Einstein's general relativity has different faces. On the one hand it presents itself as a beautiful theory which describes how matter/energy interacts with the geometry of spacetime at fundamental level. On the other hand it aims at describing all gravitational interactions at stellar, galactic and cosmological scales. Accordingly, fundamental aspects of gravitational interactions and their astrophysical implications are usually investigated by different communities. New precision observations of compact objects (black holes and neutron stars) and the imminent advent of gravitational-wave astronomy provide us with the unique opportunity to merge these disjoint efforts, and to test fundamental physics with astrophysical observations to unprecedented level. We are now entering the exciting era in which new observations can be used make contact between relativistic astrophysics and fundamental questions. The goal of this project was to connect this missing link.

Some of the major outcomes of this project are:

1) We developed a new theoretical formalism to study the deformability of spinning relativistic compact objects within general relativity. We proved that the so-called “Love numbers” of a spinning black hole are precisely zero up to second order in the spin. Furthermore, we computed for the first time the Love numbers for a spinning neutron star within general relativity. These results have important implications to estimate the effect of rotation in the context of gravitational-wave astronomy with advanced detectors (aLIGO, aVIRGO, KAGRA).

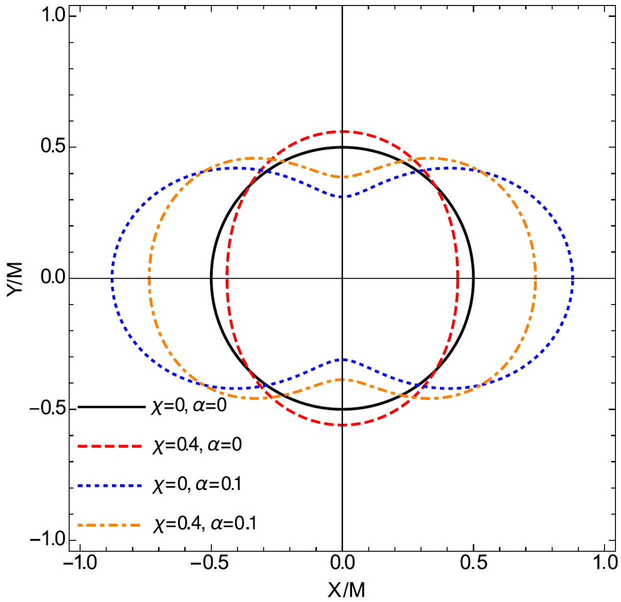

Figure 1: The intrinsic curvature of a tidally deformed spinning black hole in Cartesian coordinates and for different values of the dimensionless spin α and dimensionless amplitude of the tidal field α. Taken from [Pani et al. Physical Review D 2015]

2) We investigated possible strong-field tests of general relativity with present and future astrophysical observations. In particular, the scientist in charge and the principal researcher are two of the main authors of a Topical Review recently published by Classical and Quantum Gravity. The principal researcher has been Guest Editor for a Focus Issue “Black holes and Fundamental Fields” published on this topic.

3) We investigated the superradiant instability of spinning black holes in the presence of light bosonic fields. These results, together with astrophysical observations of spinning black holes, can be used to put constraints on light dark-matter candidates (see Figure 2 below). The principal researcher was the co-author of a monograph published by Springer in 2015 on this subject.

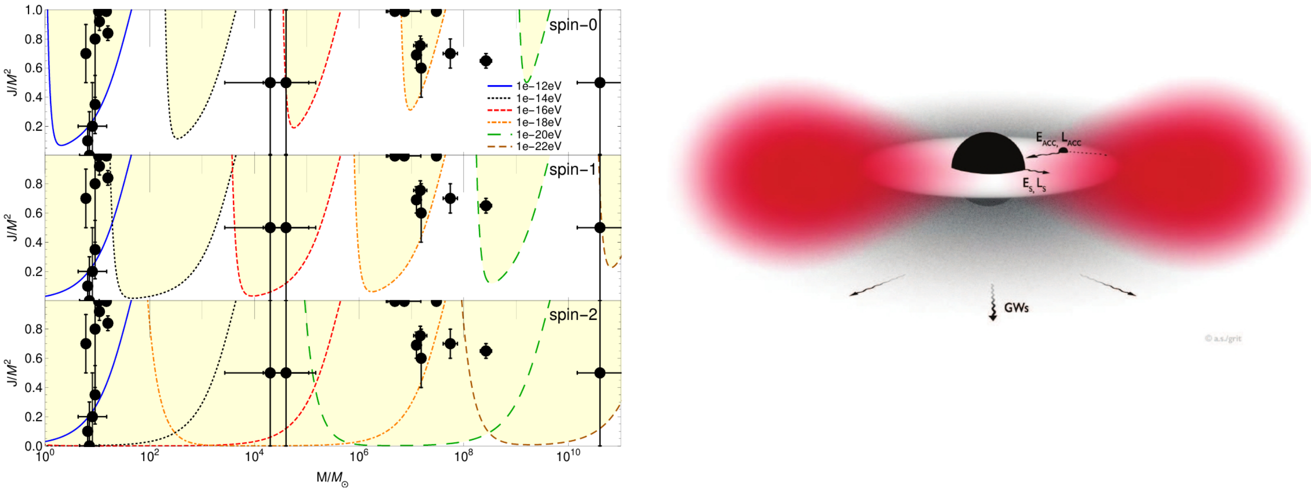

Figure 2: Left: Exclusion plots in the black-hole mass-spin plane derived from the superradiant instability against ultralight scalar, vector and tensor fields and compared with observations (results extended from monograph [Brito, Cardoso, Pani, "Superradiance", Springer 2015]). Right: the end-state of the superradiant instability: a spinning black hole surrounded by a bosonic cloud which emits gravitational waves. Taken from [Brito, Cardoso, Pani, Classical and Quantum Gravity 2015]

Overall, the results of this project can have an impact both for gravitational-wave astronomy and for fundamental physics and make a strong case for the key role that compact objects play in various areas of research, ranging from astrophysics to particle physics.

The outcomes of this project include 9 scientific papers published in leading internation peer-reviewed journals, 1 monograph published by Springer, 1 Topical Review published in Classical and Quantum Gravity, 1 Focus Issue published in Classical and Quantum Gravity, and 2 conference proceedings.

Results have been disseminated at various international conferences and workshops, including the 14th Marcel Grossmann Meetings at Sapienza (Italy) and the International Conference on Black Holes at the Fields Institute (Canada), and through invited plenary talks in leading research institutes, including the Albert Einstein Institute (Germany) and Fudan University (China). An international conference, two international workshops [including a workshop supported by the Lorentz Center (Netherlands)], and a parallel session at the 14th Marcel Grossmann were organized on the topics of this project.

All numerical codes developed and used during this project are publicly available at the webpage http://paolopani.weebly.com and the original papers are Open Access through the ArXiv database [http://www.arxiv.org].

The principal researcher as served as senior teaching assistant for the "Electromagnetism" course in Physics at Sapienza (duties included ~3hr/week of lectures, oral evaluations and preparing and correcting exams), as the co-advisor of a PhD student (Richard Brito) and as the advisor of a master student.