Space Science and Technology PhD Program

PhD National Days

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Book of Abstracts

of the posters prepared by the SST students

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Observation of the Universe

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The quest for Dual AGN: The first spectroscopic sample

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A large population of AGN pairs residing in the same galaxy - the so-called dual AGN - is expected at z > 0.5. These systems are crucial for predicting gravitational wave background levels and event rates in pulsar timing array experiments and by the future LISA mission. Furthermore, analyzing properties such as the mass function and separation distribution of the merging black holes, along with their fraction relative to the total AGN population, is essential to test numerous theoretical predictions on galaxy formation and evolution. Despite their importance, knowledge of dual AGN has been limited so far, with only a few systems detected at sub-arcsec separations. The all-sky survey Gaia is now playing a pioneering role in the search for dual candidates. In this talk, I will present the innovative 'Gaia multi-peak' (GMP) technique, which successfully selects multiple candidates at separations between 0.15" and 0.7" (~1 kpc at z> 0.5). Additional follow-up such as spatially resolved spectroscopy and high spatial-resolution imaging with HST and several ground-based AO-assisted instruments (Keck, VLT, and LBT) are fundamental to confirm the nature of these candidates and study their physical properties. In my poster, I'll showcase the first spectroscopic sample of confirmed GMP-selected dual AGN with the first statistical study to test model predictions on galaxy evolution.

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Gravitational waves and galaxies to constrain the Hubble constant

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The rapid development of gravitational wave astronomy, along with information coming from present and future galaxy surveys, has the potential to shed light on many open questions in Astrophysics and Cosmology. The combination of gravitational wave and galaxy survey datasets is especially able to provide new and unique constraints on the dynamics of the Universe. In this work, we focus on correlating dark sirens (merging black hole binaries) with galaxy catalogs to constrain the Hubble constant H_0. More specifically, with respect to the current state of the art, we aim at proposing a more refined and effective treatment of the galaxy catalog contribution and involving third-generation gravitational wave detectors in this very same methodology.

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Prospects for measurements of heavy antimatter in space

Author: Francesco Rossi[1]

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Research of antimatter heavier than $\bar{p}$ in cosmic rays (CRs) addresses fundamental physics questions, such as the nature of Dark Matter or the existence of primordial antimatter.
Anti-nuclei heavier than $\bar{d}$ are unlikely to be formed during CRs propagation, as confirmed by the PHOENIX and ALICE collaborations. Thus, Dark Matter interactions could lead to the formation of anti-nuclei, especially at low energies ($\leq$ 1 GeV/N).
Experiments dedicated to the research of heavy antimatter must possess high charge sign discrimination due to the matter-antimatter unbalance.

The AMS-02 collaboration has identified about ten anti-He candidates.
Each detector's effect, such as the rigidity resolution and the internal interactions, may lead to misidentifying matter as antimatter, producing a dominant background over rare signal candidates.
I am working on the development of a Monte Carlo simulation to mimic the response of an AMS-02-like detector, identifying several phenomena that misidentify He as anti-He. With the implementation of a fully connected neural network, trained over diverse sources of charge sign confusion, it is possible to quantify the event reconstruction quality.
This tool could reduce the He background for the research for anti-He in CRs.

The PHeSCAMI (Pressurized Helium Scintillating Calorimeter for AntiMatter Identification) project aims to identify anti-D in CRs. A segmented calorimeter of pressurized Helium is used as a target. Helium offers the unique feature of delayed annihilation ($\sim$ μs) for anti-particles stopping inside of it allowing tagging such events.
Furthermore, the topology and the multiplicity of secondaries produced by the annihilation permit us to distinguish between anti-p and anti-D.
The characteristics of a possible high-acceptance detector, to be operated on a circumpolar stratospheric balloon and based on the PHeSCAMI project, are presented.

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Detection of 0.1-30MeV cosmic photons with the Zirè instrument onboard the NUSES space mission

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Gamma Ray Bursts (GRBs) are mysterious yet powerful explosions in Universe. To understand them, numerous models and theories have been proposed. The Zirè instrument, on board the NUSES space mission, aims not only to measure cosmic electrons, protons, and nuclei (with energies below hundreds of MeV) but also to test new technologies for the detection of gamma rays in an energy range of 0.1 MeV to 30 MeV, using Silicon Photomultipliers (SiPMs) as readout tools. The focus of this work is to simulate GRB induced signals, and the corresponding background, in order to determine the Zirè instrument sensitivity.

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JWST/NIRSpec insights into the nuclear environment of Arp 220: A detailed kinematic study

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Major mergers represent an important key in the evolution of galaxy during which large quantity of gas and dust are funneled to the central regions of the system and intense star formation and possibly AGN activity are triggered.

Arp 220 represents the closest prototypical ultraluminous infrared galaxy (ULIRG) in an advanced phase of a major merger.

By using new JWST NIRSpec IFU observations, we investigated the spatially resolved gaseous (in both ionized and warm molecular phases) and stellar kinematics in the innermost 1 kpc encompassing the two bright nuclei.

We decoupled the different kinematic components through multi-Gaussian fitting. In this way, we isolated the contributions of multi-phase outflows, bubbles, streams due to the merging, as well as two counter-rotating discs around each nucleus embedded in a larger-scale rotational disc.

We identified broadening and multiple kinematic components both in warm molecular and ionized lines with velocities up to 900 km/s.
We computed the mass, mass outflow rate and energetics of each outflowing and bubble component in each gas phase. We compared these with both large-scale (10 kpc) ionized and small scale (few hundreds of pc) cold molecular outflow properties, to obtain a complete picture of the multi-phase outflow phenomenon from the nuclear to galactic scales in the nearest ULIRG.
We also investigated the presence of possible AGN, which still remains challenging due to the extreme dust obscuration.

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Long term multi-wavelength analysis of the flat spectrum radio quasar OP 313

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The flat spectrum radio quasar OP 313 showed extremely intense γ-ray activity from November 2023 to March 2024, as observed by the Large Area Telescope on board the Fermi Gamma-ray Space Telescope. This initiated a large number of follow-up campaigns at all wavelengths, resulting in a confirmation of the increase of the source activity from the radio to very high energy (VHE) bands. Remarkably, it also led to the first detection of the VHE emission from OP 313 by the Large-Sized Telescope (LST-1) of the Cherennkov Telescope Array Observatory at La Palma and it is also the most distant Active Galactic Nuclei detected at these energies.

We present a multi-wavelength analysis covering 15 years of Fermi-LAT observations, from August 2008 to March 2024. From the Fermi-LAT study of the 15-year light curve, we can identify different periods of activity states of the source: one quiescent and one flaring state that can be compared with the data available from other instruments. In our study, we include X-ray, optical, and radio data collected by Swift, the Nordic Optical Telescope, and the Medicina radio telescope, respectively. Then, we aim to model the multi-wavelength Spectral Energy Distribution of OP 313 in the flaring states with different theoretical leptonic and hadronic models to explain the source's behavior, understand the mechanisms involved in particle acceleration inside the jet, and how radiation in different wavelengths is connected.

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Assessing the scaling relations of stellar populations in galaxies in the local universe

Author: Daniele Mattolini[1]

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The evolution of galaxies is driven by a combination of complex mechanisms. Some of the most relevant concern: the assembly of dark matter structures, gas dynamics, hydrodynamics, and thermodynamics. The interplay of these mechanisms brings to star formation, and feedback. These processes, in turn, produce systematic variations between different galaxy properties. The relations that link extensive properties with intensive ones are generally known as scaling relations. Scaling relations are particularly meaningful because they keep track of the full evolutionary history of a galaxy; very much alike archaeological records. Theoretical models are commonly calibrated against such relations in the present-day Universe. Therefore, having a reliable assessment of such scaling relations, is crucial to study galaxy evolution. In this work we characterized two of the most relevant scaling relations: the mass-age, and the mass-metallicity. More precisely, we revised the results by Gallazzi et al. (2005) to provide bias-free and volume-complete scaling relations in the Local Universe. To improve with respect to the previous work we: used a bigger galaxy sample using the Sloan Digital Sky Survey DR7, improved the ingredients for Stellar Population Synthesis (e.g. stellar spectral libraries, evolutionary tracks, Star Formation History and Chemical Enrichment History prescriptions), and introduced explicit dust treatment in the modeling. We also considered corrections for the aperture effects caused by the finite aperture of SDSS optical fibers, and statistical corrections to account for biases arising from sample and Signal-to-Noise Ratio selections. In our analysis we used a bayesian approach based on a comprehensive library of Composite Stellar Populations models. We found that the prescription for the Star Formation History (SFH) and Chemical Enrichment History (CEH) can have a systematic impact on the estimates of light-weighted ages and metallicities. In particular, by allowing for an increasing phase of the SFH, a clear bimodality in the mass-age relation emerges. Corrections for the aperture effects result in an enhancement of the age bimodality and a decrease of the mean stellar metallicity. These well-characterized scaling relations constitute the fundamental local benchmark against which new high-redshift observations should be confronted.

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Birefringence angle estimation using D-estimators

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This poster focuses on harmonic estimators for the cosmic birefringence (CB) effect, the "in vacuo" rotation of the linear polarisation plane of photons during propagation. This effect is a tracer of parity-violating extensions beyond standard electromagnetism and may point to the existence of a new cosmological field (i.e. an axion) acting as dark matter or dark energy. When such an extension is modelled by a Chern-Simons interaction, the amplitude of the CB rotation is proportional to the distance traveled by photons. Hence CMB photons represent the best observable we have in nature to investigate this effect since they are linearly polarised and have traveled the longest distance in the Universe. In this poster, we describe in detail the so-called D-estimators, a methodology used for measuring the CB angle from CMB observations. Additionally, we examine the performance of these estimators when applied to subranges of the complete harmonic domain, a test that could yield valuable insights into the parameters of the axion, such as its mass.

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Extreme mass ratio inspirals in nuclear star clusters: a post-Newtonian orbit-resolved approach

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Extreme mass ratio inspirals (EMRIs) are highly eccentric and tight binary systems consisting of a massive black hole (MBH) and a compact object. These systems emit gravitational waves in the mHz frequency range during each pericentre passage, thus representing primary sources for the upcoming Laser Interferometer Space Antenna (LISA). Due to the emission of gravitational waves, the compact object slowly inspirals towards the MBH over thousands of orbits, until they eventually merge. On the other hand, if the merger occurs after few orbits or in a head-on collision it is referred to as a direct plunge (DP).

In nuclear star clusters, MBHs are surrounded by a large number of stars and compact objects. Here, the formation of EMRIs is facilitated by frequent two-body interactions that can easily scatter a compact object onto a very eccentric orbit around the MBH.

In this work we present a novel few-body/Monte Carlo approach to simulate the formation of EMRIs as a consequence of two-body relaxation in nuclear star clusters. For the first time, we depart from the commonly used approximation of averaging the effects of two-body relaxation over an entire orbit, performing our simulations in what we call "orbit-resolved" regime. Moreover, we use post-Newtonian corrections and a two-population model for the nuclear star cluster, which accounts both for the presence of Sun-like stars and of stellar-mass black holes.

We apply this model to the study of the ratio of EMRIs to DPs forming as a function of the initial semi-major axis of the orbit. It is currently believed that this ratio should always approach zero for large initial semi-major axes, where only DPs are expected to form. However, the recent emergence of "cliffhanger EMRIs" (which are EMRIs that form following a failed DP) is challenging this notion, particularly for low-mass MBHs.

Our simulations confirm the existence of cliffhanger EMRIs. Moreover, we find that both the post-Newtonian treatment and the introduction of a population of stellar-mass black holes significantly enhances the number of cliffhanger EMRIs that form from initially wide orbits. Instead, the EMRI-to-DP ratio is only slightly influenced by the choice of averaging or not the effects of two-body relaxation.

These findings call for a reassessment of predicted LISA detection rates to account for this new EMRI population in the low-mass MBH regime.

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Wiener-filter inspired cross-correlation angular power spectrum of the unresolved gamma ray background and galaxies in a multitracer framework

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Although one of the two namesakes of the ΛCDM cosmological model, the hypothesis of cold dark matter existence still chiefly relies on its gravitational effects, whilst both direct and indirect detection via non-gravitational signatures have not yet been achieved.
Weakly interacting massive particles (WIMP) are a candidate cold relic with a mass from 0.1 GeV to several TeV: they might thus annihilate or decay in γ photons. We know as well that the universe is permeated by an unresolved gamma-ray background (UGRB) detected by experiments such as Fermi – LAT. The UGRB seems to be chiefly sourced by highly energetic astrophysical sources: AGNs are the most likely sources, but exotic processess as dark matter contributions are not excluded; at low redshifts, the astrophysical contribution should even be subdominant compared to WIMP annihilation or decay signatures, as shown in previous works. More generally, the addition of dark matter to the UGRB sources was shown to improve, rather significantly at the lowest redshift, the fit compared to an astrophysics-only case.

For both astrophysical and dark matter research goals, it is interesting to relate the UGRB to the large scale structure (LSS) of the universe: if it is indeed sourced by objects clustered in the cosmic web, or by Dark Matter, whose clustering should be the ultimate responsible of the observed structure, it has to display parte of the anisotropy shown by the LSS. Indeed, although dominated by an isotropic shot-noise component, a degree of anisotropy was detected in the UGRB autocorrelation angular power spectrum in the past; the subsequently measured power spectrum of the cross-correlation with reliable LSS tracers like galaxies shows more clearly such anisotropy, suggesting a link between the UGRB and the Large Scale Structure of the Universe, at the same time allowing a better understanding of its composition.

Typical signal shapes and contribution can be analysed in terms of multipoles, redshift, gamma ray energy bin and mass range of the probed halos, to be gauged to sensitivity and resolution of present and future instruments, tuning the forecast according to observate capabilities and different research aims: hoping to extract larger and more significant information on the UGRB, we discuss the application of a multitracer technique to the galaxy-gamma ray cross-correlation signal, that is, a simultaneous fit of the galaxy autocorrelation, gamma autocorrelation and gamma-galaxy cross-correlation power spectra, taking into account the covariance between them and exploiting the increased amount of information and the possibility of overcoming part of the cosmic variance limits that the shot-noise imposes in independent fit configurations. The strategy is combined with a weighting scheme of the galaxy tracer distribution, which proved effective in enhancing the anisotropic contribution of other shot-noise-dominated LSS tracers, such as cosmic rays and gravitational waves. Its efficiency is assessed in terms of signal-to-noise ratio, comparing low and intermediate redshift galaxy surveys, and we discuss the cases of the UGRB signal being sourced either exclusively by astrophysical objects, exclusively dark matter, or both components together.

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Enhancing Cosmic Microwave Background analysis: implementing frequency-correlated noise in component separation

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This work focuses on enhancing the accuracy of Cosmic Microwave Background (CMB) data analysis by improving the treatment of noise correlations during component separation.
CMB temperature and polarization anisotropies are powerful tools for constraining cosmological models, providing fundamental information about the early stages of the Universe. Their measurement requires instruments with excellent sensitivity and control over systematic effects, as well as multifrequency observations in order to remove any contamination from astrophysical foreground emissions via component separation analysis.
For computational reasons, component separation codes currently assume uncorrelated noise between different channels, which is a reasonable approximation for past and ongoing experiments. However, including noise correlations is of potential key importance for future generations of CMB experiments measuring such a faint cosmological signal.
In order to assess the impact of cross-channel correlations on future data we developed a prototype pipeline that generates simulated maps of the microwave sky according to a given instrumental configuration and carries out a component separation analysis assuming different noise models.
Instrumental noise in microwave sky maps can very accurately be described as a zero mean Gaussian process, and its properties can then be fully described by a noise covariance matrix (NCVM).
Our pipeline allows to incorporate in the NCVM correlations between different channels, in addition to between map pixels and Stokes parameters.
Validation tests show an excellent agreement with the analytical maximum likelihood points for all the considered noise realizations.
Our preliminary results indicate that including noise frequency correlations reduces the uncertainty on the estimation of the spectral parameters, leading to sharper joint posterior distributions.
Furthermore, we are now upgrading Commander 2, a Bayesian component separation code, to take into account this more general noise model exploiting the native parallelized architecture to optimize the algebra.

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The frequency domain multiplexing layout for the LiteBIRD experiment cold readout

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LiteBIRD (Lite (Light) satellite for the studies of B-mode polarization and inflation from cosmic background radiation detection) is a future three-year space mission whose primary objective will be to observe and measure the B-modes of polarization of the Cosmic Microwave Background (CMB). The LiteBIRD satellite will be equipped with three telescopes observing the sky at different frequencies in order to separate the CMB signal from the polarized foreground. The focal planes will be populated with around 5 thousands superconducting TES (Transistor Edge Sensor) bolometers, which will be read out through a Frequency Division Multiplexing Electronics (FDM). The FDM is composed of a warm (~300 K) and a cold (1.6 K and 0.1 K) section. The cold FDM section consists of lithographed LC filters. The detectors with relative multiplexing resonators, are connected to the SQUIDs (Superconductive QUantum Interference Devices) which work as trans-amplifiers.
A systematic effect called crosstalk associated with the TESs and the LC filters that can sabotage the detection of sky signals can be defined. It can lead to a leakage of current from one leg of the circuit to the other, resulting in incorrect processing of the signal.
In this work, the operation of the multiplexed cold readout is presented, together with an example of the design of the lithographed LC chip. Preliminary studies to define the main contributors to the crosstalk affecting the LC filters are reported, with particular emphasis on the relationship between crosstalk and the layout of the LC filter chip.

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Searching for the sources of the most energetic cosmic rays

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Although more than 60 years have passed since the discovery of ultra-high-energy cosmic rays ($E > 10^{18}$ eV) (Linsley 1963), the origin of these particles remains one of the most compelling open questions in Astroparticle Physics. The recent detection of the "Amaterasu particle" by the Telescope Array Collaboration, the second most energetic cosmic ray ever detected (2.44×10^{20} eV), has motivated investigations not only into its possible candidate sources (Abbasi et al. 2023, Unger & Farrar 2024) but also into other highly energetic events. These particles are less deflected by cosmic magnetic fields due to their extremely high energy, which aids in backtracking them to their sources. However, uncertainties in the magnetic fields and in energy measurements, along with limited information about the mass composition of these particles, make these studies quite challenging. Therefore, the aim of this work is to analyze the most energetic events detected by the Pierre Auger Observatory to search for their origin. One of the goals is to calculate the localization volumes from which these particles originate using the most up-to-date Galactic magnetic field models and to statistically correlate these volumes with known astrophysical objects from catalogs. Central to our approach is the development of a new release of the Monte Carlo propagation code SimProp (Aloisio et al. 2017), which is well suited (and widely used) for phenomenological studies of ultra-high-energy cosmic ray propagation in intergalactic environments. We are currently developing updated models of photodisintegration losses of ultra-high-energy nuclei, vital for understanding the maximum production distances of these high-energy events.

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A SQUID controller unit for space-based applications: design and first performance tests

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The LiteBIRD mission, to be launched in 2032, will map the polarization of the Cosmic Microwave Background (CMB) with unprecedented resolution, to search for the tiny imprints of cosmological inflation. Its sensitivity corresponds to exploring energy scales up to 10^{16} GeV, linking the physics of inflation with that of Grand Unification of elementary forces.
To accomplish this task, LiteBIRD will use more than 4000 transition-edge sensors (TESs) distributed over three telescopes. Those cryogenic devices, living at 120 mK, will be multiplexed in frequency-domain, each group of 60s read out by a single SQUID placed at a sub-Kelvin stage.
This work presents the design and tests of the SQUID controller unit (SCU), to be used in this space mission, which fall under the responsibility of INFN groups. The unit is made of 8 boards and each board can condition four SQUID array amplifiers. The electronics boards (SCA) are designed to host space qualified components and encompass a redundancy circuitry as well as a lightweight communication protocol. The boards are hosted in a custom designed crate, providing mechanical support, EMI shielding and thermal interface to dissipate the electronics heat.
An advanced version of the board has been coupled to a dilution fridge at McGill University (Canada) and tested with a SQUID reading out a representative cryogenic electronic chain, comprised of resistors coupled to custom LC filters. Its noise performance has been measured to be compatible with the mission requirements and consistent with previous generation used in ground-based CMB telescope readout.
We will present the tests performed and those that are foreseen for its flight qualification, together with thermo-mechanical simulations.

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Systematic effects and foreground cleaning for LiteBIRD satellite

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The detection of primordial B-mode signal in CMB polarization could provide precious information about the early stages of the Universe evolution, especially by discriminating between several inflationary scenarios. *LiteBIRD*, a space-borne experiment selected by the Japanese Aerospace Exploration Agency (*JAXA*) and gathering a world-wide collaboration (US/Europe), will target the CMB B-modes to estimate the tensor-to-scalar ratio parameter r with a total uncertainty of $\sigma_r \leq 10^{-3}$. The r parameter is associated to the amplitude of primordial gravitational waves generated during inflation, an hypothetical phase of exponential expansion of the Universe which occurred right after the Big Bang. The small amplitude of B-mode signal requires an exquisite calibration accuracy and control of any sources of uncertainty that could bias measurements of primordial B-mode. The two major impediments for a CMB B-mode measurement are : (i) the systematic effects arising from an imperfect characterization and calibration of the instrument. (ii) the contamination by the emissions from our own Galaxy, dominating the CMB B-mode signal at large angular scales. This analysis consists in understanding the impact of a relative polarization gain mis-calibration on the tensor-to-scalar ratio assessment for LiteBIRD satellite. Specifically, we aim at seeing to what extent the choice of a specific component separation method affects the estimation of the tensor-to-scalar ratio in presence of gain calibration errors.

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Observing repeating radio blasts from cosmological sources with the Northern Cross telescope

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Fast radio bursts (FRBs) are powerful ms blasts of celestial origin detected only at radio frequencies. Since their discovery in 2007, about 800 FRB have been found.FRBs come from cosmological distances (within redshift $z \sim 1$) and present kJy flux densities. Due to these properties and brightness temperatures $T_{\rm B} > 10^{36}$ K, most FRB progenitor models invoke coherent emission mechanisms in strongly magnetised neutron stars (magnetars). The vast majority of FRBs are one-off events, but a fraction ($\sim 8.5\%$) are observed to repeat, excluding catastrophic events as their origin. Repeating FRBs are of particular interest, since they can be monitored over time and localised with precision. Long-term monitorings of repeating FRBs are key also to shed light on their activity patterns, the spectral and polarimetric properties of the bursts, and energetic distribution. We are studying a sample of repeating FRBs, including the newly discovered and very active FRB\,20240114A located at redshift z ~ 0.42, using the high-sensitivity Northern Cross transit telescope and the 32-m parabolic dish in Medicina, near Bologna, and the 32-m dish in Noto, Sicily. Given the large data sets, the thousands of FRB candidate signals, and the presence of strong radio frequency interferences (RFIs), we implemented for each antenna a new pipeline based on RFI mitigation tools, a transient detection algorithm, and a machine learning classification of the bursts with 11 neural network models. Furthermore, we are carrying through a monitoring of a number of Galactic magnetars to search for possible FRB-like events, which would confirm their link with FRBs.

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Landslide Susceptibility Mapping in Lunar South Pole Region

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Landslides represent one of the most hazardous geological phenomena affecting both the Earth and other celestial bodies in the solar system. These events, characterized by the rapid destructive movement of either rock or soil material along slopes, have always sparked the interest and study of scientists, as they can have shocking consequences on the environment and the utilisation of affected areas. However, while terrestrial landslides are well-documented and studied, their study on extraterrestrial planets and satellites poses a quite unique challenge. Understanding the mechanisms and causes of landslides at a planetary scale, not only provides us with valuable information about the history and evolution of those celestial bodies, but it can also help to assess risks and opportunities for future space exploration. During these initial months of PhD studies, the investigation of landslide phenomena has involved the Moon surface with a particular focus on the Southern Pole. The Lunar South Pole Region (LSPR) has garnered increasing attention due to its geological features, including permanently shadowed regions (PSRs) and volatile deposits such as water ice. The rugged terrain and the dynamic geological processes represent significant challenges for future missions aiming at exploring and utilising lunar resources. In this research work, a Landslide Susceptibility Map (LSM) was created starting from an inventory consisting of 47 gravitational events that were mapped through the photointerpretation of data from the Lunar Reconnaissance Orbiter (LRO) mission. Landslide locations were divided into 70% training and 30% validation datasets. Then, the Frequency Ratio (FR) model was applied to evaluate the landslide triggering factors and to generate the LSM. When creating the latter, it is crucial to consider both the contributing factors, which influence the predisposition of an area to geomorphological phenomena over long periods, and the triggering ones, which are short-term events that can originate landslides. Causative factors, represented by geological and morphological characteristics of an area, were derived from existing cartography and by the elaboration of Lunar Orbiter Laser Altimeter (LOLA) Digital Elevation Model (DEM – 118 m/pixel spatial resolution) within ESRI ArcGIS Pro software. Considering similar studies already carried out on the Earth, many authors have analysed the contribution of heavy rainfall (Gao et al., 2024) and earthquakes (Chen et al., 2022) as landslide triggering factors. Similarly, on the Moon, in the absence of rainfall, recent scientific papers (ex. Watters et al., 2024; Mishra & Kumar, 2022), assert that moonquakes, produced by lobate thrust fault scarps movement, have the greatest impact on regolith landslides that are triggered in the steep slopes of impact craters. In particular, to include the contribution of moonquakes into the FR model, it was decided to consider the variation of the Peak Ground Acceleration (PGA) as a function of epicentral distance, as suggested by Watters et al. (2024) and Mishra & Kumar (2022). Since PGA reaches not-significant level (~0.03 g) at farther distances, it was decided of sampling four different distances (i.e., 3, 12, 30, and 70 km) to locate shallow moonquakes of, respectively, 1, 2, 3, and 4 moment magnitude (Mw). Taking this into account, four buffer zones around the fault scarps, designated as seismic hazard zones, were defined within ESRITM ArcGIS Pro environment. Once the causative and triggering factors were implemented into the model and the LSM was produced, its accuracy was assessed by using the Area Under the Curve (AUC) method.

The study of landslide susceptibility allowed to identify the geological formations most susceptible to seismic-induced failures and it enabled to evaluate the safety conditions, not only for the sites chosen for the Artemis lunar mission landing, but also for future missions. Future developments of this work will involve: i) the integration of additional information, such as temperature variations in permanently shadowed areas; ii) the use of more accurate predictive models (ex. Weight of Evidence, Random Forest) to enhance the comprehensiveness of landslide susceptibility mapping; iii) a large-scale three-dimensional slope stability analysis in LSPR using engineering-geological data provided by past missions (ex. Luna 13, Apollo 11), iv) the application of this method to other celestial bodies (ex. Mars).

In conclusion, the methodology developed in this study provided a starting framework for evaluating landslide dynamic on celestial bodies, utilizing available data to deepen our understanding of geological hazards beyond Earth.

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The powers of the GRB 221009A soft X-ray rings

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On 2022 October 9 an extraordinarily bright gamma-ray burst (GRB 221009A) was observed behind the Galactic Plane. One day later, the X-ray Telescope (XRT) onboard the Neil Gehrels Swift Observatory, which was the first imaging X-ray telescope to react to the event, discovered 9 bright expanding rings due to the scattering of X-rays by dust clouds in our Galaxy.
The ESA satellite XMM-Newton observed these rings two and five days after the burst.
In this poster, I will illustrate the dual significance of this remarkable event.
The 20 rings that were identified in the two XMM-Newton observations allowed us to reconstruct the spectrum of the GRB prompt emission in the 0.7-4 keV energy range and to reveal a soft excess in the GRB spectrum missed by the others instruments which are sensitive only to hard X-rays (Tiengo et al. 2023).
Instead, assuming the GRB fluence and spectrum and studying the ring intensity and photoelectric absorption detected by XMM-Newton and Swift in different sectors, we have produced a detailed 3D map of the Galactic interstellar medium in the GRB direction.
This map has a better resolution, both in the plane of the sky (a few arcminutes) and in the radial direction (<1 %), than the other maps previously available for this sky area, which are mainly based on stellar extinction. It will also be used to separate Galactic absorption from the contribution of the host galaxy in the study of the X-ray afterglow, which is crucial for understanding the local environment of the GRB.

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1S Hyperfine Splitting of Antihydrogen at the ALPHA experiment

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The hyperfine structure consists on the splitting of energy levels in atoms and molecules due to the interaction between the electromagnetic multipoles of the nucleus and the orbiting electrons. The Hyperfine Splitting measurement on antihydrogen involves determining the Δf frequency associated with the splitting of the 1S state. This measure is carried out at the ALPHA experiment, one of the six experiments that are part of the complex of the antimatter factory, at CERN. The ALPHA experiment specializes in the production of antihydrogens atoms through the mixing of an antiproton and a positron plasma. The produced antihydrogen is then trapped exploiting the interaction between its magnetic momentum and the magnetic field produced by the superconducting magnet (for longitudinal confinement) and the octupole magnets (for transverse confinement) of the ALPHA-2 magnetic trap. To perform the experiment, the confined antihydrogens are irradiated with micro-wave light, which induces the energy transitions. During the micro-wave irradiation, a certain amount of antihydrogen ends up in an untrappable energy level, and thus annihilates on the trap walls of ALPHA-2. A silicon vertex detector, surrounding the trap, detects the annihilation of antihydrogen, reconstructing its vertex through the reconstruction of the tracks of pions passage. The counts of annihilations per frequency constitutes the experimental "line-shape". The Hyperfine Splitting of the 1S state of antihydrogen is extracted from the measurement of two line-shape onsets, after applying a procedure to remove the effect of the magnetic field drift over time. In this poster we present a simple Monte Carlo simulation developed within the context of this measurement. The objective of this study is to assess the statistical and systematic uncertainties associated with the procedure to extract the Hyperfine Splitting from the data collected during the 2023 data taking.

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The Morphology of Young and Massive Star Clusters as Galactic PeVatrons

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PeVatrons constitute a fascinating class of astrophysical objects capable of accelerating particles up to PeV energies (1 PeV = 10^{15} eV). These objects are some of the most energetic astrophysical sources in the Universe, but their nature and the acceleration mechanisms are still uncertain. Among PeVatron candidates, there are supernova remnants, pulsar wind nebulae, and young and massive star clusters (YMSCs). The accelerated particles can then interact with the surrounding interstellar medium and background radiation fields to produce secondary very-high-energy gamma rays (>100 TeV), which are the principal signature of both leptonic and hadronic PeVatrons. The air shower observatory LHAASO detected >100 TeV photons from dozens of sources in the Galactic Plane proving the existence of PeVatrons within the Milky Way. The next-generation ground-based Cherenkov imaging telescopes like ASTRI-Mini Array and the Cherenkov Telescope Array (CTAO) will be able to reconstruct better the energy and direction of the secondary gamma radiation, studying the Cherenkov radiation produced by particle showers in the atmosphere.

Cygnus OB2 and Westerlund 1 are particularly interesting YMSCs, because the ASTRI-Mini Array and CTAO will be able to spatially resolve them. They will therefore be essential to perform morphological studies, which will be relevant because of the insights that they can give on acceleration mechanisms and environments. We studied these YMSCs and the surrounding regions. We modeled the secondary gamma-ray emission and simulated observations of the regions with the ASTRI Mini-Array. Finally, we studied the spatial distribution of the gamma-ray emission as a function of the distance from the centre of the source and compared it with that of other simulated extended gamma-ray sources such as TeV halos, which are thought to form around middle-aged pulsars.

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Measurement of $\pi,\ K,\ p$ production in PbPb collisions at $\sqrt{s_{\mathbf{NN}}} = 5.36$ TeV using RUN 3 data

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This work presents a comprehensive investigation into the production of pions, kaons, and protons as a function of transverse momentum and centrality in Pb-Pb collisions at a center-of-mass energy of $\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV. Leveraging the recently acquired pass2 and pass3 data from the LHC23zzh data sample, our study ensures up-to-date coverage. Particle identification (PID) is achieved through the combined utilization of the Time Projection Chamber (TPC) and Time-of-Flight (TOF) detectors across various transverse momentum intervals.

Utilizing fitting models for the respective nσ distributions, we determine the integrated yields of pions, kaons, and protons. To validate the matching efficiency, extensive comparisons are conducted with a general-purpose Monte Carlo (MC) simulation. Furthermore, our analysis includes the study and presentation of combined TPC-TOF spectra corrected for secondaries from RUN3.

Additionally, our investigation delves into the ratios of kaons to pions and protons to pions, providing valuable insights into the relative abundance of these particles. Comparative analysis with corresponding results from ALICE RUN2 enables an assessment of the evolution and potential differences between the datasets.

Employing robust analysis procedures, this study aims to deliver precise measurements of particle production, elucidating the intricate interplay between transverse momentum, centrality, and collision energy in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV.

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The “MARTA” Survey: An in-depth characterisation of electron temperatures, metallicity, and ISM properties in z~2-3 galaxies via simultaneous detections of strong and faint emission lines

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Chemical abundances are crucial tools in our understanding of the processes driving galaxy evolution, but their accurate determination in high redshift galaxies is challenging.
The advent of JWST finally enabled the detection of faint auroral lines, required to perform more ‘direct’, physically motivated metallicity measurements via the Te method, in high-z sources, completely revolutionising the landscape of chemical abundance studies in the early Universe.
I will present results from ‘Measuring Abundances at high Redshift with the Te Approach’ (MARTA, PID 1879, PI Curti), a deep NIRSpec/MSA JWST GO programme aimed at delivering simultaneous, high signal-to-noise detections of rest-frame optical emission lines, including multiple temperature-sensitive auroral lines like [O III]4363, [O II]7320,30, and [S III]6312, in individual spectra of z~2-3 galaxies, and hence allowing a detailed characterisation of ionisation conditions, dust properties, metallicity, and chemical abundance patterns (e.g. N/O, S/O, Ar/O), and their constraints on the star-formation history of galaxies at the “Cosmic Noon”.
I will also show the relationship between electron temperatures probed by different ionic species, their cosmic evolution, and their impact on the metallicity determination via standard diagnostics, trying also to interpret and reproduce them in the framework of novel, multi-cloud photoionisation models.

Curricula 2

Earth and the Sun-Earth system

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The GAPS Experiment-a search for light cosmic ray antinuclei

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Abstract for Poster:As many models suggest, the Universe is made of Dark Matter (DM) and the origin and nature of DM is one of unsolved topics of modern physics .Many experiments are continuously trying to solve this mystery and GAPS – General Anti-Particle Spectrometer – could offer a unique approach to tackle the search for DM candidates. This is a balloon-borne cosmic ray detector, whose primary goal is to search for light anti-nuclei in cosmic radiation at kinetic energies below 0.25 Gev/n; this specific range is of particular interest because many DM models propose annihilation and decay into matter-antimatter pairs right around these energies. The payload – currently in its last phase of integration – consists of a tracker equipped with large-area Si(Li) detectors and surrounded by a large-acceptance ToF system made of plastic scintillators. This design has been optimized to perform a novel antiparticle identification technique based on an anti-nucleus capture and the subsequent exotic atom formation and decay, allowing more active target material and a larger geometrical acceptance. The GAPS first flight is scheduled for December 2024 from McMurdo station (Antarctica), for a cumulative 31 days of duration: as a result, GAPS is expected to study the low-energy sectors of antiproton, anti-deuteron and anti-helium nuclei spectra, having the potential to significantly expand our understanding of low-energy anti-nuclei in cosmic rays.

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Unexpected Frequency of Horizontal Oscillations of Magnetic Structures in the Solar Photosphere

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Magnetic elements are well-known to cover the entire lower layer of the Sun's atmosphere, the photosphere. These magnetic structures and their associated dynamics can potentially explain long debated questions in solar physics, such as coronal heating and the acceleration of solar wind. The aim of this work is to study the coherent transverse oscillations observed in magnetic concentrations within the lower solar atmosphere with unprecedented statistical accuracy. Exploiting unmatched high-stability and temporal coverage of magnetograms acquired by the Helioseismic and Magnetic Imager (HMI) onboard of NASA's Solar Dynamics Observatory, we investigate the dynamics of small scale elements on the photosphere over the whole operational lifetime of the instruments, currently amounting to more than 10 years. More than 1 million magnetic elements are tracked in HMI magnetograms, at disk center, for an entire solar cycle to investigate the power spectra of their horizontal velocity perturbations. A dominant frequency peak at $\approx$5 mHz is found in the power spectra of horizontal velocity perturbations. This frequency is not expected at photospheric heights, which is typically dominated by $\approx$3 mHz oscillations. Since magnetic elements are passively advected by the photospheric plasma, we suggest that the $\approx$5 mHz dominant frequency may come from the cooperative interaction between different granules that apply forces to the magnetic elements.

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Machine Learning for Detecting Time-Transient Phenomena in the Ionosphere and Correlation with Seismo-Induced Events

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The ionosphere serves as a dynamic interface between Earth's atmosphere and space, characterized by intricate temporal fluctuations influenced by diverse terrestrial and extraterrestrial factors. This research investigates the significance of scrutinizing ionospheric anomalies for the detection of seismic event precursors. A key focus is on leveraging Machine Learning algorithms for the processing and analysis of extensive ionospheric electromagnetic spectrum data obtained from observations by the Demeter satellite for the duration of 6 years from 2005 to 2010. Our earthquake data involves around 8000 events with magnitude greater than or equal to 5.0, recorded in the duration of these 6 years. The study employs a grid-based approach, dividing the Earth into equal-degree grids (20x20), and defining eleven low-energy frequency bands of spectrum data. Notably, percentile values Q1, Q2, and Q3 are the primary features of interest. Analysis entails examining variations in percentile features across each grid location on Earth for the day and night orbit spectrum data. Utilizing diverse machine learning and deep learning algorithms enables the identification of anomalies in the data for each grid location. This yields a time series of anomaly indexes, facilitating the exploration of the relationship between anomaly occurrence and earthquake data, with potential implications for interpreting unknown data. In contrast to many current methods, our approach aims to objectively analyze data without biases, ensuring fair and impartial analysis, leading to more reliable findings. This study holds the potential for enhancing early warning systems and advancing earthquake understanding.

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Advancing Solar Flare Forecasting: Predicting Solar Flares via a Deep Learning Approach Using Time Series of SDO/HMI Line-of-Sight Magnetograms

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Solar flares, sudden bursts of electromagnetic energy originating from magnetically active regions on the solar surface, pose significant risks to satellite infrastructure, communication systems, and power grids. Predicting these events is crucial for both physicists and governmental agencies. Recent observations and research have revealed that solar flares are more complex phenomena than previously thought, as they extend from the corona to the lower photosphere, underlining the interconnected nature of the Sun's atmospheric layers and emphasizing the need for a comprehensive understanding of solar flare dynamics to improve space weather forecasting and our ability to protect space-based technology and infrastructure. Conventional approaches to this problem rely on features extracted from line-of-sight (LoS) magnetograms of solar active regions, which have traditionally been linked to increased flare activity. More recent methodologies leverage temporal series of LoS magnetograms to extract as much information as possible from available data, progressing towards a fully automated flare forecasting system. Despite these advancements, recent studies with LoS magnetograms haven't shown significant improvements over previous methods, raising doubts about their effectiveness. We propose a deep learning-based approach to address this challenge. We model the solar flare forecasting problem as a binary time series classification task using line-of-sight (LoS) magnetograms obtained from the Solar Dynamics Observatory's Helioseismic and Magnetic Imager (SDO/HMI). These magnetograms provide crucial data capturing magnetic field variations on the solar surface, which are essential for predicting solar activity. Our primary objective is to distinguish between active regions likely to produce M- or X-class flares within a 24-hour window and those remaining inactive. Such a classifier could be instrumental in the development of an early warning system for solar flares. Our proposed approach consists of two phases: firstly, a Convolutional Neural Network (CNN) autoencoder performs feature extraction from the magnetograms. Secondly, a Long Short-Term Memory (LSTM) binary classifier processes the extracted features to predict flare activity. Our proposed methodology achieves a remarkable 90% test accuracy. It is validated against test case AR HARP 377, demonstrating its efficacy in solar flare prediction.

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Investigating the Role of Turbulence in Coronal Mass Ejections Using Empirical Mode Decomposition

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Coronal mass ejections (CMEs) are intense bursts of light and plasma eruptions originating from active solar regions, accompanied by large amounts of matter and magnetic flux. CMEs do not remain local in space; they are transported by the Sun's dynamic magnetic field into interplanetary space, where they can significantly impact the time-varying conditions of the inner solar system. Previous studies have established the turbulent nature of CMEs, where energy is transferred in a cascade process from larger structures to smaller ones, forming eddies. This study aims to investigate the role of turbulence at different stages of a CME to better understand factors that can potentially influence the strength of a CME. The stages considered in this study are characterized by the time of the shock arrival and the magnetic cloud region in a timeseries data set. We applied the technique of empirical mode decomposition (EMD) to break down the magnetic field signal into intrinsic mode functions (IMFs), which represent inherent oscillation modes within the data signal. The IMFs are analyzed for each component of the magnetic field (Bx, By, Bz) at different CME stages to generate Fourier power spectra and Hilbert-Huang spectra, therefore, aiming to establish a link between turbulence and CME strength.

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Analysis of Velocity Distribution Functions using the Gaussian Mixture Model

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Velocity distribution functions (VDFs) measured by space missions are complex 3D datasets that can be represented as a superposition of multiple beams (Goldman et al., 2020). Recent papers (Dupuis et al., 2020; De Marco et al., 2023) proposed the use of the Gaussian Mixture Model (GMM) to identify different populations. The method is applied systematically to space data of the Earth's magnetosphere. The conclusion of the analysis is that the GMM is capable of detecting the presence of multiple beams within an overall distribution. The GMM can define reliably the complexity of a measured dataset in terms of the number of optimal beams provided by information theory criteria. The goal of the analysis is to differentiate between simple and more complex regions based on the measured VDFs. In particular, complex shaped electron distribution have been shown to be good indicators for processes of interest such as magnetic reconnection and turbulence (Shuster et al., 2014; Hoshino et al., 2001).

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Ionospheric response to Mt.Etna eruption

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Solid Earth and fluid Earth are two open systems exchanging energy continuously with many geodynamical processes (e.g. earthquakes, volcanic eruptions, tsunami, thermal radiation). Volcanic eruptions belong to these processes because they determine an interaction between lithosphere (or idrosphere) and atmosphere. For example, the evolution of an eruptive column is a coupling process between lithosphere and lower atmosphere but, during an explosive volcanic eruption, other energy releasing occur like acoustic – gravity waves (AGWs) that can reach the upper atmosphere too. The advent of satellite systems in the last 50 years allowed to work out some detection techniques of volcanic activity, for example those based on temperature, pyroclastic or gas concentration.
The ionospheric monitoring in terms of TEC analysis (Total Electron Content) is an application representing a new research field to study volcanic eruptions with satellite technology as Global Navigation Satellite System (GNSS). The GNSS – TEC analysis is based on the electron density oscillations of the ionosphere estimated in terms of TEC Unit (1 TECU = $1{\cdot}10^{16}\ e^{-}{\cdot}m^{-2}$) from GNSS data processing. GNSS data processing algorithm is the Variometric Approach for Real-time Ionosphere Observation (VARION) already applied to detection of TEC signatures by tsunami and volcanic eruptions.
We analyzed fountain activity of Mt.Etna between 2012 – 2021 characterized by Mass Eruption Rate peak $Q_m \geq 1{\cdot}10^6\ kg \cdot s^{-1}$. The morning large scale lava fountain (LSLF) of December 4^{th} 2015 occurred during clearest TEC signatures characterized by peak A ~ 0.5 TECU, apparent horizontal velocity v_{HA} ~ 170 – 250 $m \cdot s^{-1}$ and frequency f ~ 1 – 1.5 mHz by FFT spectral analysis (Fast Fourier Transform). We applied Empirical Mode Decomposition (EMD) technique to verify TEC signature by physical meaning of its components, namely Intrinsic Mode Functions (IMFs). One IMF characterizes TEC signature with TEC peak A ~ 0.3 TECU and frequency f ~ 0.5 – 1.5 mHz. These results, specially v_{HA} and f, agree within literature ones for gravity waves of Co-Volcanic Ionospheric Disturbances (CVIDs).

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Assessment of the Precision of Precipitation and Temperature Reanalysis Data (EMO) in the Aosta Valley Basin: A Grid-Based and Sub-Basin Analysis at Daily Time Scale.

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Integrated and high-resolution Earth Observation (EO) data are indispensable for studies concerning water resource management and flood prediction, especially in high-altitude regions and mountains where data are scarce. European Meteorological Observations (EMO) represents a European high-resolution, (sub-)daily, multi-variable gridded meteorological dataset constructed from reanalysys of historical and real-time observations. The aim of this research is to assess the precision of daily precipitation records and average daily temperature estimates within the EMO dataset by using ground data. We experiment with two ways of using EMO data: grid and sub-basin; The testing area is the Aosta Valley basin (AVB), a mountainous region located in the north west of Italy. findings indicated no significant difference in precipitation data accuracy across two spatial scales. The average Kling Gupta Efficiency (KGE) and Root Mean Square Error (RMSE) values for both scales were reported as 0.6 and 5.8 millimeters, respectively when data are analyzed all together. Furthermore, our assessments reveal an absence of a clear correlation between elevation and precipitation data accuracy, although such a correlation was evident for temperature data. However, a finer analysis, distinguishing the elevations, show that the average KGE values decreased from 0.7 to -2 and 0.7 to -1.6 from low elevation to high elevation points for the grid-scale and sub-basin, while the average RMSE values increased from 3.8 to 8.4 and 3.7 to 8.1 (mm), respectively. This evident disagreement with elevations is investigated and some explanation of the fact is given.

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On the causal inference in magnetosphere / solar wind system during geomagnetic storms

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Solar storms are emissions of energy and charged particles from the Sun, such as Coronal Mass Ejection (CME), and can affect Earth's magnetic field, if directed toward Earth. The magnetosphere can usually shield Earth from solar storms, but sometimes, they can cause saturation of transformers, blackout of power systems, disturbances of international communications, damage satellites and be responsible for exposing astronauts to abnormal levels of radiation.

The energy transferred from a solar storm to Earth's magnetic field is primarily determined by the relative orientation of the interplanetary magnetic field within the CME, the source of the geomagnetic storms. If the magnetic field has a southward component for enough time, the interplanetary plasma can penetrate the magnetosphere, intensifying its current systems. This intensification, particularly of the ring current circulating in the magnetospheric equatorial plane, triggers geomagnetic storms. These events are typically monitored through the *SYM-H* geomagnetic index. Therefore, a comprehensive understanding and accurate modeling of the *SYM-H* index's dynamic features are essential for investigating about geomagnetic storms.

This work aims to study the causal relations between magnetospheric dynamics and external drivers, using a bivariate time series causality analysis, which allow us to reconstruct the causal graph of the system, following the methodology outlined by. This method takes as input a linear 2D continuous-time stochastic system for $(X(t), Y(t))^1$, and provides an estimation of the information transfer, $T_{Y\to X}$, between X and Y and vice versa. These values are normalized and subjected to statistical significance testing. Practically, each time series corresponds to a vertex in the causal graph, and a causal link is drawn between a vertex pair, say (Y, X), if the associated information flow, $T_{Y\to X}$, is statistically significant at an α level, and $|T_{Y\to X}|$ represents the weight of the edge.

The analysis focuses on finding the more relevant solar wind / magnetosphere coupling functions in terms of the normalized information transfer with respect to *SYM-H*. In detail, in order to study the response time of the magnetosphere to external solar wind drivers, we used a delayed[2] version of the net normalized information flow, i.e., $\Delta\mathcal{T}_{Y\leftrightarrow X}(\tau) = |\mathcal{T}_{Y\to X}(\tau)| - |\mathcal{T}_{X\to Y}(\tau)|$ [3], where $\mathcal{T}$ denotes the normalized information transfer. Preliminary results show important qualitatively agreement with linear correlation analysis.

[1] henceforth the dependence on time is understood

[2] In this work only Y (driver) is lagged forward in time while the past of X (response) keeps unchanged.

[3] In causal inference only the absolute value is considered.

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SunCubE OnE (SEE): A Multi-wavelength Synoptic Solar Micro Satelitte

Author: Archana Giri Nair[1]

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Sun CubE OnE (SEE) is a micro satellite for multispectral synoptic observation of the Sun. SEE mission is in the shortlist of the “Future missions for Cubesat” call of ASI. SEE is a sentinel to monitor space weather events in a wide range of energies. SEE wants to unveil solar-terrestrial relations in the UV linking for the first time spectral solar irradiance in the Mg II doublet with chromospheric structures in full disk images. SEE wants to unveil the fundamental physics at the base of particle acceleration in solar flare events exploring for the first time. X-ray emission at very high cadence (up to 10kHz). SEE could provide complementary information to current (Solar Orbiter, Parker Solar Probe, IRIS, MAXI, GOES, SDO, HINODE) and future (VIGIL, PROBA-3, SOLAR-C) missions.

Curricula 7

Economics, law and space diplomacy

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From pixels to policies: charting a path for responsible data governance in Earth Observation

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In this research is presented a study of satellite data governance for Earth Observation (EO) satellites. Since EO satellites proliferate, sensitive data regarding terrestrial observations has become more accessible than ever, necessitating robust security measures and anonymization protocol protocols to protect privacy. Accessing and sharing collected data in this field requires seamless international cooperation.

Earth observation, as defined by the United Nations Working Group on Remote Sensing of the Earth by Satellites, refers to the use of space platforms to observe, measure, and characterize phenomena on, above, and below the earth's surface. Data obtained by EO satellites exhibit high-quality images and dimensions across spatial, spectral, and temporal domains, posing pertinent questions regarding their access, transfer, and use as evidence.

The EO actors landscape includes institutions at national and European levels, as well as private operators such as SpaceX, Blue Origin, and Virgin. While EO data utilization has many benefits, it must be considered in light of its implications for peaceful use of Outer Space as well. Satellite imagery resolution profoundly influences military-security dynamics, underscored by new research on the intricate nexus between EO data and military-security dynamics. Using an interdisciplinary approach, this study contributes to the development of frameworks that balance privacy protection, international cooperation, and peaceful exploration of space.

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A new deep learning method for mapping slums in developing countries, Using Sentinel-2 Imagery

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The past few decades have witnessed unprecedented growth in urban populations, leading to a corresponding increase in slums within urban areas. Projections suggest that the slum population could reach 2 billion within the next 30 years. While the United Nations provides annual statistical reports on the global slum population, the definition of slums therein tends to lean towards informal settlements or bad housing. The broader objective of this research is to precisely define slums and to track the emergence and evolution of slums in developing countries, mainly African countries. By using multispectral high-resolution and medium-resolution Sentinel-2 images, this research aims to build a deep learning method to identify slums in urban areas. Additionally, the paper intends to analyse factors contributing to the surge in slums by combining econometric analysis with remote sensing techniques.

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A Governance framework for the future Earth-Observation Governmental Service of the European Union

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The new space economy has paved the way for new actors, cost-effective business models, and disruptive technologies, but the sector still presents significant regulation and governance gaps. In particular, the Security and Defence sector in the European Union is characterized by a weak governance, challenging its technological sovereignty and the resilience of the space value chains and space infrastructure. The European Union Space Strategy for Security and Defence supports Space-based Earth Observation (SBEO) to enhance autonomous assessment and decision–making to enable security and defence capabilities. The definition of the governance shall guarantee the access to authorised users with the appropriate security level. However, security constraints may have a relevant impact on system architecture and on costs.
This research proposes a Governance model for the future Defence and Security Governmental Service (EGOV) of the European Union by analysing potential barriers and enablers at the international, regional and national level and contributes to the definition of the Service key elements with respect to the evolution of European regulation, as well as to a national position. The study is based on an in depth research into the current state of national and federal security services around the world, which leads to the creation of a purposeful classification of models given critical parameters identified during the analysis. This first comparative analysis between different governance models is accompanied by an analysis of the influence of economic and market factors. Specifically, we study how economic and financial aspects (in the framework of the PPPs and a construction of a Market Place) related to the old and new space economy models influence the governance framework and the role of disruptive technologies and new actors in the downstream security service market. Finally, the research suggests the basic elements for a new EU Governance Service complementary to national services benefitting from national assets and taking into consideration the trade-off between national sovereignty and service usefulness and usability. The architecture for the governance model is built on a user-driven approach to consolidate governmental use cases, user needs and user requirements then translated into a gap analysis mapping users' needs against existing and planned institutional and commercial capabilities.
The proposed research innovative nature lays in the association between programmatic and technical requirements, governance elements (actors, roles, responsibilities, processes) and financial aspects (procurement schemes, CAPEX and OPEX expenditures, etc.), with a legal and regulatory dimension (EU and national laws and regulations, ownership, data policy, licenses).

Part II

Day 2 Posters - June 8th

Curricula 3

Planetary Sciences

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Celestial Mechanics Advancements: Exploring Orbital Trajectories and Stability through Variational Methods

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In recent years, significant advancements in celestial mechanics have emerged through a variational method applied to the n-body problem, leading to the discovery of novel orbital trajectories. This approach involves examining critical points of the Lagrangian action associated with the n-body problem, wherein specific periodic solutions of the dynamical system can be numerically determined by utilising evolutionary algorithms once the problem has been discretised.

Initially, emphasis is placed on scrutinising critical points, particularly minima, of the action functional pertaining to the n-body problem. These critical points, under certain assumptions, represent feasible and physically meaningful solutions of the dynamical system, manifesting as periodic orbits that satisfy the associated differential equations. By employing a blend of stochastic and deterministic algorithms, the parameter space of viable solutions can be explored to ascertain the expression of these orbits.

Subsequently, attention shifts towards assessing the functional stability of the problem. Orbit trajectories identified in the previous phase are mapped as critical points, allowing for an examination of the stability or instability within their respective neighbourhoods. This involves treating the problem as a dynamical system, analysing the gradient of the action functional $\mathcal{A}$, denoted as $\eta' = -\nabla\mathcal{A}(\eta)$. This approach not only characterises the minima discovered earlier but also delineates the basin of attraction for each minimum, derived from the algorithm's analysis of the initial input data or starting point.

Lastly, attention is directed towards analysing the boundaries of these basins of attraction. It has been established that when two boundaries converge and then separate, the point of separation asymptotically converges to a critical point that is not a minimum. Leveraging conventional algorithms such as the Newton method enables the numerical approximation of these new critical points, which differ from previously identified minima.

Despite its theoretical nature, this methodology holds practical applications in Astrodynamics, particularly in mission design and the deployment of satellite constellations into orbit.

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Spectroscopic and minero-petrological investigation of boninites from Cyprus as potential analogues of Mercury lavas

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Despite the clearly different formation conditions regarding oxygen fugacity, water contribution and iron abundance in
the source region, terrestrial boninites and komatiites are considered promising analogues for Mercury's lavas based on MESSENGER Mission data [1]. This study aims to compare terrestrial boninites with Mercury lavas, considering spectroscopic, petrological, and mineralogical characteristics. We are investigating samples coming from three distinct locations (labeled PAR, ARA, ATH) within the Troodos massif, Cyprus island. We selected representative samples for each locality and performed X-ray Fluorescence (XRF), scanning electron microscopy (SEM), electron microprobe (EPMA) analysis and reflectance spectroscopy in the spectral ranges covered by the VIHI imaging spectrometer (0.4-2.0 μm) [2] and the MERTIS spectrometer (7-14 μm) [3] onboard the ESA's BepiColombo mission. XRF bulk composition analysis gave average values (wt%) of major elements (SiO2 53.2, Al2O3 12.2; FeO 7.9; MgO 12.55; CaO 8.5) that are in good agreement with the average compositions of Mercury's geochemical terranes [1,4]. SiO2 and Al2O3 contents fall right in the ranges of Mercury's terranes; MgO content in our samples is slightly lower and CaO higher; the only major difference is the higher FeO content, as expected. The spectroscopic and compositional differences observed between the samples, reflect their different mineralogy. Samples PAR show vitrophyric texture with olivine (Fo89) and clinopyroxene (En48Wo38Fs14) phenocrysts in glassy groundmass. Plagioclase crystals are not detected. Minor weathering is visible with the presence of sporadic calcite grains. Samples ARA are composed of clinopyroxene (En47Wo30Fs13) in albitic groundmass (Ab98An2). Weathering is clearly visible with the presence of clinochlore replacing olivine. ATH sample is holocrystalline and composed by euhedral clino- (En48Wo42Fs10) and ortho-pyroxene (En82Wo4Fs14) crystals surrounded by plagioclases (from Ab97An3 to Ab7An93). Olivine is not observed and some portions are composed only of clay minerals. VNIR spectra show an absorption band at ~1 μm which is associated with olivine and pyroxene. Some samples show also clear absorption features at ~1.4 μm, ~1.9 μm and 2.3 μm due to terrestrial hydrated alteration phases. Taking into account the differences intrinsic in the acquisition methods and in the objects under analysis [e.g. 5], we tried a preliminary comparison between laboratory reflectance spectra of boninite samples and MASCS/MESSENGER Mercury data [6]. This comparison will be implemented with ongoing measurements including VNIR reflectance analysis with different acquisition angles and on smaller grain sizes and TIR emittance spectroscopy investigation. These new data, in combination with minero-petrologic characterization, could also facilitate future comparisons with mineralogical data expected from SIMBIO-SYS/VIHI and MERTIS spectrometers.

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Manifolds connections and the transport of small bodies through mean motion resonances in the Solar System

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We discuss how the transport of small bodies through the orbit of Jupiter in the Solar System is governed by the heteroclinic intersections between the stable and unstable manifolds of the unstable periodic orbits corresponding to each one of the main mean motion resonances between the body's and Jupiter's orbits. These manifolds have been extensively discussed in literature in the case of the co-orbital resonance. (manifolds of the periodic orbits around the collinear Lagrangian points), but to a lesser extent for other important mean motion resonances. Here we show how a global visualization of these manifolds can be achieved through the computation of short time Fast Lyapunov Indicator maps, allowing to depict their underlying intricate heteroclinic dynamics. A precise computation of these manifolds with direct semi-analytical methods is in progress.

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HIP 41378 b & c: Unveiling the nature of the two sub-Neptunes with transit timing variations using CHEOPS

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Super-Earths and sub-Neptunes, planets ranging in size between Earth and Neptune, are prevalent in our Galaxy, serving as a link between terrestrial and giant planets found in our Solar System.

Concerning the internal composition of the largest of the two populations, sub-Neptunes (1.7 $R_{\oplus}$ ⊠ Rp ⊠ 3.5 $R_{\oplus}$), much remains to be understood. Proposed compositions for these worlds range from ocean planets with water mantles and steam atmospheres to ultrahot rocky planets with molten lava-rich surfaces and heavyweight envelopes (Winn et al., 2018; Otegi et al., 2020).

With its two transiting sub-Neptunes, close (~1.8%) to a 2:1 mean motion resonance (MMR) exhibiting anti-correlated transit timing variations (TTVs), the multi-planet system HIP 41378 represents the perfect dynamical laboratory to investigate both dynamical and atmospheric evolution processes. We combined several photometric datasets of transit photometry (CHEOPS, TESS, HST, and Spitzer) and radial velocity (RV) (HARPS) to reassess the characteristics of the system and precisely measured the radii and masses of the planets. We find the planetary radii and masses of HIP 41378 b and c to be Rb= 2.509 ± 0.024 $R_{\oplus}$, Mb= 7.04 ± 0.59 $M_{\oplus}$, Rc= 2.635 ± 0.091 $R_{\oplus}$, and Mc = 2.18 ± 0.21 $M_{\oplus}$. Our precise determination of the masses and radii of the planets allowed us to study the interior composition of the planets and the evolution of the planetary system.

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NEO Radar Observations in Europe

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We present some results from NEO radar observations conducted in Europe in recent years as part of the ESA project "NEO Observation Concepts for Radar Systems." The project aimed to: define the functional requirements of a planetary radar system for NEO observations, assess the current and future capabilities of European assets for such observations, and conduct test campaigns utilizing European facilities.

This poster focuses on the test campaigns carried out in collaboration with the Jet Propulsion Laboratory (JPL) between 2021 and 2022, resulting in the observation of several asteroids, including (4660) Nereus and 2005 LW3, which are discussed here. These observations enabled us to derive polarization ratio and rotation period measurements, along with astrometric information. Notably, in the case of 2005 LW3, echoes revealed the binary nature of the target.

These observations, alongside the entire project, underscored that European radio telescopes, despite serving only as receivers in a limited number of experiments, could substantially contribute to the establishment of a European network for NEO monitoring, provided a suitable transmitter becomes available.

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AI Approaches to the Automatic Optimization of Instrument Acquisition Scheduling in Space Missions

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In the context of planetary missions, the optimization of the scheduling of the acquisitions of instruments in the payload is of great importance in order to maximize the scientific return.
To this end, specific acquisition plans are defined, deciding which instruments can operate at different times in order to optimize coverage while respecting both the physical constraints imposed by the target scenario and the mission resources.
Despite some automatic/semi-automatic approaches have been developed for scheduling activities of Earth observation satellites, only few studies have considered the case of space missions focused on other planets, where the usually long temporal length of the schedule and the many constraints make the problem more complex.
Most of these approaches rely on classical constraint-based optimization algorithms, with the most advanced solutions based on genetic programming.
This research work attempts to address the problem of instrument acquisitions optimization through the use of new methodologies based on AI and in particular on deep reinforcement learning.
The study is developed with respect to the operations of radar instruments, even if the methodology is general.
The task is formulated in the form of a multi-dimensional knapsack problem, and several models are currently being tested. Research is still in its early stages, directed towards the development of algorithms capable of exploiting neural networks in order to handle the large dimensionality of the combinatorial problem.
If successful, the optimizers could be used to support space missions such as JUICE and EnVision.

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Analysis of Ganymede’s gravitational field in support of JUICE mission

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In the absence of seismic data, the gravity field allows to investigate the internal distribution of mass of a planetary object. The upcoming missions JUICE (ESA), BepiColombo (ESA-JAXA) and Veritas (NASA) will measure the gravitational fields of Ganymede, Mercury, and Venus, respectively, to constrain their interiors.

The moment of inertia, derived by the gravity field coefficient J_2 and C_{22}, will enable to model the deepest structure and the level of hydrostatic equilibrium of planetary bodies. In addition, the gravitational anomalies (i.e. Free-Air and Bouguer) and the admittance Z analysis, evaluated by comparing the gravity field with the topography, will reveal variations in crustal density, crustal-mantle boundary, and, potentially, core-mantle interface.

I developed a novel code to compute gravitational anomalies and admittance’s profile $Z(n)$, following the spherical harmonic expansion approach (Wieczorek, 2015), which exploits the associated Legendre polynomials P_{nm}. The code is able to handle gravity data in the form of Stokes’ coefficients $[C_{nm}, S_{nm}]$, resulting numerically stable up to the highest available degree (~2190). In preparation for the JUICE mission, I modelled the gravitational anomalies of Mercury, Earth, Venus and Moon. The so-obtained resulting maps are consistent with those reported in the literature, validating both the code and the performed analysis.

Future works will further detail the study of the degree spectrum through the application of a new mathematical tool, called Spherical Iterative Filtering (Cicone, 2024), and the development of inversion methods.

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Chirfa meteorite: the largest specimen from Mars

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The Martian meteorites (MMs) are peculiar igneous rocks distinguished from other achondrite meteorites based on their different petrography, mineralogy, mineral-chemistry, major and trace elements, and isotopic compositions. To date, MMs are classified into three main groups: Shergottites (basalts), Nakhlites (clinopyroxenites), and Chassignite (dunite). In addition, two unique types of meteorites have been found: ALH84001 (orthopyroxenite) and NWA 7034 (and the related pairs) regolith breccias. The basaltic shergottites, the most abundant MMs (about 90% of the total MMs), can be further subdivided into the following subgroups: basaltic (45%), olivine-phyric (30%), poikilitic (18%), gabbroic (5.5%), augite-rich (0.9%) and pigeonite-rich NWA 10414 (0.5%) [1].
In this work, we present the preliminary petrographic results of a new MM found on 18th November 2023 in the Sahara Desert near Chirfa, Niger (coordinate: 21o05'12.72"N, 11o26'07.76''E). It represents the largest individual Martian sample hitherto described in the Meteorite Bulletin database – total weight ~ 24.6 Kg.
A centimeter-size fragment has been embedded and polished for petrographic investigations. Backscattered images were acquired by scanning electron microscopy (SEM) at the Centro di Servizi di Microscopia Elettronica e Microanalisi (MEMA) of the Università degli Studi di Firenze, Italy. Quantitative analyses were obtained by electron microprobe (EMPA-WDS) at the same center.
Backscattered images show a coarse-grained texture, with crystals ranging from tens to hundreds of microns, dominated by pyroxene, plagioclase (possibly maskelinite), and olivine. Large elongated prismatic pyroxene (up to 2.1 mm) and olivine (up to 2.5 mm) crystals may also occur. Oxides, phosphates, and sulfides are present as accessory phases. Pyroxenes are subhedral to euhedral (also occurring with a lath-like appearance within plagioclase) and, generally, show low-Ca cores (average En68Fs27Wo5) surrounded by Ca-rich rims (average En49Fe38Wo13), although complex zoning patterns are commonly observed. However, a poikilitic texture containing olivine chadacrysts (~100μm) enclosed by pyroxene oikocrysts (mm-size) is also present. Olivine grains are both subhedral and euhedral and generally show normal zoning from the Fo65 core to the Fo34 rim. The Fe/Mn ratio ranges from 50.4 to 55.5 and from 27.8 to 36.3 for olivine and pyroxene grains, respectively. Maskelinite mainly occurs in both lath-like and interstitial textures (~15 vol%). The size ranges from ~100μm up to 1mm, and the average composition is about An50Ab48Or2. Tiny veins (~50 μm in thickness) mainly composed of granular calcite are present.
Olivine gabbroic shergottite are coarse-grained igneous rock predominantly composed of pyroxene, olivine and makelinite. Likewise, the poikilitic shergottites contain poikilitic olivine set in a groundmass of smaller olivine, pyroxene, and maskelinite. Moreover, the olivine gabbroic shergottite, a relatively new shergottite subgroup, has been proposed as link between gabbroic and poikilitic shergottites. The coarse grained and poikilitic texture, and the abundance of maskelinite (>10 vol%) found in the Chirfa meteorite, suggest more affinities to olivine gabbroic shergottite rather than poikilitic, or other shergottite subgroup. In conclusion, we propose that Chirfa meteorite, the larger specimen from Mars, is an olivine gabbroic shergottite. Remain ambiguous the attribution of the grain size affinity – gabbroic or micro gabbroic – in which their use appears ubiquity in the literature data. However, further studies to shed light on the detail attribution are currently in progress.
We believe the argument worthy, and further petrographic, petrologic, and geochemical investigations could improve our understanding of the Martian geological processes.

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Analysis of lava flow features on Venus for radar sounder simulations

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New missions towards Venus are planned for the near future with the aim of unveiling why and how the evolution of Venus diverged from that of Earth, considered its twin planet. One of these missions is ESA's EnVision, to be launched in 2031, focused on the study of Venus geological and geodynamical evolution and its relationship with the atmosphere. The study of the geological features is performed by various instruments, among these by the subsurface radar sounder (SRS). The analysis of the performance of the radar sounder can be enhanced with simulations of the radargrams based on geological analogues of the targets of interest. This approach exploits existing radargrams in geologically analogous terrains to produce realistic simulations of the investigated target, using parameters related to the composition and morphometry of the target. Since the Venusian surface is dominated by volcanic morphology, SRS targets are focused on some volcanic morphologies, such as lava flow features. This research work aims at providing the morphological and compositional properties to be employed in the simulations of lava flow features. They compose one of the youngest geologic features and provide important insights into the stratigraphic history and current geologic activity on Venus. They have been classified based on their morphology
or based on appearance in the Magellan SAR data.
Estimates of flow thicknesses on Venus from Magellan altimeter data and
stratigraphic relationships with other features pointed out a lower limit of 10-30 m of
thickness for individual lobes, and a maximum thickness in the
order of 400 m. The extension of flows ranges from tens up to thousands of kilometres. Observations of Magellan radar backscatter of Venus flows and comparison with similar measurements on Earth indicate that they are mostly consistent with a smooth, pahoehoe-like surface roughness with limited occurrences of a'a. Roughness values of rms slopes (at Magellan resolution, 75 m) are around 2.50°-8°. The composition of lava flows has been inferred by measurements at Venera and VEGA landing sites and from morphological observations. Analyses from some of the Venera and Vega missions yield a predominantly mafic composition. The pahoehoe-like behaviour also supports a basaltic composition as on Earth. More exotic compositions for the longest flows are considered, such as carbonatite or sulphur and more evolved compositions are possible. Emissivity measurements of Venus flows range from 0.7 to 0.9, consistent with basaltic samples. Through emissivity data it is also possible to discriminate between fresh basaltic lava flows and weathered ones, providing relative dating of these features with respect to the surrounding basaltic plains. The multiplicity of eruptive environments suggests different sources and mechanism of emplacement, probably indicative of different periods of activity across Venus history. This analysis is useful in determining what could be the expected performance of SRS. The ability of the instrument to penetrate up to several hundred meters allows the discrimination between individual lobes or sequences of lava flows based on composition, porosity, surface roughness and temperature, and could provide a new stratigraphic perspective of Venus history.

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From Iceland to Mars: Characterizing Potential Regolith Analogs with Reflectance FTIR Spectroscopy

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Background and Rationale Mars is currently one of the most interesting astrobiological targets, being the focus of numerous exploration missions aimed at searching for traces of possible past life. Although the planet is now characterized by extreme and inhospitable conditions for life, it was once habitable and had an Earth-like environment with similar hydrological, geological, and atmospheric complexity. Studying the oldest rocks on the planet, which are still available on its surface due to the lack of plate tectonics, could reveal traces of past life. (Williford et al. 2018)

Aims To support in-situ analyses and future sample return missions, our work aims to characterize a potential regolith analog collected at Lambahraun, Iceland, using reflectance FTIR spectroscopy. Comparing the spectra of these samples with those obtained by the SuperCam instrument onboard the Perseverance rover will help us understand if this regolith sample is a good analog for the Jezero crater soil.

Materials and Methods At the INAF-Arcetri Astrobiology Laboratory, we used the Bruker VERTEX 70v FTIR spectrometer equipped with the Harrick Praying Mantis accessory to perform DRIFTS (Diffuse Reflectance Infrared Fourier Transform Spectroscopy) measurements. We acquired laboratory spectra in the range between 8000 cm-1 and 400 cm-1 (1.25 µm – 25 µm) with a resolution of 4 cm-1. The sample compartment was saturated with N2 to reduce atmospheric absorption during the measurements.
The Icelandic samples were collected during the NASA-ESA Mars Sample Return Sample Analogue Campaign at a site selected just south of the original target field based on previous work by Baratoux et al. (2011) and Mangold et al. (2011). The sampled sand sheet was chosen for its similarity to the images of the Jezero crater regolith, and presents fine to medium basaltic sand with some coarser grains. Samples were collected with sterilized tools to keep them organically clean.

Results We analyzed the NIR spectra of our samples in the SuperCam range (1.25 µm – 2.6 µm), detecting signals due to the presence of H2O (1.9 µm) and metal–OH bonds (about 1.4 µm, 2.2 µm and 2.3 µm). Comparing the spectra with those acquired by SuperCam at the Observation Mountain (sol 593-606 and sol 632-641), the Granite Peak (sol 594) resembles our LAM 02 A1 sample for slopes and some of the spectral features, revealing the presence in both the samples of water-bearing minerals. The other Martian spectra analyzed had fainter metal–OH features and were more similar to our other samples (LAM 02 A3, LAM 02 F1, LAM 02 J1), with slopes suggesting the predominance of high-calcium pyroxenes.
We then analyzed the MIR spectra of our spectra from 4000 cm-1 to 400 cm-1 (2.5 µm – 25 µm), confirming the basaltic nature of the Icelandic sand by examining the Christiansen Feature and the Reststrahlen Bands. In the region between 4000 cm-1 and 1250 cm-1 we confirmed the presence of water and OH features, while the region between 600 cm-1 and 400 cm-1 revealed the presence of Al-, Mg- and Fe-rich silicates.
The XRD analysis confirmed the presence of basalt in the samples, but did not detect any hydrous minerals: this means that the maximum content of water-bearing minerals in our sample is about 0.5% (the detection limit of the XRD measurement).
Very faint C–H bands were detected between 2900 cm-1 and 2800 cm-1.

Conclusion The NIR Icelandic spectra in the SuperCam range showed features and slopes similar to the Martian ones, thus can be used as mineral analogs for the Observation Mountain regolith. MIR

spectroscopic data provided a better insight on anhydrous minerals of the Icelandic samples, revealing their basaltic composition, but did not allow for quantitative compositional estimates because of nonlinear mixing effects (Ehlmann et al. 2012). In conclusion, our samples could be used as analogs for a basaltic Martian regolith that is poor in water-bearing minerals and rich in plagioclase.
In addition, the spectra suggest the presence of a very small amount of organic molecules so, as a continuation of this work, the same Icelandic soil samples could be used to perform organic extraction, simulating potential small organic signatures in the samples that will be returned from Mars.

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Curricula 4

Astrobiology, Life Sciences and Space Medicine

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Hypergravity Exposure Induces Alterations Of Erythrocyte Membrane And Antioxidant Potential Of Mice Housed In The MDS Facility

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All living organisms have evolved and adapted to live under Earth's gravitational force. To sustain safe human space exploration, it is important to understand how the different effectors, including gravitational force, influence organisms. Altered levels of gravity affect the physiological function of multiple tissues, cells, and organs in living organisms. Many adverse conditions present in Space, such as hypoxia, hypothermia, and microgravity, cause integrated alterations in the lipid membrane composition, inducing greater sensitivity to oxidative stress. Indeed, previous studies, also from our laboratory, suggested that microgravity modifies the permeability of the plasma membrane and cellular metabolism in erythrocyte, modifying cholesterol and phospholipid levels. In addition, hypergravity also affects the physiological functions of tissues and organs; furthermore, the evaluation of the effects of the hypergravity is a fundamental step towards complete knowledge of the physiological response to altered gravity. Aim of this study was to investigate in vivo the effects of hypergravity on lipid phenotype and metabolism in mice erythrocytes. Animals were housed in the Italian Space Agency's Mice Drawer System (MDS), a facility designed to house rodents on the ISS and adapted by Thales Alenia Space to the Large Diameter Centrifuge (LDC-ESA), to expose mice to a 3xg environment. Vivarium animals and MDS-like cage animals were compared as controls. After 30 days of experiment a tissue sharing protocol was performed among international researchers, to analyze all the tissue specimens. We purified and analyzed the red blood cells from whole blood. The membrane lipid phenotype was assessed by gas-chromatography and liquid-chromatography. Finally, to analyze the impact on oxidative homeostasis, the hemolyzed fractions were used to test antioxidant enzyme activities. Our results show that the exposure of mice to an altered gravity induced a modification in the fatty acid composition of 3xg mice compared to control mice, indicating a direct effect of the increased level of gravity. The cholesterol content in membranes was significantly increased. To evaluate the effect of hyper-gravity conditions on the animal's inflammatory and metabolic processes, the ratio between inflammatory eicosanoids and anti-inflammatory eicosanoid precursors was calculated, and a slight reduction in the inflammation index given by arachidonic acid/eicosapentaenoic acid ratio was observed. These findings could be due to a process of metabolic compensation during long-term exposure that leads to a resolution of inflammation. To evaluate the impact of fatty acid composition on the potential level of oxidative stress, we calculated the peroxidability index (PI), which measures the sensitivity of fatty acids to peroxidation; PI was significantly increased under 3xg conditions. Furthermore, we have analyzed the endogenous antioxidant activity in the hemolysate of scavenging enzymes, and the amount of glutathione content in the red blood cells. The enzyme activity of GSH peroxidase shows a significant increase in

3xg mice compared to control mice. This study demonstrates that hypergravity induces changes in both lipid composition and antioxidant system of erythrocytes. Our results will be integrated with other tissue and metabolic data obtained by other researchers of the team. Further studies will be necessary to identify possible countermeasures to ensure an adequate level of crew health and safety during long-duration space missions.

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Alteration of the brain-to-bone axis in microgravity as a factor for bone loss for long-term spaceflight and a potential focus for prospective countermeasures

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Space exploration in the next 30 to 50 years will proceed as follows: first return to the Moon and settle there permanently, and once successful, establish a human colony on Mars. To ensure successful human exploration beyond low Earth orbit, it is critical to investigate the effects of space environments on physiology, crew performance and overall health. While anti-resorptive drugs, a proper diet and vitamins and minerals supplementation are used to address the issue today, this is not sufficient for more than 6-month in microgravity as it is paramount for the first astronauts landing on Mars to be able to explore the red planet's surface when arriving. Even with these countermeasures and intensive postflight reconditioning, full recovery is long and leaves scars even though some studies have shown that it remains incomplete. Until recreating Earth's gravity in space becomes a reality, it is critical to understand how microgravity combined with other stressors, will impact human physiology. Additionally, mitigating bone loss in space would also significantly prevent kidney stone development as a result. Evidence shows that the main cause of muscle and bone loss is physical unloading and the subsequent lack of muscular activity. As stated by NASA's knowledge gap (M23), finding more effective countermeasures requires a thorough understanding of all factors in the space environment affecting bone and muscle loss. Muscle atrophy and strength loss may result from neurophysiological deterioration in both bone and muscle and the ability of electrical signals to propagate properly across synapses may be affected by microgravity. It has already been shown that microgravity negatively affects motor neuron functions. This research aims to better understand brain and bones interaction, especially in space. To this end, rodents will be placed in a Random Positioning Machine (RPM) 20-22 hours a day for four weeks, to determine possible denervation and a possible imbalance of targeted neuropeptides. While the experiment and subsequent analysis for this project are still ongoing, the results of this study will provide original empirical evidence on the effect of microgravity on the brain-bone axis.

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Association between hypnotizability, motor imagery and interoception.

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Background: Long exposure to extreme environments, such as microgravity during spaceflights, has been reported to induce weightlessnes-related physiological changes, including sensorimotor integration (Van Ombergen et al., 2017) and interoceptive abilities impairment (Guo et al., 2023). Among the general population, these abilities have extreme variability, also depending on the psychophysiological trait of hypnotizability. Indeed, hypnotizability is associated with behavioral and brain morphofunctional differences, including lower interoceptive accuracy, measured by heartbeat evoked cortical potential (HEP), more adaptive interoceptive sensitivity, and stronger functional equivalence (FE) between actual and imagined action/perception, which represents the neural readout of motor imagery (MI) abilities (Santarcangelo, 2024). Effective MI requires the presence of correct body representation, which is influenced by interoception (Badoud & Tsakiris, 2017), and this corroborates the mutual exacerbation of sensorimotor and interoceptive abilities in microgravity condition. In the light of the foregoing evidence, the interaction between MI and interoception can be influenced by hypnotizability. The aim of the study was to define the profiles of high, medium and low hypnotizable participants (highs, mediums, lows) regarding the association between interoception and motor imagery.
Methods: Healthy subjects aged between 19 and 35 years were recruited and categorized using the Stanford Hypnotic Susceptibility Scale, Form A. They were administered with questionnaires measuring trait absorption (Tellegen Absorption Scale, TAS) and interoceptive sensitivity (Multidimensional Assessment of Interoceptive Awareness, MAIA). They underwent electroencephalogram (EEG) and electrocardiogram (EKG) acquisitions during movement execution and MI in kinesthetic (K) and visual (V) modalities. MI performance was computed as normalized absolute difference between actual and imagined movement duration ([(actual movement duration − imagined movement duration)/actual movement duration]), MI efficacy was reported by subjects on a Numeric Rating Scale that ranged from 0 to 10. HEP analysis during MI conditions is in progress. ANOVA was used to assess between-group difference and Spearman's correlation was used to assess associations between variables in each group.
Results: 16 highs, 11 mediums, and 25 lows underwent the experimental procedure. TAS scores were significantly different between hypnotizability groups ($F(2,49) = 6.44$, $p < 0.006$) with highs' scores higher than lows ($t(1,34) = 3.21$, $p <= 0.006$), mediums higher than lows ($t(1,25)=2.82$, $p < 0.02$) and no difference between highs and mediums. Only MAIA noticing differed among hypnotizability groups ($F(2,49) = 3.74$, $p = 0.03$) with highs > lows ($p = 0.05$). Significant differences between groups were observed for kinesthetic efficacy (Ke) ($F(2,49) = 4.08$, $p = 0.02$), which was higher in mediums than in lows ($p = 0.05$), whereas visual efficacy (Ve), kinesthetic and visual chronometric variables (⊠Kd, ⊠Vd) did not differ among groups. A significant correlation was observed between Ke and Ve in highs ($\rho = .71$, $p = 0.002$) and between ⊠Kd and ⊠Vd in mediums ($\rho = .65$, $p = 0.032$) and lows ($\rho = .44$, $p = 0.027$). After Bonferroni correction ($p = 0.006$), in highs there was no significant correlations between MAIA dimensions and imagery variables, in mediums Ke correlated with MAIA self regulation ($\rho = 0.78$, $p = 0.005$) and in lows it correlated with not worrying ($\rho = 0.54$, $p = 0.006$), and attention regulation ($\rho = 0.66$, $p = 0.0003$).
Discussion: Highs' Ke was not associated with any MAIA dimensions, while it correlated with self regulation in mediums and with the ability to orient attention towards bodily signals and not be worried by unpleasant information in lows. This suggests that the experience of the kinesthetically imagined movements is independent from interoceptive sensitivity in highs, in contrast to lows and mediums. The observed correlations between visual and kinesthetic chronometric variables in mediums and lows suggest that in the majority of the general population there is no preference for visual or kinesthetic modality of imagery. Since MI could have a therapeutic effect before, during and after exposure to microgravity to counteract adverse effects of weightlessness (Guillot & Debarnot, 2019), these findings shed light on possible future application of interoceptive training to further potentiate MI effects in astronauts, on the basis of their hypnotizability level.

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Analysis of upper limb movements of astronauts performing motor imagery tasks on the ISS and on ground

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The poster presents the research work conducted during the first six months of the PhD: after a preliminary study of the available literature regarding motor coordination, mental imagery of motor tasks and sensorimotor issues related to altered gravity conditions, an analysis was conducted on previously collected motor coordination data, available at the laboratory of Fondazione Santa Lucia IRCSS.
The data consists of the 3D positions of eight retro-reflective markers applied to astronauts engaging in a motor task involving throwing and catching an imagined tennis ball, under varying gravity conditions (on ground and on-board the ISS). The data was investigated in order to extrapolate a method of analysis that could account for possible missing information and lead to the evaluation of all the parameters of interest. The following is a report about what has been analyzed so far.
Firstly, the duration between the throw and catch of the imagined ball is notably longer when envisioning zero gravity conditions compared to normal terrestrial gravitational conditions. This behavior persists in all the tested conditions, indicating that subjects maintain internal models of object motion dependent on the gravitational imagined condition, even when experiencing actual microgravity. Furthermore, the analysis reveals a consistent trend in peak and minimum velocities: both values are lower in real microgravity scenarios, irrespective of the imagined gravity condition. Investigations into the elevation angles of the limb segments during execution of the motor task offer insights into motor coordination. Despite environmental changes, these angles show characteristics that remain consistent, indicating stable motor strategies across varying conditions.
These findings offer valuable insights into motor control in space and on Earth, leaving space for further research, for a statistical analysis on larger data samples and for future experimental protocols to be performed in the next years of the PhD.

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Modulation of interoceptive processing by hypnotizability

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Imaging studies have shown lower insular grey matter volume in highly hypnotizable individuals (highs) compared to low hypnotizable individuals (lows), which may account for their lower interoceptive accuracy and lower heartbeat-evoked cortical potential (HEP) amplitudes already reported in previous studies. As medium hypnotizable individuals (mediums) represent the majority of the population, we aimed to examine interoceptive processing in all three hypnotizability groups. Stanford Hypnotic Susceptibility Scale: Form A was used to measure hypnotizability level of the participants. EEG and ECG signals were recorded in 14 highs, 14 mediums and 18 lows during two experimental phases. The first consisted of an open-eye baseline condition (10 min), while the second consisted of consecutive open-eye (2 min), closed-eye (2 min) and heartbeat counting (2 min) conditions, repeated three times, followed by a single open-eye post-counting condition (2 min). The interoceptive accuracy index, calculated as the correspondence between measured and counted heartbeats, didn't show any significant group difference, however it negatively correlated with hypnotizability scores in the first counting trial. During the first phase of the experiment, HEP amplitudes were lower in highs and mediums compared to lows in the right central region for both early and late HEP components, whereas during the second phase the same difference was observed only for the early HEP component. During the second phase, a significant interaction between hypnotizability group and condition was also observed in the left/midline regions for the late HEP component, with only mediums showing higher amplitudes during counting compared to open/closed-eye conditions and only highs showing higher amplitudes during post-counting rest compared to counting. Baseline interoceptive processing of mediums thus seems to be more similar to that of highs than to that of lows. Moreover, the effect of attention to the heartbeat on interoceptive processing may only be present in mediums, whereas interoceptive learning may be more efficient in highs.

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Ion-molecule reactions in astrochemistry and for the study of the degradation mechanisms of space-technology materials

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Polymers play a vital role in the aerospace industry, yet their vulnerability to atomic and ionic oxygen in space presents a significant challenge. Ground-based tests have confirmed that prolonged exposure in low Earth orbit (LEO) leads to degradation across various properties. Protective measures have been explored, but a comprehensive understanding of the erosion mechanisms is lacking. In this project, we introduce a novel approach to delve into the chemical erosion caused by monatomic oxygen ions (IO) at the molecular level. By deconstructing polymers into molecular moieties and subjecting them to single collision experiments, we aim to elucidate the underlying forces governing chemical attacks. Specifically, we will investigate reactions with polymers such as polystyrene and Kapton H, as well as carbon-based materials. Our experimental setup, guided-ion-beam mass spectrometry, will provide insights into reaction mechanisms and product branching ratios. This pioneering endeavor marks the first comprehensive effort to address polymer erosion in space, with potential implications for aerospace materials science.

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Genomic signatures of cyanobacterial endurance under space conditions

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Introduction

The pursuit of life beyond our planet goes through the research of biosignatures of a past or present life from potentially habitable planets in the Solar system or around other stars.
The bedrock of this assumption lies in the capability of some microorganisms to thrive on Earth in different extreme conditions that are lethal to the majority of life forms since they pose a particular threat to nucleic acids' integrity, causing cell death.
To unravel the limit of life as we know it, astrobiological experiments have been conducted by exposing extremophiles to non-Earth conditions taking advantage of space and planetary laboratory-simulations and space facilities.
Desert strains of the cyanobacterium Chroococcidiopsis are extremely resistant to desiccation and radiation and were included in a selection of extremophiles exposed to space and Mars-like conditions by using the ESA facility EXPOSE-R2 installed outside the International Space Station.
Moreover, during the EXPOSE-R2 space mission these cyanobacteria were part of the BIOMEX (BIOlogy and Mars Experiment) and BOSS (Biofilm Organisms Surfing Space).
Throughout these space missions, when exposed in the dried state and rehydrated once retrieved back to Earth, Chroococcidiopsis strains resulted to be more resistant than other cyanobacteria suggesting the presence of crucial genetic components related to space-survival, like mechanisms to limit and/or repair DNA damage.
In particular, Chroococcidiopsis sp. CCMEE 029, CCMEE 057 and CCMEE 064, together with Nostoc sp. CCCryo 231-06, showed a remarkable degree of radiation and desiccation resistance, whereas Nostoc sp. PCC7524 and Anabaena variabilis SAG1403-4b resulted to be sensitive or low tolerant to space radiation.

Aim of the study

Our work aims to elucidate the genetic core among these species that provides the means for space-related survival by performing a bioinformatic pangenome-based comparative analysis of the space sensitive and space resistant strains of the aforementioned cyanobacteria. Hence the bioinformatics analysis was performed on three space-resistant Chroococcidiopsis strains and Nostoc sp. CCCryo 231-06, on the space-sensitive, but desiccation-resistant strains Nostoc sp. PCC7524 and Anabaena variabilis SAG1403-4b and on the desiccation and radiation-sensitive strain Synechocystis sp. PCC 6803.

Materials and Methods and Results

Previously sequenced Illumina and Oxford Nanopore libraries of the three Chroococcidiopsis strains were first cleaned and filtered for low quality reads and potential contaminants, for them to be assembled into a single circular chromosome, respectively of 5.7Mbp for Chroococcidiopsis sp. CCMEE 029, Chroococcidiopsis sp. CCMEE 057 of 5.7Mbp and Chroococcidiopsis sp. CCMEE 064 of 5.08Mbp.
We retrieved the already assembled genomes of Nostoc sp. CCCryo 231-06, Nostoc sp. PCC7524, Anabaena variabilis SAG1403-4b and Synechocystis sp. PCC 6803 from the NCBI database (Accessions: GCA_023522315.1, GCA_000316645.1, GCA_003991931.1, GCA_018845095.1) and we provided all of the assembled genomes to the RIBAP pangenomic pipeline.
This software makes use of robust annotation tools such as PROKKA, producing an in-silico proteome per input genome, which get successively compared through an all-vs-all alignment computed by MMseqs2 whose result gets combined with the sequence homology information from Roary with smart pairwise ILP calculations.

We then manually curated the annotation results using reliable proteic evidence from the UniProt database, EggNog, InterProScan and BlastKoala, together with SignalP6 and Phobius softwares and literature evidence.
Finally, we examined the resulting gene clusters from RIBAP and we computed statistics.

From our analyses, we find a total of 13,414 clusters, of which 1,883 build a core gene set.
In particular, 122 genes are exclusively found among the Chroococcidiopsis strains and Nostoc sp. CCCryo 231-06. Interestingly, Nostoc sp. CCCryo 231-06 possesses a remarkable number of unique genes: 1,936, greater than the shared core genome, while Chroococcidiopsis sp. CCMEE 029, CCMEE 057 and CCMEE 064 harbor 1,107, 687 and 406 unique genes respectively and share 407 additional genes among them.
Moreover, a total of 565 genes are found in every investigated organism except for Synechocystis sp. PCC6803.

Future perspectives

It is yet to be defined whether variation in the presence/absence or in the copy number of these genes is the key to decipher what confers space-survival capabilities, i.e., the exposure in the dried state to space conditions using the EXPOSE-R2 facility, and under laboratory conditions after retrieval back to Earth. With this in mind, we will be focusing on this objective in order to get a deeper understanding of the genetics of these cyanobacteria and expand our current knowledge about space-survival mechanisms. This will also be accomplished through future RNA-sequencing experiments on cyanobacteria exposed to space conditions in the hydrated form, specifically on upcoming space platforms such as the Space Rider.

Thanks to these studies, we expect to be able to elucidate the genetic biosignatures accountable for space-survival by analyzing both the nature of gene class transcription and its levels compared to the control RNA levels. Moreover, we will be thoroughly analyzing both the shared and unique genes of these microorganisms under a functional point of view. In fact, through nucleotide and protein alignments we will be determining the presence of functional protein domains that could be ubiquitously found and thus confer the means for resistance, as well as the SNPs' impact on protein length and composition.

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Galvanic vestibular stimulation interferes with the selection of egocentric spatial navigation strategies.

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In space, changes of gravitational input strongly alter the functioning of the vestibular system, whose sensory information is important not only for postural balance, but also for relevant cognitive functions, such as spatial navigation [1]. During navigation, the surrounding environment may be encoded using different reference frames: egocentric (body-centered), allocentric (stimuli-centered), or landmark-dependent (landmark-centered) [2]. Alterations of vestibular input during parabolic flights have been recently linked to weakened egocentric reference frames [3]. However, no study has systematically investigated the selective influence of vestibular alterations on the use of all spatial navigation strategies simultaneously.
To selectively interfere with vestibular input, left-anodal (L-GVS), right-anodal (R-GVS) and sham bipolar sinusoidal GVS were administered in counterbalanced orders in 8 healthy participants. During each GVS condition, participants performed a new immersive navigation task in virtual reality. In a circular arena with four landmarks at cardinal points, they were first asked to search and reach a target platform. At the end of each trial, using a two-alternative forced choice paradigm, they were asked to indicate (1) the traveled path to reach the platform (egocentric strategy), (2) the platform position with respect to the landmarks disposition (allocentric strategy), or (3) the arena spatial map based on landmark positions (landmark-based strategy). For each stimulation condition, participants' Response Times (RTs) and the proportion of correct answers for each navigation strategy were recorded as dependent variables.
Results revealed significantly slower RTs in L-GVS condition compared to R-GVS and sham-GVS. No other comparison resulted to be significant.
This is the first evidence showing that GVS-induced vestibular alteration interferes with the selection of egocentric navigation strategies, while leaving allocentric or landmark-based strategies unaffected. This is in line with prior studies showing impaired egocentric spatial transformation during microgravity [4] and decreased use of egocentric strategies in patients with unilateral and acute vestibular disorders on Earth [5]. These results suggest that artificially-induced vestibular changes affect spatial navigation abilities, by hindering the integration of sensory stimuli with respect to the body's orientation. These findings enhance our understanding of the effects of altered gravity on human navigation and may offer relevant insights for the design of effective countermeasures to be applied in the space environment.

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Changes in bioactive lipids signalling under Space conditions

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Background. Microgravity that astronauts experience during missions has been involved in several cellular and molecular alterations, including those associated with the immune system and gastrointestinal (GI) trait [1]. Of note, the onset, progression, and outcome of inflammatory processes are regulated by specific endogenous lipids that act at the inflamed site to shape the magnitude of the immune response to avoid chronic inflammation [2]. Among these, two prominent groups of signalling lipids are represented by the specialized pro-resolving mediators (SPM) – a wide group of ω-3- and ω-6-derived compounds that act as main orchestrators of the resolution processes – and by endocannabinoids – the endogenous ligands of the receptors engaging the psychoactive compounds of Cannabis sativa and indica) [i.e. cannabinoid receptors 1 and 2 (CB1 and CB2)]. Even though these lipids have been consistently linked to immune and tissue homeostasis in virtually every known disease [2], their involvement in Space-related disorders has been largely neglected in Space biology [3]. Of note, our group has previously demonstrated that immune cells (e.g., lymphocytes) exposed to authentic microgravity – in the framework of the ROALD, RESLEM and SERiSM missions on board the International Space Station (ISS) – or to simulated weightlessness display altered metabolism and signalling pathways of the eCB system [4–6]. Yet again, to date, few studies – if any – have addressed the effect of microgravity on SPMs and the resolution system, nor its role on the lipid systems that control the GI homeostasis during Space travel. Thus, In the present study, simulated microgravity, achieved by means of the Rotary Cell Culture System (RCCS) developed by NASA, was used to assay the effect of weightlessness on the metabolism and signalling of SPMs and eCB system in human primary monocytes and on human GI cells, respectively.
Methods. PBMCs (peripheral blood mononuclear cells) were isolated from human blood samples and incubated at 1xg Earth gravity or 10-3xg RCCS-simulated microgravity for 24h [4]. Quantitative real-time PCR (qPCR) and polychromatic flow cytometry were performed to evaluate the gene and protein expression of SPM-related receptors and enzymes in PBMC-derived human primary monocytes, whereas production of bona fide SPM lipids was measured by liquid chromatography-mass spectrometry (LC-MS/MS). The activity of 5-LOX was assayed by means of commercially available fluorometric kits.
Human Caco-2 cells were chosen as a model of intestinal epithelial cells, as reported [7], and kept in adherence to Cytodex® microcarrier beads (microcarrier/cell ratio 1:20) [8] before being exposed to 1xg Earth gravity or 10-5 xg RCCS-simulated microgravity for 48h. Gene and protein expression of the eCB system enzymes and receptors were assayed by means of qPCR and Western Blotting.
Results. Human PBMCs that underwent 24h of simulated microgravity displayed an enhanced gene expression of pivotal SPM receptors such as GPR32, formyl peptide receptor 2 (FPR2, also known as ALX), GPR18 and Chemerin Receptor 23 (ChemR23), and of their biosynthetic enzyme 5-lipoxygenase (5-LOX) in respect to 1xg control samples. Furthermore, analysis of protein expression by polychromatic flow cytometry revealed that GPR32 and GPR18 underwent a significant upregulation after 24h of microgravity. This effect was specific to CD14+ monocytes, but not to CD3+ lymphocytes. Microgravity also elicited a significant downregulation of 5-LOX in monocytes, a concomitant reduction of its activity, as well as it resulted in abated production of the prominent SPM resolving (Rv) D1 in LPS-stimulated cells.
On the other hand, Caco-2 cells exposed to RCCS-simulated microgravity displayed a significant rearrangement in the expression of eCB-related elements: in particular, 48h of weightlessness resulted in significantly reduced protein expression of CB1 and CB2 receptors and downregulation of the peroxisome proliferator-activated receptor γ (PPARγ) gene product.
Conclusions and future perspectives. More than 30 years have passed since the publication

of the first papers – authored by Augusto Cogoli – that linked microgravity to immune cellular alterations. Since then, many other works have been published that characterized the molecular mechanisms underlying immune suppression processes observed in astronauts. However, very few of them addressed the role of bioactive lipids in these processes, with the vast majority investigating arachidonate-derived eicosanoids and, to a minor extent, eCBs [3], while other lipid congeners that have been pivotally involved in tissue homeostasis, (such as SPMs) have been barely studied to date. Our data show, for the first time, that short exposure to microgravity significantly affects the signalling and metabolism of SPMs in monocytes, which are among the main orchestrators of the immune response and of its resolution [9]. SPMs and the cells that produce them play a major role in avoiding irreversible damage that might arise from deviant inflammatory processes, and their impairment has been linked to virtually any pathological condition that features inflammation [2]. As a matter of fact, Space-related disorders display unresolved inflammation that might emerge from an impaired, altered or insufficient resolution system, suggesting a role of these lipids in microgravity-associated disorders. On the other hand, our preliminary data on Caco-2 cells indicate that microgravity does indeed affect eCB signalling even in the GI tract by affecting the gene and protein expression of crucial receptors of these lipid compounds.

SPM- or eCB-binding receptors and metabolic enzymes are currently investigated as clinical targets in many conditions [2,10,11], and this same strategy might well be exploited in the future to develop pharmacological countermeasures to either treat or prevent the disorders astronauts experience during missions.

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Visuomotor transformations impairment during manual tracking in a simulated microgravity condition

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In contrast to performance in cognitive tasks, tracking performance tends to deteriorate fairly consistently during spaceflight. Whereas it is clear that microgravity has several mechanical, visual, and proprioceptive effects which may impair the motor control, it is in no way settled whether the impairment of tracking performance is indeed specifically microgravity-related, due to the variety of stressors which characterize manned spaceflight and may be involved. A better understanding of the tracking task in microgravity is fundamental to develop superior control strategies for robot-human interaction in microgravity and improve human adaption protocols to such environment. We designed an experiment where a microgravity condition is applied to the upper limb of the subject who is asked to follow a moving object with such limb. Different kinematics laws and geometries are used for the moving object. The goal of this experiment is to characterise the microgravity impairment on motor control and verify whether or not it is caused by a mis-calibration of muscular forces resulting from the underestimation of masses due to weightlessness. The effect of this underestimation should be a certain 'sluggishness' of the pursuit in following the moving target, however, corrective processes may hide this under-specification of forces. A multi-directional oscillator model has been used to measure the tracking performance of the subject and investigate the presence of possible cross-effect compensation between directions.

Curricula 5

Space sensing and instrumentation

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Characterisation of the Plastic Scintillator Detector for HERD

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The Plastic Scintillator Detector (PSD) plays a crucial role in the High Energy Cosmic Radiation Detection facility (HERD). HERD is an international space mission slated to launch aboard China's Space Station (CSS) in late 2027. The PSD is specifically designed for measuring the charge of impacting particles and identifying gamma rays.
To achieve these objectives, the PSD utilizes scintillator bars coupled with silicon photomultipliers (SiPMs). Currently, in collaboration with the IFAE team in Spain, we are actively calibrating the SiPMs and characterizing the entire readout chain and the trigger system of the PSD setup. This optimized setup will be used in an upcoming test-beam at CERN. Our poster presentation will showcase some preliminary results from this optimization process.

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Characterization of 1 cm^2 Low Gain Avalanche Diodes for Space Applications

Author: Leo Cavazzini[1]

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This work explores the possibility of using Low Gain Avalanche Diodes (LGADs) for tracker-based experiments studying Charged Cosmic Rays (CCRs) in space. While conventional silicon microstrip sensors provide spatial information about the charged particle passing through the tracker, LGADs have the potential to provide additional timing information. For the first time, it has been demonstrated that an LGAD with an active area of about 1~cm^2 can achieve timing resolution (jitter) of less than 40~ps. The study includes laboratory measurements such as electrical characterization of LGADs, gain measurements using LED and an Infrared laser, as well as jitter measurements.

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Unconventional tiled array antennas for long-range wireless power transmission

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Long-range wireless power transmission (WPT) systems comprise a transmitting (TX) device capable of focusing the beam towards a desired region, usually consisting of a phased array (PA) antenna, and a receiving (RX) device, namely a rectenna, converting the electromagnetic power of the impinging microwave radiation into direct current. To maximize the end-to-end transmission efficiency, the transmitter must be able to focus the power on a limited spatial region, possibly just as large as the rectenna aperture. This imposes non-negligible challenges in the design of the transmitting antenna system, further highlighted when the TX and RX antennas are located far away.
Additionally, conventional PAs allow for highly flexible beam-forming but they are extremely expensive and difficult to realize if large antennas are needed. In this context, the proposed research activity focuses on the study of innovative unconventional PA solutions based on modular architectures able to offer optimal trade-offs between antenna complexity and transmission efficiency.

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Advanced Space Systems Enabled by Fiber Optic Sensors: Rocket Propulsion Systems Application

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The design of modern spacecraft systems and launch vehicles is more oriented towards reducing system-level assembly, integration, testing, and qualifications complexities while aiming at raising the systems' performance. In order to maintain high overall system performance while reducing these complexities among others, the use of smart materials and structures is of rising interest to advanced space systems' designers. This study discusses a well-known concept: smart space structures made of carbon fiber composites embedded with Fiber Optic Sensors (FOS), with a focus on their applications in modern spacecraft. The concept and applications referred to are nowadays sought-after for utilization in several modern spacecraft and launch vehicles design concepts, made feasible by several technological advancements. First, the significant progress in manufacturing techniques such as additive manufacturing and advanced composites manufacturing. Secondly, the emergence of the photonic integrated circuits technology realizing the miniaturization of the FOS data acquisition systems (i.e., interrogators). This technology and its miniaturization enable the employment of FOS systems in harsh space environments and a myriad of spacecraft designs. A case study on rocket propulsion of spacecraft is presented that considers the employment of FOS in the structure and propellant storage of propulsion systems to advance their operational and condition monitoring (OCM) as well as the structural health monitoring (SHM) and integrity, towards realizing the new generation of intelligent spacecraft propulsion. The study identified a number of possible future applications and assessed their employment feasibility in lights of the current technological advancements' challenges and foreseen opportunities. In addition, a novel mathematical strain-transfer model is presented to serve the proposed fiber optic sensors' embedding technique in carbon fiber structures of spacecraft.

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Temporal analysis of light-curves from transient sources

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The future of multimessenger astrophysics heavily relies on the number of joint detections of gamma-ray bursts (GRBs) and gravitational waves (GWs) achievable during observing runs conducted by LIGO, Virgo, and KAGRA. Accurate event localization through triangulation methods is increasingly pivotal for this purpose. The innovative HERMES mission is based on the distributed architecture mission concept: a CubeSats constellation enables continuous observation of the entire sky while concurrently providing the position of detected signals. The accuracy of source coordinates is strongly influenced by the type of temporal analysis employed. In particular, techniques based on cross-correlation functions (CCFs) are indispensable for estimating the delays between detectors positioned in different spatial locations. Due to the quantum measurement process of a detector, the single delay evaluated between the light curves of two detectors is a particular Poissonian realization of the true delay. The described techniques allow minimizing the "quantum noise" present in the list of Time of Arrivals (ToAs) observed by the detectors and estimating a "statistical delay" with an associated error. This is the experimental delay closest to the sought theoretical delay. The developed techniques also allow probing quantum gravity theories. Lorentz Invariance Violation can be investigated by verifying delays between high-energy light curves in different energy bands for observed GRBs at different redshifts. Estimates of delays between light curves observed in a selected emission line and those in the continuum emission allow probing both the spatial extent and the internal architecture of the broad-line region (BLR) in active galactic nuclei (AGN). The provided examples justify the broad applicability of the developed techniques in the domain of temporal analysis in the astrophysical realm.

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Optimizing GEO Orbital Monitoring: Multi-Static Radar for Improved Tracking

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Conventional surveillance radar sensors operate on monostatic radar principles. However, a better approach involves employing remote radio frequency telescopes as bistatic receivers, enhancing tracking capabilities without replacing the existing monostatic radar systems. This innovative method not only maximizes the use of existing facilities but also enhances tracking accuracy by providing supplementary information. The multi-static radar system can provide improved Geostationary Earth Orbit (GEO) coverage and enhance resident space objects' detection and tracking capabilities by utilizing multiple receive antennas and a single transmit antenna. This study investigates the conditions in which a multi-static radar is advantageous and shows concrete results based on simulated data. Here, we investigate the sensor, Tracking and Imaging Radar (TIRA) in Germany as a transmitter and a number of receivers in Europe. The results show significant improvements in Initial Orbit Determination (IOD) and tracking accuracy, offering a promising direction for future Space Surveillance and Tracking (SST) efforts.

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A Radiation Monitor for space applications

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The Radiation Monitor (RadMon) consists of a telescopic arrangement of high Z absorbers and plastic scintillators coupled with silicon photomultipliers (SiPMs). The SiPMs signals are processed and digitized with the BETA ASIC, which was specifically designed for SiPM readout in space applications. The monitor will output proton detection rates in a set of integral energy channels with expected thresholds ranging from ~ 70 MeV to ~ 1 GeV.
Here, I describe the design of the prototype built and the preliminary results of the performance evaluation from dedicated beam tests and ad hoc MonteCarlo simulations made in the framework of my PhD project research.

Curricula 6

Engineering and satellite platform technologies

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Design, Realization and Testing of an Azimuth-Stabilized Modular Stratospheric Platform

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In recent years, increasing investments from space industry are directed towards single or constellations of small satellites orbiting in LEO, which have significantly low cost with respect to other types of space missions, but require many years of development and large sums on an absolute scale. The development of new facilities that can cut costs during this phase is therefore of primary interest. One of the main cost item is the development and testing of space hardware, which shall be exposed to high-vacuum and high-level-radiation environment, that is both extremely difficult and expensive to recreate in laboratory. The cheapest option is the use of near-space platforms lifted by small-scale sounding balloons, however they are not commonly employed because state-of-the-art gondolas for said balloons do not offer a stabilized frame.

The work presented in this poster shows a successful first-iteration attempt at designing and realizing a low-cost azimuth-stabilized stratospheric platform, able of self-orienting at set azimuth direction. Active attitude stabilization was achieved via the use of a single reaction wheel placed along the main vertical axis of the platform, controlled by a PI software, and was accompanied by passive attitude stabilization techniques. Tests prove that a stabilized position can be achieved within ±5° of the selected pointing direction, which is preset or directly inputted by the user during platform operations, which gives a high degree of flexibility to the operation planning. In this poster, a first application of the platform to host a payload of four solar cells is presented, but particular emphasis was given during design phase so that the integration of a different payload would require the minimum amount of re-design, i.e. the platform was developed following a modular approach.

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The EXCITE IOD/IOV Mission

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The surge in small satellite and CubeSat deployments has led to a diversification of feasible missions, driving a shift from emphasizing simplicity and low-cost to prioritizing performance while maintaining cost-efficiency. Integration of small payloads and advancements in technology have enhanced CubeSat capabilities, enabling the development of high-performance platforms. EXCITE, a 16U CubeSat mission, will demonstrate five different technologies in the LEO environment, including propulsion systems, a reconfigurable antenna, and on-board processing capabilities. To maximize EXCITE's capabilities and accommodate diverse payloads for various mission scenarios, multiple optimization strategies have been implemented. This includes thorough orbit analysis to determine the most suitable orbit for mission objectives, considering factors such as beta angles and eclipse time. The use of a chemical thruster provides flexibility in mission design by allowing adjustments to orbital altitude and ground-track patterns. Additionally, careful scheduling of orbital maneuvers is crucial for maximizing access time to specific ground stations and optimizing data downlink opportunities. Managing complex interactions between design variables necessitates advanced optimization techniques like gradient-based algorithms. OpenMDAO offers a robust framework for tackling multidisciplinary design optimization problems efficiently, facilitating exploration of trade-offs between competing design objectives.

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Analysis and test of a critical mechanism for the LISA mission

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LISA Pathfinder (LPF) is an ESA mission which served as technology precursor for the first space-based gravitational waves detector, named LISA (Laser Interferometer Space Antenna). The scientific payload of LPF includes two Gravitational Reference Systems (GRS), each one containing the free-falling cubic test mass (TM) that constitutes the sensing body for the interferometric measurement. After commissioning, to start the science phase the TM is released into a geodesic by the Grabbing, Positioning and Release Mechanism (GPRM). The GPRM is composed of two similar halves, each one containing a cylindrical end effector, named plunger, which is moved along its longitudinal axis with a piezo-walk actuator. The plungers engage two indents machined on two opposite faces of the TM. A gold tip, coaxial to each plunger, is moved by a voltage-controlled piezo-stack actuator. When the voltage is applied, the tip protrudes from the plunger head engaging the TM. When the voltage is shorted, the tip is retracted by a pre-loaded discs spring injecting the TM into a free-fall state.
The TM release in LPF showed some anomalies, producing a release dynamics different from the nominal one. Therefore, part of the extended mission phase was dedicated to understanding the release and find risk-reduction strategies in view of LISA. Following analyses demonstrated that the anomalies could be explained by undesired interactions between the TM and the GRPM end effectors, causing excessive and non-compliant TM linear and angular velocity components at the release.
At the University of Trento an experimental setup is used to perform on-ground testing of the release procedure with the LPF Engineering Qualifying Model of the GPRM. By subtracting the effect of the undesired interactions from the in-flight data, it is shown that the on-ground tests correctly estimate the TM state in the absence of the anomalous TM-end effectors interactions. This information is used in a preliminary TM velocity budget after injection, focusing on the time lag admissible for the retraction of the release tips.
In this scenario, possible improvements regarding the increase of the nominal gap between the plungers and the TM at release and the reduction of the unwanted lateral motion of the GPRM are studied with a Breadboard Model tested at the University of Trento. These activities are part of the GPRM delta-development for LISA.

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Geometric Deep Learning for rapid prototyping of satellites

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A Satellite layout optimization design (SLOD) approach is here proposed to automatically generate effective and efficient layout configurations and guide engineers in choosing the most performing satellites designs.
In this approach the optimization of satellites layouts is addressed as a three-dimensional packing problem with layout constraints such as:

- behavioural constraints – e.g. no overlap amongst components
- technical constraints – e.g. Sun sensor placed on a specific surface of the satellite.

Main objective of the optimization problem here analysed is the determination of the optimal position of the Centre of Gravity of satellites components and their orientation. This can be solved in two sequential optimization steps:

- layers optimization - it determines the optimal distribution of individual components amongst satellite layers,
- position optimization - it determines the optimal position of components in each layer.

SLOD has been typically addressed as a single-objective optimization problem, aiming at minimizing the moment of inertia of the entire satellite.
Thus, we propose here to conduct a full analysis combining both steps described above, approaching the problem as a multi-objective optimization, accounting also for conditions such as uniformity of thermal and magnetic fields.
For this purpose, thermal and magnetic models will be built, ranging from low to high-fidelity (e.g. finite element modelling, computational electromagnetics), trying to strike a balance between accuracy and computational cost.
Finally, the high-fidelity models will be used to train surrogate models, with the aim of rapidly prototyping satellites designs, maintaining a reasonable level of predictions accuracy. A particular focus will be given to Geometric Deep Learning techniques, which allow to train AI algorithms using the 'real' shape of components.
We believe our proposed approach will bring advantages to satellites rapid prototyping, allowing to tackle the complexity associated with the optimization of such systems.

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Laboratory Performance Analysis of a 5G NTN K/Ka band link for LEO SATCOM

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5G Non-Terrestrial Networks (NTN) offer the potential to connect regions previously inaccessible or economically unviable for traditional terrestrial communication networks. K/Ka band satellite communications can achieve higher channel capacity compared to satellite services operating at lower frequency bands. This study examines the laboratory validation of a satellite link as part of the ESA ARTES Project 'Demonstration of direct 5G broadband access from LEO to small satellite terminals'. The testing setup incorporates two channel emulators to simulate real-world conditions, including link attenuation, LEO satellite Doppler effects, and latency. The objective of the project is to develop and validate a communication experiment demonstrating direct 5G broadband access from Low Earth Orbit (LEO) to very small aperture mobile terminals. The proposed communication architecture comprises a commercial Amarisoft software radio-stack and Ettus B200 SDR to generate a 5G FR1 signal, subsequently converted to K/Ka band using Block Up Converters (BUC) and Block Down Converters (BDC). Two transparent transceivers integrated aboard a LEO satellite are used in the bi-directional bent-pipe satellite link. The presented results will detail the throughput performance of the validated satellite link, providing crucial insights into the feasibility and efficacy of K/Ka band 5G in satellite communications, thus paving the way for enhanced connectivity solutions.

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Structured surfaces for anti-frosting

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We here present hydrophobic surfaces designed to delay frosting passively.
Hydrophobic structured surfaces showing coalescence induced condensation droplet jumping (CICDJ) are known to slow down frosting because of unsuccessful ice-bridging events. In a previous study we reported a kind of surfaces structured with truncated microcones covered by uniformly hydrophobic nanostructures that enable single droplet self-ejection [1]. The anti-frosting effect is improved because almost all the droplets self-eject at a precise size and all the ice-bridges are frustrated [2]. We here present these surfaces behavior under different surface temperatures (T) and air relative humidity. Higher supersaturation ratio (s) decreases the mean distance between the droplets (l). The droplet distance and diameter distributions vary with s and affect the ice-bridging parameter distribution thus frosting velocity. In particular, we analyze the regime change when l ⊠ of the cones unit cell size and the CICDJ events prevail on the self-ejection ones. Understanding the effects of environmental conditions on jumping modes (single and multiple droplets) and frost propagation types could lead to an optimal design in terms of cones size and arrangement.

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Research activity for debris deorbiting using Electrodynamic Tether technology

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The escalating accumulation of space debris poses a significant challenge to future space missions. Electrodynamic Tethering (EDT) emerges as a promising solution [1], notably for its propellant-free operation, aligning with green technology principles.
The E.T.PACK-F project [2], funded by the European Innovation Council (EIC), focuses on advancing EDT technologies. Central to this effort is the development of a Flight Model (FM) CubeSat, consisting of two modules connected by an aluminum tether, aimed at demonstrating effective space debris deorbiting.
My research activities have included some of the research in which the University is involved. Specifically, I am presently engaged in optimizing the deployment profile of the tether and refining a critical component: the In-Line Damper (ILD), designed to mitigate tether oscillation during deorbiting phase.
Regarding the last point, I have recently established an experimental setup to analyze the ILD's response to external forces. Leveraging the SPARTANS facility at the University of Padova [3], we can simulate satellite in-orbit maneuvers, utilizing a floating platform. Precise tracking of the platform's position and orientation is achieved through a motion capture system comprising six ceiling-mounted cameras within the facility.
Additionally, my research activity extends to satellite proximity navigation, critical for some approaching and capturing debris technique that is used for deorbiting [4]. As a first step in this topic, our research group is collaborating with OHB Italia to test a standard docking interface under development using the SPARTANS facility. This activity is part of ESA's In-Space Transportation Proof of Concept-1 (POC1) mission.
Presently, my focus lies on the motion capture system that is used to study the dynamics of a passive docking mechanism installed on the floating platform. Particularly, for this setup we need to study the mechanism under different initial conditions. For this purpose, we have developed a release mechanism that can change the platform's initial position, orientation, as well as linear and angular velocities. Finally, we have been able to reconstruct these parameters thanks to the motion capture system

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Study and comparison of different Slow Wave Structures (SWS) for a W-band Traveling Wave Tube (TWT).

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This poster presents possible solutions for a W-band Travelling Wave Tube (TWT) in space satellite applications. Various devices are commonly used in this context and we have analysed folded waveguide configurations as potential Slow Wave Structures (SWS) operating between 95 and 100 GHz. In order to increase the TWT performance, two possible solutions with identical cathode areas were considered: one with a circular beam and the other with a rectangular one. The simulations were carried out using CST Studio Suite.
The circular beam structure showed a gain of 7.3 dB and a bandwidth of -3 dB at 4.5 GHz, with a periodic structure of 18 periods. The device achieved these values with a cathodic voltage of 18.6 kV and a current density of 1.9 A/mm^2 . The sheet beam, with the same number of periods as the previous one, showed double the gain and a bandwidth of 5.5 GHz, supplied with a voltage of 17.8 kV and a current density of 1.7 A/mm^2. These preliminary simulation results provide a solid basis for promising improvements.