NAIF Performance Review

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Topics

- **Introductory material**
  - Scope
  - Background: What are NAIF and SPICE
- **Performance**
  - Emphasis on FY14 – 15
- **Vision and Plans**
  - Emphasis on FY16 – 21
- **Assessment of allocated funding for six years (FY16 – FY21)**
  - In guide
  - 110% of guideline
  - 85% of guideline

Scope

- **This proposal covers two activities:**
  - **SPICE* system development**
  - **NAIF Node of the Planetary Data System**

*** Spacecraft, Planet, Instrument, Camera-matrix, Events**

Background:

What is SPICE?

SPICE deals with Ancillary Data*

Navigation and Ancillary Information Facility

Reference frames

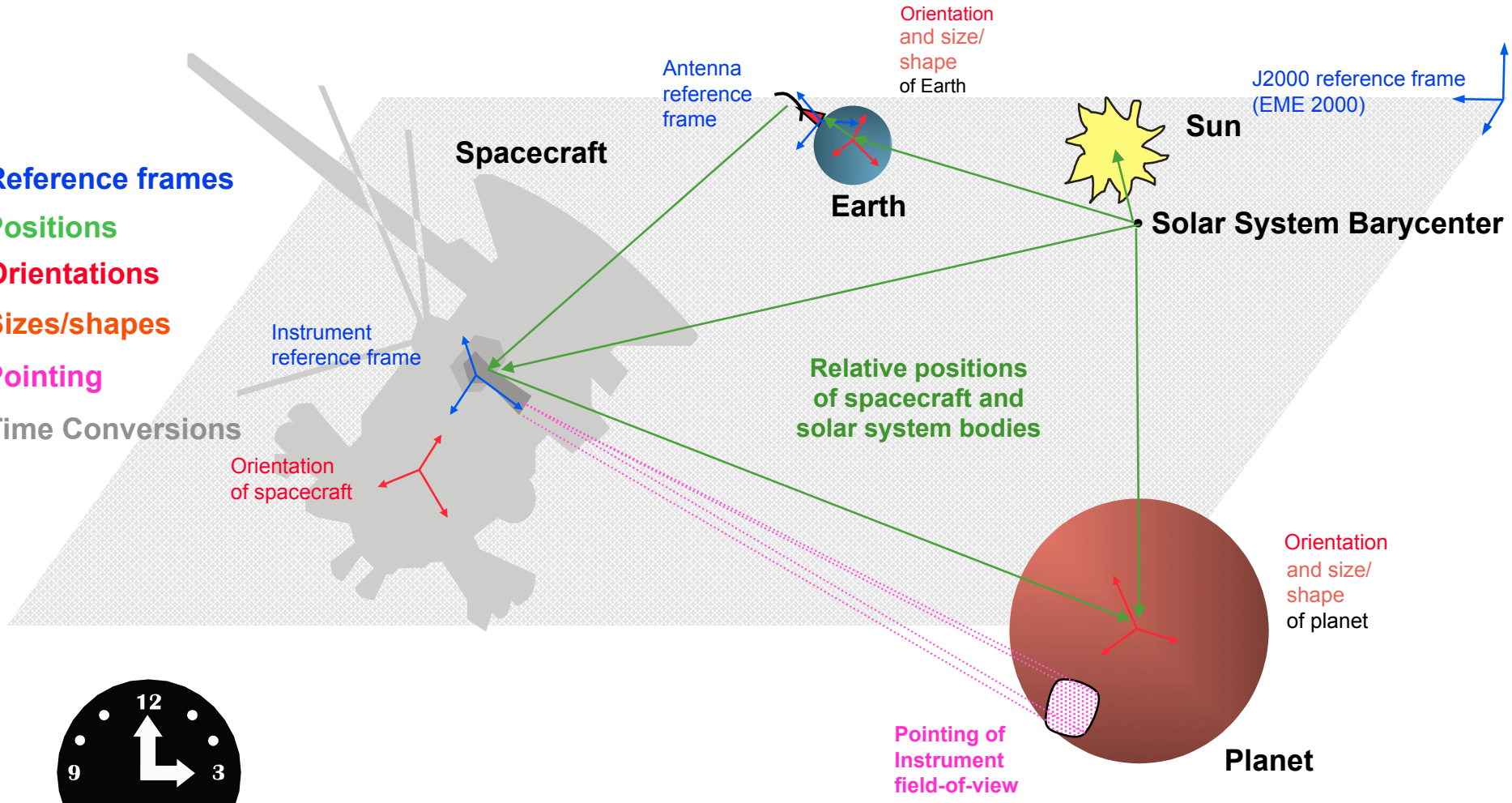
Positions

Orientations

Sizes/shapes

Pointing

Time Conversions



Time Conversion Calculations

*Also known as observation geometry data

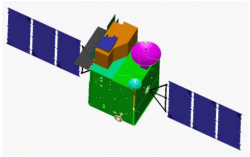
The Purpose of Ancillary Data

- **"Ancillary data" are those that help scientists and engineers determine:**
  - **where the spacecraft was located**
  - **how the spacecraft and its instruments were oriented (pointed)**
  - **what was the location, size, shape and orientation of the target being observed**
  - **what events were occurring on the spacecraft or ground that might affect interpretation of science observations**
- **In the above we've used past tense, but doing the same functions for future times to support mission planning is equally applicable**

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

Why Use SPICE?

- **Knowing observation geometry is important in:**
  - **space mission design,**
  - **mission operations engineering,**
  - **selection of observation opportunities,**
  - **preparation of science data archives, and**
  - **analysis of the science data returned from the instruments.**

- **Having proven, extensive and reusable means for producing and using ancillary data reduces cost and risk, and can help scientists and engineers achieve more substantive, accurate and timely results.**

SPICE System Components

Navigation and Ancillary Information Facility

Ancillary data files (“kernels”)……

Software (SPICE Toolkit) ……..

Documentation ……..

Tutorials …….

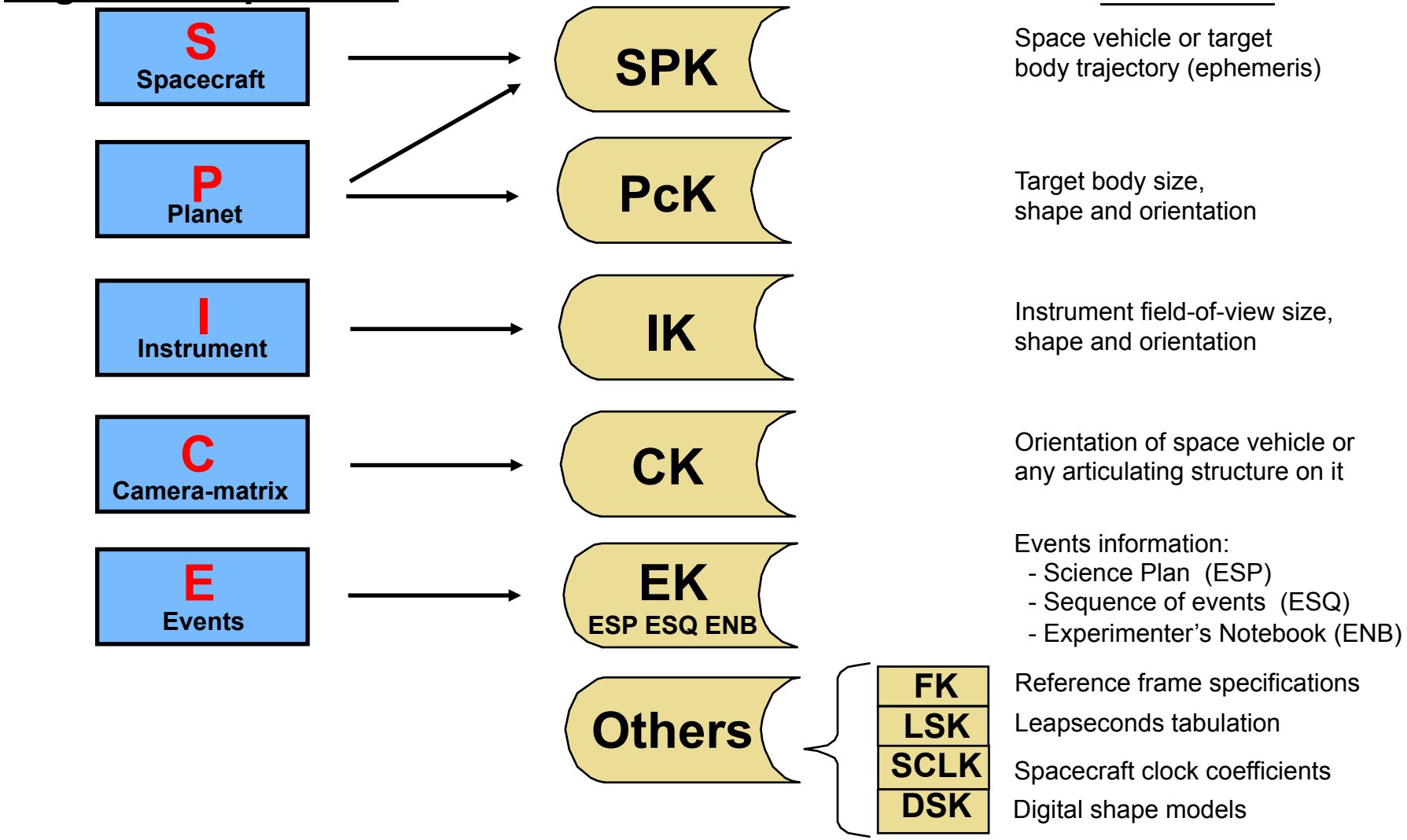
Programming lessons …..

Training classes ……

User consultation ……..

SPICE Data ("Kernels")

Navigation and Ancillary Information Facility



SPICE Software ("Toolkit")

Navigation and Ancillary Information Facility

Contents

- **Library of subroutines (~1000)**
  - Just a few are 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

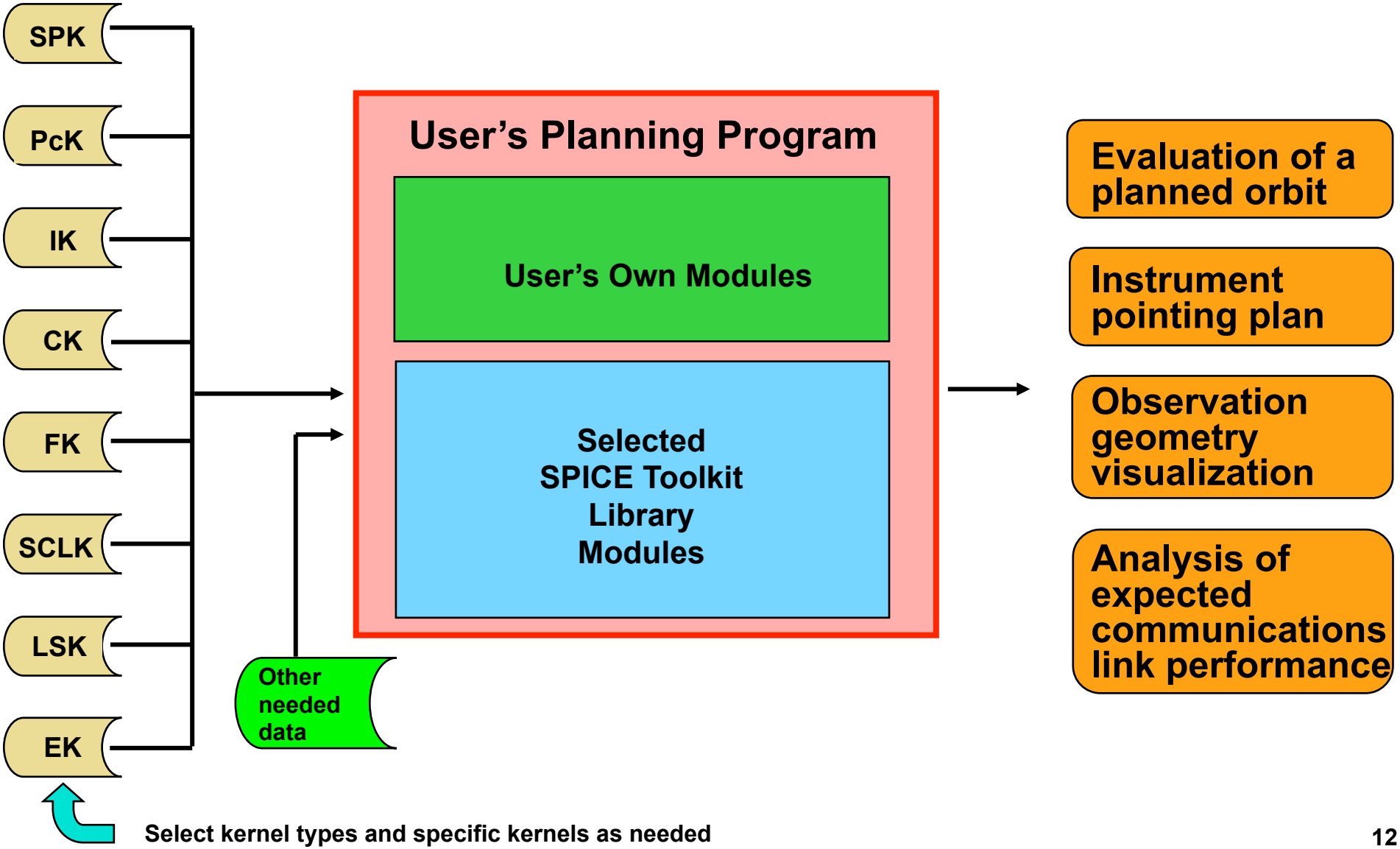
Versions

- **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

47 different combinations are supported, with still more on the way!

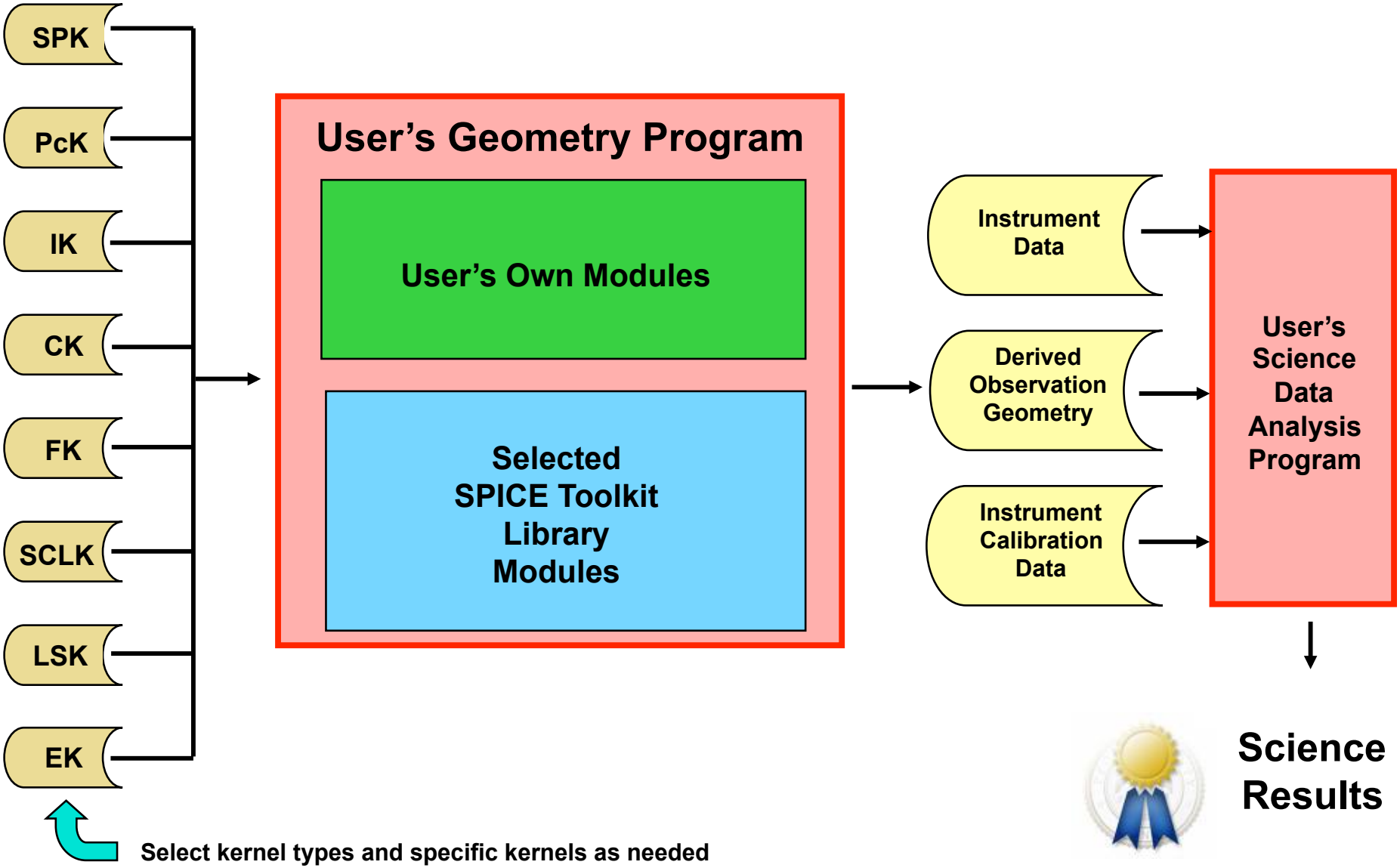
Using SPICE:
A Mission Planning Example

Navigation and Ancillary Information Facility



Using SPICE:
A Science Data Analysis Example

Navigation and Ancillary Information Facility



Using SPICE:
A Science Data Peer Review Example

Navigation and Ancillary Information Facility

SPK

PcK

IK

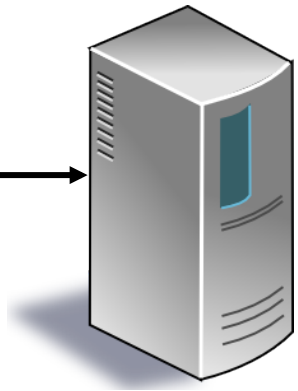
CK

FK

SCLK

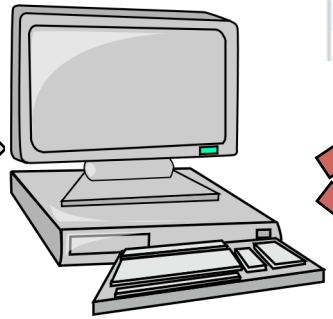
LSK

WebGeocalc Server



Internet

User's Computer
with Web Browser



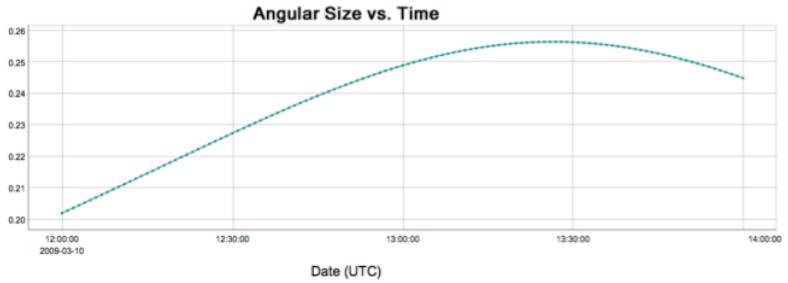
Numeric Results

Graphic Results

Tabular Results

Click a value to save it for a subsequent calculation.

	UTC calendar date	Angular Size (deg)
1	2009-03-10 12:00:00.000000 UTC	0.20212256
2	2009-03-10 12:01:00.000000 UTC	0.20294481
3	2009-03-10 12:02:00.000000 UTC	0.20377024
4	2009-03-10 12:03:00.000000 UTC	0.20459871
5	2009-03-10 12:04:00.000000 UTC	0.20543007
6	2009-03-10 12:05:00.000000 UTC	0.20626418
7	2009-03-10 12:06:00.000000 UTC	0.20710088
8	2009-03-10 12:07:00.000000 UTC	0.20794000
9	2009-03-10 12:08:00.000000 UTC	0.20878138
10	2009-03-10 12:09:00.000000 UTC	0.20962484
11	2009-03-10 12:10:00.000000 UTC	0.21047019
12	2009-03-10 12:11:00.000000 UTC	0.21131725
13	2009-03-10 12:12:00.000000 UTC	0.21216581



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

SPICE System Characteristics - 1

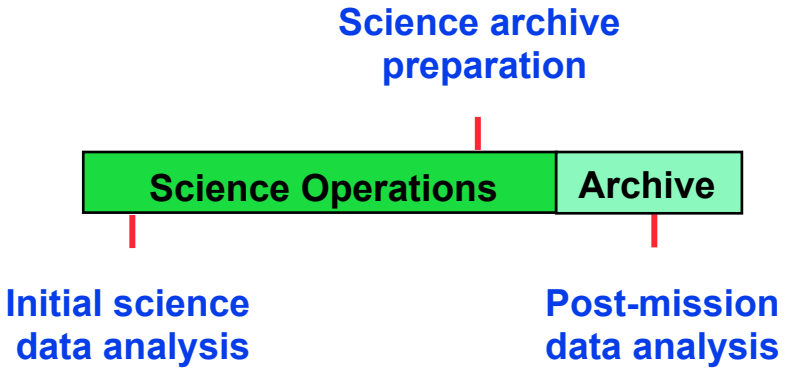
- SPICE Toolkit software is portable
- Code is well tested before being released
- New Toolkits are always 100% backwards compatible
- Well described source code is provided
  - Includes working examples
- Extensive user-oriented documentation is provided
- Software includes built-in exception handling
  - Catches and describes 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 export restrictions
  - Everyone is free to use SPICE

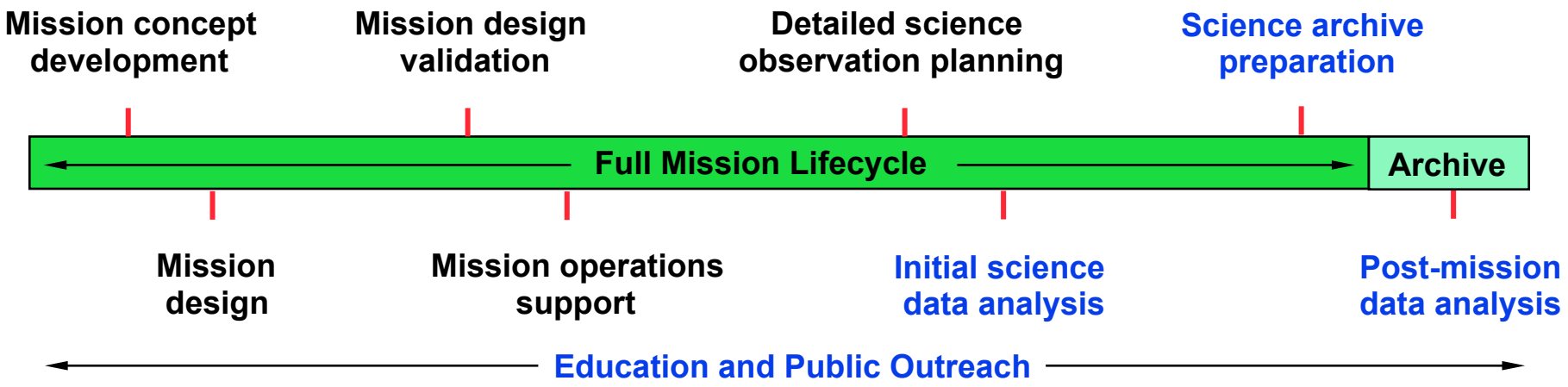
Original Purpose of SPICE

- **The original focus of SPICE was on ancillary data and associated software needed by scientists for:**
  - **initial science data analysis**
  - **science archive preparation**
  - **post-mission data analysis**



Today's Use of SPICE

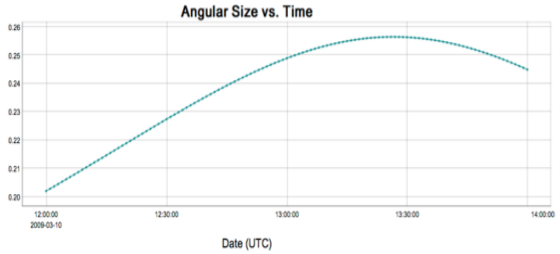
- The scope of SPICE usage has grown to cover the full mission lifecycle as well as archive uses.
- Also education and public outreach.



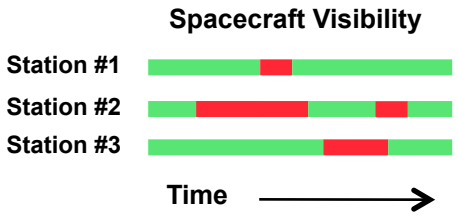
Examples of Using SPICE

Navigation and Ancillary Information Facility

Evaluation of a planned trajectory

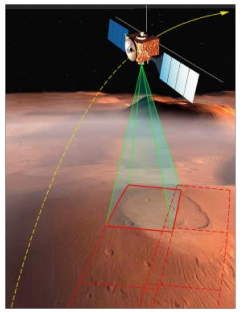


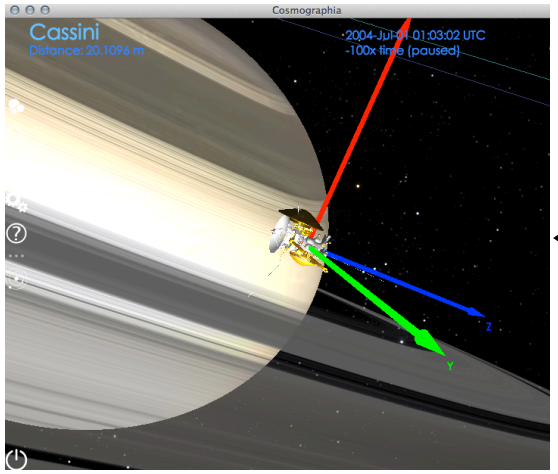
Angular size of Phobos as seen from the Mars rover "SPIRIT"



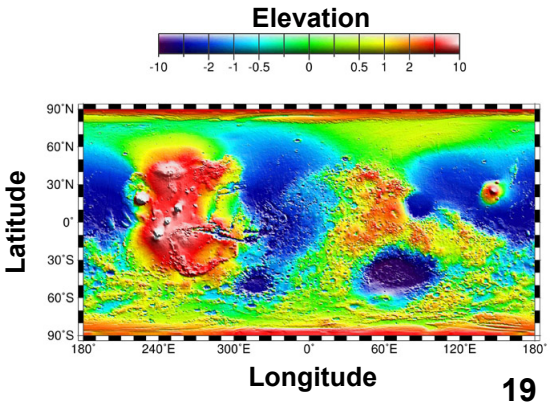
Mission engineering analyses

Planning an instrument pointing profile





Observation geometry visualization



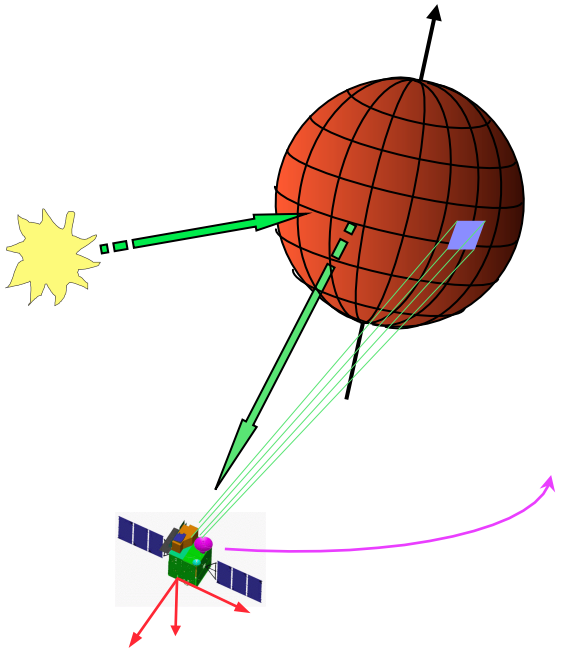
Science data archiving and analysis

What Can One Do With SPICE?

Navigation and Ancillary Information Facility

Compute many kinds of observation geometry parameters at selected times

A Few Examples



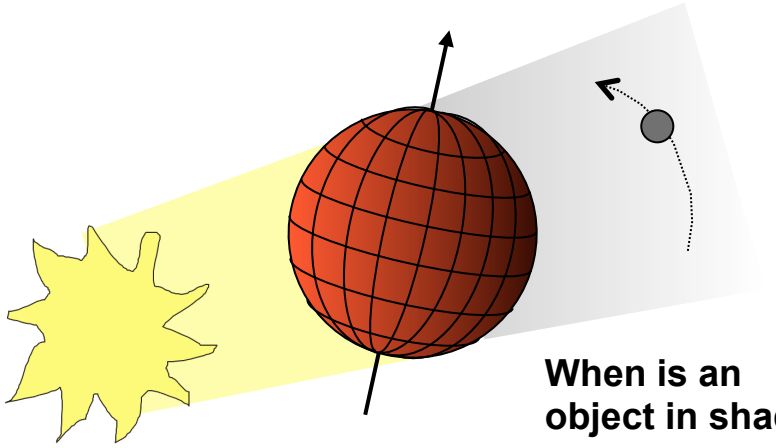
- Positions and velocities of planets, satellites, comets, asteroids and spacecraft
- Size, shape and orientation of planets, satellites, comets and asteroids
- Orientation of a spacecraft and its various moving structures
- Instrument field-of-view location on a planet's surface or atmosphere

What Can One Do With SPICE?

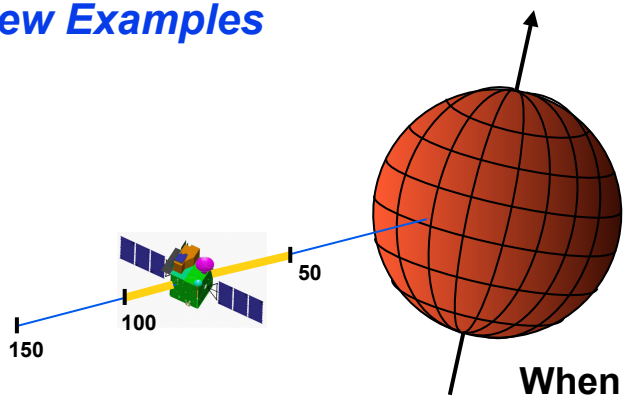
Navigation and Ancillary Information Facility

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

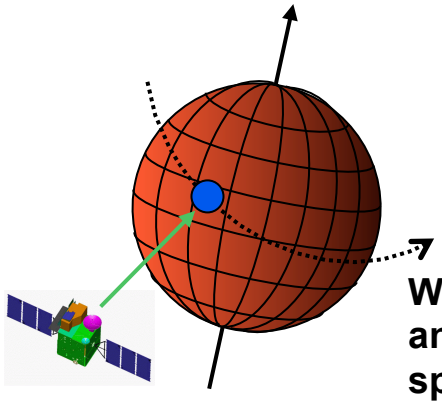
A Few Examples



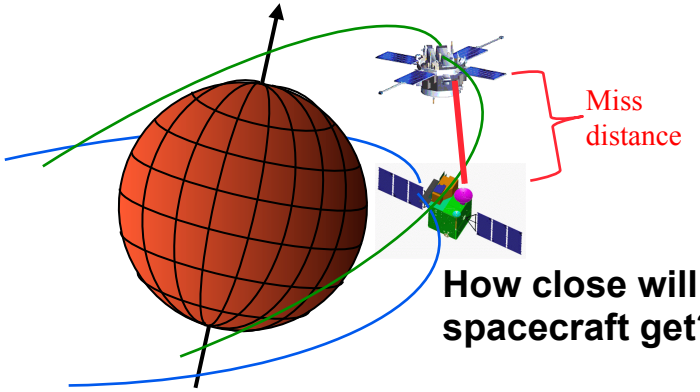
When is an object in shadow?



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?

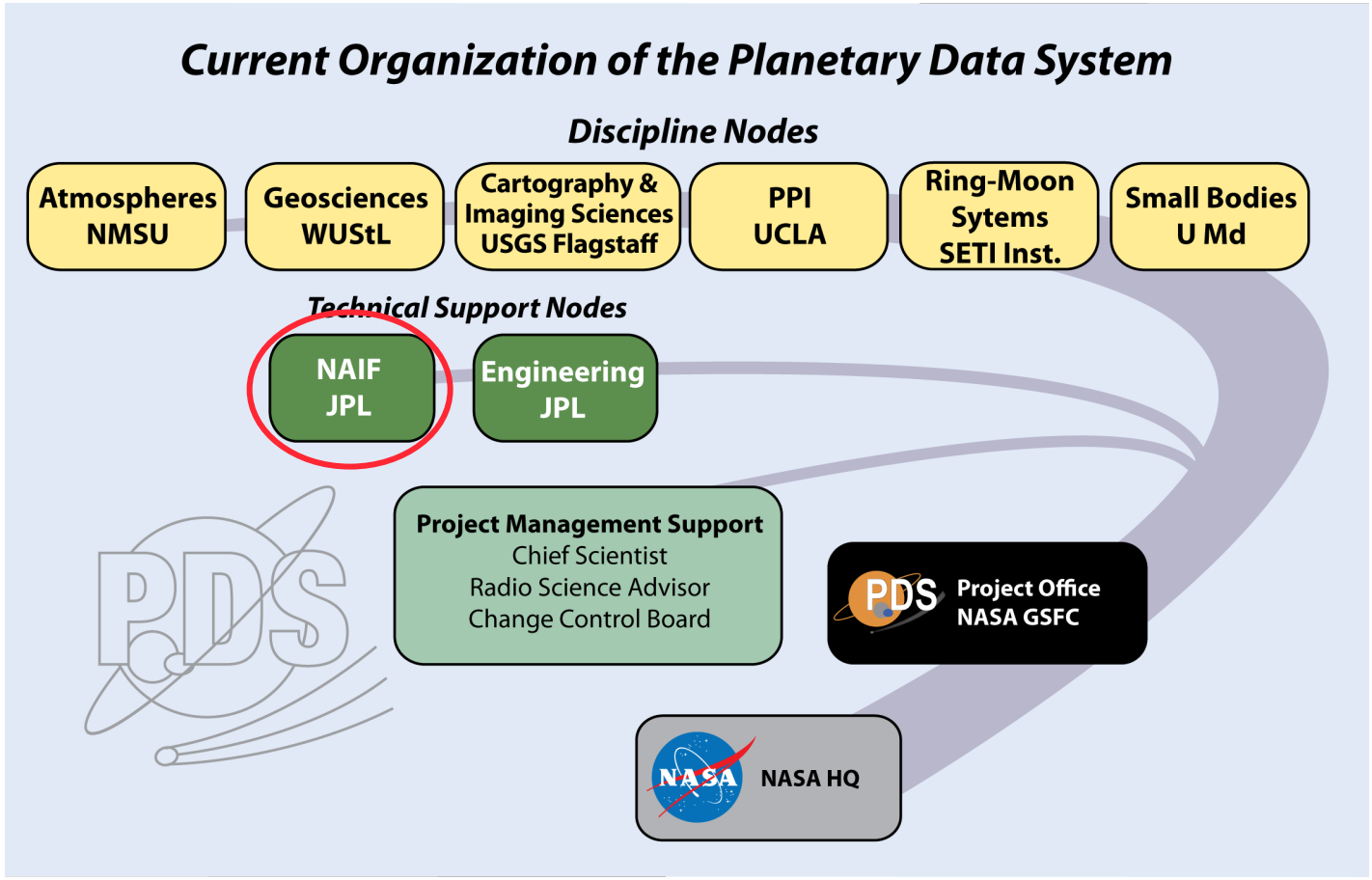
Background:

What is NAIF?

NAIF Node

Navigation and Ancillary Information Facility

- **NAIF is the "navigation node" of the PDS.**



NAIF Node Objectives

Navigation and Ancillary Information Facility

- **Archive SPICE data according to PDS standards.**
  - **Peer review archival SPICE data sets**
  - **Ingest those data sets into the NAIF archive**
    - » **In so doing, provide meta-kernels that organize SPICE kernels into convenient chunks**
  - **Provide multiple backups for safety purposes**
- **Provide easy access to archived SPICE data.**
- **Provide expert consultation to users of those data, including PDS discipline nodes, science archive producers and archive users.**

Performance:

Who Uses SPICE?

Broad Acceptance

- **SPICE has become the *de facto* worldwide planetary ancillary data system.**
  - **We know of nothing like it anywhere else.**

Examples of Flight Projects Using SPICE

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	ARM (HEOMD)
Viking Orbiters [L]	NEAR	DAWN	*Examples of External Users*
Viking Landers [L]	Deep Space 1	Mars Science Lab	Emmirates Mars Mission (UAE via LASP)
Pioneer 10/11/12 [L]	Galileo	Juno	Bevo-2 CubeSat (U.T. Austin, Texas A&M)
Haley armada [L]	Genesis	MAVEN	Space Launch Systems (HEOMD)
Phobos 2 [L] (RSA)	Deep Impact	SMAP (Earth Science)	Proba-3 (ESA)
Ulysses [L]	Huygens Probe (ESA) [L]	OSIRIS REx	Solar Probe Plus
Voyagers [L]	Stardust/NExT	InSight	EUMETSAT GEO satellites [L]
Lunar Orbiter [L]	Mars Global Surveyor	Mars 2020	MOM (ISRO)
Helios 1,2 [L]	Phoenix	Europa Clipper	BepiColombo (ESA, JAXA)
	EPOXI	NISAR (NASA/ISRO; Earth Science)	JUICE (ESA)
	GRAIL	Lunar Reconnaissance Orbiter	Solar Orbiter (ESA)
	Messenger	New Horizons	Chang'e 3 ? (CNSA)
	Phobos Sample Return (RSA) [F]	Mars Express (ESA)	Van Allen Probes [L]
	Venus Express (ESA)	Rosetta (ESA)	STEREO [L]
	Chandrayaan-1 (ISRO)	ExoMars 2016 (ESA, RSA)	Spitzer Space Telescope [L]
	Hayabusa (JAXA)	Akatsuki (JAXA)	Kepler [L]
[L] = limited use	Kaguya (JAXA)	Hayabusa-2 (JAXA)	Hubble Space Telescope [S][L]
[S] = special services	LADEE		Radioastron (RSA) [L]
[F] = mission failed	ISO [S] (ESA)		IBEX [L]
	CONTOUR [F]	Planetary Data System	James Webb Space Telescope [S][L]
	Space VLBI [L] (multinational)	Planetary Science Archive (ESA)	JPL's Solar System Dynamics Group [S][L]
Last updated: 12/3/15	Smart-1 (ESA)	NASA Deep Space Network [S]	International Astronomical Union [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.

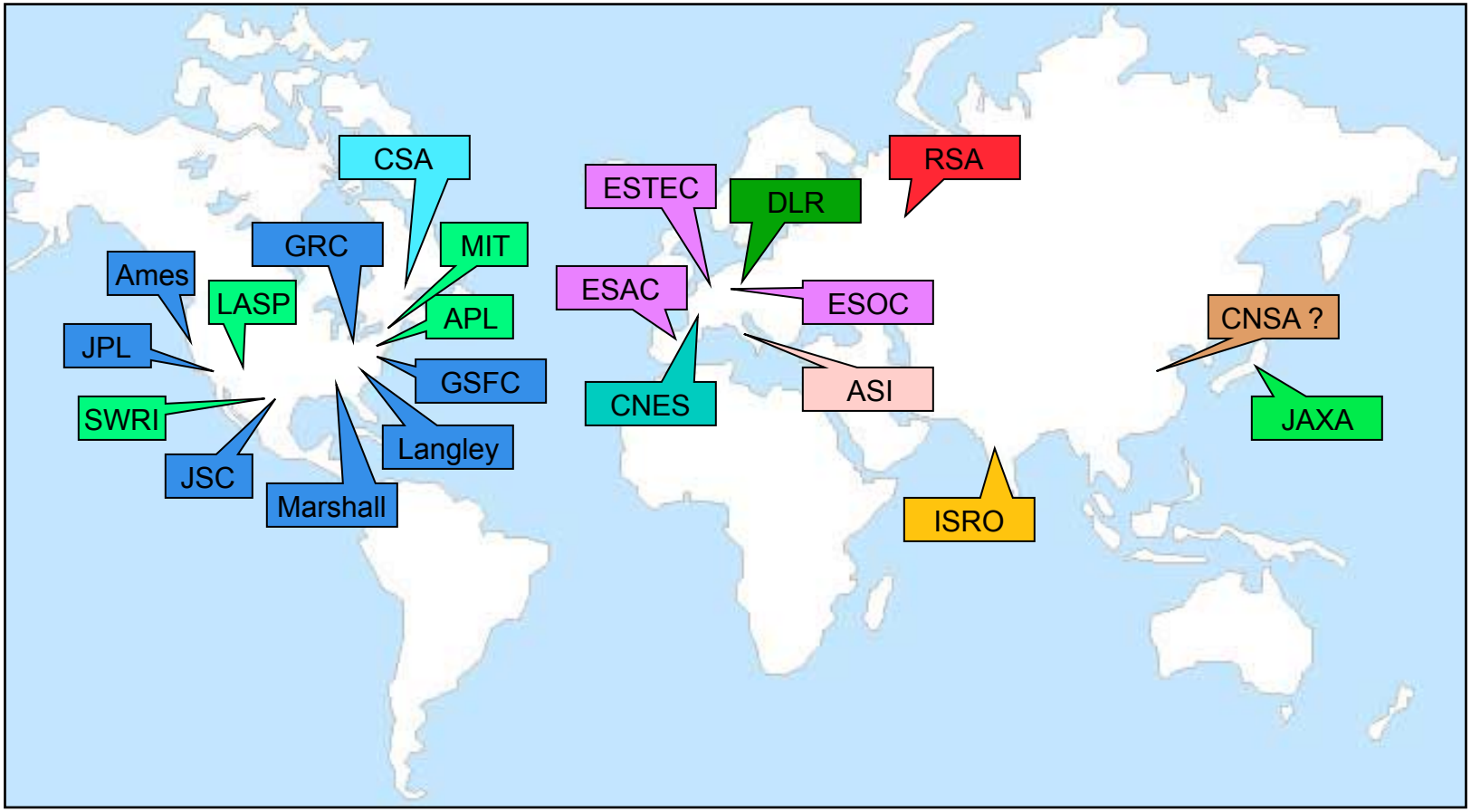
NAIF has token funding to consult with kernel producers at APL. APL provides support to science teams.

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.

Examples of “Agencies” Using SPICE

Navigation and Ancillary Information Facility



- NASA Field Centers
- U.S. Institutions
- Canadian Space Agency
- European Space Agency
- French Space Agency
- German Space Agency
- Italian Space Agency
- Indian Space Research Organization
- Japan Aerospace Exploration Agency
- Russian Federal Space Agency
- China National Space Agency

Examples of Tools Using SPICE

Navigation and Ancillary Information Facility

Tool Name	Developer
Spacecraft Trajectory Design	
Copernicus	NASA/JSC
General Mission Analysis Tool	NASA/GSFC
Optimal Trajectories by Implicit Simulation	NASA/GRC
Mission Analysis and Simulation Tool in Fortran	NASA/GRC
Spacecraft N-Body Analysis Program	NASA/GRC
Fast Spiral Trajectory Optimization Program	NASA/GRC
Hybrid Trajectory Optimization Program	Aerospace Corp.
Indirect Trajectory Optimization Program	Aerospace Corp.
Trajectory Optimization Program	Aerospace Corp.
Natural Body Ephemeris Access	
CALCEPH	CNRS/IMCCE
Ephemerides of Planets and Moon	Institute of Applied Astronomy (IAA)
Spacecraft Operations	
Activity Plan Generator	NASA/JPL
Automated Scheduling and Planning Environment	NASA/AMMOS
Science interface for robots	NASA/JPL
Sequence and Command Generation	NASA/AMMOS
Multi-mission Payload Programming System	Indian Space Research Organization
Saturn Particle Impact Risk Estimator	NASA/JPL
Mars Science Laboratory Interface	NASA/JPL and NASA/Ames
Spacecraft Attitude Visualization	NASA/JPL
Spacecraft Attitude Simulation	NASA/JPL
Multi-mission Power Analysis Tool	NASA/JPL
Telecom Forecaster & Predictor	NASA/JPL
Telecom Orbital Analysis and Simulation Tool	NASA/JPL
Orbital Trajectory Inference Engine	NASA/JPL
DSN Service Preparation Subsystem	NASA/JPL
DSN Delta-DOR Service	NASA/JPL
Global Ionospheric Model Calibration Software	NASA/JPL
DARTS Shell	NASA/JPL
Science Observation Planning	
C-kernel Viewer	DLR/IPE
Mars Express HRSC Science Opportunity Analyzer	DLR/IPE
Java Mission Planning and Analysis for Remote Sensing	Mars Space Flight Facility, Arizona State University
SciBox	Applied Physics Lab
Science Opportunity Analyzer	NASA/JPL
Dave's Event Program	NASA/JPL
Solar System Science Operations Laboratory	ESA/ESAC
Rosetta Science Planning and Scheduling Subystem	ESA/ESAC
Committee on Earth Observation Satellites Visualization Environment	SEO/NASA/LaRC

Tool Name	Developer
Science Data Analysis	
Analysts' Notebook	NASA/PDS/Geosciences Node (Wash. U.)
Orbital Data Explorer	NASA/PDS/Geosciences Node (Washington U.)
Integrated Software for Imagers and Spectrometers	USGS/Astrogeology Science Center
Unified Planetary Coordinate	USGS/Astrogeology Science Center
Planetary Image Locator Tool	USGS/Astrogeology Science Center
Map Projection on the Web	USGS/Astrogeology Science Center
3D View	Centre de Données de Physique des Plasmas (CDPP)
Automated Multi-Dataset Analysis	Centre de Données de Physique des Plasmas (CDPP)
Planet Viewers	NASA/PDS/Rings Node (SETI Institute)
Moon Trackers	NASA/PDS/Rings Node (SETI Institute)
Ephemeris Generators	NASA/PDS/Rings Node (SETI Institute)
WWW Information Processing Environment	Applied Coherent Technology Corp.
Small Bodies Image Browser	NASA/PDS/Small Bodies Node
STEER Coefficient Maker	Stanford U.
Radio Science Geometry Calculation	Stanford U.
Radio Science Simulator	UniBw Munich
Frequency Predictor	UniBw Munich
Radio Science Data Analysis	RIU-PF, Cologne University
Misc. for daily routine use	RIU-PF, Cologne University
Geometry Visualization	
Celestia	Open Source
Cosmographia	Open Source
Eyes on the Solar System	NASA/JPL
Rosetta Visualization Subsystem	ESA/ESAC
Solar System Visualization Project	NASA/JPL
Solar System Simulator	NASA/JPL
Dave's Interactive Geometry & Information Tool	NASA/JPL
Field of View Visualizer	JAXA
Luna-Glob Orbit Visualization	Russian Academy of Sciences/Space Research Institute
Fast 3D Scenario Maker	Dauria Aerospace
Multi- or Special Function	
Ephemeris generator for natural bodies	NASA/JPL
WebGeocalc	NASA/JPL (NAIF) and NASA/AMES
Satellite Orbit Analysis Program	Aerospace Corp.
Satellite Tool Kit	Analytical Graphics Inc.
Spacecraft Control Toolbox	Princeton Satellite Systems, Inc.
Spacecraft Package for DSim	Princeton Satellite Systems, Inc.
Free Flyer	A. I. Solutions
Geometry Library for PSA Archives	ESA/ESAC
Lunar Mapping and Modeling Portal	NASA, U.S. Army, U.S.G.S.
Flight Algorithm Simulation for Human Exploration	NASA/JSC, NASA/GRC

Individuals Using SPICE

- **NAIF's ftp and http metrics show many downloads of SPICE kernels (data files) and SPICE software Toolkits every day.**
  - **See next two pages for some details**
- **Logs for NAIF's on-line geometry calculator, WebGeocalc, show users throughout the U.S. and around the world.**
  - **See next third page for details.**
- **Logs from JPL's "Horizons" ephemeris generator for comets and asteroids show production of SPICE SPK (ephemeris files) files.**
  - **See next third page for details.**

One Year's HTTP and FTP Logs

HTTP Summary by Month

Month	Daily Avg				Monthly Totals					
	Hits	Files	Pages	Visits	Sites	KBytes	Visits	Pages	Files	Hits
Jan 2016	29640	21889	5404	701	4286	4911924329	9114	70253	284558	385330
Dec 2015	39771	31165	22379	796	8734	11846290595	24705	693757	966144	1232912
Nov 2015	24335	12052	3926	691	9561	8073555528	20748	117782	361567	730066
Oct 2015	126125	122172	100539	880	9266	23534617836	27288	3116715	3787352	3909879
Sep 2015	33526	30576	6604	782	8587	25082106511	23487	198120	917289	1005782
Aug 2015	51529	48030	7601	801	8168	25903983279	24841	235631	1488945	1597418
Jul 2015	29397	27084	5501	807	9138	23510580406	25034	170552	839617	911309
Jun 2015	22129	20466	3721	748	9448	15744788221	22468	111630	613987	663887
May 2015	25765	24297	3782	775	8617	32202138249	24034	117255	753207	798745
Apr 2015	30349	27036	6134	753	10082	26617274319	22606	184040	811101	910498
Mar 2015	28149	26581	5918	667	8327	29003381438	20701	183471	824020	872632
Feb 2015	19437	18247	3673	659	6508	22455434166	18475	102862	510930	544238
Totals						**248886074877**	**263501**	**5302068**	**12158717**	**13562696**

Produced by Webalyzer

FTP Summary by Month

Month	Daily Avg				Monthly Totals					
	Hits	Files	Pages	Visits	Sites	KBytes	Visits	Pages	Files	Hits
Jan 2016	2508	1794	253	77	457	342630340	1008	3296	23332	32612
Dec 2015	3485	2774	344	71	843	1184752357	2214	10692	86024	108040
Nov 2015	2718	1965	326	79	1052	802473008	2387	9792	58951	81566
Oct 2015	3763	2855	350	82	1213	1012737540	2552	10851	88533	116682
Sep 2015	3363	2647	273	86	1100	1191786882	2599	8202	79412	100890
Aug 2015	2865	1973	401	78	1012	1047016482	2420	12446	61188	88822
Jul 2015	3434	2640	285	80	1114	1073819794	2507	8856	81843	106475
Jun 2015	3123	2210	321	75	1110	977564767	2269	9655	66302	93693
May 2015	3998	3004	438	80	1128	1312703940	2490	13596	93134	123951
Apr 2015	2764	2020	183	46	597	925386845	1399	5501	60618	82927
Mar 2015	3480	2642	287	45	725	745407274	1411	8920	81912	107887
Feb 2015	3466	1863	302	52	728	554521432	1464	8477	52175	97059
Totals						**11170800661**	**24720**	**110284**	**833424**	**1140604**

Download Metrics for SPICE Archives

Navigation and Ancillary Information Facility

2014

YYYY/MM/DD	DATA_SET_ID/PDS4-BUNDLE	FILES	VOLUME_MB	HOSTS
2014	CLEM1-L-SPICE-6-V1.0	361	9079.231	40
2014	CO-S/J/E/V-SPICE-6-V1.0	23497	400921.087	298
2014	DAWN-M/A-SPICE-6-V1.0	4780	94286.599	63
2014	DI-C-SPICE-6-V1.0	422	6674.234	73
2014	DIF-C/E/X-SPICE-6-V1.0	247	7862.271	21
2014	DS1-A/C-SPICE-6-V1.0	188	7345.112	24
2014	GRAIL-L-SPICE-6-V1.0	1230	29627.554	80
2014	HAY-A-SPICE-6-V1.0	2217	3812.627	53
2014	LRO-L-SPICE-6-V1.0	10144	1682096.847	274
2014	MAVEN-PDS4-BUNDLE	0	0.000	0
2014	MER1-M-SPICE-6-V1.0	2308	17521.319	30
2014	MER2-M-SPICE-6-V1.0	1583	13228.303	24
2014	MESS-E/V/H-SPICE-6-V1.0	3600	259023.250	161
2014	MEX-E/M-SPICE-6-V1.0	1800	9655.514	198
2014	MGS-M-SPICE-6-V1.0	5036	91864.325	448
2014	MRO-M-SPICE-6-V1.0	3203	136792.484	103
2014	MSL-M-SPICE-6-V1.0	1491	3315.137	69
2014	NEAR-A-SPICE-6-V1.0	548	34263.217	38
2014	NH-J/P/SS-SPICE-6-V1.0	581	21454.976	135
2014	ODY-M-SPICE-6-V1.0	1728	53635.757	109
2014	RO/RL-E/M/A/C-SPICE-6-V1.0	0	0.000	0
2014	ROS-E/M/A/C-SPICE-6-V1.0	892	1320.520	199
2014	SDU-C-SPICE-6-V1.0	570	7391.894	23
2014	VEX-E/V-SPICE-6-V1.0	478	1802.035	46
2014	VO1/VO2-M-SPICE-6-V1.0	326	542.595	25

2015

YYYY/MM/DD	DATA_SET_ID/PDS4-BUNDLE	FILES	VOLUME_MB	HOSTS
2015	CLEM1-L-SPICE-6-V1.0	346	6171.422	51
2015	CO-S/J/E/V-SPICE-6-V1.0	52976	937473.903	250
2015	DAWN-M/A-SPICE-6-V1.0	9599	187419.113	80
2015	DI-C-SPICE-6-V1.0	505	9586.094	73
2015	DIF-C/E/X-SPICE-6-V1.0	469	14979.568	25
2015	DS1-A/C-SPICE-6-V1.0	285	10588.426	26
2015	GRAIL-L-SPICE-6-V1.0	2081	65491.229	76
2015	HAY-A-SPICE-6-V1.0	2756	5213.568	48
2015	LRO-L-SPICE-6-V1.0	18546	3233732.517	371
2015	MAVEN-PDS4-BUNDLE	2602	57340.971	36
2015	MER1-M-SPICE-6-V1.0	3671	27001.402	35
2015	MER2-M-SPICE-6-V1.0	1832	13944.917	17
2015	MESS-E/V/H-SPICE-6-V1.0	4729	348333.337	220
2015	MEX-E/M-SPICE-6-V1.0	2578	24101.511	212
2015	MGS-M-SPICE-6-V1.0	8272	190915.216	251
2015	MRO-M-SPICE-6-V1.0	12133	463367.948	148
2015	MSL-M-SPICE-6-V1.0	1682	3199.521	57
2015	NEAR-A-SPICE-6-V1.0	352	17597.742	23
2015	NH-J/P/SS-SPICE-6-V1.0	2490	75296.978	332
2015	ODY-M-SPICE-6-V1.0	4796	128211.860	150
2015	RO/RL-E/M/A/C-SPICE-6-V1.0	0	0.000	0
2015	ROS-E/M/A/C-SPICE-6-V1.0	1479	2361.341	262
2015	SDU-C-SPICE-6-V1.0	990	9782.461	20
2015	VEX-E/V-SPICE-6-V1.0	841	3370.736	53
2015	VO1/VO2-M-SPICE-6-V1.0	507	881.553	29

More Metrics

Navigation and Ancillary Information Facility

- "spice_announce" notification system
  - Over 500 users have registered
- SPICE Toolkits
  - Downloaded since the last Toolkit release = 10,043
- WebGeocalc on-line geometry calculator
  - Distinct hosts that used WGC in 2015 = 1669
- Horizons* comet/asteroid ephemeris generator
  - Average monthly download of SPK files in 2015 = 1000

* The Horizons system is operated by JPL's Solar System Dynamics Group

The Most Important Metrics of All

- NAIF has a large collection of written “thank you” emails, and receives many oral “thanks” at assorted conferences (DPS, LPSC, EPSC, etc.).
- NAIF received very strong recommendations from project managers and scientists during its application to NASA’s Software of the Year Award.
- See section 4.5 of the NAIF proposal for details.

Use of SPICE Goes Well Beyond Planetary Science

Navigation and Ancillary Information Facility

- Heliophysics, Earth science, Human exploration
- Deep Space Network:
  - Antenna scheduling and pointing, tuning of transmitters and receivers
- Telecomm analysis and frequency spectrum allocation
- Navigation teams
- Department of Defense
- A national security agency (identity unknown)
- Near Earth Object Program
- Student CubeSats
- Commercial enterprises of all sizes
- Outreach, such as:
  - Eyes on the Solar System
  - New York Times MSL Rover Tracker
  - Samford University Planetarium

Performance:

Examples of How SPICE has Advanced

Toolkit Language

Navigation and Ancillary Information Facility

WAS

- Fortran 77

IS NOW

- Fortran 77*
- C*
- IDL*
- MATLAB*
- Java Native Interface
  - Under development now

*These additions came more than two years ago.

Toolkit Interface

Navigation and Ancillary Information Facility

WAS

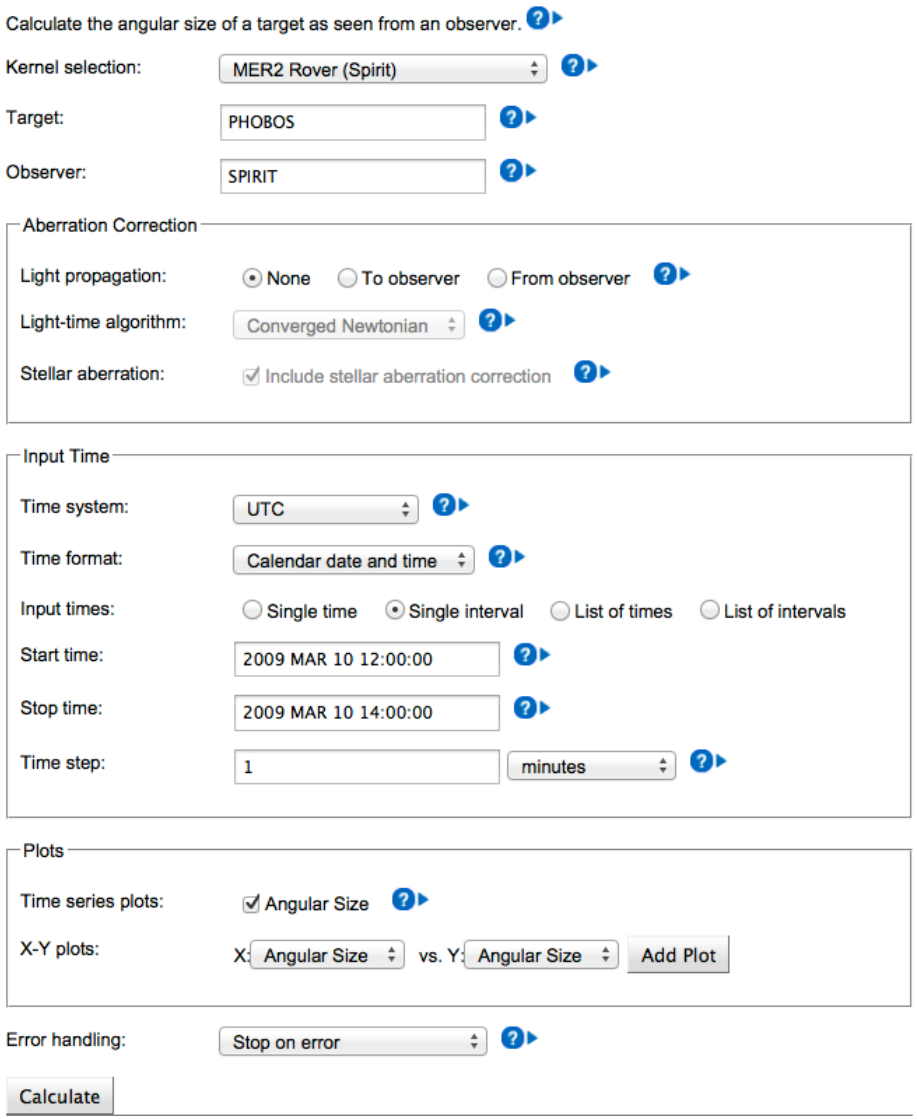
- Use SPICE data only by writing a program incorporating SPICE APIs (subroutines).

IS NOW

- Use just your browser to easily command the WebGeocalc geometry engine to make many kinds of calculations for you.
  - Fed with archived SPICE data, and more.
  - Includes optional plots.

WebGeocalc Example: The Input

Navigation and Ancillary Information Facility



- **Compute the angular size of Phobos as seen from the Mars rover "SPIRIT" over a two hour period on 2009 March 10**
- **Use typical GUI drop-down menus, fill-in boxes, radio buttons and check boxes to specify the details of the computation you wish to make**

WebGeocalc Example: Numeric Output

Navigation and Ancillary Information Facility

Input Values

Calculation type	Angular Size
Target	PHOBOS
Observer	SPIRIT
Light propagation	No correction
Time system	UTC
Time format	Calendar date and time
Time range	2009 MAR 10 12:00:00 to 2009 MAR 10 14:00:00, step 1 minutes

Summary of your input

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

Tabular Results

Click a value to save it for a subsequent calculation.

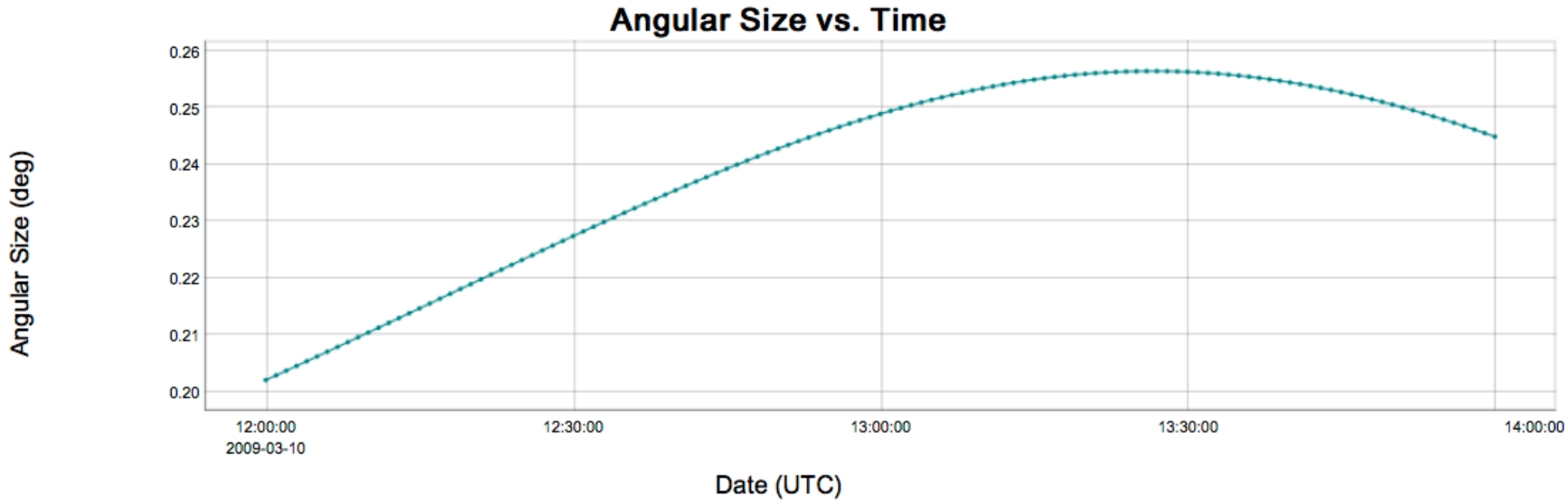
	UTC calendar date	Angular Size (deg)
1	2009-03-10 12:00:00.000000 UTC	0.20212256
2	2009-03-10 12:01:00.000000 UTC	0.20294481
3	2009-03-10 12:02:00.000000 UTC	0.20377024
4	2009-03-10 12:03:00.000000 UTC	0.20459871
5	2009-03-10 12:04:00.000000 UTC	0.20543007
6	2009-03-10 12:05:00.000000 UTC	0.20626418
7	2009-03-10 12:06:00.000000 UTC	0.20710088
8	2009-03-10 12:07:00.000000 UTC	0.20794000
9	2009-03-10 12:08:00.000000 UTC	0.20878138
10	2009-03-10 12:09:00.000000 UTC	0.20962484
11	2009-03-10 12:10:00.000000 UTC	0.21047019
12	2009-03-10 12:11:00.000000 UTC	0.21131725
13	2009-03-10 12:12:00.000000 UTC	0.21216581
14	2009-03-10 12:13:00.000000 UTC	0.21301567

Tabular results

WebGeocalc Example: Graphical Output

Navigation and Ancillary Information Facility

- **Some Geometry Calculator computations offer optional plots**



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

Toolkit Output

Navigation and Ancillary Information Facility

WAS

- Get only numeric output.

IS NOW

- Cosmographia provides user controlled 3D visual representations of mission geometry.
  - Cosmographia User's Guide Introduction

Calculations

Navigation and Ancillary Information Facility

WAS

- Compute a quantity at time *T*.

IS NOW

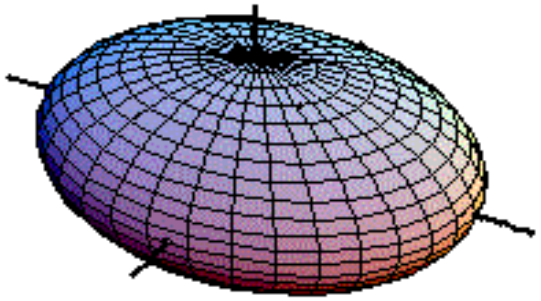
- Compute a quantity at time *T*.
- Compute time intervals when a geometric condition is “true” or when a geometric parameter is within a certain range or at a min or max.

Shape Models

Navigation and Ancillary Information Facility

WAS

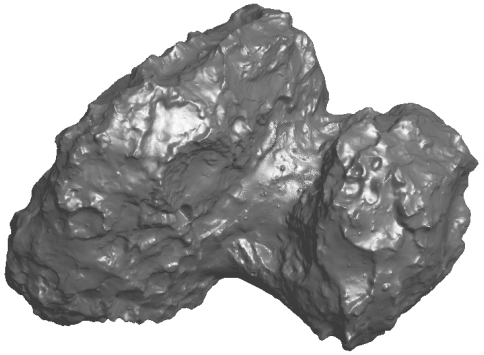
- Tri-axial ellipsoid was the only available shape



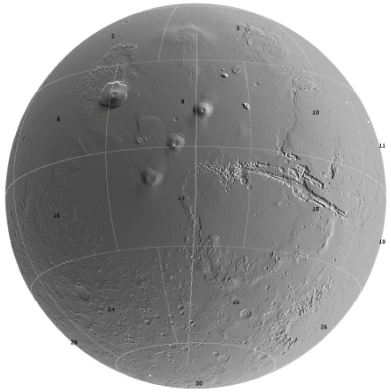
IN PROGRESS

Digital Shape Kernel (DSK)

- Tessellated plate model



- Digital elevation model



Software Speed

Navigation and Ancillary Information Facility

WAS

- Run-time performance was not a design consideration.

IS NOW

- Speed-up of 15% to 45% in many kinds of calculations involving reference frame transformations.
- Speed-up in computations involving the Digital Shape Kernel (DSK).

Data Download Efficiency

Navigation and Ancillary Information Facility

WAS

- User had to download a mission's entire SPICE archive no matter how small a chunk was wanted.

IS NOW

- Sub-setting service allows downloading of data for a user-selected time period.

Ease of Use of SPICE Archives

Navigation and Ancillary Information Facility

WAS

- User had to select each individual kernel to use.
- User must load each kernel separately.

IS NOW

- Meta-kernel* provided by NAIF "contains" all needed kernels for a given time period.
- User need load only the meta-kernel.

*The meta-kernel mechanism was added more than two years ago, but the provision of already-built meta-kernels for SPICE archives was recent.

Performance:

NAIF Node

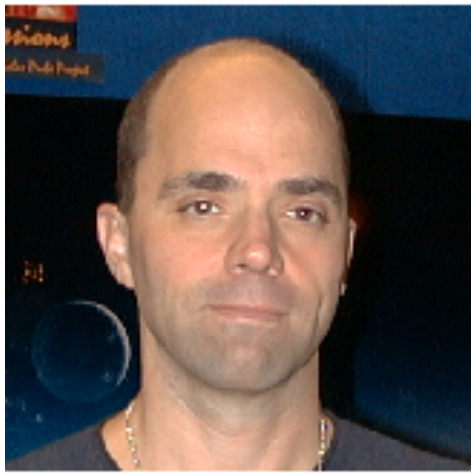
An Experienced NAIF Team

Navigation and Ancillary Information Facility

Chuck Acton
33 years on NAIF

Nat Bachman
27 years on NAIF

Boris Semenov
20 years on NAIF



Ed Wright
19 years on NAIF

Archived SPICE Data Sets

- SPICE archives from all of these missions are available from the NAIF website.
- These data are also available to the WebGeocalc on-line tool.
- Meta-kernels are provided for each data set, making the data easy to access.

Navigation and Ancillary Information Facility

Mission Name	Archive Readme	Archive Link	PDS3 or PDS4	Data Size (GB)	Start Time	Stop Time	Subset Link
Cassini Orbiter	readme	link	3	48.6	1997-10-15	2015-03-31	subset
Clementine	readme	link	3	0.8	1994-01-26	1994-05-07	subset
DAWN	readme	link	3	18.4	2007-09-27	2015-06-30	subset
Deep Impact	readme	link	3	0.7	2005-01-12	2005-08-09	subset
Deep Space 1	readme	link	3	0.9	1998-10-24	2001-12-18	subset
EPOXI	readme	link	3	1.0	2005-08-23	2011-03-01	subset
GRAIL	readme	link	3	4.3	2011-09-10	2012-12-17	subset
Hayabusa	readme	link	3	0.3	2005-09-11	2005-11-19	subset
Lunar Reconnaissance Orbiter	readme	link	3	211.8	2009-06-18	2015-06-15	subset
MAVEN	readme	link	4	4.6	2013-11-18	2015-06-15	
MER 1 (Opportunity)	readme	link	3	3.8	2003-07-07	2015-06-16	subset
MER 2 (Spirit)	readme	link	3	2.6	2003-06-10	2010-05-03	subset
MESSENGER	readme	link	3	27.8	2004-08-03	2015-04-30	subset
Mars Express	readme	link	3	2.1	2003-06-02	2013-04-30	subset
Mars Global Surveyor	readme	link	3	15.4	1996-11-06	2006-11-02	subset
Mars Odyssey	readme	link	3	20.6	2001-04-07	2015-06-30	subset
Mars Reconnaissance Orbiter	readme	link	3	174.6	2005-08-12	2015-10-01	subset
Mars Science Laboratory	readme	link	3	0.3	2011-11-26	2015-08-02	subset
NEAR	readme	link	3	2.4	1996-05-30	2001-02-28	subset
New Horizons	readme	link	3	1.2	2006-01-19	2014-08-29	subset
Rosetta	readme	link	3	1.8	2004-03-02	2015-09-09	subset
Stardust	readme	link	3	1.9	1999-02-07	2011-05-01	subset
Venus Express	readme	link	3	0.6	2005-11-09	2012-11-30	subset
Viking Orbiter	readme	link	3	0.1	1976-06-16	1980-07-30	subset

More Work to be Done

Challenges for NAIF

"SPICE has a Steep Learning Curve"

- **Dealing with space mission geometry, especially for planetary missions, is inherently complex.**
- **NAIF chooses not to dumb it down to make computations easy but possibly inaccurate or wrong.**
- **What NAIF needs to do:**
  - **Provide extensive tutorials, programming lessons, technical reference documents, highly documented APIs (subroutines).**
  - **Provide training classes.**
  - **Augment the WebGeocalc tool to better help a person validate her/his own pipeline code with some example computations.**
  - **Provide individual consultation, even though this substantially eats into time spent on other tasks.**

“Kernel Selection is Difficult”

- The addition of the “meta-kernel” capability was very helpful.
- But it is still not easy to quickly determine attributes of individual kernels residing on the NAIF server, or to compare similar kernels.
- What NAIF needs to do:
  - Provide web service mechanisms to:
    - » display key attributes of binary kernels.
    - » pictorially contrast similar binary kernels.

“Need More Calculations”

- **Despite the hundred’s of top-level APIs (subroutines) available in SPICE Toolkits, more functionality is needed to allow users to deal with ever more complex instruments and missions.**
- **What NAIF needs to do:**
  - **Pick up the pace on implementing many of the hundreds of items shown on our two work lists (Proposal Section 5.1.5)**

“Need more Models”

- **Examples:**
  - **The PDS Ring-Moon Systems node has asked NAIF to add ring models to SPICE.**
  - **The IAU and others have asked NAIF to provide time-dependency to natural body orientation models (PCKs).**
  - **Many users have asked NAIF to provide new reference frames in SPICE.**
- **What NAIF needs to do:**
  - **See if these and similar requests can be sensibly addressed.**

"SPICE Isn't Modern"

- **SPICE software has to evolve with computing technology, such as becoming thread-safe or object oriented, and it must be available in modern languages widely used in the space science community.**
  - **In years past we've added new interface languages as requested by users: C, IDL and MATLAB.**
  - **We're in the process of adding Java Native Interface.**
- **What NAIF needs to do:**
  - **Develop a Python interface as our next "flavor."**
  - **Change from Fortran 77 to a new base language, thus allowing for thread-safe and object oriented design.**
    - » **But continue support for all current languages as well.**

“Need More Training”

- **NAIF’s SPICE training classes have been very popular**
- **What NAIF needs to do:**
  - **Offer training more often and in more venues.**
  - **Offer training on advanced topics.**

More Planets to Model, Too?

Navigation and Ancillary Information Facility

Possible ~~Ninth~~ Tenth Planet

©CALTECH

Caltech researchers have found evidence of a giant planet tracing a bizarre, highly elongated orbit in the distant solar system.

Vision:

FY17 - 21

Vision Details:
SPICE Development

Navigation and Ancillary Information Facility

- Fully integrate the new shape kernel subsystem.
- Provide an official Python interface to SPICE.
- Transition the Toolkit base language from FORTRAN 77 to something that is thread safe and perhaps object oriented.
- Add fundamental new features to the SPICE system: new computations, new models, per the two “work lists.”
- Improve mechanisms for kernel selection and knowing which kernels have been used in a computation.
- Provide more, and more integrated, SPICE-based web services, including geometry visualization.
- Add important functionality to the WebGeocalc tool such as more computations and Virtual Observatory output.
- Add important capabilities to the Cosmographia tool such as multiple viewports (split window pane).

Vision Details:
NAIF Node

Navigation and Ancillary Information Facility

- Complete the migration of SPICE archive production to PDS4 standards.
- Support future PDS4 infrastructure if some geometry functions are needed, such as a “geometry engine” or mission visualization.
- Augment training opportunities and materials for SPICE users.
- Better integrate SPICE with relevant standards groups such as the IAU and CCSDS.
- Continue providing expert consultation.

Broader Vision

- **Seek the means to provide some level of SPICE support to the broad spectrum of people already or now trying to use SPICE (ref. pg. 34).**
  - **NASA heliophysics, astrophysics, earth science and human exploration.**
    - » **Science, engineering, infrastructure**
  - **NASA's partners in the U.S. and abroad**
  - **Universities involved in space exploration**
  - **Commercial firms, some of which support NASAs programs**
  - **Public outreach**

Vision Summary

Navigation and Ancillary Information Facility

- **Keep pace with the needs of new, ever more complex missions and instruments.**
- **Continue to emphasize high quality, broad usability and stability.**
- **Make SPICE capabilities as widely available as possible.**
- **Continue providing excellent user support.**

Funding Assessment

Funding Assessment – In Guide

Navigation and Ancillary Information Facility

- **Insufficient for FY16-18: need 110%**

With the In Guide funding NAIF would, at best, continue to address the high priority work listed in Sections 5.1, 5.2 and 6, with the exception of not allowing further work on the WebGeocalc and Cosmographia tools. The pace of doing this work would continue to lag well behind user's needs.

At the In Guide level there is a strong probability NAIF would not have sufficient funding to retain the current 4-person team. Thus the In Guide level is NOT considered sufficient for these early years; at least 110% is needed.

- **Highly insufficient for FY19-21: need at least 125%**

The NAIF team size would drop to three persons.

NAIF would address only the very highest priority work listed in Sections 5.1, 5.2 and 6. The pace of adding new capabilities would continue to lag behind user's needs.

NAIF would terminate assistance to users not directly identified as recipients of NASA research grants. NAIF would terminate training, eliminate substantial technical documentation review, eliminate maintenance of existing tutorials and programming lessons, not undertake development of new tutorials and programming lessons addressing new capabilities, drastically reduce user support and discontinue initiatives towards new customers and new sources of funding. NAIF management functions would be eliminated.

Support for NASA infrastructure such as the Deep Space Network, navigation teams, solar system ephemeris producers, telecommunications analysis, frequency spectrum engineering, and all aspects of the Advanced Multi-Mission Operations System (AMMOS) would be terminated.

Efforts on the peer review of SPICE archives would be reduced, leading to poorer quality science data products and resultant science data archives. All data restoration efforts would be terminated.

There would be an increase in the risk of SPICE-based failures to on-going and upcoming NASA planetary flight projects using NAIF's SPICE operations services.

Cooperation with international partners would be terminated.

NAIF's outreach efforts at scientific symposia (DPS, LPSC, etc.) and as a member of the IAU's Fundamental Standards Commission, helping to develop and publicize space geometry standards, would be terminated.

Funding Assessment – 85% Guide

Navigation and Ancillary Information Facility

- **Highly insufficient for all years.**

With a reduction to 85% of In Guide, the NAIF team size would immediately drop to three persons.

NAIF would address only the very highest priority work listed in Sections 5.1, 5.2 and 6. The pace of adding new capabilities would continue to lag behind user's needs.

NAIF would terminate assistance to users not directly identified as recipients of NASA research grants. NAIF would terminate training, eliminate substantial technical documentation review, eliminate maintenance of existing tutorials and programming lessons, not undertake development of new tutorials and programming lessons addressing new capabilities, drastically reduce user support and discontinue initiatives towards new customers and new sources of funding. NAIF management functions would be eliminated.

Support for NASA infrastructure such as the Deep Space Network, navigation teams, solar system ephemeris producers, telecommunications analysis, frequency spectrum engineering, and all aspects of the Advanced Multi-Mission Operations System (AMMOS) would be terminated.

Efforts on the peer review of SPICE archives would be reduced, leading to poorer quality science data products and resultant science data archives. All data restoration efforts would be terminated.

There would be an increase in the risk of SPICE-based failures to on-going and upcoming NASA planetary flight projects using NAIF's SPICE operations services.

Cooperation with international partners would be terminated.

NAIF's outreach efforts at scientific symposia (DPS, LPSC, etc.) and as a member of the IAU's Fundamental Standards Commission, helping to develop and publicize space geometry standards, would be terminated.

Funding Assessment – 110% Guide

Navigation and Ancillary Information Facility

- **Sufficient for FY16-18**

A 10% increase over the In Guide level would ensure the current 4-person NAIF Team would remain in tact. It should also allow a small amount of further development of the WebGeocalc and Cosmographia tools if suitable engineers could again be found. (This work could not be done by existing NAIF staff due to lack of needed skills.)

- **Insufficient for FY19-21: need at least 125%**

The NAIF team size would drop to three persons.

NAIF would address only the very highest priority work listed in Sections 5.1, 5.2 and 6. The pace of adding new capabilities would continue to lag behind user's needs.

NAIF would terminate assistance to users not directly identified as recipients of NASA research grants. NAIF would terminate training, eliminate substantial technical documentation review, eliminate maintenance of existing tutorials and programming lessons, not undertake development of new tutorials and programming lessons addressing new capabilities, drastically reduce user support and discontinue initiatives towards new customers and new sources of funding. NAIF management functions would be eliminated.

Support for NASA infrastructure such as the Deep Space Network, navigation teams, solar system ephemeris producers, telecommunications analysis, frequency spectrum engineering, and all aspects of the Advanced Multi-Mission Operations System (AMMOS) would be terminated.

Efforts on the peer review of SPICE archives would be reduced, leading to poorer quality science data products and resultant science data archives. All data restoration efforts would be terminated.

There would be an increase in the risk of SPICE-based failures to on-going and upcoming NASA planetary flight projects using NAIF's SPICE operations services.

Cooperation with international partners would be terminated.

NAIF's outreach efforts at scientific symposia (DPS, LPSC, etc.) and as a member of the IAU's Fundamental Standards Commission, helping to develop and publicize space geometry standards, would be terminated.