Description for the general public

The infall of matter onto celestial bodies, called accretion in astrophysics, can release enormous amounts of gravitational energy. Accretion onto compact bodies, i.e., black holes and neutron stars is the most powerful source of energy in the Universe in which from a few to almost forty percent of the rest-mass of the infalling matter can be released. To be compared with thermonuclear reactions where no more than a fraction of a percent of the nucleons rest-mass is released. The energy released by accretion is the source of the electromagnetic radiation observed from quasars, active galactic nuclei, gamma-ray bursts and X-ray binaries. The electromagnetic radiation released by accretion exerts a radiative force on the infalling matter. This force increases with luminosity and at some critical value (depending on the accretor's mass only) known as the Eddington luminosity the radiative and gravitational forces are equal which must influence the nature of accretion and, in some cases, even could stop the infall of matter. However, contrary to a rather widely spread opinion, the Eddington luminosity is only a critical but not a limiting luminosity: accretion can produce luminosities exceeding, even by a large amount, the critical value. First, in general accretion flows are not spherical but form discs or tori and in such a geometry the Eddington luminosity can be naturally exceeded. Second, at very high accretion rates radiation might be non-isotropic, strongly emitted along a particular axis, i.e., can be strongly collimated. In such a case the isotropy assumption may lead to a serious overestimate of the really emitted luminosity. Finally, contrary to common belief, in the case of black hole accretion there is no Eddington limit on the accretion rate because photons get trapped by the infalling matter finish falling with it under the horizon.

Contrary to the case of sub-Eddington, thin accretion discs for which a standard model exists, no such a model exists for thick super-Eddington accretion flows. The more than 40-year effort to understand the high-accretion rate physics, to which the present PI and one of the co-investigators brought important contributions, has ended with several models of super-Eddington accretion flows. These models presumably describe different aspects of the problem but their synthesis or/and unifications is clearly necessary. This synthesis is the main scientific goal of the present project. A project that has become topical due to the recent observations breakthroughs concerning the nature of super-Eddington accretion flows.

Until recently the direct unambiguous evidence of the existence of super-Eddington accretion was missing and when apparently super-Eddington luminosities were observed one was assuming that the mass of the accretor is sufficiently high to make the luminosity subcritical. This was the case of the ultra-luminous X-ray sources (ULXs) defined as sources with luminosities larger than the Eddington luminosity for 10 solar masses. It was commonly assumed that ULXs contain so-called intermediate mass black holes with masses between 500 to 10 000 solar masses (more massive black holes are found in galactic nuclei and are classified as supermassive). In this way one was solving two problems at once : one was getting rid of super-Eddington accretion and one was finding the, until now elusive, intermediate mass black holes. The source HLX-1 in the spiral galaxy ESO 243-49 is a special case: the mass of its black hole must be of the order of 10 000 solar masses for it not be super-Eddington. The situation has completely changed in 2014 when the mass of the compact body was measured in two ULXs. In both case the masses are well below the intermediate range, especially in the case of the source X-2 in the star-forming galaxy M82 where the compact body is a neutron star, whose mass therefore cannot larger than 3 solar masses. The luminosity of this source is 100 times the Eddington luminosity.

Although the PI and co-I's of this project have already worked in the past on super-Eddington accretion and made pioneering and important contributions to the field, the latest discoveries of unambiguously super-Eddington X-ray sources are an extremely strong motivation to attempt the synthesis of various ULX models and determine the evolutionary paths leading to the presently observed systems containing neutron stars and black holes. These are the objectives of this research project. The unification and synthesis will involve both numerical and analytical models.

Understanding and describing the observed variability of ULXs will be another important goal of this project. In some of these objects one observes outbursts very similar to those seen in many X-ray binary systems containing stellar-mass compact objects. It is therefore reasonable to assume that the same outburst mechanisms are at work in both types of systems especially that this mechanism concerns the outer disc regions. This conjecture will be tested by extending the outburst model (of which the PI is a co-author) to super-Eddington accretion discs. This will have a fundamental importance for solving the HLX-1 black hole mass puzzle because the characteristic times of its outbursts are in total contradiction with the assumption of an intermediate mass but fit very well a mass of few solar masses.

Finally, because the majority, or maybe all, ULXs are close binary systems containing stellar-mass compact bodies, one has to explain where they come from and where they are heading, i.e., one has to determine their evolutionary status and explain why the mass loss from the compact body's stellar companion is so high. In achieving this key scientific objective of out project the highly reputed population-synthesis and evolutionary numerical codes authored by one of the project's co-I's will be used. This will provide a synthesis of the accretion physics results with the outcome of the evolution simulations.