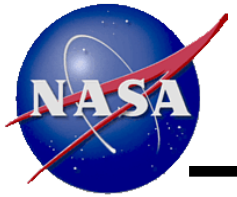


Navigation and Ancillary Information Facility

An Update on NAIF's Package of "SPICE" Astrodynamics Tools

Charles Acton

Jet Propulsion Laboratory, California Institute of Technology

charles.acton@jpl.nasa.gov

http://naif.jpl.nasa.gov

The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Background

- "SPICE[1]" is used to compute geometry used in planning for and subsequently analyzing science data obtained from robotic missions.

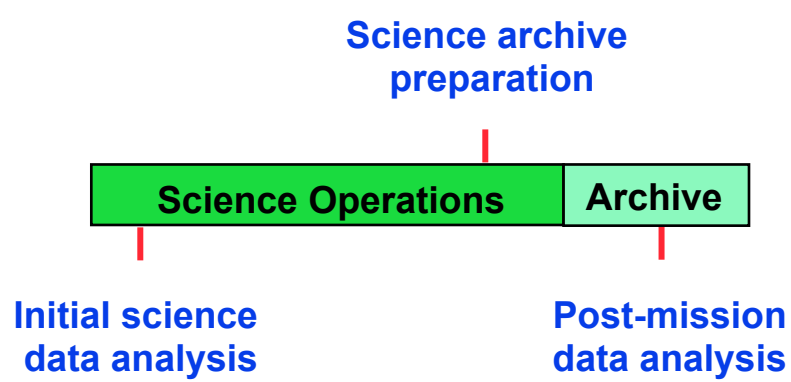
- SPICE is also used in support of numerous mission engineering functions.

[1]Spacecraft Planet Instrument Camera-matrix Events

http://naif.jpl.nasa.gov/naif/aboutspice.html

Original Purpose for SPICE

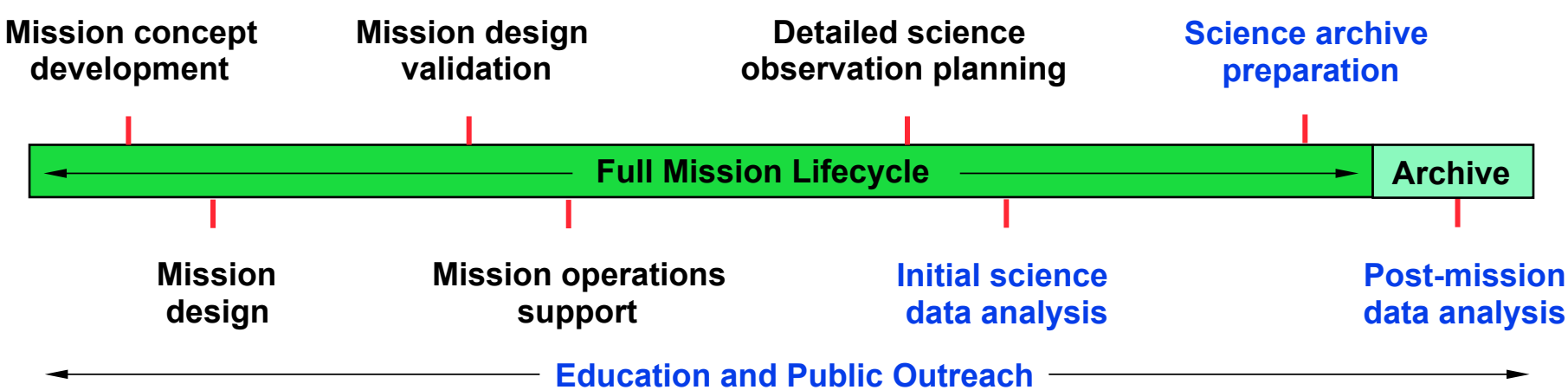
- **The original focus of SPICE was on observation geometry needed by scientists for:**
  - **initial science data analysis**
  - **science archive preparation**
  - **post-mission data analysis**

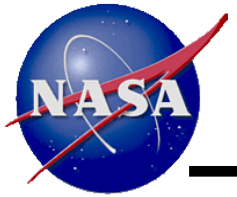


Today's Broader Use

Navigation and Ancillary Information Facility

- **The original focus of SPICE was on observation geometry needed by scientists for:**
  - **initial science data analysis**
  - **science archive preparation**
  - **post-mission data analysis**
- **The use of SPICE has grown to cover the full mission lifecycle, as well as education and public outreach.**



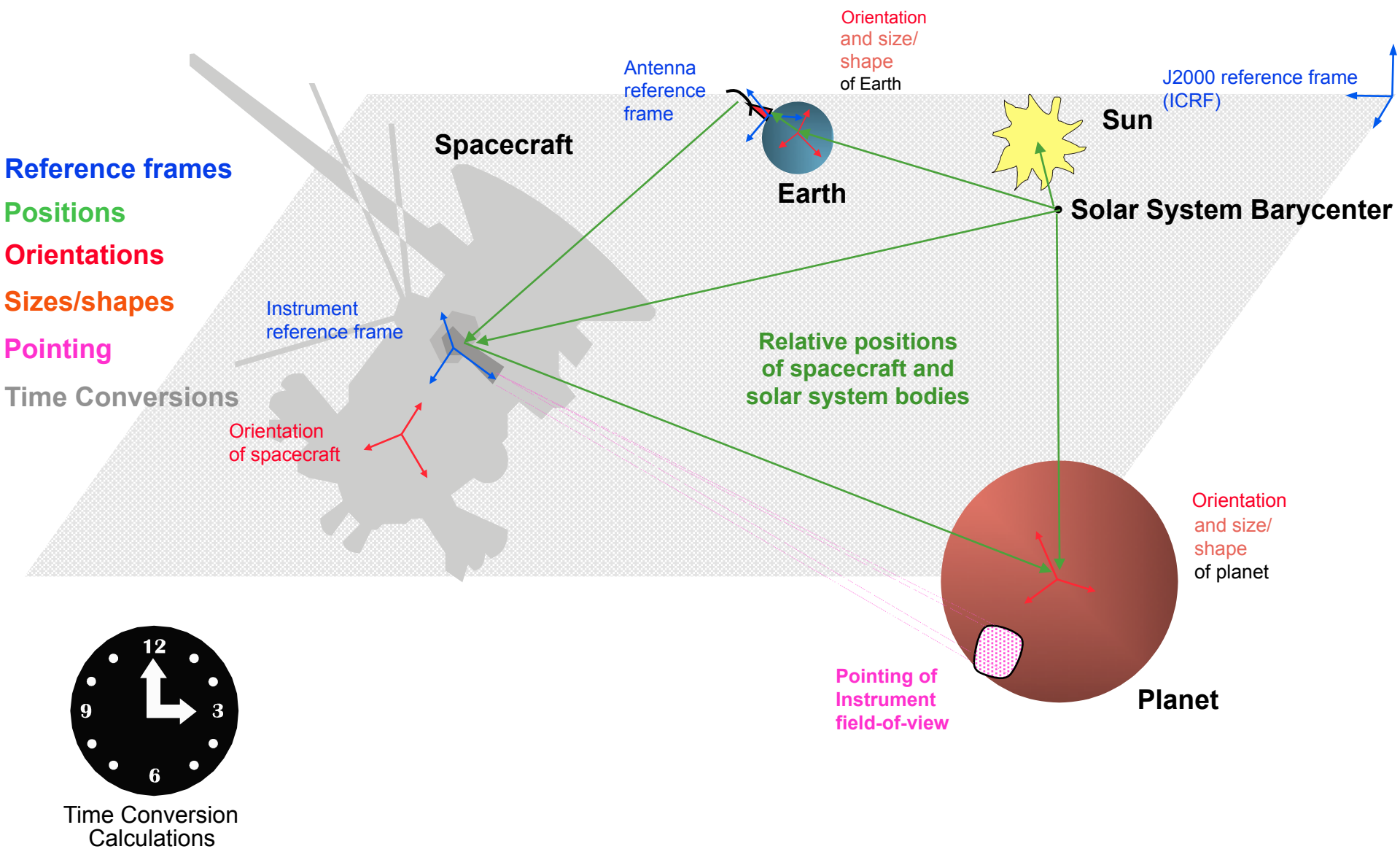


SPICE Uses Ancillary Data

- **The SPICE system uses a variety of "ancillary data" to compute observation geometry parameters such as:**
  - **range,**
  - **velocity,**
  - **lighting angles,**
  - **surface intercept LAT/LON, and**
  - **geometric conditions such as occultation, closest approach and maximum elongation.**

What are “Ancillary Data?”

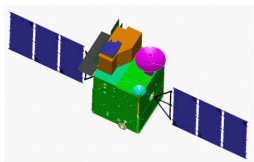
Navigation and Ancillary Information Facility



From Where do Ancillary Data Come?

Navigation and Ancillary Information Facility

- **From the spacecraft**



- **From the mission control center**

- **From the spacecraft and instrument builders**

- **From science organizations**

- **SPICE is used to organize and package these data in a collection of stable file types–called "kernels"–used by scientists and engineers.**

SPICE System Components

Navigation and Ancillary Information Facility

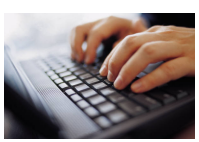
Ancillary data files (“kernels”)……..……

Software (SPICE Toolkit) ……..

Documentation ……..

Tutorials …….

Programming lessons …..

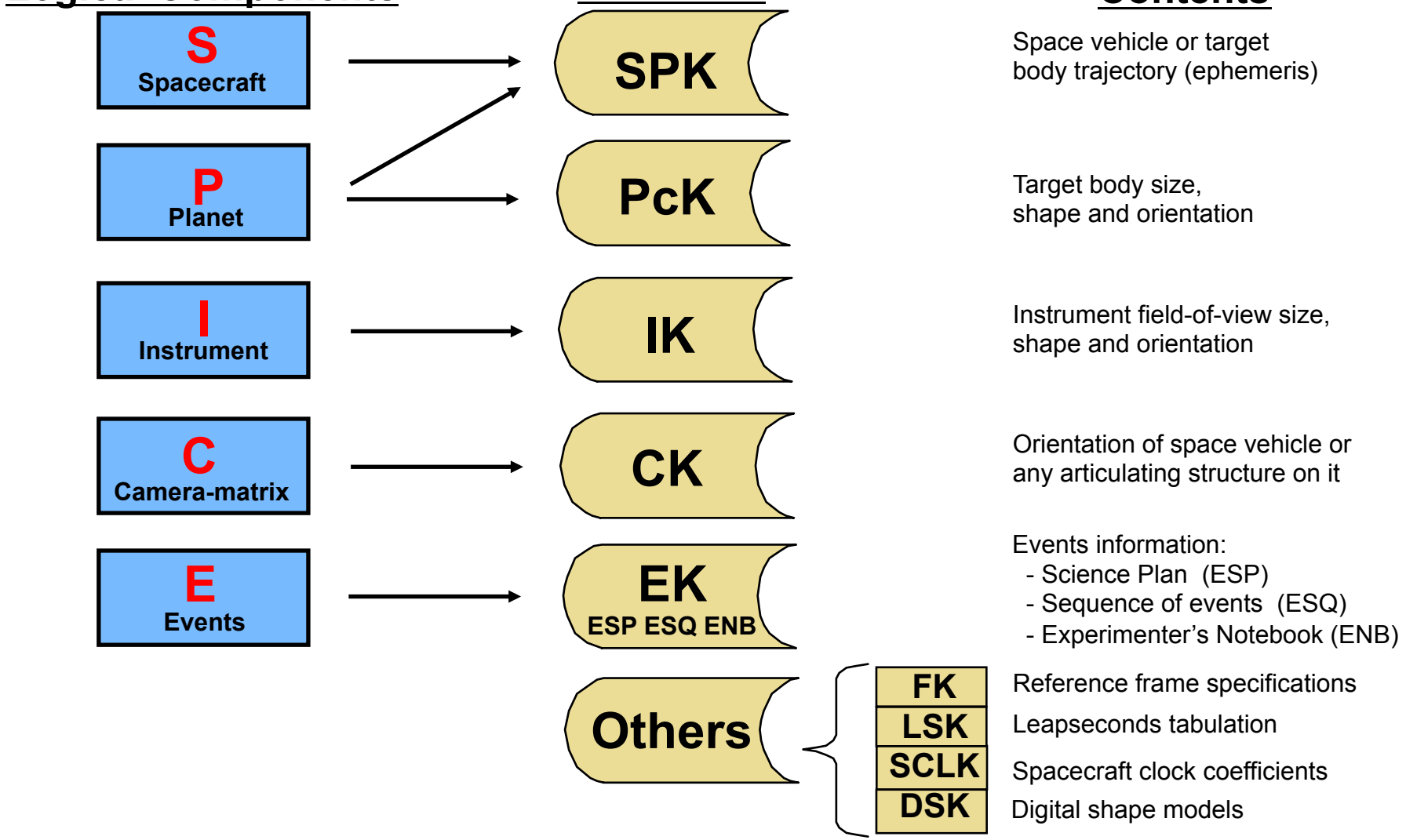


Training classes ……

User consultation ……..

SPICE Data Overview

Navigation and Ancillary Information Facility



SPICE Toolkit Software

Navigation and Ancillary Information Facility

Contents

- **Library of subroutines (~1000)**
  - Just a few used within a customer's program to compute quantities derived from SPICE data files
- **Programs (14*)**
  - SPICE data production
  - SPICE data management
- **Documentation**
  - Highly annotated source code
  - Technical Reference Manuals (23)
  - User Guides

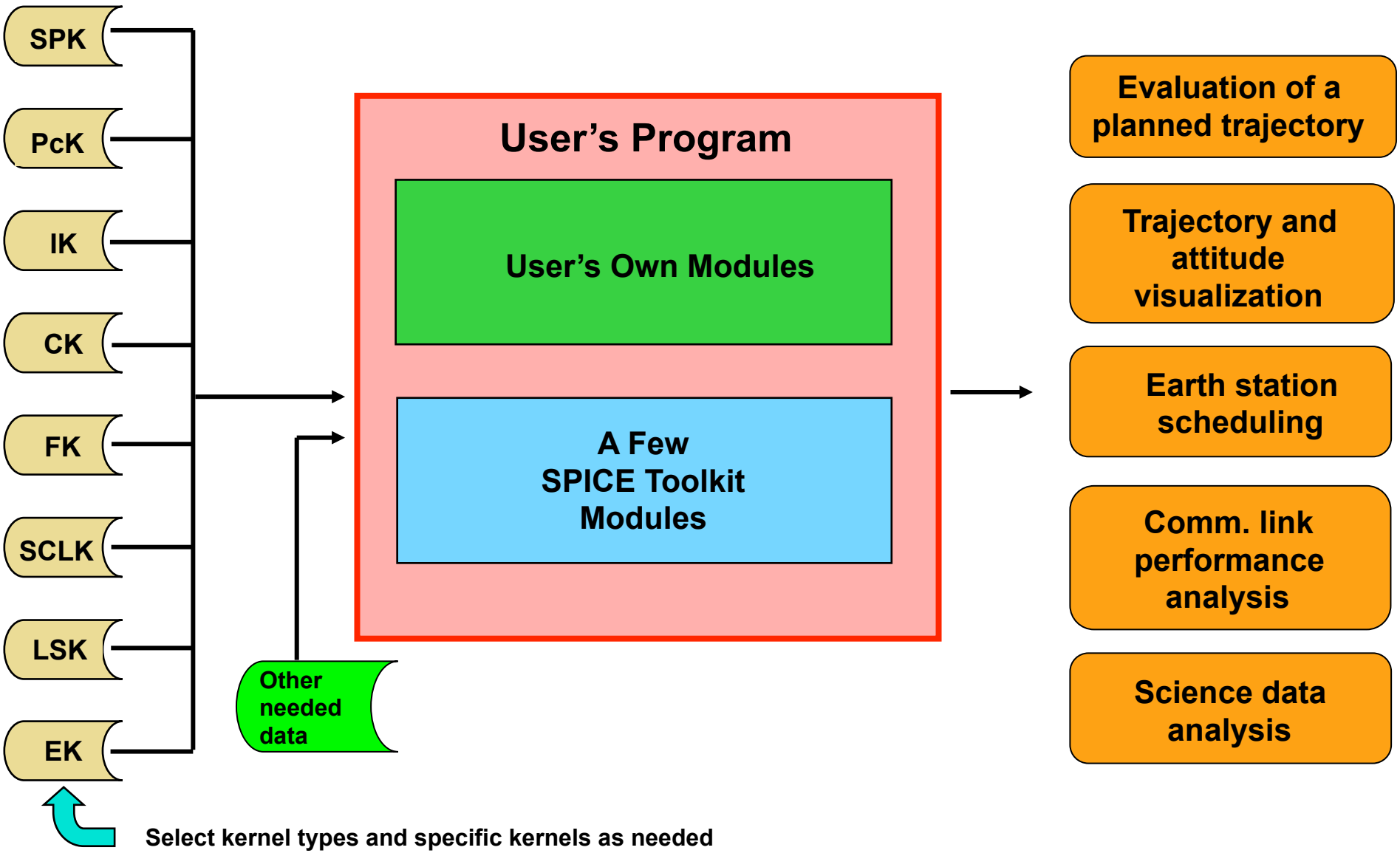
Versions

- **Four languages**
  - Fortran
  - C
  - Interactive Data Language (IDL)
  - MATLAB
  - Under development:
    - » Java Native Interface (JNI)
- **Four platforms**
  - PC/Linux
  - PC/Windows
  - Sun/Solaris
  - Mac/OSX
- **Several compilers**
  - For the Fortran and C Toolkits

* 30 are available from the NAIF website

Example of Using SPICE APIs

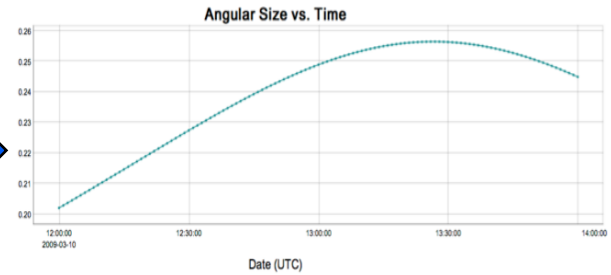
Navigation and Ancillary Information Facility



Purposes for Using SPICE

Navigation and Ancillary Information Facility

Evaluation of a planned trajectory



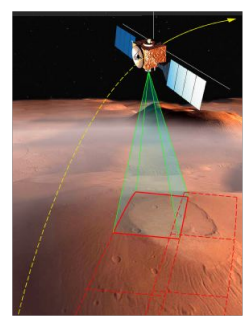
Angular size of Phobos as seen from the Mars rover "SPIRIT"

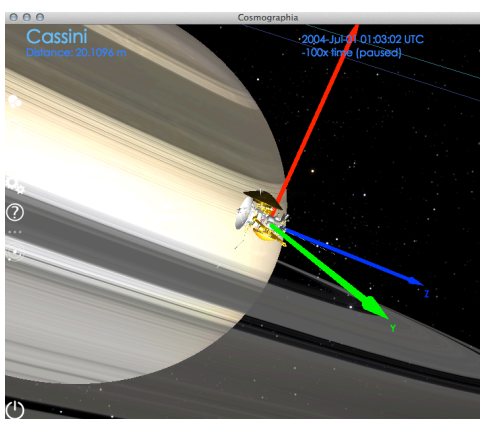
Spacecraft Visibility

Station #1
Station #2
Station #3
Time

Mission engineering analyses

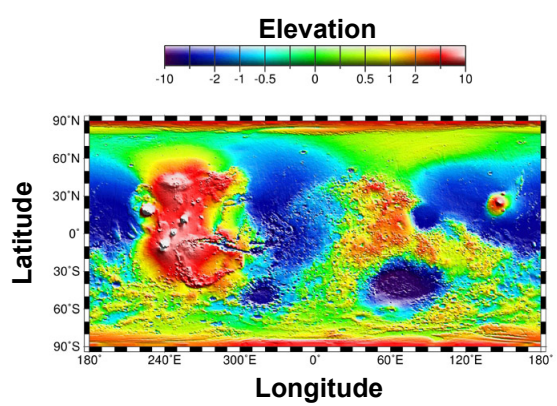
Planning an instrument pointing profile

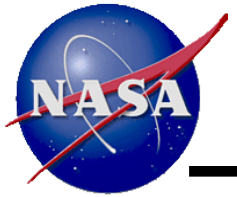




Observation geometry visualization

Science data archiving and analysis



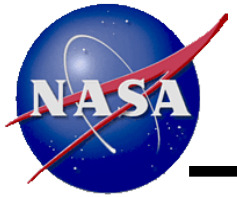


SPICE System Characteristics - 1

- SPICE Toolkit software is portable
- Code is well tested
- New Toolkits are always 100% backwards compatible
- Source code is provided, and is well documented
- Extensive user-oriented documentation is provided
- Software includes built-in exception handling
  - Catches most invalid inputs

SPICE System Characteristics - 2

- All numeric computations are double precision
- Kernel files are portable between computers
- 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 kernel family
- SPICE kernels and software are free of licensing and U.S. export restrictions
  - Everyone is free to use SPICE
- No cost to individual end users



Supported Environments

- **The SPICE Toolkit has been ported to many popular "environments"… currently 47.**
  - **Each environment is characterized by…**
    - » **Language**
    - » **Hardware type (platform)**
    - » **Operating System**
    - » **Compiler (where applicable)**
    - » **Selected compilation options (32-bit or 64-bit)**

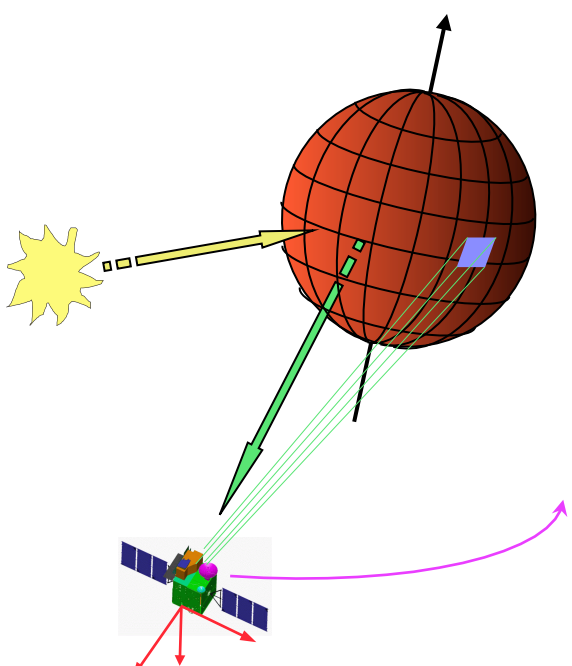
- **NAIF provides separate, ready-built SPICE Toolkit packages for each supported environment.**

What Can One Do With SPICE?

Navigation and Ancillary Information Facility

Compute many kinds of observation geometry parameters at selected times

A Few Examples



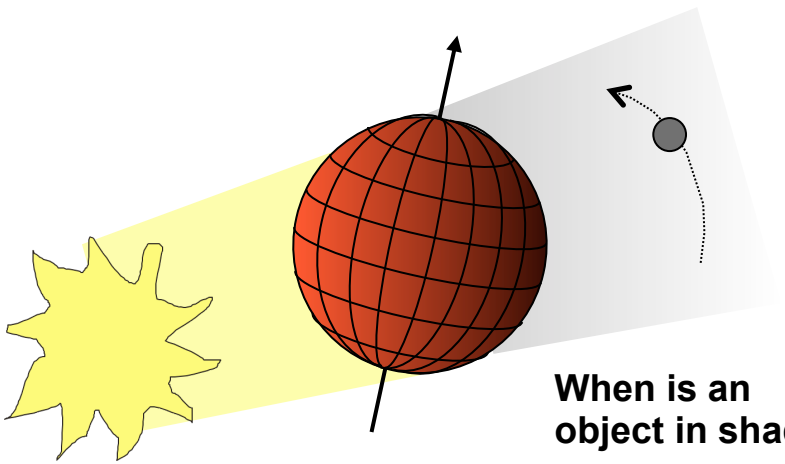
- Positions and velocities of planets, satellites, comets, asteroids and spacecraft
- Size, shape and orientation of planets, satellites, comets and asteroids
- Orientation of a spacecraft and its various moving structures
- Instrument field-of-view location on a planet's surface or atmosphere

What Can One Do With SPICE?

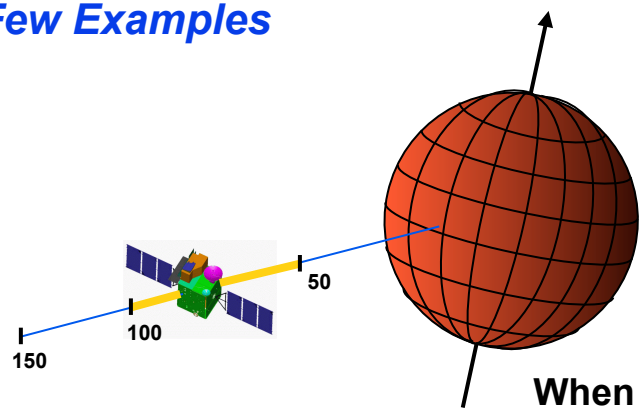
Navigation and Ancillary Information Facility

Find times when a selected "geometric event" occurs, or when a selected "geometric condition" exists

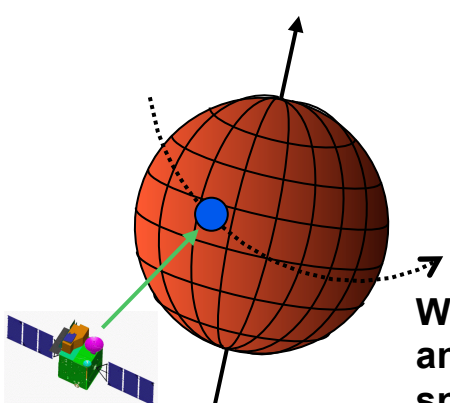
A Few Examples



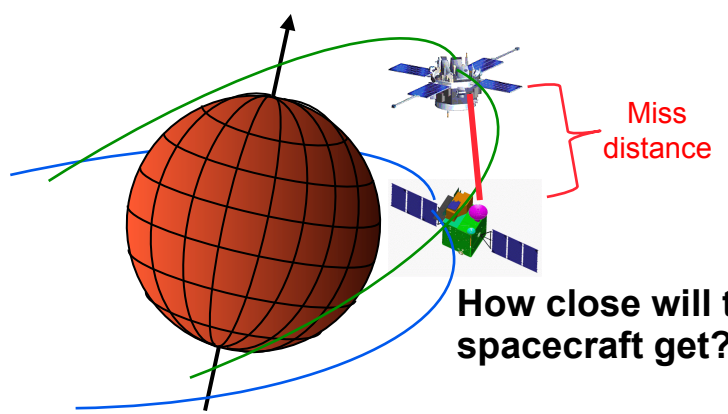
When is an object in shadow?



When is the spacecraft's altitude within a given range? (say 50 to 100 km)



When is an object in front of another, as seen from a spacecraft?



How close will two spacecraft get?

Who are Today's SPICE Users?

Navigation and Ancillary Information Facility

Data Restorations	*Selected Past Users*	*Current/Pending Users*	*Possible Future Users*
Apollo 15, 16 [L]	Magellan [L]	Cassini Orbiter	NASA Discovery Program
Mariner 2 [L]	Clementine (NRL)	Mars Odyssey	NASA New Frontiers Program
Mariner 9 [L]	Mars 96 (RSA) [F]	Mars Exploration Rover	ExoMars 2018 (ESA, RSA)
Mariner 10 [L]	Mars Pathfinder	Mars Reconnaissance Orbiter	Luna-Glob (RSA)
Viking Orbiters [L]	NEAR	DAWN	ARM (HEOMD)
Viking Landers [L]	Deep Space 1	Mars Science Lab	
Pioneer 10/11/12 [L]	Galileo	Juno	
Haley armada [L]	Genesis	MAVEN	*Examples of Users not Requesting NAIF Help*
Phobos 2 [L] (RSA)	Deep Impact	SMAP (Earth Science)	Emmirates Mars Mission (UAE via LASP)
Ulysses [L]	Huygens Probe (ESA) [L]	OSIRIS REx	Bevo-2 CubeSat (U.T. Austin, Texas A&M)
Voyagers [L]	Stardust/NExT	InSight	Proba-3 (ESA)
Lunar Orbiter [L]	Mars Global Surveyor	Mars 2020	Solar Probe Plus
Helios 1,2 [L]	Phoenix	Europa Clipper Mission Concept	EUMETSAT GEO satellites [L]
	EPOXI	NISAR (NASA and ISRO)	MOM (ISRO)
	GRAIL	Lunar Reconnaissance Orbiter	BepiColombo (ESA, JAXA)
	Messenger	New Horizons	JUICE (ESA)
	Phobos Sample Return (RSA) [F]	Mars Express (ESA)	Solar Orbiter (ESA)
	Venus Express (ESA)	Rosetta (ESA)	Chang'e 3 (CNSA)
	Chandrayaan-1 (ISRO)	ExoMars 2016 (ESA, RSA)	Van Allen Probes [L]
	Hayabusa (JAXA)	Akatsuki (JAXA)	STEREO [L]
[L] = limited use	Kaguya (JAXA)	Hayabusa-2 (JAXA)	Spitzer Space Telescope [L]
[S] = special services	LADEE	Space Launch Systems (HEOMD)	Kepler [L]
[F] = mission failed	ISO [S] (ESA)		Hubble Space Telescope [S][L]
	CONTOUR [F]	Planetary Data System	Radioastron (RSA) [L]
	Space VLBI [L] (multinational)	JPL Solar System Dynamics Group	IBEX [L]
Last updated: 12/3/15	Smart-1 (ESA)	NASA Deep Space Network [S]	James Webb Space Telescope [S][L]

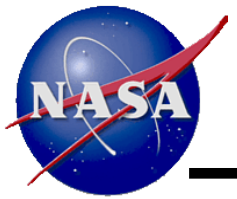
NAIF has or had project-supplied funding to support mission operations, consultation for flight team members, and SPICE data archive preparation. NAIF also has PDS funding to help scientists and students with using SPICE data that have been officially archived at the NAIF Node of the PDS.

NAIF has or had NASA funding to support a foreign partner in SPICE deployment and archive review, 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 or had modest PDS-supplied funding to consult on assembly of a SPICE archive.

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



What's "newish" that could be of interest to ICATT attendees?

- WebGeocalc Interface to SPICE (WGC)
- Cosmographia Visualization Tool
- Digital Shape Kernel (DSK)

WebGeocalc (WGC)

Navigation and Ancillary Information Facility

http://naif.jpl.nasa.gov/naif/webgeocalc.html

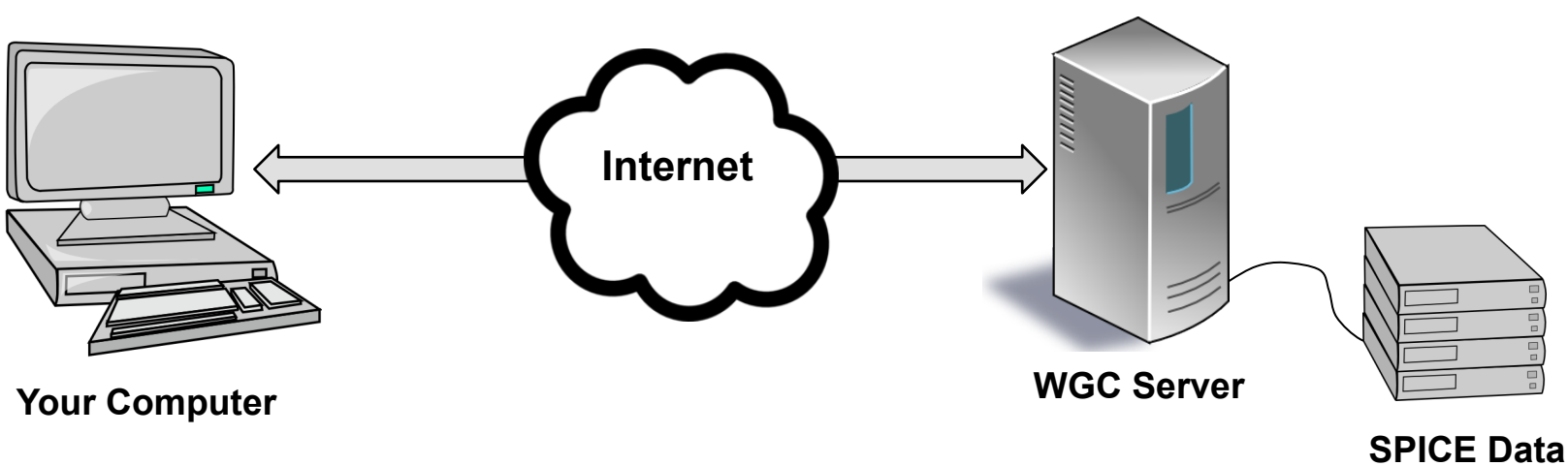
- **WGC provides a Graphical User Interface to a SPICE server running a geometry computation engine**
  - Using WGC is easier than having to write your own program that incorporates some SPICE Toolkit software
  - But WGC computations are limited in scope: the tool cannot do near as much as an own-built program that uses SPICE Toolkit APIs
- **WebGeocalc is useful in quickly making space geometry computations using SPICE ancillary data without having to write a program**
  - See the next page for a graphic depicting “ancillary data”
  - For a description of SPICE, look here:

    http://naif.jpl.nasa.gov/naif/aboutspice.html

See related talk and demo

WebGeocalc Architecture

- **WGC uses a client-server architecture**
  - **The user only needs a computer running a web browser**
  - **The browser connects via Internet to a WGC "computation engine" running on a server**
    - » **The WGC server has access to a variety of SPICE kernel files**



WebGeocalc Computations

Navigation and Ancillary Information Facility

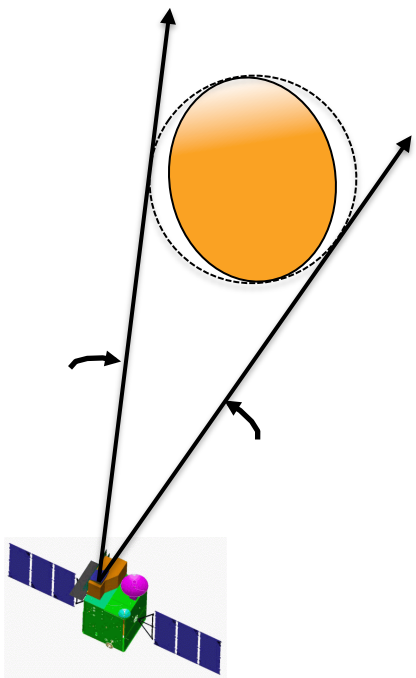
- **Three categories of SPICE computations are available**

1. **Geometry Calculator**
   - » **Compute a parameter value at a given time, or over a time range**
     - **Example: Compute the angular size of Phobos as seen from the SPIRIT Mars rover from 2009 March 10 12:00:00 to 2009 March 10 14:00:00**
2. **Geometric Event Finder**
   - » **Within a specified time bounds (the confinement window)…**
     - **Find time intervals when a particular geometric condition exists**
       - – **Example: Find time intervals when Phobos is occulted by Mars as seen from Mars Odyssey within the period 2010 June 01 to 2010 June 02**
     - **Find time intervals when a parameter is within a given range**
       - – **Example: Find time intervals when the spacecraft altitude is between 300 and 400 km**
     - **Find time intervals when a parameter has reached a local or global maximum or minimum**
       - – **Example: Find time intervals when the angular separation of a satellite from a planet, as seen from a spacecraft, has reached its minimum value**
3. **Time conversion calculator**
   - » **Convert between various time systems and time formats**

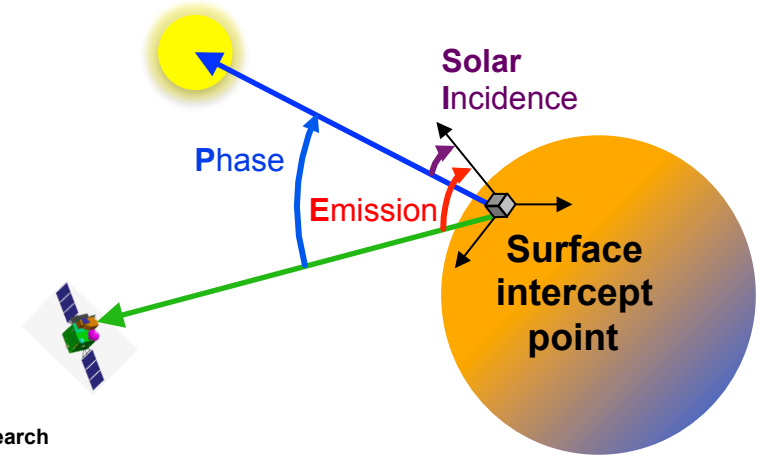
- **See some examples on the next page**

Illustrations of Three Available WGC Computations

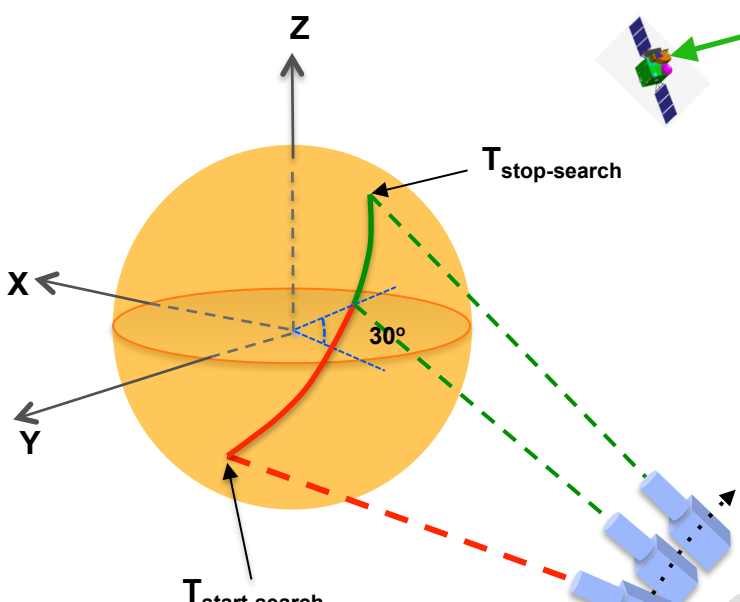
Navigation and Ancillary Information Facility



Angular Size



Illumination Angles



Camera scanning across the planet's surface

The GREEN trace shows when the latitude of the instrument boresight surface intercept is greater than 30 degrees, within the time range $T_{start\text{-}search}$ to $T_{stop\text{-}search}$.

Surface Intercept Event Finder

Cosmographia Visualization Tool

Navigation and Ancillary Information Facility

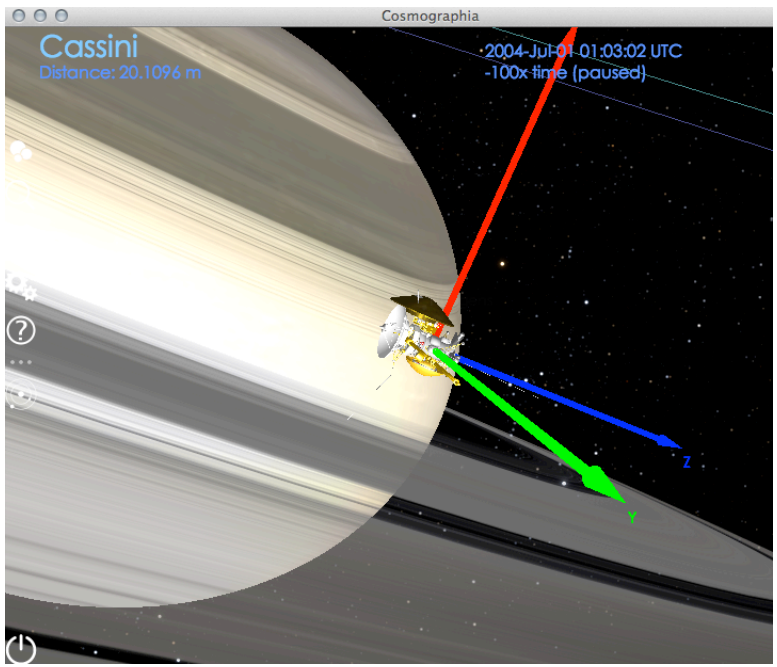
http://naif.jpl.nasa.gov/naif/cosmographia.html

- **Cosmographia is a downloadable tool used to help visualize and analyze astrodynamics and science aspects of a mission in 3D animations.**
- **It can depict such things as:**
  - **spacecraft trajectory and orientation**
  - **target body ephemeris and size, shape and orientation**
  - **reference frames (coordinate systems)**
  - **vectors and angles**
  - **ranges**
  - **instrument view cones and footprints**
  - **… and more.**
- **The SPICE-enhanced Cosmographia distributed by NAIF makes use of SPICE kernels.**

See related talk and demo

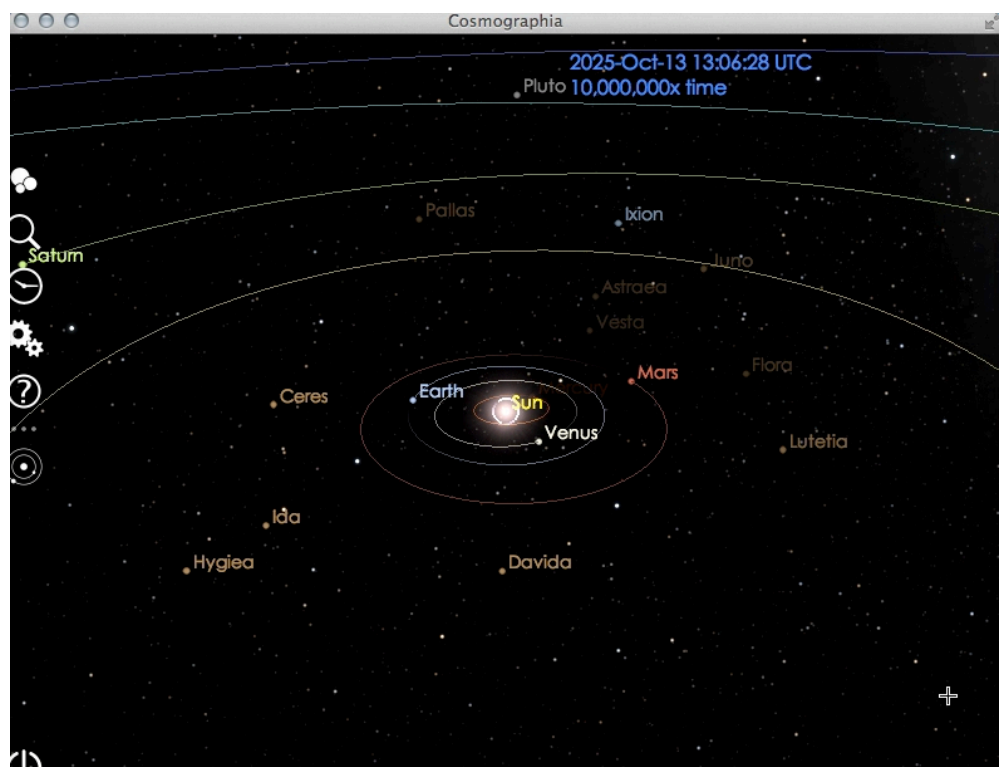
Some Cosmographia Snapshots

Navigation and Ancillary Information Facility



Cassini

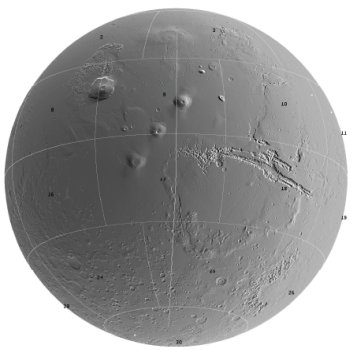
Solar System



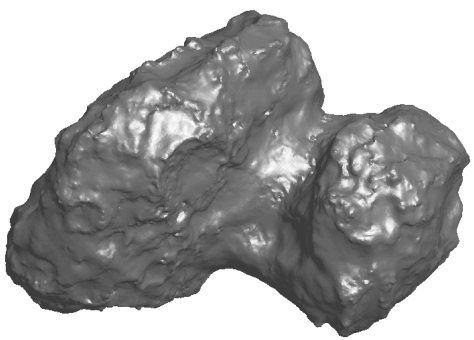
Digital Shape Kernel (DSK)

Navigation and Ancillary Information Facility

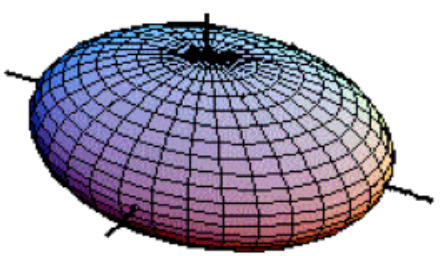
- **The DSK subsystem can handle two representations of shape data:**
  - **Digital elevation model**

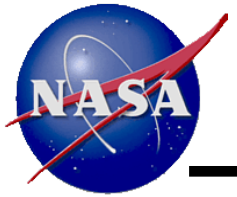


  - **Tessellated plate model**



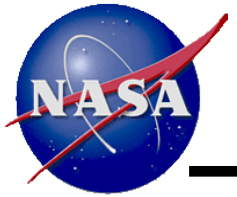
- **DSK supplements the tri-axial ellipsoid shape model already available in SPICE**





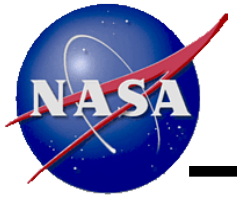
Making DSKs

- NAIF doesn't produce shape models… others do that.
- The DSK subsystem is able to ingest many popular forms of shape data, both tessellated plate and digital elevation model types.
  - The SPICE Toolkit contains a program for producing DSKs from these shape data sets.



Why Use DSK?

- **If your shape data is in SPICE DSK format you can use SPICE Toolkit APIs to determine an assortment of observation geometry based on the tessellated plate or DEM data. Examples:**
  - **Compute sub-observer point on surface and height of observer above surface**
  - **Compute intercept of ray with surface**
  - **Determine whether a portion of a target body's surface is within the FOV of specified instrument at specified time.**
  - **Determine occultation/transit state of a point target**
  - **Compute limb and terminator location**
  - **Compute Illumination angles at a specified surface point**



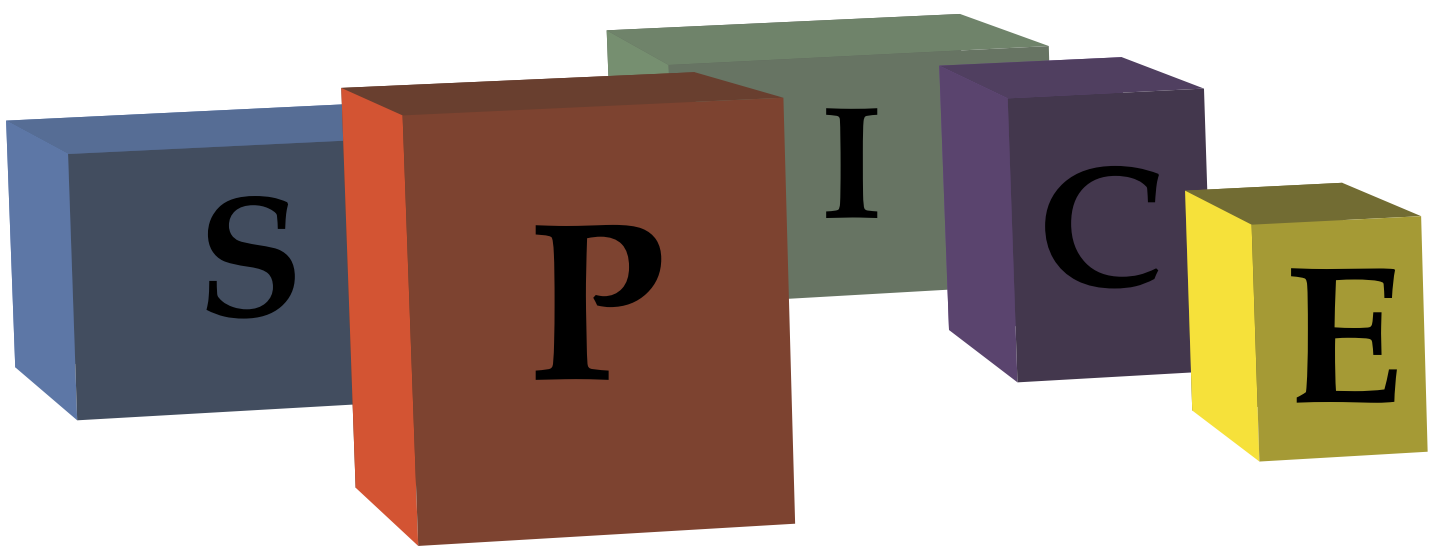
DSK Subsystem Status

- **For the tessellated plate component…**
  - **An alpha-test version has been used by Rosetta and DAWN.**
  - **The full system will be released as part of the next SPICE Toolkit, version N66, very shortly.**
- **For the digital elevation model component…**
  - **An engineering version is being used on NASA's Soil Moisture Active and Passive (SMAP) earth science mission.**
  - **Official release in a SPICE Toolkit is still some ways off… perhaps late in CY2016.**

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 supporting multi-mission, international space exploration programs.



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.