Title: Towards a data-driven digital twin for satellites
Speaker: Nicola Parolini, MOX, Dipartimento di Matematica, Politecnico di Milano
Abstract:

Predictive maintenance of satellites is crucial for extending their operational lifespan and ensuring mission success, particularly in the context of thermal management systems. In this talk, we present a mathematical modeling framework for learning a reduced-order model of a satellite's thermal subsystem, combining physics-based and data-based strategies. The primary challenge stems from the lack of detailed geometric data and material properties, coupled with the inherent complexity of the satellite's structure, which precludes the use of high-fidelity numerical methods; nonetheless, while high-fidelity thermal models are routinely employed during the satellite design phase, reduced order models become crucial for real-time thermal operation management, fault detection, and predictive maintenance.

We develop a methodology grounded in scientific machine learning (SciML), where the thermal behaviour of the satellite is approximated using a Lumped Parameter Thermal Model (LPTM). This model represents the thermal dynamics through a graph-based structure, exploiting the sparsity of heat transmission paths connecting the satellite's subsystems for which thermal telemetric data are available. The LPTM parameters, which correspond to both nodal and connective thermal properties, are learned during training on data collected from on-board sparse thermal sensors. In addition, physical constraints such as incoming heat flux from solar radiation and heat dissipation by satellite's electrical systems and active heat lines are integrated into the model, to account for both mission and spacecraft platform operational conditions.

This hybrid approach, which combines data-driven learning and physically informed modeling, offers a computationally efficient alternative for real-time thermal prediction and monitoring. The resulting digital twin can support predictive maintenance without requiring high-resolution structural information, making it a practical tool for supporting operational decision-making processes aiming at extending satellite lifetime.

Joint work with Stefano Pagani, Luca Sosta, Francesco Regazzoni (MOX, Dipartimento di Matematica, Politecnico di Milano), Carlo Ciancarelli, Francesco Corallo, Davide Di Ienno, Alice Nervo, Leonardo Marini (Thales Alenia Space Italia)