OSSSB@LSST

Outer Solar System Small Bodies in the era of LSST

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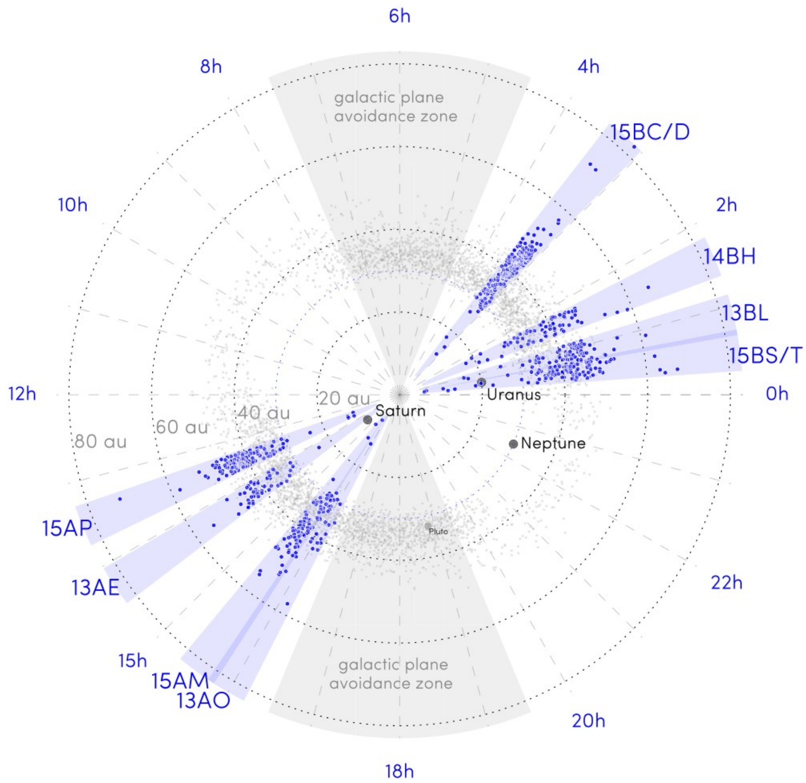
Start date: 1 October 2024
Duration: 2 years

Master: CompuPhys

Abstract:
Solar system study is one of the main scientific drivers of LSST. A large international effort has been put in place for the detection of Solar System Small Bodies (SSSB), mainly those interior to the orbit of Jupiter. Thanks to our expertise on TransNeptunian Objects (OTN), we have been asked to deal with these populations in the LSST data. TNO observations face specific issues and we participate in the fine tuning of observing sequence and in developping particular algorithms and codes to detect and characterize TNOs. Asteroids and other fast moving SSSBs separate themselves from TNOs due to their trailing in LSST images. We'll thus develop particular detections tools for TNOs, based on those we developped in our previous surveys, and adapt them to the specific observating cadence of LSST. Beyond initial detection, these tools must provide the link between various observations of a given TNO. In order for the survey to be of scientific interest, we MUST be able to model it, since it will be incomplete, especially at small sizes. This will allow to link observations tothe real world hiden in the outer reaches of the Solar System. This survey charaterization is what makes the strength of our previous surveys, and we'll apply our expertize to this new project.

Scientific rationale:
Our project aims at improving our understanding of the formation and evolution (including the modern-time circulation of materials) of our Solar System. For this, we focus on the various populations of small bodies of the Solar System [SSSBs] (Near Earth asteroids [NEAs], Asteroids, Centaurs, Trans-Neptunian Objects [TNOs], in increasing distance from the Sun). Thanks to their large numbers, their physical, compositional and dynamical characteristics hold statistically significant clues on their origin and evolution. Though they contain a negligible fraction of the mass of the Solar System, the SSSBs are to the Solar System the equivalent of the *radioactive isotopes* to the study of rocks. Such a study will be instrumental in understanding the formation of habitable planetary systems, and the possible emergence of life.
An exhaustive study of the various populations of SSSBs resides in the search for their physical, compositional and, for some of them, mineralogical properties. Connecting the **physics** to the **dynamics** of these objects, we will answer fundamental questions related to cosmogony and our civilization: What were the conditions that allowed the formation of our Solar System ? What was the structure of the planetesimals that made the terrestrial planets ? What is the link between interplanetary organic materials and life on Earth ? What is the link between SSSBs and meteor streams ? Improving our understanding of these tracers of the Solar System formation and evolution will allow differentiating between several models still in debate.
To achieve our goal, we need to increase and refine our census of the small bodies of the Solar System, with their physical and dynamical characterization, for which we resort to the up-coming wide area Legacy Survey of Space and Time [LSST] that will be performed at the Vera C. Rubin Observatory.

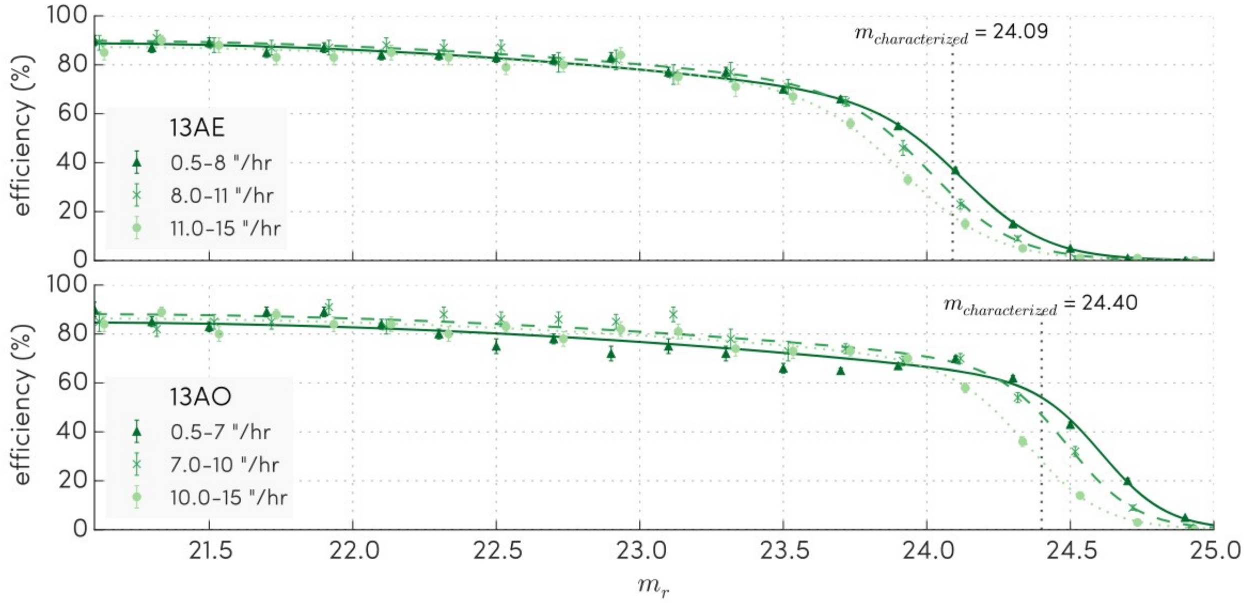
The Vera C. Rubin Observatory is a very large (8.4 m) optical survey telescope under construction at Cerro Pachón in Chile. The LSST project will have its First Light in January 2023 and Start of Operation in October 2023, for a 10 years operation. This wide and deep optical survey is designed to address four main science themes, **among which n° 2)** *Taking an Inventory of the Solar System*, **where our team is contributing within the Solar System Science Consortium [SSSC]**.
Scanning the entire accessible sky twice a week , LSST will cover millions SSSBs, and increase their known populations by an order of magnitude or more. At an average of 400 observations per object, we enter the big- and complex-data domain, enabling a broad array of transformative Solar System science investigations. The basic detection of new objects and orbit computation will be largely handled by LSST and the Minor Planet Center (MPC). However, to reach our goal, specialized algorithms need to be implemented, and even new methods will be elaborated. Substantial and dedicated development of software tools by our team is critically required to generate higher-order data products.



Spatial relationship of the regions of sky targeted by OSSOS (blue wedges) to the geometry of the outer solar system, projected onto the Ecliptic plane. The blocks were placed to avoid the dense star fields of the galaxy (schematically indicated by gray shading). All deep surveys of the Solar System suffer from this partial azimuthal coverage, as well as in altitude with respect to the Ecliptic plane. LSST will coevr a 10° strip on each side of the Ecliptic and the whole South half of the celestial sphere, thus observing more than half of the entire sky, offering us a far less biased view of our environment.

The various components of TNOs and they relative population tell us about the migration of the ice giant planets: was it grainy or smooth ? was it fast or slow ? The **size distribution** and **binary** population shed light on the formation and collisional evolution processes: forming large bodies (up to ~400km) in an almost empty environment seems to work only with Streaming Instability [SI], which also tends to favor similar mass **binaries**, with separations from very close (Arrokoth) to very wide (2001 QW322).
Most samples will still be incomplete at the faint end (which corresponds to objects smaller than 100 km for TNOs) but are very valuable in our quest, once properly *characterized*. **Characterization** is the required tool to model the survey selection biases, thus creating the link between the real world that hides in the sky and our observations. Detectability of binarity or

activity crucially depends on the quality of image (seeing); detection of objects of a given size depends on their distance to the Sun, hence their position on their orbit at time of observation. Precise characterization allowed us to make breakthrough contributions to our knowledge of the outer Solar System with our previous smaller-scale surveys we have conducted (CFEPS, HiLat, OSSOS) which we conducted over the last 20 years.



Total combined OSSOS detection efficiency of 2 observing blocks (20 square degrees each): fraction of planted sources recovered by the overall data reduction as a function of magnitude and rate of apparent sky motion. This approach is too costly to be applied to LSST and we need to find new methods to determine this efficiency from global parameters of each image, thus the use of Machine Learning.

The goal of the project is two-fold. On one hand, we seek man-power to develop and deploy the new algorithms necessary to the specific detection of TNOs and characterization of observations (1 Post-Doc fellowship and 2 Master 2 Internships). On the other hand, we need to have access to the processing pipelines and to the raw data (real or simulated) to achive our project. TO this end, we have to pay for the LSST acess fee, to be paid to the IN2P3 institute of CNRS, at 5.5k€ per year, for 2 years.

This funding will ensure participation of UTINAM Institute to the LSST international project, and thus the international visibility of UBFC, UFC, OSU THETA and UTINAM in the global astronomical landscape. This project will have two lever-arm effects on the future of astronomy in Franche Comté. It will be the first step in preparing an ANR proposal which will gather all the French community of SSSBs involved in LSST under the leadership of UTINAM, and thus UFC. Second, it will coincide with the request of a Chaire de Professeur Junior that UFC is about to deposit to the MESR, based on our needs in expertise in Machine Learning and Artificial Intelligence aplpied to Astronomy. It will help us prepare the coming of the future CPJ laureate in the ASTRO team of UTINAM.