Extended Bright Bodies – Flight and Ground Software Challenges on the Cassini Mission at Saturn

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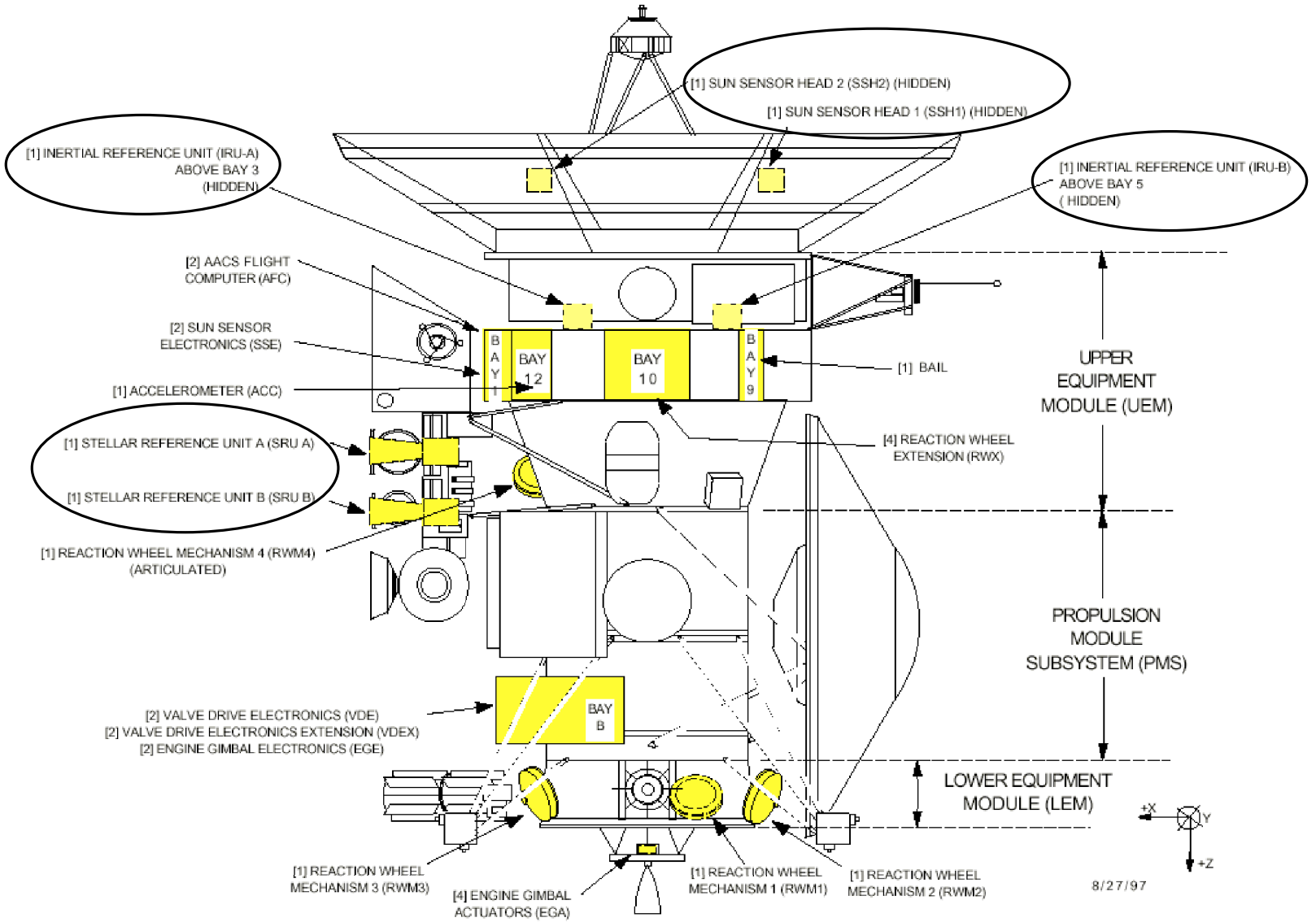
January 8, 2016

The Cassini Spacecraft

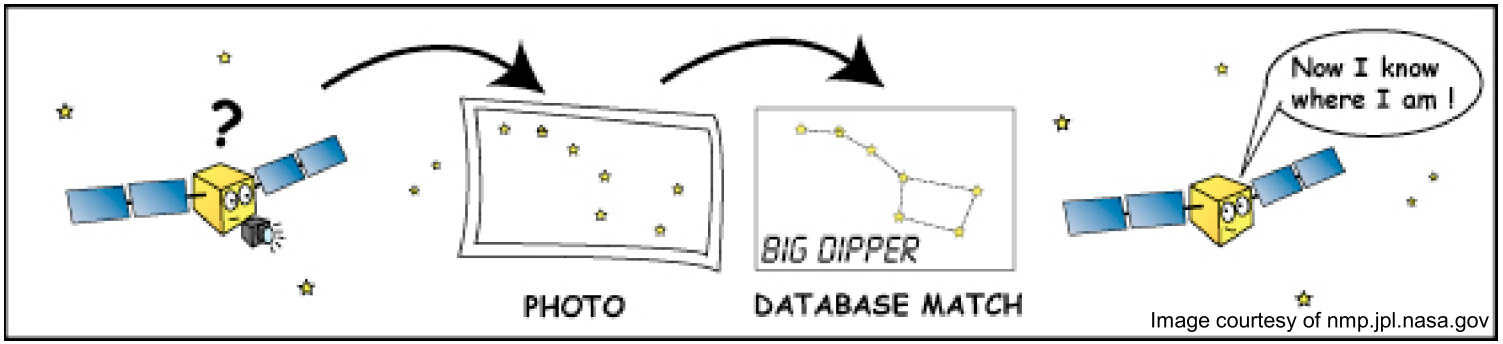


Sensors for Establishing Attitude Knowledge

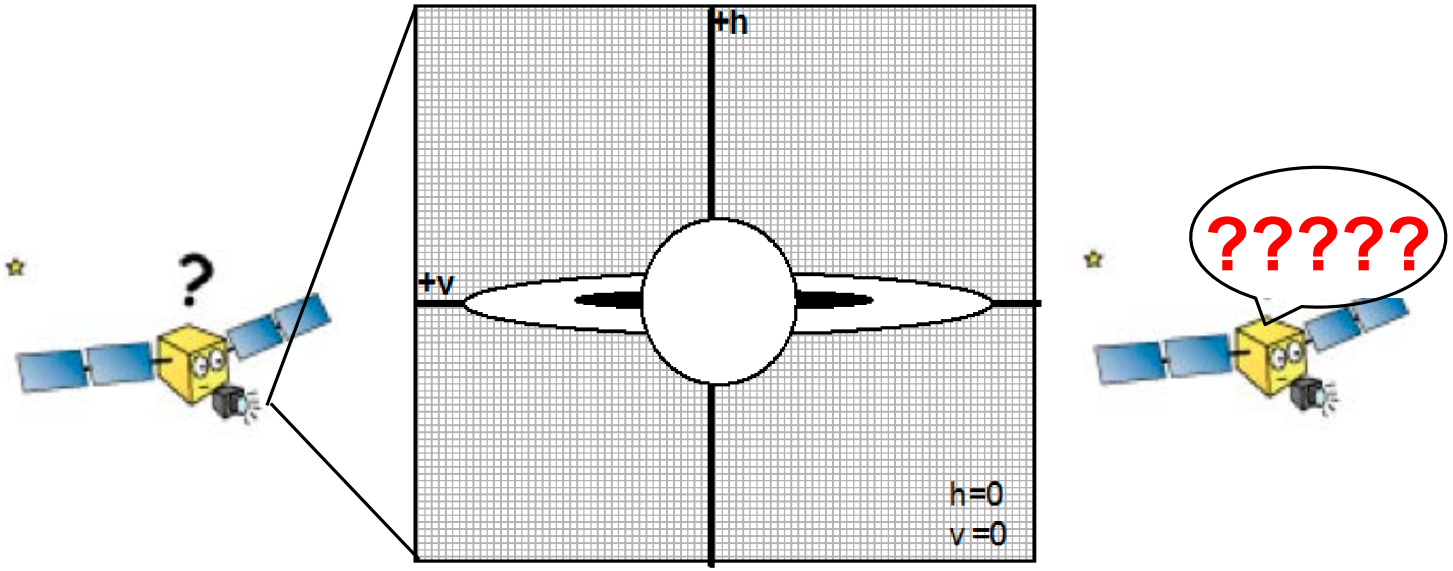
- **Sun Sensor Assemblies (SSA)**
  - Data used to construct “sun line” vector for the flight software.
  - Typically used to initialize the spacecraft attitude estimation.
- **Inertial Reference Unit (IRU)**
  - Hemispheric Resonator Gyroscopes that sense rotational motion.
  - Data filtered into spacecraft body-rate to update the 3-axis inertial attitude estimation.
- **Stellar Reference Unit (SRU)**
  - Detect stars in its field-of-view and compares them with an onboard star catalog.
  - 3-axis attitude reference is determined with 2-5 stars.
  - Prime sensor used for attitude determination, supplemented by the IRU measurements.

Extended Bright Body Interference to SRUs

- When adequate stars are acquired:



- When extended bright bodies enters the SRU's field-of-view:

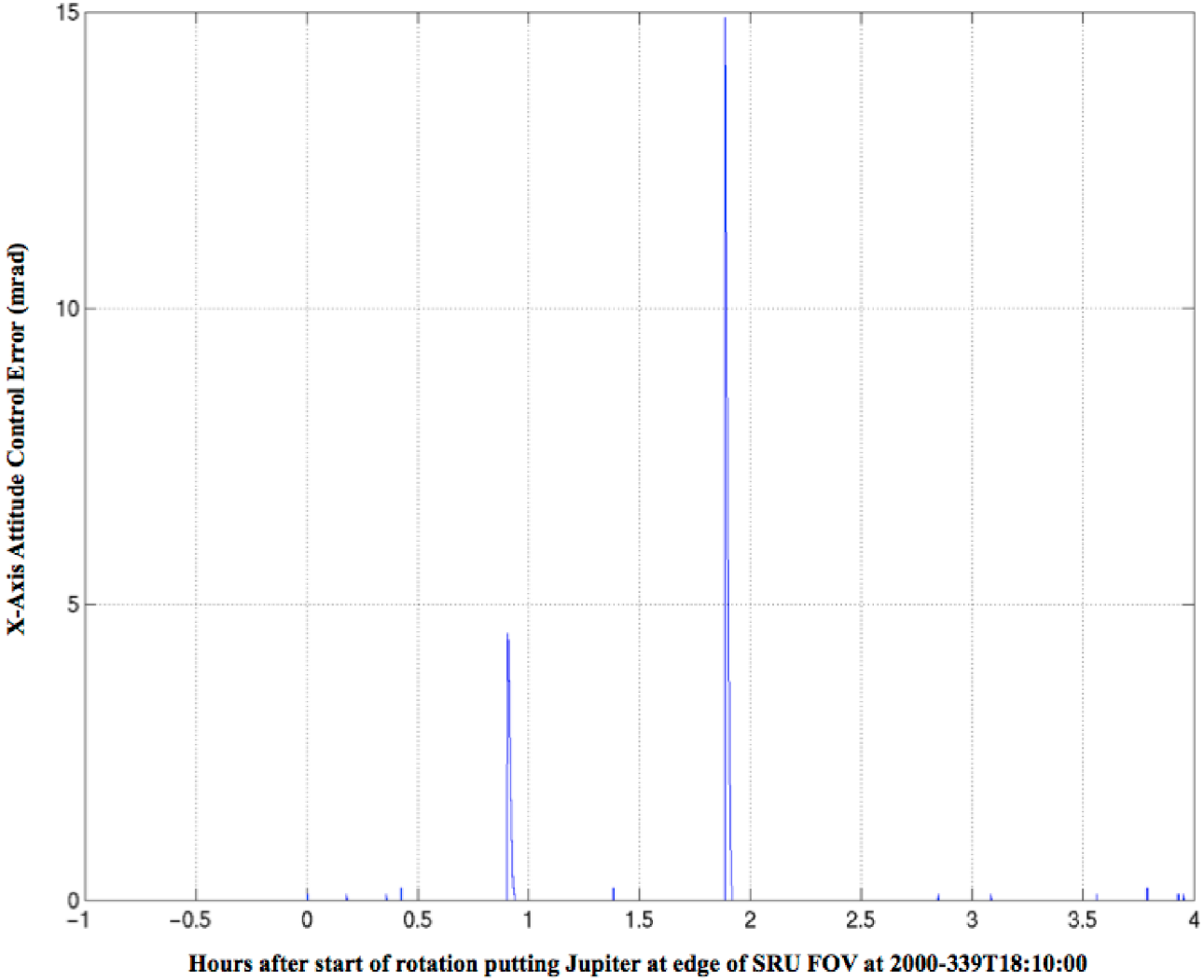


Suspension of Star Identification

- During cruise to Saturn, Cassini flew by Jupiter in December of 2000. Each time Jupiter entered the corner of the SRU's field-of-view, all stars were lost.
- To overcome this challenge, star identification (SID) needs to be suspended during predicted interference period.
- Instead, the flight software must propagate inertial attitude knowledge using the IRU data alone.
- At the end of each SID suspend period, star identification is re-enabled and any attitude error induced by IRU-only estimation is quickly corrected.
- A set of flight rules was established to define when to suspend star identification based on bright body geometry, expected albedo of Saturnian objects, the star tracker behavior, and the SID flight software.

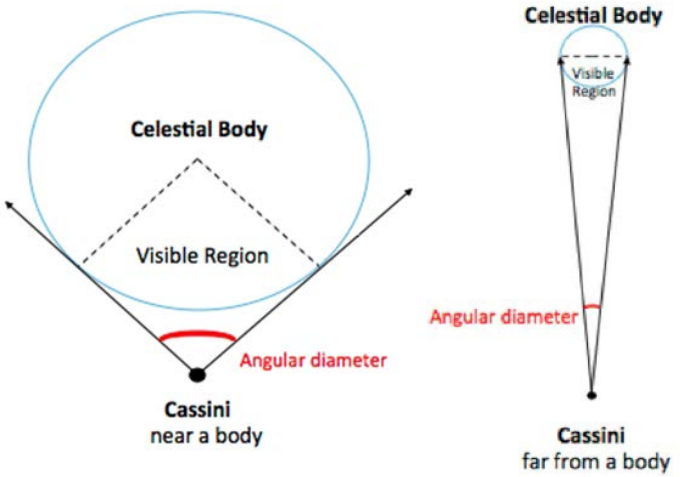
Attitude Control Error from Jupiter's Interference

This was before SID Suspends were implemented

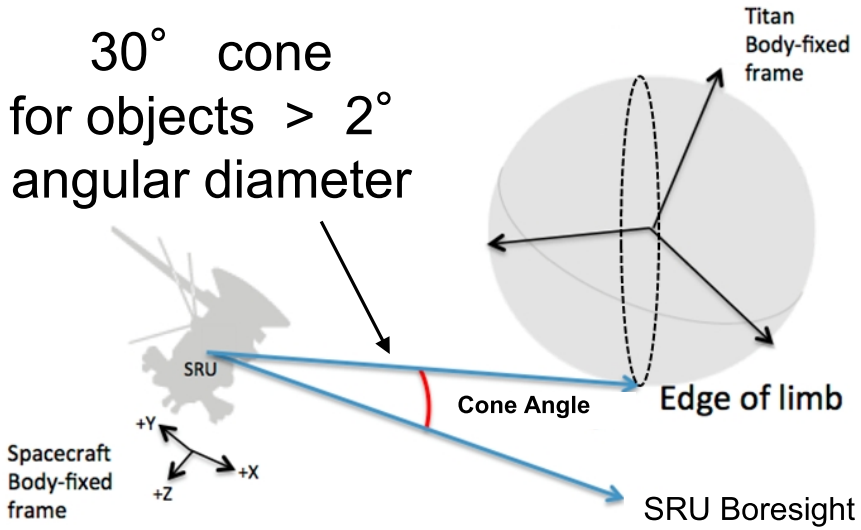


Bright Body SID Suspend Criteria

- How big does the bright body have to be to cause problematic interference?
  - Minimum angular diameter threshold was selected: 0.5 degrees



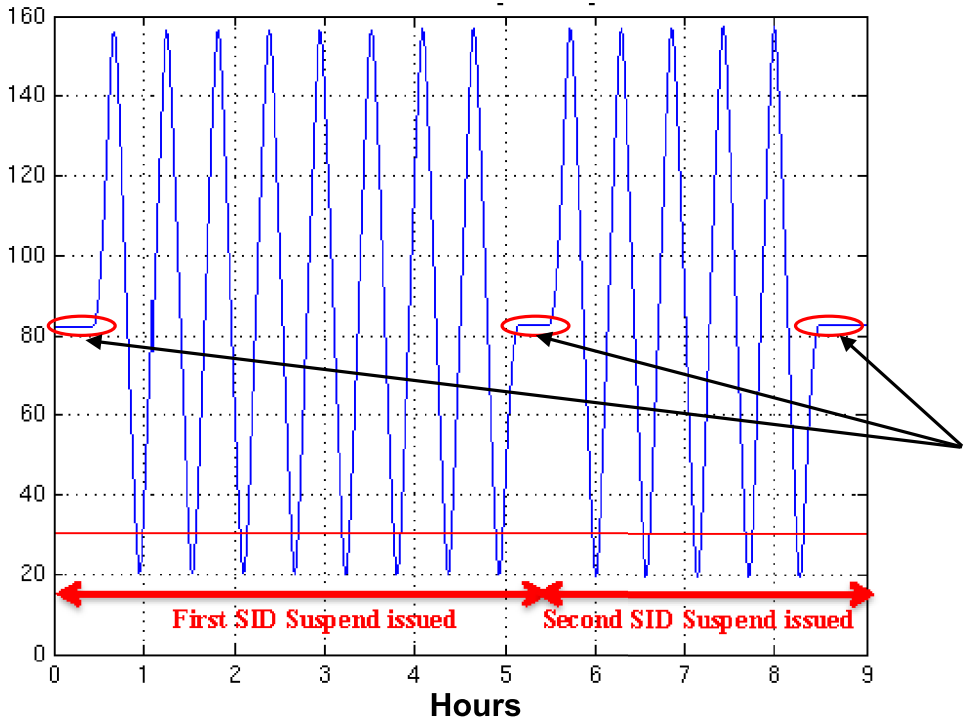
- How close?
  - Suspend SID if bright body enters stray light "cone".



SID Suspends – When and for How Long?

- How long can the star identification be suspended?
  - Maximum of 5 hours duration
  - Selection based on gyro scale factor errors and maximum slew rate
- A quiescent spacecraft is needed at start and end of each suspend
  - Ensures good star knowledge at start/end time of each suspend

SRU-to-Saturn Angle (deg) during a rolling downlink

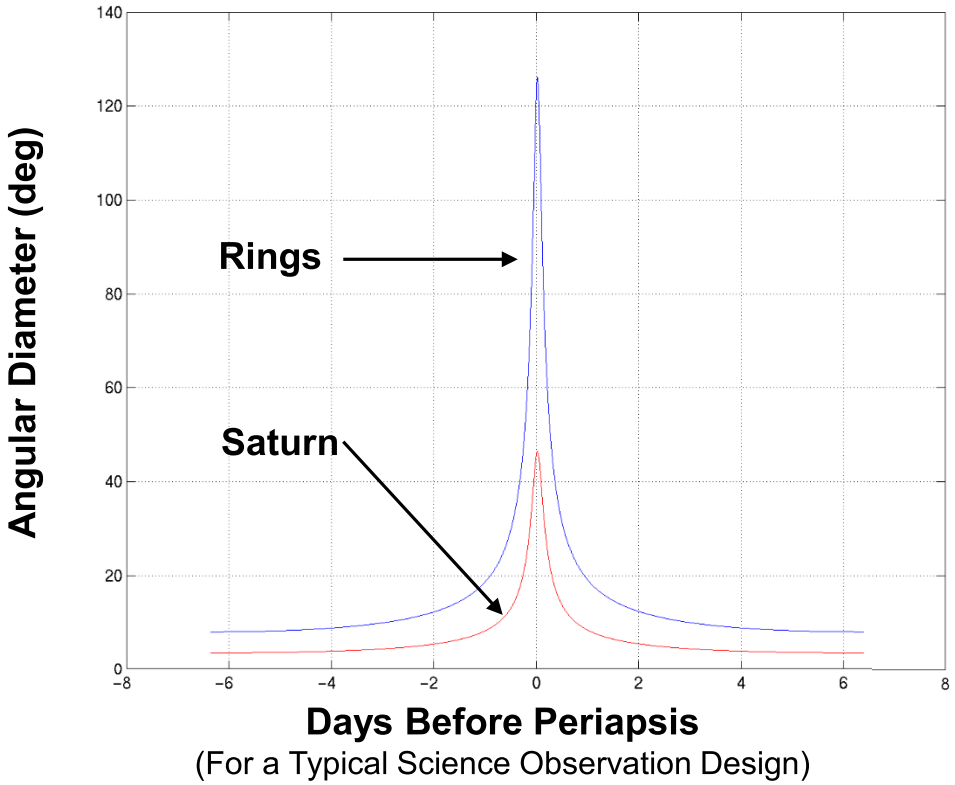


Using Ground Software to Enforce Flight Rules

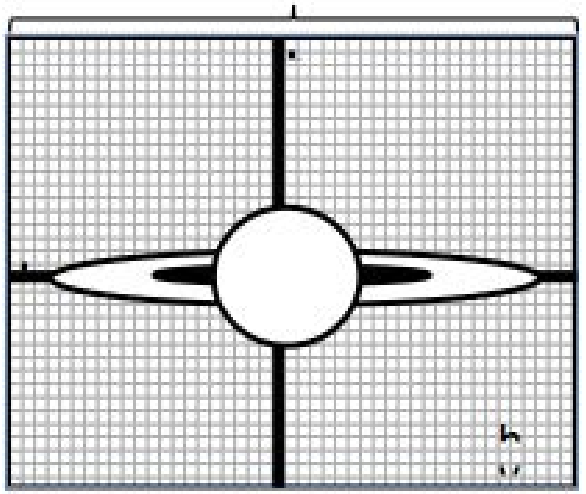
- The Kinematic Predictor Tool (KPT) ground software models a whole sequence of pointing, tracking, and slewing events at 500 times real-time processing speed.
- KPT determines when SID suspends are needed for extended bright bodies in the SRU's field-of-view.
  - NASA's Navigation and Ancillary Information Facility (NAIF) toolkit is used to calculate the position and relative geometry between celestial bodies and the spacecraft.
  - SID suspend flight rules are implemented in KPT to identify when SID suspends are necessary.
- KPT generates SID suspend commands, which are then merged with the background sequence to be uplinked to the spacecraft.
- If SID suspend commands cannot be generated due to flight rule violations, KPT flags the violations for ground operators to investigate.

Angular Size of Saturn/Rings change a lot during an orbit

- Rings are modeled as a very thin (< 1 km) ellipsoid
  - Long axes are 2.26 Rs (Rs is equatorial radius of Saturn)



(For a Typical Science Observation Design)

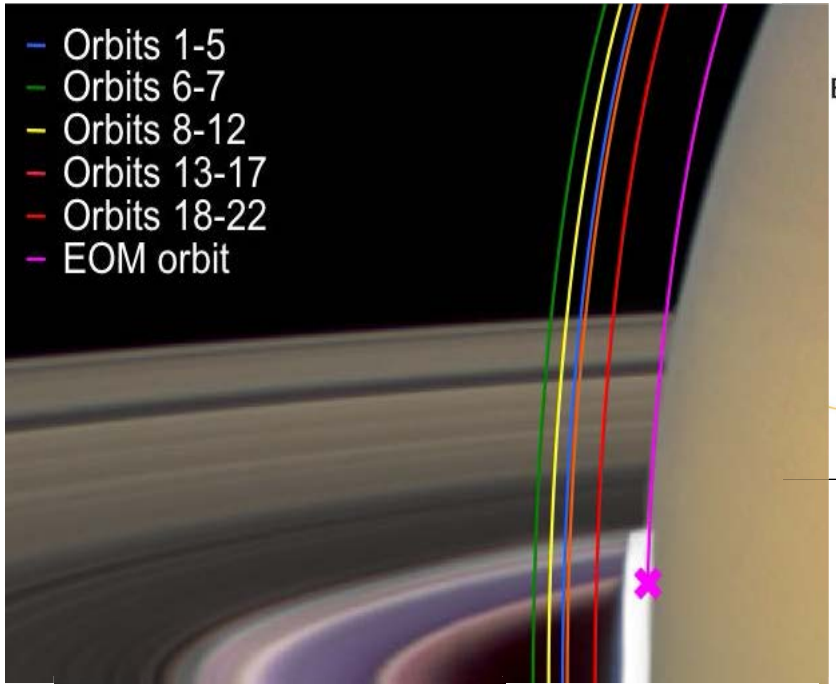


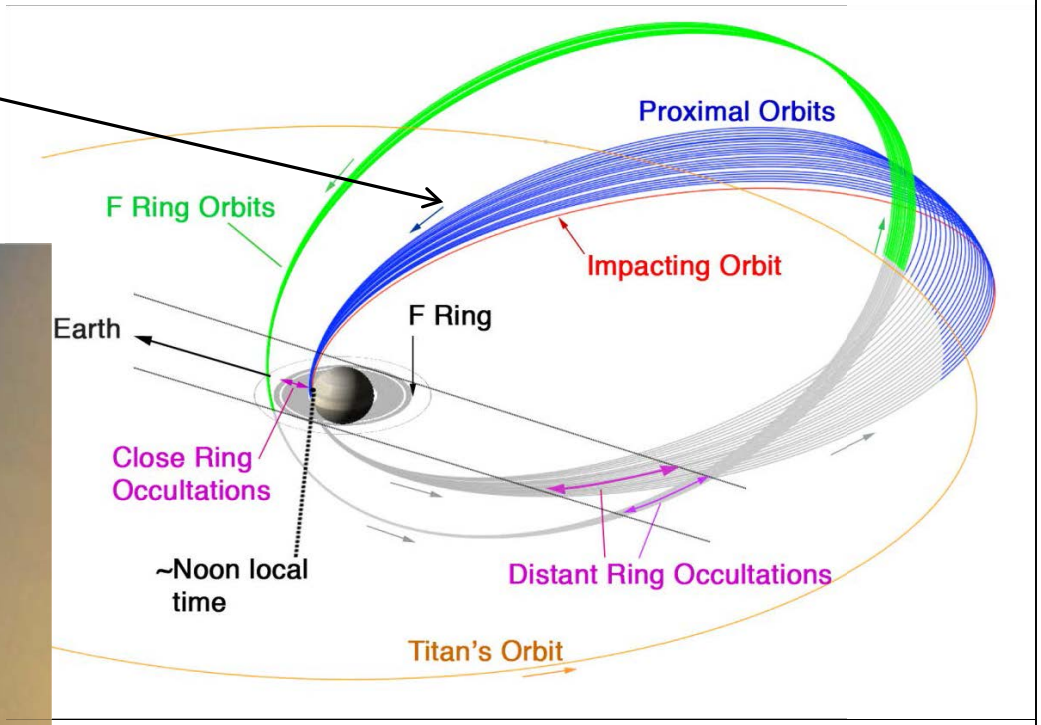
- The moons, especially Titan, can disrupt star identification as well
  - In all, 11 object (Sun, Saturn, Rings, and moons) are tracked in KPT

Cassini's Proximal Orbit Mission

- In the spring, summer, and fall of 2017, Cassini will fly through the ring plane just above Saturn's cloud tops for 22 high inclination orbits, called "proximal orbits".

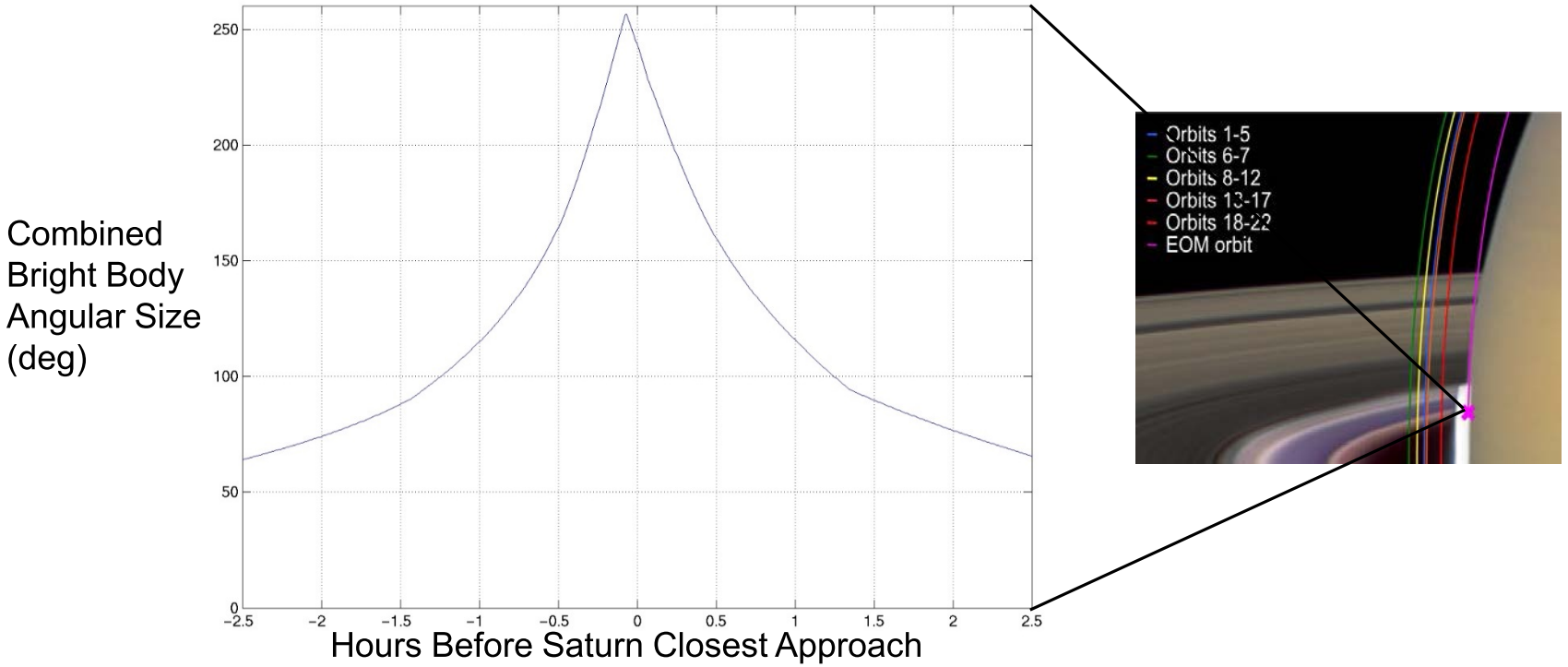
22 Ballistic Orbits Inside Rings





No Problem Meeting Bright Body Flight Rules Even During Proximal Periapses

- Cassini velocity relative to Saturn is about 31 km/s
  - Time spent where Saturn + Rings > 180° is less than 1 hour
  - Time passing through the ring plane is almost instantaneous.
- Plot below shows the "combined" angular size of Saturn plus Rings, from Cassini's perspective, right before and right after periapsis.



SID Suspend Challenges for Proximal Orbits

- For nominal flybys, SID suspend commands can be generated per usual process, as long as flight rules are not violated.
- However, the safe mode attitude has to be carefully selected to minimize bright body obstructions.
  - If Cassini enters safe mode, all nominal sequences would be stopped, and the spacecraft would autonomously turn to the safing attitude (HGA to Earth) to await ground response.
  - Safe mode attitude must ensure a command-able spacecraft, a benign thermal environment, a clear star field, and the ability to play back data.
  - Nominally, safe mode attitude is chosen to keep Saturn and its rings outside of the 30-degree cone surrounding SRU boresight. For proximal orbit operations, it is only possible to “minimize” exposure.
    - 60 to 90 minutes without star updates will not trigger additional fault protection.

Conclusion

- The SID Suspend practice and procedure have worked well over the past 11 years at Saturn.
- No major concerns over Proximal Orbit operations.
- Find more information in the paper:
  - Detailed description of Cassini's attitude determination sensors.
  - The list of flight rules developed for SID suspends.
  - Flight telemetry that shows the effects of extended bright body interferences.
  - Flight telemetry that shows the effects of IRU propagation in between SID suspends.
  - Overcoming challenges of Proximal Orbit operations.