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

Version 2.2 — May 7, 2021

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 updated as necessary, such as when new data products are developed.

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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 HI Ly-α (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 with the exception of 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 (TBD) throughout most of Solar Orbiter orbit.
The data product availability will start during the Nominal Mission Phase (NMP).
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 develops the observing program and prepares the resulting commands that meets weekly to discuss and develop the observing program for each orbit according to the scientific plan devised during the SWT.
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.

Marco Romoli (marco.romoli@unifi.it)	Principal Investigator (PI)
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Gianalfredo Nicolini	Instrument Scientist

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Vincenzo Andretta (vincenzo.andretta@inaf.it)	Operations Scientist
Daniele Spadaro (daniele.spadaro@inaf.it)	Scientific Team Coordinator
Ester Antonucci (ester.antonucci@inaf.it)	Former Metis PI

1.3 Data Use Policy

The Metis data are made available freely and without restrictions to all parties and for all purposes after three months from the science telemetry download. 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 Nominal Mission Phase (NMP).

First result publication and relevant «first» publications related, for example, to first minimum perihelion (4/2022 @0.32AU) and first high heliolatitude (2/2027 -25 deg) shall have the PI as a first author, the contributors, the Metis Core Team and Co-Is as co-authors.

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 correct DOI of the dataset used in the paper
    - add to the acknowledgments the text given in Appendix C.
    - include the members of the operations team (as defined in Appendix B under the columns *Short term planning*) involved in the acquisition of data in the list of authors
    - include the PO (as defined in Appendix B) in the list of authors for data acquired during the NMP
    - cite the instrument paper (Antonucci et al., A&A, 2019)

2. In case of any doubt about the instrument, 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.

2 Accessing the Data

2.1 Universal access from anywhere

Three months after the data from an orbit are downlinked to the ground, 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).

2.2 Data Formats/Products

Metis makes several data products available in FITS format:

Level 0: uncalibrated 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.)
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 and secondary science data: light curves and cosmic ray log matrix.
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.

2.3 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.

2.4 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 also indicated in the filename. Version zero (V0) in the filename indicates a quick-look data product; it's VERSION number in the header may increment but the quick-look filename will not change.

2.5 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.

2.5.1 IDL

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

2.5.2 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.

2.5.3 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.

2.5.4 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.

3 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 PO and operations team

Project Office, Co-PIs

Marco Romoli	PI	Dip. di Fisica e Astronomia, Università di Firenze Via Sansone 1, 50019, Sesto Fiorentino (FI), Italy
Vincenzo Andretta	Operations Scientist	INAF – Osservatorio Astronomico di Capodimonte Salita Moiarello 16, 80131, Napoli, Italy
Ester Antonucci	Former PI	INAF – Osservatorio Astrofisico di Torino Via Osservatorio 20, 10025 Pino Torinese (TO), Italy
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Luca Teriaca	Co-PI	Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany

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. 1.3 applies to the members of the operations team listed in the columns under Short term planning):

LTP period	**Long term planning**	**Short term planning**		**Data verification and validation**
		IOR writing	**IOR validation**	
LTP01 (Jun 2020)	Andretta Spadaro	Sasso Susino	Nicolini Pancrazzi	(Andretta Sasso Susino)
LTP02 (Jul-Dec 2020)	Andretta Spadaro	Sasso Susino Landini	Nicolini Pancrazzi	(Andretta Sasso Susino)
LTP03 (Jan-Jun 2021)	Andretta Spadaro	Landini Sasso Susino Jerse Slemer	Nicolini Pancrazzi	(Andretta Landini Sasso Susino Jerse)
LTP04 (Jul-Sep 2021)	Andretta Spadaro	Landini Jerse	Pancrazzi	To be assigned
LTP05 (Oct-Dec 2021)	Andretta Spadaro	Frassati, Jerse, Landini	Pancrazzi	To be assigned

LTP06 (Jan-Mar 2021)	Andretta Spadaro	Frassati, Abbo	Nicolini, Sasso	To be assigned
LTP07 (Apr-Jun 2021)	Andretta Spadaro	To be assigned	To be assigned	To be assigned

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.