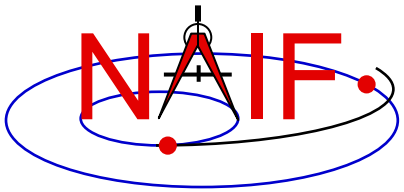


Navigation and Ancillary Information Facility

An Overview of SPICE

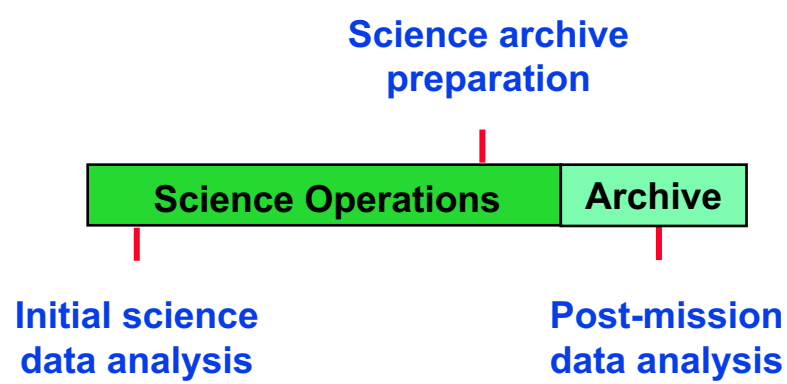
NASA's Ancillary Data System for Planetary Missions

January 2017

Original Purpose for SPICE

Navigation and Ancillary Information Facility

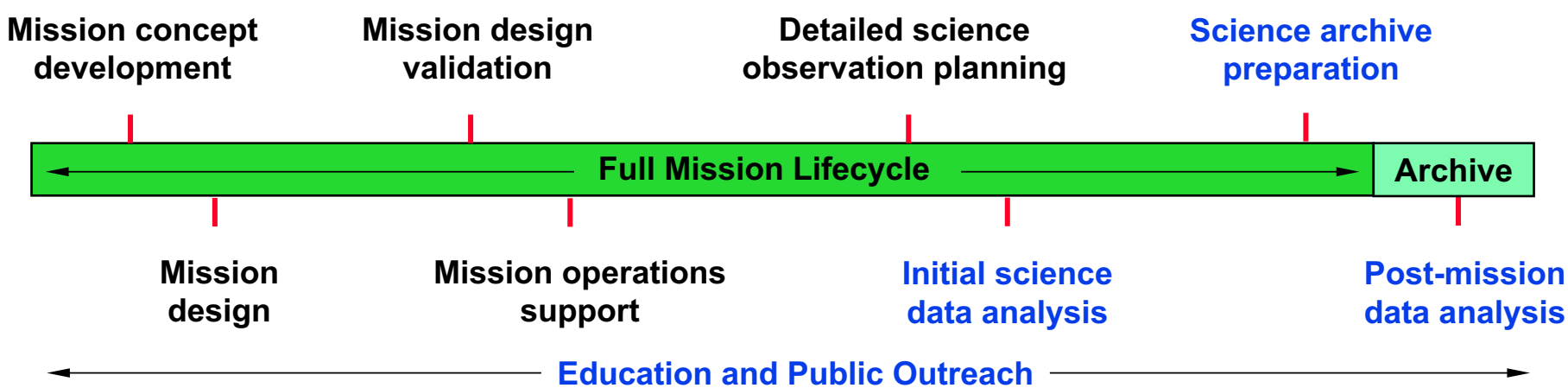
- **The original focus of SPICE was on ancillary data and associated software needed by planetary scientists for:**
  - **initial science data analysis**
  - **science archive preparation**
  - **post-mission data analysis**

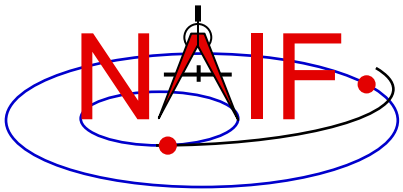


Large Breadth of Use

Navigation and Ancillary Information Facility

- The original focus of SPICE was on ancillary data and associated software needed by planetary 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.

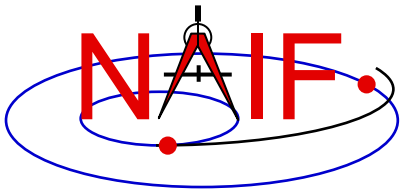




More Than Just Planetary Science

Navigation and Ancillary Information Facility

- **Today SPICE is used well beyond just planetary science missions.**
  - **Heliophysics**
  - **Earth science**
  - **Observations from terrestrial observatories**
  - **National defense applications**
  - **Probably still more…?**



History

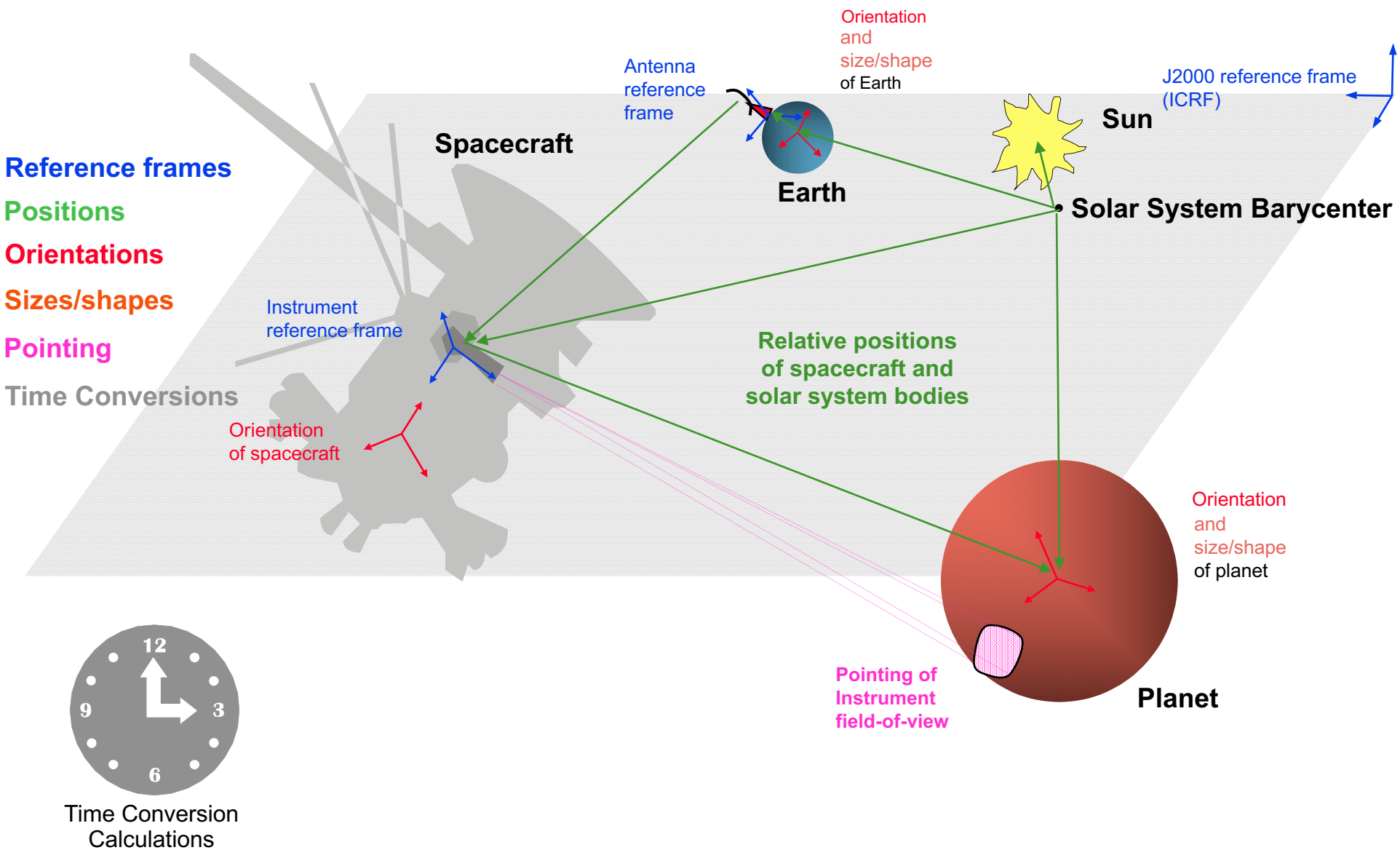
- Implementation of a precursor to SPICE was initiated in 1984 as part of a major initiative to improve archiving and distribution of space science data in all NASA disciplines

- At that time 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



How Use “Ancillary Data”?

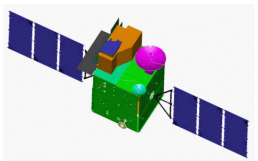
- “Ancillary data” are those that help scientists and engineers determine:
  - where the spacecraft was located
  - how the spacecraft and its instruments were oriented (pointed)
  - what was the location, size, shape and orientation of the target being observed

- 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

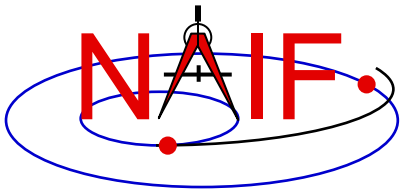


- From the mission control center

- 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?

- **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 a 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”)……..……

1100
1010
0101

Software (SPICE Toolkit) ……..

Documentation ……..…..

Tutorials ……..…..

Programming lessons …..

Training classes ……

User consultation ……..…..

Origin of the SPICE Acronym*

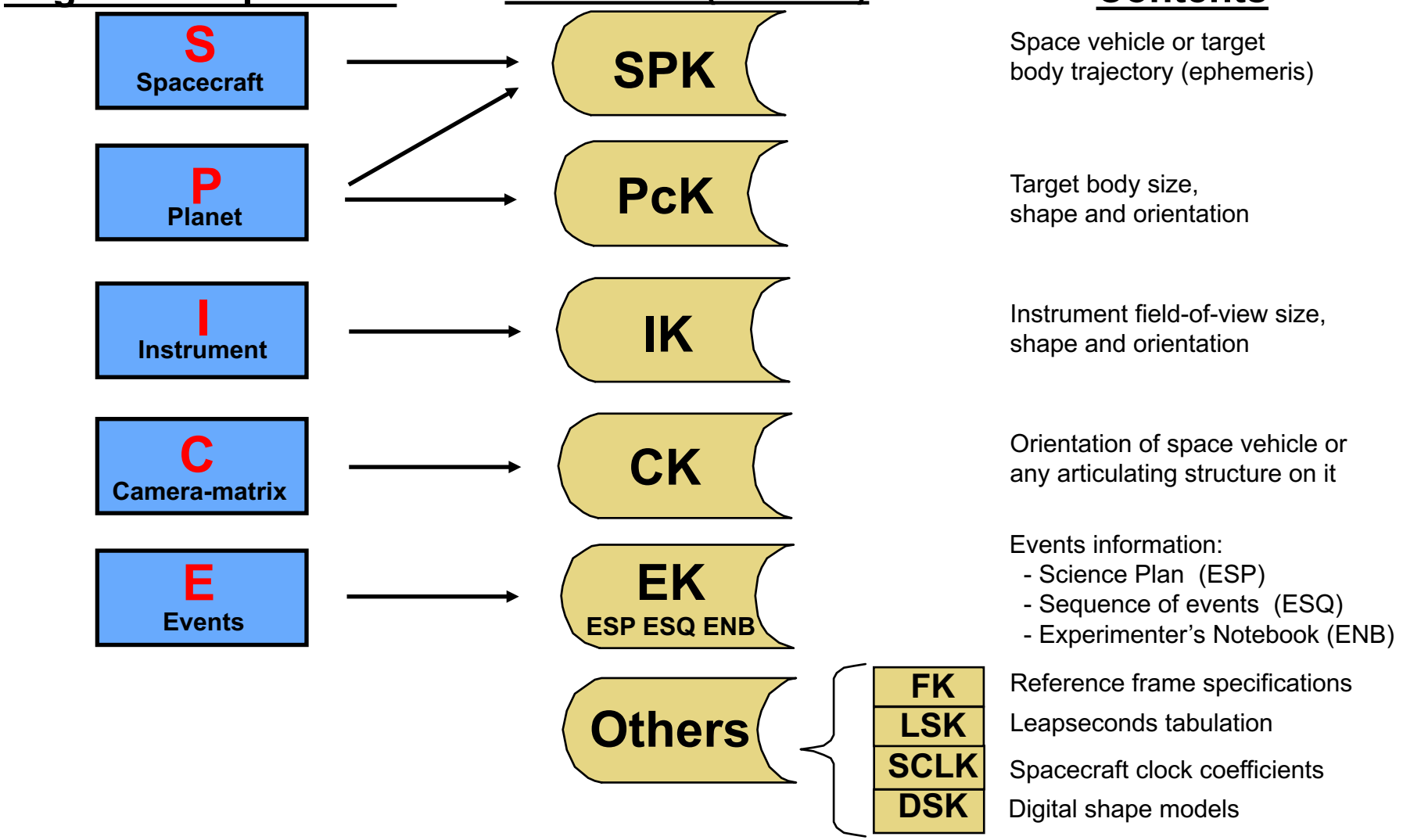
Navigation and Ancillary Information Facility

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



SPICE Kernels 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 Kernels 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 Kernels Details - 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)

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 (~1400)**
  - But typically just a few are 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

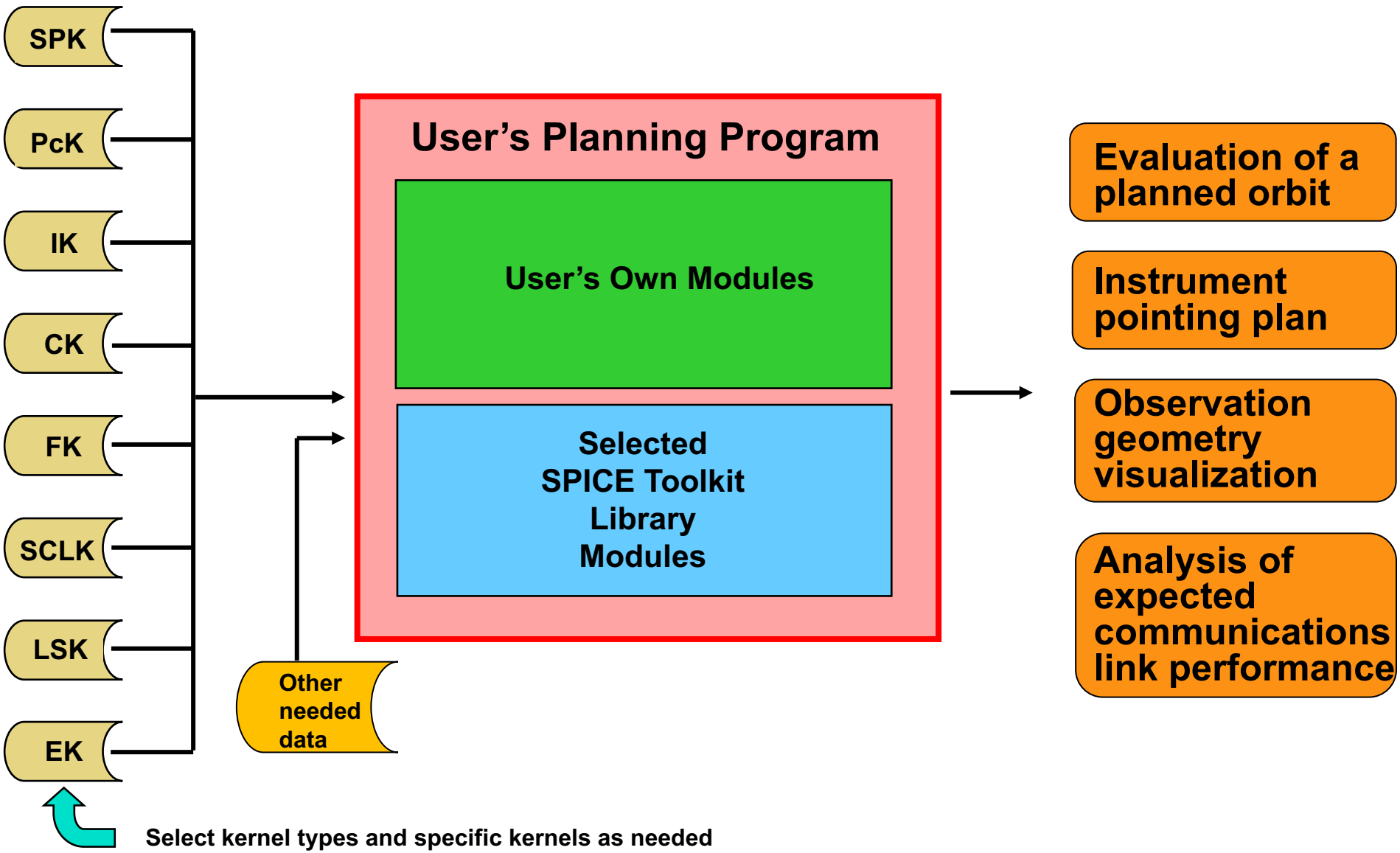
* 30 are available from the NAIF website

Versions

- **Five languages**
  - Fortran 77
  - C
  - Interactive Data Language (IDL)
  - MATLAB
  - Python (provided by others)
  - An alp[ha-test version of a Java Native Interface toolkit is also available for those interested
- **Four platforms**
  - PC/Linux
  - PC/Windows
  - Sun/Solaris
  - Mac/OSX
- **Several compilers**
  - For the Fortran and C Toolkits

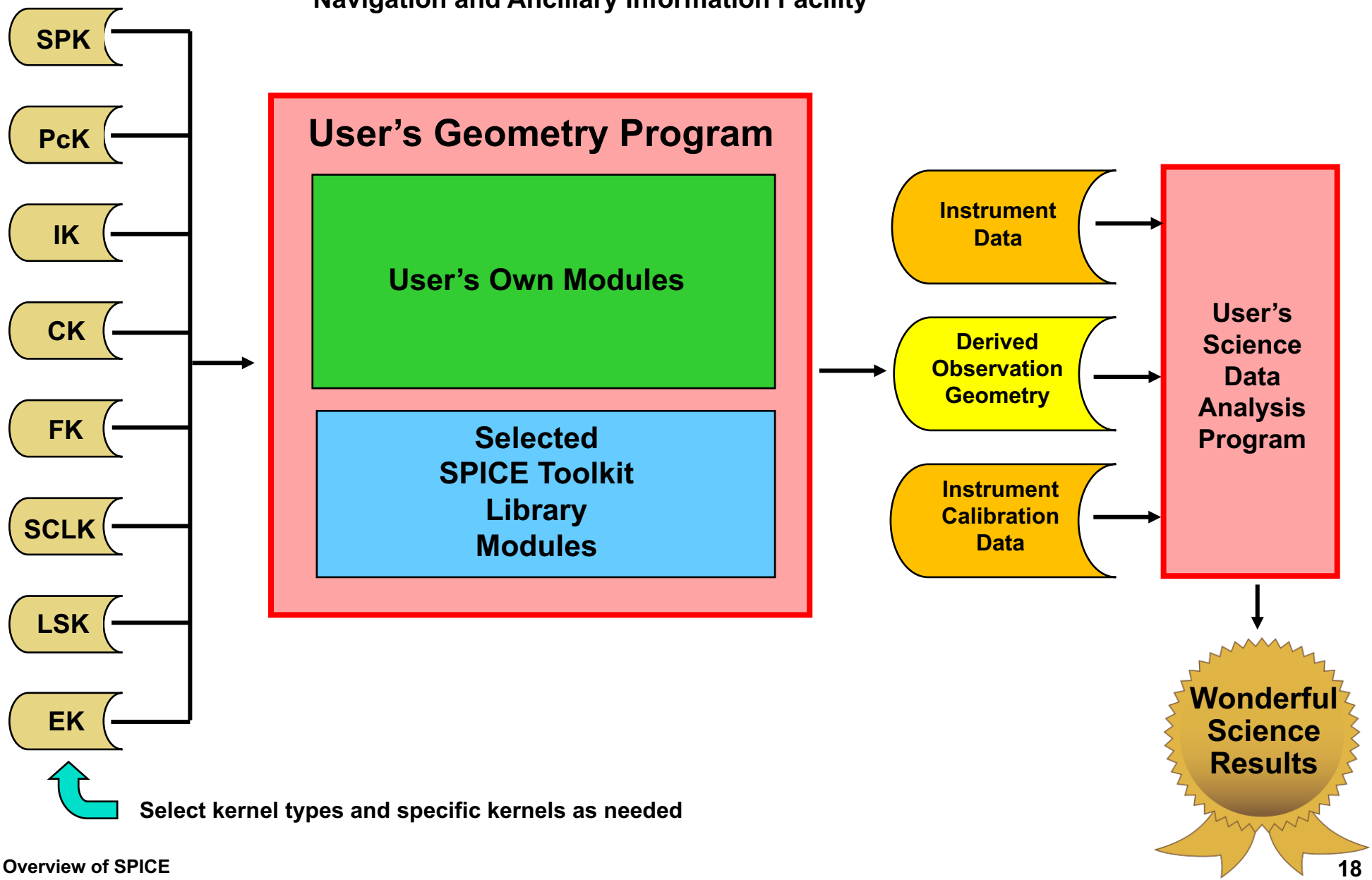
Using SPICE: A Mission Planning Example

Navigation and Ancillary Information Facility



Using SPICE: A Science Data Analysis Example

Navigation and Ancillary Information Facility



Using SPICE: A Science Data Peer Review Example

Navigation and Ancillary Information Facility

SPK

PcK

IK

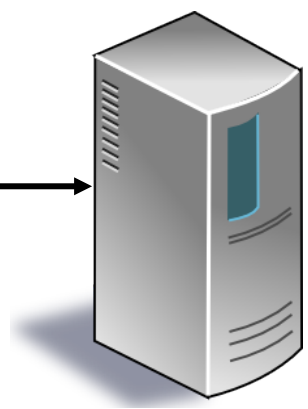
CK

FK

SCLK

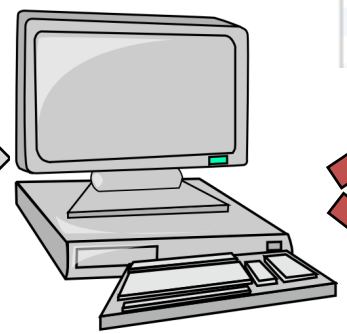
LSK

WebGeocalc Server



Internet

User's Computer with Web Browser



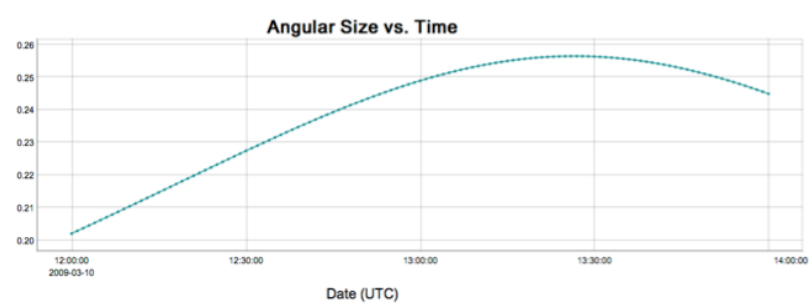
Tabular Results

Click a value to save it for a subsequent calculation.

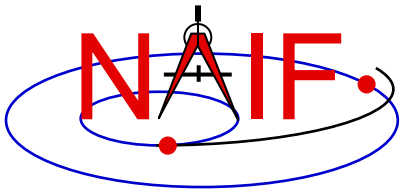
	UTC calendar date	Angular Size (deg)
1	2009-03-10 12:00:00.000000 UTC	0.20212256
2	2009-03-10 12:01:00.000000 UTC	0.20294481
3	2009-03-10 12:02:00.000000 UTC	0.20377024
4	2009-03-10 12:03:00.000000 UTC	0.20459871
5	2009-03-10 12:04:00.000000 UTC	0.20543007
6	2009-03-10 12:05:00.000000 UTC	0.20626418
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

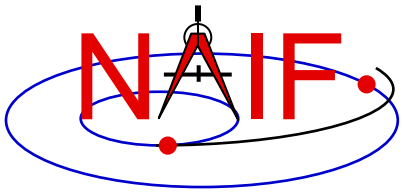
Navigation and Ancillary Information Facility

- SPICE Toolkit software is portable between computers
- New Toolkits are released irregularly, as need and time permit
- Code is very 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

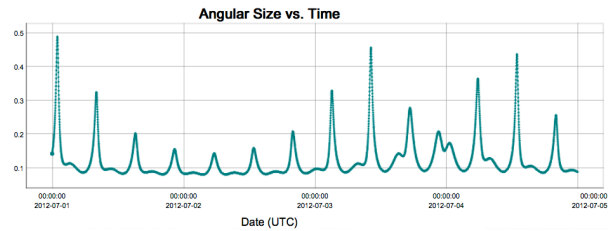
- The SPICE Toolkit has been ported to many popular "environments"
  - Each environment is characterized by…
    - » Language
    - » Hardware type (platform)
    - » Operating System
    - » Compiler (where applicable)
    - » Selected compilation options (32-bit or 64-bit)

- 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

Examples of How SPICE Is Used

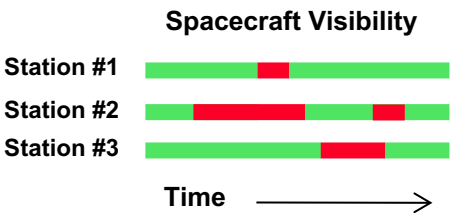
Navigation and Ancillary Information Facility

Evaluation of a planned trajectory

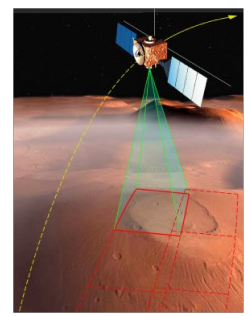


Angular size of Phobos As seen from the MEX spacecraft

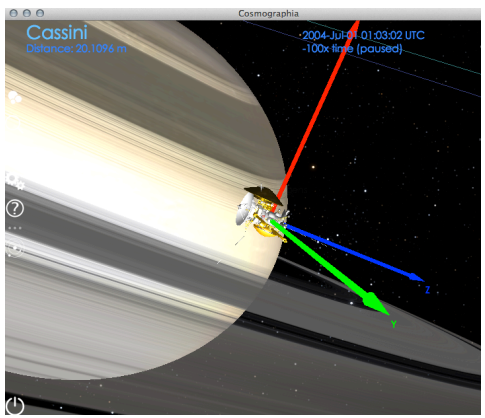
Mission engineering analyses



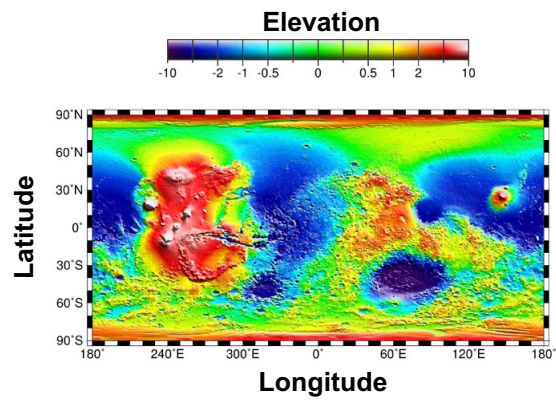
Planning an instrument pointing profile



Observation geometry visualization



Science data archiving and analysis

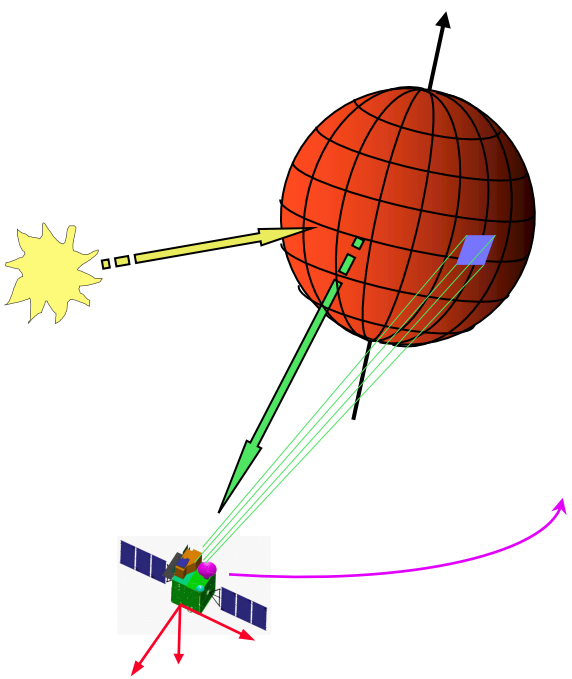


What Can One Do With SPICE?

Navigation and Ancillary Information Facility

Compute many kinds of observation geometry parameters at selected times

A Few Examples



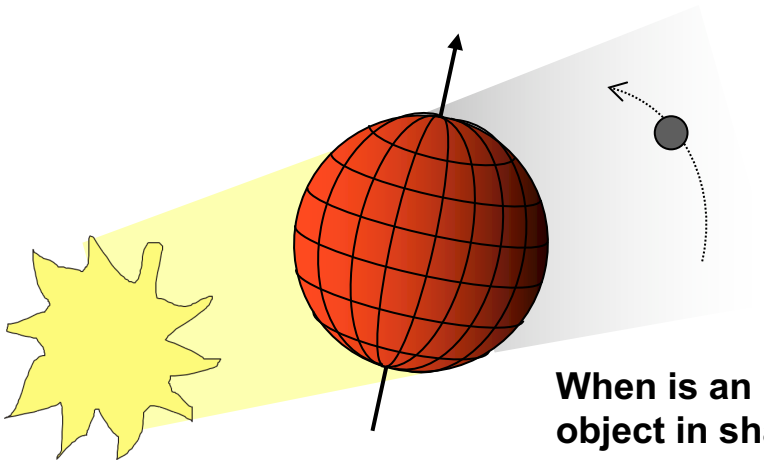
- **Positions and velocities of planets, satellites, comets, asteroids and spacecraft**
- **Size, shape and orientation of planets, satellites, comets and asteroids**
- **Orientation of a spacecraft and its various moving structures**
- **Instrument field-of-view location on a planet's surface or atmosphere**

What Can One Do With SPICE?

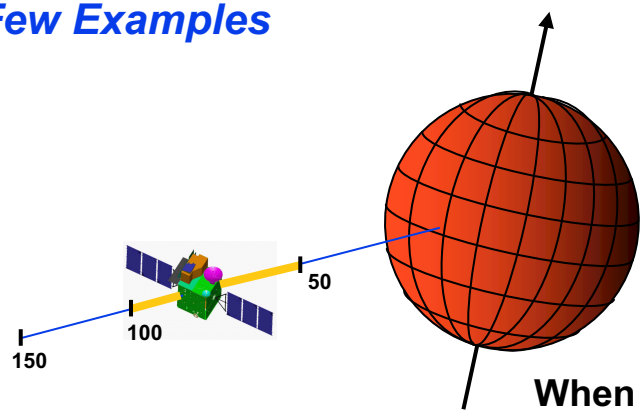
Navigation and Ancillary Information Facility

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

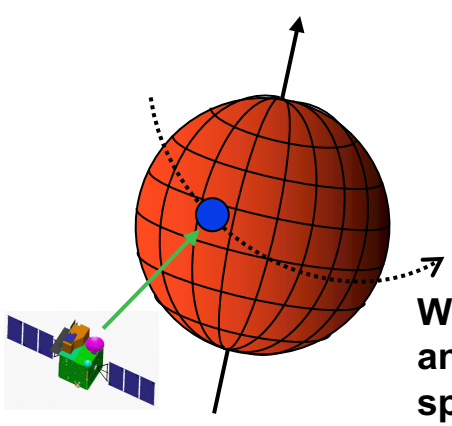
A Few Examples



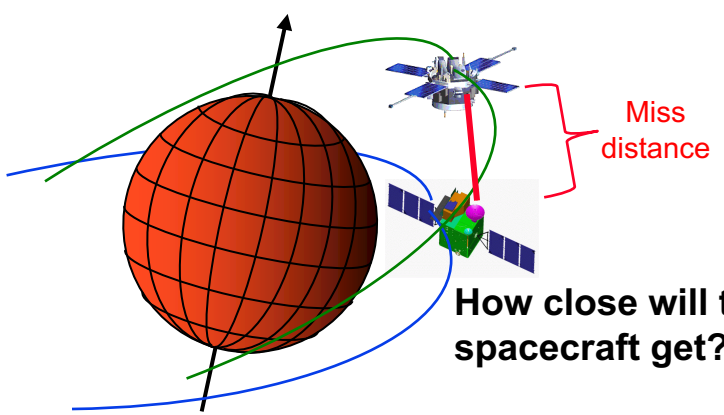
When is an object in shadow?



When is the spacecraft's altitude within a given range? (say 50 to 100 km)



When is an object in front of another, as seen from a spacecraft?



How close will two spacecraft get?

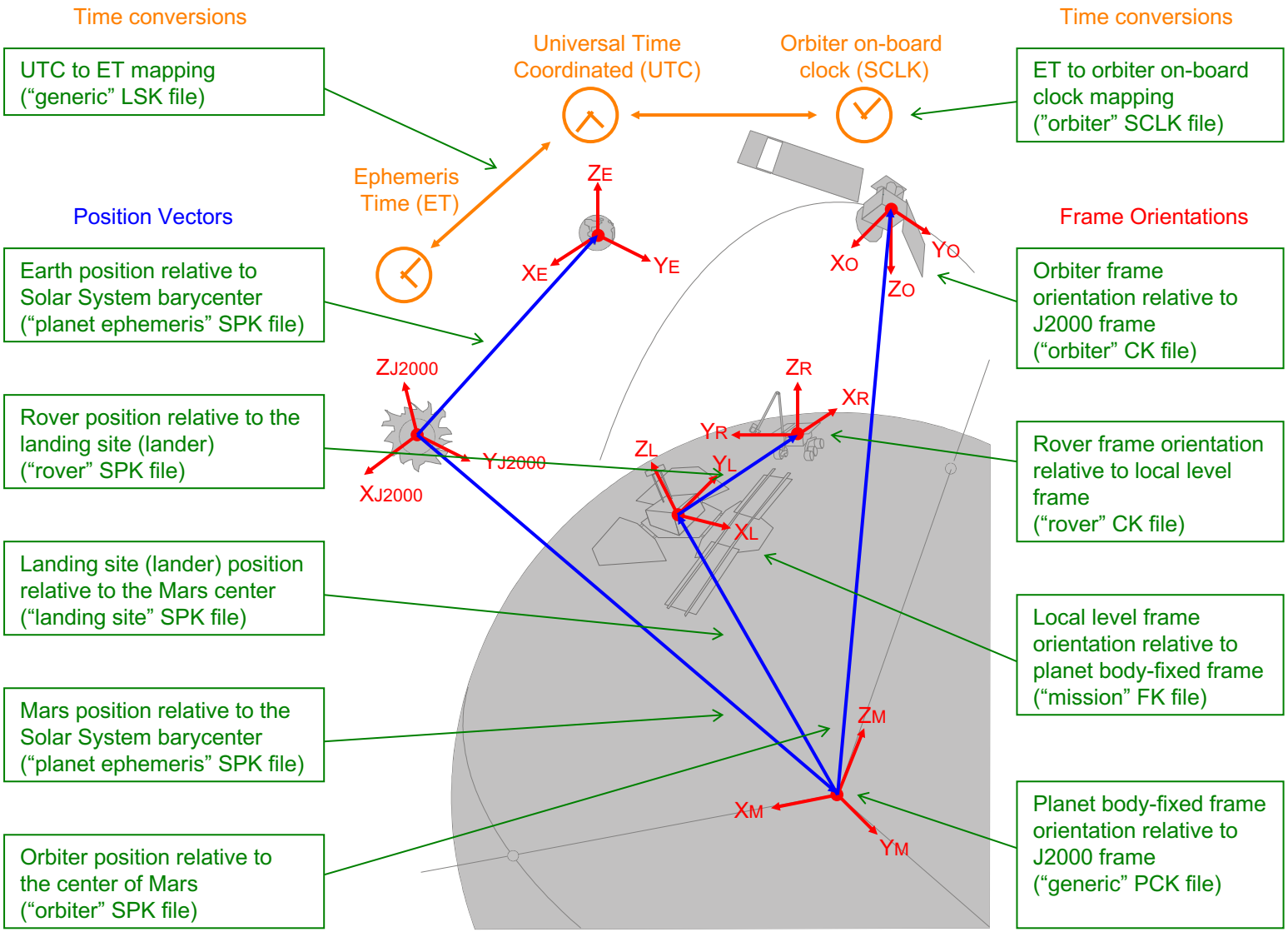
What "Vehicle" Types Can Be Supported?

- **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

* Not yet demonstrated

Global SPICE Geometry

Navigation and Ancillary Information Facility



Orbiter Geometry

Navigation and Ancillary Information Facility

Position Vectors

Spacecraft position relative to planet center (“spacecraft” SPK file)

High gain antenna gimbal position relative to spacecraft (“structures” SPK file)

High gain antenna phase center location relative to high gain antenna gimbal (“structures” SPK file)

Solar array gimbal position relative to spacecraft center (“structures” SPK file)

Magnetometer position relative to solar array gimbal (“structures” SPK file)

Frame Orientations

Spacecraft frame orientation relative to inertial frame (“spacecraft” CK file)

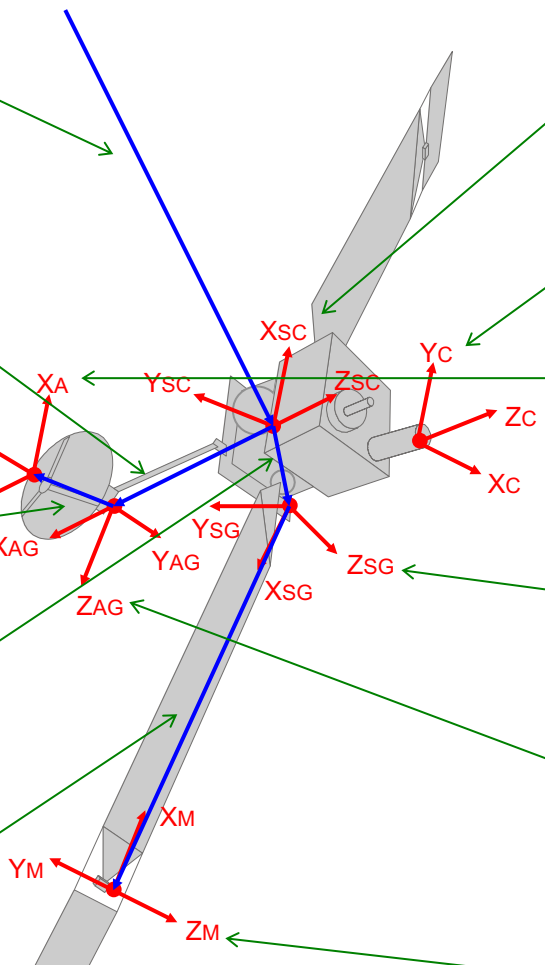
Camera frame orientation relative to spacecraft frame (“mission” FK file)

High gain antenna frame orientation relative to high gain antenna gimbal frame (“mission” FK file)

Solar array gimbal frame orientation relative to spacecraft frame (“solar array” CK file)

High gain antenna gimbal frame orientation relative to spacecraft frame (“antenna” CK file)

Magnetometer frame orientation relative to solar array gimbal frame (“mission” FK file)



Lander Geometry

Navigation and Ancillary Information Facility

Position Vectors

Left and right mast camera positions relative to camera head (“structures” SPK file)

Robotic arm gimbal and camera relative positions (“structures” SPK file)

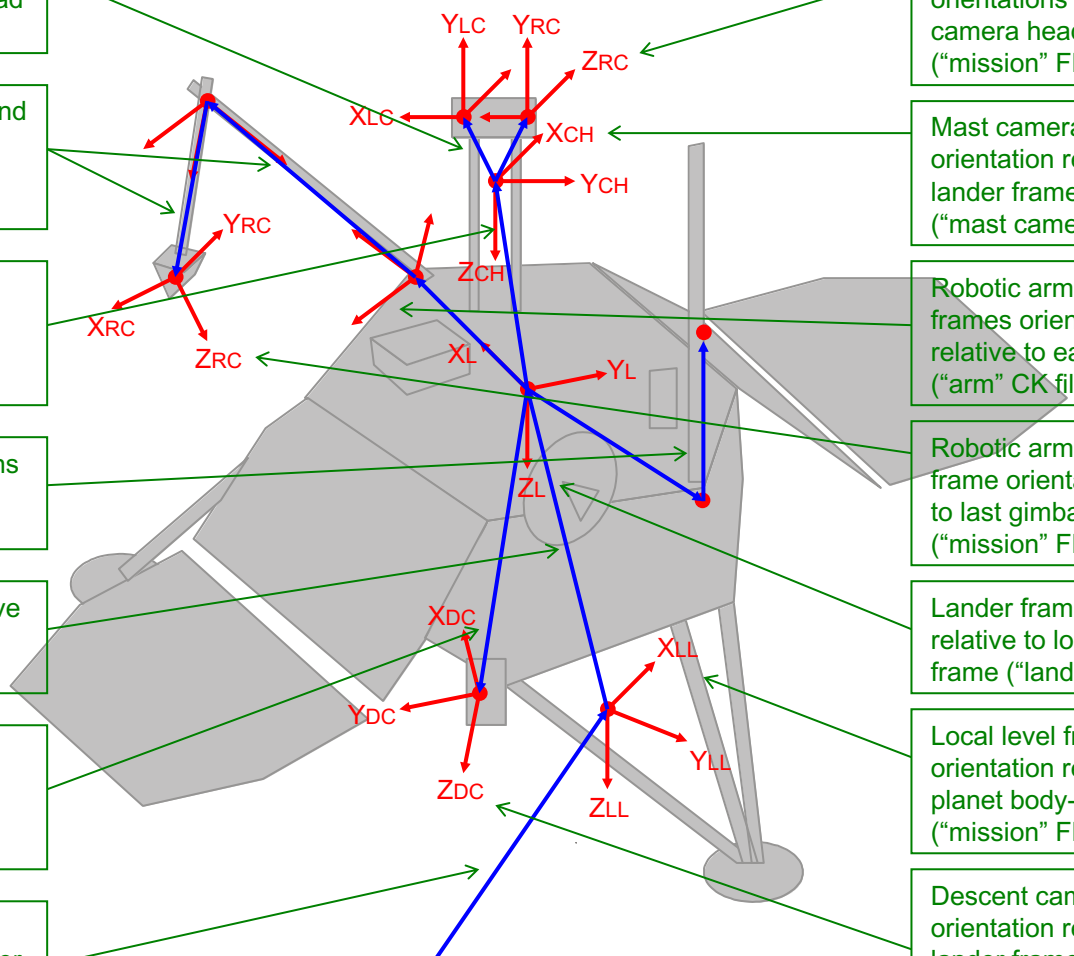
Mast camera head position relative to lander (“structures” SPK file)

Meteo sensor positions relative to lander (“structures” SPK file)

Lander position relative to landing site (“lander” SPK file)

Descent camera position relative to lander (“structures” SPK file)

Landing site position relative to planet center (“landing site” SPK file)



Frame Orientations

Left and right mast camera frame orientations relative to camera head frame (“mission” FK file)

Mast camera head frame orientation relative to lander frame (“mast camera” CK file)

Robotic arm gimbal frames orientations relative to each other (“arm” CK file)

Robotic arm camera frame orientation relative to last gimbal frame (“mission” FK file)

Lander frame orientation relative to local level frame (“lander” CK file)

Local level frame orientation relative to planet body-fixed frame (“mission” FK file)

Descent camera frame orientation relative to lander frame (“mission” FK file)

Rover Geometry

Navigation and Ancillary Information Facility

Position Vectors

Left and right mast camera center positions relative to end of mast (“structures” SPK file)

End of mast position relative to elbow gimbal (“structures” SPK file)

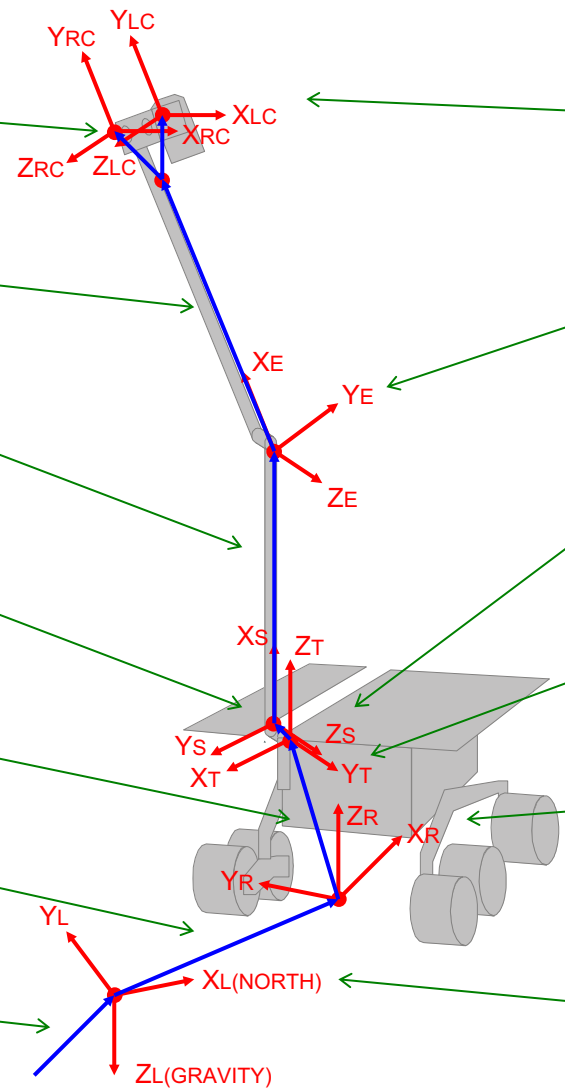
Mast elbow gimbal position relative to shoulder gimbal (“structures” SPK file)

Mast shoulder gimbal position relative to torso gimbal (“structures” SPK file)

Mast torso gimbal position relative to rover (“structures” SPK file)

Rover position relative to landing site (“rover” SPK file)

Landing site position relative to planet center (“landing site” SPK file)



Frame Orientations

Left and right mast camera frames orientation relative to mast elbow frame (“mission” FK file)

Mast elbow frame orientation relative to mast shoulder frame (“mast” CK file)

Mast shoulder frame orientation relative to mast torso frame (“mast” CK file)

Mast torso frame orientation relative to rover frame (“mast” CK file)

Rover frame orientation relative to local level frame (“rover” CK file)

Local level frame orientation relative to planet body-fixed rotating frame (“mission” FK file)

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 are also 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

Data Restorations	Selected Past Users	Current/Pending Users	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) [F]	Mars Exploration Rover	ExoMars 2018 (ESA, RSA)
Mariner 10 [L]	Mars Pathfinder	Mars Reconnaissance Orbiter	Luna-Glob (RSA)
Viking Orbiters [L]	NEAR	DAWN	ARM (HEOMD)
Viking Landers [L]	Deep Space 1	Mars Science Lab	Korean Pathfinder Lunar Orbiter (KARI)
Pioneer 10/11/12 [L]	Galileo	Juno	Assorted CubeSats
Haley armada [L]	Genesis	MAVEN	***Examples of Users not Requesting NAIF Help***
Phobos 2 [L] (RSA)	Deep Impact	SMAP (Earth Science)	Emmirates Mars Mission (UAE via LASP)
Ulysses [L]	Huygens Probe (ESA) [L]	OSIRIS REx	Bevo-2 CubeSat (U.T. Austin, Texas A&M)
Voyagers [L]	Stardust/NExT	InSight	Proba-3 (ESA)
Lunar Orbiter [L]	Mars Global Surveyor	Mars 2020	Solar Probe Plus
Helios 1,2 [L]	Phoenix	Europa Clipper Mission Concept	EUMETSAT GEO satellites [L]
	EPOXI	NISAR (NASA and ISRO)	MOM (ISRO)
	GRAIL	Lunar Reconnaissance Orbiter	BepiColombo (ESA, JAXA)
	Messenger	New Horizons	JUICE (ESA)
	Phobos Sample Return (RSA) [F	Mars Express (ESA)	Solar Orbiter (ESA)
	Venus Express (ESA)	Rosetta (ESA)	Van Allen Probes [L]
	Chandrayaan-1 (ISRO)	ExoMars 2016 (ESA, RSA)	STEREO [L]
	Hayabusa (JAXA)	Akatsuki (JAXA)	Spitzer Space Telescope [L]
[L] = limited use	Kaguya (JAXA)	Hayabusa-2 (JAXA)	Kepler [L]
[S] = special services	LADEE	Space Launch Systems (HEOMD)	Hubble Space Telescope [S][L]
[F] = mission failed	ISO [S] (ESA)	Planetary Data System	Radioastron (RSA) [L]
	CONTOUR [F]	Planetary Science Archive	IBEX [L]
	Space VLBI [L] (multinational)	JPL Solar System Dynamics	James Webb Space Telescope [S][L]
Last updated: 11/16/16	Smart-1 (ESA)	NASA Deep Space Network [S]	

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

NAIF has or had NASA funding to support a foreign partner in SPICE deployment and archive review, and to consult with flight team

NAIF has token funding to consult with kernel producers at APL. APL provides support to science teams.

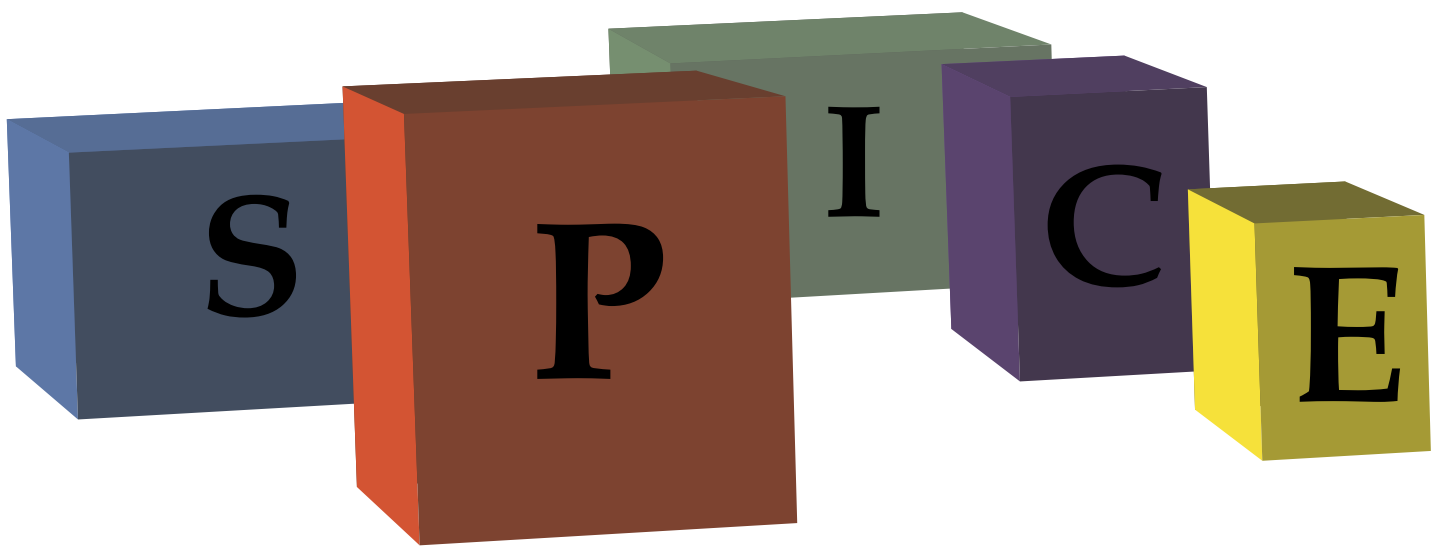
NAIF has or had modest PDS-supplied funding to consult on assembly of a SPICE archive.

NAIF has PDS funding to help NASA funded scientists use SPICE data 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 building blocks for constructing 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.