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The interview with the author of the PhD thesis:

„Radiative simulations of moderately magnetized accreting pulsars as ultraluminous X-ray sources“

What first sparked your interest in the universe and astrophysics?

I developed an interest in physics when I first studied it in school. It felt exciting to me immediately, and I knew I wanted to become a physicist. Later, during my bachelor's studies, I explored astronomy, which sparked my curiosity about space and celestial objects, and I became an amateur astronomer. Later, in my master's study, I was drawn to compact objects like neutron stars and exotic ones like quark stars – very dense and extreme systems where the laws of physics extend far beyond what we know and can experience on Earth.

Over time, I became more interested in high-energy astrophysics and began working with numerical simulations during my PhD. I was fascinated by how powerful computational methods can assist us in exploring these extreme environments and answering complex scientific questions that would otherwise remain out of reach.

What has been the biggest challenge in your research?

One of the biggest challenges in my research has been integrating complex physics with numerical methods. I study extreme environments, such as extremely high accretion rates onto neutron stars. These systems involve very strong magnetic fields and high-energy processes, which make it challenging to model.

To study these astrophysical systems properly, we need a deep understanding of fundamental physics, along with advanced computational techniques. Ensuring that the simulations are stable, accurate, and realistic takes considerable effort. It also requires access to powerful computers and well-optimised code.

How have the resources of the ACC Cyfronet AGH contributed to the part of your research involving numerical simulations?

The computational resources provided by ACC Cyfronet AGH were essential for my research. Having access to high-performance supercomputers allowed me to run large and complex simulations that would not have been possible on regular computers.

I utilised Cyfronet's resources to conduct a detailed parameter study of my model, resulting in findings with significant impact in the field of ultraluminous X-ray sources (ULXs). The capacity to run a number of large-scale simulations efficiently enabled me to explore various physical scenarios and gain a much deeper understanding of these systems. This played a central role in shaping my PhD research and the scientific conclusions I reached.

What's the most surprising thing you've learned through your research?

The focus of my PhD research is understanding ULXs through numerical simulation. These objects seem to emit more X-rays than expected from typical accreting stellar-mass compact objects, but less than the accreting supermassive black holes found at the centre of galaxies. Although numerous models have been proposed to explain their unusual luminosity, their nature remains not fully understood. One of the possible scenarios is Super-Eddington accretion onto magnetized neutron stars. Simulating such systems is very challenging due to the presence of a solid surface and the strong magnetic fields of the neutron stars. This is one reason why only a few realistic simulation models exist for these systems.

What surprised me in my research was the role of the neutron star's magnetic field strength in determining whether the object appears as a ULXs. In my simulations, I found that neutron stars with moderate magnetic field strength, on the order of 10^{10} Gauss, can appear as ULXs if they accrete above the Eddington limit. However, if the magnetic field is about one order of magnitude stronger, the apparent luminosity is significantly reduced, and the system no longer falls into the ULXs category.

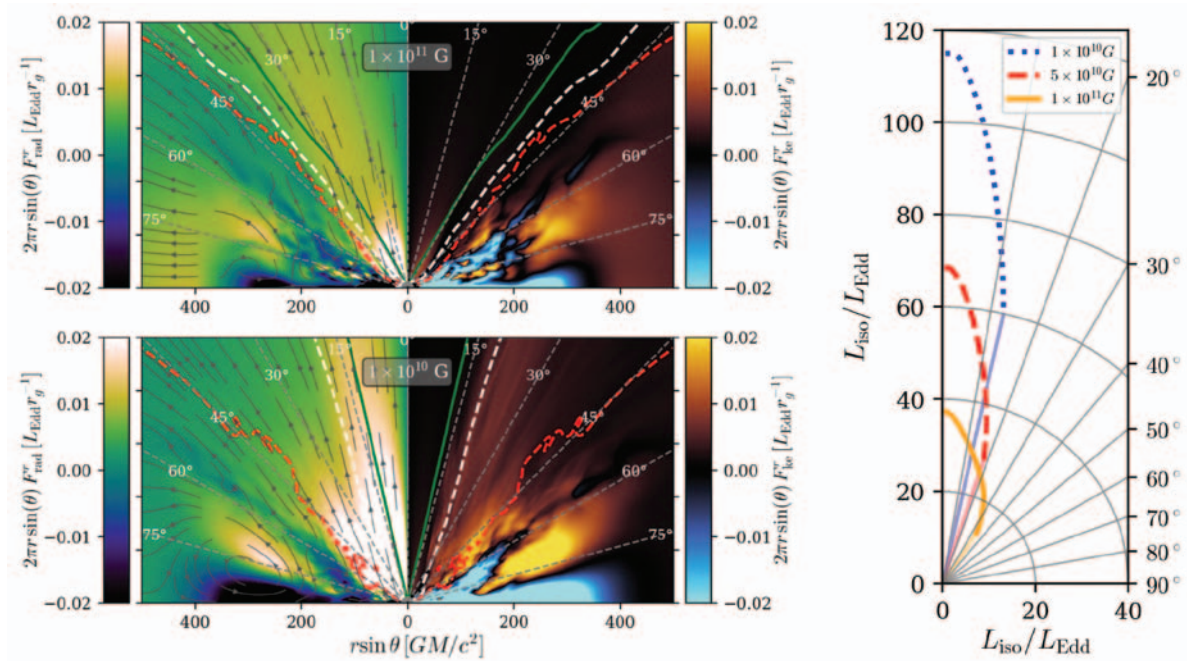
This result was particularly interesting because a theoretical model suggests that magnetars, which have extremely strong magnetic fields, could power ULXs. However, these models are somewhat inconsistent with observational data. An alternative model, more aligned with the observations, proposes that ULXs are powered by neutron stars with moderate magnetic fields. In this scenario, the extraordinary luminosity arises from radiation beaming rather than extreme magnetic strength. Our simulations provided new support for this latter idea and showed how the strength of the magnetic field influences the system.

What advice would you give to young scientists entering the field today?

Stay curious and don't give up easily. Astrophysics needs both creativity and deep thinking. Don't be afraid to ask bold questions or take on difficult problems.

Modern science works best when analytical models, simulations, and observations come together, so be open to collaborating with people from different areas of science. It's also important to learn how to code and analyse data.

And once again, be patient with yourself. Science takes time, and progress doesn't always follow a straight path. Things won't always go as planned, but even those moments can teach you something valuable. Every step you take helps you grow as a scientist.



Kinetic and radiation flux of simulations with two different magnetic dipole strengths for the neutron star, along with the polar diagram of apparent luminosity L_{iso} computed for three models, which indicates that ULXs can be accreting neutron stars with a magnetic dipole of 10^{10} Gauss. (From: Kayanikhoo et al., 2025)