An Update on SPICE for ESA Missions

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ESA SPICE Service

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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).

"Ancillary data" are those that help scientists and engineers determine:

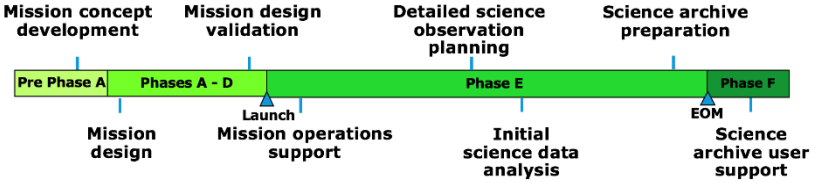
where the **spacecraft** was **located**

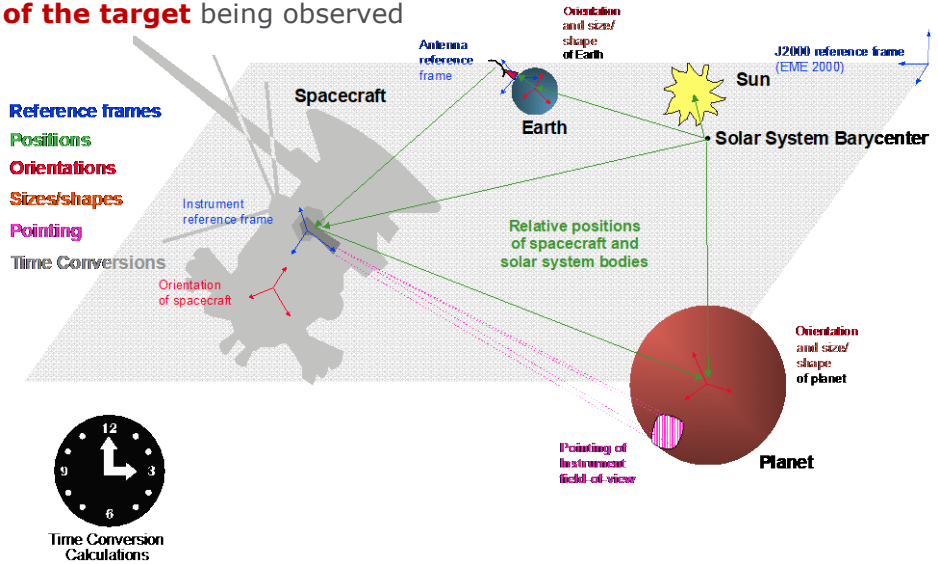
how the spacecraft and its instruments were **oriented** (pointed)

what was the **location, size, shape and orientation of the target** being observed

what **events were occurring** on the spacecraft

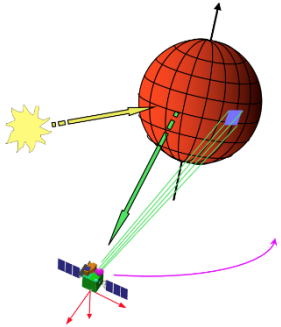
- SPICE provides users a large suite of SW used to read SPICE ancillary data files to compute observation geometry.
- The ancillary data (kernels) comes from: The S/C, MOC/SGS, S/C manufacturer and Instrument teams, Science Organizations.





SPICE in a nutshell

Compute many kinds of observation geometry parameters at selected times

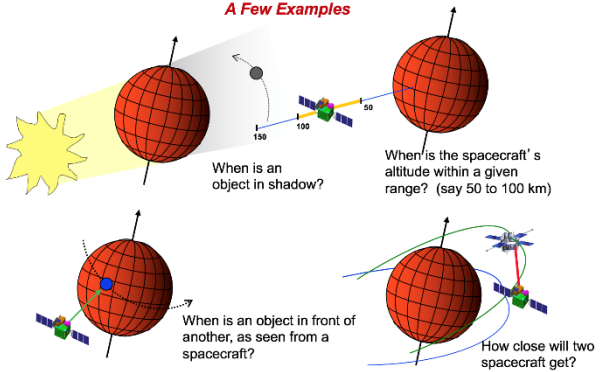


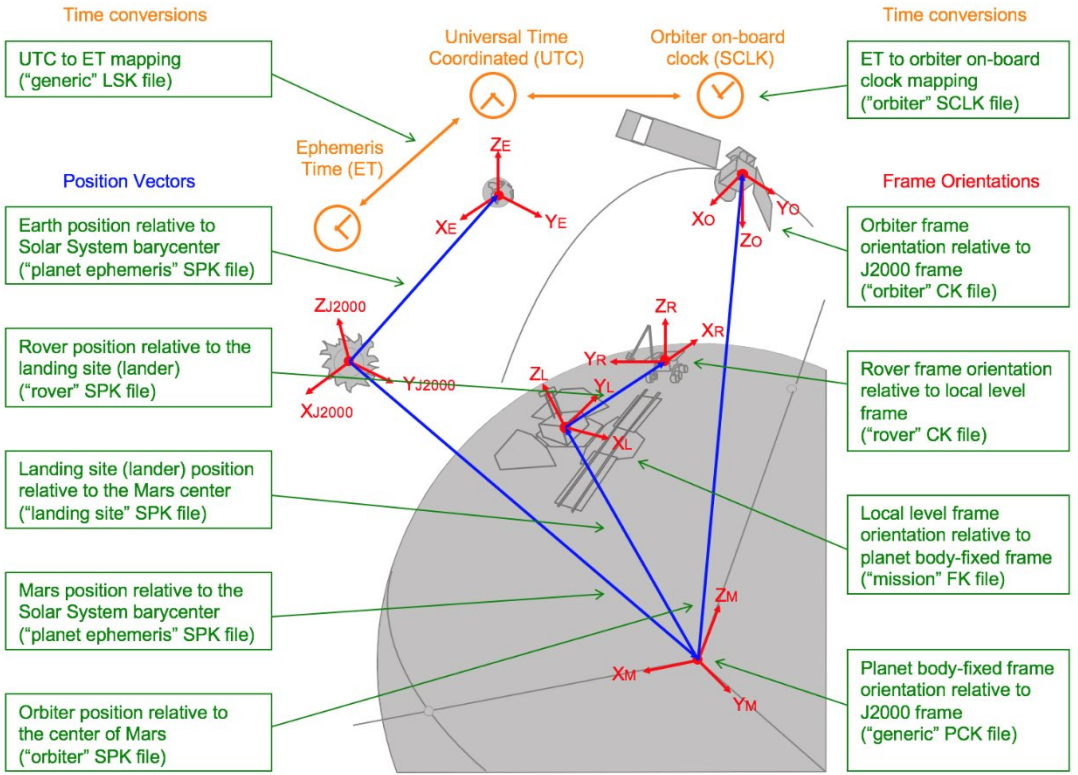
A Few Examples

- 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 New Toolkit version N0067

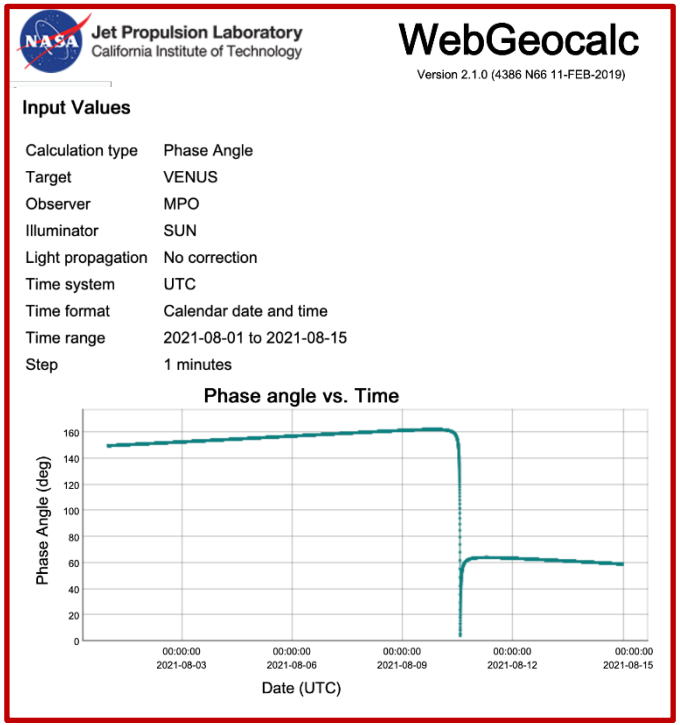
- Released January 3rd, 2022
  - Previous N0066 Toolkit released in April 2017
- Available in 5 programming languages:
  - FORTRAN, C, IDL, MATLAB, and alpha-test Java Native Interface (JNI)
  - SpiceyPy 5.0.0 (Python) switched to N67 CSPICE, no new wrapper functions yet

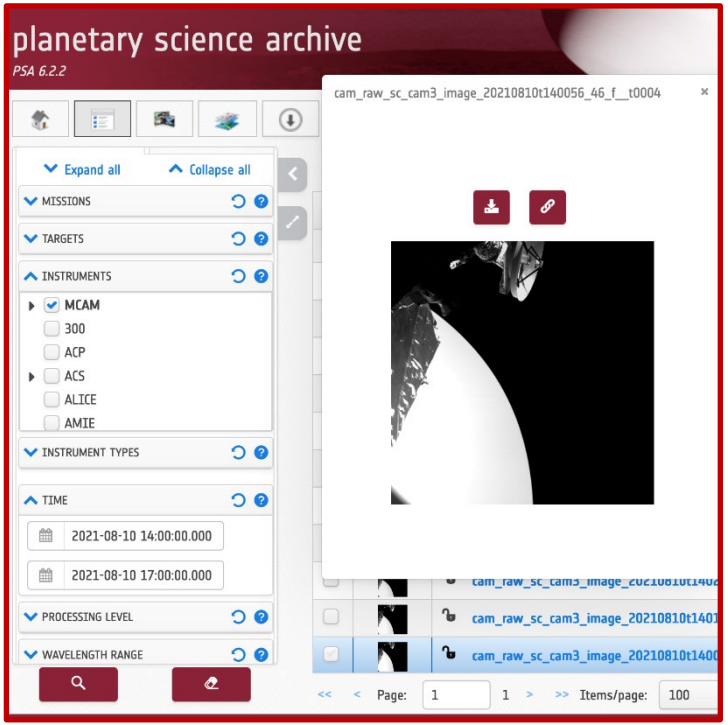
- **New N0067 Toolkits are 100% backward compatible**

- New high-level routines in all languages
  - Tangent point (TANGPT), Target separation (TRGSEP)
- New reference frame types
  - Switch frames choose at run time other frames with which to align their orientation.
  - Product frames defined by a product of one or more frame transformations.

Using SPICE

- We want to analyze **BepiColombo Venus fly-by images** from the **MCAM** instrument, more concretely images with Phase angle (angle between illumination source and viewing location) smaller than 90 deg → **WebGeocalc or GF System**
- Then we could constrain our search in the PSA UI.



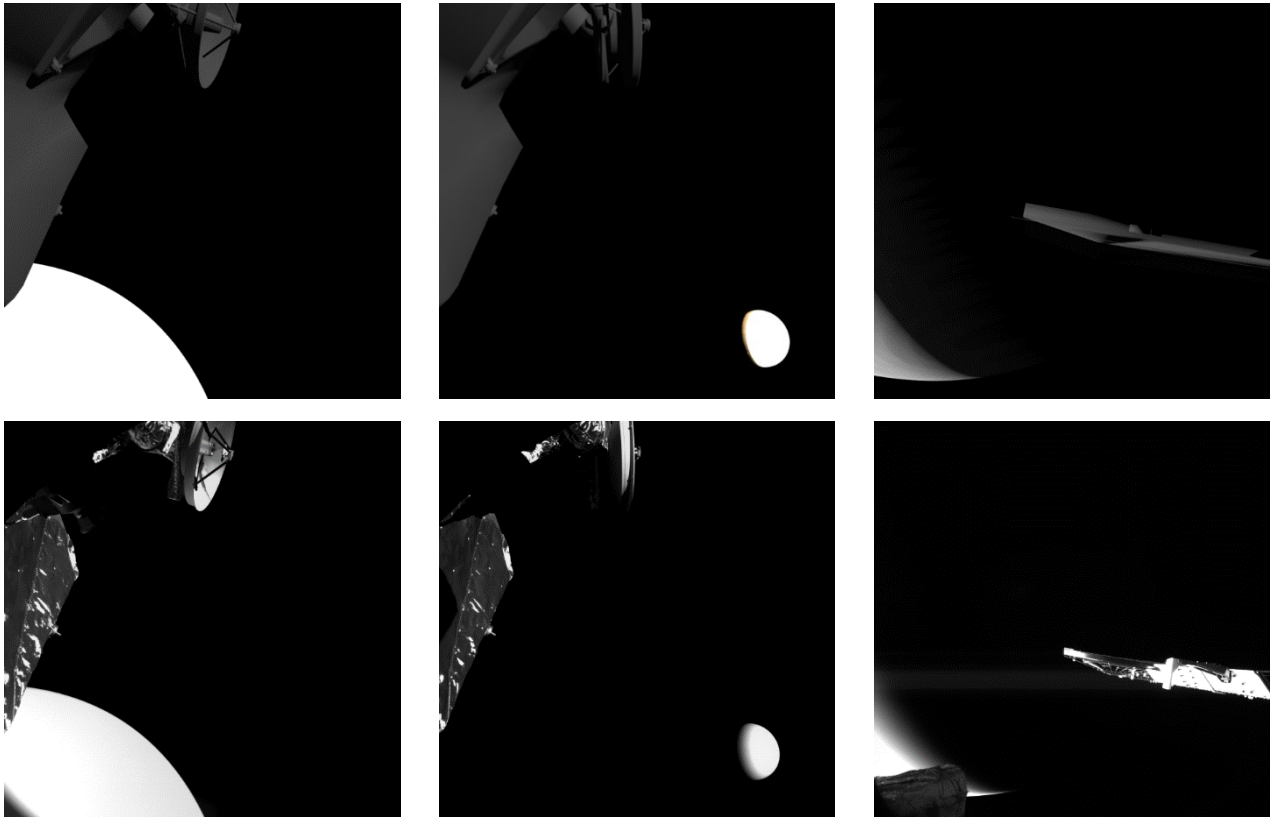


Using SPICE – Synthetic Image Generation

- **BepiColombo Venus fly-by #2**

  load last meta-kernel
  load dsk
  loop per pixel
  spice.getfov
  spice.sincpt
  spice.illumf
  adjust matrix

  75 lines of code

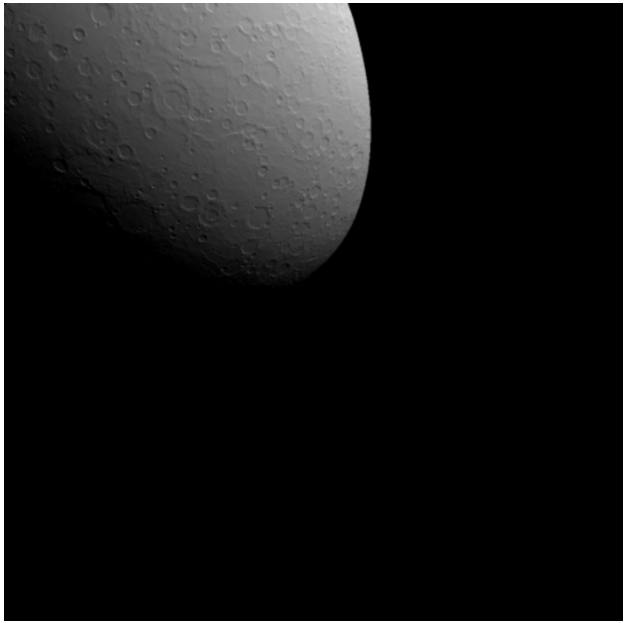


Using SPICE – Tiled DSKs

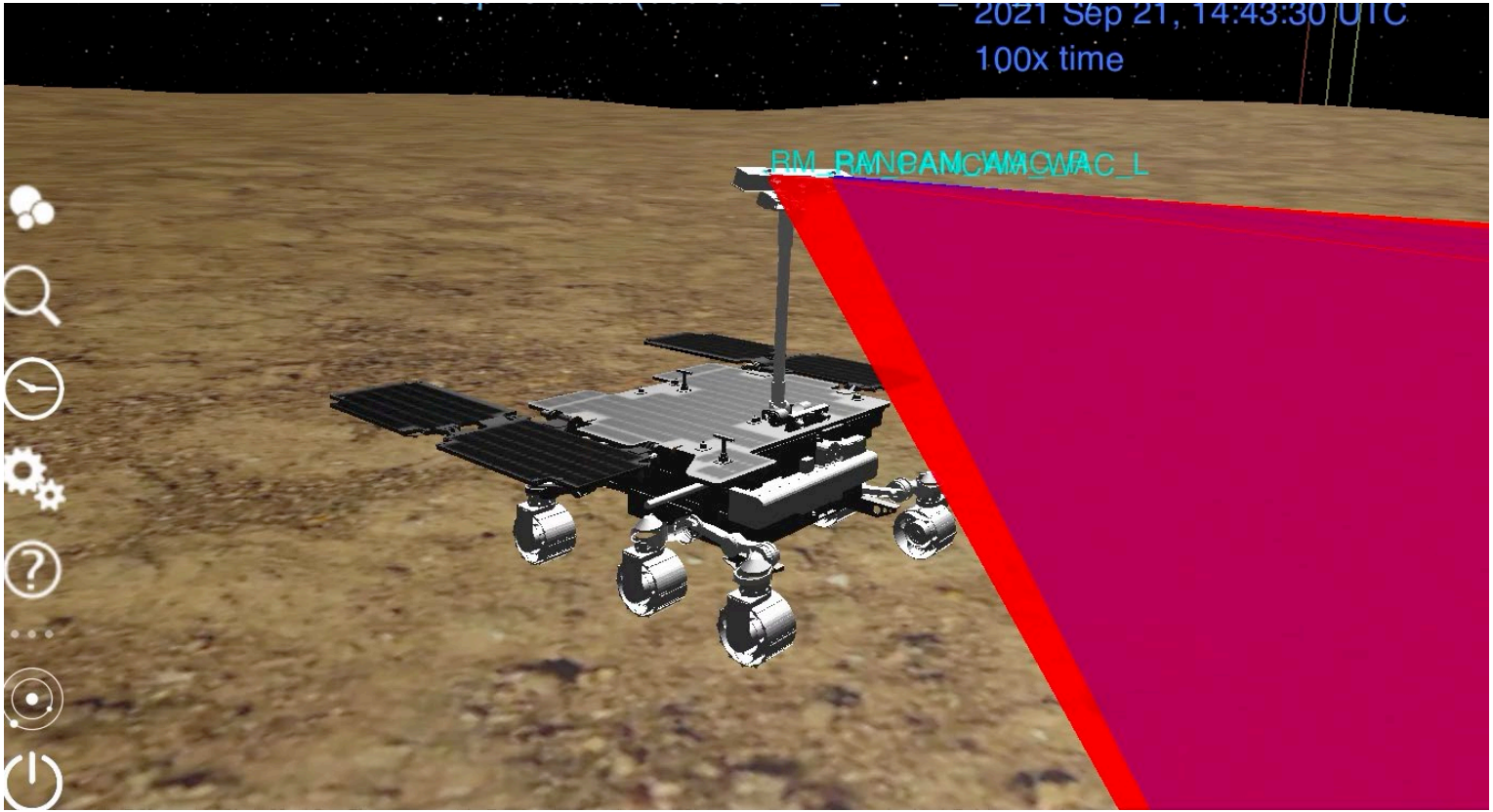
- Generated high-resolution tiled global DSK for **Mercury** based on Messenger 665m/px global DEM and for **Mars** based on MOLA 463m/px global DEM
- Available at the esa_generic SKD in spiftp (not included in BitBucket due to large size)
  - https://spiftp.esac.esa.int/data/SPICE/esa_generic/kernels/dsk/tiled/

Index of /data/SPICE/esa_generic/kernels/dsk/tiled

Name	Last modified	Size	Description
Parent Directory		-	
mars_mola_463m/	2022-03-10 13:54	-	
mercury_messenger_665m/	2022-03-10 18:59	-	

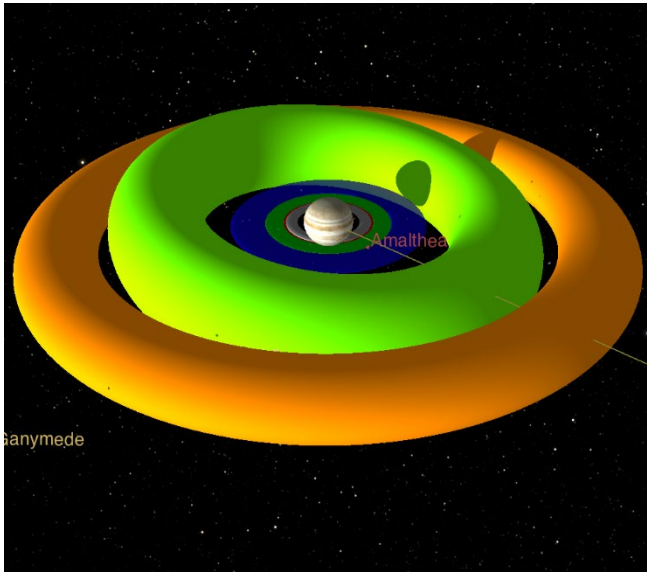


Using SPICE – EMRSP Surface Operations

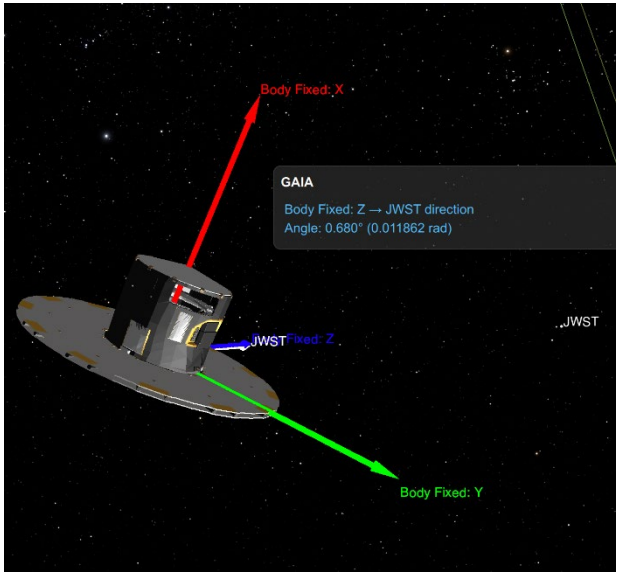


Using SPICE – Other Studies

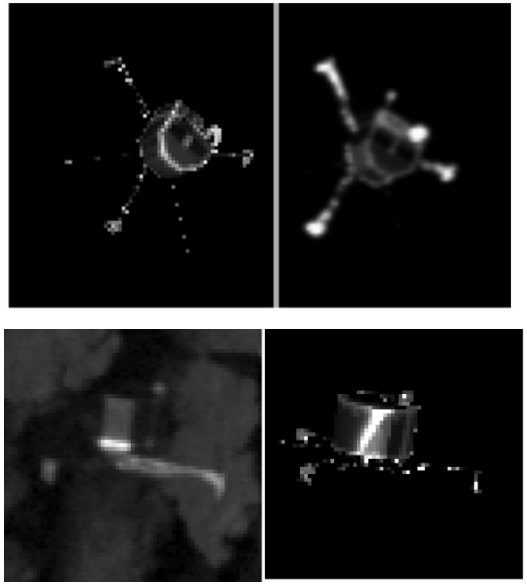
Jupiter Rings and Plasma Torus DSKs



James Webb Space Telescope seen by Gaia



Philae Final Position Reconstruction



- DSKs can be loaded into Cosmographia from version 4.1

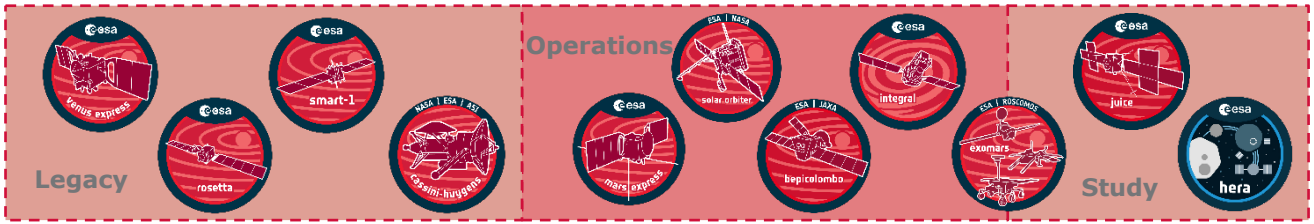
ESA SPICE Service

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 Planetary Missions (and Solar Orbiter);
- 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.

Available, SPICE Kernels Datasets:

Releases and support to the community is provided



ESA SPICE Service are: Alfredo Escalante, Ricardo Vallés and (sometimes) a trainee, the group is managed by Christophe Arviset.

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

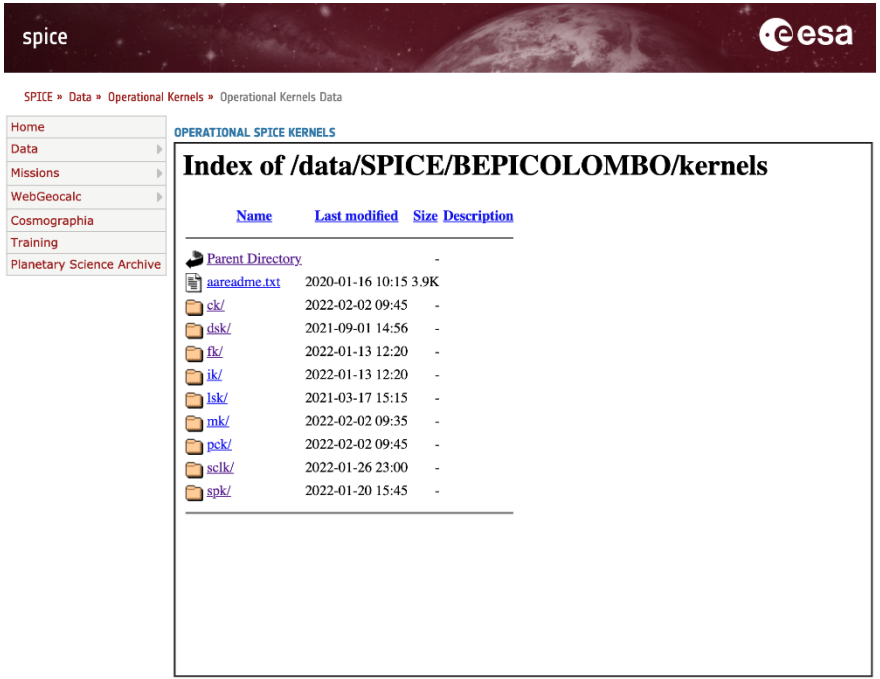
- **WebGeocalc** is a web-based interface to some SPICE Functions, extremely powerful for quick-look data analysis
- **Cosmographia** is a 3D-Visualization Tool for a full SPICE Scenario.

We provide **SPICE Training Classes** in Europe in a biannual basis. Last training June 2020 was cancelled due to the pandemic.

Recording of last SPICE Training at ESAC is available in YouTube

ESA SPICE Service - Updates

- We have introduced HTTPS browsing to our spiftp server:
  - https://www.cosmos.esa.int/web/spice/data



SKD Version Control and Distribution

Version and Configuration Control

- All SKDs are under configuration control and new release happen constantly.
- SKDs are released on a regular basis when STKs are updated and when in operations are time tagged in a daily/weekly basis when TVKs are updated.

The distribution of SKDs is done via:

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

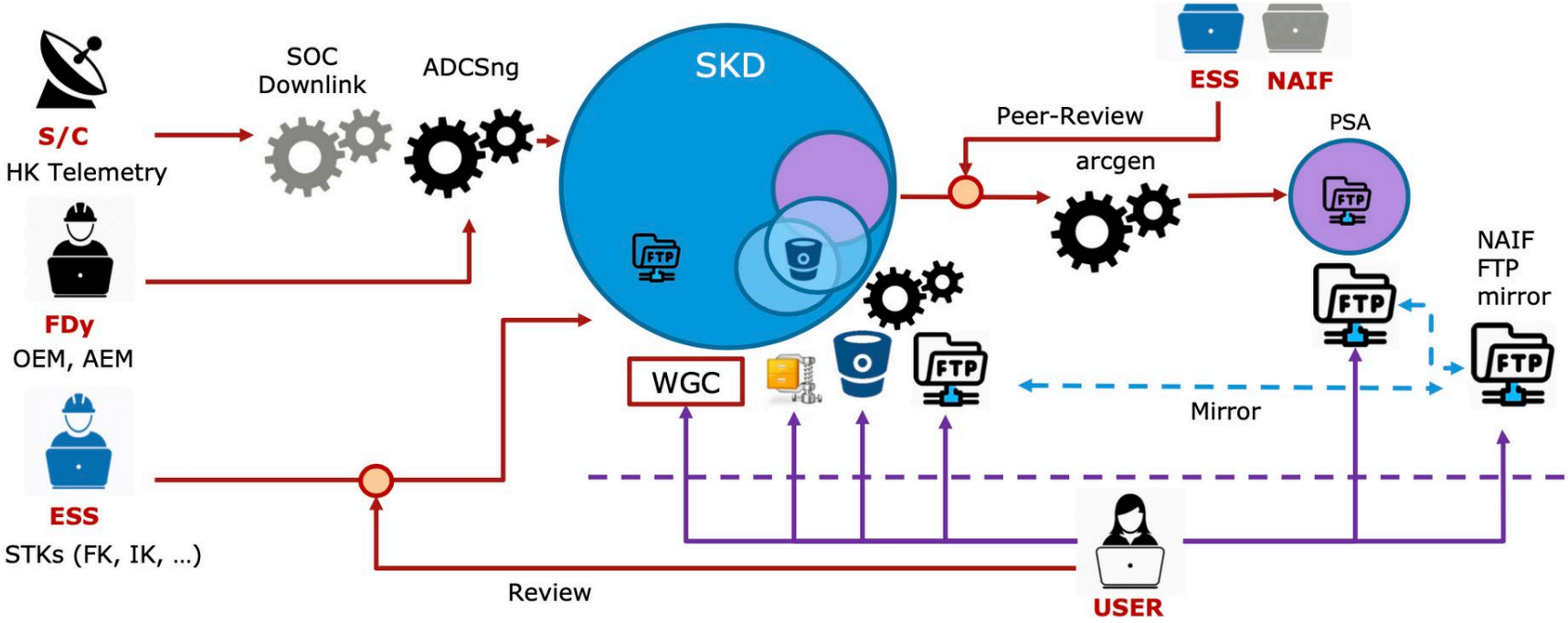
A permanent link to a ZIP file that contains the latest operational subset of the SPICE Kernels

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**

Cosmo configuration is available in the misc directory of the SPICE Kernels Dataset

Sensor model is available for each instrument (if not, let us know)

SPICE Kernel Dataset Workflow



- The Auxiliary Data Conversion System next-generation (ADCSng) generates the time-varying kernels when the mission is in operations and provides up-to-date time correlation, trajectory and orientation information to users.

ESA SKD Status

Solar System Exploration	Planetary Defense
Heliophysics	Space Observatories

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									
INTEGRAL	OPERATIONAL									
Gaia	OPERATIONAL									
James Webb	OPERATIONAL									
JUICE	STUDIES		PDS4							
ExoMarsRSP	STUDIES		PDS4							
Hera	STUDIES		PDS4							
Comet Interceptor	STUDIES									
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							

SKDs in the PSA/PDS

PDS3 SPICE datasets and PDS4 SPICE bundles for the archive produced by the ESS are/will be available from the PSA UI, the PSA FTP server and the NAIF FTP server. Increments of the archives are published every 4-6 months.

PDS3 Archives

- Current PDS3 Archived SPICE datasets available:
  - Mars Express **Last updated 2022-06-01** Next increment ~ Summer 2022
  - Rosetta **Last updated 2022-01-19** Next increment ~ Summer 2022
  - Venus Express **Last updated 2020-12-29**

PDS4 Archives

- First PDS4 SPICE Bundle is **ExoMars2016 last updated 2022-02-15**.
- First **BepiColombo PDS4 Bundle release follows in Summer 2022.**
- The PDS4 approach with SPICE is to minimize the effort required to archive SPICE kernels; the idea is to apply minimal changes to an operational SPICE Kernel Dataset.
- Bundle structure agreed with NAIF, used by JAXA as well and adopted by the IPDA.
- More details available at the PSA PDS4 Archiving Guide, available under request.

Citing the SPICE data

- We have incorporated DOIs for the SPICE Kernels Datasets (Operational and Archived).
- Please use them to cite your work.

ESA SPICE Service, BepiColombo Operational SPICE Kernel Dataset, https://doi.org/10.5270/esa-dwuc9bs

- DOI is indicated in the SPICE collection label of the PDS4 Bundle.
- We will also implement version control of the DOIs but a new DOI will not be issued per version
- And please do the same with the other ESA SPICE Kernel Datasets that you use.

- In addition please keep citing the 'SPICE' paper
- DOI: 10.1016/0032-0633(95)00107-7

Acton, C. H. 1996, Planet. Space Sci., 44, 65

Operational SPICE Kernel Dataset
DOI: 10.5270/esa-dwuc9bs

Operational SPICE Kernel Dataset Information

IDENTIFIER	BEPICOLOMBO
NAME	BepiColombo SPICE Kernel Dataset
TYPE	Operational Dataset
VERSION	Click for latest version
DESCRIPTION	The BepiColombo SPICE kernel dataset (SKD) contains the operational observation geometry and other ancillary data in the form of SPICE System kernel files for the MPO, MMO and MTM spacecrafts and its instruments and targets.
SEARCH/ACCESS DATA	BepiColombo SPICE Kernel Dataset (FTP) BepiColombo SPICE Kernel Dataset Subset (Git) BepiColombo SPICE Kernel Dataset Subset (ZIP)

Citation	
AUTHOR LIST	ESA SPICE Service
DOI	10.5270/esa-dwuc9bs
GUIDELINE	ESA SPICE Service, BepiColombo Operational SPICE Kernel Dataset, https://doi.org/10.5270/esa-dwuc9bs

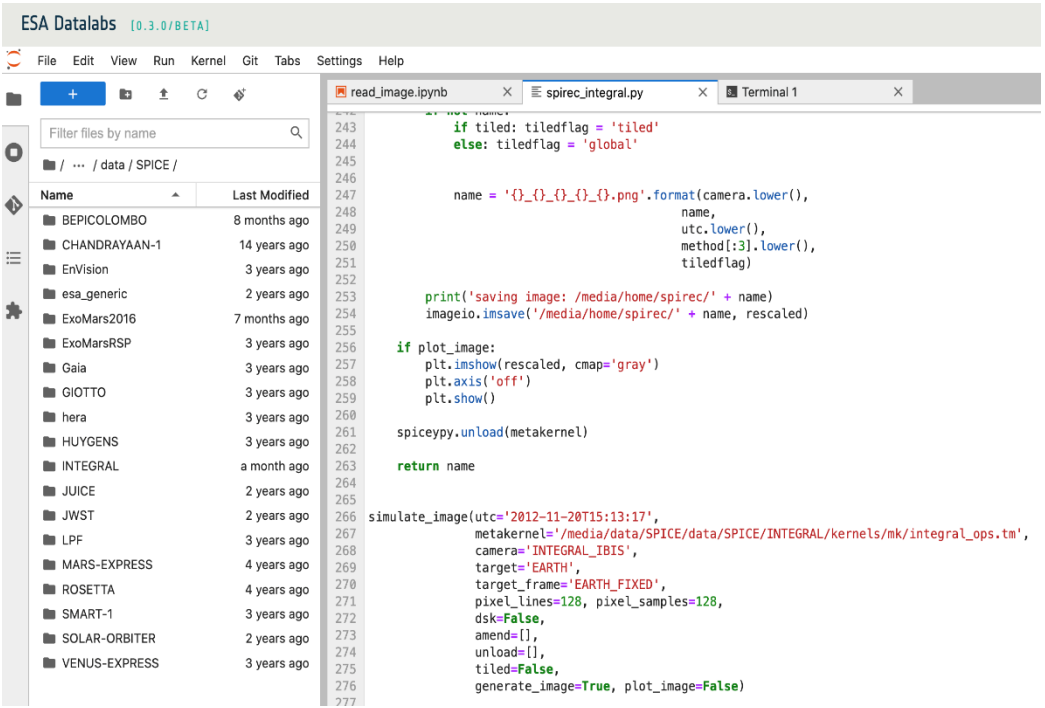
Context	
START DATE TIME	2015-01-01T00:00:00.000Z
STOP DATE TIME	2050-01-01T00:00:00.000Z
INVESTIGATION	BepiColombo
OBSERVING SYSTEM	MPO, MMO, MTM
TARGET	MERCURY

Contact Points	
Prime	ESA SPICE Service
Backup	Alfredo Escalante Lopez

Related Datasets	
PDS4 Bundle	
Ancillary Data Collection	urn:esa:psa:bc:miscellaneous
Operational Ancillary Data Dataset	BEPICOLOMBO

SPICE in ESA Datalabs

- ESA Datalabs allows bringing the code directly to ESA's infrastructure – there is a great set of tools and programming languages are flexible – and execute it with direct access to ESA's archives.
  - https://datalabs.esa.int/
- ESA datalabs offers a catalog of datalabs you can use. They range from new tools that are quickly become de facto standards to older software that has been repackaged to run inside virtual computers. All are accessible via your web browser.
- Once a Datalab has been launched, Data Volumes can be mounted.
- The SPICE Data Volume (all content available at spiftp) is already available in Datalabs



What is next for ESS ?

- Final review and implementation of several SPICE Kernel Datasets: ExoMars2016, BepiColombo, JUICE, Hera, EnVision
- Consolidation of the SPICE Validation Pipeline
- Consolidation of ESS Python packages for the public
  - SPIREC (render images), SPINST (SPICE Setup wizard)
- Implementation of DSKs for extended bodies in all SKDs including:
  - Targets (Small Bodies, planet DEMs, etc)
  - Spacecrafts (Bus, rotating Solar Arrays, HGAs, etc)
- Exploit and share SPICE usage through ESA Datalabs
  - Tutorials, tools, etc

[redacted]

mex-vmc.ipynb

Python 3 (ipykernel)

SPICE for Mars Express VMC Tutorial

This Notebook aims for showing some of the SPICE applications to compute geometry for a planetary mission. In this tutorial, we will focus on the geometry of VMC (Visual Monitoring Camera) onboard Mars Express.

Loading the SPICE Data Volume

In order to load the SPICE Data Volume into this ESA Datalab, the SPICE Volume has to be configured first. To do so, go to Data Volumes at the ESA Datalabs toolbar and introduce the following configuration:

- **Name**: SPICE
- **Path in datalab**: /media/data/spice
- **Connection type**: nfs
- **Server**: netapp3.evsp.lan
- **Path**: /mex_spiftp01

Once, the SPICE Volume has been configured, go back to the Datalab and select the SPICE Volume in the toolbar at the top right.

Loading the SPICE Kernel Dataset

We will begin by loading some Python packages. We'll use NumPy to create some random data, and Matplotlib to visualize it. SpiceyPy is the Python wrapper to the NAIF's SPICE Toolkit.

[1]:
```
import spiceypy as cspice
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.dates as mdates
from PIL import Image
import datetime
import os
```

Then, the SPICE kernels can be loaded into the pool by using *furnsh*.

Please note that we should change the working directory to the meta-kernel directory within the SKD (SPICE Kernel Dataset) because the PATH_VALUES within MEX_OPS.TM is set to the relative path from that file to the kernels directory. If the PATH_VALUES field is updated to the absolute path to the *kernels* directory, it could be loaded from any working directory.

[2]:
```
# Go to the meta-kernel directory of the Mars-Express SKD in the loaded data volume
os.chdir('/media/data/spice/data/SPICE/MARS-EXPRESS/kernels/mk')

# Load the meta-kernel into the kernel pool
cspice.furnsh('MEX_OPS.TM')
```

Computing Mars Express Position

Once the meta-kernel has been loaded, we can start computing geometric quantities. Let's begin with the Mars Express position with respect to Mars in the Mars centered body-fixed frame.

[3]:
```
# define start and end times
et0 = cspice.utc2et('2021-12-01')
etf = cspice.utc2et('2021-12-02')
times = range(int(et0), int(etf), 10)

# compute Mars Express position wrt Mars
pos_car = cspice.spkpos('MEX', times, 'IAU_MARS', 'NONE', 'MARS')[0]
print(pos_car[-5:])
```

Keeping in touch

https://github.com/esaSPICEservice https://twitter.com/SpiceEsa https://tinyurl.com/y77bxntk

COMMUNICATE

- Everything is accessible from: **http://spice.esac.esa.int**
- Contact the service via e-mail **spice@sciops.esa.int**
- You can also join the OpenPlanetary Slack channel: **http://openplanetary.co**

COLLABORATE

- If you are a SPICE Kernel producer or a bi-product of your investigations are Ancillary Data (Reconstructed Trajectory, S/C Orientation, Natural Body Ephemeris) please contact us and share your data with the community.