

**User Guide for Solar Orbiter / Metis Investigation  
Data Products and Publication Policy**

**Version 4.1 — May 8, 2023**

This document is developed and updated by the Metis team to provide a reference guide for users of Metis data. This is a “living document” that will be periodically updated.

1	Introduction.....	3
1.1	Overview of Metis .....	3
1.2	Data Providers and contact information.....	3
1.3	Data Use Policy.....	4
1.4	File naming conventions and FITS header definition.....	7
1.5	Revision Management.....	8
2	Accessing the Data.....	7
2.1	Universal access from anywhere.....	7
2.2	Data Formats/Products .....	7
2.3	Computer setup .....	8
2.3.1	IDL.....	8
2.3.2	Python .....	8
2.3.3	JHelioviewer .....	8
2.3.4	SAO Image DS9.....	9
3	List of acronyms.....	10
	Appendix A – Metis Topical Teams .....	11
	Appendix B – Metis PO and operations team.....	12
	Appendix C - Acknowledgments .....	17

# 1 Introduction

## 1.1 Overview of Metis

The Metis instrument aboard Solar Orbiter spacecraft is an externally occulted coronagraph designed to take images of the solar corona in two channels: VL linearly polarized broadband (580–640 nm) and UV narrowband H I Ly- $\alpha$  (121.6 nm). The telescope FoV covers the full corona from 1.6° to 2.9° from disk center.

The primary data products are UV images, VL polarized brightness (pB) images, VL total brightness (tB) images, and VL fixed polarization (FP) images. Secondary data products are low latency UV and VL images, VL light curves and cosmic ray log matrices.

These data will provide direct and indirect estimates of electrons and hydrogen coronal densities and their fluctuations, solar wind velocities, high cadence imaging of the evolution of coronal transients, and the F-corona. Additional targets observed for scientific and calibration purposes include planets, comets, and stars.

The current baseline for all RS Solar Orbiter instruments, including Metis, is to observe inside Remote-Sensing dedicated windows except for specific targets of opportunities, such as UV stars, comets or special reciprocal positions with other spacecrafts (conjunctions, quadratures, etc.).

Metis will also run a synoptic program throughout most of Solar Orbiter orbit.

The data product availability will start during the Nominal Mission Phase (NMP).

The planning for the operations takes place with the following steps:

- Mission Level Planning (MLP): planning of a full orbit at science level, performed 6 months in advance during Science Working Team meetings (SWT)
- Long Term Planning (LTP): detailed science planning for three months intervals, performed three months in advance during Science Operation Working Group meetings (SOWG)
- Short Term Planning (STP): sequences to be uploaded (Instrument Observation Request – IOR), performed three weeks ahead of observations start
- Very Short Term Planning (VSTP): final adjustments with no impact on budgets, performed a few days before the observations start.

More information about the Metis experiment, the team and the data are available through the Metis webpage: <http://metis.oato.inaf.it>.

## 1.2 Data Providers and contact information

The PI coordinates the Metis Team, composed of the Co-PIs, Co-Is, associate scientists and key persons, with knowledge of the instrument and expertise in operations planning.

The Metis team meets weekly to discuss about science, operations and ground support activity; it develops the observing program for each orbit according to the scientific plan devised during the SWT and plans the LTPs and the STPs.

Metis co-investigators lead topical teams (see Appendix A) to coordinate data analysis and suggest science planning relative to specific topics.

Questions regarding the use or interpretation of these data may be directed to the individuals listed below.

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## 2 Data Use Policy

The Metis data produced during the Nominal Mission Phase (NMP) are made available freely and without restrictions to all parties and for all purposes after three months from the science telemetry download. Data acquired during the Commissioning and Cruise Phase (CP) are available upon request.

This is fully consistent with ESA's open data policy.

As part of the development of collaboration with the broader solar and heliophysics community, however, Metis mission has defined some rules to govern how Metis instrument data should be used.

The rules will apply starting from the beginning of the NMP.

### 2.1 Restricted use of Metis data

The Metis Team has the privilege to use Metis data from Cruise Phase (CP) and from the

Nominal Mission Phase (NMP) before they become publicly available in the Solar Orbiter Archive (SOAR), but everyone is invited and welcome to collaborate with the team.

Two approaches are used in case of use of restricted use of Metis data:

1. Papers led by a Metis Team scientist
2. Papers led by other scientists

### **2.1.1 Restricted use of Metis data: papers led by a Metis team scientist**

Four categories of publications/conference communications/posters are defined:

1. Core papers: “first” and “relevant” results submitted to journals classified as Q1 in SJR ranking : these papers shall have a designated Metis team member as first author (a provisional list of “first” and “relevant” publication is given in Appendix D)
2. Other papers subject to peer-to-peer review
3. Conference proceedings
4. Conference communications/posters

**Metis team first authors have to send with enough time in advance to the PI the title and the abstract or draft of the paper/communication/poster, the list of contributing authors including the operation team, and a submission category proposal.** The PI, in coordination with the scientific team Coordinator, will approve the submission, will assign the suitable category among the four previously listed, and will define the author list order. In case the submission is considered as “Core paper”, also the Project Office has to approve it and to assign the first author.

For the Metis Team this policy applies also when Metis data are from SOAR, at least within one year from the data publication to SOAR.

The following guidelines generally applies:

1. Core papers and first publications of each topical team (Cat.1) have to include the Metis Core Team in the author list (as defined in Appendix B)
2. Other Metis led papers subject to peer-to-peer review (Cat.2) must include Metis PO (table 1 of Appendix B) and the operations team (Table 2 of Appendix B).
3. Conference proceedings (Cat.3) should include the operations team.
4. The Conference communication/poster (Cat.4) author list has to contain the contributors to the work and “and the Metis Team”.
5. All publications using Metis data have to:
  - acknowledge the sources of data used by mentioning the version of the dataset used in the paper
  - add the long version of the acknowledgments for the core papers and the short version of the acknowledgments for the rest of the papers (as given in Appendix C)
  - cite the instrument paper (Antonucci et al., A&A, 2020, and Fineschi, Naletto,

et al. , Exp. Astron., 2020)

6. All submitted works have to be sent to the PI to keep record of Metis publications
7. Low latency data are not intended for science analysis or publication and should not be used for this purpose.

### **2.1.2 Restricted use of Metis data: papers led by other scientists**

Papers subject to peer-to-peer review led by other instrument team members the following guidelines generally applies:

1. Papers led by other instrument teams (Cat.3) have to include in the author list the operations team (Table 2 of Appendix B), in addition to the contributors from the Metis team.
2. All publications using Metis data have to:
  - a. acknowledge the sources of data used by mentioning the version of the dataset used in the paper
  - b. add the short version of the acknowledgments given in Appendix C
  - c. cite the instrument papers (Antonucci et al., A&A, 2020, and Fineschi, Naletto, et al. , Exp. Astron., 2020)
3. All submitted works have to be sent to the PI to keep record of Metis publications
4. In case of any doubt about the instrument and its calibration, users are encouraged to contact the PI to discuss the appropriate use of instrument data or model. Metis team should facilitate this process, serving as the contact point between PI and users in most cases.
5. Low latency data are not intended for science analysis or publication and should not be used for this purpose.

## **2.2 Public Metis data from SOAR**

Three months after the NMP data are downlinked to the ground and processed they are released to the public and are available through the Solar Orbiter SOAR (<http://soar.esac.esa.int/soar>) and can be freely used.

The PI recommends that scientists adhere to the following guidelines:

1. All publications using Metis data should:
  - be sent to the PI after submission to keep record of Metis publications
  - acknowledge the sources of data used in all publications, presentations, and reports mentioning the data release version used in the paper
  - add the short version of the acknowledgments given in Appendix C
  - include the members of the operations team (as defined in Appendix B) involved in the acquisition of data in the list of authors
  - cite the instrument paper (Antonucci et al., A&A, 2020 , and Fineschi,

Naletto, et al. , Exp. Astron., 2020)

2. In case of any doubt about the instrument and its calibration, users are encouraged to consult with the PI to discuss the appropriate use of instrument data or model. Metis team should facilitate this process, serving as the contact point between PI and users in most cases.
3. Low latency data are not intended for quantitative analysis and therefore they should not be used for scientific purposes.

### **3 Accessing the Data**

#### **3.1 Universal access from anywhere**

Three months after the data from an orbit are downlinked to the ground and processed, and starting from the NMP, they are released to the public and are available through the Solar Orbiter SOAR (<http://soar.esac.esa.int/soar>).

#### **3.2 Data Formats/Products**

Metis makes several data products available in FITS format:

**Level 0:** uncalibrated primary data (units of DN) obtained from telemetry packets, that are decompressed and formatted in standard FITS format. (The metadata contain only the information that is available from the telemetry packet headers.). Secondary science data: light curves and cosmic ray log matrices.

**Level 1:** uncalibrated data (units of DN). (The metadata contain extra engineering data from housekeeping telemetry packets and scientific coordinate systems (WCS) keywords.)

**Level 2:** calibrated data (physical units). (Corrections for bias, dark current, flat-field, and vignetting, exposure normalisation, pointing, and radiometric calibration are applied). They consist of primary science data: UV images; VL Stokes parameters, total/polarised-brightness images, polarisation angle/fraction.

All the available orbital and attitude information is used and coordinates expressed in scientific coordinate systems (WCS).

**Level 3:** science data derived from L2 data, (Movies, Carrington maps; and data obtained after scientific analysis, i.e., electron-density maps, solar-wind outflow velocity maps.)

Level 2 data release is made public and will start within the beginning of the NMP (> Nov 2021). Level 0 and 1 data will be available upon request.

In most circumstances, we recommend use of the Level-2 or Level-3 data products for essentially all scientific analyses, both qualitative and quantitative.

#### **3.3 File naming conventions and FITS header definition**

All Metis image data are in the FITS file format.

FITS naming convention is described in the document SOL-SGS-TN-0009 *Metadata Standard*, available from the SOC Confluence pages:

<https://issues.cosmos.esa.int/solarorbiterwiki/display/SOSP/Solar+Orbiter+SOC+Public>

The FITS image file contains an ASCII header followed by the binary image data. The header consists of keywords followed by the value. The content of the header is described in the document METIS-OATO-SPE-021 *Metis Data Product Description Document*, available from the Metis webpage.

### **3.4 Revision Management**

The data product version number (VX in the FITS file name) indicates how many times the product has been generated. Modifications to processing software, changes to calibration or other input files, and header (metadata) changes are all examples that would cause the version number to increase. Data entry errors, transmission problems or other types of failures may also cause a product to be re-released and thus have the data product version number incremented. The data product version is tracked by the VERSION keyword in the FITS header and indicated in the filename. Version zero (V0) in the filename indicates a quick-look data product; its VERSION number in the header may increment but the quick-look filename will not change.

### **3.5 Computer setup**

The FITS image files conform to the CCSDS standard, and so are readable through many different systems. The traditional system for us has been the Interactive Data Language (IDL). If using IDL, make sure to compile the appropriate Solarsoft libraries. Information on solarsoft is available at <https://sohowww.nascom.nasa.gov/solarsoft/>. Python is also a capability that can be used. There are also two stand-alone applications that are very useful for viewing FITS images, DS9 and Jhelioviewer.

#### **3.5.1 IDL**

To read and process Metis images, use the IDL procedures in the Metis tree in the Solarsoft directory.

A Metis package will be made available to be included in the Solarsoft library.

#### **3.5.2 Python**

The Astropy Python library contains a suite of procedures that can be used to read, analyze, and visualize Metis images. Numerous tutorials, documentation, and code examples can be found on the Learn.Astropy website, located at <https://learn.astropy.org>.

In addition to that, SunPy is the community-developed, free and open-source solar data analysis environment for Python (<https://sunpy.org>).

A Metis package will be made available to be included in the SunPy library.

#### **3.5.3 JHelioviewer**

A useful tool for visualizing solar images of various types is JHelioviewer. It also a free, standalone application. For more information visit their website <http://www.jhelioviewer.org>. It is particularly useful for combining images of different spatial coverage such as EUV or magnetogram images of the solar disk with coronal imagery.



### **3.5.4 SAO Image DS9**

Another useful tool to view the FITS files in a standalone mode, SAO Image DS9 is a very useful tool. Download instructions and the user manual are available at <https://sites.google.com/cfa.harvard.edu/saoimageds9>. It is a general astronomical imaging and data visualization application. DS9 is a free, stand-alone application supporting FITS images and binary tables, multiple frame buffers, etc. You can manipulate the images by zooming and changing the color table and see the FITS header.

## 2 List of acronyms

ASI	Italian Space Agency
AU	Astronomical Unit – the mean distance of the Earth from the Sun
ESA	European Space Agency
ESAC	European Space Astronomy Centre
ESOC	European Space Operations Centre
F-corona	Fraunhofer Corona – scattering of photospheric light by dust
FITS	Flexible Image Transport System
FOV	Field of View
FSW	Flight SoftWare
HGA	High Gain Antenna
IDL	Interactive Data Language
INAF	National Institute for Astrophysics, Italy
IOR	Instrument Observation Request
JH	JHelioviewer
K-corona	Kontinuerlich Corona – scattering of photospheric light by electrons
L1, L2, L3	Data Processing Levels
LTP	Long Term Planning
MLP	Mission Level Planning
MOC	Mission Operations Center (at ESOC)
MPPU	Metis Power and Processing Unit
NMP	Nominal Mission Phase
NASA	National Aeronautics and Space Administration
OBSW	On board Software
OBT	On Board Time
OS	Operative System
PI	Principal Investigator
PO	Project Office
RS	Remote Sensing
RSW	Remote Sensing Window
S/C	Spacecraft
SOC	Spacecraft Operations Center (at ESAC)
STP	Short Term Planning
VO	Virtual Observatory
VSO	Virtual Solar Observatory
VSTP	Very Short Term Planning
WCS	World Coordinate System

## Appendix A – Metis Topical Teams

- TT1 - Wind diagnostics (R. Susino, INAF-OATO, Italy)
  - Electron density (and electron temperature) (S. Fineschi, INAF-OATO, Italy)
  - Hydrogen density (J.C. Vial, IAS, France)
  - Wind velocity with Doppler dimming (R. Susino, INAF-OATO, Italy)
- TT2 - F-corona (F. Landini, INAF-OATO, Italy)
- TT3 - Combined synoptics (L. Teriaca, MPS, Germany)
- TT4 - Helium Diagnostics (V. Andretta, INAF-OACn, Naples, Italy)
- TT5 - Image enhancements (F. Frassetto, CNR/IFN, Padua, Italy)
- TT6 - Solar Wind (D. Telloni, INAF-OATO, Italy)
- TT7 - Large scale magnetic configuration and evolution, Streamers and pseudo-streamers (L. Strachan, NRL, USA)
- TT8 - CMEs, prominence eruptions and blobs (P. Heinzel, AIAS, Czech Republic)
- TT9 - Coronal shocks, particle acceleration (G. Zimbardo, UniCal, Italy)
- TT10 - Plasma density fluctuations and waves (G. Nisticò, UniCal, Italy)
- TT11 - Flux emergence, magnetic field reconnection, coronal heating, flares (F. Reale, UniPa, Italy)
- TT12 - Modelling of CME propagation/evolution in corona and solar wind in connection with space weather (A. Bemporad, INAF-OATO, Italy)
- TT13 - Cosmic Rays (C. Grimani, UniUrb, Italy)
- TT14 - Sun grazing comets and other solar system bodies (V. Da Deppo, CNR/IFN, Padua, Italy)

## Appendix B – Metis Core Team and Operations Team

The Metis Core Team consists of the following researchers, that contributed and are contributing to the making, the characterization, and the operations of Metis, who are part of:

- The Project Office
- A list of Co-Is, Associate scientists and key persons
- The Operations Team

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**Operations Team:**

The operations team includes, for each RSW, the planners and the data validators, and are listed below (the publication policy described in Sec. 2 applies to the members of the operations team listed in the columns under Short term planning):

<b>CRUISE PHASE</b>	
<b>LTP period</b>	<b>Short term planning / IOR writing and validation</b>
LTP01* (June 2020)	Andretta, Nicolini, Pancrazzi, Sasso, Susino
LTP02* (July-December 2020)	Andretta, Nicolini, Pancrazzi, Sasso, Susino
LTP03* (January-June 2021)	Andretta, Landini, Jerse, Nicolini, Pancrazzi, Sasso, Susino
LTP04* (July-September 2021)	Jerse, Landini, Nicolini, Pancrazzi Burtovoi, Capuano, Giordano, Guglielmino, Liberatore, Romano, Russano, Sasso, Susino, Zangrilli
LTP05* (October-November 2021)	Frassati, Jerse, Landini, Nicolini, Pancrazzi, Sasso, Susino Burtovoi, Capuano, Giordano, Guglielmino, Liberatore, Romano, Russano, Zangrilli
<b>NOMINAL MISSION PHASE</b>	
The operation team is defined by STP in the table: <a href="#">NMP Operation Team</a>	

(\*) In case the UV data of the cruise phase are used, include Teriaca, Uslenghi, De Leo, Andretta (and Russano for LTP05)



## **Appendix C - Acknowledgments**

*Short version for Science papers:*

Solar Orbiter is a space mission of international collaboration between ESA and NASA, operated by ESA. Metis was built and operated with funding from the Italian Space Agency (ASI), under contracts to the National Institute of Astrophysics (INAF) and industrial partners. Metis was built with hardware contributions from Germany (Bundesministerium für Wirtschaft und Energie through DLR), from the Czech Republic (PRODEX) and from ESA.

*Long form for Acknowledgements in core papers:*

Solar Orbiter is a space mission of international collaboration between ESA and NASA, operated by ESA. The Metis program is supported by the Italian Space Agency (ASI) under the contracts to the National Institute of Astrophysics (INAF): Accordi ASI-INAF N. I-043-10-0 and Addendum N. I-013-12-0/1, Accordo ASI-INAF N.2018-30-HH.0 and under the contracts to the industrial partners OHB Italia SpA, Thales Alenia Space Italia SpA and ALTEC: ASI-TASI N. I-037-11-0 and ASI-ATI N. 2013-057-I.0. Metis was built with hardware contributions from Germany (Bundesministerium für Wirtschaft und Energie (BMWi) through the Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)), from the Czech Republic (PRODEX) and from ESA.

In case Ester Antonucci is not in the list of authors add:

Metis team thanks the former PI, Ester Antonucci, for leading the development of Metis until the final delivery to ESA.

## **Appendix D – Tentative list of most relevant publications**

### **“First” Metis papers include all names (Co-Is included)**

First light (Solar Orbiter First results Issue 1)

First perihelia, key objectives (Wind velocity, density fluctuations, high cadence observations, quadratures, and in general, new discoveries)

First out-of-ecliptic key objectives (2025)

First in-flight calibration

Author list: PI, paper authors, PO, Metis Core Team

Long form for acknowledgments (Appendix C)

### **Instrument calibration papers (lead by a Team member)**

On-ground calibrations

In-flight calibrations

Author list: paper authors, Metis Core Team

Long form for acknowledgments (Appendix C)

### **Relevant first Proceedings (lead by a Team member)**

Author list: paper authors, Metis Core Team

Short form for acknowledgments (Appendix C)

### **First TT papers**

Author list: TT Leader, paper authors, Metis Core Team

Long form for acknowledgments (Appendix C)

### **Science papers**

Author list: Paper authors, Metis Operations Team

Short form for acknowledgments (Appendix C)

### **Instrument, Calibration, and simulations papers**

Author list: Paper authors, (Metis Operations Team in case of use of Metis data)

Short form for acknowledgments (Appendix C)