Modeling spin equilibrium in Be X-ray binary pulsars

The research project is offered by PI G. Vasilopoulos in collaboration with Profs. D. Hatzidimitriou and M. Petropoulou. The project can be a part of an undergraduate or master thesis depending on the applicants interest. Interested parties can contact the PI via email before May 30^{th}, applications will be evaluated in the order they are received until position is filled.

1 Research project

X-ray pulsar (XRPs) systems are composed of a highly magnetized neutron star (NS) that accretes from a donor star. Typically an accretion disk (Keplerian) may be formed around the NS, however due to the high magnetic field of the NS the disk is truncated at 100 times the NS radius, where the magnetic pressure is balanced by pressure from accreting gas. X-rays are produced as the dynamic energy of the infalling material is converted to radiation. The bulk of the observed X-ray radiation is produced near or on the NS surface, thus we observe X-ray pulsations as the NS rotates. A result of the mass transfer from the accretion disk onto the NS is the transfer of angular momentum resulting in changes in the NS spin. If mass accretion was stable here would be a unique state where the NS would end-up rotating at constant frequency, this frequency would be a function of mass accretion and magnetic filed. However, XRPs are highly variable systems as mass transfer is not stable between the two stars. In many cases variability is caused by eccentric orbits that result in outbursts during periastron passage. Changes in mass transfer result in changes in mass accretion causing the inner radius of the accretion disk to change accordingly. In cases of low mass accretion, the inner disk radius might be large enough. At these radii the disk may rotate more slowly than the NS, hence the disk steals angular momentum from the NS instead of depositing more.

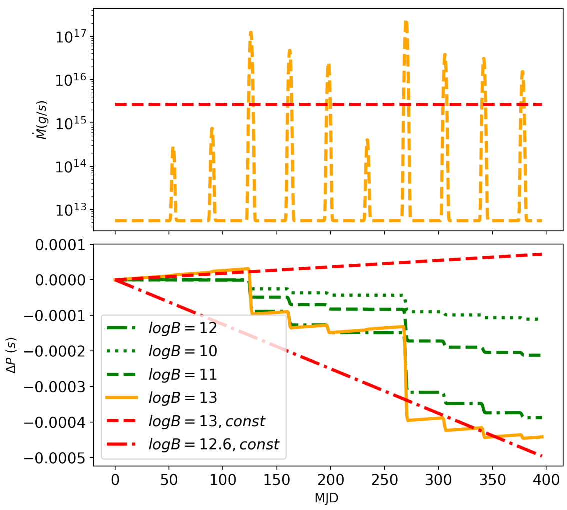

Figure 1: ***Upper:*** Here we see a fictitious duty cycle for changes of mass accretion in a binary with 36 d orbit and a NS with a 15 s spin period over a period of about 1 year. Red line denotes the average mass accretion rate over the same period. ***Lower:*** Changes of the spin period of the NS for various magnetic field strengths between 10^{10} -10^{13} G. Red lines denote the change assuming a constant mass accretion rate, while all other lines incorporate a variable mass accretion rate. Notice the spin-down trends between outburst.

The evolution of the spin period of pulsars takes thousands of years. Most of the systems we observe in our life span are rotating near some kind of equilibrium. This means that the gain and loss of angular momentum, during epochs of increased and decreased accretion are balanced. To make things more complex the transfer of angular momentum is not a linear process, so a process with variable mass rate cannot be replaced by a steady mass accretion rate and we need to treat this process in a dynamic way.

As part of this project you will learn the physical mechanisms involved in the systems described above and you be asked to perform simulations of analytical models that mimic variable mass transfer. The goal would be to perform a parametric study of the main parameters that dictate the evolution of such systems. The questions that we would like to answer involve the short term and long term behavior of these pulsars. In short timescales (years-decades) what do we learn by observing these systems near equilibrium, can we make estimates on the magnetic field strength of the NS, or is the accretion duty cycle more important? On long time-scales (10^{3-6} yr) what spin equilibrium periods should we expect from systems with same initial periods but different magnetic fields and accretion duty cycles. What is more important than their final spin period, the mass accretion cycle or the magnetic field?

Requirements, skills, qualifications:

1. Creativeness, motivation, and independence are especially welcome.
2. Experience with astrophysics, statistics is appreciated.
3. Good experience with Python is mandatory.
4. Proficiency in English.

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