Thoughts on Producing “Ancillary Data” in support of Space Science Flight Projects

The NAIF Team

August 2021

Topics

- What are "ancillary data?"
- Why are such data needed?
- Approach and skills needed to produce ancillary data files
- Information about the "SPICE" methodology for producing and using ancillary data
- Backup material:

  Graphics Depicting SPICE Data

  Contents of SPICE Kernels

  Ancillary Data Production Challenges

  Graphic Depicting How SPICE Kernels are Made

Caution Regarding Terminology

- This presentation uses terminology familiar to the NAIF team. It could be that "our" interpretation and "your" interpretation of a term are different.

What Are "Ancillary Data"?

- "Ancillary data" refers, at a minimum, to spacecraft trajectory (position/velocity) and spacecraft orientation (attitude)
- "Ancillary data" often also include some or all of:
  - reference frame* specifications
  - instrument mounting alignment and instrument field-of-view specifications
  - target body physical and cartographic constants
    - » size, shape and orientation
  - data needed for time system conversions
- The next chart provides a pictorial representation of ancillary data in the broad sense

*Outside of SPICE the term "coordinate system" is sometimes used instead of "reference frame"

Pictorial of Ancillary Data

Reference frames

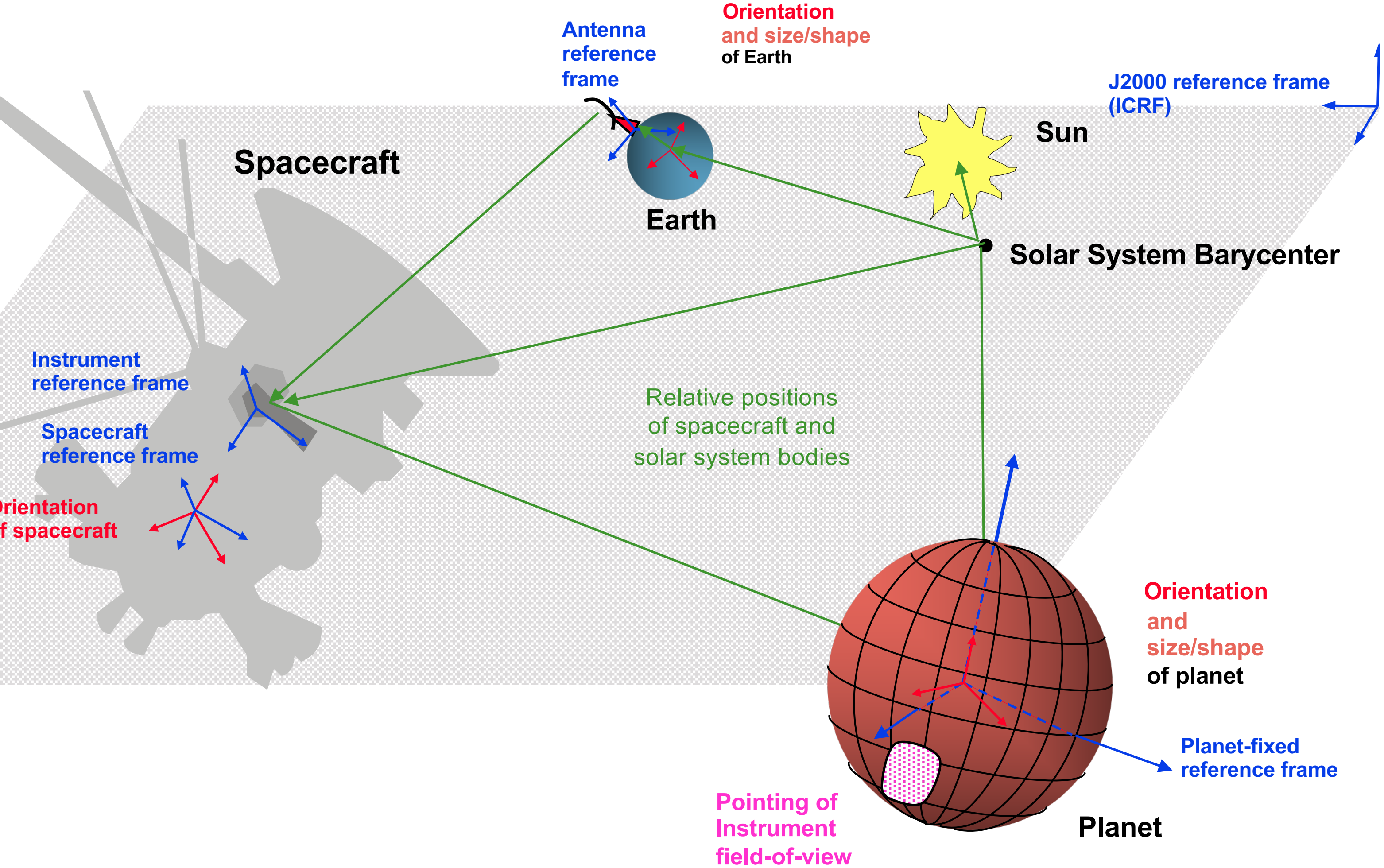
Positions

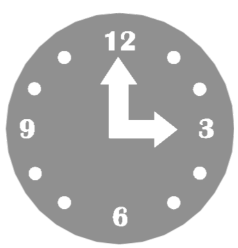
Orientations

Sizes/shapes

Pointing

Time Conversions





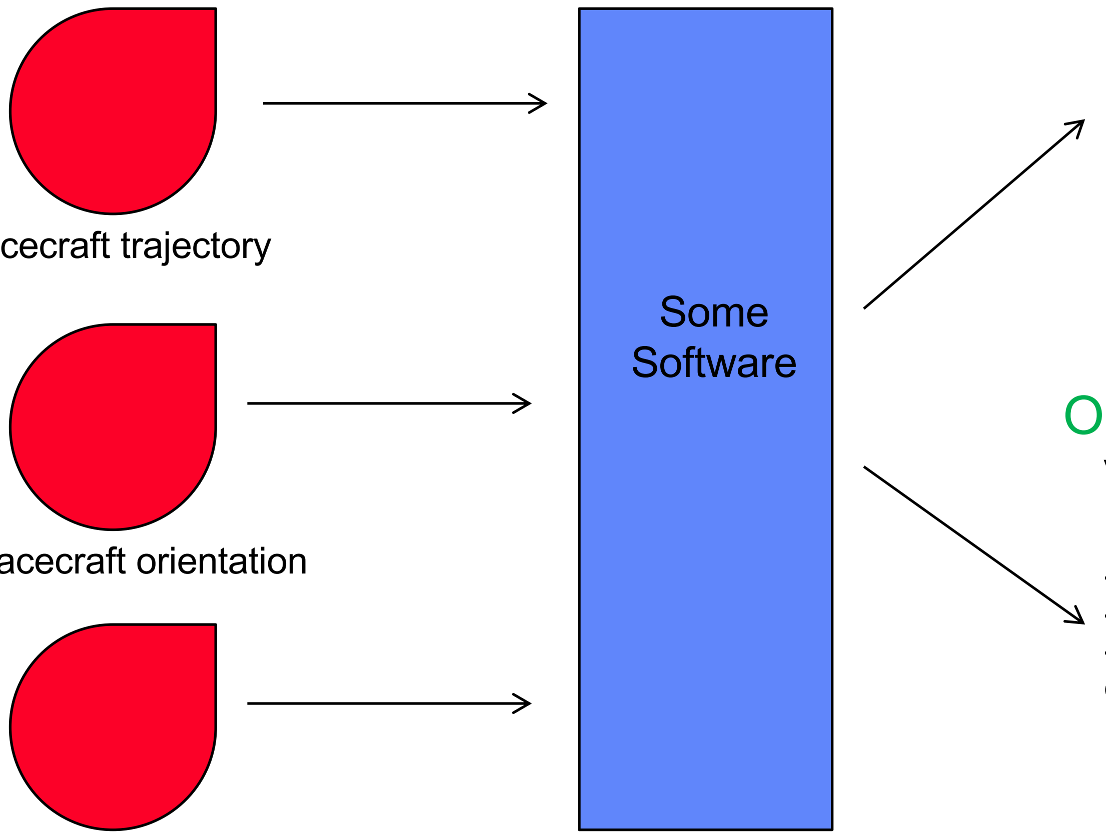
Time System Conversion Calculations

Purposes for Ancillary Data

- **Help mission engineers and scientists converge on a mutually acceptable spacecraft orbit design**
- **Compute observation geometry parameters and conditions needed by mission engineers for tasks such as…**
  – communications station view period calculations
  – communications station antenna pointing and tuning
  – thermal and telecom analyses
- **Compute observation geometry parameters and conditions needed by instrument team scientists for tasks such as…**
  – science observation planning
  – science data analysis
  – science archive preparation

Contrast “Ancillary Data” and “Observation Geometry”

Ancillary Data
Files



Spacecraft trajectory

Spacecraft orientation

Spacecraft clock correlation

etc.

Observation Geometry
Derived Parameters

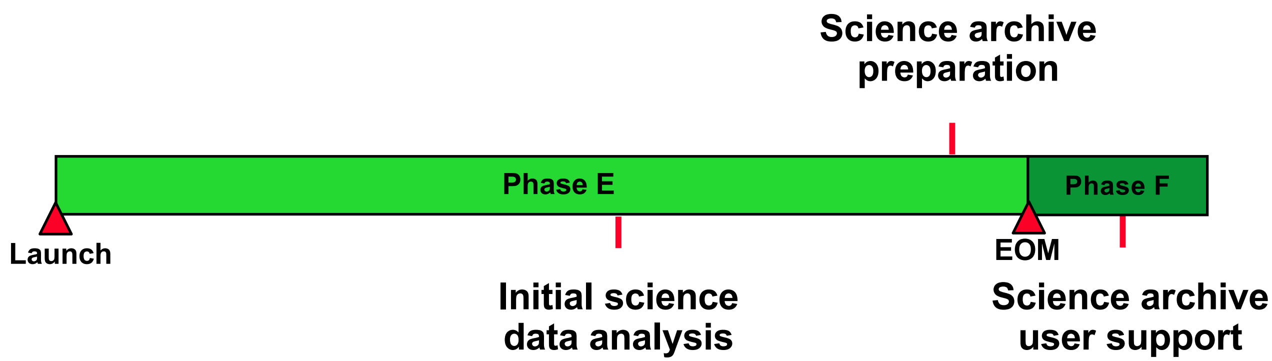
Altitude = xxx km.
Latitude = xxx deg.
Longitude = xxx deg.
Phase angle = xxx deg.

etc.
etc.

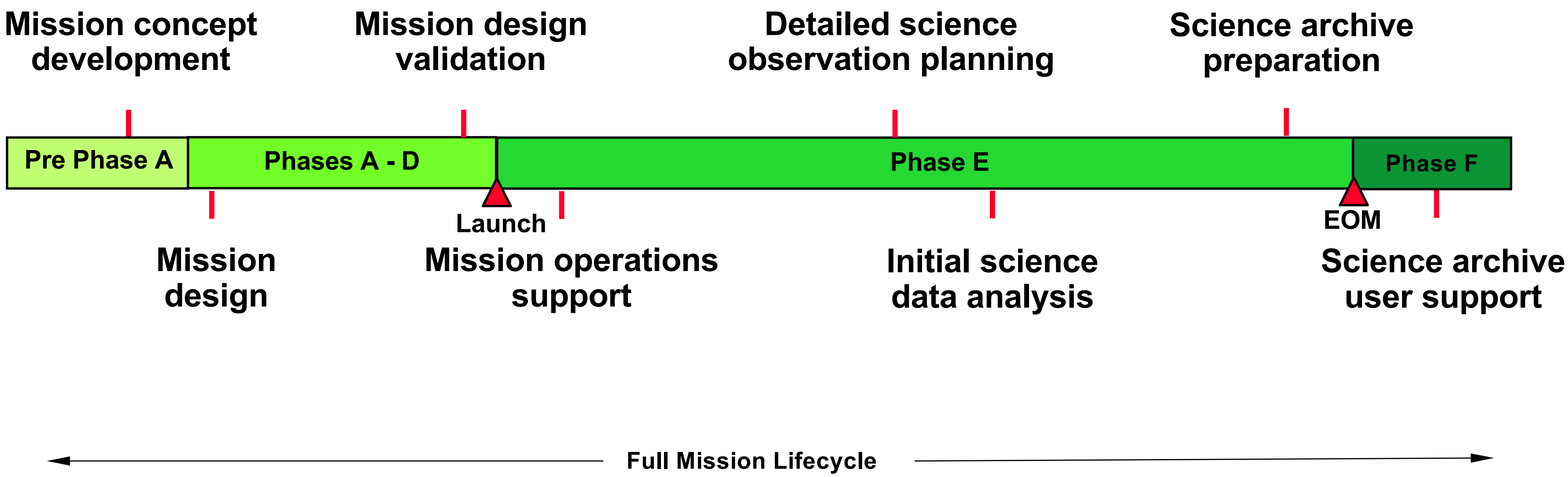
Observation Geometry
Viewing Conditions

- Spacecraft is in occultation by Mars
- Altitude is at a global maximum
- Phase angle is in the range of 24 to 38 degrees

When are Ancillary Data Used?
A Minimal View



When are Ancillary Data Used?
A More Useful View



What Approach Might Be Taken to Provide Ancillary Data?

- **Minimal approach–the project provides:**
  - a table of reconstructed, time-tagged spacecraft position vectors
  - a table of reconstructed, time-tagged spacecraft orientation quaternions

  … with the above tables using UTC time tags (sometimes called SCET)
  - The project leaves it to end users to use these data–probably some other data as well–in conjunction with the user's own-built software to compute needed observation geometry parameters
- **Maximal approach– the project provides a complete "SPICE" or SPICE-like capability as described later on**
- **Certainly other, middle-ground approaches exist**

What Skills are Needed to Produce Ancillary Data?

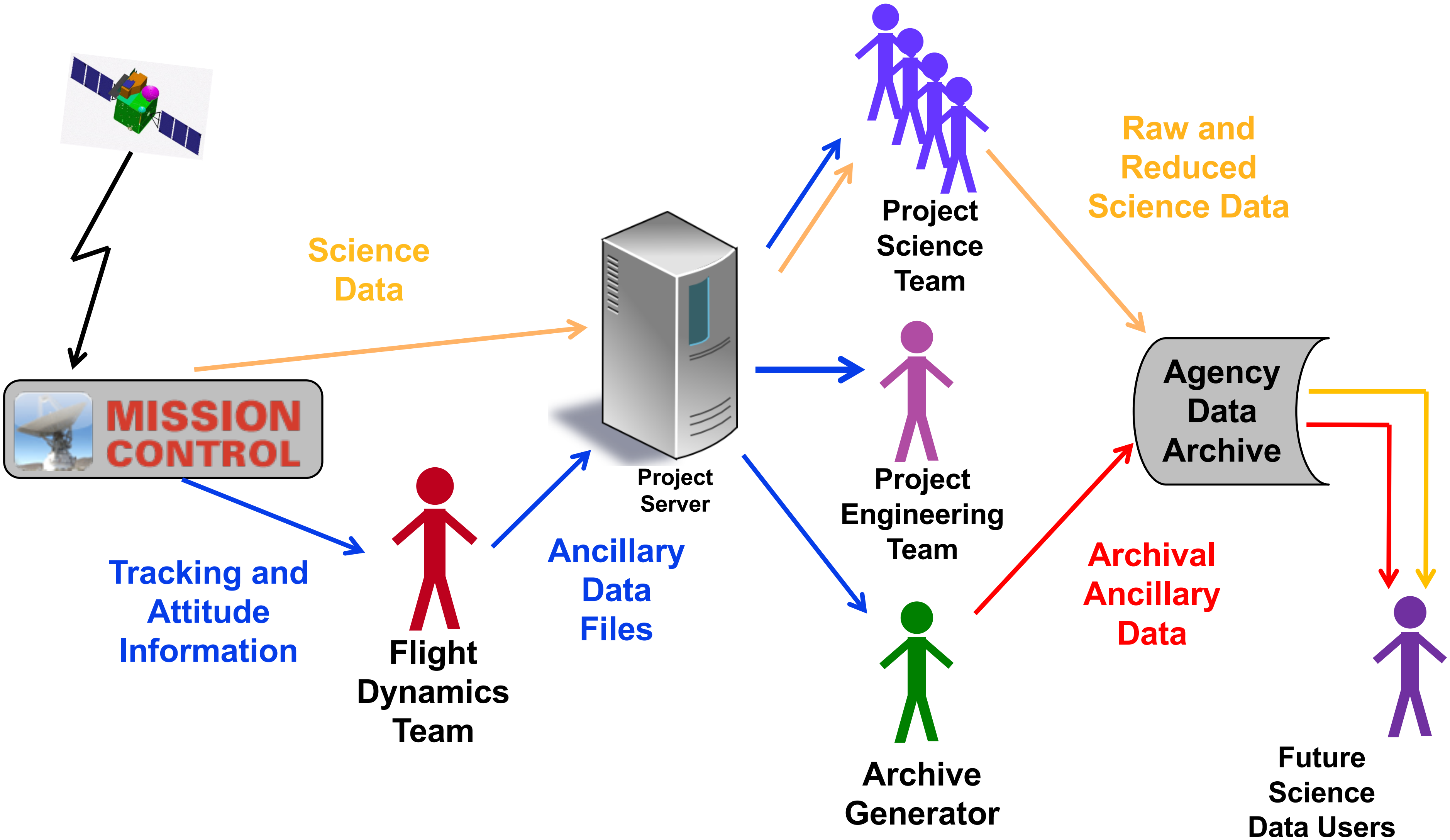
- The skills needed could vary depending on:
  - the scope and requirements the project has agreed to
  - the approach taken
  - end-user expectations
- Generally speaking, doing a good job is not trivial. It requires some knowledge of:
  - astrodynamics (orbital mechanics)
  - spacecraft dynamics
  - spacecraft and ground-based time systems
  - software programming and testing
  - ground data system workings and automation
  - insight and tools needed to validate ancillary data
- It also requires an ability to help end users resolve problems in using the ancillary data

Ancillary Data Production Functions: A Minimal Model

- **At a minimum, project personnel will need to produce, validate, distribute and archive reconstructed ("definitive") spacecraft orbit and attitude data**
  - Perhaps the production, validation and distribution would be accomplished by a Mission Operations Center (MOC) flight dynamics team
  - Perhaps the archive preparation would be accomplished by another member of the MOC
  - The next graphic depicts this minimalist approach

Ancillary Data Production & Use

A Minimalist Model



Advantages and Disadvantages of the Minimalist Model

- Advantages
  - May utilize local tools and processes already in place
  - Might minimize the direct cost to the project by possibly placing some of the cost burden on other scientists
  - Possibly minimizes some components of a project's schedule
- Disadvantages
  - Some ancillary data needed by some end users is not provided
    - » Users must find the rest for themselves, or make it up
    - » The archive could be rather sparse and so not of much help to scientists after the mission is over
  - How to use the provided ancillary data, along with other data, to compute needed observation geometry is largely left up to the end user
    - » Requires special effort on the part of each instrument team, maybe even individual team members
      - Easy to make mistakes

A Somewhat Maximal Model: The SPICE Approach

- NASA’s Planetary Science Division, NASA’s Planetary Data System (PDS) and the multi-national Interplanetary Data Alliance (IPDA) recommend planetary projects use the “SPICE” system

- “SPICE” is described later on in this presentation

Your Considerations

- **When selecting an approach to providing ancillary data, consider several points as noted on the next four charts**

Planetary Ancillary Data are Complex

- Almost everything is moving and/or rotating
  - Often with multiple data sources providing different values
  - Proper accounting for light-time and stellar aberration corrections is frequently a problem
- Many reference frames are used
  - There may be multiple definitions
  - The data/parameters used to realize them may be changing
- Many coordinate systems are used
  - Standard definitions may not exist
- Size and shape estimates for target bodies are constantly evolving
  - The various mechanisms used for modeling size/shape also evolve
- Several time systems are used
  - Mishandling of time tags is a common problem

Ancillary Data Production Often Gets Little Attention

- Ownership of the job is often distributed among several entities
- When, where and how the data will be used is often not well understood
- Deciding on an ancillary data production schema, announcing that decision, and putting the system in place often come too late during mission development
- Producing ancillary data is often seen as a rather simple and boring archiving job, thus getting insufficient attention

Ancillary Data Users Haven’t Much Patience

- Many–perhaps most–end users of ancillary data don’t want to be bothered dealing with these data
  - Using ancillary data is just one of many steps along the way to achieving science or engineering results
  - Using ancillary data is generally viewed as difficult
  - Many users simply want *the* answer, or even *an* answer, to geometry questions made readily available to them
  - Users often prefer to use what is already familiar to them, even if a better solution is available

Takes Real Effort

- No matter the approach used for producing and using ancillary data, doing so requires non-trivial resources
  - Smart, experienced, motivated people
  - Planning
  - Time
  - Funding
  - Training and consulting

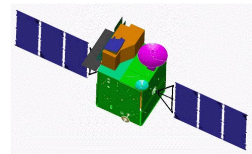
- Giving insufficient attention to producing and using ancillary data can result in frustrated engineers, angry scientists, incorrect science results and a poor archive
  - Could even jeopardize a mission

How does SPICE Differ from a Minimal Ancillary Data System?

- More kinds of ancillary data are provided
- SPICE provides users a large suite of software used to read SPICE ancillary data files and to subsequently compute observation geometry
  - Thus end users have a great deal of help in writing their own software that requires some use of geometry parameters
- SPICE is fully multi-mission: can be used repeatedly (assuming new missions adopt SPICE)
- SPICE is supported with tutorials and programming lessons, and is highly documented
  - NAIF offers a training class for end users about every 18 months

From Where do SPICE Ancillary Data Come?

- 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 files, called "kernels."

SPICE includes software for writing kernels, reading kernels, and computing observation geometry based on those kernels.

SPICE System Components

Ancillary data files ("kernels")……………………

1100
1010
0101

Software (SPICE Toolkit) ………….

Documentation …………....

Tutorials ……….......

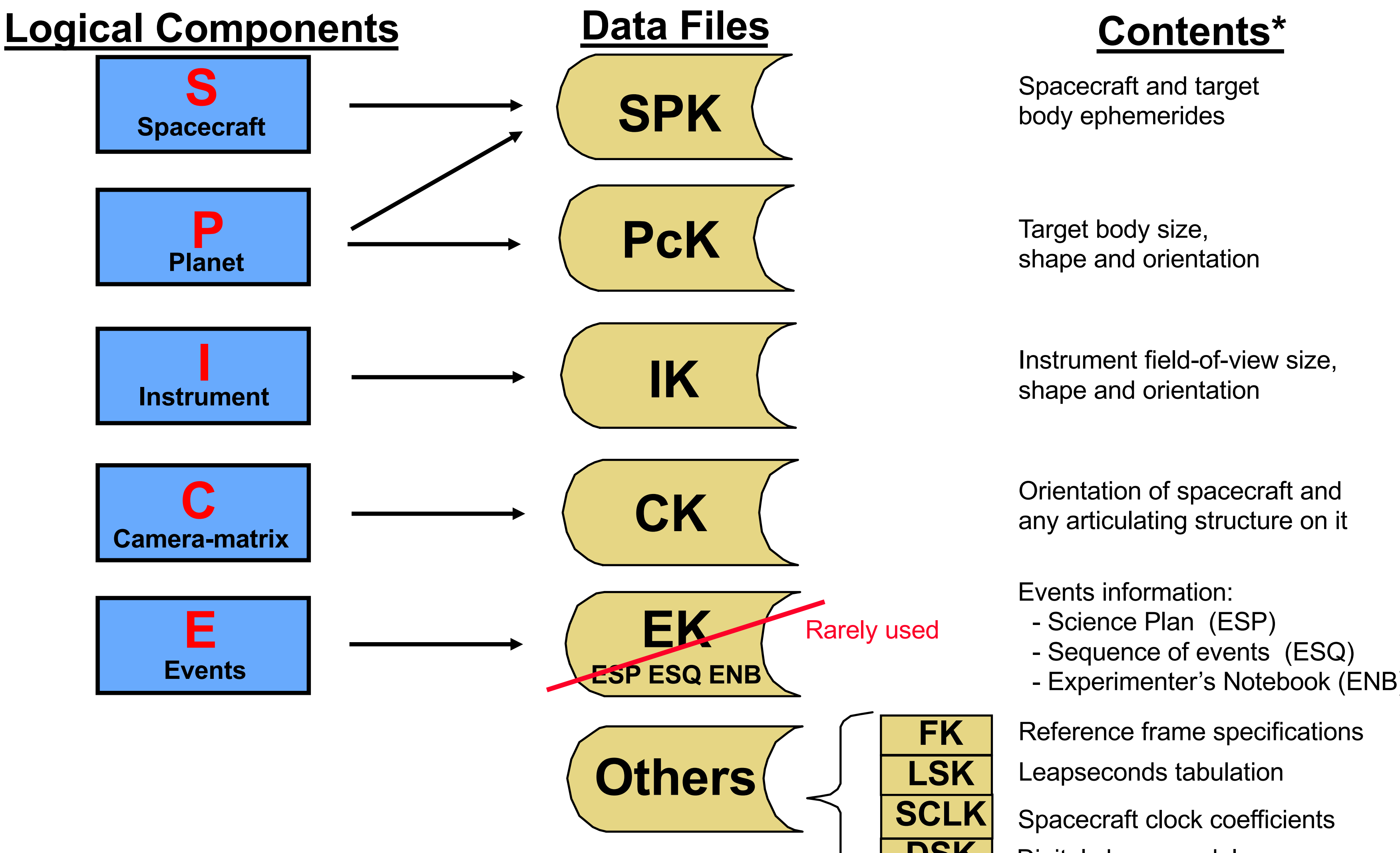
Programming lessons …..

Training classes ……………………

User consultation ………………………………...

Navigation and Ancillary Information Facility (NAIF)

SPICE Data Overview



* See the Backup section for details

SPICE Toolkit Software Overview

Contents

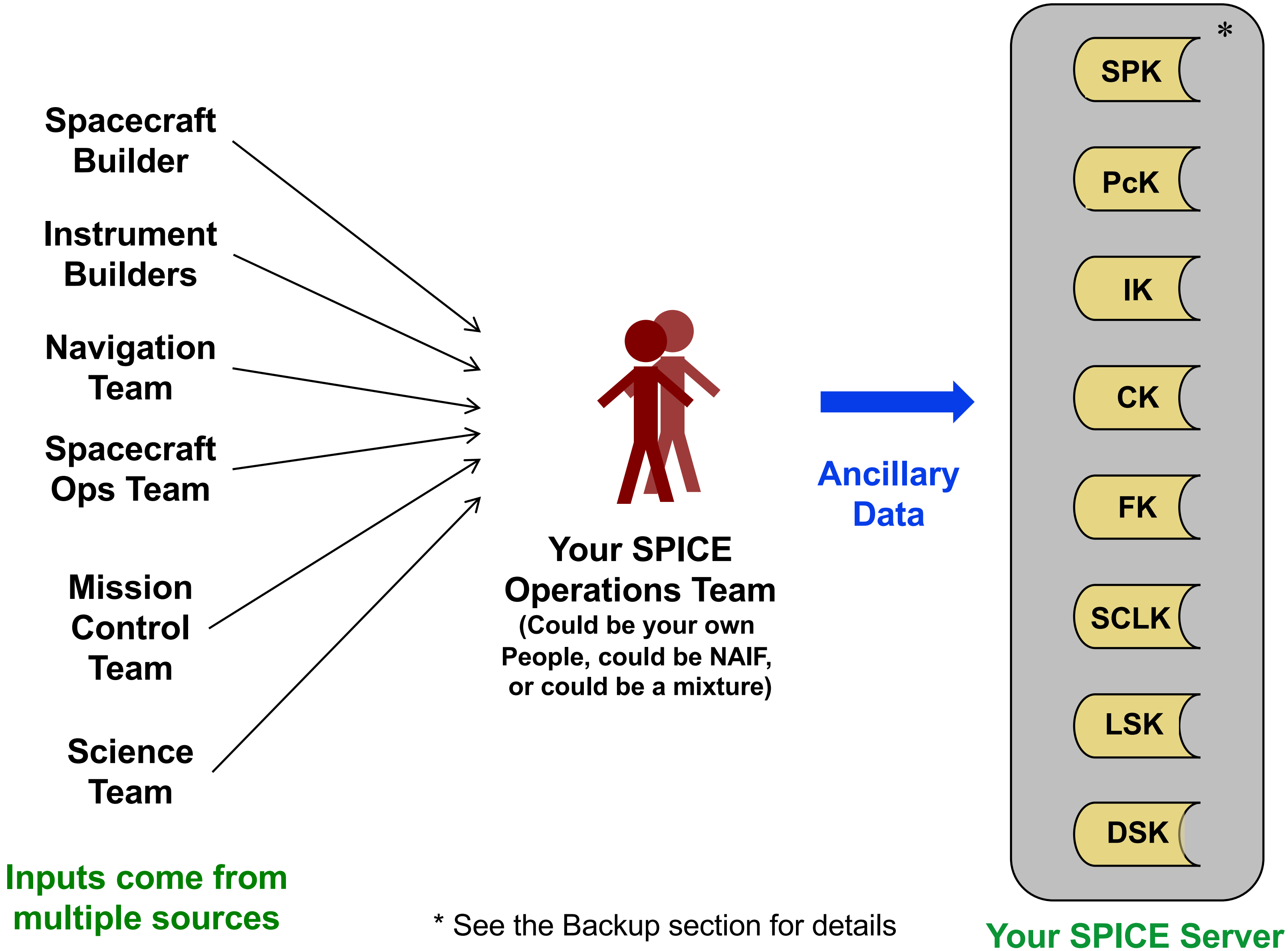
- **Library of subroutines**
  - Just a few used within a customer’s program to compute quantities derived from SPICE data files
- **Programs**
  - For SPICE data production
  - For SPICE data management
- **Documentation**
  - Highly annotated source code
  - Technical Reference Manuals (23)
  - User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

Versions*

- **Eight languages**
  - Fortran
  - C
  - Interactive Data Language (IDL)
  - MATLAB
  - Java Native Interface (JNI)
  - Available from 3rd parties:
    - Python
    - Ruby
    - Swift
- **Five platforms**
  - PC/Linux
  - PC/Windows
  - PC/Cygwin
  - Sun/SPARC/Solaris
  - Mac/OSX
  - Working on Raspberry Pi
- **Several compilers**
  - For the Fortran and C Toolkits

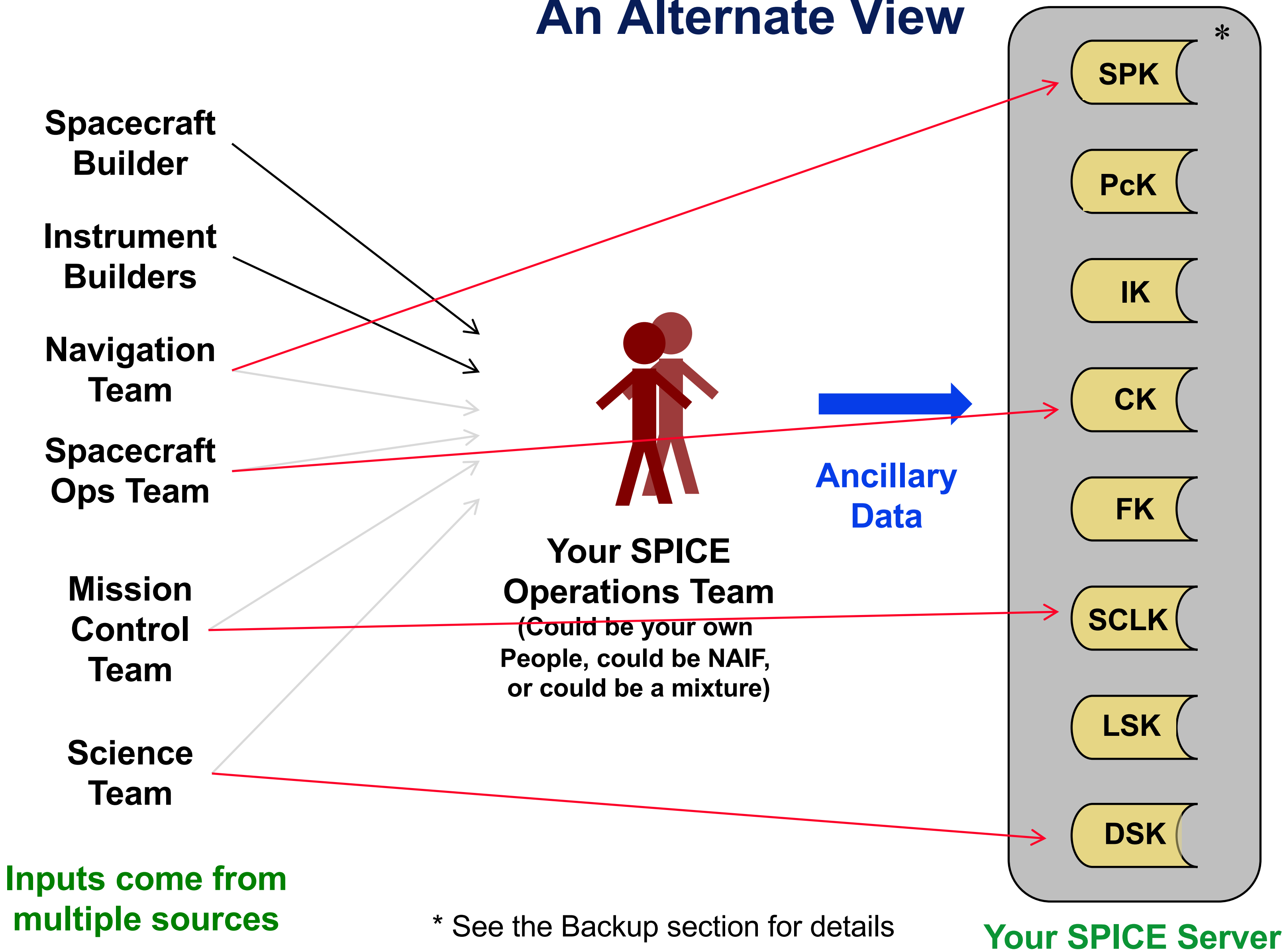
* As of August 2021

Producing SPICE Ancillary Data

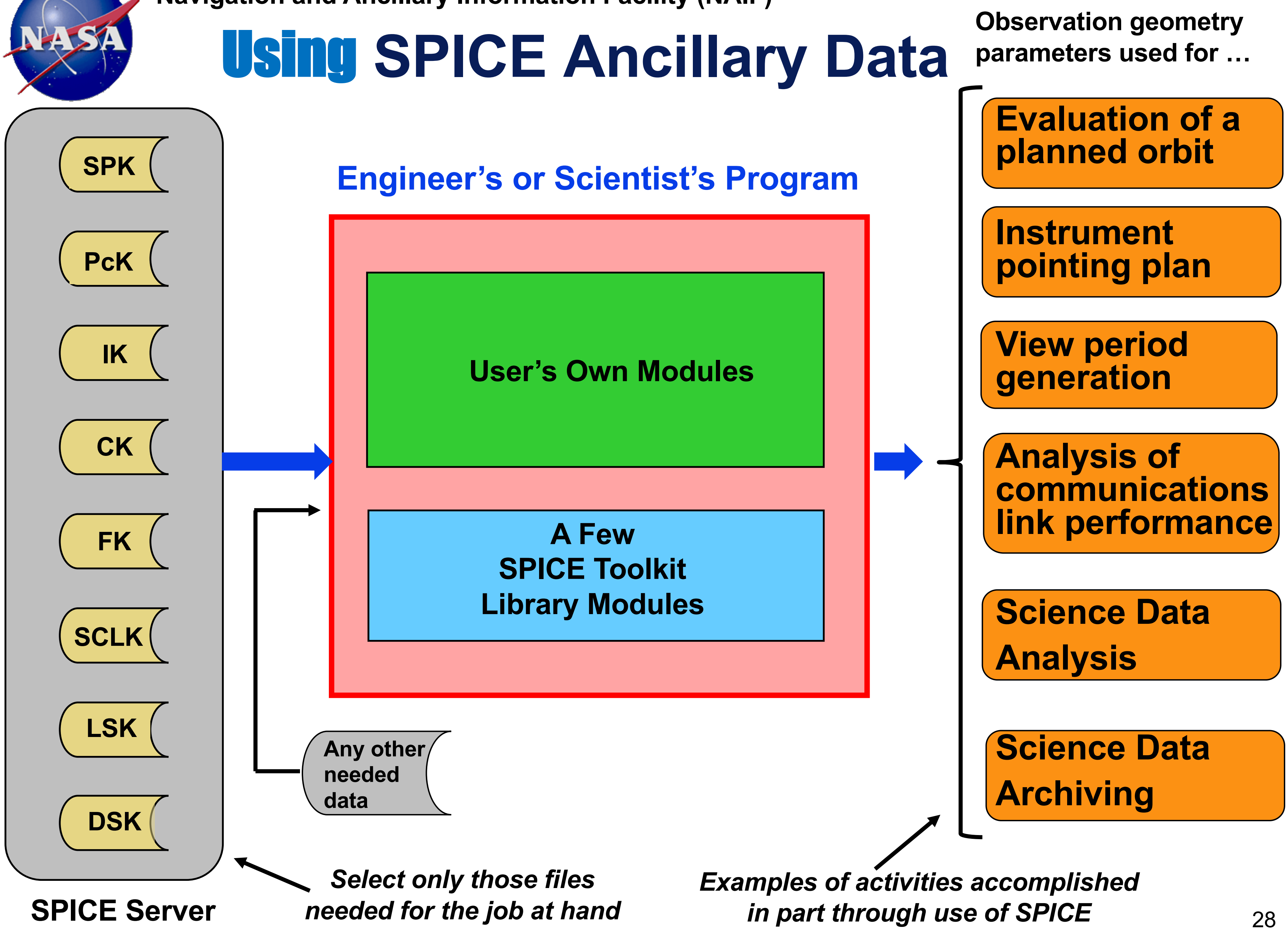


* See the Backup section for details

Producing SPICE Data
An Alternate View

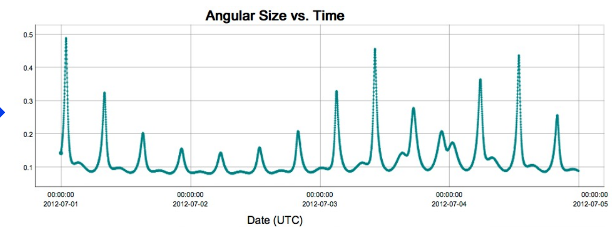


Using SPICE Ancillary Data



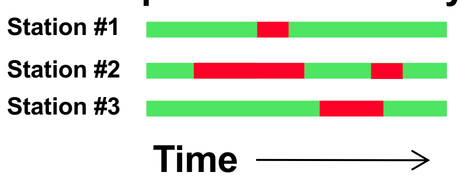
Typical Uses of SPICE

Evaluation of a planned trajectory



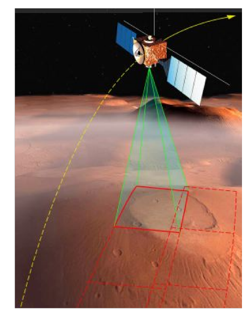
Angular size of Phobos as seen from the Mars Express spacecraft

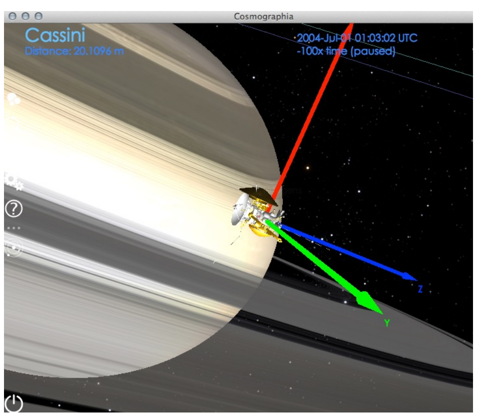
Spacecraft Visibility



Mission engineering analyses

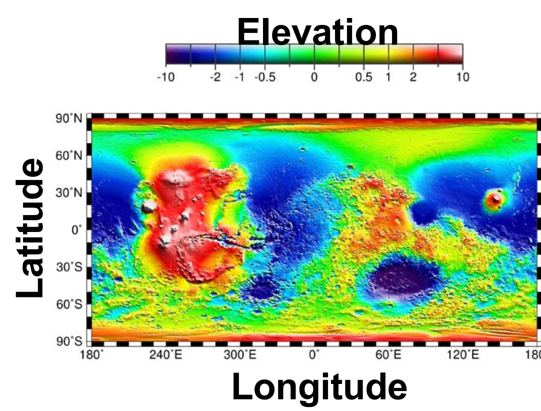
Planning an instrument pointing profile





Observation geometry visualization

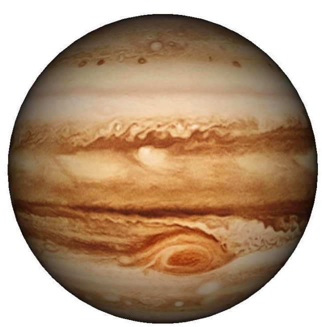
Science data analysis and archiving



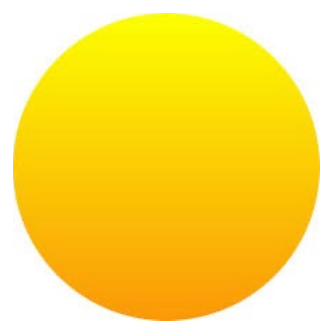
Kinds of Projects Using SPICE

- **Cruise/Flyby**
  - Remote sensing
  - In-situ measurement
  - Instrument calibration
- **Orbiters**
  - Remote sensing
  - In-situ measurement
  - Communications relay
- **Landers**
  - Remote sensing
  - In-situ measurements
  - Rover or balloon relay
- **Rovers**
  - Remote sensing
  - In-situ sensing
  - Local terrain characterization
- **Space Technology Demos**

  - e.g. optical communications



Planetary Science



Heliophysics

A bit of Earth Science

Kinds of Instruments Using SPICE

Insitu Instruments

- High and low energy particle detectors
- Plasma instruments
- Dust detectors
- Magnetometers
- Plasma wave detectors
- Mass spectrometers

Remote Sensing Instruments

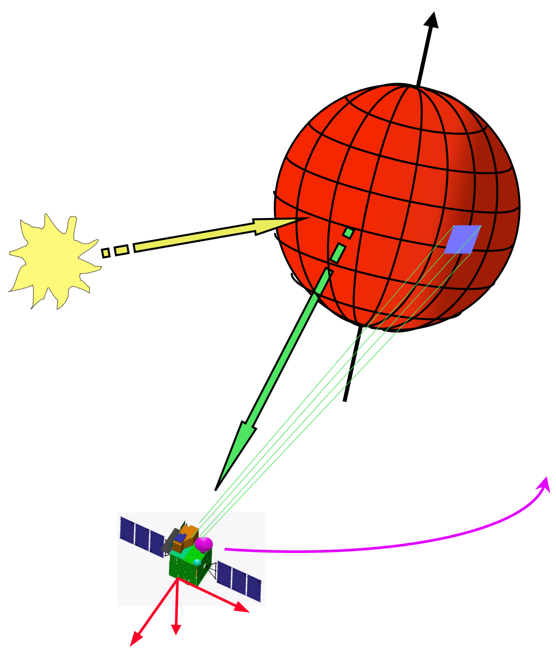
- Framing imagers
- Line-scan imagers
- Polarimeters
- Photometers
- Spectrometers
- Radiometers
- Synthetic Aperture Radar
- Altimeters

- Radio science experiments

What One Can Do Using SPICE - 1

Compute many kinds of observation geometry parameters at selected times

A Few Examples

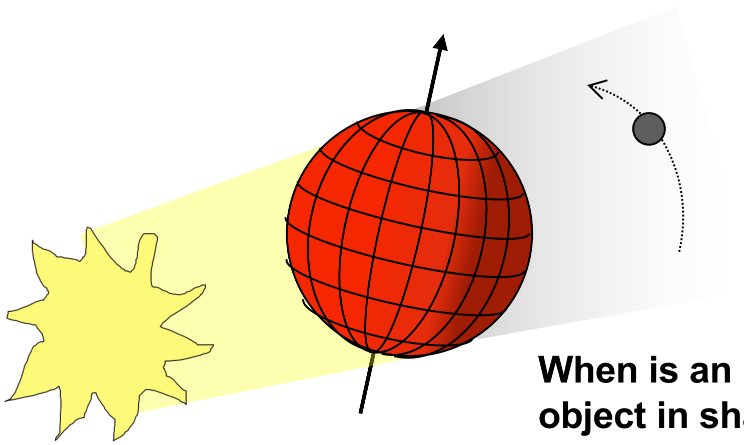


- **Positions and velocities of planets, satellites, comets, asteroids and spacecraft**
- **Size, shape and orientation of planets, satellites, comets and asteroids**
- **Orientation of a spacecraft and its various moving structures**
- **Instrument field-of-view location on a planet's surface or atmosphere**

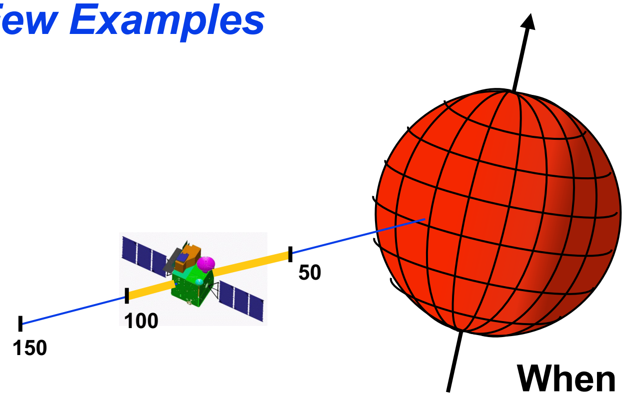
What One Can Do Using SPICE - 2

Find times when a specified “geometric event” occurs

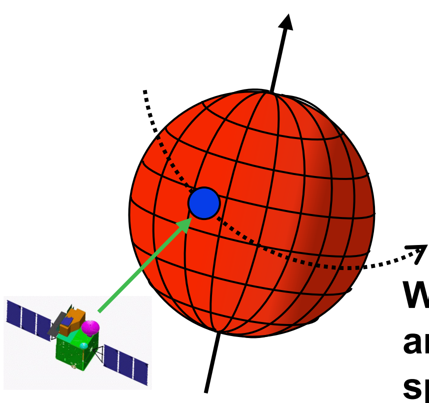
A Few Examples



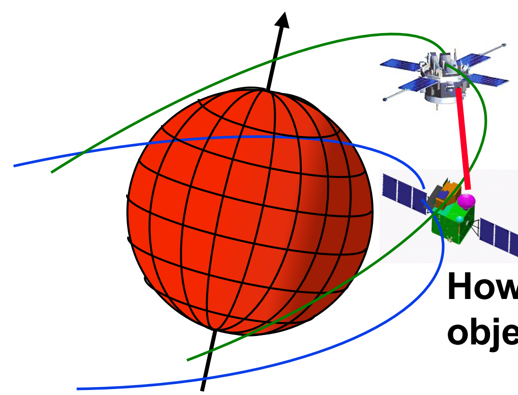
When is an object in shadow?



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?

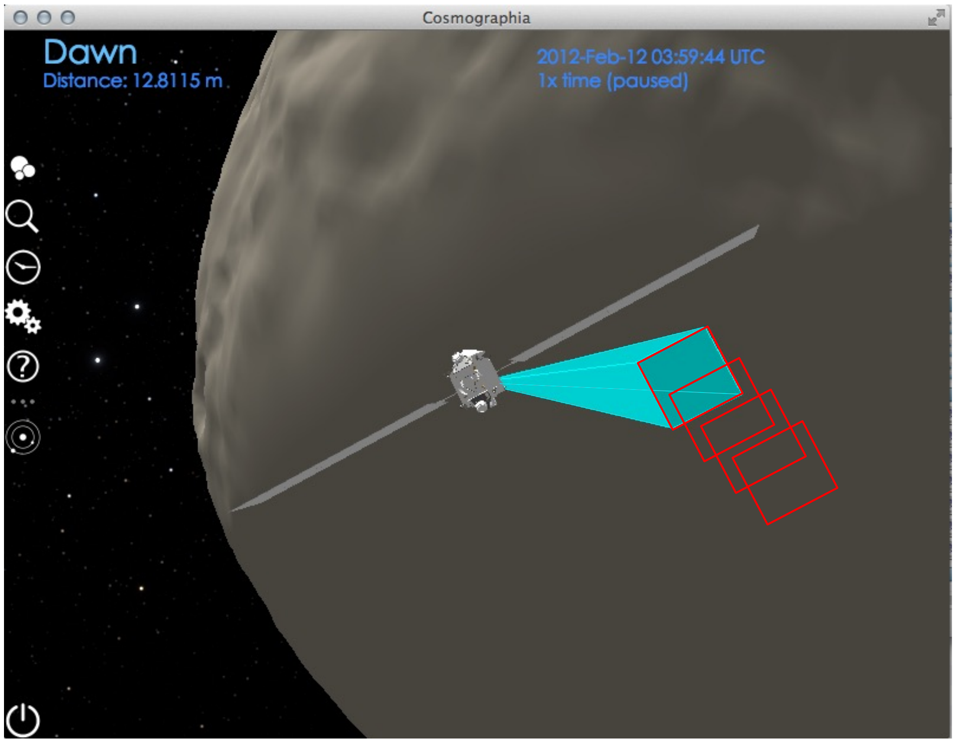


How close will two objects come?

Navigation and Ancillary Information Facility (NAIF)

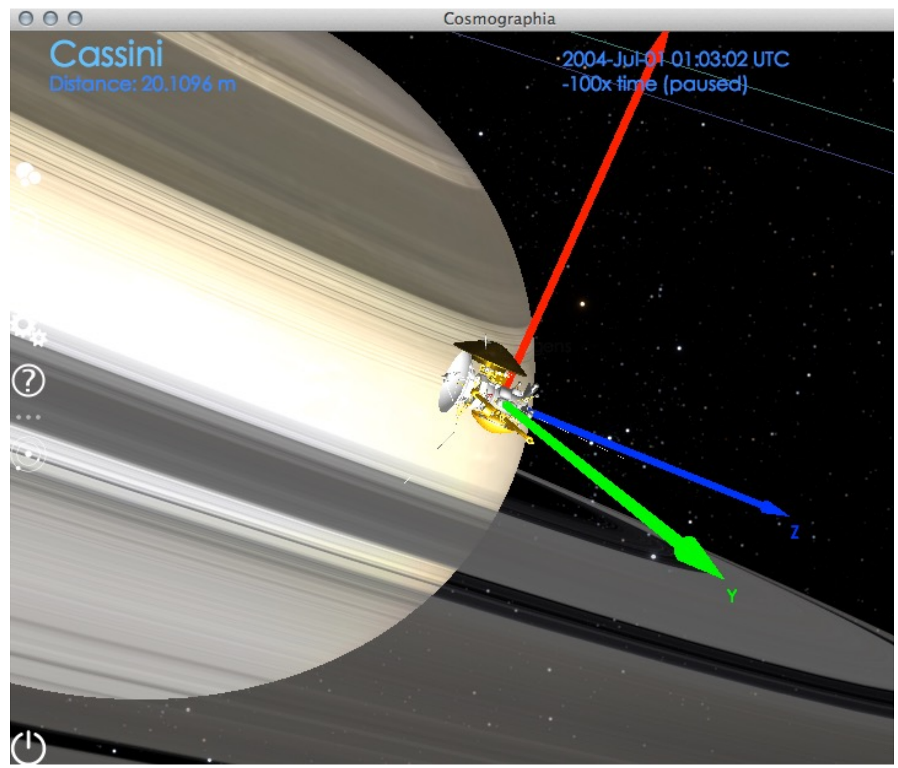
What One Can Do Using SPICE - 3

Produce 3D Mission Animations



Cosmographia* visualization of DAWN's framing Camera photographing Vesta, including display of image footprints

Cosmographia* visualization of Cassini in Orbit at Saturn, showing spacecraft axes



* SPICE-Enhanced Cosmographia is part of the SPICE tools suite

Advantages of Using SPICE

- Provides lots of geometry computational capability
- Software is very well tested, works on many computing environments, and is always 100% backwards compatible
- Data formats are unchanging
- Having proven, extensive and reusable means for producing and using ancillary data can reduce cost and risk, and can help scientists and engineers achieve more substantive, accurate and timely results
- Many scientists and engineers around the world are already familiar with SPICE; it is truly multi-mission
- No U. S. ITAR restrictions; no licensing
- SPICE is the NASA-preferred geometry computation and archive mechanism
- SPICE components are free for all users; see details later on in this presentation

Challenges Associated with Using SPICE

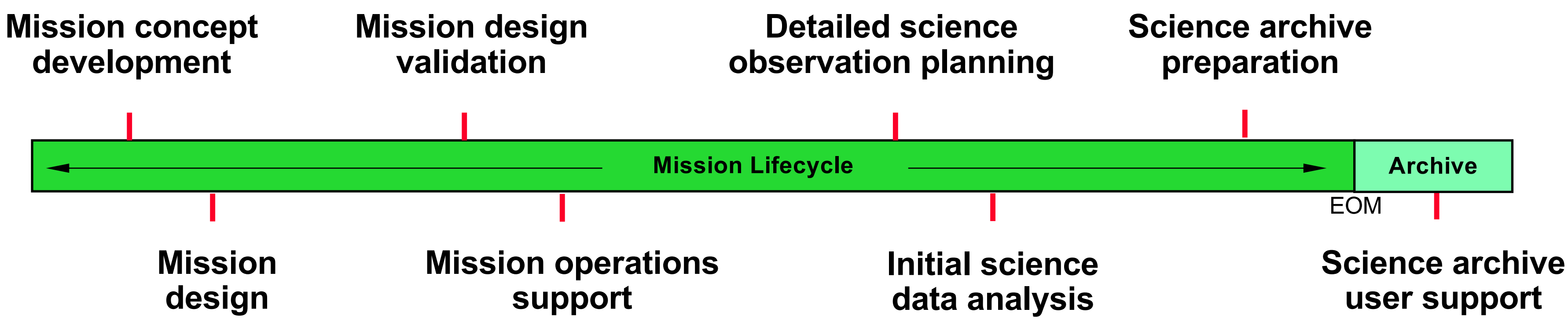
- Production and use of SPICE data requires use of SPICE software
  - Maybe your project doesn't wish to count on "outside" software?
  - Maybe the SPICE Toolkit is not available in the language(s) or for the operating system(s) you use?
- Learning to correctly <u>produce</u> SPICE data requires effort and at least some domain knowledge
- Learning to correctly <u>use</u> SPICE data and software also requires effort
  - Some scientists and engineers don't wish to take the time to do so
- SPICE doesn't specifically handle instrument geometric calibration
- You'll need to provide SPICE-aware problem solving and user consultation services throughout the life of the mission

- Of course, some if not all of these challenges could apply to any other approach taken

Keep reading if you are considering using SPICE

Timeline Big Picture

- **SPICE is frequently used throughout the mission life cycle and beyond: from pre-Phase A to well past EOM**



- **You'll need to plan and budget for various components of SPICE support consistent with the extent of your project's planned use of SPICE**
- **Your funding agency should have an archive willing to ingest SPICE data and to support future users of the SPICE archive**

Who Needs to Learn What?

- Mission Operations people need to learn: SPICE data production
- Scientists and Mission Ops people need to learn: SPICE data use
  - How to write SPICE-aware software used for mission and science planning, science data analysis, and mission engineering
- Someone needs to learn: SPICE archive production
  - Possibly a single product
  - Possibly a pipeline operation with incremental deliveries every 3 to 6 months
- Someone needs to provide: User consulting
  - Know enough about SPICE…
    - » to be able to provide advice to your project on how to use SPICE
    - » to be able to help solve user's problems

- See the next three pages for some details

SPICE Data Production*

- Time-invariant SPICE data files are usually made once–pre-launch–with perhaps a few subsequent updates
  - Mission Frames Kernel (FK)
  - Mission instrument Kernels, one for each instrument (IK)
  - Planetary Constants Kernel (PCK)**
  - Leap seconds kernel (LSK)**
- Time varying SPICE data files are produced regularly throughout the mission lifecycle
  - Planet, satellite, comet or asteroid ephemeris (SPK)***
  - Spacecraft trajectory (SPK)
  - Spacecraft orientation (CK)
  - Spacecraft clock correlation (SCLK)
  - Digital Shape Kernel (DSK), if useful to the project (optional)

* Only the most commonly used files are shown
** A generic version provided by NAIF may be all that is needed
*** A one-time generic version provided by NAIF using data provided by JPL's Solar System Dynamics Group may be all that is needed

Learning How to Produce SPICE Data

- Time invariant kernels are mostly made using any convenient text editor or word processor
  - The amount of actual data needed in the mission-specific text kernels (FK and IK) is quite small, but the associated documentation explaining the data is typically quite extensive.
    - FK and IK tutorials, the "Frames Required Reading" technical reference document, and examples of FKs and IKs from ongoing projects are the best sources of information for someone embarking on making her/his own text kernels
  - The generic text kernels (PCK and LSK) are provided by NAIF
- Time varying kernels (binary kernels) are made using SPICE utility programs, or with SPICE APIs placed in your own program
  - NAIF offers tutorials on binary kernel production, as well as several technical reference manuals and user guides for the utility programs
  - NAIF also offers an assortment of utilities useful in examining and validating these kernels
- It is likely someone new to SPICE will need some consultation with NAIF or other SPICE experts

SPICE Data Use

- **A user of SPICE kernels generally writes her/his own application program to accomplish some task, and includes in that application calls to a few SPICE APIs to compute needed observation geometry**
  - **Sometimes users make use of an application written by others**
- **Another means for using SPICE kernels to compute observation geometry is to use NAIF's on-line WebGeocalc tool**
  - **https://naif.jpl.nasa.gov/naif/webgeocalc.html**

Learning How to Use SPICE Data

- **Tutorials and sample SPICE-based programs are available from the NAIF website**
- **All of the high-level SPICE APIs contain substantial documentation and working examples**
- **NAIF offers a free, three-day SPICE User's training class about once every 18 months**
  - **Consists of a mix of lectures and hands-on, open book programming exercises done by the students**
  - **See the "Announcements" page at the NAIF website**
- **These class materials are also available from the NAIF website for use in self-training, under the "Training" link**
  - **https://naif.jpl.nasa.gov/naif/training.html**

SPICE Archive Production

- Involves numerous details, especially for production of the very first increment
- Examples…
  - Ensure there are no missing files
  - Validate all files
  - Get orbit (SPK) and attitude (CK) data producers to fill in gaps where possible
  - Ensure any updates from instrument teams are included in the frames kernel (FK) and instrument kernels (IKs)
  - Produce/complete descriptive documentation of all files
  - Produce needed archive labels
  - Conduct a peer review
  - Fix liens from peer review and deliver final version
- This requires careful analysis and great attention to details and archive standards

Learning How to do SPICE Archive Production

- **Someone planning to produce a SPICE archive should examine several existing SPICE archives**
- **One also needs some familiarity with the Planetary Data System's "PDS4" archive standards**
  - See the PDS website for access to details
- **Proposed SPICE archives must pass NAIF peer review if intended to be archived at the NAIF Node of the Planetary Data System**
  - NAIF is quite demanding of very high quality!
- **It is likely a SPICE archive producer will need some consultation with NAIF staff**

SPICE User Consultation

- **A project should have someone trained to be able to help scientists and engineers use SPICE correctly and effectively**

Learning How to Provide SPICE User Consultation

- There’s no formal training for this; one needs to have been working with SPICE for some time to be able to help others

What You'll Need to Provide

- Capable personnel who have learned how to produce and validate SPICE kernels
- A data production infrastructure for producing and distributing SPICE kernels
- Careful oversight of the SPICE production process
- Analysis and correction of problems encountered in SPICE production
  - Often requires good knowledge of your spacecraft and/or its ground data system
- Any needed training for your scientists and engineers intending to consume your SPICE data
  - If the timing works out, perhaps they can attend the SPICE training class mentioned on the previous page
- Consultation for your project's SPICE consumers

What NAIF Can Provide for Free

- **The SPICE Toolkit, available at the NAIF website**
  – https://naif.jpl.nasa.gov/naif/toolkit.html
  – Includes numerous utilities useful in producing, validating and managing SPICE data files
  – Includes a large amount of user-focused documentation
- **Access to all archived and generic SPICE data available at the NAIF website**
  – https://naif.jpl.nasa.gov/naif/data.html
- **A collection of SPICE tutorials and "open book" SPICE programming lessons, also available at the NAIF website**
  – https://naif.jpl.nasa.gov/naif/tutorials.html
  – https://naif.jpl.nasa.gov/naif/lessons.html
- **For NASA's planetary missions:**
  – peer review of archive submissions and archiving of the peer reviewed SPICE data in the PDS*
  – consultation on using SPICE for NASA-funded scientists using planetary mission SPICE data archived at the NAIF Node of the PDS*
- **About once every year and a half, a three day SPICE training class**
  – This class is focused on "beginners": people largely new to using SPICE data and software
  – This class is focused on SPICE data users: to date there have been no classes for SPICE data producers or archivers
  – Location is usually near Pasadena, but might be elsewhere

*PDS = NASA's Planetary Data System

What NAIF Could Provide if Funded

- Many flight projects at JPL and elsewhere within NASA elect to fund NAIF to do some or all of:
  - SPICE data production
  - training and consultation for project SPICE users
  - archive production
- A few times NASA has funded NAIF to provide some support for a foreign flight project
- NAIF could provide training for others on data production or archive production
- What's the cost for such support?
  - There's not a simple answer, but for recent projects for which NAIF has a substantial role, NAIF ops support has ranged from about $30K to $70K per year, usually spanning from Phase C into Phase F
  - The yearly cost typically varies quite a bit depending on what effort is needed

To Learn More

- To learn more about technical or programmatic details please contact the NAIF manager

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Backup

Graphics Depicting SPICE Data

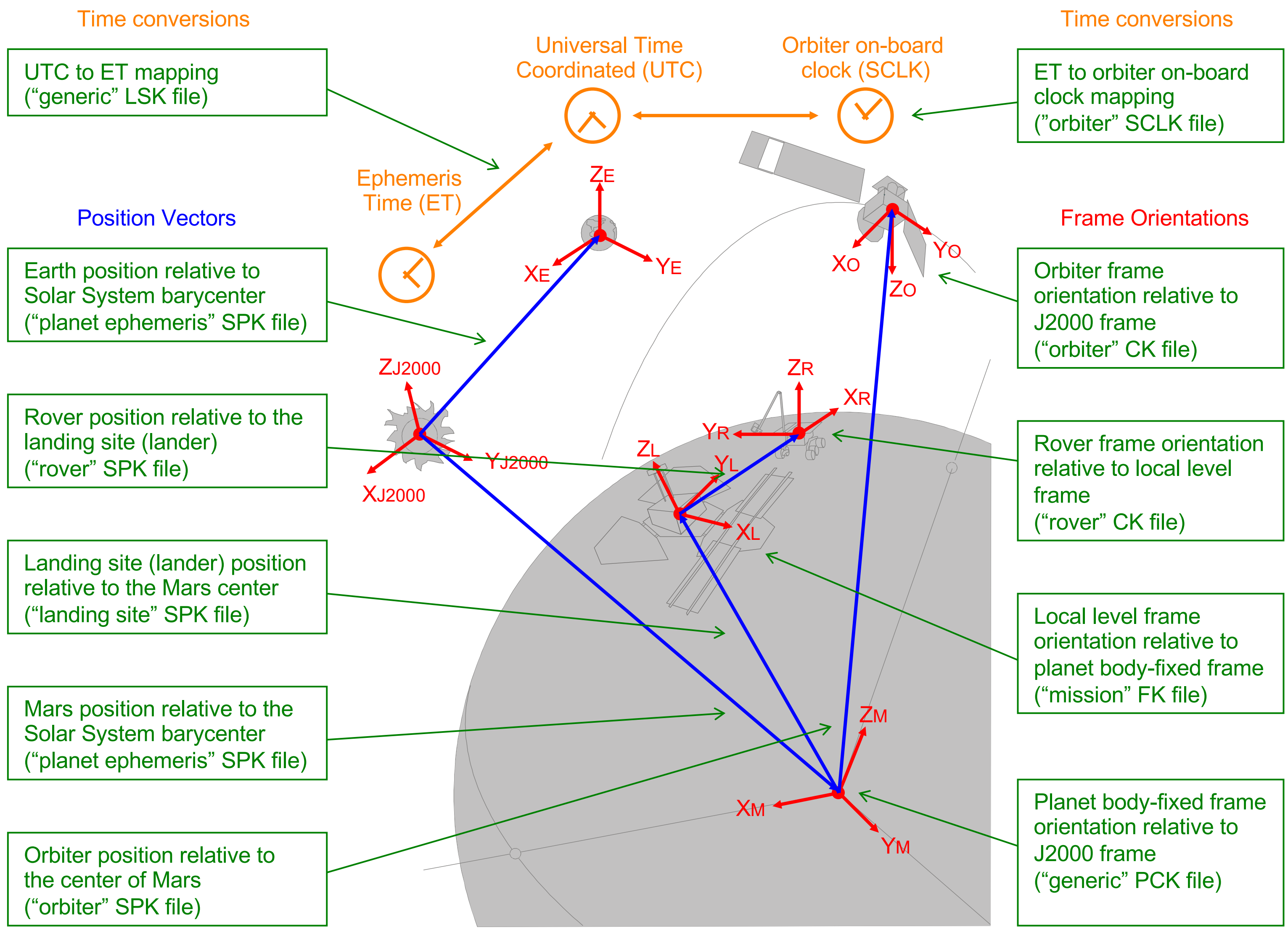
Contents of SPICE Kernels

Ancillary Data Production Challenges

Graphics Depicting How SPICE Kernels are Made and Modified

Graphics Depicting SPICE Data

Global SPICE Geometry



Orbiter Geometry

Position Vectors

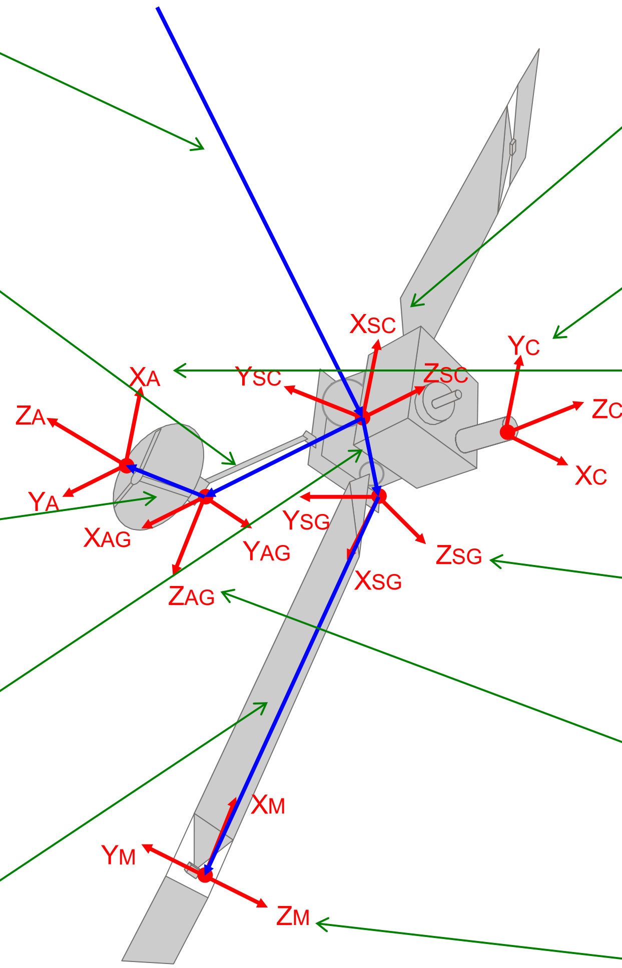
Spacecraft position relative to planet center ("spacecraft" SPK file)

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)

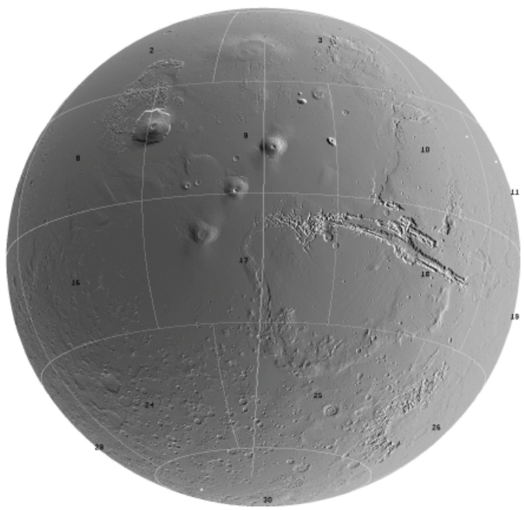
Solar array gimbal frame orientation relative to spacecraft frame ("solar array" CK file)

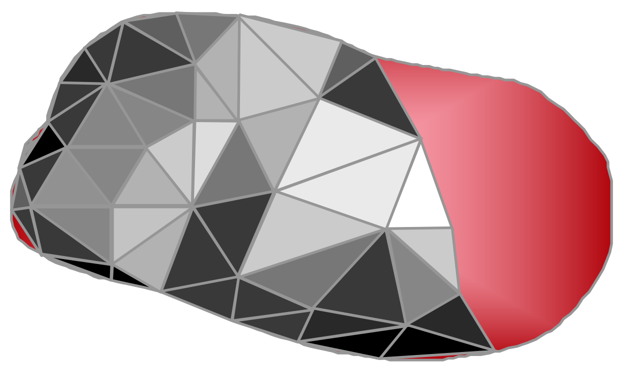
High gain antenna gimbal frame orientation relative to spacecraft frame ("antenna" CK file)

Magnetometer frame orientation relative to solar array gimbal frame ("mission" FK file)

Digital Shape Kernel

The two DSK types shown here are used to provide high fidelity shape models needed by modern experiments. Would be used instead of, or in addition to, the spherical, spheroidal and ellipsoidal models available in a PCK.





Digital elevation model

For large, regular bodies such as Earth, Moon and Mars

Tessellated plate model

For small, irregular bodies such as asteroids and small satellites

Contents of SPICE Kernels

SPICE Data Details- 1

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 field-of-view size, shape, orientation
- Possibly additional information, such as internal timing

SPICE Data Details- 2

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**

EK is not much used

SPICE Data Details - 3

FK

- **Frames**
  - Definitions of and specification of relationships between reference frames (coordinate systems)
    - Both “fixed” and “dynamic” frames are available

LSK

- **Leap seconds Tabulation**
  - Used for UTC <--> TDB (ET) time conversions

SCLK

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

DSK

- Shape models (digital elevation model and tessellated plate model) (DSK)

Under development now

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

Ancillary Data Production Challenges

Ancillary Data Production and Usage Challenges

Introduction

- No matter what approach is selected for providing engineers and scientists (and an archive) with ancillary data, real effort is needed to provide an effective system, and to detect and resolve the inevitable problems that arise
- Even when good ancillary data are made available, end users often have trouble using these data
- The next several charts provide some examples

Examples of Ancillary Data Production & Usage Challenges

Spacecraft Trajectory

- Will users need both predicted as well as reconstructed ("definitive") trajectory data?
  - Often both types need be available; how distinguish between these?
  - Need you combine both reconstructed and predicted data in one file?
  - How to manage the many files needed?
- Need to reduce or eliminate gaps in coverage
- How avoid "jumps" between adjacent trajectory solutions?
- How to handle improved trajectory solutions:
  - resulting from long arc fits
  - resulting from use of better gravity model
- How to notify end users when new data are available, and for what purpose?
- Will the time system used be a problem for end users?
- Any special requirements placed by tracking stations?
- Any issues resulting from a changing time step size?
- Need you provide end users an evaluation/interpolation algorithm?

Examples of Ancillary Data Production & Usage Challenges

Spacecraft Attitude (Orientation)

- **Are predicted attitude data needed in addition to reconstructed data? (Perhaps for observation planning purposes.) With what fidelity, and how achieve that fidelity?**
- **Are the accuracy and frequency of downlinked (reconstructed) attitude data sufficient for all users?**
- **How accurate are reconstructed attitude data time tags?**
- **How does the attitude file producer deal with gaps in downlinked (reconstructed) attitude telemetry?**
- **How will end users know about and deal with gaps in reconstructed attitude data? (Encountering such gaps is inevitable!)**
- **Must end users deal with simultaneous use of predicted and reconstructed attitude data?**
- **Is the volume of attitude data too excessive for end users?**
- **How does one name and document attitude data files so as to meet end user needs?**

Examples of Ancillary Data Production & Usage Challenges

Spacecraft Clock Calibration

- Often the science data and the spacecraft attitude data returned from a spacecraft have time tags determined by an on-board clock
- If this is the case, the ground system must be able to convert such time tags to another time system, such as UTC or TAI or ?
  - Requires the flight system generate and downlink time correlation "packets," and that these be used to calibrate the spacecraft clock to the accuracy required by the project
  - Doing this sort of calibration well can be quite difficult
  - Calibration can be complicated by inadequate frequency of returned calibration packets, clock temperature changes, unplanned clock resets, and planned clock "jumping"

Examples of Ancillary Data Production & Usage Challenges

Reference Frames and Coordinate Systems

- Planetary missions tend to make use of multiple reference frames and coordinate systems
- In many cases the definition of the frame or coordinate system is not a true standard
  - For some reference frames the defining data are not well documented, and/or are disputed, and/or are evolving over time
  - For some coordinate systems what is meant by a name can be uncertain or totally left up to the creator
- Some end users do not know how to write code to convert between frames or between coordinate systems
- The above can result in confusion, inconsistencies and outright errors in geometry parameter computations

Examples of Ancillary Data Production & Usage Challenges

Instrument Geometry

- Geometry pertaining to “instruments” is important to understanding the science data acquired
  - Where the instrument is mounted, and with what orientation
    - » Could involve multiple “view ports”
  - If applicable, also need to know the instrument’s field-of-view size and shape
- Such data are often built-in to an instrument’s ground software, and thus hidden from other flight team members and users of the instrument archive
- A good ancillary information system makes these data readily available and clearly documented
  - Must be checked using real flight observations, since errors of 90 or 180 degrees often crop up
- The same info is often needed, or useful, for antennas, solar arrays, star trackers, etc.

Examples of Ancillary Data Production & Usage Challenges

Target Body Shape Data

- Gone are the days when every target body was modeled as a sphere, spheroid or tri-axial ellipsoid
  - Either tessellated plate models for small, irregular objects, or digital elevation models, for large bodies are becoming the norm
- Estimating such shapes is generally in the purview of instrument experiments
  - But making such shapes readily available to other scientists, and to project engineers, is increasingly important. This is complicated due to:
    - » multiple methods used for modeling
    - » rapidly evolving model data
    - » lack of standard software for using models
- A modern ancillary data system should address these challenges

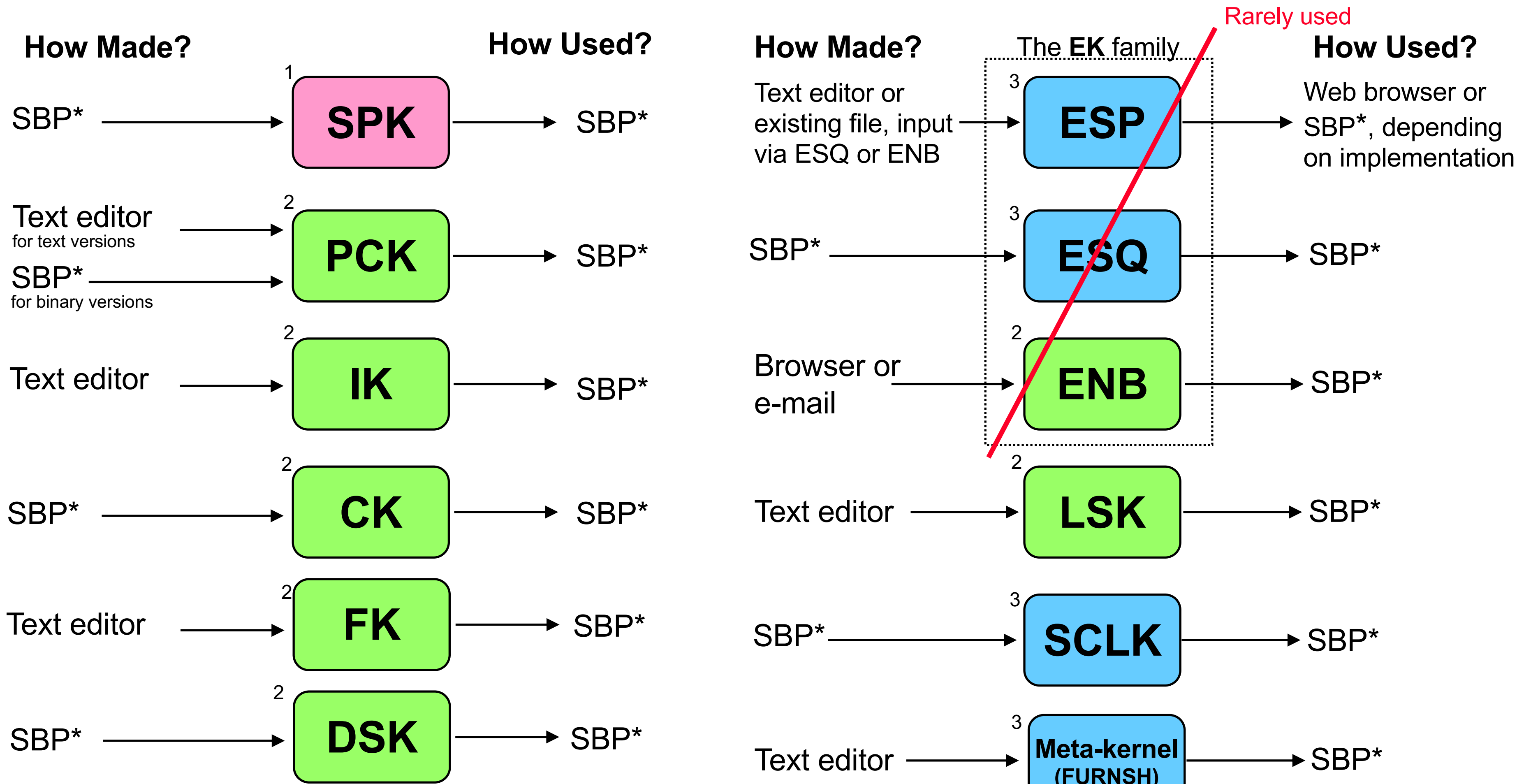
Data Availability Notification

- What method will be used to notify data users when each newly produced ancillary data file becomes available?
- How will the project handle notifications of errors and replacement files?

Graphic Depicting How SPICE Kernels are Made

Navigation and Ancillary Information Facility (NAIF)

How Kernels are Made and Used at JPL



Who usually makes the kernels at JPL?

1 NAV and NAIF

2 NAIF

3 NAIF or other

This represents current practice for most JPL missions, but is by no means a requirement. Anyone can make SPICE files.

***SBP** = SPICE-based program that uses modules from the SPICE Toolkit. In some cases the Toolkit contains such a program already built. In some cases NAIF may have such a ready-built program that is not in the SPICE Toolkit.