TFAWS Passive Thermal Paper Session

Europa Clipper System TVAC Planning

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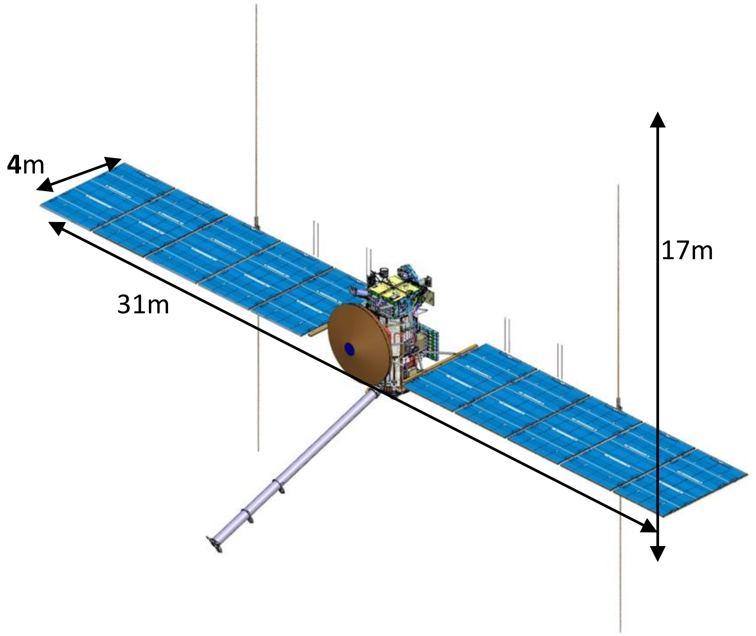
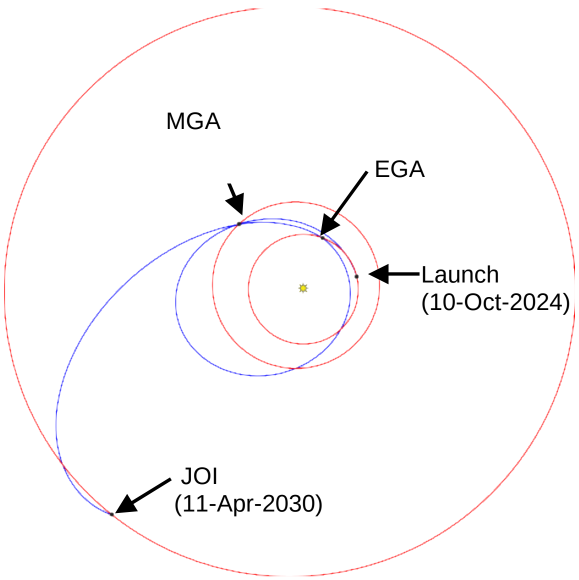
Europa Clipper Mission Overview

- Launch Window Oct 2024
- Launch Vehicle: Falcon Heavy
- Trajectory:
  - 5.5 year cruise, Mars Earth Gravity Assist (MEGA) trajectory
  - 0.82 AU closest approach to sun
- 3 Year Science Tour
  - 4.9AU - 5.6 AU
  - Multiple flyby encounters of Europa (and other moons)
  - 9.2 hour eclipse
- ~100m^2 Solar Array
  - >700W EOM
- 9 science instruments



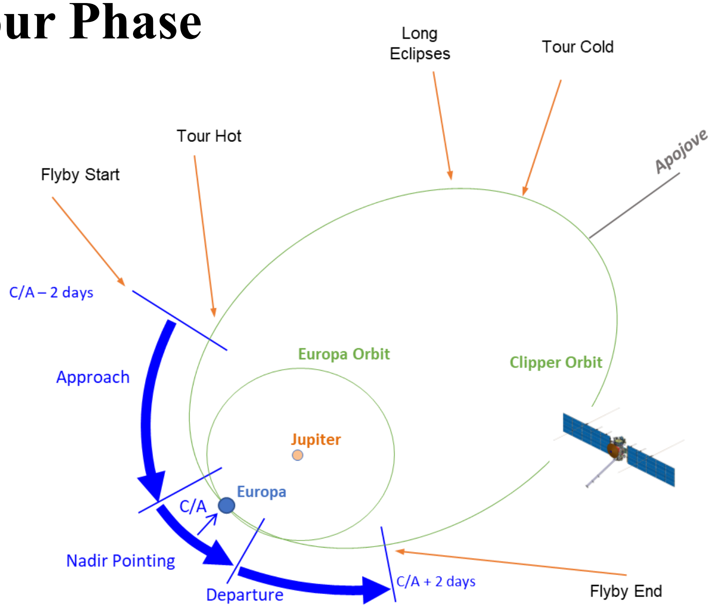
Mission Trajectory and Environments

Cruise Phase



- 5.5 year tour
  - Closest distance to sun: 0.82AU
  - Furthest distance from sun: 5.6 AU
- EGA and MGA
  - Flyby environments are not driving
- Minimal spacecraft operations:
  - Trajectory correction maneuvers
  - Data downlink/uplink
  - Instrument checkouts/calibrations
  - Deployments

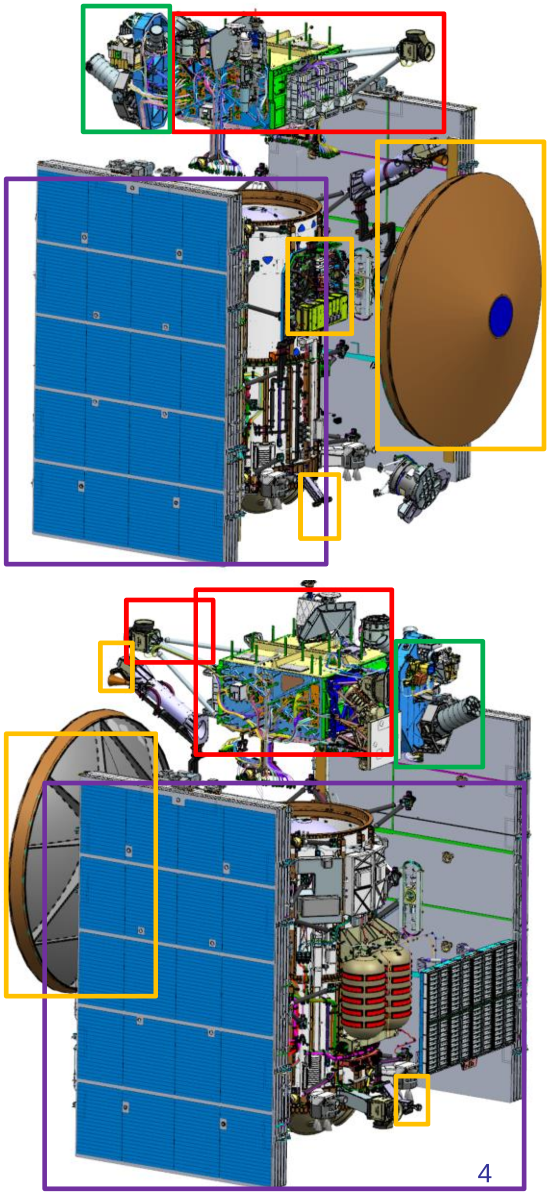
Tour Phase



- 14 day Orbit around Jupiter
  - Long Eclipses only near Apojove
  - Most of Science during Flyby window
- Flyby Window is Four Days
  - +/-2 days from Closest Approach
  - Majority of science operations occur in this window
- Minimal Science Occurs outside of Flyby:
  - PIMS Instrument
  - MASPEX Apojove science
  - Magnetometer
  - Data downlink/uplink, recharge of batteries
  - Long Eclipses 9.2 hour long

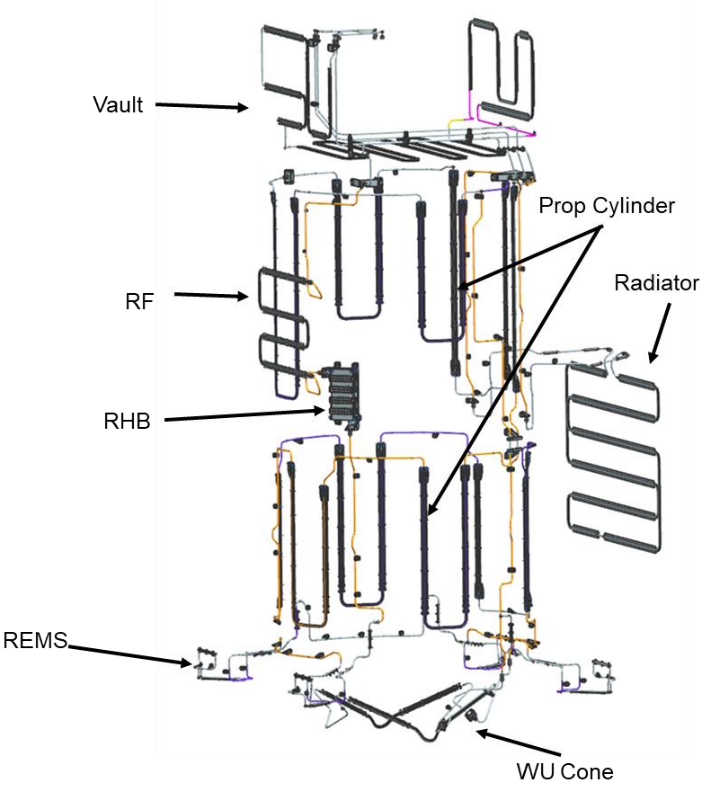
Flight System

- Avionics Vault Module (Red)
  - Instrument/Spacecraft E-boxes, batteries
  - MASPEX, MISE, SUDA, PIMS Upper
- Propulsion Module (Purple)
  - Prop tanks x2, press tanks x2, Rocket Engine Modules (REM) x 4
  - SA wings and HRS radiator, RHB
  - ECM, PIMS Lower, REASON
- RF Module (Orange)
  - 3m Diameter HGA, LGA, FBA, MGA
  - RF Panel and mini-vault housing electronics
- Nadir Platform (Green)
  - Star Trackers
  - EIS NAC/WAC, E-THEMIS, UVS



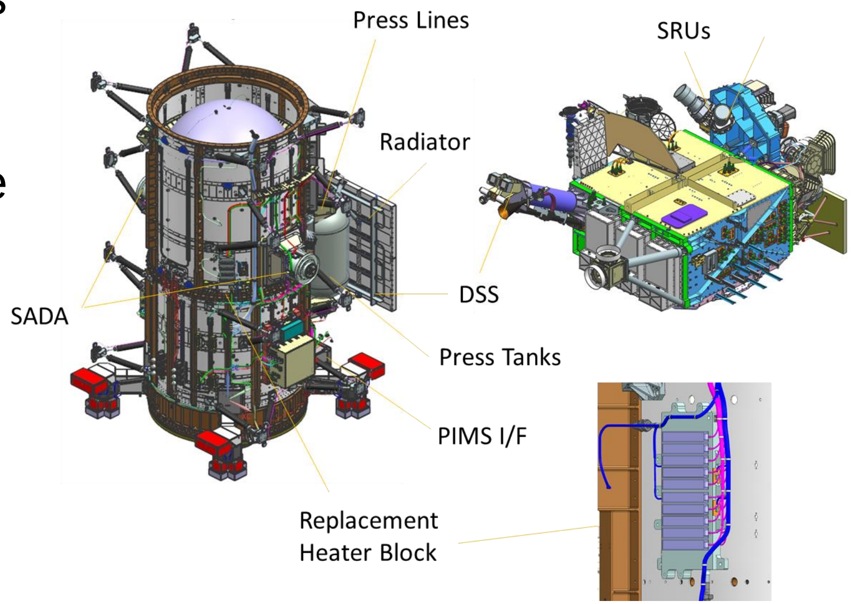
Thermal Subsystem (1/2)

- Active HRS Control for Vault and Prop Module:
  - Reclaim waste heat from Vault/RF electronics, distribute heat to propulsion system
  - CFC 11 Mechanically pumped fluid loop system (6 pumps total, 1 pump nominally operation providing 0.9 lpm at Vault, RF, REMS, split flow at PM cylinders)
  - Replacement Heater Block maintains prop inlet >15degC.
  - Passive Mixing valves modulate radiator fluid flow
  - Louvers limit radiator heat loss to space during WCC



Thermal Subsystem Architecture (2/2)

- Thermal Isolation and Passive Thermal Control outside the loop
  - Thermally Isolate external appendages and instruments
  - MLI covers all spacecraft components
  - Use of Sunshades (HGA, Vault sunshade, separation ring sunshade) to limit sun loading during inner cruise
- Heater Control for certain components
  - Flight Software controlled heaters for Star Trackers, sun sensors, SA gimbal, Pressurant tanks, and instrument sensor assemblies
  - Some heaters “on-loop” as well (RHB, radiator, and “watchdog” FP monitor)



Thermal System Characteristics

- Major sources of heat:
  - Solar loading (during inner cruise). Certain exposed components are sensitive to solar loading.
  - Vault Electronics and RF electronics waste heat generation (up to 750W dissipated on the loop during flybys)
- Major Sources of heat loss:
  - Radiative heat loss through MLI
  - HRS radiator heat loss
  - Large external passive structures (HGA, Solar Array, MagBoom Cannister)
- Largest heater power demand:
  - Minimum power (on-loop) required to keep prop subsystem above min AFTs in worst-case cold scenarios: ~410W

Test Scope and Objectives

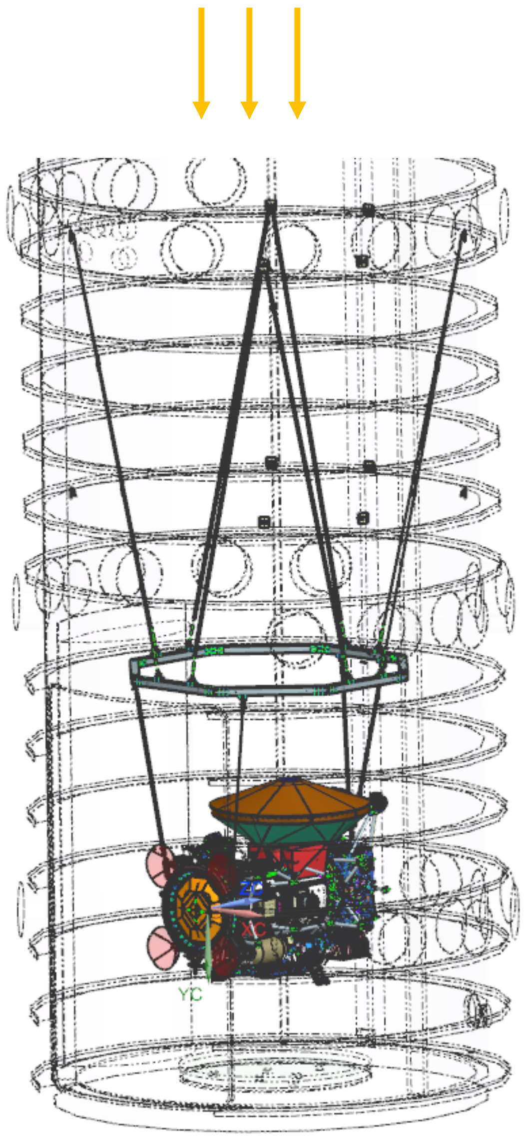
- Test Article: Clipper Spacecraft plus instruments
- Test Location: JPL 25 ft Space Simulator with Solar Sim
- Test Durations: ~18 days
- Test Start Date: Late December
- Scope:
  - System-level thermal design validation and functional testing
- Objective:
  - Verify Allowable Flight Temperature compliance
  - Verify Workmanship of TCS hardware
  - Validate integrated spacecraft design over temp
  - Obtain sufficient data for thermal model correlation to be used in final flight predictions

Test Facility

- Spacecraft suspended in center of 25ft Space Simulator
- Solar Simulator with 19' lens
  - Intensities up to 1.4 solar constants can be achieved.
  - Kendall Radiometer present
  - Full flux mapping done before test
- The walls and floor are lined with cryogenic shrouds.
  - Planned temperature control -185℃
  - Operating pressure is <1x10^-6 torr.

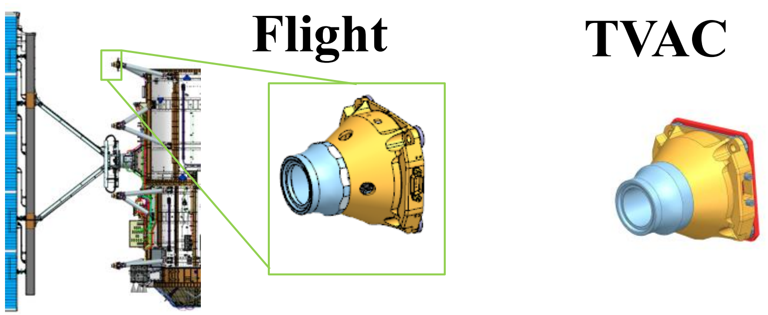
Test Configuration

- Solar Simulator Heating from the top
  - 0.82AU to 5.6 AU fluxes, along with eclipses to be simulated
- Vehicle suspended in horizontal position
  - with the HGA pointed up
  - Radiator pointed to floo
  - Note: cruise orientation is HGA pointed to sun +/-5deg
- Floor and Wall shrouds are flooded with LN2 (-180℃)
  - Floor may be warmer (-150 ℃)
- MagBoom, Solar Array, LV separation system, not in test
  - Simulators planned to match thermal performance/heat balance

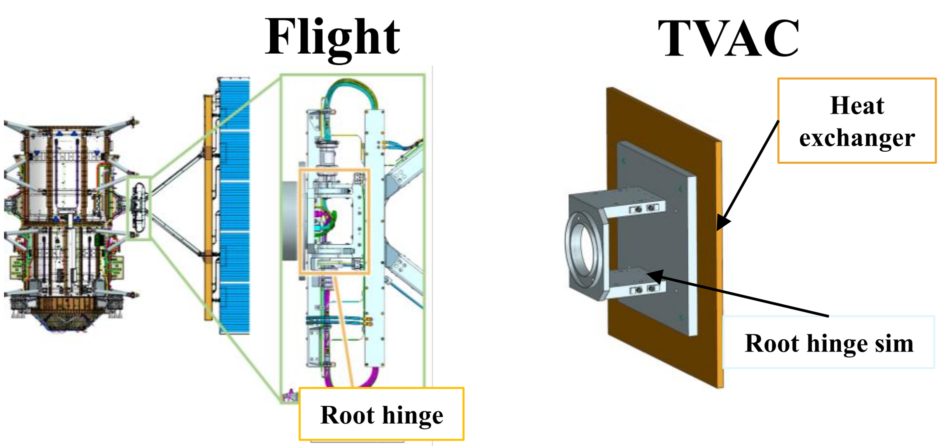


Simulated Hardware

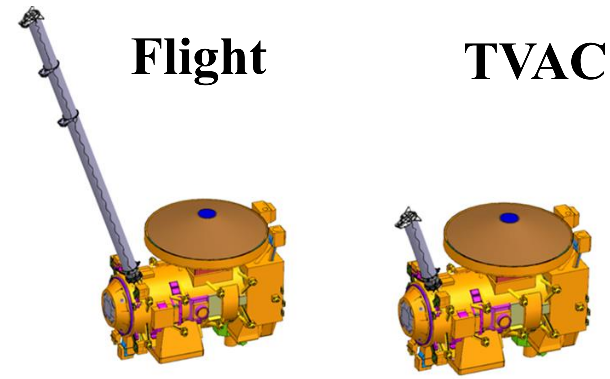
- Not all hardware will be available in time for TVAC
- Additionally, some hardware can't be used due to facility constraints
- All simulators design to replicate heat loss of missing flight hardware.



- Solar Array HDRMs simulators
  – Simplified geometry of 18 HDRMs matching primary dimensions and material properties



- Solar Array Assembly root hinge simulator
  – GSE assembly with heat exchangers to simulate solar array boundary condition and heat loss
  – Flight-like thermal isolator between root hinge sim and Solar array drive assembly

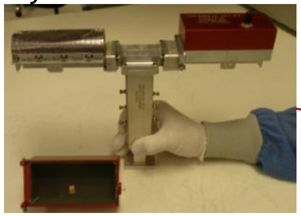


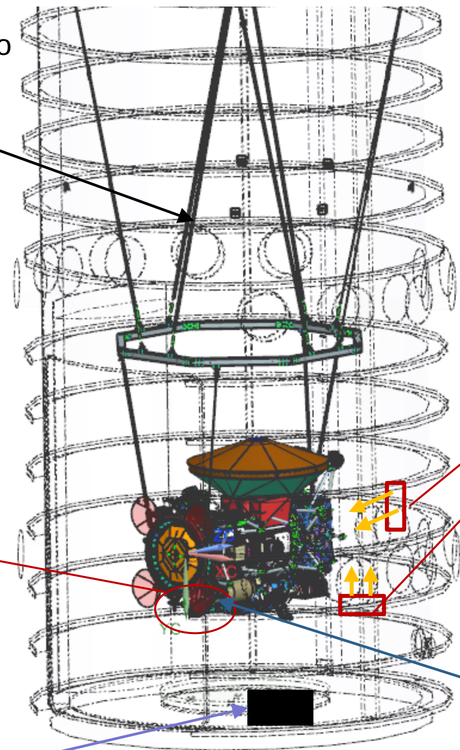
- Magnetometer Boom Simulator
  – Shortened assy. to fit in chamber.
  – Replicates flight hardware, including thermal isolation coatings, and heaters.
  – Key focus on cannister assembly thermal isolation and FG mass model thermal isolation.

MGSE hardware

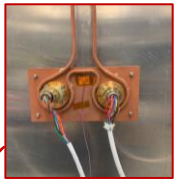
- Lift fixture Assembly
  - Suspends Spacecraft
  - Designed to limit solar sim shadowing
  - Thermal isolation at SC mounting fixtures to limit heat transfer

- RF Hat couplers:
  - Red anodized aluminum surfaces used for functional testing of antennas.
  - Only allowed on shadowed antennas

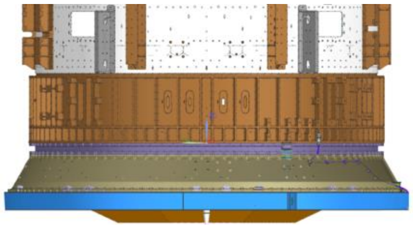




- CQCMs 2x :
  - Measure deposition of outgas volatiles. Temperature controlled with GN2/LN2
  - Two locations, near instruments



- E-themis Target:
  - Located on floor of chamber, used for Functional test of instrument
  - In view of HRS radiator, impacts appear negligible

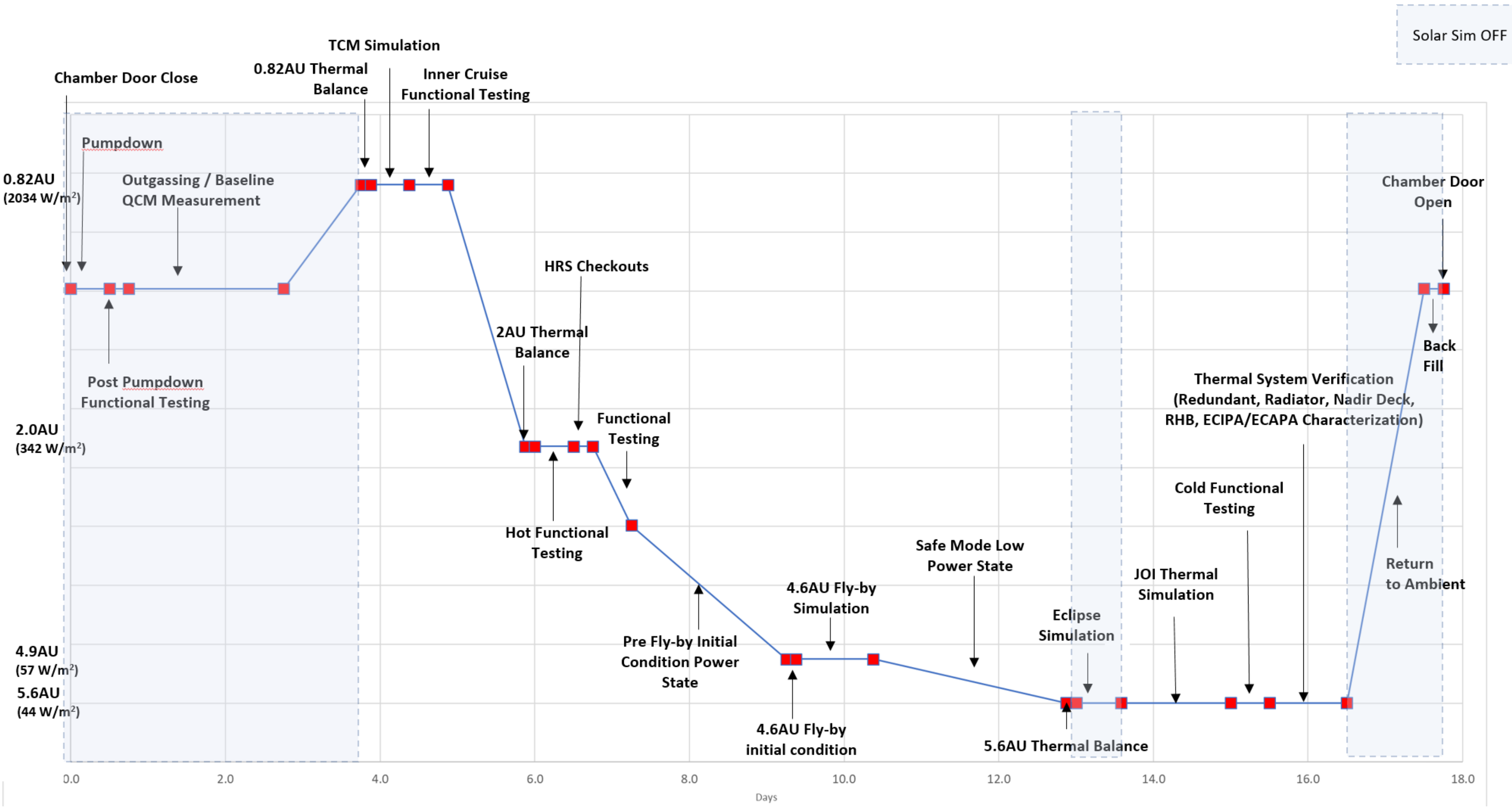


- Horizontal Lift Ring:
  - Interfaces with LVA and acts as attachment point for GSE lift fixture
  - Simulates flight clamp-band sep system optical properties
  - Significant non-flight mass coupled

Test Instrumentation

- Labview Data Acquisition System
- Thermocouples (TCs) Type E TCs, 26 AWG
  - Approximate 550 TCs planned
- Louver Cameras:
  - For observing louver open/close angle
- T_sink measurement
  - 12”x12” MLI with TC facing floor
- Test Heaters:
  - SA Simulator heaters: Support warm-up and back-up for boundary condition maintenance.
  - Horizontal Lift Ring heaters: Support warm-up and contingency heaters
  - Harness Guard heaters: for non-flight harness to zero out heat loss

Test Profile



Key Test Cases

- Inner Cruise Thermal Balance (0.82 AU):
  - Verify AFTs in WCH sun environment
  - Stressing for Sun sensors, RF Antennas, Prop Module hardware
- Outer Cruise Thermal Balance (2 AU):
  - Verify AFTs in WCH outer cruise environment
  - Stressing for RF Radios and Potentially Batteries
- Jupiter Tour Hot Thermal Balance (4.9 AU):
  - Thermal balance point at Jupiter and initial condition for flyby
- Jupiter Tour Flyby 12 hour transient (5.6 AU):
  - Verify AFTs in WCH flyby operations.
  - Stressing for Vault hardware.
- Jupiter Tour Cold Thermal Balance (5.6 AU):
  - Verify AFTs are met in WCC flyby operations
  - Verify Heater Duty Cycle and Avg. Power demand
  - Simulate 9.2 hour Eclipse after thermal balance
  - Simulate JOI pre-conditioning after eclipse

Considerations for Modeling and Correlation

- Test used to correlate thermal model and key uncertainties are targeted
  - MLI blanket effective emittance (and absorptance)
  - Heat loss from secondary support structures and instrument assemblies
  - Transient response for stressing flyby
- Plan to limit uncertainties due to non-flight GSE
  - Provide sufficient instrumentation across non-flight like interfaces
  - Measure optical properties and design deterministic geometries
  - Characterize solar simulator via solar flux mapping
  - Obtain T_sink estimate for radiator FOV

Summary

- Clipper Flight System TVAC is planning and implementation stages. Campaign is scheduled to start in December 2023
- Primary objective is to validate the thermal design of the spacecraft
- Test Campaign will expose spacecraft to flight like environments including 0.82AU solar flux and Jupiter Cold environments
- Simulators planned for flight hardware not available for use in TVAC to account for missing heat leaks/sources
- Ground support equipment designed to limit impacts to spacecraft heat balance