Avenues of Quantum Field Theory in Curved Spacetime

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ento di Scienze Fisiche, Informatiche e Matematiche, Università degli Studi di Modena e Regg

Scientific Programme

Lagrangian Formalism for (Super)fluids and (Super)Solids

An effective field theory lagrangian formalism of four scalar DoF allows to describe both self gravitating non dissipative fluids and generic massive gravity models as identical systems. We elaborate on the stability of massive gravity models with six DoF and on the behaviour of cosmological perturbations.

Chiral fermions and trace anomalies

We discuss chiral fermions in gauge (and gravitational) backgrounds,
and focus on the structure of their trace anomalies.
We regulate the quantum theory with Pauli-Villars fields
and do not find party-odd terms in the trace anomalies.
The latter have been the object of recent analyses.

Gravity from worldlines

In this talk I will present the first-quantized description of Einstein gravity in terms of a point particle model with N=4 local worldline supersymmetries. In particular, I will discuss how the quantum consistency of the underlying first-quantized system produces fully nonlinear Einstein field equations for the target space metric, thus showing that this is not a peculiarity of string theory.
As a warmup, I will first present the simpler case of a worldline model with N=2 supersymmetries, describing Yang-Mills, and then move to the recently found results for gravity.

Aspects of scale invariant gravity

In this talk we discuss the possibility that tensor-scalar gravity is naturally scale-invariant, at least at the classical level. This assumption has a number of phenomenological consequences on the physics of the Universe at large scale and of black holes. We consider some of these to assess whether scale-invariance is a viable and fundamental symmetry.

Contact quantization: from the harmonic oscillator to the anharmonic one, and back

We will show how quantization together with quantum dynamics can be simultaneously formulated as the problem of finding an appropriate flat connection (named contact connection) on a Hilbert bundle over a contact manifold. In this setting we will discuss the local, formal gauge equivalence for a broad class of quantum dynamical systems; just as classical dynamics depends on choices of clocks, local quantum dynamics can be reduced to a problem of studying gauge transformations. As an example and application of this new approach to the quantization procedure, we discuss the gauge tranformation relating the contact connection for the HO to the AHO one, and possibly discuss the space of solutions of the parallel section problem.

Infrared dynamics in asymptotically FLRW spacetime

In various cosmological models, the curvature perturbation ζ has a constant solution in the infrared (IR) limit and ζ fulfills the soft theorem, a.k.a, the consistency relation. However, it has not been very clear what ensures these properties. We show the existence of the constant solution and the soft theorem, assuming the asymptotically FLRW geometry and the invariance under the large gauge transformation. In this regard, the situation is quite similar to gauge theories in asymptotically flat spacetimes (Strominger et al., 13). Based on this, we propose a general classification of cosmological models according to different IR behaviors.

Fakeons, microcausality and quantum gravity: the FLRW metric

Under certain assumptions, it is possible to make sense of higher derivative theories by quantizing the unwanted degrees of freedom as fakeons, which are later projected away. Then the true classical limit is obtained by classicizing the quantum theory. Since quantum field theory is formulated perturbatively, the classicization is also perturbative. After deriving a number of properties in a general setting, we consider the theory of quantum gravity that emerges from the fakeon idea and study its classicization, focusing on the FLRW metric. We point out cases where the fakeon projection can be handled exactly, which include radiation, the vacuum energy density and the combination of the two, and cases where it cannot, which include dust. Generically, the classical limit shares many features with the quantum theory it comes from, including the impossibility to write down complete, “exact” field equations, to the extent that asymptotic series and nonperturbative effects come into play.

Force-free electrodynamics near the rotation axis of a Kerr black hole

Despite their potential importance for understanding astrophysical jets, physically realistic exact solutions for magnetospheres around Kerr black holes have not been found, even in the force-free approximation. Instead, approximate analytical solutions such as the perturbative solution in the spin parameter proposed by Blandford and Znajek, as well as numerical solutions, have been constructed. I will introduce a new approach to the analysis and construction of such magnetospheres by considering force-free electrodynamics close to the rotation axis of a magnetosphere surrounding a Kerr black hole assuming axisymmetry. This is the region where the force-free approximation should work the best and where the jets are located. I will illustrate a systematic study of the asymptotic region with (split-)monopole, paraboloidal and vertical asymptotic behaviors. In the (split-)monopole case, I will show that by demanding regularity in the asymptotic region, at the rotation axis and the event horizon, restricts solutions of the stream equation so much that it is not possible for a solution to be continuously connected to the static (split-)monopole around the Schwarzschild black hole in the limit where the rotation goes to zero. This provides independent evidence to the issues discovered with the asymptotics of the Blandford-Znajek (split-)monopole from which it follows that its perturbative construction is inconsistent.

Towards a Worldline Monte Carlo approach in curved space

Numerical Worldline MonteCarlo techniques in flat spacetime have been deeply developed in order to extract physical information from QFT systems. We study a possible way to extend such procedures to the case of (Euclidean) curved spaces, where the proper-time discretization of a bosonic worldline point-particle is treated similarly to a time-slicing regularization for the associated quantum path integral. In particular, it induces a well-known counterterm in the theory which, together with curvature effects arising directly from the curved metric tensor, plays the role of a potential. To test the setup, we focus on the calculation of the free heat kernel of a bosonic point-particle on a D-sphere, for which the expressions of the effective potential and of the metric tensor were provided in closed form. Here, the curved space problem was turned into a flat space one, making the verification of our numerical method quite straightforward.

Superlines and Integration on Supermanifolds

Gauging 1-form center symmetries, Mixed anomalies and Infrared dynamics in SU(N) gauge theories

Consequence of gauging 1-form discrete center symmetries are studied in some simple SU(N) gauge theories. In particular, we discuss how the dynamics of strongly coupled chiral gauge theories is constrained by the mixed anomalies involving the new, 1-form symmetries and conventional 0-form symmetries.

A worldline quantization approach to higher spin theories

Using the effective action method, we investigate the higher spin actions in flat spacetime that can be obtained by integrating out a fermion field coupled to external higher spin source fields. In particular, an approach based on worldline quantization allows to identify the gauge symmetry of these models and to find the L_infinity structure that characterizes many (classical) field theories, including closed string field theory. This structure is also found to be consistent with a Yang-Mills-like model, where a limited amount of non-locality plays a crucial role in granting the absence of ghosts at perturbative level.

One-loop effective action of quantum gravity with fakeons and its phenomenology

In this talk I will expose the features of a new local higher-derivative theory of quantum gravity. The model is based on the concept of “fakeons” or “fake degrees of freedom”, which solves the problem of ghosts and leads to a unitary, renormalizable theory. In particular, I will show the absorptive part of the graviton self-energy at one loop and its contributions to the effective action, both in pure gravity and in the theory coupled with any type of matter field. I will point out the differences with respect to the usual treatment of higher-derivative gravity and some phenomenological implications. Finally, possible applications in cosmological pertrubation theory will be addressed.

Einstein-Maxwell theory in the worldline formalism

I will give a review on which types of quantum processes in Einstein-Maxwell can presently be performed using the worldline path-integral formalism in curved space, and what the advantages of such a formulation can be in favorable cases. The focus will be on one-loop photon-graviton amplitudes in vacuum and in a constant field, as well as the corresponding effective actions.

Thermal field theory with acceleration, entropy current and Unruh effect

We evaluate the thermal expectation values in a free quantum field theory at global thermodynamic equilibrium with acceleration in Minkowski space- time. It is found that Unruh temperature TU = A/2π is an absolute lower bound for the comoving temperature along the hyperbolic flow lines. We also present a method to determine the entropy current, and we find that at the Unruh temperature the integral of the entropy current yields the en- tanglement entropy of the right Rindler wedge in the Minkowski vacuum state.