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TFAWS 2019, 26-30 August 2019
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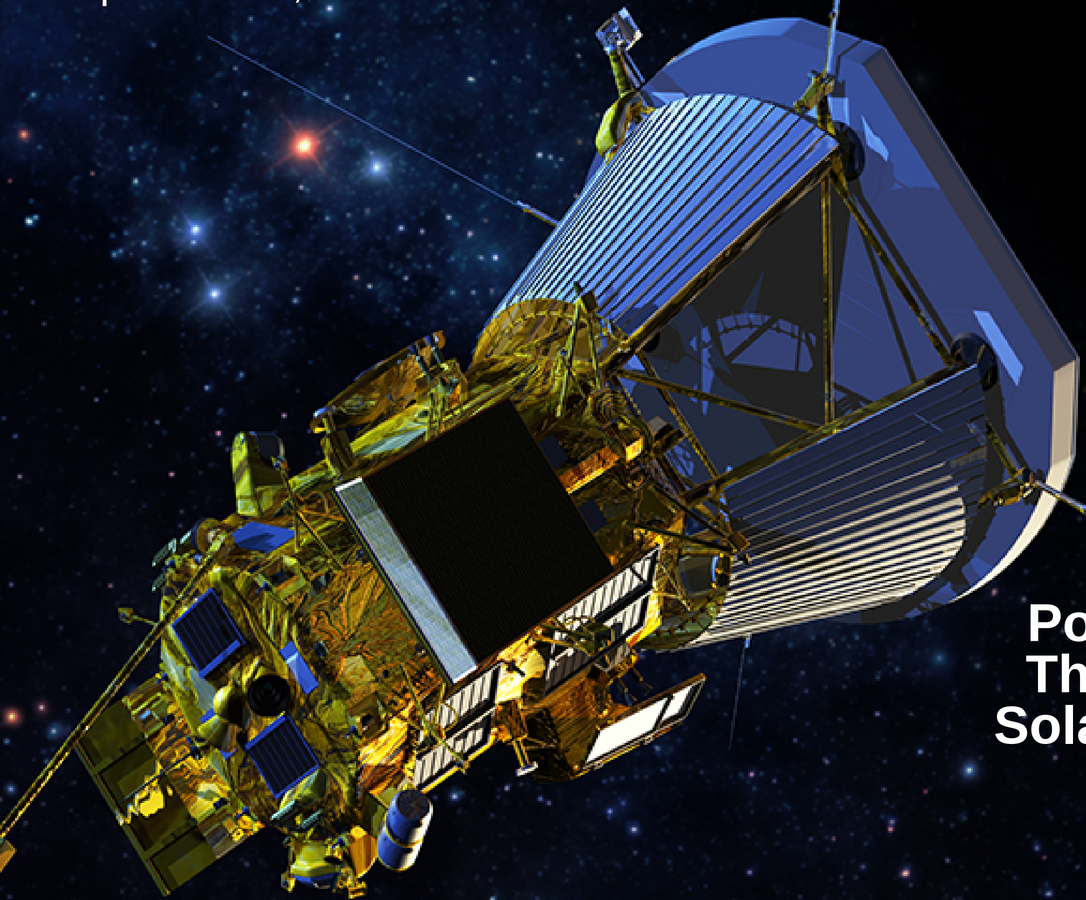

Post-Launch and Early Mission Thermal Performance of Parker Solar Probe through the First Two Solar Orbits

TFAWS19-AT-07

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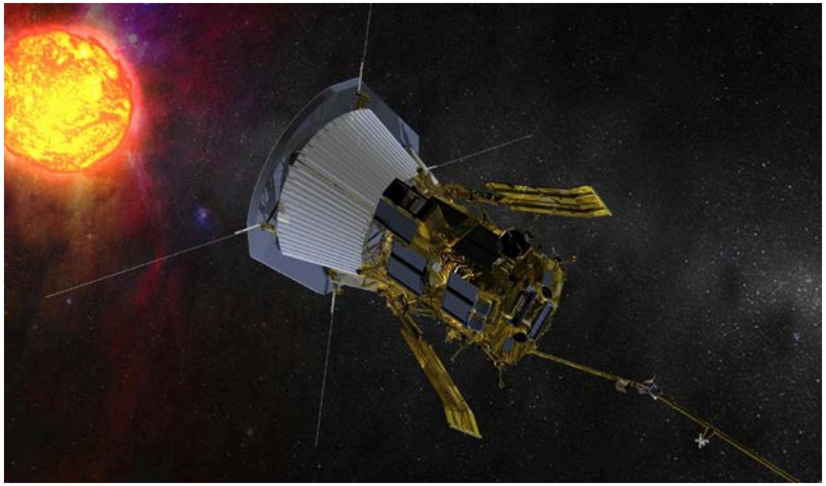
Parker Solar Probe

A NASA Mission to Touch the Sun

NASA

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Parker Solar Probe Mission Summary



Overview

Using in-situ measurements made closer to the Sun than by any previous spacecraft, Parker Solar Probe (PSP) will determine the mechanisms that produce the fast and slow solar winds, coronal heating, and the transport of energetic particles.

PSP will fly to 9.86 solar radii (Rs) of the Sun, having "walked in" from 35.7 Rs over 24 orbits, two of which have been completed to date.

Sponsor: NASA SMD/Heliophysics Div

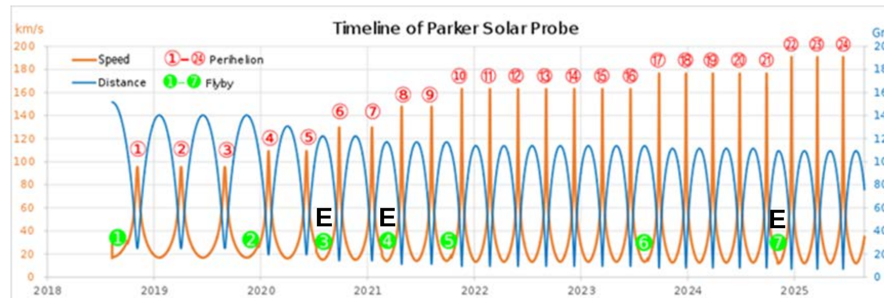
- Program Office – GSFC/LWS
- Project Scientist - APL
- Project Management - APL
- S/C Development & Operations – APL
- Science Investigations selected by AO:
  - SWEAP - Smithsonian Astrophysical Observatory
  - FIELDS - UC Berkeley
  - WISPR - Naval Research Laboratory
  - ISOIS – Southwest Research Institute

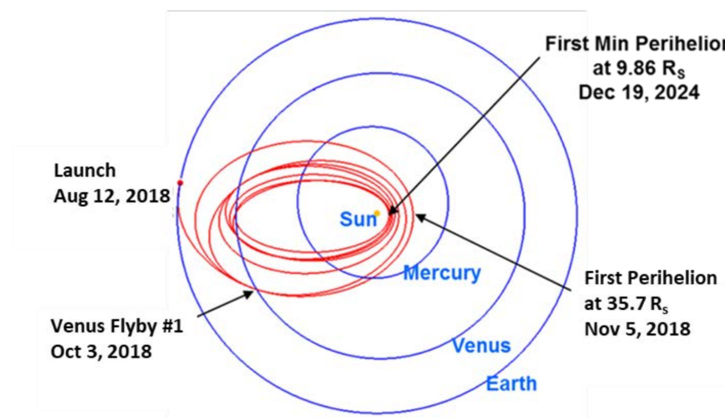
Preliminary Mission Milestones

Pre-Phase A:	07/2008 – 11/2009
Phase A:	12/2009 – 01/2012
Phase B:	02/2012 – 03/2014
Phase C/D:	03/2014 – 12/2018
Phase E:	01/2019 – 09/2025
Launched:	August 12, 2018, 07:31 UTC

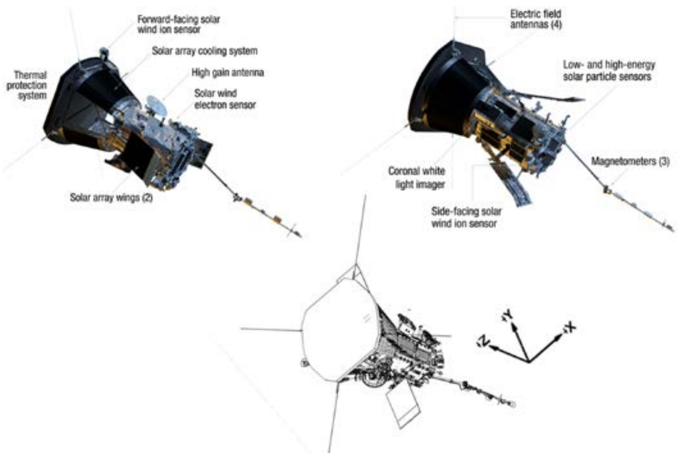
Trajectory: 9.86Rs Minimum Perihelion

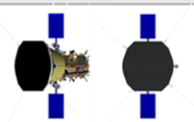
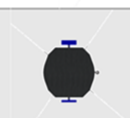
- **Launch**
  - 13-day launch period from Aug 11 to Aug 23, 2018
  - Maximum launch C3 of 154 km2/s2
  - S/C wet mass 685 kg
  - Launch system: Delta-IVH Class + Star48 BV
- **Mission Trajectory**
  - A V7GA type of trajectory requiring 7 Venus gravity assist flybys, three of which have 11 minute eclipses (denoted by E)
  - No deterministic deep space maneuvers
  - Consisting of 24 solar orbits, 3 has minimum perihelion
  - Perihelion gradually decreasing to 9.86 RS
- **Final Solar Orbit**
  - Perihelion of 9.86 RS
  - Aphelion of 0.73 AU
  - Orbit inclination of 3.4 deg from ecliptic
  - Orbit period of 88 days
- **Mission Timeline**
  - Launch to 1st perihelion: 3 months
  - Launch to 1st min perihelion (9.86 RS): 6.4 years
  - Mission duration (including 3 passes at 9.86 RS): 7 years





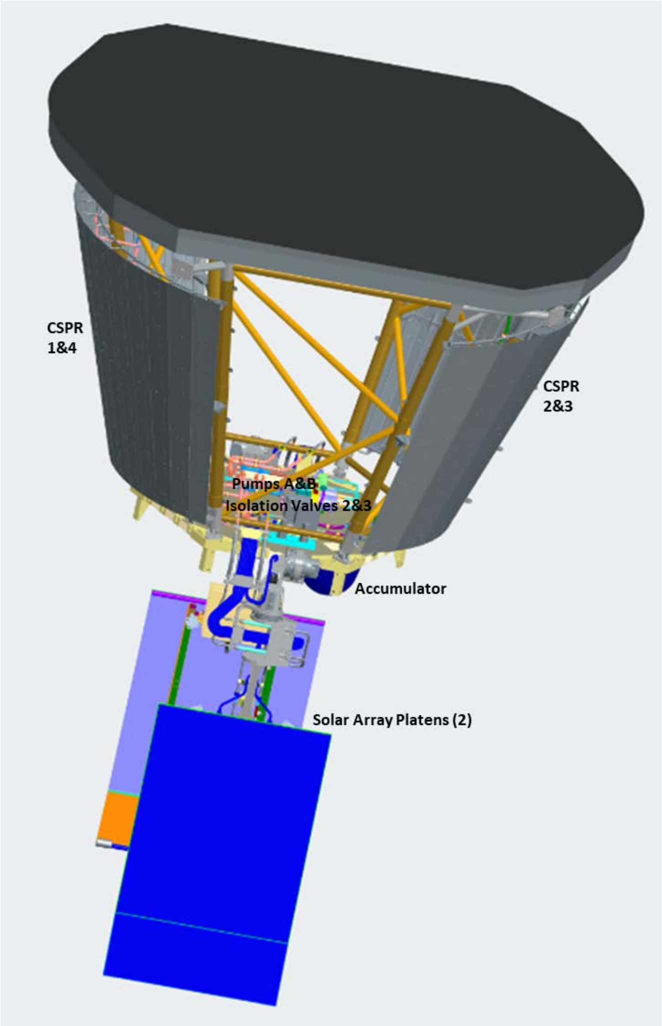
Spacecraft Overview



Solar Distance	Description / View from Sun	
1.02 AU to 0.82 AU	Aphelion (+Z to –X: 45°)	
0.82 AU to 0.7 AU	Aphelion-Umbra Variable (+Z to –X: 0° to 45°)	
0.7 AU to 9.86Rs	Umbra/ Encounter	

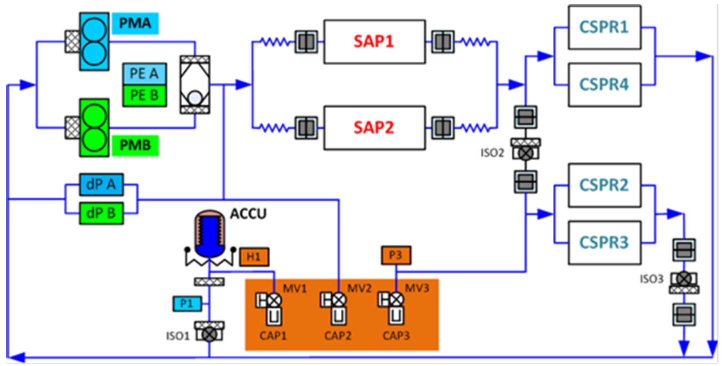
- PSP is a three-axis-stabilized spacecraft and its most prominent features are the thermal protection system (TPS) and Solar Array Cooling System (SACS)
- The TPS is designed to protect the spacecraft bus and most of the payload within its umbra during the multiple solar encounters and will always be pointed toward the sun, except during the cooling system activation and other spacecraft required orientations at solar distances > 0.7 AU.
- The various operational steady-state attitude modes are utilized to maintain the proper thermal environments for the observatory and SACS. Inside of 0.70 AU, the TPS is always maintained normal to the sun (+Z to the sun).

SACS Description

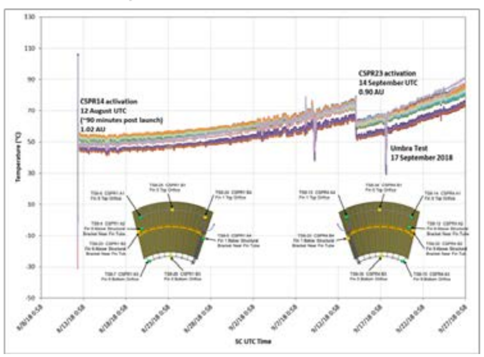


- The primary requirement of the Solar Array Cooling System (SACS) is to provide SA cooling from 9.86 RS to 1.02-AU solar distances.
- The system will provide this cooling with an operating fluid (deionized water) temperature of +10°C (test minimum) to +150°C (test maximum/platen) depending on heat load and mission timeline.
- The system is designed for a survival fluid temperature of +200°C.
- A custom-designed accumulator is used to store the water from launch until initial system activation (~90 minutes after launch) as well as maintain a pressure cap on the system to prevent boiling for temperatures up to 210°C.
- The major components of the SACS are the four custom-designed CSPRs, two diffusion bonded SAPs, and the SACS flight components located on both sides of the spacecraft top deck.
- The SACS top-deck components consist of a redundant pump package, total and redundant delta pressure transducers, three latching valves, and the accumulator.
- The three latching valves allow for the initial system activation and the strategic wetting of the final two radiators.

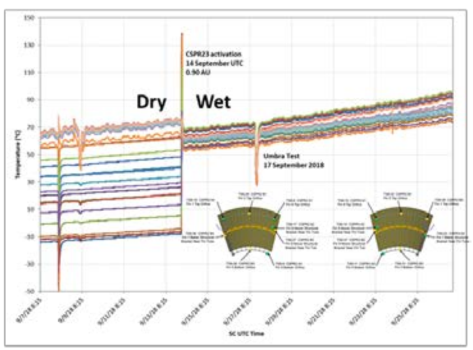
SACS Activation was successful



A – CSPR14 Operation



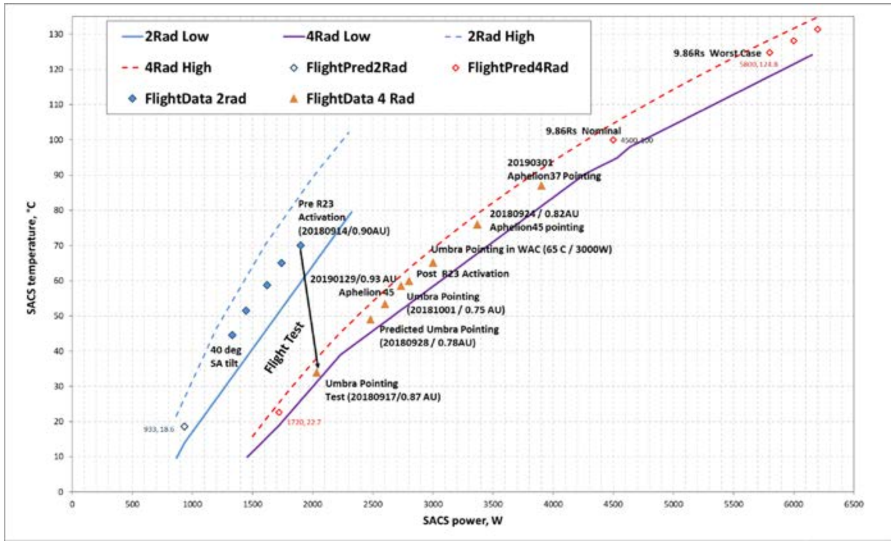
B – CSPR23 Operation



Name	View from Sun	Solar Distance	Duration
Activate Radiators 1 and 4	(+X)	1.02 AU	~ 1 hr
Activate Radiators 2 and 3	(-X)	0.9 AU to 0.89 AU	< 1 hr

- PSP was designed to maintain the SACS water temperature above its freezing temperature during the period between launch and SA wings deployment by launching the system dry and strategically activating the system as heat load became available and launch correction attitude uncertainty was reduced.
- All the SACS water was stored in the accumulator, which is mounted on the underside of the PSP top deck. Utilizing Delta IV ground support equipment umbilical power, accumulator heaters, and thermostats, the water temperature was controlled between +45°C and +50°C before launch to overcome any cold spots in the inlet/outlet tubing when the system is initially activated after launch.
- Approximately 90 minutes after launch and 45 minutes in CSPR14 activation attitude, the temperatures of the SAPs and CSPRs were verified as acceptable, and the water was released from the accumulator, wetting the SAPs, CSPR1 and CSPR4, and the pump.
- At this solar distance (~1.02 AU), the solar load is not high enough to maintain the SACS temperature at the safe level if the water were released to all four CSPRs, which is why only two of the four CSPRs are flooded at this stage.
- Thirty-three days later when the spacecraft reached 0.90 AU, the spacecraft was slewed to −X to the sun, and the final SACS activation was successfully executed with the wetting of CSPR2 and CSPR3.
- Shown are the CSPR temperatures as measured by the 32 temperature PT103 temperature sensors (eight per radiator) during the two activation events. The thermal "spike" at the beginning of each CSPR activation represents the orientation illustrated

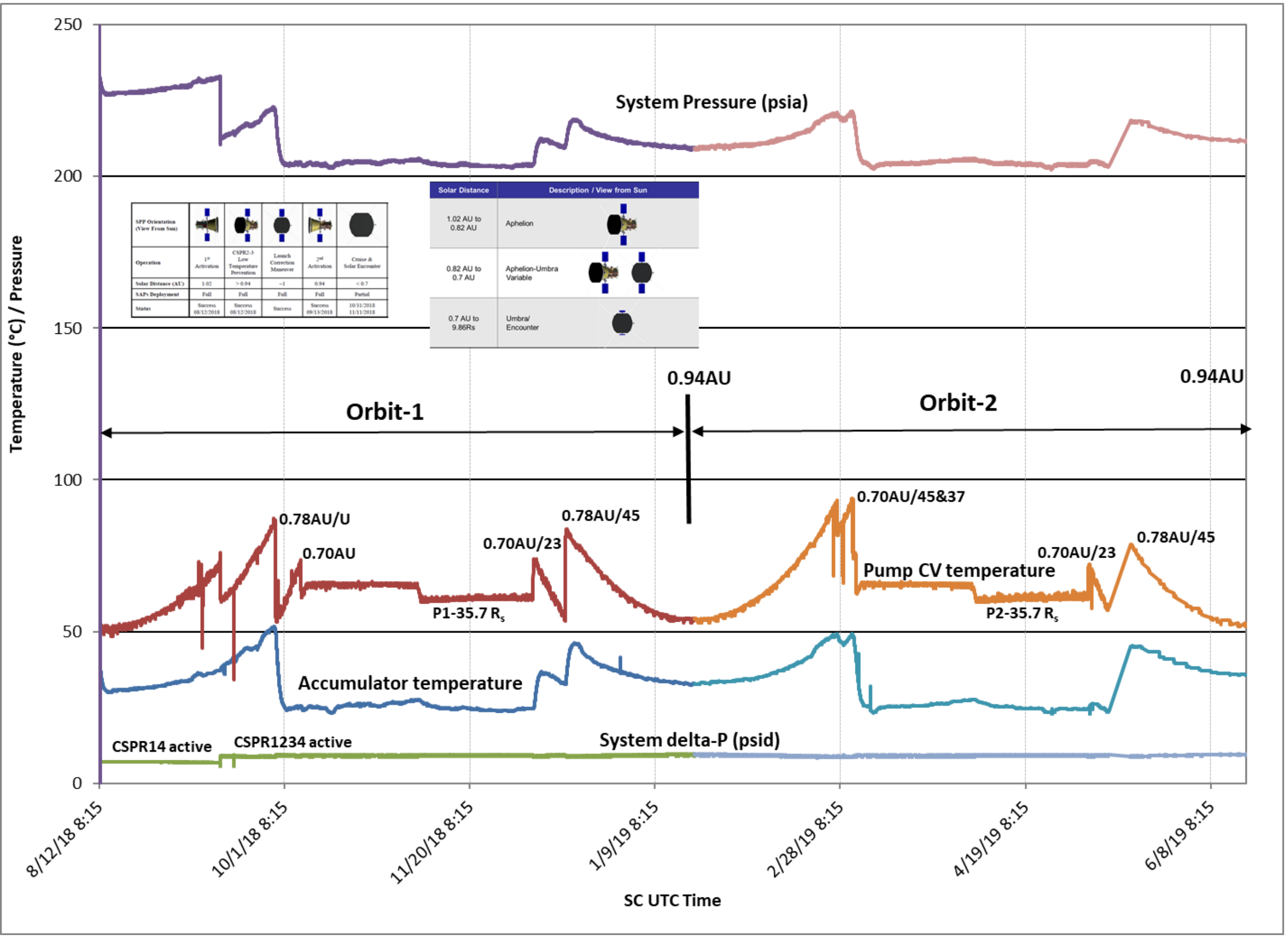
SACS Model Verification



Measured SACS CV (system reference) temperature and corresponding SACS heat load are within the boundaries of the preflight predictions for two and four active radiator operation indicated by 2Rad and 4Rad low and high

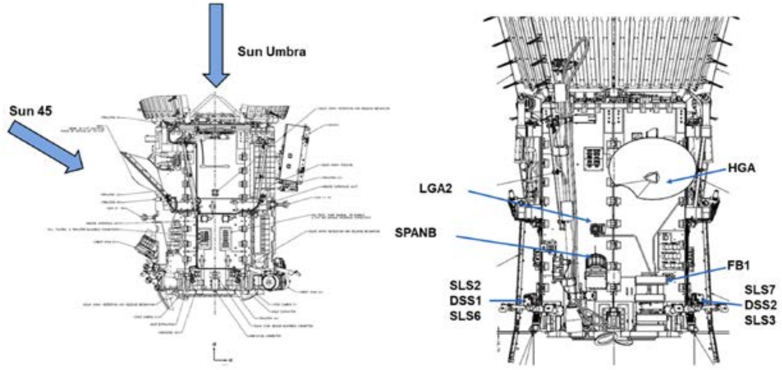
- **The SACS was comprehensively calibrated over the operating temperature range (referenced at the pump CV) as a function of input power during the integrated thermal vacuum test (ITVT) in March 2017.**
- **The SACS thermal model developed for the ITVT was correlated against the test data and was used and adjusted during observatory thermal vacuum test in early 2018.**
- **Prior to wetting CSPR2 and CSPR3, the SACS heat load based on the measured pump check valve (CV) temperature, 70°C, was estimated to be 1900 W using the correlated (flight) SACS thermal model.**
- **Three days later, the umbra test was performed, where the heat load from the recently wetted CSPR2/CSPR3 was reduced to zero due to the umbra attitude, and the heat load to the SACS came exclusively through the SAs.**
- **Correcting for the decrease in solar distance, the 1900 W predicted on 14 September 2018 (0.90 AU) became 2033 W (0.87 AU). After approximately 3 hours in umbra attitude, the measured steady-state temperature was ~33°C. This lined up very well with the model prediction for the 2033-W power input and four active radiators.**
- **In flight, there is no way to independently or directly measure SACS input power, so it must be estimated based on temperature using the flight model**

SACS Performance has been Nominal through O-2 (and to date)

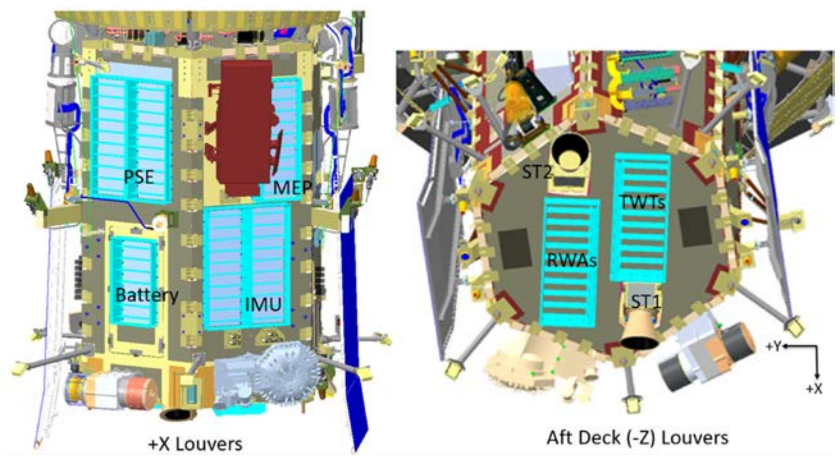


- Shown are the pump CV and accumulator temperatures (°C) as well as the system total pressure (psia) and delta-P (psid).
- When inside of 0.70 AU (Umbra Attitude) the solar array flap angle is adjusted as a function of solar distance to keep the SACS operating temperature between 60 °C and 65 °C.
- To date, the system has performed as designed

Spacecraft TCS Overview



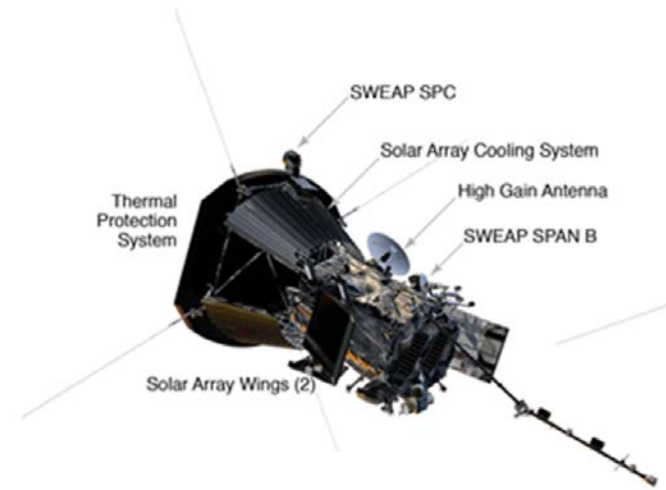
Sun-side geometry and the externally mounted components illuminated during aphelion attitude (>0.80 AU) and aphelion-variable attitude (0.70 to 0.80 AU). At solar distance less than 0.70 AU, the spacecraft flies in umbra attitude

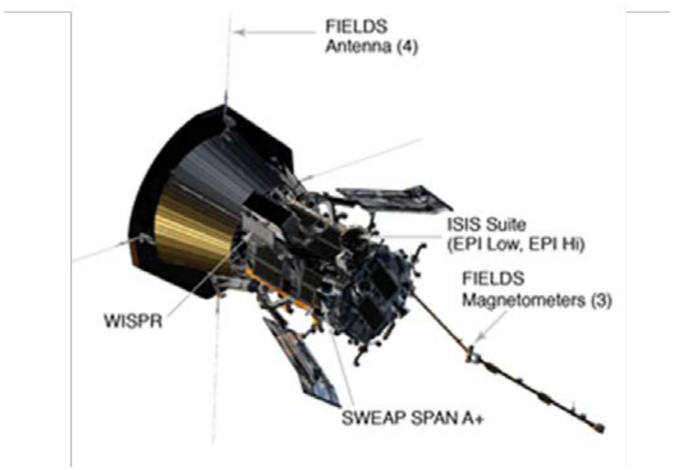


Spacecraft louver locations. Other than for short transients, all louvers are maintained in solar shadow. The flight louvers were manufactured by the Sierra Nevada Corporation, Louisville, CO. Also visible are ST-1 and ST-2

- **The spacecraft (excluding the SACS) is a passive thermal design that utilizes louvers, multilayer insulation (MLI), and heaters along with waste electronics heat dissipation to maintain the core bus temperature between +10°C and +50°C.**
- **The internally mounted SACS and propulsion components (the propellant tank and the accumulator, pressure transducers, latching valves, and fill and drain valves) are thermally coupled to the bus and rely on the bus bulk temperature to keep their respective temperatures above freezing (both hydrazine and water freeze at nearly the same temperature) during cold spacecraft conditions.**
- **Two 20-blade and three 10-blade louvers are utilized to help minimize bus heater power and maintain the bulk bus temperature above 10°C.**
- **The battery is thermally isolated from the bus and uses a seven-blade louver and software-controlled heaters to maintain its nominal temperature between 0°C and 15°C.**
- **The majority of the high-powered radio frequency (RF) components are located on or near the −Z aft deck and utilize two of the 10-blade louvers to reduce bus heat leak when the RF system is powered off**

Instrument TCS Overview



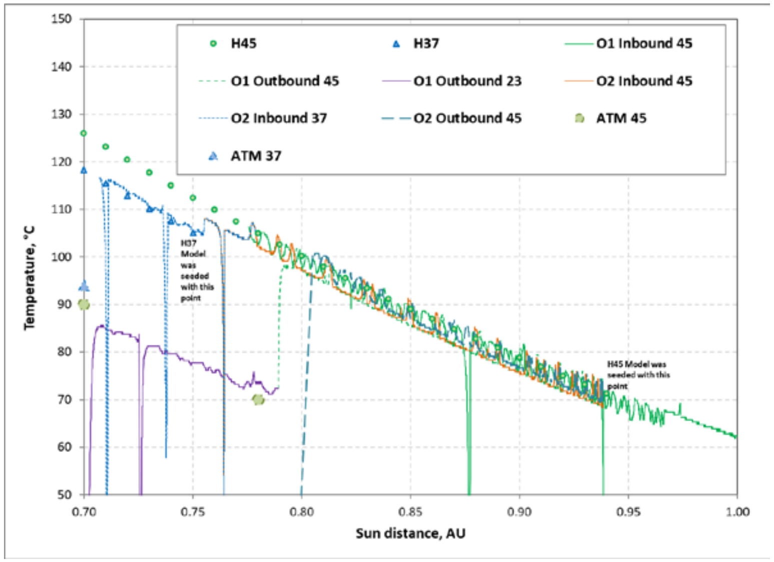


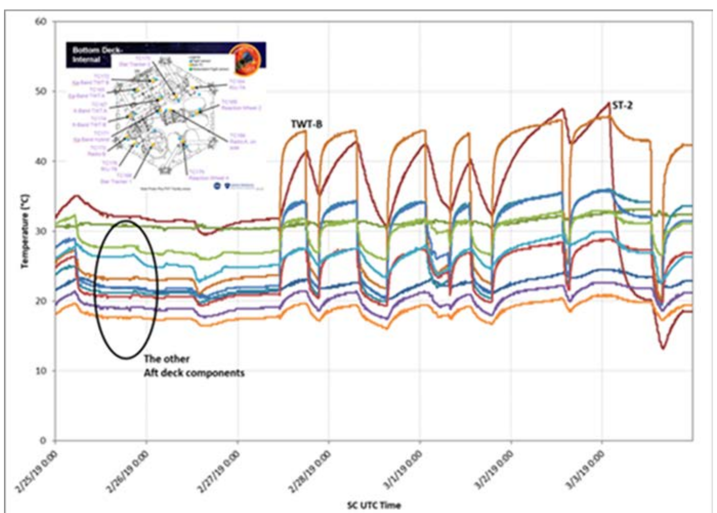
- **The body-mounted instruments are thermally isolated from the bus and, with the exception of Solar Probe Analyzer (SPAN)-B, are located with the louvers on the "cold side" of the spacecraft (+X).**
- **The truss structure assembly-mounted instruments, the four Electromagnetic Fields Investigation instrument suite (FIELDS) antennas, and the Solar Probe Cup (SPC) are completely isolated from the bus and are the only instruments designed to withstand the full solar constant when at minimum perihelion.**
- **The FIELDS magnetometers are located on a 3.4-m boom and also are thermally isolated from the bus**

Aphelion and Aphelion Variable Attitude: Hot Case

- **During aphelion operation (outside of 0.70 AU), the spacecraft is tilted so as not to exceed 45° from +Z toward −X to allow for X-band (fan beam) and KA-band (HGA) communications.**
- **Inside of 0.82 AU, this angle can be adjusted anywhere between umbra pointing and 45° to allow for proper HGA pointing toward Earth and also to relax the thermal input into the SACS, the externally mounted bus components, and the bus as long as the thermal attitude does not interfere with HGA-KA-band operations.**
- **During this period, the externally mounted components on the −X side of the spacecraft experienced near-mission-maximum temperatures (0.70 AU/45° tilt), and some the internally mounted components experienced mission-maximum temperatures as well.**
- **These conditions are dependent on sun angle and will most likely repeat several more times as the spacecraft adjusts its attitude to allow proper HGA pointing for KA-band downlink.**
- **So far in the mission, the spacecraft has experienced one of its two hot cases: during O-2 when near 0.70 AU and in aphelion-variable attitude while tilted 37° (1 March 2019) for KA - band downlink using the high-gain antenna (HGA).**
- **In the second and more severe hot case, predicted for the mission minimum perihelion (9.86 R_S), the external components will stay relatively cold and the temperature gradient inside of the spacecraft will be from top to bottom (+Z to −Z) instead of from side to side (−X to +X) so the internal components that were warm during this hot case will be a bit cooler during the perihelion hot case and vice versa.**

SP-AR-844: The FBA-1, DSS-1, and Star Tracker-2 Anomaly

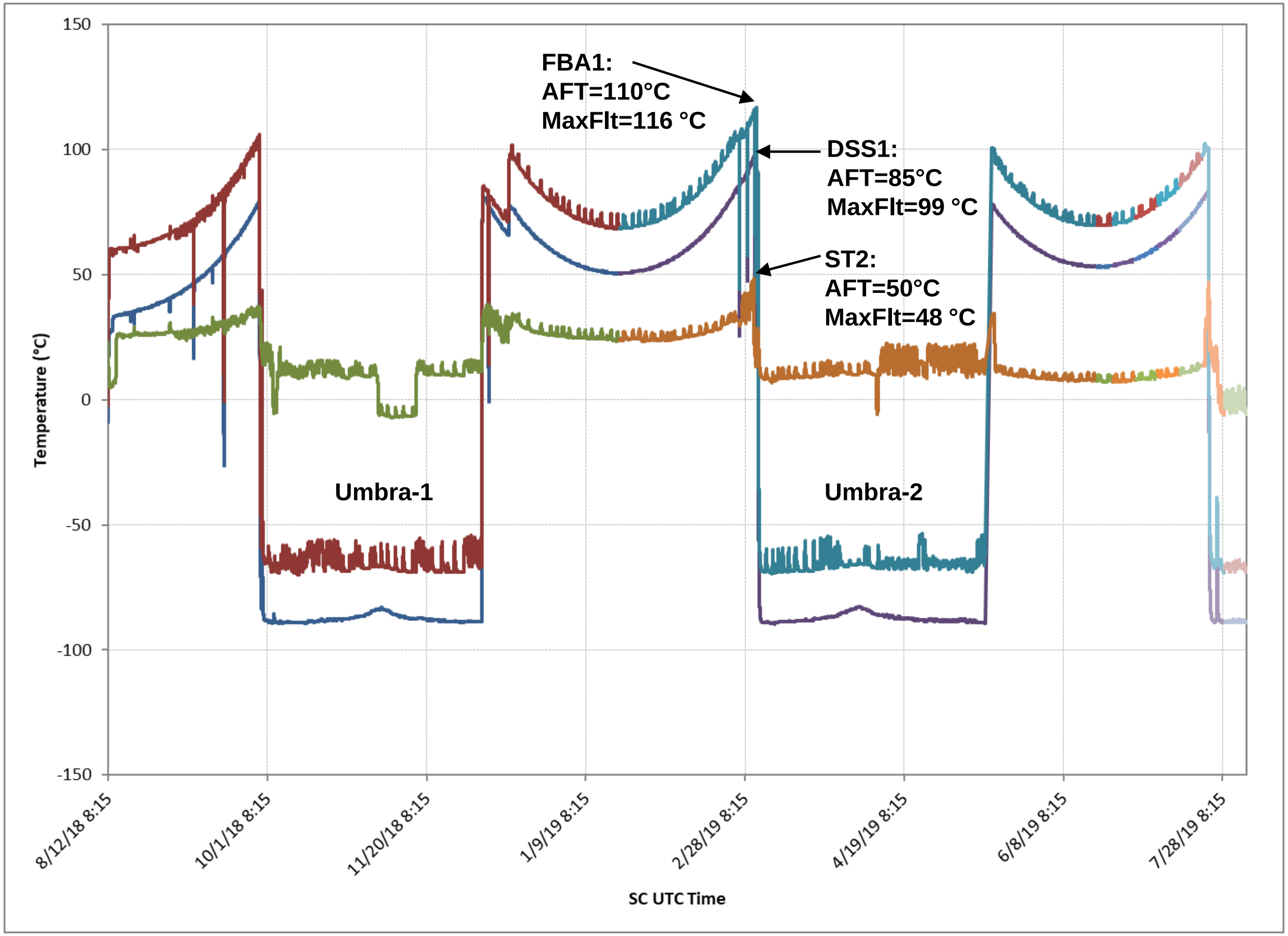




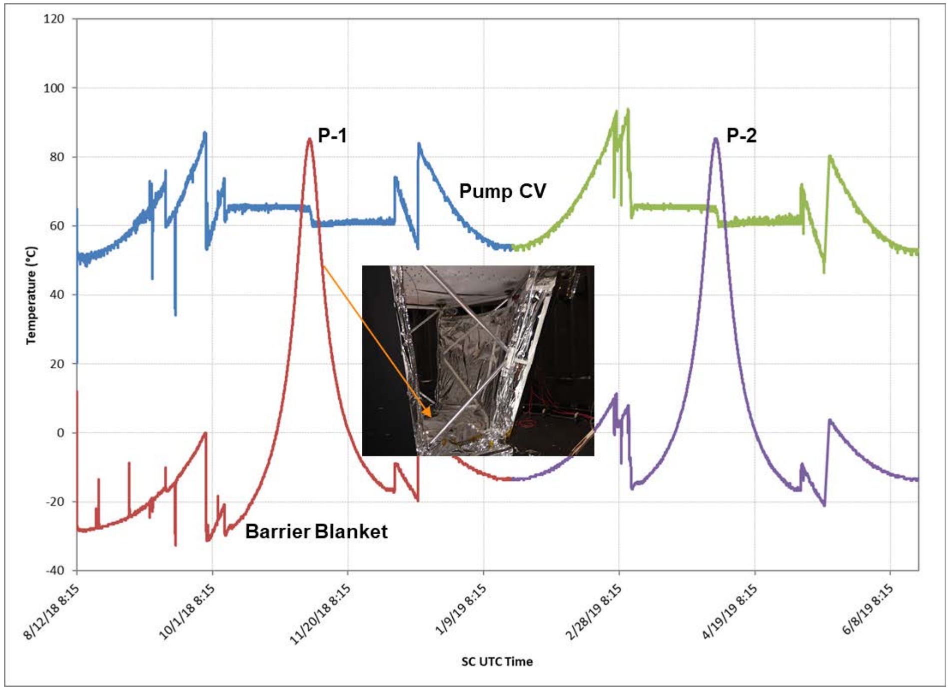
On 3 March 2019, ST-2 was powered off by spacecraft autonomy when the input power exceeded 11.1 W. As shown, the major influence on its temperature is the operation of the KA-band TWT. All other components of the spacecraft aft deck were not overly affected by KA-band operation

- During aphelion attitude, 37° tilt, of O-2, the externally mounted FBA-1 and the DSS-1 exceeded their allowable flight temperature (AFT) hot limits by 7°C and 14°C, respectively.
- An empirical/heuristic model was developed to re-predict the worst-case temperatures for these and the other external sun-side components when at 45° tilt and 0.70 AU, as shown FBA-1. As can be seen the ATM very much under-predicts the FBA-1 temperature, whereas the heuristic model (H37 and H45) is very accurate once a “seed” temperature is measured for constant sun angle and a known solar distance, the remaining temperature profile for that component as a function of solar distance can be computed for that sun angle.
- From the heuristic model predictions at the 45° tilt, it is expected that FBA-1 will reach 126°C (16°C > AFT) and DSS-1 will slightly exceed 100°C (15°C > AFT). The heuristic predictions also indicate that remaining sun-side components will stay below their respective AFT limits when in the maximum tilted (45°) condition.
- A second part of the anomaly report (AR) is the operational current (power) exceedance of star tracker-2 (ST-2). During the same period, when the spacecraft was in highly tilted aphelion-variable attitude, there was an increase in operational power for ST-2 that was coincident with KA-band traveling-wave tube (TWT) operation, as shown, while the other aft deck components were fairly unaffected
- This input power correlated exactly to the power needed by the TEC to maintain the ~50°C delta between the housing and optical element. Operationally, the STs were tested to a housing temperature of +50°C so the correlation between ST-2 temperature and required TEC power matched perfectly

FBA1, DSS1 and ST2 to date



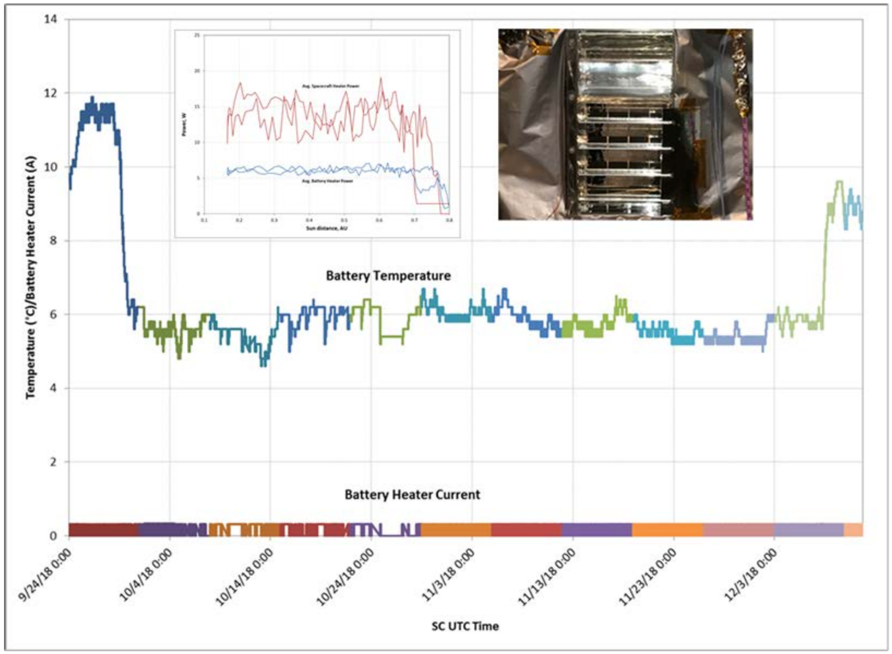
Umbra Attitude: Cold Case

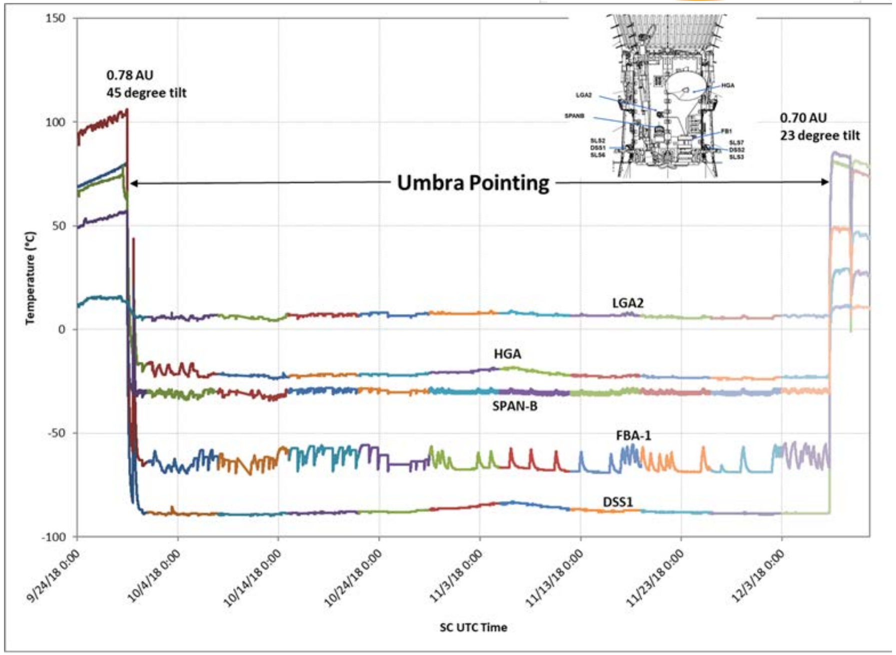


On 6 November 2018 and 5 April 2019, PSP reached its first (P-1) and second (P-2) of 24 perihelion conditions (35.7 RS/38 suns) as indicated by the temperature sensors on the barrier blanket. It is expected that the barrier blanket temperature sensors will reach a maximum of ~250°C when at minimum perihelion (9.86 RS) in December 2024. Also shown is the SACS CV temperature in WAC mode, being maintained between 60°C and 65°C when inside of 0.70 AU. Thermnal model estimates of the barrier blanket prior to encounter predicted peak adiabatic temperature to be ~100 C (measured T_{max}=85 °C)

- **On 4 March 2019, PSP crossed 0.70 AU and was autonomously transitioned into umbra attitude**
- **SA WAC was invoked to maintain the average SA temperature between 60°C and 65°C. During the final three orbits, 22–24 (minimum perihelion orbits), the umbra attitude will represent both the extreme hot and cold spacecraft thermal conditions**
- **Currently, however, it only represents the extreme cold conditions for the internally and externally mounted bus components that are in the umbra created by the TPS**
- **During O-1 perihelion-1 (P-1), the maximum solar constant approached 40 suns but was well attenuated by the TPS and was not noticed by the underlying spacecraft.**
- **Shown is the thermal effects as seen by the spacecraft barrier blanket PT103 temperature sensors of the quickly increasing and decaying solar constant as the spacecraft moved toward and then away from P-1.**
- **It should be noted that because there was/will be no Venus flyby during O-2 and O-3, perihelion-2 (P-2) and perihelion-3 (P-3) will be identical to P-1, and the thermal performance is expected to be the same as those experienced during O-1**

Sunside Components and the battery

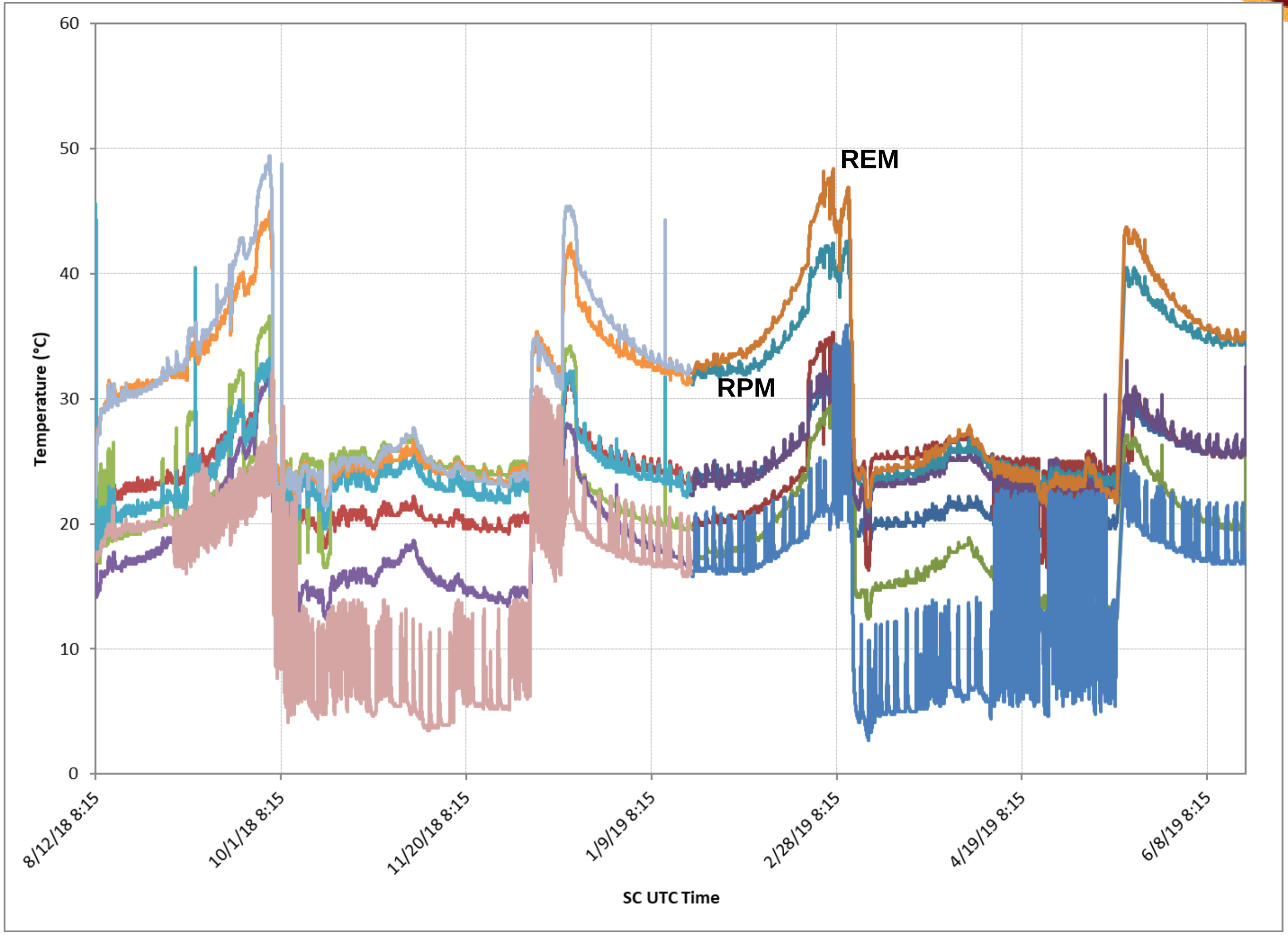




Shown is the battery temperature and associated heater current during O-1 umbra conditions (0.78 AU inbound to 0.70 AU outbound). Because of the highly attenuated solar heating, the battery temperature and heater current are nearly constant during umbra attitude and are independent of solar distance. Note louver and heater power inlays: During spacecraft thermal balance testing, it was determined that the battery temperature was higher than desired by ~15°C. The flight fix, verified during spacecraft thermal-cycle testing, pinned four of the seven louver blades fully open to mitigate the hot condition and keep the heater duty cycled below 75% during the umbra cold case, as shown. Maximum battery heater power is 10.5 W, and the maximum calculated duty cycle is 62%.

Shown are a few of the external sun-side (−X) components during O-1 umbra attitude. As illustrated by the nearly constant temperatures, the 38-sun solar environment is being well attenuated by the TPS. The small temperature spikes for FBA-1 are due to X-band operation

IMU^L, PDU, PSE^L, REM, RPM, TWTA-A^L, and MEP^L



Temperature Summary to date (20190812)

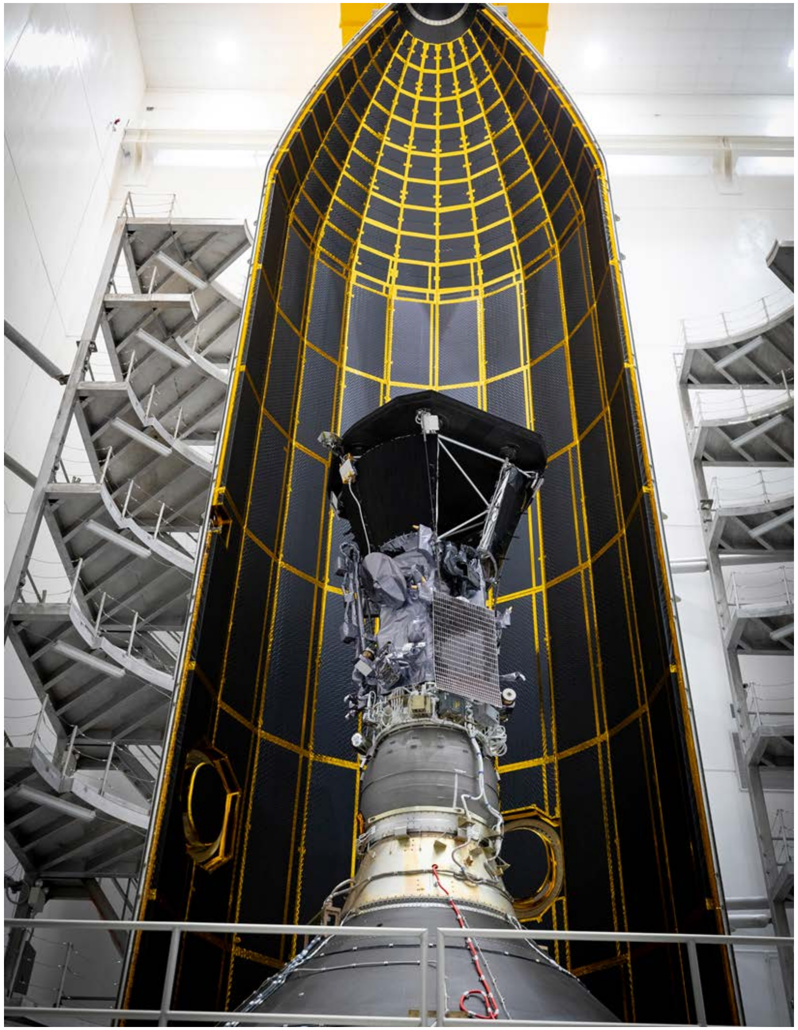
Item	Flight data Min	Flight data Max	AFT Cold	AFT Hot	Margin Cold	Margin Hot
Telecommunications						
HGA Dish	-25	79	-170	160	145	81
Ka TWT	1	47	-25	85	26	39
Ka EPC	-4	45	-25	65	21	20
X TWT	5	36	-25	85	30	49
X EPC	4	47	-25	65	29	18
Fan beam	-70	117	-120	110	50	-7
LGA	-1	92	-100	110	99	18
RF switch plate	-1	41	-25	65	24	24
Radio	6	33	-25	55	31	22
Guidance and Control						
IMU	17	33	-10	60	27	27
Star tracker	-7	48	-30	50	23	2
Wheels	18	51	-20	60	38	9
SSE	20	56	-25	65	45	9
DSS	-92	99	-120	85	28	-14
Power						
PSE	18	41	0	55	18	14
Battery	4	12	5	35	-1	23
Solar Array Cooling System (SACS)						
Pump chk valve	33	94	10	135	23	41
SACS elect	20	42	0	60	20	18
Accumulator	23	52	20	60	3	8
Fill/drain vlv	27	59	10	90	17	31
TotalP Sensor	27	53	10	75	17	22
DP sensor	27	51	10	65	17	14
Avionics						
RPM	21	45	-25	60	46	15
REM	21	49	-25	65	46	16
PDU	12	32	-25	60	37	28
RIU	4	58	-25	65	29	8
Propulsion						
Tank	15	43	10	50	5	7
Lines	14	61	10	75	4	15
Pressure trans	13	36	10	75	3	39
Latch valve	14	37	10	50	4	13
Service valve	11	42	10	50	1	8
Thruster valve	18	79	10	110	8	31

Item	Flight data Min	Flight data Max	AFT Cold	AFT Hot	Margin Cold	Margin Hot
Mechanical						
SA actuator	-17	72	-25	85	8	13
HGA actuator	-22	79	-40	85	18	6
ECU	16	52	-25	65	41	13
Instrument Electronics						
FIELDS MEP	16	37	-25	60	41	23
SWEAP SWEM	11	52	-25	65	36	13
WISPR DPU	12	39	-25	55	37	16
Fields						
Fields Pre Amp	-76	33	-83	91	7	59
SPC Pre Amp	-37	32	-40	81	3	49
SPAN A/B						
SPAN A Ebox	-40	-4	-40	50	0	54
SPAN B Ebox	-41	61	-40	85	-1	24
SPAN A Pedestal	-22	0	-90	65	68	65
SPAN A Top Ana	-70	-4	-90	65	20	69
SPAN B Pedestal	-34	64	-40	85	6	21
SPAN B Top Ana	-45	87	-70	115	25	28
WISPR						
WISPR Cam Elec	-50	-37	-55	60	5	97
WISPR ERM	-87	-38	-120	55	33	93
WISPR In T DRB	-50	-33	-55	65	5	98
WISPR In T LBA	-57	-34	-60	60	3	94
WISPR Out T DRB	-47	-18	-55	65	8	83
WISPR Out T LBA	-51	-29	-57	60	6	89
EpiLo/Hi						
EpiLo A	-37	-25	-43	62	6	87
EpiLo B1	-37	-28	-43	62	6	90
EpiLo B2	-36	-27	-43	62	7	89
EpiHi Box 1,2	-29	-15	-40	60	11	75
EpiHi HET	-35	-21	-40	60	6	81
EpiHi LET1	-35	-21	-40	60	5	81
EpiHi LET2	-34	-21	-40	60	6	81

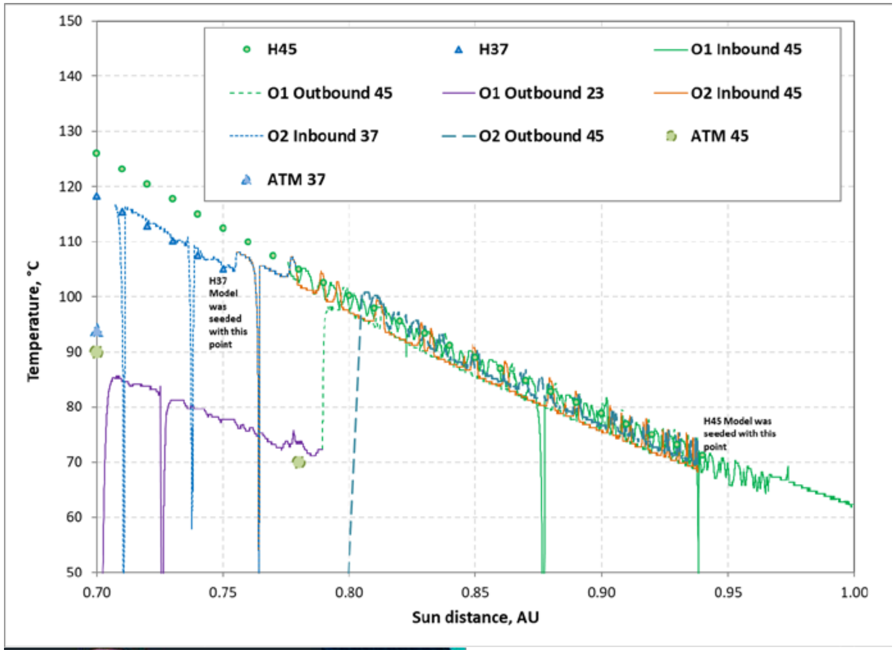
Summary

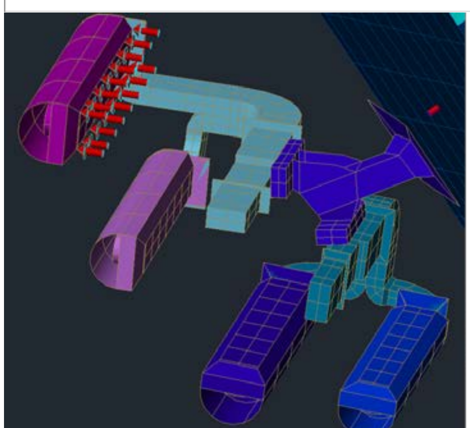
- To date, PSP has performed essentially as expected, and the to-date temperature performance, ATFs, and margins are summarized by Table 2 in the paper.
- Other than the previously discussed anomalous behavior of FBA-1, DSS-1, and ST-2, the spacecraft temperatures for the electronics, propulsion, instruments, and SACS have been nominal and without problems.
- Critical activation events for the SACS were also nominal, and for the most part, thermal models have been accurate regarding SACS and internal bus behavior.
- Even though temperature limits were violated for FBA-1 and DSS-1 during O-2, engineering was completely involved with the decision to keep KA-band downlink attitude and to offload the spacecraft SSR because the perceived hardware risk was minimal based on vendor input and heritage testing from the MESSENGER program.
- As the mission progresses, umbra attitude will not be as benign as shown here, but that is to be expected. Overall, PSP remains healthy and is ready to continue to explore the inner solar system where no spacecraft has ever gone before

PSP is shown prior to final encapsulation while at Astrotech Space Operations



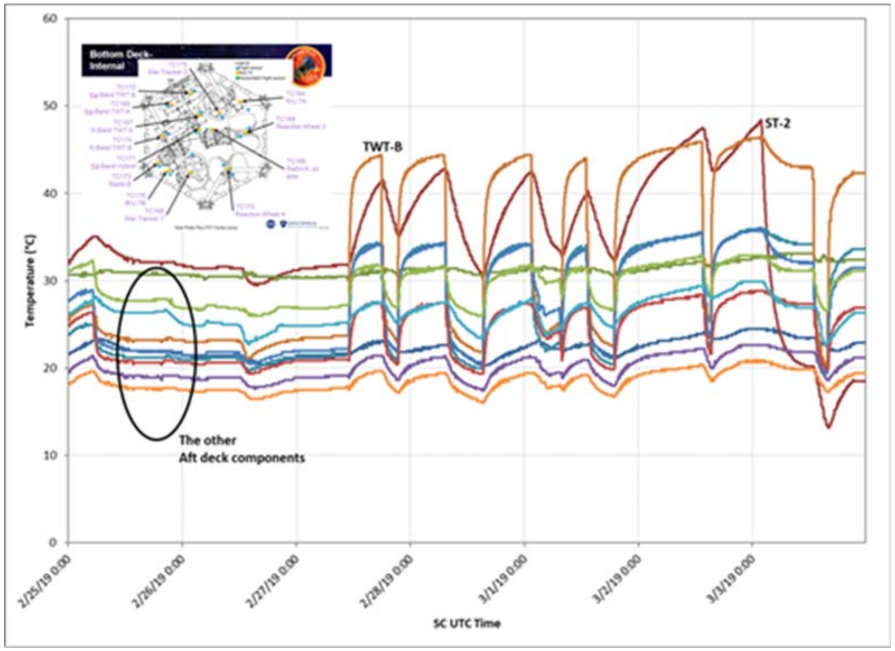
SP-AR-844: The FBA-1, DSS-1, and Star Tracker-2 Anomaly





- During aphelion attitude, 37° tilt, of O-2, the externally mounted FBA-1 and the DSS-1 exceeded their allowable flight temperature (AFT) hot limits by 7°C and 14°C, respectively.
- Early mission temperature measurements of these components indicated that they were running hotter than the pre-launch predictions using the analytical thermal model (ATM) when in aphelion attitude.
- An empirical/heuristic model was developed to re-predict the worst-case temperatures for these and the other external sun-side components when at 45° tilt and 0.70 AU, as shown FBA-1. As can be seen the ATM very much under-predicts the FBA-1 temperature, whereas the heuristic model (H37 and H45) is very accurate once a “seed” temperature is measured for constant sun angle and a known solar distance, the remaining temperature profile for that component as a function of solar distance can be computed for that sun angle.
- From the heuristic model predictions at the 45° tilt, it is expected that FBA-1 will reach 126°C (16°C > AFT) and DSS-1 will slightly exceed 100°C (15°C > AFT). The heuristic predictions also indicate that remaining sun-side components will stay below their respective AFT limits when in the maximum tilted (45°) condition.
- Based on packaging symmetry it was expected that DSS-1 and DSS-2 would run at nearly the same temperature and both would be below the AFT at maximum tilt when at 0.70 AU.
  - However, DSS-1 is running ~18°C hotter (equivalent to 25% higher heating) than DSS-2, and the two companion SLSs co-located with DSS-1 are running warmer than the two companion SLSs co-located with DSS-2
  - From the optical property degradation analysis, the AZ-93 white paint used on the SLSs and DSSs is degrading in family, currently increasing ~3% per orbit, and nothing abnormal is being observed
- For FBA-1, it is believed that there is ~2 W of thermal trapping between the open radome end and the gold-plated antenna cups that is not being properly resolved by flight ATM

SP-AR-844: The FBA-1, DSS-1, and Star Tracker-2 Anomaly (2)



On 3 March 2019, ST-2 was powered off by spacecraft autonomy when the input power exceeded 11.1 W. As shown, the major influence on its temperature is the operation of the KA-band TWT. All other components of the spacecraft aft deck were not overly affected by KA-band operation

- **A second part of the anomaly report (AR) is the operational current (power) exceedance of star tracker-2 (ST-2). During the same period, when the spacecraft was in highly tilted aphelion-variable attitude, there was an increase in operational power for ST-2 that was coincident with KA-band traveling-wave tube (TWT) operation, as shown, while the other aft deck components were fairly unaffected.**
- **This power increase was directly related to ST-2 thermoelectric cooler (TEC) operation due to the increasing delta-T between the ST housing and the optical element that is being controlled to 0°C. ST-2 exceeded the maximum operating power limit for autonomy rule 294 and was powered off during this Ka-band period when the input power reached 11.1 W.**
- **This input power correlated exactly to the power needed by the TEC to maintain the ~50°C delta between the housing and optical element. Operationally, the STs were tested to a housing temperature of +50°C so the correlation between ST-2 temperature and required TEC power matched perfectly.**
- **To be clear, this condition is the combination of two elements that make "the perfect storm": highly tilted aphelion-variable attitude when inside of 0.75 AU combined with KA-band operation. During the outbound portion of O-1, the aphelion-variable attitude was set to 23° between 0.70 and 0.75 AU (~5 days).**
- **ST-1 is thermally insensitive to KA-band, as verified during spacecraft TVAC and flight operation**

SP-AR-844: Path Forward

- **As part of the path forward, the AFTs for the FBAs and DSSs will be increased to reflect qualification instead of flight hardware acceptance test temperature limits.**
  - **The FBAs are of MESSENGER heritage that were acceptance tested to 150°C, and the DSSs, which were manufactured by the Adcole Corporation, can be associated by design similarity to units that were tested above 125°C.**
  - **Also, to further reinforce the AFT change for the FBA, temperature qualification testing using the flight-spare PSP FBA was successfully completed, and the limits of the test reflected those that were used for MESSENGER (−100°C to +150°C).**
- **Moving forward, there are three possible solutions to remedy this situation:**
  - **(1) limit ST-2 usage during KA-band operation when inside of 0.75 AU and highly tilted (Use ST-1 inside of 0.75 AU)**
  - **(2) increase the optical element control temperature from 0°C to say 5°C or 10°C to decrease the control delta-T and related TEC thermal output**
  - **(3) raise the AFT to say 55°C and proportionally increase the allowable current (power) draw to be consistent with a 0°C control temperature for the optical elements**
  - **Option 1 is currently be evaluated as the operations plan for the future. Issues with redundancy and autonomy are being worked.**
- **As with FBA-1 and DSS-1, corrective action is still a work in progress, and the plan is to have resolution before February 2020**