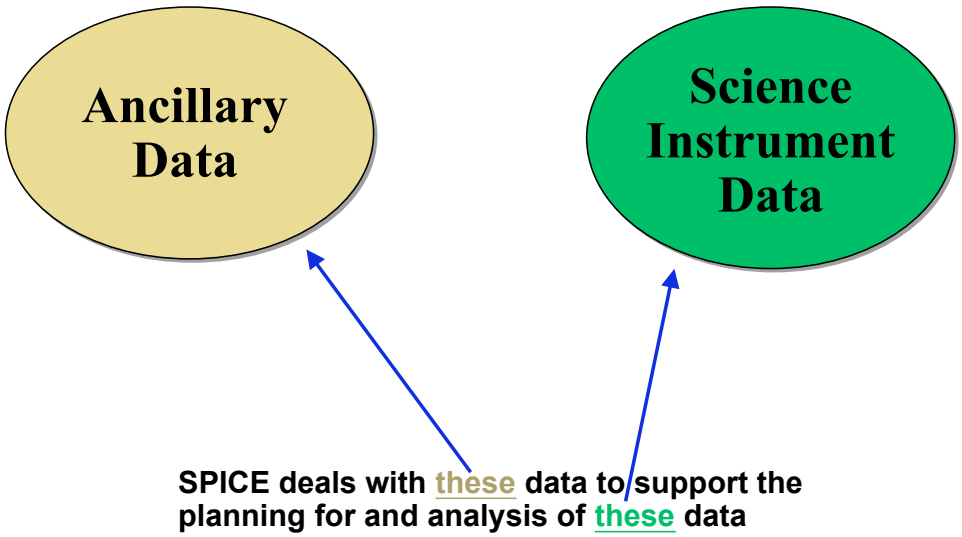
An Overview of SPICE

March 2006

The SPICE system has been developed by the Jet Propulsion Laboratory, California Institute of Technology,
under contract with the National Aeronautics and Space Administration

Navigation and Ancillary Information Facility

Space Science Data: Two Kinds

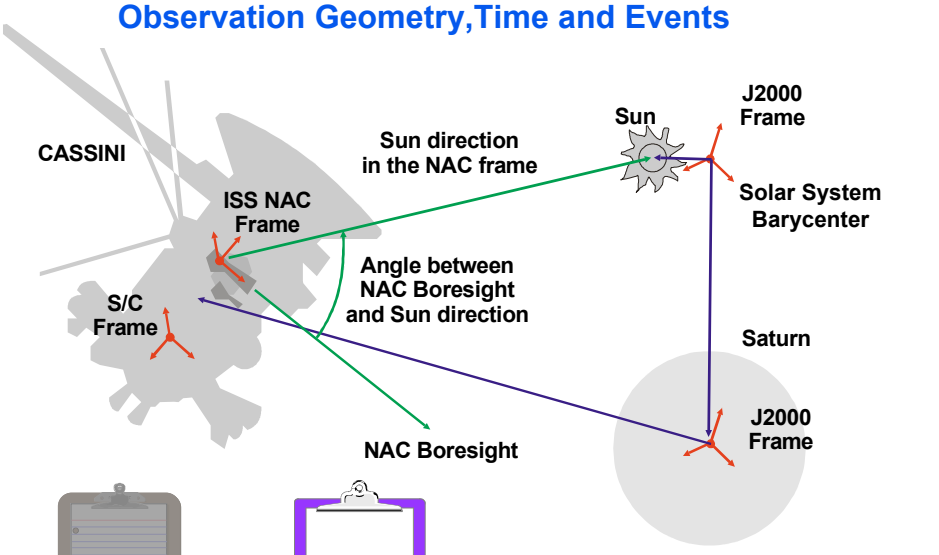


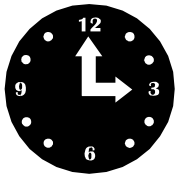
SPICE deals with these data to support the planning for and analysis of these data

The Subjects of SPICE

Navigation and Ancillary Information Facility

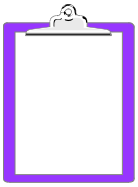
SPICE ancillary data deal with Observation Geometry,Time and Events





SCLK or SCET

Today's Plan of Events



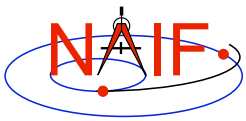
Log of Yesterday's Events

ISS = Imaging Science System:
- NAC = Narrow Angle Camera
- WAC = Wide Angle Camera

What are "Ancillary Data"?

Navigation and Ancillary Information Facility

- "Ancillary data" are those that help scientists and engineers determine:
  - when and how an instrument was acquiring data
  - 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
    - » spacecraft systems performance



From Where do Ancillary Data Come?

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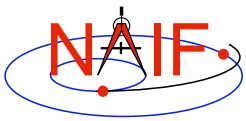
- Some come from the spacecraft
- Some come from the mission control center
- Some come from the spacecraft and instrument builders
- Some come from scientists

NAIF validates, organizes and packages these data, then makes them available to scientists and engineers in a consistent fashion, along with software to help use those data.



SPICE System Components

Navigation and Ancillary Information Facility

- The principal SPICE system components are two
  - Data files, often called "kernels" or "kernel files"
  - Software, known as the SPICE Toolkit
    - » The principal component is an extensive subroutine library
    - » Also included are some:
      - broadly useful application programs
      - utility programs
      - examples of how to use SPICE Toolkit subroutines
- Also part of SPICE are:
  - standards
  - documentation
  - customer support
  - system maintenance and continuing development

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

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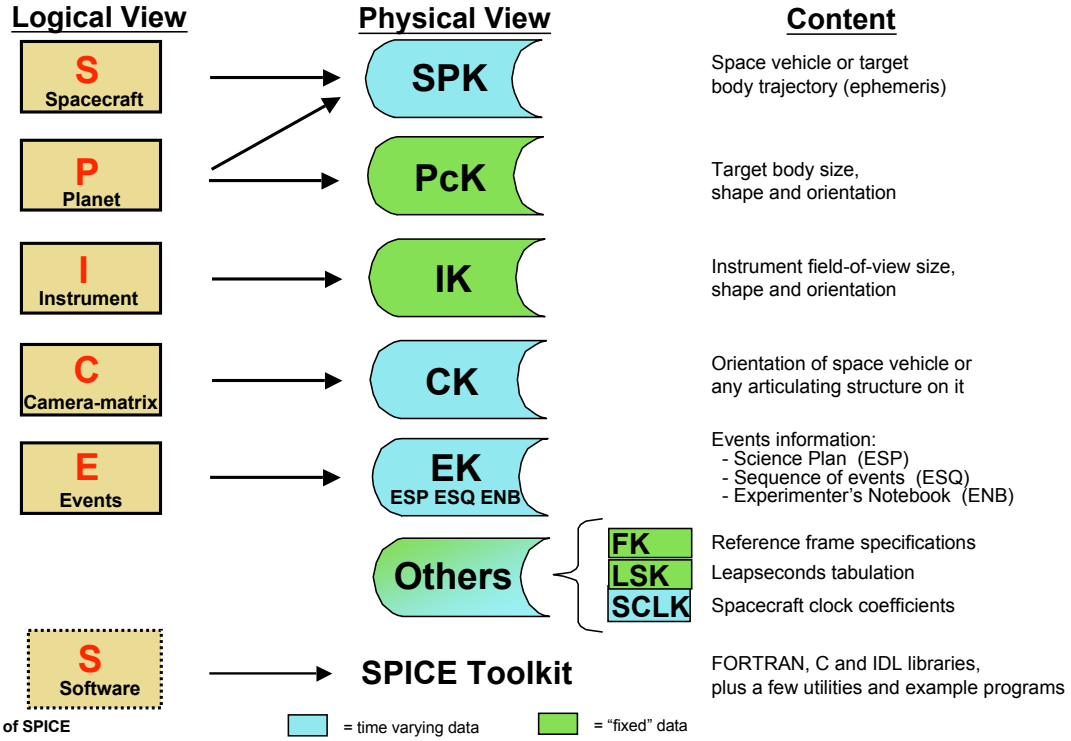


SPICE System Contents - 1

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 specifications
  - Internal timing

SPICE System Contents - 2

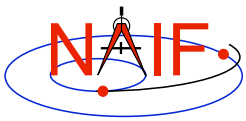
Navigation and Ancillary Information Facility

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: Spacecraft "notebooks" and ground data system logs



SPICE System Contents - 3

Navigation and Ancillary Information Facility

FK

- **Frames Definitions**
  - Definitions of and specification of relationships between reference frames (coordinate systems)

LSK

- **Leapseconds Tabulation**
  - Used for UTC <--> ET time conversions

SCLK

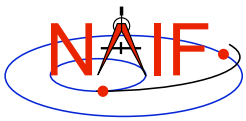
- **Spacecraft Clock Coefficients**
  - Used for SCLK <--> ET time conversions

Other Kernels

- Mission (mappings between names and ID codes)
- Star (sky) catalog*
- Plate model for irregular bodies*

* = under development

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



SPICE System Contents - 4

Navigation and Ancillary Information Facility

SPICE Toolkit

FORTRAN

C

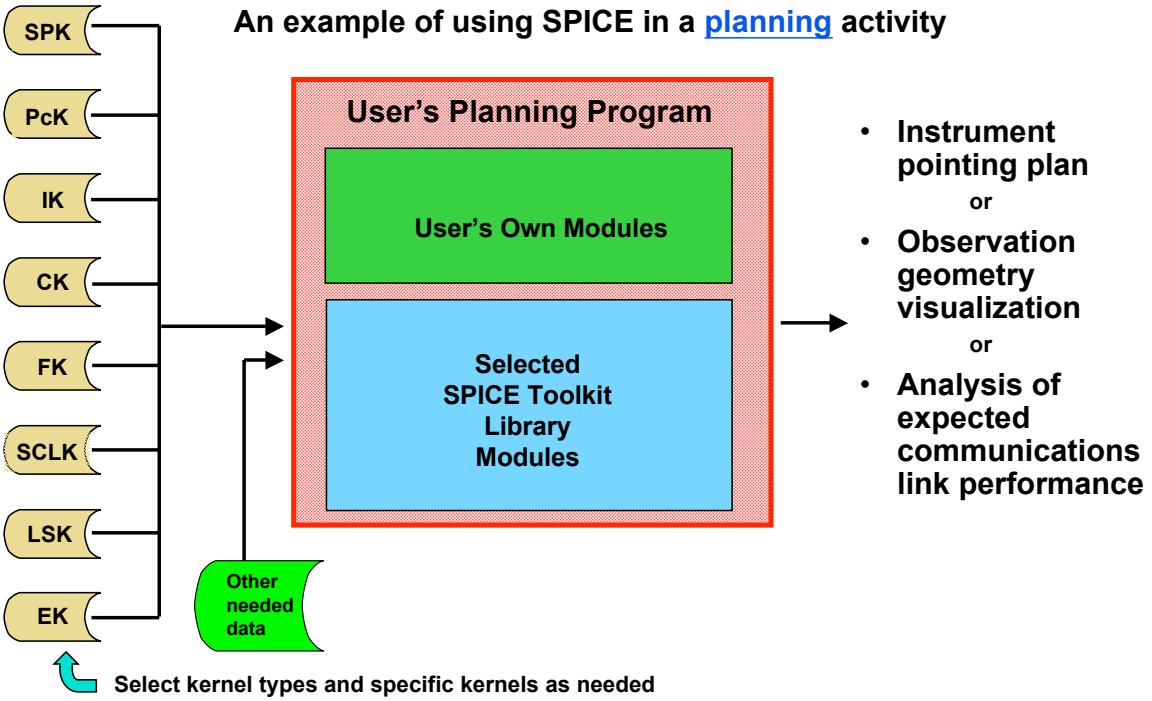
IDL

- **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 management
- **Application programs (a few)**
  - e.g. “chronos” time conversion application
- **Kernel production programs (a few)**
  - e.g. “mkspk” trajectory generator

Using SPICE Library Modules

Navigation and Ancillary Information Facility

An example of using SPICE in a planning activity

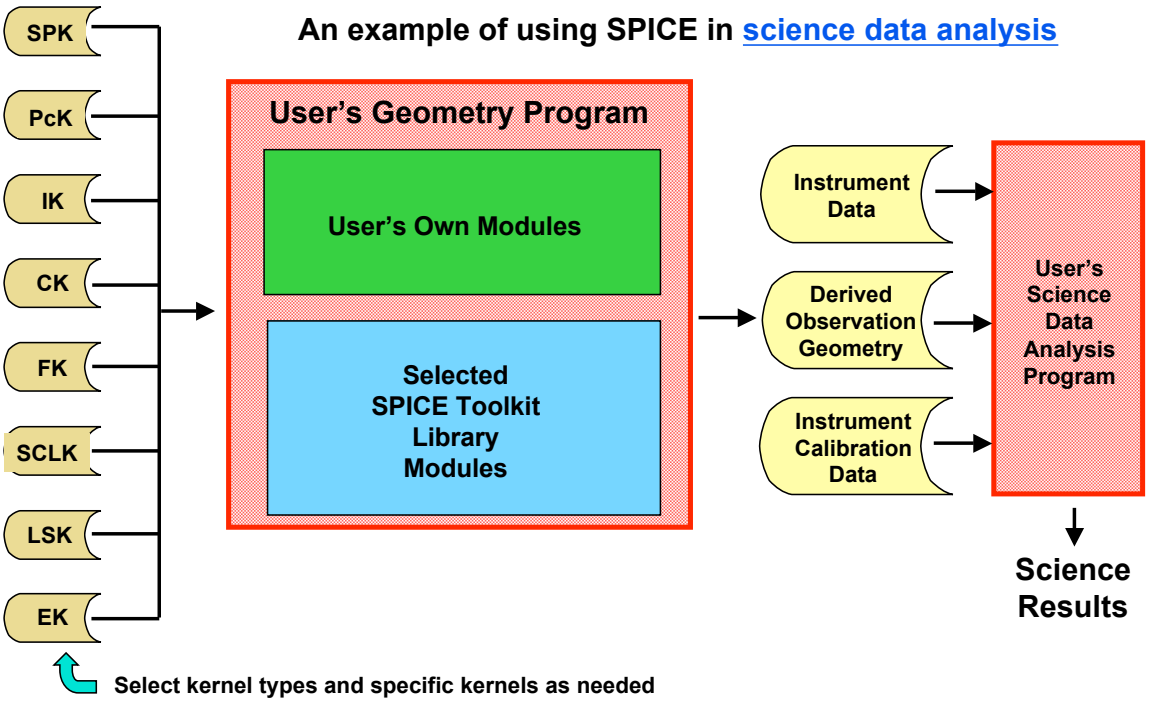


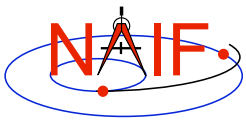
- Instrument pointing plan
  or
- Observation geometry visualization
  or
- Analysis of expected communications link performance

Using SPICE Library Modules

Navigation and Ancillary Information Facility

An example of using SPICE in science data analysis

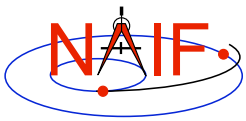




SPICE System Characteristics - 1

Navigation and Ancillary Information Facility

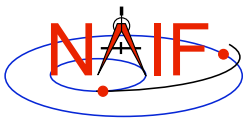
- Portable SPICE kernel files
- Portable SPICE Toolkit software
- Focus is on the customer
- Code is well tested before being released to users
- Once released, code functionality is never changed or removed
  - Except NAIF does reserve the right to fix bugs
- Extensive user-oriented documentation is 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

Navigation and Ancillary Information Facility

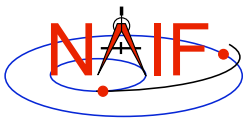
- Computations are double precision
- System includes built-in exception handling
  - Catches most invalid inputs
  - Offers a traceback and configurable action upon detection of a problem
- Gives you access to most of JPL's integrated ephemerides for spacecraft and natural bodies (planets, satellites, 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
- Broad applicability and good value
  - Multimission and multidiscipline (see list of major projects)
  - SPICE development and maintenance costs are shared across many customers



SPICE System Characteristics - 3

Navigation and Ancillary Information Facility

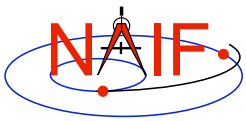
- **Broad applicability, means good value**
  - **Multimission and multidiscipline (see list of major projects)**
    - **»Use it over and over again, no matter which mission you're working on**
      - **Includes several non-NASA missions**
  - **SPICE development and maintenance costs are shared across many customers**
    - **»So no one entity has to pay very much**



SPICE System Characteristics - 4

Navigation and Ancillary Information Facility

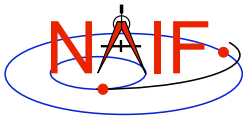
- **The SPICE Toolkit is free to individual users**
  - **Core SPICE system development is funded by NASA's Solar System Exploration Office**
  - **NASA flight projects fund NAIF and/or others to adapt and deploy SPICE in support of NASA's planetary missions and some cooperative missions**
- **Very few restrictions on distribution and use of SPICE software and SPICE files**
  - **Distribution of SPICE software is generally not restricted under U.S. Government regulations**
    - **» SPICE is classified TSPA ("Technology and Software Publicly Available")**
    - **» No ITAR restrictions**
  - **Commercial use of SPICE software is encouraged, with 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 platform
  - (Don't try porting the Toolkit to some new environment yourself… unless you first 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 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

Examples - 2
What Can You Do With SPICE ?

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

What "Vehicle" Types Can Be Supported ?

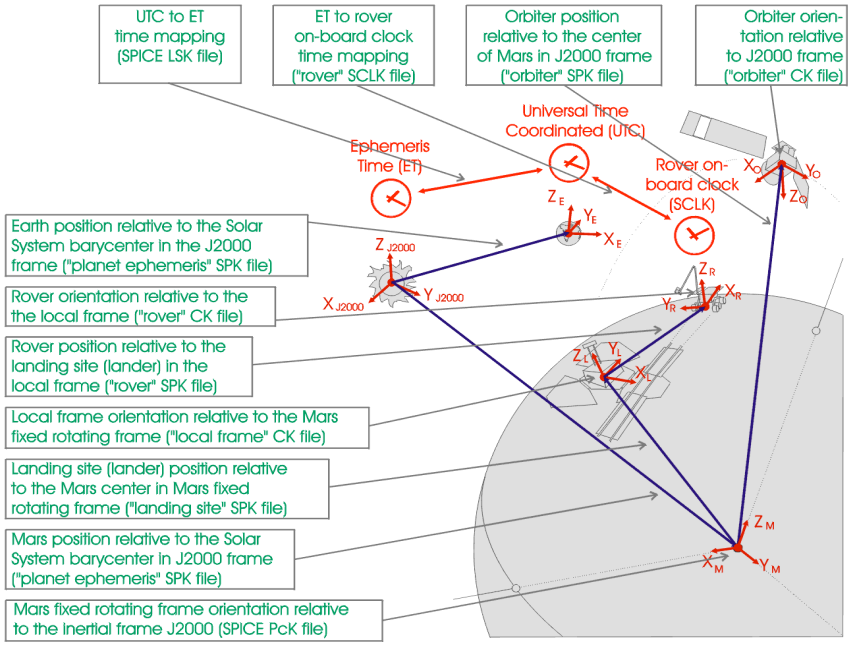
Navigation and Ancillary Information Facility

- **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

* Not yet demonstrated

Global SPICE Geometry

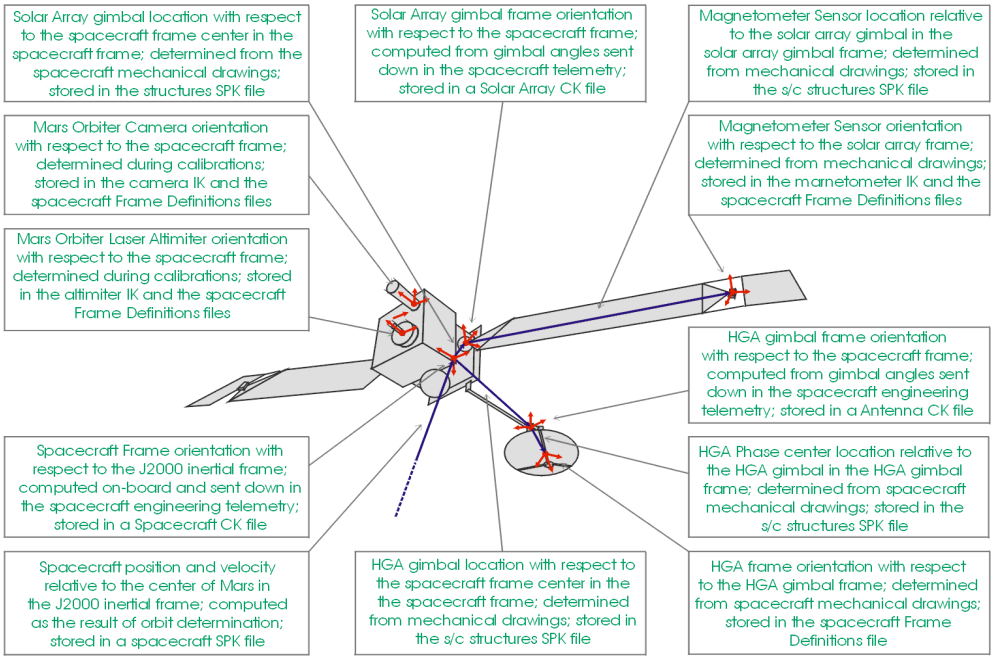
Navigation and Ancillary Information Facility



Applying SPICE to a Full Planetary Investigation: Orbiter, Lander, Rover

Orbiter Geometry

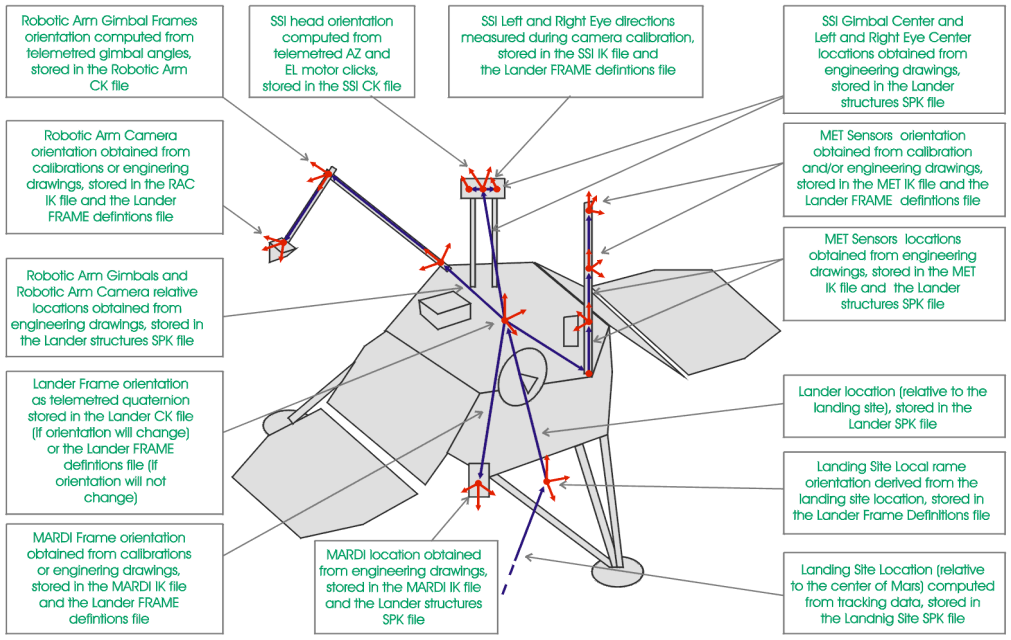
Navigation and Ancillary Information Facility



Applying SPICE to an Orbiter (MGS)

Lander Geometry

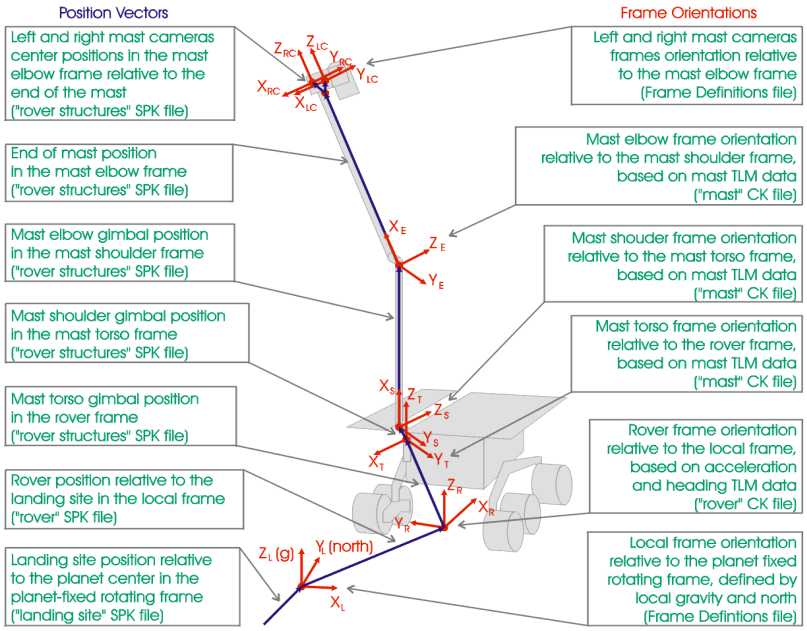
Navigation and Ancillary Information Facility



Applying SPICE to a Lander (M98)

Rover Geometry

Navigation and Ancillary Information Facility



Applying SPICE to a Surface Rover (Rocky-7)

Why Use SPICE? - 1

Navigation and Ancillary Information Facility

- **Knowing mission geometry and events is an important element in the design of space missions, in mission operations engineering, and in the analysis of the science data returned from a mission's instruments.**

- **Having extensive, well proven and reusable standard methods for producing and using ancillary data reduces cost and risk, and can help scientists and engineers achieve more meaningful and more accurate results.**

Why Use SPICE? - 2

Navigation and Ancillary Information Facility

- SPICE has a proven track record in a broad application domain
  - SPICE is used formally on every NASA planetary exploration mission
  - SPICE is used informally by scientists on several ESA planetary missions and on some JAXA planetary missions.
  - SPICE is used formally to one degree or another on a number of NASA and foreign space physics and astrophysics missions
  - SPICE is used from mission conception to post mission data analysis
  - SPICE is used in support of many mission engineering applications as well as for science
- SPICE is well accepted and widely used by the worldwide space science community

Why Use SPICE? - 3

Navigation and Ancillary Information Facility

- SPICE is free of export restrictions (ITAR)
- SPICE is free of licensing restrictions
- SPICE software is of very high quality and is provided as essentially open source
- NASA supports NAIF in seeking the widest possible use of SPICE, including internationally
- NASA supports the continuing development of new capabilities within SPICE.

Major SPICE Users

Navigation and Ancillary Information Facility

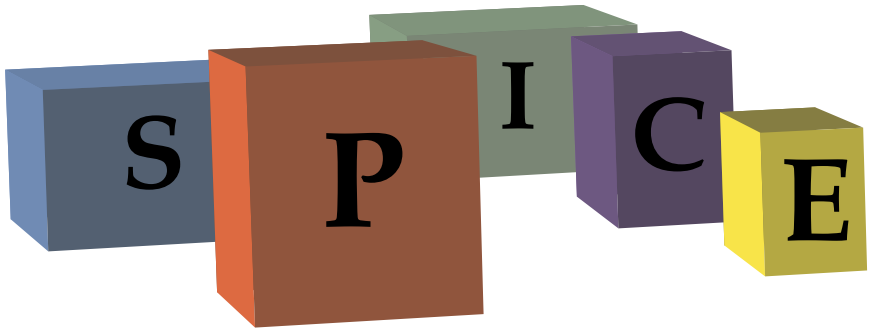
Restorations	Past Customers	Current Customers	Anticipated
Apollo 15, 16 [P]	Magellan [P]	Deep Space Network ops	SIM
Mariner 9 [P]	Clementine (NRL)	Mars Global Surveyor	Mars Program
Mariner 10 [P]	Mars Observer	Cassini	Discovery Program
Viking Orbiters [P]	Mars 96 (Russia)	Mars Odyssey	Scout Program
Pioner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

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

Building Blocks for Your Applications

Navigation and Ancillary Information Facility

NAIF offers the "SPICE" ancillary information system as a model and a core set of blocks for building tools that can help execute a multimission, international space exploration program



NAIF: the JPL entity responsible for development and deployment of SPICE.
SPICE: the ancillary information system that NAIF builds and often operates.
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.