ORN NDA/MEFISTO Sun EDR FITS
Dataset Specification, version 1.0

Alexia Duchêne[3], Laurent Lamy[1,2,3], Alan Loh[1,2],
Baptiste Cecconi[1,2], Cédric Viou[2], Patrice Renaud [2]

[1] LESIA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Université Paris Cité, Meudon, France

[2] Observatoire de Radioastronomie de Nancay, Observatoire de Paris, Université PSL, CNRS, Université Orléans, Nancay, France

[3] Aix-Marseille Université, CNRS, CNES, LAM, Pythéas, Marseille, France

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Version History:

Date	Version	Change record	Authors
2022-05-10	0.1	First Release	A.Duchêne
2022-06-13	0.2	Update metadata keys	A.Duchêne
2022-06-15	0.3	Update Data acquisition	L.Lamy
2022-07-21	0.4	Update for mefisto receiver	A.Duchêne
2022-08-05	0.5	Revision and page layout	A.Duchêne
2022-08-23	1.0	Revision	L.Lamy

1 Data acquisition

The Nançay Decameter Array (NDA) hosted at the Observatoire Radioastronomique de Nançay (ORN) in the Sologne forest (France) is a phased array of 144 « Teepee » helicoidal antenna, composed of two subarrays of 72 antenna each, sensitive to Right Handed (RH) and Left Handed (LH) circular polarization, respectively. Since January 1978, the NDA has been acquiring quasi-daily decametric observations of Jupiter (typically within 10-40 MHz) and the Sun (typically within 10-80 MHz), together with punctual transit observations of intense radiosources for calibration purposes, with several analog (<1990) and digital (>1990) receivers. [1] [2] [3]

The *MEFISTO* (MEdian FIlter Solar specTrOmeter) receiver is operational since 2013, since which it is used for daily observations of the Sun only (a different receiver, called JunoN, is used instead for Jupiter observations). This receiver, based on a FPGA architecture, records data on 2 channels simultaneously, sensing the auto-correlations on both RH and LH sub-arrays between 5 to 35 MHz. The specificity of MEFISTO is to filter the data on-the-fly to mitigate human induced radio frequency itnerferences (RFI) with a median filter [4]. The filtered data enables one an easier extraction of so-

lar emissions. They also facilitate the cross-comparison with in-space radio observations overcoming 10 MHz, that makes the receiver an excellent ground-based support for space missions such as Wind, STEREO, Parker Solar Probe or Solar Orbiter.

This digital receiver benefits a large dynamics (14-bits ADC) and continuously samples the signal over a 40 MHz band at a 80 Msamples/second cadence. 65536 channels Transforms provide instantaneous spectra which are rebinned as follows. Frequency channels are averaged by groups of 64, yielding a final fixed spectral step of 76.823 kHz. 389 frequency channels thus sample the 5.07-34.95 MHz range. For standard daily observations, 128 successive spectra are averaged together, yielding an effective temporal cadence of 106.633 msec. When compared to *Routine* (swept-frequency) observations, *MEFISTO* standard observations of RH/LH autocorrelations display better signal-to-noise ratios, typically larger by factor of $\sim$ 18, while sampling instantaneously the full spectral range. When compared to *NewRoutine* observations, RH/LH autocorrelations display a sligtly lower spectral resolution but a 5 times better temporal cadence.

As for the other receivers, *MEFISTO* observations include hourly calibration sequences. In practice, such calibration sequences are executed as follows. The signal summed up over each bloc of 8 antennas is replaced by the signal of a reference noise diode which delivers a fixed power of 42 dB ENR (or -72 dBm/MHz). This signal is then attenuated by 30 dB, 20 dB, 10 dB and 0 dB and measured over 10 s long exposures for each attenuation factor. The 30 dB attenuation factor approximately corresponds to the mean sky level. These calibration sequences can in turn be used to calibrate the RH/LH flux densities.

2 General structure of the dataset

The *ORN NDA / MEFISTO Solar EDR Dataset* [5] provides uncalibrated experiment data record (EDR), together with time series of pointing and instrumental parameters. The data are distributed in the FITS (Flexible Image Transport System) format. A FITS datafile is composed of a primary Header and Data Unit (HDU), and of 3 additional extensions [6]. Documents and links introducing to FITS are available at NASA/GSFC (Goddard Space Flight Center).

The primary header is made of three sections, describing the data, the instrumental configuration and providing relevant physical ephemeris. It also contain the required metadata to be compliant with ISTP (International Solar Terrestrial Program), the PDS4 (NASA Planetary Data System version 4) , and the EPNcore data model used by the VESPA project for its data distribution protocol EPN-TAP [7]. The primary HDU does not contain data. The exact content of the primary header is detailed in section 3.

The 3 additional extensions, each associated to a specific header, provide setup, science and acquisition data, respectively. More precisely :

- Extension # 1 (see section 4 for details) provides the frequency channels;

- Extension # 2 (see section 5 for details) provides the data epoch time series and the scientific data (in V^2/Hz). When transposed to decibels and compared to *Routine* data, the background level of *MEFISTO* RH/LH autocorrelation data is typically $\sim$ 4dB larger;

- Extension # 3 (see section 6 for details) provide time series of the NDA pointing, of the NDA filters in use and of the attenuation factors corresponding to calibration sequences.

3 Primary Header

This section lists the metadata stored in the primary header. Keywords, and their associated value and comment are presented as written in the FITS file, with some additional information provided whenever useful.

```
DATA DESCRIPTION
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TITLE	value: ORN NDA mefisto SUN EDR Dataset comment: Title of the dataset
ORIGIN	value: ORN comment: Observatoire Radioastronomique de Nancay

Identifies the organization or institution responsible for creating the FITS file [6].

CONTACT	value: contact_nda at obs-nancay.fr comment: Contact email address

For any questions and/or collaborative purposes, the ORN/NDA team can be contacted at the contact email address.

PI_NAME	value: L.Lamy comment: Principal Investigator
PUBLISHE	value: Obs. Paris/ORN/PADC comment: Publisher of the dataset

Identifies the organization or institution responsible for the publishing of the data set, here being Observatoire de Paris, Observatoire Radioastronomique de Nancay, and Paris Astronomical Data Center.

OBJECT	value: Sun comment: Target observed

Identifies the object observed [6].

DATE	value: *Updated by script* comment: Date of file creation

Date on which the HDU was created, written as `YYYY-MM-DD` [6].

FILENAME	value: *Updated by script*

File name of the FITS file. The convention filing name is `orn_nda_mefisto_sun_edr_yyyymmddhhmm _yyyymmddhhmm_VX-X-X,` containing the date (yyyy-mm-dd) and time (hh:mm) of the start and end of

the observation, as well than the version of the file as a triple digit `X-X-X`.

OBSRVTRY	value: `ORN`
	comment: `Observatoire Radioastronomique de Nancay`

Name of the observatory [8].

TELESCOP	value: `NDA`
	comment: `Nancay Decameter Array`

Identifies the telescope used to acquire the data associated with the header [6].

OBSGEO-L	value: *47.380510*
	comment: `Geographic longitude of ORN/NDA in deg`

Defines the longitude in the ITRS Cartesian coordinates [9].

OBSGEO-B	value: *2.193226*
	comment: `Geographic latitude of ORN/NDA in deg`

Defines the latitude in the ITRS Cartesian coordinates [9].

OBSGEO-H	value: *135*
	comment: `Geographic altitude of ORN/NDA in meters`

Defines the altitude in the ITRS Cartesian coordinates [9].

INSTRUME	value: `mefisto`
	comment: `Receiver`

Identifies the instrument used to acquire the data associated with the header [6].

DATE-BEG	value: *Updated by script*
	comment: `Begin date of observation`

Identifies the date of the start of the data acquisition in the `UTC` time system by default [8]. The date is written as `YYYY-MM-DD.`

DATE-END	value: *Updated by script*
	comment: `End date of observation`

Identifies the date of the end of the data acquisition in the `UTC` time system by default [8]. The date is written as `YYYY-MM-DD.`

TSTART	value: *Updated by script*
	comment: `Begin time of observation`

Identifies the time of the start of the data acquisition in the `UTC` time system by default [9]. The time is written as `hh:mm:ss.sss`.

| TSTOP | value: *Updated by script*
comment: End time of observation |

Identifies the time of the end of the data acquisition in the `UTC` time system by default [9]. The time is written as `hh:mm:ss.sss`.

| OBS_MODE | value: Spectroscopy
comment: Observation technique |

| SUBJECT | value: Solar science
comment: Science discipline |

| DATATYPE | value: EDR
comment: Experiment Data Record |

| VERSION | value: *Updated by script*
comment: Version number of dataset |

Identifies the version of particular FITS data file. The version is a number on 3 digits, incremented every time the file is updated.

| INFO-URL | value: http://www.obs-nancay.fr
comment: Data Website |

| REFERENC | value: https://doi.org/10.1553/PRE8 s455
comment: Reference article |

Citing the reference where the data associated with the header are published [6].

| REFDATA | value: http://www.obs-nancay.fr
comment: Reference dataset |

| REFSPEC | value: http://www.obs-nancay.fr
comment: Reference data description |

INSTRUMENTAL CONFIGURATION

| DATE-MER | value: *Updated by script*
comment: Date of passage of the object at meridian |

The date is written as `YYYY-MM-DD`.

TIME-MER	value: *Update by script* comment: Time of passage of the object at meridian

The time is written as `hh:mm:ss.sss`

ACC	value: *Update by script* comment: Accumulation factor

The number N of successive spectra averaged together.

FREQMIN	value: *Updated by script* comment: Minimum frequency in MHz
FREQMAX	value: *Updated by script* comment: Maximum frequency in MHz
DF	value: *Updated by script* comment: Frequency resolution in MHz
DT	value: *Updated by script* comment: Time resolution in seconds
CHANNEL1	value: LL comment: Left-Handed (LH) sub-array Autocorrelation

Channel 1 withhold the decontaminated data from the autocorrelation measured on the Left-Handed (LH) sub-array in V^2/Hz.

CHANNEL2	value: RR comment: Right-Handed (RH) sub-array Autocorrelation

Channel 2 withhold the decontaminated data from the autocorrelation measured on the Right-Handed (RH) sub-array in V^2/Hz.

VIRTUAL OBSERVATORY COMPLIANCE

DSCPLN	value: Solar Physics>Waves comment: ISTP attribute

Science discipline and sub-discipline [10].

DSCRTR	value: MEFISTO_Sun comment: ISTP attribute

Identifies the name of the instrument/sensor that collected the data [10].

| INS-TYPE | value: `Radio Telescope`
comment: `ISTP attribute` |

Instrument type to facilitate the choice through CDA Web (Coordinated Data Analysis) [10].

| MODS | value: *Updated by script*
comment: `ISTP attribute` |

Denote the history of modifications made to the dataset [10], which is a standard global attribute of NSSDCA. If the value is set to `None`, the data file has been through no modifications.

| PARENTS | value: *Updated by script*
comment: `ISTP attribute` |

List of the parent FITS for files of derived and merged data sets [10]. If the value is set to `Original File`, the data file is itself the parent file.

| RULE-USE | value: `http://www.obs-nancay.fr`
comment: `ISTP attribute` |

The link contain the information on citability and PI access restrictions, referring to this specification document. [10]

ORN/NDA observations in open access can be freely used for scientific purposes. Their acquisition, processing and distribution is ensured by the ORN/NDA team, which can be contacted for any questions and/or collaborative purposes at the contact email address (contact.nda@obs-nancay.fr). We kindly request the authors of any communications and publications using the data to let us know about them, include minimal citation to the reference, and appropriate acknowledgments whenever needed.

| SFW-LANG | value: `python3`
comment: `ISTP attribute` |

Software language used for the processing [10].

| PDS_TYPE | value: `Radio`
comment: `PDS attribute` |

Identifies the observation type [10].

| VES-TYPE | value: `DS>Dynamic Spectrum`
comment: `VESPA attribute` |

Identifies the organization of the data product from an enumerated list [7].

| OBJ-CLAS | value: `star`
comment: `VESPA attribute` |

Identifies the target type from an enumerated list [7].

| OBJ-REGN | value: Solar Wind, Heliosphere
comment: VESPA attribute |

Identifies the type of region of interest [10].

| FEA-NAME | value: Solar radio bursts
comment: VESPA attribute |

Identifies the secondary name, can be the standard name of region os interest [10].

| MSR-TYPE | value: phys.flux.density; em.radio; phys.polarization
comment: VESPA attribute |

Identifies a physical characterization of the data [10], using UCD (Unified Content Descriptor) as defined by IVOA (International Virtual Observatory Alliance).

| ACC-FORM | value: application/fits
comment: VESPA attribute |

Identifies the format type using the MIME (Media) type in a two-part identifier [10].

ASTRONOMICAL EPHEMERIS

DECOBJ-B	value: *Updated by script* comment: Object declination at start of acquisition
DECOBJ-E	value: *Updated by script* comment: Object declination at end of acquisition
RAOBJ-B	value: *Updated by script* comment: Object right ascension at start of acquisition
RAOBJ-E	value: *Updated by script* comment: Object right ascension at end of acquisition
DISTE-B	value: *Updated by script* comment: Earth-target distance in AU at start
DISTE-E	value: *Updated by script* comment: Earth-target distance in AU at end
DISTE-1	value: *Updated by script* comment: Minimum Earth-target distance in AU
DISTE-2	value: *Updated by script* comment: Maximum Earth-target distance in AU

SUBELATB	value: *Updated by script* comment: Sub-terrestrial latitude in deg at start
SUBELATE	value: *Updated by script* comment: Sub-terrestrial latitude in deg at end
SUBELAT1	value: *Updated by script* comment: Minimum Sub-terrestrial latitude in deg
SUBELAT2	value: *Updated by script* comment: Maximum Sub-terrestrial latitude in deg
SUBELONB	value: *Updated by script* comment: Central Meridian Longitude in deg at start
SUBELONE	value: *Updated by script* comment: Central Meridian Longitude in deg at end
CARROT-B	value: *Updated by script* comment: Carrington Rotation number at start
CARROT-E	value: *Updated by script* comment: Carrington Rotation number at end

4 Extension 1: Setup data

The extension named 'SETUP' (extension #1) contains the 1D array of frequencies ('frq' extension). Those are provided in MHz, and recorded as single-precision floating points.

5 Extension 2: Science data

The extension named 'SCIENCE' (extension #2) contains the 1D array of observing times and time-frequency 2D data arrays.

- The observing times ('jd' extension) are given in julian days, and recorded as double-precision floating points ;
- The data arrays ('data' extension) are provided in V^2/Hz, and recorded as single-precision floating points. They are provided in the order given in the main header (keywords CHANNEL1, CHANNEL2).

6 Extension 3: Acquisition data

The extension named 'ACQUISITION' (extension #3) contains tracking and instrumental informations as a function of (pointing) time.

The pointing times ('`time`' extension) are given in julian days, and recorded as double-precision floating points. Contrary to the observing times, they are sampled every 10 sec or more (the sampling can be irregular).

The sky pointing coordinates are provided in two different systems, both expressed in degrees as single-precision floating points :

- azimuth and altitude ('`azimuth`' and '`altitude`' extensions): horizontal coordinate system ;

- right ascension and declination ('`right_ascension`' and '`declination`' extensions): equatorial coordinate system.

The provided instrumental parameters are the following ones :

- the field bandpass filter in use defined by two limit frequencies ('`filter_min_field` and '`filter_max_field`' extensions) : integer values expressed in MHz ;

- the laboratory high-pass filter defined by a cutoff frequency ('`filter_lab`' extension) : integer value expressed in MHz ;

- the attenuation factor for calibration sequences ('`at`' extension) : integer value in dB (30, 20, 10, 0 during calibration sequences, -1 elsewhere).

References

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