Astroinformatic and Digital Planetology Laboratory in INAF

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Introduction

The LAPD (Astroinformatic and Digital Planetology Laboratory) is a distributed research infrastructure involving several INAF institutes and University Sections and covering multiple research fields in the computational domain. Its main task is to design and develop algorithms for data analysis and simulations. Each code is validated and optimized in strict contact with scientific teams: the final users of the tools. The optimization task takes into account the specific hardware infrastructure used for the production phase, that is the input for the hardware deployment and optimization. In addition, the Laboratory designs, develops and validates the ground segment, the archives, and the dissemination systems for some INAF-led international space missions and payloads. The team supports the deployment of software, hardware, and, last but not least, dissemination of the acquired know-how.

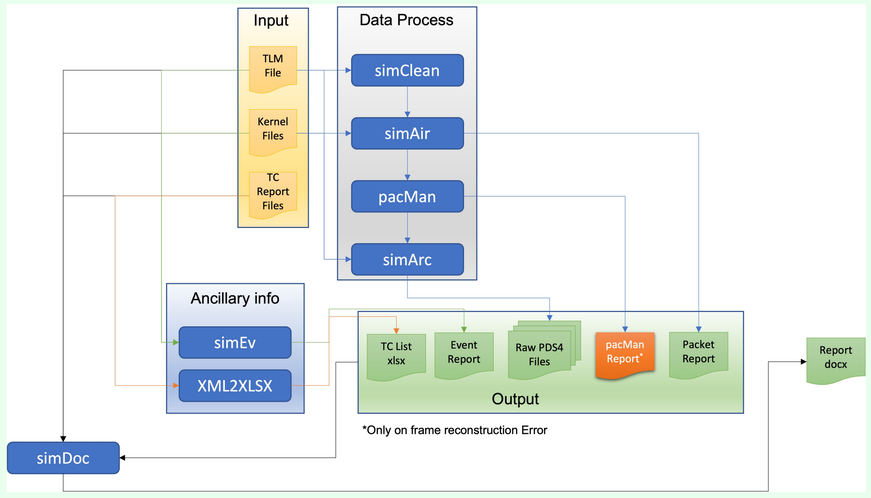
The Laboratory activities are grouped in the following fields:

- Space Missions Ground Segment
- Data Archive
- Simulation of observation
- Numerical simulation
- High Performance and High Throughput Computing
- Robotic and Drones.

Space Mission Ground Segment

This is the historical activity of the laboratory and the first field of joint collaboration of the LAPD members. We work on the two areas of the ground segment, the uplink and the downlink. The uplink consists in the preparation and validation of the instrument command stack that will be sent to the spacecraft (after multiple interactions with the Space Operation Center of the Space Agency). The downlink consists of generating the raw and calibrated data file, starting from the instrument telemetry. An example of downlink pipeline is shown in Figure.

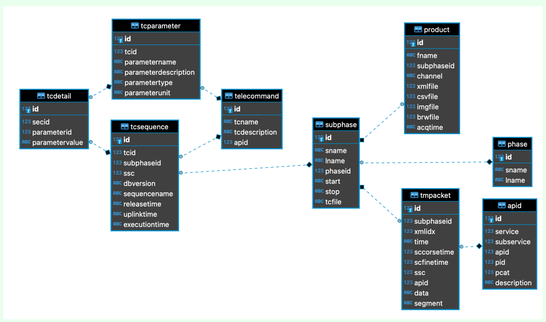
For this activity, we are involved in many current and future ESA planetary missions, i.e., BepiColombo, and JUICE, as well as Space observatories like ARIEL. Some examples of the products of this activity can be found in [1] and [2].



Block diagram of the pipeline developed for BepiColombo SIMBIO-SYS.

Data Archive

This activity is linked to space missions as well. We work on the design of the storage structure, sometimes also from an HW point of view, and the metadata identification for the best description of the experiment results. The managed archive follows the standards for the long-term preservation archives recommended by the planetology community (PDS3 -Planetary Data System - for the heritage archives and PDS4 for the present ones). We also work on the short/medium-term archives using more friendly formats like CDF, netCDF, or relational databases (e.g., PostgreSQL). Recently, we have started to work on not planetological archives (e.g., ARIEL archives) and archives for ground observation with a close collaboration with INAF IA2.

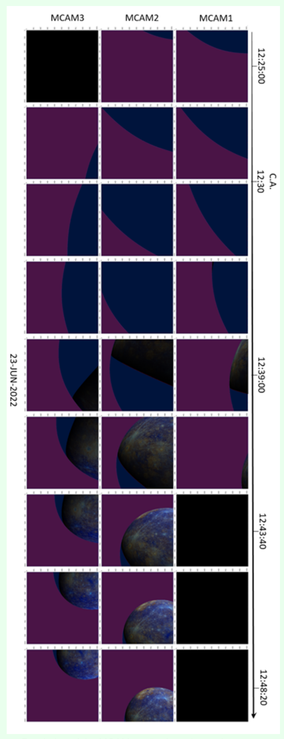


Database for the correlation between packet and Telecommand for the JANUS camera onboard the ESA JUICE mission.

Simulation of Observations

All the Space missions to Solar System Bodies required, in all their phases, the development of tools to simulate acquisitions, verify and optimize the observation strategy, and define the essential parameters for Operations. The LAPD developed the Simulator for Operation of Imaging Missions (SOIM)[3,4], a flexible software tool for simulating such payloads that represents a transversal activity to different research lines favoring the optimization of performances and, with the collaboration of the scientific group, the validation of scientific requirements.

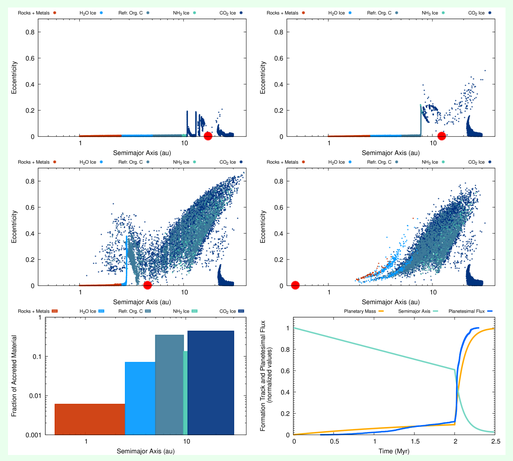
This tool is currently used on the ESA BepiColombo mission to plan the Monitoring Cameras (M-CAM) [5] acquisitions during the several flybys in the cruise phase and the SIMBIO-SYS suite observations to the Mercury surface. An example of the output is shown in Figure.



Rendering of the MCAMs at 5-minute intervals in a neighborhood of the C.A of Mercury flyby.

Numerical Simulation

LAPD is associated with Arxes, a multidisciplinary INAF research program aiming to answer the fundamental questions of planetary formation and supporting many ground- and space-based national and international projects by developing new methods, theoretical models, and computational tools. The overarching scientific goal of Arxes is to link the compositional characteristics and the architectures of planetary systems to their formation and evolution histories, to shed light on the sources of their differences and similarities. LAPD supports Arxes through code parallelization, development of numerical libraries, multi-language programming and automation scripting, as well as by managing its computational cluster Genesis.



Illustrative example of the planet formation studies enabled by Mercury-Arxes. Mercury-Arxes allow to simulate the mass growth and migration of forming planets as well as their interactions with the surrounding planetesimal disk. Figure from Pacetti et al. (2022), where an animated version of the figure is also provided.

HPC and HTC

While the code developed and distributed by the LAPD is generally serial, when addressing problems associated with marked computation loads we develop parallel and GPU-accelerated codes, e.g., the Mercury-Arxes n-body code. This activity has allowed us to be part of the National High-Performance, Big Data, and Quantum Computing Center since its creation, and in particular, we are involved in two spokes of the PNRR HPC project (Fundamental Physics and Space Economy and Astrophysics and Cosmos). In parallel, we are also working on High throughput computing focusing on the archive (re)generation and analysis.

Leonardo the pre-exascale supercomputer at ICSC (Centro Nazionale di Ricerca in HPC, Big Data e Quantum Computing)

Robotics and Drones

The laboratory developed several projects using drones to explore terrestrial terrains analogous to planetary surfaces. Those projects aim to demonstrate the potentiality of these drones (especially the flying ones) to study efficiently and with high-resolution selected regions of space bodies. As secondary products of those researches, there are some terrestrial applications, e.g., the detection of re-trigger points after fires. This kind of application also requires a particular type of computation called Urgent Computing, fast computing, and prioritized access to HPC infrastructure for emergency computations such as fires or severe weather prediction during matters of immediate concern.

Other Stuff

A transversal activity is outreach. The LAPD is involved in several initiatives, e.g., the European Researchers' Night or lectures in schools of different levels. The Laboratory is also working on an outreach project describing the ESA BepiColombo Mission through a virtual reality application usable by modern mobile phones.

References

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