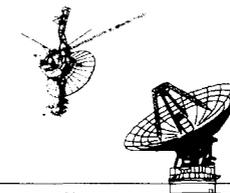




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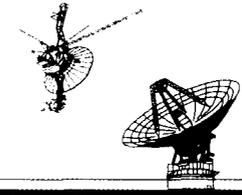
**Advances in Science
Planning Tools with
Opportunity Analyzer (SOA)
*Mission Services & Applications***

**Carol A. Polanskey, Barbara
Streiffert, Taifun O'Reilly, and
Joshua E. Colwell**

**Jet Propulsion Laboratory
Pasadena CA**

October 11, 2002

SpaceOps 2002

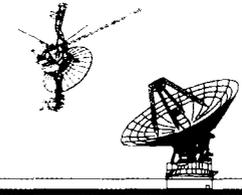


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Background

- Scientists on spacecraft instrument teams need the ability to identify and design observations for their instruments.
- They generally do not want or have access to detailed spacecraft commanding software.
- SOA has been developed as a multi-mission science planning tool that allows scientists to design, check, and modify observations and feed those designs into the detailed uplink software system without having to use the entire uplink software system.
- Initial SOA design used Quality Functional Deployment to survey the user community to incorporate their requirements into the software requirements.
- SOA is java-based, and makes use of the JPL Navigation and Ancillary Information Facility (NAIF) SPICE software toolkit.



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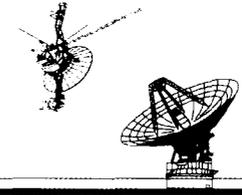
What is SOA?

- **First tool a scientist/mission planner will use.**

- Identify key opportunities & check out the feasibility of potential observations.
- Easy to use by wide range of non-JPL science team members and support staff.
- Run on multiple platforms: SunOS, Windows, Linux.
- Based on standard NAIF/SPICE tools providing high fidelity.

- **Revisit observation following changes to the “plan”.**

- Retrieve new time window or validate observation following updates to the s/c trajectory.
- Communicates with other downstream sequence development software to validate observations following integration.

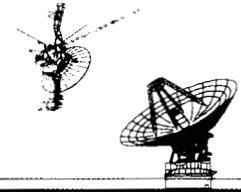


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SOA is a Multi-Mission Tool

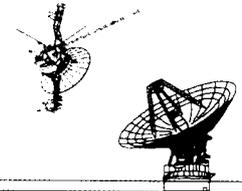
- SOA is configurable to a specific mission.
 - This process is called “adaptation”. Adaptation adds the mission specific data for SOA to work with. This mission specific data will include flight rules, observation types, physical phenomena models, celestial body data, instrument data, spacecraft-specific data and a spacecraft trajectory. Much of this data can be provided through the use of JPL navigation files.
- SOA’s first customer is the Cassini/Huygens mission to Saturn.
 - Examples in this presentation are for the Cassini mission. Cassini arrives at Saturn July 1, 2004, to begin a four year orbital “tour” of the Saturn system, including planet, rings, satellites, and magnetosphere. SOA is designed to handle observations of each of these diverse targets.



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SOA Capabilities

- Visualization
 - Visualize the system in 3D and 2D from the point of view of any object in the system, including the spacecraft, or from an arbitrary point of view.
 - Visualize observations, with projections of instrument fields of view onto any object in the system, including observations designed in other software.
 - Animate the view for arbitrary times or for the period of an observation.
- Opportunity Search
 - Search for a science opportunity, i.e., one or more time “windows” when a science observation can occur (uses Percy and EVENTS search engines)
 - Use visualization to validate observation geometry.



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List of times when user-specified geometric criteria are met, returned by one of two opportunity search engines used by SOA: Percy and EVENTS.

Science Opportunity Analyzer (SOA) V2.2 Thu Mar 21 13:43:44 PST 2002

File Edit Print View Load Unload Script Search Engine Data Output Help

System: SATURN Spacecraft: CASSINI File: C:\soaV22_032102\soq\kernels\hal\0007.tls

Opportunity Search [] Communications Global/Kernel []

New/Edit Query Delete Query Search Cancel Search Load Query Save Query

| Query Name | Query Expression | Query Start | Query End |
|------------|------------------|-------------------------|-------------------------|
| Query1 | Periapsis | 2004 JAN 01 12:00:00... | 2008 JUN 30 12:00:00... |

| Query Name | Window | Begin Time | End Time | Additional Info. |
|------------|--------|--------------------------|--------------------------|------------------|
| Query1 | 1 | 2004 JUL 01 02:40:02.900 | 2004 JUL 01 02:40:02.900 | |
| Query1 | 2 | 2004 NOV 29 09:47:59.510 | 2004 NOV 29 09:47:59.510 | |
| Query1 | 3 | 2005 JAN 16 05:10:26.240 | 2005 JAN 16 05:10:26.240 | |
| Query1 | 4 | 2005 FEB 17 01:40:15.670 | 2005 FEB 17 01:40:15.670 | |
| Query1 | 5 | 2005 MAR 09 11:49:55.570 | 2005 MAR 09 11:49:55.570 | |
| Query1 | 6 | 2005 MAR 29 22:59:19.980 | 2005 MAR 29 22:59:19.980 | |
| Query1 | 7 | 2005 APR 14 22:51:04.490 | 2005 APR 14 22:51:04.490 | |
| Query1 | 8 | 2005 MAY 03 00:30:05.300 | 2005 MAY 03 00:30:05.300 | |
| Query1 | 9 | 2005 MAY 21 05:09:35.580 | 2005 MAY 21 05:09:35.580 | |
| Query1 | 10 | 2005 JUN 08 10:03:44.040 | 2005 JUN 08 10:03:44.040 | |
| Query1 | 11 | 2005 JUN 26 15:27:37.250 | 2005 JUN 26 15:27:37.250 | |
| Query1 | 12 | 2005 JUL 14 22:13:50.370 | 2005 JUL 14 22:13:50.370 | |
| Query1 | 13 | 2005 AUG 02 05:28:49.710 | 2005 AUG 02 05:28:49.710 | |
| Query1 | 14 | 2005 AUG 20 11:24:33.340 | 2005 AUG 20 11:24:33.340 | |
| Query1 | 15 | 2005 SEP 05 12:20:40.210 | 2005 SEP 05 12:20:40.210 | |
| Query1 | 16 | 2005 SEP 23 20:13:40.330 | 2005 SEP 23 20:13:40.330 | |
| Query1 | 17 | 2005 OCT 12 01:48:11.590 | 2005 OCT 12 01:48:11.590 | |
| Query1 | 18 | 2005 OCT 29 23:23:37.480 | 2005 OCT 29 23:23:37.480 | |
| Query1 | 19 | 2005 NOV 27 11:35:37.720 | 2005 NOV 27 11:35:37.720 | |
| Query1 | 20 | 2005 DEC 24 21:43:02.130 | 2005 DEC 24 21:43:02.130 | |
| Query1 | 21 | 2006 JAN 17 07:34:37.460 | 2006 JAN 17 07:34:37.460 | |

Delete Results Load Results Save Results Create Observation Create Epoch View New Viewer

Select "Load Query" button to input search criteria from file, or select "New/Edit Query" button to start the Query Builder and create a new query. You may edit an existing query by double-clicking the desired query in the Query Table



3D
Perspective
View of Saturn
as seen from
Cassini, June
2008

SOA Viewer created on Mon Sep 23 12:55:35 MDT 2002

File View Options Print Help

Frame: J2000 Rotation Method: Not Available

Obs. ID: [] View Time: 2008 JUN 08 12:00:00.000 Target: SATURN Observer: CASSINI Reference Object: SATURN

Angular Semi-Diameter: 5.8659deg
Dust RAM Head: 204.2443deg/10.2905deg
Dust RAM Tail: 24.2443deg/10.2905deg
Dust Velocity Magnitude: 9.9002km/s
Mag Field Magnitude: 40.2159nT
MagField Vector Head: 172.7396deg/33.3333deg
MagField Vector Tail: 352.7396deg/33.3333deg
Phase Angle: 64.0521deg
Plasma RAM Head: 250.3442deg/2.4657deg
Plasma RAM Tail: 70.3442deg/2.4657deg
Plasma Velocity Magnitude: 51.1901km/s
S/C Altitude: 645918.0491km
S/C Dist. to Body Center: 589685.3328km
S/C RAM Head: 332.5173deg/16.5174deg
S/C RAM Tail: 152.5173deg/-16.5174deg
S/C Velocity Magnitude: 8.7035km/s
Solar Incidence Angle: 64.0521deg
Sub Reflection Lat on: 22.3571deg/20.0000deg

1:3D Perspective Projection

Inertial

- Celestial Sphere
- RA-Dec Grid
- J2000 Axes

Solar System

- Spacecraft

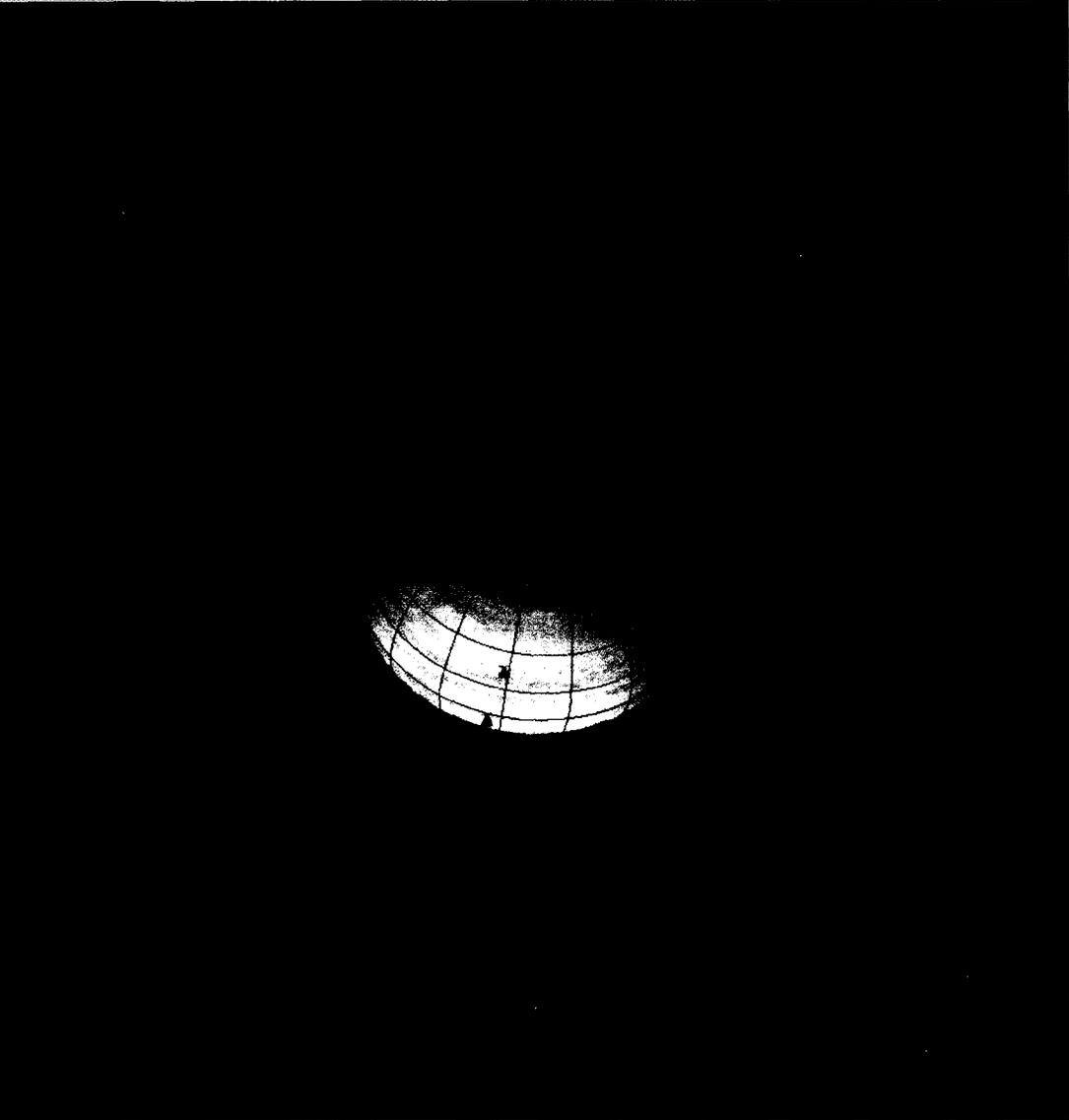
Settings

Animation Time Window

Start: 2008 JUN 08 12:00:00.000
End: 2008 JUN 30 12:00:00.000
Step interval (seconds): 60.0

Animation Control

Start Stop Resume Step Undo Zoom Restore to Original View Release Activity Control Footprint Data



X: 0 30 60 90 120 150 180 210 240 270 300 330 360
Y: 0 30 60 90 120 150 180 210 240 270 300 330 360
Z: 0 30 60 90 120 150 180 210 240 270 300 330 360

Zoom



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3D
Perspective
View of Saturn
as seen from
a user
specified
vantage point,
June 2008.
The Cassini
spacecraft is
visible at
upper right,
along with
spacecraft
and satellite
trajectories.

The screenshot displays the SOA Viewer application window. At the top, it shows the title "SOA Viewer created on Mon Sep 23 12:55:35 MDT 2002" and various settings: "Frame: J2000", "Rotation Method: Cumulative Rotation", and "Euler Angles: X=70.0, Y=0.0, Z=0.0". The main interface includes a menu bar (File, View Options, Print), a toolbar with "View", "Time", and "Target" buttons, and a status bar with "Obs. ID", "Time: 2008 JUN 08 12:00:00.000", "Target: SATURN", "Observer: CASSINI", and "Reference Object: SATURN".

On the left side, there is a list of parameters for Saturn, such as "Angular Semi-Diameter: 5.8659deg", "Dust RAM Head: 204.2443deg/-10.290", "Mag Field Magnitude: 40.2159nT", and "Phase Angle: 64.0521deg". Below this is a "1:3D Arbitrary Observer" section with a tree view of celestial bodies and their associated features. Saturn is selected, and its features include "SATURN Texture M", "SATURN Label", "SATURN Lat/Lon Gr", "SATURN Labels Sys", "SATURN System", "SATURN Intercepts", "SATURN Rings", "SATURN Body Fixed", "SATURN Equatorial", "SATURN Ecliptic Ax", "Physical Phenomena", and "Spacecraft".

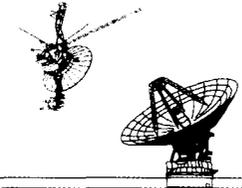
The central area is a 3D perspective view of Saturn and the Cassini spacecraft. The spacecraft is visible in the upper right corner. To the right of the view are three vertical sliders for X, Y, and Z coordinates, each ranging from 0 to 360. Below these is a "Zoom" slider.

At the bottom, there is an "Animation Control" section with buttons for "Start", "Stop", "Resume", "Step", "Undo Zoom", "Restore to Original View", "Release Activity Control", and "Export Data".

October 11, 2002

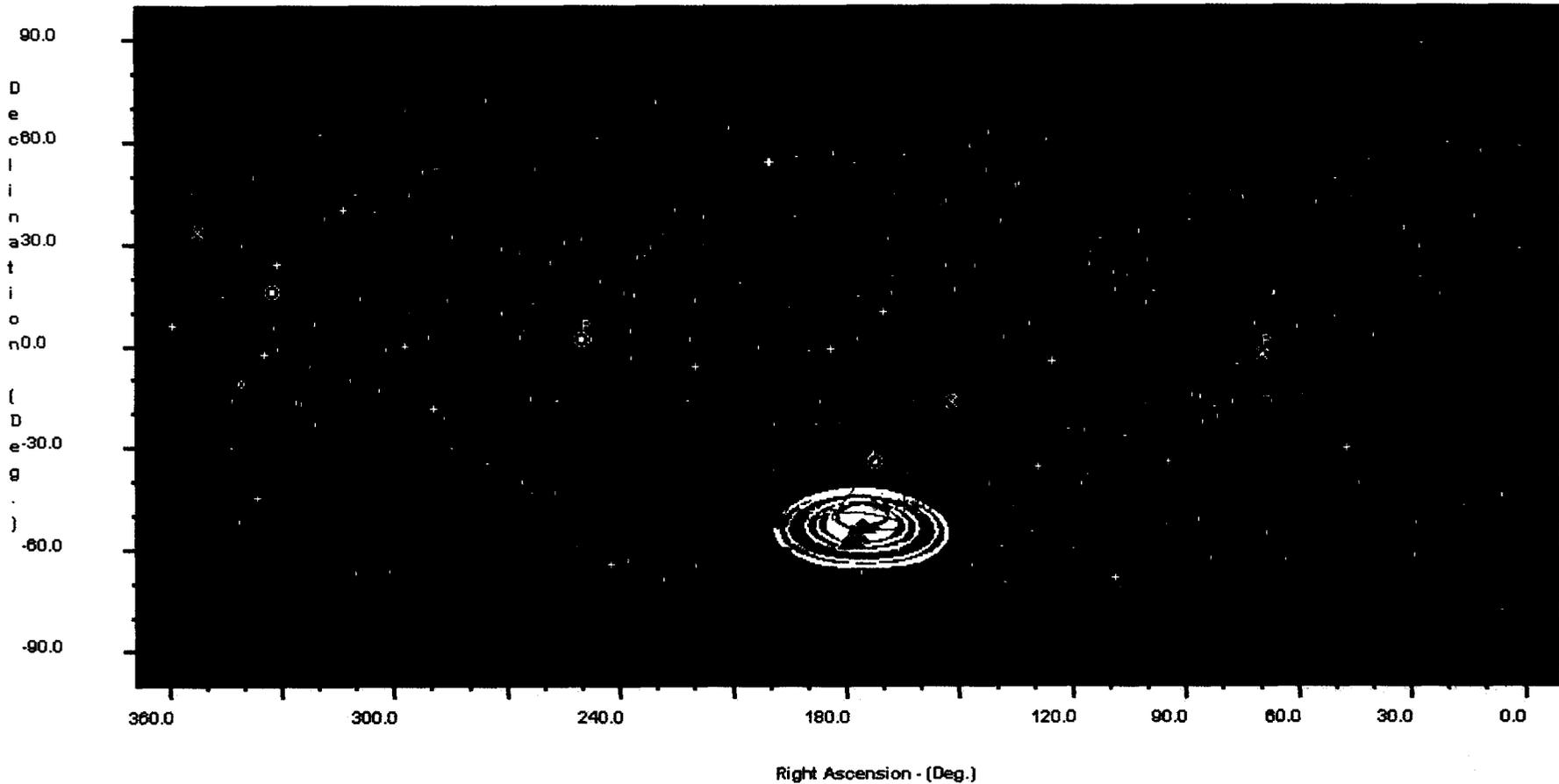
SpaceOps 2002

8



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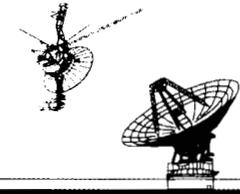
1: SOA 2D Rendering - Sky Map



2D Sky Map at the same time, as seen from Cassini.

October 11, 2002

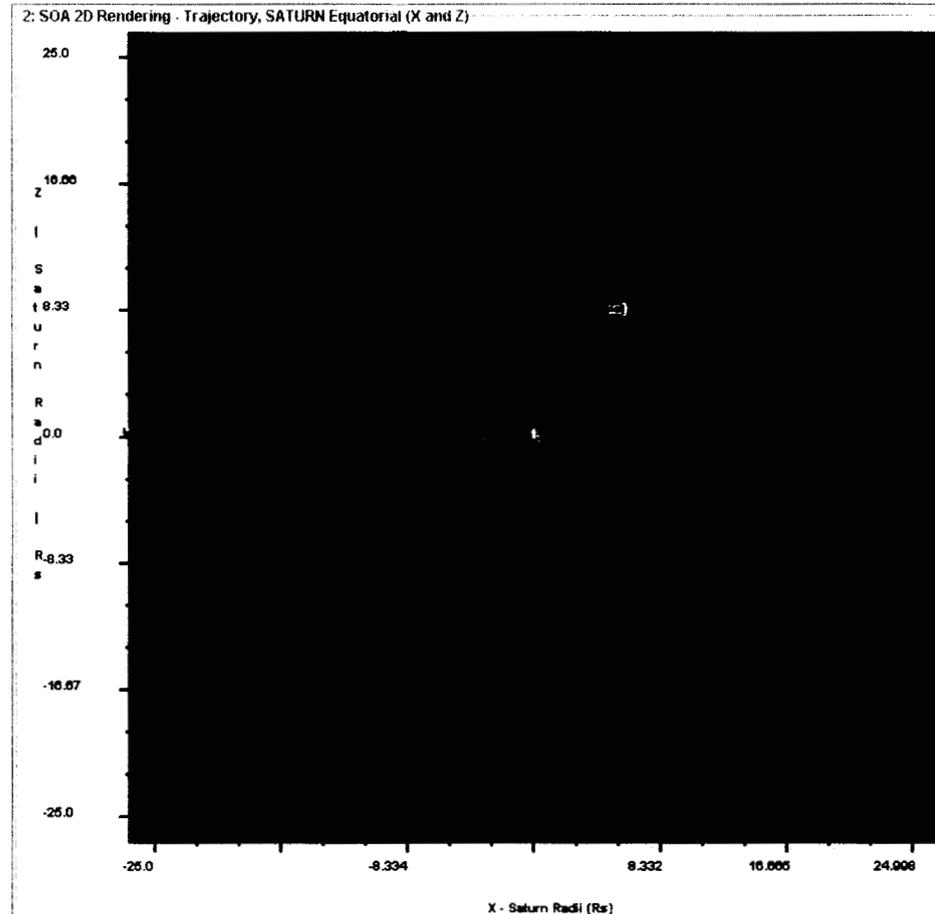
SpaceOps 2002



2D Trajectory View of the X-Z plane, with spacecraft and satellite trajectories shown. Time tick marks help the user identify times of interest for an observation.

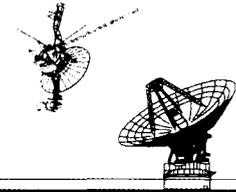
Multiple viewers with various view types may be opened at one time.

All views may be animated and manipulated for zoom and rotation.



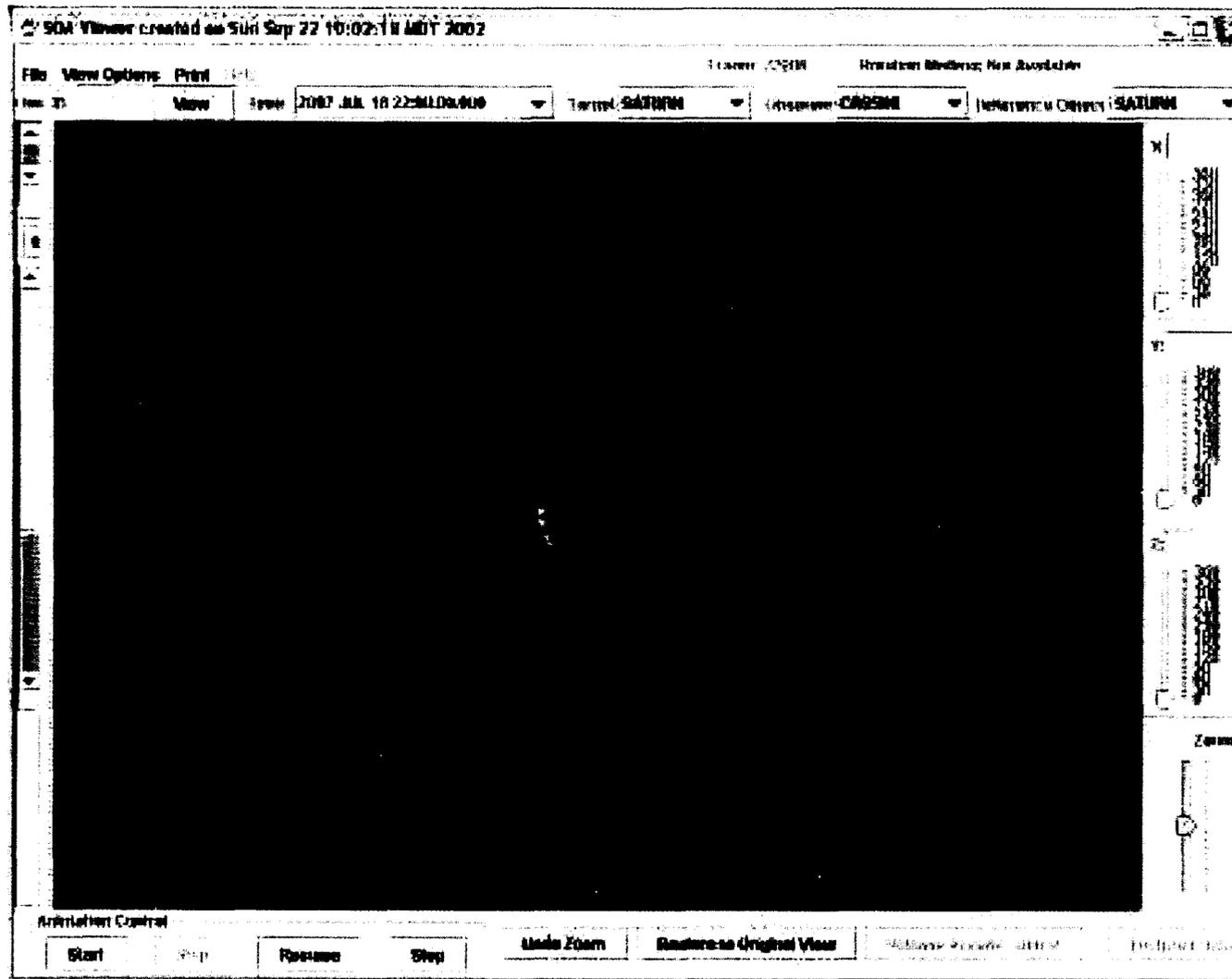


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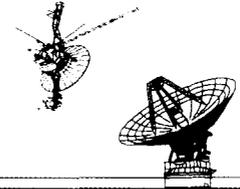
October 11, 2002

SpaceOps 2002

11

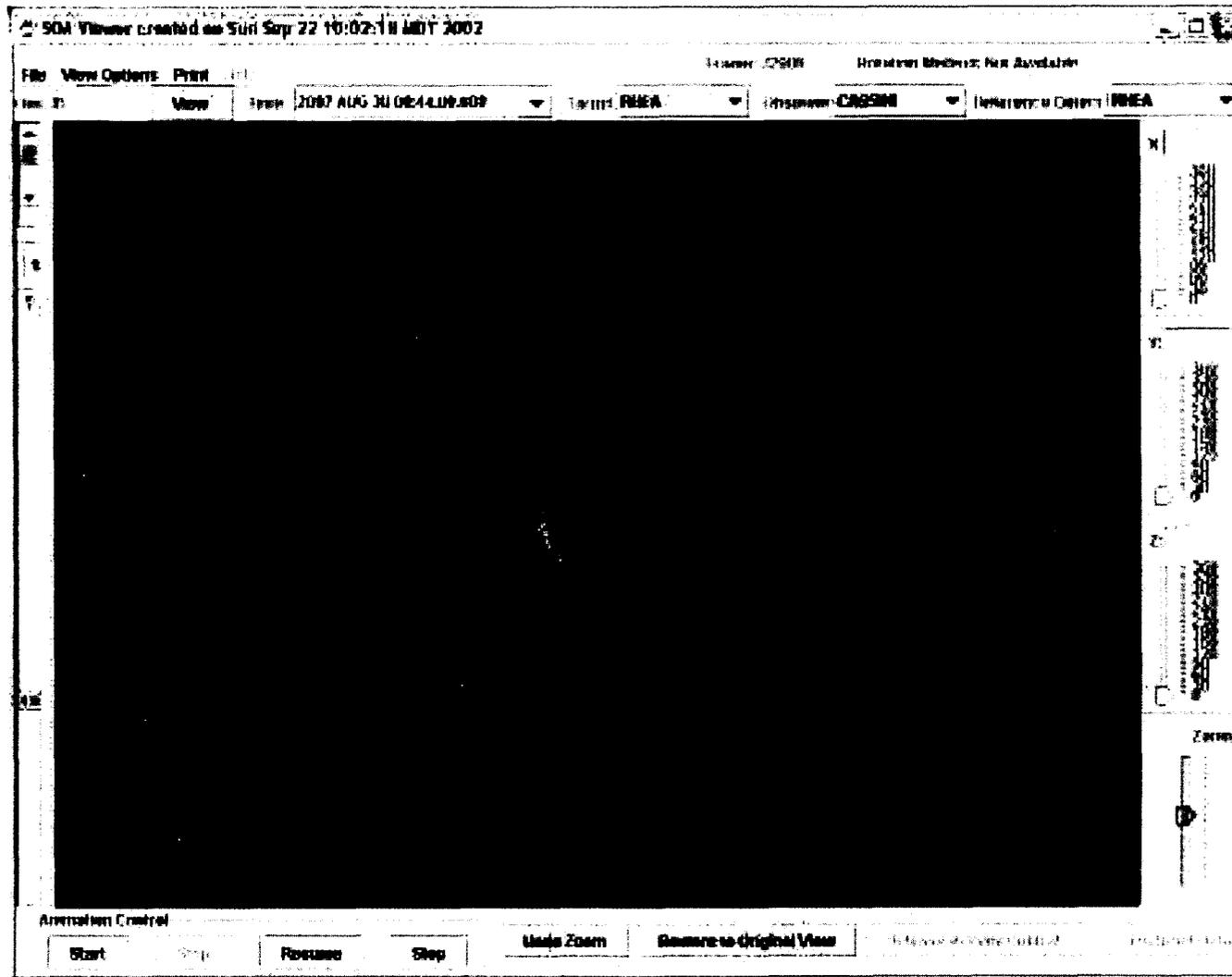


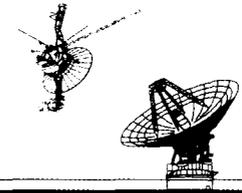
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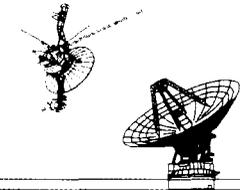


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SOA Capabilities (cont.)

- Observation Design
 - Plan & design science observation(s) at the times(s) suggested by the opportunity search.
 - Scientist control and verification of observation parameters to ensure desired observation objectives will be met (exposure times, target coverage, observing geometry).
 - Detailed parameter control with mapping to spacecraft sequence generation software parameters.
 - High level “Scoping” design tool for “what if” studies.
- Constraint Checking
 - Checks high level observation design constraints early in the sequence development process.
 - Provides feedback on violations.
 - Permits user-level and project-level rule checking.



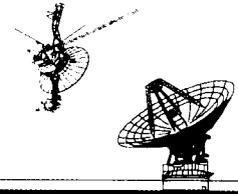
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| | | | | | | | | | |
|----------------|--------------------|--------------|----------------------|--------------------------|------------------------|-------------------------|---------------|-------------|-------------------|
| New Obs | Convert Obs | Apply | Write to list | Module Parameters | Nominal Twist ▼ | Check Constraint | 00 violations | View | New Viewer |
|----------------|--------------------|--------------|----------------------|--------------------------|------------------------|-------------------------|---------------|-------------|-------------------|

New Observation: START_STOP_MOS

| Name | Value | Default | Range | Comment |
|----------------------------|--|------------------|--------------------------|--|
| Activity Start Time | | 2005 Jun 08 ... | | Time S/C starts to acquire target |
| Observation Start Time | 2004 JAN 01 12:00:00.000 | 2005 Jun 08 ... | | Valid S/C orientation is acquired |
| Observation End Time | | 2005 Jun 08 ... | | Last time S/C orientation is maintained |
| Planned Duration | 00:16:00.0 | 00:16:00.0 | | Total time allocated for the activity |
| Activity Duration | | 00:00:01 | | Total time calculated from parameters |
| Targeting Allowance | 0:05:00.000 | 0:05:00.000 | | Time to acquire target S/C attitude |
| Targeting Margin | 0:05:00.000 | 0:05:00.000 | | Margin applied to Targeting Allowance |
| Observation Duration | | 0:01:00.000 | | Calculated duration of valid S/C orientation |
| Observation Margin | 0:05:00.000 | 0:05:00.000 | | Observation Margin |
| Step Interval | 00:00:01 | 00:00:01 | | Frequency of calculations |
| Primary Target | SATURN Center | SATURN Cen... | | Tracking reference point |
| Secondary Target | Align to SATURN pole | Align to SATU... | | Used to specify S/C orientaiton around Primary ... |
| Target Offsets | X:0 deg;Y:0 deg;Z:0 deg | X:0 deg;Y:0 d... | | Target Offsets |
| Primary Observer | S/C X Axis ▼ | S/C X Axis | S/C X Axis,S/C -X Axi... | Vector pointed at Primary Target + Offsets |
| Secondary Observer | S/C Z Axis ▼ | S/C Z Axis | S/C X Axis,S/C -X Axi... | Secondary Observer |
| Mosaic Specification | Flyback;1per strip;1 total; angles ... | Flyback;1per ... | | Detailed mosaic parameters |
| Target Motion Compensation | OFF ▼ | OFF | ON,OFF | Tracking of the target during observation |

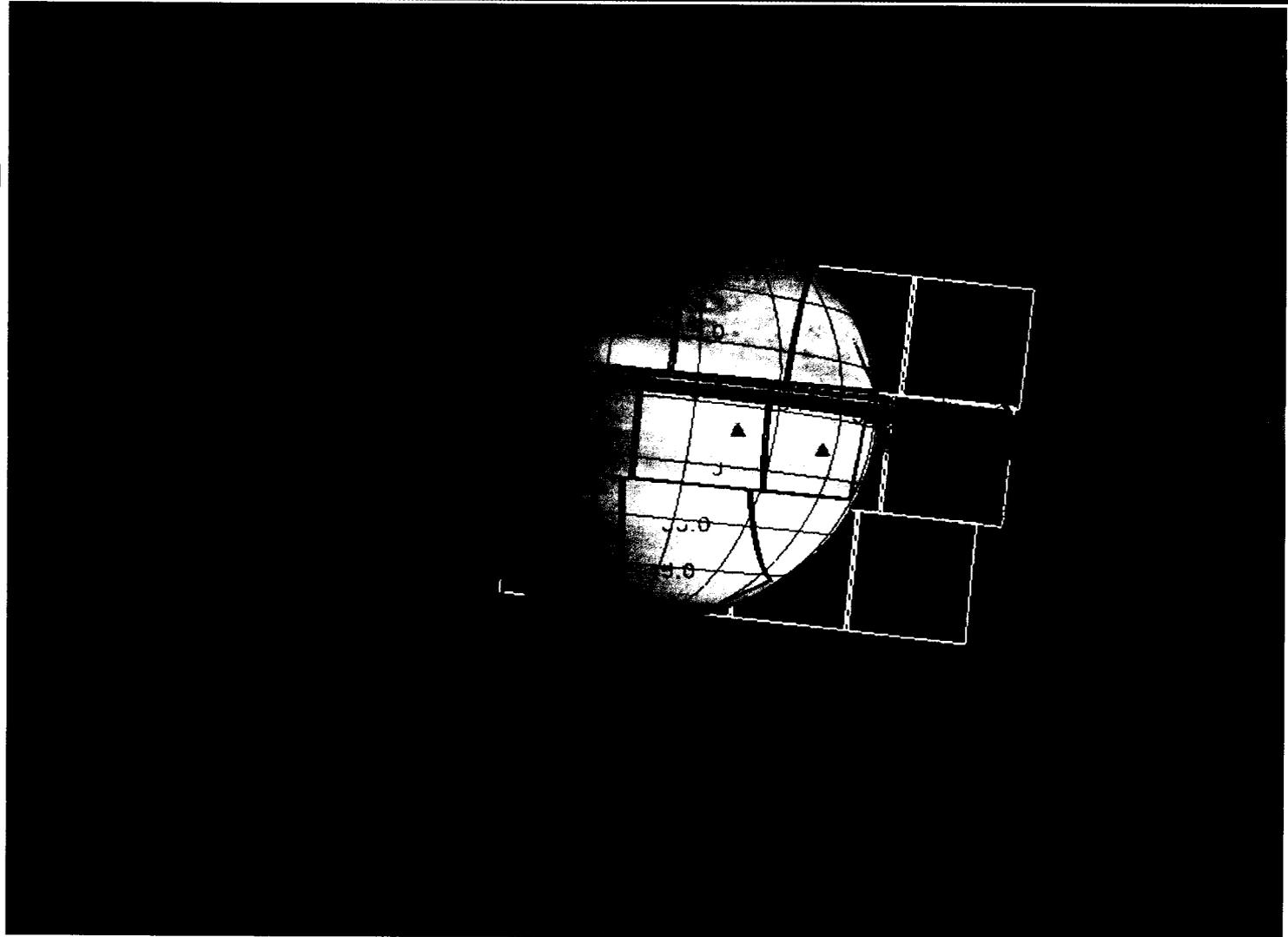
Observation design screen of SOA allows the user to specify the time, duration, target, instrument, and style of observation. Additional input screens accept detailed mosaic information.

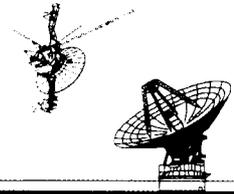


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Example mosaic showing the footprints of the Cassini Wide Angle Camera. Pink footprints indicate intercepts on the target body. Yellow footprints show the pointing in inertial space.

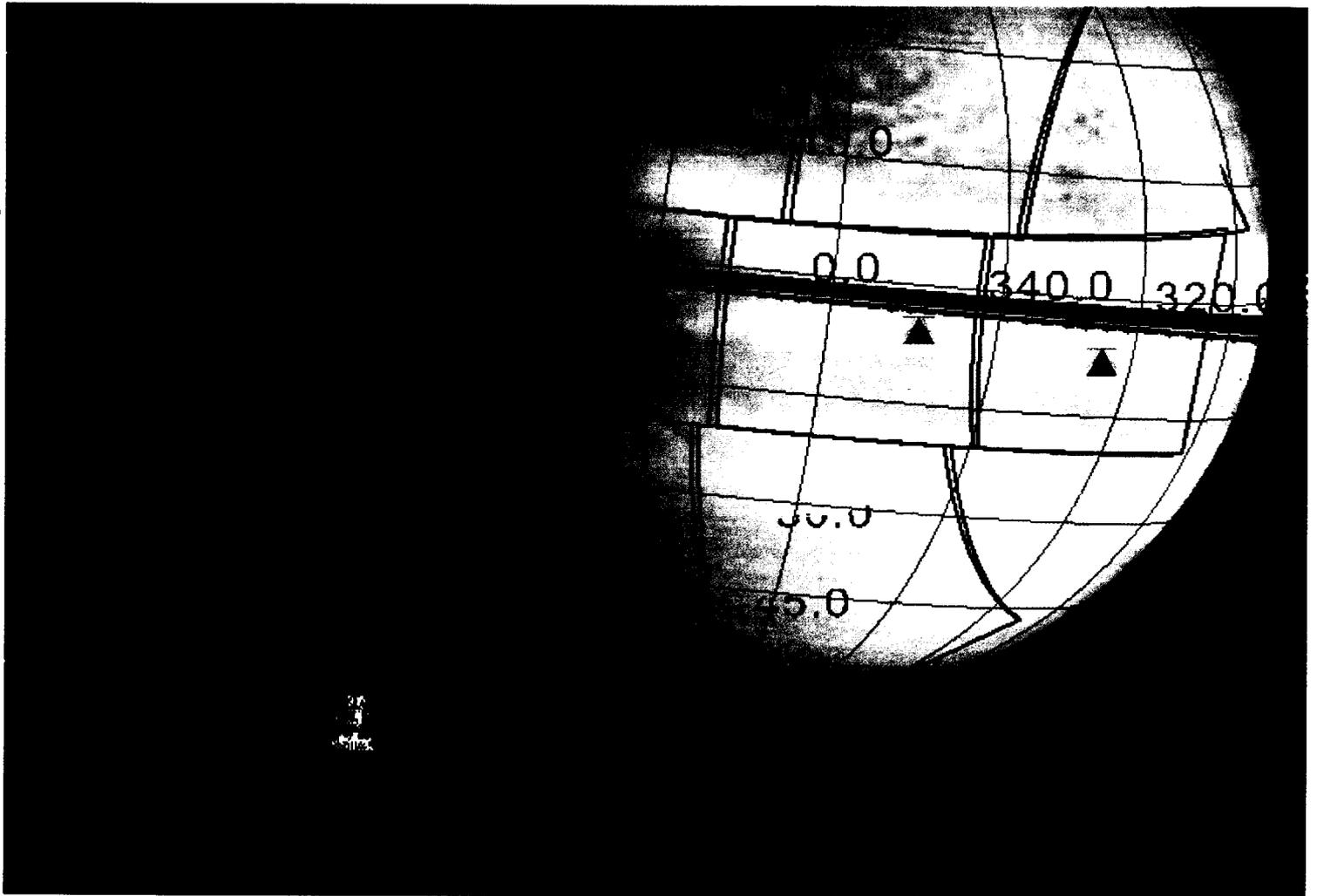


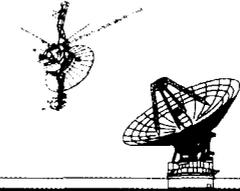


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The same mosaic viewed from outside the spacecraft. Here, scientists can see the orientation of the spacecraft for possible secondary measurements.





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Opportunity Search **Copy Flight** Flight Rules Data Output Communications Global/Kernel

Default Activity Rules:

All On

New/Edit Rule

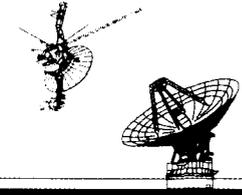
Delete Rule

Load Rules

Save Rules

| Rule Name | Enabled | Rule Expression | Description |
|-----------------------|-------------------------------------|----------------------------|--|
| AngleTest | <input type="checkbox"/> | Angle | ISS WAC 5 deg of Sun |
| AngleTest20min | <input checked="" type="checkbox"/> | Angle | ISS WAC 5 deg of Sun for 20 min |
| AngleTest30min | <input type="checkbox"/> | Angle | ISS WAC 5 deg of Sun for 30 min |
| AngleASDTest | <input type="checkbox"/> | Angle + ASD | ISS NAC 2 deg of Saturn |
| AngleASDTest2hr | <input type="checkbox"/> | Angle + ASD | ISS NAC 2 deg of Saturn for 2 hours |
| AngleASDTest1day | <input type="checkbox"/> | Angle + ASD | ISS NAC 2 deg of Saturn for 1 day |
| AngleASDTest2day | <input type="checkbox"/> | Angle + ASD | ISS NAC 2 deg of Saturn for 2 day |
| AngleDistanceTest1 | <input type="checkbox"/> | Angle + Distance | ISS WAC 5 deg of Sun from 4-5 AU |
| AngleDistanceTest2 | <input checked="" type="checkbox"/> | Angle + Distance | ISS WAC 5 deg of Sun from 5-12 AU |
| AngleASDTest2 | <input type="checkbox"/> | Angle + ASD | ISS NAC between 2 & 4 deg of Saturn |
| AngleASDTest3 | <input type="checkbox"/> | Angle + ASD | ISS NAC between 4 & 6 deg |
| AngleASDDistanceTest1 | <input checked="" type="checkbox"/> | Angle + ASD + Distance | ISS NAC 2 deg of Saturn & Cassini within 1 million km |
| AngleASDDistanceTest2 | <input type="checkbox"/> | Angle + ASD + Distance | ISS NAC 2 deg of Saturn & Cassini between 1-5 million km |
| AngleASDDistanceTest3 | <input type="checkbox"/> | (Angle + ASD AND Distance) | ISS NAC 2 deg of Saturn s/c between 4-5 AU |
| AngleASDDistanceTest4 | <input type="checkbox"/> | (Angle + ASD AND Distance) | ISS NAC 2 deg of Saturn s/c between 5-12 AU |
| CompoundAngleTest | <input checked="" type="checkbox"/> | (Angle OR Angle OR Angle) | ISS WAC multiple Sun conditions |
| FR07B4 | <input checked="" type="checkbox"/> | Angle + ASD + Distance | |
| rateTest1 | <input checked="" type="checkbox"/> | TurnRate | max rate = 0.0016 rad/s (default) |
| accelTest1 | <input checked="" type="checkbox"/> | TurnAccel | max accel = 1.0E-5 rad/s/s (default) |
| rateTest2 | <input type="checkbox"/> | TurnRate | max rate = 0.0001 rad/s |
| accelTest2 | <input type="checkbox"/> | TurnAccel | max accel = 10 rad/s/s |
| accelTest3 | <input type="checkbox"/> | TurnAccel | max accel = 8.0E-6 rad/s/s |
| ruleTest1 | <input checked="" type="checkbox"/> | Angle + ASD | ISS WAS RAD sun constraint |

The constraint checking screen of SOA allows the user to define and control constraints that observations must meet. All violations of these constraints are identified by SOA in a time-ordered listing generated on the observation design screen.

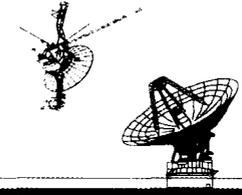


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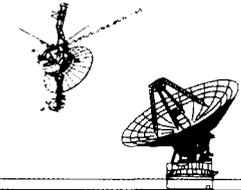
SOA Capabilities (cont.)

- Communications
 - Communicate opportunity & design results to other software tools in the uplink process.
 - Reads and writes the standard Spacecraft Activity Sequence File (SASF) format
 - Interaction with Activity Plan Generator (APGEN) timeline software to work within the “science plan.”
 - Interaction with Seq_Pointer (simulates actual spacecraft hardware and software) for more detailed constraint checking.
 - Interaction with Seq_Gen (generates uplink files) to become part of the official sequence product.
 - First SEQ tool to be designed from the beginning to communicate with other tools.



SOA Capabilities (cont.)

- Ancillary Data Output
 - Generate data files with geometric information as a function of time with user-customized parameter list for any period of time, or for an observation.
 - Plot ancillary geometric data for any period of time.
 - Provides complementary method for identifying observation opportunities and for validating geometry for designed observations.



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Opportunity Search Flight Rules | Data Output | Communications | Global/Kernel

Source: **Trajectory Related**

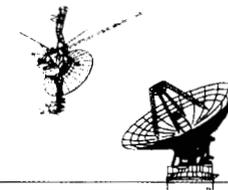
Start Time: **2005 Jun 08 12:00:00.000** End Time: **2005 JUN 08 13:00:00.000**

Data Interval: Time Format: UTC ISO DOY ISO SFOC

Target: **SATURN** Target Coordinate System: **Planetocentric**

| | |
|--|--|
| <input type="checkbox"/> Angular Semi-Diameter <input checked="" type="radio"/> deg <input type="radio"/> rad | <input type="checkbox"/> S/C Altitude <input checked="" type="radio"/> km <input type="radio"/> planetary radii |
| <input type="checkbox"/> Dust RAM Head <input type="text" value="Ra/Dec"/> <input checked="" type="radio"/> deg <input type="radio"/> rad | <input type="checkbox"/> S/C Dist. to Body Center <input checked="" type="radio"/> km <input type="radio"/> planetary radii |
| <input type="checkbox"/> Dust RAM Tail <input type="text" value="Ra/Dec"/> <input checked="" type="radio"/> deg <input type="radio"/> rad | <input type="checkbox"/> S/C RAM Head <input type="text" value="Ra/Dec"/> <input checked="" type="radio"/> deg <input type="radio"/> rad |
| <input type="checkbox"/> Dust Velocity Magnitude <input checked="" type="radio"/> km/s | <input type="checkbox"/> S/C RAM Tail <input type="text" value="Ra/Dec"/> <input checked="" type="radio"/> deg <input type="radio"/> rad |
| <input type="checkbox"/> Mag Field Magnitude <input checked="" type="radio"/> nT | <input type="checkbox"/> S/C Velocity Magnitude <input checked="" type="radio"/> km/s |
| <input type="checkbox"/> MagField Vector Head <input type="text" value="Ra/Dec"/> <input checked="" type="radio"/> deg <input type="radio"/> rad | <input type="checkbox"/> Solar Incidence Angle (sub S/C point) <input checked="" type="radio"/> deg <input type="radio"/> rad |
| <input type="checkbox"/> MagField Vector Tail <input type="text" value="Ra/Dec"/> <input checked="" type="radio"/> deg <input type="radio"/> rad | <input type="checkbox"/> Sub Reflection Lat/Lon <input checked="" type="radio"/> deg <input type="radio"/> rad |
| <input type="checkbox"/> Phase Angle (sub S/C point) <input checked="" type="radio"/> deg <input type="radio"/> rad | <input type="checkbox"/> Sub S/C Lat/Lon <input checked="" type="radio"/> deg <input type="radio"/> rad |
| <input type="checkbox"/> Plasma RAM Head <input type="text" value="Ra/Dec"/> <input checked="" type="radio"/> deg <input type="radio"/> rad | <input type="checkbox"/> Sub Solar Lat/Lon <input checked="" type="radio"/> deg <input type="radio"/> rad |
| <input type="checkbox"/> Plasma RAM Tail <input type="text" value="Ra/Dec"/> <input checked="" type="radio"/> deg <input type="radio"/> rad | <input type="checkbox"/> Target Angular Rate <input checked="" type="radio"/> mrad/s <input type="radio"/> degrees/s |
| <input type="checkbox"/> Plasma Velocity Magnitude <input checked="" type="radio"/> km/s | <input type="checkbox"/> Target Ra/Dec (sub S/C point) <input checked="" type="radio"/> deg <input type="radio"/> rad |

Select or customize ancillary data for plotting or file output.

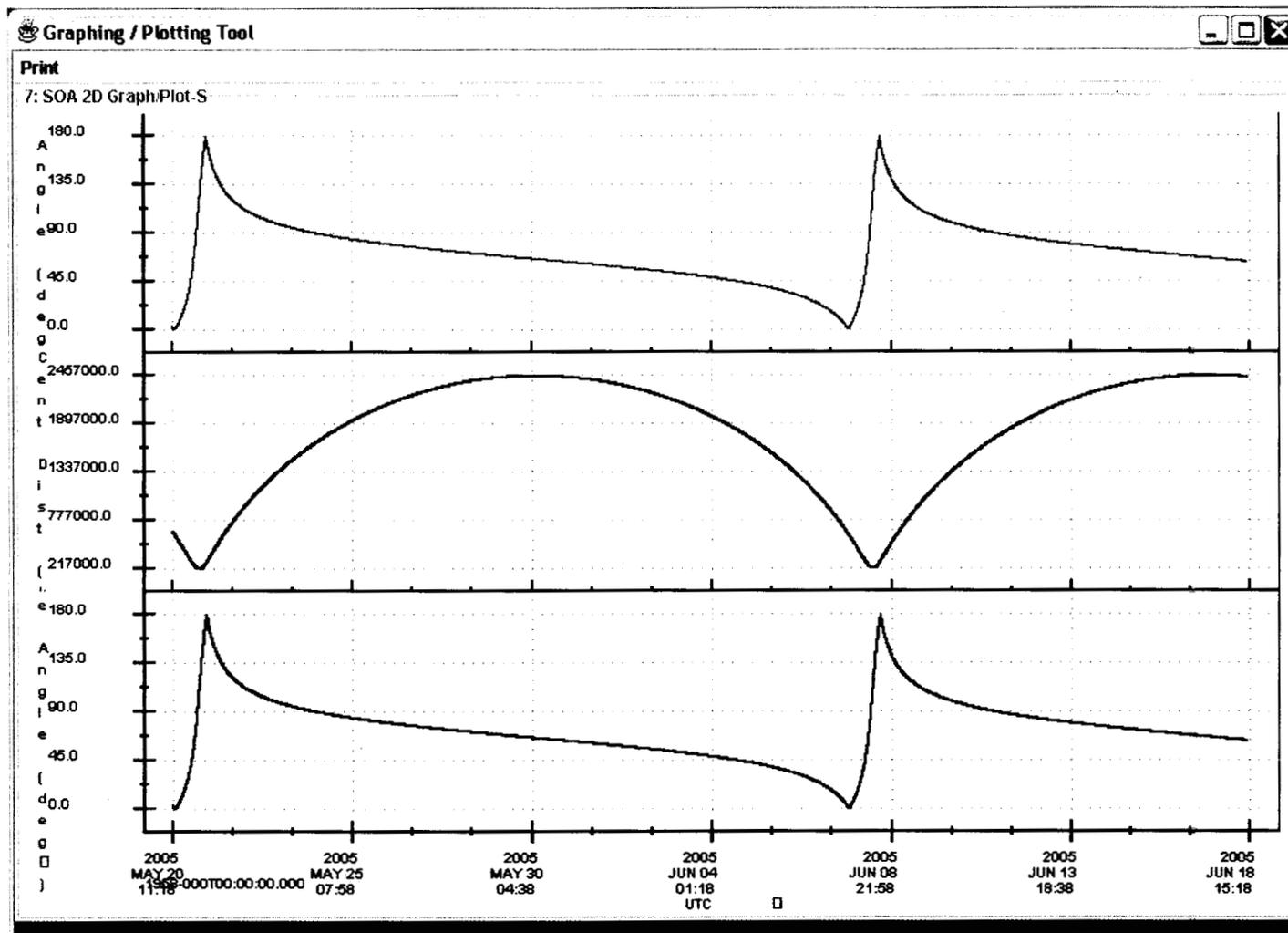


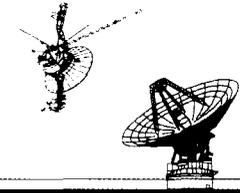
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Example of stacked plot of ancillary geometric data:

phase angle, solar incidence angle, and distance from Saturn as functions of time.





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SOA's Present and Future

- **Current Mission Support**
 - SOA is being used by the Cassini project, an international planetary spacecraft with a four year orbital tour at Saturn beginning July 1, 2004. Cassini scientists have been involved in detailed tour planning for more than 6 years. SOA is making observation design and planning more efficient in a time-constrained mission environment.
 - SOA's ability to show the same information in multiple ways (multiple visualization formats, data plots, listings, and file output) are essential when meeting the needs of a broad and diverse user community such as the Cassini Science Group.
 - **Multi-Mission Design**
 - SOA is designed for use with any space mission. Project-specific capabilities are added to the core software as needed in the adaptation step.