Overview of the Thermal Design and Challenges for the Comet Astrobiology Exploration SAmple Return (CAESAR) Mission

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Agenda

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  - Sample Acquisition System (SAS)
  - Sample Containment System (SCS) and Gas Containment System (GCS)
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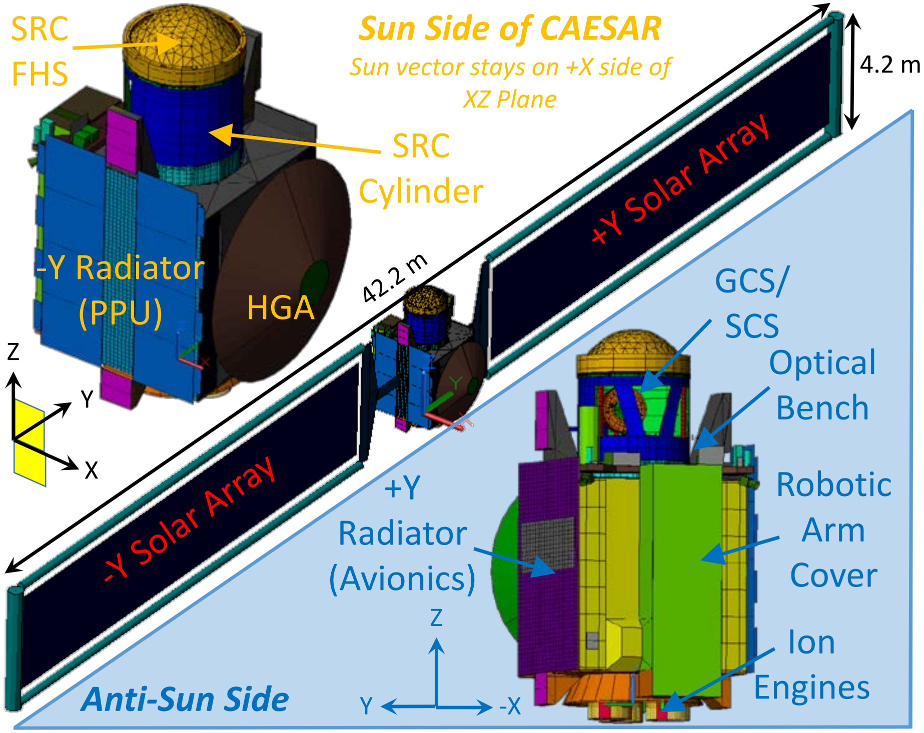
- Thermal Design
- Thermal Challenges
  - Power variation for Solar Electric Propulsion (SEP)
  - Pointing orientation for SEP
  - GCS Cooling
  - Keeping sample cold through re-entry and recovery
- Conclusion and Path Forward

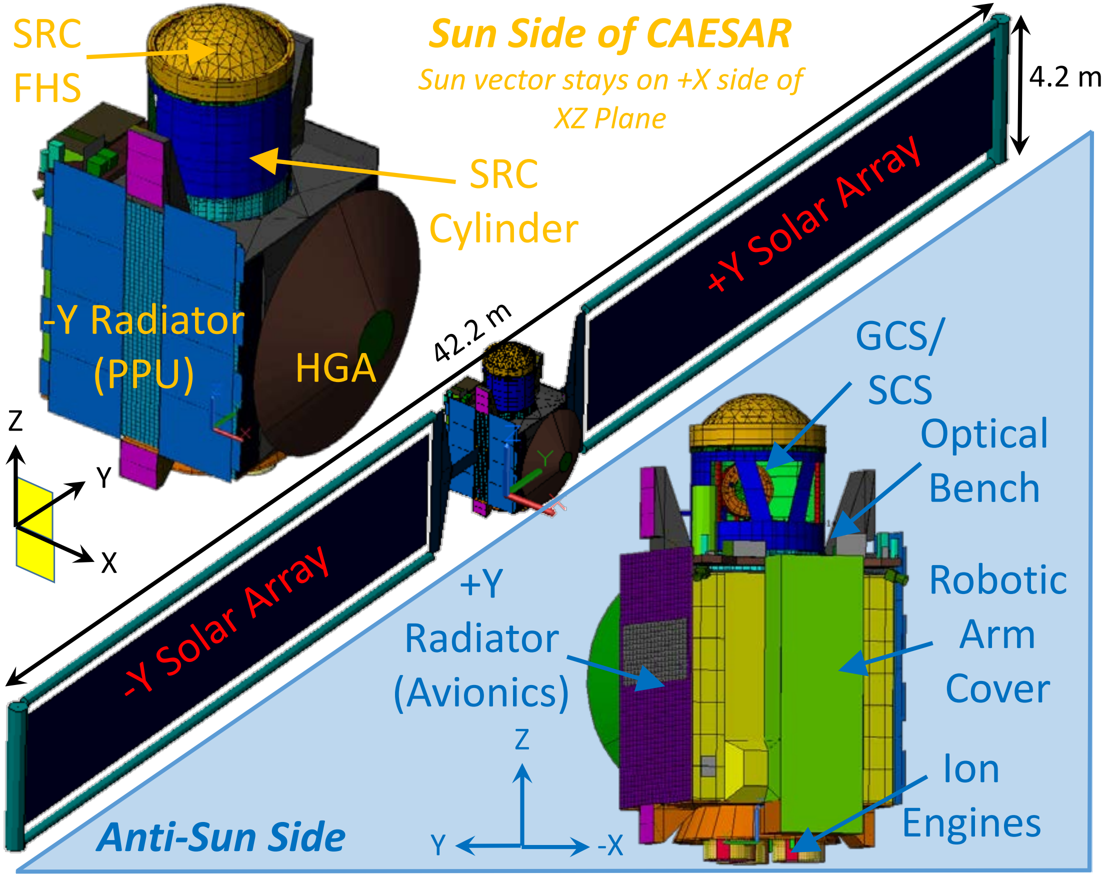
Mission Overview

- CAESAR proposes to follow other New Frontier's missions New Horizons, JUNO, and OSIRIS-REx in exploring bodies in our solar system
- The Comet Astrobiology Exploration SAmple Return (CAESAR) Mission was submitted to NASA's New Frontiers 4 Announcement of Opportunity
- CAESAR proposes to return >80 g of comet sample from the nucleus of comet 67P/ Churymov-Gerasimenko, the same comet studied by ESA's Rosetta mission
- The CAESAR mission architecture is based on four cornerstone principles
  - *Collect sample from only one target: 67P/CG*
  - *Utilize solar electric propulsion to enable almost any launch date*
  - *Include only the hardware necessary to collect and preserve the sample: no science instruments*
  - *Leverage the OSIRIS-REx mission architecture and operations to reduce risks*
- High level mission parameters:
  - Launch in January 2025
  - Solar Electric thrusting when < 3.2 AU
  - Solar vector remains in XZ plane
  - ~4 year outbound cruise, 5 year proximity operations, 5 year inbound cruise
  - SRC Lands in Utah November 2038



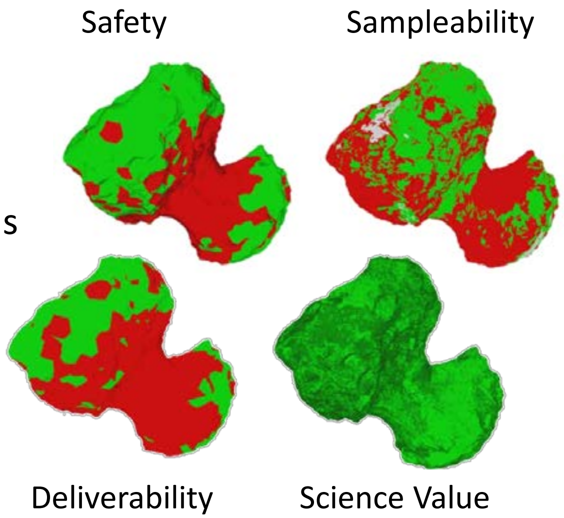
CAESAR Spacecraft Overview

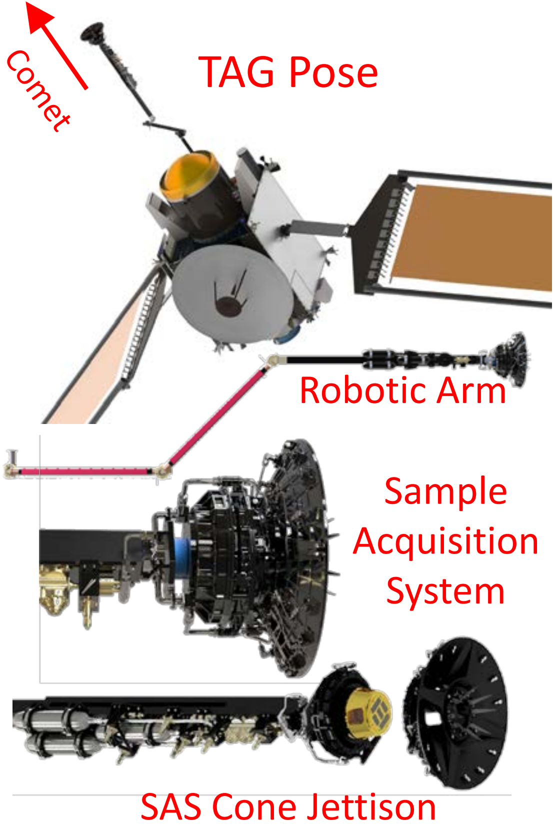
- 3 NEXT-C ion engines on the –Z side provide thrusting notionally in the +Z direction
- Gimballed, Roll Out Solar Arrays provide power and allow thrust vector to rotate about Y axis
- Large High Gain Antenna on +X side
- +Y side includes a radiator for the spacecraft avionics
- -Y side includes eight loop heat pipe and radiator assemblies for the SEP
- -X Side includes enclosure for TAG Arm; SAS mounted at end of arm
- Optical Bench and Camera Suite mounted on –X edge of +Z panel
- SRC Support cylinder mounted to spacecraft +Z deck
  - SRC includes Back Heat Shield (BHS) and Forward Heat Shield (FHS)
  - Lifting Table moves BHS up to latch to FHS
  - BHS contains GCS and SCS
  - SRC Cylinder includes opening for GCS Radiator to view space
  - TAG Arm inserts sample into SCS



CAESAR Spacecraft Subsystems

- Like OSIRIS-REx, the Camera Suite on the Optical Bench creates four maps to determine ideal sampling locations on comet
  - Safety: avoid local hazards to spacecraft
  - Sampleability: likelihood of successful sample collection
  - Science Value: Rosetta and CAESAR measurements for scientifically rich areas
  - Deliverability: ability of flight dynamics/spacecraft to maneuver to location





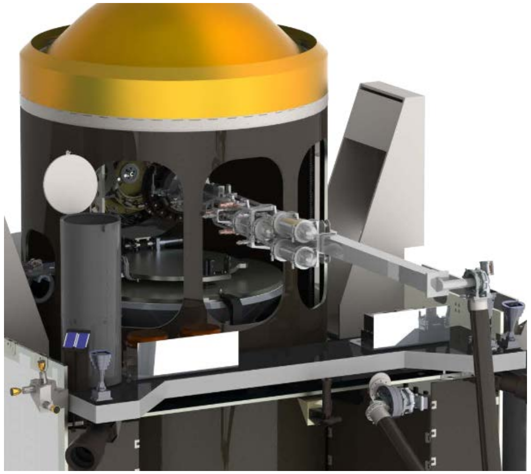
- Once a sample site is selected…
- TAG Arm does baseline tare with empty sample container, extending straight and rotating about shoulder. Torque measurement used to compute mass.
- TAG Arm extends into TAG pose orientation for up to three attempts to collect sample in Touch-and-Go maneuver
- SAS uses nitrogen pneumatics to drive sample into sample container while in contact with surface for ~ 5 sec
- TAG Arm does second tare measurement to determine sample mass difference from empty baseline tare
- Once sufficient sample is collected, sample cone is jettisoned
- Once sample cone is removed, sample is ready for storage in Sample Containment System

CAESAR Spacecraft Subsystems

- Once the sample is ready to store, the SCS lid translates and rotates to the open position
- The sample is then inserted by the TAG Arm; locking features capture the sample container as it is released from the SAS.
- The lid is rotated back and a clamping mechanism hermetically seals the sample in the SCS
- The SCS is mounted within the GCS tank and plumbing surrounding it
- The GCS includes Phase Change Material and a dedicated radiator
- The SCS is slowly heated to sublimate the volatile species of the sample, which are driven to the colder GCS tank
- Once the volatile transfer is complete, valves seal the tank contents for the return cruise
- The SCS is then vented to space to desiccate the sample for the return cruise
- Just prior to re-entry, the vent to space is sealed

Gas Containment System

Sample Insertion

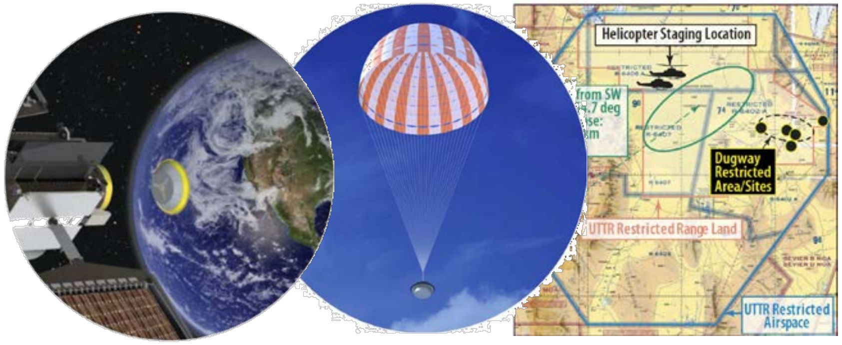


Sample Containment System

CAESAR Spacecraft Subsystems

- Once CAESAR has returned to Earth, the GCS closes blocking the radiator’s view to space
- The lifting table moves the BHS and payload up to latch with the FHS
- Once latched, the lifting table returns to its nominal position (with no BHS)
- The spin separation mechanism releases the closed SRC towards Earth
- As the SRC re-enters the atmosphere, the heat shields protect the payload
- After the drogue chute release, the FHS is dropped, followed by the main chute release
- The remaining components descend to Earth under parachute control to land in Utah
- The assembly is quickly retrieved and the entire unit is placed into cold storage for transport to the curation facility and future study

GCS Closure to SRC Closure



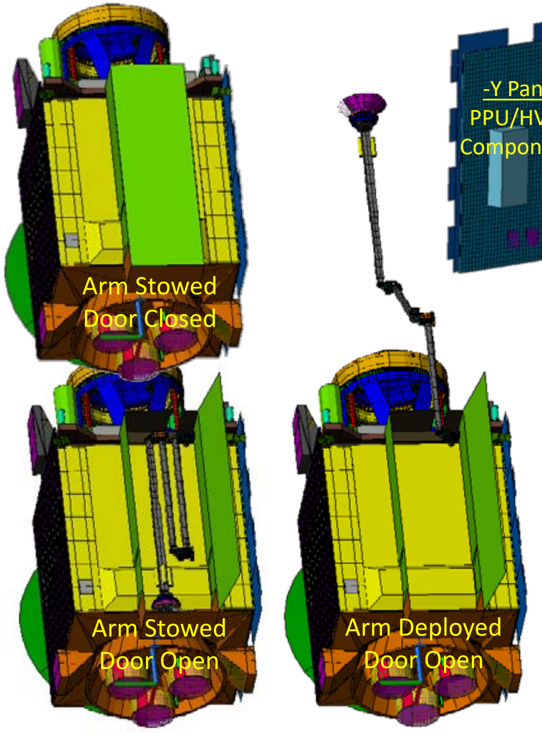
Entry Descent Landing

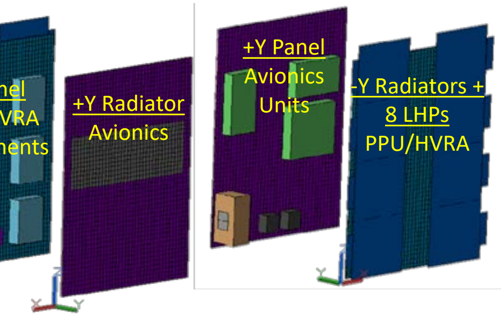
CAESAR Thermal Design Drivers

- Three major thermal design drivers (two of which are driven by SEP)
  - ***Power variability when thrusting vs. not thrusting***
  - ***Need to minimize solar illumination of radiators***
  - ***Available power over large range of distance from the sun (0.9 AU out to 5.76 AU)***
- Power Variability
  - When thrusting, the Power Processing Units and High Voltage Relay Assemblies dissipate nearly 1 kW of waste heat. When not thrusting these values are nearly zero
  - This drives the need for large radiators and a turn-down approach in the thermal control system to minimize heater power
  - ***Design: 8 propylene Loop Heat Pipe/Radiator assemblies manage the temperatures under the varying dissipations***
- Minimize Solar Illumination of Radiators
  - With large radiators, minimizing the solar illumination is key.
  - Additional absorbed solar loading that must be rejected increases radiator size and mass
  - ***Design: Keep solar vector in XZ plane (parallel to radiators)***
- Power generated over large sun distances
  - While the large arrays are needed to generate sufficient power for SEP, they are actually sized based on power needs for proximity operations at the comet at 5.76 AU
  - With cold environments and limited available power, the heater power for maintaining components within limits must be carefully considered
  - ***Design: Minimize heater power as much as possible as these represent quasi-steady power loads***

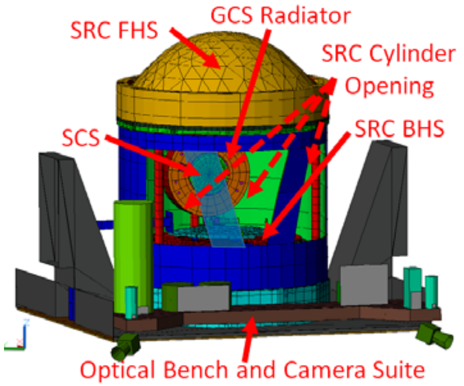
CAESAR Thermal Design (5 Zones)

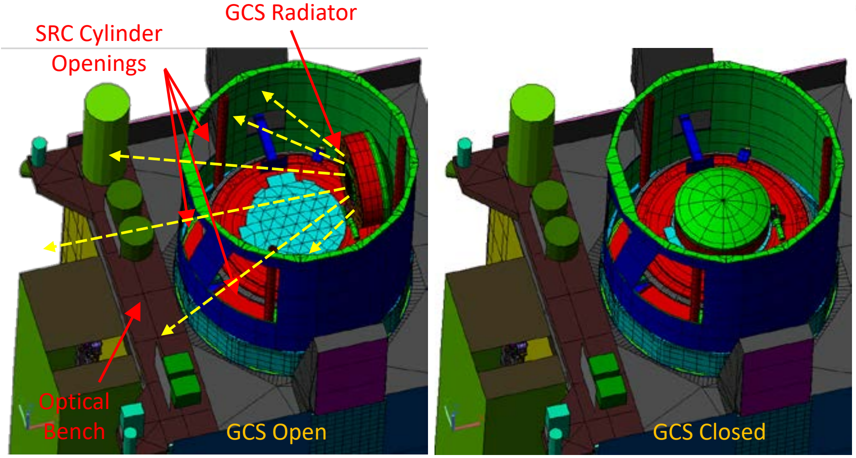
1. **North and South Radiator for Electronics**
    - *-Y Panel includes 8 Propylene LHP/ Radiator assemblies to manage PPU/HVRA dissipations*
    - *+Y Panel includes embedded heatpipes to manage heat from remaining avionics*
2. **Dedicated Optical Bench for Camera Suite**
    - *Low CTE panel to minimize misalignment*
3. **Thermal Enclosure for Stowed TAG Arm**
    - *Minimize TAG Arm power during cruise by providing warm enclosure*
4. **Gimbal System for Thrusters**
    - *Manage their own heat*





Avionics Panels





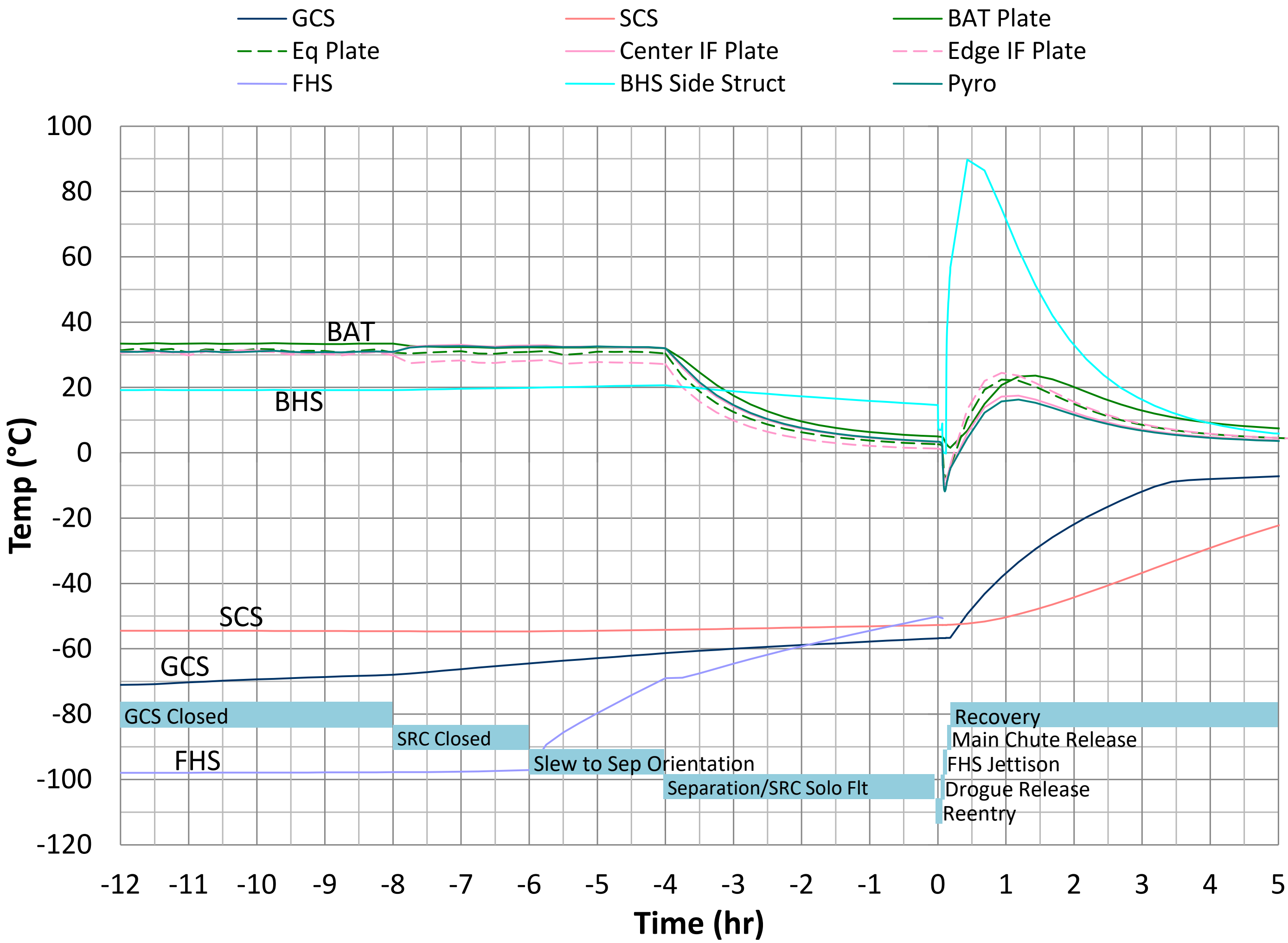
5. **Opening in the SRC Cylinder for the GCS Radiator**
    - *GCS Radiator does not have a clear Field-of-View to deep space (FHS Removed in left image)*
    - *Radiates through opening in SRC Cylinder*
    - *Challenge to specify the requirement for the GCS radiator based on its necessary location and all the components in its FOV*

CAESAR Thermal Challenges

- A sample return mission to a deep space target and the need to keep the sample sufficiently cold drive the CAESAR thermal design
- **Deep Space Target**
    - Need to sample comet near perihelion where comet activity is low (5.76 AU) ***– Operations***
    - Large arrays needed to generate sufficient power at 5.76 AU ***- Power***
    - Heater power must be minimized to keep array size manageable ***- Power***
    - Sufficient fuel needed for outbound and inbound cruise and proximity operations ***- Mass***
    - SEP needed to maximize launch window opportunities ***– SEP capability strongly tied to Mass***
    - SEP drives spacecraft pointing and radiator sizing with turn-down capabilities for large variations in SEP related power. SEP thrusting occurs over much longer time periods than traditional hydrazine thrusters. When not thrusting, communications drives orientation to point HGA towards Earth.
    - Minimizing solar illumination drives need to keep solar vector within constraints ***- Operations***
- **Keep the sample cold**
    - Preventing chemical or other alteration of sample is critical to science
    - Concern with aqueous alteration, H_2O ice melting into liquid form which would not happen in normal comet activity in the vacuum of space
    - Colder temperatures also inhibit chemical reactions of other expected non-H_2O volatile species
    - Drives need for GCS radiator and sufficient view to deep space for cooling; specifies requirements for backloading on radiator and total view to space + backloading sources
    - During Re-Entry, no cooling sink is available. Therefore, the design relies on pre-cooling and thermal capacitance to keep sample below required temperature through recovery.
    - Phase Change Material Assemblies (Dodecane, with a melting temperature of -9.6°C) are used as a low mass component to maintain temperature as energy is absorbed during warmup to change phase isothermally.

CAESAR SRC Warmup profile

- Warmup profile from GCS Closure through Recovery and shown below for key SRC components



- Requirement of 4 hours to recover SRC
- Field tests performed showed that times of about 1 hour are achievable
- Batteries and SRC equipment remain between -10°C and 30°C
- GCS and SCS remain below -2°C for at least 5 hours after re-entry
- About 3.5 hours after re-entry, the effect of the PCM is evident in the GCS curve, evidenced by the flattening of the curve

CAESAR Conclusion and Path Forward

- The CAESAR Concept study Report was submitted in Dec 2018 with a site visit by the review panel in May 2019 and an announcement of the next New Frontiers mission expected in July 2019.
- If selected, CAESAR would follow in the footsteps of other New Frontier's missions: New Horizons, JUNO, and OSIRIS-REx
- CAESAR would ramp up in early 2020, and while adhering to the cornerstone principles, will evolve, mature, and test the design towards a launch date in Jan 2025
- After 13 years of operations, through outbound cruise, proximity operations, inbound cruise, re-entry and recovery, a sample including both volatiles and non-volatiles would be returned to earth.
- Study of this sample would leverage all the power of the worlds greatest laboratories to unlock some of the mysteries about the formation and origins of life, allowing CAESAR to take its place among the greatest scientific discoveries in history

CAESAR Acknowledgements

First, thanks go to the Principal Investigator, Steve Squyres, whose vision and leadership brought together an amazing team from around the world to make CAESAR a reality

Second, thanks to all the team members who put forth efforts befitting a flight project on a proposal budget. CAESAR would also not be possible without the countless hours of hard work and dedication from all the organizations involved