Solar System geometry tools with SPICE for ESA's planetary missions

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SPICE is an information system that uses *auxiliary 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).

What do we understand by *auxiliary data*?
Ancillary Data

- Space flight projects need a set of “ancillary data” to support:
  - Mission design
  - Science Ground Segment design, development and testing
  - Flight engineering operations
  - Science observation planning
  - Quick look science data analysis
  - Science data archive preparation
  - And maybe most important of all: science data analysis!

We use ancillary data in the whole mission lifecycle.
Ancillary Data

- When we talk about "ancillary data" we talk, *minimum* of spacecraft trajectory and orientation.
- An in-house "minimal" model can be put in place: personnel will need to produce, validate, distribute and archive reconstructed sc orbit and attitude data but... The big picture is complex:
  - Almost everything moves and/or rotates (with multiple sources providing different values)
  - Many reference frames (defined multiple times) are used
  - Many coordinate systems are used (without standard definitions)
  - Size and shape estimates of target bodies do change
  - Several time systems are used
  - National/inter-project interest might be in conflict.

- Maybe Dogbert the consultant was wrong.
Ancillary data also includes:

- Reference frame (aka coordinate system) specs
- Instrument specs (mounting alignment and field-of-view specs)
- Target body (planets, small bodies) physical and cartographic constants
- Time systems conversions
SPICE in a nutshell

- **SPICE** provides users a large suite of SW used to read SPICE ancillary data files to compute observation geometry
- **SPICE** is multi-mission and can be used in any kind of planetary mission* (flyby, orbiter, lander, rover...)
- **SPICE** is open, very well tested, extensively used and provides tons of resources to learn it and implement it.
- **SPICE** is the recommended means of archiving ancillary data by NASA’s PDS and by the International Planetary Data Alliance
- **SPICE** ancillary data comes from:
  - The Spacecraft
  - MOC/SGS
  - Spacecraft manufacturer and Instrument teams
  - Science Organisations
- **SPICE** is used to organise and package these data in a collection of files called “kernels”
- **SPICE** includes SW for writing, reading kernels and computing observation geometry from kernels
WebGeoCalc demo

**Input Values**
- Calculation type: Distance Event Finder
- Target: EUROPA
- Observer: GANYMEDE
- Light propagation: No correction
- Time system: UTC
- Time format: Calendar date and time
- Time range: 2031-01-01T00:00:00 to 2032-01-01T00:00:00, step 60 seconds
- Event condition: is global minimum
- Output time unit: seconds
- Complete result window: No
- Result interval adjustment: No adjustment
- Result interval filtering: No filtering

**Tabular Results**
Click a value to save it for a subsequent calculation.

<table>
<thead>
<tr>
<th>Start Time</th>
<th>Stop Time</th>
<th>Duration (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2031-08-01 21:00:06, 235902 UTC</td>
<td>2031-08-01 21:00:06, 235902 UTC</td>
<td>0.0000000000+00</td>
</tr>
</tbody>
</table>

Click and drag to zoom, shift-click and drag to pan. Double-click or use button to reset zoom level.

**Distance Finder Time Interval Plot**

Date (UTC)
Cosmographia demo
SPICE tools – Rosetta SGS tools

SPICE tools are used are used in the Long Term Plan planning cycle which features interactions between liaison scientists and the instrument teams to produce a skeleton plan for the Medium Term Plan periods:

- **3dtool**: web-based tool used to analyze the feasibility – in terms of science observations – of the early skeleton trajectories that SGS was designing during the Rosetta Escort phase.

- **Flying potato**: helps the instrument teams operations engineers to generate pointing snippets for observations that are used to build up the Pointing Timeline requests for FD.

- **ASPEN**: automated and semi-automated scheduling software

- **Cost function**: quantifies the total amount of nadir available for a consolidated Attitude timeline: the In-Situ instrument teams evaluate it.
Cosmographia setup for JUICE and the following kernels:

- KERNELS/lsk/naif0009.tls
- KERNELS/spk/mantra.jup_a5d_140a_lau_fin_bet_500.bsp
- KERNELS/spk/de405.bsp
- KERNELS/spk/jup230.bsp
- KERNELS/ck/quaternions_europa_flybys.bc
- KERNELS/sclk/juice_YYMMDD_step.tcp
- KERNELS/pck/pck00010.tpc
- KERNELS/fk/juice_v01.tf
- KERNELS/ik/juice_janus_v00.ti
**SPICE kernels**

**Components**
- **S** Spacecraft
- **P** Planet
- **I** Instrument
- **C** Camera-matrix
- **E** Events

**Data Files**
- **SPK**
- **PcK**
- **IK**
- **CK**

**Contents**
- **SPK**: Spacecraft and target body ephemerides
  - Binary files
- **PcK**: Target body size, shape and orientation
  - Text and binary files
- **IK**: Instrument field-of-view size, shape and orientation
  - Text files
- **CK**: Orientation of spacecraft and any articulating structure on it
  - Binary files

**Producers**
- **MOC** provides data, **SGS** generates kernels.
- Science institutions for natural bodies.
- Science institutions
- SGS and Instrument teams
- SGS for pre-operational and sci-planning purposes
- MOC provides data, SGS generates kernels for ops
- SGS and Science Institutions
- NAIF
- MOC provides data. SGS generates kernels
- TBD

**Source**
- **Fdyn & Mission Analysis’ OEM**
- **Fdyn AEM**
- **SC HK data**
- **SGS**
- **SC HK data**
- **SGS**

*For binary data. Text files are manually produced.*

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Conclusion

- Evaluation of a planned trajectory
- Mission engineering analyses
- Planning an instrument pointing profile
- Observation geometry visualization
- Science data archiving and analysis

- BepiColombo and Juice: Suite of tools and scripts, webgeocalc
- Rosetta: ASPEN
- Rosetta: Flying potato, 3dtool, Cost Function
- VEX, MEX, Juice: SOLab, Cosmographia
EXTRA Slides – SPICE status at ESAC

- **Currently:**
  - VEX, MEX, Rosetta, EM16, BepiColombo, Solar Orbiter, JUICE are serviced
  - Pipeline in place for VEX, MEX, Rosetta to generate operational kernels
  - FTP with all kernels available
  - Existing suite of tools/scripts/pipelines
  - WebGeoCalc for JUICE and BepiColombo

- **In development:**
  - Pipeline for EM16, BepiColombo, JUICE and Solar Orbiter to generate operational kernels
  - Extension and consolidation of adhoc suite of tools/scripts/pipelines
  - Dedicated SPICE servers for kernels
  - WebGeoCalc for all serviced missions
  - Cosmographia for all serviced missions