A Challenging Example of Using WebGeocalc (WGC)

When will the MER-1 Rover ("Opportunity") be in Phobos' Shadow?

March 2018
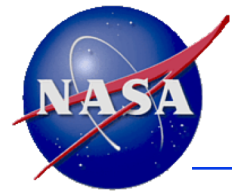
Introduction

- **This set of charts presents an example of using NAIF's WebGeocalc tool to make a multi-step geometry computation using WGC.**

- **The backup section of this presentation illustrates how improper choices for some parameters can lead to erroneous results.**

- **If you haven't already done so, first try using the tutorial providing some easy examples of using WGC (wgc_easy_usage_example).**

- **You'll need some understanding of SPICE concepts and terminology to make sense of this tutorial.**

Your Problem Statement

- **You wonder if the shadow of Phobos passed over the MER-1 rover ("Opportunity").**
    - **This could be stated as "Did Phobos (partially) occult the sun as seen from MER-1?"**
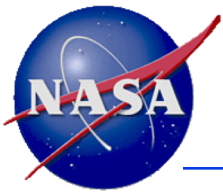

Mars' ephemeris

Mars' spin axis

MER-1 Rover (Opportunity)

Mars

Phobos' ephemeris

Sun

3
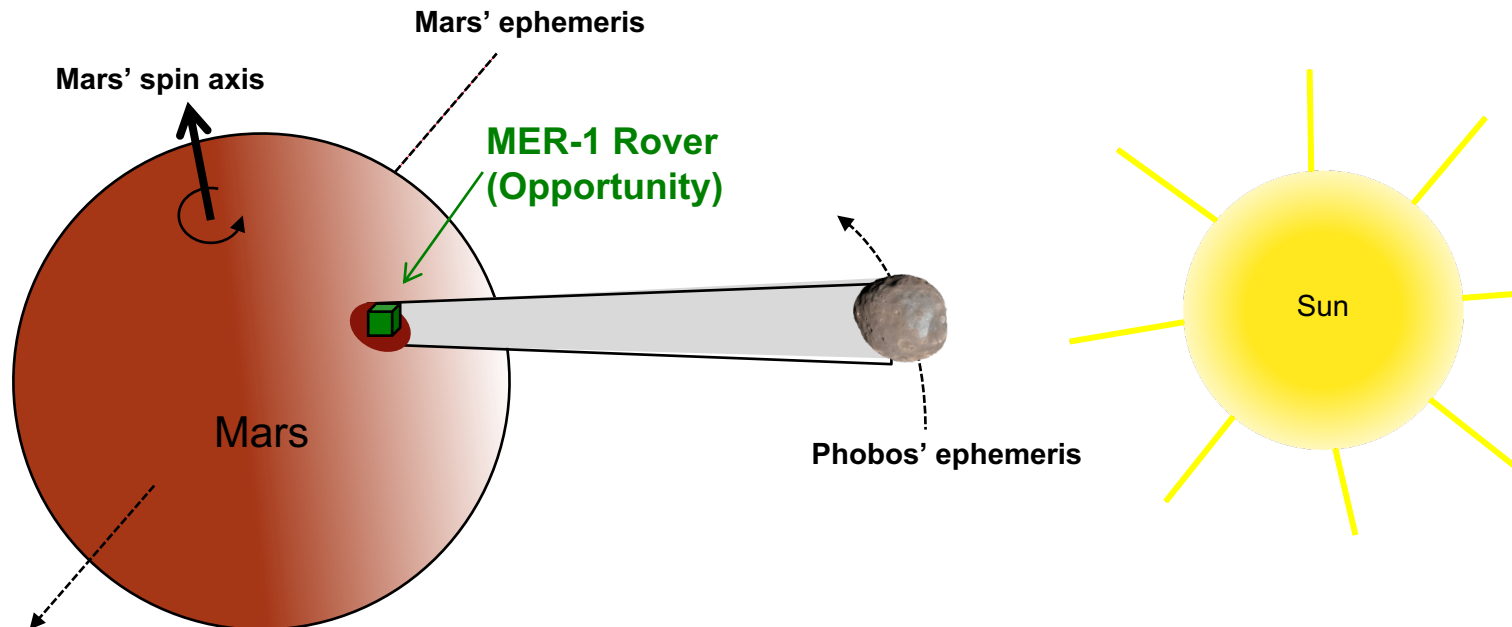
Try the "Obvious" Approach

Navigation and Ancillary Information Facility

- **Select the Occultation Finder calculation.**
- **Load the MER-1 Rover (Opportunity) kernel set.**
- **Select "Any" occultation type.**
- **Select Phobos as the front body.**
  - WGC automatically picks "Ellipsoid" as the shape, since a "point" can't occult something.
- **Select IAU_PHOBOS as the front body frame.**
- **Select the sun as the back body, with ellipsoidal shape and IAU_SUN as the reference frame.**
- **Select MER-1 as the observer.**
- **Select light propagation "To observer" to account for one-way light-time effects. Leave the LT algorithm set to "Converged Newtonian."**
- **Use the UTC time system, with calendar format.**
- **Specify the confinement window over which to search: Start: 2004 Jan 27   Stop: 2014 Jan 26**
  - You can find the MER-1 landing time using Google: start just after that time, thus about 2004 Jan 27
  - Hover your cursor over the MER-1 kernel set name to see how late the archive goes: pick a stop time no later than that. (For this example let's pick ten years after landing–2014 Jan 26)
- **Picking step size is not straightforward: you rather arbitrarily select one day.**
- **Any occultation won't last long, so in the "Result Window" panel select "minutes" for the output time units; leave the other settings unchanged.**
- **At the bottom-left press "Calculate" and see what happens (next page).**
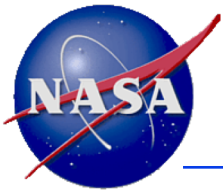
No Results

The calculation generated no result rows.

- **You got no results. Does this mean Phobos' shadow never passed over MER-1 during this time period?**

- **Maybe the step size of one day was too long?**

- **Try a one hour step size instead. (This takes a bit longer to run.)**
  - **You get the same result: "no result rows."**

- **Try a step size of ten minutes. (Takes longer, still.)**
  - **Finally you get one interval**

	Start Time	Stop Time	Duration (mins)
1	2004-03-07 18:29:59.932668 UTC	2004-03-07 18:30:35.804342 UTC	0.59786123

- **You wonder, is that really the only occultation in ten years?**
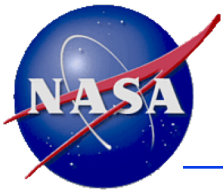
- **Maybe try 1 minute as the step size?**

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You Keep Trying

- **You try a step size of one minute.**

Time step is too small. This version of WebGeocalc requires the time step to be at least 1.0E-6 times the size of the time window. The requested time step is only 1.9015455581650895E-7 times the size of the window. Either specify a smaller time range or a larger time step.

- **You've got a new problem… you've asked WGC for more time steps than it allows, as configured by NAIF.**

- **You could keep adjusting the step size, trying to find one that is allowed by WGC. But you'll miss some occultations if it's not small enough.**

- **You could break the search window (the confinement window) into several chunks, trying each one with a sufficiently small step size.**

- **But there is a better approach…**

Use a Cascading Search

- **Try using a "cascading" search.**
    - **Do a first, quick search based on angular separation to find rather short time intervals within your original confinement window when occultations might be possible.**
    - **Then use those resulting intervals as inputs to a second search–the occultation search computation.**
        - » **For the second search you'll be searching over a much smaller total time span (the confinement window), so you can use the small step size needed without running up against the WGC limit on the number of steps.**
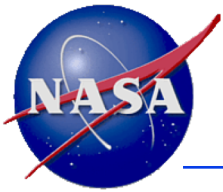
First of Two Searches

- **First use the Angular Separation Finder to find times when the angular separation of Phobos and the sun as seen from MER-1 is fairly small.**

  – **This kind of search runs rather quickly, and it narrows down the time intervals you need to search for an occultation.**

  – **WGC allows you to easily save the result intervals from the angular separation search and use them as the input intervals for the occultation search.**
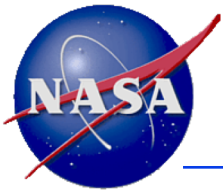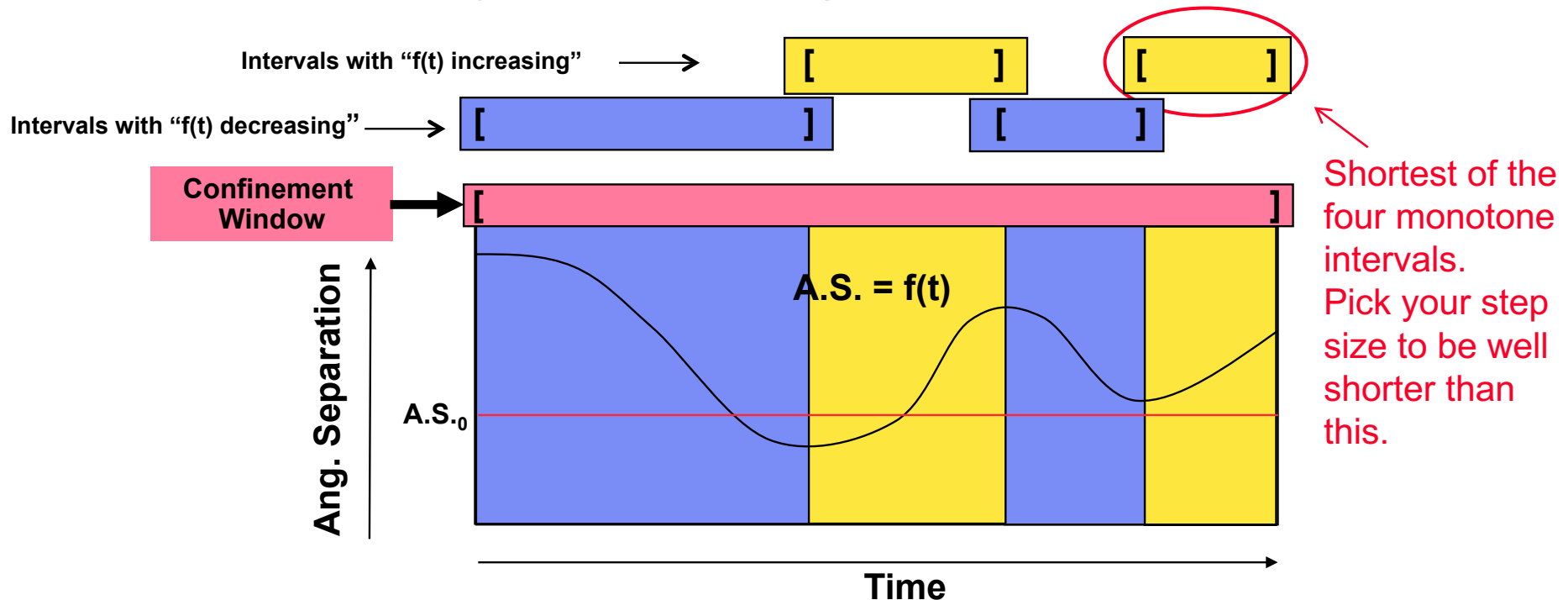
Angular Separation Finder Setup - 1

- Select the **Angular Separation Finder** computation.

- Select Phobos as one target and the sun as the other target. Since you'll be looking for rough results you can leave the shapes set to "Point."

- MER-1 is already selected as the observer: good.

- Again, because you're looking for only rough results you could ignore aberration corrections. But since the "To observer" selection remains from your previous search, it's ok to leave it that way. (And you'll want to use this selection in subsequent work anyway.)

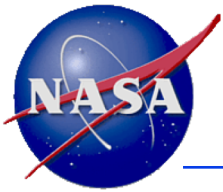- The Start and Stop times you input earlier are still there: good.
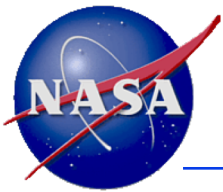
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- **Picking an appropriate step size takes some thought!**
- **Page 53 of the Geometry Finder tutorial states:**

"For numeric searches… the step size must be shorter than any interval on which the function is monotonically increasing or decreasing."

- **This is illustrated below (for an arbitrary separation angle–not the Phobos-sun angle of our example).**
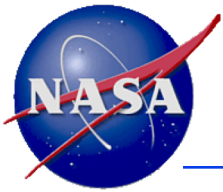
Intervals with "f(t) increasing"

Intervals with "f(t) decreasing"

Confinement Window

A.S. = f(t)

A.S._0

Ang. Separation

Shortest of the four monotone intervals. Pick your step size to be well shorter than this.

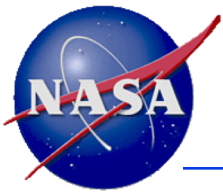Time

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Navigation and Ancillary Information Facility

- **You need to pick a step size that is shorter than the shortest time interval over which the angular separation of Phobos and the sun as seen from MER-1 is either monotonically (continuously) increasing or monotonically decreasing.**

- **How can this be determined? Two methods.**

  1. **Of all the objects involved (Phobos, Sun, Mars and MER-1), use your own knowledge and/or available resources to decide which one's motion has the shortest periodicity; pick a number substantially smaller than half of that.**

  2. **Use WGC's "Angular Separation" calculation with its associated plot to determine periodicity, then pick a number substantially smaller than half of that.**
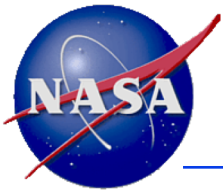
Independent Periodicity Analysis Approach

- **Mars moves very slowly around the sun, so this motion has a LONG period.**

- **MER-1 is roving on Mars, but very slowly and very little, so its motion has no real periodicity.**

- **Mars is rotating. Check any available resource to find Mars' rotation rate – it's a little longer than one earth day (24 hours).**

- **Phobos orbits Mars in a little over 7 hours.**

- **Thus, Phobos' orbital motion has the shortest period of all motions involved in this example.**
  - **You might pick a step size as something less than half of that 7 hours– let's say <u>3 hours</u> to give some safety margin.**

- **The next page explains an alternative method for picking a safe step size.**

WGC Angular Separation Analysis Approach

- **Use WGC's "Angular Separation" calculation to find the separation of Phobos and the sun as seen from MER-1. Check the "Angular Separation" time series box near the bottom as you'll want to examine the plot of angular separation versus time to determine what is the shortest monotone interval.**

- Caution: you need to compute and plot the angular separation value at a high enough frequency to be confident you can determine what is the shortest monotone duration.

- Read on for more…

Angular Separation Results
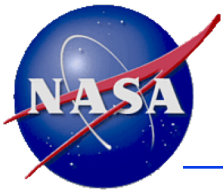
- **You'll need to compute and plot angular separation using a small step size. To allow WGC to do this you'll have to run the computation over a short time span, and assume this will be representative of any time within your confinement window.**

- **As an example, try:**
  - **Start: 2004 JAN 27, Stop: 2004 JUN 26, Step: 10 minutes**

- **You see a dense plot, but after zooming in a bit you'll see something like this.**
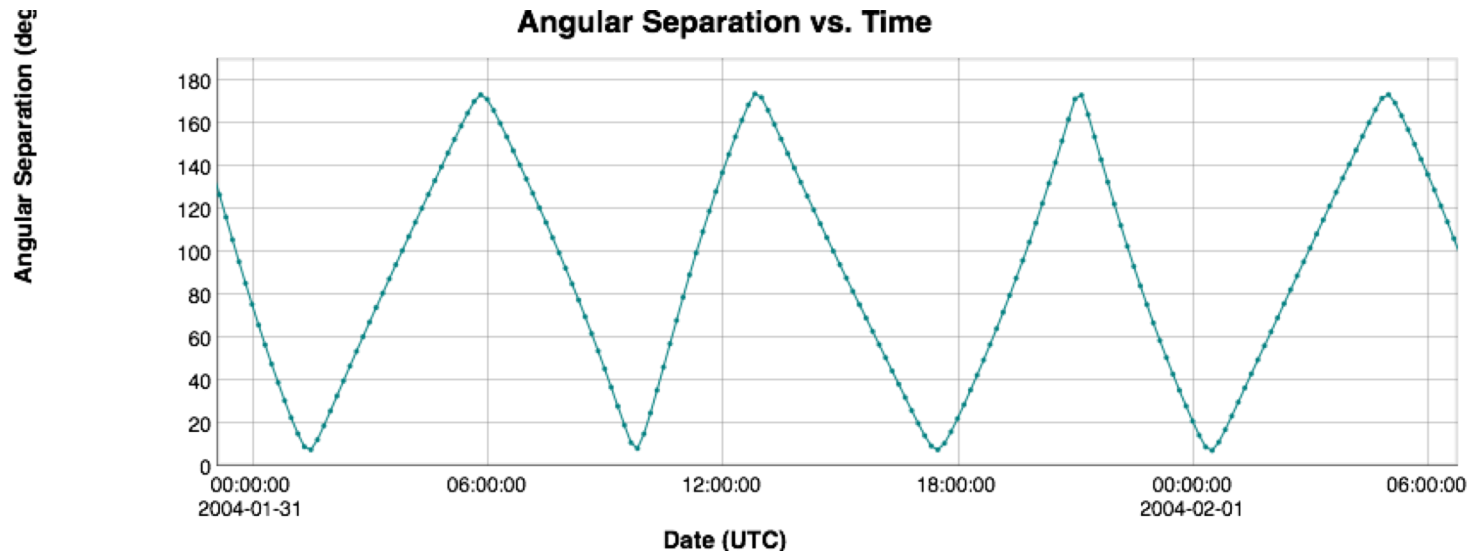
- **There are enough data points to let you determine the duration of monotone intervals. There is some variation, but with a bit of examination you can see the shortest monotone interval is on the order of 180 minutes (3 hours). To be safe, pick 2.5 hours as the step size.**

Results for Picking the Step Size

- **Just considering the periodicities of our problem, we came up with a step size of 3 hours.**

- **Examining the actual angular separation over time, we came up with a step size of 2.5 hours.**

- **Let's try 2.5 hours in the Angular Separation Finder calculation.**

- **Now, let's get back to setting up that calculation…**
  - **Re-check all the previously selected inputs, most especially the start and stop times.**
    - » **Start: 2004 Jan 27**
    - » **Stop: 2014 Jan 26**
    - » **Step size: 2.5 hours**
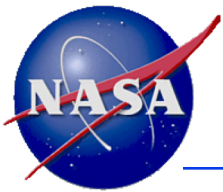
Navigation and Ancillary Information Facility

- **For the separation condition, select "is less than" and choose 5 degrees as the value.**
  - **A more precise value would be found by using the "Angular size" calculation to find the sizes of Phobos (0.25 deg) and the sun (0.4 deg) as seen from MER-1, add these together, and then pick a slightly larger number… say 1 degree.**

- **Select "minutes" for Output time units in the "Result Window" pane.**

- **Don't use "Complement," "Adjust endpoints" or "Filter."**

- **Press Calculate. It will take two or more minutes to get your results; be patient.**
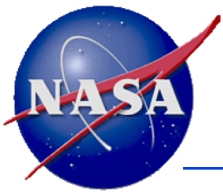
Angular Separation Results

- **You get 1564 result rows and a corresponding plot.**
- **Press the "Save All Intervals" button.**
  - You'll see those intervals saved in the upper-right "Saved Values" field.
 - You'll now use these as the input times for the occultation search.
- **Press the "Calculation Menu" button and then select the "Occultation Finder" calculation.**
- **You can see all the previous inputs you used are still selected.**
  - This is mostly ok, but you need to use the time intervals you just saved as the time inputs.
- **Click the "List of intervals" radio button.**
- **Click and hold on your saved intervals in the upper-right and drag them to the "List of intervals" fill-in box.**
- **Note that the time step is still set to 1 minute. (This might be too long.)**
- **Select "Seconds" for "Output time units."**
- **Press calculate.**

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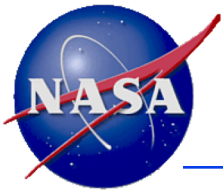
Found Occultations

- ## You found 29 occultation intervals.
  - (You'll need to scroll to the bottom of the Tabular Results window to see this.)

- ## Maybe the step size of one minute is too large?
  - **Try 10 seconds.**
    - » **You get 76 intervals, so the one minute step size was definitely too long.**
      - **Interval durations range from around 11 to around 42 seconds.**
  - **Try 1 second. (Be patient!)**
    - » **You again get 76 intervals, so the 10 second step size was ok.**
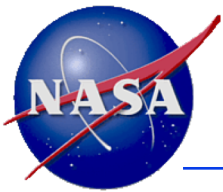
But Wait–What Kind of Occultations?

- **You used "Any" as the occultation type in the previous occultation searches.**

- **Maybe you only want to find "annular" occultations, where ALL of the figure of Phobos is in front of the sun, thus not accepting partial occultations when the Phobos image grazes the edge of the sun. If so, do the next step, below.**

- **Select "Annular" as the occultation type and repeat the occultation search. Go back to using 10 seconds as the step size. Press "Calculate."**
  - **You see 31 result rows, so we know some of the original 76 occultations were partial ("grazing").**
  - **You decide to work with just the 31 annular occultations.**
    - » **The occultation durations range from about 3 to about 22 seconds.**

- **To be sure you have all the annular occultations, repeat the occultation search using a 1 second step size.**
  - **This time you get 35 annular occultation intervals.**
    - » **The occultation durations still range from about 3 to about 22 seconds.**
  - **Trying to confirm this by using a still smaller step size doesn't work with WGC as currently configured: you'll see the "Too many steps" error message.**
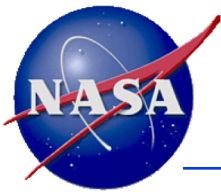
Maybe Mars is in the Way?

- **Maybe Phobos is over the horizon as seen from MER-1?**
    - **The occultation search doesn't consider this condition.**
- **Click "Save all intervals" to save the 35 previously found annular occultation intervals to use as inputs for computing the declination of Phobos as seen from MER-1, in MER-1's topocentric reference frame. (See the next page.)**
    - **If Phobos' declination is less than 0 degrees, Phobos is out of view and so Phobos' shadow cannot fall on the MER-1 rover.**
        - » **(Yes, we're ignoring local terrain considerations!)**

Positive declination

Negative declination

MER-1

Local level

Mars

Phobos

Sun
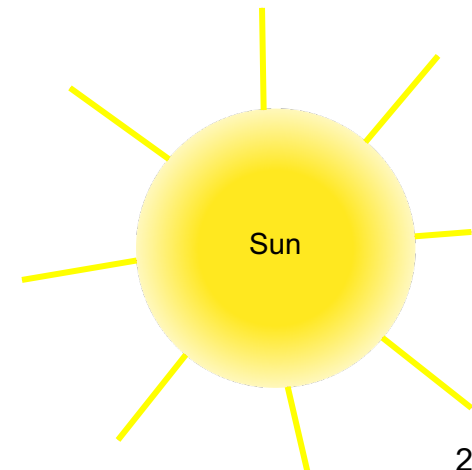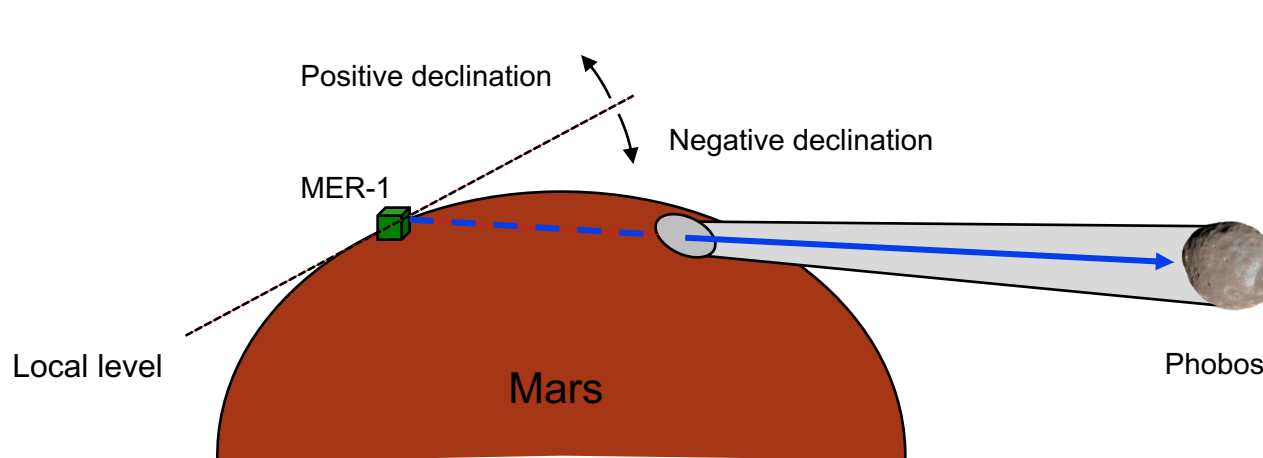
When Is MER-1 in Phobos' Shadow?

Navigation and Ancillary Information Facility

- Select the **Position Finder** calculation.

- Select Phobos as the Target.
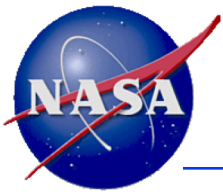
- MER-1 remains selected as the Observer; good.

- Select MER-1_TOPO as the reference frame.
  - This is a topocentric frame, centered at the MER-1 rover on the surface of Mars.

- Continue to use "Converged Newtonian" and "To observer" for the aberration correction specifications.

- Select "List of intervals." Delete the data currently in this field.
  - As example, use Ctrl-A to select all entries and press your delete key.

- Drag to the "List of intervals" box the 35 intervals you found using "annular" occultation type.

- Since the declination of Phobos will change very little over any occultation interval, and since the search will always include the beginning and end of each search interval, the step size you use is not important: pick 1 minute.

- Select "Right ascension, declination, range" as the Coordinate system. Select "Declination" "is greater than" and zero degrees as the value. Press "Calculate."
  - You're looking for times when the declination of Phobos as seen by MER-1 is > 0.

- The Tabular Results box shows 14 intervals, ranging from about 2 to 12 seconds in length.
  - You could use the "Download Results" button to download these interval times/durations for use elsewhere.
  - You could use the "Save All Intervals" button to save these results for use in another WGC calculation.

Some confirmation and Further Information

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- **You could come up with some confirmation of your results, plus some additional information that might be helpful.**

- **Select the State Vector calculation.**

- **Phobos remains selected as the Target; good.**

- **MER-1 remains selected as the Observer; good.**

- **Select MER-1_TOPO as the reference frame.**
  - **This is a topocentric frame, centered at the MER-1 rover on the surface of Mars.**

- **Select "List of intervals." If needed, clear out any data in this field.**
  - **As example, use Ctrl-A to select all entries and press your delete key.**

- **Drag to the "List of intervals" box the 35 intervals you found using "Annular" occultation type.**

- **In order to make calculations only for the beginning and end points of each of the 35 annular occultation intervals, select a step size longer than the longest occultation interval, which was about 22 seconds. Pick 30 seconds or longer.**

- **Select "Right ascension, declination, range" as the State representation. Check the "Declination" plot box. Now press "Calculate."**
  - **You're looking for times when the declination of Phobos as seen by MER-1 is > 0.**

- **The Tabular Results box shows 70 RA/DEC calculations, one pair for each of your 35 input interval Begin and End times.**
  - **As shown in the tabular results, and in the plot (see next page) , only fourteen of the pairs or sets of times have a declination greater than zero, matching the results from use of the Position Finder calculation. One additional, negative declination pair comes very near to zero declination.**

Plot of Declination Using State Vector

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Fourteen real occultations, those having positive declination of Phobos as seen from the MER-1 rover

Declination vs. Time

One occultation with almost zero declination. Depending on local topography, MER-1 might have seen Phobos' shadow at this time.