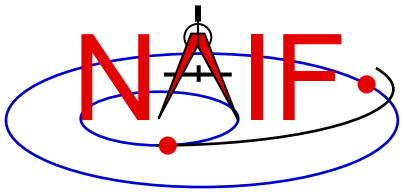


Navigation and Ancillary Information Facility

An Overview of SPICE

NASA's Observation Geometry System for Space Science Missions

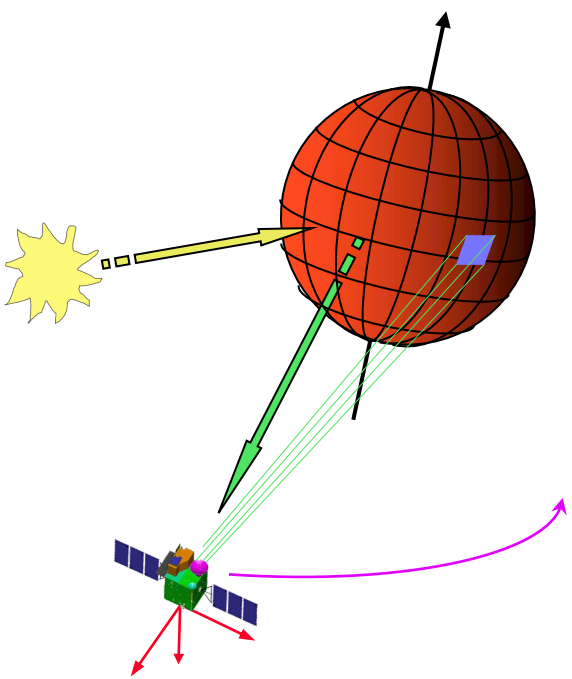
April 2023

What Can One Do With SPICE?

Navigation and Ancillary Information Facility

Compute many kinds of observation geometry parameters at selected times

Examples



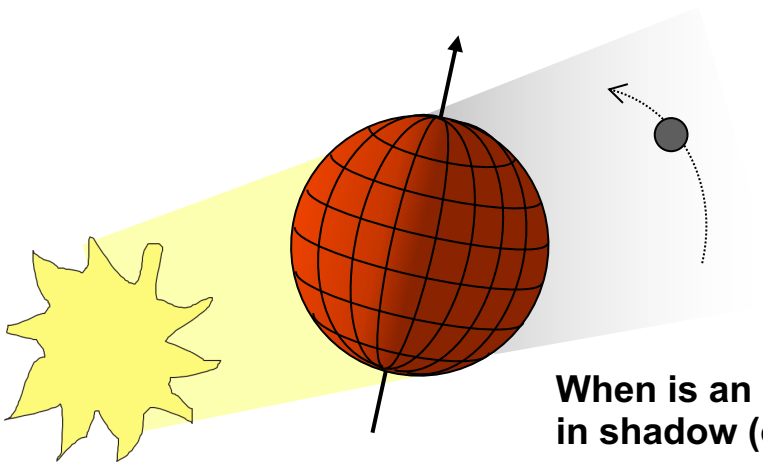
- **Positions and velocities of planets, satellites, comets, asteroids and spacecraft**
- **Size, shape and orientation of planets, satellites, comets and asteroids**
- **Orientation of a spacecraft and its various moving structures**
- **Instrument field-of-view location on a planet's surface or atmosphere**

What One Can Do With SPICE

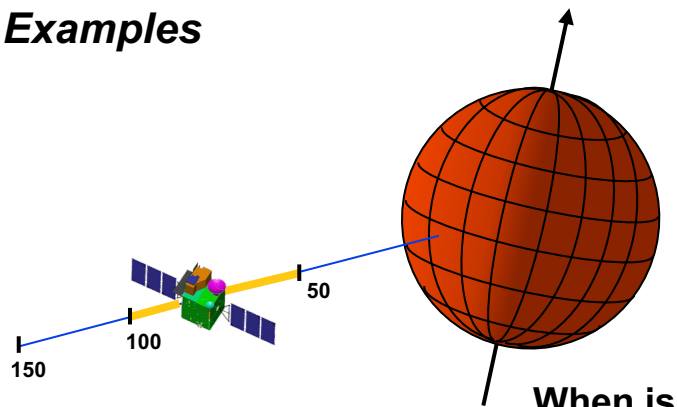
Navigation and Ancillary Information Facility

Find times when a specified "geometric event" occurs

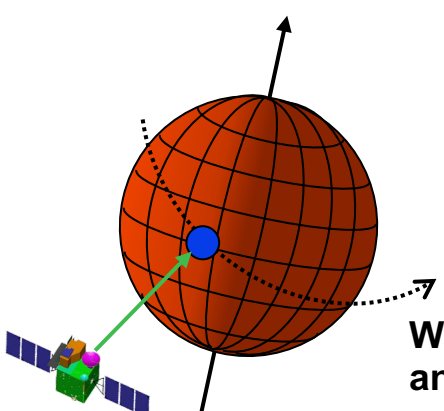
Examples



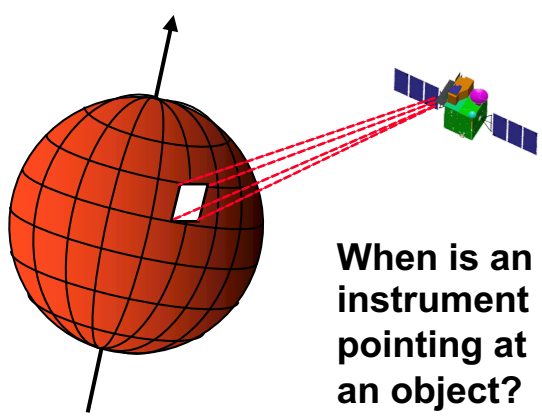
When is an object in shadow (occultation) ?



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 (transit)?

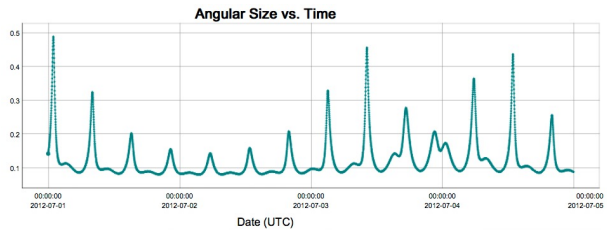


When is an instrument pointing at an object?

Examples of How SPICE Is Used

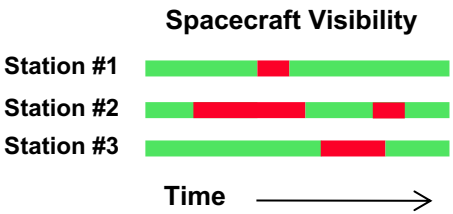
Navigation and Ancillary Information Facility

Evaluation of a planned trajectory

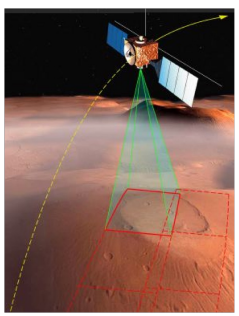


Angular size of Phobos as seen from the MEX spacecraft

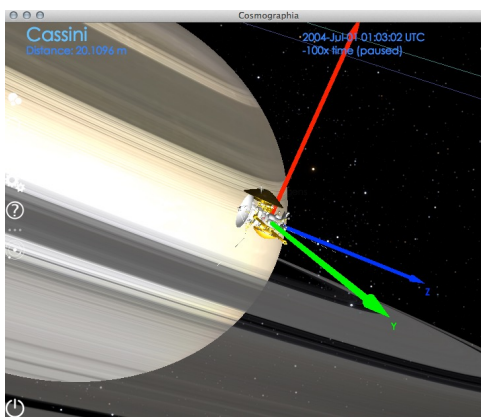
Mission engineering analyses



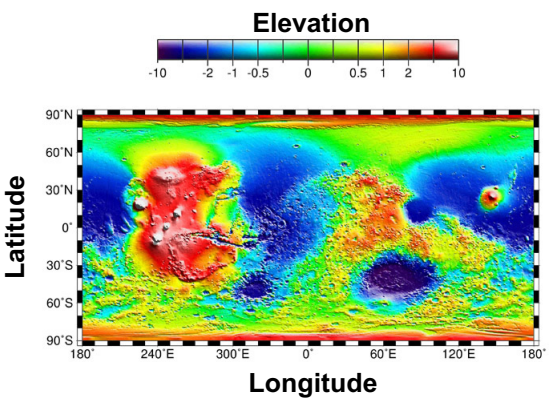
Planning an instrument pointing profile



Observation geometry visualization



Science data archiving and analysis



SPICE Pictorial Summary

Navigation and Ancillary Information Facility

From assorted sources

Planet ephemeris

S/C trajectory

S/C orientation

SPICE Utility Programs

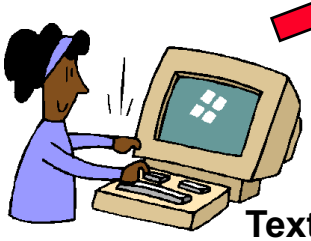
SPICE Kernels (Data)

Your Program

Your Modules

A Few SPICE Modules

Distances
Velocities
Altitudes
Latitudes
Longitudes
Lighting Angles
etc., etc.



Text editor

Spacecraft geometry

Instrument geometry

Planet size, shape, orientation

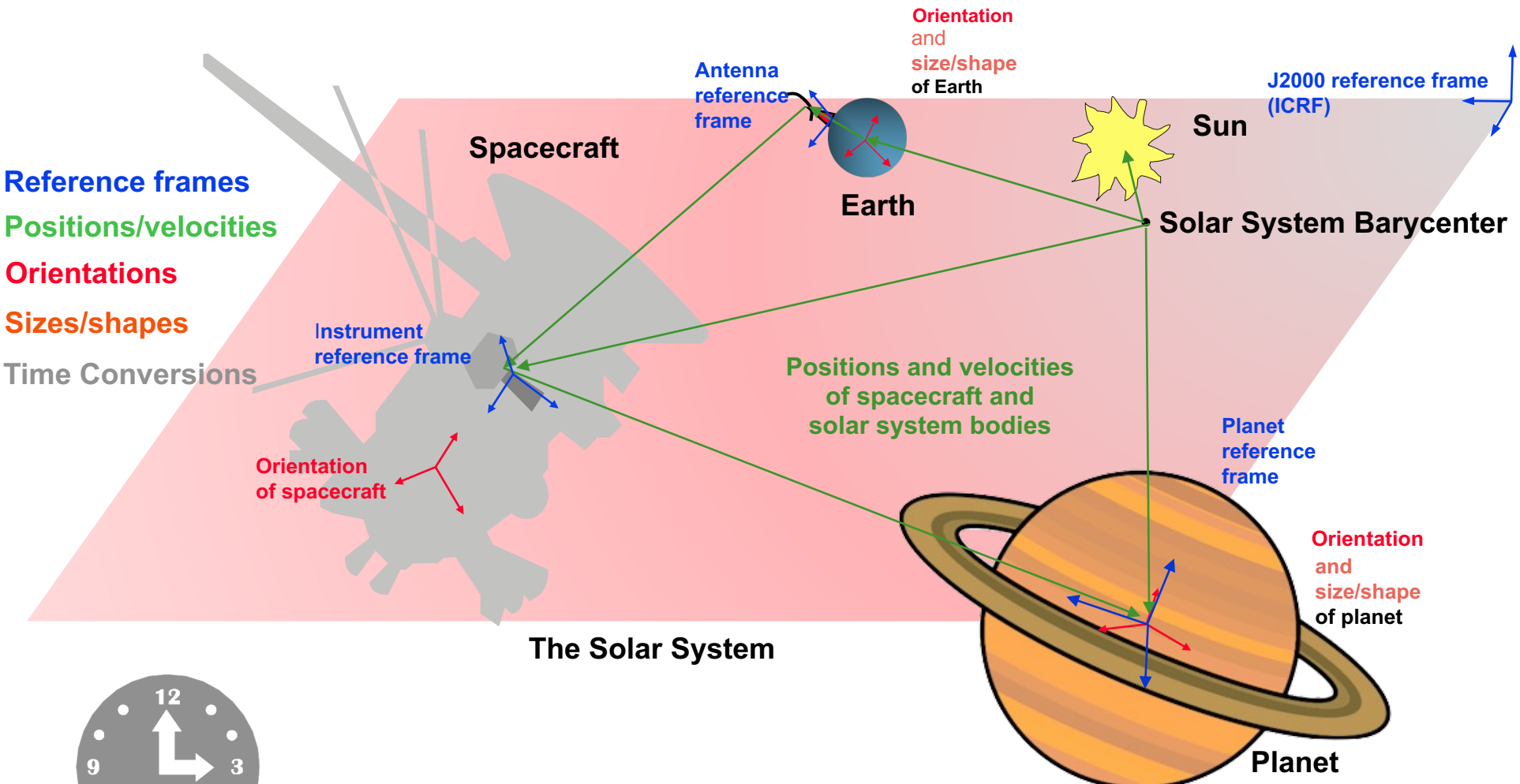
From assorted sources

Ancillary Data Files

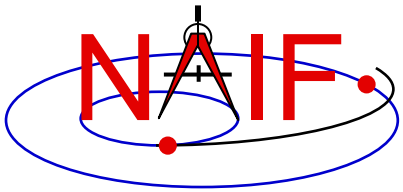
Observation Geometry Parameters or Time Intervals

What are “Ancillary Data?”

Navigation and Ancillary Information Facility



Time Conversion Calculations



How Use Ancillary Data?

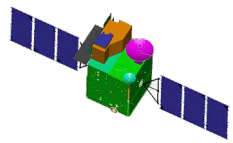
Navigation and Ancillary Information Facility

- **Ancillary data** are those that help scientists and engineers determine **observation geometry**, such as:
  - 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
  - where on the surface the instrument was looking
- The text above uses 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

IAU

- 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 geometric 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*

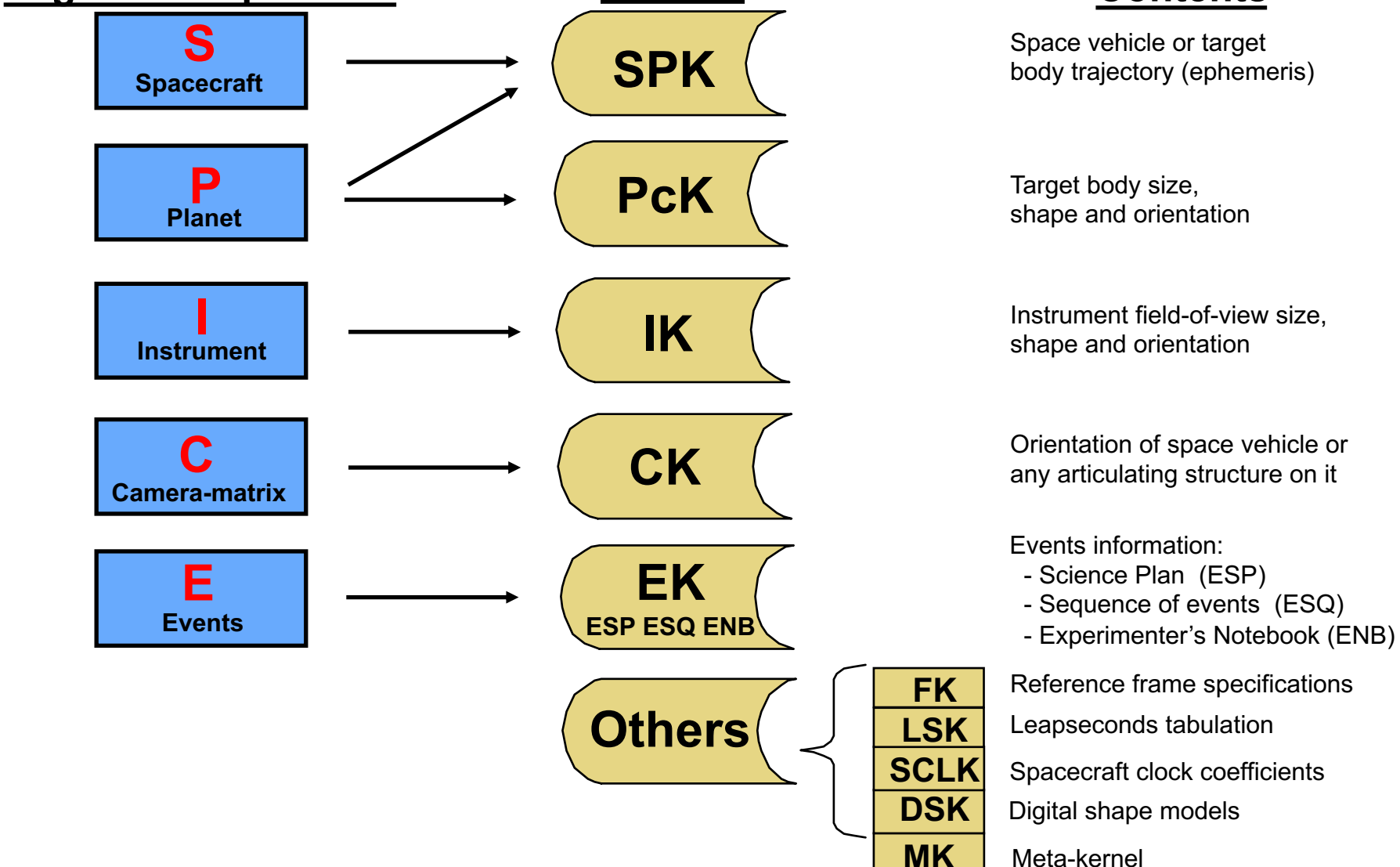
Navigation and Ancillary Information Facility

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 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 (tessellated plate model and digital elevation model*) (DSK)**

*DEM portion under development

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

SPICE System Data - 4

Navigation and Ancillary Information Facility

- **Meta-kernel**
  - A means to conveniently specify a collection of real kernels you would like to use together

SPICE Toolkit Software

Navigation and Ancillary Information Facility

Contents

- **Library of APIs (modules)**
  - But typically just a few are used within a customer's program to compute quantities derived from SPICE data files
- **Programs**
  - SPICE data production
  - SPICE data management
- **Documentation**
  - Highly annotated source code
  - Technical Reference Manuals
  - User Guides

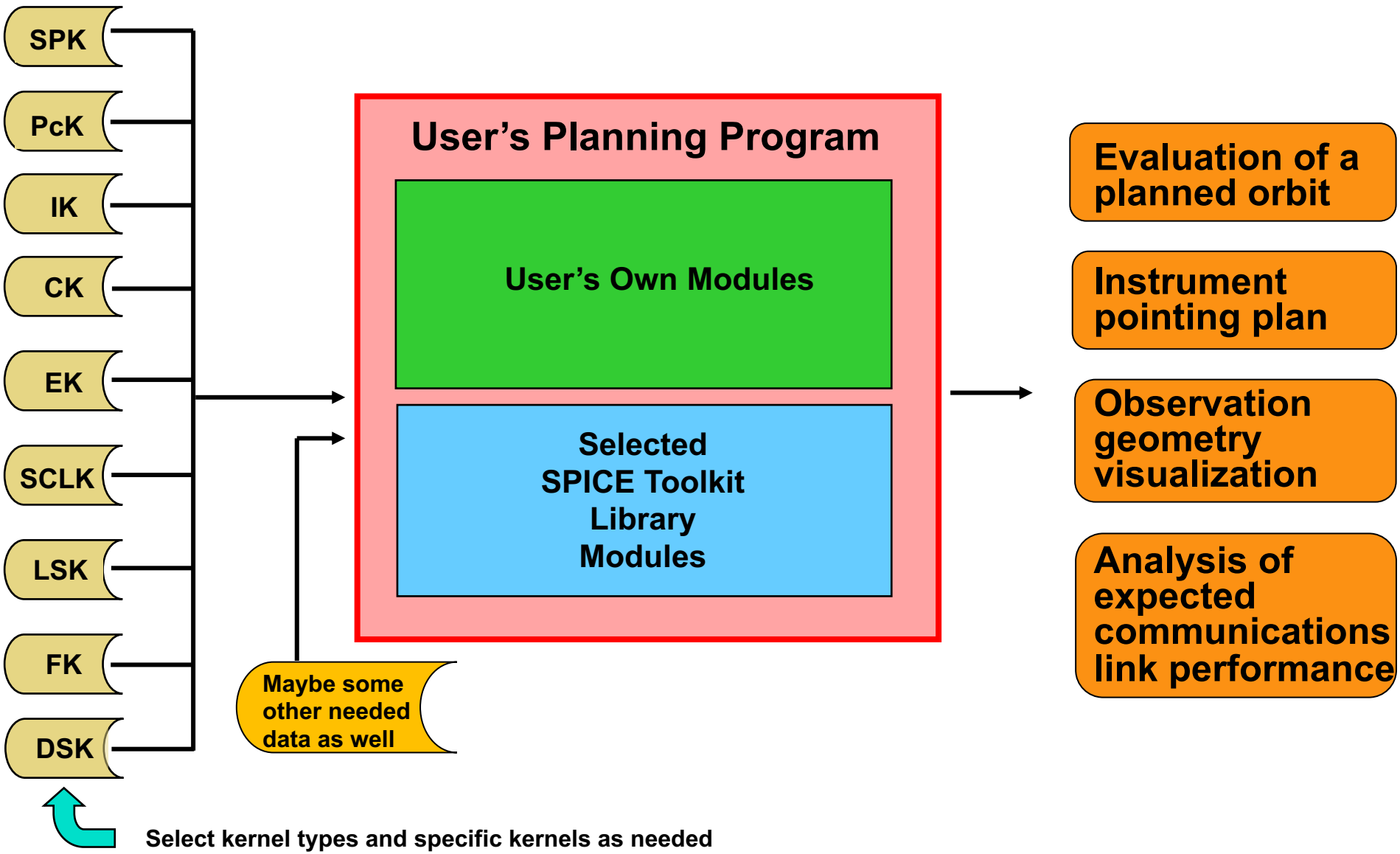
Versions

- **Five (ten) languages**
  - Fortran 77
  - C
  - IDL
  - MATLAB
  - Java Native Interface (JNI)
  - Python, Ruby, Swift, Julia, Unreal Engine (provided by 3rd parties)
- **Four platforms**
  - PC/Linux
  - PC/Windows
  - Sun/Solaris
  - Mac/OSX
- **Several compilers**
  - For the Fortran and C Toolkits

All combinations provided by NAIF are fully built and individually tested before being made available to customers

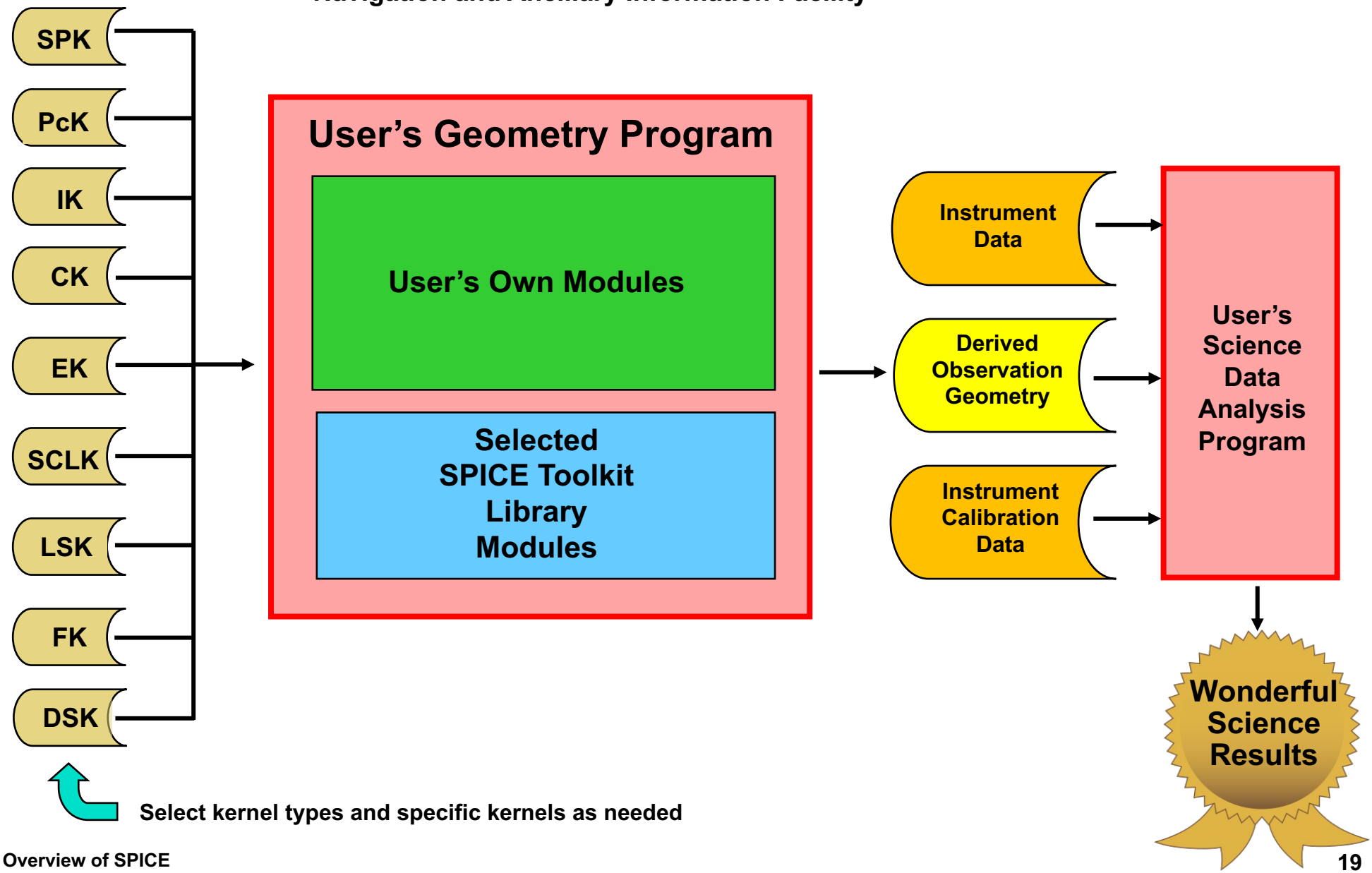
Using SPICE:
Mission Planning Example

Navigation and Ancillary Information Facility



Using SPICE:
Science Data Analysis Example

Navigation and Ancillary Information Facility



Using SPICE:
Science Data Peer Review Example

Navigation and Ancillary Information Facility

SPK

PcK

IK

CK

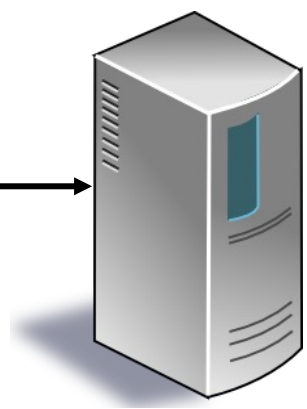
FK

SCLK

LSK

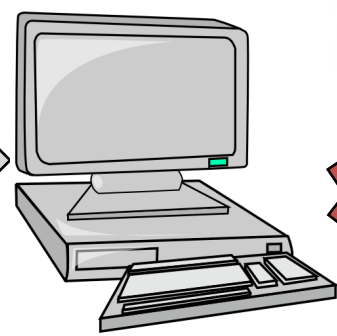
DSK

WebGeocalc Server



Internet

User's Computer with Web Browser



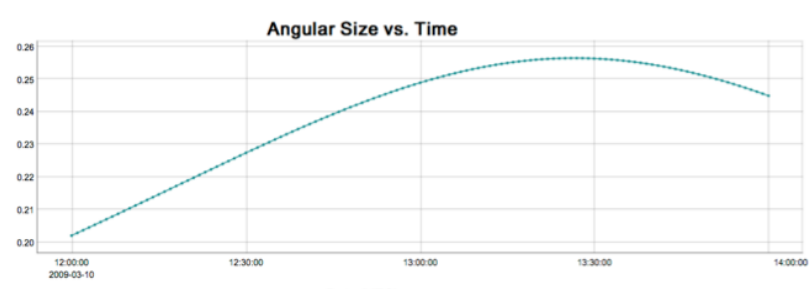
Tabular Results

Click a value to save it for a subsequent calculation.

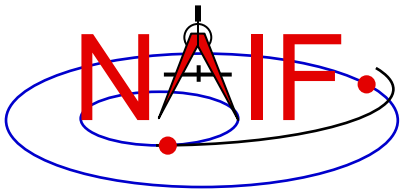
	UTC calendar date	Angular Size (deg)
1	2009-03-10 12:00:00.000000 UTC	0.20212256
2	2009-03-10 12:01:00.000000 UTC	0.20294481
3	2009-03-10 12:02:00.000000 UTC	0.20377024
4	2009-03-10 12:03:00.000000 UTC	0.20459871
5	2009-03-10 12:04:00.000000 UTC	0.20543007
6	2009-03-10 12:05:00.000000 UTC	0.20626418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

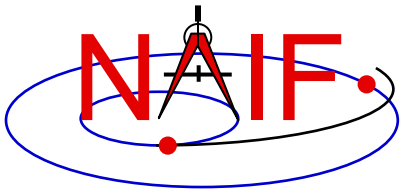


SPICE System Characteristics - 1

- SPICE Toolkit software is portable between computers
- New Toolkits are released irregularly, when enough new capability warrants it
- 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

- 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
- 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**

What "Vehicle" Types Can Be Supported?

- **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 telescopes
  - Radiometric tracking & comm
  - Optical tracking & comm

* Not yet demonstrated

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**
  - **Space technology demos**
  - **Planetariums**
  - **Probably still more…?**

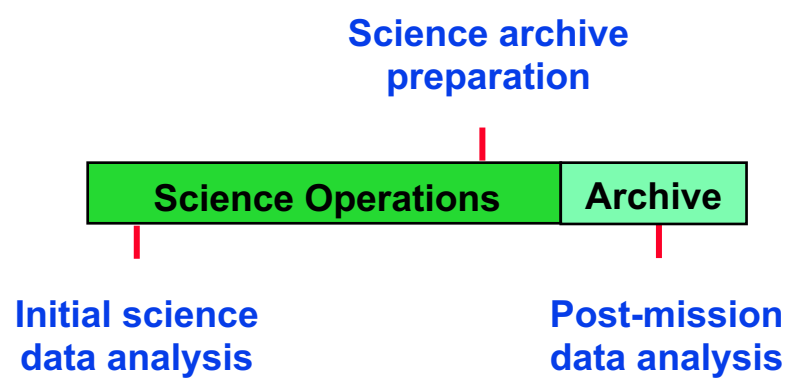
History

- A SPICE precursor 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

Original Purpose for SPICE

Navigation and Ancillary Information Facility

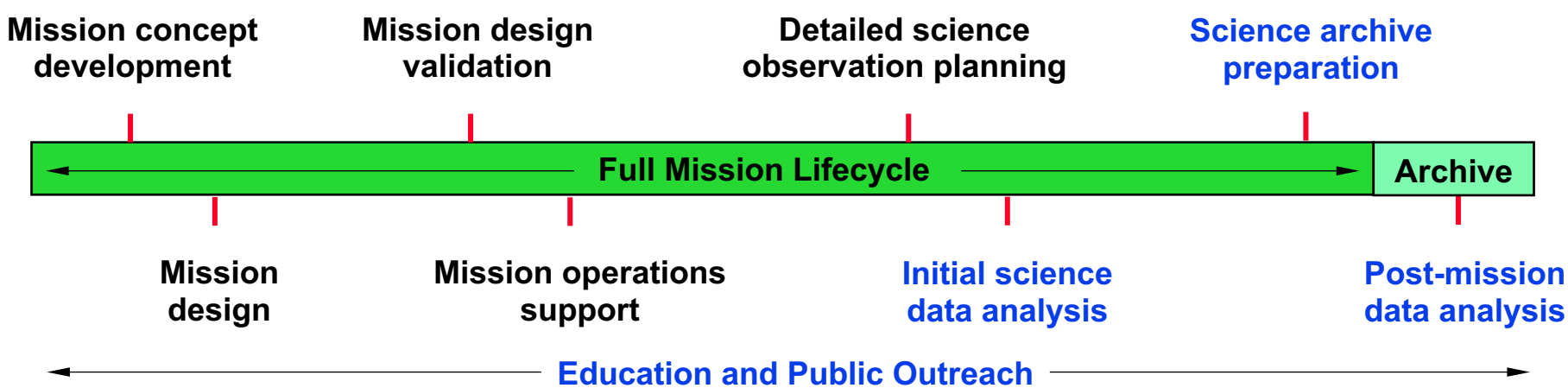
- **The original focus of SPICE was on ancillary data and associated software needed by planetary scientists for:**
  - **science data analysis, both during and after the mission operations**
  - **science archive preparation**



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:
  - science data analysis, both during and after the mission operations
  - science archive preparation
- The scope of SPICE usage has grown to cover the full mission lifecycle.
- Also education and public outreach.



Ancillary Data Archives

Navigation and Ancillary Information Facility

- SPICE is the U.S. Planetary Data System's recommendation for archiving ancillary data
- Use of SPICE is recommended by the International Planetary Data Alliance
- 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*	*Users*
Apollo 15, 16 [L]	Magellan [L]	Mars Odyssey	Parker Solar Probe
Mariner 2 [L]	Clementine (NRL)	Mars Reconnaissance Orbiter	Hubble Space Telescope [S][L]
Mariner 6 [L]	Mars Pathfinder	Mars Science Laboratory	James Webb Space Telescope [S][L]
Mariner 7 [L]	NEAR	Juno	Lunar Gateway
Mariner 9 [L]	Deep Space 1	MAVEN	Dragonfly
Mariner 10 [L]	Galileo	SMAP (Earth Science)	IMAP
Viking Orbiters [L]	Genesis	OSIRIS REx	MAIA
Viking Landers [L]	Deep Impact	InSight	NEO Surveyor
Pioneer 10/11/12 [L]	Stardust/NExT	Mars 2020	NEOWISE
Haley armada [L]	Mars Global Surveyor	Europa Clipper	SPHEREx
Phobos 2 [L] (RSA)	Phoenix	NISAR (NASA and ISRO)	SunRISE
Ulysses [L]	EPOXI	Psyche	TESS
Voyagers [L]	GRAIL	Lucy	LunaH-Map (Arizona State)
Lunar Orbiter [L]	DAWN	Janus	Lunar IceCube (Moorehead State)
Helios 1,2 [L]	Cassini Orbiter	Lunar Flashlight	GOLD (LASP, UCF) (Earth Science) [L]
Huygens Probe (ESA) [L]	Mars Exploration Rover	VERITAS	Emmirates Mars Mission (UAE via LASP)
	Mars Express (ESA)	DAVINCI+	Armadillo (CubeSat, by UT)
	Venus Express (ESA)	JUICE (ESA)	ExoMars RSP (ESA, RSA)
	Rosetta (ESA)	Bepicolombo (ESA, JAXA)	Proba-3 (ESA)
	Mars 96 (RSA)	Korean Pathfinder Lunar Orbiter (KARI)	Solar Orbiter (ESA)
	Phobos Sample Return (RSA)	ExoMars 2016 (ESA, RSA)	Hera (ESA)
	Messenger	Akatsuki (JAXA)	EnVision (ESA)
	Chandrayaan-1 (ISRO)	New Horizons	Gaia (ESA)
	Hayabusa (JAXA)	Deep Space Network	INTEGRAL (ESA)
	Kaguya (JAXA)	Voyager	GEO satellites (EUMETSAT) [L]
	LCROSS	Lunar Reconnaissance Orbiter	MMX (JAXA)
	LADEE	Hayabusa-2 (JAXA)	SLIM (JAXA)
	Spitzer Space Telescope	DART	Aditya-L1 (ISRO)
	STEREO	NEA Scout	MOM (ISRO)
	Kepler	VIPER	Chandrayan-2 (ISRO)
[L] = limited use	ISO [S] (ESA)		Altius (Belgian earth science satellite)
[S] = special services	Smart-1 (ESA)		Spectrum-RG (RSA)

- NAIF had, has, or will have project-supplied funding to support mission operations, consultation for flight team members, and SPICE data archive preparation.
- NAIF had, has, or will have NASA funding to support a foreign partner in SPICE deployment and archive review, and to consult with flight team SPICE users.
- NAIF had, has, or will have token funding to consult with kernel producers.
- NAIF had or has PDS authorization and funding to consult on assembly of a SPICE PDS archive.
- NAIF had performed data restoration under PDS funding.
- Missions that used, use, or will be using SPICE without any help from NAIF.

Building Blocks for Your Applications

Navigation and Ancillary Information Facility

The “SPICE” observation geometry system can serve as a set of building blocks for constructing tools supporting multi-mission, international space exploration programs.