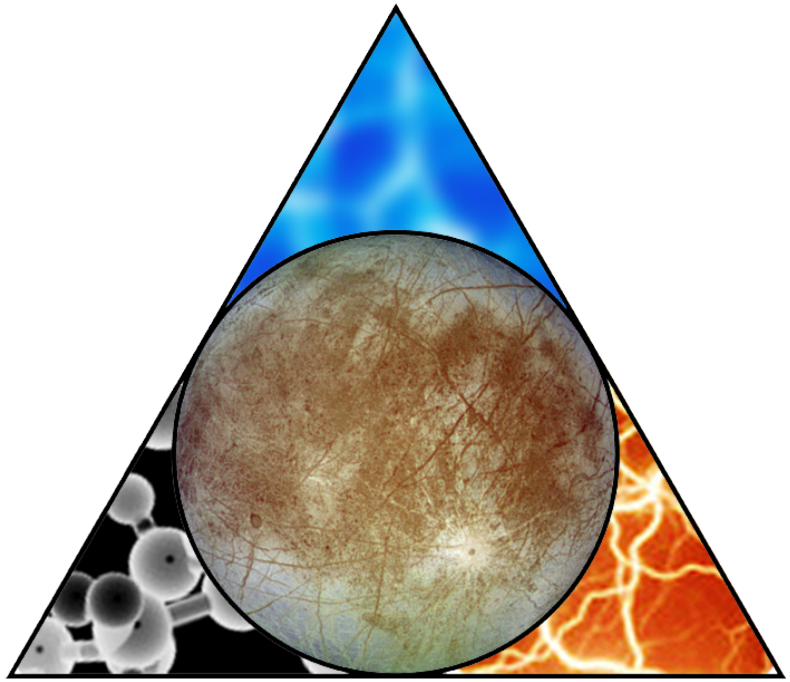


Orbiter Element

Brian Cooke

Science as a Driver of Mission Architecture

Science traceability leads to a two element mission concept:

Orbiter Element: _Geophysical measurements that can be achieved only from orbit_

- Payload focused primarily to address "Ocean" objective:
  - Radio Subsystem (RS)
  - Laser Altimeter (LA)
  - Magnetometer (MAG)
  - Langmuir Probe (LP)
  - Mapping Camera (MC)
- Have readily accommodated those instruments that are:
  - Less massive
  - Lower power
  - Lower data rate

Flyby Element: Remote measurements that can be accomplished via multiple flybys

- Payload focused primarily to address "Chemistry" and "Energy" themes:
  - Ice Penetrating Radar (IPR)
  - ShortWave IR Spectrometer (SWIRS)
  - Ion and Neutral Mass Spectrometer (INMS)
  - Topographical Imager (TI)
- Have readily accommodated those instruments that are:
  - More massive
  - Higher power
  - Higher data rate

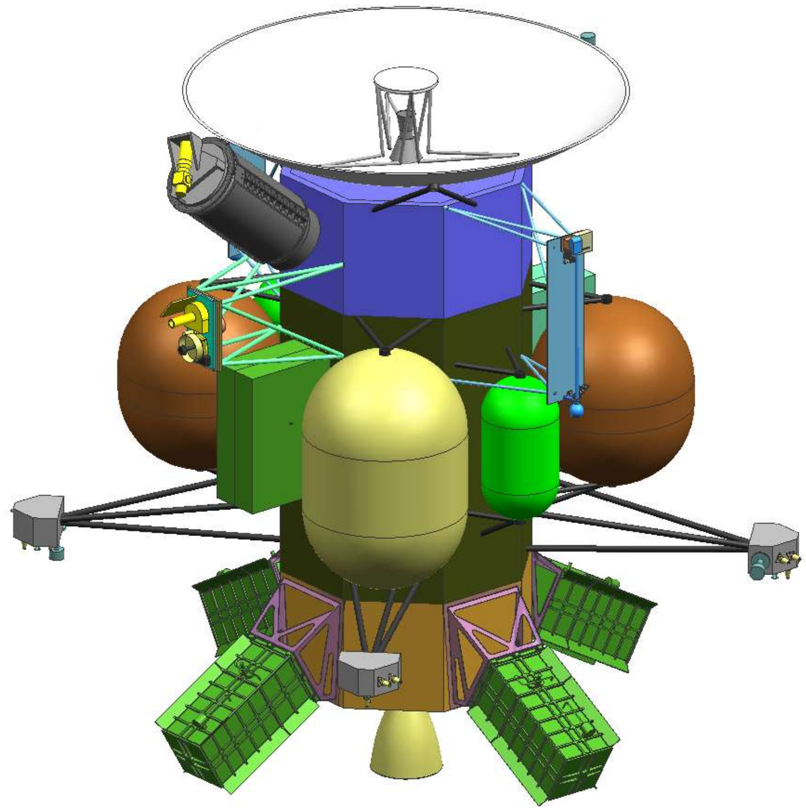
Key Science Drivers & Requirements

Instrument(s)	Key Accommodation Requirements	Element
Radio Subsystem + Laser Altimeter	Low altitude (~100+ km), circular, near-polar orbit, for at least 30 days. Unperturbed orbital arcs (no thrusting) of at least 3 days.	Orbiter ✔
Magnetometer + Langmuir Probe	Low altitude (~100+ km), circular, near-polar orbit, for at least 30 days. Cover approximately 12 hours of Europa local time.	Orbiter ✔
Mapping Camera	Low altitude (~100+ km), ≥ 80% global coverage under near uniform lighting conditions, solar incidence angle > 45° (70° preferred).	Orbiter ✔
Ice Penetrating Radar	≥ 800 km tracks in 11 of 14 globally distributed regions, intersected by at least 1 other track, with track lengths measured from ≤ 400 km alt. ~25–100 km closest approach at ≤ 6 km/s.	Flyby
ShortWave IR Spectrometer	Ability to target specific geologic locations with a wide range of surface locations, lighting between 9:00am and 3:00pm. Attitude stability < ½ IFOV over integration time, flyby speed < 6 km/s.	Flyby
Topographical Imager	High resolution stereo imagery aligned with IPR coverage; lighting conditions solar incidence angle > 20° (70° preferred).	Flyby
Ion and Neutral Mass Spectrometer	Low altitude (< 200 km with lower altitudes desired) at ≤ 7 km/s; long integration times and low altitudes (≤ 100 km) preferred.	Flyby

✔ = areas accommodated in Orbiter concept

Orbiter Element Configuration Overview

- 3-axis stabilized, functionally redundant spacecraft
- High heritage science instruments:
  - Radio Subsystem
  - Mapping Camera
  - Laser Altimeter
  - Magnetometer
  - Langmuir Probe
- 4 ASRGs, 40 Ahr Battery
- X/Ka-band, 2.4 m fixed HGA, 70 kbit/sec average downlink
- Dual mode, Bi-prop 890 N main engine, 16 RCS thrusters. Capable of 2.4 km/s Delta-V
- Atlas V 551
- 1298 kg dry mass (40% mass margin)

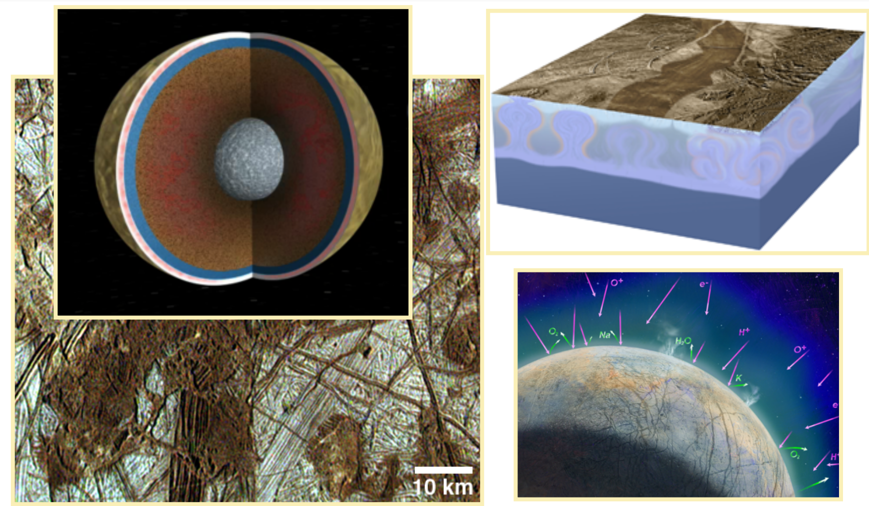


Capable spacecraft tailored to focused science objectives
High heritage, low complexity payload

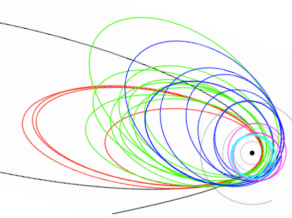
Orbiter Element Mission Overview

IP Cruise

- Launch on Atlas V 551
- VEEGA trajectory (11/2021 Launch)
- 6.5 years
- Annual launch opportunities
- Low cost operations
- No planned science



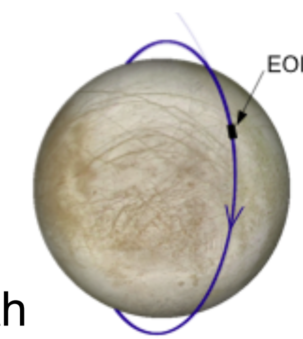
Jupiter Cruise



- JOI (ΔV ≈ 900 m/s)
- 1.5 years
- ~15 Gravity Assist flybys before EOI
- Low Cost Operations
- No planned science
- Radiation environment ~ 1.2 Mrad

Europa Science

- EOI (ΔV ≈ 600 m/s)
- Near polar, 2-4 pm orbit
- 100 km altitude
- 1 month science mission
- 400 krad TD over 1 month
- Disposal on Europa



Flexible mission design with annual launch opportunities

Mission Architecture Drivers

- Launch in the 2021-2024 timeframe w/ annual backup opportunity
- Existing Launch Vehicle: Atlas V 551 or smaller
- Utilize ASRGs. No limit on number, but strong desire to minimize ^{238}Pu usage
- Mission Duration < 10 years, launch to EOM
- Use commercially available 300 krad radiation hardened parts
- Design mission to accomplish the baseline science objectives only
- ESDT Inputs:
  - 100 km, circular Europa orbit. 50° to 80° solar beta angle for imaging
  - Long unperturbed orbit arcs for gravity science
  - Map 80% of surface in wideband monochromatic stereo
- <u>Optimized design for cost</u>! We were looking for the lowest cost possible while achieving baseline science

Pre-Decisional — For Planning and Discussion Purposes Only

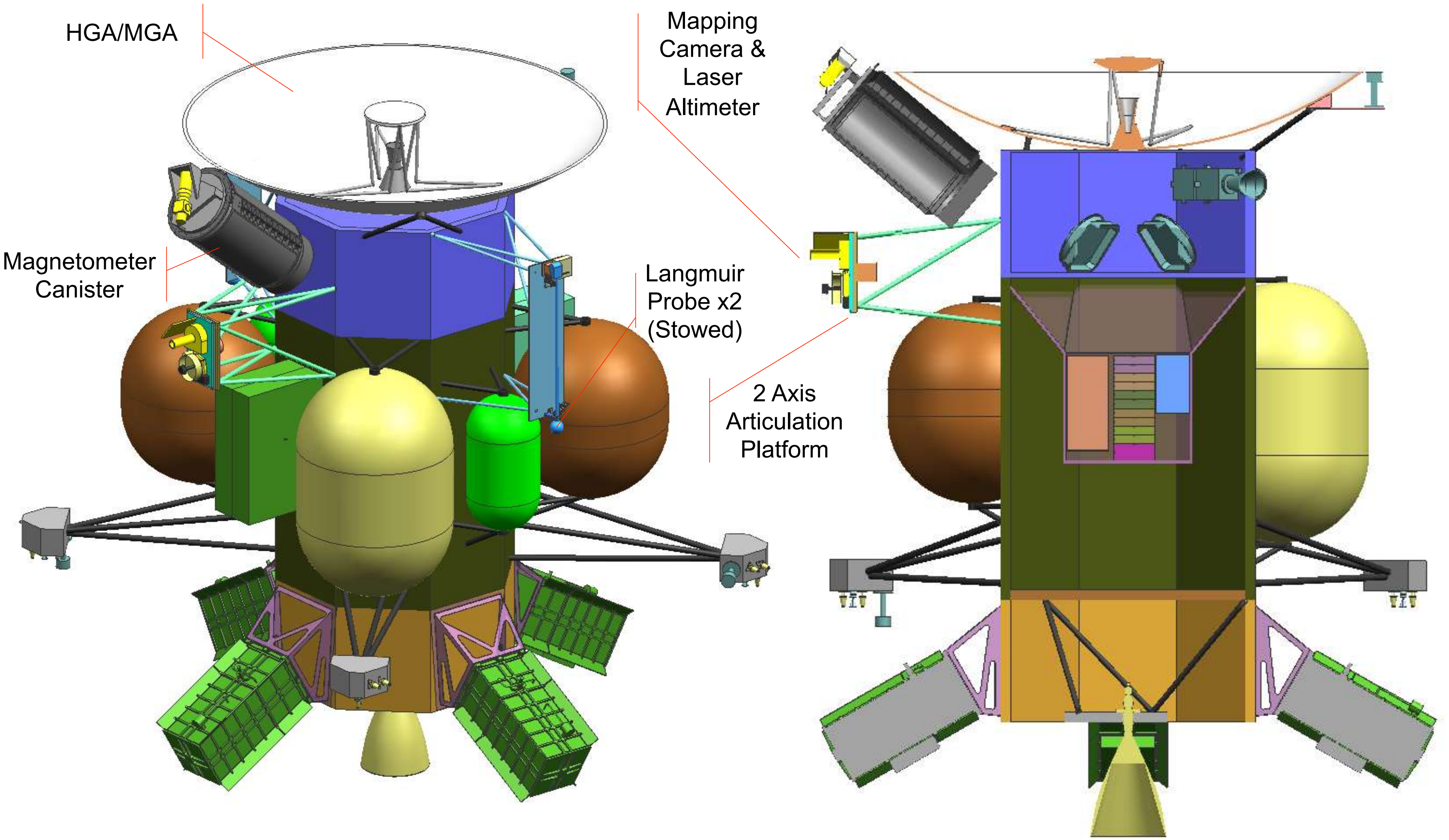
Minimal Mission Cost Design Strategies

- Design for the lightest, most compact spacecraft
- Simplify implementation and integration using modular designs
- Design for low maintenance, low cost cruise operations
- Balance mission design and spacecraft delta-V requirements
- Reduce radiation dose to commercially available parts tolerance levels:
  - Improve use of self shielding and propellant to reduce dedicated shielding mass
  - Reduce required shielded volume to make optimum use of dedicated shielding mass
  - Locate critical / sensitive components deep in structure to increase nested shielding
  - Develop detailed transport models to accurately assess nested shielding benefit

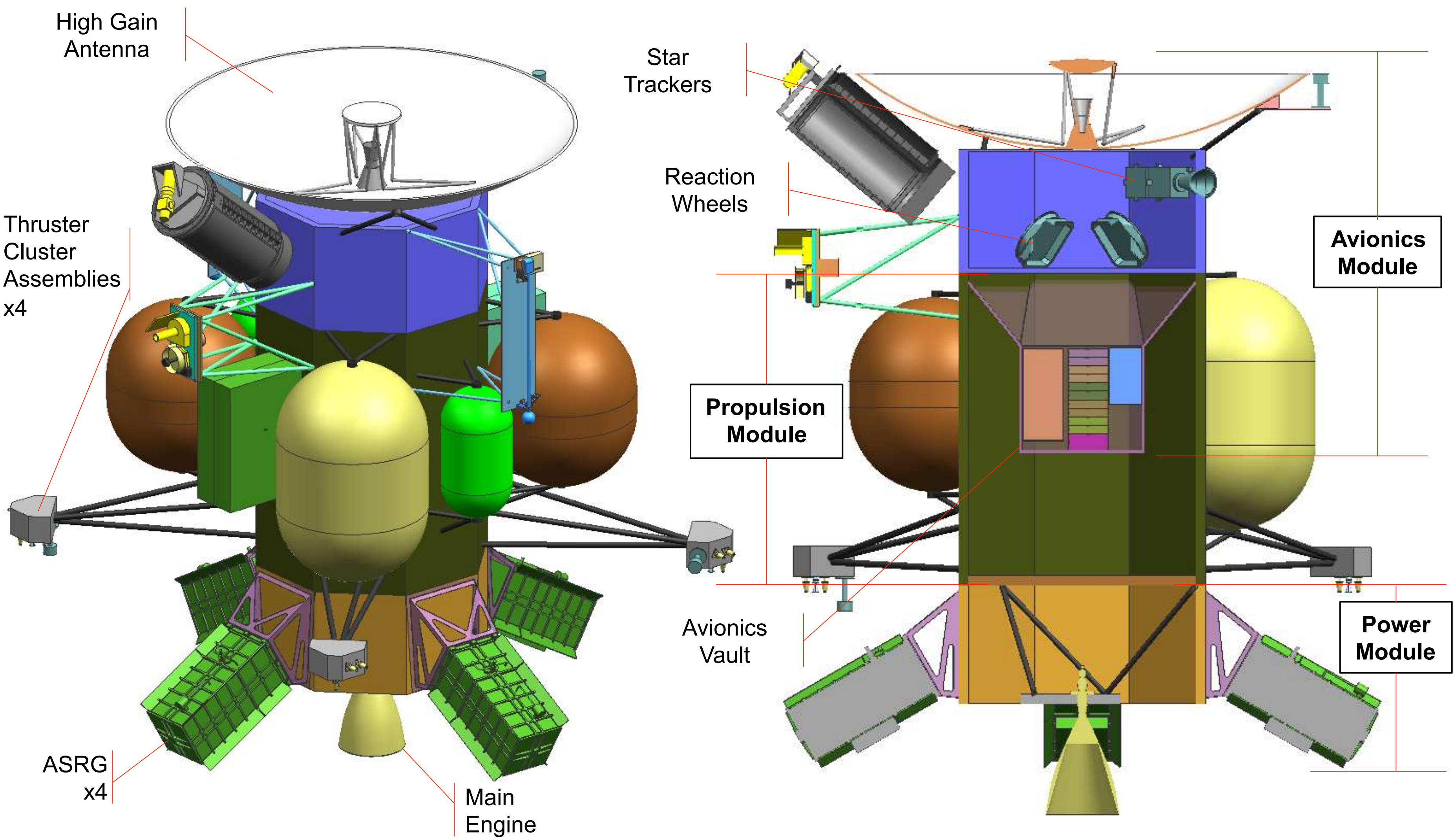
Orbiter Model Payload Resource Summary

Instrument	Unshielded Mass (kg)	Shielding Mass (kg)	Total Mass (kg)	Power (W)	Data Rate (kbps)	Comments
Radio Subsystem (RS)	Provided by existing RF subsystem					
Laser Altimeter (LA)	5.4	4.6	10.1	15.0	2	Always on
Magnetometer (MAG)	3.3	0.0	3.3	4.0	4	Always on
Langmuir Probe (LP)	2.7	0.0	2.7	2.3	2	Always on
Mapping Camera (MC)	2.5	1.5	4.0	6.0	106	Stereo monochromatic dayside imaging; 3:1 lossy compression; ~360 Mb/orbit, ~12.9 Gb/map
Totals:			**20.1**	**27.3**	**114**	

EHM Orbiter Instrument Accommodation

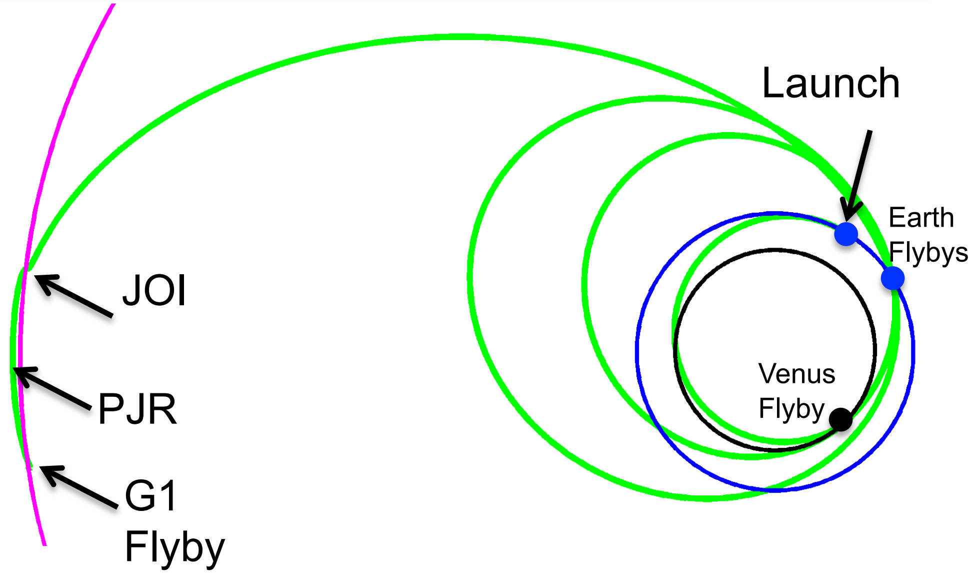


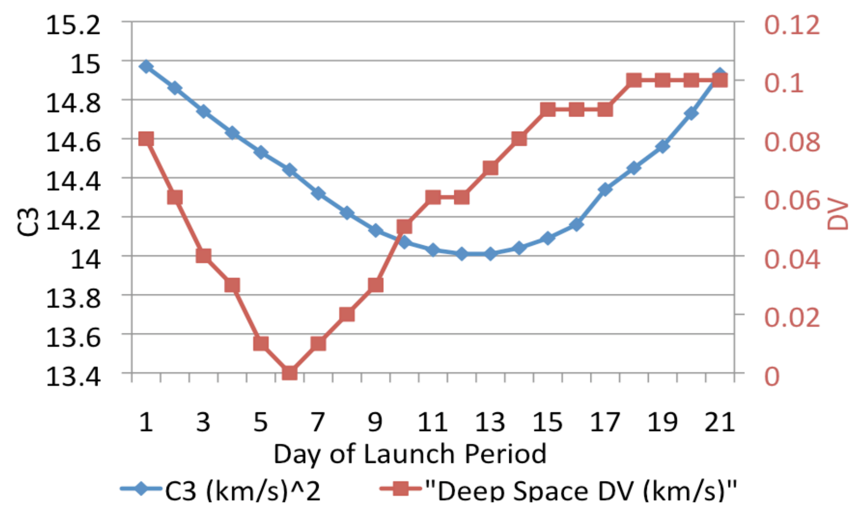
EHM Orbiter Engineering Configuration



Interplanetary Trajectory

	Date	Flyby Alt. (km)
Launch	21-Nov-2021	
Venus	14-May-2022	3184
Earth	24-Oct-2023	11764
Earth	20-Oct-2025	3336
G0	03-Apr-2028 15:00	500
JOI	04-Apr-2028 03:32	12.8 Rj
PJR	20-Aug-2028	238 Rj
G1	21-Oct-2028	

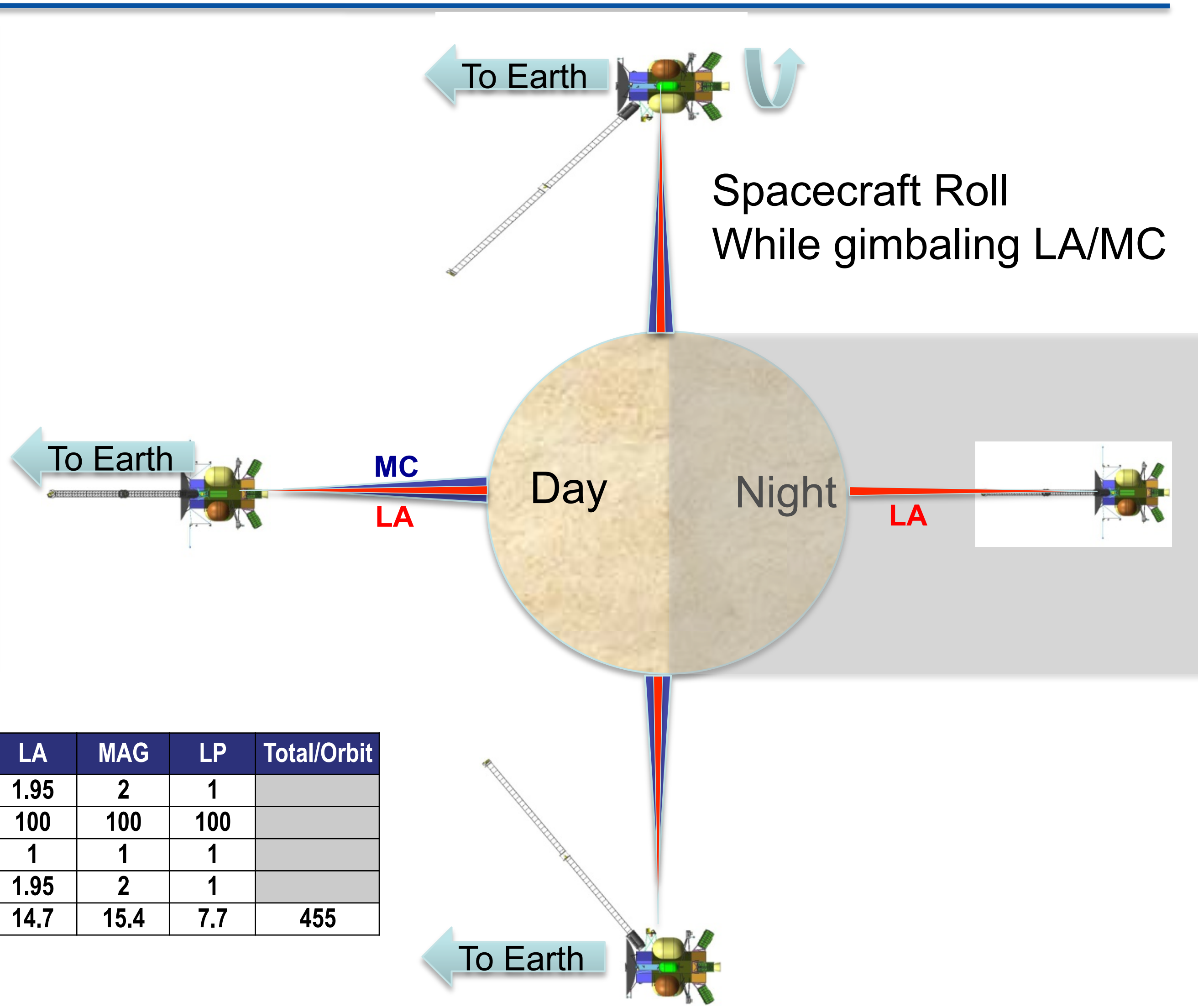




Science Operations Concept

Campaign:

- Gravity science while not occulted, HGA always pointed to Earth
- MAG & LP all the time
- LA all the time; on 2 axis scan platform with MC
- Mapping Camera on during day, on 2 axis scan platform with LA
- Telecom while in view of Earth; DSN 34m
- Low power mode at night (telecom to standby)



	MC	LA	MAG	LP	Total/Orbit
Raw Data Rate (Kpbs)	319	1.95	2	1	
On-time per orbit (%)	50	100	100	100	
Data Reduction Factor	3	1	1	1	
Effective Output Rate (Kbps)	53.2	1.95	2	1	
Average Data Per Orbit (Mbit)	401.7	14.7	15.4	7.7	455

Mass, Delta-V, Power Summary

Flight System Mass

Atlas V 551 Capability	4494 kg
Propellant (Max for LV Cap)	2377 kg
Dry Mass CBE	1298 kg
LV and Payload Adapter	89 kg
Total Wet Mass (CBE + Prop)	3764 kg
% Margin to CBE Dry Mass	38.7%

Flight System Delta-V Budget

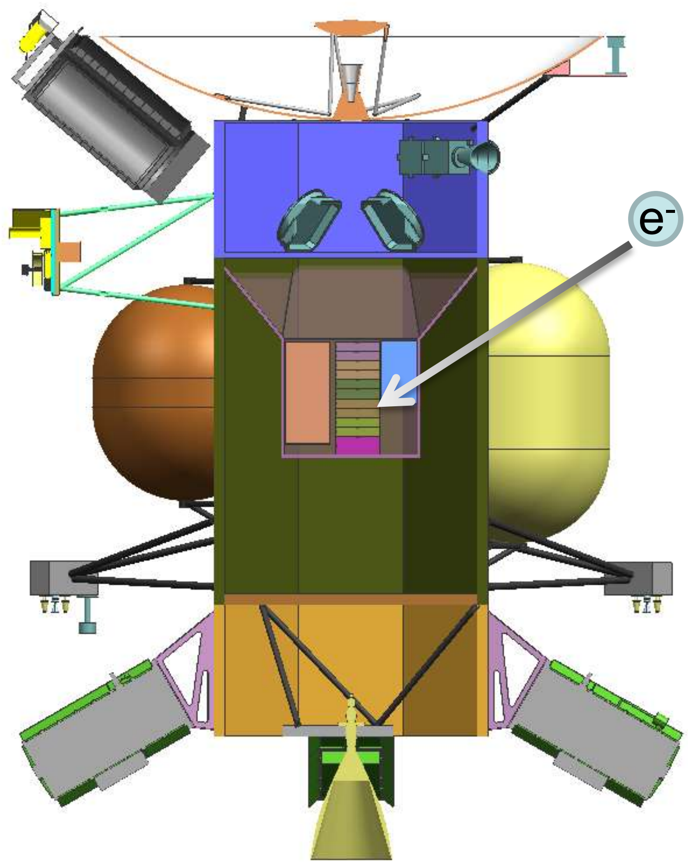
Burn Type	Delta-V, m/s		
	Deterministic	Statistical	Total
Launch Injection Cleanup	20		20
Earth Bias DV	50		50
Deep Space Maneuver	150		150
IP Statistical DV Cleanup		50	50
JOI	900		900
Perijove Raise	80		80
Jovian Cruise & End Game	200	120	320
EOI & Europa Science	705		705
Total	2105	170	2275

Power Budget

	Launch	Inner Cruise	Safe (Inner Cruise)	Outer Cruise	Safe (Outer Cruise)	Orbit Insertion / TCM	Europa Day - side	Europa Occulted	Disposal
Spaceraft Total	104 W	232 W	196 W	232 W	196 W	309 W	266 W	205 W	91 W
Payloads Total	0 W	0 W	0 W	0 W	0 W	0 W	6 W	5 W	0 W
Harness Losses	3 W	7 W	6 W	7 W	6 W	9 W	8 W	6 W	3 W
Flight System Demand	107 W	238 W	202 W	238 W	202 W	318 W	281 W	216 W	93 W
ASRG Power Available	369 W	420 W	420 W	403 W	403 W	396 W	396 W	396 W	396 W
Unallocated Available Powe	262 W	181 W	218 W	164 W	201 W	77 W	115 W	179 W	303 W
Power Margin	71%	43%	52%	41%	50%	40%	35%		76%

Radiation Mitigation Approach

Aluminum Thickness (mils)	Total Ionizing Dose (krad Si)			
	Electron	Photon	Proton	Total
100	1500	5.3	51.7	1560
200	685	6.0	12.1	703
400	258	7.0	2.1	267
600	134	7.6	1.0	143
800	80.5	8.1	0.6	89.2
1000	53.4	8.4	0.4	62.2
1200	37.9	8.7	0.3	46.9
1400	28.1	8.8	0.2	37.1
1600	21.6	8.9	0.2	30.7



Planetary Protection

Article IX of the Outer Space Treaty of 1967 requires the prevention of "harmful contamination" of extraterrestrial solar system bodies. NASA's compliance with this treaty is documented in NPR 8020.12C. Europa missions, in particular, are covered in section A.3.1 stating:

"Requirements for Europa flyby, orbiter, or lander missions, including microbial reduction, shall be applied in order to reduce the <u>probability of inadvertent contamination of an Europan ocean to less than 1x10^{-4} per mission.</u>"

- Orbiter strategy is to decommission spacecraft on surface of Europa
  - ASRG heat output minimized
  - Must be prepared for uncontrolled impact
- Probability of contamination of a protected body is a function of:
  - Total bioburden at launch (DHMR)
  - Sterilization during cruise (minimal)
  - Sterilization in Jovian System (much)
  - Probability of impact with a protected body (100%)
  - Sterilization during impact event (some)
  - Probability of burial under radiation penetration depth of ice (some)
  - Probability of survival and proliferation (minimal)

<u>System level sterilization at appropriate temperature / duration planned</u>

Science Data Return

- 414Mbits/orbit (200Mbyte storage accommodates 1 missed pass)
- Ka Downlink rates highly affected by DSN elevation angles. Rate stepping will be required to make best use of Ka band throughput. Modulate both X and Ka bands to maximize downlink
- Downlink Rate: 129 Kbps (worst case @ 5.5AU)
- Time to downlink 414Mbits @ 129 Kbps ~53 minutes worst case
- Downlink time limited by occultation depending on geometry (no occultation at target arrival).
- CFDP will be used to ensure timely and efficient data playback, and to ensure complete science return between encounters

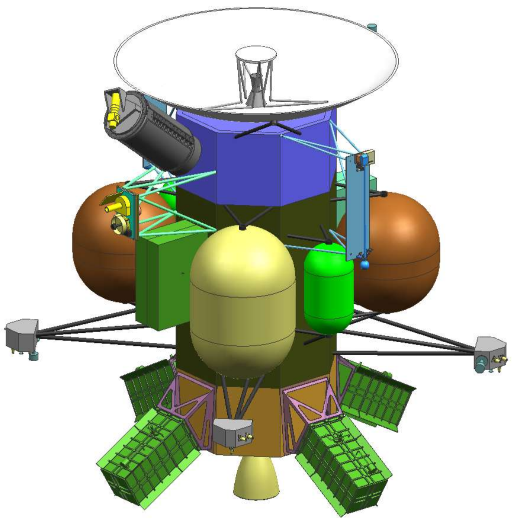
Data Downlink Budget

	MC	LA	MAG	LP	Total/Orbit
Raw Data Rate (Kbps)	319	1.95	2	1	
On-time per orbit (%)	50	100	100	100	
Data Reduction Factor	3	1	1	1	
Effective Output Rate (Kbps)	53.2	1.95	2	1	
Average Data Per Orbit (Mbit)	401.7	14.7	15.4	7.7	455
Worst Case Downlink Rate (Kbps)					122
Downlink Time Required (Hrs)					1.04
Downlink Time Available/orbit(Hrs)					2.1
Downlink Margin					51%

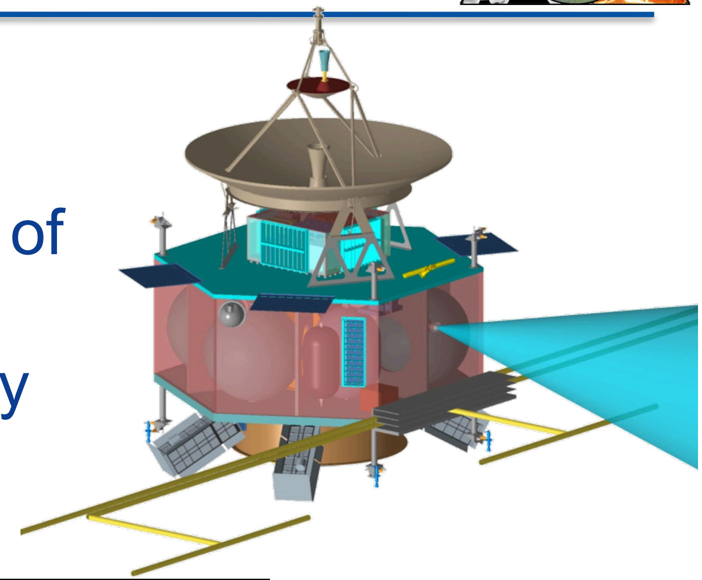
Orbiter Concept Summary

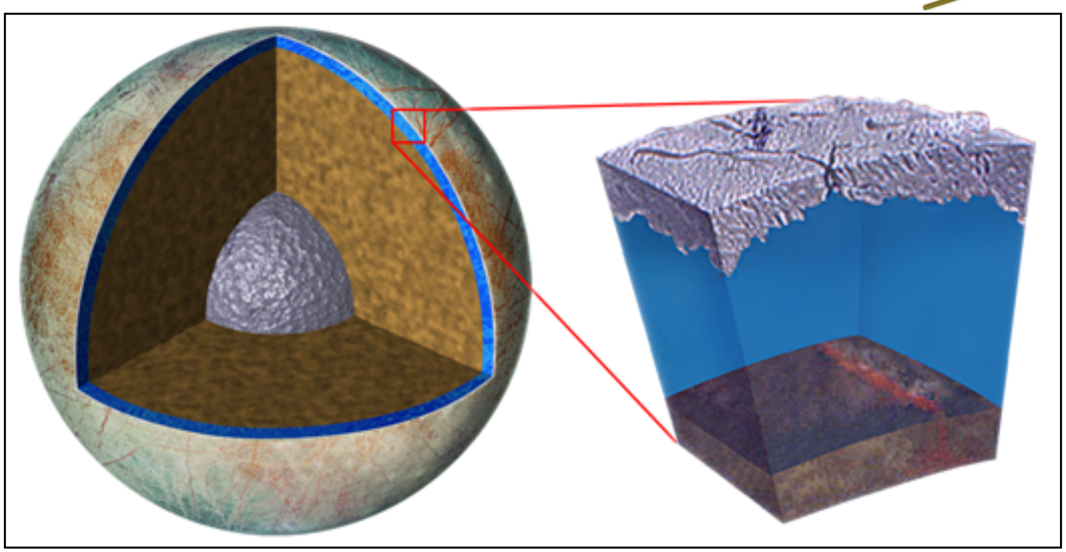
The EHM Orbiter Concept responds to the 2011 Planetary Decadal Survey:

- Reduced system complexity / efficient payload accommodation
- Reduced mass to fit the Atlas V class launch vehicle
- Uses ASRGs / 4x improvement in conversion efficiency over MMRTG / Much less ^{238}Pu
- Improved trajectory reduces radiation dose by ~ 50% (compared to JEO) & improved self shielding maximizes use of existing, qualified components
- Simplified, modular development / low cost operations concepts
- Proven technical approach / consistent with previous outer planets missions
- Cost estimated at ~$1.5B (FY15)



The EHM Orbiter delivers a robust science investigation of Europa with large margins, significantly reduced risk at an affordable cost.





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