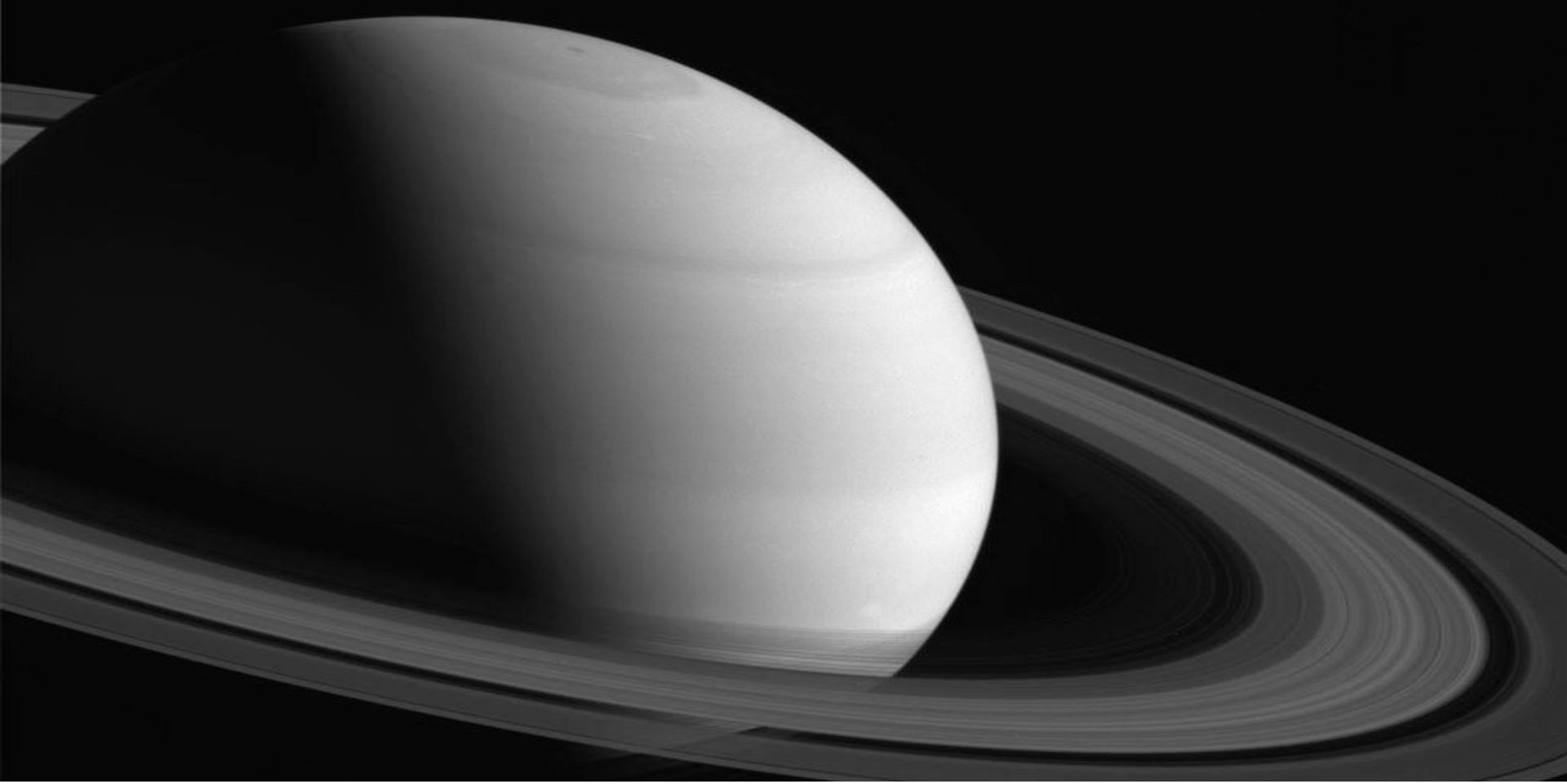

Preparation for Cassini Grand Finale – Validation of Saturn Ring Heating in TSS

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Jet Propulsion Laboratory
California Institute of Technology

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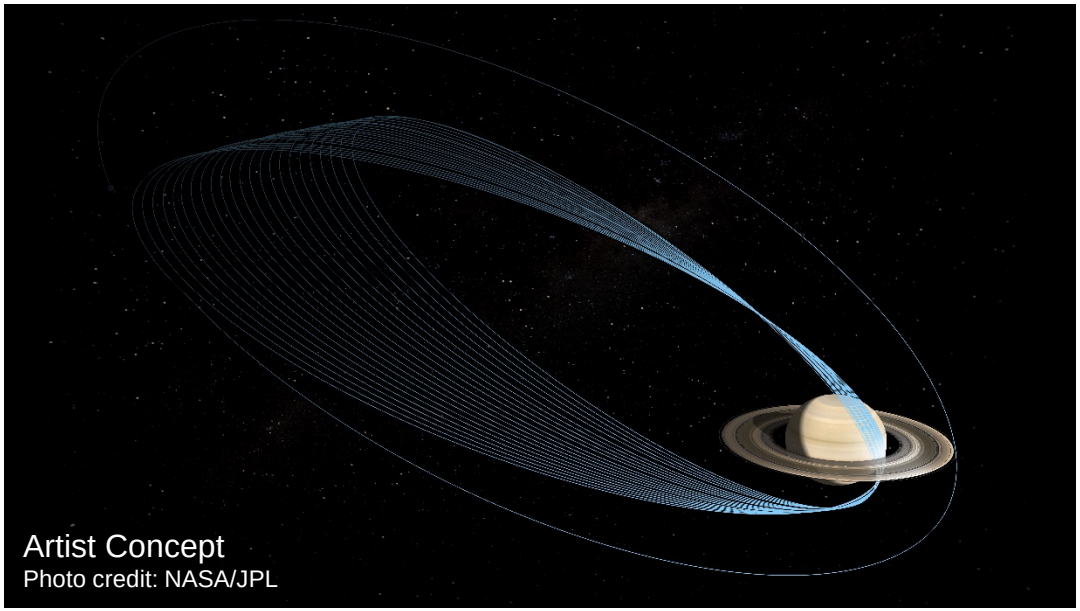
Cassini Background

- Cassini-Huygens was launched in October 1997 and arrived at Saturn on July 1, 2004
- Cassini's primary mission was competed in 2008, but has been extended twice
  - The first mission extension allowed for observations during the equinox season (completed in 2010)
  - The second mission extension allowed for observations during the summer solstice in the northern hemisphere, F-Ring Proximal Orbits (FRPO), and disposal of the spacecraft (Complete 2017)
    - The FRPO and disposal of the spacecraft are often referred to as the Grand Finale

FRPO Orbit Definitions

- FRPO is currently scheduled to begin in late 2016
- FRPO consists of 20 orbits just outside of Saturn's F-Ring followed by 22 orbits between Saturn's innermost ring and Saturn's cloud tops
- The Cassini spacecraft will complete a series of complex rotations and maneuvers to allow all instruments on board to make various observations of Saturn and Saturn's rings



Cassini Spacecraft Overview

- The Cassini spacecraft supports 12 individual instruments, not including the Huygens probe
- The Visual and Infrared Mapping Spectrometer (VIMS) consists of two spectrometers, one each in the visible and infrared spectrums
- VIMS-IR, the infrared portion was built by JPL

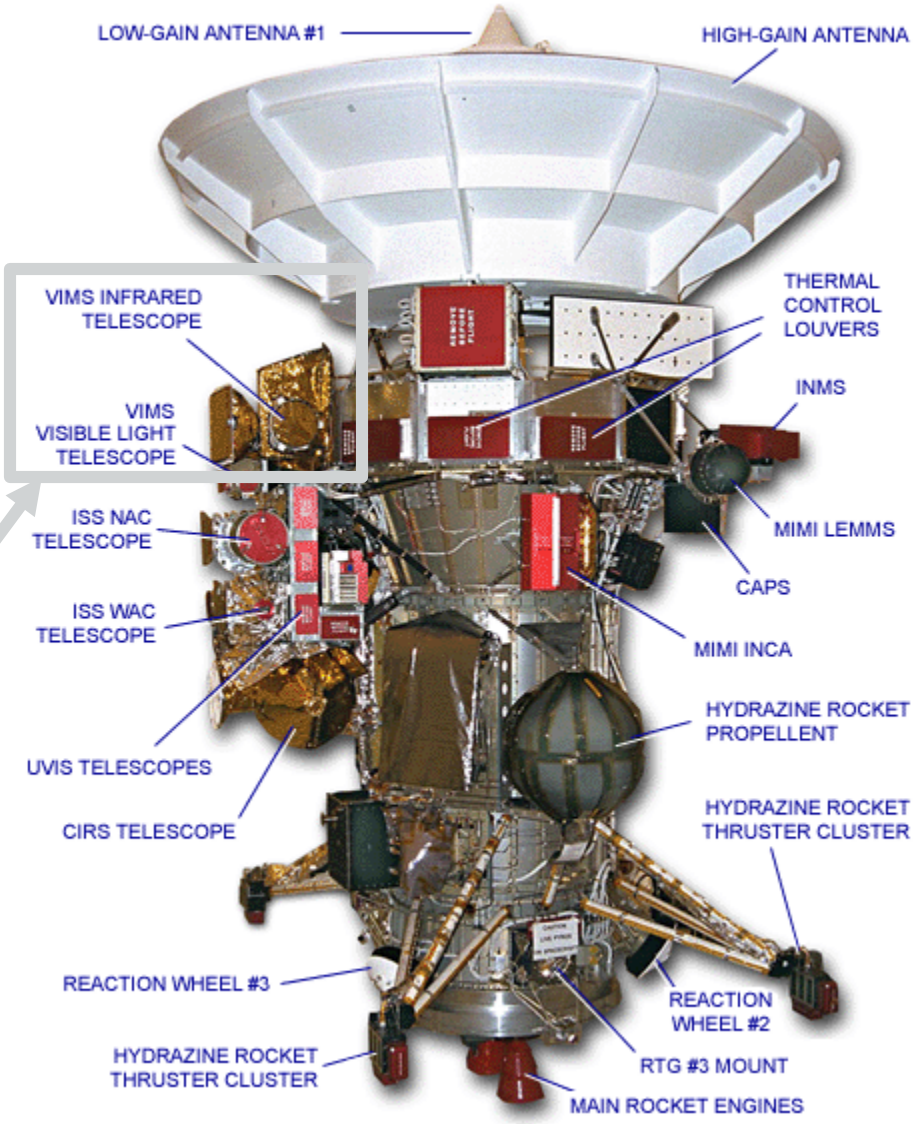


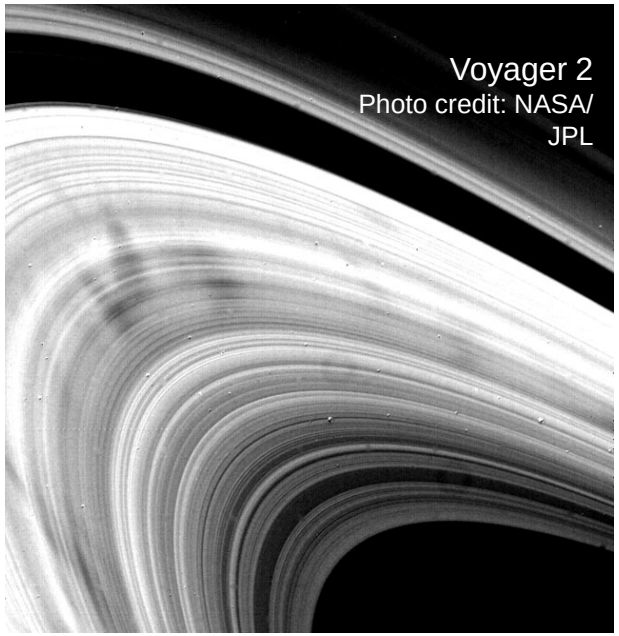
Photo Credit: NASA/JPL

VIMS-IR Passive Cooler

- The focal plane on VIMS-IR is cooled to its operational temperature range of ~60 K through the use of a passive cooler
- Since the focal plane is very sensitive to changes in temperature, temperature rises greater than 2 K were marked as programmatic consumables
  - Only 40 were allowed for the entirety of the mission
  - The time constant to return to nominal temperatures is on the order of hours to days
  - Knowledge of fluxes external to the spacecraft is imperative to accurately plan for spacecraft maneuvers, such as the complex FRPO maneuvers

Original VIMS-IR Thermal Model

- A thermal model including the VIMS passive cooler was generated prior to launch of Cassini in the mid-1990s
  - This model consisted of three main external components: sunshield, top rim, and radiator patch
  - FPA was not directly modeled, as temperature predictions are generated from the patch temperature and capacitance of FPA
- Historical FPA temperatures indicated the existing thermal model greatly underpredicted changes in FPA temperature when Saturn was in the view of the radiator
  - This model only accounted for heat fluxes from the Sun and Saturn as little was known about Saturn's rings
- Saturn was visited only 3 times before Cassini's arrival, and all were fly-by missions



Saturn’s Rings – A New Heat Source

- Vast majority of knowledge about Saturn’s rings has been acquired during Cassini’s time at Saturn
- During Cassini’s residence at Saturn, it was learned that although the rings are colder than Saturn, they are warmer than the steady state temperature of the radiator
  - Since the FRPO orbits will bring the VIMS-IR radiator even closer to this “new” heat source, Saturn’s rings needed to be accounted for
  - No commercially available thermal tools existed with Saturn’s rings as a source of external heating
  - Spacedesign, the makers of TSS, agreed to incorporate heating from Saturn’s rings in their analysis package

Model Correlation Results

Orbit Definitions and Success Criteria

- Each fly-by is designated by a sequence number (S02 = Sequence 2)
- A series of seven historical cases were run to validate TSS and VIMS Light models against existing historical data
  - SOI/S02 (Saturn Orbit Insertion)
  - S05
  - S07
  - S26
  - S42
  - S54
  - S60
- These orbits were chosen as they featured fairly large heating events (>1 K) and varied in their heating sources (solar, Saturn, Saturn ring, etc.)
- Success criteria was determined by temperature differences less than 5 K between either the TSS or VIMS Light model and historical data
- Two FRPO predictive cases were also run: S286 and S289

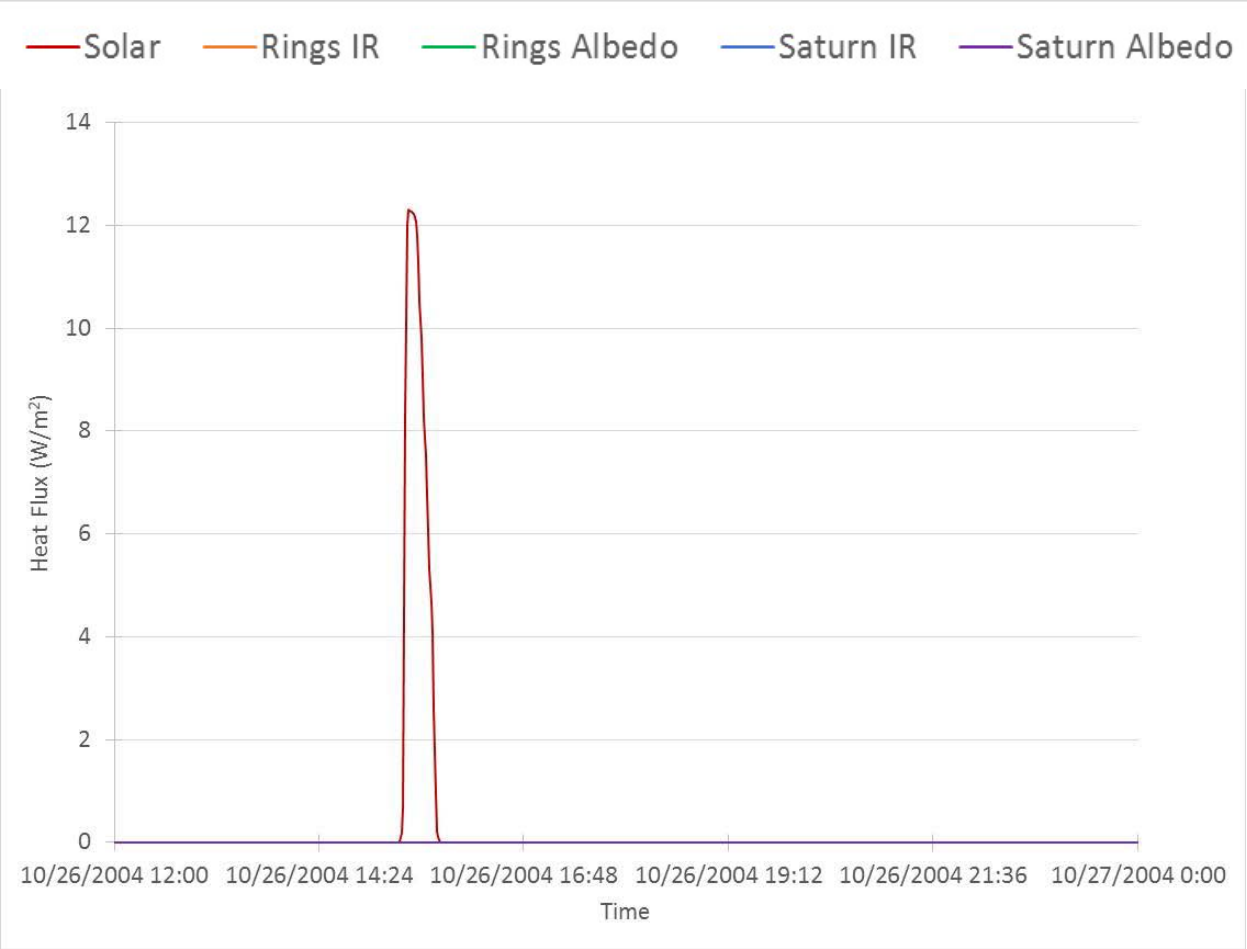
TSS Modeling & VIMS Light

- FPA has two main states, active and sleep, so the internal power dissipation was adjusted accordingly
- TSS external fluxes were broken down into five individual contributions:
  - Solar
  - Saturn IR
  - Saturn Albedo
  - Saturn Ring IR
  - Saturn Ring Albedo
- The TSS model was verified through a bottom-up approach, starting with verification of spacecraft pointing (S05 & S07) followed by the addition of Saturn heating (S54) and then followed by ring heating (SOI, S26, S42, etc.)
- A second tool, “VIMS Light”, was also developed in parallel with the TSS work
  - This tool was to be used by orbital planners as a quick way to determine FPA temperature rises with various spacecraft maneuvers
  - TSS thermal model used to validate final sequence temperatures

Historical Results

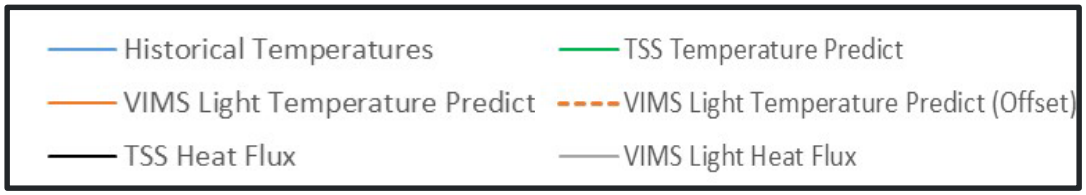
S05 TSS Heat Rate Sources

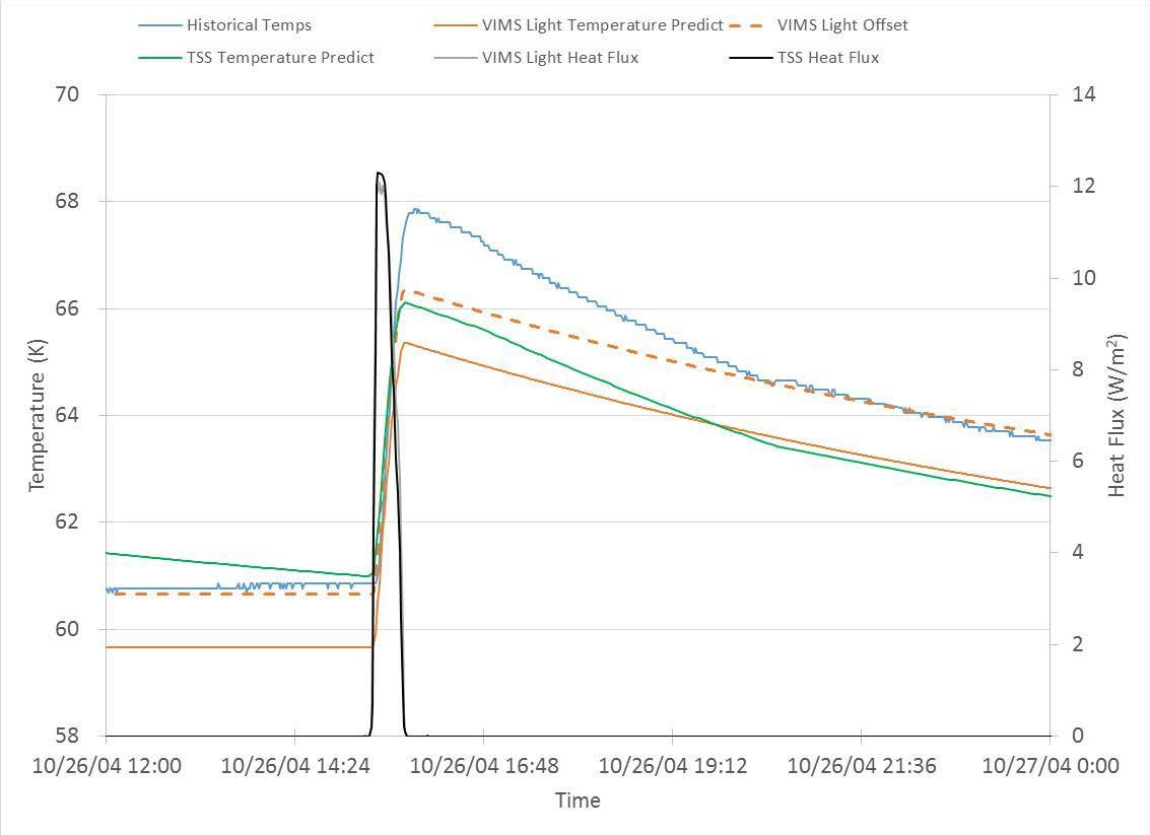
- S05 featured a single solar event, when the VIMS-IR radiator was pointed toward the sun



S05 VIMS Light vs. TSS Model

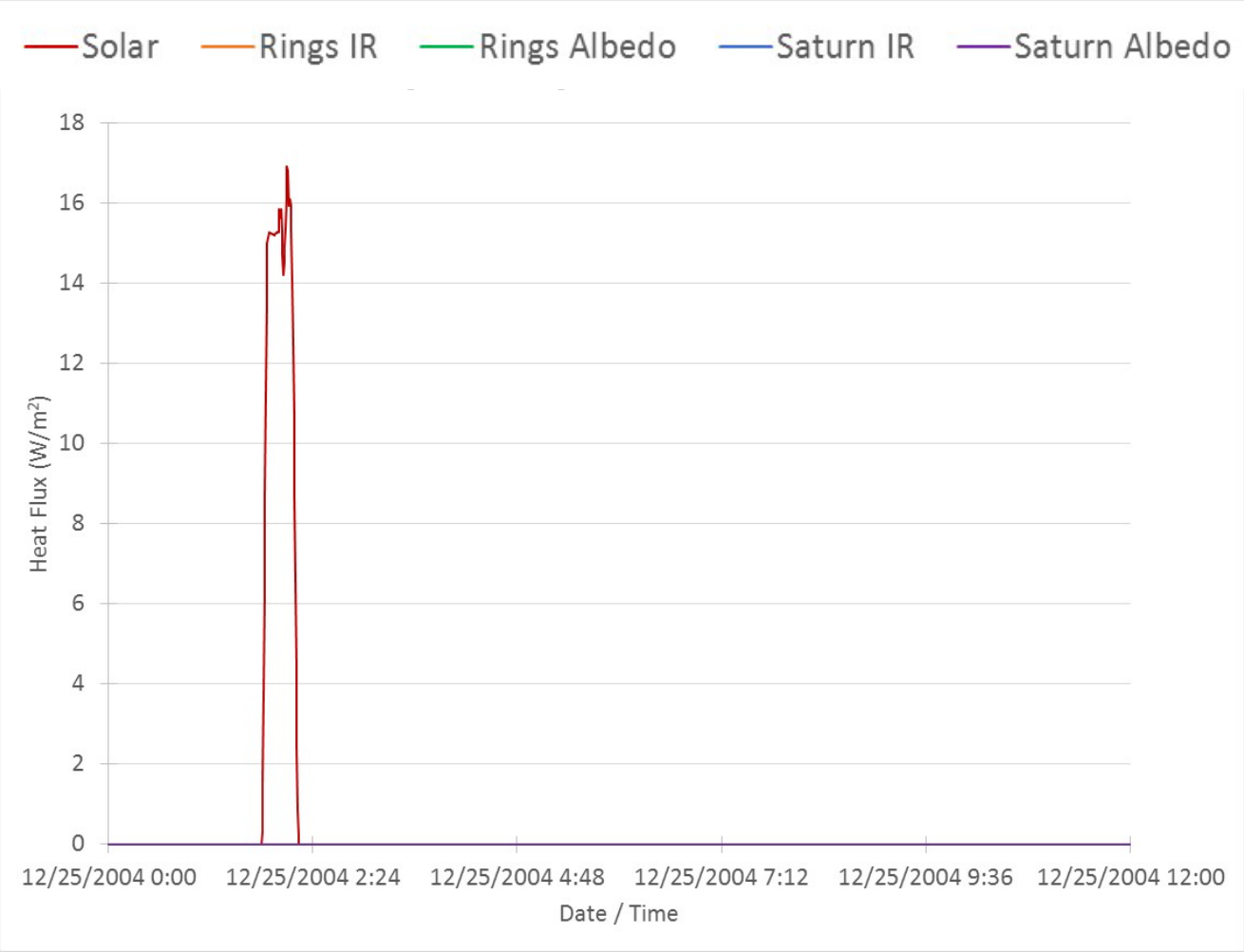
- S05 underpredicts the historical data by 3K when adjusted for starting temperature
- VIMS Light does not decay as quickly as TSS because VIMS Light was run with the FPA in active mode for the entire sequence
- This is also true in S07 (shown next), suggesting TSS consistently underpredicts solar heating





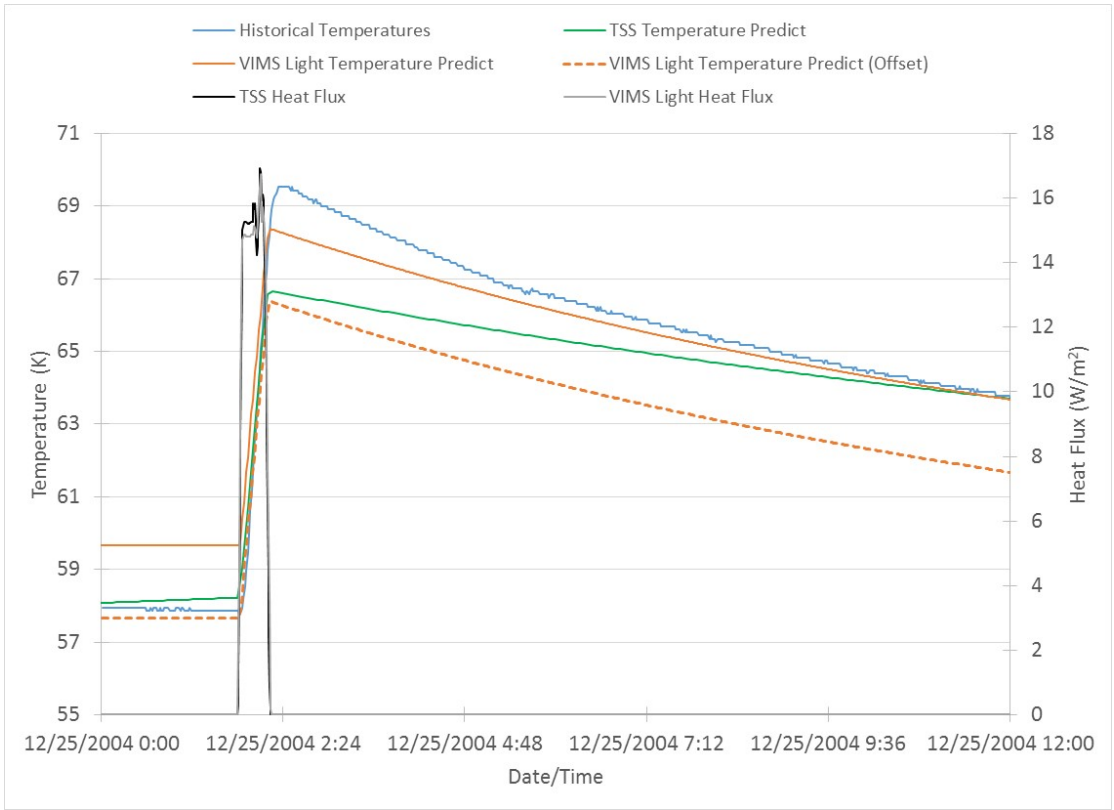
S07 TSS Heat Rate Sources

- S07 was chosen due to the heating event being caused exclusively by solar loading
- This orbit allowed for verification of spacecraft pointing with a known source



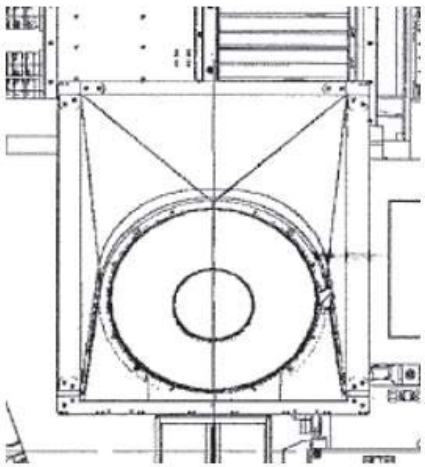
S07 VIMS Light vs. TSS Model

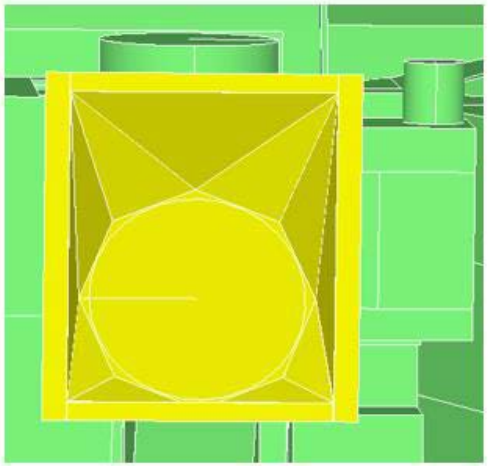
- VIMS Light and TSS model agree very well with respect to heat rate values, confirming correct pointing of the spacecraft
- TSS and VIMS Light differ from the historical data by ~3 K, suggesting the presence of an additional external heating source



Modeling Differences May Cause Lower Solar Flux

- Both of the solar only sequences underpredict the FPA temperature and delta-T rise
  - VIMS Light and TSS indicate the solar fluxes occur at the same time, thus suggesting correct pointing of the spacecraft
- Two possible causes of different solar loading:
  - Potentially caused by oversimplification of the radiator surface in TSS/VIMS Light
  - Both S05 and S07 were specialized orbits
    - S05 included a Titan fly-by, which was not included in this thermal analysis
    - S07 involved in the release of the Huygens probe, and spacecraft pointing files were reconstructed from this event

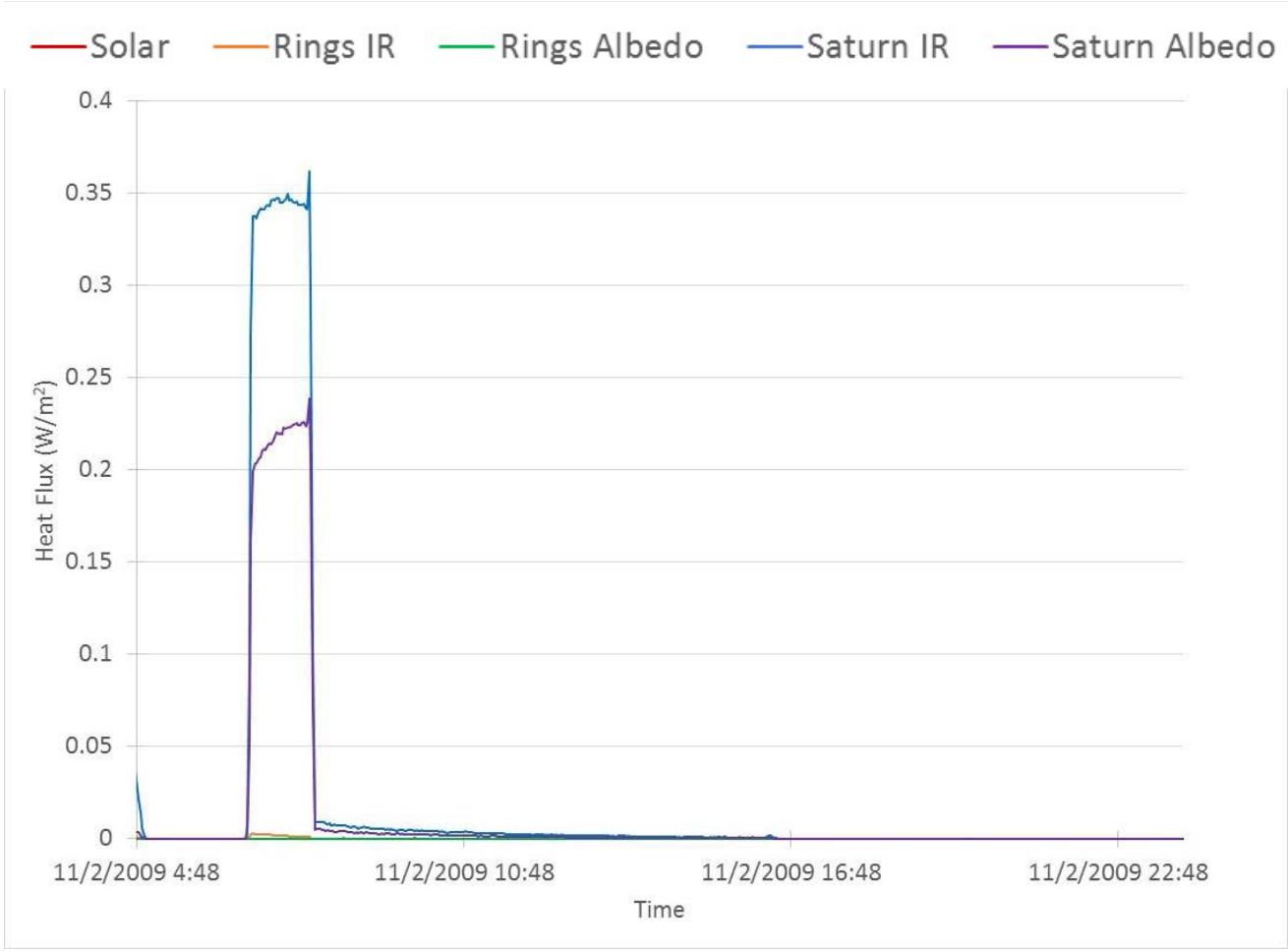




VIMS-IR Radiator Drawing (Left), VIMS-IR TSS Thermal Model Radiator (Yellow, Right)

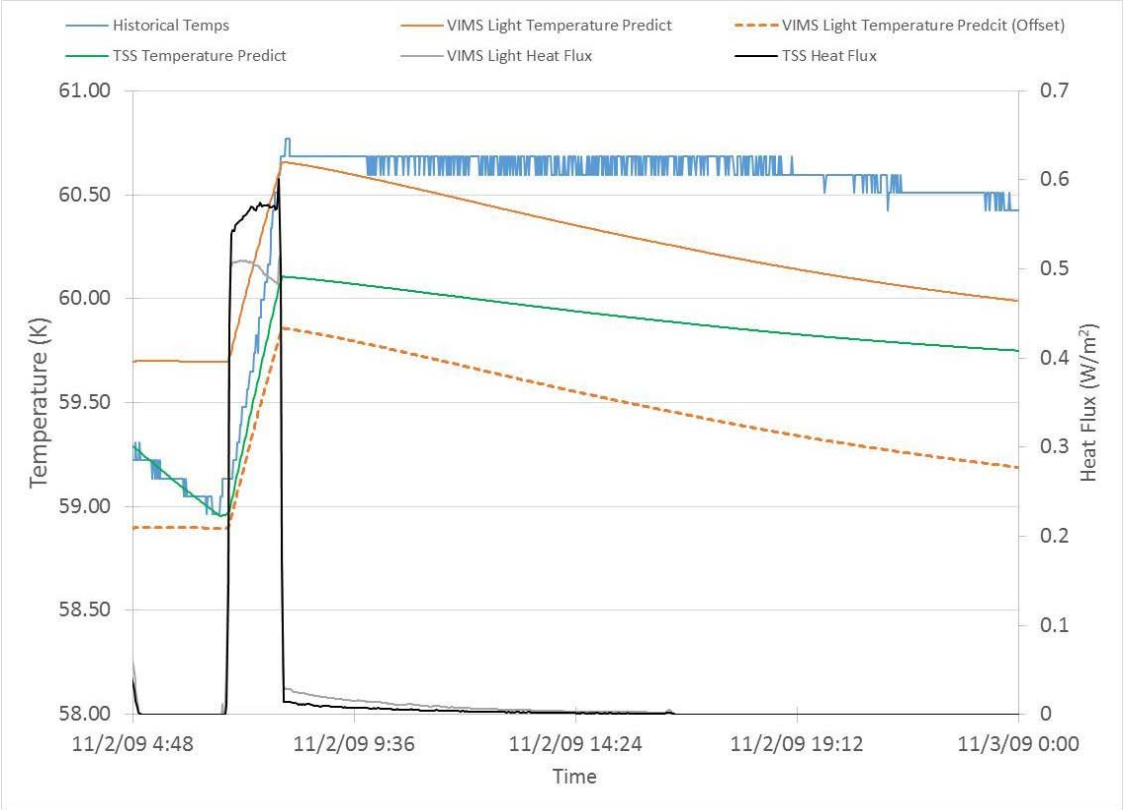
S54 TSS Heat Rate Sources

- Next, S54 was investigated to confirm Saturn heating (no ring loading)



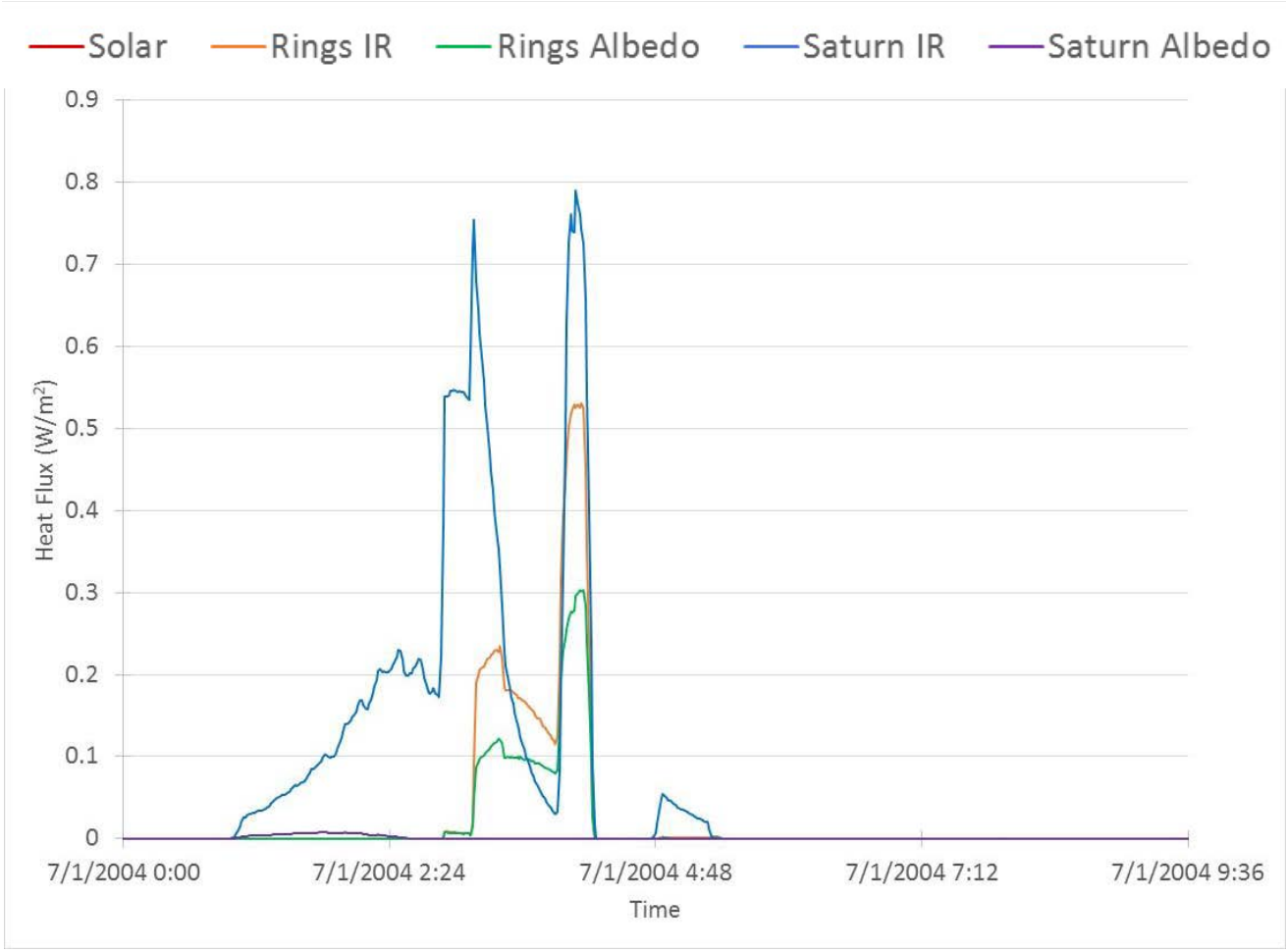
S54 VIMS Light vs. TSS Model

- Sharp decline at beginning of sequence caused by the FPA going to sleep mode
- Both the TSS and VIMS Light models are in very good agreement with historical data, < 1 K difference
- VIMS Light model was offset due to the assumption the FPA is on at a constant heat load. TSS model accounted for on/off periods



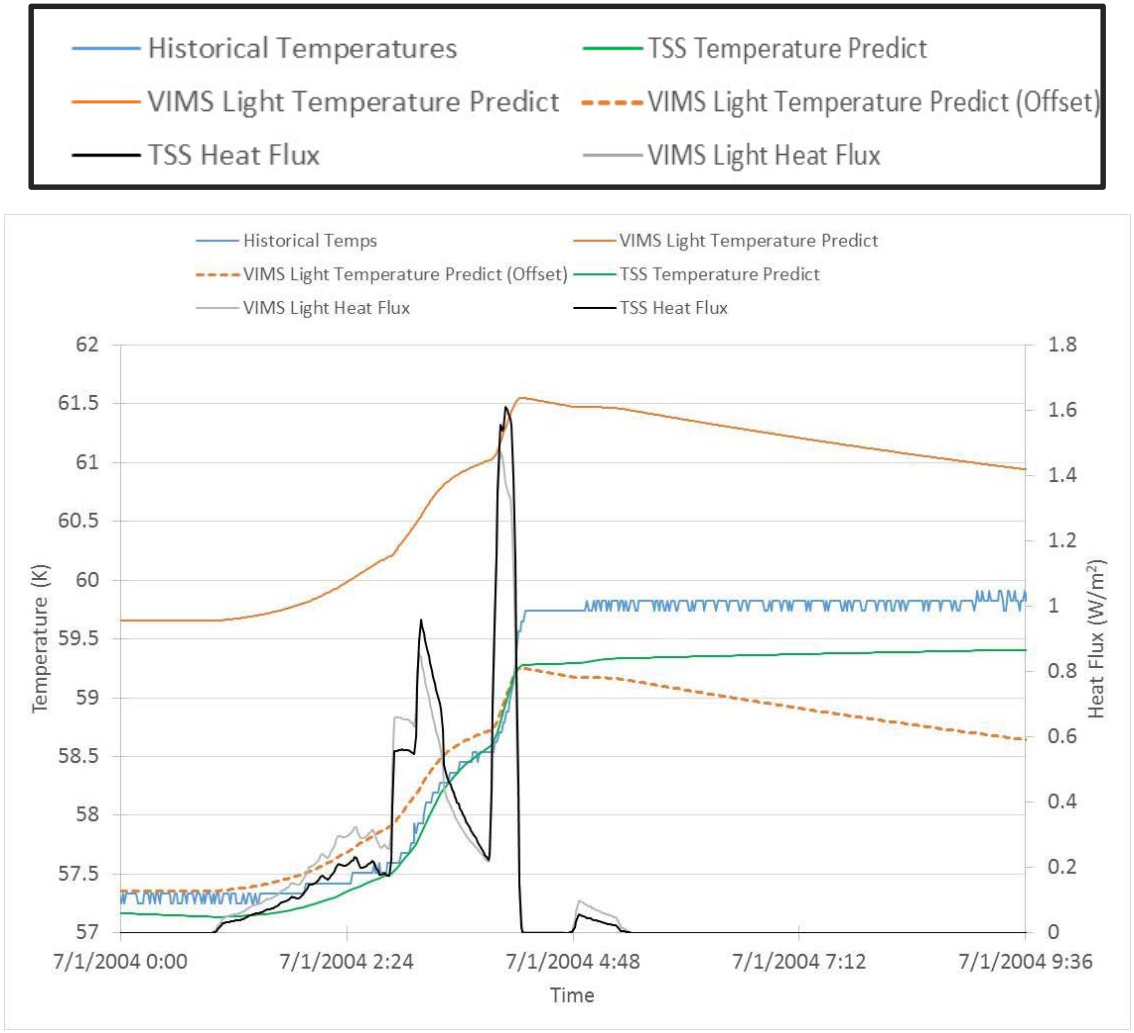
SOI TSS Heat Rate Sources

- SOI/S02 has loading from several sources, however does not have any solar loading
- This was the first case run with Saturn and Saturn ring heat rates
- TSS has difficulty with times prior to insertion (ecc >1) so TSS data is only shown post-Saturn insertion



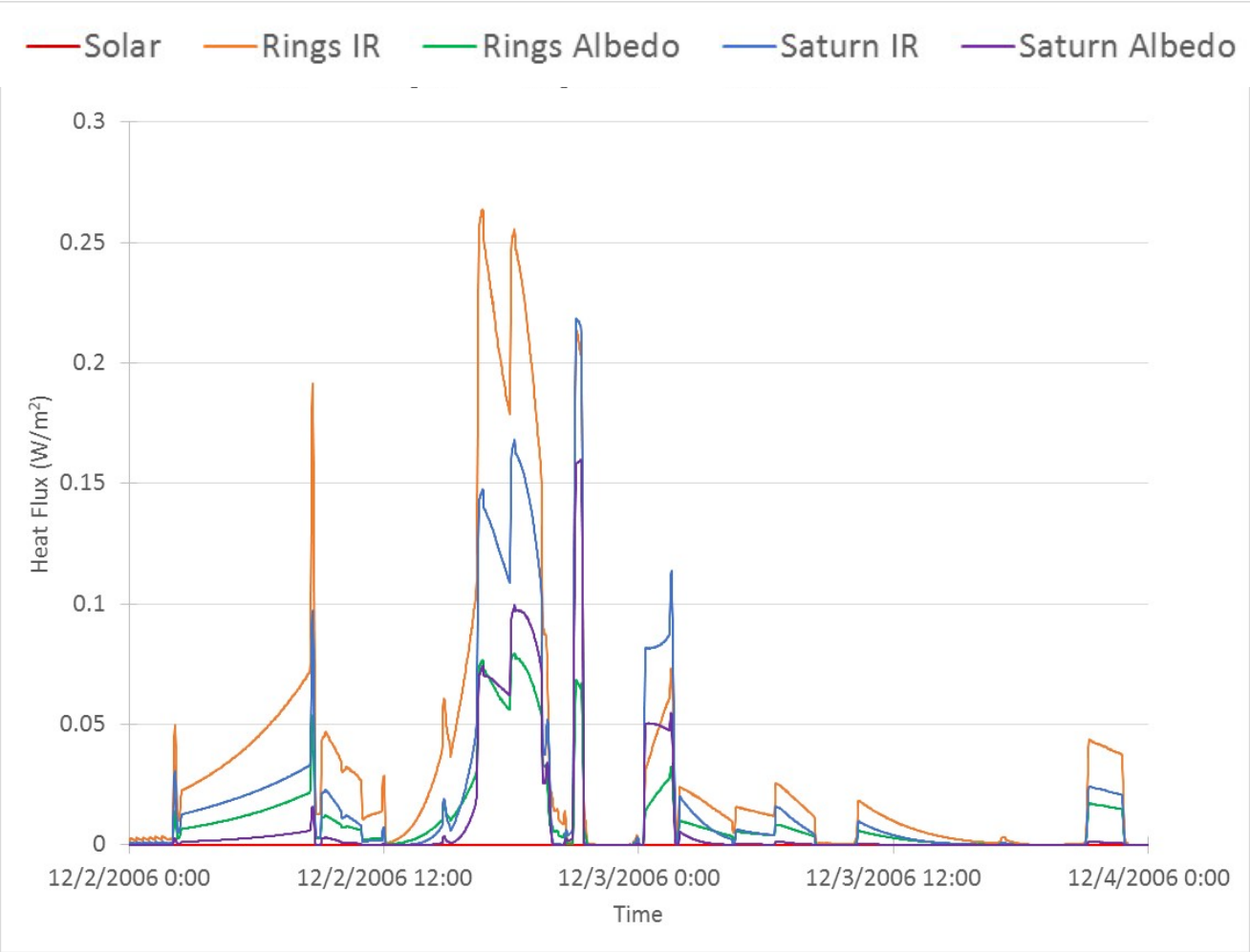
SOI VIMS Light vs. TSS Model

- Both models again show excellent agreement with heat rate values, slight divergence in temperature after heating event
- Both models are within 1 K of historical data
- Temperature rise in TSS prediction after external sources are removed is caused by FPA internal heating as it is in active mode



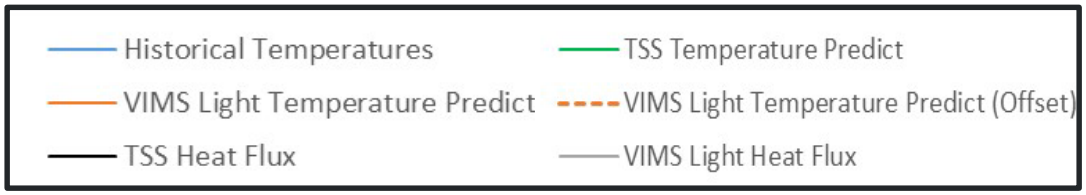
S26 TSS Heat Rate Sources

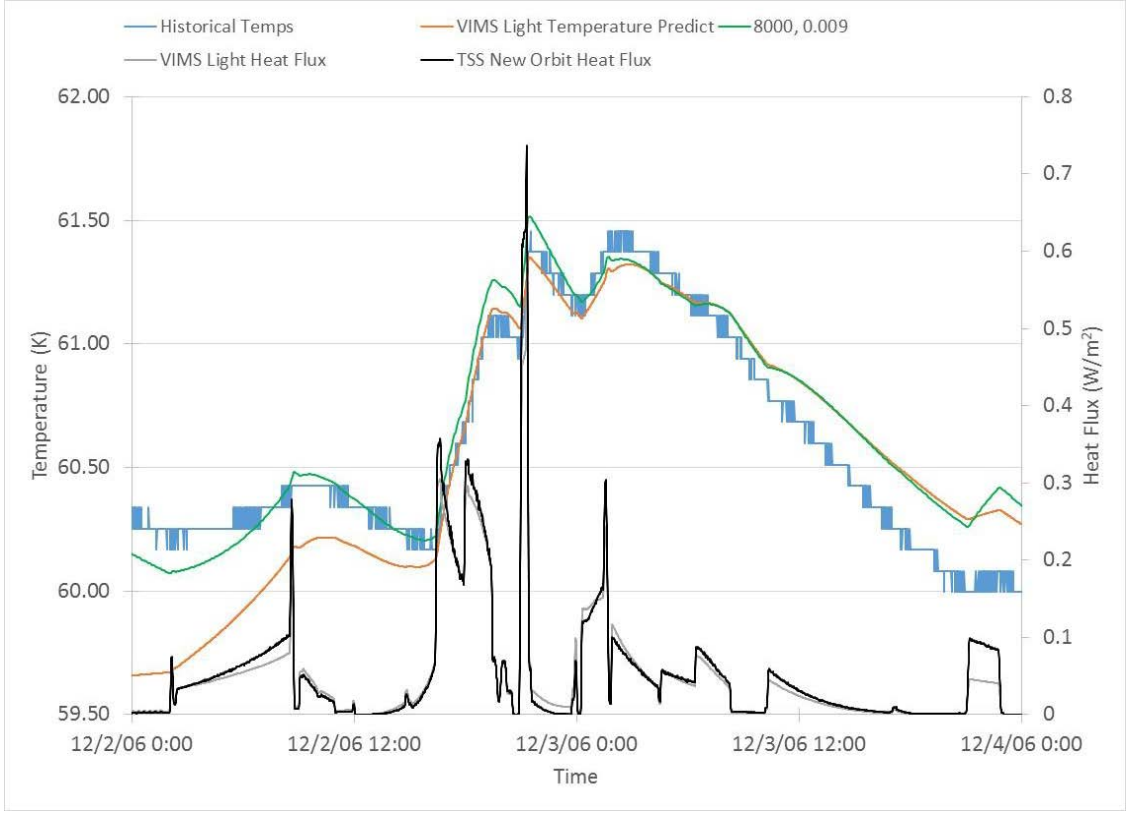
- As seen in SOI/S02 runs, S26 loading on the VIMS cooler was exclusively from Saturn and the rings, no solar loading observed
- Only historical case to have the largest heat flux component from Saturn's rings
- Although the FPA was in "active" mode during the period of interest, a large number of spacecraft maneuvers during this orbit resulted in varied heat loads



S26 VIMS Light vs. TSS Model

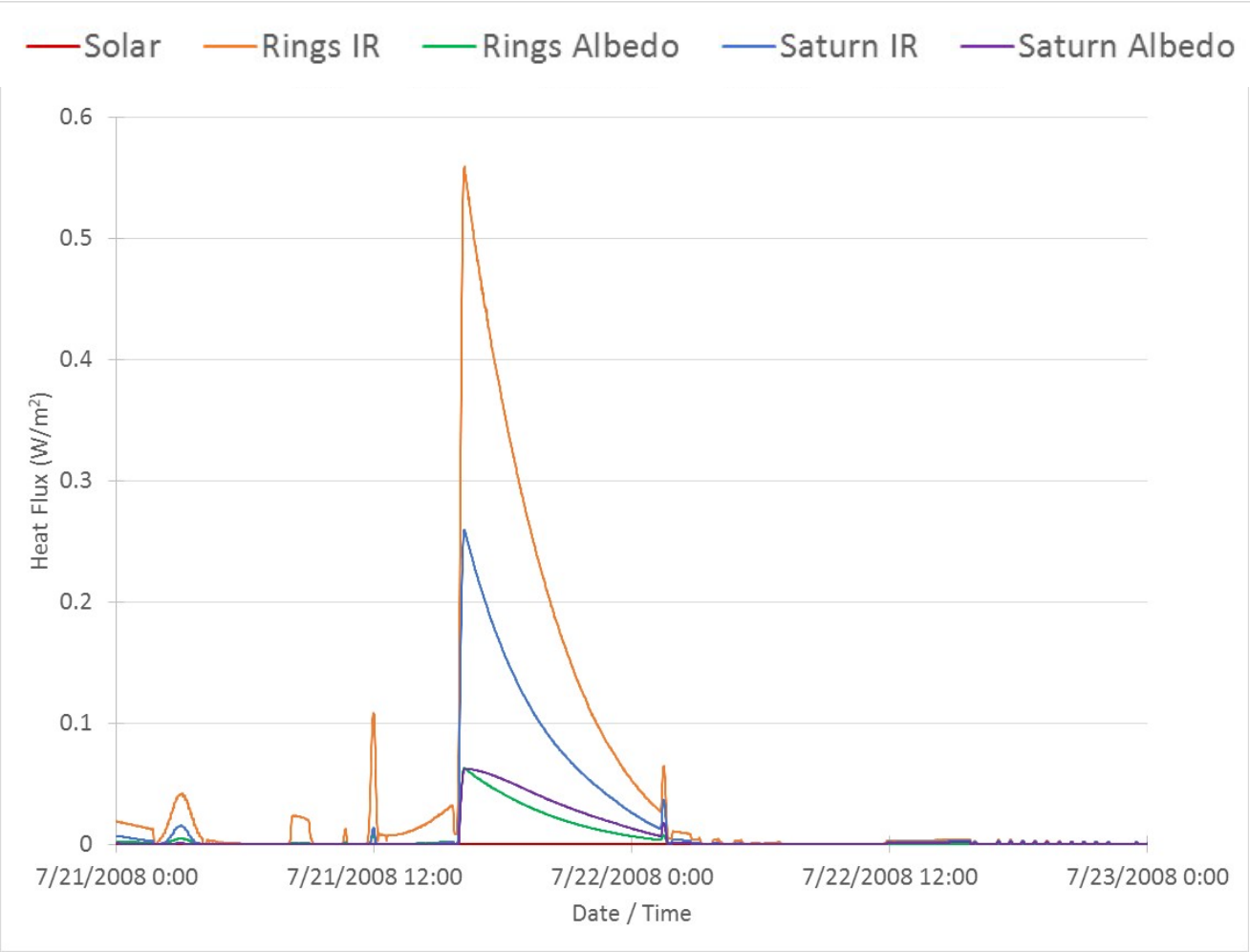
- Both TSS and VIMS Light show nearly identical profiles, with TSS slightly higher than VIMS Light
- Heat flux differences are less than 0.05 W/m^2
- Temperature of both models agrees well with historical data, with both models within 0.5 K of historical temperatures





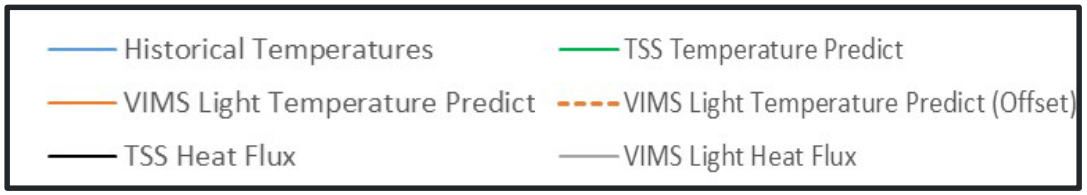
S42 TSS Heat Rate Sources

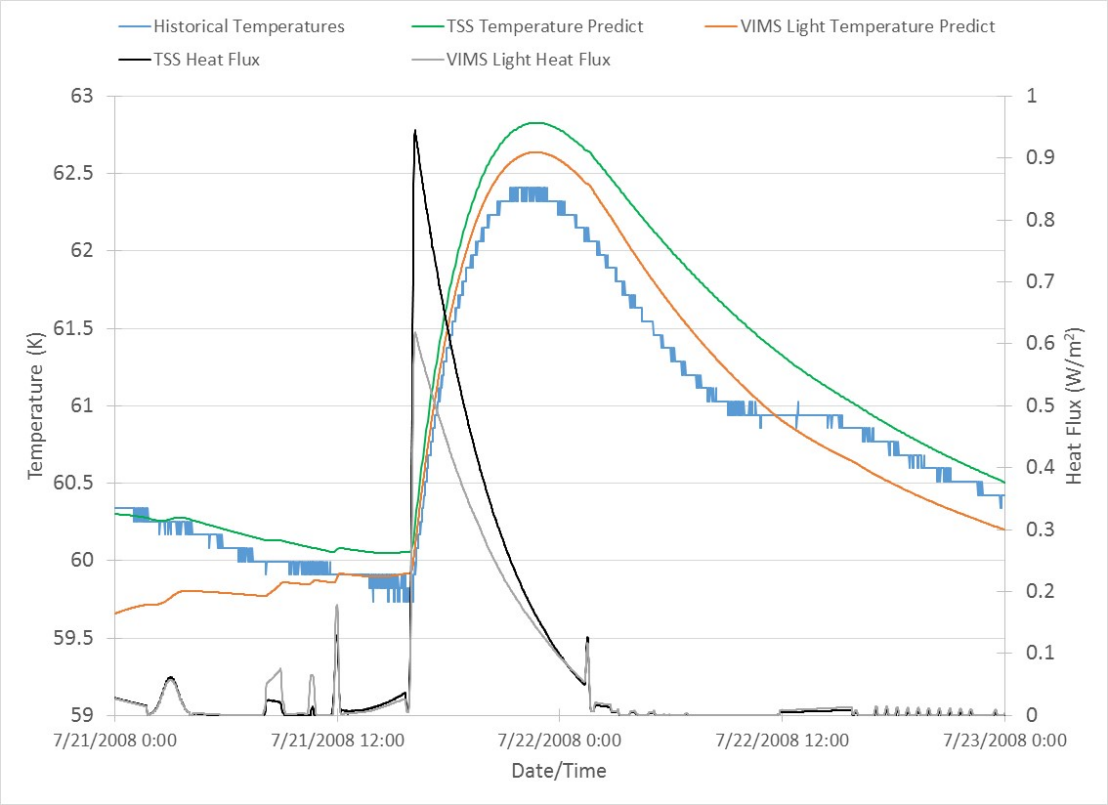
- IR heating dominated S42, with the majority of heating coming from the rings, followed by Saturn
- No solar loading was observed during this orbit



S42 VIMS Light vs. TSS Model

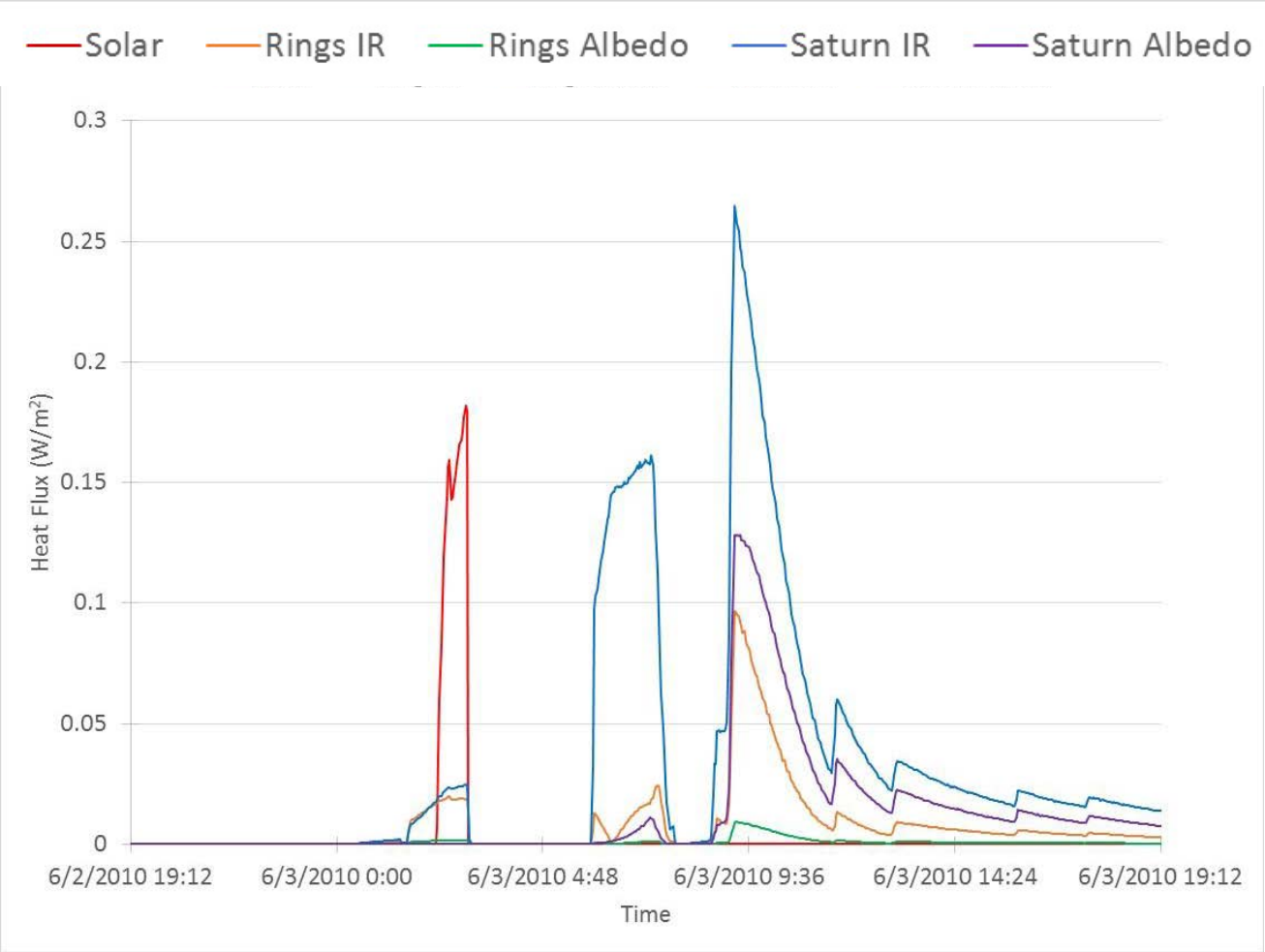
- As seen in S26, the heat rates for both the TSS and VIMS Light models are similar in shape, suggesting correct pointing of the spacecraft
- However, there is a difference between the two model heat rate outputs
- Temperatures for both models agree with historical data to within 1 K





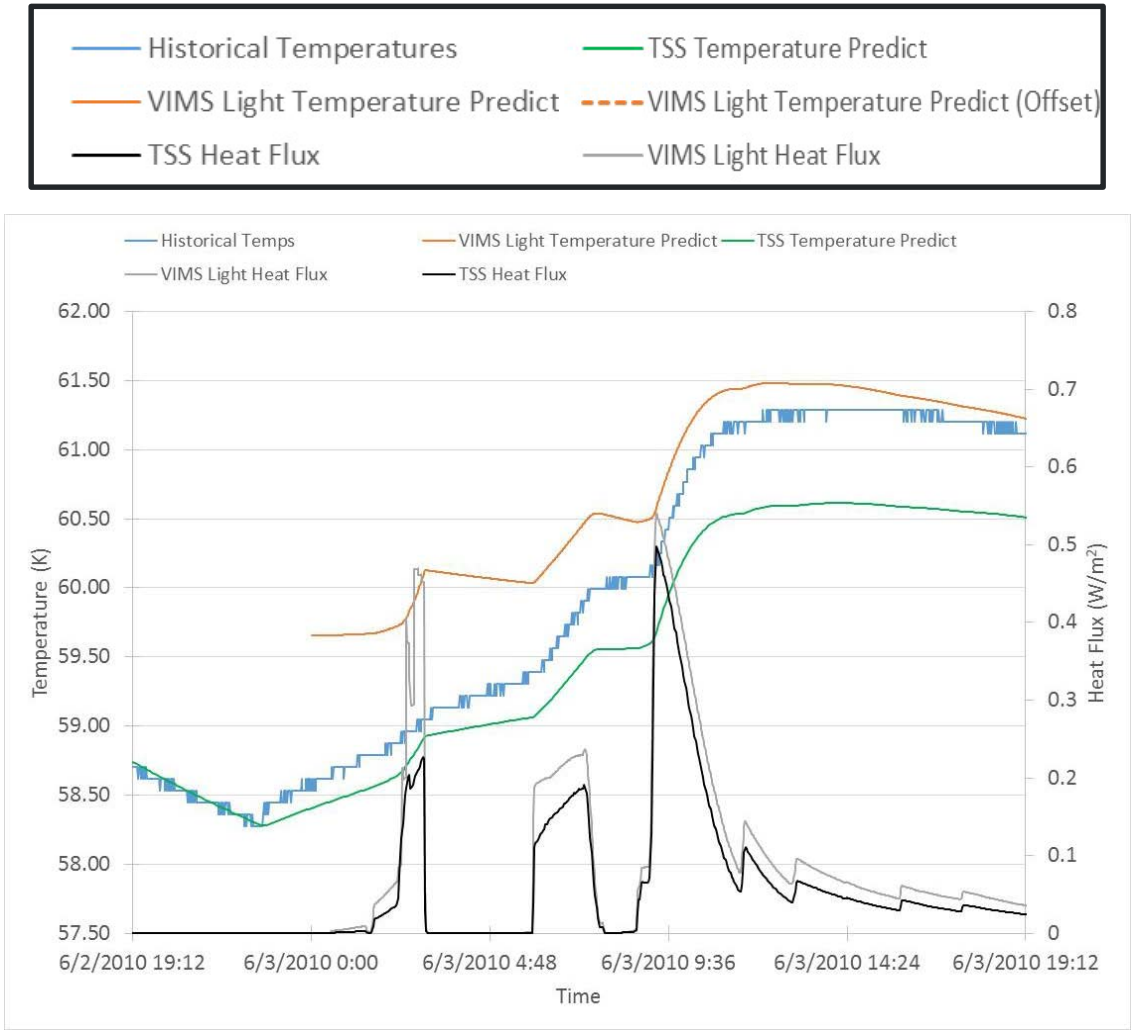
S60 TSS Heat Rate Sources

- S60 combines solar heating with Saturn heating and minimal heating from the rings
- Three separate heating events observed as Cassini rotated during the fly-by



S60 VIMS Light vs. TSS Model

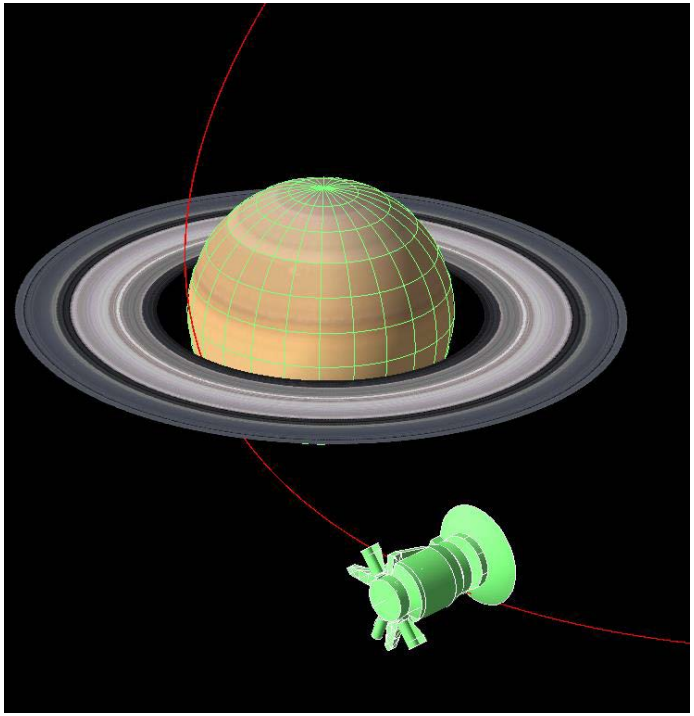
- TSS and VIMS Light have similar heat rate profiles, however they differ in several areas, particularly during the solar heating event
  - May be caused by differences in geometry
- Temperatures remain within 1 K for both models, suggesting no major impact by difference in heat rates



Predictive FRPO Cases

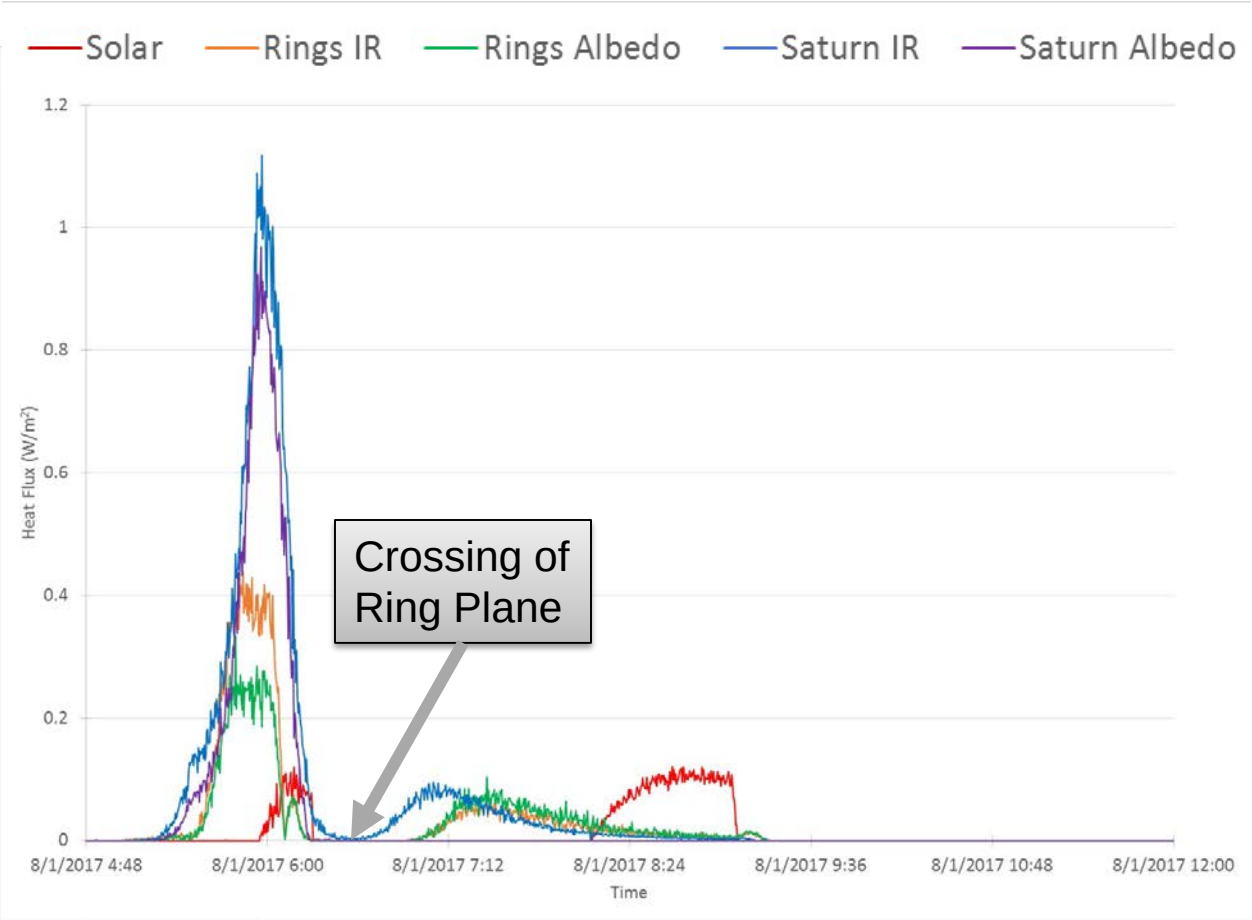
Predictive Proximal Orbits

- Both of the predictive cases (S286 and S289) are proximal sequences, where Cassini passes between the inner D-ring and the planet atmosphere
- Since historical data is not yet available, it is imperative that VIMS Light and TSS are in good agreement for mission planning



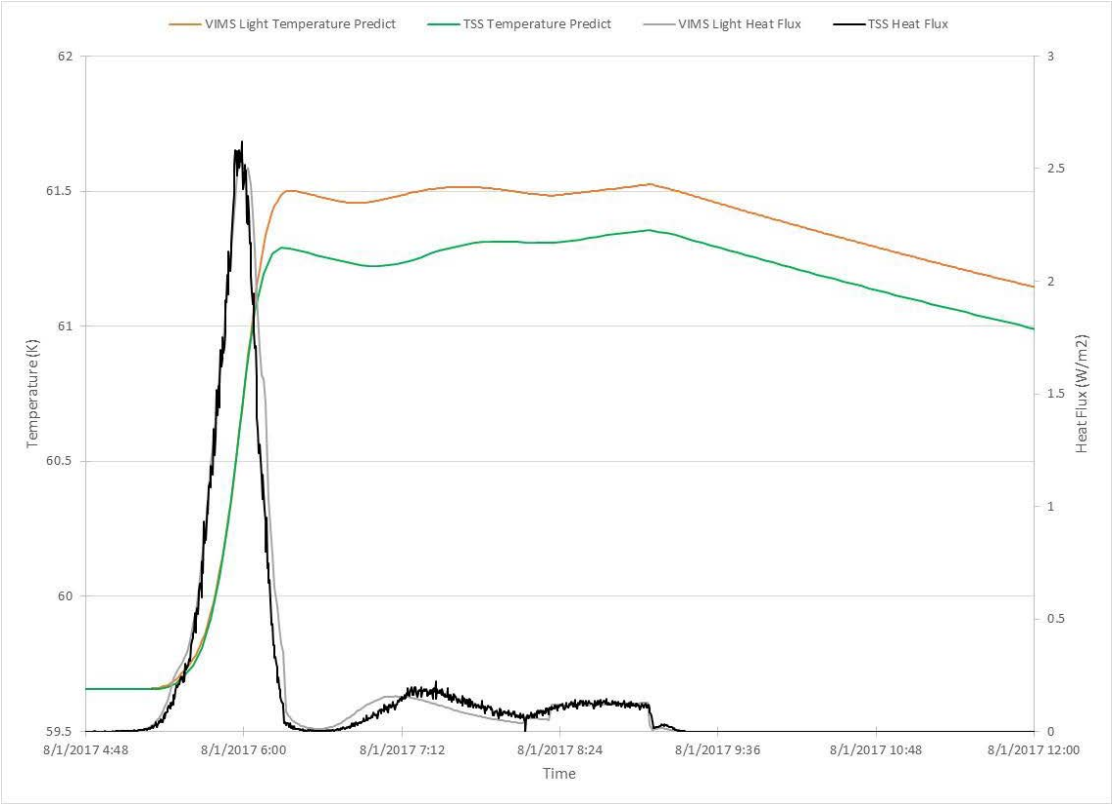
S286 TSS Heat Rate Sources

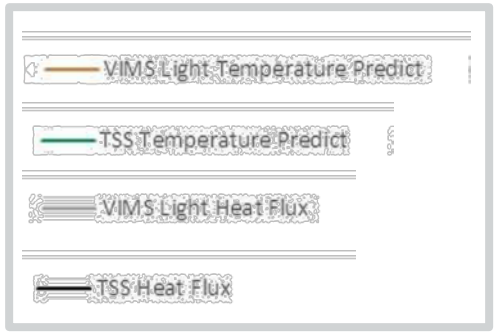
- S286 has a mixture of all heating sources, including Saturn, Saturn rings, and solar
- Most predominant heating comes directly from Saturn immediately before ring plane crossing



S286 VIMS Light vs. TSS Model

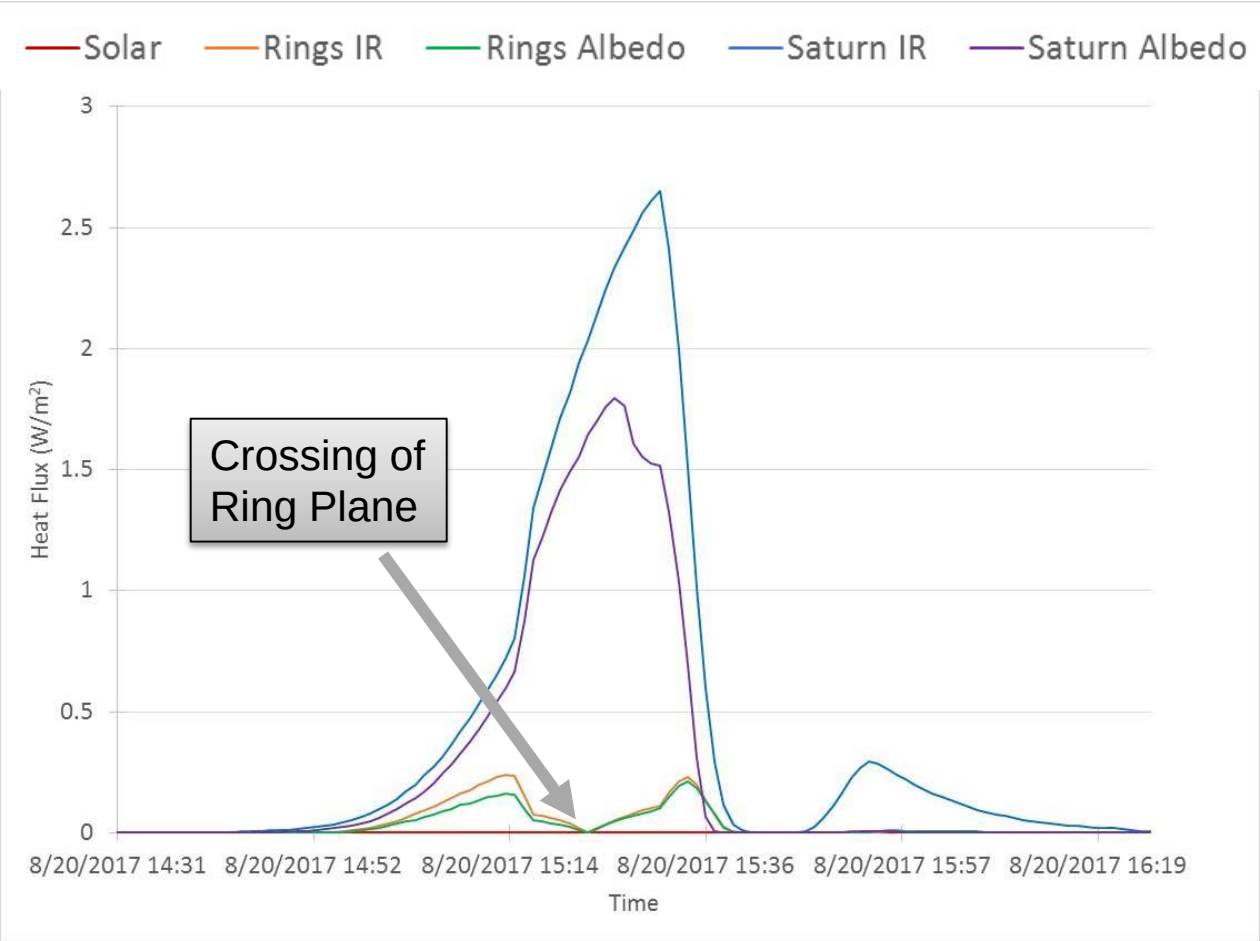
- VIMS Light and TSS model agree very well with respect to heat rate values, confirming correct pointing of the spacecraft
- TSS and VIMS Light are well below 0.5 K of each other





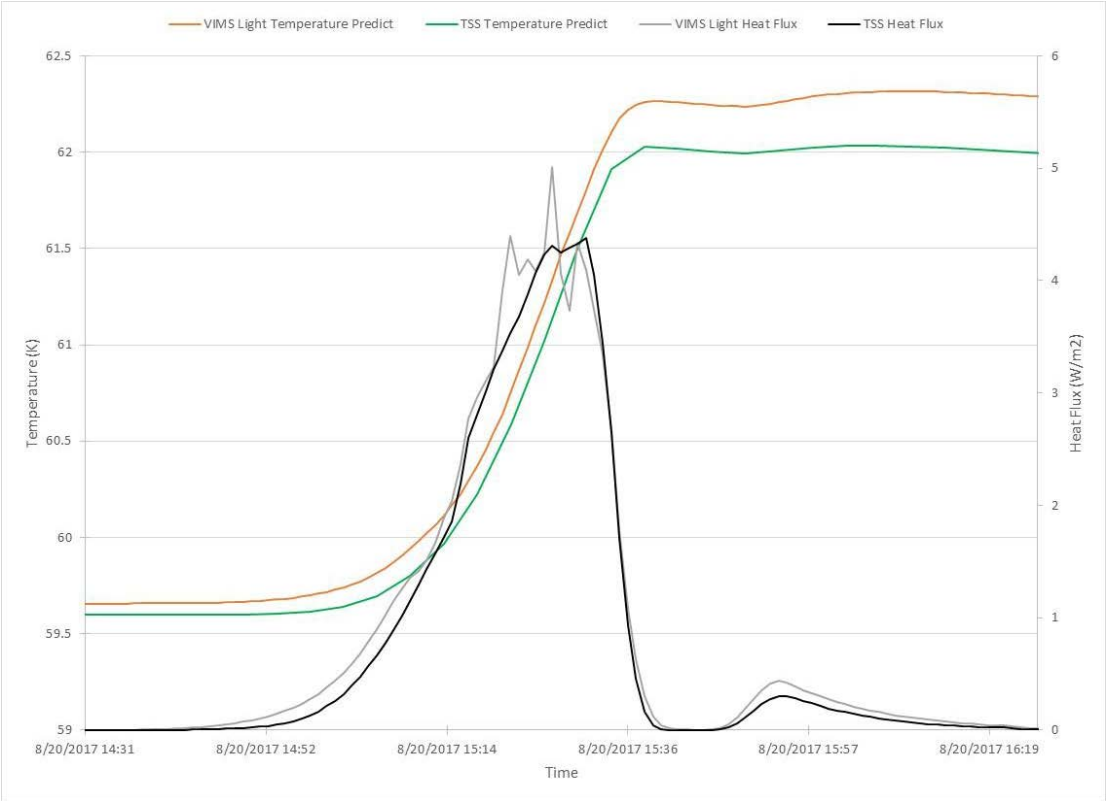
S289 TSS Heat Rate Sources

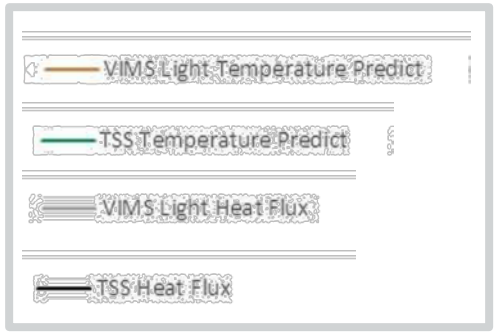
- In S289, heating is almost exclusively from Saturn, slight heating from Saturn rings
- Ring plane crossing occurs when Saturn ring IR and albedo fall to zero
- In this case, the radiator has a view of Saturn through the ring crossing



S289 VIMS Light vs. TSS Model

- VIMS Light and TSS model agree very well with respect to heat rate values
- TSS and VIMS Light predict FPA temperatures well within 0.5 K of each other





Conclusions

- Through the use of seven historical cases, TSS has been proven to accurately determine the heat flux impinged on the Cassini VIMS-IR radiator when exposed to solar, Saturn planetary and Saturn ring sources
- Largest uncertainty surrounds solar loading cases, which are likely caused by modeling simplifications or other external sources
- TSS predictions are within 2 K of historical results, suggesting good predictions for FRPO cases and future Saturn mission planning

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