Searching for stability criterion of differentially rotating neutron stars

Neutron stars are one of the most exotic objects in the universe. After finishing nuclear synthesis, cores of massive stars collapse under their own gravity, and, if the star is massive enough, they explode as supernovae. The remnant of such an event can be black hole or a neutron star – an object with densities comparable with densities of an atom nucleus.

Currently a maximal mass of nonrotating neutron stars is estimated to be a little more than twice the mass of the Sun. If this limit is exceeded, instead of a neutron star a black hole is formed. Nevertheless, young neutron stars right after formation in a supernova explosion can rotate very rapidly, with hundreds of rotations per second. Additionally, at the very beginning they do not behave like rigid bodies; the internal layers of the star may rotate faster than the external ones. Because of those effects neutron stars can support mass even four times larger than non-rotating ones.

However, not all theoretically possible configurations of mass have the chance to survive. Some neutron stars are unstable; even small perturbations may cause them to collapse and form a black hole.

The goal of our project is to study the threshold between stable and unstable models of young remnants of supernova explosions and find the maximum mass, which a stable neutron star can reach.

One of the most important problems in modern studies of neutron stars is the limited knowledge about the properties of matter from which they are built. Such dense matter cannot be produced and studied in any Earth-based laboratory. Because of that, our main sources of information about it are observations of neutron stars. There are many different models that describe the properties of dense matter. In our studies, we will choose a subset that currently fits the observational data.

The proposed project will rely on numerical simulations of these types of object. Using code developed by us we will choose a set of configurations that are close to the hypothetical limit of stability. For each configuration we will perform a simulation of its evolution, checking if introducing small perturbations will cause a prompt collapse to a black hole. Thanks to those results, we will find a threshold between stable and unstable neutron stars.

We will study the stability threshold in terms of the astrophysical parameters of the neutron stars, e.g. mass or rotational speed. Based on those information we will find a criterion of stability that is independent of the model we choose.

Our results will help with proper interpretation of observational data of neutron stars, in particular in the gravitational waves domain. Good undersanding of the properties of neutron stars will help in studying areas of physics that are otherwise unavailable.