October 26, Monday

Session [I–A] Causality preservation and Chronology violation, CTCs

Chair M. Crosta

09:00 Time Machines: a new frontier of physics *Fernando de Felice [key-speaker]*

Abstract

Time may run forward but also backwards with respect to a selected observer and under extreme space-time conditions. One of these conditions is the occurrence of a curvature singularity which is naked with respect to asymptotic regions. Curvature singularities hide themselves inside black holes so their existence is implicitly accepted once black holes are accepted as astrophysical objects. Black holes however may not necessarily form as result of gravitational collapse so naked singularities may stand as a physical reality responsible of unusual effects. Once a naked singularity forms, a general theorem by Clark and de Felice (C.J.S. Clarke and F. de Felice "Globally non causal space-times. II-naked singularities and curvature conditions" Gen. Rel. Gravitation 16 ,1984, 139-148) assures that a region around the singularity exists where time runs backwards with respect to null infinity. A practical example of such a situation is offered by Kerr solution where an effective cosmic time machine can be realized. Chronology can then be violated and it is consequential that causality can be violated as well. However we shall not consider this as a real possibility being the conservation of causality a fundamental principle of physics, hence it is essential to find the way how Nature operates in order to preserve causality according to the "causality preservation principle" . Explicit indications of a space-time behavior which helps to avoid the insurgence of pathologies can be found in the Kerr black hole solution. It is well known that this solution describes a rotating black hole whenever the rotational parameter "a" is less than "m", where "a" is the specific angular momentum of the object which is collapsed to a black hole and "m" is its total mass so that "a<m". If that condition is violated then the black hole would no more exist and the resulting space-time solution would describe a naked singularity. When this circumstance manifests concretely then the space-time appears to react becoming "repulsive" preventing the above circumstance to occur.

Similarly, the existence and consequential swallowing by a Kerr black hole of negative energy mass as it would arise from Casimir-like effects in the vicinity of a black hole may violate the black hole condition. In this case and as will be illustrated by Sorge in his talk, the reaction of the black hole leads to decrease the amount of exotic mass which would be permitted to exists nearby a black hole. In all the above cases, the space time solution behaves as if it realizes that the occurrence of pathologies is approaching so the response appears timely consequent. It is then essential to analyze the persistence of this space time "precognition effect" in different solutions. This will be illustrated by Bini and Geralico in the next talk.

The most intriguing result of the above analysis shows that the space-time physics is still far from being fully understood.

09:45 Casimir energy in Kerr space-time *Francesco Sorge [invited]*

Abstract

We investigate the vacuum energy of a scalar massless field confined in a Casimir cavity moving in a circular equatorial orbit in the exact Kerr space-time geometry. We find that both the orbital motion of the cavity and the underlying space-time geometry conspire in lowering the absolute value of the (renormalized) Casimir energy as measured by a co-moving observer, respect to whom the cavity is at rest. This, in turn, causes a weakening in the attractive force between the Casimir plates. In particular, we show that the vacuum energy density $\langle \in vac \rangle ren \to o$ when the orbital path of the Casimir cavity comes close to the co-rotating or counter-rotating circular null orbits (possibly geodesic) allowed by the Kerr geometry. Such effect could be of some astrophysical interest on relevant orbits, as the Kerr ISCO's, being potentially related to particle confinement (as in some interquark models).

The work in Phys. Rev. D 90, 084050 (2015) generalizes previous results obtained by several Authors in the weak field approximation.

10:15 **Turning a charged black-hole into a naked singularity: a perturbative approach**
Donato Bini and Andrea Geralico [invited]

Abstract
A perturbative solution describing a two-body system consisting of a Reissner-Nordstrom black hole and a charged massive particle at rest is discussed. The properties of both the perturbed metric and electromagnetic fields are analyzed, with special attention to the conditions under which the background black-hole metric can evolve into a naked singularity solution.

10:45 COFFE BREAK

Session [I–A] Causality preservation and Chronology violation, CTCs

Chair F.Sorge

11:15 **Causal structure, spacetime singularities, and a new kind of time machine**
Ovidiu Cristinel Stoica

Abstract
In General Relativity, the causal structure (the lightcones) and a measure giving the volume determine the manifold structure and the metric, hence they may be more fundamental. However, starting with apparently healthy lightcones and volume may lead to singular metrics. Is this a bug, or a feature allowing to fix the singularities? I show that examples of spacetimes with healthy lightcone structure and measure include FLRW and other big-bang singularities. For standard black holes the causal structure appears to be broken, but I show that the Schwarzschild and Reissner-Nordström solutions can be embedded in spacetimes with healthy causal structure. This provides another reason why the causal structure is more fundamental. In addition, I show that if the lightcones are more fundamental, new pathologies of spacetimes are possible, allowing particles to exceed the speed of light without accelerating, and new kinds of time machines.

11:35 **Tangled up in Spinning Cosmic Strings** *Slagter Reinoud*

Abstract
A self-gravitating cosmic string (CS) is one of the few interesting solutions of compact objects of GR theory, just like the famous Kerr solution. However, they probably will not survive inflation. On a warped 5D brane world space time, it is conjectured there will be observable imprint of these so-called cosmic superstrings on the induced effective 4D brane space time. The space time around a spinning cosmic string shows additionally un-physical behaviour: it would possess closed time-like curves (CTC). However, it was recognized that these solutions violate physical boundary conditions. On a time dependent space time, complications arise, because one no longer can consider the CS as infinitely thin. Firstly, a spinning string must have a boundary separating the interior vortex solution from the exterior conical space time. Without the scalar-gauge field one encounters a serious problem, when approaching the boundary from the interior, in smoothly matching the angular momentum J(r) to a constant Jo . The weak energy condition is also violated. Additional fields must be added to compensate for this failure. The exterior space time can be written in diagonal form with rcs > Jo/(1-4πGμ) [μ<4πG], with μ the mass per unit length, at the expense of time-

helicity. From the interior field equations, J(r)/(1-4πGμ) can become larger than rcs. It was found that the metric component gϕϕ becomes negative for suitable values of the VEV. When one approaches the core of the string to experience the CTC, the proper time on the core stops flowing. This in contrast to the Kerr solution, where the CTC is always hidden behind the horizon. Secondly, stress-energy on the core of the mass acts as source for gravitational radiation due to the jump in the first derivative of the metric components. After the aperiodic emission of gravitational waves, the angular momentum should return to its original state, while the mass (or angle deficit of the CS) will decrease. However, there will also be an interaction between the scalar-gauge fields and the gravitational waves, not present in the zero-thickness vacuum CS. The core radius of the CS decreases as is observed from the numerical solutions. Thirdly, the exterior metric still has the constant angular momentum Jo , so non-diagonal. To obtain the desired flat non-conical space time far from the core (to restore boost invariance), one has to introduce a helical structure of time by the transformation t ⟶ t + Joϕ , also not desirable. It is conjectured that on a warped 5-dimension brane world space time many problems mentioned above disappear, because the induced effective 4D space time shows no conicallity. As a side effect, the CTC obstruction of "cosmons" on the 4D space time is weakened, but at the expense of resulting discrete values of the angle deficit.

11:55 Spacetime: pre-existing classical label vs. acquired quantum observable *Vikram Athalye*

Abstract

I'll take a quick review of different types (Aristotelian, Galilean and relativistic) associated with the notion of `spacetime'. Then I'll briefly discuss two topics: One involving reference frame dependent order of occurrence of disturbances, which leads to the requirement of the existence of antiparticles – i.e. an example from elementary particle physics; and the other involving description of a certain efficient quantum communication protocol to be implemented without definite causal order – proposed recently in the article 'Quantum correlations with no causal order' [Oreshkov et al, Nature Commun. 3, 1092 (2012)]. In the second half of the talk, with the help of the topics mentioned, I wish to bring forth different conceptual issues related with the notion of causality and with its violation. These invoke the meaning of existence of physical systems and the distinction between spacetime as (i) pre-existing classical label and (ii) acquired quantum observable.

12:15 Experiments testing macroscopic quantum superpositions must be slow *Giacomo De Palma*

Abstract

We consider a thought experiment where the preparation of a macroscopically massive or charged particle in a quantum superposition and the associated dynamics of a distant test particle apparently allow for superluminal communication. We give a solution to the paradox which is based on the following fundamental principle: any local experiment, discriminating a coherent superposition from an incoherent statistical mixture, necessarily requires a minimum time proportional to the mass (or charge) of the system. For a charged particle, we consider two examples of such experiments, and show that they are both consistent with the previous limitation. In the first, the measurement requires to accelerate the charge, that can entangle with the emitted photons. In the second, the limitation can be ascribed to the quantum vacuum fluctuations of the electromagnetic field. On the other hand, when applied to massive particles our result provides an indirect evidence for the existence of gravitational vacuum fluctuations and for the possibility of entangling a particle with quantum gravitational radiation.

12:40 LUNCH