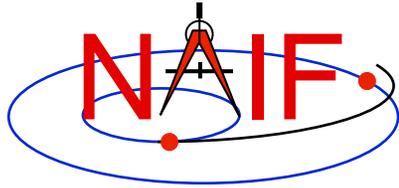


Navigation and Ancillary Information Facility

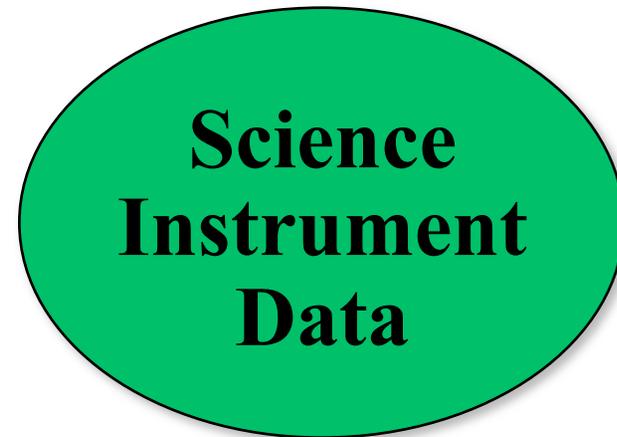
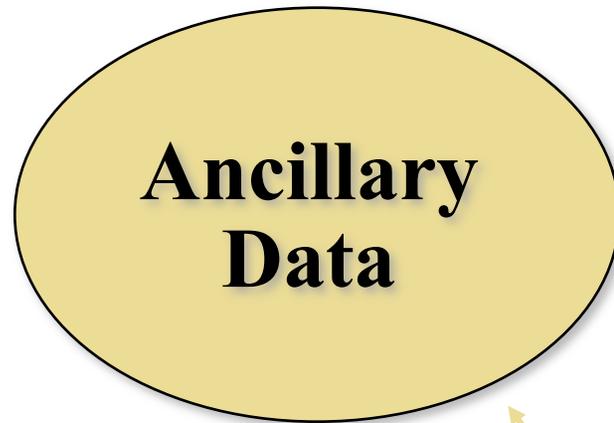
An Overview of SPICE

January 2012

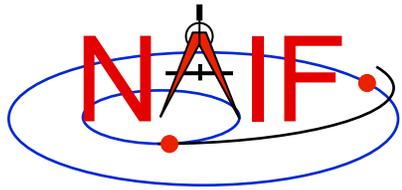


Space Science Data: Two Kinds

Navigation and Ancillary Information Facility

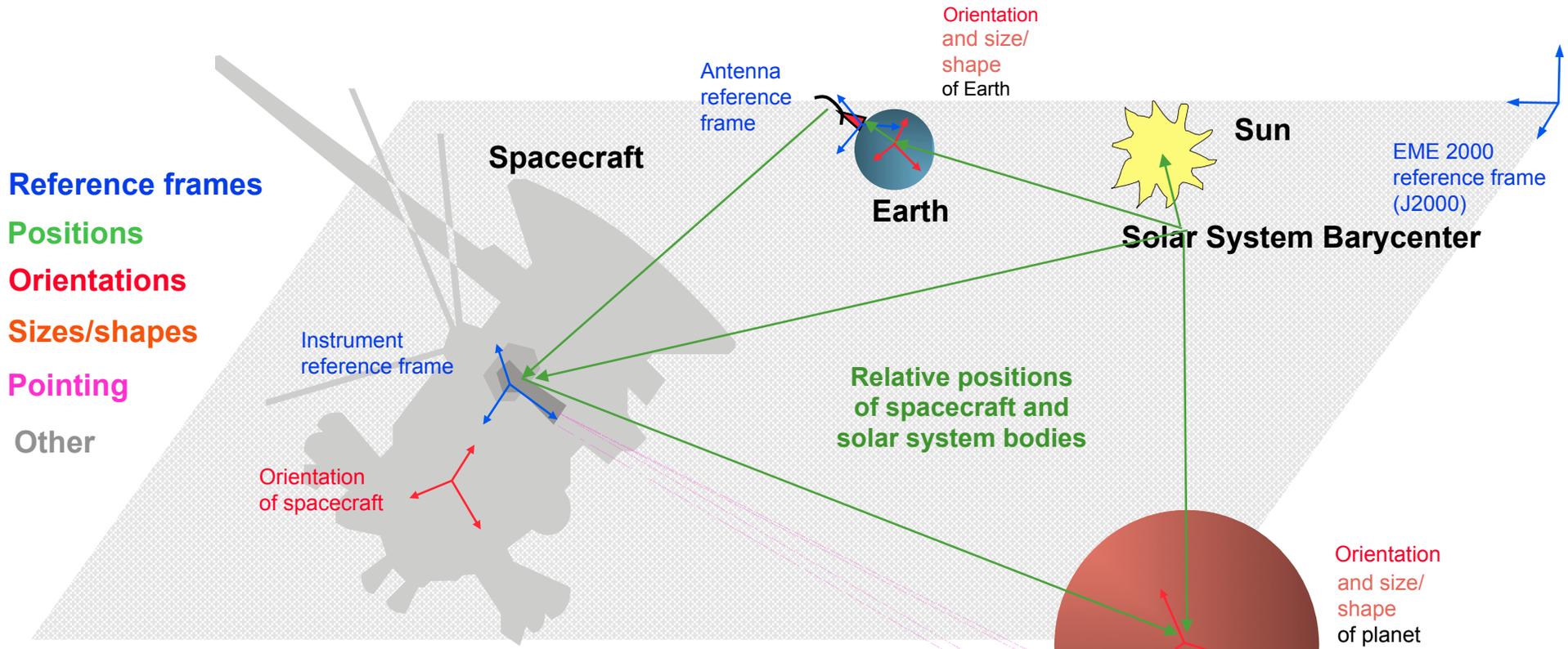


SPICE deals with **these** data to support the planning for and analysis of **these** data



What are “Ancillary Data?”

Navigation and Ancillary Information Facility



Reference frames

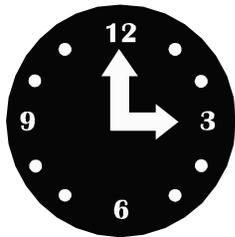
Positions

Orientations

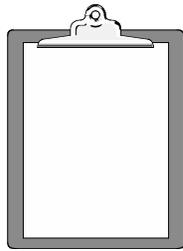
Sizes/shapes

Pointing

Other

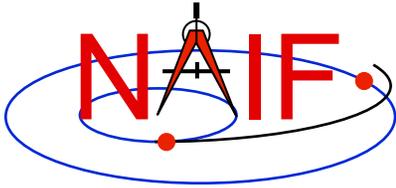


Time Conversion Calculations



Logs of Commands and Events

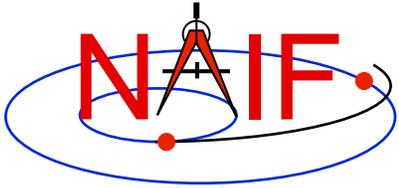
Overview of SPICE



What are “Ancillary Data”?

Navigation and Ancillary Information Facility

- **“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 or ground that might affect interpretation of science observations
- **In the above we’ve used past tense, but doing the same functions for future times to support observation planning is equally applicable**

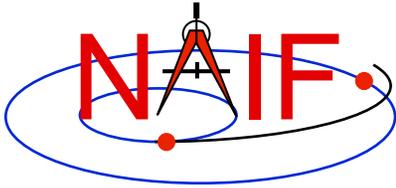


From Where do Ancillary Data Come?

Navigation and Ancillary Information Facility

- **Some come from the spacecraft**
- **Some come from the mission control center**
- **Some come from the spacecraft and instrument builders**
- **Some come from scientists**

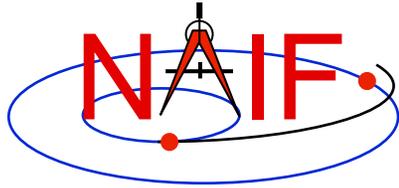
- **SPICE is used to organize and package these data in a collection of useful, stable file types—called "kernels."**
- **The kernels are made available, along with SPICE Toolkit software:**
 - **to help scientists in the planning for and analysis of science observations, and**
 - **to help engineers in planning for and analysis of spacecraft and ground system operations.**



Why SPICE?

Navigation and Ancillary Information Facility

- **Knowing observation geometry and events is an important element:**
 - in the design of space missions,
 - in the selection of observations,
 - and in analysis of the science data returned from the instruments.
- **Having proven, extensive and reusable means for producing and using ancillary data reduces cost and risk, and can help scientists and engineers achieve more substantive, accurate and timely results.**



SPICE System Components

Navigation and Ancillary Information Facility

Data files (“kernels”).....



SPICE Toolkit software.....



Documentation



Tutorials



Programming lessons

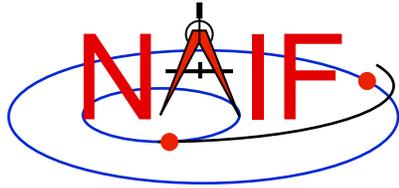


Training classes



User consultation





Genesis of the SPICE Acronym*

Navigation and Ancillary Information Facility

S

Spacecraft

P

Planet

I

Instrument

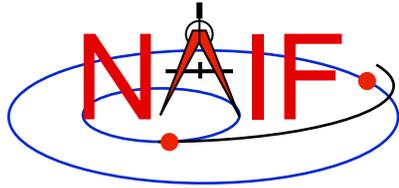
C

C-matrix

E

Events

* Coined by Dr. Hugh Kieffer, USGS Astrogeology Branch, Flagstaff AZ



An Overview of SPICE Data

Navigation and Ancillary Information Facility

Logical Components

S
Spacecraft

P
Planet

I
Instrument

C
Camera-matrix

E
Events

Physical Files

SPK

PcK

IK

CK

EK
ESP ESQ ENB

Others

FK

LSK

SCLK

DSK

Contents

Space vehicle or target body trajectory (ephemeris)

Target body size, shape and orientation

Instrument field-of-view size, shape and orientation

Orientation of space vehicle or any articulating structure on it

Events information:

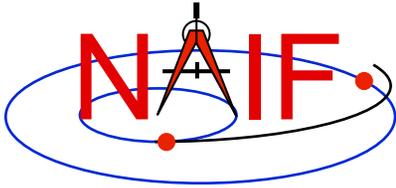
- Science Plan (ESP)
- Sequence of events (ESQ)
- Experimenter's Notebook (ENB)

Reference frame specifications

Leapseconds tabulation

Spacecraft clock coefficients

Digital shape models



SPICE System Data - 1

Navigation and Ancillary Information Facility

SPK

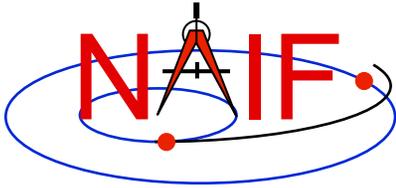
- **Space vehicle ephemeris (trajectory)**
- **Planet, satellite, comet and asteroid ephemerides**
- **More generally, position of something relative to something else**

PcK

- **Planet, satellite, comet and asteroid orientations, sizes, shapes**
- **Possibly other similar “constants” such as parameters for gravitational model, atmospheric model or rings model**

IK

- **Instrument field-of-view size, shape, orientation**
- **Possibly additional information, such as internal timing**



SPICE System Data - 2

Navigation and Ancillary Information Facility

CK

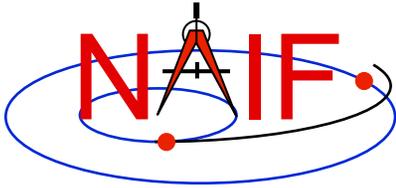
- Instrument platform (e.g. spacecraft) attitude
- More generally, orientation of something relative to a specified reference frame

EK

3 components

- “Events,” broken into three components:
 - ESP: Science observation plans
 - ESQ: Spacecraft & instrument commands
 - ENB: Experiment “notebooks” and ground data system logs

EK is not much used



SPICE System Data - 3

Navigation and Ancillary Information Facility

FK

- **Frames**
 - Definitions of and specification of relationships between reference frames (coordinate systems)
 - Both “fixed” and “dynamic” frames are available

LSK

- **Leapseconds Tabulation**
 - Used for UTC <--> TDB (ET) time conversions

SCLK

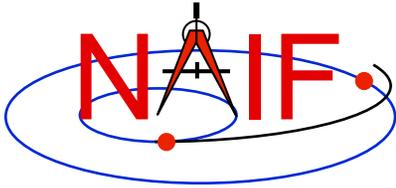
- **Spacecraft Clock Coefficients**
 - Used for SCLK <--> TDB (ET) time conversions

**Under
Development**

- **Shape models (DEM and tessellated plates) (DSK) ¹**
- **Star (sky) catalog ²**

¹ under development now

² development is stalled



SPICE Toolkit Software

Navigation and Ancillary Information Facility

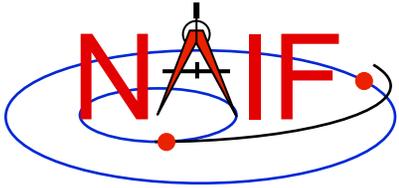
Contents

- **Library of subroutines (~1500)**
 - Used within a customer's program to compute quantities derived from SPICE data files
- **Programs (~30)**
 - SPICE data production
 - SPICE data management
- **Documentation**
 - Highly annotated source code
 - Technical Reference Manuals (23)
 - User Guides

Versions

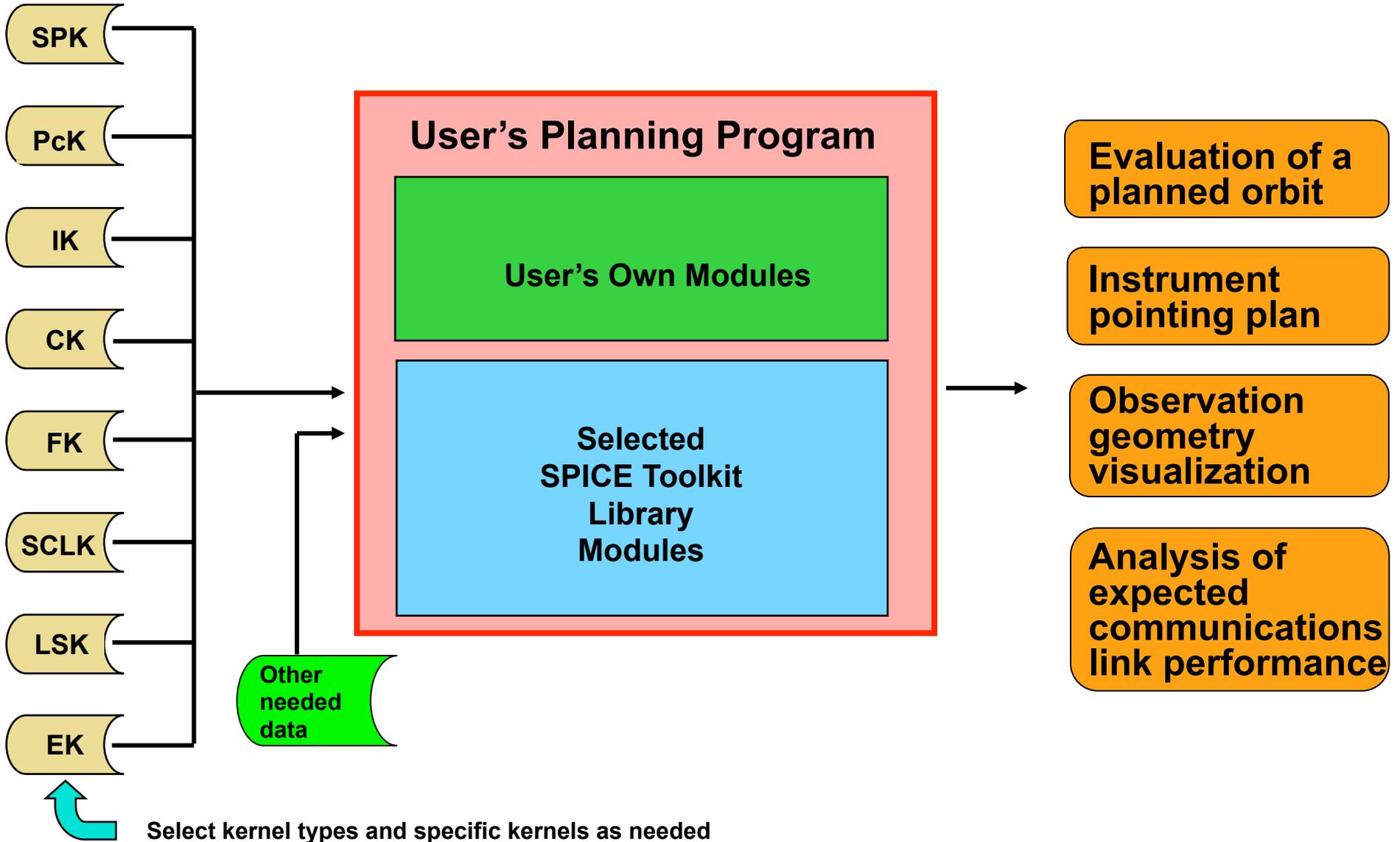
- **Four languages**
 - Fortran
 - C
 - Interactive Data Language (IDL)
 - MATLAB
 - Coming soon:
 - » Java Native Interface (JNI)
 - » Python
- **Five platforms**
 - PC/Linux
 - PC/Windows
 - Sun/Solaris
 - Mac/OSX (even iPhone)
 - Hewlett Packard/HP-UX
- **43 environments supported now**
 - Language + platform + OS + compiler

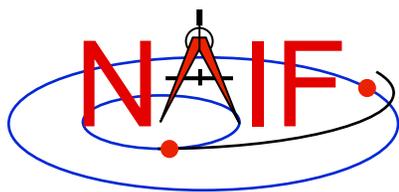
≈ 2 million source lines of code



Example: Using SPICE in Mission Planning

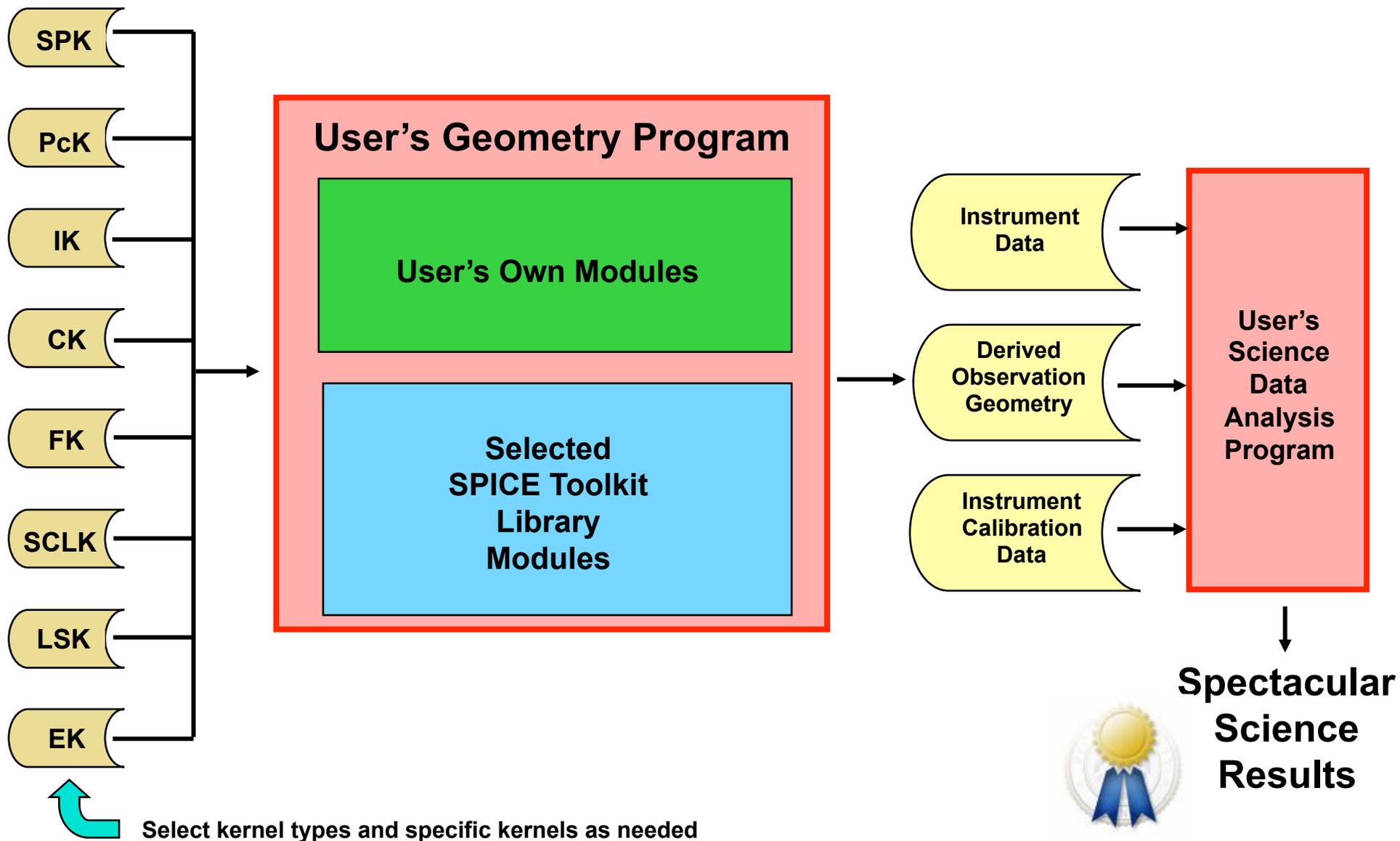
Navigation and Ancillary Information Facility





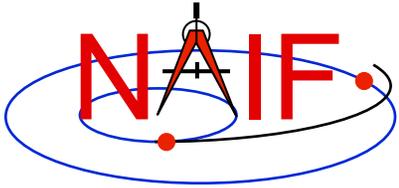
Example: Using SPICE in Science Data Analysis

Navigation and Ancillary Information Facility



Select kernel types and specific kernels as needed
Overview of SPICE

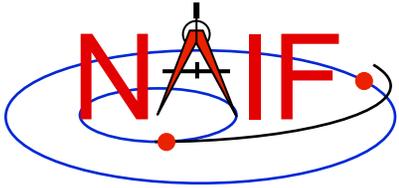




SPICE System Characteristics - 1

Navigation and Ancillary Information Facility

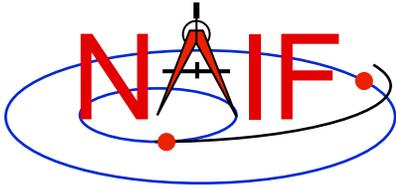
- **SPICE Toolkit software is portable between computers**
- **New Toolkits are released about every 10-15 months**
- **Code is well tested before being released to users**
- **New Toolkits are always 100% backwards compatible**
- **Source code is provided (and is well documented)**
- **Extensive user-oriented documentation is provided**
- **SPICE tutorials are available**
- **“Open book” programming lessons are available**
- **NAIF offers a free annual training class**



SPICE System Characteristics - 2

Navigation and Ancillary Information Facility

- **All numeric computations use double precision numbers**
- **System includes built-in exception handling**
 - Catches most invalid inputs
- **kernel files are portable between computers**
- **Kernel files are separable**
 - Use only those you need for a particular application
- **Kernel files are extensible**
 - New data “types” can be added within a family
- **New kinds of kernels can be developed as needed**
- **SPICE users have access to JPL’s integrated ephemerides for spacecraft and natural bodies (planets, satellites, comets, asteroids)**

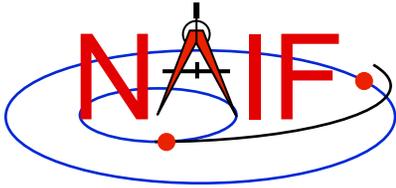


SPICE System Characteristics - 3

Navigation and Ancillary Information Facility

- **Funding**
 - **SPICE system development is funded by NASA's Planetary Science Division (PSD)**
 - **NASA PSD flight projects fund NAIF or others to deploy and operate SPICE in support of NASA's planetary missions**
 - **Foreign institutions fund their own people for deployment and operation of SPICE in support of their own projects**
 - **SPICE Toolkit software is free to individual end users**
 - **Access to SPICE kernels produced by NAIF is not restricted**
 - » **Includes mission operations kernels as well as those archived in the PDS**
 - **Consultation from NAIF is mostly restricted to paying, and paid for, users**
 - » **See chart near the end of this tutorial for details**

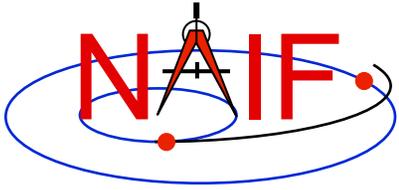
- **Distribution of SPICE software and data is not restricted under U.S. Government regulations**
 - » **SPICE is classified TSPA ("Technology and Software Publicly Available")**
 - » **There are no ITAR restrictions on data, training or consulting**
 - **NASA or the U.S. Government may nevertheless restrict training in specific situations**



Supported Environments

Navigation and Ancillary Information Facility

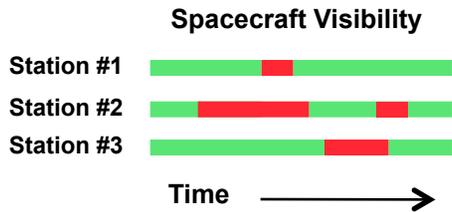
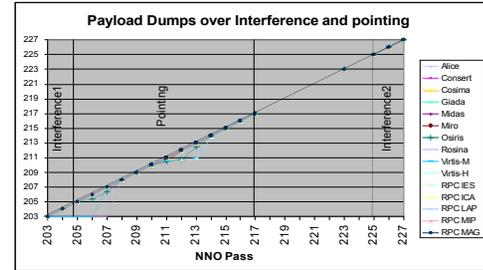
- **The SPICE Toolkit has been ported to a wide variety of popular “environments”**
 - Each environment is characterized by...
 - » Language
 - » Hardware type (platform)
 - » Operating System
 - » Compiler (where applicable)
 - » Sometimes even selected compilation options
- **NAIF provides separate, ready-built SPICE Toolkit packages for each supported environment**
 - If you need to port the Toolkit to a new environment yourself, consult with NAIF staff first



How is SPICE Used ?

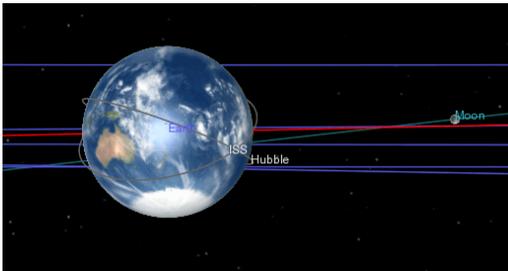
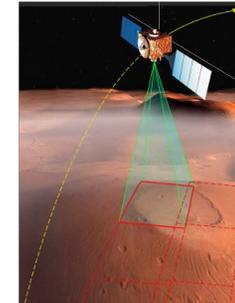
Navigation and Ancillary Information Facility

Evaluation of a planned trajectory



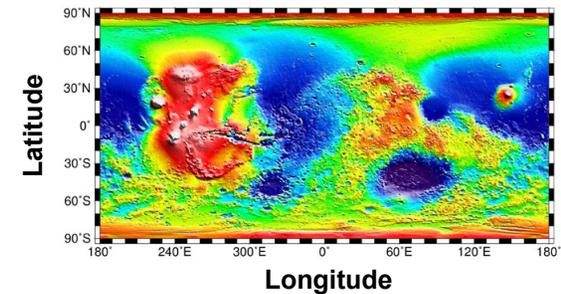
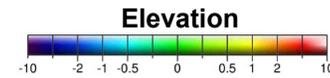
Mission engineering analyses

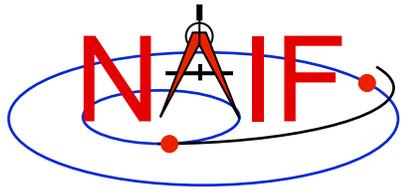
Planning an instrument pointing profile



Observation geometry visualization

Science data archiving and analysis



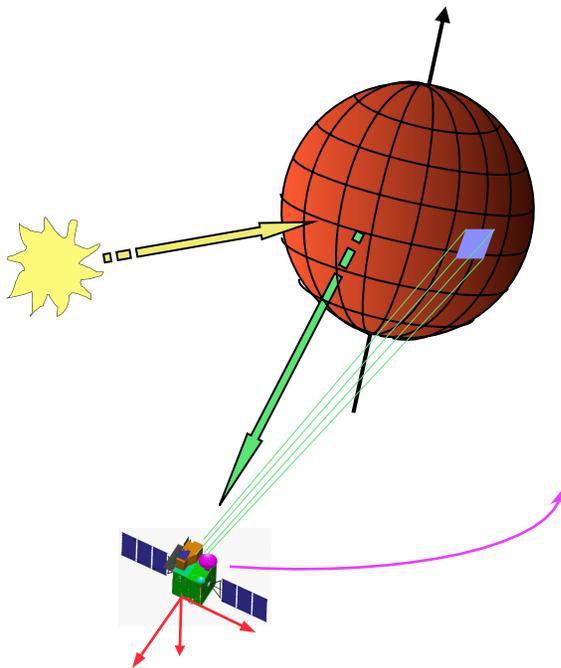


What Can One Do With SPICE?

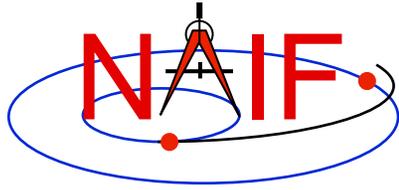
Navigation and Ancillary Information Facility

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

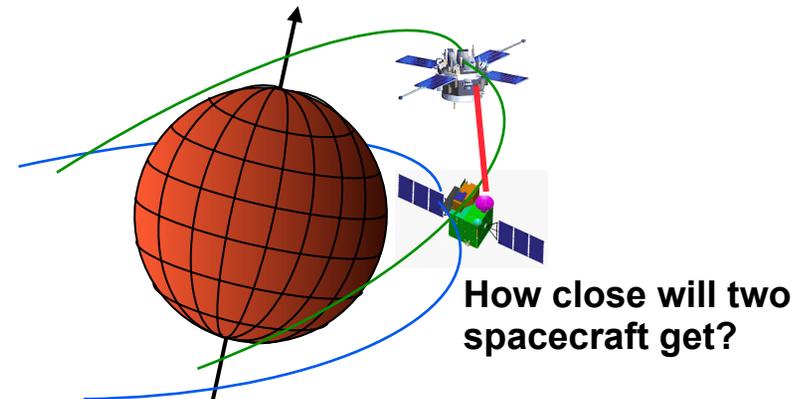
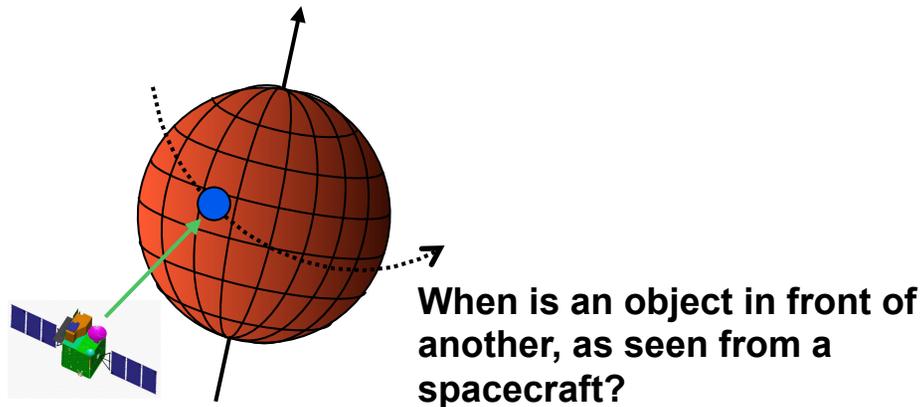
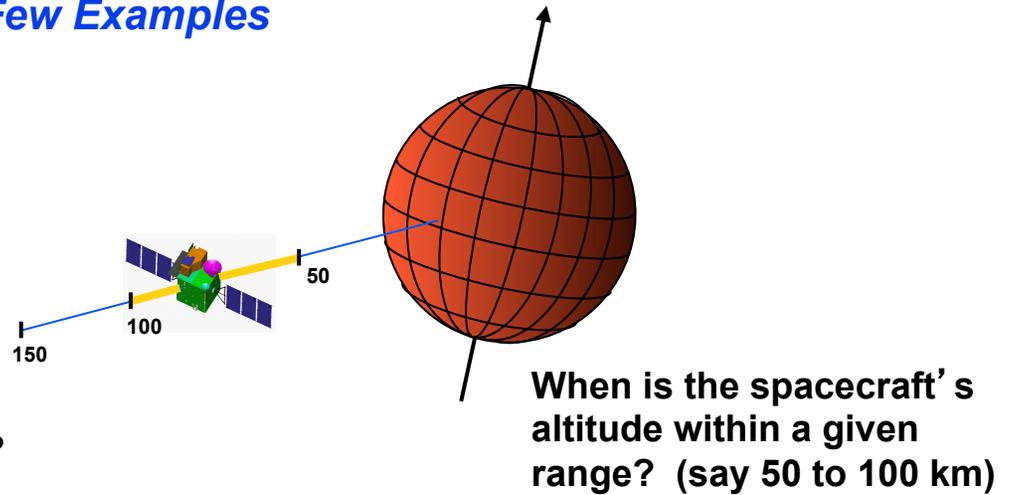
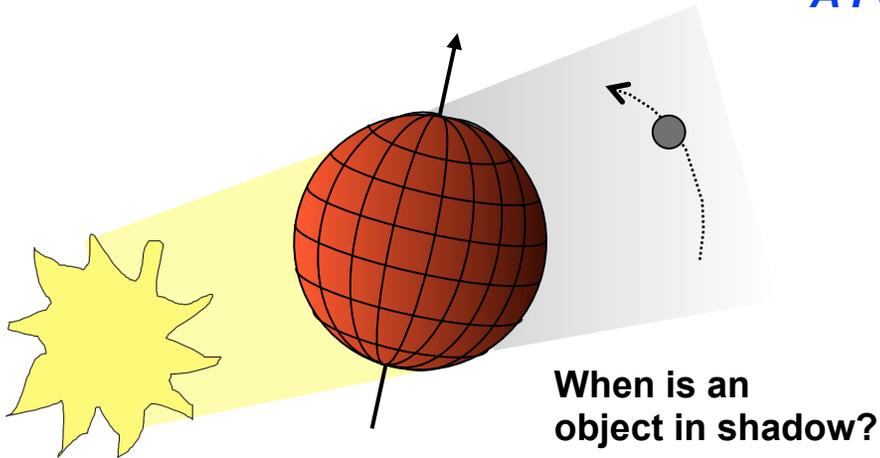


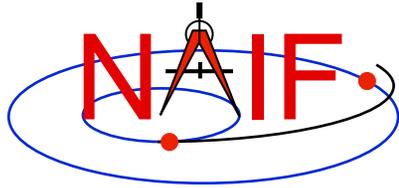
What Can One Do With SPICE?

Navigation and Ancillary Information Facility

Find times when a selected “geometric event” occurs, or when a selected “geometric condition” exists

A Few Examples

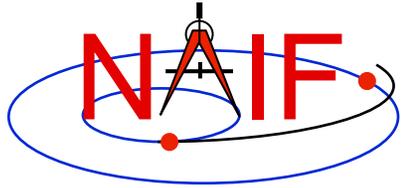




What “Vehicle” Types Can Be Supported?

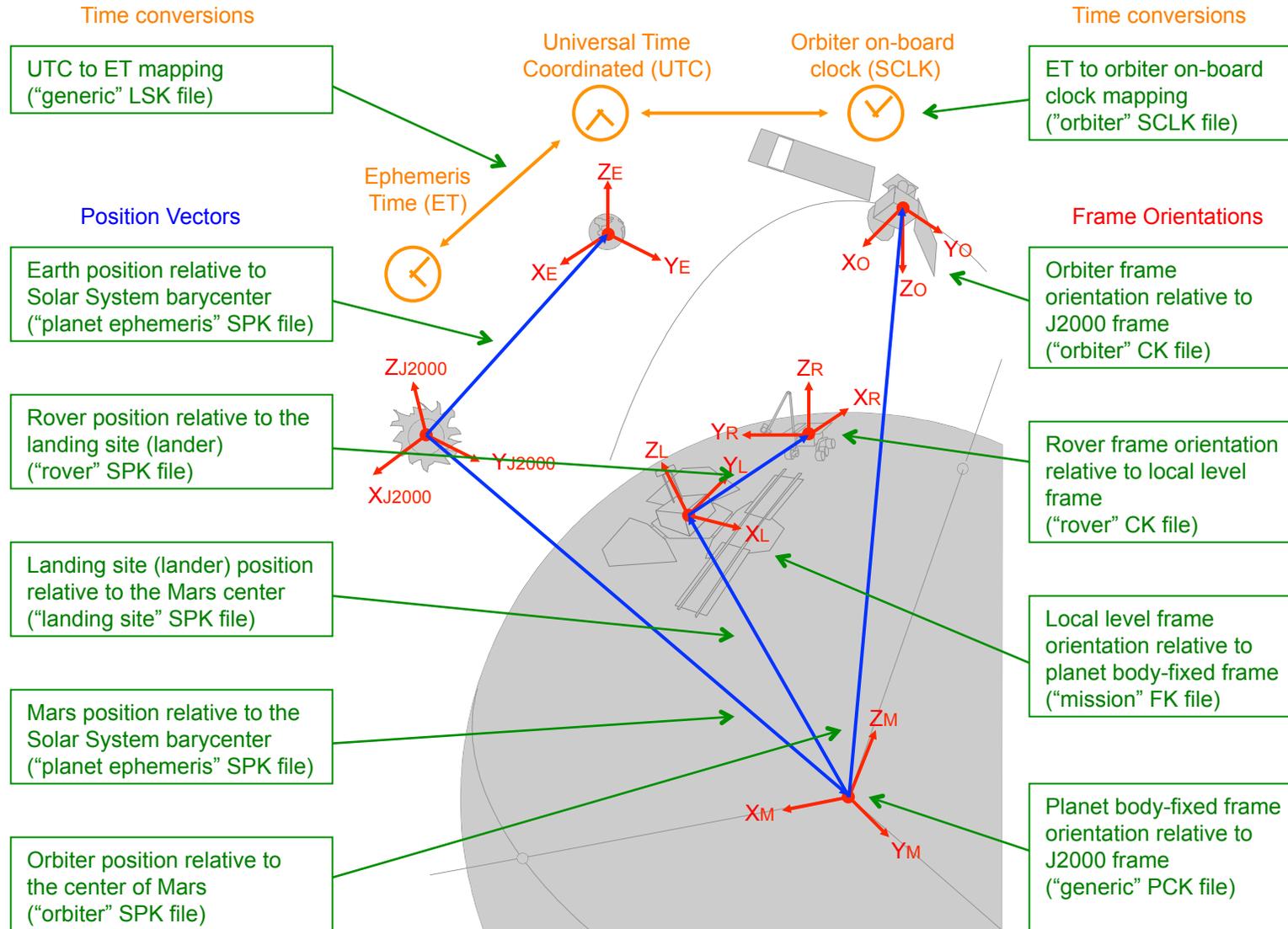
Navigation and Ancillary Information Facility

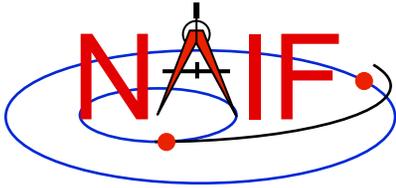
- **Cruise/Flyby**
 - Remote sensing
 - In-situ measurement
 - Instrument calibration
- **Orbiters**
 - Remote sensing
 - In-situ measurement
 - Communications relay
- **Balloons***
 - Remote sensing
 - In-situ measurements
- **Landers**
 - Remote sensing
 - In-situ measurements
 - Rover or balloon relay
- **Rovers**
 - Remote sensing
 - In-situ sensing
 - Local terrain characterization
- **Terrestrial applications**
 - Ephemerides for observers
 - Tracking station needs



Global SPICE Geometry

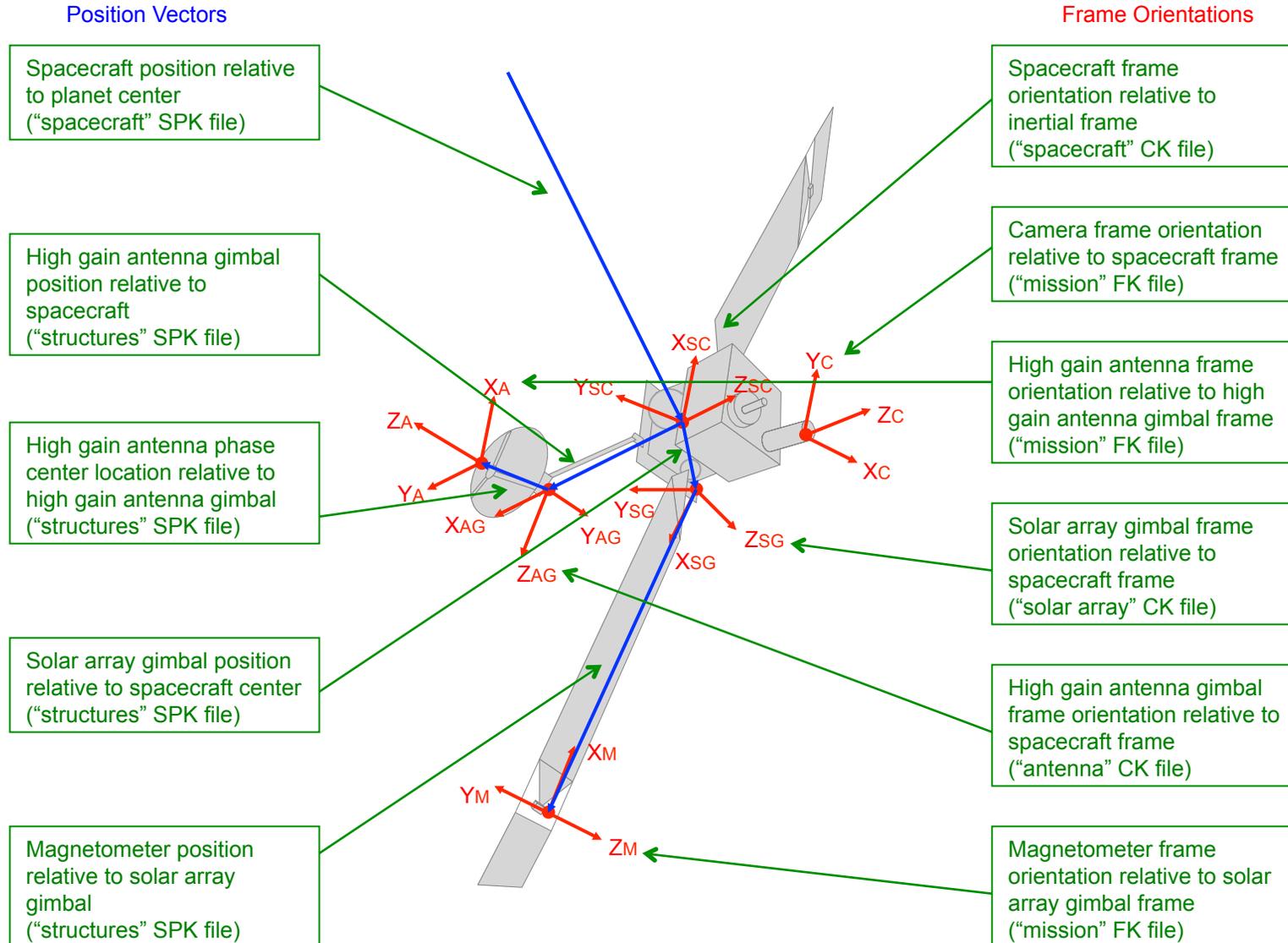
Navigation and Ancillary Information Facility

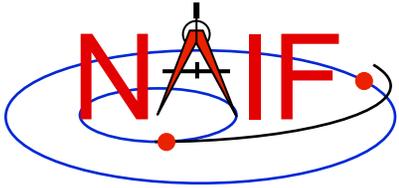




Orbiter Geometry

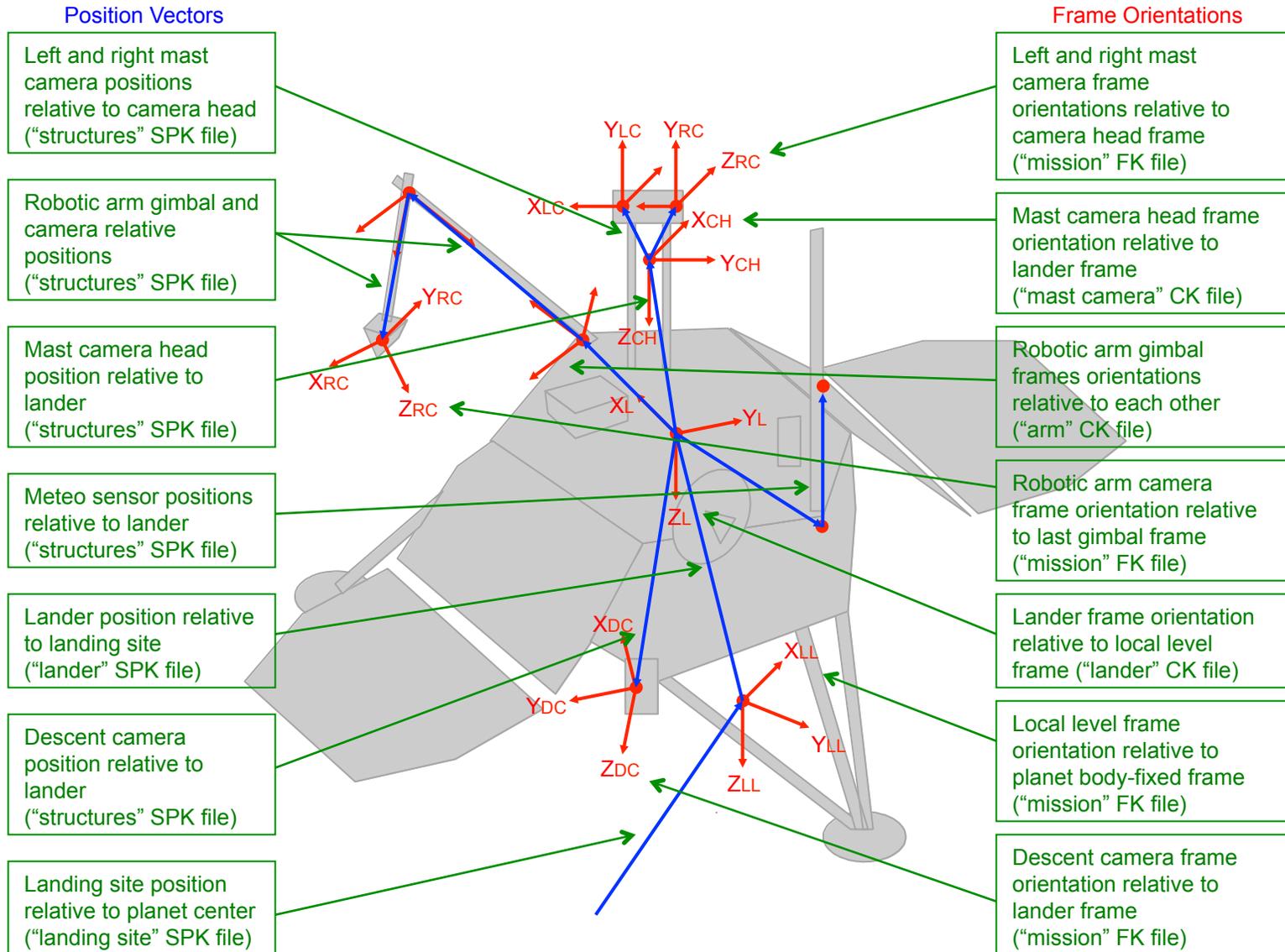
Navigation and Ancillary Information Facility

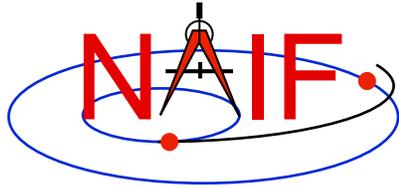




Lander Geometry

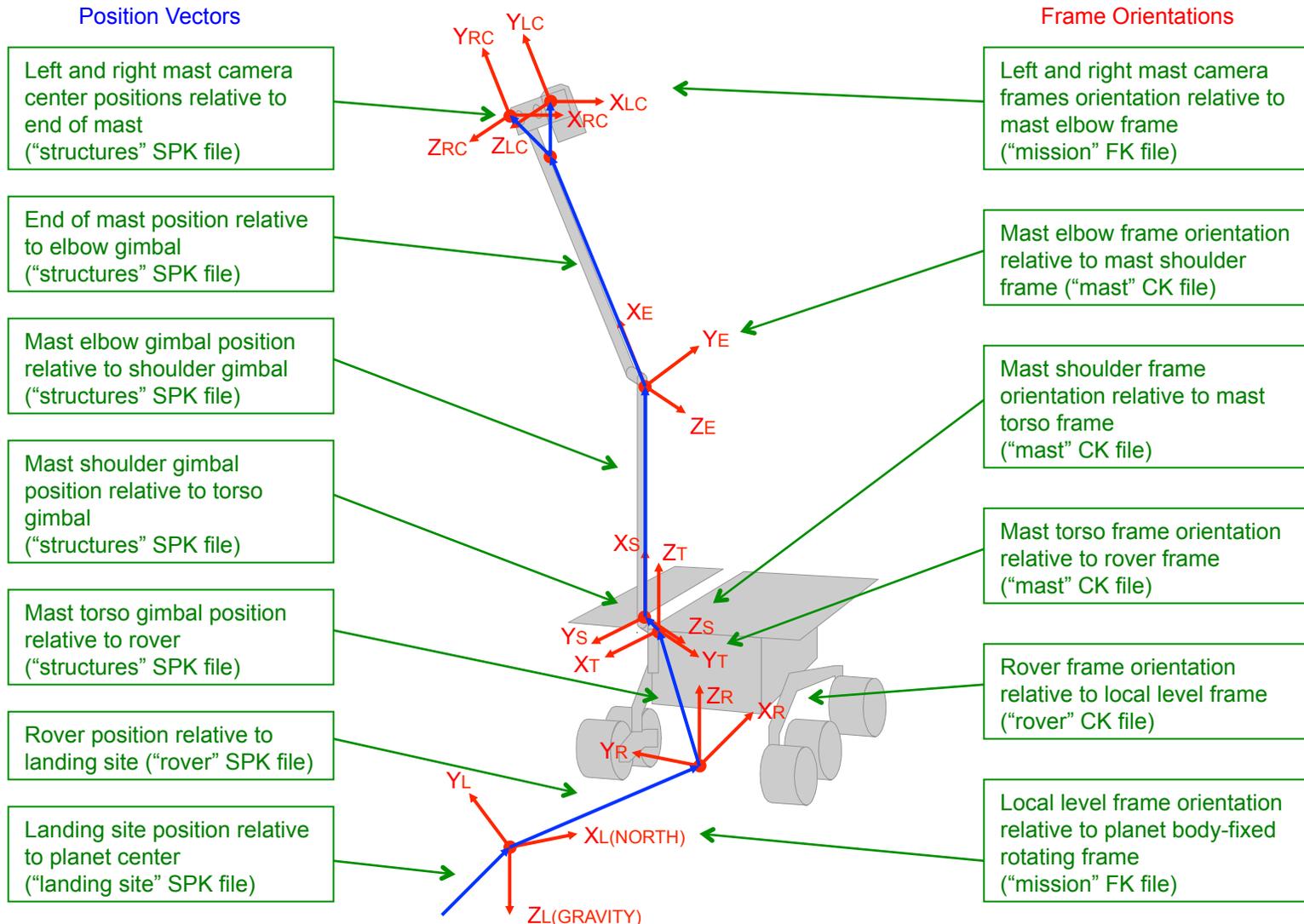
Navigation and Ancillary Information Facility

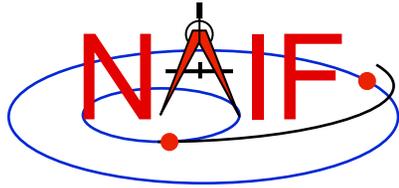




Rover Geometry

Navigation and Ancillary Information Facility





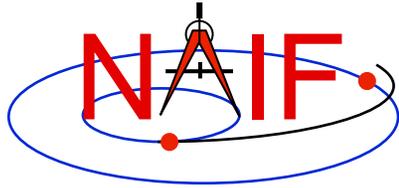
Flight Projects Using SPICE

Navigation and Ancillary Information Facility

12/28/11

<i>Data Restorations</i>	<i>Past Users</i>	<i>Current Users</i>	<i>Anticipated</i>
Apollo 15, 16 [L]	Magellan [L]	Cassini Orbiter	LADEE
Mariner 9 [L]	Clementine (NRL)	Mars Odyssey	Mars 2016/2018 (ESA and NASA))
Mariner 10 [L]	Mars Observer [F]	Mars Exploration Rover	NASA Discovery Program
Viking Orbiters [L]	Mars 96 [F] (RSA)	Mars Reconnaissance Orbiter	NASA New Frontiers Program
Viking Landers [L]	Mars Pathfinder	DAWN	BepiColombo (ESA)
Pioneer 10/11 [L]	Mars Climate Orbiter [F]	Mars Science Lab	
Haley armada [L]	Mars Polar Lander [F]	Juno	
Phobos 2 [L] (RSA)	NEAR	SMAP	<i>Future ?</i>
Ulysses [L]	Deep Space 1	MAVEN	Jupiter (NASA)
Voyagers [L]	Galileo	GRAIL	Jupiter (ESA)
Lunar Orbiter [L]	Genesis	Osiris-Rex	Akatsuki (JAXA)
	Deep Impact		Luna-Resurs (ISRO/RSA)
	Huygens Probe (ESA)	Lunar Reconnaissance Orbiter	Luna-Glob (RSA)
	Stardust/NExT	New Horizons	
	Mars Global Surveyor	Messenger	
[L] = limited use	Phoenix		<i>Examples of Other SPICE Users</i>
[S] = special services	EPOXI	Mars Express (ESA)	NASA AMMOS
[F] = mission failed	Hubble Space Telescope [S]	Venus Express (ESA)	NASA Deep Space Network
	ISO [S] (ESA)	Rosetta (ESA)	STEREO
	CONTOUR [F]		Spitzer Space Telescope
	Space VLBI [L] (multinational)	Hayabusa (JAXA)	Kepler
	Smart-1 (ESA)	Kaguya (JAXA)	Planck (ESA)
	Chandrayaan-1 (ISRO)		WISE
	LCROSS	Planetary Data System	IBEX
	Phobos Sample Return (RSA)	Planetary Science Archive (ESA)	

- NAIF has/had project-supplied funding to support mission operations, consultation for flight team members, and SPICE data archive preparation. NAIF also has PDS funding to help scientists and students with using SPICE data that have been officially archived at the NAIF Node of the PDS.
- NAIF has NASA funding to support ESA/RSA in SPICE operations and review of SPICE archive, and to consult with flight team SPICE users.
- NAIF has token funding to consult with kernel producers at APL. APL provides support to science teams.
- NAIF has/had modest PDS-supplied funding to consult only on assembly of a SPICE archive.
- NAIF has PDS funding to help scientists and students with using SPICE data that have been officially archived at the NAIF Node of the PDS.
- User consultation is provided by ESA's Science Operations Department.

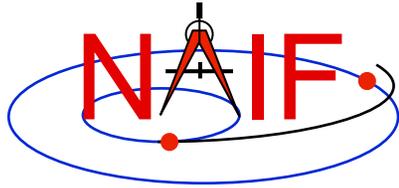


Flight Projects Using SPICE

Navigation and Ancillary Information Facility

<i>Data Restorations</i>	<i>Past Users</i>	<i>Current Users</i>	<i>Anticipated</i>
Apollo 15, 16 [L]	Magellan [L]	Cassini Orbiter	LADEE
Mariner 9 [L]	Clementine (NRL)	Mars Odyssey	NASA Discovery Program
Mariner 10 [L]	Mars Observer [F]	Mars Exploration Rover	NASA New Frontiers Program
Viking Orbiters [L]	Mars 96 [F] (RSA)	Mars Reconnaissance Orbiter	BepiColombo (ESA)
Viking Landers [L]	Mars Pathfinder	DAWN	Osiris-Rex
Pioneer 10/11/12 [L]	Mars Climate Orbiter [F]	Mars Science Lab	
Haley armada [L]	Mars Polar Lander [F]	Juno	<i>Examples of Possible Future Use ?</i>
Phobos 2 [L] (RSA)	NEAR	SMAP	Jupiter (NASA)
Ulysses [L]	Deep Space 1	MAVEN	Jupiter (ESA)
Voyagers [L]	Galileo	GRAIL	Akatsuki (JAXA)
Lunar Orbiter [L]	Genesis	Lunar Reconnaissance Orbiter	Luna-Resurs (ISRO/RSA)
Helios 1,2 [L]	Deep Impact	New Horizons	Luna-Glob (RSA)
	Huygens Probe (ESA)	Messenger	Solar Probe
	Stardust/NExT	Mars Express (ESA)	Solar Orbiter (ESA)
	Mars Global Surveyor	Venus Express (ESA)	
	Phoenix	Rosetta (ESA)	
	EPOXI		<i>Examples of Other SPICE Users</i>
	ISO [S] (ESA)		NASA Deep Space Network
	CONTOUR [F]		NASA AMMOS
	Space VLBI [L] (multinational)		STEREO
[L] = limited use	Smart-1 (ESA)		Spitzer Space Telescope
[S] = special services	Chandrayaan-1 (ISRO)		Kepler
[F] = mission failed	Hayabusa (JAXA)		Hubble Space Telescope [S]
	Kaguya (JAXA)	Planetary Data System	WISE
	Phobos Sample Return (RSA)	Planetary Science Archive (ESA)	IBEX

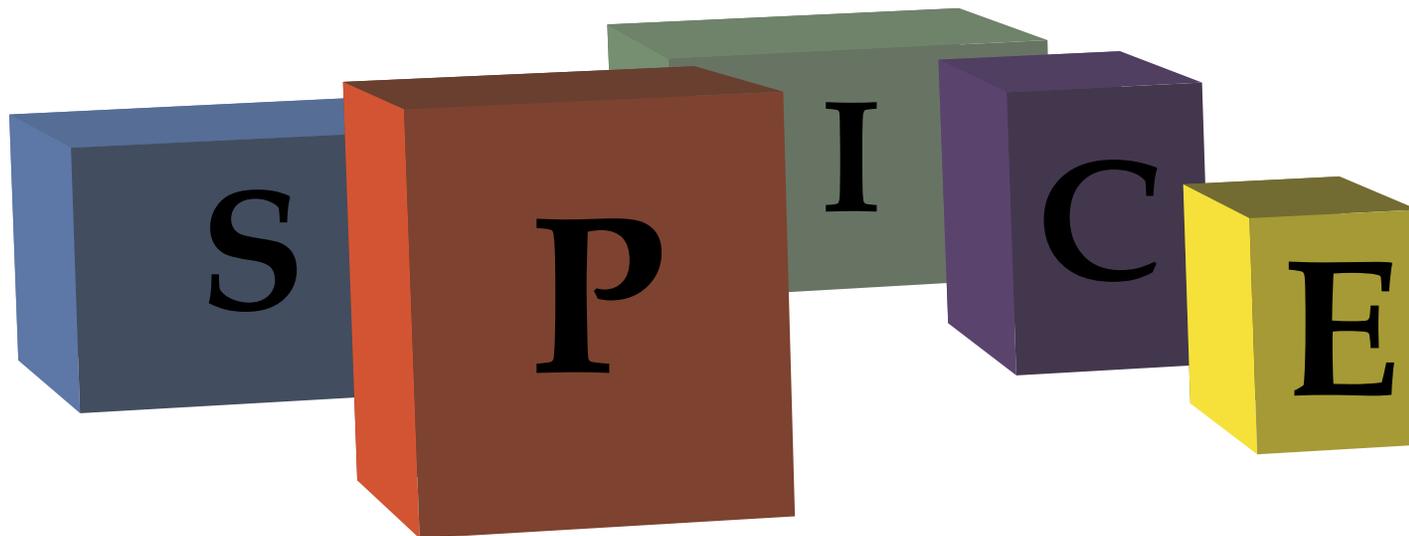
- NAIF has/had project-supplied funding to support mission operations, consultation for flight team members, and SPICE data archive preparation. NAIF also has PDS funding to help scientists and students with using SPICE data that have been officially archived at the NAIF Node of the PDS.
- NAIF has NASA funding to support ESA/RSA in SPICE deployment and review of a SPICE archive, and to consult with flight team SPICE users.
- NAIF has token funding to consult with kernel producers at APL. APL provides support to science teams.
- NAIF has/had modest PDS-supplied funding to consult on assembly of a SPICE archive.
- NAIF has PDS funding to help scientists and students with using SPICE data that have been officially archived at the NAIF Node of the PDS.
- User consultation is provided by ESA's Science Operations Department.



Building Blocks for Your Applications

Navigation and Ancillary Information Facility

The “SPICE” ancillary information system can serve as a set of blocks for building tools that can help execute a multi-mission, international space exploration program



SPICE: the ancillary information system that NAIF builds and often operates.

NAIF: the JPL entity responsible for development and deployment of SPICE.

NAIF Node of the PDS: one responsibility of the NAIF Group--archiving and providing long-term access to SPICE data for the worldwide science community.