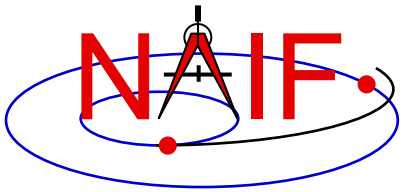


Navigation and Ancillary Information Facility

An Overview of SPICE

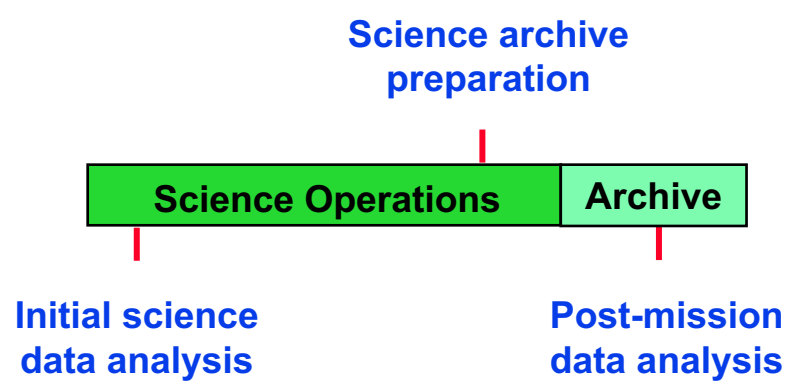
NASA's Ancillary Data System for Planetary Missions

January 2017

Original Purpose for SPICE

Navigation and Ancillary Information Facility

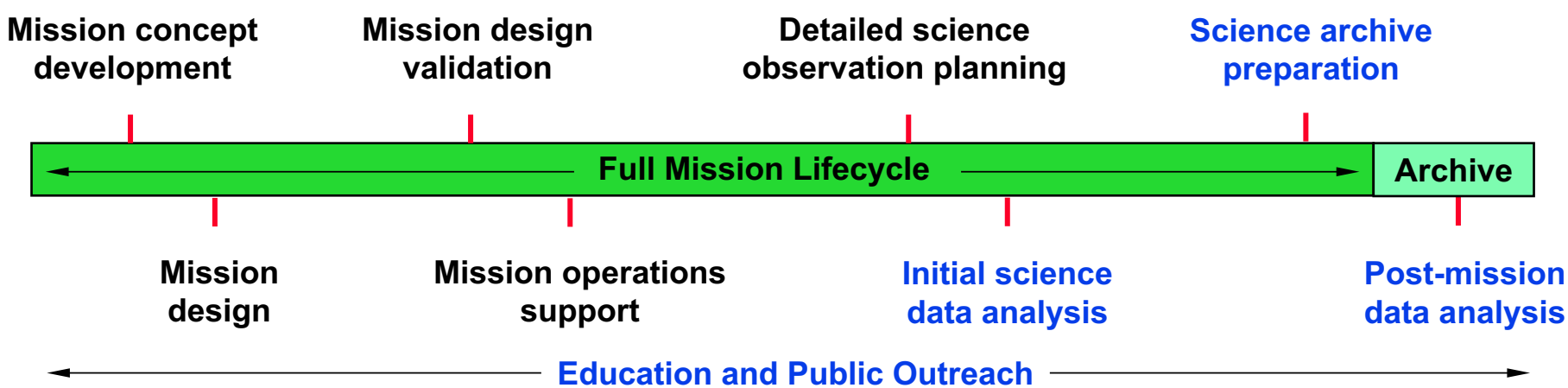
- **The original focus of SPICE was on ancillary data and associated software needed by planetary scientists for:**
  - **initial science data analysis**
  - **science archive preparation**
  - **post-mission data analysis**



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.



What are "Ancillary Data?"

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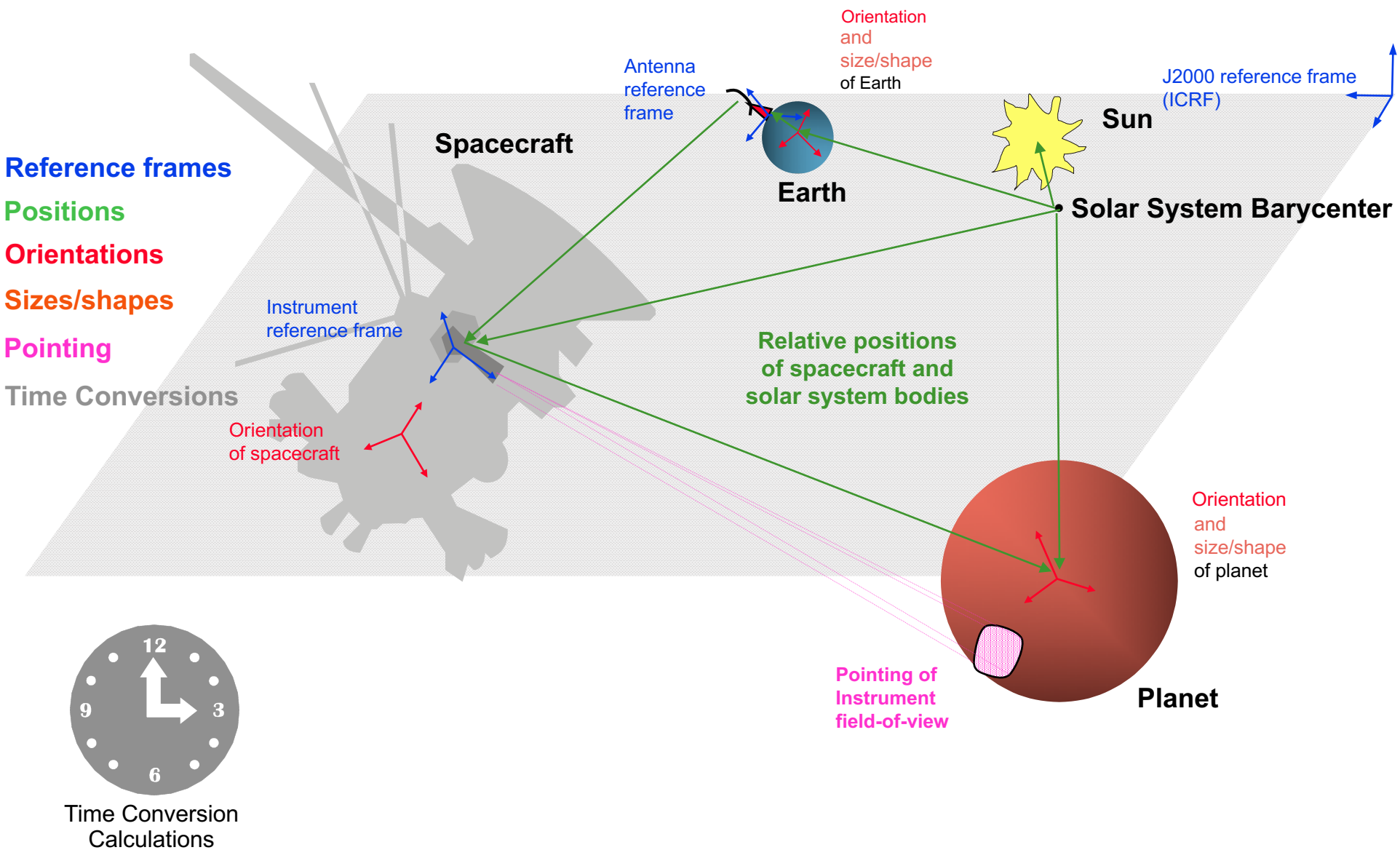


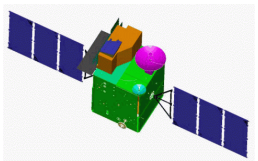
How Use “Ancillary Data”?

- **“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

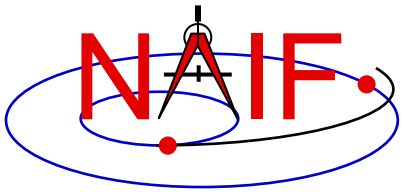


- From the mission control center

- 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*

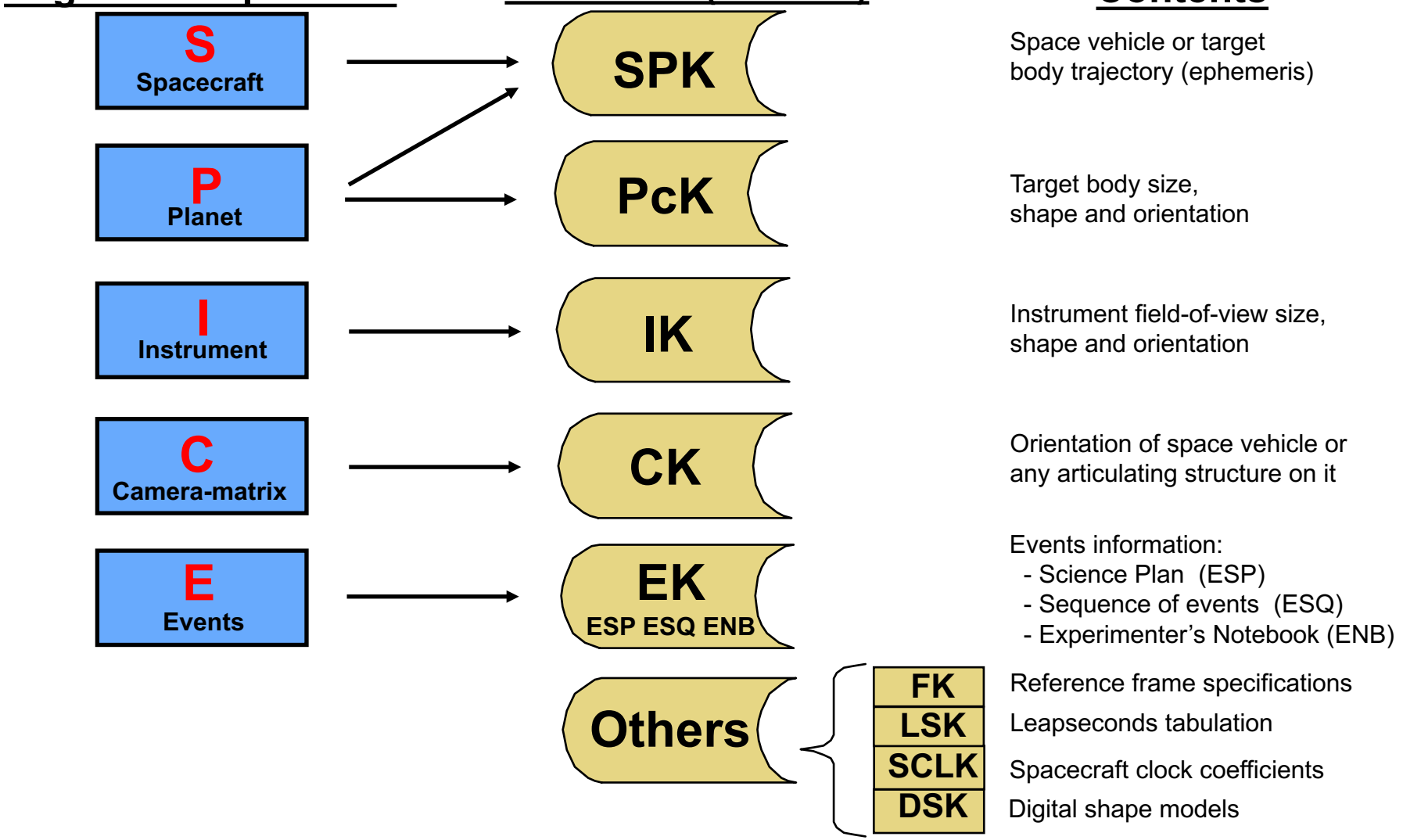
Navigation and Ancillary Information Facility

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

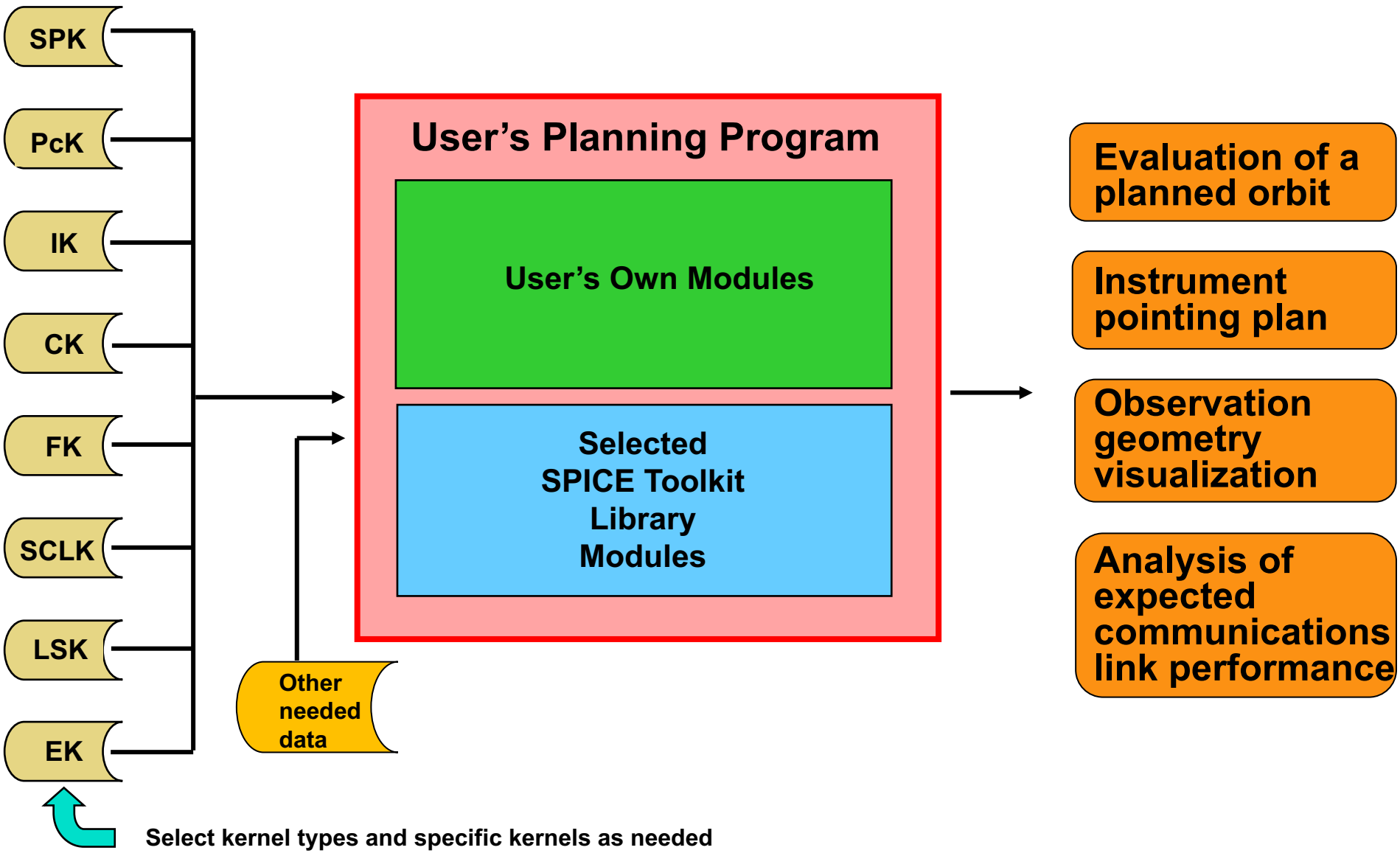
* 30 are available from the NAIF website

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

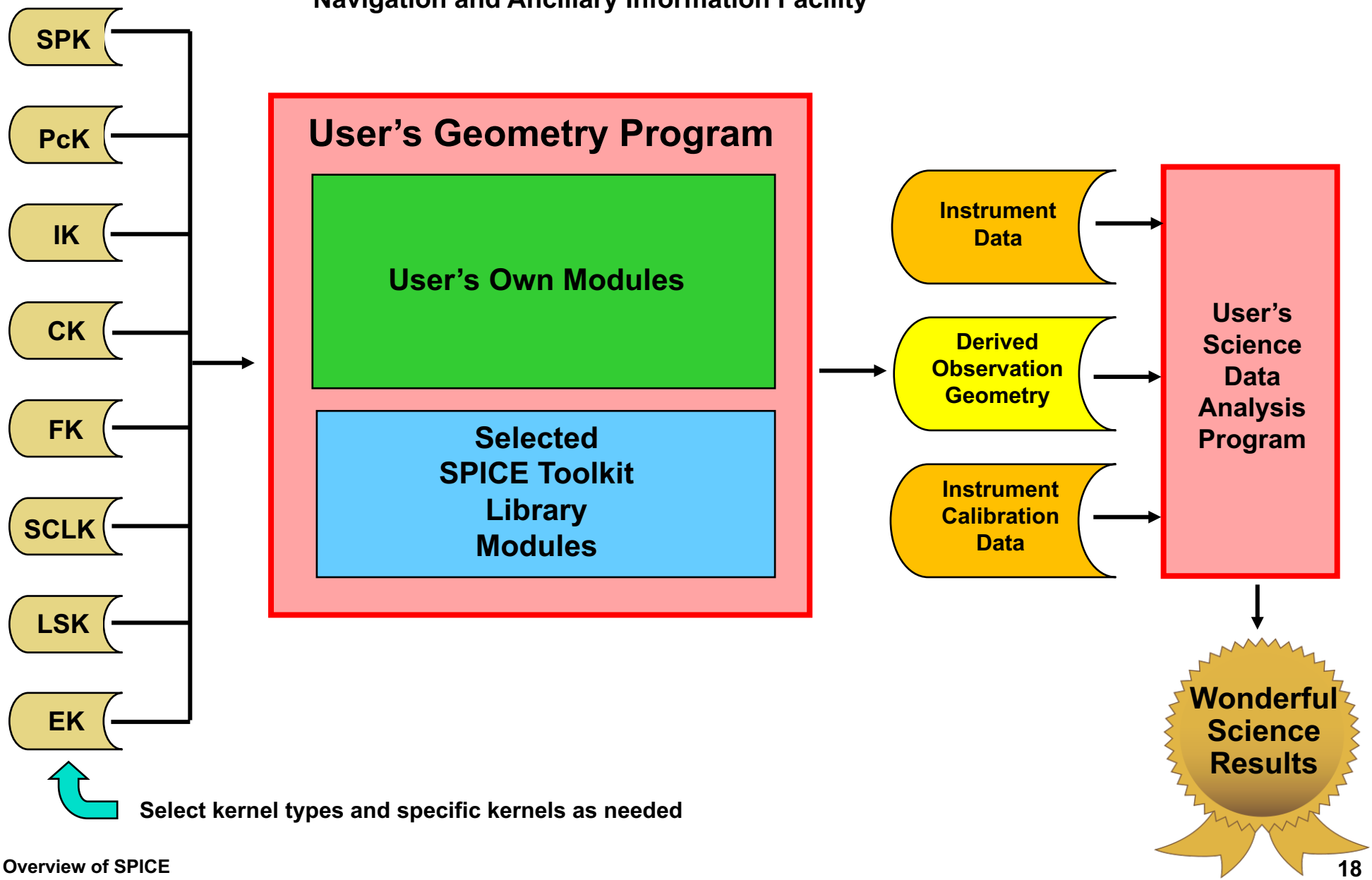
Using SPICE: A Mission Planning Example

Navigation and Ancillary Information Facility



Using SPICE: A Science Data Analysis Example

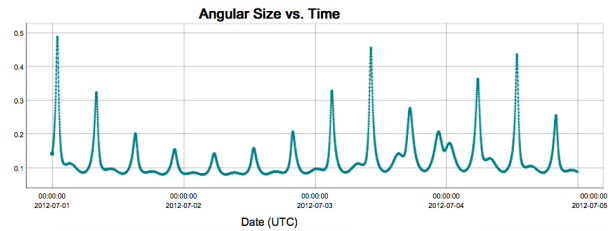
Navigation and Ancillary Information Facility



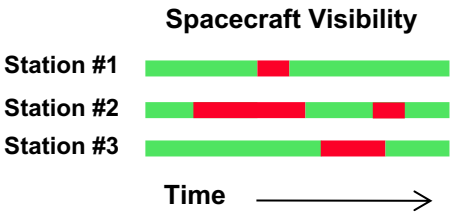
Examples of How SPICE Is Used

Navigation and Ancillary Information Facility

Evaluation of a planned trajectory

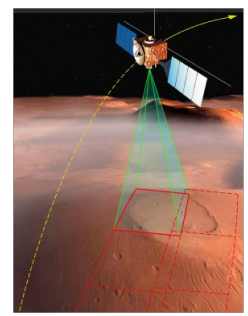


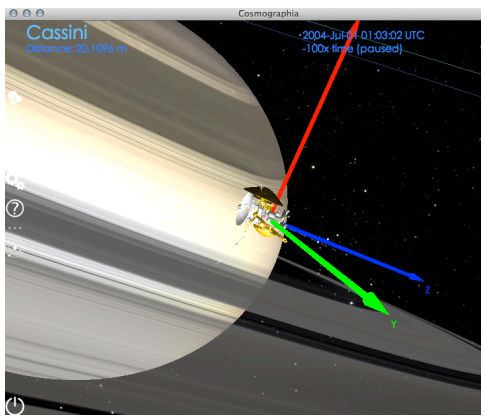
Angular size of Phobos
As seen from the MEX spacecraft



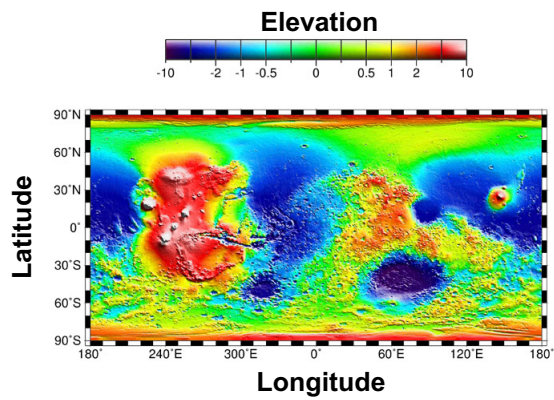
Mission engineering analyses

Planning an instrument pointing profile





Observation geometry visualization



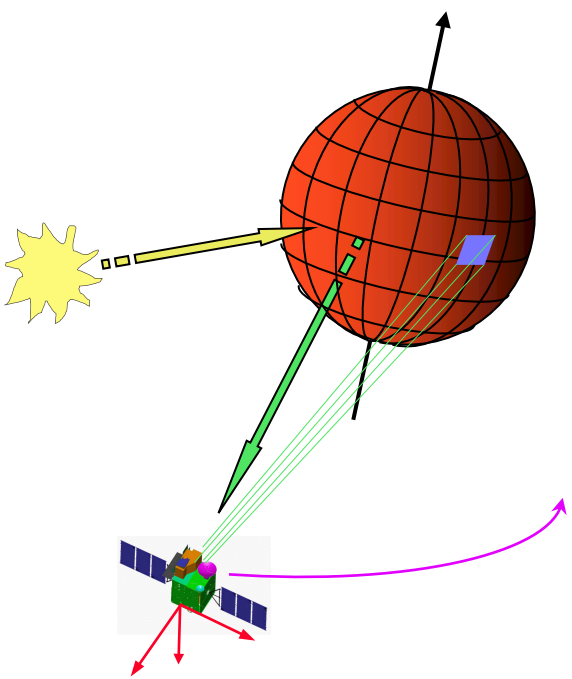
Science data archiving and analysis

What Can One Do With SPICE?

Navigation and Ancillary Information Facility

Compute many kinds of observation geometry parameters at selected times

A Few Examples



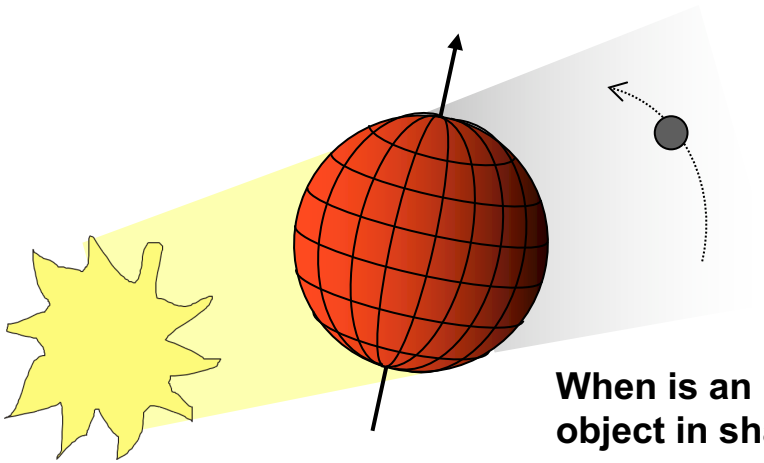
- **Positions and velocities of planets, satellites, comets, asteroids and spacecraft**
- **Size, shape and orientation of planets, satellites, comets and asteroids**
- **Orientation of a spacecraft and its various moving structures**
- **Instrument field-of-view location on a planet's surface or atmosphere**

What Can One Do With SPICE?

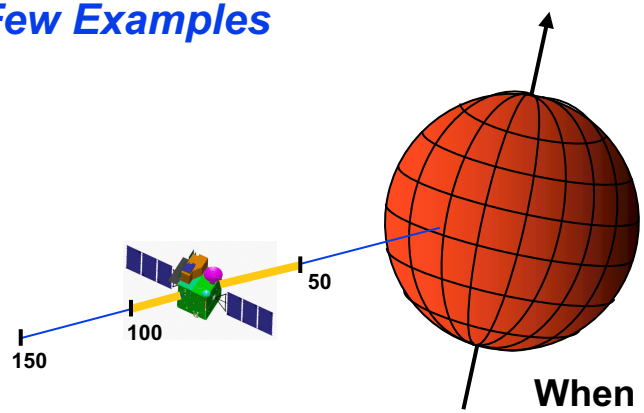
Navigation and Ancillary Information Facility

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

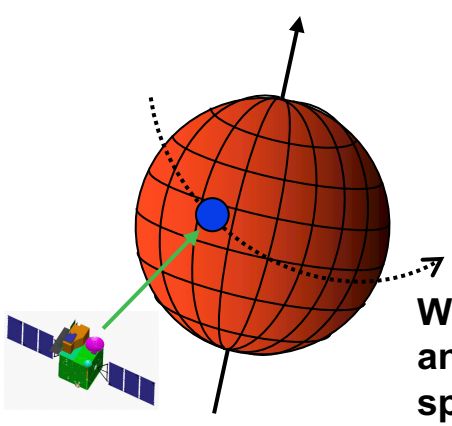
A Few Examples



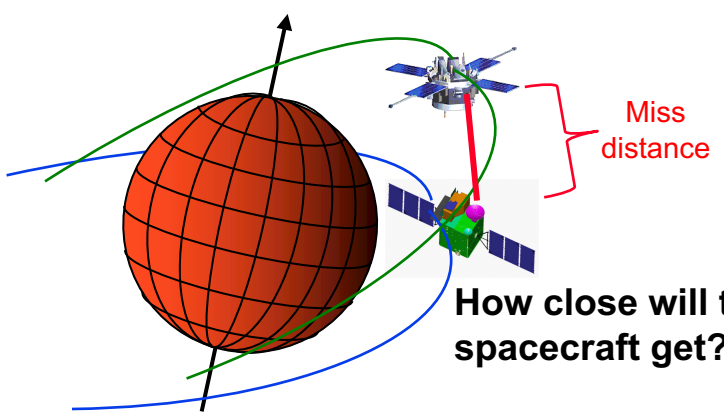
When is an object in shadow?



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



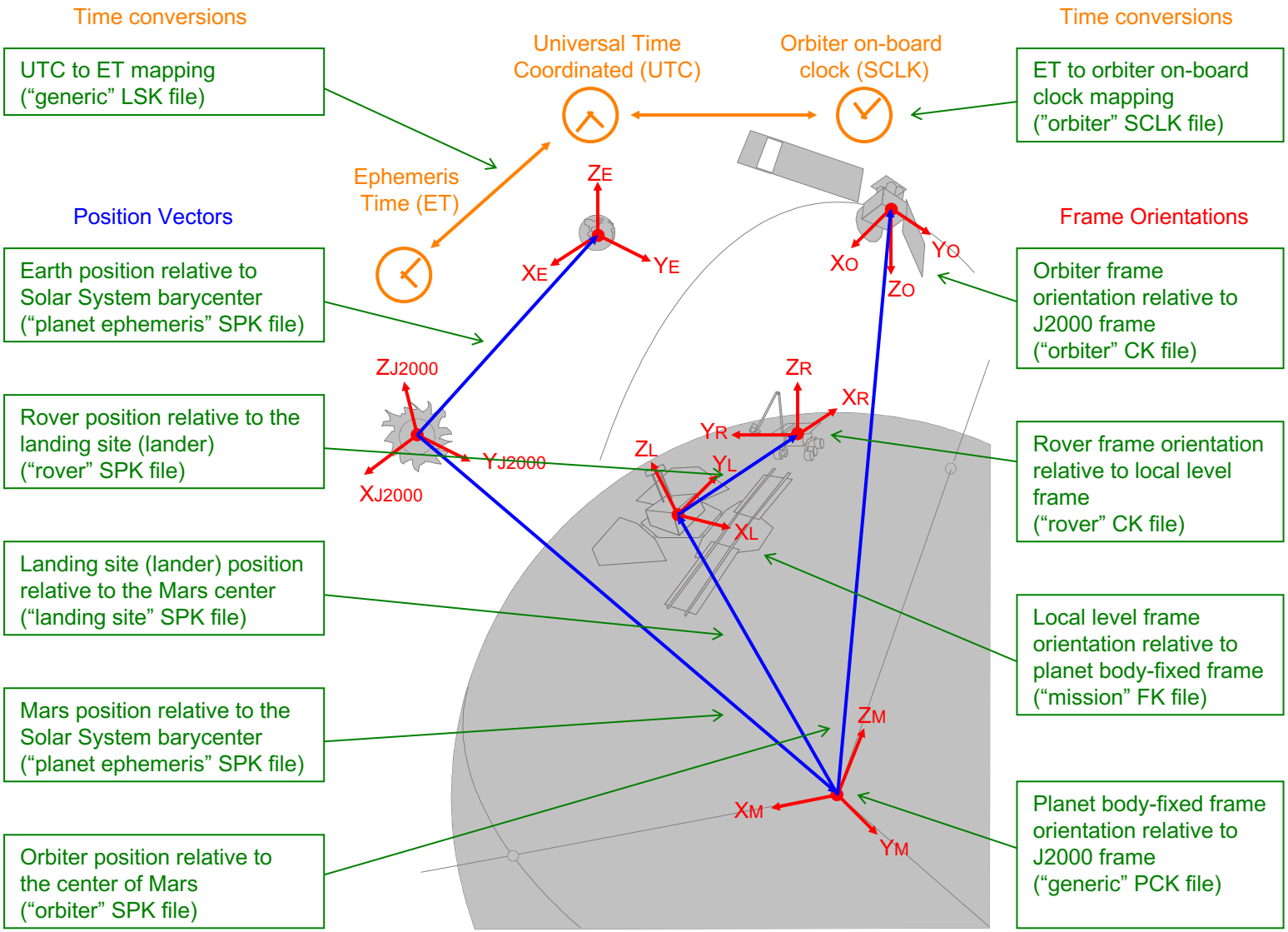
When is an object in front of another, as seen from a spacecraft?



How close will two spacecraft get?

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)

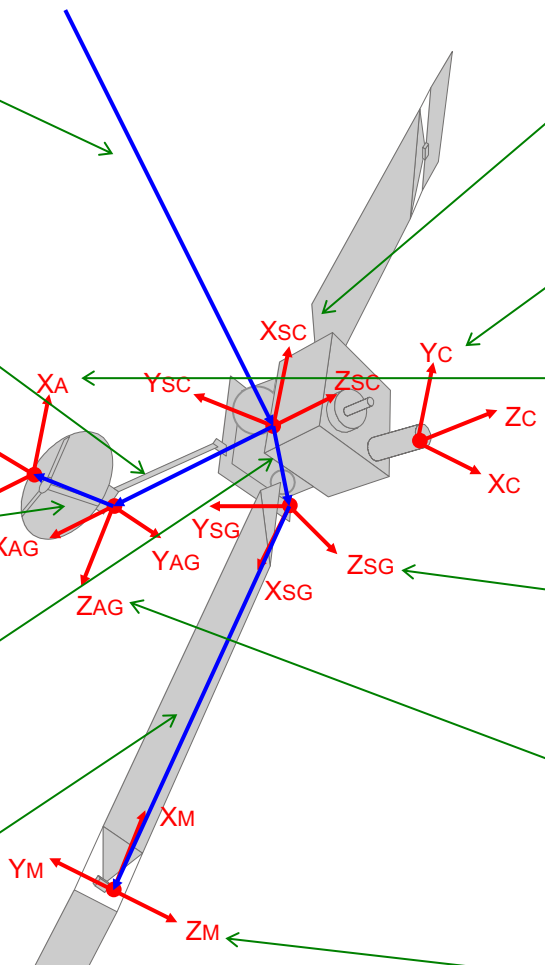
Camera frame orientation relative to spacecraft frame (“mission” FK file)

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)



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.