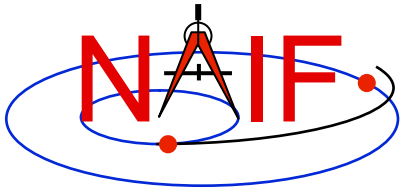


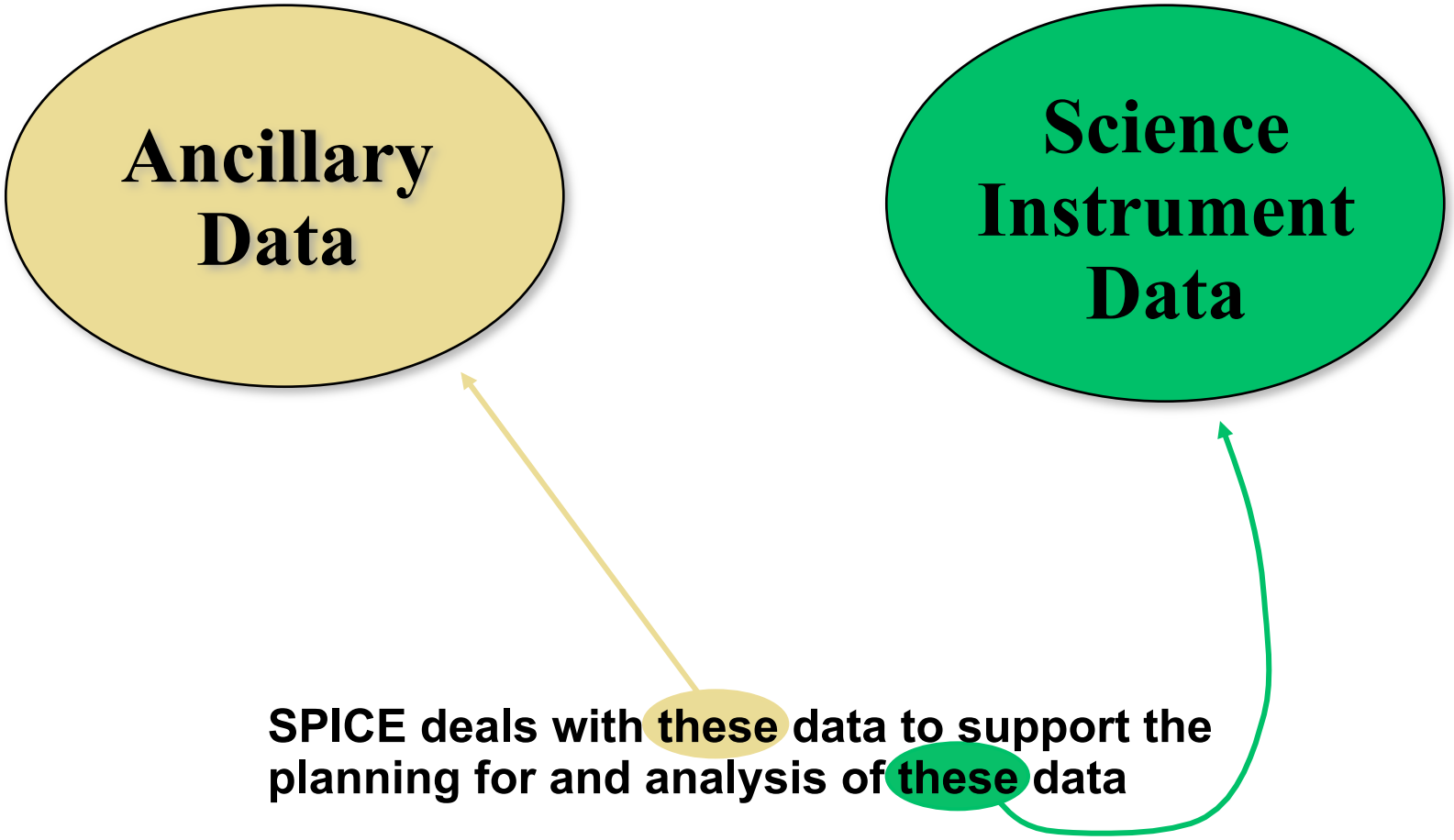
Navigation and Ancillary Information Facility

An Overview of SPICE

March 2010

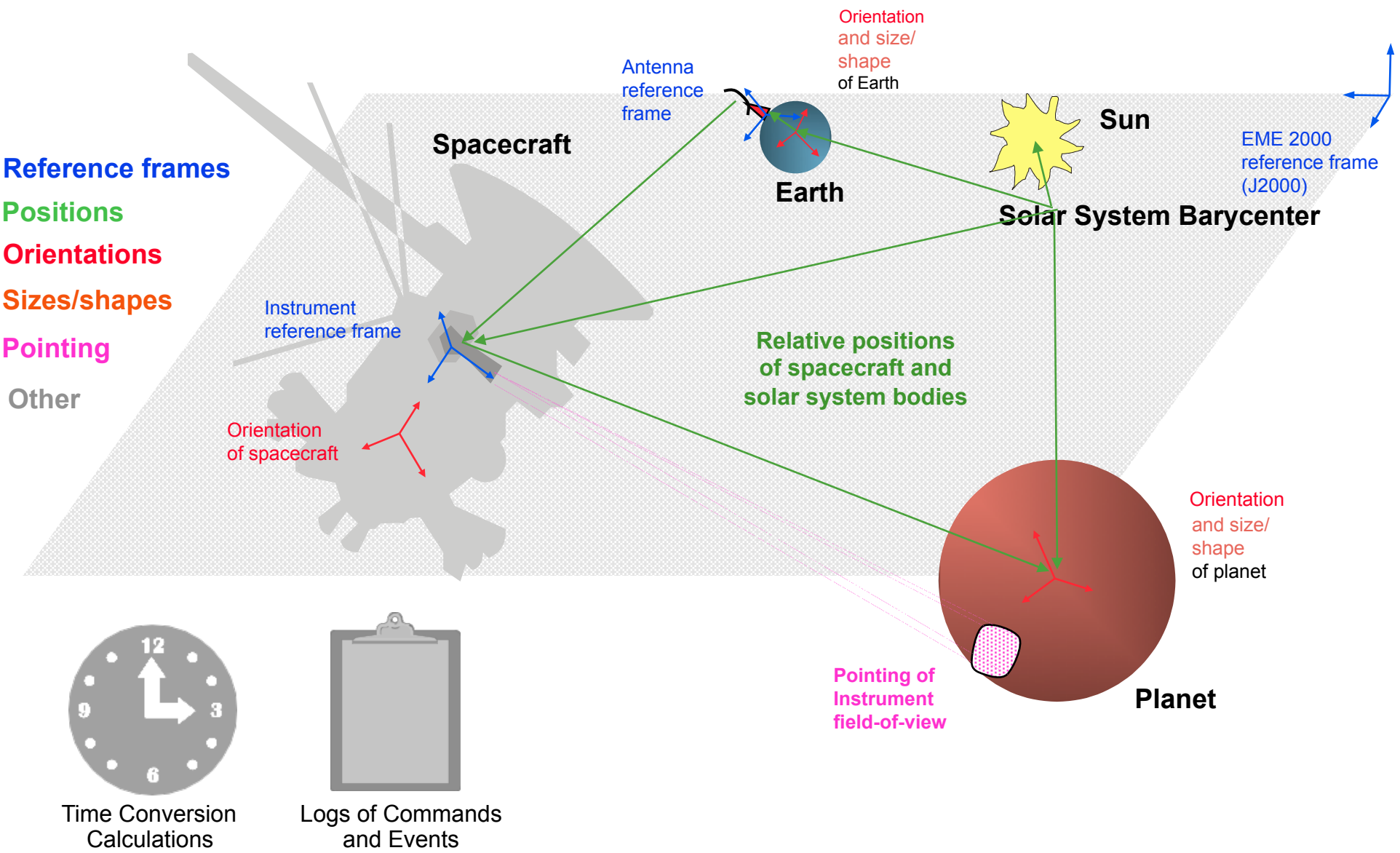
Space Science Data: Two Kinds

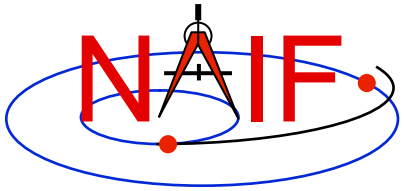
Navigation and Ancillary Information Facility



What are "Ancillary Data?"

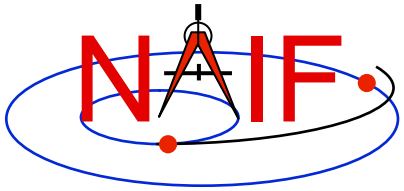
Navigation and Ancillary Information Facility





What are "Ancillary Data"?

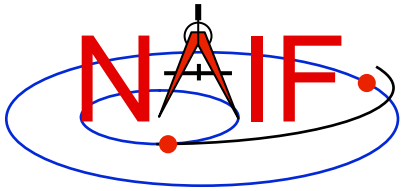
- "Ancillary data" are those that help scientists and engineers determine:
  - where the spacecraft was located
  - how the spacecraft and its instruments were oriented (pointed)
  - what was the location, size, shape and orientation of the target being observed
  - what events were occurring on the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

- Some come from the spacecraft
- Some come from the mission control center
- Some come from the spacecraft and instrument builders
- Some come from scientists

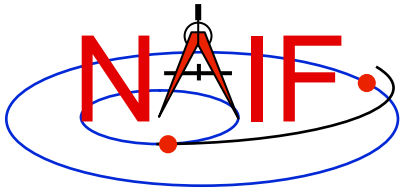
- SPICE is used to organize and package these data in a collection of useful, stable file types–called "kernels."
- The kernels are made available, along with SPICE Toolkit software:
  - to help scientists in the planning for and analysis of science observations, and
  - to help engineers in planning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



Why SPICE?

- **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.**

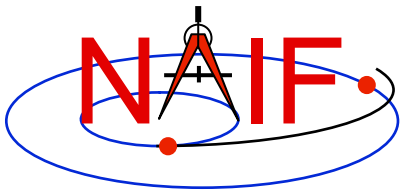
- **Having proven, extensive and reusable means for producing and using ancillary data reduces cost and risk, and can help scientists and engineers achieve more substantive, accurate and timely results.**



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*

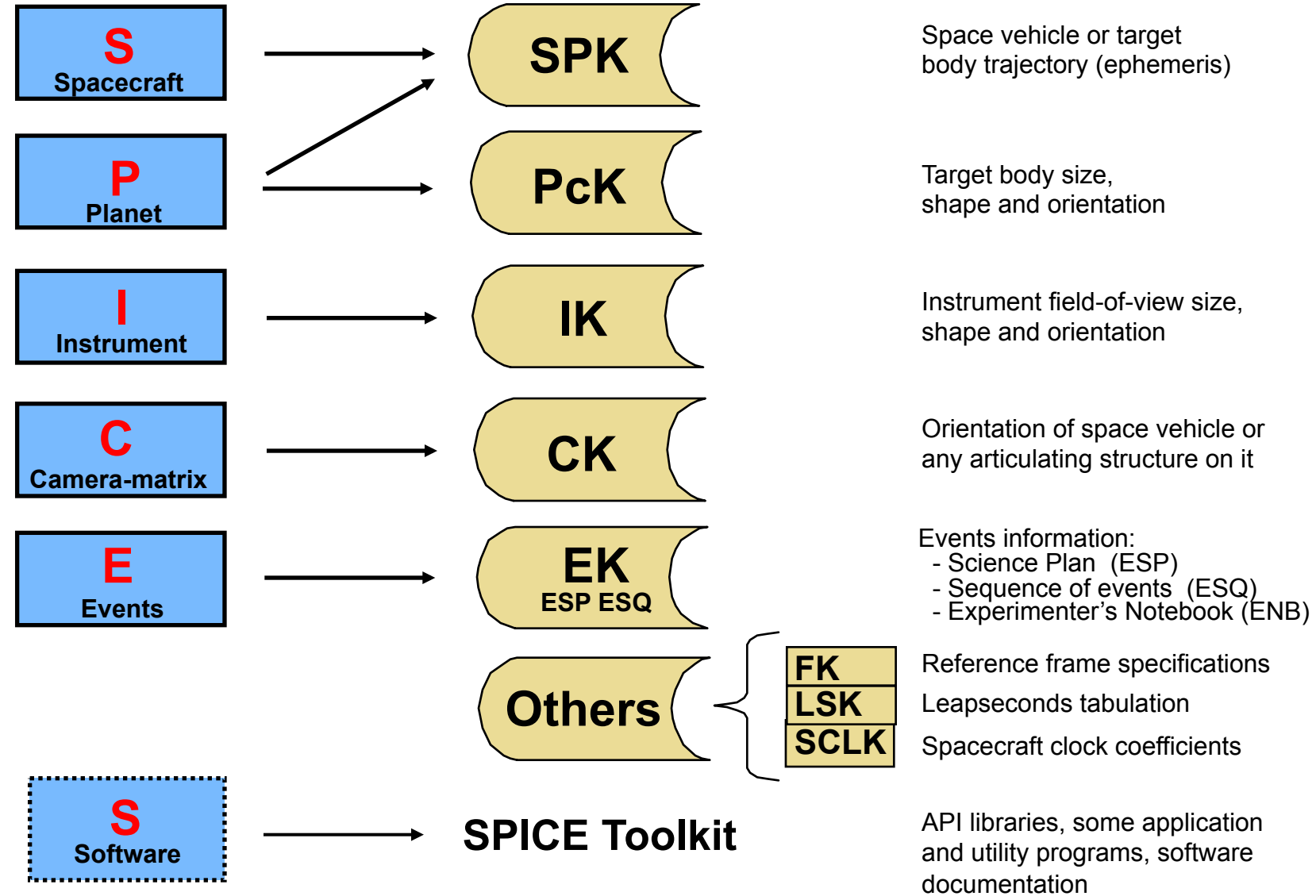
Navigation and Ancillary Information Facility

S	**S**pacecraft
P	**P**lanet
I	**I**nstrument
C	**C**-matrix
E	**E**vents

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

Logical versus Physical View

Navigation and Ancillary Information Facility

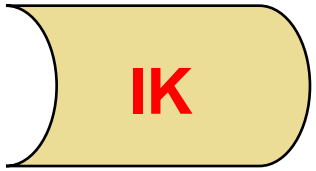


SPICE System Contents - 1

Navigation and Ancillary Information Facility

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

- Planet, satellite, comet and asteroid orientations, sizes, shapes
- Possibly other similar “constants” such as parameters for gravitational model, atmospheric model or rings model



- 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 <--> TDB (ET) time conversions

SCLK

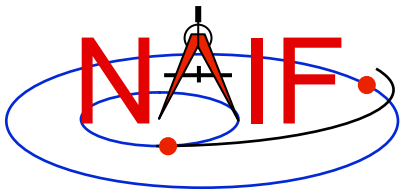
- **Spacecraft Clock Coefficients**
  - Used for SCLK <--> TDB (ET) time conversions

Other Kernels

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

[1] under development
[2] development is stalled

UTC = Coordinated Universal Time ET = Ephemeris Time SCLK = Spacecraft Clock Time



SPICE System Contents - 4

Navigation and Ancillary Information Facility

SPICE Toolkit

FORTRAN

C

IDL

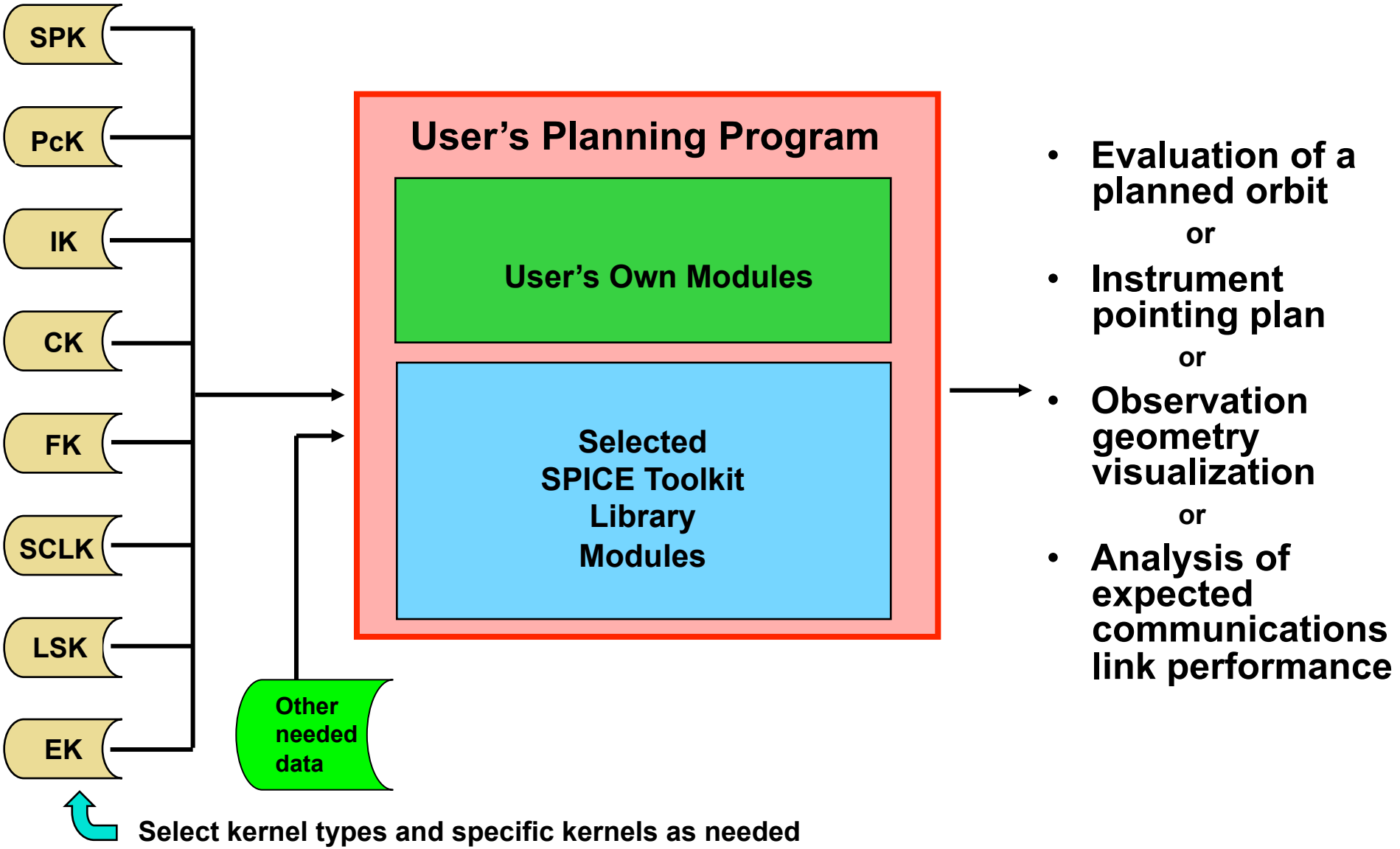
MATLAB

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



- Evaluation of a planned orbit

or

- Instrument pointing plan

or

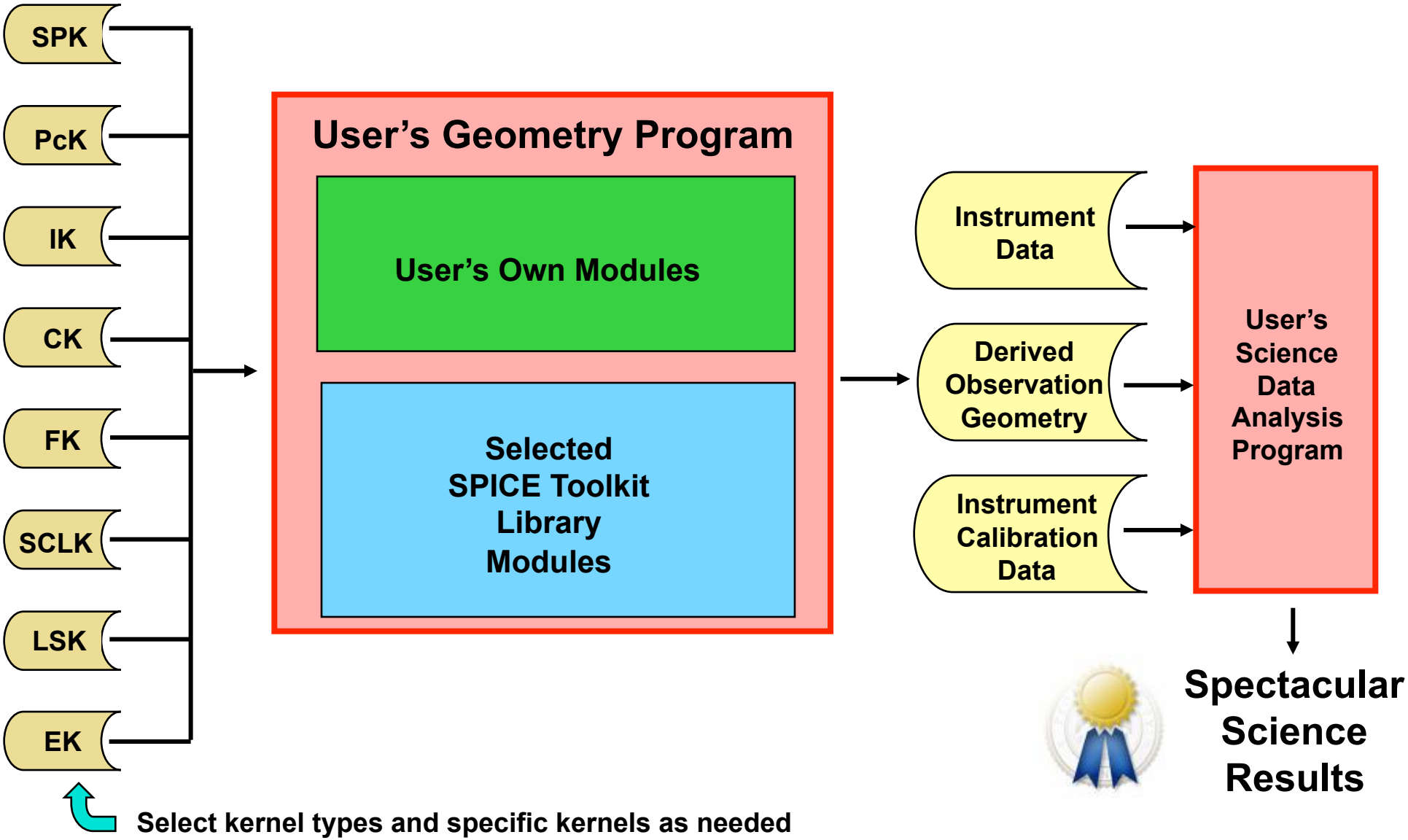
- Observation geometry visualization

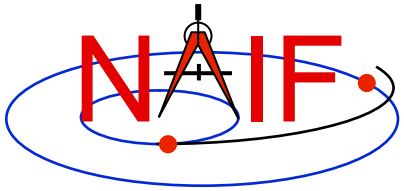
or

- Analysis of expected communications link performance

Using SPICE in Science Data Analysis

Navigation and Ancillary Information Facility

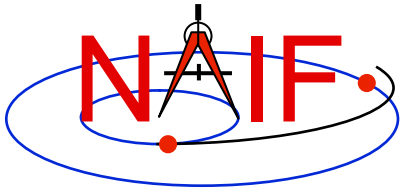




SPICE System Characteristics - 1

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

- 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

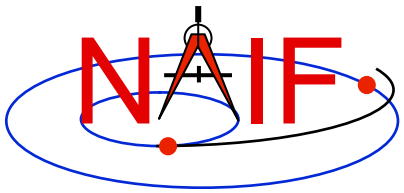
- **Funding**
  - SPICE system development is funded by NASA's Planetary Science Division
  - NASA PSD flight projects fund NAIF or others to deploy and operate SPICE in support of NASA's planetary missions
  - Foreign institutions fund their own people for deployment and operation of SPICE in support of their own projects
  - SPICE Toolkit software is free to individual end users
  - Access to SPICE kernels produced by NAIF is not restricted
    - » Includes mission operations kernels as well as those archived in the PDS
  - Support and consultation from NAIF is restricted to paying and paid for users
    - » See chart near the end of this tutorial for details

- **Distribution of SPICE software and data 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

Supported Environments

Navigation and Ancillary Information Facility

- **The SPICE Toolkit has been ported to a wide variety of popular "environments"**
  - **Each environment is characterized by…**
    - » **Language**
    - » **Hardware type (platform)**
    - » **Operating System**
    - » **Compiler (where applicable)**
    - » **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 ?

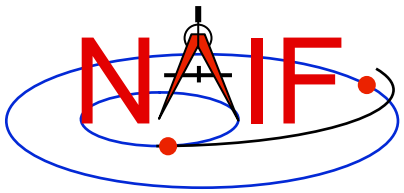
Navigation and Ancillary Information Facility

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

The original focus of SPICE

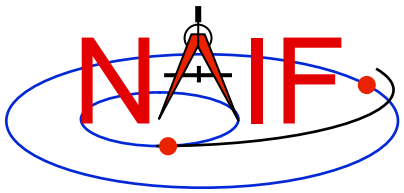
- Education and Public outreach



Examples - 1
What Can You Do With SPICE ?

Navigation and Ancillary Information Facility

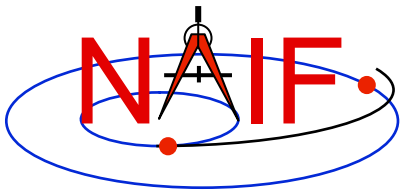
- **Mission Design**
  - Compute interesting orbit properties; compare these with those of another design, or of another mission
  - Evaluate possibilities for relay link times and duration
- **Mission Operations (mission engineering)**
  - Predict or evaluate telecommunications link performance
  - 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



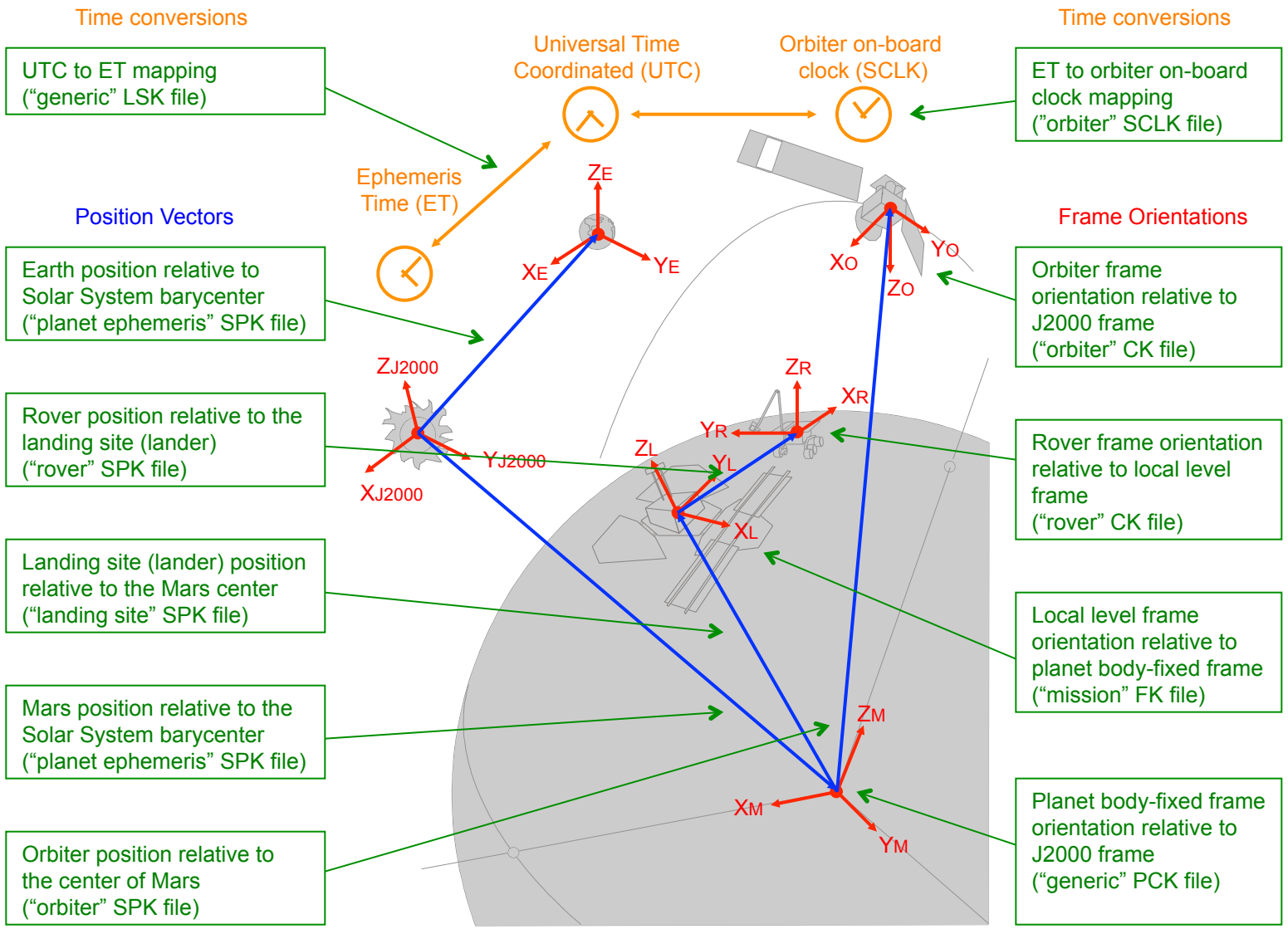
What "Vehicle" Types Can Be Supported ?

- **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

* 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)

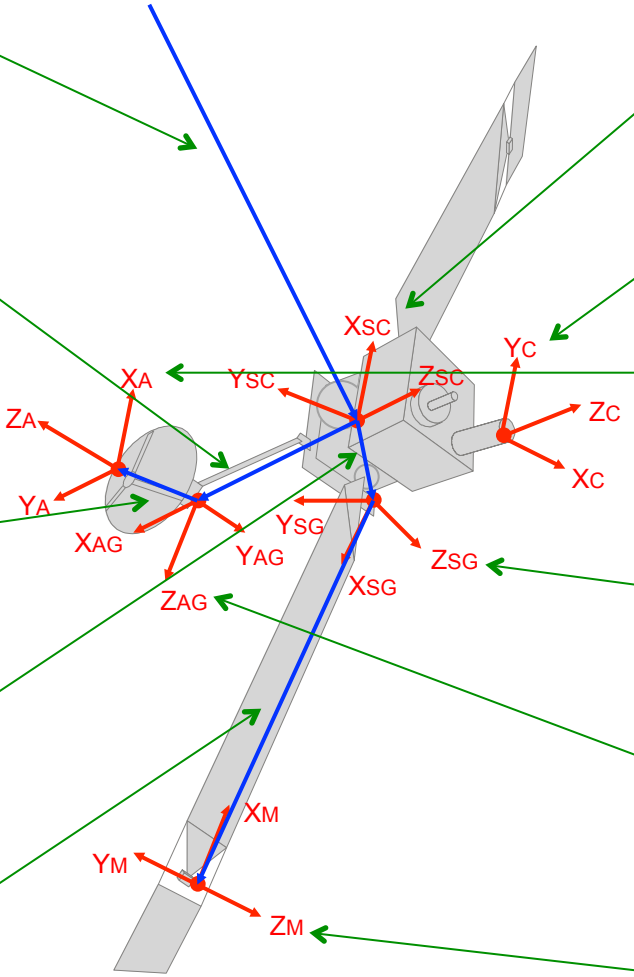
Camera frame orientation relative to spacecraft frame ("mission" FK file)

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)

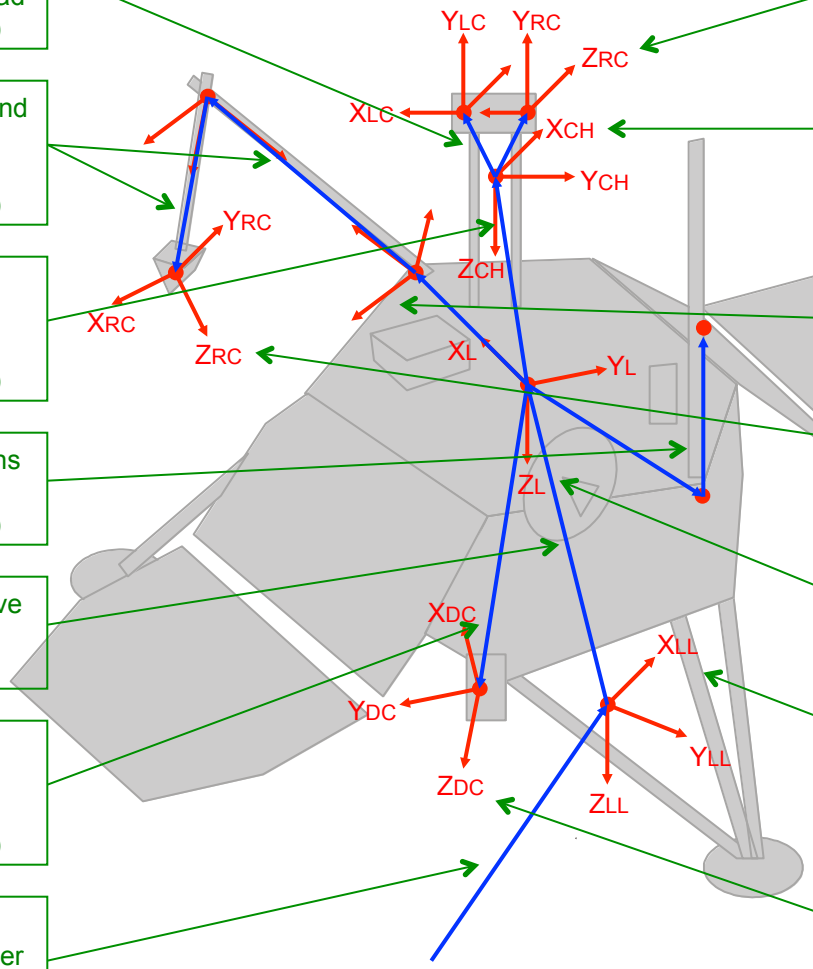


Lander Geometry

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)

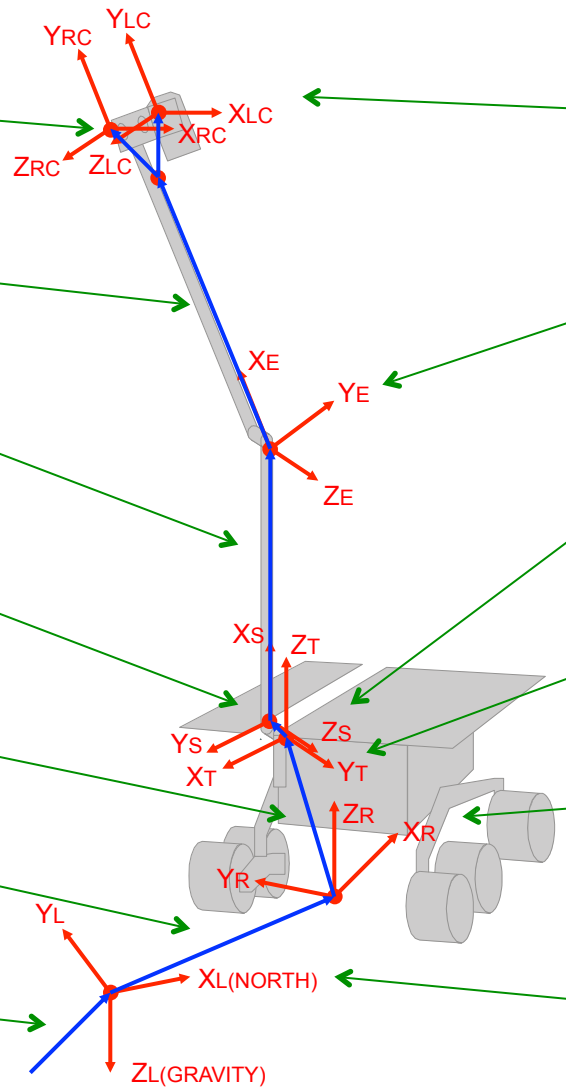
Mast elbow gimbal position relative to shoulder gimbal (“structures” SPK file)

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)

Major SPICE Users

Navigation and Ancillary Information Facility

2/4/10

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

NAIF has/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 NASA funding to support ESA or RSA in SPICE operations and review of SPICE archive, 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/had modest PDS-supplied funding to consult only on assembly of a SPICE archive.

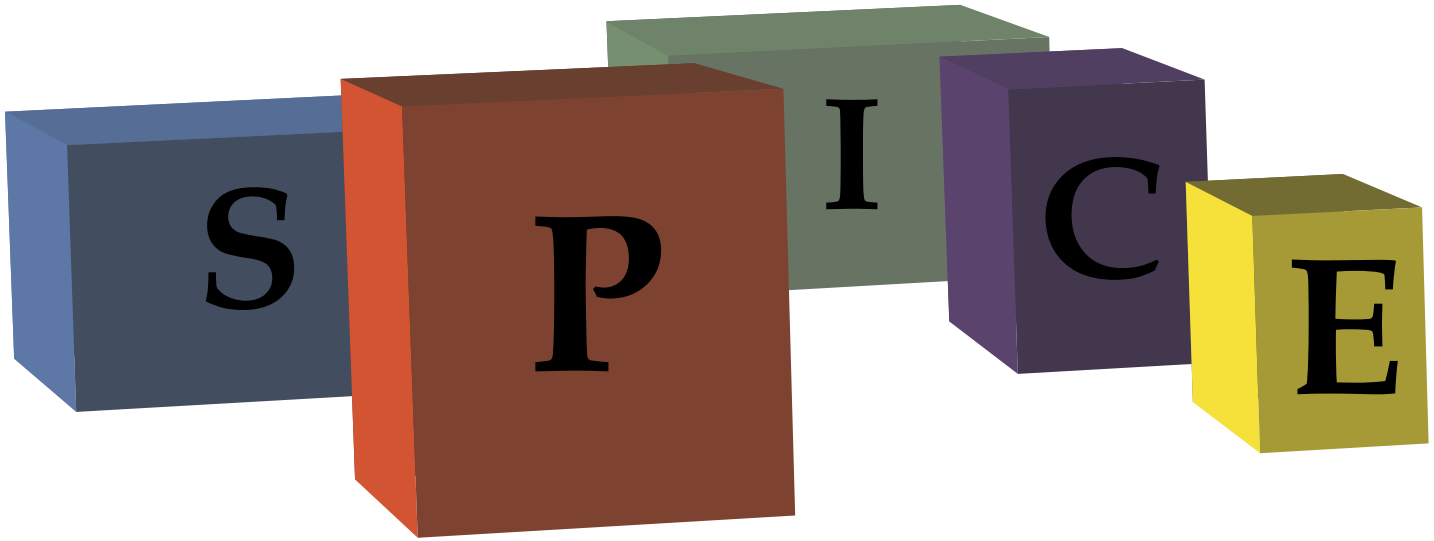
NAIF has PDS funding to help scientists and students with using SPICE data that have been officially archived at the NAIF Node of the PDS.

Consultation is provided by ESAC's Research and Scientific Support Department.

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 that can help execute a multi-mission, 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.