Introduction au logiciel

SPICE

Xavier Bonnin

Qu'est-ce que c'est?

- Logiciel développé et maintenu par le **Navigation and Ancillary Information Facility (NAIF)** situé au Jet Propulsion Laboratory (JPL) à Pasadena (Californie)
- Utilisé pour l'ensemble des projets NASA d'exploration planétaire (Missions martiennes, Cassini, Deep Impact, Messenger, Juno)
- Support à certaines missions «astrophysiques» (Hubble, Spitzer, Kepler, etc.)
- Utilisé pour de nombreuses missions européennes (Smart-1, Mars/Venus Express, Rosetta, Huygens, etc.), russes (Mars 96), japonaises (Hayabusa, SELENE), indienne (Chandrayaan-1)
- Utilisé pour le NASA DSN

A quoi ça sert?

Reference frames

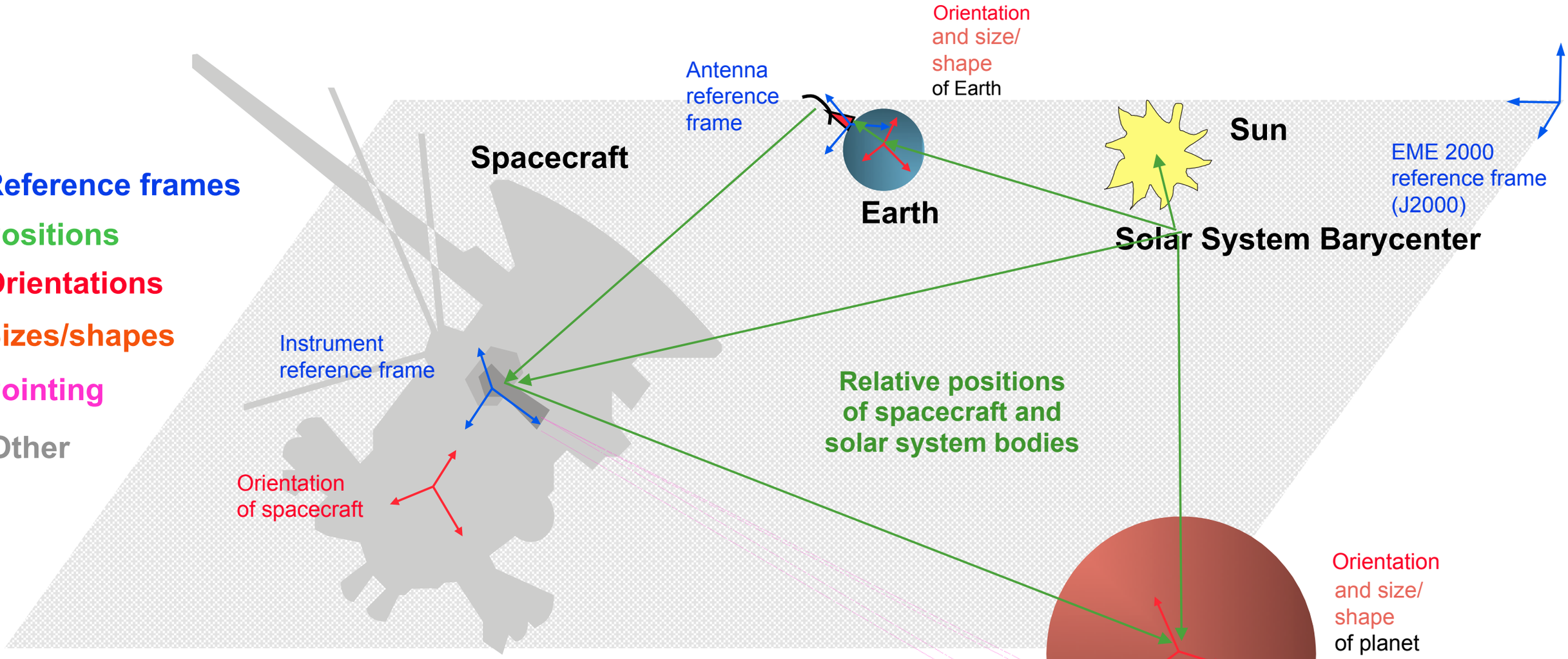
Positions

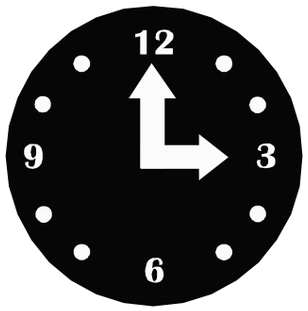
Orientations

Sizes/shapes

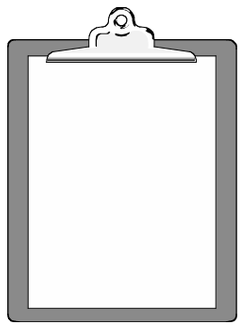
Pointing

Other





Time Conversion Calculations



Logs of Commands and Events

Overview of SPICE

Quoi est où par rapport à quoi (à quel moment et dans quel repère)?

(spice_overview, p3)

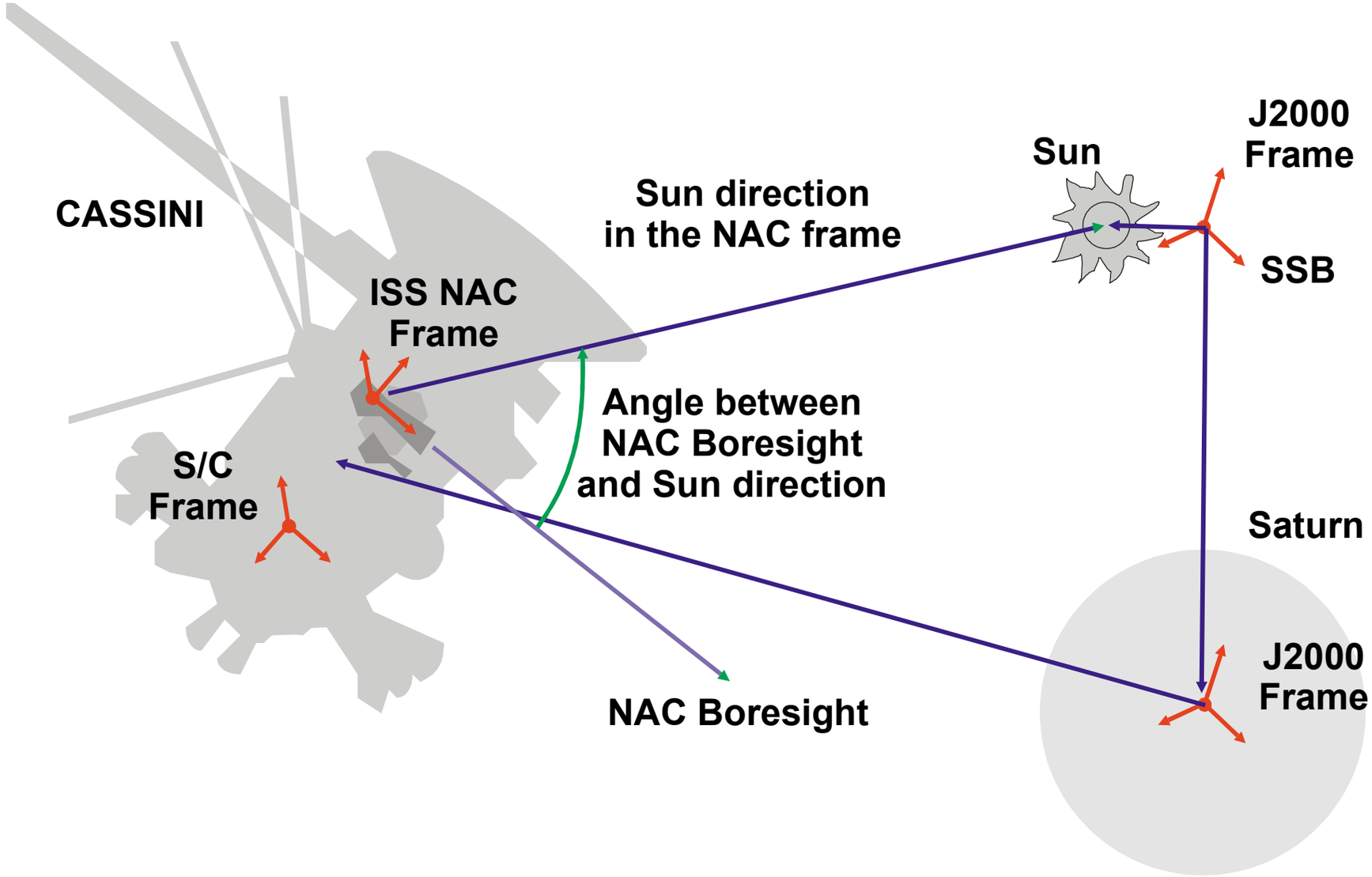
Ça veut dire quoi?

S	**S**pacecraft
P	**P**lanet
I	**I**nstrument
C	**C**-matrix
E	**E**vents

*** Coined by Dr. Hugh Kieffer, USGS Astrogeology Branch, Flagstaff AZ**

(spice_overview, p8)

Exemple I

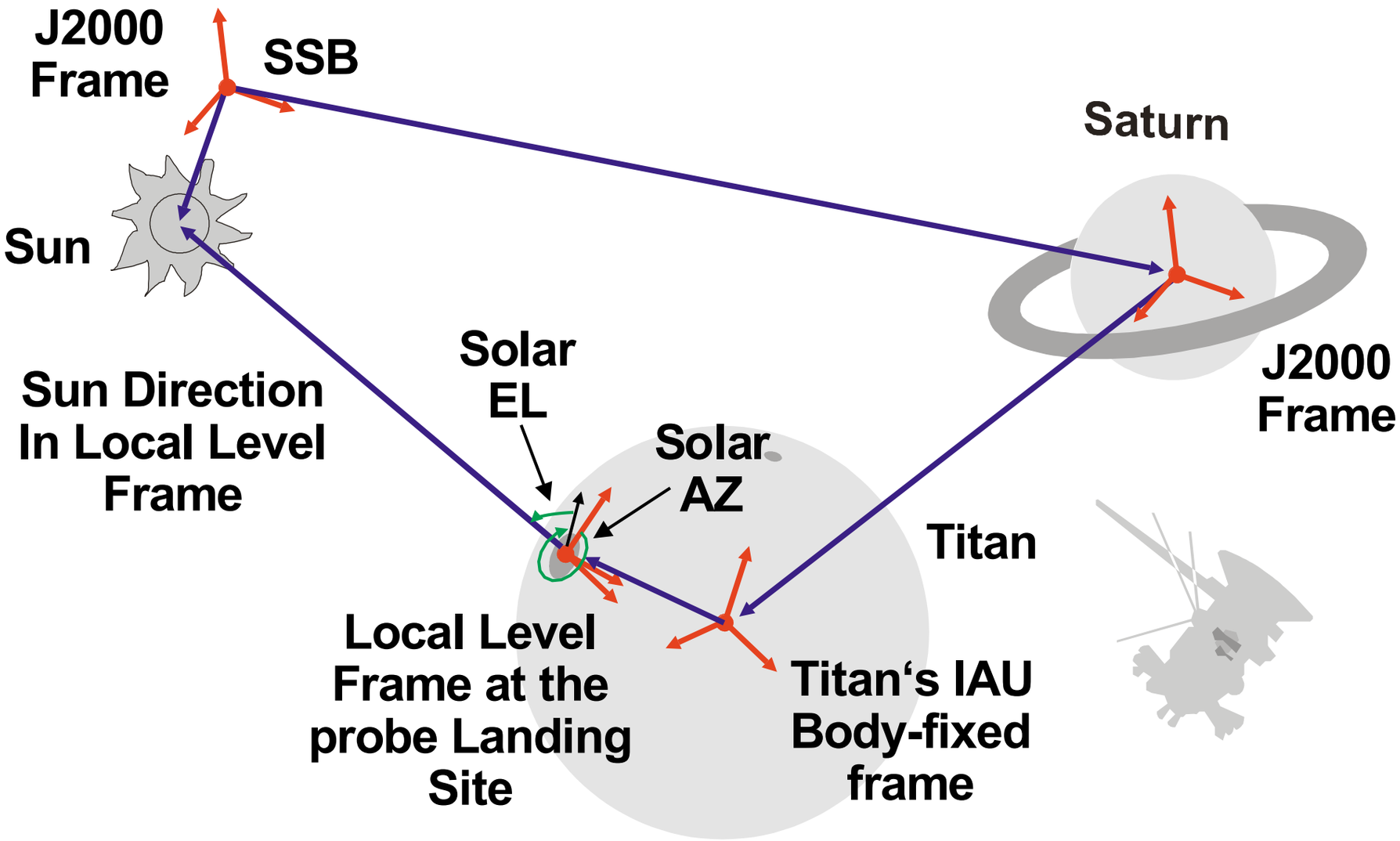


Check whether the angle between the camera boresight and the direction to the Sun is within the allowed range:

```
CALL SPKPOS( 'SUN', ET, 'CASSINI_ISS_NAC', 'LT+S', 'CASSINI', SUNVEC, LT )
ANGLE = VSEP( NAC_BORESIGHT_nac, SUNVEC )
IF ( ANGLE .LE. CONSTRAINT ) WRITE(*,*) 'WE ARE IN TROUBLE!'
```


(using_frames, p4)

Exemple 2

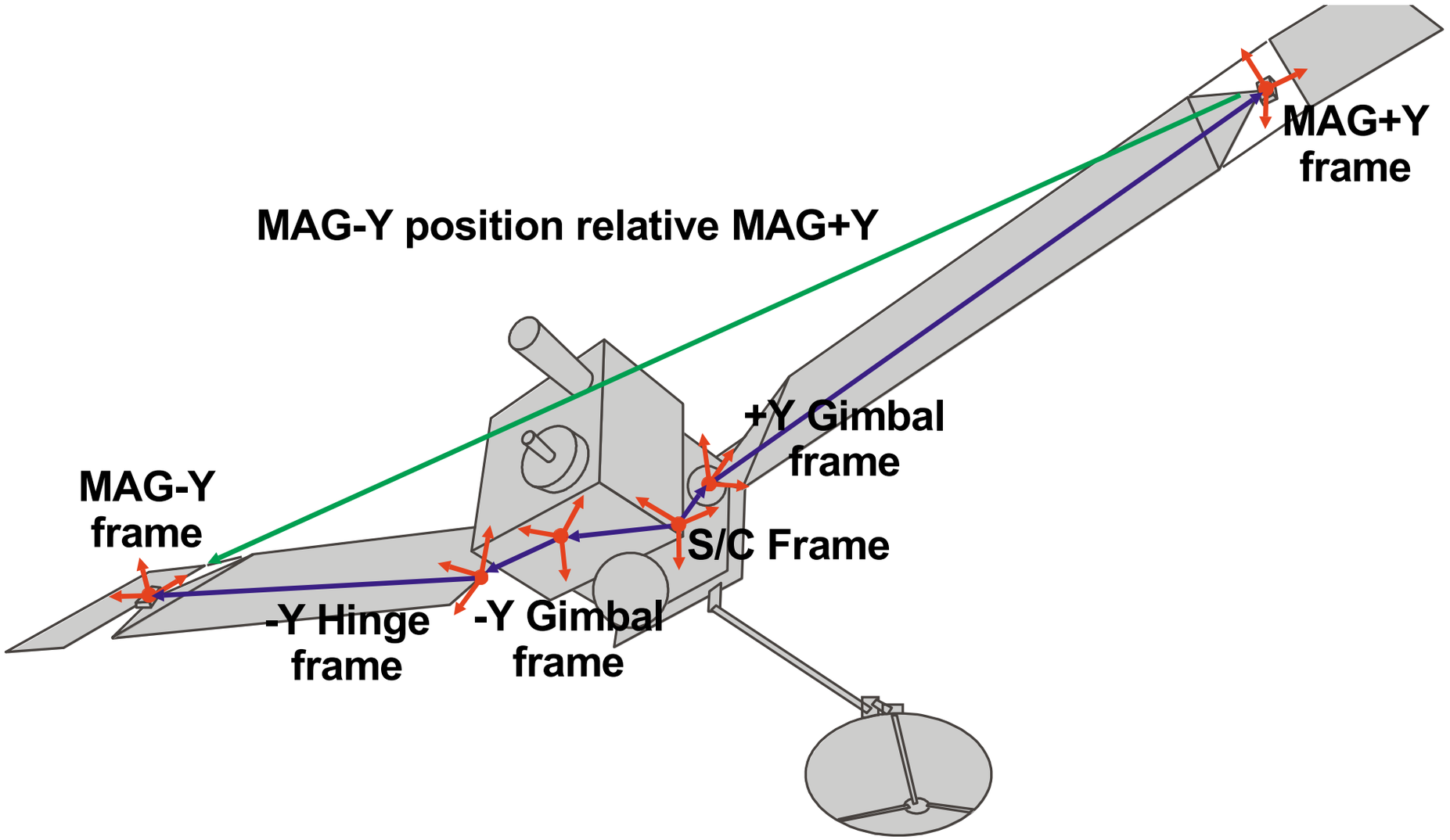


Compute solar azimuth and elevation at the Huygens probe landing site

```
CALL SPKPOS('SUN',ET,'HUYGENS_LOCAL_LEVEL','LT+S','HUYGENS_PROBE',SUNVEC,LT)
CALL RECLAT(SUNVEC, R, AZIMUTH, ELEVATION)
ELEVATION = -ELEVATION
IF (AZIMUTH .LT. 0.D0) THEN
   AZIMUTH = AZIMUTH + TWOPI()
ENDIF
```


(using_frames, p5)

Exemple 3

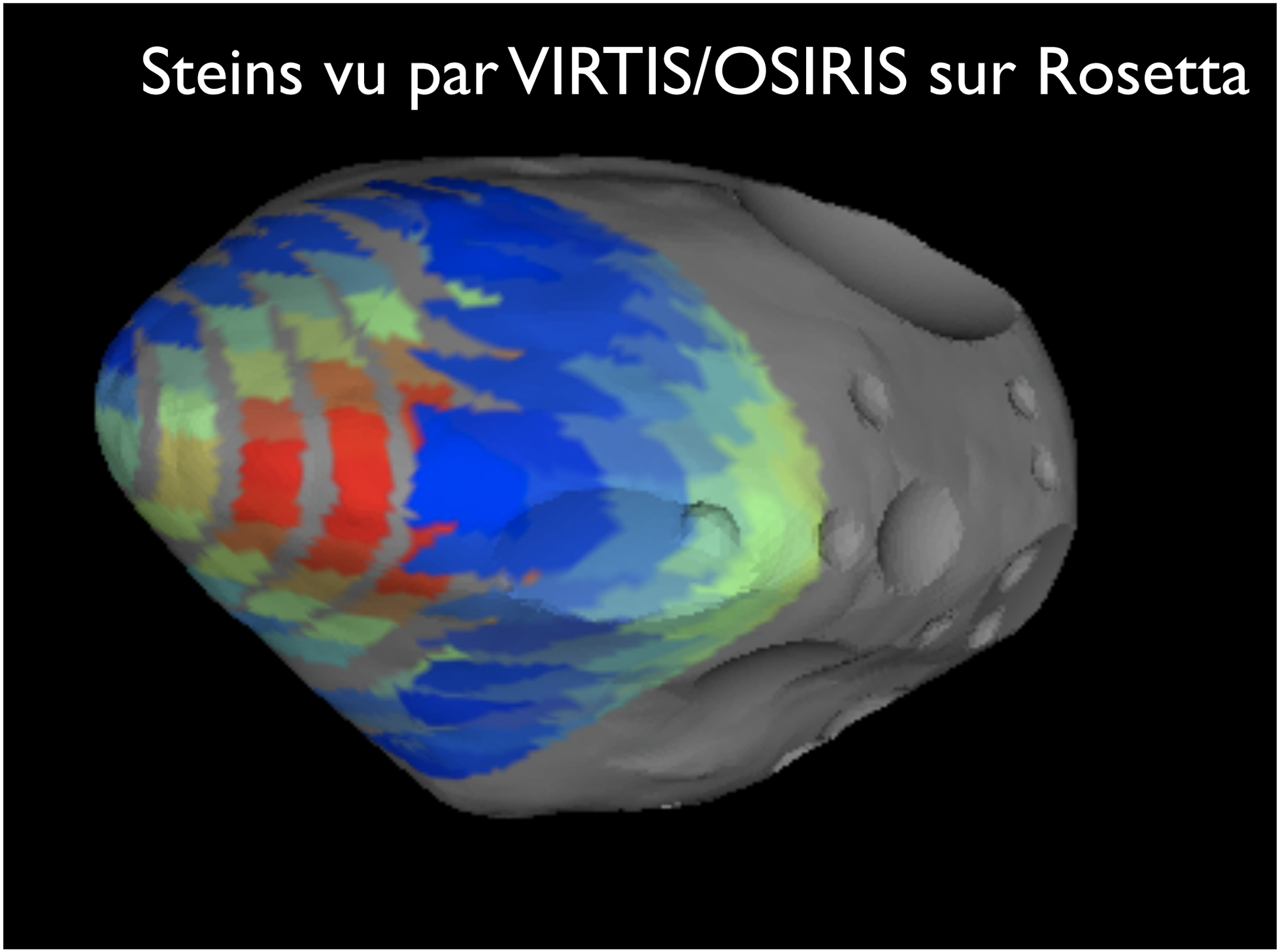


Find the position of one MGS MAG sensor with respect to the other in the MGS s/c frame. Also find the relative orientation of the sensors:

```
CALL SPKEZR('MGS_MAG-Y', ET, 'MGS_SPACECRAFT', 'NONE', 'MGS_MAG+Y', STATE, LT)
CALL PXFORM('MGS_MAG_+Y_SENSOR', 'MGS_MAG_-Y_SENSOR', ET, MAT)
```

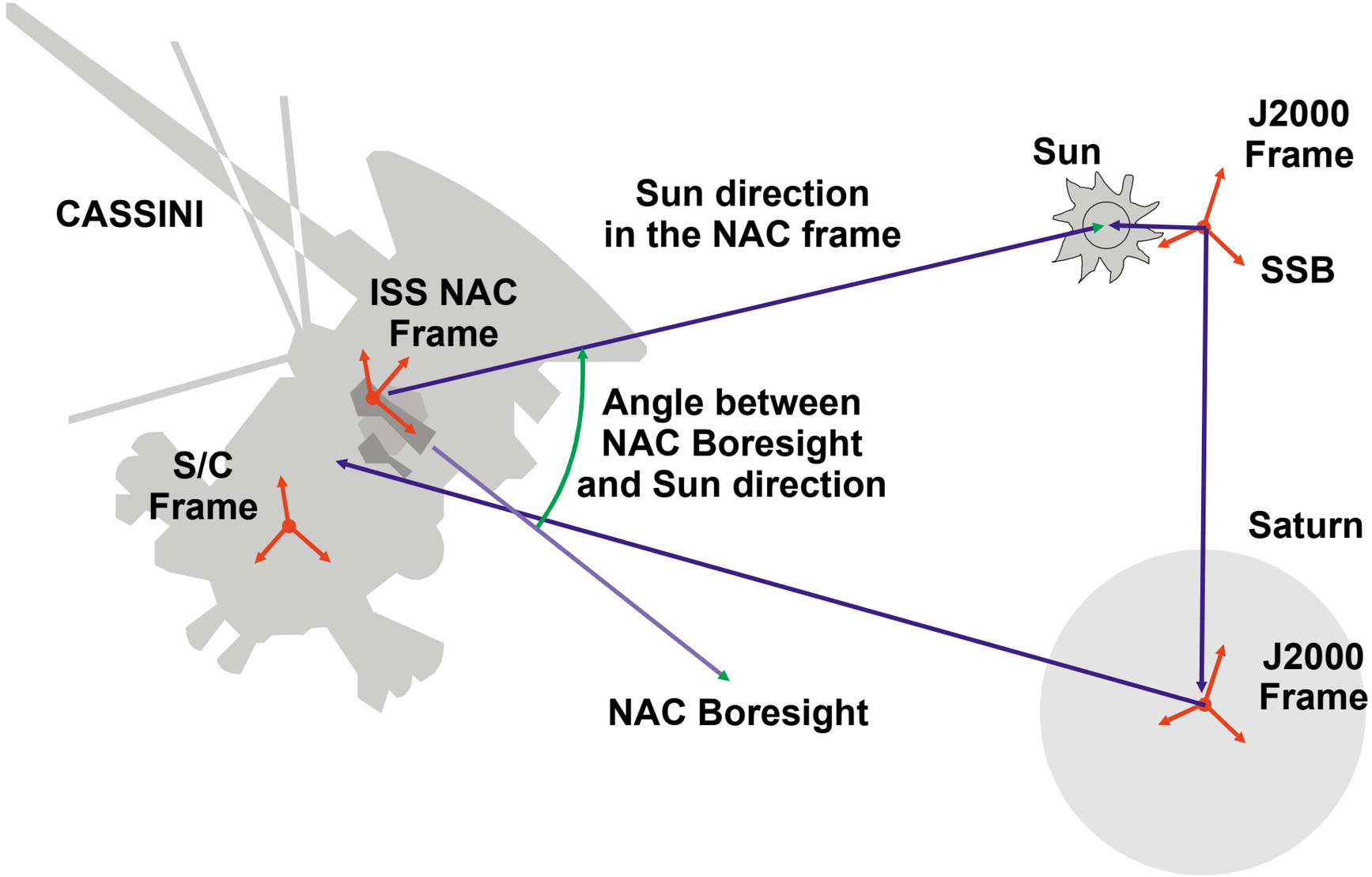

(using_frames, p6)

Exemple 4 (officieux)



(Version Alpha)

Inputs/Outputs



Check whether the angle between the camera boresight and the direction to the Sun is within the allowed range:

```
CALL SPKPOS( 'SUN', ET, 'CASSINI_ISS_NAC', 'LT+S', 'CASSINI', SUNVEC, LT )
```

Target (objet)

Observer (objet)

(using_frames, p4)

Gestion des names/IDs

- **SPICE uses IDs and names to identify:**
  - **physical objects**
  - **reference frames**
- **An ID is an integer number**
- **A name is a text string**

- **IDs are used primarily as data identifiers inside SPICE kernels**
- **Names are used primarily as input and output arguments in SPICE software interfaces (APIs)**

(naif_ids, p2)

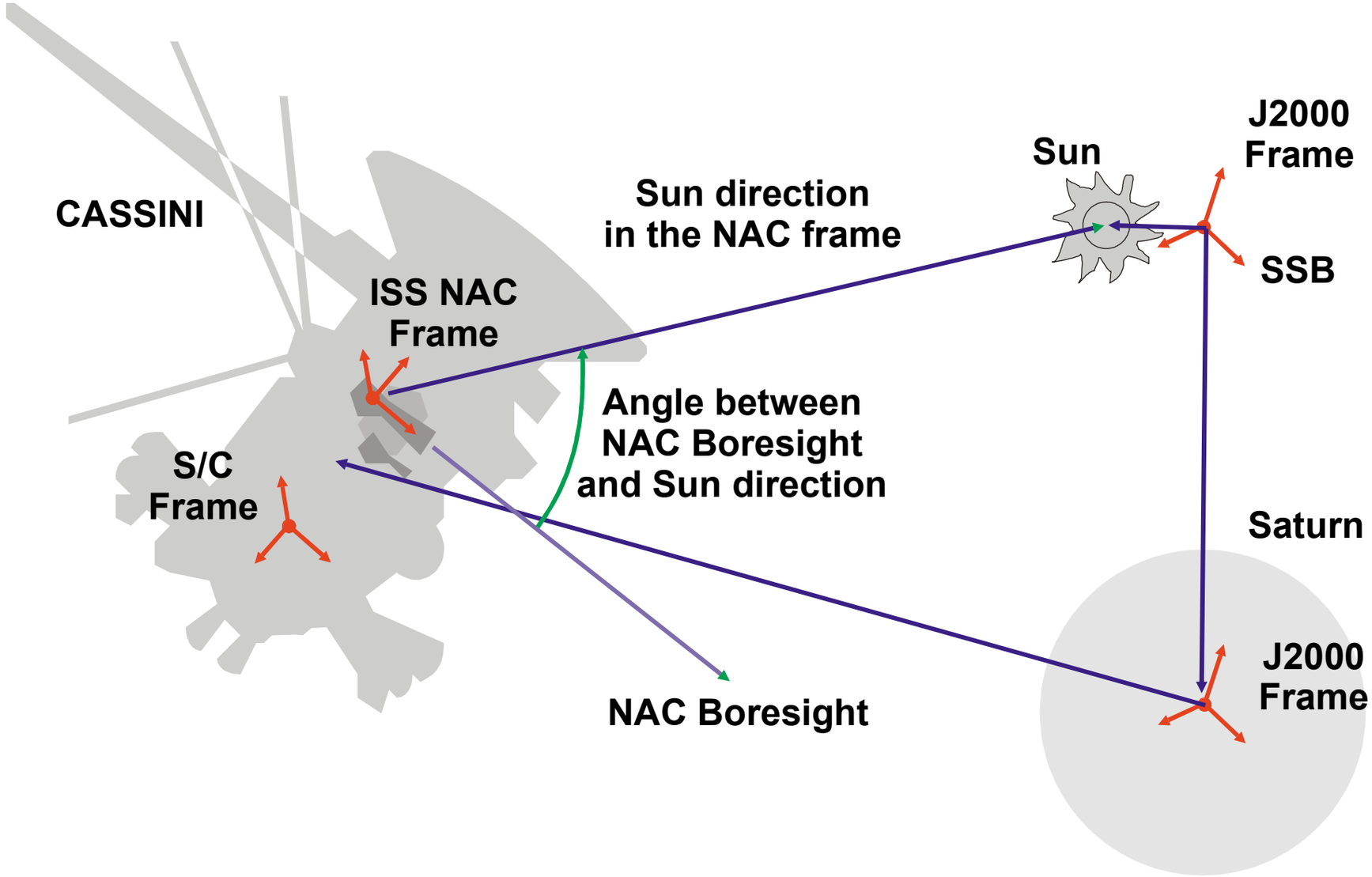
Exemples d'IDs/Names

- **Spacecraft (negative numbers)**
  - **Within NASA, this number is generally the negative of the numeric ID assigned by the NASA control authority at GSFC**
    - **-6 'PIONEER-6', 'P6'**
    - **-7 'PIONEER-7, 'P7',**
    - **-82 'CASSINI', 'CAS'**
    - **-94 'MARS GLOBAL SURVEYOR', 'MGS'**
    - **…**
- **Sun and Solar System Barycenter (10 and 0)**
  - **0 'SOLAR SYSTEM BARYCENTER', 'SSB'**
  - **10 'SUN'**
- **Planetary system barycenters (numbers from 1 to 9)**
  - **1 'MERCURY BARYCENTER'**
  - **2 'VENUS BARYCENTER'**
  - **3 'EARTH MOON BARYCENTER', 'EMB', …**
  - **4 'MARS BARYCENTER'**

  …
  - **9 'PLUTO BARYCENTER'**

(naif_ids, p10)

Inputs/Outputs



Check whether the angle between the camera boresight and the direction to the Sun is within the allowed range:

```
CALL SPKPOS( 'SUN', ET, 'CASSINI_ISS_NAC', 'LT+S', 'CASSINI', SUNVEC, LT )
```

Reference (frame)

(using_frames, p4)

Systèmes de référence (I)

- **A reference frame is an ordered set of three mutually orthogonal (possibly time dependent) unit-length direction vectors, coupled with a location called the frame's "center" or "origin."**
  - **SPICE documentation frequently uses the shorthand "frame" instead of "reference frame."**
  - **The ordered set of axes of a reference frame is also called a "basis."**
- **A coordinate system specifies the method of locating a point within a reference frame.**
- **A reference frame's center is an ephemeris object whose location is coincident with the origin (0, 0, 0) of the frame.**
  - **The center of the IAU_<body> frame is <body>.**
  - **The center of any inertial frame is (in SPICE) the solar system barycenter.**

(naif_ids, p22)

Systèmes de référence (II)

- **Inertial**
  - **Non-rotating**
    - » **With respect to fixed stars**
  - **Non-accelerating origin**
    - » **Velocity is typically non-zero; acceleration is negligible**
  - **Examples:**
    - » **J2000 (also called ICRF), B1950**
- **Non-Inertial**
  - **Examples**
    - » **Body-fixed**
      - **Centered at body center**
      - **Topocentric**
    - » **Instrument**
    - » **Dynamic frames**
      - **For example, frames defined by time-dependent vectors**

(International Celestial Reference Frame)

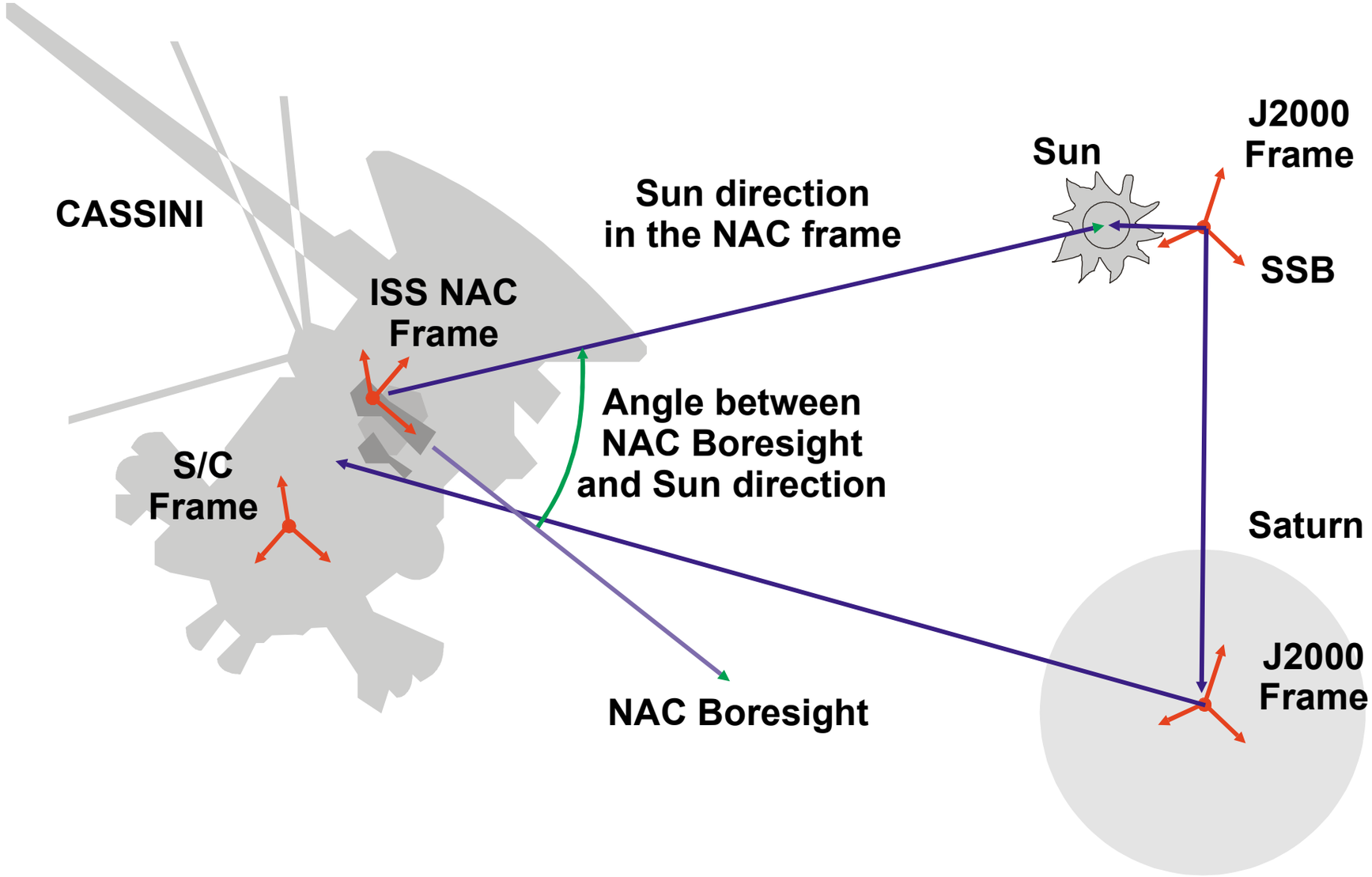
(naif_ids, p22)

Systèmes de référence (III)

- **Inertial frames (positive integers starting at 1)**
  - **1 ‘J2000’**
  - **…**
  - **16 ‘MARSIAU’**
  - **17 ‘ECLIPJ2000’**
  - **…**
- **Body-fixed frames (positive integers starting at 10001)**
  - **10001 ‘IAU_MERCURY_BARYCENTER’**
  - **…**
  - **10011 ‘IAU_MERCURY’**
  - **…**
  - **10020 ‘IAU_MOON’**
  - **…**
  - **10081 ‘EARTH_FIXED’**
  - **…**

(naif_ids, p22)

Inputs/Outputs



Check whether the angle between the camera boresight and the direction to the Sun is within the allowed range:

```
CALL SPKPOS( 'SUN', ET, 'CASSINI_ISS_NAC', 'LT+S', 'CASSINI', SUNVEC, LT )
```

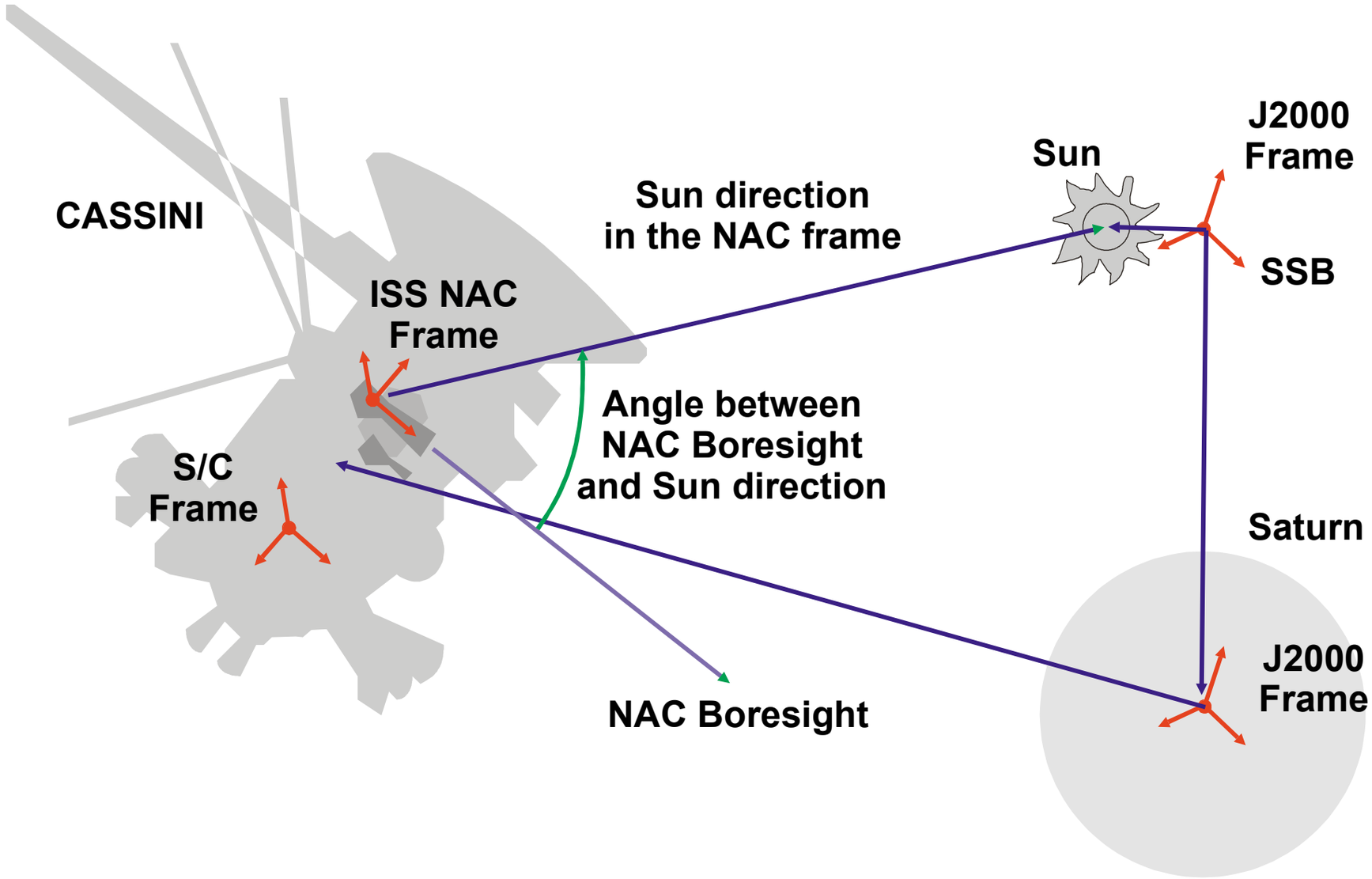
(Ephemeris) Time

(using_frames, p4)

Gestion du temps

- **Time inputs and outputs in users' SPICE-based programs are usually strings representing epochs in these three time systems:**
  - **Coordinated Universal Time (UTC)**
  - **Spacecraft Clock (SCLK)**
  - **Ephemeris Time (ET, also referred to as Barycentric Dynamical Time, TDB)**
- **Time stamps in kernel files, and time inputs and outputs to SPICE routines reading kernel data and computing derived geometry, are double precision numbers representing epochs in these two time systems:**
  - **Numeric Ephemeris Time (TDB), expressed as ephemeris seconds past J2000**
  - **Encoded Spacecraft Clock, expressed as clock ticks since the clock start**
- **SPICE provides routines to perform conversions between string and numeric times using data from these two kernels:**
  - **Leapseconds Kernel (LSK) containing data for UTC <=> ET conversion**
  - **Spacecraft Clock Kernel (SCLK) containing data for ET <=> SCLK conversion**

Inputs/Outputs



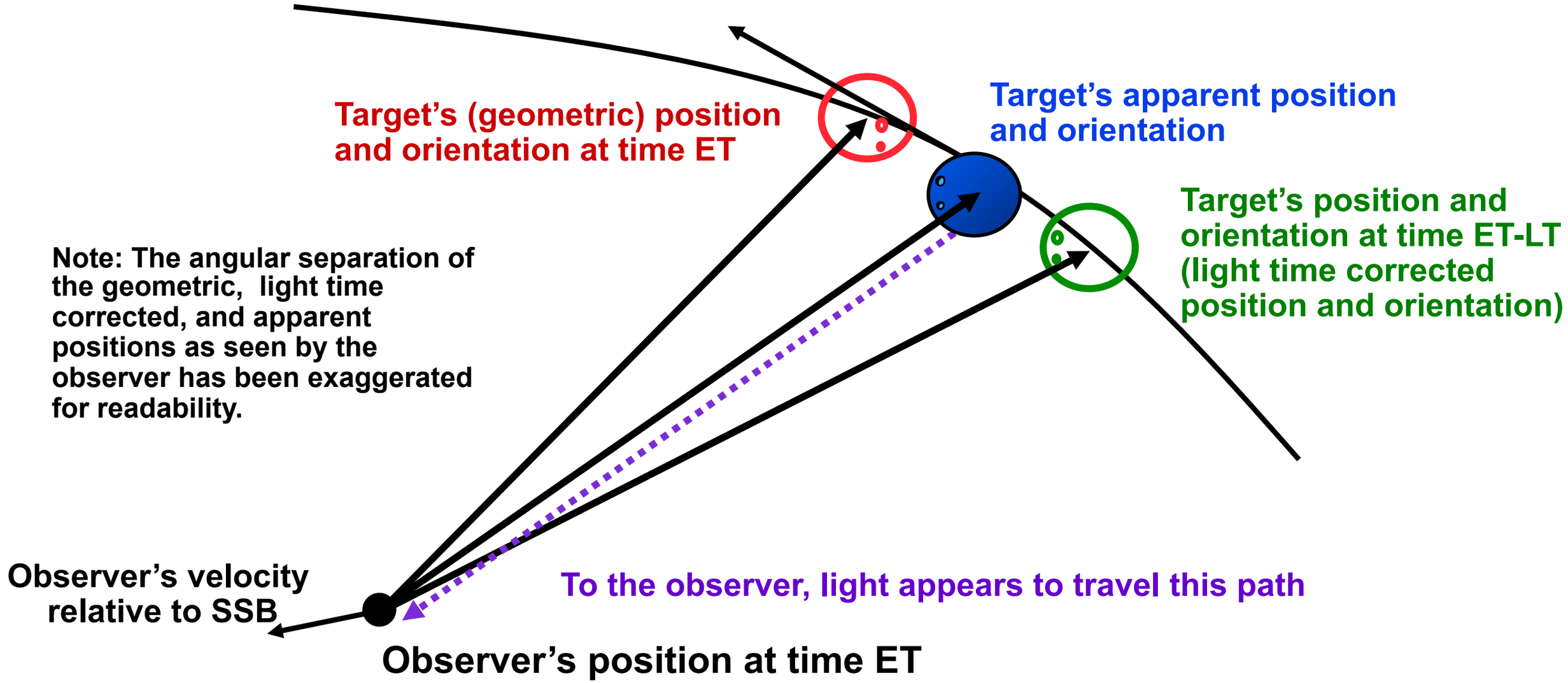
Check whether the angle between the camera boresight and the direction to the Sun is within the allowed range:

```
CALL SPKPOS( 'SUN', ET, 'CASSINI_ISS_NAC', 'LT+S', 'CASSINI', SUNVEC, LT )
```

Light Time + Stellar aberration-corrections

(using_frames, p4)

Correction position apparente/réelle



At time ET, the observer's camera records photons emitted from the target at time ET-LT, where LT is the one-way light time.

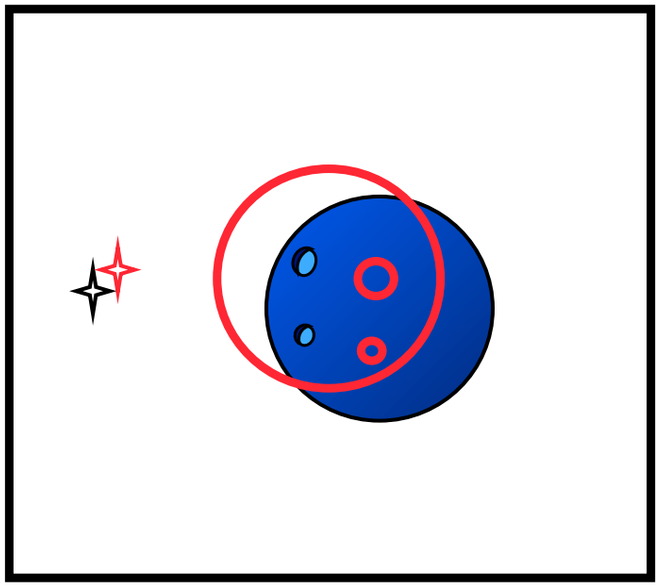
The vector from the observer at ET to the location of the target at ET-LT is displaced by a physical phenomenon called stellar aberration. The displaced vector yields the apparent position of the target.

(concepts, p31)

Correction position apparente/réelle

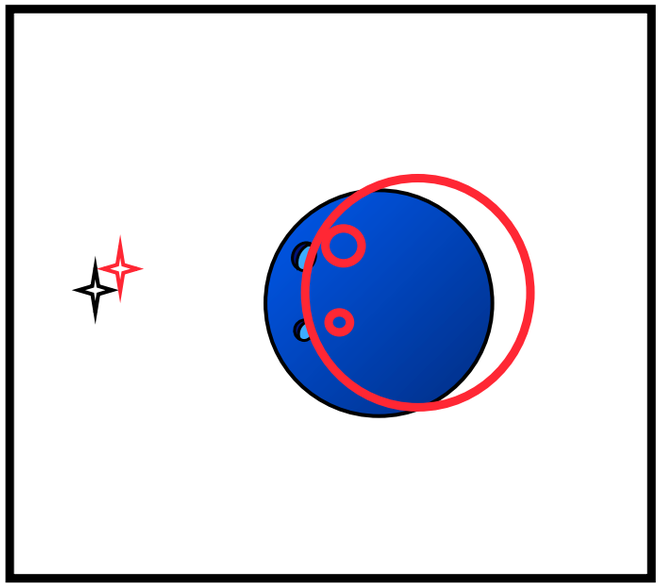
We compare the predicted appearance of a photograph from an optical camera against the actual photograph. We show three predictions derived using different aberration corrections: NONE, LT ("light time only"), and LT+S ("light time plus stellar aberration").

For each prediction, we use red overlays to indicate the expected location in the photo of the images of an extended target body (for example, a natural satellite), of features on the surface of the target body, and of a star.



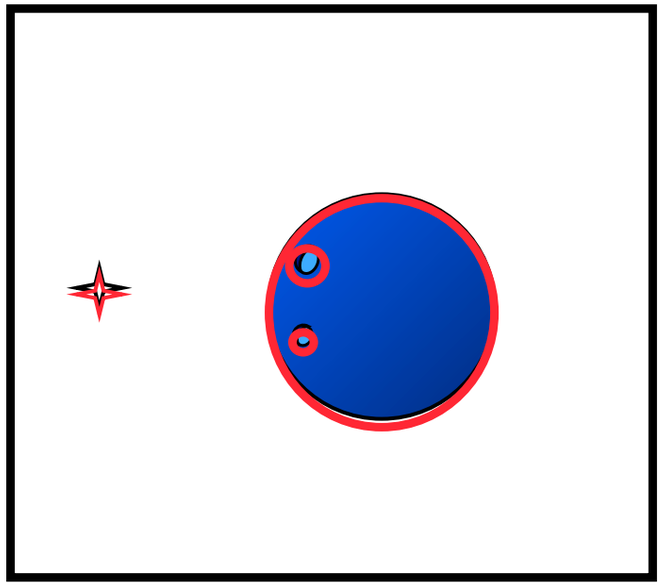
NONE

Predicted images using uncorrected target position and orientation and uncorrected star direction vector



LT

Predicted images using light time-corrected target position and orientation and uncorrected star direction vector

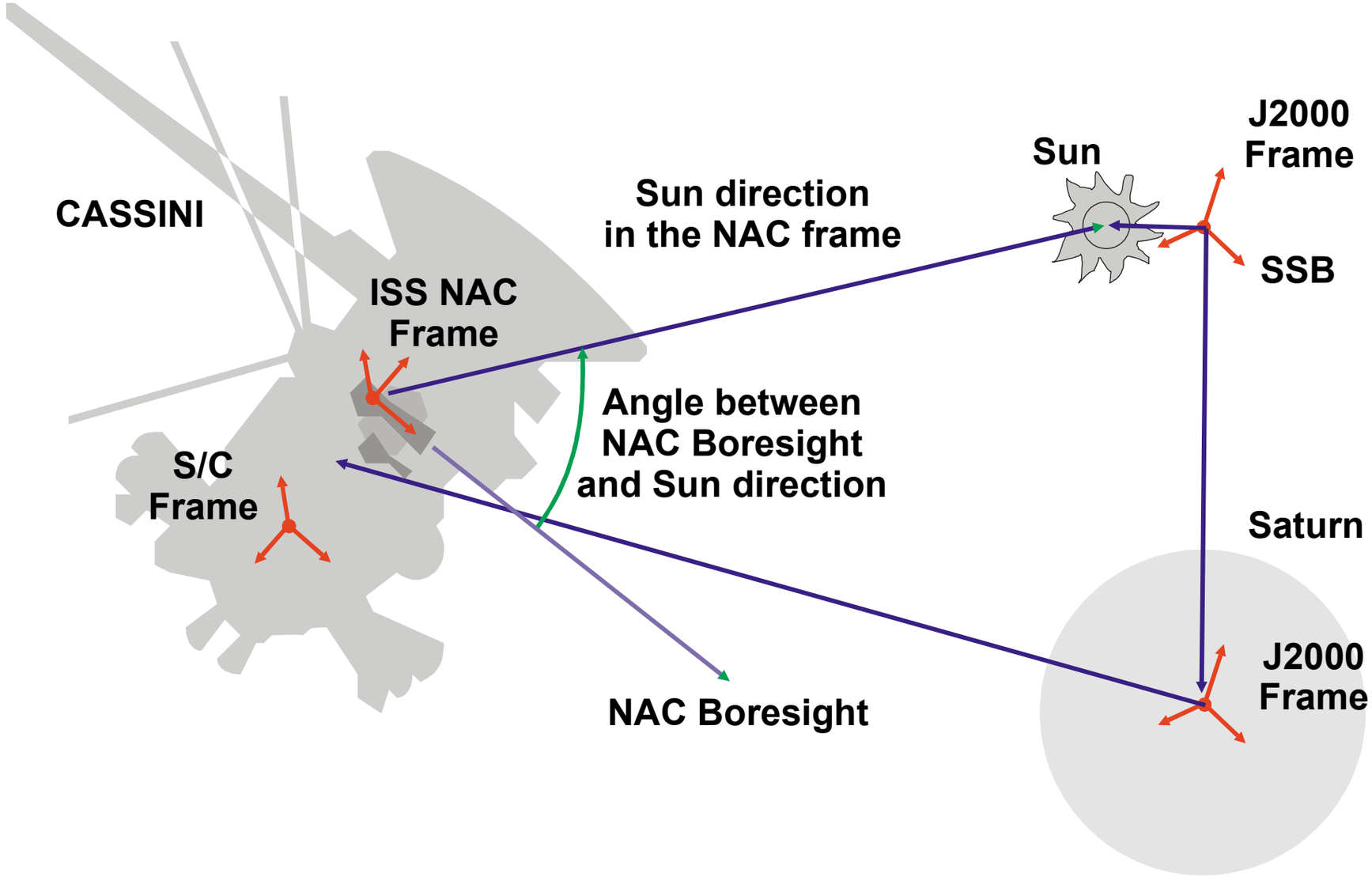


LT+S

Predicted images using light time and stellar aberration-corrected target position, light time-corrected target orientation, and stellar aberration-corrected star direction vector

(concepts, p27)

Fichiers de données (kernels)



Required Kernels:

- Generic LSK
- Mission FK
- Spacecraft SCLK
- Camera IK
- Planetary Ephemeris SPK
- Spacecraft SPK
- Spacecraft CK

Check whether the angle between the camera boresight and the direction to the Sun is within the allowed range:

```
CALL SPKPOS( 'SUN', ET, 'CASSINI_ISS_NAC', 'LT+S', 'CASSINI', SUNVEC, LT )
```

Use the FURNSH routine to load all kernels–text and binary.

```
CALL FURNSH ( 'name.ext' )
```


(using_frames, p4)

Types de kernels (I)

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_overview, p10)

Types de kernels (II)

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_overview, p11)

Types de kernels (III)

FK

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

LSK

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

SCLK

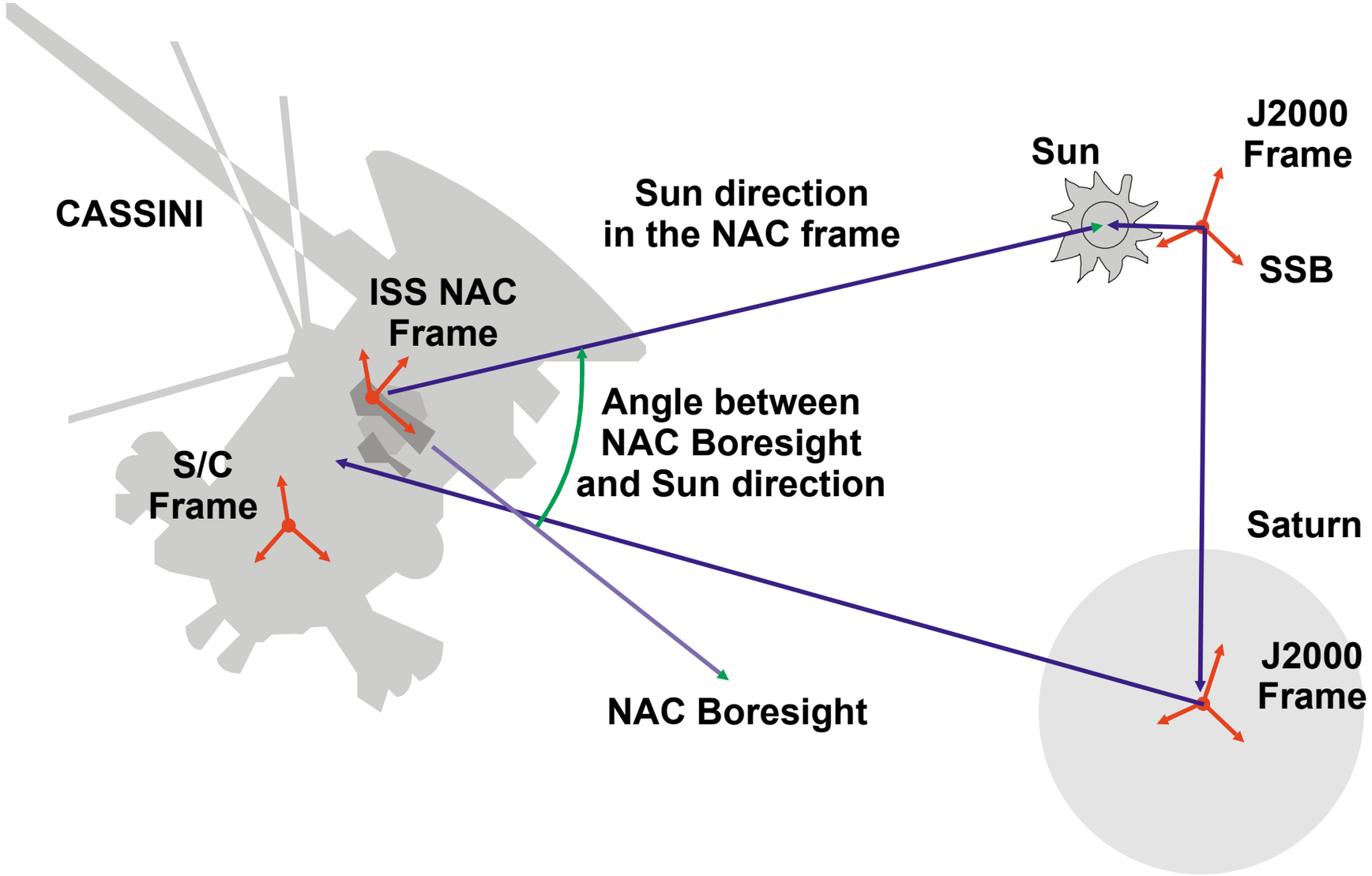
- **Spacecraft Clock Coefficients**
  - Used for SCLK <--> TDB (ET) time conversions

Under Development

- Shape models (DEM and tessellated plates) (DSK) [1]
- Star (sky) catalog [2]

[1] under development now
[2] development is stalled

Exemple I



Required Kernels:

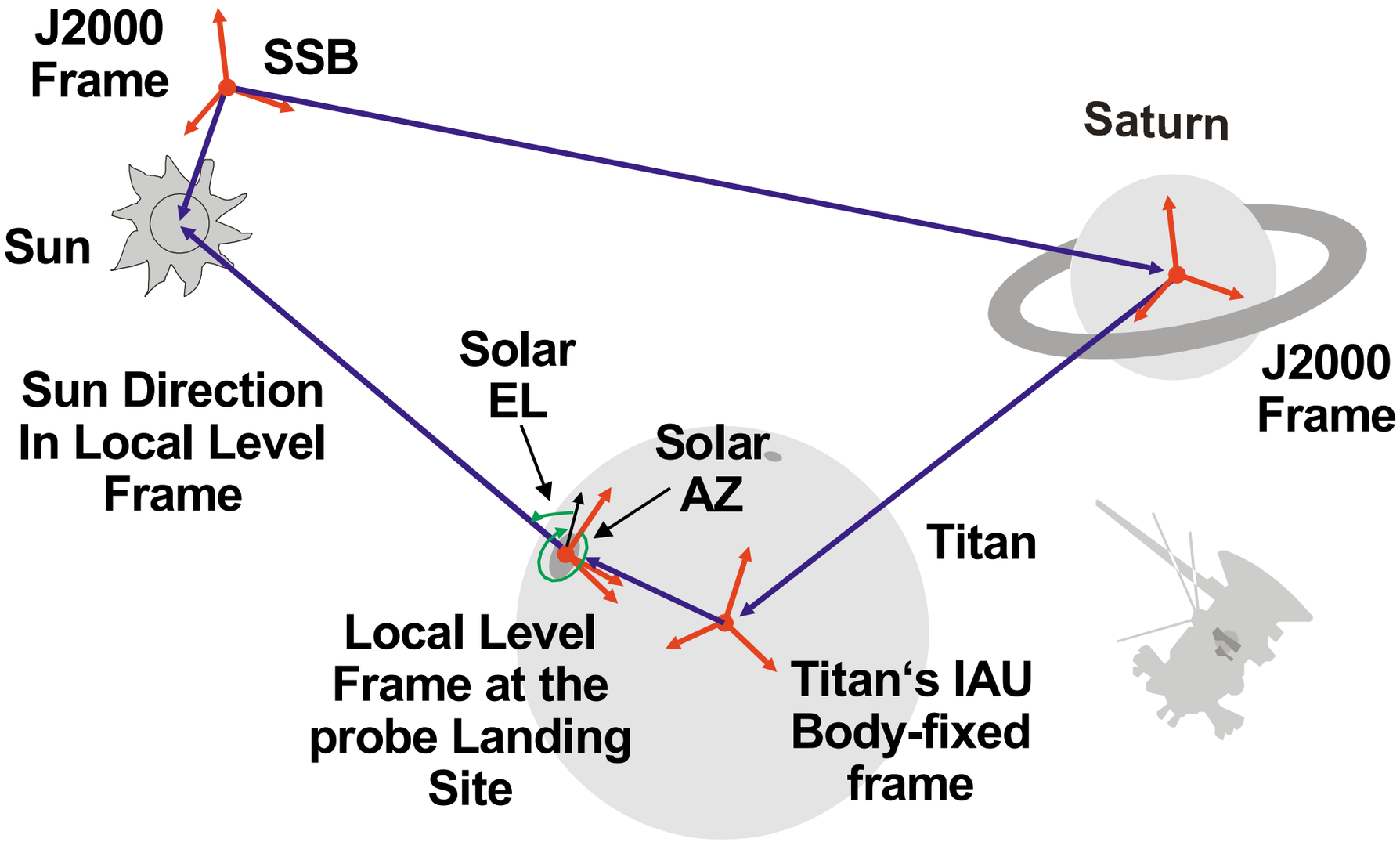
- Generic LSK
- Mission FK
- Spacecraft SCLK
- Camera IK
- Planetary Ephemeris SPK
- Spacecraft SPK
- Spacecraft CK

Check whether the angle between the camera boresight and the direction to the Sun is within the allowed range:

```
CALL SPKPOS( 'SUN', ET, 'CASSINI_ISS_NAC', 'LT+S', 'CASSINI', SUNVEC, LT )
ANGLE = VSEP( NAC_BORESIGHT_nac, SUNVEC )
IF ( ANGLE .LE. CONSTRAINT ) WRITE(*,*) 'WE ARE IN TROUBLE!'
```


(using_frames, p4)

Exemple 2



Required Kernels:

- Generic LSK
- Generic PCK
- Mission FK
- Planetary Ephemeris SPK
- Satellite Ephemeris SPK
- Landing Site SPK

Compute solar azimuth and elevation at the Huygens probe landing site

```
CALL SPKPOS('SUN',ET,'HUYGENS_LOCAL_LEVEL','LT+S','HUYGENS_PROBE',SUNVEC,LT)
CALL RECLAT(SUNVEC, R, AZIMUTH, ELEVATION)
ELEVATION = -ELEVATION
IF (AZIMUTH .LT. 0.D0) THEN
   AZIMUTH = AZIMUTH + TWOPI()
ENDIF
```


(using_frames, p5)

En pratique

- **Software** http://naif.jpl.nasa.gov/naif/toolkit.html
  - **Subroutine libraries, with source code**
    - » **SPICELIB (Fortran)**
    - » **CSPICE (C)**
    - » **Icy (C)**
    - » **Mice (C and Matlab script)**
  - **Executable programs**
    - » **application and utility programs**
    - » **cookbook examples**
  - **Installation/build scripts**
- **Documentation** http://naif.jpl.nasa.gov/naif/tutorials.html
  - **Available in ASCII and HTML**
- **Data** http://naif.jpl.nasa.gov/naif/data.html
  - **kernel files**

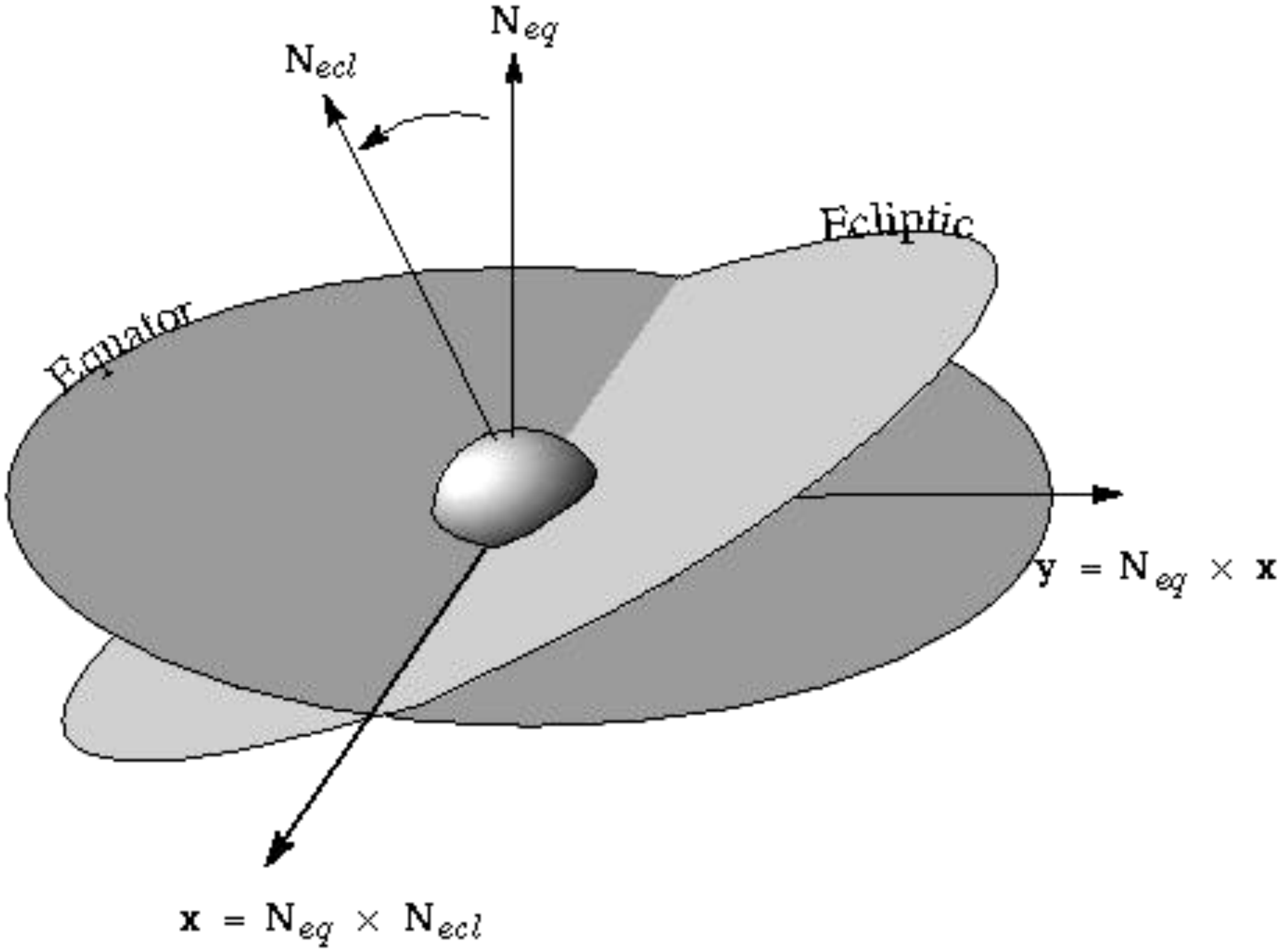
Question?

Précision?

Point obscure?

Suggestion?...

J2000 (ICRF)


$\mathbf{N}_{eq}$
$\mathbf{N}_{ecl}$
Ecliptic
Equator
$\mathbf{y} = \mathbf{N}_{eq} \times \mathbf{x}$
$\mathbf{x} = \mathbf{N}_{eq} \times \mathbf{N}_{ecl}$

Format et extension des kernels

SPK:

.bsp	binary SPK file

PCK:

.tpc	text PCK file (The most common type PcK)
.bpc	binary PCK file (Very few instances of this)

IK:

.ti	text IK file

FK:

.tf	text FK file

LSK:

.tls	text LSK file

CK:

.bc	binary CK file

SCLK:

.tsc	text SCLK file

MK:

.tm	text meta-kernel file ("FURNSH kernel")

DSK:

.bds	binary DSK file

(conventions, p9)

Barycentric Dynamical Time

Navigation and Ancillary Information Facility

- **Barycentric Dynamical Time (TDB) and Ephemeris Time (ET) are synonyms in SPICE documentation.**
- **TDB is**
  - **a mathematical Ideal used in the equations of motion.**
  - **used as the independent time variable for many SPICE subroutine interfaces.**
  - **related to ideal time at the Solar System Barycenter (TCB) by a scale factor, so that TDB advances on average at the same rate as TAI.**

Les fichiers de données (kernels)

- **SPK**
  - **Spacecraft and Planet Ephemeris**
- **PcK**
  - **Planetary Constants, for natural bodies**
    - » **Orientation**
    - » **Size and shape**
- **IK**
  - **Instrument**
- **CK**
  - **Pointing (“C-matrix”)**
- **EK**
  - **Events, up to three distinct components**
    - » **ESP: science plan**
    - » **ESQ: sequence**
    - » **ENB: experimenter’s notebook**
- **FK**
  - **Reference frame specifications**
- **SCLK**
  - **Spacecraft clock correlation data**
- **LSK**
  - **Leapseconds**
- **Meta-Kernel** **(a.k.a. “FURNSH kernel”)**
  - **Mechanism for aggregating and easily loading a collection of kernel files**
- **DSK (under development)**
  - **Digital shape kernel**
    - » **Tesselated plate model**
    - » **Digital elevation model**

- **SCLK string formats vary from one spacecraft clock to the next.**
  - **Cassini: Maximum reading for partition 1 = 1/4294967295.255**
    - » **Partition number: 1**
    - » **Seconds: 4294967295**
    - » **Ticks (for Cassini, unit = 1/256 second): 255**
  - **Galileo: Maximum reading for partition 1 = 1/16777215:90:09:07**
    - » **Partition number: 1**
    - » **"RIM" count (unit = 60 2/3 seconds): 16777215**
    - » **"Mod 91" count (unit = 2/3 second): 90**
    - » **"RTI" count (unit = 1/15 second): 9**
    - » **"Mod 8" count (unit = 1/120 second): 7**
- **The format of spacecraft clock and the relationship between tick count and other time systems (usually UTC) is captured in a SPICE SCLK kernel**