Science Opportunity Analyzer – Not Just Another Pretty Face

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Cassini, a mission to Saturn, is the first Jet Propulsion Laboratory (JPL) mission to have distributed science operations. Prior to this time all operations tasks were performed at the Laboratory by operations and spacecraft engineers. Of course, the uplink software to support operations has been written with the engineering community in mind. In addition, these tools run on workstations behind firewalls. Now the scientists were going to have a larger role in creating and specifying their experiments. This group needed software tools that allowed them to accurately visualize these experiments and also get ancillary data about them, but the software also needed to flow easily into the other project uplink software being used by the engineers. Science Opportunity Analyzer (SOA) was created to bridge the gap.

Currently, there are visualization tools that provide views of the solar system either as still shots or some form of animation. Some of these tools can show an instrument's field of view (aperture) projected onto a celestial body or the sky. Some provide ancillary data about the display or the spacecraft. No tool provided them all. However, SOA accurately provides all of these capabilities and performs geometric searches for observation opportunities and constraint checking as well.

In order to ensure that the tool meets the needs of the user community, a survey was conducted. The results of the survey specified that the scientists needed to be able to:

1. Identify observation opportunities
2. Create accurate, detailed designs for their observations
3. Verify that the observations meet their objectives
4. Check the observations against project flight rules as well as spacecraft and other constraints
5. Communicate their observations back to JPL for integration into the uplink plan

In addition, the tool needed to be created in such a way that it would be easy for scientists to use in their own environment.

In order to meet the accuracy requirements SOA has been based on the JPL Navigation and Ancillary Information Facility (NAIF) SPICE System. SPICE stands for Spacecraft, Planet, Instrument, Constant and Events. SPICE consists of a library of functions that perform coordinate transformations and kernels that provide the data needed for the transformations. In addition, the search engine SOA uses to find geometric observation opportunities is also based on SPICE. Using this system allows SOA to provide consistent accurate information throughout the software.

To provide flexibility and portability SOA has been built using Java and Java 3D. SOA currently runs on Unix, PC Windows, and Linux. Plans are in the works to port SOA to Mac OS10. It is also a multi-mission tool that allows each project to configure SOA to its mission. This adaptation can range from only changing the configuration file and related SPICE files to creating the project's activities and spacecraft turn model.

SOA consists of seven major functions: Configuration, Opportunity Search, Visualization, Observation Design, Constraint Checking (Flight Rules), Data Output and Communications. Each of these functions except for visualization has a separate tab (see Figure 1.1 for the SOA main screen). Visualization is available from several of the functions tabs.

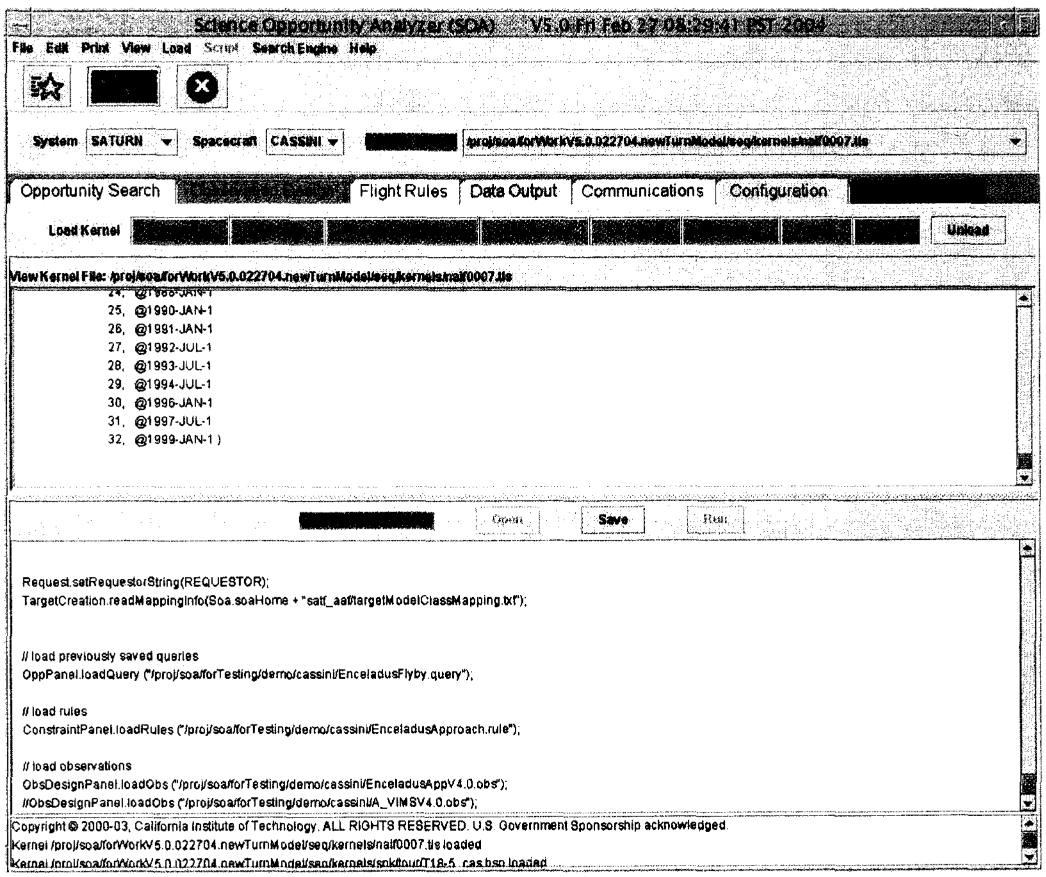

Figure 1 – The SOA main screen with the function tabs of Opportunity Search, Observation Design, Flight Rules (Constraint Checking), Data Output, Communications, and Configuration

The Configuration tab is used for setting SOA up for a specific mission. SOA uses a configuration file to populate its various internal models. The SPICE files provide the spacecraft trajectory, planetary information such as size and spin rate, the instrument fields of view (apertures) and their locations on the spacecraft as well as other important spacecraft and celestial information. In addition, mission name, spacecraft name and user specific information can be entered in the configuration file. Once the configuration information is entered, the scientist is ready to begin work.

Opportunity Search is the portion of SOA that looks for the occurrence of geometric events given a span of time and the spacecraft trajectory. This section of the program activates a search engine developed by JPL navigation to determine when these events occur. This search engine uses continuous mathematical functions and determines when (or if) a change in sign occurs. The change of sign indicates that the opportunity window or discrete event has been found. Some examples of searches include: distance from a given body, occultation, eclipse, periapsis, etc. SOA allows scientists to combine searches together with AND, OR or NOT operators. For example, an excellent photo opportunity might be when one of the moons of Saturn transits across the face of Saturn, but it is important to be within a specific distance of Saturn. The scientist can combine the transit and the distance into one complex search criteria. SOA reduces the complexity of using this search engine by creating a drag-and-drop interface. In addition, it provides help and comments for all the searches. Another example of using Opportunity Search is shown in Figure 3. In this case the scientist wanted to perform an observation of the Saturn moon Enceladus at closest approach. After performing a search, March 9, 2005 09:29:46.000 was found to be the closes approach time. The scientist decided to start the observation 2 hours prior to closest approach and continue the observation for the next 4 hours.

Visualization is one of the key elements of SOA. Currently, SOA provides four different types of visualization – 3-Dimensional Arbitrary Observer, 3-Dimensional Perspective Projection, 2-Dimensional Equidistant Projection Skymap, and 2-Dimensional Trajectory plot. Each of these can provide the scientist with a different view of the same information. All of these views take into consideration the spacecraft trajectory. The 3-Dimensional Arbitrary Observer view presents the user-selected target from an arbitrary point of view in space. The 3-Dimensional Perspective Projection presents the user-selected target from the viewpoint of the spacecraft. The 2-Dimensional Equidistant Projection Skymap shows a Right Ascension/Declination map of the solar system from the position of the spacecraft and the 2-Dimensional Trajectory plot displays the path of the spacecraft over a selected time interval. All of these views can be animated. The user can elect to see one or more displays either on one screen or on multiple screens. Each of the views goes through a series of coordinate transformations starting with J2000 and ending with either the spacecraft coordinate frame or the target body coordinate frame depending on the operation. The process of performing the coordinate transformation creates accurate views that allow the scientist to assess their observations. Figure 2 is a 3-Dimensional Perspective Project of an Ultra Violet Imaging Spectrograph (UVIS) observation. UVIS is an instrument on the Cassini mission to Saturn. This view shows the field of view (aperture) of the high-speed photometer in the ring shadow. The purpose of the experiment is to observe the flashes produced by meteoroid impacts on the rings. The view indicated to the scientist that the design could be improved because they were very close to the shadow edge. In Figure 2 the blue square (UVIS field of view) is close to the red ellipse (the shadow line).

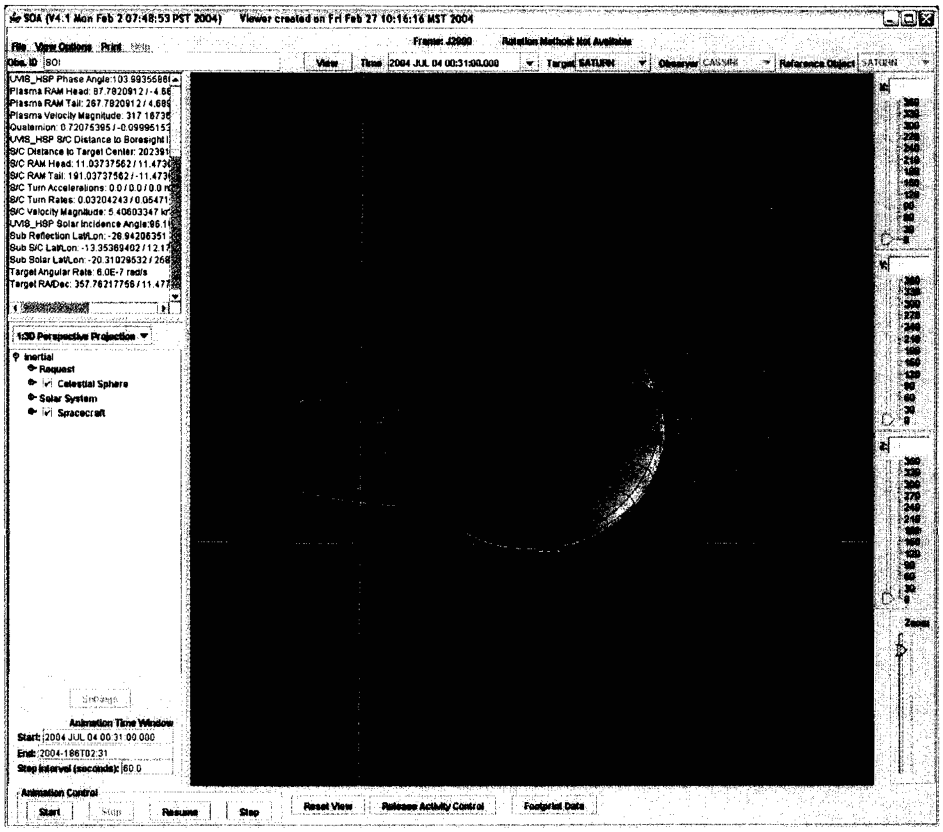

Figure 2 – Blue UVIS field of view near the boundary of the light/dark terminator of Saturn's Rings.

Observation Design allows scientists to determine the specifics of their observations. SOA supports five types of observations: 1. scoping, 2. simple target tracking 3. start-stop mosaic, 4. continuous scan mosaic and 5. roll scan mosaic. Each of these observations can be selected individually or combined into a group of observations, called a request. The scoping observation is a "what-if" study and allows the scientist to look at a picture of the observation with a single field of view. This type of observation has the fewest parameters (only 6) dealing with the time and the spacecraft attitude. The tracking observation allows the scientist to perform an observation while the spacecraft maintains a specific target. The start-stop mosaic is an observation where the spacecraft dwells at specific locations to acquire a series of discrete images in rows and columns. This observation is often called an NXM mosaic. The continuous scan mosaic differs from the start-stop mosaic in that the observation acquires the images while the spacecraft is moving along a path. Finally, the roll scan mosaic is an observation that is performed while the spacecraft is rotating around one of its axes. For all of these observation types the movement of the spacecraft must be simulated. In SOA there are three turn model approximations that can be used. The Cassini mission has an engineering pointing tool that is used by the spacecraft team. This Cassini tool contains the flight software algorithms and requires extensive knowledge of the spacecraft. However, length of the turn time that SOA indicates is required has been compared against this tool for each delivery. SOA is within 5 seconds for 95% of tests against this much higher fidelity tool. Therefore, scientists can use SOA, a tool built for them and easier for them to use, and still expect similar results when this information is sent downstream to the higher fidelity tool. Figure 3 shows a series of Cassini scoping observations of Enceladus at closest approach. This observation was used to determine when the UVIS field of view could be seen on Enceladus as it emerged from behind Saturn. Then the field of view tracked Enceladus until closest approach to determine if uncharted territory was going to be in the observation (it will be – the lack of a body texture map for that area in Figure 3 indicates that this area hasn't been observed yet.).

The next function, Flight Rules (Constraint Checking) is essential to ensure that observations don't harm the spacecraft or an instrument on the spacecraft. There are two different types of constraint checking. One type deals with the hardware capabilities of the spacecraft. This type generally refers to how fast the spacecraft can turn (rates) and how fast it can achieve that rate from its current rate (acceleration). All observations are checked to make sure that the rates and accelerations are sufficient to achieve the target without exceeding either one. In the software the scientist is not prevented from making the turn or performing the observation, but is alerted to the violation by a message that pops onto the screen. The other type of constraint checking deals with geometric constraints and generally involves "exclusion" zones. These zones are areas that the scientist needs to avoid so that parts of the spacecraft aren't damaged. A camera optics exposed to the Sun or another bright body falls into this category. The scientist can build his own set of "rules" or the project can create them as part of the project adaptation. These rules have an easy-to-use drag and drop screen that is similar to Opportunity Search. Once the rules have been created. The scientist can check constraints on any observation or set of observations by merely pressing a button. If there are constraint violations the user is alerted to their existence by the constraint button turning orange and showing the date and time of the first violation. The user can look at the constraint log for a complete report or a visualization of the observation. The constraint log lists the date and time of the constraint and the name of the rule that has been violated. If the scientist views this observation, the field of view involved in the constraint is drawn in red. A bright body rule was created for Saturn because the Stellar Reference Unit (star tracker) on Cassini is sensitive to bright bodies. An observation was created to start when Enceladus is emerging from behind Saturn, when the constraint-checking button is pressed, a violation occurs and the user is notified. The first picture in Figure 3 shows the visualization display that was created with the UVIS field of view in red indicating the violation.

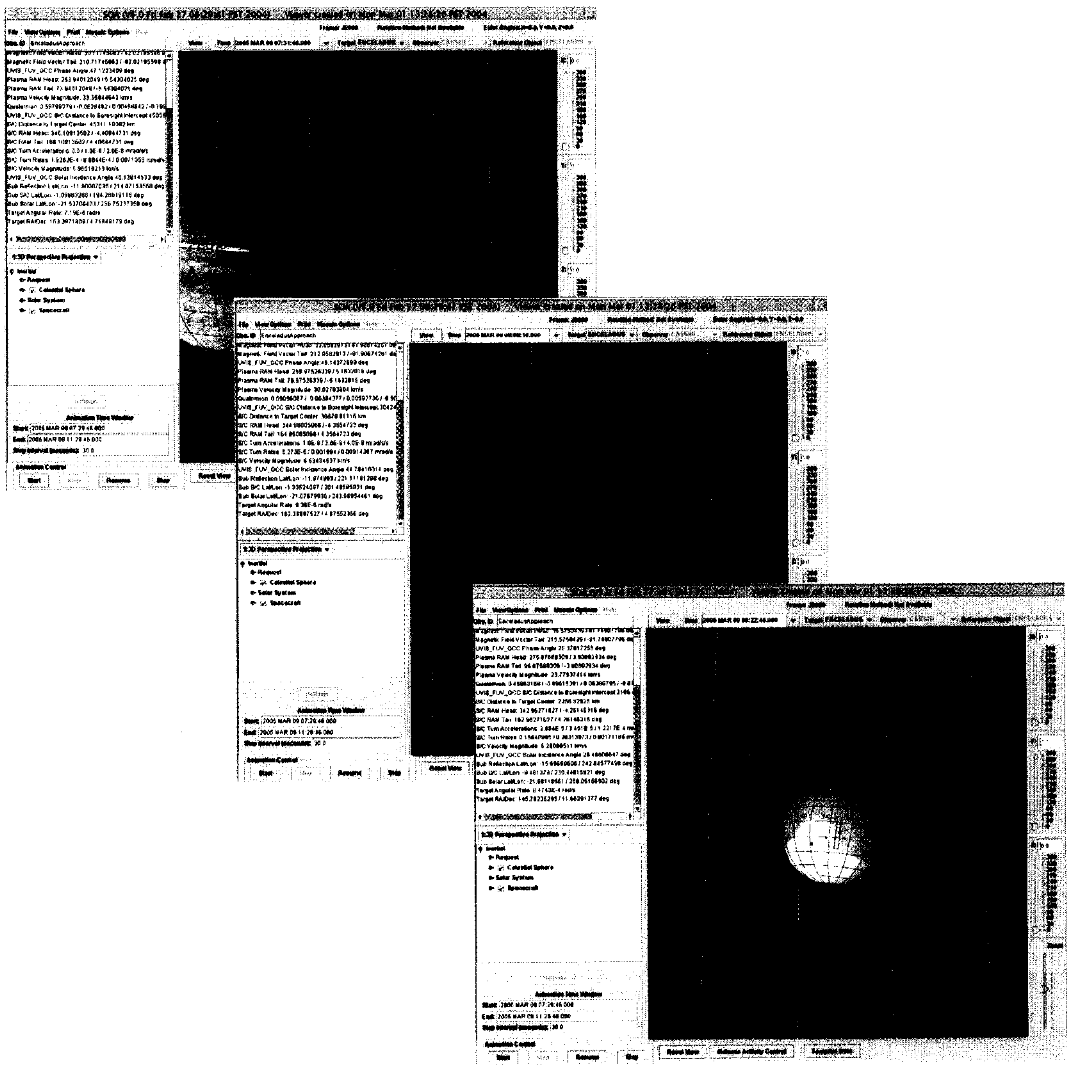

Figure 3 The first picture shows a red UVIS field of view on Enceladus (indicating a constraint violation) as it emerges from behind Saturn. The second picture shows that the spacecraft has moved out of the constraint zone and the third picture shoes the closest approach at Enceladus and the unmapped area that will be observed.

Next, Data Output provides another way for scientists to verify their observations and their assumptions. SOA provides three different types of ancillary data: 1. Trajectory Related Data, 2.

Observation Related Data, and 3. Opportunity Search Related Data. The Trajectory Related Data allows the scientist to pick from 23 different data items including items such as Phase Angle, Sub-Reflection point, Spacecraft Altitude, etc. This type of data only requires knowledge of the spacecraft trajectory, but does not require knowledge about the spacecraft orientation. The Observation Related Data includes the items in Trajectory Related Data, but also permits additional items that are based on the spacecraft's orientation such as the spacecraft distance to the point where the instrument field of view intercepts the planet. Finally, the Opportunity Search Related data selection is the same as the Trajectory Related Data, but the items are calculated at the times of the search results. Data Output has one selection that relates to all three types and that's the angle builder. The angle builder allows the scientist to create angles that he/she wants to be measured. For example, the scientist may be interested in the angle between his/her field of view and the Sun. Exclusion zones are expressed as angular areas in the solar system. By specifying the exculsion angle the user can determine the severity of the violation. In many cases starting the observation a few minutes later or ending it a few minutes early will correct the violation as can be seen by the second picture in Figure 3. The angle builder can help the user understand the violation and then show him/her how to modify the observation to avoid the violation.

In addition, the project can adapt SOA to calculate information that is relevant to that mission. Currently, Cassini has several instruments and their radiators that are sensitive to temperature. In the Cassini adaptation there are data items specifically for these instruments. The user can get tabulated output of the instrument's and its radiator's temperature over time. In another case prior to completing an observation design one of the Cassini UVIS team members generally checks the phase angle and the distance to the target to determine both the resolution of the camera on the target (distance) and if the phase angle is sufficiently low enough to get good illumination of the target object. This same check can be used for making trades with other scientists. One scientist may ask another to move his/her observation slightly. Plotting the phase angle and distance can be performed in seconds and allow them to tell if the movement is a viable option or not. Finally, another benefit of using Data Output is for performing trade studies. Figure 4 shows plots of two different orbits that are under consideration for the Dawn mission. These two plots are of the spacecraft altitude and the spacecraft distance to the center of the asteroid Vesta, one of Dawn's targets. Scientists and mission planners can use plots like these to decide which orbit provides the best observation opportunities.

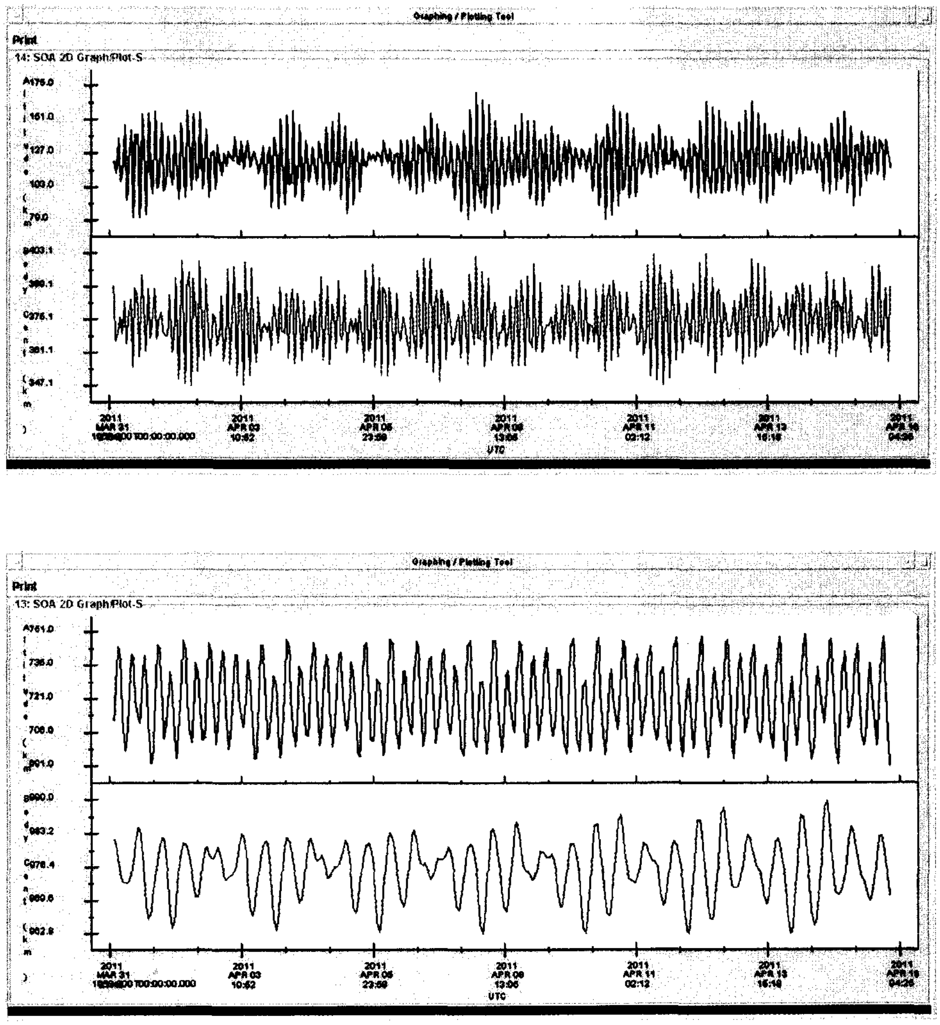

Figure 4 The Data Output plots show two different Dawn trajectories. The plots show the spacecraft altitude and the spacecraft distance to Vesta.

The final functional area is communication. Since the Cassini mission is using distributed science operations, it is important to them that their science-planning tool be able to communicate with the other uplink tools. Therefore, communication has always been a key element for SOA. In addition, scientists also wanted to be able to communicate their observation designs to other scientists either in their own team or in other teams. SOA has direct interprocess communications with the Cassini scheduling tools. SOA also generates a file that all of the other uplink tools can read and process called the Spacecraft Activity Sequence File. Finally, SOA creates a file called a C-kernel. In the SPICE system C-kernel files specify the spacecraft attitude over time. Scientists can exchange these files and look at each other's observations. Figure 6 shows the visualization display of a C-kernel that was created by a Cassini uplink tool.

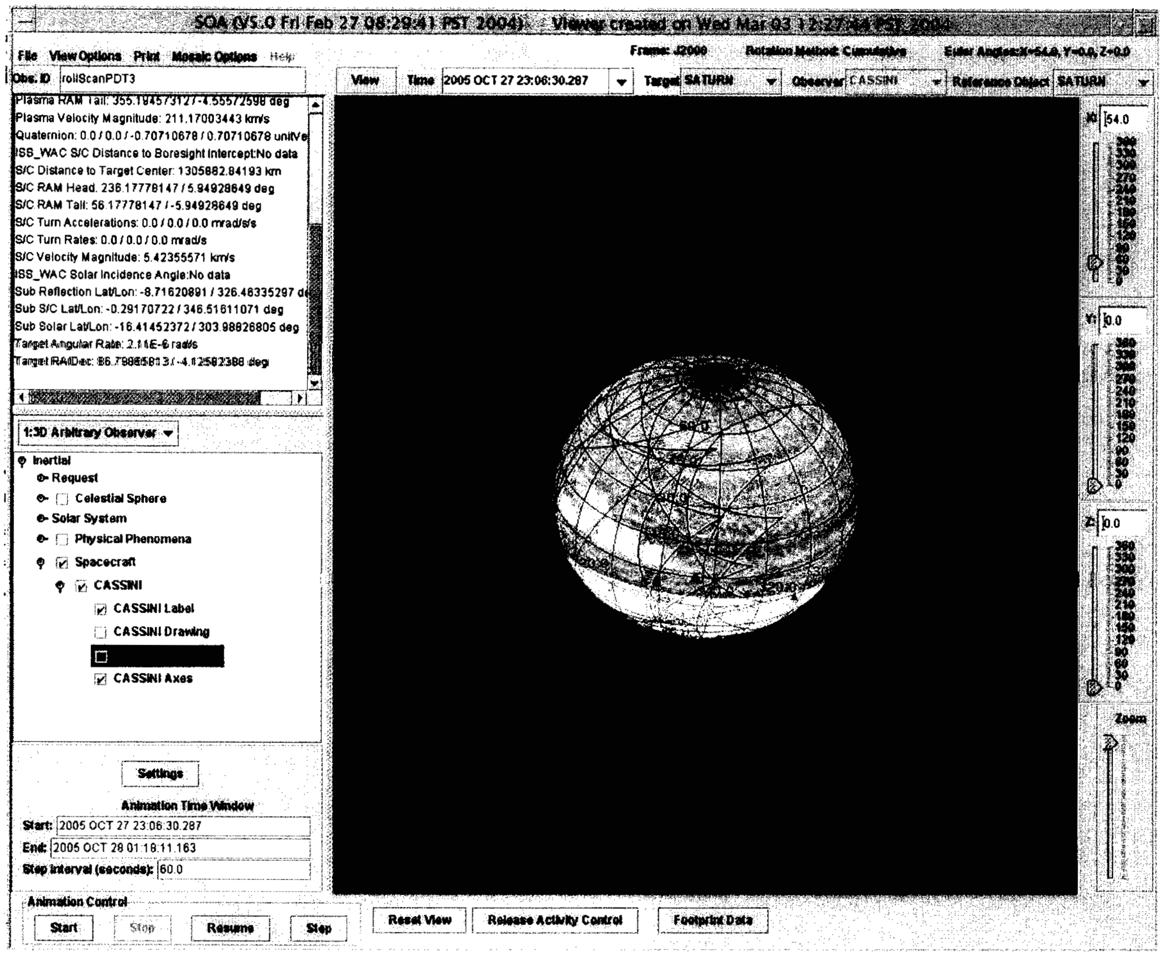

Figure 6 This display is a Roll Scan observation that was saved as a C-kernel and imported to SOA. It is displayed using 3-Dimensional Arbitrary Observer and rotating the picture to look more closely at the observation.

Science Opportunity Analyzer is a multi-mission tool that provides a bridge between science and uplink operations while at the same time providing a broad base of functionality for the science planning process. It is accurate (JPL navigation based), flexible (runs on many platforms and is adaptable to a project's needs), and easy to use (based on user feedback). SOA is not just another pretty face; it has brains too.

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