



# ÉCOLE DOCTORALE

## SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT ET PHYSIQUE DE L'UNIVERS, PARIS

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**Titre du sujet : Unveiling the universal coupling between accretion and ejection: from microquasars to extragalactic transients**

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Équipe d'accueil : *AIM-LEPCHE*

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**Développement du sujet :** (Maximum 2 pages)

### **Scientific context and motivation**

Accretion and ejection are two intimately connected processes that govern the growth and energetic output of compact objects, in particular black holes of all masses, throughout the Universe. Microquasars—stellar-mass black hole or neutron star binaries exhibiting relativistic jets—represent bright nearby and rapidly evolving laboratories to study these phenomena in real time. Their various behaviors offer a unique window into the universal physical processes at work linking accretion flows and jet formation across many orders of magnitudes in mass (from stellar systems to active galactic nuclei), time scales (seconds in gamma-ray burst to millions of years in star formation), and distance in the Universe (local to cosmological). Yet, despite decades of observation, the physical coupling between the inner accretion flow and the launch and collimation of relativistic outflows remains only partially understood.

Accretion/ejection is a key driver of energy feedback in the Universe, regulating star formation and shaping the evolution of galaxies. By controlling how black holes and neutron stars interact with their environment, these processes connect small-scale plasma physics to large-scale cosmic structures. Understanding the accretion/ejection intimate coupling is therefore essential not only for galaxy formation and cosmology, but also for interpreting the various populations of **astrophysical transients**—such as tidal disruption events (TDE, disruption of stars by a supermassive black hole) and relativistic flares in AGNs—that reveal accretion and jet activity in action across cosmic time.

We aim at extending our long-term work, based on multi-wavelengths (radio to gamma-rays) observations, on Galactic sources to **TDEs**. This is essential, as they provide unique opportunities to observe the onset of accretion (in X and gamma-rays) and jet formation (mostly in radio) around previously dormant supermassive black holes. In particular, **jetted TDEs** represent extreme cases where relativistic outflows are launched in response to a sudden accretion episode, directly probing new aspects of the accretion/ejection causal links. Current new facilities such as **Einstein Probe** and **SVOM** will greatly increase the number of detected TDEs and related transients, allowing detailed studies of their intermediate-timescale variability, a key regime to understand how jets respond to

changes in the inner accretion flow. Meanwhile, the **Vera Rubin Observatory (LSST)** will unveil thousands of new optical transients, and the next generation of radio facilities (e.g. **MeerKAT, SKA** precursors) will provide the crucial complementary view of jet emission and energy feedback. Combining these discoveries with insights from microquasars will allow us to probe the fundamental physics of jet launching and energy feedback, linking the behavior of stellar-mass systems to the growth and impact of supermassive black holes in shaping galaxy evolution.

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## Objectives and key questions

This PhD project aims to elucidate the universal coupling mechanisms between accretion and ejection by conducting a comprehensive, multi-wavelength investigation of microquasars. The candidate will:

1. **Characterize the inner accretion flow–jet connection** through time-resolved spectral and timing analyses, linking X-ray states to radio jet signatures.
  2. **Model the physical drivers** (magnetic fields, radiation pressure, plasma instabilities, timing the exact jet ejection by tracing the jets proper motion) responsible for transitions between accretion regimes and jet production.
  3. **Extend the findings** to other transient phenomena—such as tidal disruption events (TDEs) and newly emerging classes of relativistic transients—to test the universality of the accretion–ejection coupling across scales.
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## Methodology and data

The project will exploit data from **SVOM** (Space-based multi-band astronomical Variable Objects Monitor), combining its sensitive X-ray and optical observations with coordinated **radio follow-up** from new-generation facilities (e.g. MeerKAT, SKA precursors, upgraded ATCA). This synergy will allow for unprecedented temporal and spectral coverage of microquasar outbursts and TDE flares.

The CEA/IRFU/Dap team plays a central role in the SVOM mission, particularly in the development and operation of its real-time transient detection and alert system, which enables the rapid identification and follow-up of high-energy variable sources and cosmic transients across multiple wavelengths.

The PhD student will be part of the SVOM collaboration, and as such will participate to the real-time survey of the sky and will therefore be in the forefront to detect eventual new transient phenomena associated with the systems we aim at studying. The PhD student will also conduct cross-correlation studies between different energy bands, and use theoretical modeling and simulations to interpret the observed variability patterns in terms of physical processes in the accretion–jet system.

Equally important is the ability to **analyse and re-interpret the wealth of data already available in current archives**, which provide invaluable long-term baselines and context for new detections. Combining archival studies with upcoming observations will ensure a comprehensive view of the temporal and spectral evolution of astrophysical sources, maximizing the scientific return of both past and future missions.

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## Expected impact

By bridging observations of Galactic microquasars with extragalactic transient phenomena, this project will significantly advance our fundamental understanding of how matter accretes onto compact objects and how energy and momentum are released into their surroundings. The anticipated results will contribute to a unified framework of accretion–ejection physics, essential for interpreting the rapidly growing number of transient discoveries expected from new and upcoming missions and facilities such as **SVOM**, **Athena**, **LSST**, **ngVLA** and **SKA**.

Furthermore, the advent of these powerful new facilities in both the **radio** and **high-energy domains** is revolutionizing time-domain astrophysics. The PhD student will therefore develop original competences through emerging approaches designed to explore the transient sky, including the use of artificial intelligence to process and classify the vast number of alerts expected from surveys such as LSST. By fully exploiting multi-wavelength data on transient phenomena, the PhD student will also learn to interpret these observations within robust theoretical frameworks. The analytical and computational methods acquired during the project are broadly applicable and will equip the candidate with valuable skills transferable well beyond astrophysics, whatever career path they choose to pursue after the PhD.

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## PhD coordination

Supervisor: Prof. Stéphane Corbel

Co-supervisor: Dr. Jérôme Rodriguez

S. Corbel is Core Member of the SKA transients working group, he led the French effort for ten years in order to build up the French community behind SKA. He is Co-I of the long-term XKAT program (formerly ThunderKAT, active for 8 years) to weekly observe any X-ray binary in outburst and PI of a MeerKAT program dedicated to jetted-TDEs. He also led many multi-wavelengths proposals (including Chandra, Hubble, ...) to study the jet properties and their feedback on the ISM. He discovered the radio/X-ray coupling in microquasars that latter led to the discovery of the fundamental plane of black hole activities.

J. Rodriguez is an expert in high energy emission from compact object and a recognized expert in X-ray timing, and analysis of hard X-ray observations based on coded mask telescopes (such as the SVOM/ECLAIRs one), including non-trivial measures of polarimetric properties. He is a SVOM CoI, and as such as access to the SVOM observations. He is a co-convener of the SVOM working group on general program observations, and will, through his roles, permit the PhD student to be a SVOM affiliate scientist. This will permit them to participate to all activities related to the real-time survey of the sky and thus be at the forefront of eventual discoveries of (new) sources. JR is also Co-I of Einstein Probe accepted observing program, which means guaranteed access to those two missions.

Collaboration: Oxford University, University Cape Town, (XKAT program), Chinese collaborators for SVOM and Einstein Probe

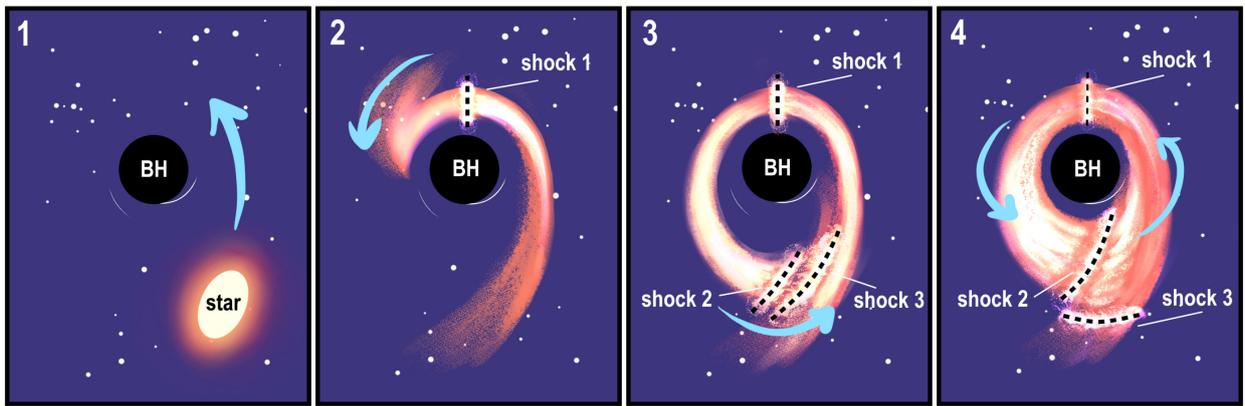


Figure 1: In a Tidal Disruption Event, a star moves close enough to a supermassive black hole so that the gravitational pull of the black hole bends the star until it is destroyed (image 1). The stellar matter from the destroyed star forms an elliptical stream around the black hole (image 2). Tidal shocks are formed around the black hole as the gas hits itself on its way back after circling the black hole (image 3). The tidal shocks create bright outbursts of polarised light that can be observed in optical and ultraviolet wavelengths. Over time, the gas from the destroyed star forms an accretion disk around the black hole (image 4) from where it is slowly pulled into the black hole. The scale of the image is not accurate.

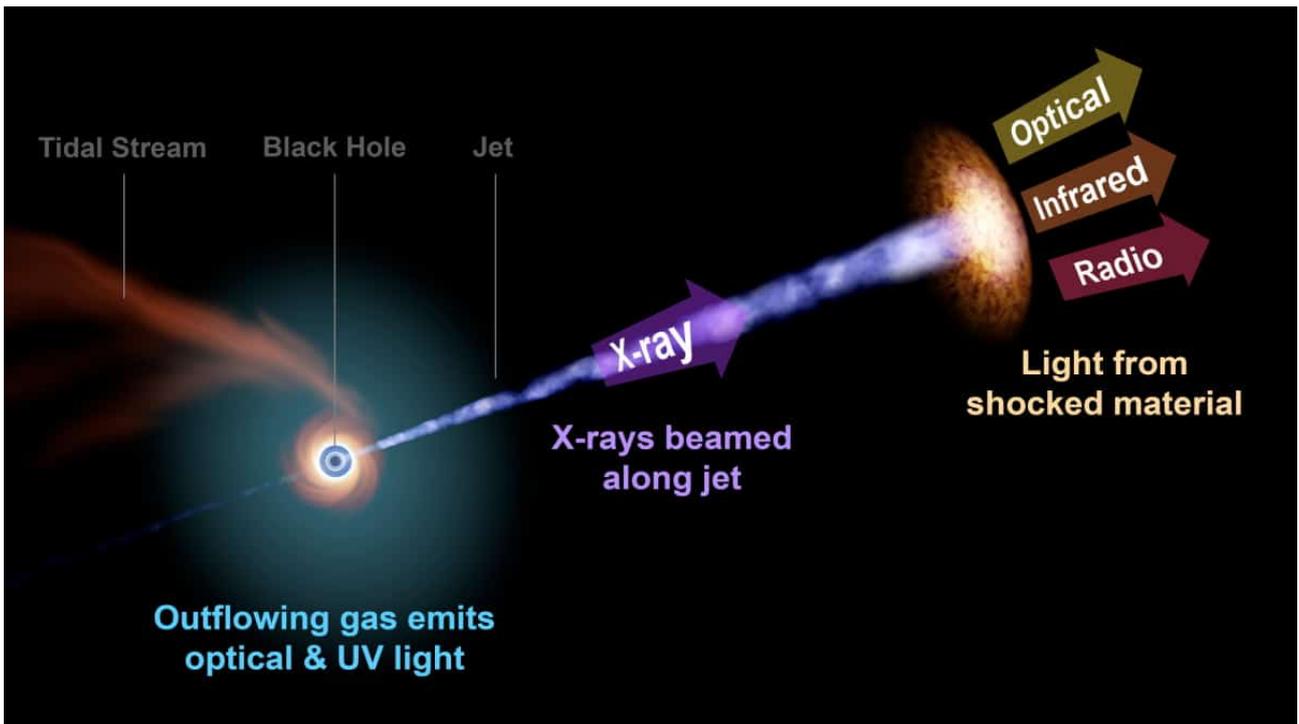


Figure 2: Tidal disruption event. A black hole devours a star that has come too close. In rare circumstances, this may also result in jets moving with almost the speed of light that generate light at many frequencies.