Virtual SPICE Training Class
BepiColombo

Marc Costa Sitja

ESA SPICE Service
by RHEA Group

21st July 2020, Webex

Agenda

Tuesday (21st July)

- 09:30 – 10:00 Introduction to SPICE (00)
- 10:00 – 11:00 SPICE fundamentals (01-02)
- 11:15 – 13:00 SPICE fundamentals (03-08)
- 13:00 - 14:00 Lunch Break
- 14:00 - 16:15 SPICE fundamentals (09-12)
- 16:30 – 17:00 Setting up SPICE
- 17:00 - 17:30 Hands-on SPICE (I): Remote Sensing Observation Tutorial

Wednesday (22nd July)

- 09:00 - 10:30 SPICE fundamentals (12-17)
- 10:30 - 11:00 Hands-on SPICE (II): Remote Sensing Observation Tutorial
- 11:15 - 12:00 WebGeocalc and SPICE-enhanced Cosmographia
- 12:00 - 13:00 SPICE for BepiColombo
- 12:00 - 13:00 SPICE for BepiColombo
- 13:00 - 14:00 Lunch Break
- 14:00 – 16:15 Hands-on SPICE (II): Venus first swingby
- 16:30 – 17:30 Wrap-up: Open Discussion, Q/A, AOBs

Welcome & Logistics

- **WebEx sessions** for the training:
  - **Tuesday 21st:** https://esait.webex.com/esait/j.php?MTID=m405a5988f63451aadfef5dd860a12fe3
  - **Wednesday 22nd:** https://esait.webex.com/esait/j.php?MTID=m849920b7f6d75a90780a319cb05b5659
- **MATERIAL:** All the required information can be obtained from the dedicated GitHub Repository: https://github.com/esaSPICEservice/ess_workshop_4pdw
- **SET UP SPICE:** It is recommended to install the SPICE Toolkit in advance (we recommend you to use some time during the lunch break if you have not done so yet). 30 minutes will be dedicated to set up SPICE but it would be better to use that slot to answers questions. We also recommend to download the BepiColombo SPICE Kernel dataset and to install SPICE-enhanced Cosmographia.
- **LANGUAGES**: The hands-on lessons will be provided in Python using SpiceyPy. Users of other programming languages are supposed to have enough knowledge of the language such that she or he can conduct the hands-on lessons.
- The hands-on lessons will be done synchronously; we will give you some time to answer each of the sections of the hands on lessons and then the solution of that section will be provided.
- Feel free to interrupt me anytime during the lessons and to ask questions during the hands-on lessons.
- This training will be recorded and distributed to the BepiColombo community (if everyone agrees).

An Introduction to SPICE & the ESA SPICE Service

Marc Costa Sitja

ESA SPICE Service
by RHEA Group

21st July 2020, Webex

Ancillary Data

are those that help scientists and engineers determine:

- where the S/C was located, how the S/C and its instruments were oriented
- what was the location, size, shape and orientation of the target body
- what events were occurring on the S/C

The ancillary data comes from: The S/C, MOC/SGS, S/C manufacturer and Instrument teams, Science Organizations.

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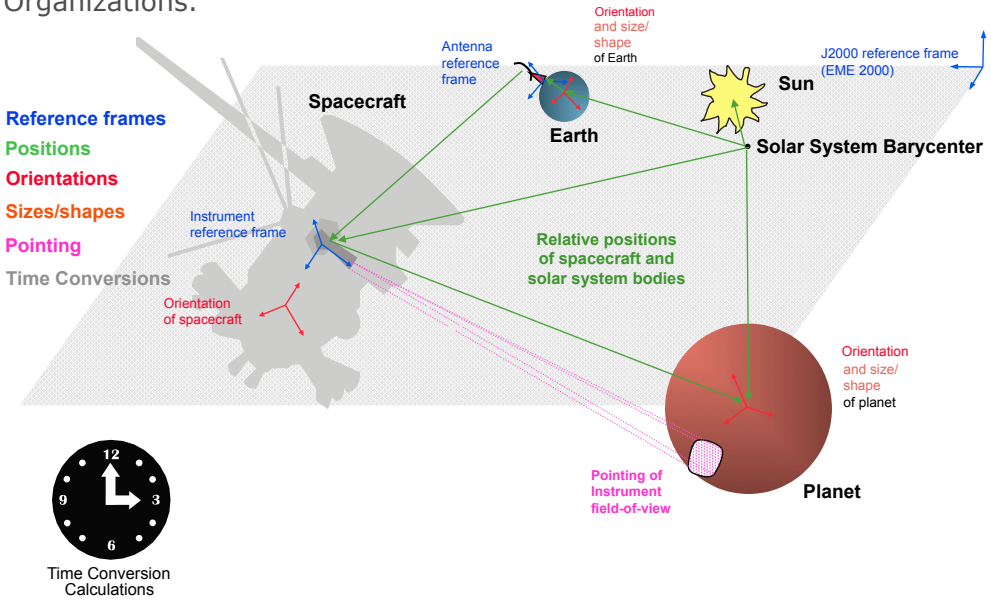

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ORMM_FDRMMA_DA_070901000000_00419.MEX

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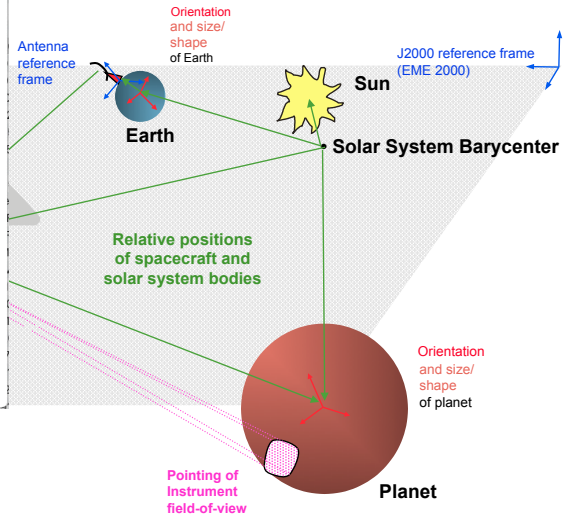

Time Conversion Calculations

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ments were oriented

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ORMM_FDRMMA_DA_070901000000_00419.MEX

```
ESOC_TOS_GFI_ORBIT_FILE_VERSION = 1.0


META_START
OBJECT_NAME          = MARS EXPRESS
OBJECT_ID            = 41
CENTER_NAME          = MARS
REF_FRAME            = EME2000
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OBJECT_NAME     = MARS EXPRESS
OBJECT_ID       = 41
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REF_FRAME       = EME2000
START_TIME      = 2003-06-02T19:18:21.79999999
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DERIVATIVES_FLAG = 0
META_STOP

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2003-06-02T19:18:21.80000160 -0.5547164052939074D+00  0.1880967866597057 2D+00  0.4639426567451245 8D+00  0.6645799572246480 8D+00


META_START
OBJECT_NAME     = MARS EXPRESS
OBJECT_ID       = 41
TIME_SYSTEM     = TDB
REF_FRAME       = EME2000
START_TIME      = 2003-06-02T19:18:21.80000160
STOP_TIME       = 2003-06-03T00:56:31.79999999
CREATION_DATE   = 2003-07-11T07:30:36
FILE_TYPE       = ATTITUDE FILE
VARIABLES_NUMBER = 4
DERIVATIVES_FLAG = 0
META_STOP

2003-06-02T19:18:21.80000160 -0.5547164052939013D+00  0.1880967866597061 7D+00  0.4639426567451251 4D+00  0.6645799572246415 8D+00
2003-06-02T19:20:21.79999999 -0.5863302031495473 1D+00  0.1366424017509324 8D+00  0.5427412089622871 7D+00  0.5856430030423844 8D+00
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2007-08-31T23:38:41.85878831  0.6880614830527455 0D+04 -0.1654794685190933 3D+04  0.8342390768805154 3D+03 -0.9680609298080881 1D+00  0.1225503474634626 1D+01 -0.2144454796910546 1D+01
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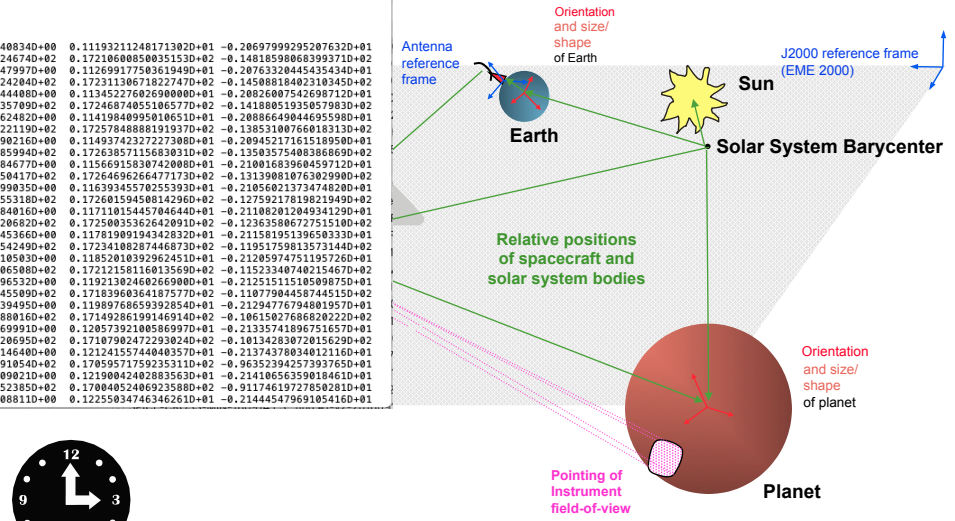

Time Conversion Calculations

Ancillary Data are those that help scientists and engineers determine:

ments were oriented

ORMM_FDRMMA_DA_070901000000_00419.MEX

```
ESOC_TOS_GFI_ORBIT_FILE_VERSION = 1.0


META_START
OBJECT_NAME          = MARS EXPRESS
OBJECT_ID            = 41
CENTER_NAME          = MARS
REF_FRAME            = EME2000
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META_START
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OBJECT_ID      = 41
TIME_SYSTEM    = TDB
REF_FRAME      = EME2000
START_TIME     = 2003-06-02T19:18:21.79999999
STOP_TIME      = 2003-06-02T19:18:21.80000160
CREATION_DATE    = 2003-07-11T07:30:36
FILE_TYPE        = ATTITUDE FILE
VARIABLES_NUMBER = 4
DERIVATIVES_FLAG = 0
META_STOP

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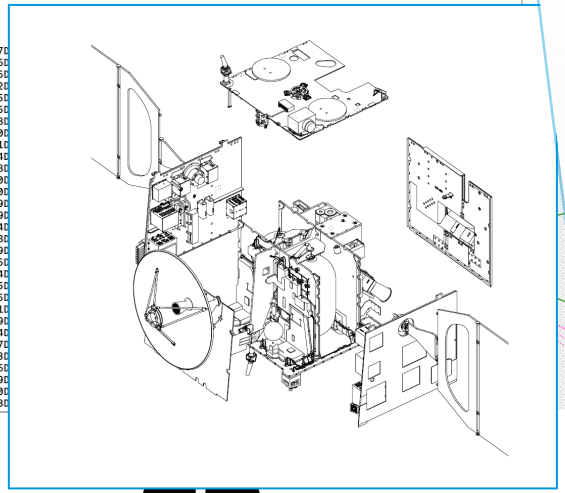
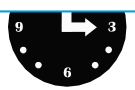
2003-06-02T19:18:21.80000160 -0.5547164052930974D+00  0.1880967866597057 2D+00  0.4639426567451245 8D+00  0.6645799572246408 0D+00


META_START
OBJECT_NAME    = MARS EXPRESS
OBJECT_ID      = 41
TIME_SYSTEM    = TDB
REF_FRAME      = EME2000
START_TIME     = 2003-06-02T19:18:21.80000160
STOP_TIME      = 2003-06-03T00:56:31.79999999
CREATION_DATE    = 2003-07-11T07:30:36
FILE_TYPE        = ATTITUDE FILE
VARIABLES_NUMBER = 4
DERIVATIVES_FLAG = 0
META_STOP

2003-06-02T19:18:21.80000160 -0.5547164052930913 0D+00  0.1880967866597061 7D+00  0.4639426567451251 4D+00  0.6645799572246415 8D+00
2003-06-02T19:20:21.79999999 -0.5863302031495473 3D+00  0.1366424017509324 8D+00  0.5427412089622871 7D+00  0.5856430030423844 8D+00
2003-06-02T19:22:21.79999999 -0.6347782508702981 6D+00  0.3568465047226562 1D-01  0.6063927037253985 5D+00  0.4775678661837690 1D+00
2003-06-02T19:24:21.79999999 -0.6809218255375135 5D+00 -0.1139311043108668 0D+00  0.6380994857857639 1D+00  0.3480743249335742 0D+00
2003-06-02T19:26:21.79999998 -0.6958443908660239 0D+00 -0.2668719395320877 2D+00  0.6325507898986346 0D+00  0.2108540959925568 0D+00
2003-06-02T19:28:21.79999998 -0.6818551076779865 2D+00 -0.3827141704801418 4D+00  0.6116677031865553 8D+00  0.1202750881250528 6D+00
```

```
2007-08-31T23:37:01.58917582  0.6973652901866532 4D+04 -0.1776686181551965 3D+04  0.1048732293461083 4D+00
                             -0.7675186118619993 8D+05  0.1041758677490811 0D+06 -0.1843408099879398 7D+00
2007-08-31T23:37:35.35325258  0.6943214306708067 9D+04 -0.1735862746549695 2D+04  0.9766283563894934 3D+00
                             -0.7903486476541086 4D+05  0.1047527056285118 5D+06 -0.1846746262138664 6D+00
2007-08-31T23:38:08.77534489  0.6912198317059978 8D+04 -0.1695231117957110 9D+04  0.9051295300437462 9D+00
                             -0.8133111645221362 4D+05  0.1053219663609134 4D+06 -0.1849880709419192 0D+00
2007-08-31T23:38:41.85878831  0.6880614830527435 5D+04 -0.1654794685190933 3D+04  0.8342390768805154 3D+00
```





Time Conversion Calculations

Ancillary Data are those that help scientists and engineers determine:

ments were oriented

ORMM_FDRMMA_DA_070901000000_00419.MEX

```
ESOC_TOS_GFI_ORBIT_FILE_VERSION = 1.0

META_START
OBJECT_NAME          = MARS EXPRESS
OBJECT_ID            = 41
CENTER_NAME          = MARS
REF_FRAME            = EME2000
```

ATNM_FDLMMA_DAP030602191822_00021.MEX

```
ESOC_TOS_GFI_ATTITUDE_FILE_VERSION = 1.0

META_START
OBJECT_NAME    = MARS EXPRESS
OBJECT_ID      = 41
TIME_SYSTEM    = TDB
REF_FRAME      = EME2000
START_TIME     = 2003-06-02T19:18:21.79999999
STOP_TIME      = 2003-06-02T19:18:21.80000160
CREATION_DATE  = 2003-07-11T07:30:36
FILE_TYPE      = ATTITUDE FILE
VARIABLES_NUMBER = 4
DERIVATIVES_FLAG = 0
META_STOP

2003-06-02T19:18:21.79999999 -0.554716404924469830+00  0.188096787296308270+00  0.463942655657096580+00  0.66
2003-06-02T19:18:21.80000160 -0.554716405293090740+00  0.188096786659705720+00  0.463942656745124580+00  0.66
```

vmc_model.edf — Edited

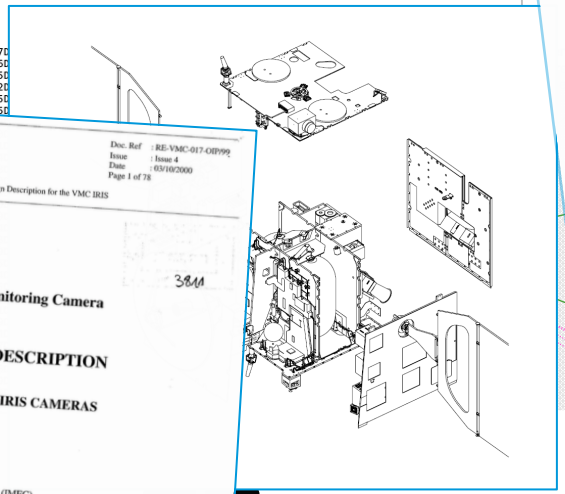
```
# This file contains the VMC modelling
#
# $Log: vmc_model.edf,v $
# Revision 1.1  2016/02/29 13:48:30  acardesin
# Test VMC model
#

# Experiment FOV definitions

# Rectangular FOV: 40deg along+Y, 30deg along+X
FOV: VMC
FOV_lookat: 0.0 -0.32557 0.94552
FOV_upvector: 0.0 1.0 0.0
FOV_type: RECTANGULAR
FOV_geometric_angles: 30.00 40.00 [degrees]
FOV_active: \
            MODE ON     \
            MODE DUMMY

# Rectangular FOV: 0.4deg along+Y, 0.3deg along+X
FOV: VMC_centre
FOV_lookat: 0.0 -0.32557 0.94552
FOV_upvector: 0.0 1.0 0.0
FOV_type: RECTANGULAR
FOV_geometric_angles: 0.3 0.4 [degrees]
FOV_active: \
            MODE ON     \
            MODE DUMMY

# Rectangular FOV Corners X-Shape
```



OIP
Opronic Instruments & Products
Wenteringe 21
B - 9700 Oudenaarde

Doc. Ref : RE-VMC-017-OIP/99
Issue : Issue 4
Date : 03/10/2000
Page 1 of 78

VMC: Design Description for the VMC IRIS

3811

Visual Monitoring Camera

DESIGN DESCRIPTION

for the VMC IRIS CAMERAS

PREPARED BY :	L. DE VOS W. OGIERS (IMEC)
APPROVED BY :	L. DE VOS
RELEASED BY :	G. BRANDT
UPDATED FOR MEX:	ESTEC-TOS-ETD

European Space Agency

Directorate of Operations and Infrastructure

Ground Systems Engineering Department

ROSETTA / MARS EXPRESS / VENUS EXPRESS

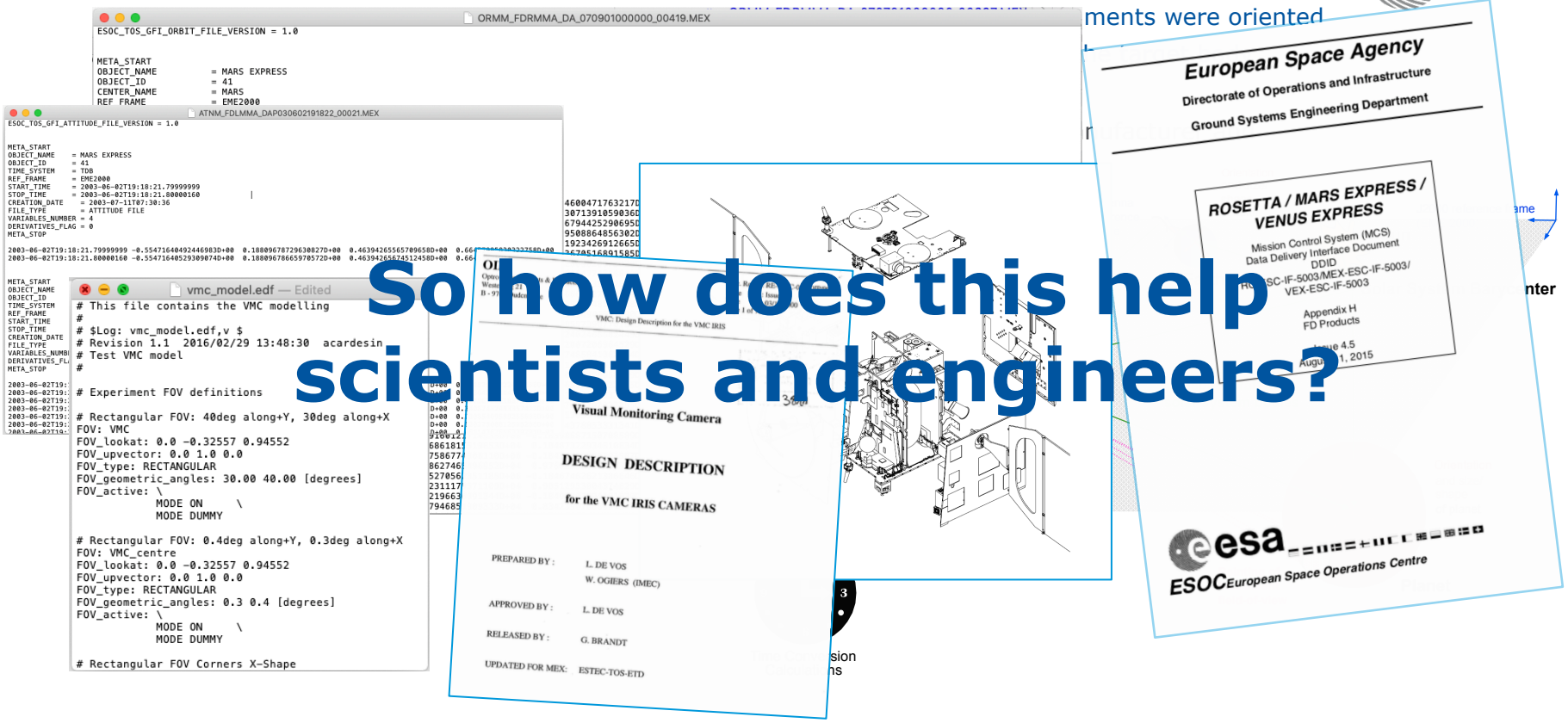
Mission Control System (MCS)
Data Delivery Interface Document
DDID
RO-ESC-IF-5003/MEX-ESC-IF-5003/
VEX-ESC-IF-5003

Appendix H
FD Products

Issue 4.5
August 11, 2015

esa ESOC European Space Operations Centre

Ancillary Data are those that **help scientists and engineers** determine:



So how does this help scientists and engineers?

SPICE in a nutshell

SPICE is an **information system** that uses **ancillary data** to provide Solar System geometry information to scientists and engineers for planetary missions in order to plan and analyze scientific observations from space-born instruments. SPICE was originally developed and maintained by the Navigation and Ancillary Information Facility (NAIF) team of the Jet Propulsion Laboratory (NASA).

SPICE in a nutshell

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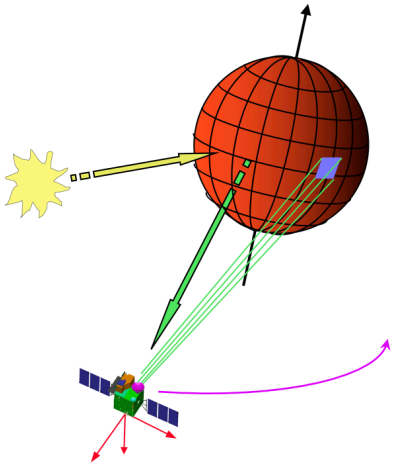
Compute many kinds of observation geometry parameters at selected times

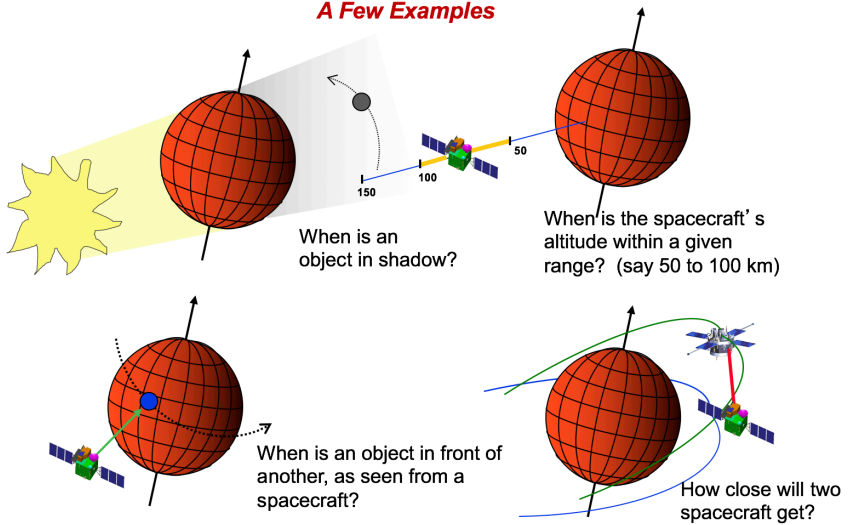


A Few Examples

- Positions and velocities of planets, satellites, comets, asteroids and spacecraft
- Size, shape and orientation of planets, satellites, comets and asteroids
- Orientation of a spacecraft and its various moving structures
- Instrument field-of-view location on a planet's surface or atmosphere

Find times when a specified "geometric event" occurs, or when a specified "geometric condition" exists

A Few Examples



SPICE components

- Ancillary data files (”kernels”)
- Software Library (SPICE Toolkit)
- Documentation
- Tutorials
- Programming lessons
- Training Classes
- User Consultation

Library of subroutines

Typically just a few are used within a customer’s program to compute quantities derived from SPICE data files

Programs

SPICE data production

SPICE data management

Documentation

Highly annotated source code

Technical Reference Manuals (23)

User Guides for programs

Highlights of the most useful subroutines

SPICE components

- Ancillary data files (”kernels”)
- Software Library (SPICE Toolkit)
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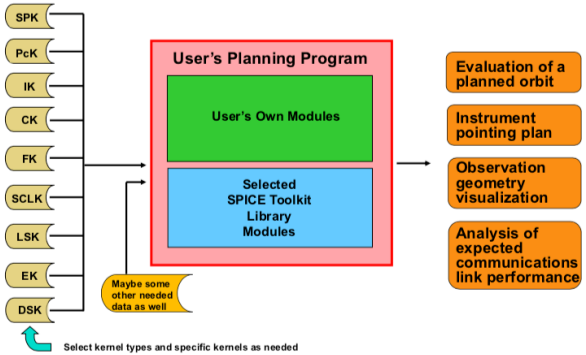

Library of subroutines

Typically just a few are used within a customer’s program to compute quantities derived from SPICE data files

Programs

SPICE data production

SPICE data management

Documentation

Highly annotated source code

Technical Reference Manuals (23)

User Guides for programs

Highlights of the most useful subroutines

Using the SPICE Library (      julia) 

Using the SPICE Library (







)

spice.funrsh(meta-kernel)
loop per pixel
spice.getfov
spice.sincpt
spice.illumf

Using the SPICE Library (









julia)

spice.funrsh(meta-kernel)
loop per pixel
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spice.illumf

Using the SPICE Library (C++ Fortran MATLAB IDL Java Python Ruby Swift julia) esa

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spice.sincpt
spice.illumf

spice.funrsh(meta-kernel)
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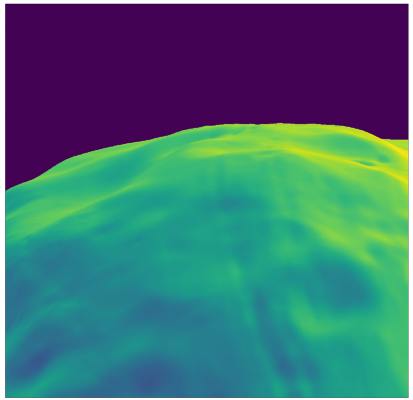

Using the SPICE Library (









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loop per pixel
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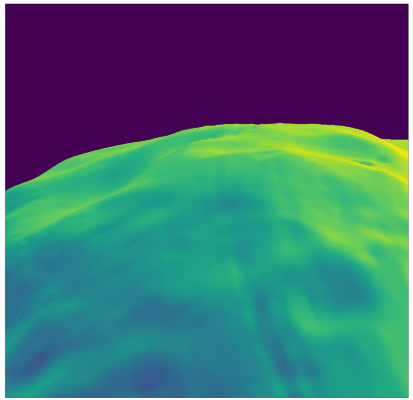
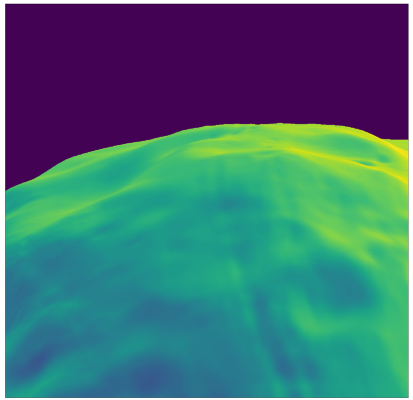
spice.sincpt
spice.illumf
adjust matrix

Using the SPICE Library (Fortran julia) esa

spice.funrsh(meta-kernel)
loop per pixel
spice.getfov
spice.sincpt
spice.illumf

spice.funrsh(meta-kernel)
spice.funrsh(dsk)
loop per pixel
spice.getfov
spice.sincpt
spice.illumf



spice.funrsh(meta-kernel)
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Using the SPICE Library (C++ Fortran MATLAB IDL Java Python Ruby Swift julia) esa

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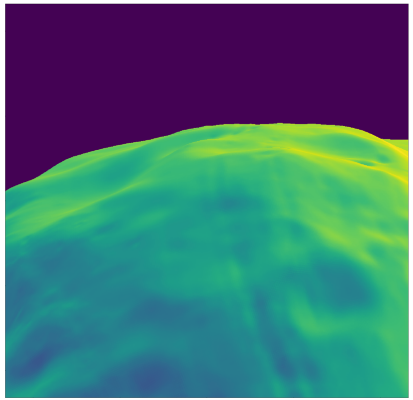
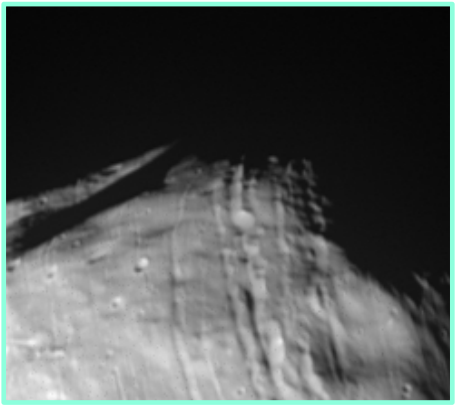


spice.funrsh(meta-kernel)
spice.funrsh(dsk)
loop per pixel
spice.getfov
spice.sincpt
spice.illumf
adjust matrix

Current Data

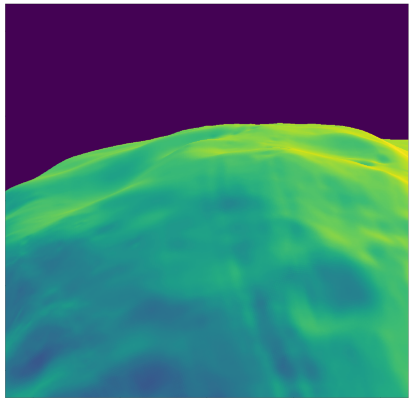


Using the SPICE Library (C++ Fortran MATLAB Java Python Ruby Swift julia) esa

spice.funrsh(meta-kernel)
loop per pixel
spice.getfov
spice.sincpt
spice.illumf

Lines of code 37

spice.funrsh(meta-kernel)
spice.funrsh(dsk)
loop per pixel
spice.getfov
spice.sincpt
spice.illumf

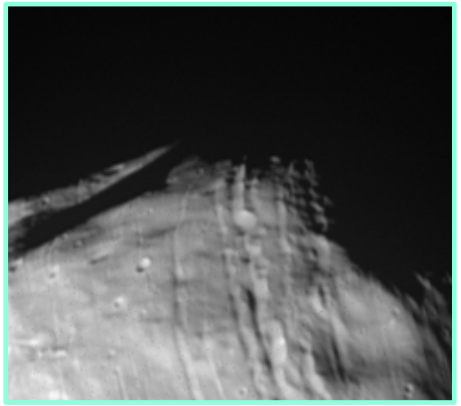


Lines of code 38

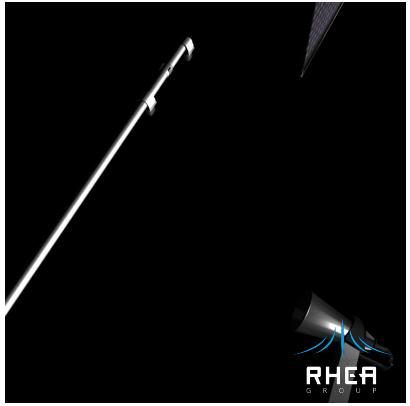
spice.funrsh(meta-kernel)
spice.funrsh(dsk)
loop per pixel
spice.getfov
spice.sincpt
spice.illumf
adjust matrix

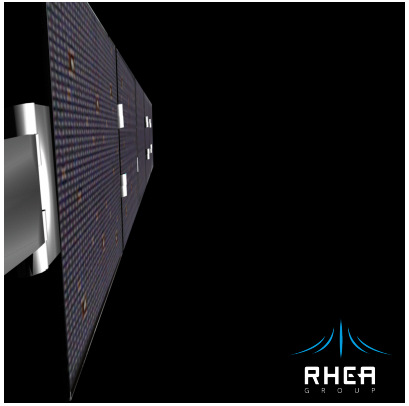
Lines of code 75

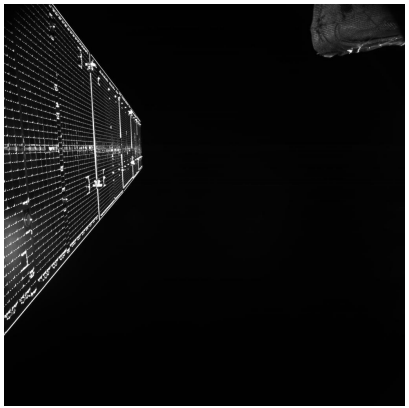
Current Data



These are the things we do with SPICE







These are the things we do with SPICE

ESA SPICE Service

The ESA SPICE Service (ESS) based at ESAC leads the SPICE operations for ESA's planetary missions. Its main activities are:

- Generate, develop, maintain and archive the SPICE Kernel Datasets (SKD) for the ESA Solar System Explorers
- Develop and operates software to convert orbit, attitude, telemetry and spacecraft clock correlation data into the corresponding SPICE formats;
- Provide consultancy and support to the Science Ground Segments and the Science Community of the planetary missions for SPICE and ancillary data management.

ESA SPICE Service is provided by Rhea System for ESA:

- Marc Costa Sitja
- Alfredo Escalante Lopez
- and a Trainee (Marina de Brito)

ESS also provides an instance of WebGeocalc and the Cosmographia configuration for ESA missions:

- **WebGeocalc** is a web-based interface to some SPICE Functions, extremely powerful for quick-look data analysis
- **Cosmographia** is a 3D-Visualization Tool for a full SPICE Scenario.

We provide **SPICE Training Classes** in Europe in a biannual basis.
Small Workshops on SPICE held regularly in conferences or for instrument teams

SPICE Kernel Dataset

- A SKD consists on a complete set of SPICE Kernels that cover the whole mission lifespan including long term predicted trajectory and orientation. Kernels in a SKD can be classified in two main types:
  - **Setup kernels (STK)** [FK, IK, PCK, LSK] are developed by the ESA SPICE Service (ESS) and are reviewed and iterated with the SGS and with the Instrument Teams when need be during the whole duration of the mission.
  - **Time-varying kernels (TVK)** [SPK, CK, SCLK, MK] are generated by ESS with an operational pipeline and the source data is provided by the Flight Dynamics or the given SGS Downlink group in terms of OEMs, AEMs and Housekeeping TM data.

- The distribution of the SKDs is done via:

An operational FTP with all the kernels that were ever produced: **ftp://spiftp.esac.esa.int/data/**SPICE

Peer-reviewed kernels are published as PDS3/4 Bundles in the PSA FTP

A permanent link to a ZIP file that contains the the latest operational subset of the SPICE Kernels

A BitBucket Git repository with a given subset of the SPICE Kernels (operational, planning, archived etc.). **Https://repos.cosmos.esa.int/socci/projects/SPICE_KERNELS**

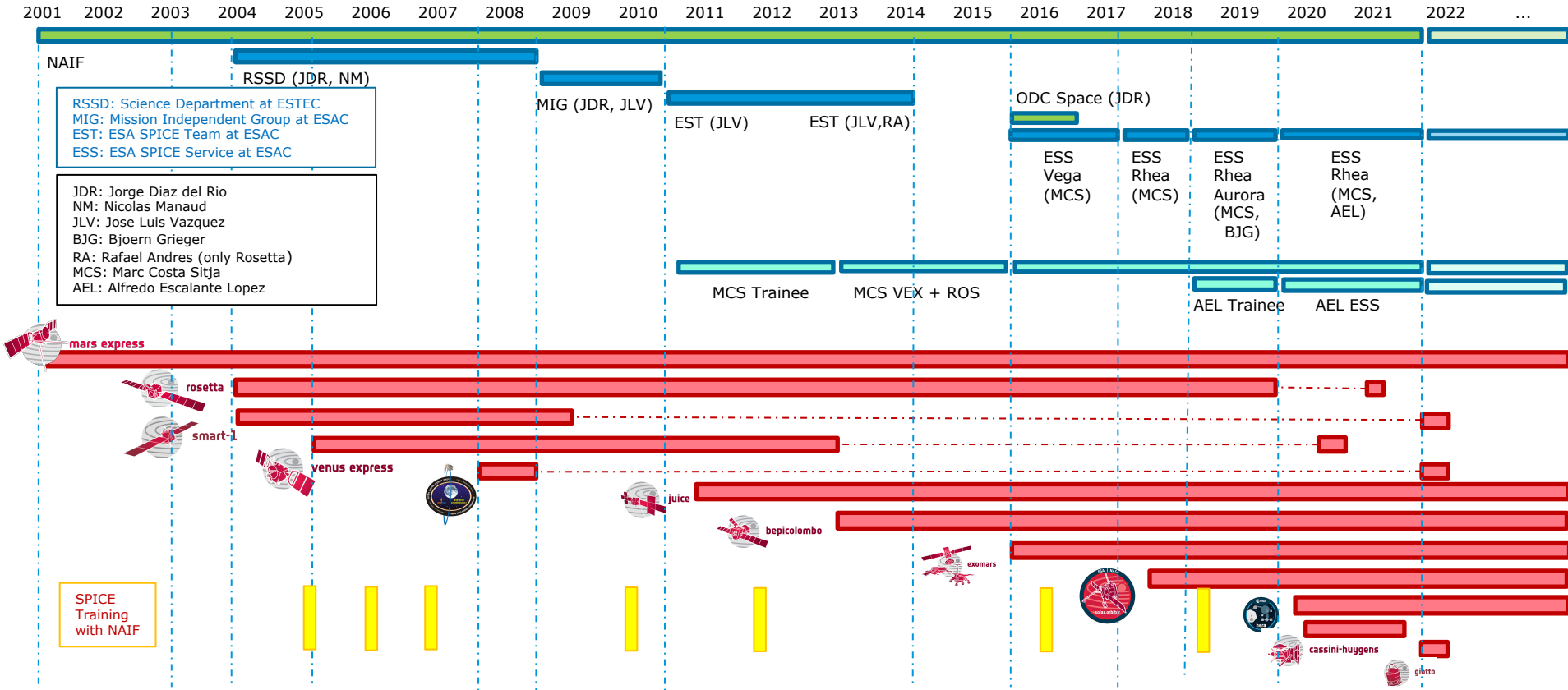
ESA SKD Status

Mission	Status	BitBucket	Archive	WGC	Cosmo	Frames and sensors	Predicted Orbit & Attitude	Reconstructed Orbit & Attitude	OBT conversion	S/C Element and Payload Orientation
ExoMars2016	OPERATIONAL		PDS4							
Mars Express	OPERATIONAL		PDS3							
BepiColombo	OPERATIONAL		PDS4							
Solar Orbiter	OPERATIONAL									
JUICE	STUDIES		PDS4							
ExoMarsRSP	STUDIES		PDS4							
Hera	STUDIES		PDS4							
EnVision	STUDIES		PDS4							
Rosetta	LEGACY		PDS3							
Venus Express	LEGACY		PDS3							
SMART-1	LEGACY		PDS3							
Chandrayaan-1	LEGACY		PDS3							
(Cassini-) Huygens	LEGACY		PDS3							
Giotto	LEGACY		PDS3							

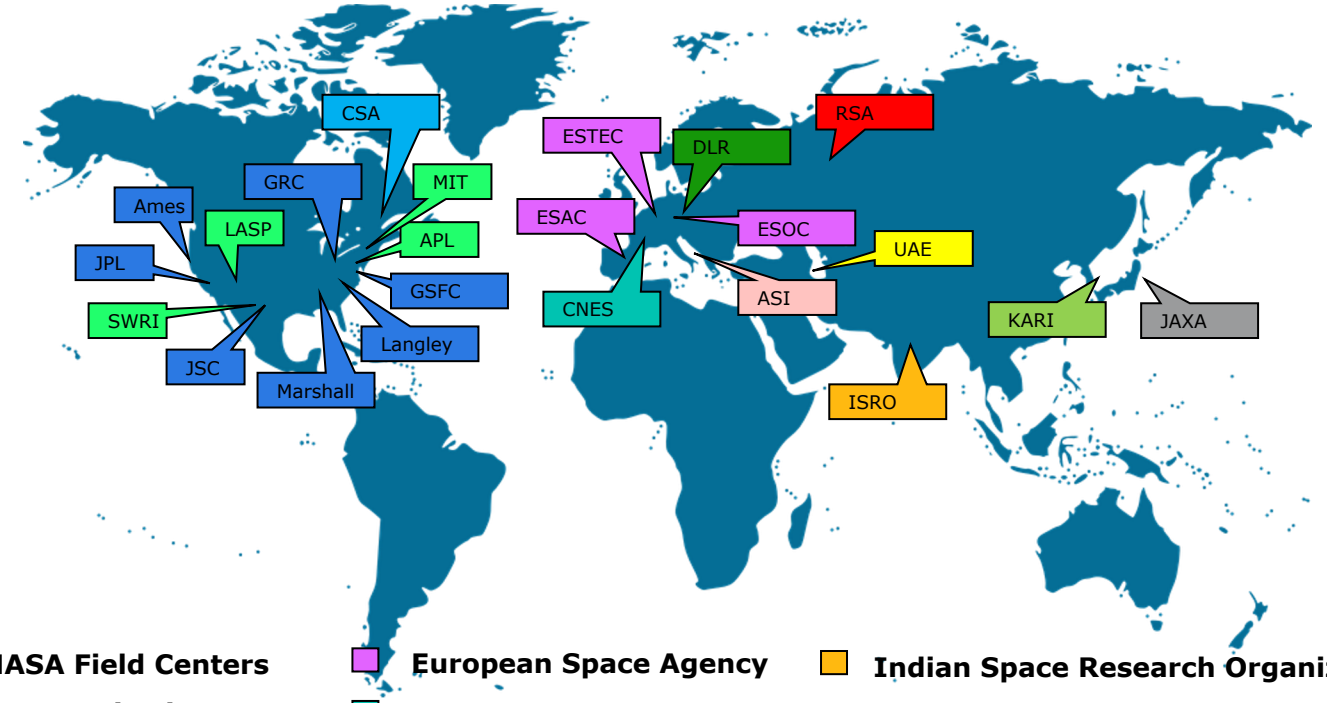
Example of SPICE Users

Data Restorations	Selected Past Users	Current/Pending Users	Examples of Possible Future Users
Apollo 15, 16 [L]	Magellan [L]	Cassini Orbiter	NASA Discovery Program
Mariner 2 [L]	Clementine (NRL)	Mars Odyssey	NASA New Frontiers Program
Mariner 9 [L]	Mars 96 (RSA)	Mars Exploration Rover	Lunar IceCube (Moorehead State)
Mariner 10 [L]	Mars Pathfinder	Mars Reconnaissance Orbiter	LunaH-Map (Arizona State)
Viking Orbiters [L]	NEAR	Mars Science Laboratory	Luna-Glob (RSA)
Viking Landers [L]	Deep Space 1	Juno	Aditya-L1 (ISRO)
Pioneer 10/11/12 [L]	Galileo	MAVEN	**Examples of Users not Requesting NAIF Help**
Haley armada [L]	Genesis	SMAP (Earth Science)	GOLD (LASP, UCF) (Earth Science) [L]
Phobos 2 [L] (RSA)	Deep Impact	OSIRIS REx	Hera (ESA)
Ulysses [L]	Huygens Probe (ESA)	InSight	ExoMars RSP (ESA, RSA)
Voyagers [L]	Stardust/NExT	Mars 2020	Emmirates Mars Mission (UAE via LASP)
Lunar Orbiter [L]	Mars Global Surveyor	Europa Clipper	Hayabusa-2 (JAXA)
Helios 1,2 [L]	Phoenix	NISAR (NASA and ISRO)	Proba-3 (ESA)
Giotto [L]	EPOXI	Psyche	Parker Solar Probe
	GRAIL	Lucy	EUMETSAT GEO satellites [L]
	DAWN	Lunar Reconnaissance Orbiter	MOM (ISRO)
	Messenger	Mars Express (ESA)	Chandrayan-2 (ISRO)
	Phobos Sample Return (RSA)	ExoMars 2016 (ESA, RSA)	Solar Orbiter (ESA)
	Venus Express (ESA)	Akatsuki (JAXA)	STEREO [L]
	Rosetta (ESA)	Korean Pathfinder Lunar Orbiter (KARI)	Spitzer Space Telescope [L]
[L] = limited use	Chandrayaan-1 (ESA/ISRO)	New Horizons	Kepler [L]
[S] = special services	Hayabusa (JAXA)	JUICE (ESA)	Hubble Space Telescope [S][L]
	Kaguya (JAXA)	Bepicolombo (ESA, JAXA)	James Webb Space Telescope [S][L]
	LADEE	Gaia (ESA) [S]	Altius (Belgian earth science satellite)
	ISO [S] (ESA)	Lisa Pathfinder (ESA) [S]	Armadillo (CubeSat, by UT at Austin)
	Smart-1 (ESA)	Deep Space Network	Spectrum-RG (RSA)

SPICE at ESA Timeline



Space Agencies Using SPICE



- NASA Field Centers
- U.S. Institutions
- Canadian Space Agency
- United Arab Emirates Space Agency
- European Space Agency
- French Space Agency
- German Space Agency
- Italian Space Agency
- Indian Space Research Organization
- Japan Aerospace Exploration Agency
- Russian Federal Space Agency
- Korean Aerospace Research Institute

Take Home (but not yet!)

- SPICE has been in use since the Magellan mission to Venus in 1990, without any failures. Pretty much all worldwide planetary missions since Magellan have used SPICE, with the likely exception of Chinese missions (China have shown interest).
- SPICE has been adopted by many space agencies and is adopted as a standard by the International Planetary Data Alliance.
- SPICE is free of export and licensing restrictions, and SPICE is free of cost.
- It takes a small effort for an expert to setup a basic SPICE configuration
- While conceived for planetary missions, today it is also used for heliophysics, earth science, astronomy and tech demonstrations (and NASA DSN!).
- NAIF has consistently had, and has now, solid funding from NASA, ESA supports NAIF them through the MOUs.

SPICE is the de-facto standard system for ancillary data and solar system exploration geometry for the Planetary Science Community. We don’t see why this could not be expanded to missions of other nature.