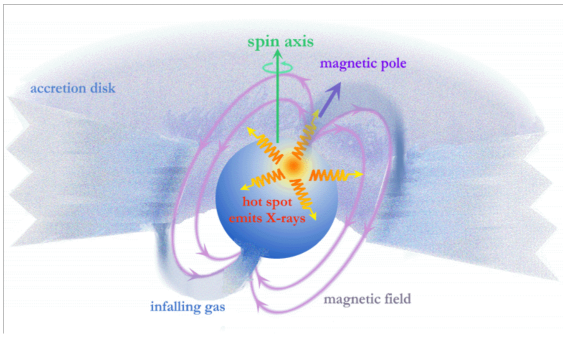
Accreting highly magnetized Neutron Stars



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 Credit: CXC/S. Lee)

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 & Maria Petropoulou

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). However, the story goes on; the disk itself can produce soft X-rays, or reprocess the pulsating emission. This is confirmed by the presence of a a non pulsating soft component in the X-ray spectrum of many XRPs.

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]). Depending on the applicants interests it is possible to work on either of the following topics; **(1)** Study of physical spectral models for the radiative emission of the accretion column, with the goal of identifying patterns of variability during outbursts and with application in observations, **(2)** focus on numerical methods and the development of a toy model for the radiation from the accretion column, or **(3)** exploring the possibility of replacing computationally expensive models with those trained via neural networks (e.g. see similar application [4]).

Last but not least for the project you will be given the opportunity to work on either archival data, or data from new outbursts that were obtained within 2024 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 (100%): 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] Koliopanos, F. & Vasilopoulos, G. 2018 A&A, 614A, 23
- [3] Vasilopoulos et al. 2020, MNRAS, 494, 5350
- [4] Tzavelas et al. 2024 A&A 683A, 185

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