Feeding the Magnetized Whirlwind

SUMMARY.

A unique laboratory for the study of radiation processes in extreme accretion are X-ray pulsars. These are found typically in high-mass X-ray binaries (HMXBs), while the brightest and most variable ones are those where the donor is a Be star (i.e. BeXRBs). Their environment combines some of the strongest magnetic fields ($> 10^{12}$ G) and effects of strong gravity, while also gives us the opportunity to gain insight onto the Neutron Stars (NS) equation of state. Bright outbursts of BeXRBs have also helped us understand the most bright binary systems, the so called Ultra-luminous X-ray sources. The goal of this Meteor project is to gain a broad understanding of high energy astrophysics and accretion processes in magnetized NS, while also working with state of the art methods and tools. (Illustration concept by G. Vasilopoulos, created with the assistance of AI (OpenAI, DALLůE))

OBJECTIVES

- *What will students learn? (**Knowledge:** non-thermal radiation processes, accretion onto compact objects, neutron star physics)*
- *What will students learn to do? (**Skills:** problem solving, data analysis, spectral fitting)*

INSTITUTE

- Department of Physics, National and Kapodistrian University
- NKUA , PI webpage
- Un. Campus, Zografou, Athens

THEORY

by Georgios Vasilopoulos

X-ray pulsars (XRPs) are systems composed of a highly magnetized neutron star (NS) that accretes from a donor star (see review [1]). Typically a Keplerian accretion disk 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. Particles travel (almost free falling) towards the NS magnetic poles following the magnetic lines, until near the NS surface their fall is halted by radiation pressure. Depending on parameters like the NS magnetic field and mass accretion rate, a shock might form just above (a few meters or even Km high) the accreting poles, and almost all radiation we observe from X-ray pulsars come from this area that we commonly call accretion column. Since the bulk of the observed X-ray radiation is produced near or on the NS surface, we tend to observe X-ray pulsations as the NS rotates (due to misalignment of rotation and magnetic axis). A critical aspect of the above picture is the transfer of angular momentum from and to the NS as material is accreted and the magnetic lines interact with the accretion disk and outflowing material. In this interplay we can rely on physical models to connect observables (i.e. Flux and spin evolution) to fundamental parameters of the system (NS magnetic field and mass accretion rate).

APPLICATIONS

by Georgios Vasilopoulos

In order to better understand the properties of the BeXRBs one need to perform detailed spectral and temporal analysis of data collected during outbursts where the sources are bright (e.g. [2],[3]). A way to do this is via application to torque models, where based on measured fluxes, one can compute spin-up/down rates and compare them with spin-evolution of a NS during outbursts (e.g. [4]).

Depending on the applicants interests it is possible to work on projects related to (or variations of those); **(1)** Applications of torque models for major outbursts, or for long-term/secular evolution of spin period between outburst. **(2)** Data analysis of X-ray observations either archival data, or data from new outbursts that were obtained from telescopes like XMM-Newton, NuSTAR, NICER and Swift.

MAIN PROGRESSION STEPS

- `Tier 1:` High-Energy Astrophysics course and exercises
- `Tier 2:` project - data analysis
- `Tier 3:` project - modeling

EVALUATION

- `Theory grade [20%]` Exercises - simple problems based on lectures (50%), Presentation of an article in journal club (50%)
- `Practice grade [40%]` Project: clarity of code, understanding of context, short written report, presentation skills
- `Defense grade [40%]`
  - Oral and slides quality
  - Context
  - Project / Personal work
  - Answers to questions

BIBLIOGRAPHY & RESOURCES

- [1] Mushtukov, A. & Tsygankov, S. 2022; arXiv:2204.14185
- [2] Young H. N 2025, MNRAS, 536, 1357
- [3] Vasilopoulos et al. 2020, MNRAS, 494, 5350
- [4] Stierhof et al. 2025, A&A accepted

CONTACT

Georgios Vasilopoulos
☎ +30.210.727.6825
✉ gevas@phys.uoa.gr