Observation Planning Made Simple with Science Opportunity Analyzer (SOA)

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Abstract:

As NASA undertakes the exploration of the Moon and Mars as well as the rest of the Solar System while continuing to investigate Earth's oceans, winds, atmosphere, weather, etc., the ever-existing need to allow operations users to easily define their observations increases. Operation teams need to be able to determine the best time to perform an observation, as well as its duration and other parameters such as the observation target. In addition, operations teams need to be able to check the observation for validity against objectives and intent as well as spacecraft constraints such as turn rates and acceleration or pointing exclusion zones. Science Opportunity Analyzer (SOA), in development for the last six years, is a multi-mission toolset that has been built to meet those needs. The operations team can follow six simple steps and define his/her observation without having to know the complexities of orbital mechanics, coordinate transformations, or the spacecraft itself.

SOA is a multi-mission tool developed in Java using the Navigation and Ancillary Information Facility (NAIF) files containing spacecraft trajectory as well as other spacecraft and planetary information. SOA has six major functions: Opportunity Search, Observation Design, Visualization, Data Output, Constraint Checking (Flight Rules) and Communications. Each of these functions performs a specific task. Opportunity Search allows the operations person to find specific geometric events or windows in time. There are 34 search options available including searches for occultations, eclipses, flyby distance from a target, etc. Observation Design allows the user to start with an idea for an observation and to continue to work on it through its final design using one or a combination of the five available observation types provided with SOA. Visualization displays the observation in either a 2-dimensional or a 3-dimensional representation. A new function in this area currently under development will allow the display of a 2-dimensional target body map – a needed representation for Earth, Moon and Mars mapping observations. Data Output lets the operations team check data related to an opportunity search, the spacecraft trajectory or the observation under construction. The data can be represented as a graph or as tabular columns that can be entered into commercial spreadsheet software. Constraint Checking (or Flight Rules) allows the user to see if the observation violates any spacecraft constraints such as spacecraft rates or acceleration or any exclusion zones such as the Sun angle. Finally, Communications allows the user to communicate with other planning software through interprocess communications or via files. In addition to other formats, SOA uses a widely accepted C-Kernel file format that contains spacecraft orientations in quaternions that other software can read.

Six simple steps provide a typical scenario for using SOA:

1. Start SOA and run the Configuration File. The Configuration File contains the spacecraft trajectory information as well as other data to run SOA.
2. Select the Opportunity Search tab. Select an opportunity search option from the 34 available. Fill in the search parameters. Save the search and then run it.
3. Select one of the returned search result windows and view it in either 2-D or 3-D displays by pressing the View button.
4. Select the Observation Design tab. Select to create a new observation. Create the observation using one of the five observation types (scoping, mosaic, continuous scan, track-a-target, or roll-about-an-axis). Fill in the parameters and save it.
5. Press the constraint-checking button. Correct any constraint violations and then view the observation. If the observation meets the users criteria, then save the observation for later retrieval or for sharing with others.
6. Finally, select the Data Output tab and select any of the data items that are desired and the type of data required (opportunity search, trajectory related or observation related). Select the type of output – graph or tabular data.

Any of the steps may be repeated as often as the user wishes, but it only requires these six simple steps to use SOA. In addition, SOA has a detailed User's Guide that contains both reference information and tutorials to support the user. Finally, SOA runs on PC Windows XP and 2000, Linux, Sun Workstations and is currently being ported to Mac OS10.

Science operations teams on the Cassini Mission to Saturn are currently using SOA to help them plan their observations. Not only is SOA simple to use, it is easy to learn and it can be run on the users' own hardware.

1.0 INTRODUCTION

At Jet Propulsion Laboratory on June 30, 2004 Pacific Daylight Time the Cassini spacecraft successfully performed its Saturn Orbit Insertion. For the Cassini project personnel including the Cassini scientists it was an evening full of success and promise. Cassini is an international project and the Cassini instrument teams are located throughout the United States and across Europe. On this mission there are twelve instruments and each instrument is bolted to the spacecraft. This fact means that the Cassini science community must command the spacecraft to turn while performing their experiments. Generally, in the past science operations teams have indicated the turns they needed to make for their observations, but they haven't always had access to needed spacecraft information and often don't understand how to use it. This challenge was met by building a multi-mission tool for the science community called Science Opportunity Analyzer (SOA).

This multi- mission tool has been in development for six years and is implemented in Java. It runs on PC Windows, as well as PC Linux, Sun Workstations and is currently being ported to the Mac. It is based on the Navigation and Ancillary Information Facility (NAIF) toolkit containing spacecraft trajectory as well as other spacecraft and planetary information. SOA has six major functions: Opportunity Search, Observation Design, Visualization, Data Output, Constraint Checking (Flight Rules) and Communications providing science operations teams with a complete toolkit. These functions allow the science user to conceive an experiment and build it into a viable experiment that runs on the spacecraft.

2.0 SCIENCE OPPORTUNITY ANALYZER FUNCTIONS

Each of the major SOA functions performs a specific job. An operations team member can use each of the functions in any order and can repeat the functions as often as necessary. Opportunity Search, Observation Design and Data Output have their own tabs. Visualization can be accessed from both Opportunity Search and Observation Design. Constraint Checking has two different operations. The first operation is to build the rules to be checked, and the second operation of checking for violations is activated by pressing a button on the Observation Design tab. Communications also has multiple ways to access it. The user can select the communications tab to send data to other JPL uplink software or he/she can write a standard NAIF C-kernel file of spacecraft attitudes. The following figure is a simple diagram of SOA's functions and their relationship with each other.

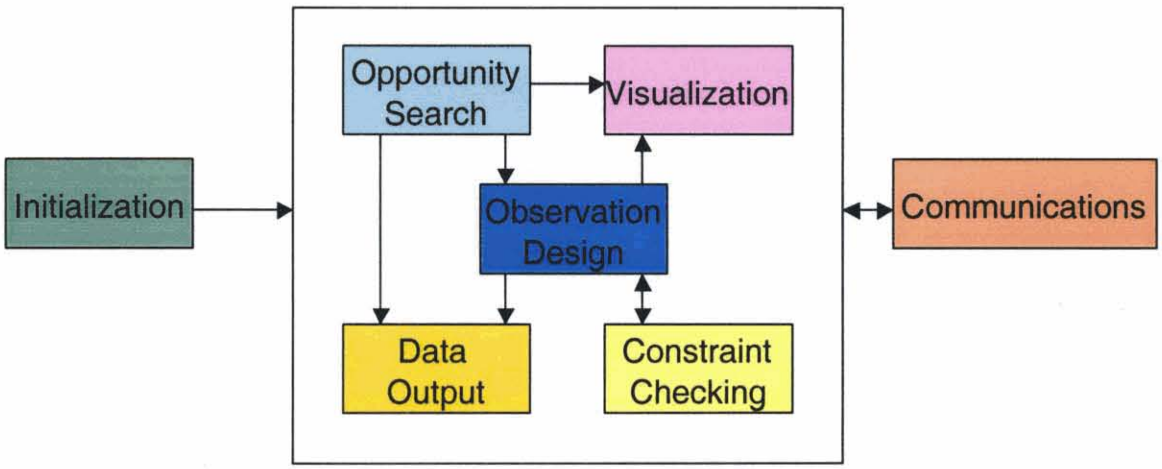

Figure 2.0—1 shows the relationship among the functions of SOA. Once SOA has been initialized the user can select any function.

Opportunity Search

Opportunity Search has the job of finding geometric times of scientific interest. For example, the operations person can look for times when the spacecraft is the closest to a planet or a moon. He/she can also look for times when a planet or moon is in occultation. There are 34 different searches that can be performed.

Observation Design

Observation Design allows the operations user to start with a time and a concept of the experiment and then proceed to a final design. Initially, the user can select a scoping level activity that allows him/her to visualize the geometry, or he/she can go straight to a more complex type of experiment.

Visualization

Visualization is a key capability for SOA. The science operations users want to "see" the experiments. They wants to make sure that the idea that their in their minds corresponds to the actual geometry of the time period. SOA gives them a choice of displays – 3-dimensional perspective projection, 3-dimensional arbitrary observer, 2-dimensional Sky Map or 2-dimensional Trajectory. The user can choose to look at a display from either the Opportunity Search tab or from the Observation Design tab.

Data Output

Data Output provides a choice of ancillary data related to an opportunity search, trajectory or an observation. These data can be saved in a tabular format or plotted in a graph over time. Often the science operations users need to understand this additional information to make a decision about whether to proceed with their current experiment.

Constraint Checking

Constraint Checking allows the operations users to make sure that this experiment will not harm the spacecraft or another instrument. Constraint Checking can check for dynamic constraints or geometric constraints. Checking that the maximum rates and accelerations of the spacecraft are not exceeded is an example of a dynamic constraint. Checking that an instrument's optics is not directly pointed at the Sun is an example of a geometric constraint.

Communications

Finally, there is Communications. SOA was built with communications in mind. It communicates directly with other JPL uplink tools, but it also produces a file of the spacecraft attitude in a more common NAIF format called a C-kernel.

3.0 SIX SIMPLE STEPS

SOA's most important quality is that it is straightforward to use. There has been an SOA User's Guide for each delivery that has been written by Dr. Joshua Colwell, a scientist on the Ultra Violet Imaging Spectrograph (UVIS) instrument team. It has tutorials as well as "how to's" for creating different types of experiments using SOA. Using the six simple steps the operations user can start with a concept and finish with a constraint checked observation that is ready to be sent to the spacecraft. The first step is:

1. **Start SOA and run the Configuration File. The Configuration File contains the spacecraft trajectory information as well as other data to run SOA.**

The configuration file tells SOA the spacecraft and its trajectory as well as providing information about the planets and other celestial bodies. It also gives SOA information about other software models that are used in all the functional areas. The configuration file is selected and run from the Configuration Tab (see Figure 3.0—1). Once SOA has been configured the user can go to step 2.

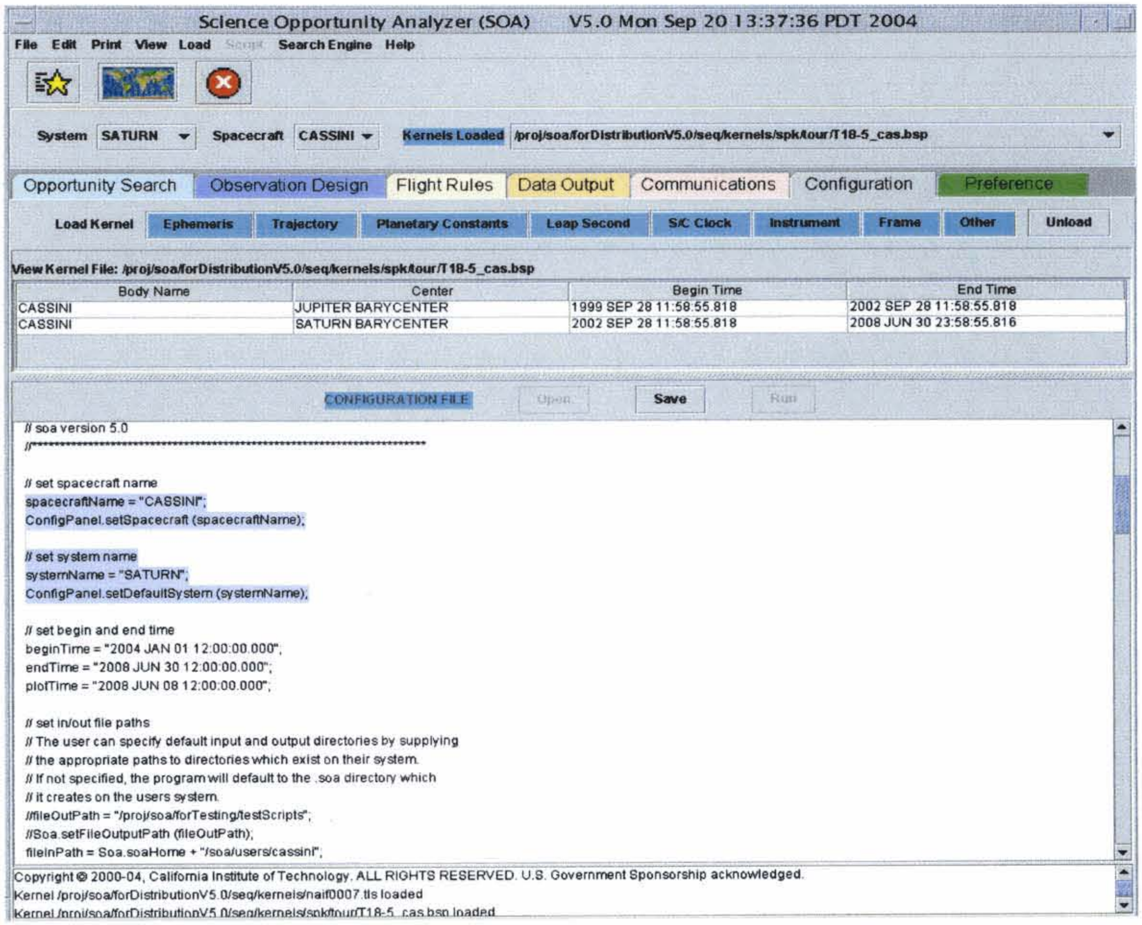

Figure 3.0-1 shows the Configuration Tab. The spacecraft trajectory dates are shown in the upper panel and the spacecraft name and system name are highlighted in the configuration file panel.

2. **Select the Opportunity Search tab. Select an opportunity search option from the 34 available. Fill in the search parameters. Save the search and then run it.**

At this point the user can select any of the tabs. However, usually he/she will want to find a geometrically interesting time period for the experiment. It is possible to use Data Output or just perform a trial and error study using the SOA's visualization capability to find an appropriate time for the experiment. For this scenario the user has chosen to perform an experiment at Enceladus, one of the Saturn moons. This science operations user is looking for a close flyby of Enceladus. One of the types of Opportunity Search is to find times that the spacecraft is less than a specific distance from a celestial body. He/she uses the drag and drop selection screen and enters the desired input information, saves the search criterion and selects the search button on the Opportunity Search tab (see Figure 3.0-2). SOA starts the search engine and it returns with the time windows that meet the criterion. At this point the user can either view one or more of the windows, go to Data Output to verify some of his/her calculations or move directly to Observation Design. In this case the user selects to go to view the opportunity – Step 3.

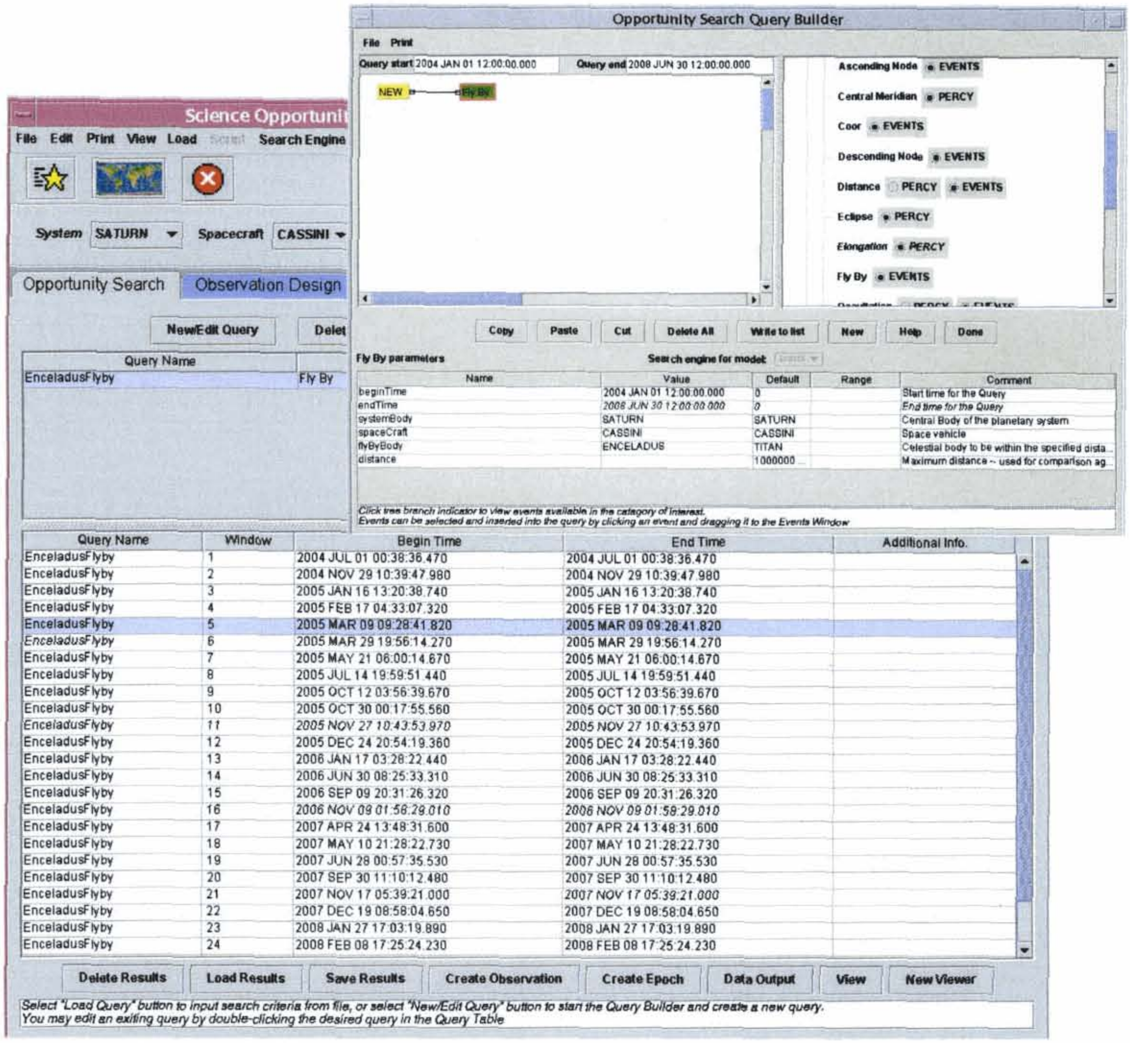

Figure 3.0-2 shows the Search Query Builder with a flyby query and its parameters as well as the Search Results with the Enceladus closest approach search result highlighted.

3. **Select one of the returned search result windows and view it in either 2-D or 3-D displays by pressing the View button.**

The science operations user wants to look at the geometry of this time period. He/she can select from four different view options – 3-D Perspective Projection, 3-D Arbitrary Observer, 2-D Sky Map or 2-D Trajectory. The 3-D Perspective Projection display is a view from the perspective of the spacecraft. The 3-D Arbitrary Observer display is a view of the selected target from an arbitrary point in space. The 2-D Sky Map display is an equidistant map projection of the solar system. The 2-D Trajectory display is a projection of the spacecraft trajectory onto a 2-D plane. Each of these views allows the user to see different information and different relationships of the spacecraft, the celestial bodies and the instruments. It is possible to have multiple displays visible at the same time either in separate windows or in the same window. The following series of pictures shows samples of the various displays that the science user selected for his Enceladus experiment (see Figures 3.0-3 and 3.0-4). The user can also animate the displays, but first he/she needs an observation. If the science operations user likes the geometry portrayed in the display, he/she can go to Observation Design – Step 4.

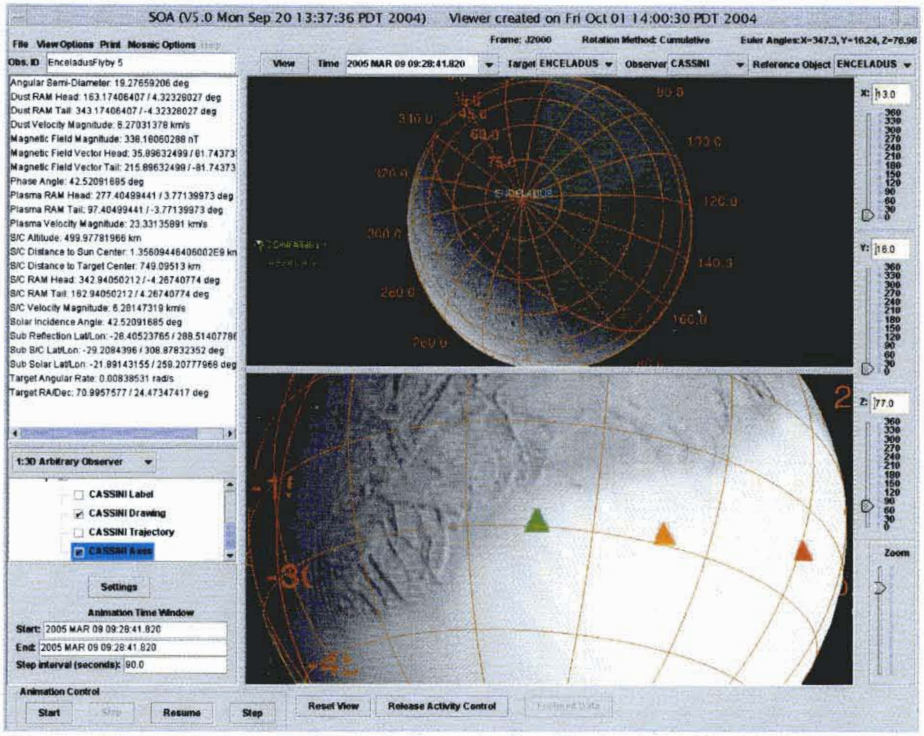

Figure 3.0-3 shows both the 3-D Perspective Projection display (bottom) and the 3-D Arbitrary Observer display (top). The Cassini spacecraft appears on the left side of the top display.

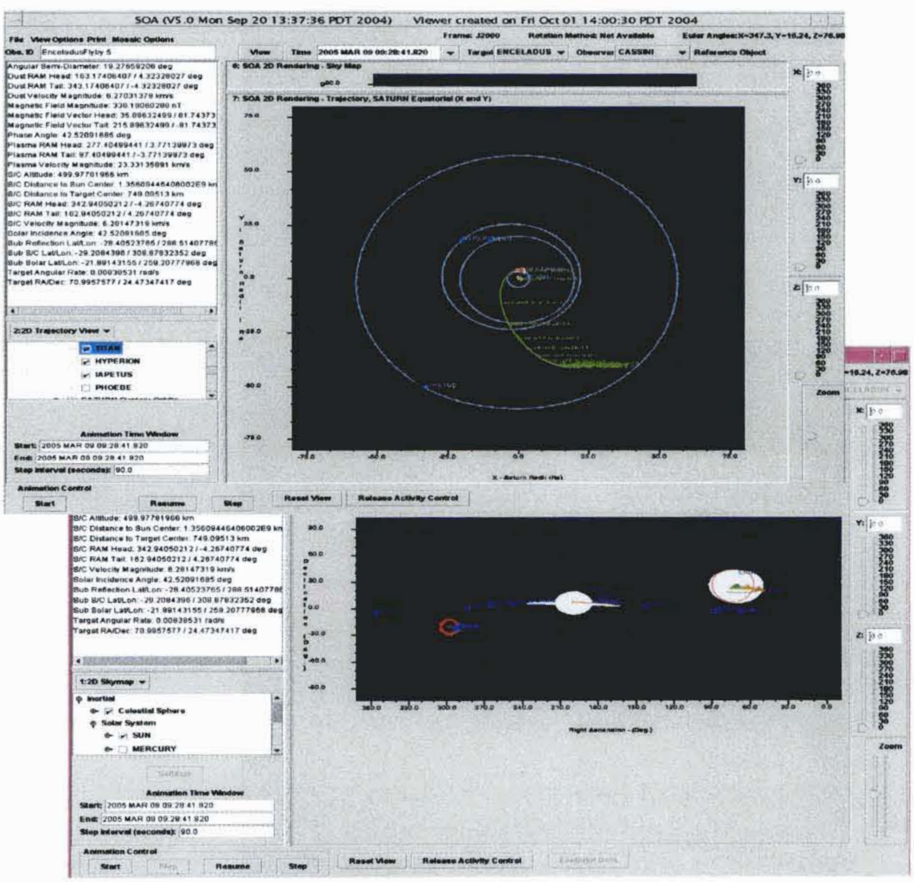

Figure 3.0-4 shows the 2-D Trajectory display and the 2-D Sky Map display.

4. **Select the Observation Design tab. Select to create a new observation. Create the observation using one of the five observation types (scoping, mosaic, continuous scan, track-a-target, or roll about an axis). Fill in the parameters and save it.**

This science user decides to pick a time from the resultant search windows to create a "scoping" level observation (or activity). This type of activity requires very few parameters, and it isn't a full experiment design, but it allows the user to display the geometry of the observation in one of the visualization screens with the instrument's field of view (aperature) projected onto Enceladus. The following are the required parameters:

1. The start time and the duration
2. Two vectors – a primary vector and a secondary vector from the observer (either a spacecraft axis or an instrument on the spacecraft) to the target (generally a celestial body or an Right Ascension/Declination celestial sphere value)
3. Any offsets from the target that the user wishes to use.

If the user wants to start immediately designing the observation, he/she could select from four basic types: a mosaic, a continuous scan, a track-a-target or a roll-about-an-axis. The mosaic creates a pattern like tiles on a floor. Generally, the spacecraft stops or dwells for a time while the observation is made. Often this type of activity is to take a picture. The continuous scan performs observations while the spacecraft is moving in a specific pattern. The track-a-target activity has the spacecraft follow the specified target until the observation is completed. The roll-about-an-axis activity has the spacecraft spin around one or more axes while the experiment is performed. These types come standard with SOA. Now the user is ready to check the observation to make sure that this observation doesn't cause any problems for the spacecraft (Step 5).

5. **Press the constraint-checking button. Correct any constraint violations and then view the observation. If the observation meets the users criteria, then save the observation for later retrieval or for sharing with others.**

In this step the user simply presses the button on the Observation Design tab and the active constraints will be checked. If the button turns orange and is labeled with a date, then a violation has occurred. The user can then check the constraint log to see which violation that occurred. However, for this step to operate correctly the Flight Rule tab must have been selected and rules must have been entered. The flight rule builder is very easy to use. Like Opportunity Search the user simply drags and drops the selected rule into the upper left hand side of the builder window. When the rule is selected, its parameters appear. The user fills in the appropriate values and saves the rule to the list. It is also possible for the rule to be saved in a file and retrieved for each SOA session. There are three types of rules – activity duration, distance and exclusion zone. The activity duration rule is to check to make sure that an activity doesn't exceed the specified amount of time. The distance rule checks to see if the spacecraft is within the required distance from an object. Finally, the exclusion zone rules check to make sure that a specific area is avoided so that the spacecraft is not harmed. These rules are geometric rules. The rules dealing with hardware restrictions are checked with the models of the hardware. For example, checking that spacecraft rates and accelerations are within limits fall into this category. The following series of displays (Figure 3.0 –5) shows the Enceladus observation as it moves out of the constraint violation.

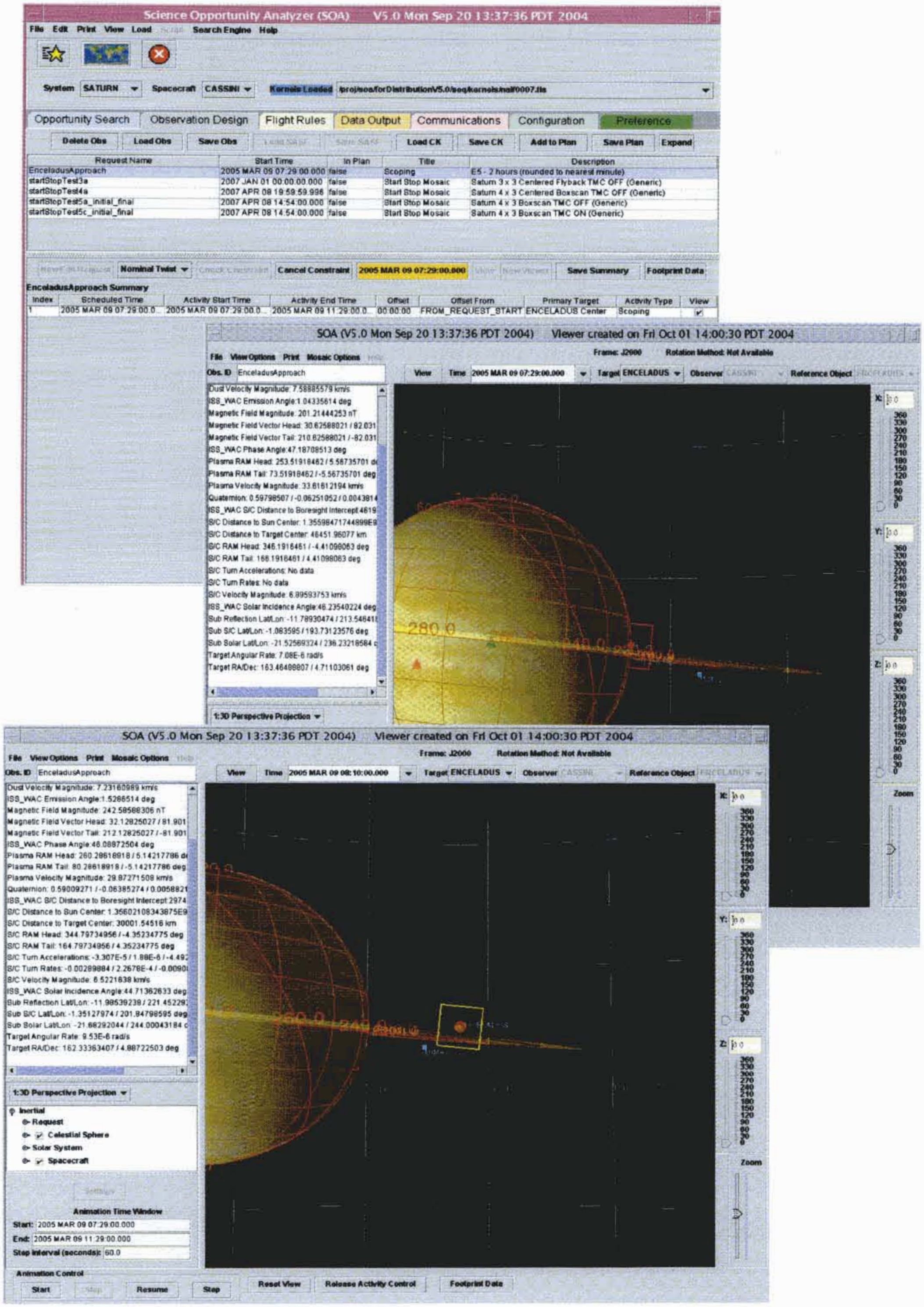

Figure 3.0—5 shows the orange constraint-checking button on the Observation Design Tab indicating there is a constraint violation. The 2nd display shows the Cassini camera's field of view (FOV) projected onto Enceladus. The red FOV indicates that there is a constraint violation. After animating the display, the FOV turns yellow indicating that at this time there is no violation.

6. **Finally, select the Data Output tab and select any of the data items that are desired and the type of data required (opportunity search, trajectory related or observation related). Select the type of output – graph or tabular data.**

Finally, the operations user is ready to look at ancillary data to make sure that this observation meets his/her objectives. The user can look at data related to the opportunity search that was performed or the spacecraft trajectory or the observation that he/she has just made. There are approximately 25 different types of ancillary data that can be selected. The list ranges from spacecraft distance to the target center to the magnetic field magnitude. In addition, to obtaining specific data selections, the user can also select to build any angle between celestial bodies or between a spacecraft axis or instrument and a celestial body. It even allows the user to create an angle with any of the Deep Space Network facilities. Once the user selects the data it can be saved to a tabular file that can be put into commercial third party spread sheet software or it can be graphed. The graphing function allows for the plots to be stacked or in separate windows. This step is completely optional; however, many users prefer to inspect this data as well as looking at it visually. For the Enceladus observation the science user can build an angle between the camera (for Cassini the ISS_WAC) and Saturn to check when the flight rule is no longer violated. Then he/she can begin the observation at that time.

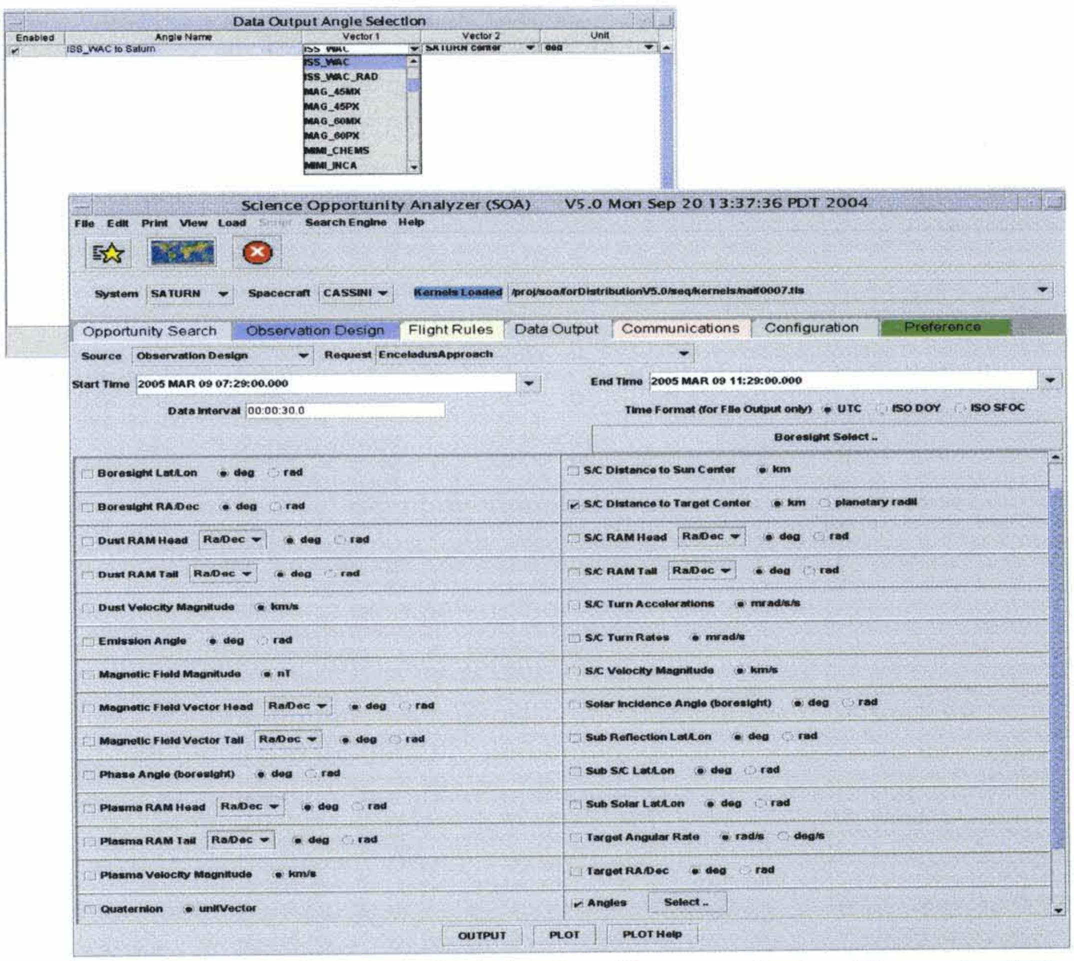

Figure 3.0—6 shows the angle builder for Data Output on the top. The angle of the camera (ISS_WAC) to Saturn is the angle that has been built. The plot of this angle will show when there is a constraint violation and when it will be safe to perform the observation. The middle picture is of the Data Output Tab and it shows some of the available data.

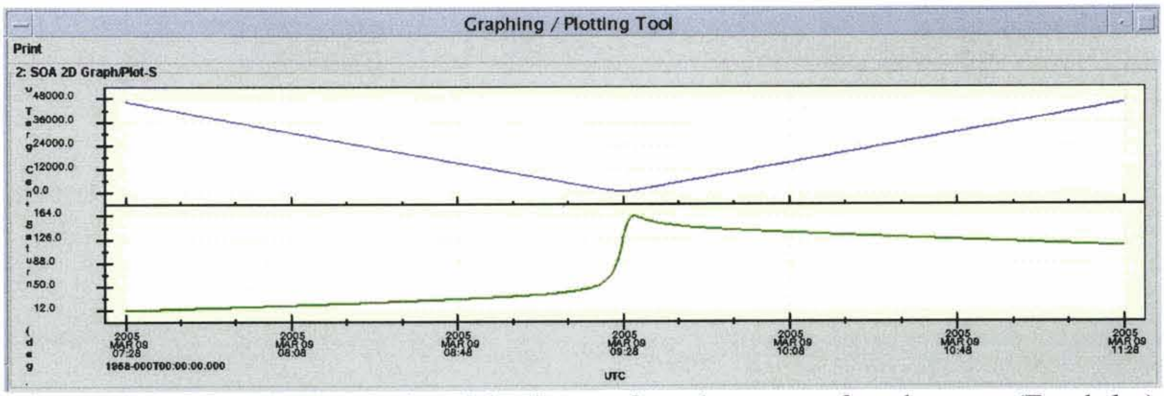

Figure 3.0—7 shows the a stack plot of the distance from the spacecraft to the target (Enceladus), the top plot, and the angle between the camera (ISS_WAC) and Saturn. The science user can look at this graph and tell the time that there is no constraint violation.

Now the user has an observation. He/she can save it in one of several formats including saving it to a NAIF C-kernel for sharing with other science operations team members. One user claimed that by using SOA he is able to complete work in hours that used to take him a week.

4.0 Conclusion

Science Opportunity Analyzer is a toolset that enables operations teams to create their experiments without having to understand the spacecraft, orbital mechanics or coordinate transformations. SOA's ability to show the same accurate information in multiple ways (multiple visualization formats, data plots, listings, file output) is essential to meet the needs of a diverse, distributed science operations environment. And on top of everything else it's simple to use.

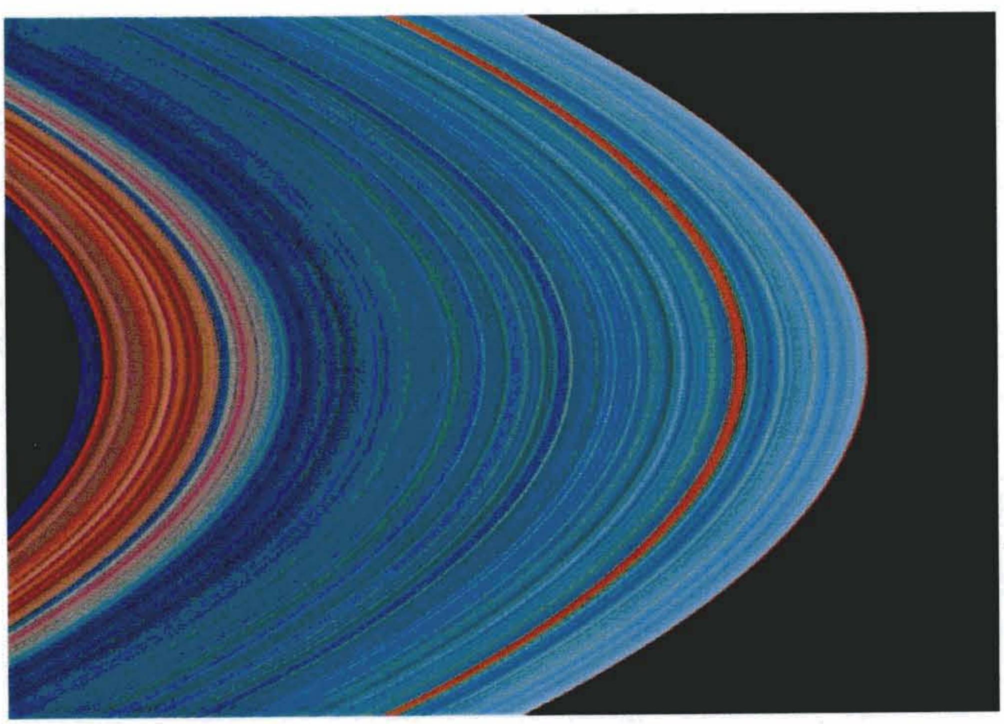

Figure 4.0—1 shows the rings of Saturn taken by the Cassini Ultra Violet Imaging Spectrograph - an actual Cassini spacecraft experiment. Picture courtesy of NASA/JPL/University of Colorado.

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