# NASA'S SPICE SYSTEM MODELS THE SOLAR SYSTEM

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**Abstract.** The Navigation Ancillary Information Facility (NAIF) at Caltech's Jet Propulsion Laboratory, acting under the directions of NASA's Office of Space Science, has built a data system–named SPICE–to assist scientists in planning and interpreting scientific observations. SPICE provides geometric and some other ancillary information needed to recover the full value of science instrument data, including correlation of individual instrument data sets with data from other instruments on the same or other spacecraft.

The primary SPICE data sets are called "kernels." One of these kernel types provides ready access to ephemerides of spacecraft, planets, satellites, comets and asteroids. A second kernel type provides a set of data specifying target body size, shape and orientation. These data are currently based primarily on IAU/IAG/-COSPAR models.

The SPICE system includes FORTRAN subroutines needed to read the kernel files and to calculate many common observation geometry parameters. Users integrate these SPICE "Toolkit" subroutines into their own application programs to compute needed information.

## 1. Introduction

NASA's SPICE ancillary information system (Acton, 1996) is used by many space science flight projects and individual scientists and engineers to help design missions, evaluate mission designs, plan observations and reduce the data returned from flight instruments. Two components of the SPICE system model certain physical and cartographic aspects of the solar system. The SPK component provides ephemerides of planets, satellites, comets and asteroids. It also provides ephemerides of many planetary exploration spacecraft. The PCK component provides simple models of the size, shape

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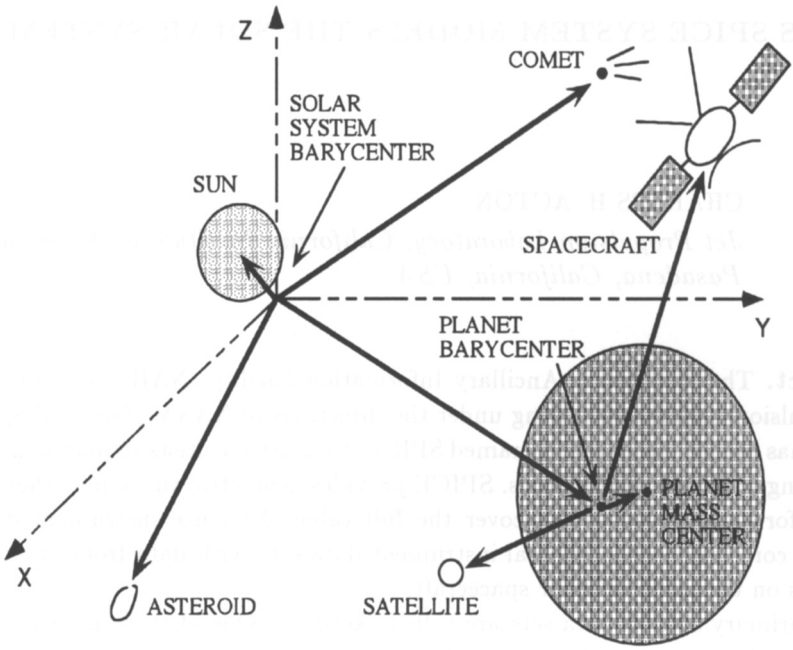


*Figure 1.* Examples of cartesian state vectors available from SPICE SPK files.

and orientation of planets and their satellites, based on published IAU information. Researchers involved in solar system dynamics and astrometry studies could find some of these data useful. Users of SPICE files receive the SPICE Toolkit which contains "reader" subroutines for SPICE files as well as many additional routines typically useful in dealing with space geometry information.

## 2. SPK Files

SPK files hold ephemeris information for natural bodies (planet mass center, satellite, comet, asteroid, Sun), for planet barycenters and for spacecraft. An SPK file returns the Cartesian state (position and velocity) of a "target" with respect to an "observer" at a user supplied request time. Figure 1 depicts the kinds of state vectors typically available from SPK files.

An SPK file can hold data for one or any combination of these objects, and the data need not cover identical time spans. For example, one SPK

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file could hold data for Jupiter, the Earth and the Sun covering 1990 to 2005, and data for the Galileo spacecraft covering June 1, 1996 to December 7, 1997. Another SPK file could hold data for Jupiter and the Earth and Sun covering 1979 through 1997, for the Voyager spacecraft covering March through August of 1979, and for the Galileo spacecraft covering 1996 and 1997. An SPK file provides a continuous representation of the ephemeris during whatever time span is covered for each object.

SPK files can hold ephemeris data in a variety of forms–there is a whole family of SPK data types in existence, and new types are easily added. Essentially any scheme for representing an ephemeris using double precision numbers can be made into an SPK data type by adding only two new subroutines to the SPICE Toolkit–one which packs the numeric data into the data structure upon which SPK files are built, and one which can evaluate a chunk of the data to yield the state of the target relative to its center of motion. An SPK file can accommodate one or many of these data types.

Until recently SPK files had to hold data representing an ephemeris given in an inertial reference frame, such as the J2000 frame widely used today. However, the current implementation of SPICE allows for use of body-fixed non-inertial frames as well. One benefit of this extension is that it is now easy to create an SPK-format ephemeris for a point on the surface of the Earth such as an observatory or a tracking station, or on a planet, such as a lander on Mars.

SPK files are binary files, providing rapid, direct access to the data needed to fill a user's request. The NAIF Toolkit includes several easily used subroutines for reading SPK files and for doing considerable processing of the data within the SPK files–the user is not burdened with these details. One such "reader" subroutine is named SPKEZR and has the following inputs and outputs:

```
CALL SPKEZR (target, time, frame, correction, observer, state, lt)
```

Input arguments are:

- `target`: name of the object for which the state is requested
- `time`: epoch at which the state is requested (ephemeris time)
- `frame`: name of the reference frame in which the computed state should be returned
- `correction`: flag indicating whether light time or stellar aberration corrections should be applied, or if a pure geometric state vector is needed
- `observer`: name of the object to be used as the center [0,0,0] for specifying the state of the target

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Output arguments are:

- `state`: Cartesian position and velocity of the target with respect to the observer at the requested epoch, given in the requested reference frame and with any requested corrections applied
- `lt`: one-way light time from the target to the observer

A user may "load" more than one SPK file at run time, thus gaining access to a variety of ephemeris data spread over multiple SPK files; SPICE Toolkit software handles all of the data management issues needed to provide this flexibility while keeping user involvement limited to the least possible.

Included in the SPICE Toolkit are utility programs for:

- porting SPK files between dissimilar computers,
- summarizing the contents of an SPK file,
- adding, revising, extracting or deleting descriptive metadata from the so-called "comment area" which is part of each SPK file,
- merging portions of two or more SPK files into one,
- subsetting an SPK file by objects or time coverage or both.

## 3. PCK Files

SPICE PCK files provide simple models for the size, shape and orientation of planets, satellites, the Sun and a few asteroids. Most of the PCK data are taken from IAU/IAG/COSPAR published results (Davies *et al.*, 1996). These data provide spin axis and prime meridian orientation as a function of time. They also provide estimated tri-axial ellipse radii for each body, to the extent such estimates are available. When processed with allied SPICE Toolkit software, one can use a PCK file to easily compute the transformation from the body-fixed frame to an inertial frame such as J2000.

The ephemeris and Earth orientation portions of the SPICE system will soon be used in determining antenna pointing and frequency predictions for NASA's Deep Space Network (DSN) antennas as they track a large variety of space vehicles. This has required the addition of a high precision Earth orientation model to the PCK subsystem. This special Earth PCK includes precession, nutation, timing and polar motion effects, allowing topographic calculations that agree to better than one centimeter with similar calculations produced by JPL's precision Topex/Poseidon orbit determination software.

PCK files can also hold additional information, such as GM estimates or other physical or cartographic "constants."

As with the SPK file, PCK files consist of a family of data types. In this case one type is an ASCII text file. The other PCK types are binary files, and SPICE utility programs are used to port them between dissimilar computers.

## 4. SPICE Toolkit

The principal component of the SPICE Toolkit is a subroutine library called SPICELIB. This consists of several hundred ANSI FORTRAN subroutines, some of which are used in reading SPICE files and others of which are used in making derived computations based in part on data obtained from SPICE files. Each subroutine includes a header containing detailed specifications on how the routine is used. While new capabilities are regularly added, backwards compatibility is maintained.

The SPICE Toolkit also includes a number of SPICE utility programs, several small example programs ("cookbook programs") showing how to use SPICELIB routines, and extensive SPICE documentation.

## 5. SPICE System Characteristics

NAIF has designed the kernel file and software Toolkit architectures with flexibility as a principal goal. As an example, the SPICE ephemeris subsystem handles over a dozen different common representations of ephemeris data, such as Chebyshev, Lagrange and Hermite polynomials, NORAD two-line elements and classical conic elements. The addition of new data types is easily accomplished and will not impact the commitment to backwards compatibility.

Portability of software and kernel files is also a key requirement. SPICE Toolkit software and kernel files may be used on any platform that supports ANSI FORTRAN 77, and C language interfaces to the most used Toolkit subroutines are now being added.

## 6. SPICE Data Availability

A core set of SPICE components is in place and is available to the space science community, subject to NASA and JPL/Caltech licensing and distribution policies. While the principal use is in the planetary science discipline, astrophysics, and Earth science projects are also using this technology.

SPK files for the natural bodies of our solar system are produced at JPL using the best available data from JPL's Solar System Dynamics Group (Jacobson, Lieske, Standish, Yeomans, *et al.*). SPK files are also available from JPL for most NASA planetary missions, and for a small number of additional flight projects–both U.S. and international. A summary of major SPICE data producers is given in Table 1.

TABLE 1. SPICE project customers.

| Past | Current | Future possibilities |
|---|---|---|
| Mariner 9, 10 (R,P) | Hubble Telescope (S) | Clementine 2 |
| Viking 1,2 (R,P) | Infrared Space Obs. (S) | Mars 01, 03 |
| Pioneer 10,11 (R,P) | Gallileo | Discovery |
| Voyager 1,2 (R,P) | NEAR | Pluto Express |
| Phobos 88 (R,P) | MSTI 3 (P) | Solar Probe |
| Ulysses (R,P) | Mars Global Surveyor | SIRTF |
| Magellan (P) | Mars Pathfinder | New Millennium |
| Clementine 1 | Mars 96 | EOS |
| | Space Interferometry (P) | Rosetta |
| | Cassini | Planet B |
| | Stardust | space physics missions |
| | Mars 98 | |
| | JPL's Solar System Dynamics Group | |

R = restoration, P = partial use, S = special tools

## 7. Looking Ahead

Extension and adaptation of the SPICE system to encompass broader functionality and to meet specific needs of new customers is an ongoing endeavor. The NAIF Group at JPL solicits suggestions for additions and improvements from the astronomical community.

Development of the SPICE system is carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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