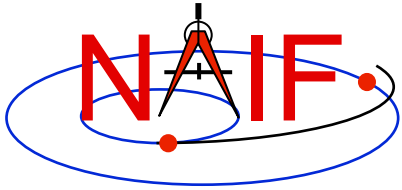


Navigation and Ancillary Information Facility

# **An Overview of SPICE**

**NASA's Ancillary Data System  
for Planetary Missions**

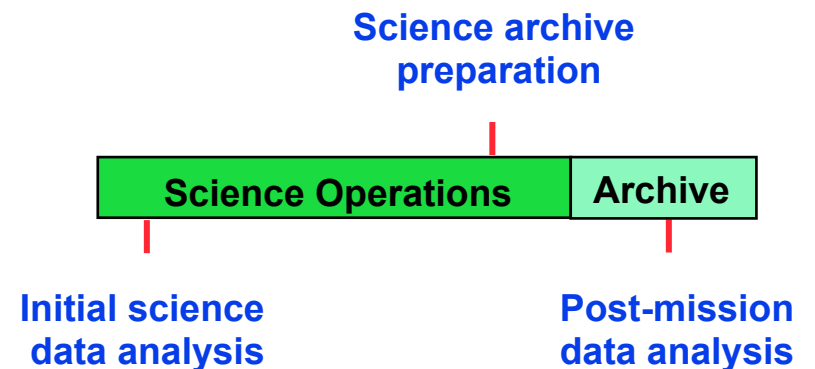
**April 2016**

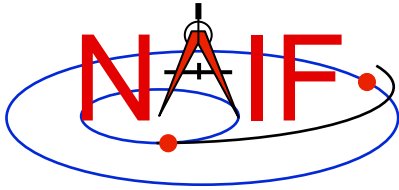


# Original Purpose for SPICE

Navigation and Ancillary Information Facility

- The original focus of SPICE was on ancillary data and associated software needed by scientists for:
  - initial science data analysis
  - science archive preparation
  - post-mission data analysis

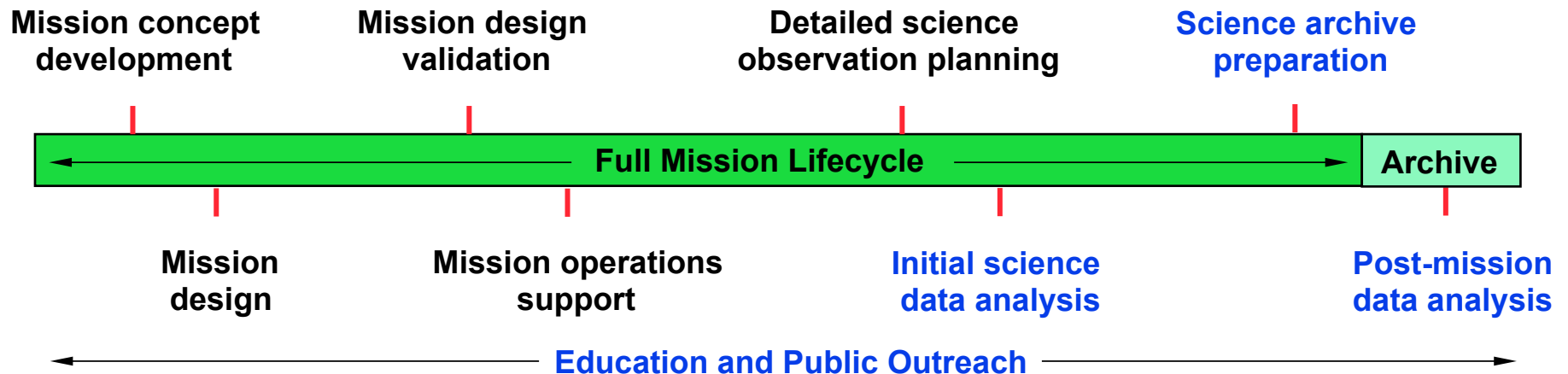


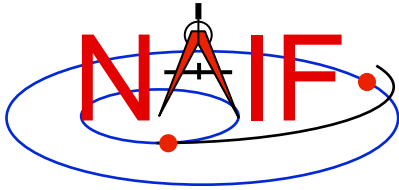


# Large Breadth of Use

Navigation and Ancillary Information Facility

- The original focus of SPICE was on ancillary data and associated software needed by scientists for:
  - initial science data analysis
  - science archive preparation
  - post-mission data analysis
- The scope of SPICE usage has grown to cover the full mission lifecycle as well as archive uses.
- Also education and public outreach.



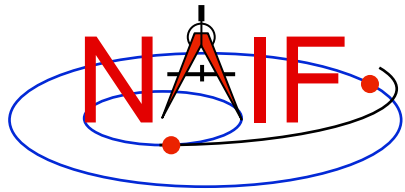


# History

---

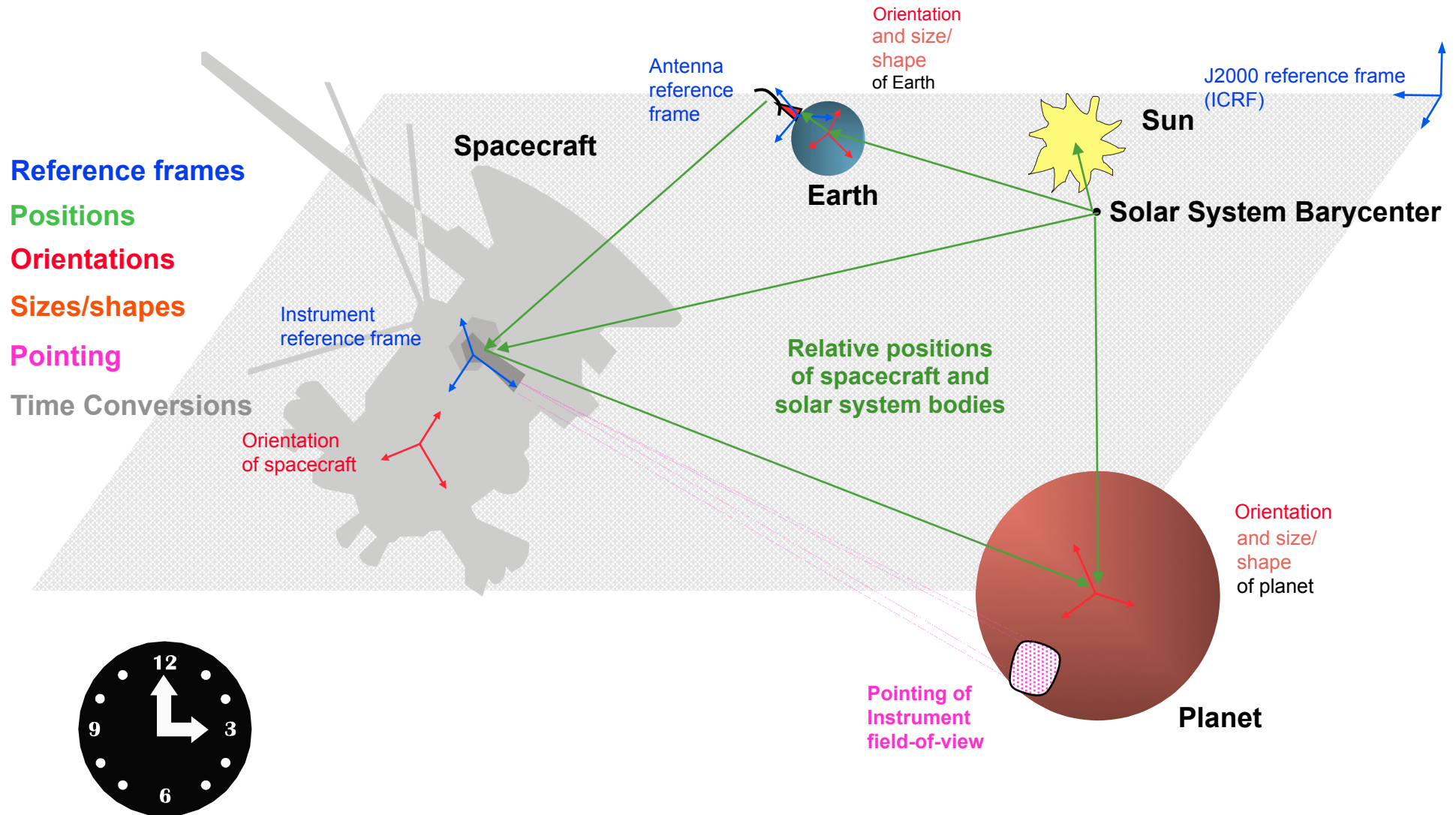
Navigation and Ancillary Information Facility

- **Implementation of a precursor to SPICE was initiated in 1984 as part of a major initiative to improve archiving and distribution of space science data in all NASA disciplines**
- **Responsibility for leading SPICE development was assigned to the newly-created Navigation and Ancillary Information Facility (NAIF), located at the Jet Propulsion Laboratory**
- **Today's SPICE system dates from about 1991**



# What are “Ancillary Data?”

Navigation and Ancillary Information Facility



Reference frames

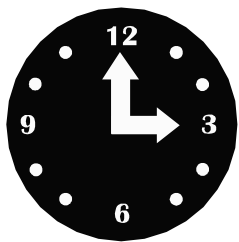
Positions

Orientations

Sizes/shapes

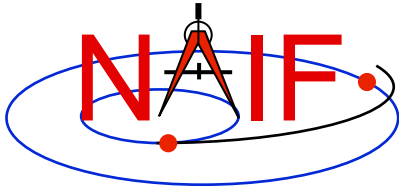
Pointing

Time Conversions



Time Conversion  
Calculations

Overview of SPICE

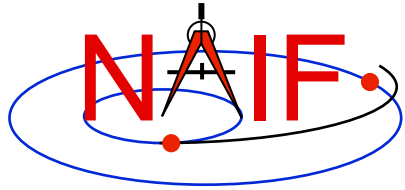


# How Use “Ancillary Data”?

---

Navigation and Ancillary Information Facility

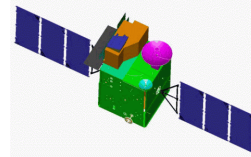
- **“Ancillary data” are those that help scientists and engineers determine:**
  - where the spacecraft was located
  - how the spacecraft and its instruments were oriented (pointed)
  - what was the location, size, shape and orientation of the target being observed
  - what events were occurring on 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 mission planning is equally applicable**



# From Where do Ancillary Data Come?

Navigation and Ancillary Information Facility

- From the spacecraft



- From the mission control center



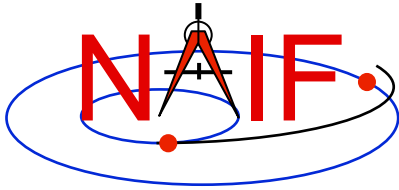
- From the spacecraft and instrument builders



- From science organizations



- **SPICE** is used to organize and package these data in a collection of stable file types—called "kernels"—used by scientists and engineers



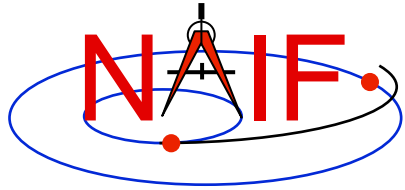
# Why Use SPICE?

---

Navigation and Ancillary Information Facility

- **Knowing observation geometry and events is an important element of:**
  - space mission design,
  - selection of observation opportunities,
  - analysis of the science data returned from the instruments,
  - mission engineering activities, and
  - preparation of science data archives.
- **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

Ancillary data files (“kernels”).....



Software (SPICE Toolkit) .....



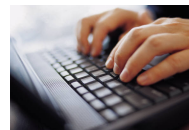
Documentation .....



Tutorials .....



Programming lessons .....

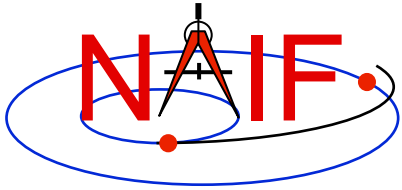


Training classes .....



User consultation .....





# Genesis of the SPICE Acronym\*

Navigation and Ancillary Information Facility

**S**

**S**pacecraft

**P**

**P**lanet

**I**

**I**nstrument

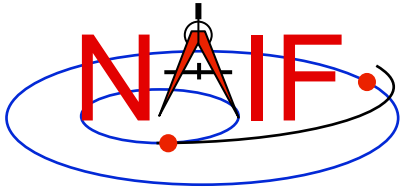
**C**

**C**-matrix (“Camera matrix”)

**E**

**E**vents

\* Coined by Dr. Hugh Kieffer, USGS Astrogeology Branch, Flagstaff AZ, circa 1985



# SPICE Data Overview

Navigation and Ancillary Information Facility

## Logical Components

**S**  
Spacecraft

**P**  
Planet

**I**  
Instrument

**C**  
Camera-matrix

**E**  
Events

## Data 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:

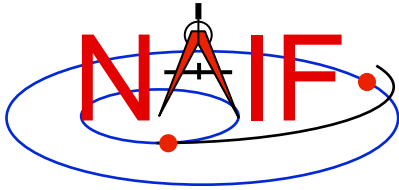
- Science Plan (ESP)
- Sequence of events (ESQ)
- Experimenter's Notebook (ENB)

Reference frame specifications

Leapseconds tabulation

Spacecraft clock coefficients

Digital shape models



# SPICE Data Details- 1

Navigation and Ancillary Information Facility

**SPK**

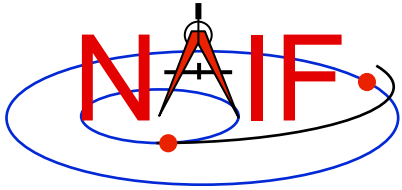
- Space vehicle ephemeris (trajectory)
- Planet, satellite, comet and asteroid ephemerides
- More generally, position of something relative to something else

**PcK**

- Planet, satellite, comet and asteroid orientations, sizes, shapes
  - See also DSK
- 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 Data Details- 2

Navigation and Ancillary Information Facility

**CK**

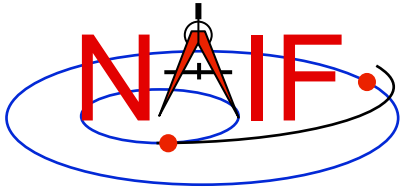
- Instrument platform (e.g. spacecraft) attitude
- More generally, orientation of something relative to a specified reference frame

**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**

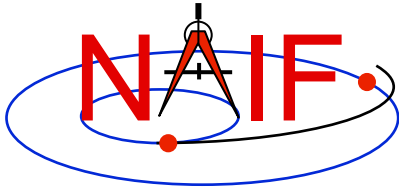
- **Spacecraft Clock Coefficients**
  - Used for SCLK <--> TDB (ET) time conversions

**DSK**

- **Shape models (digital elevation model and tessellated plate model) (DSK)**

Under development now

UTC = Coordinated Universal Time    TDB = Barycentric Dynamical Time    ET = Ephemeris Time    SCLK = Spacecraft Clock Time



# SPICE Toolkit Software

Navigation and Ancillary Information Facility

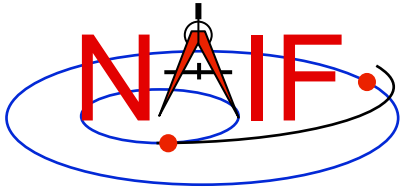
## Contents

- **Library of subroutines (~1000)**
  - Just a few used within a customer's program to compute quantities derived from SPICE data files
- **Programs (14\*)**
  - SPICE data production
  - SPICE data management
- **Documentation**
  - Highly annotated source code
  - Technical Reference Manuals (23)
  - User Guides

## Versions

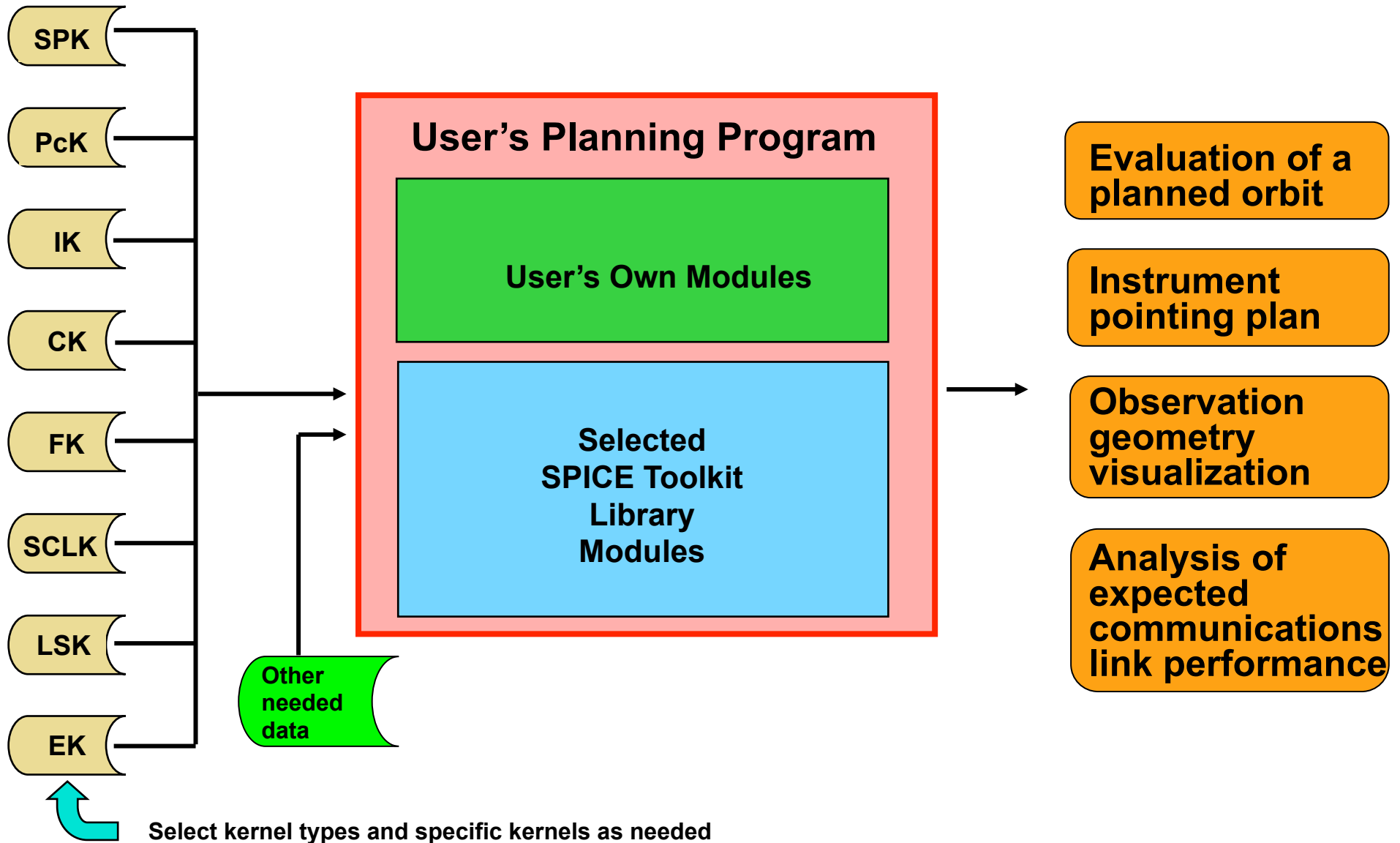
- **Four languages**
  - Fortran
  - C
  - Interactive Data Language (IDL)
  - MATLAB
  - Under development:
    - » Java Native Interface (JNI)
- **Four platforms**
  - PC/Linux
  - PC/Windows
  - Sun/Solaris
  - Mac/OSX
- **Several compilers**
  - For the Fortran and C Toolkits

\* 30 are available from the NAIF website

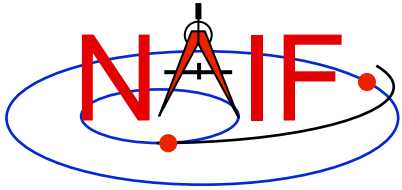


# Mission Planning Example

Navigation and Ancillary Information Facility

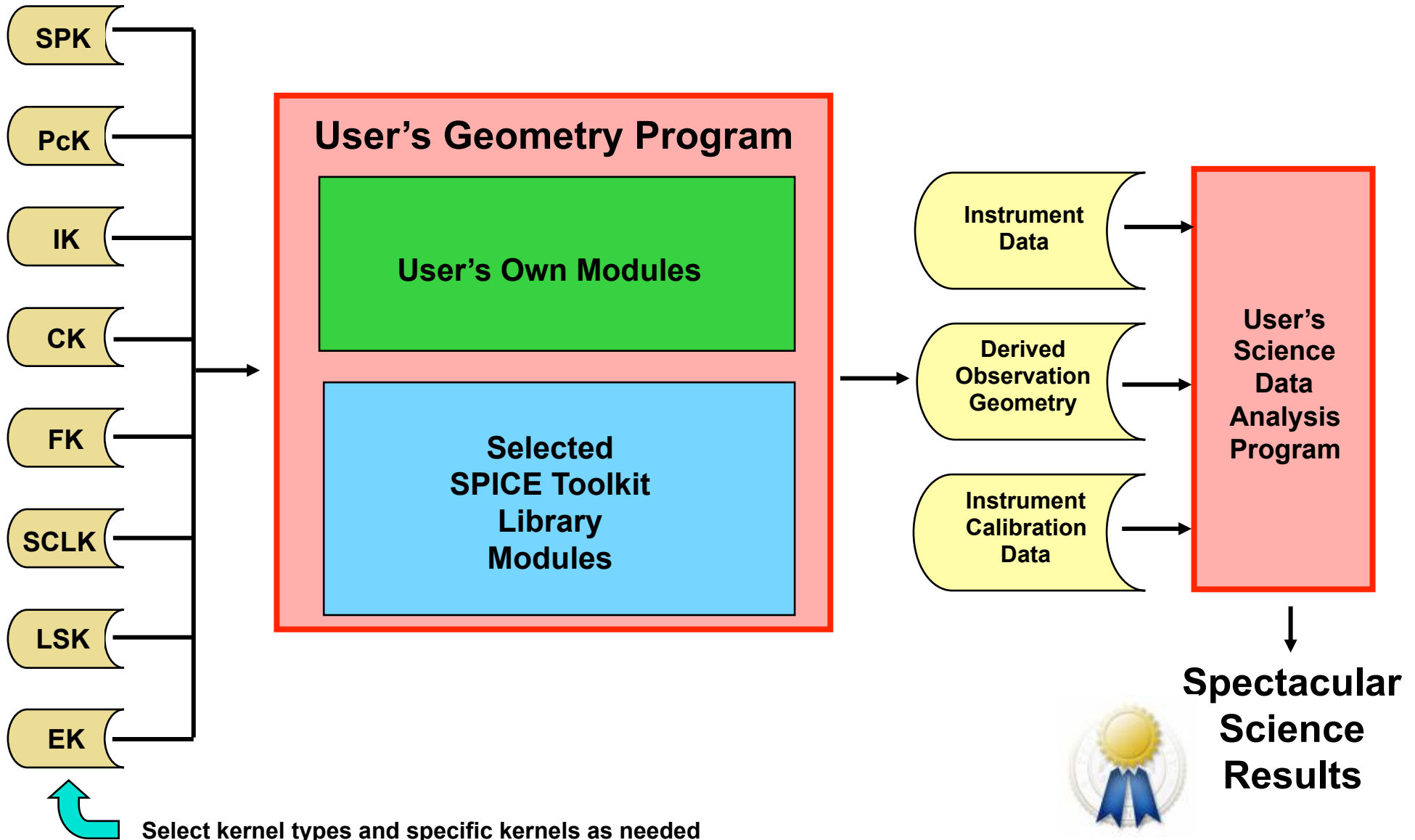






# Science Data Analysis Example

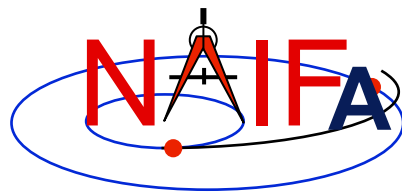
Navigation and Ancillary Information Facility



Select kernel types and specific kernels as needed  
Overview of SPICE

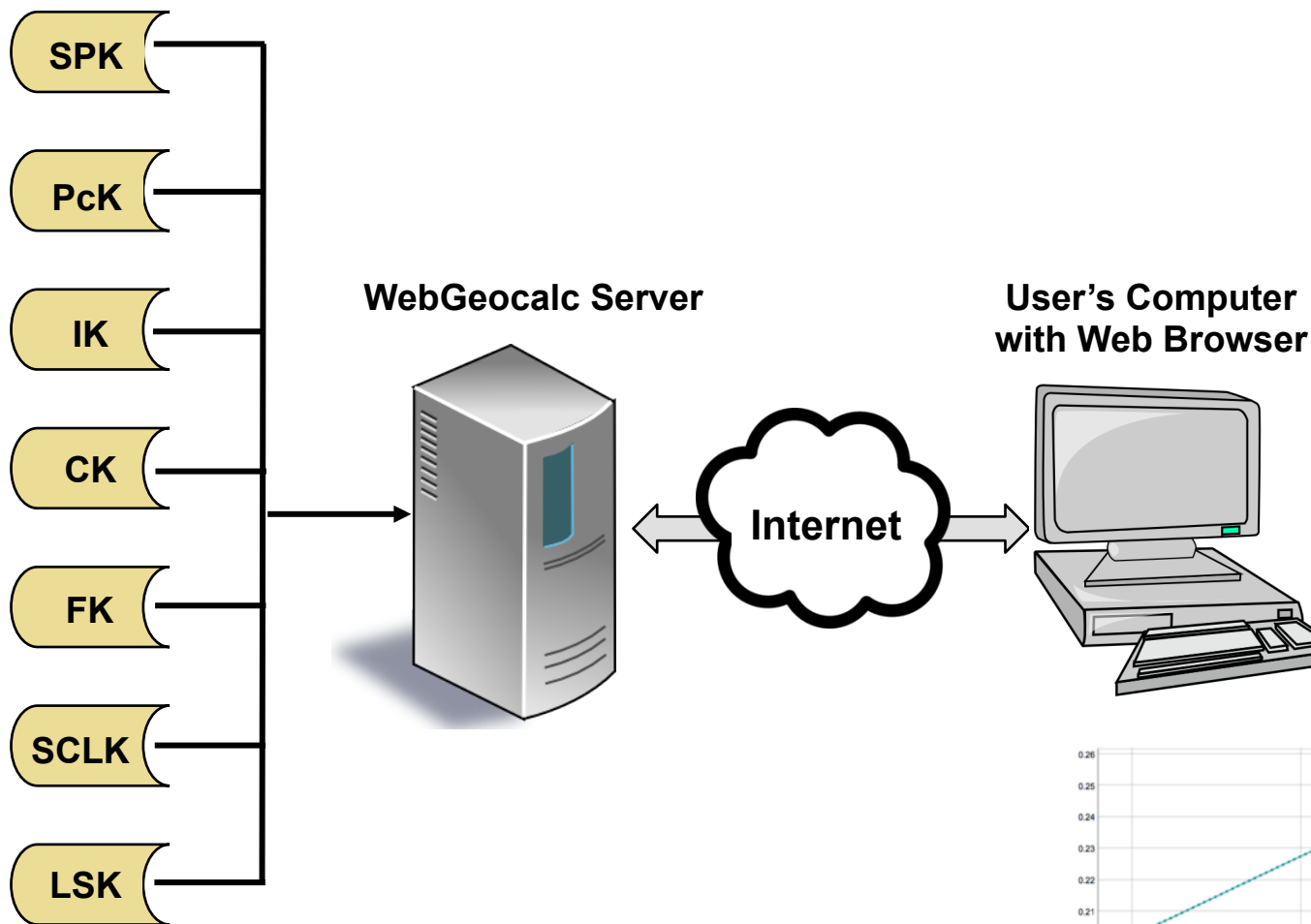


Spectacular  
Science  
Results



# Using SPICE: Science Data Peer Review Example

Navigation and Ancillary Information Facility

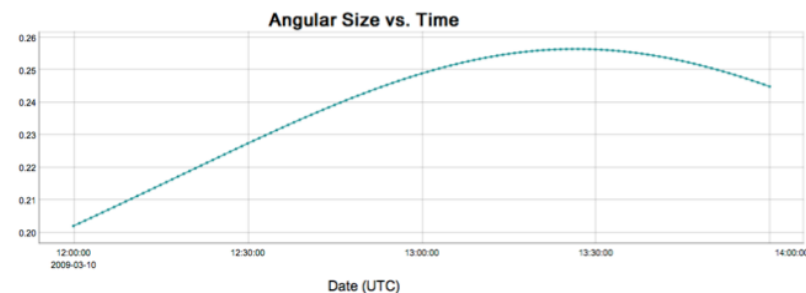


## Tabular Results

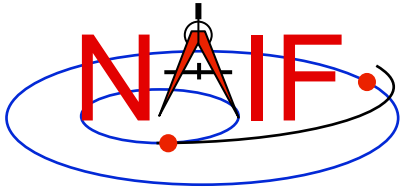
Click a value to save it for a subsequent calculation.

	UTC calendar date	Angular Size (deg)
1	2009-03-10 12:00:00.000000 UTC	0.20212256
2	2009-03-10 12:01:00.000000 UTC	0.20294481
3	2009-03-10 12:02:00.000000 UTC	0.20377024
4	2009-03-10 12:03:00.000000 UTC	0.20459871
5	2009-03-10 12:04:00.000000 UTC	0.20543007
6	2009-03-10 12:05:00.000000 UTC	0.20626418
7	2009-03-10 12:06:00.000000 UTC	0.20710088
8	2009-03-10 12:07:00.000000 UTC	0.20794000
9	2009-03-10 12:08:00.000000 UTC	0.20878138
10	2009-03-10 12:09:00.000000 UTC	0.20962484
11	2009-03-10 12:10:00.000000 UTC	0.21047019
12	2009-03-10 12:11:00.000000 UTC	0.21131725
13	2009-03-10 12:12:00.000000 UTC	0.21216581

**Numeric Results**  
**Graphic Results**



*Angular size of Phobos as seen from the Mars rover "SPIRIT"*

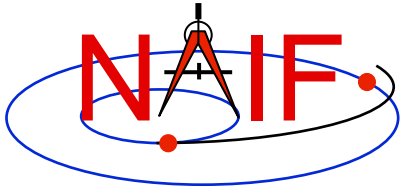


# SPICE System Characteristics - 1

---

Navigation and Ancillary Information Facility

- **SPICE Toolkit software is portable between computers**
- **New Toolkits are released irregularly, as need and time permit**
- **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**
- **Software includes built-in exception handling**
  - **Catches most invalid inputs**



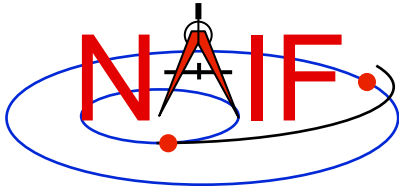
# SPICE System Characteristics - 2

---

Navigation and Ancillary Information Facility

- **All numeric computations are double precision**
- **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 kernel family
- **SPICE kernels and software are free of licensing and U.S. ITAR restrictions**
  - Everyone is free to use SPICE
- **No cost to individual end users**



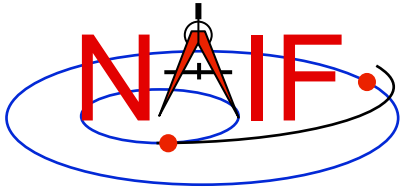


# Supported Environments

---

Navigation and Ancillary Information Facility

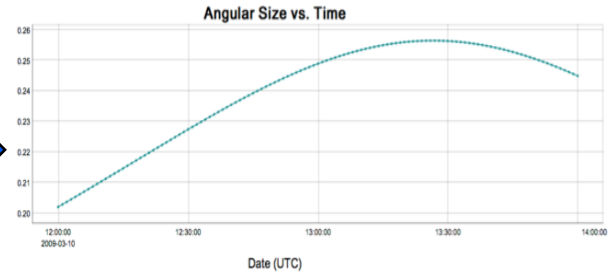
- **The SPICE Toolkit has been ported to many popular “environments”**
  - Each environment is characterized by...
    - » Language
    - » Hardware type (platform)
    - » Operating System
    - » Compiler (where applicable)
    - » Selected compilation options (32-bit or 64-bit)
- **NAIF provides separate, 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



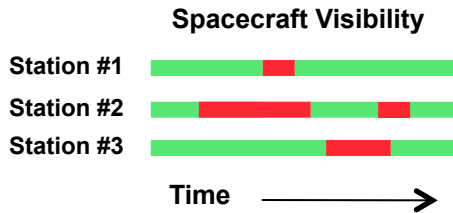
# How is SPICE Used ?

Navigation and Ancillary Information Facility

Evaluation of a planned trajectory

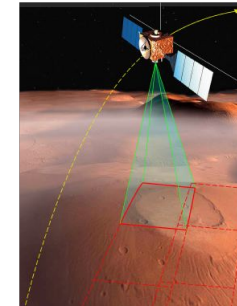


Angular size of Phobos as seen from the Mars rover "SPIRIT"

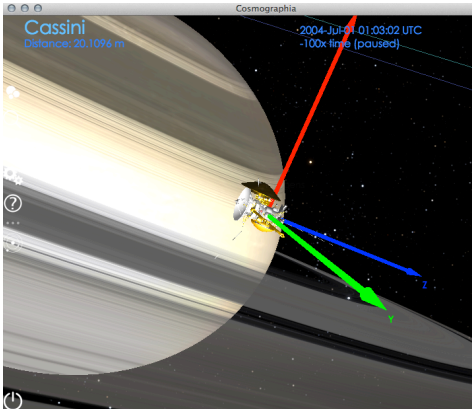


Mission engineering analyses

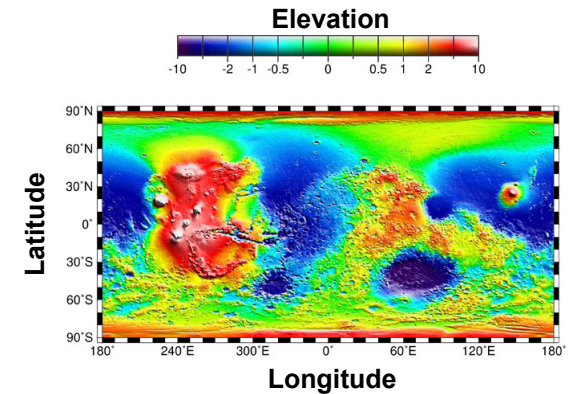
Planning an instrument pointing profile

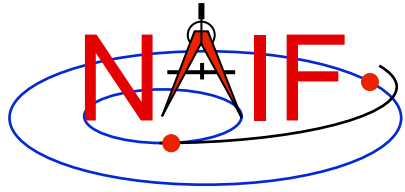


Observation geometry visualization



Science data archiving and analysis



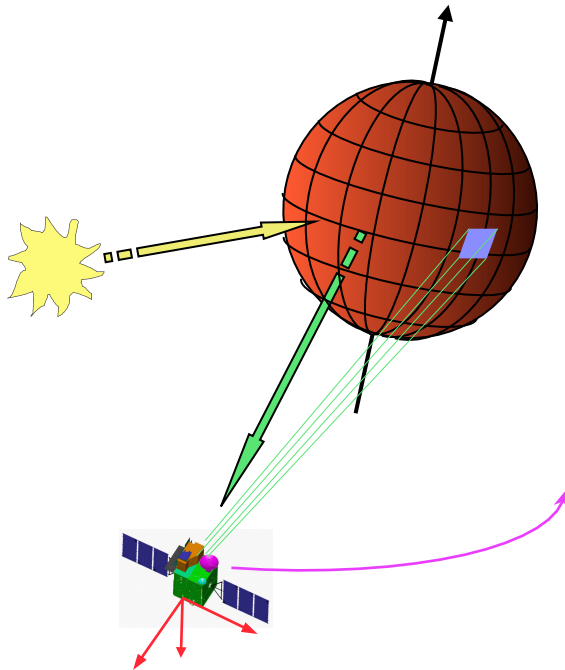


# What Can One Do With SPICE?

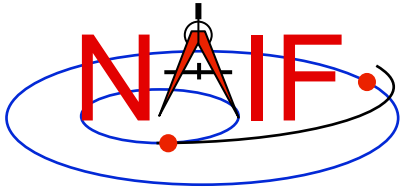
Navigation and Ancillary Information Facility

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

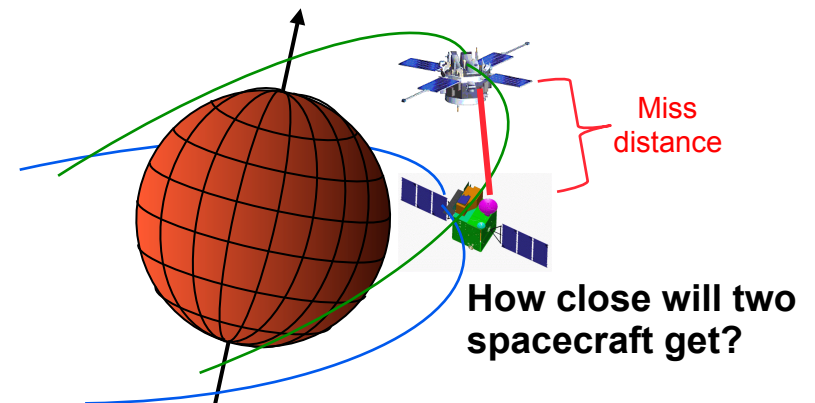
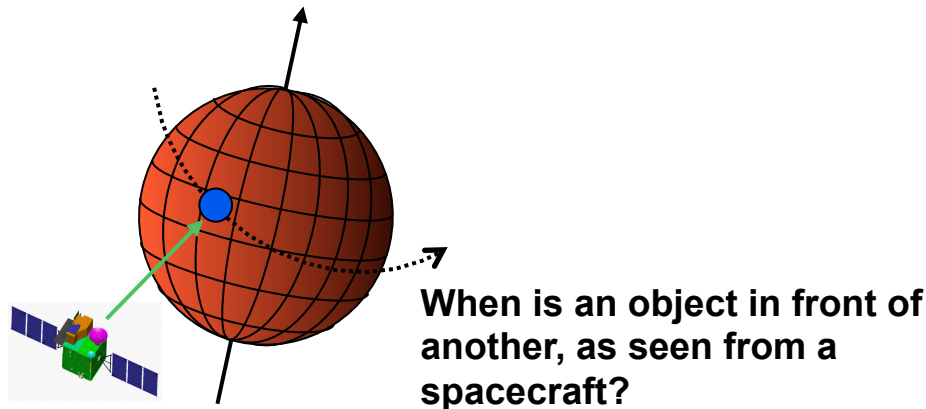
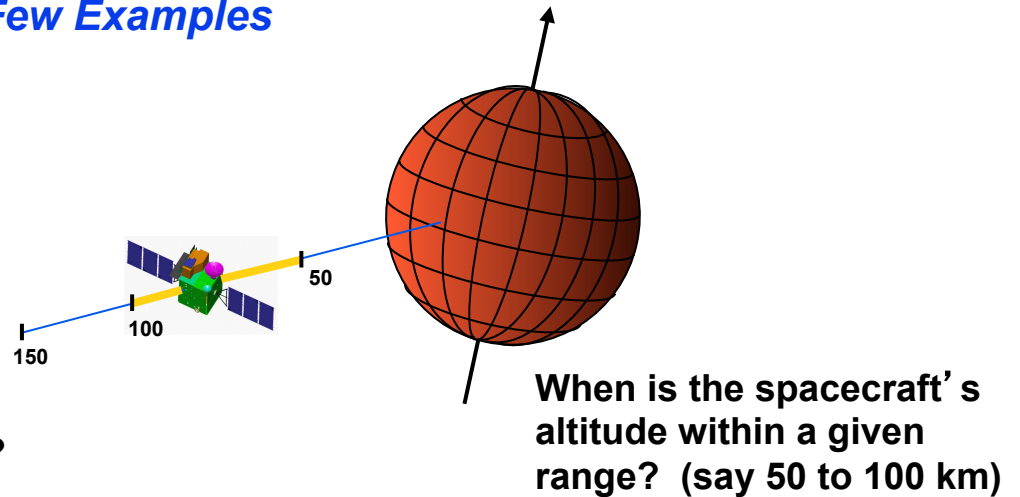
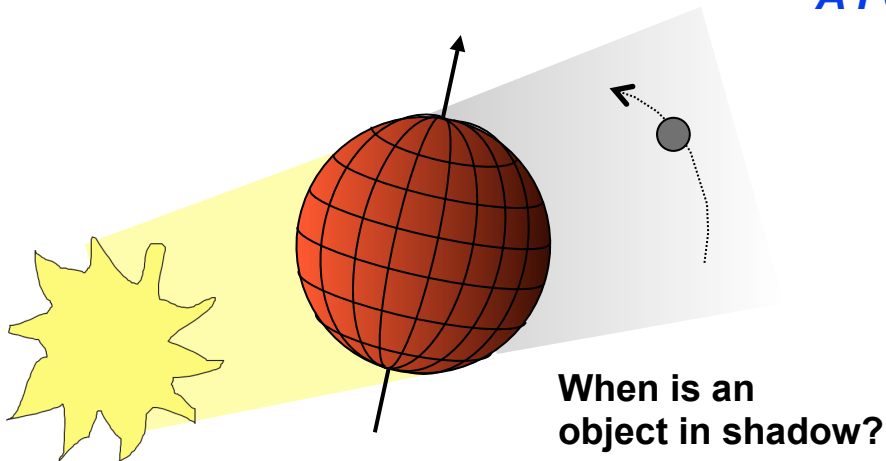


# What Can One Do With SPICE?

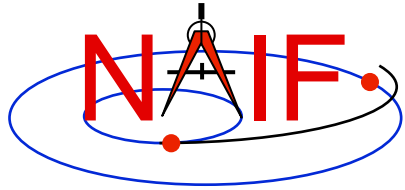
Navigation and Ancillary Information Facility

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

## A Few Examples



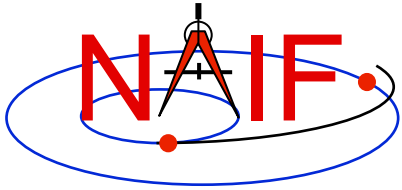




# What “Vehicle” Types Can Be Supported?

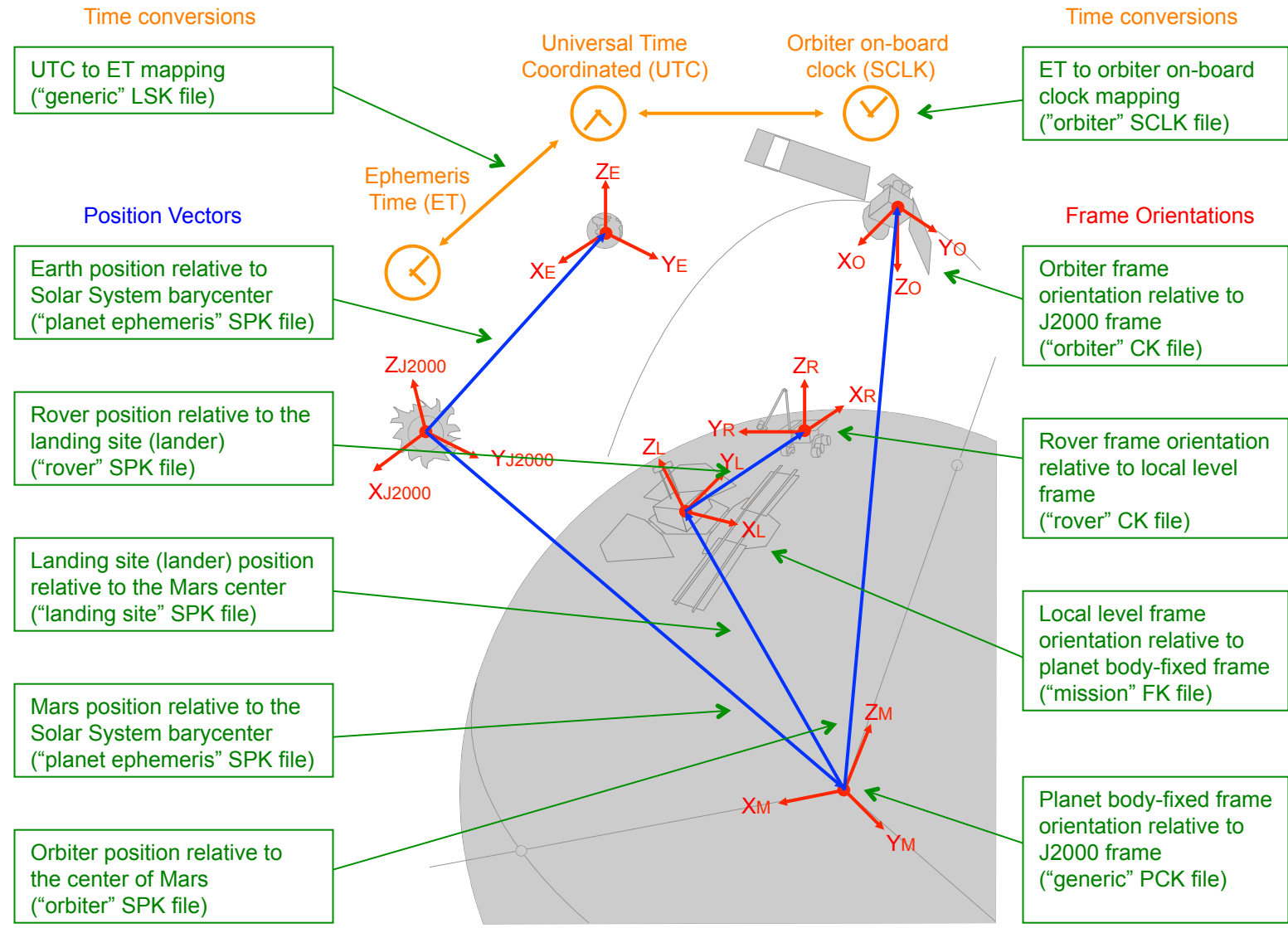
Navigation and Ancillary Information Facility

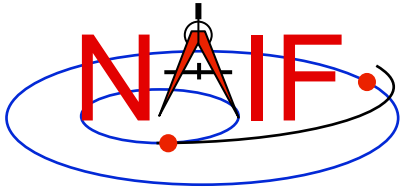
- **Cruise/Flyby**
  - Remote sensing
  - In-situ measurement
  - Instrument calibration
- **Orbiters**
  - Remote sensing
  - In-situ measurement
  - Communications relay
- **Balloons and aircraft\***
  - Remote sensing
  - In-situ measurements
- **Landers**
  - Remote sensing
  - In-situ measurements
  - Rover or balloon relay
- **Rovers**
  - Remote sensing
  - In-situ sensing
  - Local terrain characterization
- **Terrestrial applications**
  - Ephemerides for telescopes
  - Radiometric tracking & comm
  - Optical tracking & comm



# Global SPICE Geometry

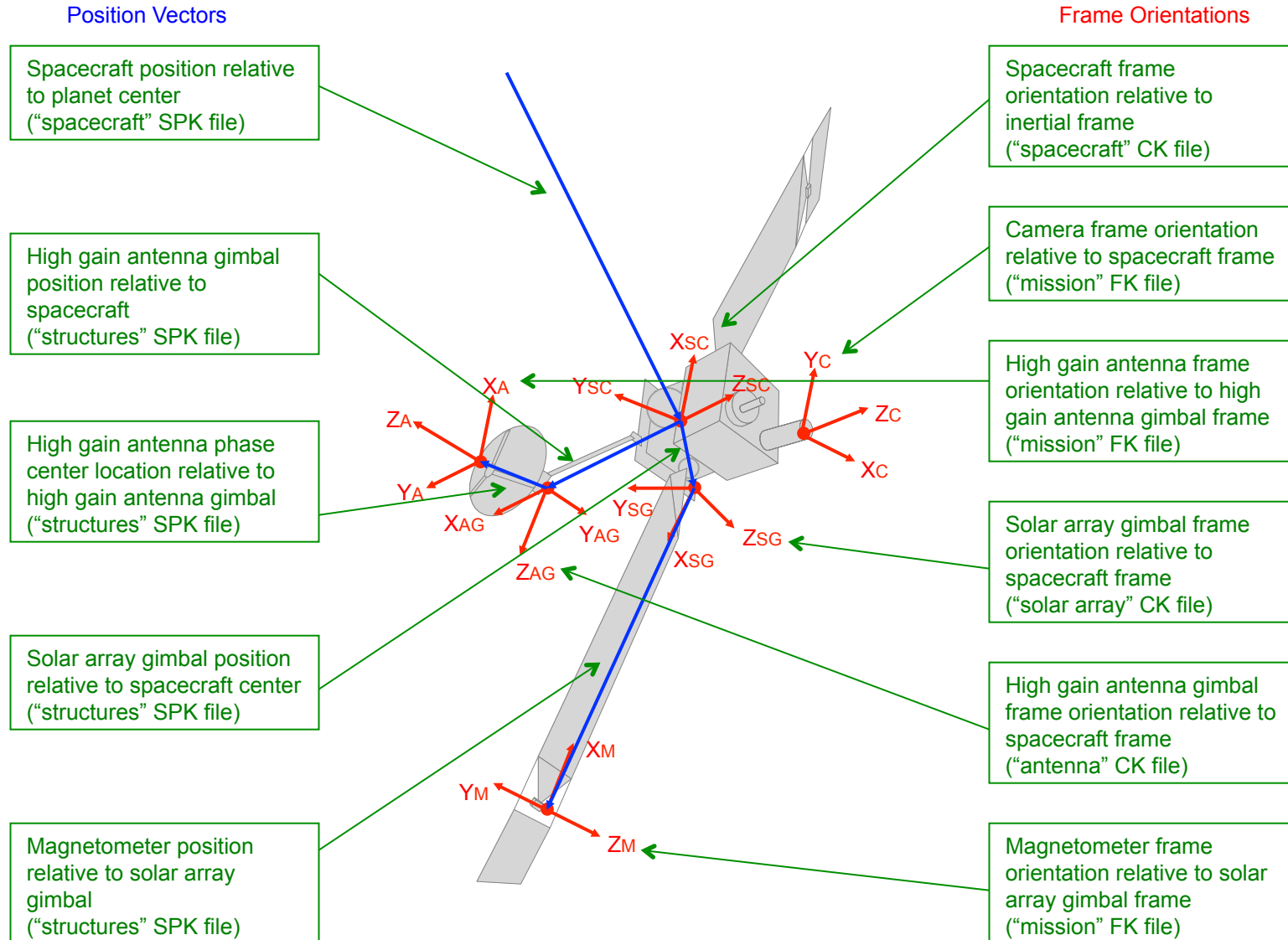
## Navigation and Ancillary Information Facility

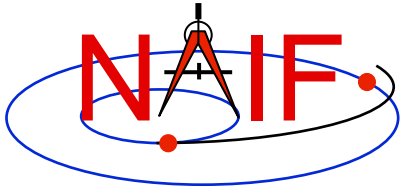




# Orbiter Geometry

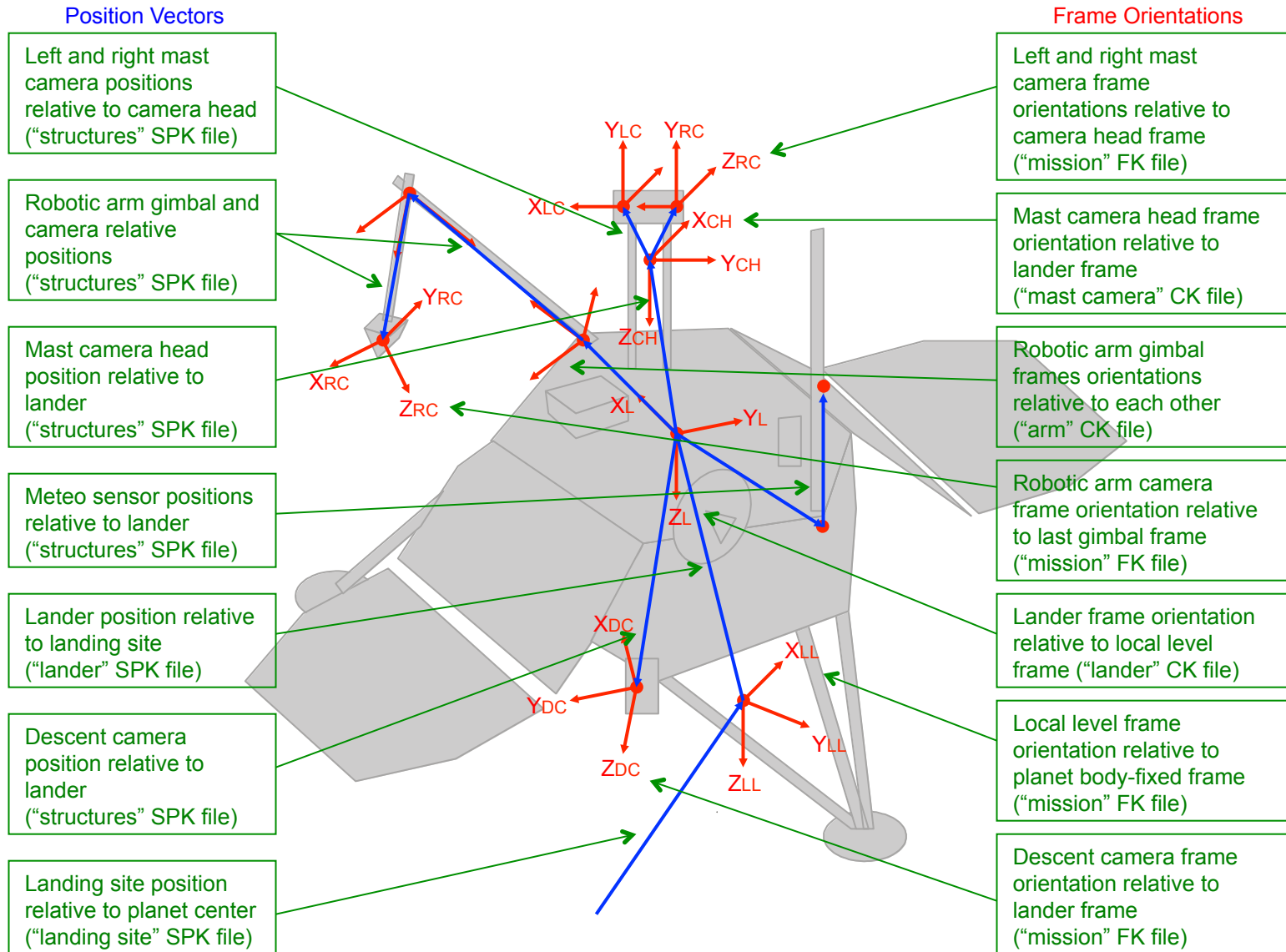
## Navigation and Ancillary Information Facility

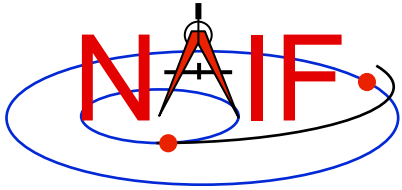




# Lander Geometry

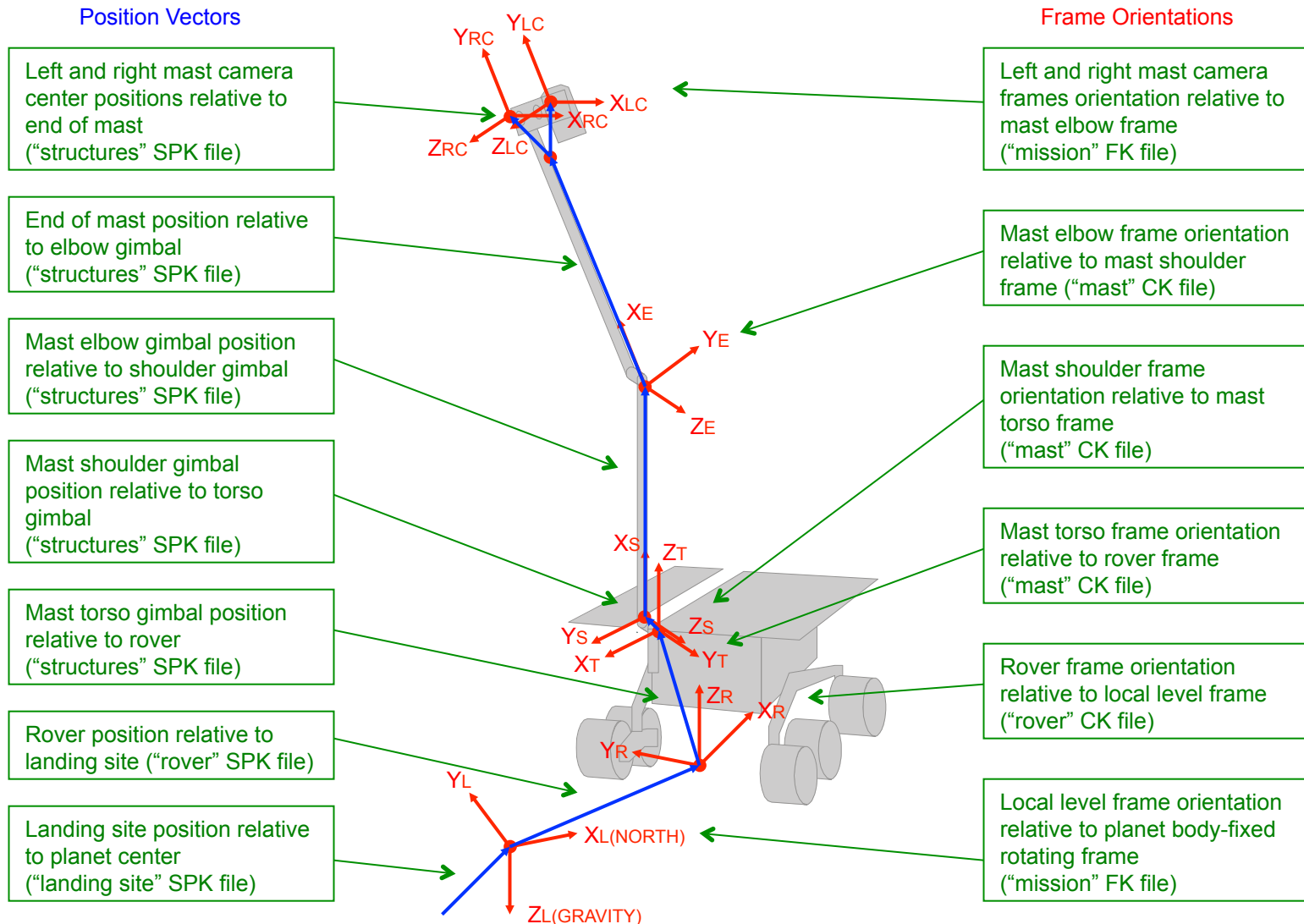
## Navigation and Ancillary Information Facility

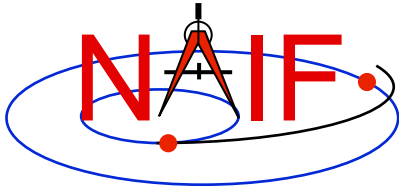




# Rover Geometry

## Navigation and Ancillary Information Facility



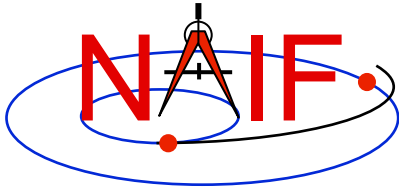


# Ancillary Data Archives

---

Navigation and Ancillary Information Facility

- **SPICE is the U.S. Planetary Data System's de facto standard for archiving ancillary data**
  - But its use is not a formal requirement
- **Use of SPICE is recommended by the International Planetary Data Alliance**
  - But its use is not a requirement
- **SPICE data for European planetary missions are archived in ESA's Planetary Science Archive**
  - Some of these data will be mirrored on the NAIF server
- **SPICE data for some Japanese, Indian and Russian missions may be available from their local archives**

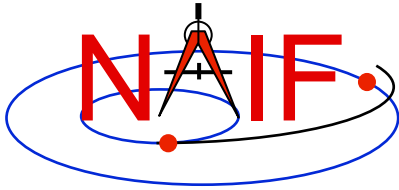


# SPICE Users

## Navigation and Ancillary Information Facility

<i>Data Restorations</i>	<i>Selected Past Users</i>	<i>Current/Pending Users</i>	<i>Possible Future Users</i>
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) [F]	Mars Exploration Rover	ExoMars 2018 (ESA, RSA)
Mariner 10 [L]	Mars Pathfinder	Mars Reconnaissance Orbiter	ARM (HEOMD)
Viking Orbiters [L]	NEAR	DAWN	<b><i>Examples of External Users</i></b>
Viking Landers [L]	Deep Space 1	Mars Science Lab	Emmirates Mars Mission (UAE via LASP)
Pioneer 10/11/12 [L]	Galileo	Juno	Bevo-2 CubeSat (U.T. Austin, Texas A&M)
Haley armada [L]	Genesis	MAVEN	Space Launch Systems (HEOMD)
Phobos 2 [L] (RSA)	Deep Impact	SMAP (Earth Science)	Proba-3 (ESA)
Ulysses [L]	Huygens Probe (ESA) [L]	OSIRIS REx	Solar Probe Plus
Voyagers [L]	Stardust/NExT	InSight	EUMETSAT GEO satellites [L]
Lunar Orbiter [L]	Mars Global Surveyor	Mars 2020	MOM (ISRO)
Helios 1,2 [L]	Phoenix	Europa Clipper	BepiColombo (ESA, JAXA)
	EPOXI	NISAR (NASA/ISRO; Earth Science)	JUICE (ESA)
	GRAIL	Lunar Reconnaissance Orbiter	Solar Orbiter (ESA)
	Messenger	New Horizons	Chang'e 3 ? (CNSA)
	Phobos Sample Return (RSA) [F]	Mars Express (ESA)	Van Allen Probes [L]
	Venus Express (ESA)	Rosetta (ESA)	STEREO [L]
	Chandrayaan-1 (ISRO)	ExoMars 2016 (ESA, RSA)	Spitzer Space Telescope [L]
	Hayabusa (JAXA)	Akatsuki (JAXA)	Kepler [L]
[L] = limited use	Kaguya (JAXA)	Hayabusa-2 (JAXA)	Hubble Space Telescope [S][L]
[S] = special services	LADEE		Radioastron (RSA) [L]
[F] = mission failed	ISO [S] (ESA)		IBEX [L]
	CONTOUR [F]	Planetary Data System	James Webb Space Telescope [S][L]
	Space VLBI [L] (multinational)	Planetary Science Archive (ESA)	JPL's Solar System Dynamics Group [S][L]
<b>Last updated: 12/3/15</b>	Smart-1 (ESA)	NASA Deep Space Network [S]	International Astronomical Union [L]

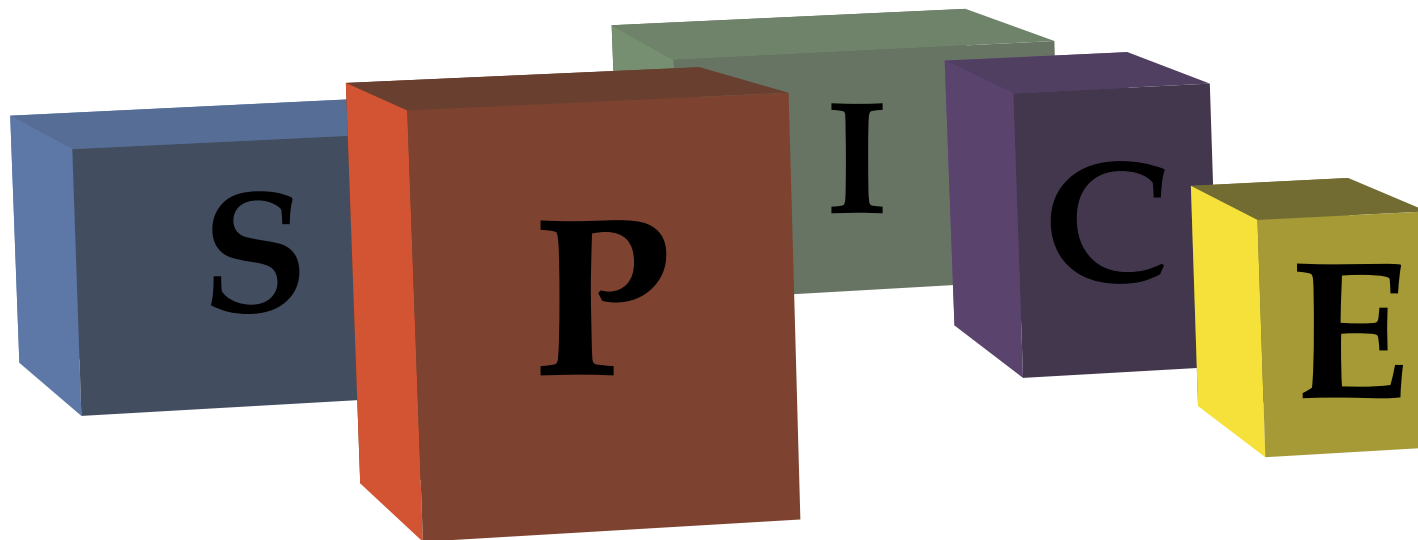
- NAIF has or had project-supplied funding to support mission operations, consultation for flight team members, and SPICE data archive preparation. NAIF also has PDS funding to help scientists and students with using SPICE data that have been officially archived at the NAIF Node of the PDS.
- NAIF has or had NASA funding to support a foreign partner in SPICE deployment and archive review, 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 or had modest PDS-supplied funding to consult on assembly of a SPICE archive.
- NAIF has PDS funding to help NASA funded scientists using SPICE data that have been officially archived at the NAIF Node of the PDS.



# 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 supporting multi-mission, international space exploration programs.



**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.