Thermal Control Architecture Power Trade Study for the Europa Clipper Mission Study

THERMAL & FLUIDS ANALYSIS WORKSHOP

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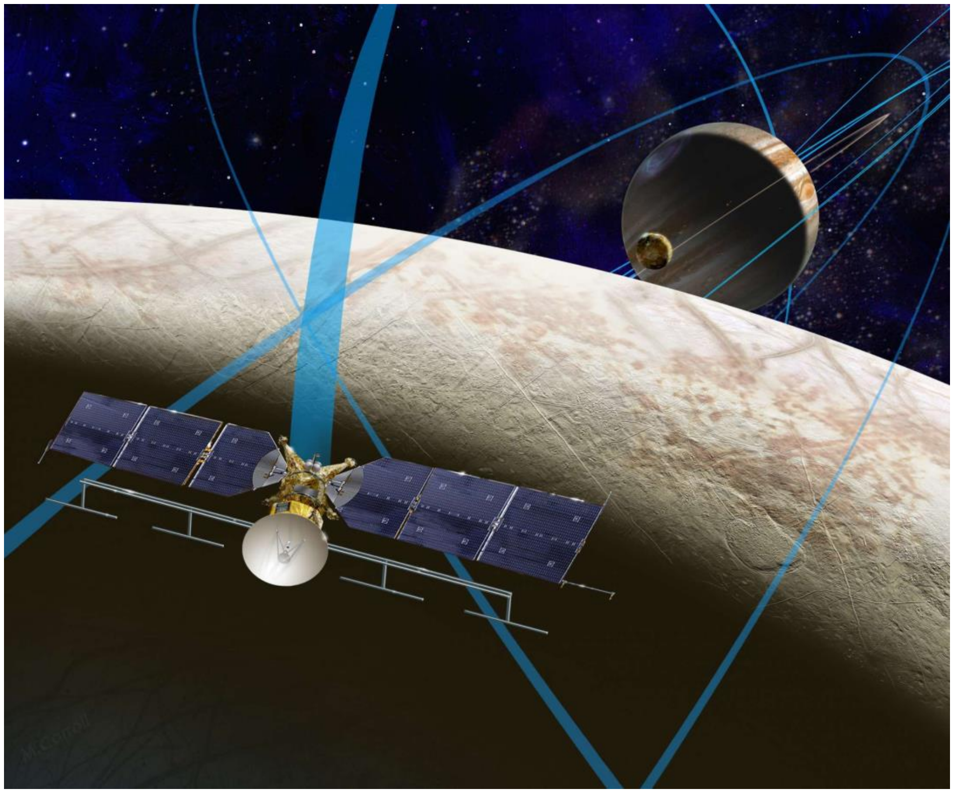
Agenda

1) Europa Clipper Concept and Mission Trajectory
2) Reference Spacecraft Description
3) Active Thermal Architecture
4) Passive Thermal Architecture
5) Thermal Model Inputs & Assumption
6) Comparison of Results
7) Conclusion

Europa Clipper Mission Concept



"Because of this ocean's potential suitability for life, Europa is one of the most important targets in all of planetary science"
(Space Studies Board 2011).

Goals & Objectives:

- Characterize ice shell and ocean properties and surface-ice-ocean exchange
- Understand ocean composition and chemistry
- Understand the geology and characterize high science interest localities

Mission Design:

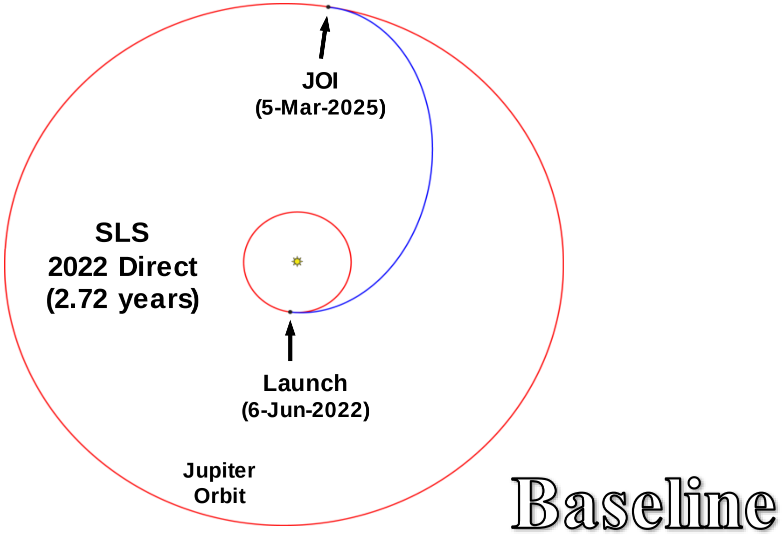
- Reference Flight System is Solar Powered
- SLS baseline launch vehicle (2022)
- VEEGA interplanetary cruise (backup)
- 8+ year mission lifetime
- Jovian Radiation Environment
- 9 hour Eclipse at Jupiter
- 45+ Europa flybys

Interplanetary Delivery Approach

Direct

Using Space Launch System

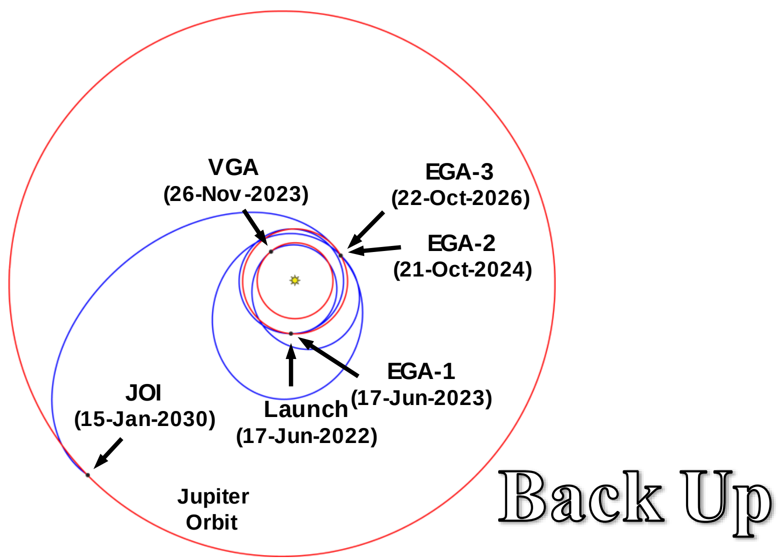
- **Solar Closest Approach: 1.0 AU**
- **Max Eclipse Duration 4.5 hours**
- **Time of Flight to Jupiter**
  - **June 2022 Direct: 2.7 yr**
  - **July 2023 Direct: 2.5 yr**



Gravity Assisted

EVEEGA or VEEGA using Atlas V 551 or Delta IVH

- Solar Closest Approach: 0.6 AU
- Max Eclipse Duration 9.1 hours
- Time of Flight to Jupiter
  - June 2022 EVEEGA: 7.6 yr
  - June 2023 VEEGA: 6.7 yr



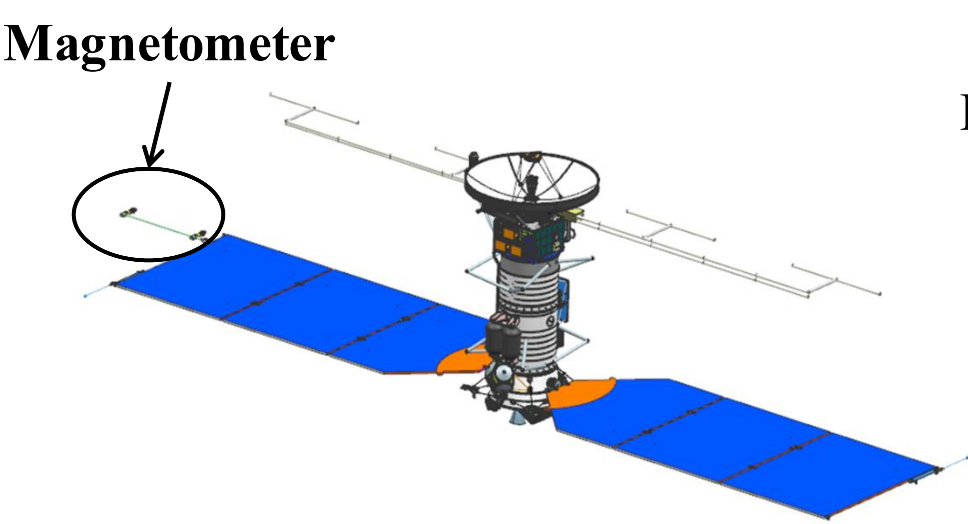
Active Passive Trade Study

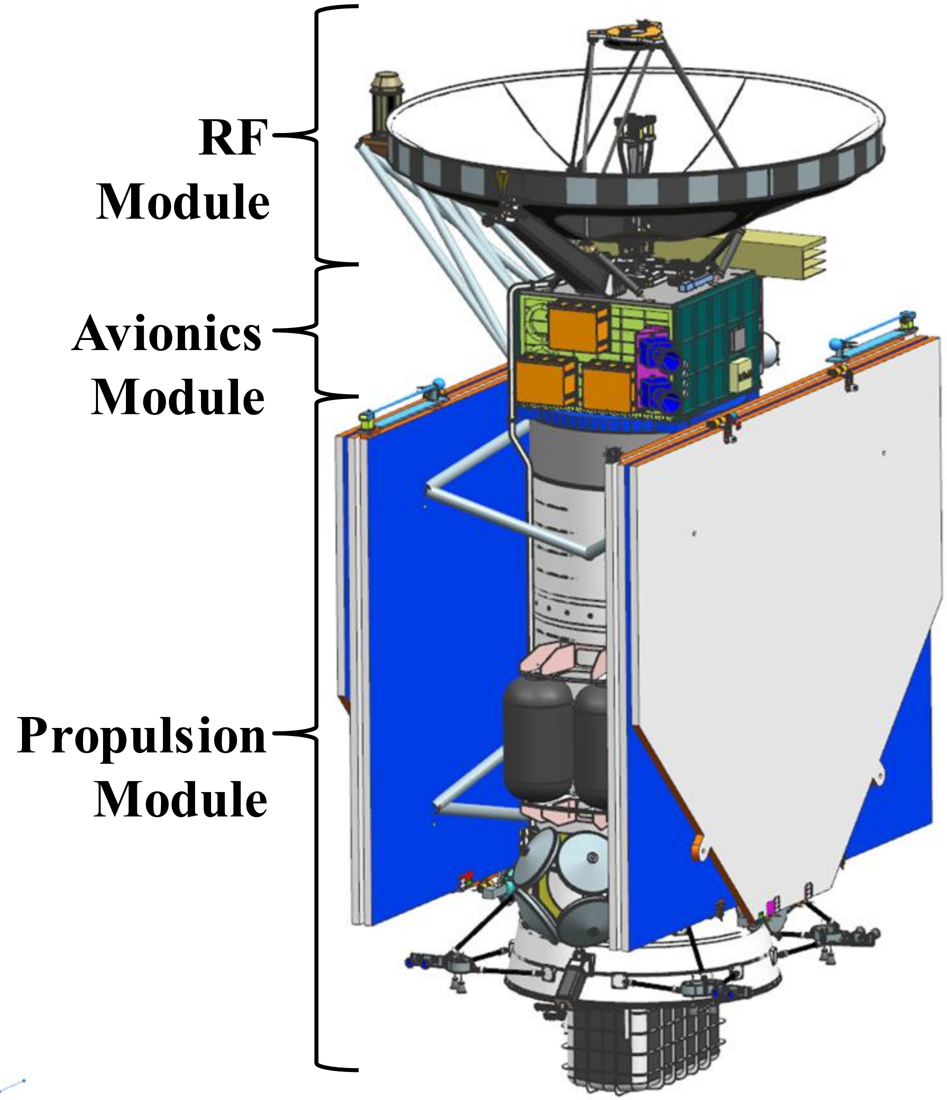
- Presentation and paper discuss a given thermal architecture's impact on ***power*** consumption and ***mass*** impacts for Europa Clipper
  - Additional assessments were made on the simplicity, robustness, development, integration, test complexity, risk, and reliability, (not discussed)

- Thermal Control Architectures Considered:
  - Active: Heat Rejection and Harvesting System (HRS) using mechanically pumped fluid loop
  - Passive: Cold-biased design with electrical heating and passive heat transport

Reference Spacecraft

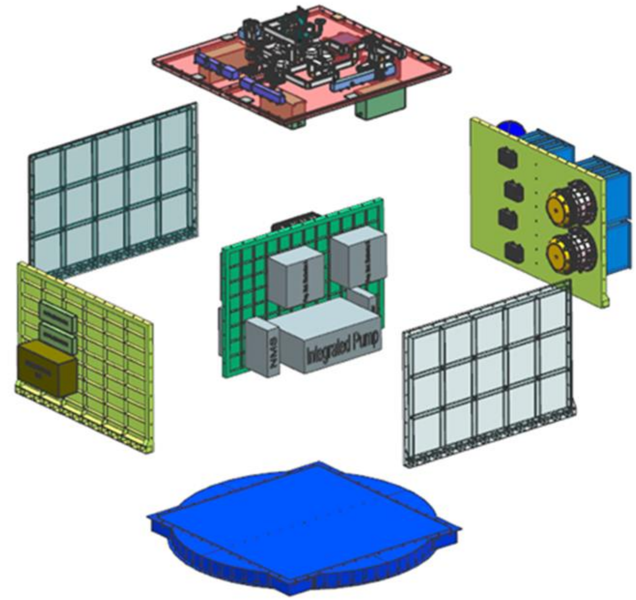
- 6.4 m tall
- HGA 3 m diameter
- 53 m^2 SA cell area, 625 W EOM
- 23 m span (with mag deployed)
- Vault Assembly for radiation protection

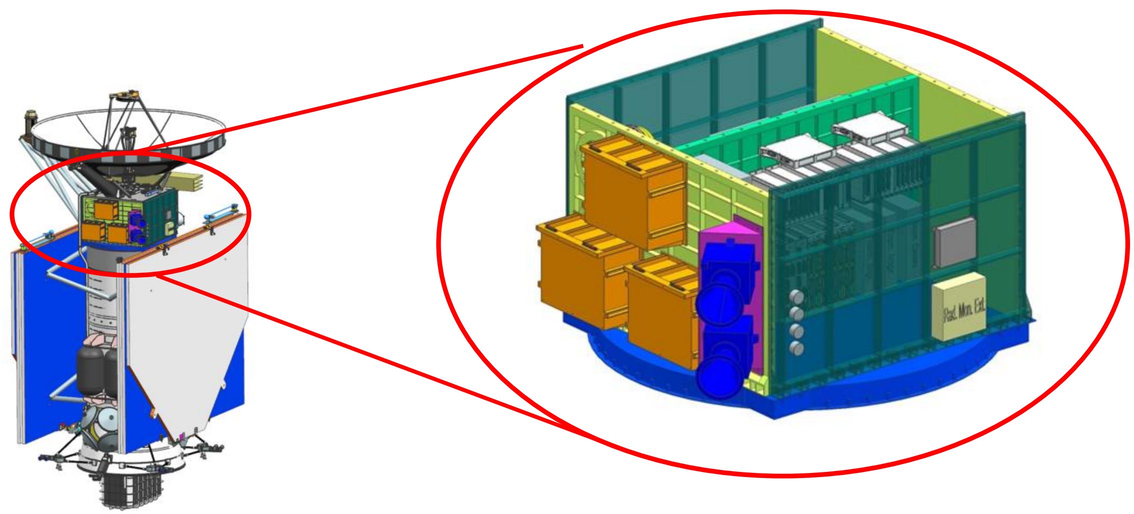




Vault Assembly

- Protects spacecraft and instrument electronics against Jovian Radiation environment
- Majority of electronics mounted onto center panel
- RF Panel closes out +Z side





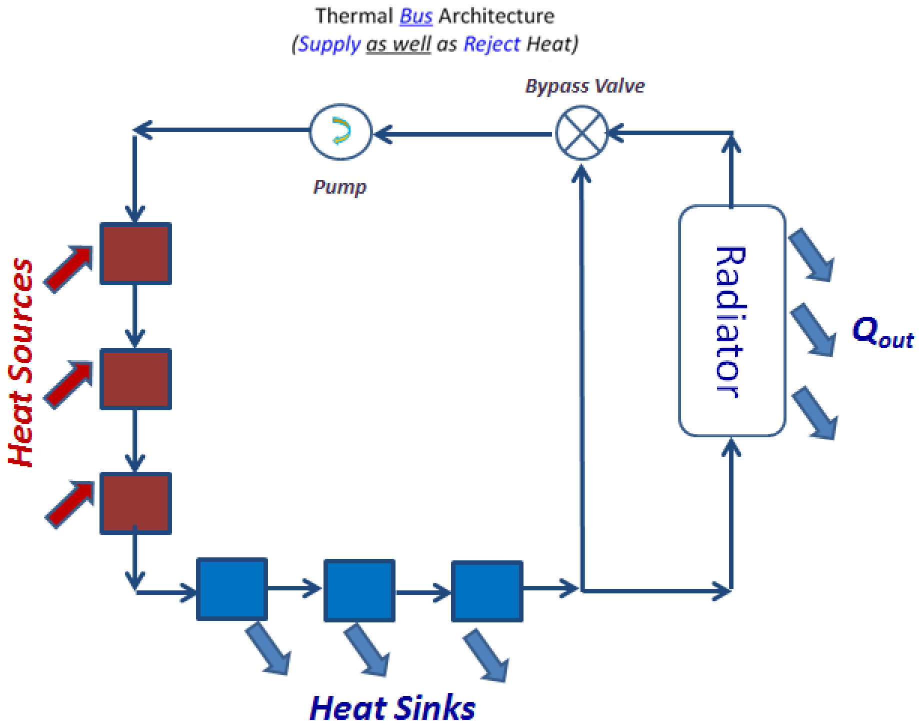
Active and Passive Architecture

- Both thermal architecture must be capable of meeting all Allowable Fight Temperature requirements

- Both Architectures share certain design features:
  - MLI enclosure of spacecraft
  - Thermal isolation of spacecraft extremities
  - Use of High Gain Antenna as a spacecraft sun-shield during inner cruise

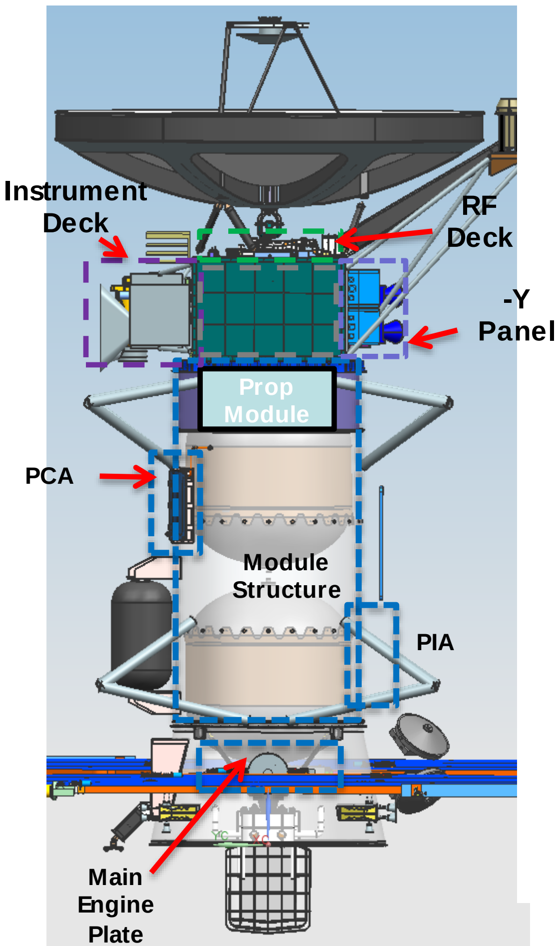
- Both Architectures avoided use of certain technologies
  - No RHUs
  - No heat pipes

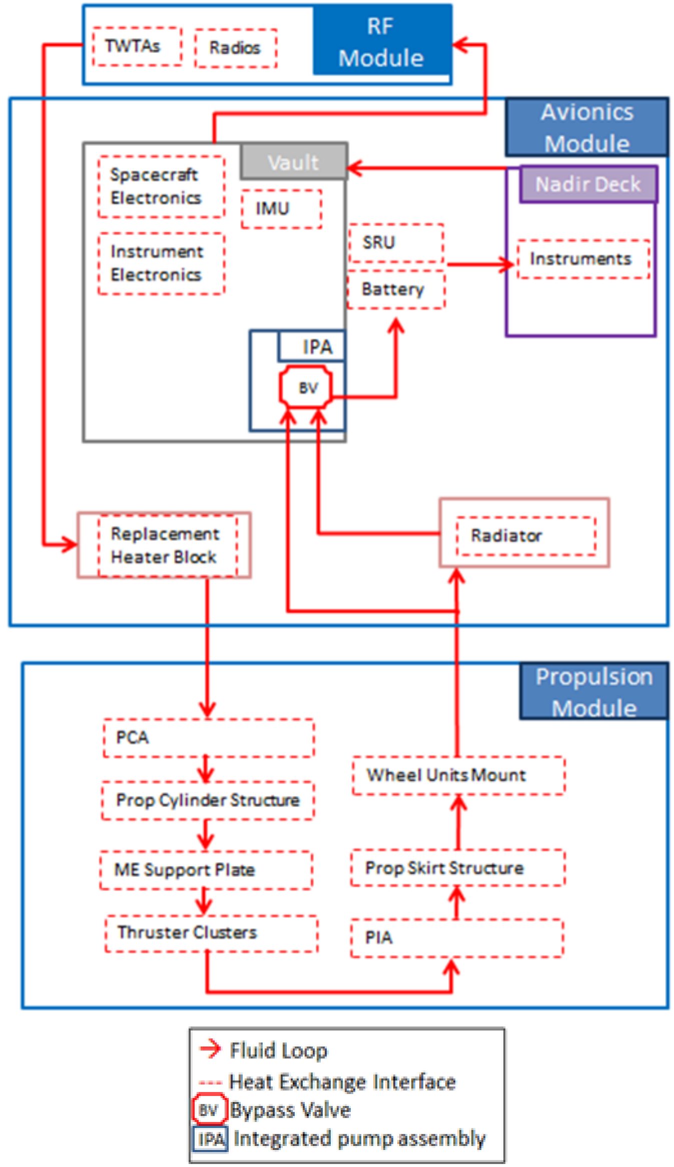
Active Heat Rejection and Recovery System (HRS)

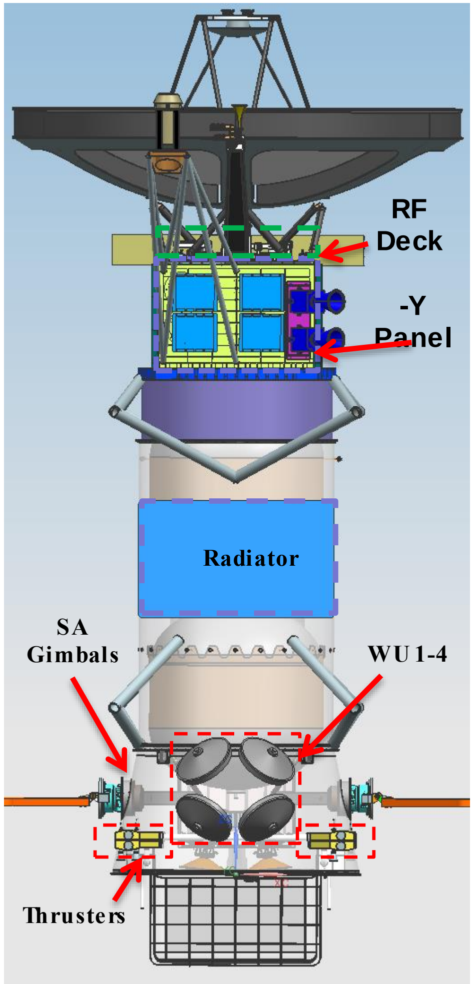


- Use waste heat from electronics plus a replacement heater block
- Pick up or reject large amounts of heat at small temperature differences
- Transport heat over large distances

Active Architecture – HRS Routing



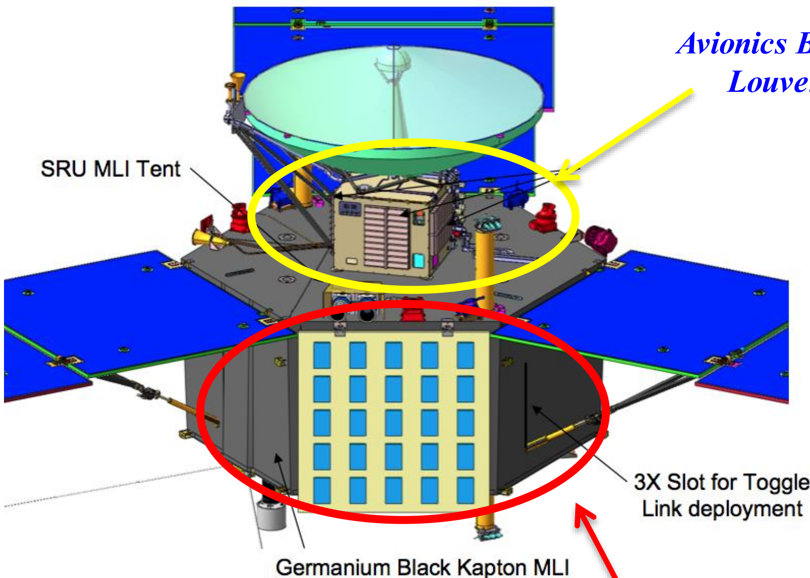




For planning and Discussion Purposes Only

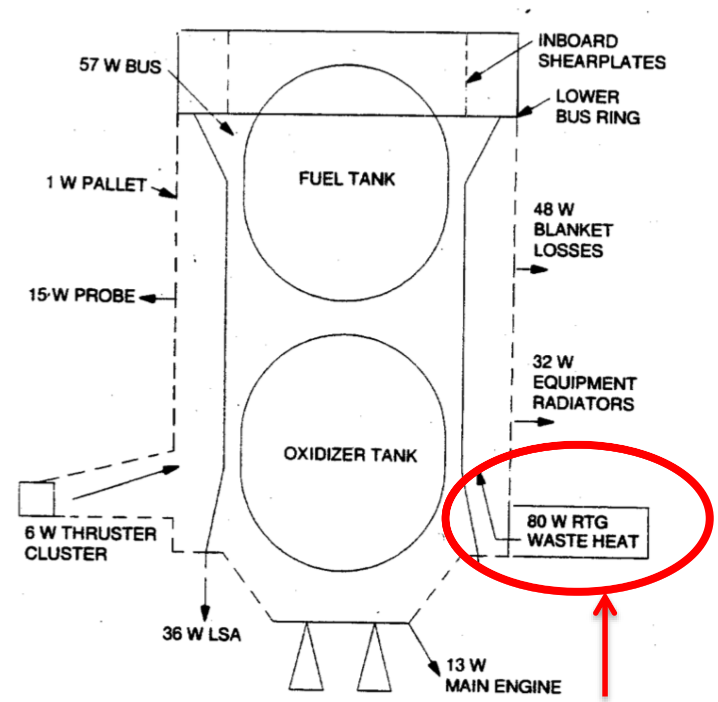
Passive Architecture of previous outer planet missions

Juno



~130-170W thermal balance on prop module

Cassini

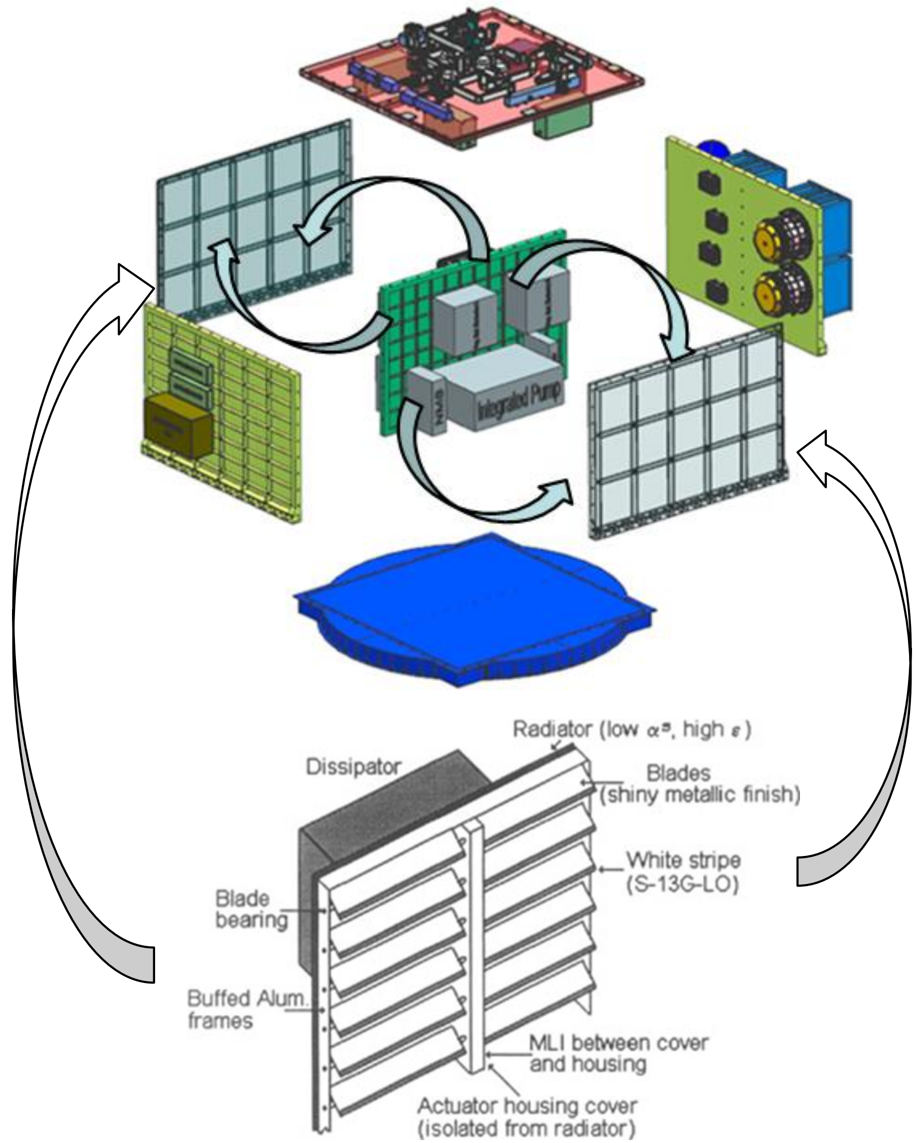


RTG Waste Heat reclamation

Passive Architecture for Europa Clipper

- Requires a change in vault configuration
  - Louvers at sides of the vault
  - Size increase due to area required for louver implementation

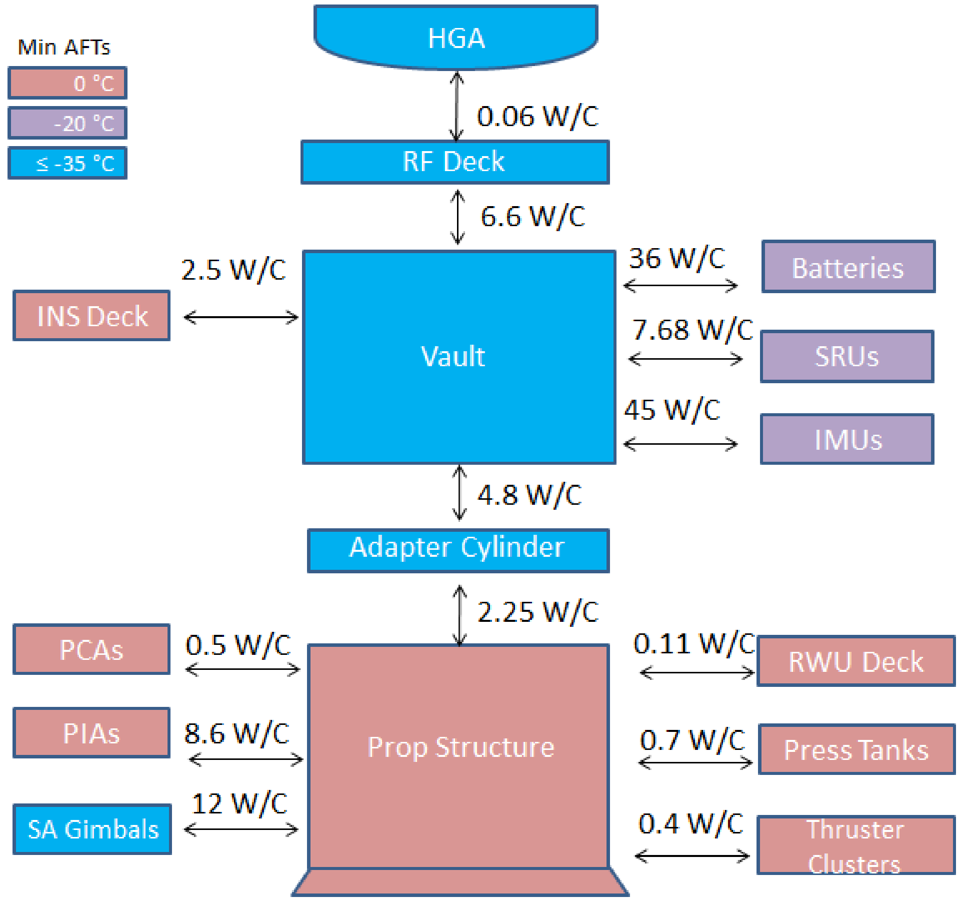
No spacecraft reconfiguration
besides the louver accommodation.



Ref. Satellite Thermal Control for Systems Engineers

Thermal Models

- ThermXL models based off mechanical CAD models
- Active: estimated appropriate fluid routing accommodation.
- SA assumed isolated from the rest of the s/c



Active Model Parameters		Passive Model Parameters	
S/C MLI Area [m^2]	33	S/C MLI Area [m^2]	32
Radiator Area [m^2]	0.32	Louver Area [m^2]	1
Radiator Fin eff	0.77	Radiator Fin eff	0.77
Bypass Set Points [˚C]	0-15	Louver packing eff	0.8
Fluid Conductors [W/C]	16.6	Louver Set Points [˚C]	2-20
HRS Interface G [W/(m-C)]	2.2		

Thermal Environment

- HGA sun pointed
- No planetary loads
- Eclipse transient 8 hours
- Inner Cruise hot transient 6 hours
- MLI e* ranges based off Cassini Thermal Design Handbook

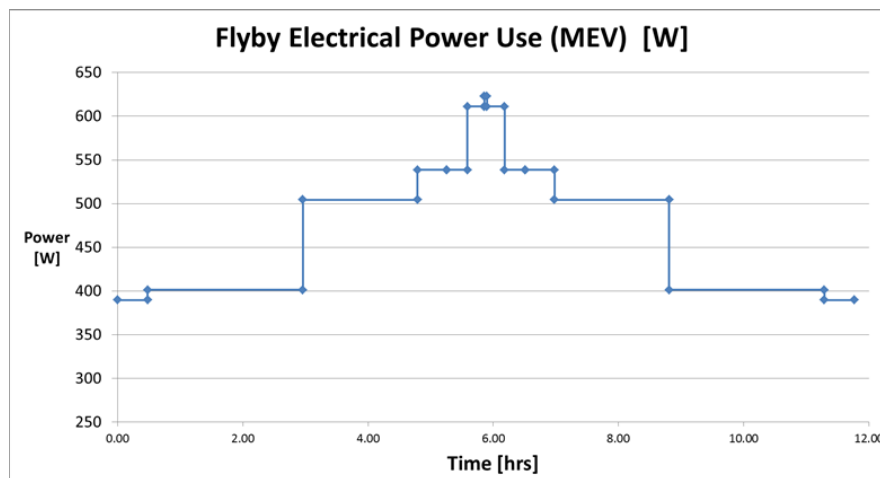
Parameter	Inner Cruise	Outer Cruise
A.U. Distance [A.U.]	0.6	5.5
Solar Flux [W/m^2]	3799	45
HGA Radome solar absorptivity	0.49	0.1
MLI > 1m^2, e*	0.01	0.02
MLI < 1m^2, e*	0.025	0.035
Louver e*	0.37	0.14

Power Modes

- Power Conditioning Units (PCU)
  - 10% tax on all solar array power generation
  - Off during eclipse cases

- Flyby Scenario
  - Bounding flyby scenario
  - Assumed active PCU

Component	Inner Cruise		Outer Cruise	
	Steady State [W]	Transient [W]	Steady State [W]	Transient [W]
RF Deck	9	62	9	9
Vault	79	80	114	114
Instrument Deck	17	17	17	17
IPA*	14	14	14	14
SRU	4	4	4	4
IMU	36	36	36	36
PIA	26	26	6	6
PCA	1	1	1	1
ME Plate	0	0	0	0
Thrusters	0	0	0	0
SA Gimbal	13	13	13	13
Other-"Off-Loop"	9	57	37	37
PCU**	10%	10%	10%	0%
Total	**208**	**309**	**251**	**251**

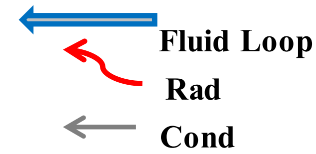


Temperature Requirement Assumptions

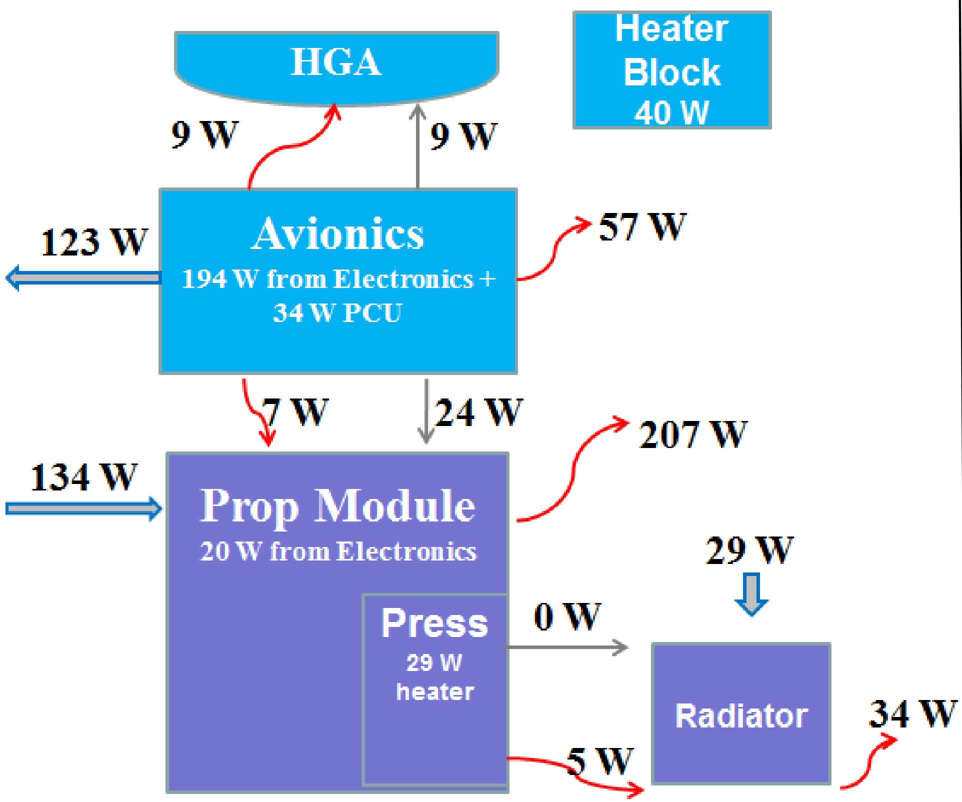
Spacecraft Component	Minimum AFT [˚C]	Maximum AFT [˚C]
RF Deck	-35	50
Nadir Deck	0	50
Vault	-40	50
Batteries	-20	30
SRU	-20	45
IMU	-20	50
Prop Structure 1	0	50
Prop Structure 2	0	50
Prop Structure 3	0	50
Pressurant Tank	0	50
PIA	0	50
PCA	0	50
Thrusters	0	50
ME Plate	0	50
Wheel Units	0	65
SA Gimbal	-55	50

- Must also keep appropriate gradients: Pressurant/PCA +2 ˚C above fuel tanks

Results: Heat Balance (Cold Case)

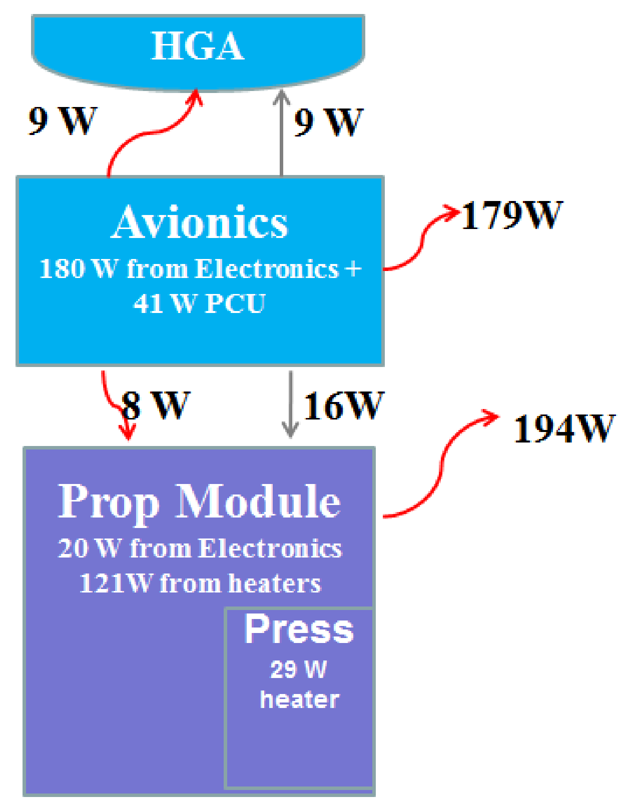


Active Architecture



Net heat loss: 316 W

Passive Architecture



Net heat loss: 391 W

Results: Power

- Steady State Cold:
  - Passive: Vault heat loss to space larger due to louvers
- Transient Cold :
  - "Ride out" transient
  - Active: No PCU dissipation harvesting
  - Passive: Local heater power demand decreases at propulsion module
- Flyby Case:
  - Localized heating at top fuel tank due to additional vault dissipation

Thermal Subsystem Power Demand		
Power Scenaro	**Active Arch. [W]**	**Passive Arch. [W]**
Steady State Cold	83	150
Transient Cold	83	129
Peak Flyby	5	157

Results: Mass

- Passive Architecture needs **39 kg *smaller* mass** (CBE) for **Thermal subsystem**, when compared to the active architecture

- Passive Architecture needs **110 kg *larger* mass** (CBE) for the **Power Subsystem**, when compared to the active architecture

- Passive Architecture needs **40-80 kg *larger* mass** (CBE) for **Mechanical subsystem**, when compared to the active architecture

- Hence, the overall Flight System mass is significantly more for the passive thermal architecture (compared to the active) by ~110-150 kg (CBE)

Conclusion

- Active thermal architecture demand lower than passive architecture for all power cases investigated
- ***Flight System*** peak power demand is substantially more for the passive architecture (656 W active vs. 780 W passive)
- Flight System mass impact is substantially more for the passive architecture (110 kg – 115kg CBE)
- These mass and power estimates are only a part of the full trade which also trades robustness, reliability, complexity, and risks

Acknowledgements

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