The physics of Hollywood's blockbuster movie *Interstellar*

The movie Interstellar (see the short report by M. Fontez in La Sience & Vie, November 2014) 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 in the public.

But alas, it is only Hollywood's science fiction, not science, despite the science adviser.

However, the physics of the movie might not be realistic, because important aspects of quantum physics were not considered. The warped spacetime picture (described as ultrarealistic by M. Fontez) seems to indicate 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 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 in physics, 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.

For those who are closely following theoretical physics, it came to a major surprise, when recently Ambjorn (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 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 integral (Prof. Kip Thorne, Interstellar's science advisor, holds the Feynman chair at the California Institute of Technology).

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) into the numerical procedure, 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, 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, general relativity should work down to this length scale, which is many orders of magnitude smaller than the Compton wavelength of the heaviest known material particle. Going further down to the Planck lengthscale, 10^(-35) m, spacetime dimension (fractal) will reduce to two. 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, that spacetime is curved, even when matter and energy are absent, but its shape is spherical. In other words,there are no wormholes. Since wormholes do not exist, space travel based on traversable wormholes or any other similarconcept is impossible. That is, these ideas are no longer valid, even in science fiction. They are outside physics. Of course, there is no doubt that Einstein's filed equation of general relativity 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 equations that 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. Quantum constraints (not present in general relativity) have to be obeyed from the very beginning of the Universe. 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 Scientific American already recognized this: *The Self Organizing Quantum*, July 2008, who clearly stated: wormholes now seem exceedingly unlikely etc. They conclude that space travel based on wormholes is not a realistic option.

Fifth, does this mean that we are stuck? Perhaps not.

For those who are interested in other (speculative) ideas of space flight without propellant, as in the NASA program from 1996-2001 with their breakthrough physics propulsion program (without any success), might wish to have a look at the latest edition of the Journal of Space Exploration, Mehta Press, Vol 3, Issue 2, November 2014. Of course, novel physics is needed, beyond general relativity and current quantum physics, already presented in many public lectures by the visionary physicist Michio Kaku (check his Youtube videos).

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