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On Closed Timelike Curves, Cosmic Strings and Conformal Invariance

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Abstract

In general relativity theory (GRT) one can construct solutions which are related to real physical objects. The most famous one is the black hole solution. One now believes that in the center of many galaxies there is a rotating super-massive black hole, the Kerr black hole. Because there is an axis of rotation, the Kerr solution is a member of the family of the axially symmetric solutions of the Einstein equations. A legitimate question could be: are there other axially or cylindrically symmetric asymptotically flat solutions of the equations of Einstein with a classical or non-classical matter distribution and with correct asymptotical behavior, just as the Kerr solution? Many attempts are made, such as the Weyl-, Papapetrou- and Van Stockum solution. None of these attempts result is physically acceptable solution. Often, these solutions possess closed timelike curves (CTC's). The possibility of the formation of CTC's in GRT seems to be an obstinate problem to solve in GRT. At first glance, it seems possible to construct in GRT causality violating solutions. CTC's suggest the possibility of time-travel with its well-known paradoxes. Although most physicists believe that Hawking's chronology protection conjecture holds in our world, it can be alluring to investigate the mathematical underlying arguments of the formation of CTC's. There are several spacetimes that can produce CTC's. Famous is the Tipler-cylinder. Most of these spacetimes can easily characterized as un-physical.

The problems are, however, more deep-seated in the vicinity of a (spinning) cosmic string or in the so-called Gott-spacetime. These cosmic string models gained much attention the last decades. Two cosmic strings, approaching each other with high velocity, could produce CTC's. If an advanced civilization could manage to make a closed loop around this Gott pair, they will be returned to their own past. However, the CTC's will never arise spontaneously from regular initial conditions through the motion of spinless "cosmons"("Gott's pair"): there are boundary conditions that has CTC's also at infinity or at an initial configuration. If it would be possible to fulfil the CTC condition at t0, then at sufficiently large times the cosmons will have evolved so far apart that the CTC's would disappear. The chronology protection conjecture seems to be saved for the Gott spacetime. There are still some unsatisfied aspects around spinning cosmic strings. If the cosmic string has a finite dimension, one needs to consider the coupled field equations, i.e., besides the Einstein equations, also the scalar and gauge field equations. It came as a big surprise that there exists a vortex-like solution in GRT comparable with the magnetic flux lines in type II superconductivity. Many of the features of the Nielsen-Olesen vortex solution and superconductivity will survive in the self-gravitating situation. These vortex lines occur as topological defects in an abelian U(1) gauge model, where the gauge field is coupled to a charged scalar field. It can easily be established that the solution must be cylindrically symmetric, so independent of the z-coordinate and the energy per unit length along the z-axis is finite. There are two types, local (gauged) and global cosmic strings. We are mainly interested in local cosmic strings, because in a gauge model, strings were formed during a local symmetry breaking and so have a sharp cutoff in energy, implying no long range interactions. It turns out that spinning cosmic string solutions can cause serious problems when CTC's are formed which are not hidden behind a horizon, as is the case for the Kerr metric. One can "hide" the presence of the spinning string by suitable coordinate transformation in order to get the right asymptotic behaviour and without a residue of the angle deficit. One obtains then a helical structure of time, not desirable. Further, it is not easy to match the interior on the vacuum exterior and to avoid the violation of the weak energy condition (WEC). Many attempts are made to find a physically acceptable solutions, but all failed. It is clear

that an additional field must be added to compensate for the energy failure close to the core of the string. That part of the mass density of a rotating string due to its angular deficit is insufficient. In general one can conclude that there is an urgent need for a satisfying physical interpretation of CTC's in this spacetime.

In my talk I will consider the spinning string in conformal gravity, where the interior consists of a gauged scalar field. Conformal invariance in GRT considered as exact at the level of the Lagrangian but spontaneously broken, is an approved alternative for disclosing the small-distance structure when one tries to describe quantum-gravity problems. Moreover, the conformal invariant cosmological models could solve the dark energy/matter problem.

We will write the metric as g_μν=ω^2 g˜_μν , with ω a dilaton field, handled on equal footing with the Higgs field and g˜_μν the "unphysical"metric. By demanding regularity of the action, no problems emerge when ω⟶0. For the vacuum exterior, exact (Ricci-flat) solutions are found with the correct asymptotic features which can be matched on the numerical interior solution. For global cosmic strings, the existence of CTC's can be avoided or pushed to infinity by suitable values of the integration constants. These constants can be used to fix the parameters of the cosmic string by the smooth matching of the solutions at the boundary. There seems to be no problems in order to fulfil the weak energy condition.

Our result could be a new possible indication that local conformal invariance and spontaneously broken in the vacuum, can be a promising method for studying quantum effects in GR, as was found in many other studies.

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