

Navigation and Ancillary Information Facility

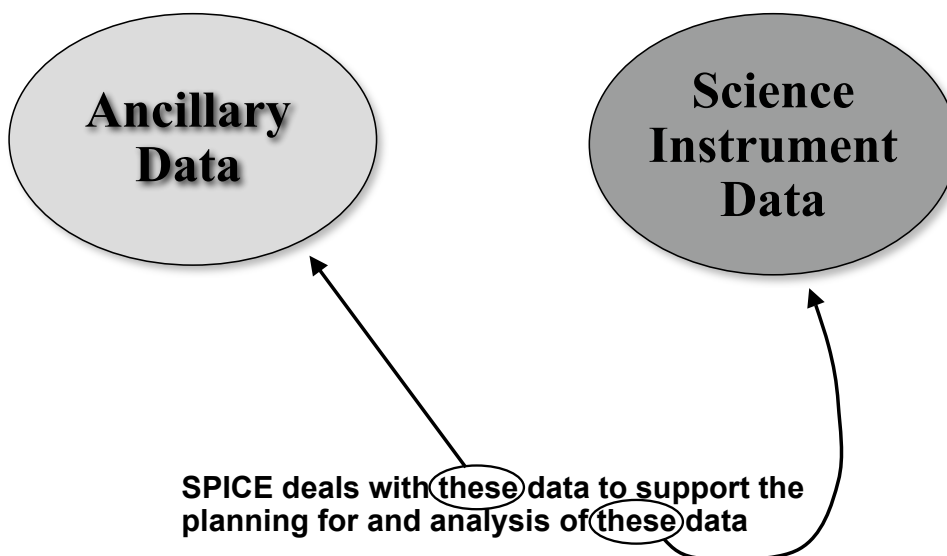
# An Overview of SPICE

October 2007



## Space Science Data: Two Kinds

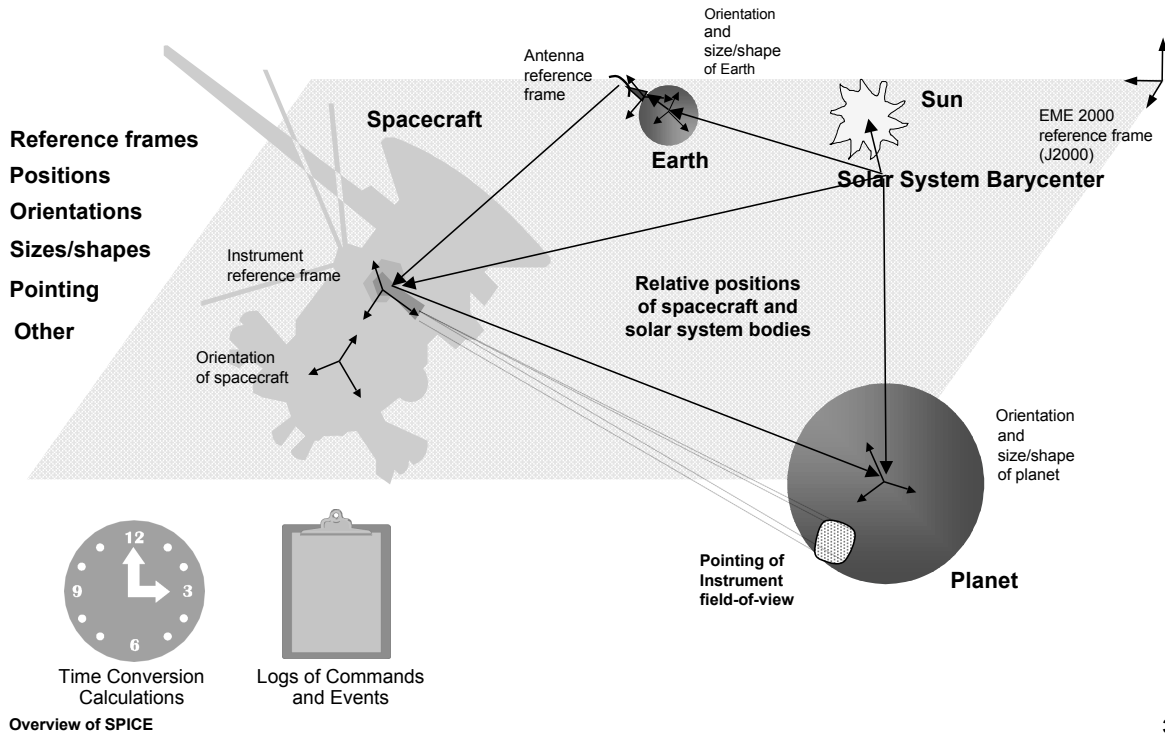
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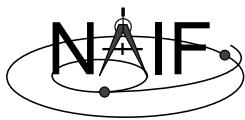


# What are “Ancillary Data”?

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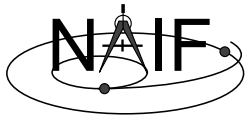
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# What are “Ancillary Data”?

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- “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?

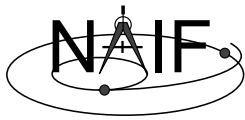
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- **Some come from the spacecraft**
- **Some come from the mission control center**
- **Some come from the spacecraft and instrument builders**
- **Some come from scientists**

**SPICE is used to organize and package these data in useful, stable packages—what we call “kernels.”**

**The kernels are made available to scientists and engineers, along with NAIF Toolkit software, to help in the planning and analysis of science observations.**



## Why SPICE?

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- **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.**



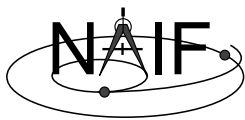
# SPICE System Components

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- **The principal SPICE system components are:**
  - **Data files, often called “kernels” or “kernel files”**
  - **Software, known as the SPICE Toolkit, consisting of:**
    - » **a subroutine 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 built around SPICE**
    - » Include tips, data, and NAIF’s solution code and numeric results

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## Genesis of the SPICE Acronym\*

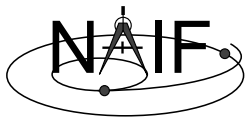
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<b>S</b>	Spacecraft
<b>P</b>	Planet
<b>I</b>	Instrument
<b>C</b>	C-matrix
<b>E</b>	Events

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

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# Logical versus Physical View

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## 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

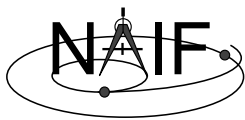
Leapseconds tabulation

Spacecraft clock coefficients

API libraries, some application  
and utility programs, software  
documentation

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# SPICE System Contents - 1

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**SPK**

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

**PcK**

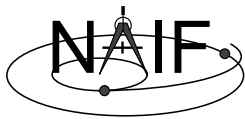
- Planet, satellite, comet and asteroid orientations, sizes, shapes
- Possibly other similar "constants" such as parameters for gravitational model, atmospheric model or rings model

**IK**

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

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## SPICE System Contents - 2

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**CK**

- Instrument platform (e.g. spacecraft) attitude
- More generally, orientation of something relative to a specified reference frame

**EK**

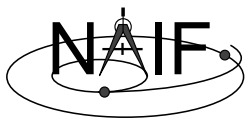
3 components

- **“Events,” broken into three components:**
  - ESP: Science observation plans
  - ESQ: Spacecraft & instrument commands
  - ENB: Experiment “notebooks” and ground data system logs

*The Events kernel idea has not taken hold.  
After Cassini it will probably disappear.*

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## SPICE System Contents - 3

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**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

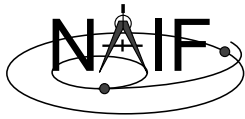
**SCLK**

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

**Other  
Kernels**

- Shape models (DEM and tessellated plates) (DSK) \*
- Star (sky) catalog (??K) \*

\* under development



## SPICE System Contents - 4

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### SPICE Toolkit

FORTRAN

C

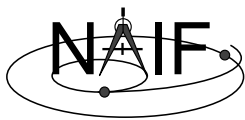
IDL

MATLAB

- **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

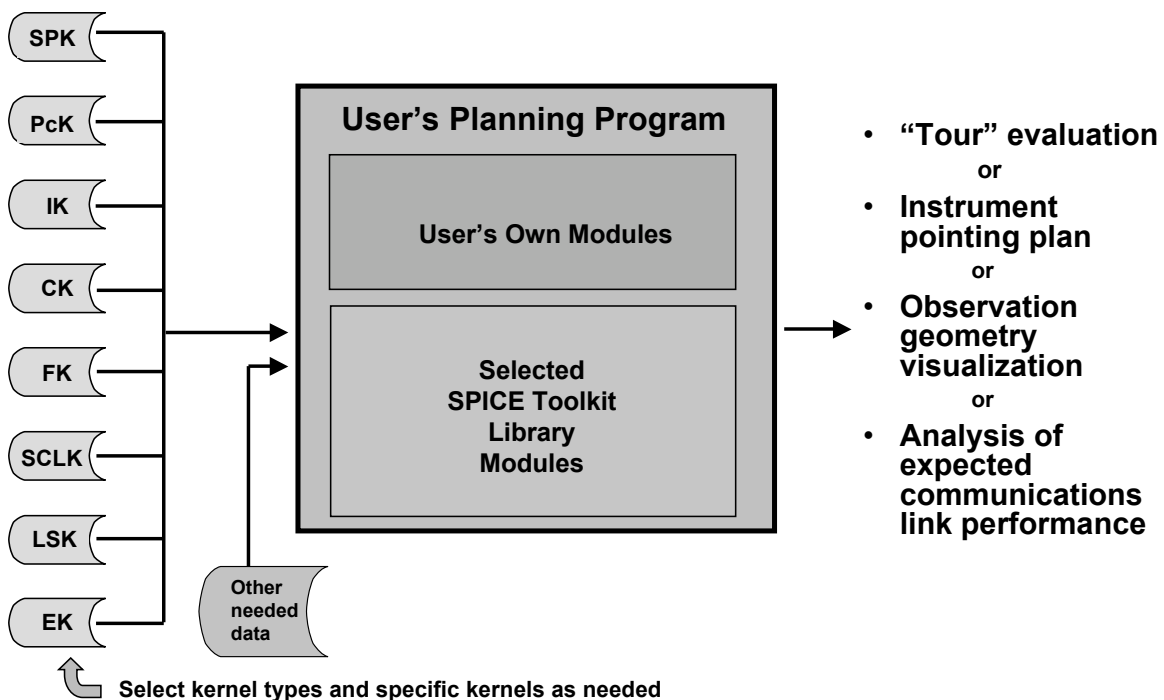
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## Using SPICE in Science Planning

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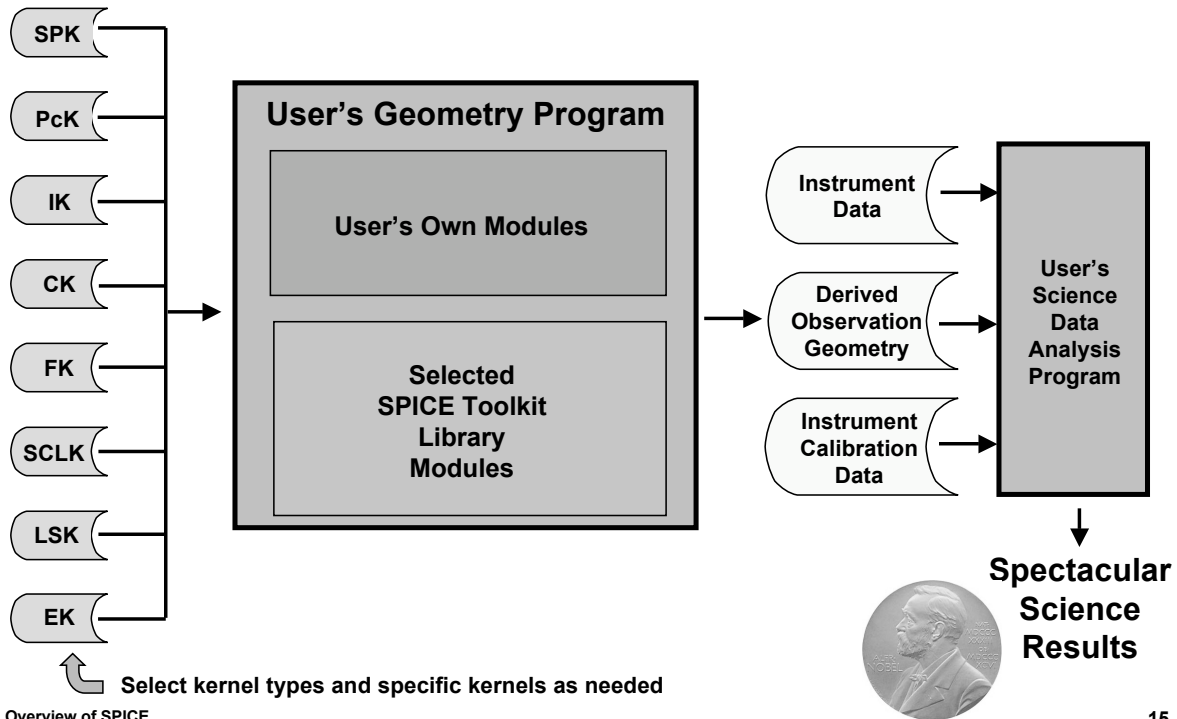
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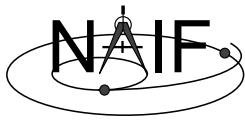


## Using SPICE in Science Data Analysis

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## SPICE System Characteristics - 1

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- Portable SPICE kernel files
- Portable NAIF Toolkit software
- Focus is on the customer
- Code is well tested before being released to users
- Once released, code functionality is never changed or removed
  - Except NAIF does reserve the right to fix bugs
- Extensive user-oriented documentation is provided
  - Includes highly documented source code
- An extensive set of SPICE tutorials is available
- “Open book” programming lessons are offered as a part of each NAIF-provided training class



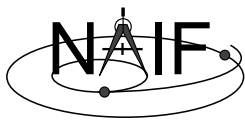


## **SPICE System Characteristics - 2**

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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



## **SPICE System Characteristics - 3**

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Navigation and Ancillary Information Facility

- **Broad applicability, means good value**
  - **Multimission and multidiscipline**
    - » Use it over and over again, no matter which NASA mission you're working on
  - **The growing use of SPICE outside of the U.S. is helping extend the multimission applicability**



## **SPICE System Characteristics - 4**

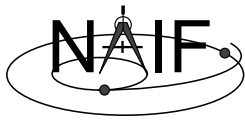
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Navigation and Ancillary Information Facility

- **The SPICE Toolkit is free to individual users**
  - Core SPICE system development is funded by NASA's Solar System Exploration Office
  - NASA flight projects fund NAIF and/or others to adapt and deploy SPICE in support of NASA's planetary missions and some cooperative missions
- **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 encouraged**
  - No license fees or other restrictions

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## **Supported Platforms**

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- **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

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## For What Jobs is SPICE Used ?

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Increasing  
mission  
maturity  
(time)

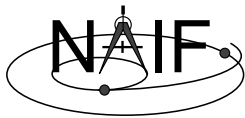
- Mission planning, modeling and visualization
- Pre-flight mission evaluation from a science perspective
- Detailed science observation planning
- Mission operations engineering functions

- 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

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## Examples - 1 What Can You Do With SPICE ?

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

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## Examples - 2

### What Can You Do With SPICE ?

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Navigation and Ancillary Information Facility

- **Science**

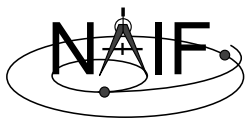
- Design specific observations to be acquired
- Compute observation geometry needed for science data product labels, to later be used in searching a catalog for science data of interest
- Compute observation geometry needed to analyze some data or to correlate multiple data sets
  - » Examples of “observation geometry”:
    - Lighting angles (phase, incidence, emission)
    - Location (LAT/LON) of instrument footprint
    - Range and local time
    - Local season

- **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 orbiter location and orientation, instrument footprint projected on the surface, and locations of surface assets or natural features of interest

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## What “Vehicle” Types Can Be Supported ?

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- **Cruise/Flyby**

- Remote sensing
- In-situ measurement
- Instrument calibration

- **Landers**

- Remote sensing
- In-situ measurements
- Rover or balloon relay

- **Orbiters**

- Remote sensing
- In-situ measurement
- Communications relay

- **Rovers**

- Remote sensing
- In-situ sensing
- Local terrain characterization

- **Balloons\***

- Remote sensing
- In-situ measurements

- **Terrestrial applications**

- Ephemerides for observers

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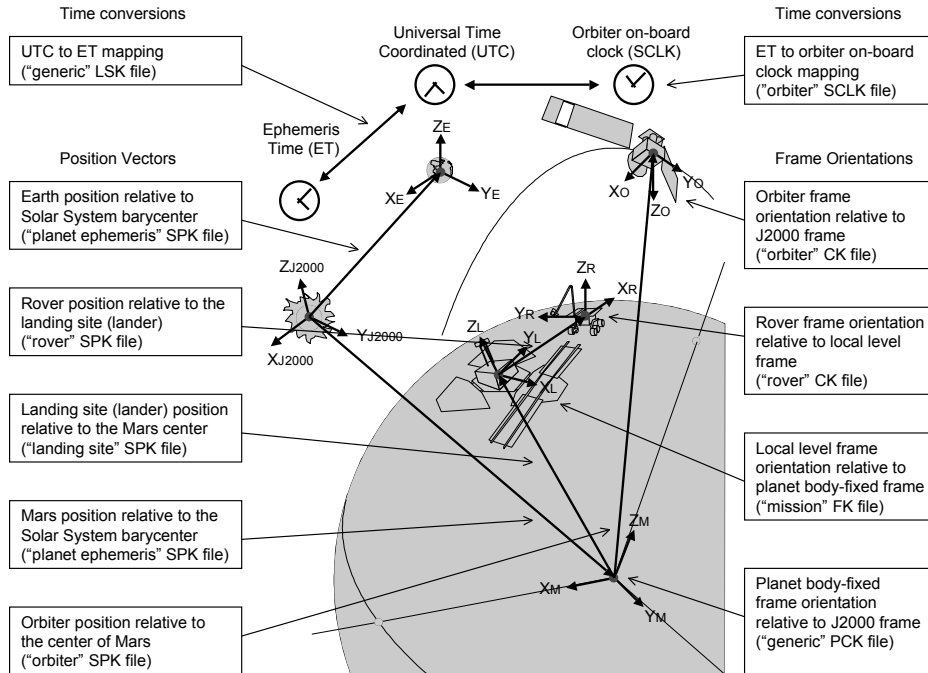
\* Not yet demonstrated

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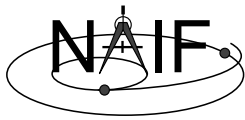
# Global SPICE Geometry

## Navigation and Ancillary Information Facility



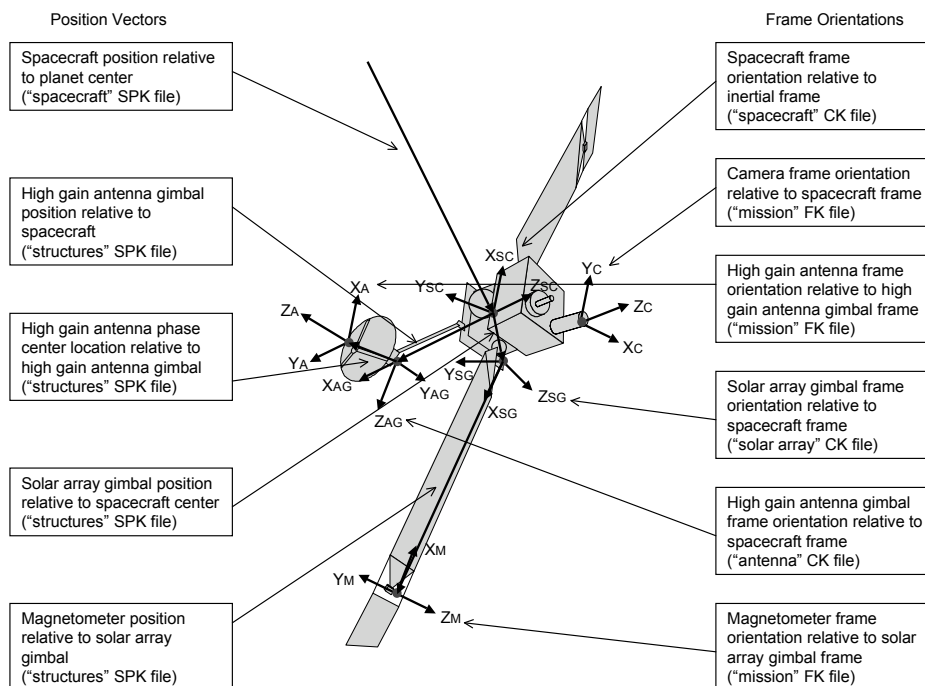
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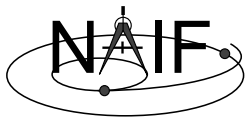
# Orbiter Geometry

## Navigation and Ancillary Information Facility



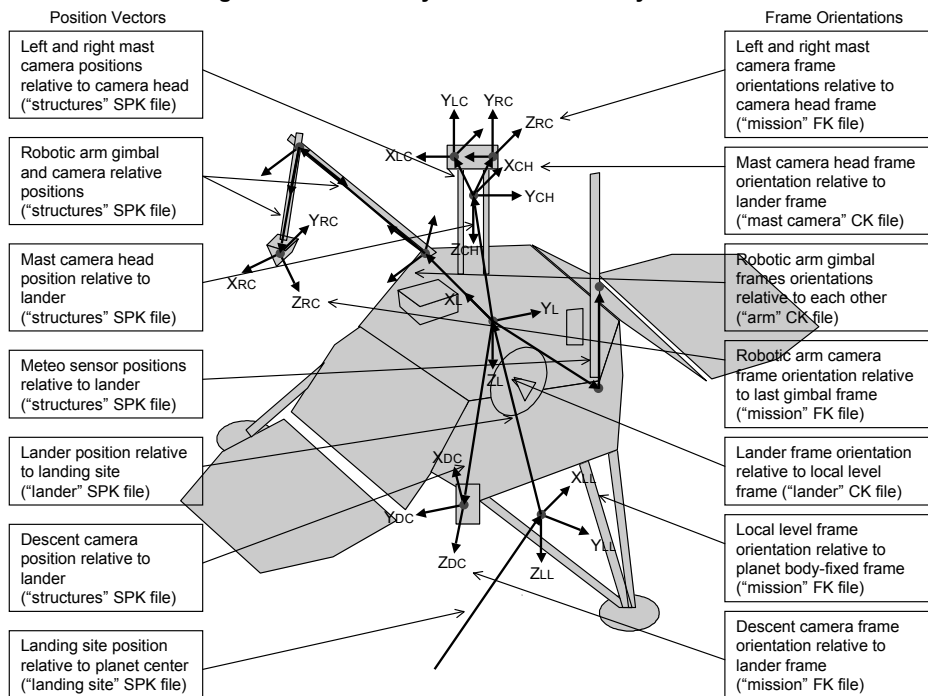
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# Lander Geometry

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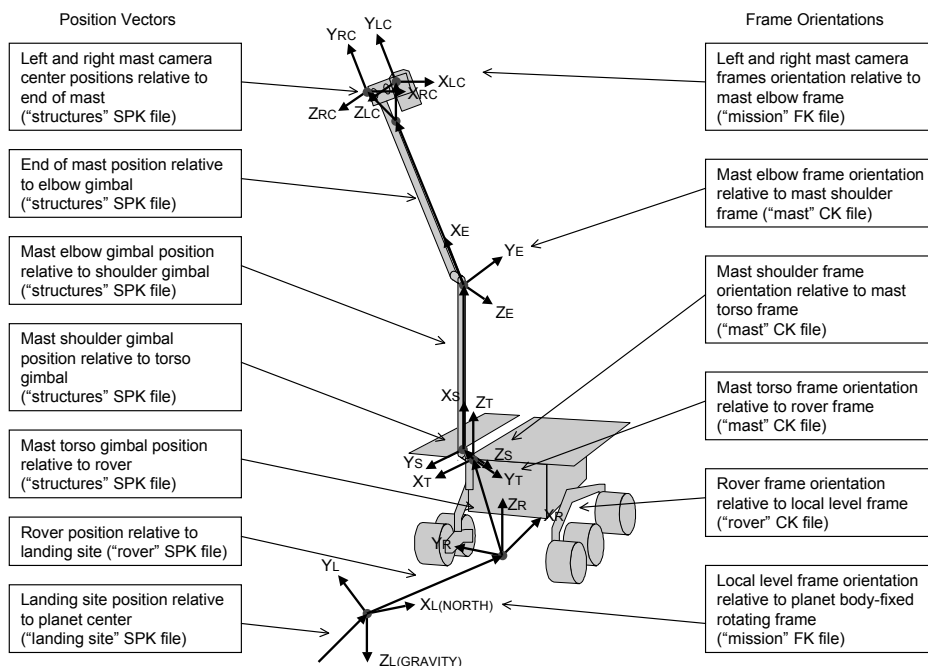
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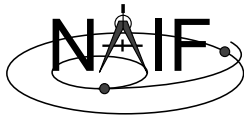
# Rover Geometry

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## Major SPICE Users

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Restorations	Past Users	Current Users	Anticipated
Apollo 15, 16 [P]	Magellan [P]	Deep Space Network	Chandrayaan (ISRO)
Mariner 9 [P]	Clementine (NRL)	Cassini	Beppi Colombo (ESA)
Mariner 10 [P]	Mars Observer	Mars Odyssey	Mars Program
Viking Orbiters [P]	Mars 96 (RSA)	Mars Exploration Rover	Discovery Program
Viking Landers [P]	Hubble Telescope [S]	Spitzer Telescope [P]	Scout Program
Pioneer 10/11 [P]	ISO [S] (ESA)	Mars Express (ESA)	New Frontiers Prgm.
Haley armada [P]	MSTI-3 (by ACT Corp.)	Mars Recon. Orbiter	
Phobos 2 [P] (RSA)	OTD (by MSFC)	DAWN	
Ulysses [P]	Mars Pathfinder	Phoenix	Future ?
Voyagers [P]	Mars Climate Orbiter	New Horizons (APL)	Chang'e (China)
Lunar Orbiter [P]	Mars Polar Lander	Messenger (APL)	Grunt (RSA)
	NEAR	Mars Science Lab	Constellation
	Deep Space 1	Rosetta (ESA)	SIM
	CONTOUR	Venus Express (ESA)	ExoMars (ESA)
	Space VLBI [P]	Smart-1 (ESA)	
	Galileo	Hayabusa (JAXA) [P]	
	Genesis	Selene (JAXA) [P]	
	Deep Impact	NExT, EPOXI	
	Huygens	Kepler	
	Stardust	Planck (ESA)	
	Mars Global Surveyor	LCROSS (Ames)	
		Lunar Recon. Orb. (GSFC)	
		Juno	

[P] = partial use of SPICE [S] = special tools or services provided by NAIF

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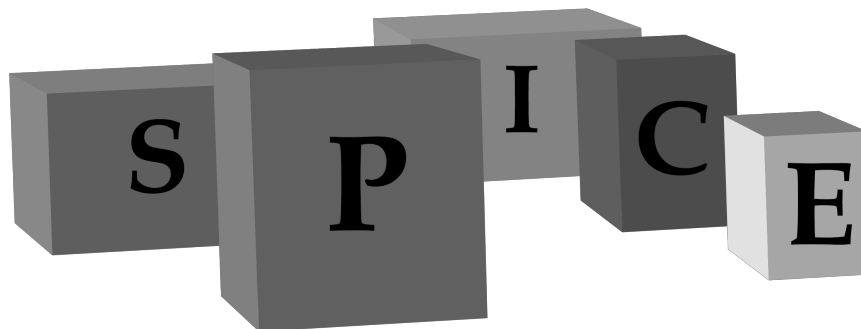
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## Building Blocks for Your Applications

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.

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