Proposition de sujet de thèse

Intitulé français du sujet de thèse proposé :
Approche asymptotique à la dynamique et forme d'onde de la fusion d'une binaire de trous noirs

Intitulé en anglais :
Asymptotic approach to the binary black hole merger dynamics and waveform

Unité de recherche :
Institut de Mathématiques de Bourgogne (IMB)

Nom, prénom et courriel du directeur (et co-encadrant) de thèse :
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Domaine scientifique principal de la thèse :
General Relativity.

Domaine scientifique secondaire de la thèse :
Ordinary and Partial Differential Equations, Classical Field Theory, Integrable systems.

Description du projet scientifique
Antecedents: The detection by the LIGO and Virgo antennae of the gravitational wave signals emitted by binaries of stellar mass black holes has initiated a new stage in astrophysical and cosmological observational research, boosting an intense activity involving the collaboration among different communities in astrophysics, physics and mathematics. Together with the promising new prospects in the astrophysical setting, these detections (and the associated general relativity numerical simulations) have posed new questions and challenges in fundamental physics and in the mathematical modeling of the related physical processes. One of these challenges is provided by the (apparent) simplicity (and universality) of the detected waveform at the merger phase, the most violent and dynamical part of the process. Whereas the initial inspiral phase is well modeled by so-called post-Newtonian methods and the late ringdown is well understood in perturbation theory, the intermediate phase is modeled by the full numerical resolution of Einstein equations or by effective methods (e.g. the Effective One Body (EOB) approach) that reproduce correctly the observed signal but fail to offer a comprehensive qualitative understanding of the underlying physical mechanisms behind the waveform simplicity. Such unexpected genericity could actually offer a probe into a structural feature of theory. Assessing such a possibility defines the setting of this Ph.D project.
Objective: The ultimate goal is to construct an explicit effective model unveiling the physical mechanism underlying the simplicity and universality of the binary black hole waveform. Specifically, to assess if the generic simple form of the gravitational waveform responds to a specific structural characteristic of the theory or if, on the contrary, it is rather a generic feature of such kind of merger transitions actually insensitive to the details of the theory.
Methodology: The problem of extracting and understanding the physical mechanisms behind observational results and/or numerical simulations is a general feature in non-linear theories, as it is exemplified in the case of fluid dynamics with Navier-Stokes equations. Motivated by this fluid case, a starting point for the methodology will consist in the construction of an asymptotic formulation of the problem by performing a multi-scale expansion of the general relativistic description, leading to a 'wave-mean flow' description of the problem. The separation of the dynamics in terms of slow degrees of freedom providing the support for the

propagation of fast degrees of freedom will set the framework to import tools from dispersive hydrodynamics, namely in the context of the study of PDE phase transitions and its associated integrability and universality features. The incorporation of the structural particularities of black hole perturbation theory will feedback into the construction of the effective model.
Programme: As a tentative working program sketch, research stages are articulated around the following milestones: i) Multi-scale expansion of the PDE system coming from Einstein equations and adapted to the binary black hole model setting; ii) identification of the slow ('mean flow') and fast ('wave') dynamics and study of the scattering theory of the waves in (solitonic) solutions of the mean flow; iii) study of the PDE phase transition process from the inspiral post-Newtonian phase to the ringdown perturbative phase and identification of its generic functional dependence; iv) implementation of that functional dependence into an effective gravitational waveform template aimed at analyzing LIGO-Virgo data; identification of potential conserved quantities, in particular in an integrable systems theory approach.

Connaissances et compétences requises : General Relativity, elements of PDEs and ODEs, Classical Field Theory. Recommended: integrable systems theory.