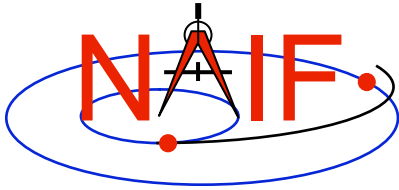


Navigation and Ancillary Information Facility

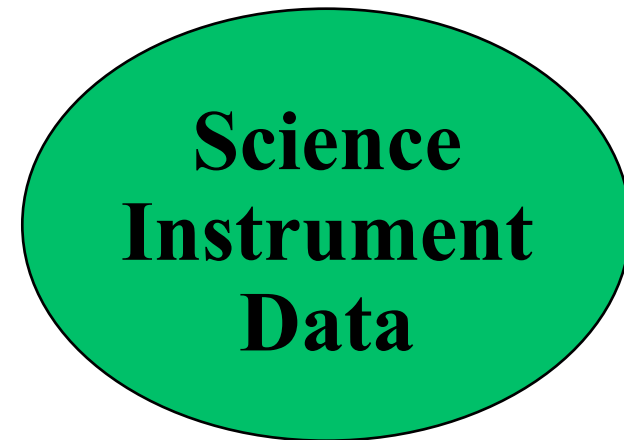
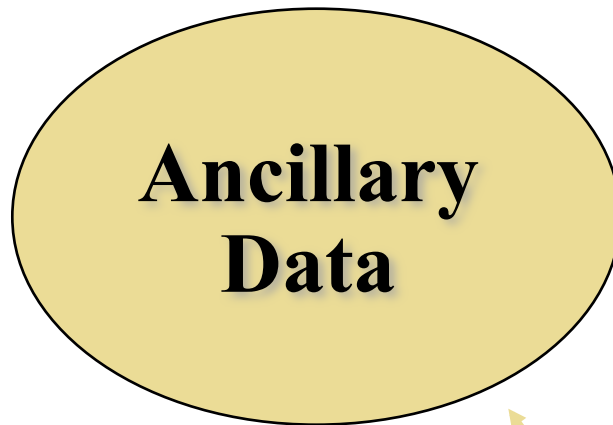
An Overview of SPICE

September 2009

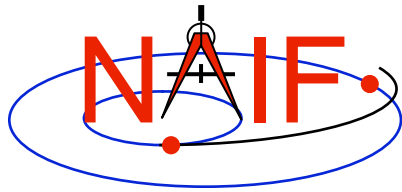


Space Science Data: Two Kinds

Navigation and Ancillary Information Facility

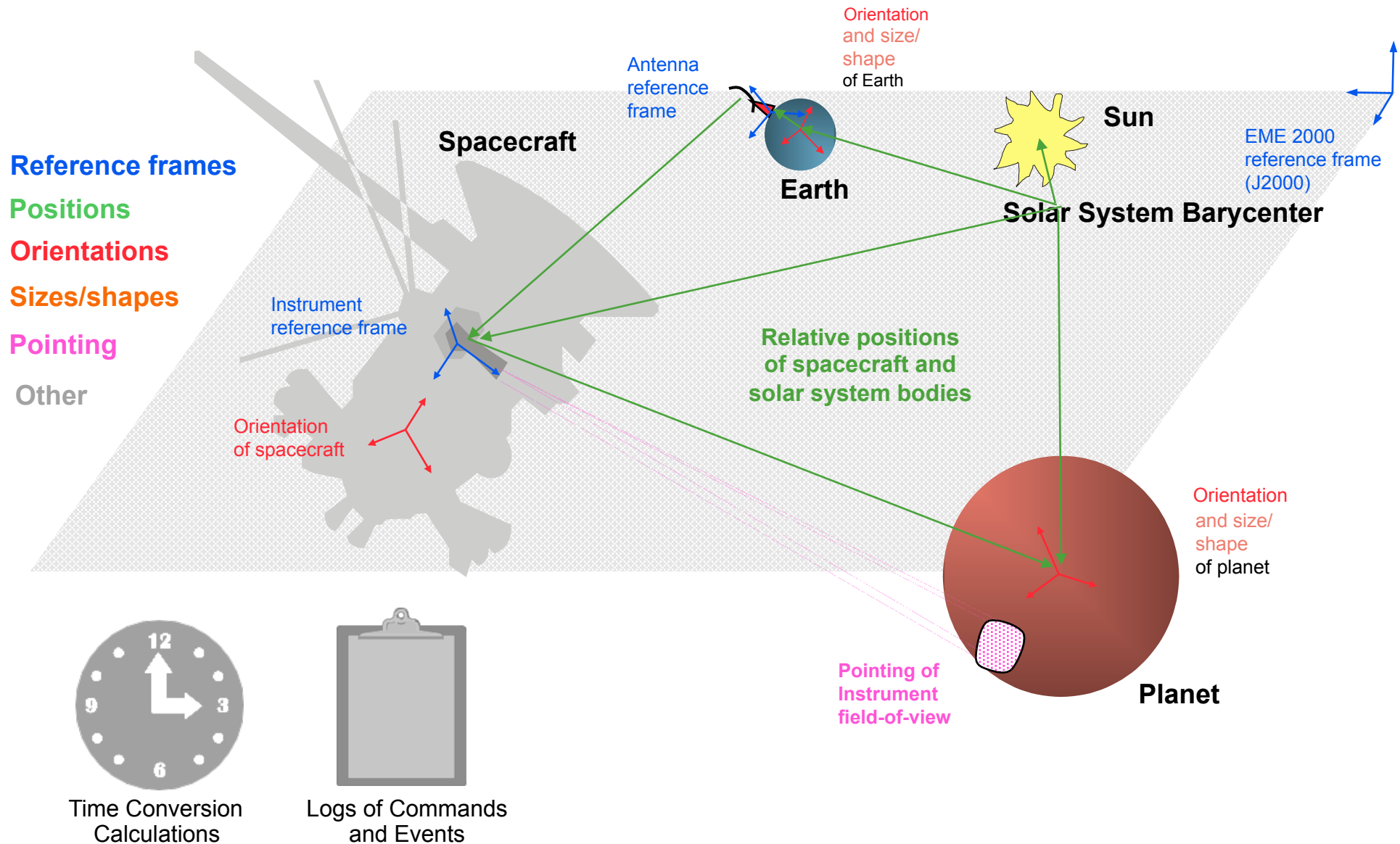


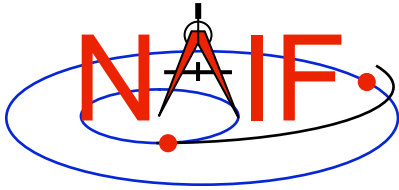
SPICE deals with **these** data to support the planning for and analysis of **these** data



What are “Ancillary Data?”

Navigation and Ancillary Information Facility

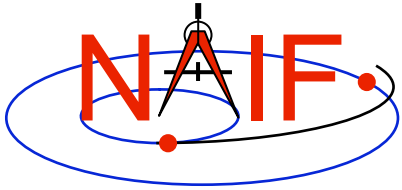




What are “Ancillary Data”?

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 is equally applicable**

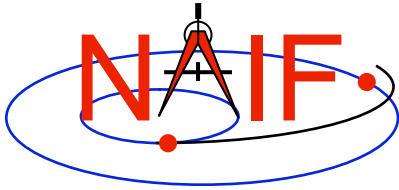


From Where do Ancillary Data Come?

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**

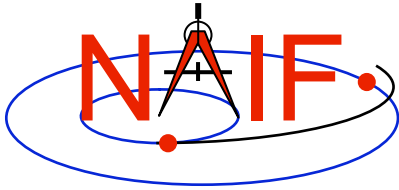
- **SPICE is used to organize and package these data in a collection of useful, stable file types—called "kernels."**
- **The kernels are made available, along with SPICE Toolkit software:**
 - **to help scientists in the planning for and analysis of science observations, and**
 - **to help engineers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



Why SPICE?

Navigation and Ancillary Information Facility

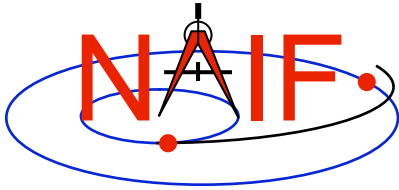
- **Knowing observation geometry and events is an important element:**
 - in the design of space missions,
 - in the selection of observations,
 - and in analysis of the science data returned from the instruments.
- **Having proven, extensive and reusable means for producing and using ancillary data 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

- **The principal SPICE system components are:**
 - **Data files**, often called “kernels” or “kernel files”
 - **Software**, known as the SPICE Toolkit, consisting of:
 - » a subroutine/function library
 - » a number of programs (executables)
 - Some are “meaty” applications
 - Some are “simple” utilities focused on kernel management
 - » a few “cookbook” programs
 - Simple examples of using SPICE toolkit subroutines
 - **Documentation**
 - User Guides for programs
 - Substantial source code documentation for all subroutines
 - Provided explicitly for those who will use Toolkit subroutines to make their own application programs
 - Technical reference documents for major families of subroutines
 - A permuted index
 - **Tutorials**
 - **Programming lessons**, which focus on using SPICE subroutines
 - » Include tips, data, and NAIF’s solution code and numeric results



Genesis of the SPICE Acronym*

Navigation and Ancillary Information Facility

S

Spacecraft

P

Planet

I

Instrument

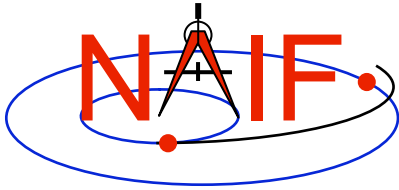
C

C-matrix

E

Events

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



Logical versus Physical View

Navigation and Ancillary Information Facility

Logical View

S
Spacecraft

P
Planet

I
Instrument

C
Camera-matrix

E
Events

S
Software

Physical View

SPK

PcK

IK

CK

EK
ESP ESQ

Others

FK
LSK
SCLK

SPICE Toolkit

Content

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

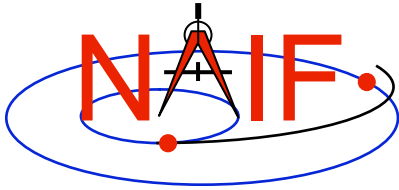
Events information:
- Science Plan (ESP)
- Sequence of events (ESQ)
- Experimenter's Notebook (ENB)

Reference frame specifications

Leapseconds tabulation

Spacecraft clock coefficients

API libraries, some application
and utility programs, software
documentation



SPICE System Contents - 1

Navigation and Ancillary Information Facility

SPK

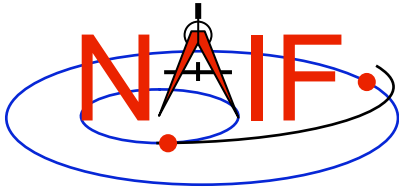
- Space vehicle ephemeris (trajectory)
- Planet, satellite, comet and asteroid ephemerides
- More generally, position of something relative to something else

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 information such as:
 - Field-of-view size, shape, orientation
 - Internal timing



SPICE System Contents - 2

Navigation and Ancillary Information Facility

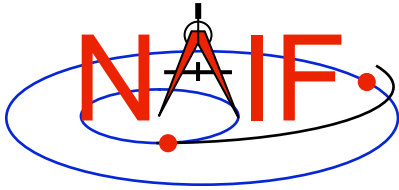
CK

- 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



SPICE System Contents - 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 <--> ET time conversions

SCLK

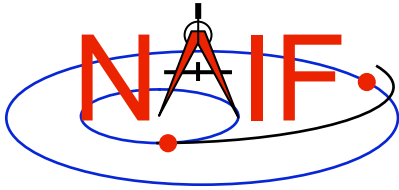
- **Spacecraft Clock Coefficients**
 - Used for SCLK <--> ET time conversions

**Other
Kernels**

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

¹ under development

² development is stalled



SPICE System Contents - 4

Navigation and Ancillary Information Facility

SPICE Toolkit

FORTRAN

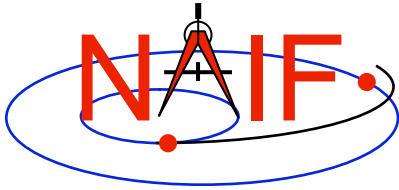
C

IDL

MATLAB

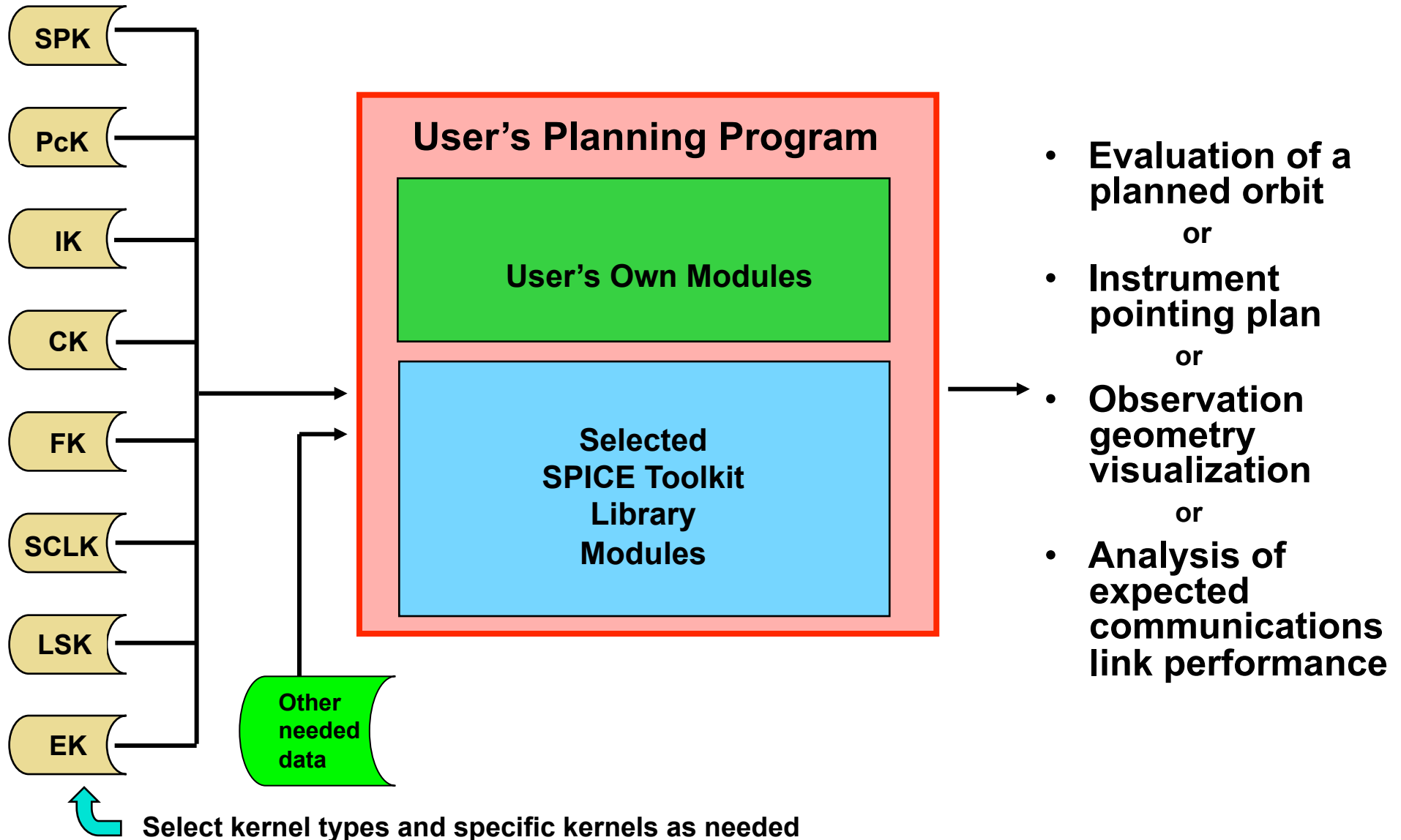
Under development:
Java Native Interface
Python

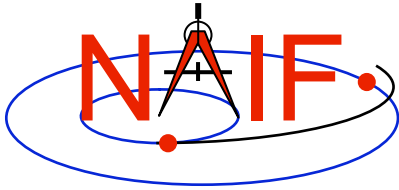
- **Library of modules used to:**
 - write binary SPICE kernel files
 - read all (binary and text) SPICE kernel files
 - compute quantities derived from SPICE kernel data
- **Example (“cookbook”) programs**
- **Utility programs**
 - Kernel summarization or characterization
 - Kernel porting
- **Application programs (a few)**
 - e.g. “chronos” time conversion application
- **Kernel production programs (a few)**
 - e.g. “mkspk” SPK production program



Using SPICE in Science Planning

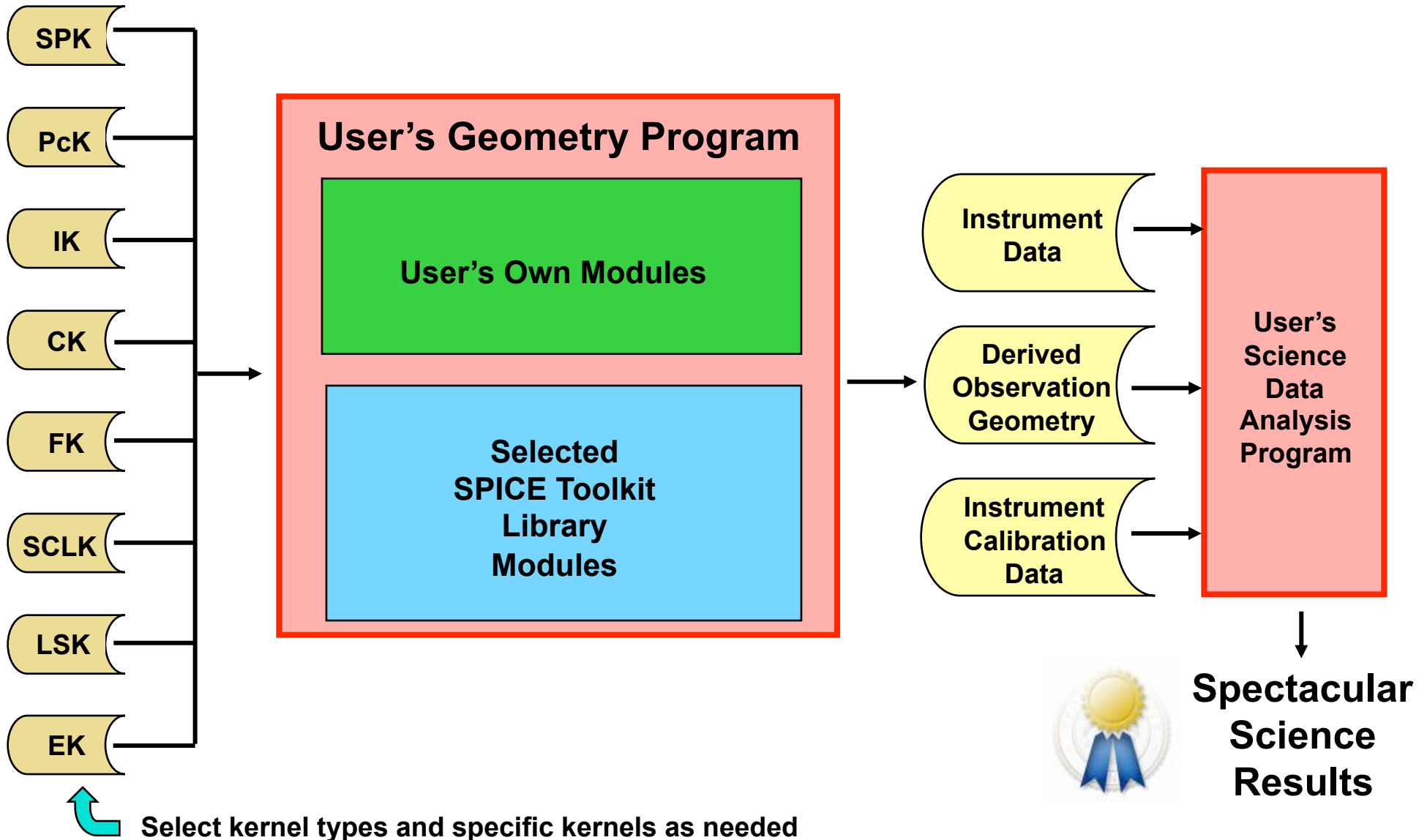
Navigation and Ancillary Information Facility

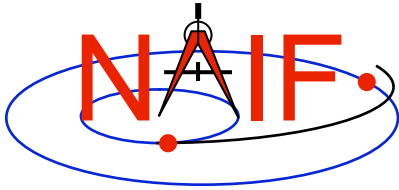




Using SPICE in Science Data Analysis

Navigation and Ancillary Information Facility

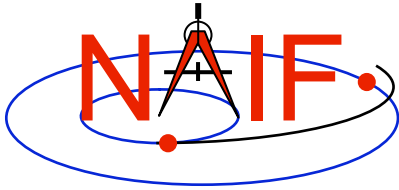




SPICE System Characteristics - 1

Navigation and Ancillary Information Facility

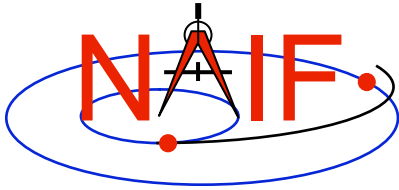
- **Portable SPICE kernel files**
- **Portable NAIF Toolkit software**
- **Code is well tested before being released to users**
- **New Toolkits are always backwards compatible**
- **Extensive user-oriented documentation is provided**
- **A set of SPICE tutorials is available**
- **“Open book” programming lessons are offered as a part of each NAIF-provided training class**



SPICE System Characteristics - 2

Navigation and Ancillary Information Facility

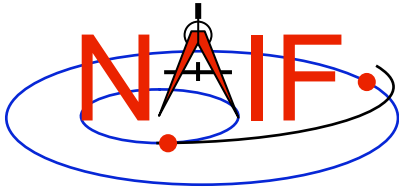
- **All numeric computations use double precision**
- **System includes built-in exception handling**
 - Catches most invalid inputs
 - Offers a traceback and configurable action upon detection of a problem
- **Gives you access to most of JPL's integrated ephemerides for spacecraft and natural bodies (planets, satellites, comets, asteroids)**
- **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
- **Broad applicability, means good value**
 - Multi-mission and multi-discipline
 - » Use it over and over again, no matter which mission you're working on



SPICE System Characteristics - 3

Navigation and Ancillary Information Facility

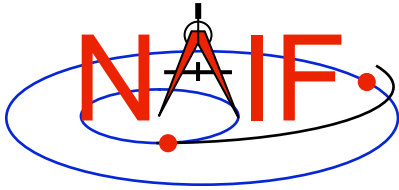
- **Funding**
 - SPICE system development is funded by NASA's Planetary Science Division
 - NASA flight projects fund NAIF or others to deploy and operate SPICE in support of NASA's planetary missions
 - Foreign institutions fund their own people for deployment and operation of SPICE in support of their own projects
 - SPICE Toolkit software is free to individual end users
 - Access to SPICE kernels produced by NAIF is free and open to all
 - » Includes mission operations kernels as well as those archived in the PDS
 - Access to SPICE kernels produced by others so far appears free
 - » But access restrictions often exist prior to data archiving
- **Distribution of SPICE software is not restricted under U.S. Government regulations**
 - » SPICE is classified TSPA ("Technology and Software Publicly Available")
 - » No ITAR restrictions on data, training or consulting
- **Commercial use of SPICE software is allowed**
 - No license fees or other restrictions



Supported Platforms

Navigation and Ancillary Information Facility

- **The SPICE Toolkit has been ported to a wide variety of popular “environments”**
 - Each environment is characterized by...
 - » Hardware type (platform)
 - » Operating System
 - » Compiler
 - » 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



For What Jobs is SPICE Used ?

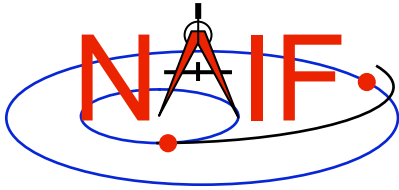
Navigation and Ancillary Information Facility

Increasing
mission
maturity
(time)



- Mission planning, modeling and visualization
- Pre-flight mission evaluation from a science perspective
- Detailed science observation planning
- Mission operations engineering functions
- Science data analysis, including correlation of results between instruments, and with data obtained from other missions
- Data archiving, for future use by others
- Education and Public outreach

← The original focus of SPICE



Examples - 1

What Can You Do With SPICE ?

Navigation and Ancillary Information Facility

- **Mission Design**

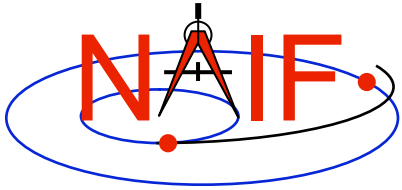
- Compute interesting orbit properties; compare these with those of another design, or of another mission
- Evaluate possibilities for relay link times and duration

- **Mission Operations (mission engineering)**

- Predict or evaluate telecommunications link performance
- Analyze spacecraft orientation history
- Determine elevation and rise/set times of sun and tracking stations
- Compute location and lighting conditions for a rover
- Find times or time spans when a particular geometric condition exists, or when a particular geometric parameter is within a given range

- » **Examples**

- Occultation, transit, eclipse, etc.
- Altitude or phase angle within a specified range, etc.

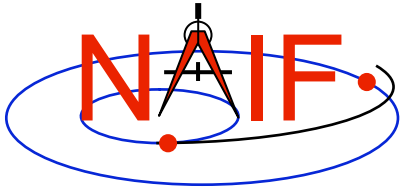


Examples - 2

What Can You Do With SPICE ?

Navigation and Ancillary Information Facility

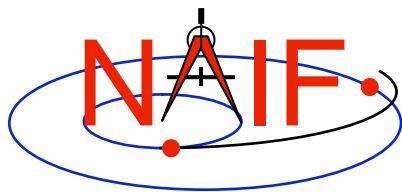
- **Science: Planning, Product Generation and Data Analysis**
 - Design observations
 - Compute observation geometry needed for science data product labels, to later be used in searching a catalog for science data of interest
 - Compute observation geometry needed to analyze science data, or to correlate multiple science data sets
 - » Examples of “observation geometry”:
 - Lighting angles (phase, incidence, emission)
 - Location (LAT/LON) of instrument footprint
 - Range and local time
 - Local season
 - Find times or time spans when a particular geometric condition exists, or when a particular geometric parameter is within a given range
- **Visualization, Education and Public Outreach**
 - Provide geometry used to drive web pages giving interesting parameters such as ranges, velocities, time of day on Mars
 - Provide geometry for animations showing spacecraft location and orientation, instrument footprint projected on the surface, and locations of surface assets or natural features of interest



What “Vehicle” Types Can Be Supported ?

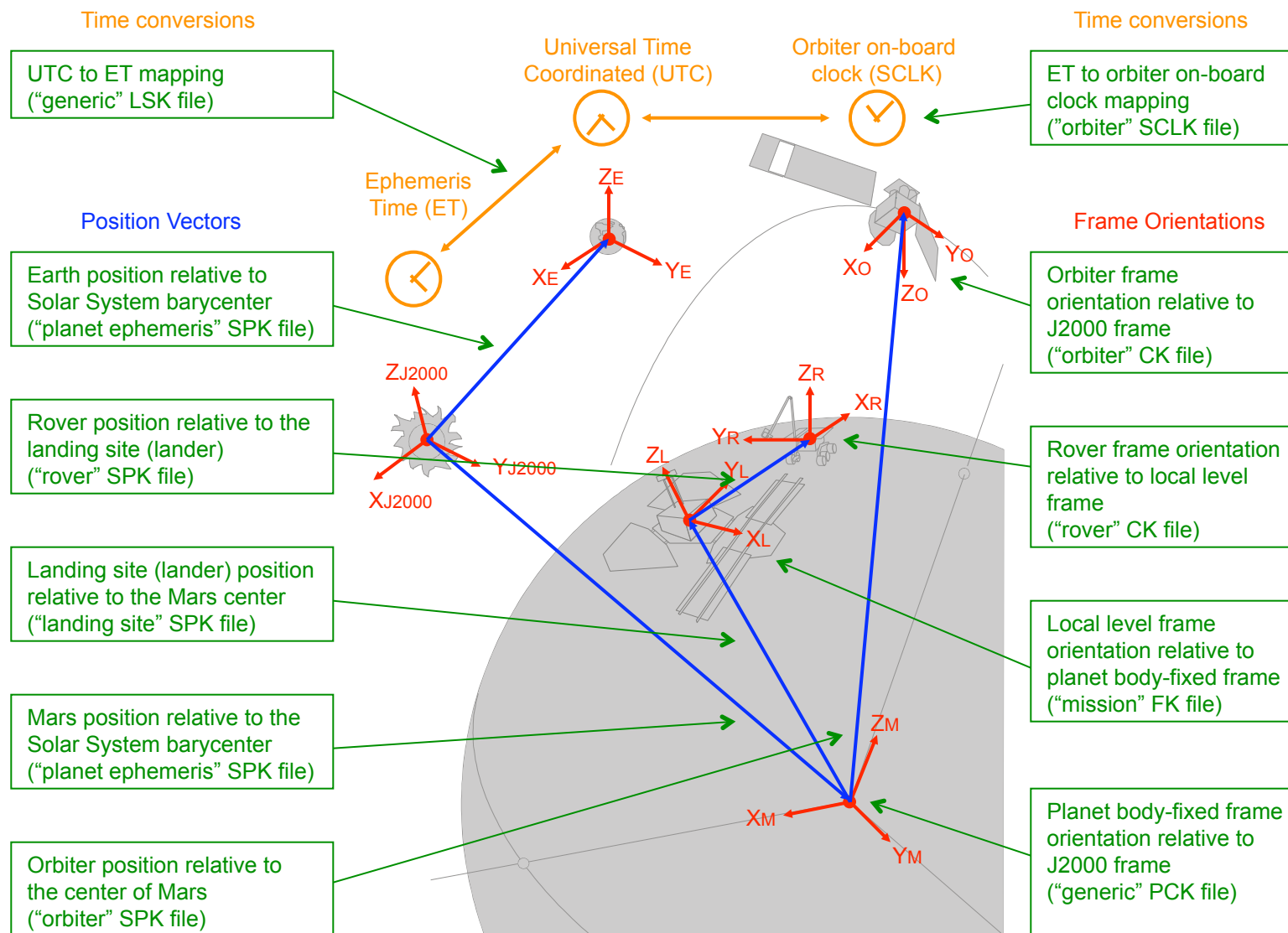
Navigation and Ancillary Information Facility

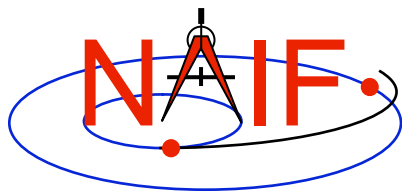
- **Cruise/Flyby**
 - Remote sensing
 - In-situ measurement
 - Instrument calibration
- **Orbiters**
 - Remote sensing
 - In-situ measurement
 - Communications relay
- **Balloons***
 - Remote sensing
 - In-situ measurements
- **Landers**
 - Remote sensing
 - In-situ measurements
 - Rover or balloon relay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



Global SPICE Geometry

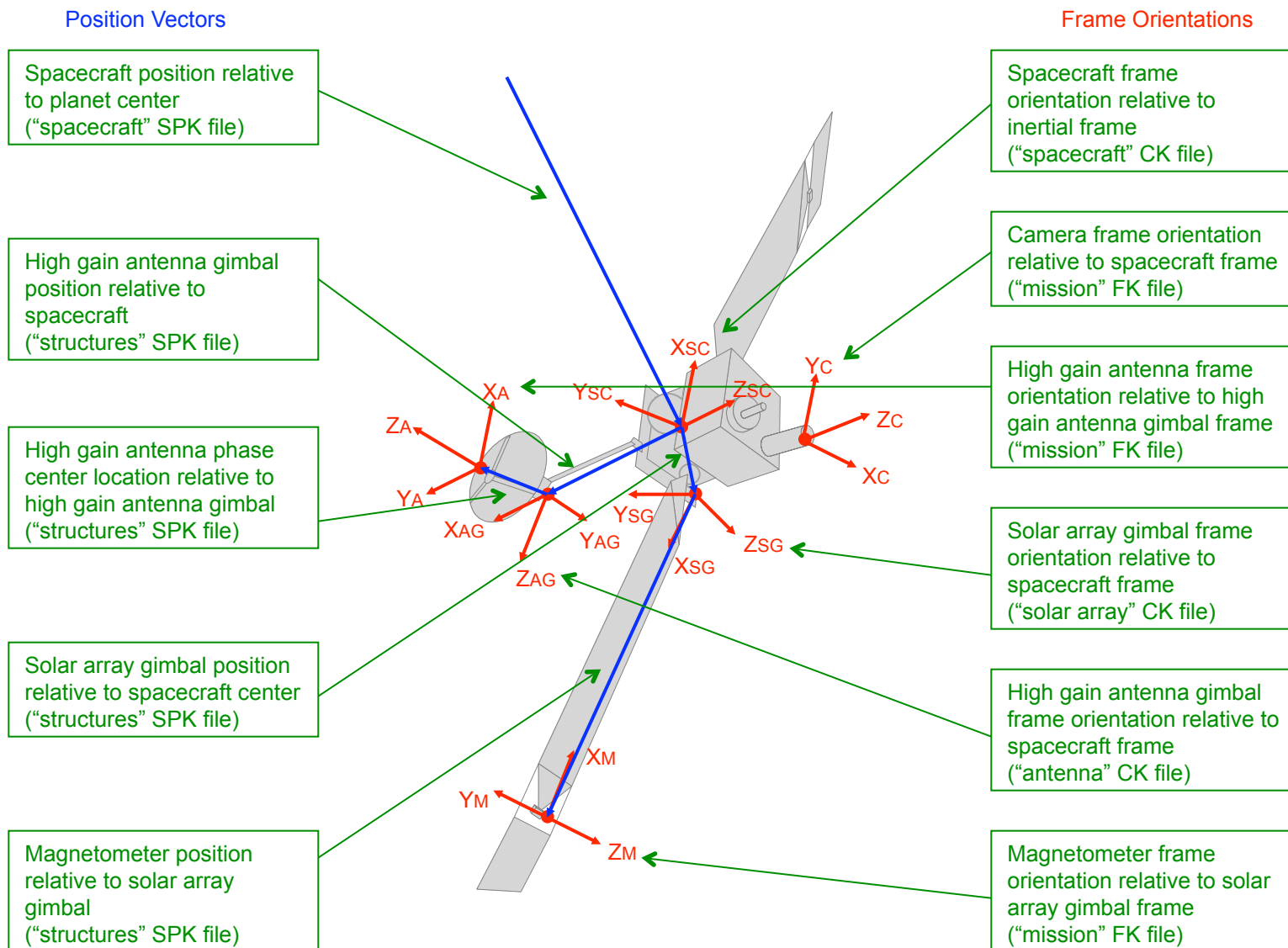
Navigation and Ancillary Information Facility

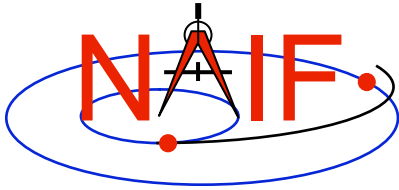




Orbiter Geometry

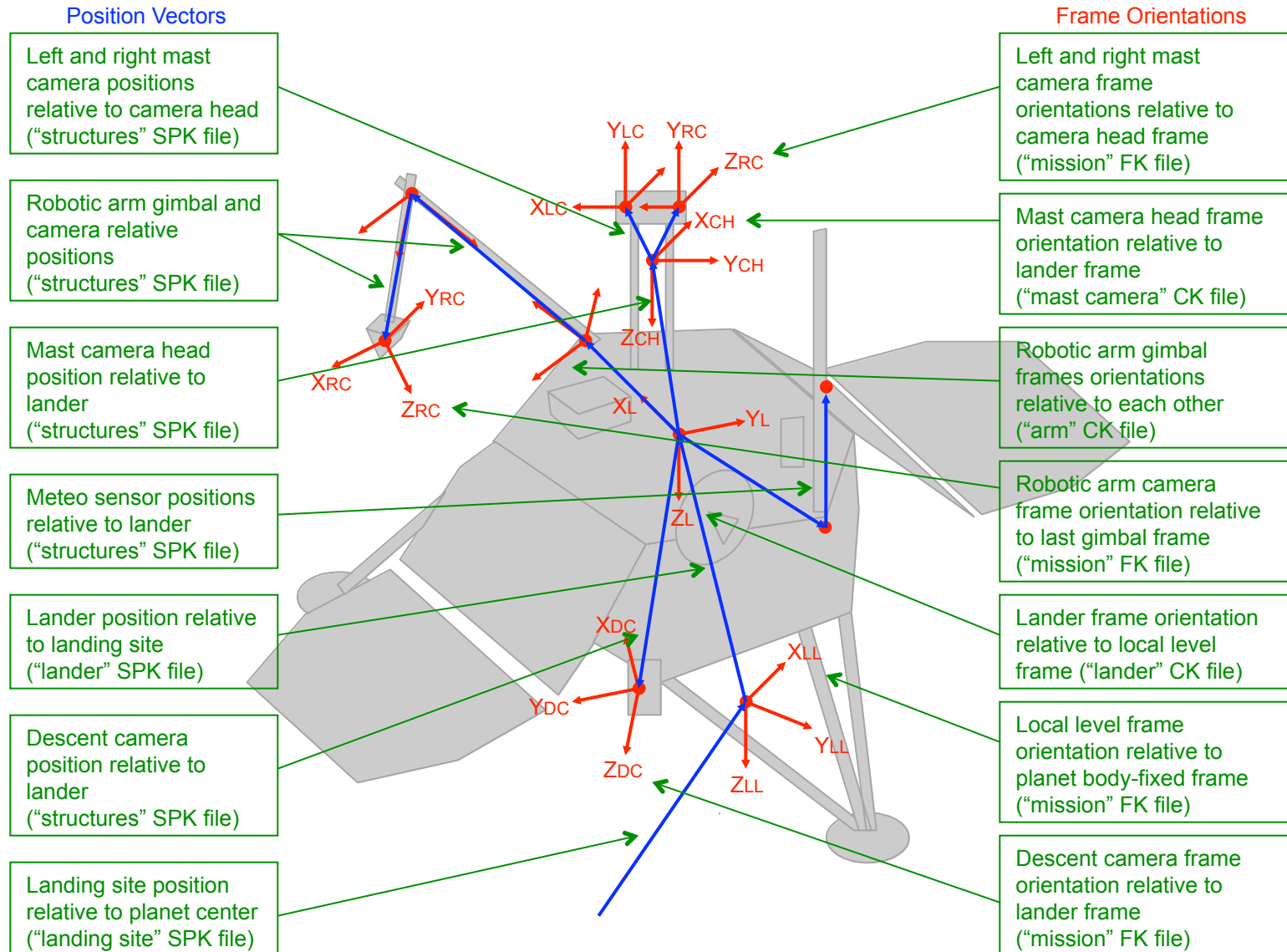
Navigation and Ancillary Information Facility

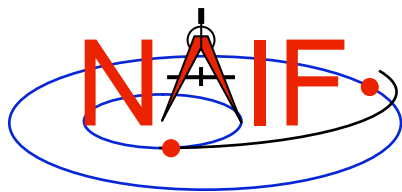




Lander Geometry

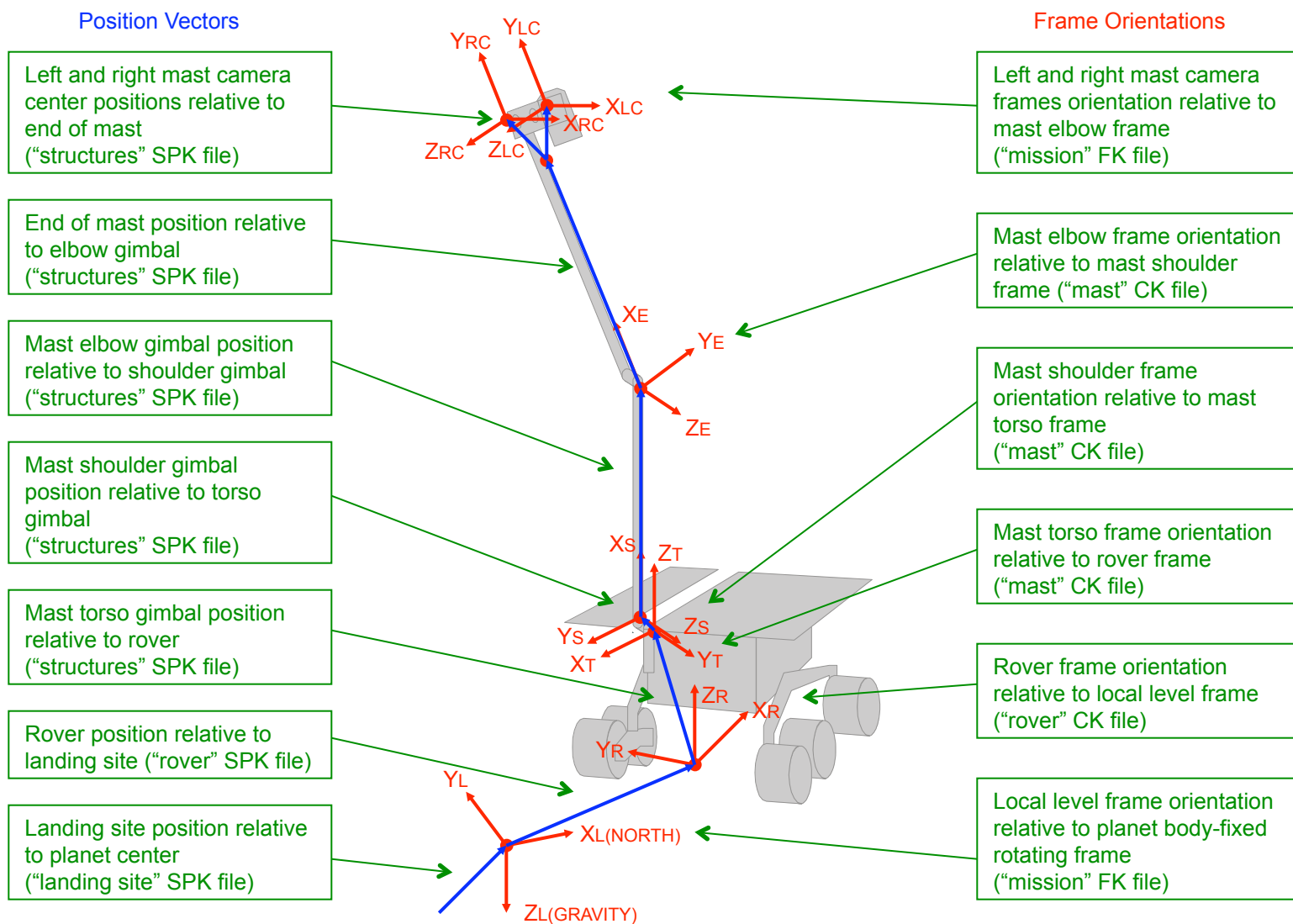
Navigation and Ancillary Information Facility

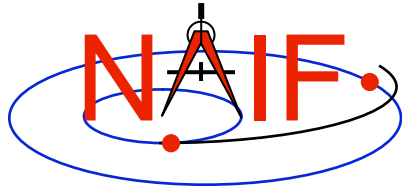




Rover Geometry

Navigation and Ancillary Information Facility



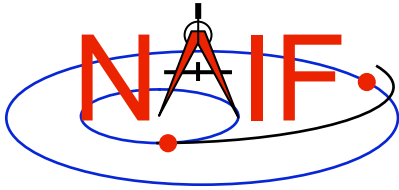


Major SPICE Users

Navigation and Ancillary Information Facility

<i>Restorations</i>	<i>Past Users</i>	<i>Current Users</i>	<i>Anticipated</i>
Apollo 15, 16 [L]	Magellan [L]	Cassini Orbiter	
Mariner 9 [L]	Clementine (NRL)	Mars Odyssey	Jupiter Ganymede Orbiter
Mariner 10 [L]	Mars Observer	Mars Exploration Rover	Jupiter Europa Orbiter (ESA)
Viking Orbiters [L]	Mars 96 [F] (RSA)	NExT, EPOXI	NASA Mars Program
Viking Landers [L]	Hubble Space Telescope [S]	Mars Reconnaissance Orbiter	NASA Discovery Program
Pioneer 10/11 [L]	Mars Pathfinder	DAWN	NASA Scout Program
Haley armada [L]	Mars Climate Orbiter [F]	Mars Science Lab	NASA New Frontiers Program
Phobos 2 [L] (RSA)	Mars Polar Lander [F]	Juno	
Ulysses [L]	NEAR	Mars Express (ESA)	<i>Future ?</i>
Voyagers [L]	Deep Space 1	Rosetta (ESA)	Constellation
Lunar Orbiter [L]	Galileo	Venus Express (ESA)	ExoMars (ESA)
	Genesis	Phobos Sample Return (RSA)	Future ISRO planetary missions
	Deep Impact	New Horizons	Future JAXA missions
	Huygens Probe (ESA)	Messenger	<i>Examples of Current Unaffiliated Users</i>
	Stardust	LCROSS	
[L] = limited use	Mars Global Surveyor	Lunar Reconnaissance Orbiter	
[S] = special services	Phoenix	Hayabusa (JAXA)	
[F] = mission failed	ISO [S] (ESA)	Kaguya (JAXA)	Kepler [L]
	MSTI-3 (NRL/ACT Corp.)	Chandrayaan (ISRO)	Planck [L] (ESA)
	Optical Transient Detector	Planet-C (JAXA)	WISE [L]
	CONTOUR [F]	BepiColombo (ESA)	IBEX
	Space VLBI [L] (multinational)		NASA Deep Space Network
	Smart-1 (ESA)	Planetary Data System	
	Spitzer Space Telescope [L]	Planetary Science Archive (ESA)	

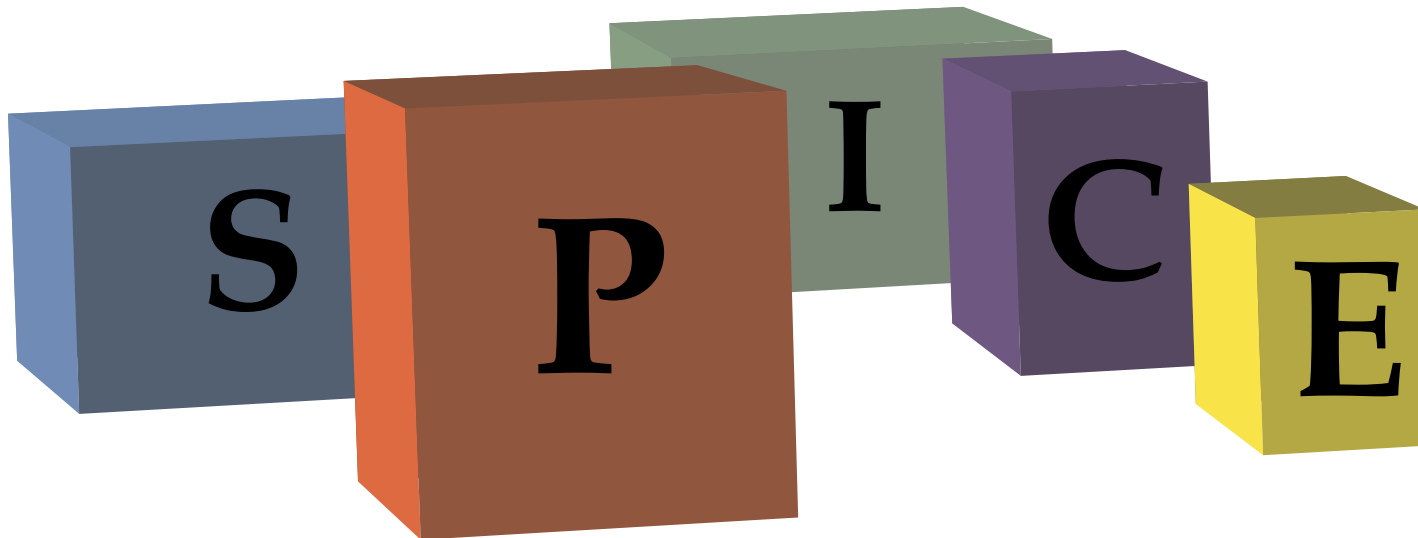
- NAIF has/had project-supplied funding to support mission operations, consultation for flight team members, and data archive preparation.
- NAIF has NASA funding to support ESA or RSA in SPICE operations and review of SPICE archive, and to consult with flight team users.
- NAIF has token funding to consult with kernel producers at APL. APL provides support to science teams.
- NAIF has modest PDS-supplied funding to consult only on assembly of a SPICE archive.
- NAIF has PDS funding to help any professional scientist or student with using SPICE data that have been archived at the NAIF Node of the PDS: http://naif.jpl.nasa.gov/naif/data_pds_archived.html
- Consultation provided by ESAC's Research and Scientific Support Department



Building Blocks for Your Applications

Navigation and Ancillary Information Facility

NAIF offers the “SPICE” ancillary information system as a set of blocks for building tools that can help execute a multimission, 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.