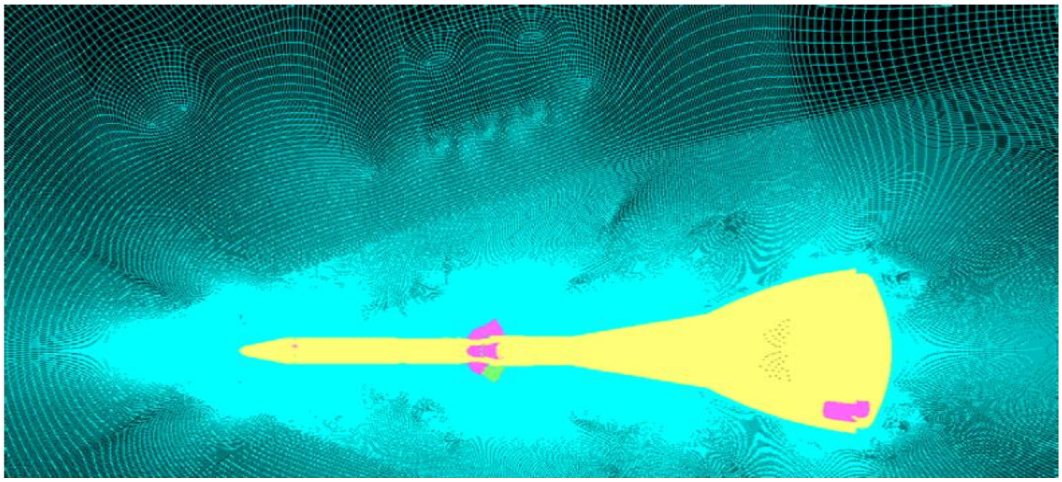

**Figure 3 : The figure (generated by the GridPro software package) shows a cross section of the (highly complex) Orion spacecraft grid (successfully launched on December 5, 2014) to be used for re-entry simulation. Only computer simulation of the Navier-Stokes equations can provide a realistic picture of the extreme heat flux to be expected. No analytic solution of the Navier-Stokes equations would be able to provide this kind of physical realism. In the same way, computer simulations using *CDT* can provide a physically realistic picture of the emerging physical spacetime, *unobtainable* by analytic solutions of *GR*. In order to succeed, *CDT* combines *both GR* and the quantum principle, and only relies on few basic physical principles.**

considered history. In the same way, the quantum field theory, *QFT,* of the future will rely on computer simulation, replacing many of the comprehensive approximate theoretical tools of high-energy physics, developed over the last fifty years. Thus, it is understandable that theoretical physicists see *CDT* with a certain degree of suspicion. Computer simulation by *CDT* will allow us witnessing the formation and evolution of cosmic structure and, by modifying the governing parameters, their impact on the structure of the *Universe* can be modeled, something that pure mathematical procedures cannot accomplish. Moreover, in principle, instead of Monte Carlo simulation, powerful finite volume techniques could be employed to numerically solve any type of Feynman path integral.

The generation of highly complex three-dimensional grids (e.g. about a complete aircraft or for turbines) is well established[14] and special numerical techniques for the solution of a system of coupled non-linear hyperbolic partial differential equations (parabolic with friction) have been developed since the 1970s, both in fluid dynamics and astrophysics, even permitting the capturing of discontinuous phenomena (e.g. shocks, contact discontinuities etc.).

## PROPELLANTLESS PROPULSION ALTERNATIVE: GRAVITY-LIKE FIELDS?

Not only the physics, but also the resulting technology must be feasible for the realization of advanced space propulsion. Space travel by wormholes is impossible because, when both *GR* and *QP* (quantum physics) are combined, a wormhole that exists as a mathematical possibility in *GR* is rendered unphysical by the additional constraints of *QP* as has been demonstrated by the computer simulations of Ambjørn, Jurkiewicz, Loll et al. over the last several years.

Does this mean that propellantless propulsion has to remain a pipe dream?

It is obvious that any future breakthrough in propulsion science (or energy generation), in order to become a real game changer, needs to be functioning without fuel. This insight is *not* new. Already in his 1960 book[10] R. C. Corliss not only discussed all the advanced space propulsion concepts still researched today, but already foresaw the need for propulsion without fuel and coined the term field propulsion (a comprehensive discussion of field propulsion can be found in[11]). Field propulsion (apart from gravity assist) was actively researched in industry and academia at that time. It means that there exist novel long-range physical fields (outside current physics) that can be used to accelerate a spacecraft. Eventually this avenue of research was given up, since no novel physical principle could be found. The situation might have been changed recently, since extreme gravitomagnetic fields might have been generated in several experiments, which are, however not conclusive. A comprehensive analysis of these experiments is given in[8,9]. If these fields are accepted as cause for the observed anomalous experimental effects, they are obviously outside both *GR* and the standard model of particle physics. For those who are interested in the most recent (speculative) ideas of space flight without propellant (remember the unsuccessful NASA breakthrough physics propulsion program from 1996-2001), might find novel ideas in the latest edition of the Journal of Space Exploration, Mehta Press, Vol. 3, Issue 2, October 2014, dedicated to the topic of *Spaceflight*

*Perspectives from Novel Concepts of Spacetime, Gravitation and Symmetries*.

Of course, novel physics is needed, beyond general relativity and current quantum physics, as, for instance presented in[7]. Another novel idea, proposed by W. Dröscher and the author, is that there exists an interaction between the weak force and gravitation, triggered by *symmetry breaking* at cryogenic temperatures[8,9,11], that is, electromagnetic fields might be converted into extreme gravitomagnetic fields. It may be possible that these fields already might have been observed experimentally, for instance, in the experiments carried out by M. Tajmar et al.[9,12] since 2006.

One very recent speculative idea is to assume that a reduction of the spatial dimensionality of spacetime occurs in the gravitomagnetic experiments (as analyzed in[9]) in the presence of special materials, i.e., spacetime is reduces from Minkowski space SO(3,1) to a space SO(2,1). This might be a consequence of the quantum principle.

In quantum mechanics there is the phenomenon of *indistinguishability* of particles. In general, particles are either bosons or fermions, that is, any total wave function of identical particles that is symmetric describes bosons (integer spin, arbitrary number of particles in each state), e.g. photons. If the wave function is antisymmetric (sign change) under the exchange of any two particles, the system is comprised of fermions (half-integer spin, one particle only in each quantum state), e.g. electrons, stability of matter. If spacetime is of type SO(2,1), new quasi-particles can exist, termed anyons (see, for instance, R. Laughlin[15] and F. Wilczek[16]) that continuously obey statistics ranging from fermion to boson behavior. There is already a theory of high-temperature superconductivity based on the features of anyons. According to F. Wilczek, under certain circumstances, matter does indeed behave as if it were two-dimensional, depending on its internal crystal structure, for instance, having surface layers that are only a few atoms thick, and also in materials like graphite or copper oxide high-temperature superconductors (the atomic planes may be stacked on top of one another). If this effect occurred in the extreme gravitomagentic experiments, there could be an explanation for the extreme strength of the possibly observed gravitomagnetic fields, since the gravitational field lines are now condensed into two dimensions instead of three.

According to W. Dröscher the presence of anyons could also be responsible for the reported *parity violation* in the gravitomagentic experiments, which means that the gravitomagentic fields generated by clockwise or counter-clockwise rotation of the rotating disk or ring[9] possess highly different field strengths (about a factor 5). Moreover, there might be a possibility to generate strong gravity-like fields at room (high) temperature in analogy to high-temperature superconductors, depending on the material composition (there seem to be 20 different materials necessary). There are also ideas how the hierarchy problem (that is, physical parameters in form of the coupling constants for the fundamental interactions are vastly different) could be solved, since it has become unlikely that the so-called super theories (string, symmetry, gravity etc.) do reflect physical reality, and thus cannot offer a solution anymore.

That these novel physical ideas might have a certain degree of reality, can also be learned from the visionary theoretical physicist *Michio Kaku*, who, when being interviewed about the reality of UFOs, expressed his belief in their existence, but also mentioned that the smoking gun has not yet been found. The most credible UFO reports are from the Belgian Air Force[13], who observed air activities of unknown origin during the period of 1989-91 in their airspace. Air Force pilots tried (in vain) to engage the unidentified crafts, but reported, that their flight performance was far superior compared to the most advanced aerospace technology on *Earth* with respect to acceleration, maneuverability, and also slow motion or even hovering. NATO F-16 aircraft could not intercept the alleged crafts, because these vehicles seemed to jump huge distances in seconds and were accelerating beyond human capacity (for a detailed description by the Belgian Chief of Operations at the Air Staff see[13]).

As already presented in many public lectures by M. Kaku (check his videos on Youtube) truly *advanced physics* is needed for genuine space travel. In any case, according to Prof. Kaku, these UFOs must have mastered physics totally alien to us, including superluminal propulsion.

On the other hand, fact is, that even after sixty years of UFO observations, not a shred of *technical information* (except for strange light effects, so called spotlights) has been gathered. In this regard, it will not matter whether or not UFOs exist, except, that one could take their presence as proof for the existence of unknown (to us) but far superior physical laws. Now it is the time that mankind develops their own space propulsion technology. The next step, therefore, is to find the proper, novel physics that can serve as the basis for such a space technology. It is clear that this physics must be sought beyond *GR* and the *standard model of particle physics* as well as the *standard model of cosmology*, because the technology that follows from these models has been known for several decades, but it is far too limited in providing the breakthrough concepts needed for future spaceflight.

## CONCLUSIONS

In conclusion, *GR* is providing a mathematical framework for spacetime topologies, but these solutions are subject to further restrictions owing to quantum physics. As was *shown* by *CDT* simulations, the admissible solutions of *GR* have to satisfy additional severe constraints, that is,

1. they have to obey the causality principle,
2. must be compatible with the existence of a repulsive gravitational force, at least in the form of a cosmological constant,
3. must be based on quantum mechanics in the form of the Feynman path integral, i.e., the quantum interference principle is governing the development of a four-dimensional spacetime.

As learned from *CDT*, these requirements result in a *de Sitter* spacetime (simply connected manifold of positive curvature) topology (Einstein and de Sitter 1917), which excludes[3-5] the existence of all kind of wormholes. Therefore, the physically relevant solution set of *GR* is substantially reduced by the additional requirements from *QP*. Hence, *all* attempts of mathematical constructions of so-called traversable wormholes (though mathematically fully correct, see, for instance, the very well written paper by E. Davis[6], appear to be fruitless, since they are based on the existence of wormholes that are ruled out by the additional quantum mechanical constraints applied in *CDT*.

The same holds true for all other advanced space propulsion concepts, e.g. antimatter or fusion propulsion, fully known since the 1960s. The only alternative seems to be *field propulsion*, as foreseen by Corliss more than fifty years ago. If M. Kaku is correct, this novel physics might indeed exist providing us with the possibility for this type of propulsion. But we must come up with our own effort to unravel these novel principles in order to become a member of the club, i.e., to develop the technical capabilities similar to those demonstrated by the unidentifiable flying objects over the Belgian airspace about 20 years ago.

Perhaps it is gravity-like fields that might have been observed in various experiments (and theorized) as described in[7-9,11], which could serve as the basis of unconventional physical concepts. It is obvious that radically novel ideas are needed, since even our most advanced physical theories do *not* contain any hints for the development of advanced propulsion systems.

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