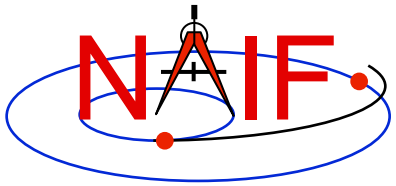


Navigation and Ancillary Information Facility

SPICE Geometry Finder (GF) Subsystem

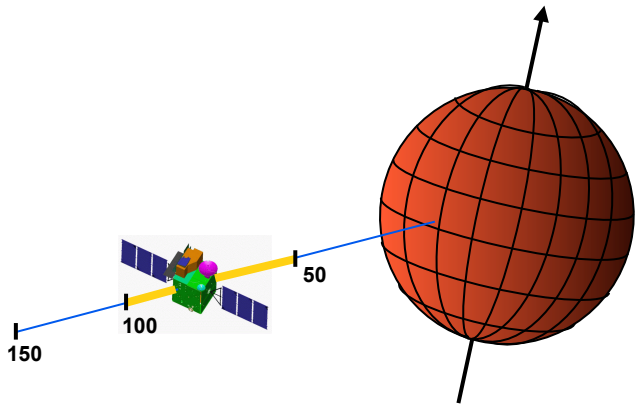
Searching for times when specified geometric conditions occur

April 2016

Purpose

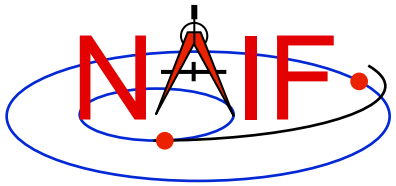
- **Much SPICE software computes a geometry parameter at a given time, t, i.e. *x = f(t)*.**
  - **Example: on 2011 MAR 30 14:57:08, what is the spacecraft's altitude above Mars?**

- **The Geometry Finder subsystem does the inverse.**
  - **Example: within some time bounds, when is the spacecraft's altitude between 50 and 100 km?**



Some Examples

- **The SPICE Geometry Finder (GF) subsystem finds times when specified geometric events occur.**
  - **A "geometric event" is an occurrence of a given geometric quantity satisfying a specified condition. For example:**
    - » **Mars Express distance from Mars is at a local minimum (periapse)**
    - » **Elevation of the Cassini orbiter is above a given threshold angle as seen from DSS-14**
    - » **Titan is completely occulted by Saturn**
    - » **The Mars Reconnaissance Orbiter is in the penumbral shadow of Mars**
    - » **The Saturn phase angle as seen by the Cassini orbiter is 60 degrees**
  - **Each GF search is conducted over a user-specified time window.**
    - » **A "time window" is a union of time intervals.**
  - **The result of a GF search is the time window over which the specified condition is met.**



Types of GF APIs

- **GF provides two primary types of event-finding APIs**
  - **Boolean: a geometric condition (an event) is true or false**
    - » **Example: Phobos is occulted by Mars**
    - » **Example: Vesta is not in the OSIRIS instrument's field of view**
  - **Sometimes we call these binary conditions**
  - **Numeric: a geometric quantity has a given value, is within a given range or has achieved a local or global maximum or minimum**
    - » **Example: spacecraft altitude is between X and Y km above the surface**
    - » **Example: angular separation of Titan from Saturn has reached the maximum (within the search window being used)**

GF High-Level API Computations

Navigation and Ancillary Information Facility

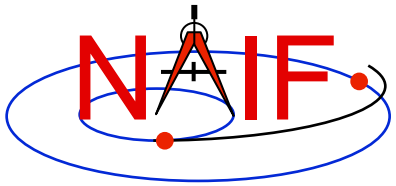
The current GF subsystem allows one to search for events involving the geometric quantities listed below.

Boolean

- Occultations or transits
- Ray containment in an instrument's field of view
- Target body appears in an instrument's field of view
- User-defined Boolean quantity

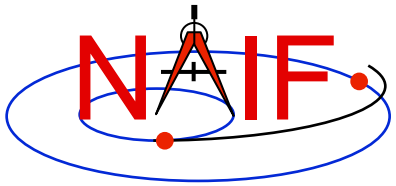
Numeric

- Observer-target distance
- Observer-target range rate
- Target body angular separation
- Phase angle
- Illumination angles
- Ray-body surface intercept coordinates
- Position vector coordinates
- Sub-observer point coordinates
- User-defined scalar quantity



GF High-Level API Routines

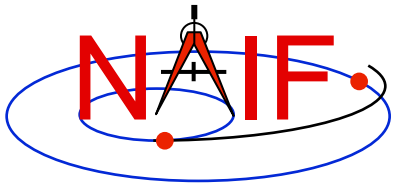
- **The GF subsystem provides the following high-level API routines; these search for events involving the respective geometric quantities listed below**
  - **GFDIST: observer-target distance**
  - **GFILUM: illumination angles**
  - **GFOCLT: occultations or transits**
  - **GFPA: phase angle**
  - **GFPOSC: position vector coordinates**
  - **GFRFOV: ray is contained in an instrument's field of view**
  - **GFRR: observer-target range rate**
  - **GFSEP: target body angular separation**
  - **GFSNTC: ray-body surface intercept coordinates**
  - **GFSUBC: sub-observer point coordinates**
  - **GFTFOV: target body appears in an instrument's field of view**
  - **GFUDB: user-defined boolean quantity (only Fortran and C)**
  - **GFUDS: user-defined scalar quantity (only Fortran and C)**



The SPICE Window

Navigation and Ancillary Information Facility

- The high-level GF routines return search results as SPICE windows.
- A SPICE window is a list of disjoint intervals arranged in ascending order.
  - An interval is specified by a pair of double precision numbers, with the second greater than or equal to the first.
- GF uses SPICE windows to specify intervals of time when some set of user constraints are satisfied.
- In simple terms, one can describe a SPICE time window as:
  - A span of time defined by a start time and an end time,
  - A time-ordered sequence of zero or more time intervals, each having zero or non-zero length
    - » A zero-length interval is often called a “singleton”



SPICE Windows Operations

Navigation and Ancillary Information Facility

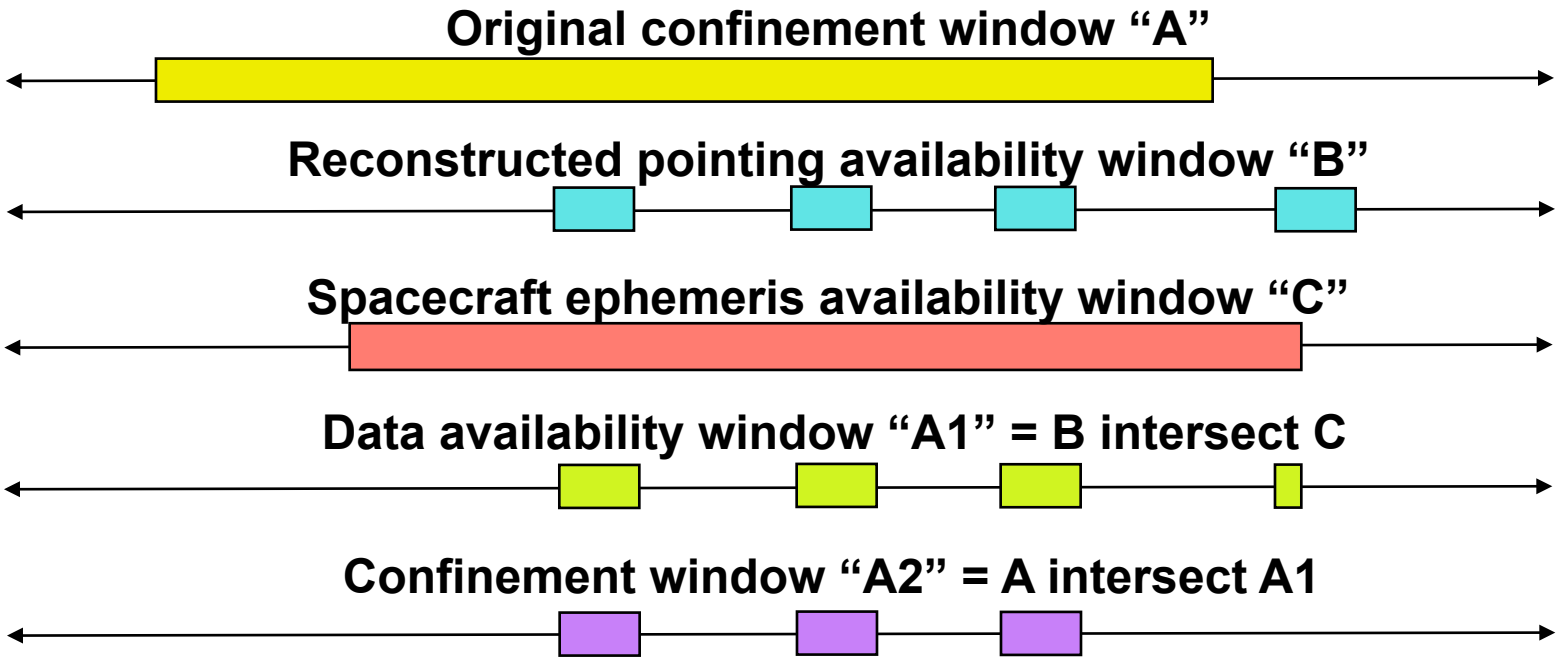
- SPICE provides routines to:
  - compute unions, intersections, and differences of windows
  - contract each interval within a window …
    - » by increasing the left endpoint and decreasing the right endpoint
- See the next page for an example

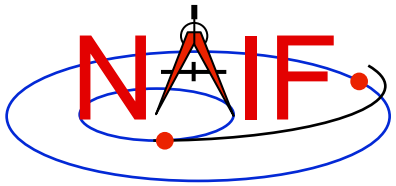
Example of Window Operations

Navigation and Ancillary Information Facility

Given an initial confinement window, restrict that window to times when required CK and SPK data are available.

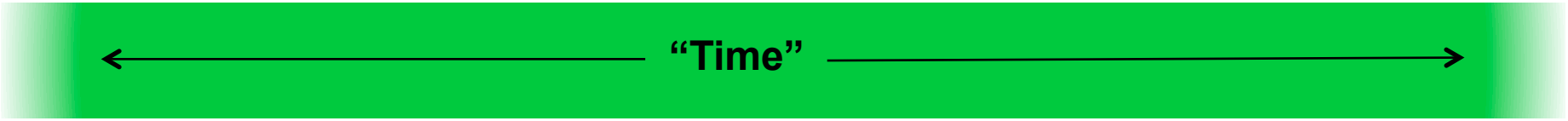
Use CKCOV and SPKCOV to find CK and SPK availability windows. Contract CK window slightly to avoid round-off problems. Contract SPK window by a few seconds if discrete differentiation is used by search algorithms (e.g. for acceleration or for "is function decreasing?" tests).





Using Time Windows in GF

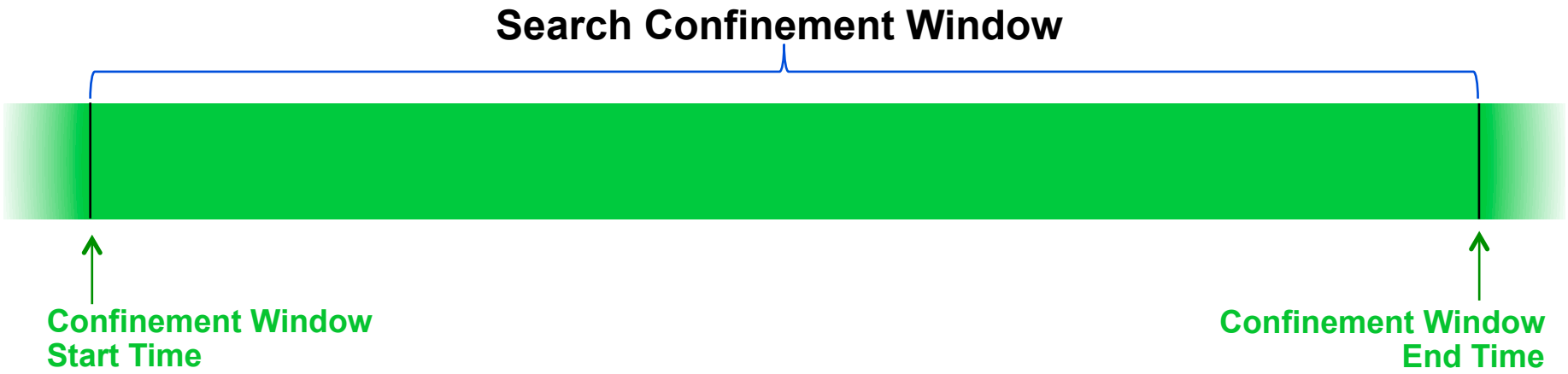
Navigation and Ancillary Information Facility



Using Time Windows in GF

Navigation and Ancillary Information Facility

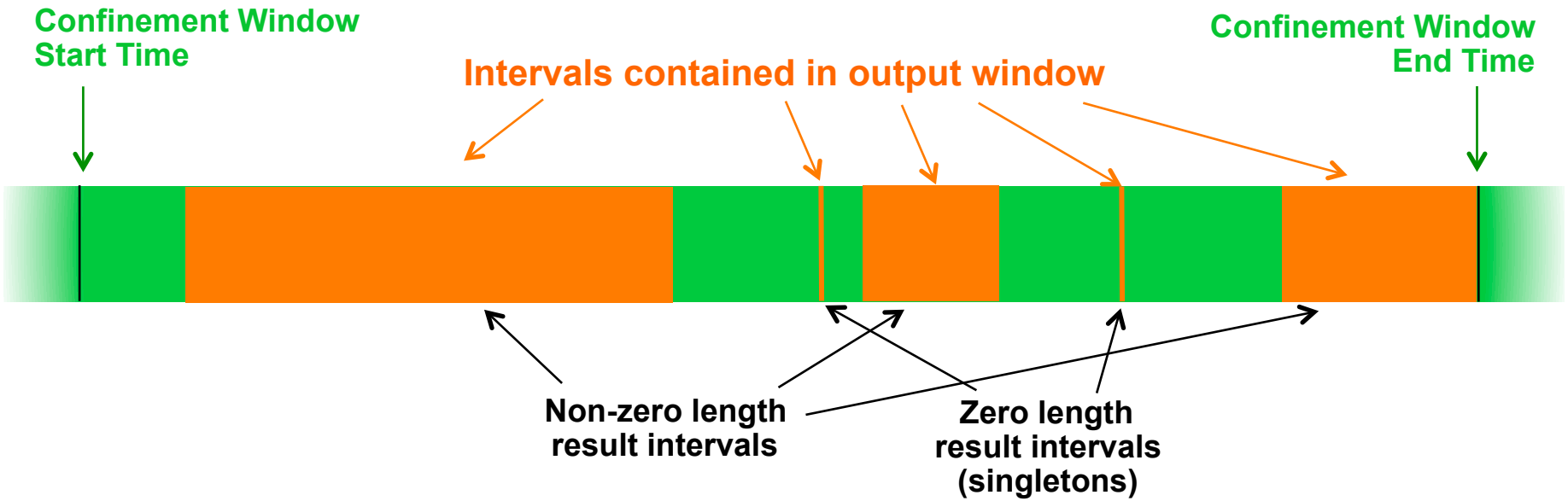
- **GF uses a SPICE window to:**
  - **confine the time bounds over which a search is to take place**



Using Time Windows in GF

Navigation and Ancillary Information Facility

- **GF uses SPICE windows for input and output**
  - **Input: confine the time bounds over which a search is to take place**
  - **Output: contain the time intervals that meet the search criteria**
    - » **There may be none, one or multiple result intervals**
    - » **The result intervals can be of non-zero or zero length**
      - **A zero-length interval is simply an epoch–an instant in time**



Cascading Search Using Multiple SPICE Windows

- **The result window from one search can be used as the confinement window for another.**
  - **This is often a convenient and efficient way of performing searches for times when multiple constraints are met.**
  - **This technique can be used to accelerate searches in cases where a fast search can be performed to produce a small confinement window for a second, slower search.**
    - » **See the next chart and the example program "CASCADE" in the Geometry Finder Required Reading document**

Cascading Search Example

Navigation and Ancillary Information Facility

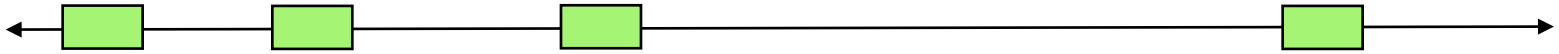
Example: accelerate a solar occultation search.

First search for times when the angular separation of the figures of the Sun and Moon, as seen from DSS-14, is less than 3 degrees.

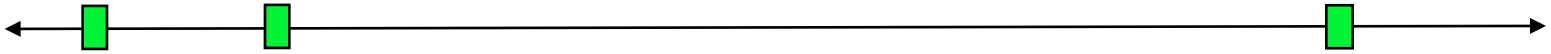
Use the result window of the angular separation search as the confinement window of an occultation search.

Because the angular separation search is much faster than the occultation search (on the original confinement window), the total search time is greatly reduced.

Original confinement window



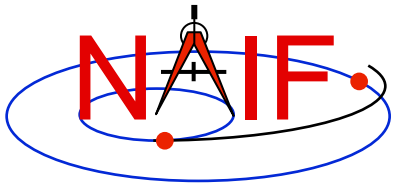
Result of angular separation search: second confinement window



Result of occultation search

GF Documentation

- The GF module headers contain complete example programs for each GF API routine
- The GF Required Reading document (gf.req) contains lots of details
- Documentation on SPICE windows:
  - The WINDOWS Required Reading windows.req
  - The Other Functions tutorial
  - API documentation for SPICE window routines



And more…

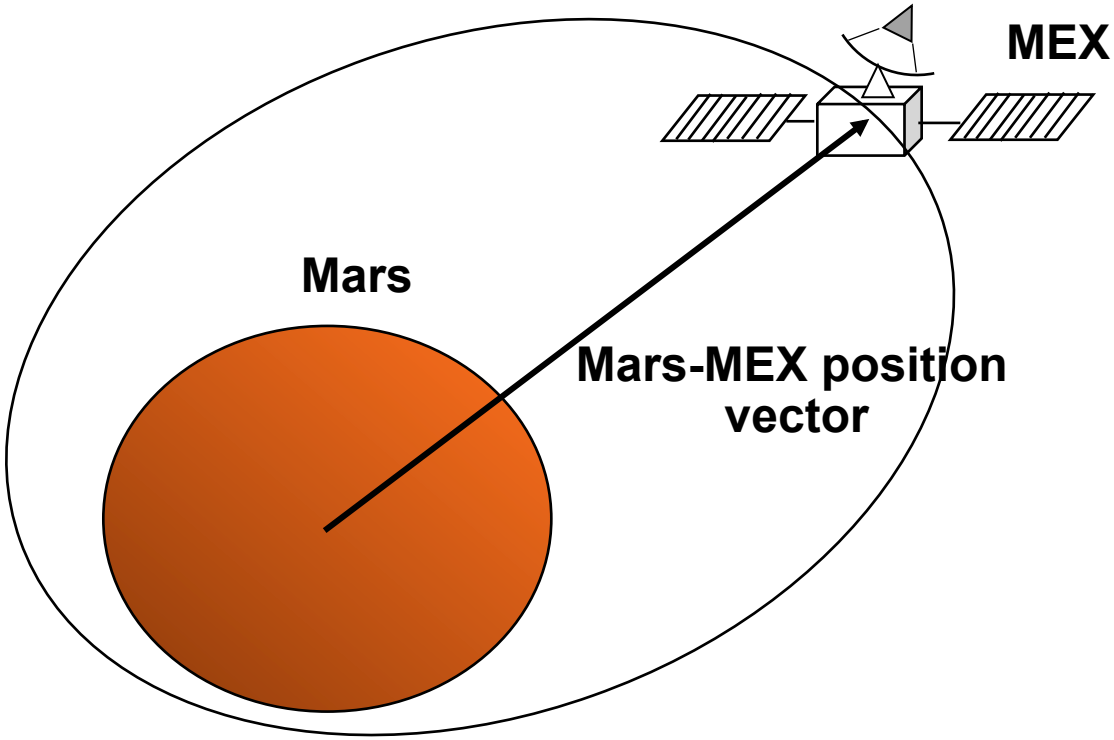
- **There are many more details covered in the on-line GF tutorial. You are strongly encouraged to look at this if you intend to use GF software.**

GF Search Examples

Distance Local Maximum

Navigation and Ancillary Information Facility

Find the times of apoapse of the Mars Express Orbiter (MEX)

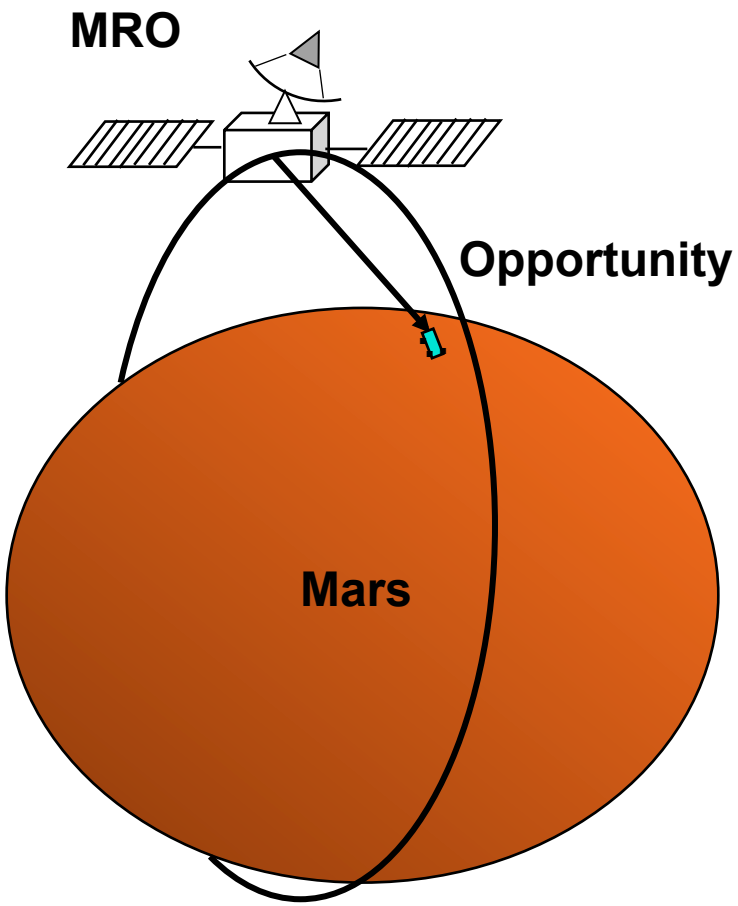


API: GFDIST

Distance Within a Range

Navigation and Ancillary Information Facility

Find the time periods when the Mars Reconnaissance Orbiter (MRO) is within 500km of the Opportunity rover.

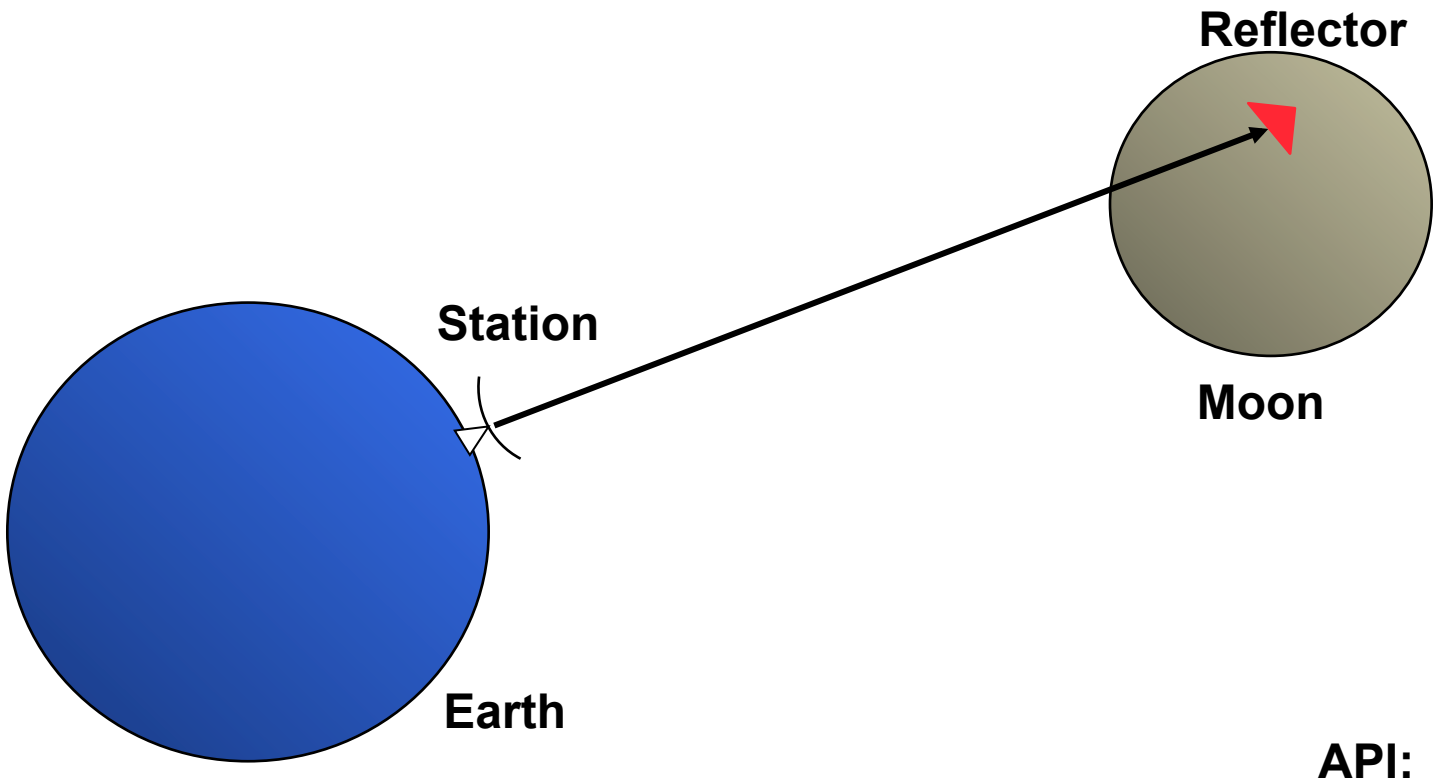


API: GFDIST

Range Rate Extremum

Navigation and Ancillary Information Facility

Find the time periods when the range rate of a lunar reflector, as seen by an Earth station, attains an absolute extremum.

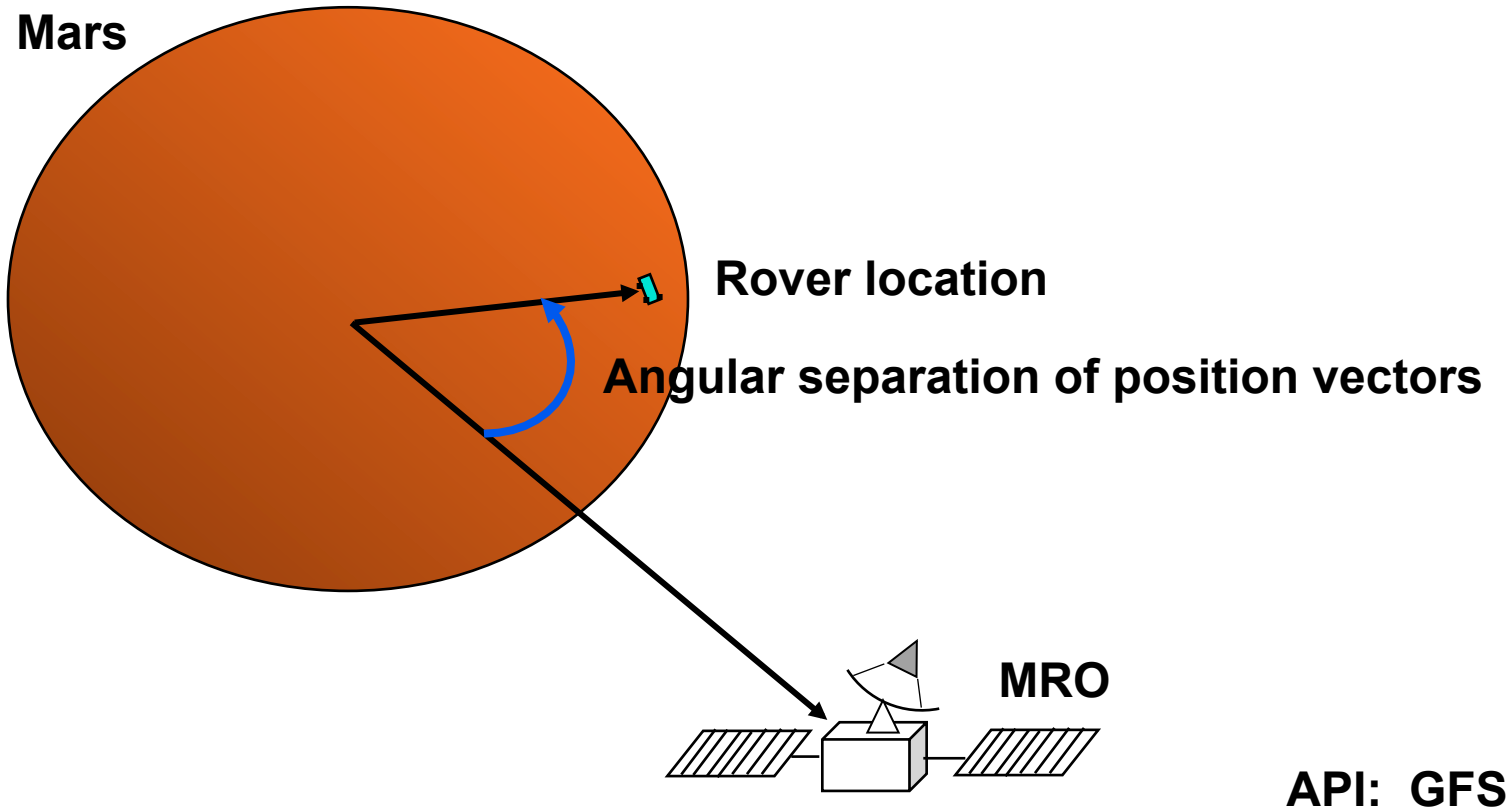


API: GFRR

Angular Separation Inequality

Navigation and Ancillary Information Facility

Find the time periods when the angular separation of the Mars-to Mars Reconnaissance Orbiter (MRO) and Mars-to-Opportunity Rover position vectors is less than 3 degrees. Both targets are modeled as points.

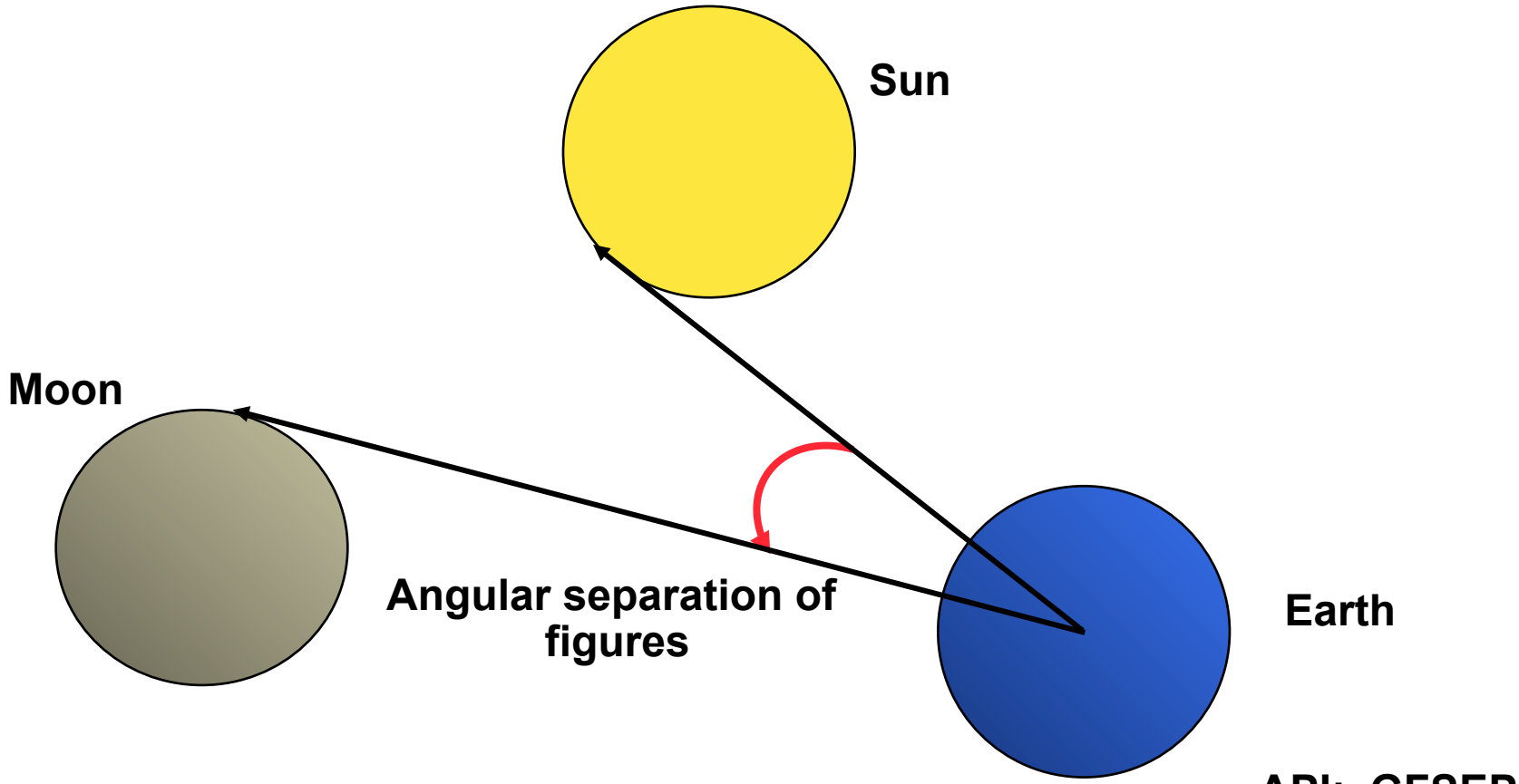


API: GFSEP

Angular Separation Inequality

Navigation and Ancillary Information Facility

Find the time periods when the angular separation of the figures of the Moon and Sun, as seen from the Earth, is less than 1 degree. Both targets are modeled as spheres.

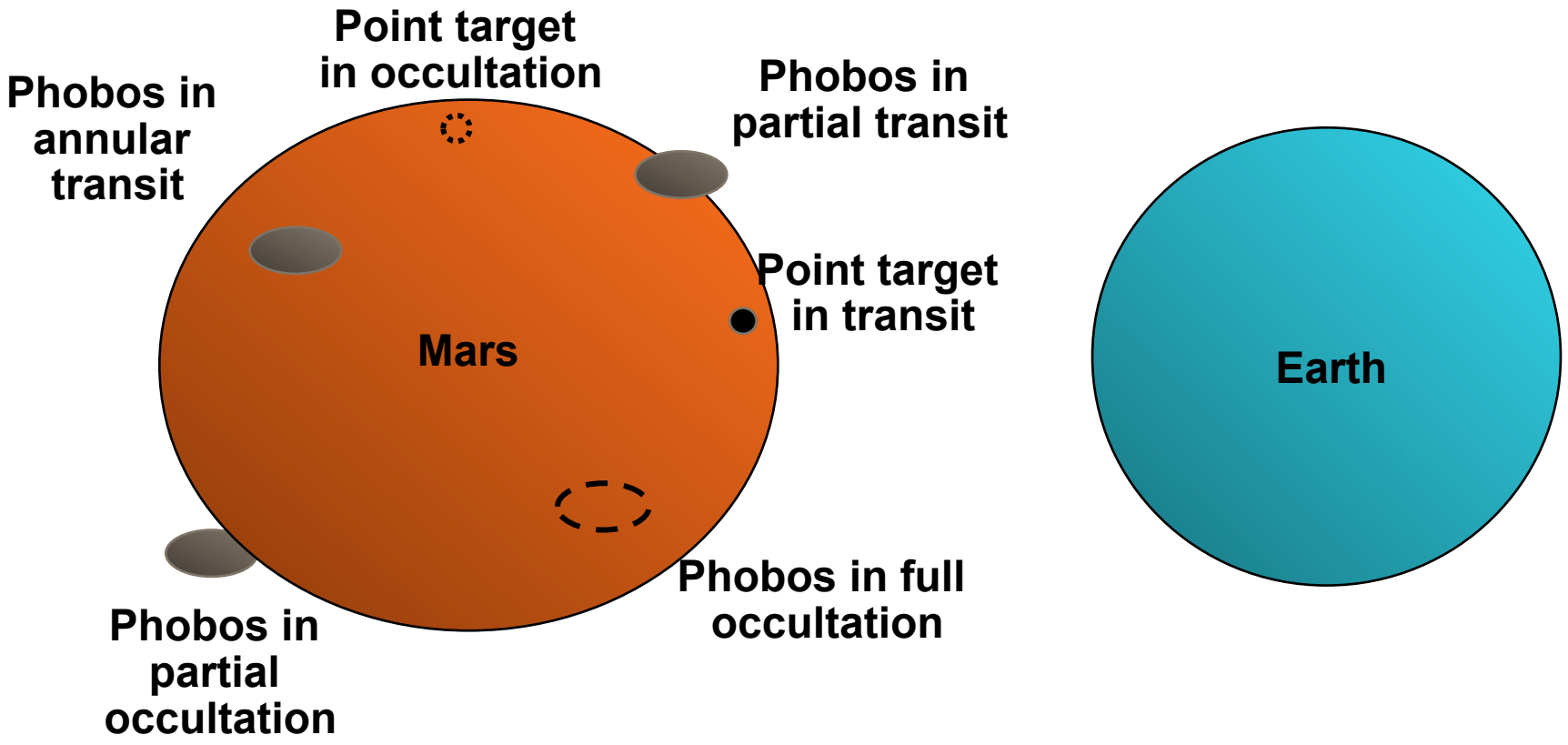


API: GFSEP

Occultation/Transit Search

Navigation and Ancillary Information Facility

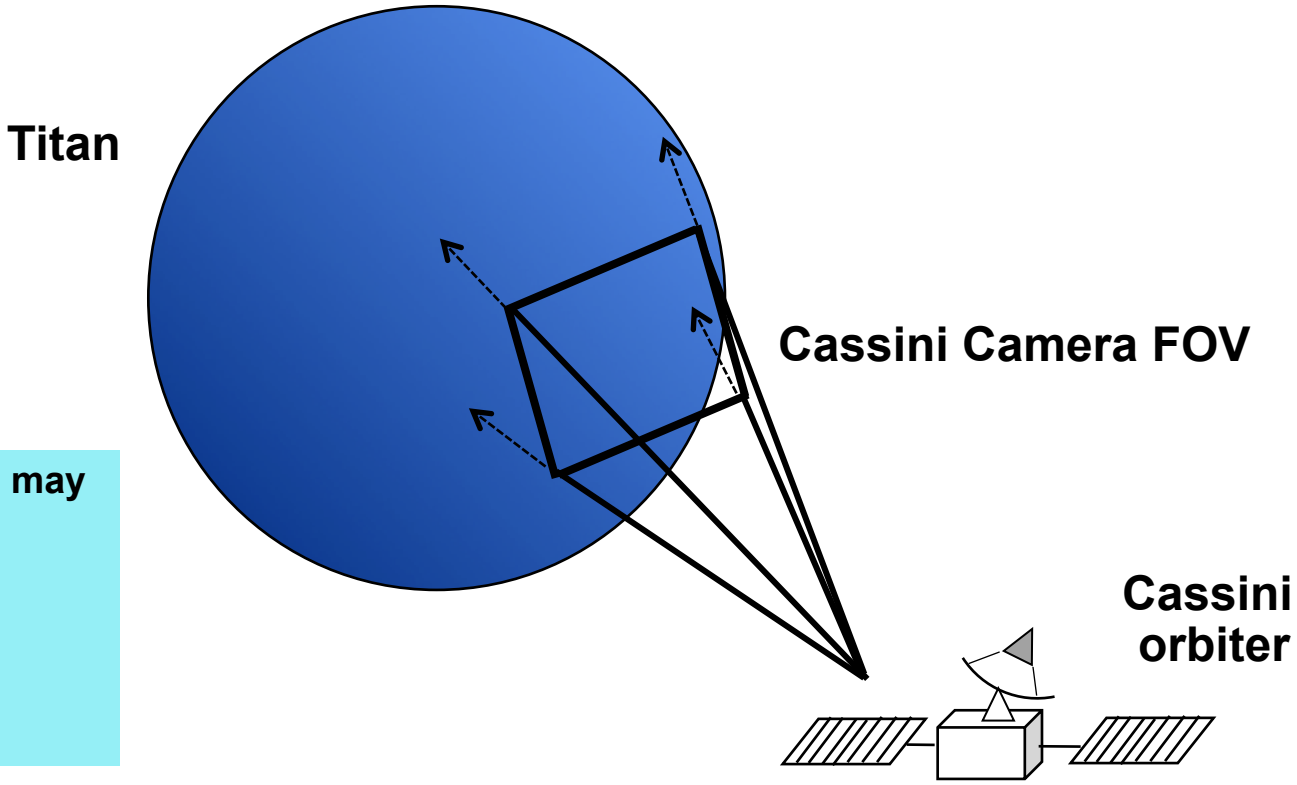
Find the ingress and egress times of an occultation of Phobos by Mars, as seen from Earth. Both targets are modeled as triaxial ellipsoids.



API: GFOCLT

Target in Field of View

Find the time periods when Titan appears in the FOV of the Cassini ISS Narrow Angle Camera (NAC). The target is an ephemeris object; the target shape is modeled as an ellipsoid. (Point targets are also supported.)



The FOV shape may be any of:

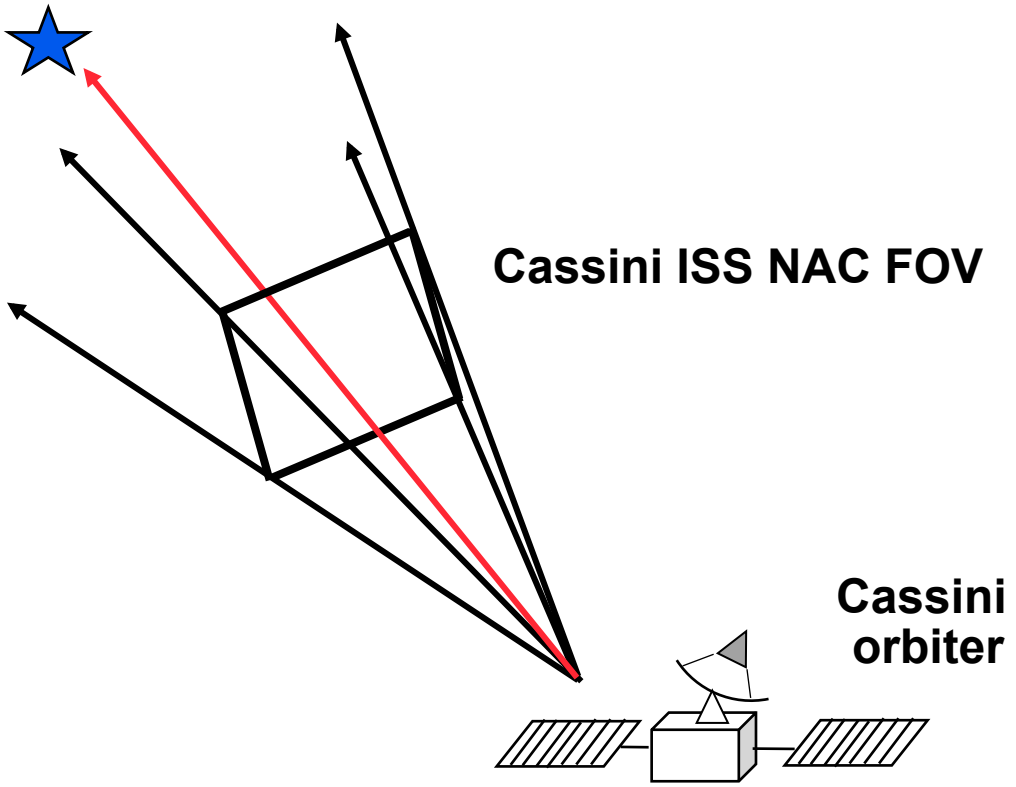
- **Rectangle**
- **Circle**
- **Ellipse**
- **Polygon**

API: GFTFOV

Ray in Field of View

Navigation and Ancillary Information Facility

Find the time periods when a ray pointing at a star having appears in the FOV of the Cassini ISS Narrow Angle Camera (NAC).



The FOV shape may be any of:

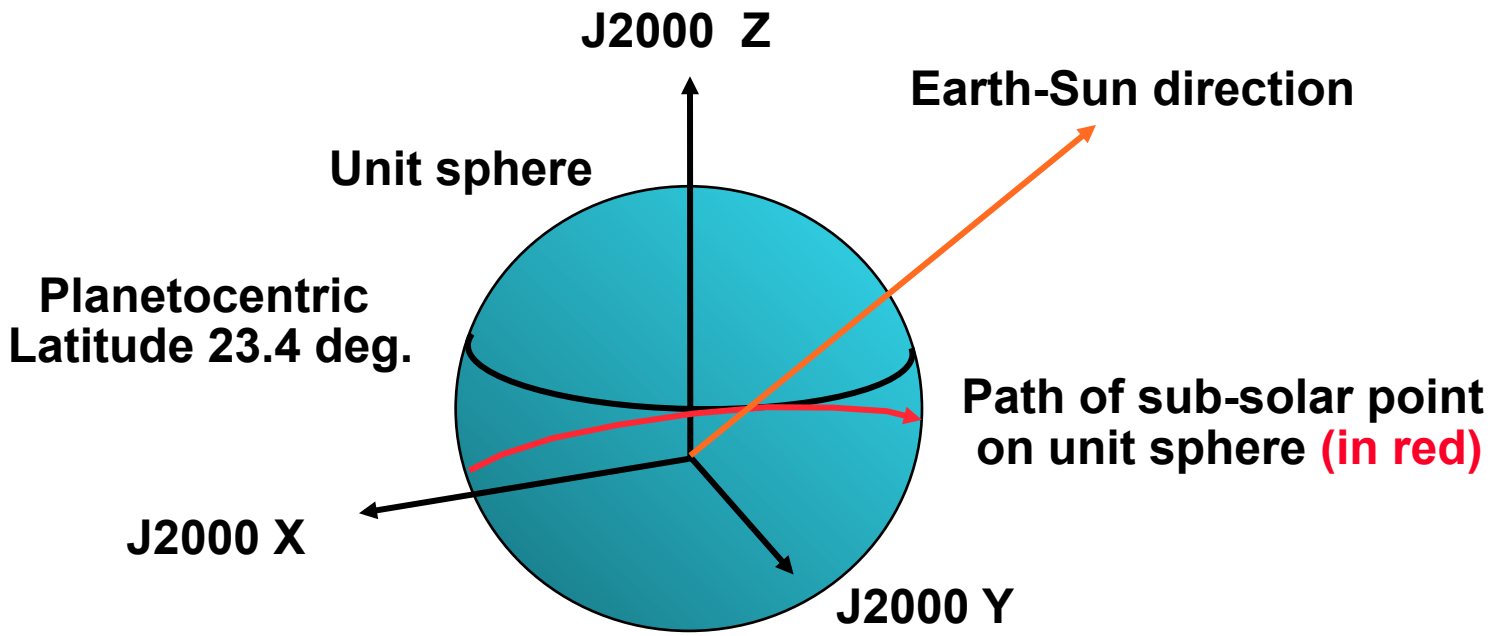
- Rectangle
- Circle
- Ellipse
- Polygon

API: GFRFOV

Position Coordinate Local Extremum Search

Navigation and Ancillary Information Facility

Find the time(s) at which the planetocentric latitude of the Earth-Sun vector, expressed in the J2000 frame, is at a local maximum.

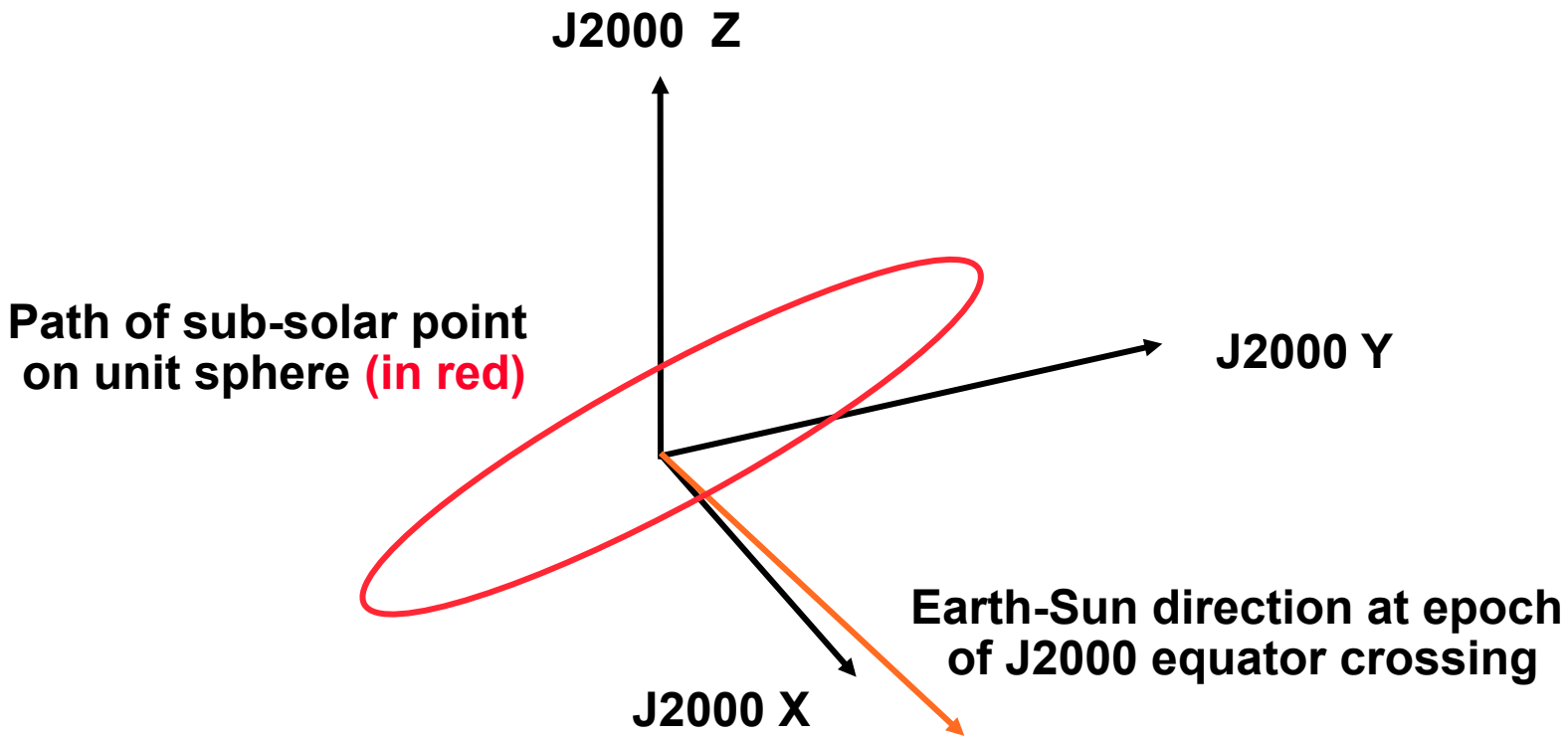


API: GFPOSC

Position Coordinate Equality Search

Navigation and Ancillary Information Facility

Find the time(s) at which the Z component of the Earth-Sun vector, expressed in the J2000 frame, is 0.

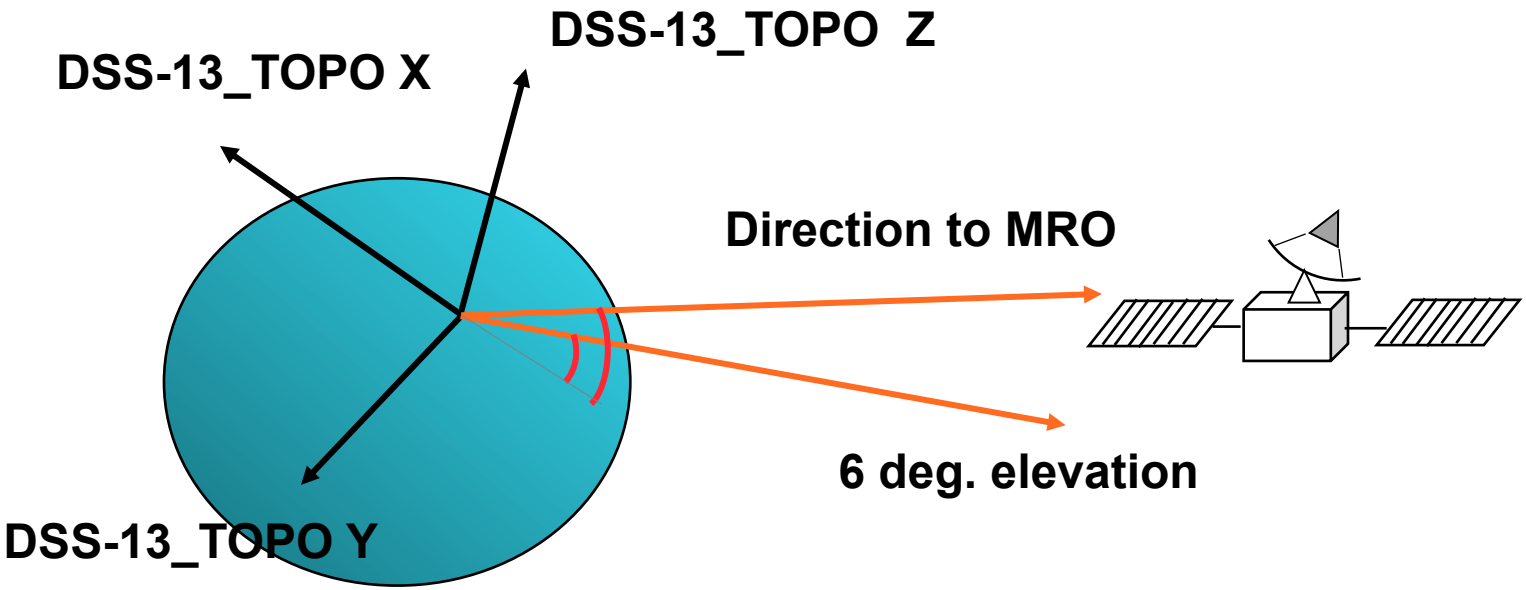


API: GFPOSC

Position Coordinate Inequality Search -1

Navigation and Ancillary Information Facility

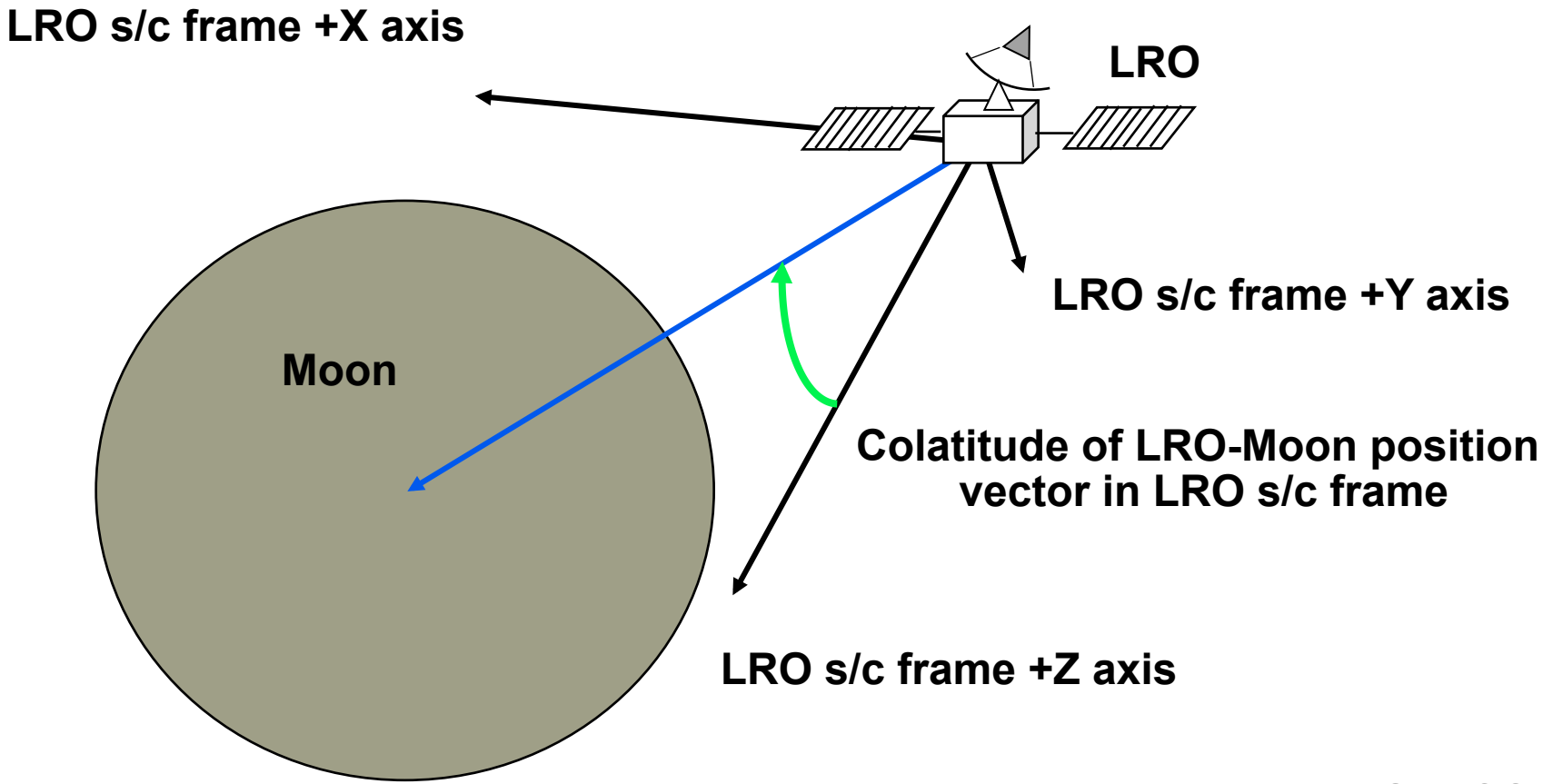
Find the time periods when the elevation of the DSS-13 to Mars Reconnaissance Orbiter (MRO) spacecraft vector, expressed in the DSS-13 topocentric frame, is greater than 6 degrees.



API: GFPOSC

Position Coordinate Inequality Search -2

Find the time periods when the Lunar Reconnaissance Orbiter's (LRO) off-nadir angle exceeds 5 degrees.

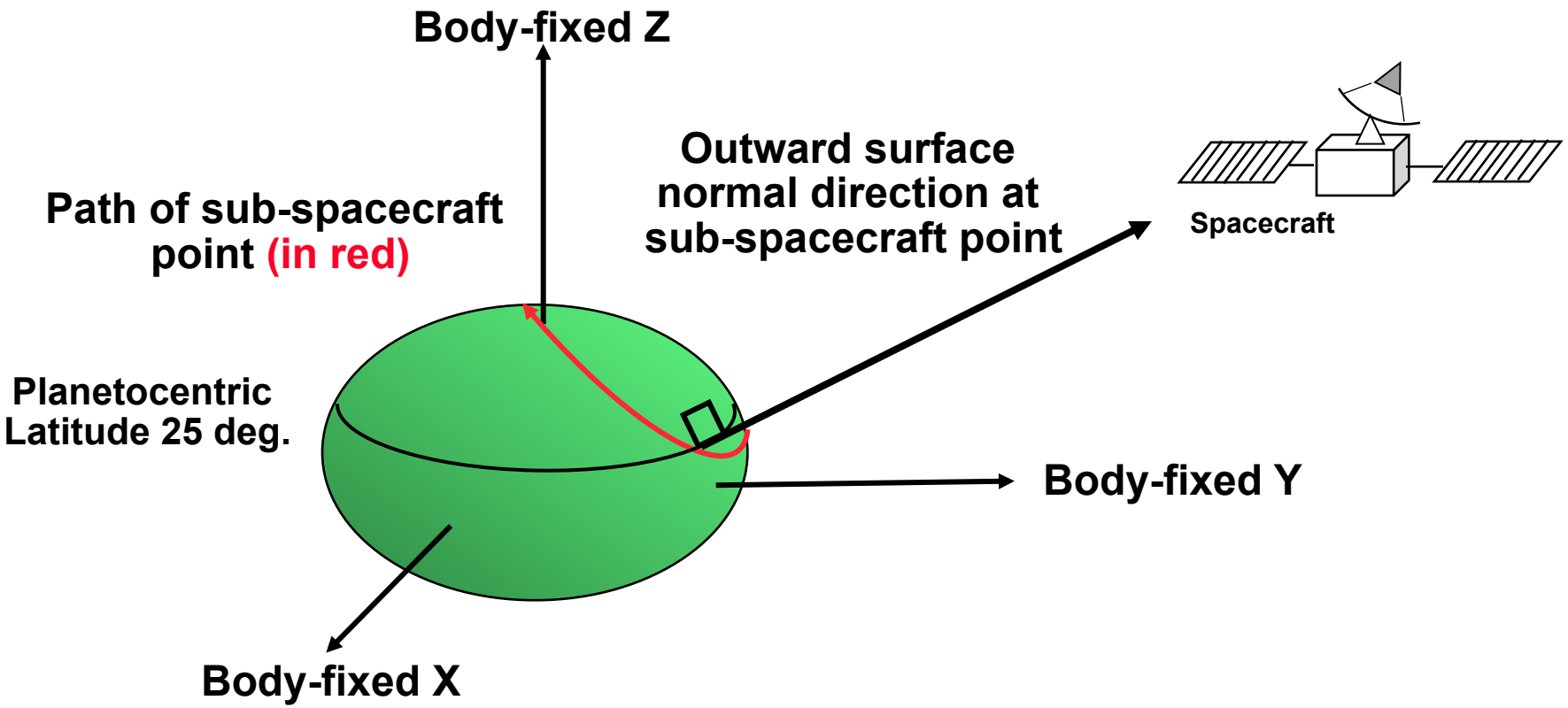


API: GFPOSC

Sub-Observer Point Coordinate Equality Search

Navigation and Ancillary Information Facility

Find the times at which the planetocentric latitude of the sub-spacecraft point is 25 degrees.

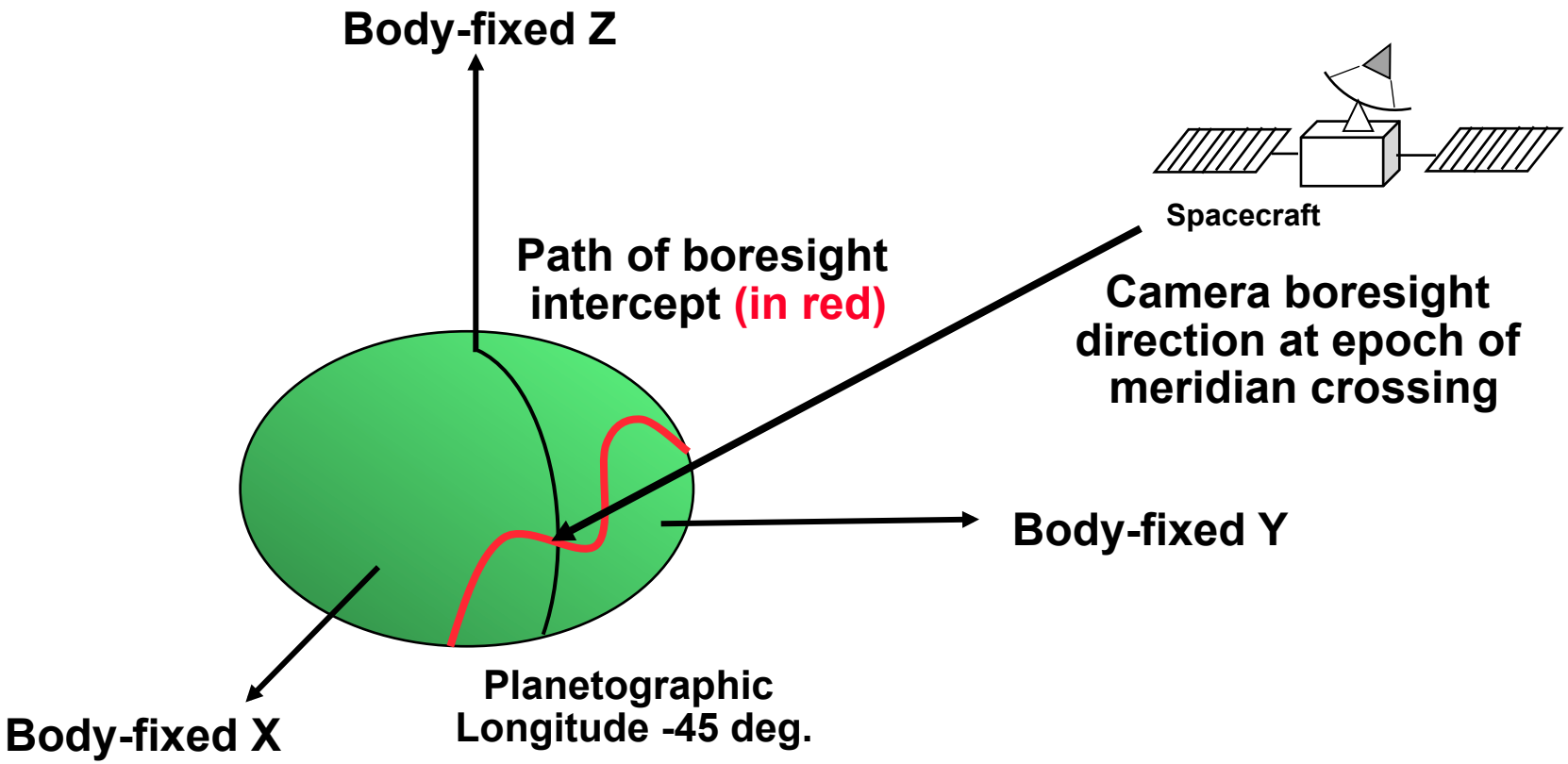


API: GFSUBC

Surface Intercept Coordinate Equality Search

Navigation and Ancillary Information Facility

Find the times at which the planetographic longitude of a given camera boresight surface intercept is -45 degrees.



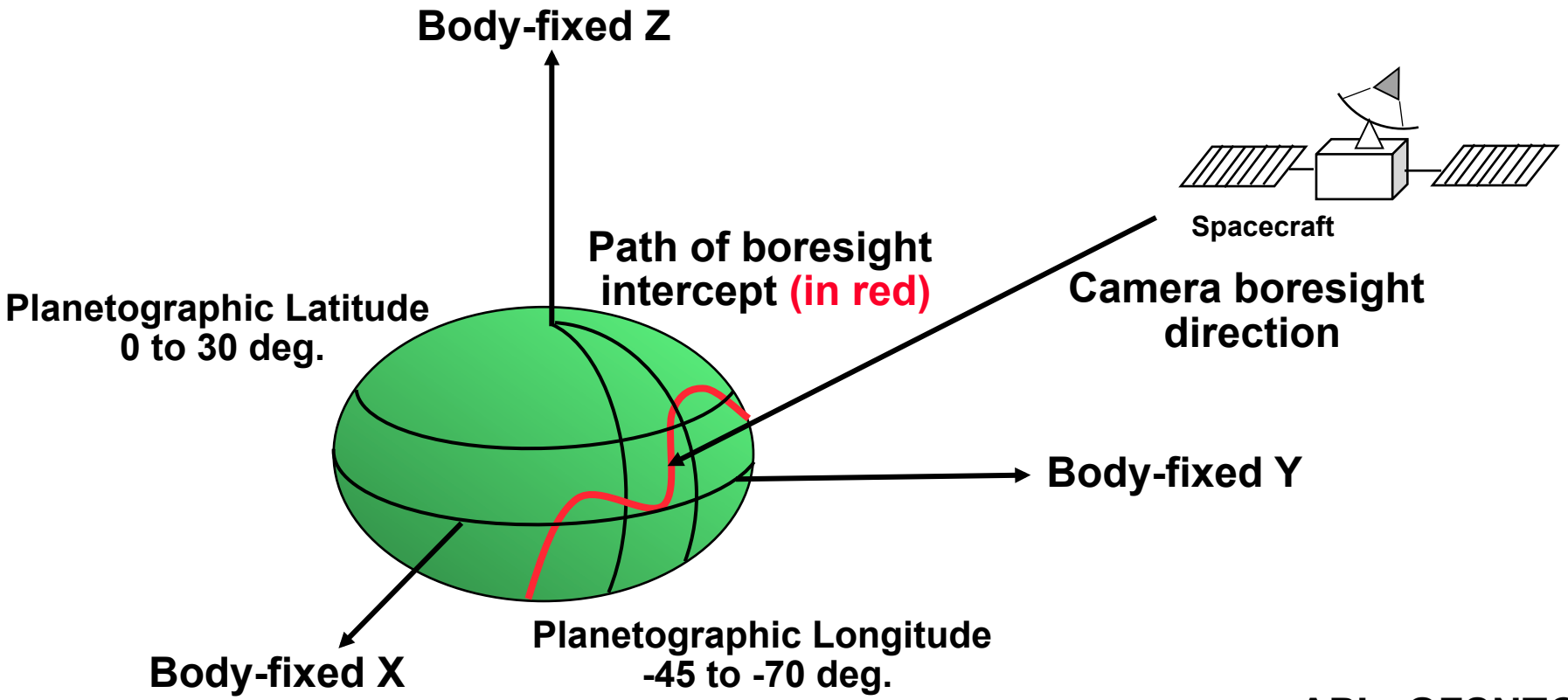
API: GFSNTC

Surface Intercept "Box" Search

Navigation and Ancillary Information Facility

Find the time periods when the planetographic longitude of a given camera boresight surface intercept is between -70 and -45 degrees, and the intercept latitude is between 0 and 30 degrees.

The solution requires four (cascading) inequality searches.



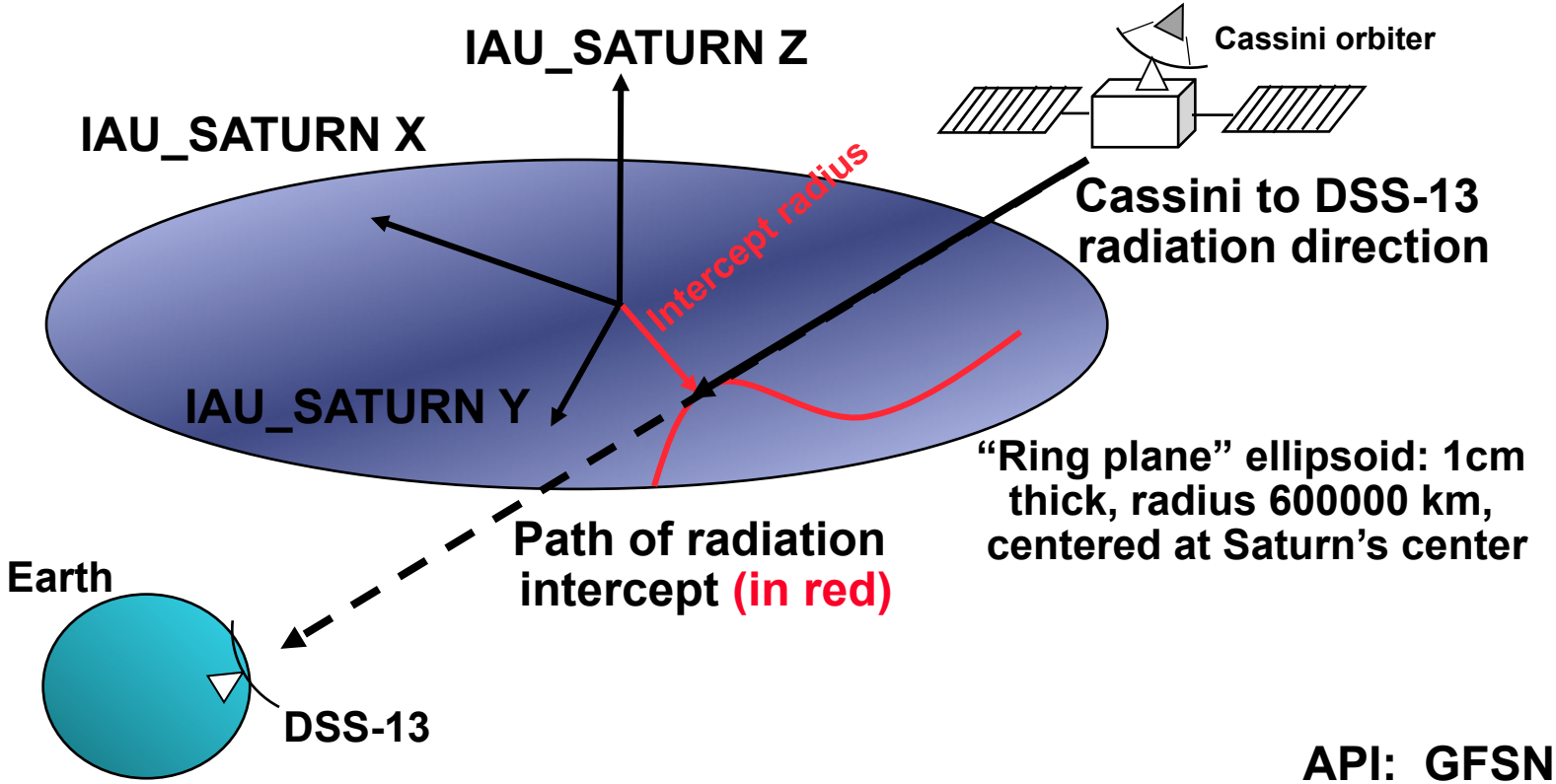
API: GFSNTC

Surface Intercept Coordinate Equality Search

Navigation and Ancillary Information Facility

Find the times at which the ring plane intercept of the Cassini to DSS-13 vector, corrected for transmission light time (stellar aberration correction is unnecessary), has radius 300,000km.

The solution requires a SPICE dynamic frame for which one axis points along the radiation path.

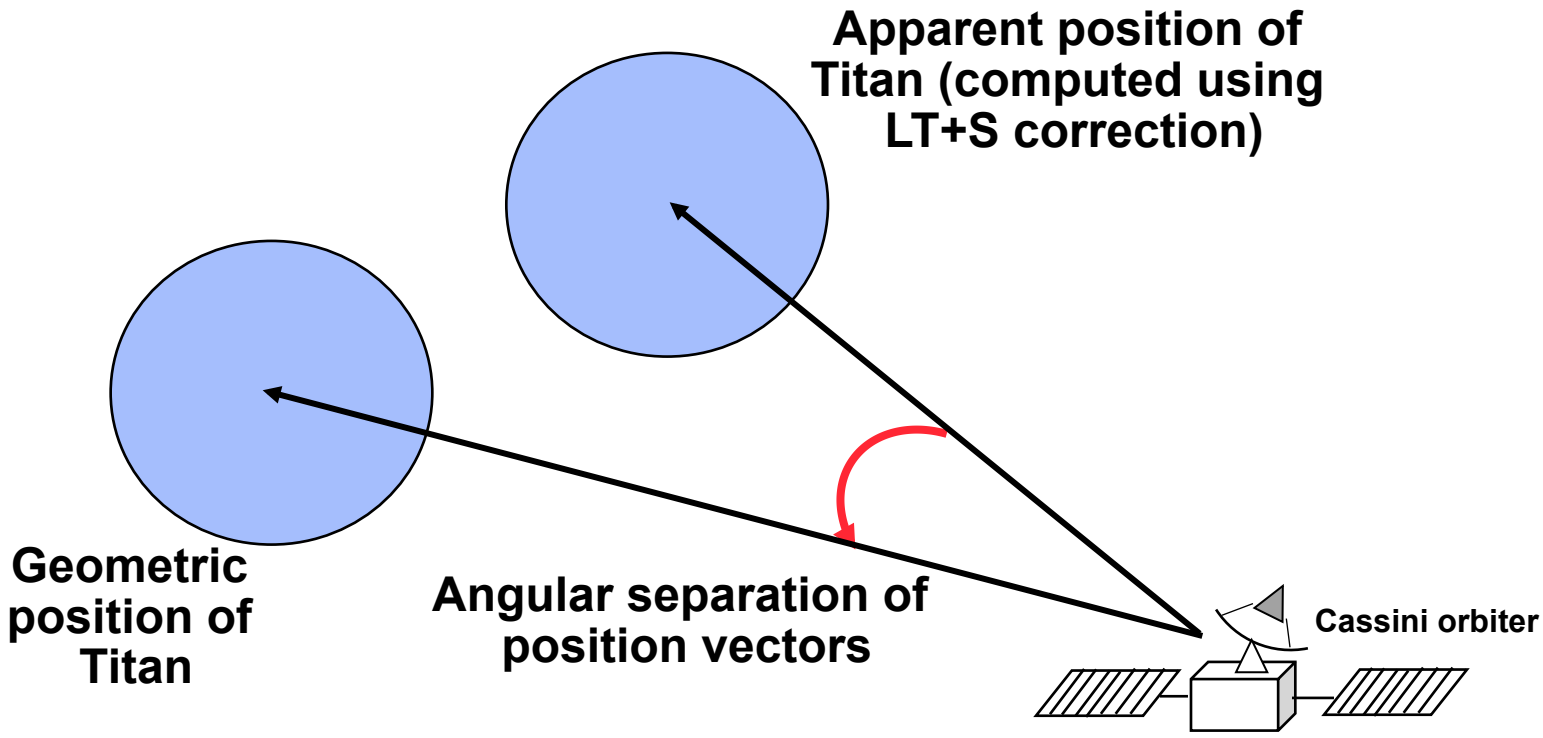


API: GFSNTC

User-Defined Quantity Extremum Search

Navigation and Ancillary Information Facility

Find the time periods when the angular separation of the geometric and apparent positions of Titan as seen from the Cassini orbiter attains an absolute maximum.



API: GFUDS