9th Metis Workshop

Wednesday, 24 January 2024 - Friday, 26 January 2024

Catania (Italy) - Museo Diocesano di Catania

Programme

Table of contents

Wednesday, 24 January 2024

Session 1 (15:00 - 16:40)

-Conveners: Daniele Spadaro

Welcome and Introduction (15:00)

Presenters: SPADARO, Daniele, ROMOLI, Marco

Giancarlo Noci and the Solar Wind Science (15:10)

Presenter: ANTONUCCI, Ester

ASI contributions to Heliophysics Missions (15:30)

Presenter: STANGALINI, Marco

Lyman-alpha Solar Telescope aboard the ASO-S mission (15:40)

Presenter: FENG, Li

The ASO-S mission has three payloads, a Full-disk vector MagnetoGraph (FMG) to measure photospheric magnetic Fields, a Hard X-ray Imager (HXI) to observe non-thermal signals from 30 to 200 keV, and Lyman-alpha Solar Telescope (LST) to take images of the Sun in Lyman-alpha and white light. In this presentation, we focus in the LST payload including the introduction to its three instruments, the current calibration progresses, and early observations and data processing. Particularly, we will discuss the Carrington map of the disk Lyman alpha emission, diagnostics of prominences by combining Lyman alpha and other wavelengths, etc.

The SOLAR-C mission (16:00)

Presenter: ANDRETTA, Vincenzo

SOLAR-C is the next JAXA-led solar physics mission, scheduled to be launched in mid 2028. The main mission payload is EUVST (EUV High-Throughput Spectroscopic Telescope), an EUV imaging spectrometer with slit-jaw imaging system whose science goal is to understand how underlying physical processes, acting on small scales, lead to the formation of the outer solar atmosphere and the solar wind, and how the solar atmosphere becomes unstable, releasing the energy that drives solar flares and eruptions. The mission payload is complemented by the EUV Solar Spectral Irradiance Monitor (SoSpIM) whose main goal is to determine the flare-related variability of solar irradiance, which impacts the Earth’s thermosphere and the mesosphere. The EUVST instrument, crucial for achieving the mission scientific goals, is designed to simultaneously probe the solar atmosphere from the chromosphere to the corona with a spatial resolution as low as 0.4" and a temporal cadence as high as 1 s. The Italian contribution to the mission consists in science support and in providing the slit assembly, a critical subsistem of the instrument, which also feeds the imaging system providing context to the spectroscopic observation. In this talk, I will summarise the status of the mission and provide further details on the Italian contribution.

The MUSE mission and the modeling of reconnection events (16:20)

Presenter: REALE, Fabio

The MUSE NASA mission, with significant ASI-INAF contribution, will use EUV spectroscopy in 3 single-line bands to probe basic magnetic and heating processes in the solar corona. The lines are sensitive to plasma emission at about 1, 2.5 and >8 MK and can therefore track the evolution of plasma when it is heated up and then cools down. Resolving the lines will allow to obtain information about non-thermal processes and plasma dynamics, and the 35 slits will allow to have this information at good time and space resolution. It will be possible to have reconnection processes at the origin of space-weather confined and eruptive events as a direct target. Even with this innovative design it is well known that the complex plasma physics make it very difficult to address reconnection processes directly, and therefore the use of MHD modeling becomes fundamental. We discuss state-of-art forward modeling of coronal loop stressing and interaction for comparison with observations.

Coffee Break (16:40 - 17:10)

Session 2 (17:10 - 18:25)

-Conveners: Vincenzo Andretta

Exploring the Corona With the new Upgraded Coronal Multi-Channel Polarimeter (UCoMP) Coronagraph at Mauna Loa (17:10)

Presenter: BURKEPILE, Joan

Science data products are now available from the new Upgraded Coronal Multi-Channel Polarimeter (UCoMP) installed at the Mauna Loa Solar Observatory [https://www2.hao.ucar.edu/mlso]. UCoMP is a major upgrade of the CoMP instrument. Its expanded capabilities include: observations of multiple coronal emission lines over a wide range of coronal temperatures to explore the magneto-thermal structure of the corona; a larger field-of-view; higher spatial resolution; and dramatically faster collection of the full Stokes polarization that provides higher quality polarimetry measurements. UCoMP provides powerful diagnostic measurements of the coronal magnetic field and plasma properties. The larger field-of-view allows it to explore the magnetic and thermal properties of coronal structures and coronal mass ejections (CMEs) out to ~2 solar radii. The UCoMP observations complement the MLSO K-Cor white light coronagraph, that is designed to track CMEs at a very high cadence (15 seconds) out to 3 solar radii. We provide examples of the variety of UCoMP science data products and highlight some of the science that can be explored with these exciting new observations. We illustrate how UCoMP and K-Cor coronagraph data can be combined and used with other coronal observations and models to explore coronal magnetic field and plasma conditions. We highlight synergies of UCoMP and K-Cor observations with Metis.

Metis, ASPIICS and CODEX: Perspectives for Joint Science (17:30)

Presenter: FINESCHI, Silvano

In 2024, the coronagraphs ASPIICS and CODEX will be launched on the formation flying PROBA-3 ESA mission and on the ISS with a NASA-KASI-INAF mission, respectively. The 150-m separation between the formation-flying Coronagraph and Occulter satellites of PROBA-3 will allow long-duration, eclipse-like imaging of the inner corona, down to heliocentric heights of 1.1 solar radii. Besides the cold (1.e+4 K) He I D3 587.6 nm, and hot (1.e+6 K) Fe XIV 530.3 nm emission-lines, ASPIICS will image the visible-light, broadband polarized brightness (pB) of the K-corona. CODEX will measure the K-coronal intensity ratios at 390 nm and 410 nm where the strong absorption lines are concentrated in the photospheric spectrum, i.e., Ca II lines and the G band. The shape of the continuous coronal spectrum can offer a direct measure of the coronal electron temperature. The inner field-of-view of ASPIICS will complement that of Metis and the coronal electron temperature from CODEX will provide a critical physical parameter for the Metis Doppler-dimming diagnostics of the solar wind speed. The presentation will review the perspective opportunities for Metis, ASPIICS and CODEX joint science.

EUI very wide field observations in synergies with METIS and SPICE (17:50)

Presenter: PARENTI, Susanna

The Full Sun Imager (FSI), as part of the Solar Orbiter/EUI suite of instruments, is a wide field channel of 3.8° x 3.8° FOV, imaging the corona in two bands: 17.4 (Fe IX-Fe X) and 30.4 nm (He II). A coronagraphic mode of observation was added late in the development of the instrument, to provide new insight into a region largely unexplored corona in these EUV bands. In fact, depending on the distance of the probe to the Sun along its orbit, this corresponds to 14 to 4 solar radii, to be compared to the 3.5 Rs of STEREO/EUVI or Proba2/SWAP. Here, I will introduce the coronagraphic mode of operation of FSI showing the first images and results. The data in the 174 band reveals solar structures extending up to 5 Rs which, to our knowledge, is the furthest ever recorded at these wavelengths. I will then present the opportunities for a further joint science with the spectrometer UV SPICE and METIS.

The Solaris Mission: A focused solar polar view from outside the ecliptic plane (18:10)

Presenter: HASSLER, Don

Solaris is a transformative Solar Polar mission concept to address crucial outstanding questions that can only be answered from a polar vantage. Solaris will image the Sun's poles from 75° latitude, providing new insight into the workings of the solar dynamo and the solar cycle, which are at the foundation of our understanding of space weather and space climate. Solaris will also provide enabling observations for improved space weather research, modeling and prediction, revealing a unique, new view of the corona, coronal dynamics and CME eruptions from above the ecliptic plane.

Social Dinner (20:30 - 23:00)

Thursday, 25 January 2024

Session 3 (09:00 - 10:40)

-Conveners: Silvano Fineschi

Aditya-L1 (09:00)

Presenter: BANERJEE, Dipankar

Solar Orbiter Status (09:20)

Presenter: WILLIAMS, David

Metis Status (09:40)

Presenter: ROMOLI, Marco

Metis is the coronagraph on board Solar Orbiter. It provides images of the full corona in an annular FoV from 1.7 to 3 degrees, in the broadband linearly polarised light and in the narrowband UV hydrogen Lyman-alpha line. Metis is successfully operating both during the remote sensing windows and throughout the full orbit in a synoptic mode of acquisition. A summary of its performance are given, included the known issues, and highlights on the major science results.

Metis data (09:55)

Presenter: SUSINO, Roberto

Metis planning management (10:10)

Presenter: SASSO, Clementina

Up to a few months before the launch of Solar Orbiter, observation windows were planned to be scattered throughout the orbit and mostly concentrated during perihelia. Moreover, perihelia would have been probably dominated by high resolution instruments, with potential off-pointings not compatible with the Metis instrument. As the launch approached, the possibility arose of having a larger data volume than had been anticipated before launch, and it was decided to set up a synoptic program to allow the imagers to observe continuously. Therefore, the Metis team needed to compose a multi-person team to take care of planning observations and, consequently, to set common tools and guidelines, define a hierarchy for editing, review and approval of observational timelines, and to develop a practical and versatile tool for their creation. This presentation describes the planning team and the tools that have been developed to undertake the delicate task of moving the planning process forward.

MOF: the Ground Support to Metis Operations (10:25)

Presenter: CHIARAMIDA, Vincenzo

Metis is the coronagraph of the scientific payload of Solar Orbiter, an ESA-NASA mission which aims to study the Sun poles and the circumsolar region. The activities necessary to operate Metis are implemented through the Metis Operations Facility (MOF). The MOF is the collection of functionalities and subsystems which allows to plan the instrument observation, validate the observation command sequence, process the data, distribute the data and make them available. It is built, run, and maintained by ALTEC in close collaboration with INAF, and funded by Italian Space Agency in the frame of the industrial contract n. 2020-10-I.0. The MOF can be divided into 5 subsystems: Data Processing, Mission Database, TM/TC Monitoring, Observation Planning (which contains the Metis Reference Model - MRM) and Infrastructure. The Data Processing runs the pipelines for the data processing, and interacts with other components of the MOF and with external interfaces. The Mission Database, besides storing all the Metis data products, provides a set of functions to enrich products metadata and make them accessible to the scientific team. The TM/TC Monitoring is the subsystem responsible for monitoring the telemetry incoming from Metis and, partially, from the spacecraft. It is based on the ESA SCOS-2000 suite. The Observation Planning S/S integrates the MISO software (Multi Instrument Sequence Organizer) developed for creating the Command Request Files (CRF) to be delivered to the MRM and to MOC. The former is an electronic model which provides a test bench for the generated CRF, and is used to validate TC sequences in IOR preparation before sending them to the actual instrument. The MOF interfaces with two external entities: the Mission Operation Centre (MOC), from which the TM/TC packets are downloaded, and the Science Operations Centre (SOC), from which planning and auxiliary data are retrieved. Metis data products are finally uploaded to the Solar Orbiter Archive (SOAR) after validation by the scientific team via the Mission DB S/S. In 2023, the MOF was upgraded from v3 to v4; new processing pipelines for levels L1 and L2, and workflows for data validation and data quality have all been tested and integrated. Generation of L2 data is underway for both VL and UV images. Finally, activities for migration to a new and more efficient infrastructure have started with the installation of new hardware components. In the talk, MOF architecture will be presented in detail, as well as the interfaces with external facilities. The current state and the execution of daily and cyclic operations will be discussed, together with

exciting upcoming evolutions enabled by Metis data availability and new technologies.

Coffee Break (10:40 - 11:10)

Session 4 (11:10 - 13:00)

-Conveners: Petr Heinzel

AI-based approaches to data integration for Solar Orbiter instruments (11:10)

Presenter: PIANA, Michele

At a general level, the goal of this talk is to outline possible computational approaches for the integration of data recorded by different Solar Orbiter instruments and for a multi-modal extraction information contained in these measurements. At a more technical level, this contribution will propose a possible AI-based pipeline for the identification of correlations between the signatures of solar flares encoded in STIX visibilities and the signatures of CMEs encoded in METIS images.

Observations of galactic cosmic rays and solar energetic particles with Metis/Solar Orbiter (11:25)

Presenter: GRIMANI, Catia

The Solar Orbiter Metis coronagraph captures images of the solar corona in both visible (VL) and ultraviolet (UV) light. Tracks ascribable to the passage of galactic and solar particles appear in the Metis images. An algorithm implemented in the Metis processing electronics allows us to separate the pixels fired by VL photons from those crossed by high-energy particles. The Metis particle observations are used to test the VL instrument performance and to study the spacecraft inner charging from solar minimum towards the next solar maximum. We considered the VL instrument only, since the process of separating the particle tracks from pixels fired by photons in the UV images has been proved to be very difficult for a quantitative analysis. The visual analysis of Metis cosmic-ray matrices gathered from May 2020 through February 2023 with galactic cosmic rays (GCRs) only and on February 25, 2023 with both GCRs and solar energetic particles is compared to Monte Carlo simulations of the VL instrument during the same period. We have estimated the solar modulation parameter associated with the GCR proton energy spectrum modulation and found that Metis plays the role of a monitor of galactic and solar protons.

Investigating solar wind outflow from open-closed magnetic field structures using coordinated Solar Orbiter and Hinode observations. (11:40)

Presenter: NGAMPOOPUN, Nawin

The launch of Solar Orbiter allows us to study the solar corona at closer distances and from different perspectives, which helps us gain significant insights regarding the open question in solar physics concerning the origin of solar wind. In this work, we present an analysis of solar wind outflows from two locations: the S-web magnetic topology between two solar filaments, and the boundary of a small coronal hole. These outflows were observed off-limb by the Metis coronagraph onboard the Solar Orbiter and on-disk by the EIS spectrometer onboard Hinode, during the Coronal-Hole Boundary Expansion SOOP campaign on 9 April 2023. The magnetic field extrapolations suggest that the upflow regions seen in EIS were connected with the outflowing solar wind in Metis. Hence, this observation provides a unique opportunity to study the solar wind in the formation region in the low corona and the acceleration region in the middle corona at the same time. This work aims to explore the evolution of solar wind from two different source regions in the distance from 1-3 solar radii. We analyse and compare the electron density and outflow velocity inferred from the two source regions, at two different heights in the corona. We also investigate the relationship between the evolution of visible-light features in the middle corona and the EUV features in the low corona. These new results will provide a better understanding of the formation and acceleration process of the solar wind and how the variability of the source regions contributes to it.

Unraveling Solar Dynamics: Metis Observations of Eruptive Flux Ropes and Magnetic Disturbances (11:55)

Presenter: ROMANO, Paolo

This study presents observations of a solar eruption captured by the Metis coronagraph on October 12, 2022. Utilizing total brightness data with normalized running differences, we measured the inclination of helicoidal structures, revealing a notable trend: as the polar angle increases, the inclination decreases. Further analysis, including the examination of EUI images, reveals evidence of an eruptive flux rope in the lower corona with distinguishable footpoints. Despite a 2-minute time cadence limiting direct correspondence among filamentary structures in consecutive frames, we speculate that Metis helicoidal features may be interpreted as a consequence of the growing and opening flux tube in the outer corona. Additionally, we measured the helix pitch and plan to compare these measurements with parameters from the high-resolution magnetohydrodynamics simulation by Wyper et al. (2022). This comparison aims at exploring disturbances launched into the solar wind via intermittent/bursty interchange reconnection and assess how Metis observations align with the repeated ejection of plasmoid flux ropes into the solar wind obtained from the simulation.

Local clusters of internal magnetic field structures in a filament related CME event (12:10)

Presenter: CAPPELLO, Greta

Parker Solar Probe (PSP; launched in 2018) and Solar Orbiter (SoLO; launched in 2020) observe the Sun from unprecedented close-in and out-of-ecliptic orbits. This unique and high-resolution data give us new insights about the initiation and early evolution of coronal mass ejections (CMEs) in the inner heliosphere. We investigate the morphology and propagation behavior of distinct small-scale structures belonging to the coronal mass ejection (CME) caused by a filament eruption, together with the CME-aftermath. We aim to shed more light on the evolution of internal small-scale magnetic field structures of a CME and how these behave in the global CME context. We are interested on how they get formed, how they change in shape over time and how they are related to the erupting filament and flux rope, respectively. Due to the fast PSP motion in its orbit, we apply a single-spacecraft triangulation technique to derive coordinates and kinematics of each tracked feature and to relate them to the erupting filament structures as observed in EUV. We find distinct groups of small-scale features clustered in longitude that constitute the global CME. We obtained a large range of longitude among the different blobs related to the post-CME current sheet. Thread-bundles are identified in the inner heliosphere, which can be related to so-called vertical threads which evolved during the filament eruption. We notice how the global appearance of the CME appears to be different from 1~AU and PSP at 0.18~AU, as the global outer front is not well observed in PSP.

Parameter effects on the total intensity of H I Lya line for a modeled CME and its driven shock (12:25)

Presenter: YING, Beili

The combination of the H I Lyα (121.6 nm) line formation mechanism with white-light and ultraviolet (UV) Lyα observations provides an effective method for determining the electron temperature of coronal mass ejections (CMEs). A key to ensuring the accuracy of this diagnostic technique is the precise calculation of theoretical Lyα intensities. This study performs a modelled CME and its driven shock via the three-dimensional numerical magneto-hydrodynamic simulation. Then, we generate synthetic UV images of the CME and shock to quantify the impact of different assumptions on the theoretical Lyα intensities, such as the incident intensity of the solar chromospheric Lyα line (I_{disk}), the geometric scattering function ($p(\theta)$), and the kinetic temperature (T_{n}) assumed to be equal to either the proton (T_p) or electron (T_e) temperatures. Through comparing relative variations of the Lyα intensities of the CME and shock under these assumptions, we find that: (1) Using the uniform or Carrington maps as input for I_{disk} underestimates the Lyα intensity (with relative errors below 10%) compared to the Real-time map, but the Carrington map yields better results than the uniform disk. (2) Neglecting the geometric scattering process leads to a relatively symmetric influence, with an error reversal interface at a latitude of approximately 40°. The Lyα intensity is overestimated above this latitude and underestimated below it. The relative errors increase with heliocentric distance, but do not exceed 10%. (3) Compared to the assumption $T_n=T_p$, using $T_{n}=T_e$ leads to more complex relative errors in CME Lyα intensity. The CME core and void are almost overestimated, with maximum values exceeding 50%. In the CME front, both overestimates and underestimates exist with relative uncertainties of less than 35%. However, the electron temperature assumption has a smaller impact on the shock, with an underestimated relative error of less than 20%.

Discussion (12:40)

Session 5 (15:00 - 16:30)

-Conveners: Giampiero Naletto

CMEs eruptions with very intense UV emission observed by the Metis coronagraph on-board Solar Obiter (15:00)

Presenter: RUSSANO, Giuliana

Metis, the coronagraph on board Solar Orbiter (SolO), offers the unique capability to simultaneously track the evolution of coronal mass ejections and solar eruptions in the ultraviolet H I Ly-α line and polarized visible light. This comprehensive analysis allows for valuable insights into the dynamics, time evolution, mass contents, and outflow propagation velocity of plasma in the expanding corona. We present the results of a recent work that focuses on observing six eruptive events with Metis during the SolO cruise phase. These events show a very strong emission of UV radiation and can be interpreted as due to eruptive prominences. Leveraging the exceptional spatial and temporal resolution of Metis, we follow the evolution of these structures by studying their morphology and kinematic state and providing estimates of their volume, densities and temperature, also in synergy with other coronagraphs in space. We will conclude by focusing on future investigations and ongoing work for these peculiar events.

First Metis Detection of the Helium D3 Line Polarisation in a Large Eruptive Prominence (15:15)

Presenter: HEINZEL, Petr

Metis on board of Solar Orbiter is the space coronagraph developed by an Italian-German-Czech consortium. It is capable of observing solar corona and various coronal structures in the visible-light (VL) and UV (hydrogen Lyman α) channels simultaneously for the first time. Here we present observations of a large eruptive prominence of April 25-26, 2021, in the VL, taken during the mission cruise phase, and demonstrate that apart from the broad-band continuum emission which is due to the Thomson scattering on prominence electrons we detect a significant radiation in the neutral-helium D$_3$ line (587.6 nm) which lies within the Metis VL passband. We show how the prominence looks like in the Stokes I, Q, and U. We consider two extreme cases of the prominence magnetic field, and we separate the Stokes I and Q signals pertinent to Thomson scattering and to the D$_3$ line. The degree of linear polarisation of the D$_3$ line (both Q and U) indicates the presence of the prominence magnetic field, hence Metis can serve as a magnetograph for eruptive prominences located high in the corona.

Revealing the differences between two eruptive events observed by Metis on October 28, 2021 (15:30)

Presenter: DE LEO, Yara

On October 28, 2021 the first X-class solar flare of Solar Cycle 25 occurred in active region NOAA AR 12887 with a peak at 15:35 UT, producing the rare event of ground-level enhancement of the solar relativistic proton flux and a global extreme ultraviolet (EUV) wave, along with a fast halo coronal mass ejection (CME) as seen from Earth's perspective. A few hours before the flare, a slower CME had erupted from a quiet Sun region just behind the northwestern solar limb. Solar Orbiter was almost aligned with the Sun-Earth line and, during a synoptic campaign, its coronagraph Metis detected the CME events in both the VL and UV channels. The earlier CME took place in the north-west (NW) sector of Metis field of view, while several bright features of the flare-related event appeared mostly to the south-east (SE). The NW and SE events have two distinct origins, but were both characterized by an exceptionally bright emission in HI Ly-alpha in the UV images of Metis up to 8 solar radii. This work is a follow-up study of two out of the six events analyzed by Russano et al. 2023, aimed at investigating the evolution of these two almost co-temporal CMEs but originating in such distinct source regions. To that end, we extensively inspect data sets from numerous remote-sensing instruments observing the Sun in several spatial and spectral regimes. We track the erupting prominences associated with both CMEs with respect of their outer envelopes, from their source regions until the outer corona, by means of three-dimensional reconstruction techniques. Preliminary results of this work in progress point to notable differences between these two events showing significant UV emission in the corona.

First multi-view observations of an erupting prominence in the UV Lyman-alpha line with SolO/Metis and ASO-S/LST instruments (15:45)

Presenter: LI, Shuting

A prominence eruption associated with a limb CME were observed on April 12, 2023 by the multi-channel Metis Coronagraph on-board the Solar Orbiter mission. The prominence, seen in the Metis UV Lyman-alpha images as a very bright and elongated arch propagating southward, is instead much weaker in Metis visible light (VL) images. The elongated arch splits into several blobs and becomes fainter with time as the prominence evolves. In our work, we studied the 3D position of the prominence to understand the reason for such a significant difference between these two channels. By considering the different processes responsible for the emissions, we obtained the time evolution of the electron density and the temperature of one blob of the prominence from VL and UV images, respectively. The derived thermodynamic evolution suggests the existence of unknown physical processes providing additional heating source during the plasma expansion, as also previously found with observations acquired by the UVCS spectrometer on-board SOHO. We also applied the same method to another branch of the prominence to further understand the physical process inside the entire prominence. The Lyman-alpha Solar Telescope (LST) on-board the Advanced Space-based Solar Observatory (ASO-S) mission also observed this eruption along the Earth-Sun view. The solar disk imager (SDI) on-board the LST – observed the prominence lifting from the south-west solar limb, with the south leg fixed onto the Sun as the prominence expand. Another purpose of this work is to combine observations acquired by Metis and SDI to study the prominence from the Lyman-alpha emission. In particular, Carrington maps of chromospheric Lyman-alpha emission measured by SDI will be employed to constrain the radiative component of the Lyman-alpha emitted by the prominence plasma expanding through corona.

Joint investigation of coronal mass ejections with Metis observations, numerical simulations and in situ spacecraft data (16:00)

Presenter: ZIMBARDO, Gaetano

A new research activity has been started which aims at a comprehensive study of coronal mass ejections (CMEs) and their interplanetary counterpart, including the study of the CME driven shock and the associated energetic particles. This activity is going to use Solar Orbiter/Metis, SOHO/LASCO, and STEREO/COR1 and COR2 coronagraphic data for imaging CMEs in the corona; these observations will be used as an input for numerical simulations of the interplanetary CME evolution to be done with the RIMAP code, which is based on the PLUTO magnetohydrodynamic (MHD) code; the results of the RIMAP simulations are used for comparison with in situ data, gathered by Solar Orbiter and by other spacecraft, to check the CME time of arrival and the plasma parameter changes, as well as the characteristics of the shock and of shock accelerated particles. Our scientific

methodologies are: 1. Determine the physical properties of CME-driven shocks from white-light coronagraphs and extreme UV observations of the low corona; 2. Trace the evolution of the CME-driven shocks from the source to the Earth's orbit, with the support from MHD and hybrid MHD/PIC numerical simulations (PLUTO code), using new approaches such as RIMAP to identify where the structure of the Parker spiral leads to shock generation. 3. Analyse solar energetic particles and energetic storm particles using in-situ data in the inner heliosphere and compare them with the observations of coronal shocks and the output from hybrid MHD/PIC simulations, for better understanding acceleration and propagation processes. Our approach involves a strong connection between data analysis (both from remote-sensing and in situ) and numerical simulations linking large scales to local processes. In this work, some preliminary results on the events of 5 September 2022 and 4 November 2023 will be presented, with Metis observations giving the closest-to-the-sun coronagraphic input to the workflow. This work is supported in part by the Italian PRIN 2022, project 2022294WNB entitled "Heliospheric shocks and space weather: from multispacecraft observations to numerical modeling".

Theoretical relations between the plasma parameters and Metis observables for eruptive prominences and CMEs (16:15)

Presenter: JEJČIČ, Sonja

The Metis coronagraph simultaneously detects the integrated intensity of the hydrogen Lyman α line and the continuum intensity of the visible light, over the entire field of view. We focus on 2D non-LTE modeling of eruptive prominences or cores of CMEs up to eight solar radii, using a range of flow velocities to account for the Doppler dimming effect. We consider isothermal and isobaric 2D non-LTE models and show various relations between plasma physical parameters and radiation outputs. We discuss the relative role of the radiative and collisional excitation of Lyman α and also show the importance of hydrogen photoionization and collisional ionization. The full non-LTE treatment allows us to consider models with a range of optical thicknesses in the Lyman α line and we thus can demonstrate the importance of the opacity effects. Our results based on an extended grid of models will be helpful for interpreting the Metis observations.

Coffee Break (16:30 - 17:00)

Session 6 (17:00 - 18:30)

-Conveners: Giampiero Naletto

Joint science with PSP (17:00)

Presenter: RAOUAFI, Nour

Python software for Metis (17:20)

Presenter: BURTOVOI, Aleksandr

A software tool for computing Solar Wind Speed through Doppler Dimming diagnostics (17:30)

Presenter: GIORDANO, Silvio Matteo

The Metis instrument operating on board the Solar Orbiter provides simultaneous images in the Visible Light (VL) and Ultraviolet (UV) of the solar corona in the range of distances from about 2 up to over 10 solar radii with a spatial scale of 10 arcsec in VL and 20 arcsec in UV. VL observations enable to determine the coronal electron density, then the Doppler Dimming diagnostics, combining the data of both channels, provides full coronal maps of the proton outflow velocity. The accuracy and reliability of the diagnostic technique is related to the calculation of expected Ly-alpha intensity, thus it depends on a number of parameters which define the chromospheric and coronal model, and on geometrical assumptions about the 3D shape of these parameters. In this presentation, we show the Doppler Dimming Tool, DDT, a software package developed in IDL for computing the solar wind map from a couple of polarized Brightness, pB, and Ly-alpha intensity maps, taking under control all the setup and input parameters. This code can be run through a GUI or in batch-mode over a large number of different models to study the effects of different assumptions on wind speed results. We present a quick tutorial on how to install, run the code, display the output maps, and some results obtained with data from the cruise phase and the first year of the nominal mission. We will discuss also the plan to release the package and to develop a Python version.

Out of ecliptic science (18:00)

Presenter: SPADARO, Daniele

Discussion (18:10)

Friday, 26 January 2024

Session 7 (09:00 - 10:50)

-Conveners: Vania Da Deppo

Waves in corona observed by Metis (09:00)

Presenter: ANDRETTA, Vincenzo

The Metis coronagraph observes the solar corona at spatial resolution that can rival or surpass other instruments, either ground-based or space-borne. In addition, the instrument design allows observations at high temporal cadences that were difficult to achieve before in the extended corona. During the perihelia of the Solar Orbiter nominal mission, these capabilities have been exploited to provide observations that are opening a new window on the dynamics of the solar corona in a range of parameters never explored before. We present, in particular, the detection of density perturbations in the corona above 2 solar radii that we interpret as due to leakage in the extended corona of surface p-modes.

A 3D MHD Model for Metis CMEs (09:20)

Presenter: PAGANO, Paolo

High resolution and high cadence coronagraphic images from Metis are helping addressing outstanding scientific questions on the structure an propagation of CMEs. At the same time, these observations are opening up new opportunities to observationally constrain existing models and to develop a new generation of advanced, complex models that combine lower and outer coronal domains. In this work we present a CME MHD model where a CME lifts off from the solar surface in a domain where we have assembled a potential force free field with a solar wind and a transition region plasma distribution that we can tune to to match the Metis pre-CME estimations for temperature, density and plasma speed. Starting from this initial condition for the whole 3D solar corona up to 15 Rs and including thermal conduction, radiative losses, and coronal heating we can model the propagation of a specific using as inputs the time of the corresponding synoptic magnetogram and the active region identified as source of the flux rope ejection. The CME triggering is modelled as a simple shear between opposite polarities. I will present some preliminary results of this modelling approach on the CME observed by Metis on April, 25th 2021.

Study of transient events in the solar corona through combined analysis of images acquired by the Metis multi-channel coronagraph on board the ESA Solar Orbiter mission (09:35)

Presenter: AMATO, Emanuele

On November 09-11 2021 the Metis coronagraph on-board ESA Solar Orbiter mission observed a sequence of interesting transient events in the solar corona. First, starting from 18:00 UT on November 09 the instrument observed over the West limb the reconfiguration phases immediately after a major Coronal Mass Ejection (CME), also observed by the LASCO coronagraphs on-board SOHO. The VL images show the propagation of multiple plasma blobs around the main CME propagation latitude, likely related with magnetic reconnections going on after the transit of the eruption. The same blobs were not observed in the UV Lyman-α channel and this information provided us constraints on the blob plasma temperature. We identified and tracked 5 blobs, measuring their propagation speed and for the brightest among them we measured radius, and volume, as well as their average electron density and thus total mass. The corresponding estimates of kinetic, thermal and potential energies dragged by the blobs have been used to infer both the heliocentric distances and times where these blobs were formed by magnetic reconnection. It turns out that all the blobs were formed between 2.7 and 5.3 R_sun, hence below the inner edge of the Metis field-of-view (located around 5 R_sun), and inside the LASCO/C2 field-of-view. The images acquired by LASCO/C2 show a morphology supporting these results. Moreover, in the same dataset, a second slow eruption was observed by Metis above the East limb. This weak event showed interestingly only an expanding bubble-like feature darker than the surrounding corona both in the VL and UV Lyman-alpha channels, without any clear core or front, suggesting that what we observed was a slowly expanding hollow flux-rope. The LASCO/C2 images confirm that this feature formed in the inner corona and thus entered in the Metis field-of-view. After a determination of its kinematical properties (hence an estimate of the UV Doppler dimming coefficient), the VL and UV Lyman-α images have been analysed with the direct ratio “Doppler dimming” technique to obtain 2D maps of electron temperature inside the expanding flux-rope and derive information on the thermal evolution of the embedded plasma. First results are presented here.

Study of solar brightness profiles in the 18 - 26 GHz frequency range with INAF radio telescopes: evidence for coronal emission (09:50)

Presenter: MARONGIU, Marco

One of the most important objectives of solar physics is the physical understanding of the solar atmospheric structure (still a matter of debate in the literature), including a full description in terms of the density (n) and temperature (T) distributions. In our analysis we aim to constrain the n and T distributions through observations in the centimetric radio domain. We employ single-dish observations from two of the INAF radio telescopes: the newly-appointed Medicina "Gavril Grueff" Radio Telescope and the

Sardinia Radio Telescope (SRT), in the context of the SunDish project, designed for the monitoring of the Sun and its atmosphere at the radio K-band frequencies (18 – 26 GHz, and up to 100 GHz in perspective) since 2018 to date. The uniform exposure of the entire solar disk and its surroundings, together with the low noise, accurate absolute calibration, and good sensitivity of these radio telescopes, make our data set crucial to analyse and model the solar atmospheric emission in this frequency range. In this talk we present our first results about the evidence of the significant coronal emission in the 18-26 GHz radio band, using about 300 radio solar maps obtained in the context of the SunDish project. We describe our methods to prove the physical origin of the coronal emission and to analyse the Physics (we assumed the thermal bremsstrahlung as the emission mechanism) of the solar atmosphere. The modelled brightness profiles are compared with those observed with the Grueff Radio Telescope by averaging solar maps obtained at 18.3 and 25.8 GHz during the minimum of solar activity (2018 – 2020). Finally, we discuss and compare our results with those of literature, also including the Metis density distributions.

Intercomparison of the Metis/VL, LASCO-C2 and COR2-A coronagraphs (10:05)

Presenter: BURTOVOI, Aleksandr

We present the comparison of the coronal visible light (VL) images obtained with the currently operating coronagraphs, such as Metis/Solar Orbiter, LASCO-C2/SOHO and COR2/STEREO-A. We compared the total (*B*) and polarized (*pB*) brightness data that was collected during various conjunctions and oppositions of these instruments in 2020-2023. Analyzing the latitudinal profiles of *pB* and *B* images obtained with each pair of coronagraphs, we found that they are in general highly correlated. As a result, we estimated additive and multiplicative scaling factors between these instruments.

The Metis contribution in cometary science: an initial assessment of the first three years of activities (10:20)

Presenter: CORSO, Alain Jody

Throughout the initial three years of the operative mission, METIS coronagraph carried out numerous scientific observations, including some focused on comets. Among the observed cometary targets, there are periodic comets, like 2P/Encke, sunskirters, such as 96P/Machholz, some sungrazers, and even a long-period comet, the C/2021 A1 (Leonard), having an orbital period of approximately 80,000 years. Although many of these observations, especially of periodic comets, were specifically planned, some comets were also identified a posteriori on images collected for solar corona studies. The ability of METIS to perform simultaneous imaging in a narrow UV band around HI Ly-alpha and in the visible wavelength range can be highly impactful in cometary studies. UV images enable the study of neutral hydrogen coma morphology and the estimation of the water outgassing rate from the comet nucleus. Conversely, visible polarization images allow the derivation of comet parameters correlated with the physical properties (distribution, density, size, ...) of the dust grains in the coma. In this work, a summary of the activities and main results obtained so far is presented, highlighting some original results obtained from METIS comet observations and sharing some valuable “lessons learned" from these three years of activity.

Density fine structuring of the solar corona inferred from the trail of sungrazing comets and Metis observations (10:35)

Presenter: NISTICÒ, Giuseppe

Comet C/2011 N3 (SOHO) and Comet C/2011 W3 (Lovejoy) are, up to the present, the only two comets observed to have transited inside the inner solar corona at distances below two solar radii. The observations captured by the Solar Dynamics Observatory in EUV with the Atmospheric Imaging Assembly have revealed the comet tails structured as a sequence of striations, apparently distributed quasi-periodically in space. Such striations, even known as "striae", are represented by a beam of oxygen ions released by the comet nucleus that diffuses along the local magnetic field. However, it is still unclear if the sequence of striae reflects the hidden structuring of the solar corona or is merely caused by an internal process in the comet (e.g., a rapid rotation of the comet nucleus causing a periodic injection of the oxygen ions). We present a preliminary analysis of the striations formed after the passage of the comets by quantifying length, width, and number of striae per unit of length as a function of the altitude from the solar surface. The apparent transverse motion of the striae presents relevant consequences in the context of coronal seismology. Furthermore, we also relate our findings to the recent high-resolution observations from the SolO-Metis coronagraph.

Coffee Break (10:50 - 11:30)

Session 8 (11:30 - 13:00)

-Conveners: Marco Romoli

Characterizing the streamer belt with Metis and EUI instruments on Solar Orbiter (11:30)

Presenter: ABBO, Lucia

We have analyzed combined coronal observations acquired by Metis and the Extreme Ultraviolet Imager (EUI) on Solar Orbiter, to infer typical physical parameters of the streamer belt, fundamental to better characterize the physical structure and properties of

the slow solar-wind sources and to constrain global coronal models. This work aims to derive a set of physical parameters of streamers and nearby regions by using observations in March 2021, almost at the minimum of solar activity. In particular, we use the Full Sun Imager (FSI) channel of EUI in coronagraphic mode, which allows stray-light free off-limb observations. First, we superimpose the EUV images by EUI of the disk and of the inner corona in Fe ix/Fe x 17.4 nm with the images by Metis of the outer corona in HI Lya 121.6 nm and in visible light. A comparison of the same radial structures is performed. Then, we compute the electron density from the polarized brightness measured by Metis and, using the emission measure analysis, an estimate of the electron temperature is obtained and discussed in the overlapping region between the fields of view of the two instruments (at 4-4.5 Rsun) as a function of the latitude across the streamer belt. Moreover, through the Doppler dimming technique, the outflow velocity of the protons is derived from 4 to 6 Rsun in the regions nearby the streamers.

Evolution of the streamer belt and magnetic-field topology in the middle corona: the Metis coronagraph point of view (11:45)

Presenter: FRASCELLA, Francesco

The analysis of the variability of the streamer belt and coronal magnetic field topology is one of the key questions listed among the scientific objectives of the Metis coronagraph, on board the Solar Orbiter spacecraft. To address this science question, we selected a set of polarised visible-light data (VL-pB) that Metis acquired in the first two years of the Nominal Mission Phase (i.e., from the 1 st December 2021 to the end of 2023). We observe a variability in the intensity of the VL-pB data due to increasing solar activity. The streamer belt moves towards mid to high latitudes and the coronal magnetic field starts to deviate more and more from the typical axial symmetry it assumes during the minimum. We present both a long time-lapse variability of the VL-pB date and some preliminary comparisons with the coronal field topology inferred from magnetic extrapolations obtained with the magneto-hydrodynamic model developed by Predictive Science Inc. (PSI-MAS), to shed light on the correlation, at a qualitative level, between the field line topology in the plane of the sky and the local VL-pB intensity. The aim of this work is twofold: on the one hand, we would like to study the evolution of the solar corona from the Metis point of view during the ascending phase of the 25 th solar cycle, on the other hand we want to assess the differences between the coronal magnetic field topology as time-averaged over a solar rotation in the PSI-MAS model, and the observed, highly dynamic field topology during the rising solar cycle.

Discussion (12:00)