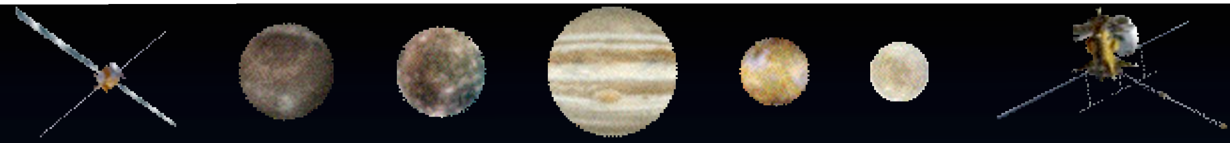


Jupiter Europa Orbiter Status and Plans

Karla B. Clark

NASA–JEO Study Lead

Jet Propulsion Laboratory

California Institute of Technology

August 25, 2009

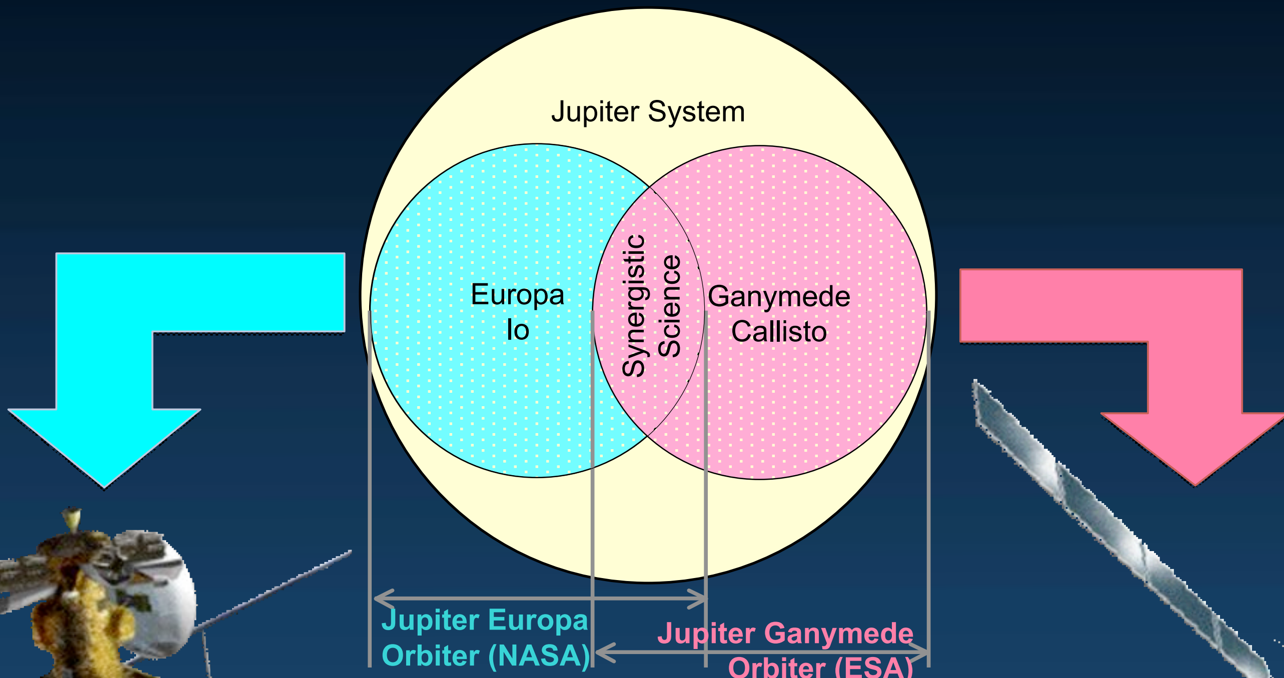
Jupiter Europa Orbiter

The NASA Element of the Europa Jupiter System Mission

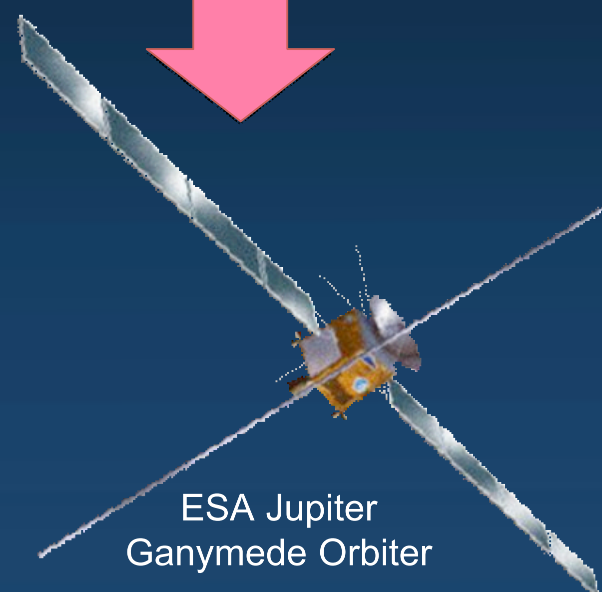
Study Timeline

- Study Report issued Nov. 2, 2008
  - Public version at www.opfm.jpl.nasa.gov
- STMC Review Site Visit on Dec. 11, 2008
- Prioritization announced Feb 18, 2009
- Teams debriefed Feb. 23, 2009
- Risk Mitigation Activity On-going
  - Products posted on website
  - Limited 2009 funding focused on July workshop
- Instrument Workshop on July 15-17, 2009
  - Focus was on radiation and planetary protection project work and challenges
  - All presentations available on website

EJSM Concept Decomposition



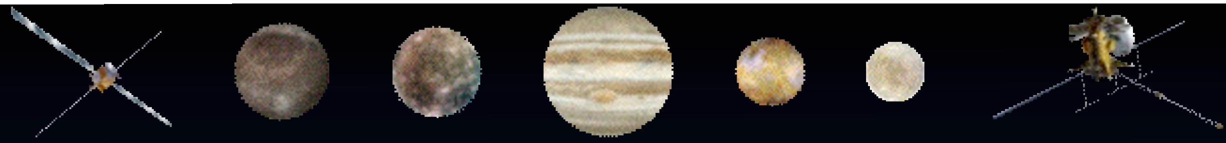
NASA Jupiter
Europa Orbiter



ESA Jupiter
Ganymede Orbiter

JEO Baseline Mission Overview

- NASA-led portion of EJSM extensively studied in 2007–2008
- Objectives: Jupiter System, Europa
- Launch vehicle: Atlas V 551
- Power source: 5 MMRTG or 5 ASRG
- Mission timeline:
  - Launch: 2018 to 2022, nominally 2020
    - Uses 6-year Venus-Earth-Earth gravity assist trajectory
  - Jovian system tour phase: 30 months
    - Multiple satellite flybys: 4 Io, 6 Ganymede, 6 Europa, and 9 Callisto
  - Europa orbital phase: 9 months
  - End of prime mission: 2029
  - Spacecraft final disposition: Europa surface impact
- 11 Instruments, including radio science
- Optimized for science, cost, and risk
- Radiation dose: 2.9 Mrad (behind 100 mils of Al)
  - Handled using a combination of rad-hard parts and tailored component shielding
  - Key rad-hard parts are available, with the required heritage
  - Team is developing and providing design information and approved parts list for prospective suppliers of components, including instruments

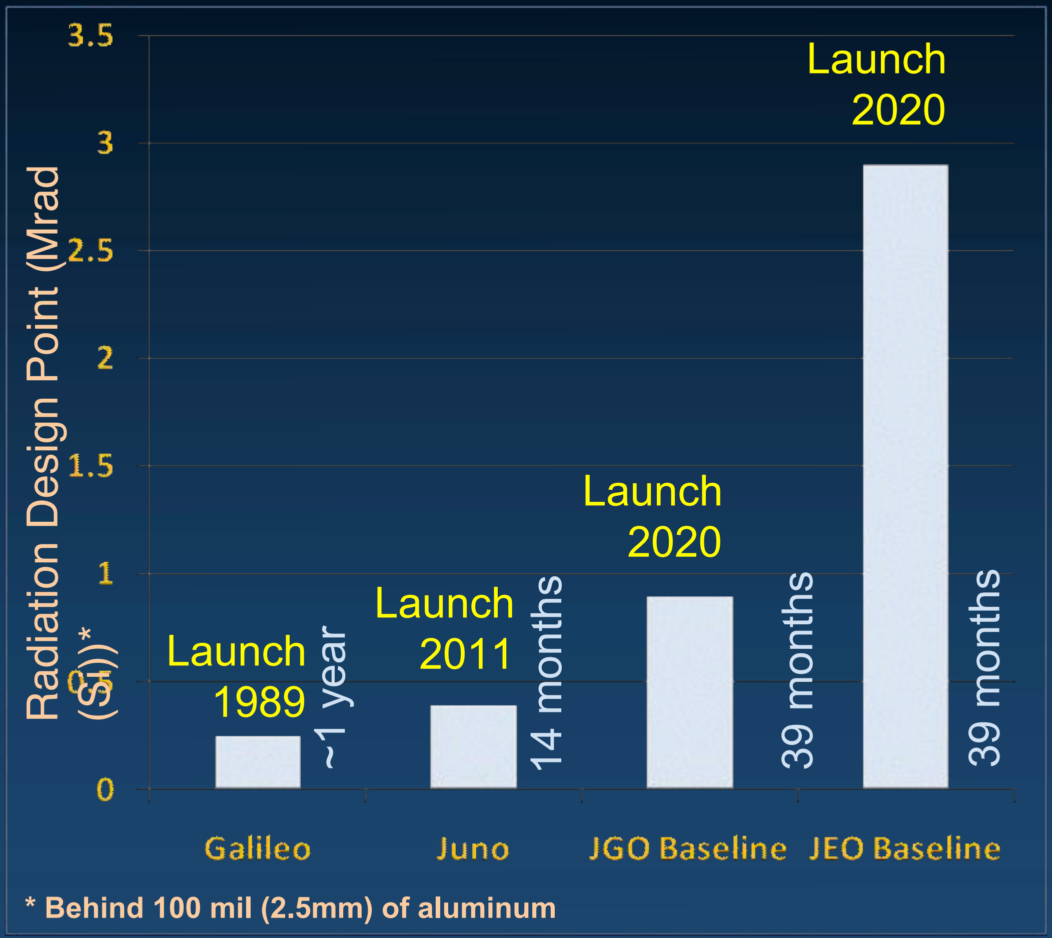


Significant STMC Findings

- Form A - Science rated *excellent*
  - Looked at both EJSM and JEO-only science
- Form B – Science Implementation rated *Low Risk*
  - Rated the ability of the proposed instrumentation and the operational strategies to meet the science objectives
  - Major strength on the Traceability Matrix
- Form C – Technical, Management and Cost rated *Low Risk*
  - Cost was rated *Medium Risk*
    - Cost concerns were mainly related Instrument costs
  - Low Risk implies that the basic plan is solid and that the project can be implemented AS PLANNED (except cost)
    - Concept maturity reduces implementation risk
    - Operations concepts excellent and "impact on flight segment has clearly been considered"
    - "technical approach to risk identification and mitigation demonstrates excellent understanding of majors risks and actions" to mitigate them
  - Plan must be executed and early risk mitigation is recommended

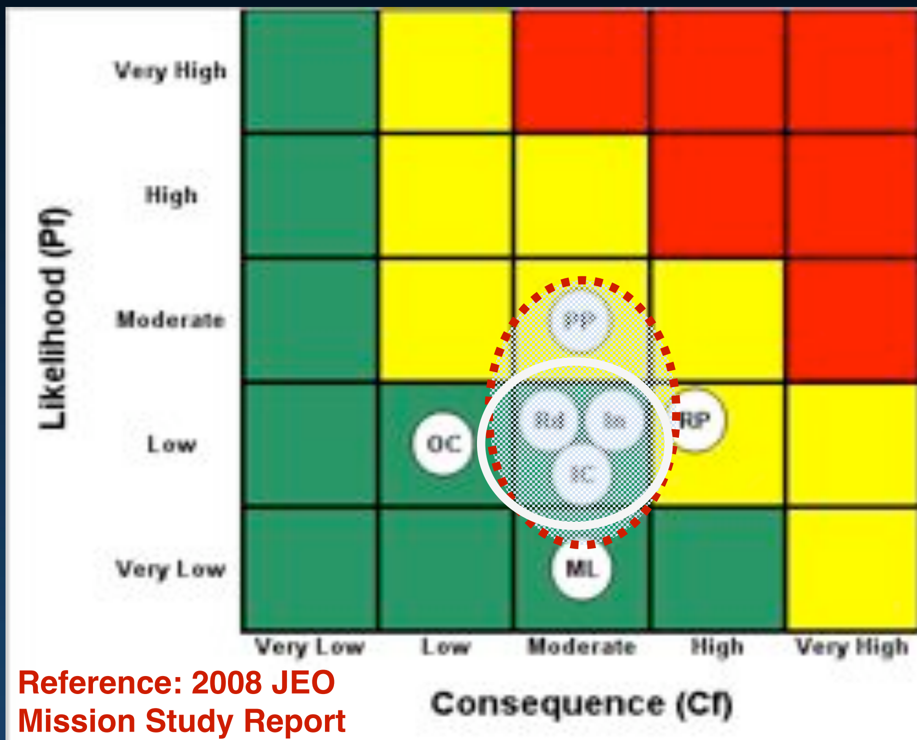
APPROACH TO MEETING THE RADIATION CHALLENGE

Mission Radiation Challenge



Estimated radiation dose levels unprecedented for NASA/ESA missions

JEO Mission Risk Assessment



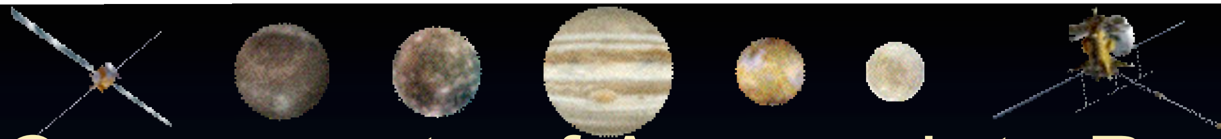
Reference: 2008 JEO Mission Study Report

- "Rd", "IC' and "In" are radiation related risk categories
- Instrument Development is one of the three radiation risk categories
- PP compliance requires in-flight sterilization via radiation

Risk Categories

Rd Radiation effects in parts, materials, & sensors
IC Internal charging
In Instrument development
PP Planetary protection
OC Operational complexity
RP Radioisotope power source
ML Mission life time

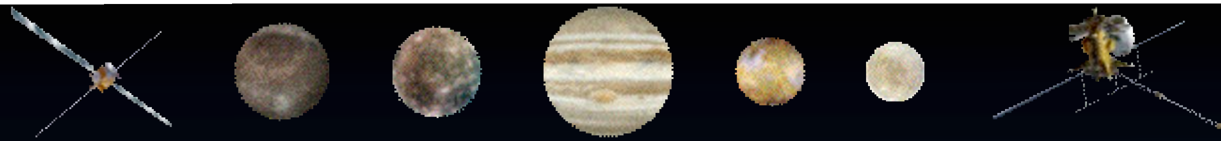
Radiation and PP are major risk categories for the JEO mission



Major Components of Approach to Radiation Challenge

- Risk Mitigation Plan (Pre-Phase A)
  - Early emphasis on reducing risk
  - Periodic peer reviews of plan
- Early emphasis on Instrument development
- Management and System Engineering Teams augmented
- External Advisory Board of Experts
- Extended schedule
- Increased cost for parts, testing, analysis, redesign
  - No heritage
- Design Approach
  - Rad-hard by Process
  - Rad-hard by Design
  - Rad-Hard by shielding
  - Rad-hard by “system”

Challenge being addressed as a “system”



System Design Process

Analysis

Input Variables

- Science Objectives
- Mission Design—Environment
- Launch Vehicle Capabilities
- Part Capabilities

Dependent Components

- Shielding Design
- Instrument and Circuit Design
- Margin Assessment
- Risk Analysis
- Cost Analysis

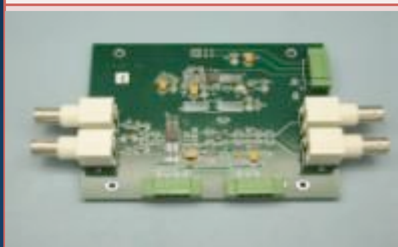
Iteration

- System design iterative process continues through Phase B as capabilities evolve and science instrument capabilities solidify
- Acceptable cost and risk posture is a joint discussion between project and NASA Headquarters

Risk Mitigation Plan

Key Elements and Sample Accomplishments

• **Risk Mitigation Plan: Radiation and Planetary Protection** • **Focuses on Pre–Phase A activities** • **Defining & validating approach** • **Obtaining data**	**1.0 System Reliability Model** **2.0 Environment and Shielding Model** **3.0 Radiation Design Methods** **4.0 Sensors and Detectors** **5.0 Parts Evaluation and Testing** **6.0 Approved Parts and Materials List (APML)**



Signal Chain Circuit Breadboard

Developed and validated worst-case analysis as part of radiation tolerance design methodology

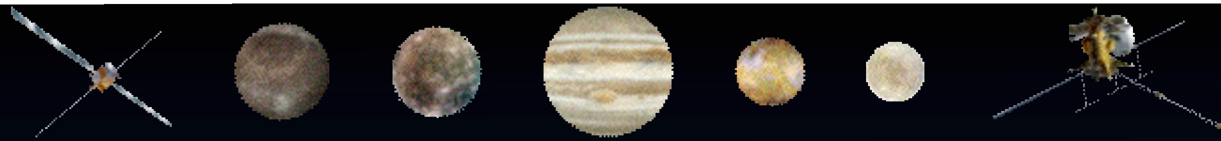
Image from hardened CMOS test array after 1 Mrad TID provides proof of concept for JEO science imagers

Radiation-tolerant design methodology developed and validated in the laboratory provides design guidelines for subsystem and instrument providers

Recent Accomplishments

- 2007: Five (5) external, independent peer reviews on radiation risks held between April 17 and May 21, 2007
  - Radiation environment and modeling
  - Transport analysis and shielding design
  - Parts and materials
  - Systems engineering and operations
  - Integrated systems
- From peer review inputs, a plan was developed to address issues
  - Endorsed by the 2007 TMC panel
  - Additional suggestions provided on Forms B and C of the 2007 EE Study
- 2008: Plan was refined and execution began
  - Reviewed by top engineers and managers at JPL and APL
    - John Casani, Tom Gavin, Gentry Lee, Ted Mueller, Matt Landano, Richard Brace, etc.
  - Documented current information and made available to potential instrument providers
  - Funded high-leverage parts testing including memory, Juno parts test extensions
  - Developed structure for longer-term effort, including Approved Parts and Materials List, System Model, radiation testing procedures
  - Held first workshop for potential Instrument providers in June 2008

Continued peer reviews will ensure that expertise from industry and other agencies is integrated into the JEO approach



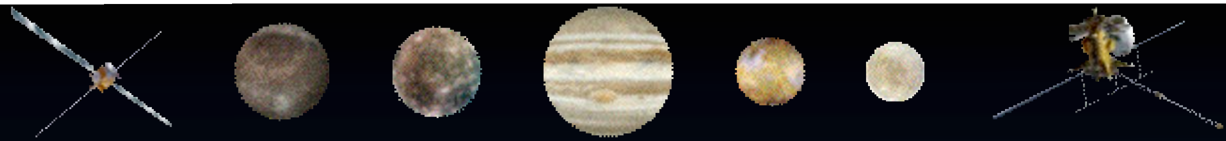
2009 EJSM Instrument Workshop

- Purpose of the Workshop
  - Prepare the instrument provider community to be ready to propose to the JEO and JGO opportunities
  - Enable an interaction between the radiation capability community and the instrument providers
- Topics covered
  - Background and Context
  - System Engineering, Radiation and Planetary Protection Challenges
  - Designing for Key Challenges
  - Instrument Solicitation and Expectorations
- Attendees
  - Over 275 people attended
  - 38 radiation capable companies/vendors had posters or booths
- All presentations, registrant list can be downloaded from the web

www.opfm.jpl.nasa.gov

EJSM Risk Reduction

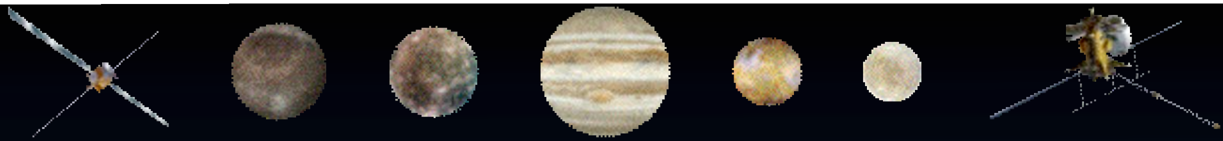
- Likely 2 workshops in 2010, one in US and one in Europe
  - Soliciting input on focus of the workshops
- Increase technical efforts on
  - APML, parts testing and evaluation
  - Core components identification (PCU, microprocessors, FPGAs/ASICs)
  - Shielding approach for sensors/detectors
  - System modeling



Sample Documents Available for Download

Theme	Title	Download
System	EJSM Risk Mitigation Plan: Radiation and Planetary Protection	
	Return to Europa: Overview of the Jupiter Europa Orbiter Mission	
	Radiation Challenges and Risk Mitigation for the JEO Mission	
Environment	Jupiter Europa Orbiter Radiation Environment	
Radiation Effects	Designing Circuits and Systems for Single Event Effects	
	Test Method for Enhanced Low Dose Rate Sensitivity (ELDRS)	
	Radiation Effects on Detectors and Key Optical Components	
Design Guidelines	Avoiding Problems caused by S/C on-orbit Internal Charging Effects	
	EJSM Radiation Design Guidelines	
	Total Dose and Displacement Damage Design Guideline	
	ASIC via FPGA Gu*ideline* with Addendum on Europa	
	OPFM Long Life Design Guidelines	
Parts	Memory Investigation for JEO Mission	
	JEO Parts Program Requirements	
	Approved Parts and Materials List	

http://www.opfm.jpl.nasa.gov



Two Step AO Process

- The stricter radiation and planetary protection requirements for JEO have significant implications for instruments
- NASA is considering using a two step selection process to provide:
  - for proposers, opportunity to add to understanding of implementation issues and cost risk under NASA funding
  - for the project, an opportunity to modify the design to optimize instrument accommodations
  - for NASA, a more informed selection of final flight instruments that benefits from the above
- At Step 1, NASA overselects (by instrument category) teams for competitive Phase A
- During Phase A, teams work with Project on instrument concepts
- Teams deliver Concept Study Report and undergo final TMC assessment
- NASA and ESA downselect to flight instruments
  - Instruments must be on contract prior to Instrument Concept Review/Phase A-B transition

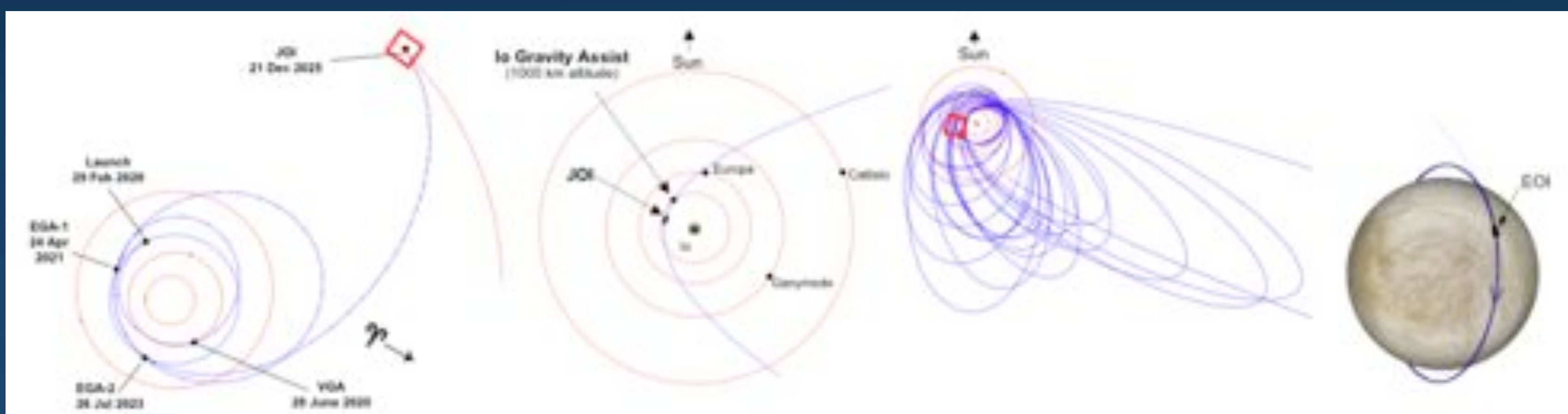
Preparing for JEO Instrument Announcement of Opportunity (AO)

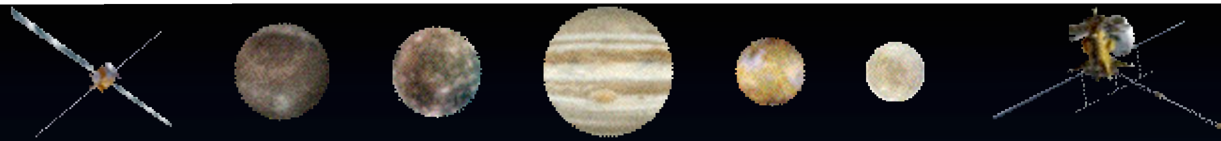
- Need to define with HQ the approach to instrument selection
  - Project involvement
    - AO content (criteria, info requested etc)
    - Proposal evaluation
    - Involvement in Step 2
  - Define 2-step process
  - Issues to be addressed by Project Scientist with SDT/community
  - JGO coordination
- Identify and create additional documents required for AO
- Project Information Package (PIP)
  - Identify and performing trades and technical work required
  - Identifying System Engineering/development processes needing definition

JEO OVERVIEW

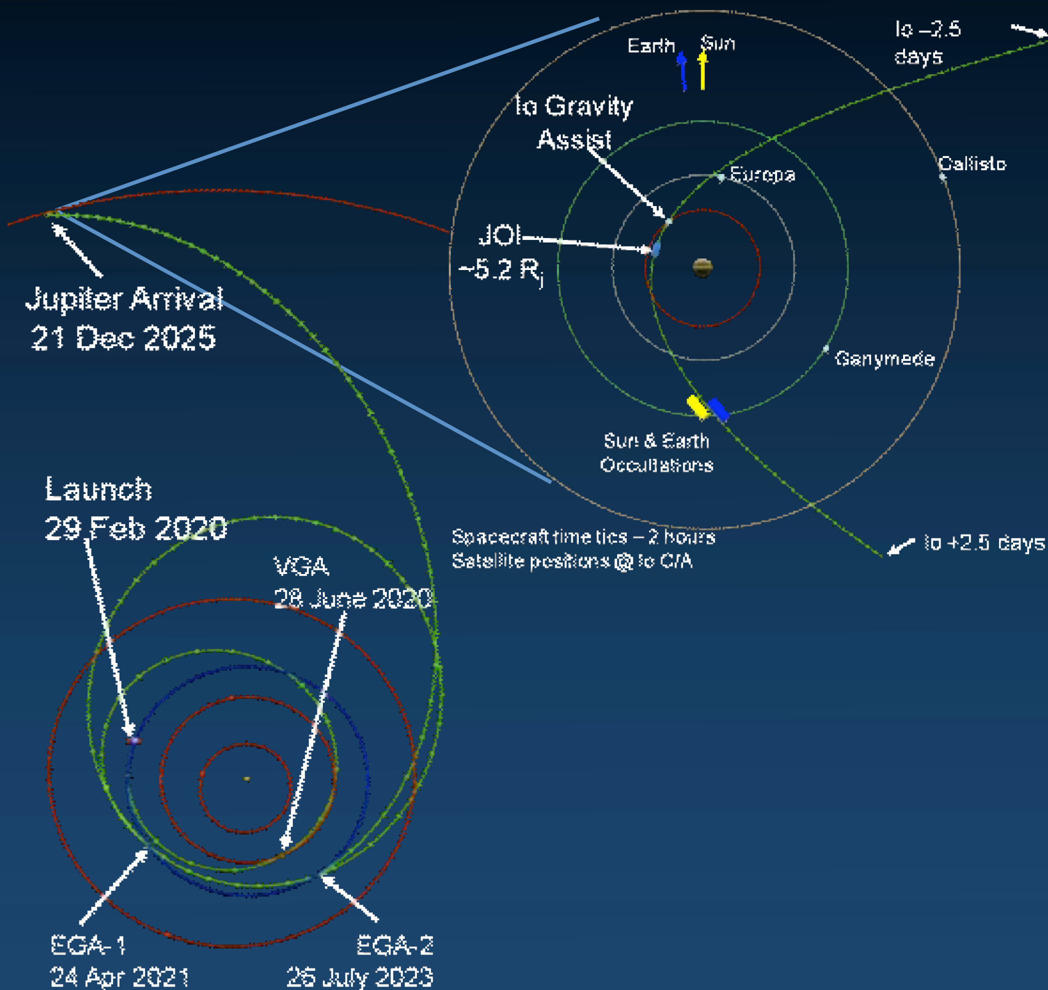
JEO Mission Design Overview

- Interplanetary trajectories feature gravity-assists to greatly reduce the required specific energy of launch
- Jupiter Orbit Insertion occurs low in Jupiter's gravity well, significantly reducing ΔV
- Gravity-assist tour of Jovian satellites greatly reduces size of Europa Orbit Insertion maneuver





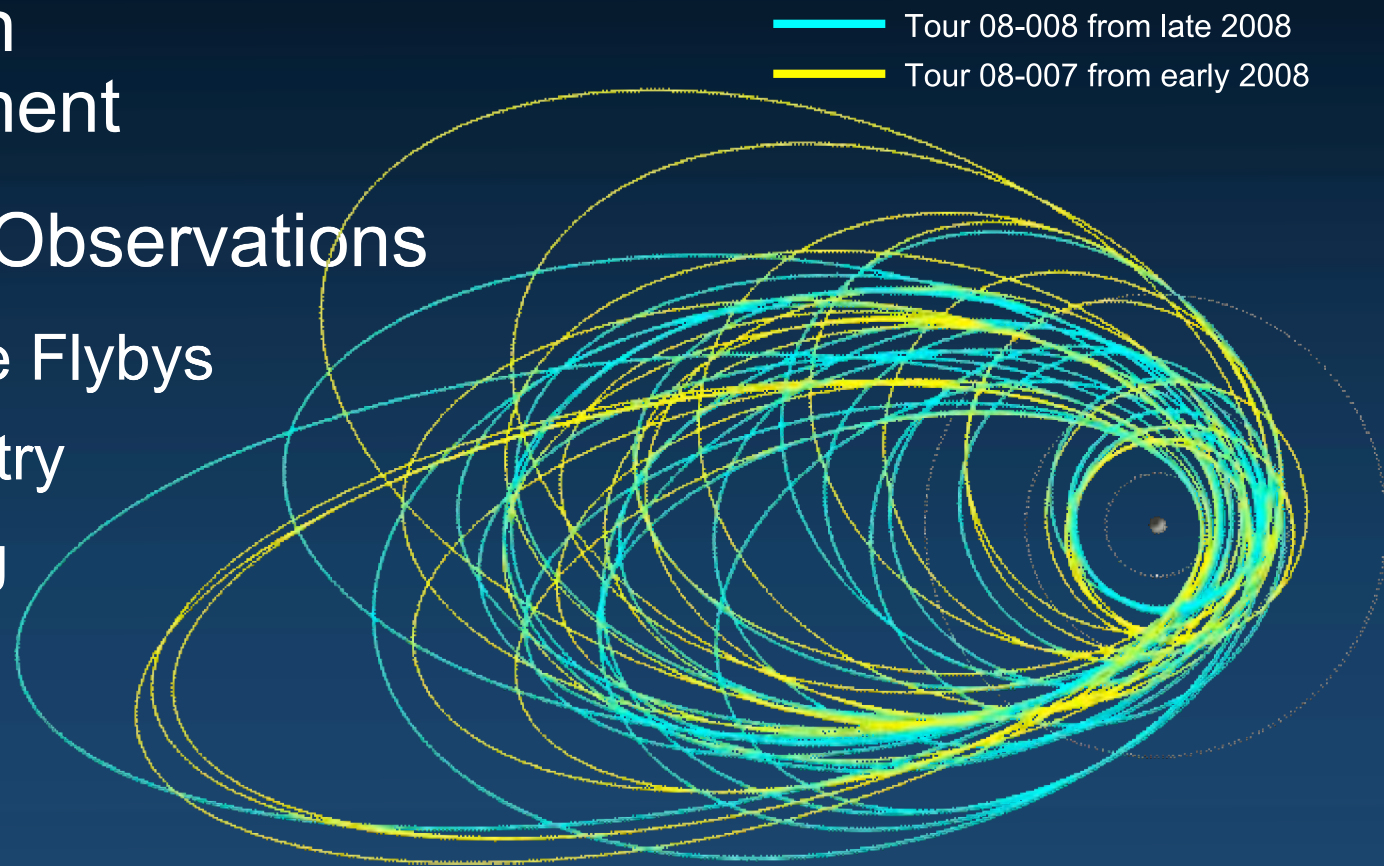
JEO Baseline Trajectory & Orbit Insertion



- Launch on Atlas V
- 4733 kg wet mass
- Venus-Earth-Earth Gravity Assist (VEEGA)
- Minimum range to Sun ≥ 0.7AU
- JOI date: 21 December 2025
- JOI range: 5.2 Rj
- 200-day initial orbit post-JOI
- Io gravity assist
- Science tour starts post JOI

JEO Tour Design Drivers

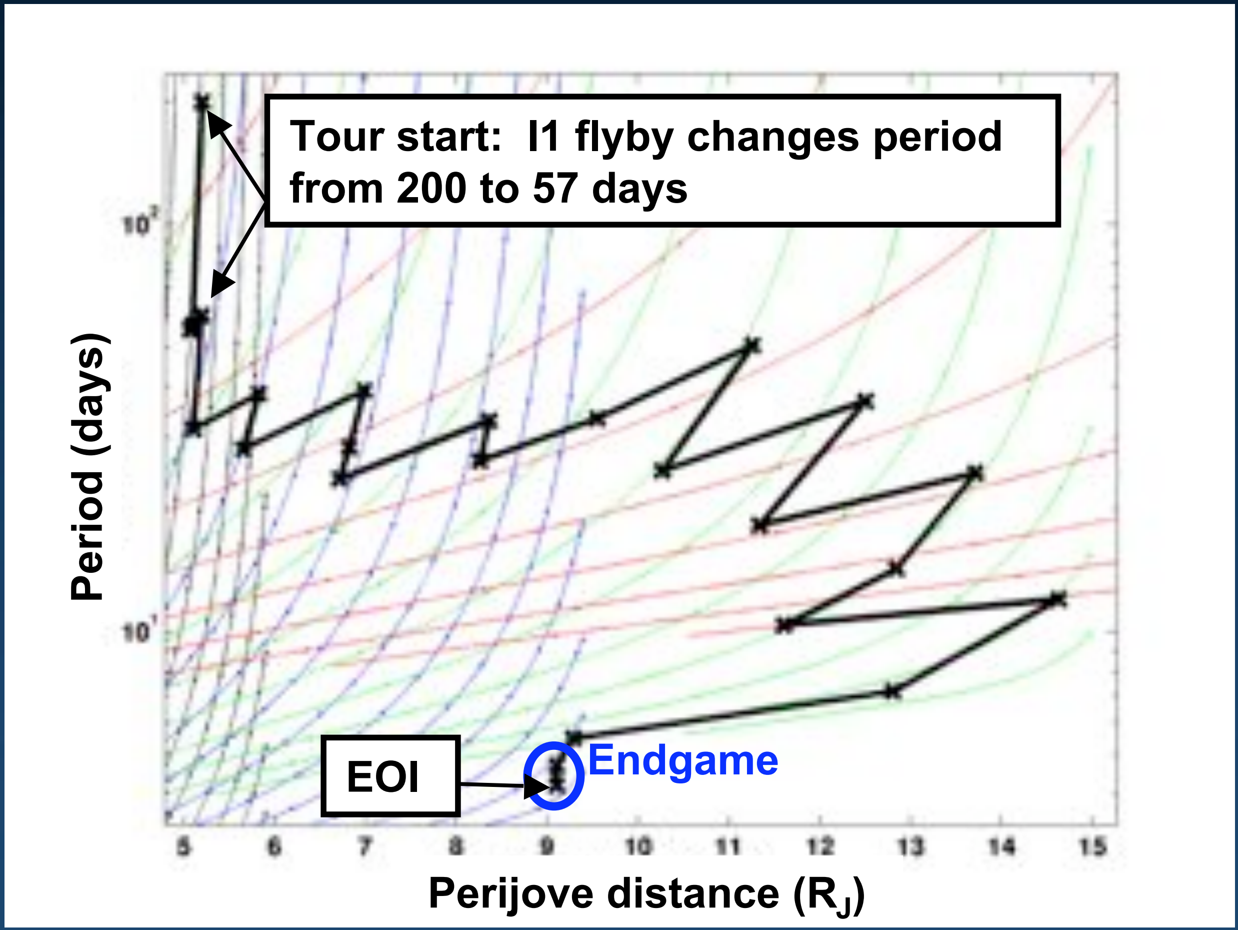
- Radiation Environment
- Science Observations
  - Satellite Flybys
  - Geometry
  - Lighting
- Duration

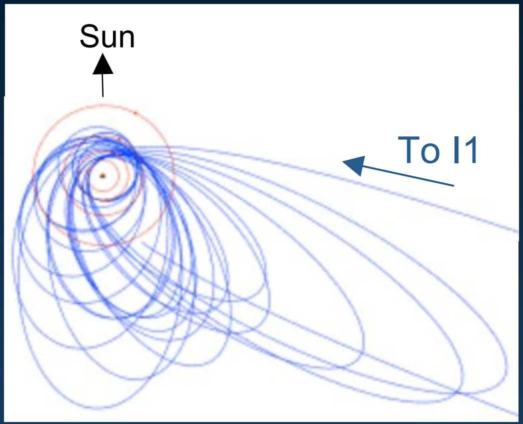


Tour design continues to evolve

JEO Tour Design

- Many tours possible. Baseline tour T08-008 shown here
- No deterministic ΔV between I1 and start of endgame



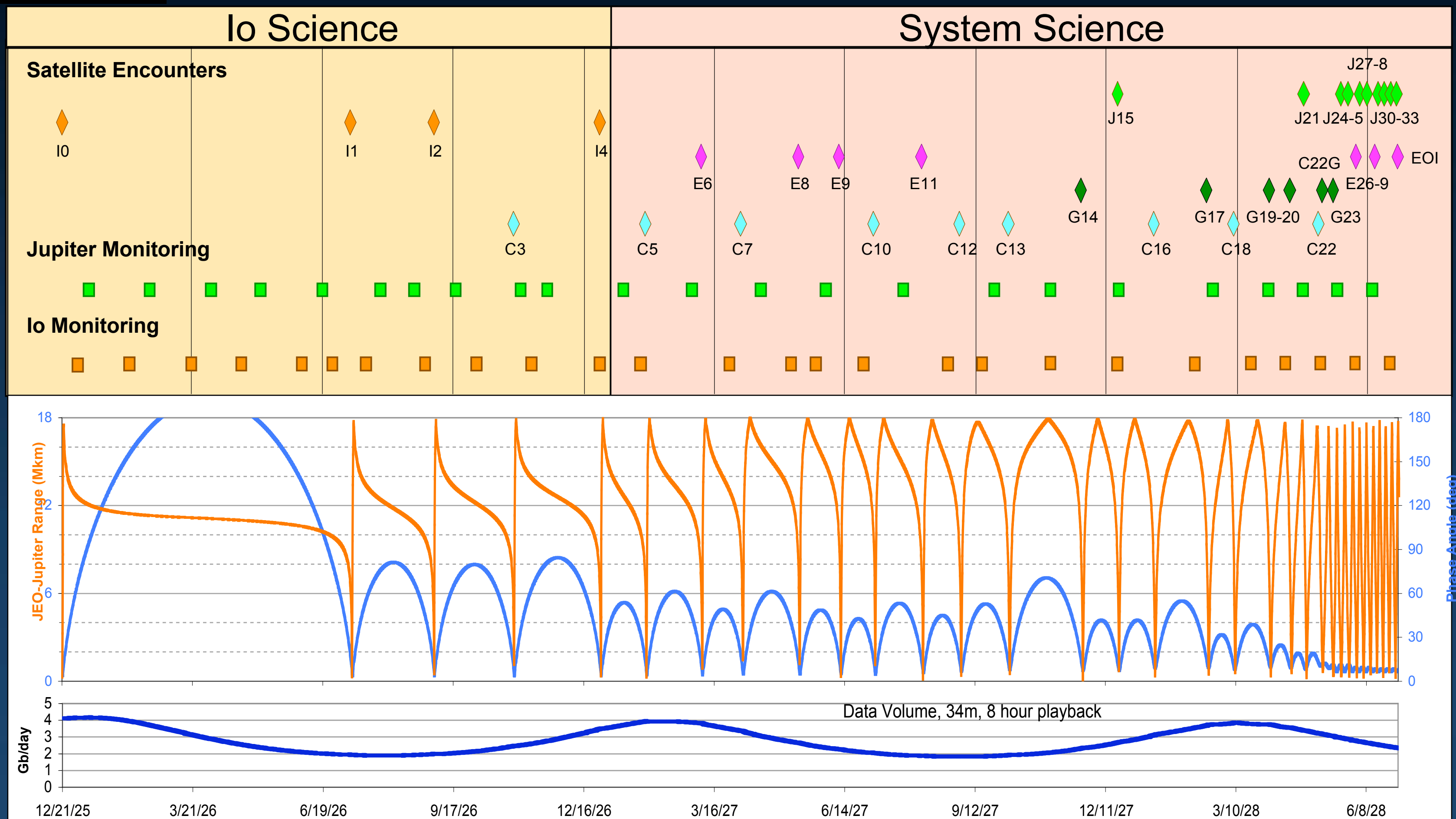


- Periapsis raised early in the tour to minimize radiation exposure (and the attendant shielding)

Jovian Tour Phase

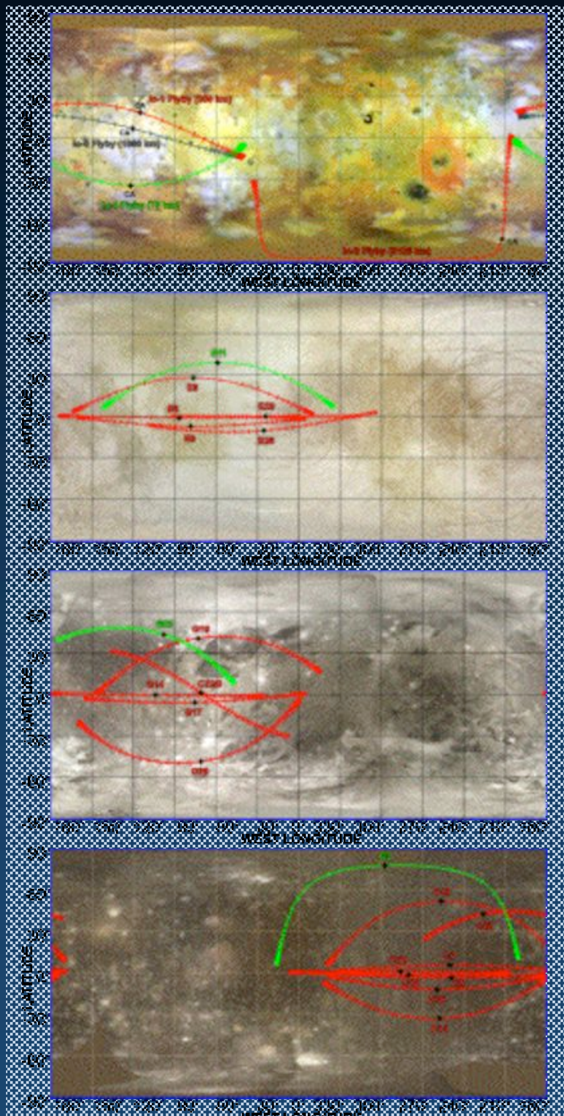
Phase:
100 deg

Phase:
120 deg



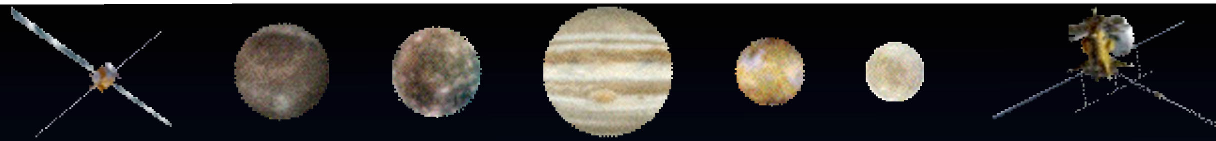
Extensive opportunities exist to acquire Jupiter System Science

JEO Tour Satellite Science



- Io: 3 flybys
  - Opportunities for imaging, IR spectroscopy, and altimetry
  - In situ analysis of extended atmosphere with INMS at 75 km
- Europa: 6 flybys
  - Radar and altimetry characterization and calibration
  - Imaging at up to 10–50 m resolution, NIR 250–1250 m
- Ganymede: 6 flybys
  - Radar sounding of grooved and dark terrains
  - Range of lats, lons for magnetosphere sampling
- Callisto: 9 flybys
  - High-latitude flyby for gravity field determination
  - Ocean characterization with magnetometer
  - Radar for subsurface structure of ancient cratered terrain

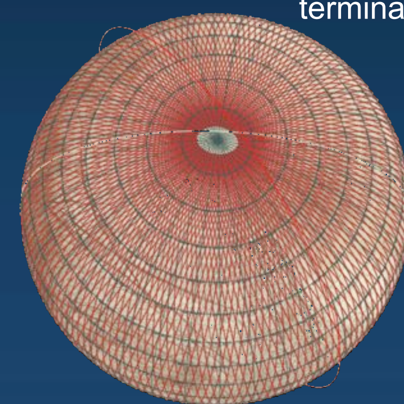
Satellite	≤1000m	≤200m	≤50m	≤10m	Length IPR (km)	Length LA (km)
Io	30%	20%	5%	-	1000	7400
Europa	60%	60%	15%	0.01%	6600	19000
Ganymede	50%	50%	10%	0.02%	17000	28000
Callisto	85%	75%	5%	0.01%	15000	30000



Europa Science Orbit

- 200 km altitude for early science in the first 28 days, then transition to a 100 km altitude
- Initial orbit at ~2:30 pm LST
- Inclination selected to balance lighting and coverage
  - $85° \le i \le 95°$ (selected 95° for slowest orbit rotation)
  - Orbit rotates 0.1 to 0.4 deg/day
- Ground track repeat cycle selected for ground track separation and global imaging coverage
  - Repeat cycle would be set for science needs, would be optimized when payloads are selected
  - 4-eurosol repeat at 200 km gives global coverage in 3 eurosols (~10 days) using every other orbit

Orbit Altitude (km)	Period (min)	Occultation Dur (min)	Orbits Per Day	Ground Speed (km/s)
200	138	46 (33%)	10.4	1.1
100	126	47 (37%)	11.4	1.3



Groundtracks cover 95% of Europa surface

Poles could be imaged off-nadir (some layover)

Europa Science Campaigns

JOI to EOI	Jul 2028	Aug 2028	Sep 2028	Oct 2028

JOI

Satellite/Jupiter Science

EOI

Eng Assessment (6d)

Observing Strategies for Europa Campaigns 1-3
Always on: LA, MAG, PPI, TI, INMS (50%)
2-orbit ops scenario permits power/data rate equalization:
- Even orbits emphasize optical remote sensing:
- Odd orbits emphasize radar sounding to locate water

Targets collected with residual data volume

Europa Science Campaigns

1A | 1B

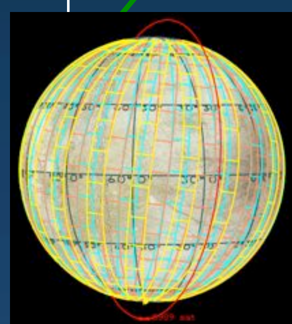
2A | 2B

3

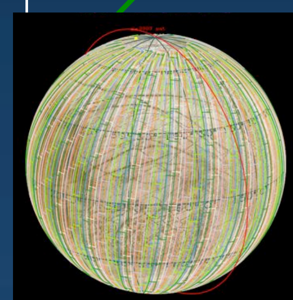
4

Initial Europa Orbit
Altitude: 200 km
Inclination: 95-100 deg
(~85° N lat)
Lighting: 2:30 PM LST
Repeat: 4 Eurosols

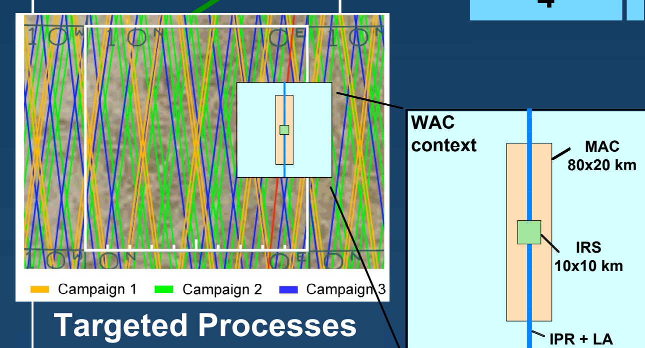
After Campaign 1
Altitude: 100 km
Repeat: 6 Eurosols



Global Framework
200 km altitude
(200 m/pixel WAC)
8 eurosols ≈ 28 days

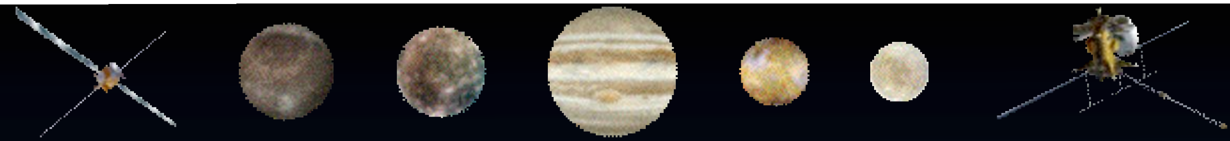


Regional Processes
100 km altitude
(100 m/pixel WAC)
12 eurosols ≈ 43 days

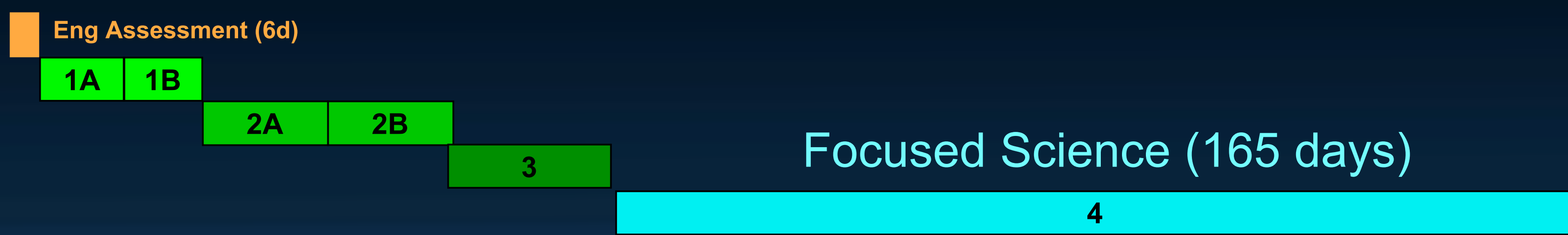


Targeted Processes
100 km altitude
8 eurosols ≈ 28 days

Europa Campaigns 1-3 total 99 days



Europa Science Campaigns



<u>By end of Europa Campaign 3:</u>

99 days orbital science
4 global maps
- 2 @ 200m Color + Stereo
- 2 @ 100m Stereo

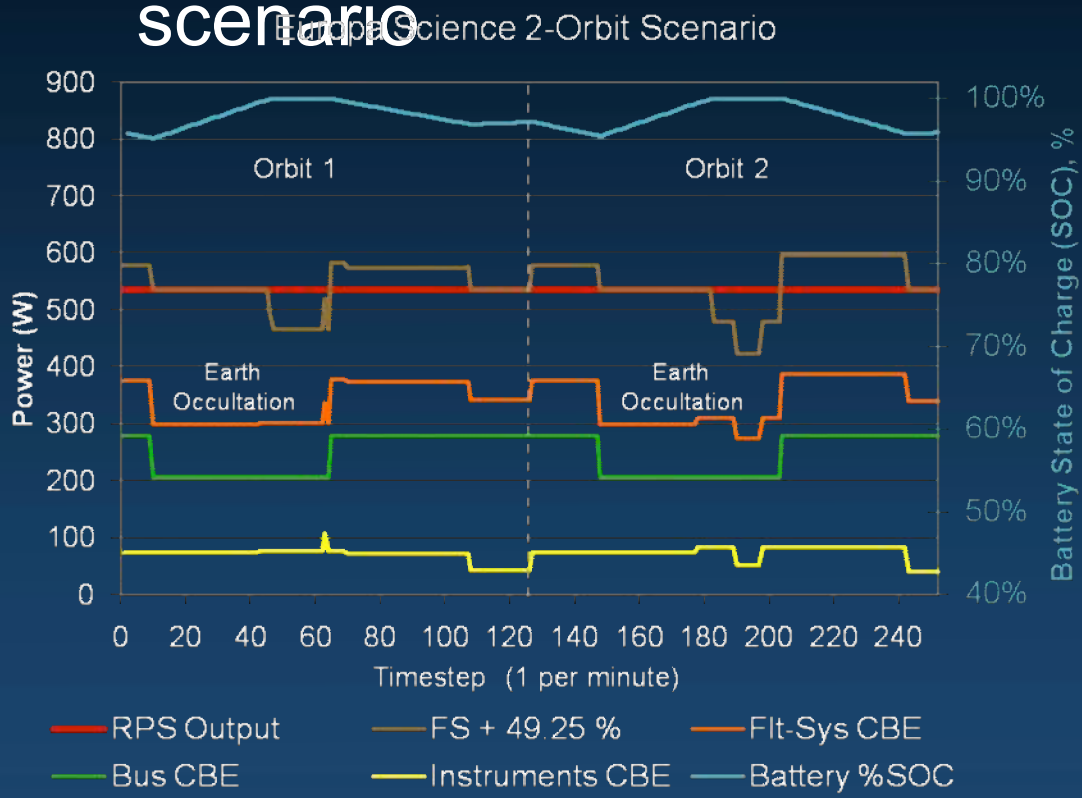
730 imaging and radar targets
18 km profile spacing for LA and TI
35 km spacing for IPR and VIRIS
400 UVS stellar occultations
700 Gb data return

- Follow up on discoveries
- Finer global and regional grid of profiling observations (IPR, VIRIS, TI)
- Continue gravity, laser altimetry, and fields and particles measurements
- Additional coordinated target sets
  - Investigate new discoveries and priorities
  - Characterize candidate future landing sites
- Off-nadir NAC stereo images
- Lower altitude operations
- Monitor Io and Jupiter, 1 to 2 times per week

Extended time in Europa orbit allows additional investigations and exploration

Science Scenarios

Driving scenario is the baseline Europa Science scenario

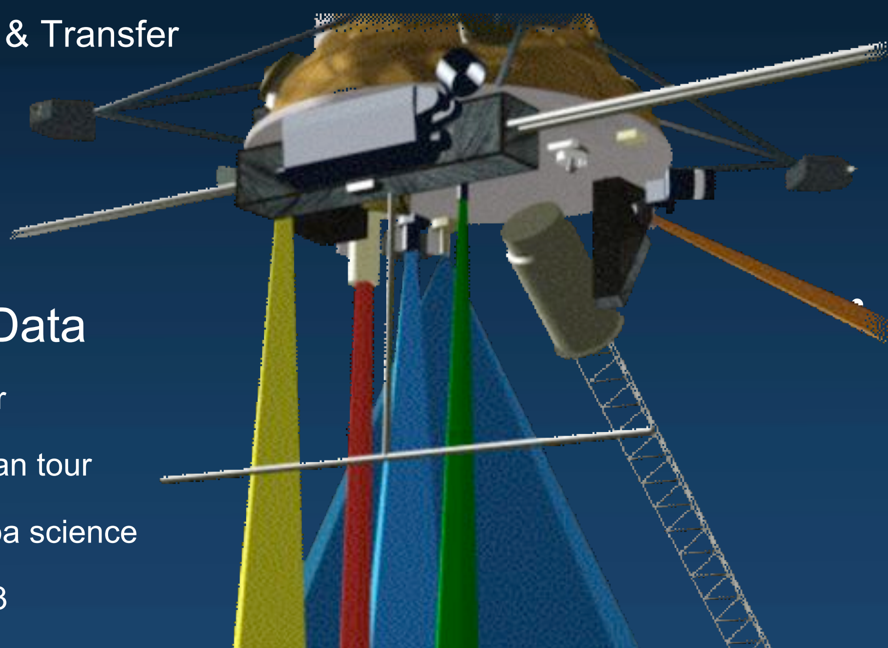


- Power is highly constrained
  - Limits instrument modes and downlink data rates
- Science observation scenario is data storage limited
  - Data is transferred real-time to the ground
- 2-orbit operations scenario permits power/data rate balance

Evolving science scenarios will be limited by power and data storage

Payload Design Drivers

- 165 kg total mass
  – Including Contingency
- 71 W average power
  – Data Collection & Transfer
  – Actuators
  – Thermal
  – Stand-by
- Command and Data
  – Rad750 Processor
  – 17 Gb during Jovian tour
  – 1 Gb during Europa science
  – SpaceWire & 1553
- Pointing
  – S/C pointed Nadir during Europa science
  – Instruments must provide own articulation

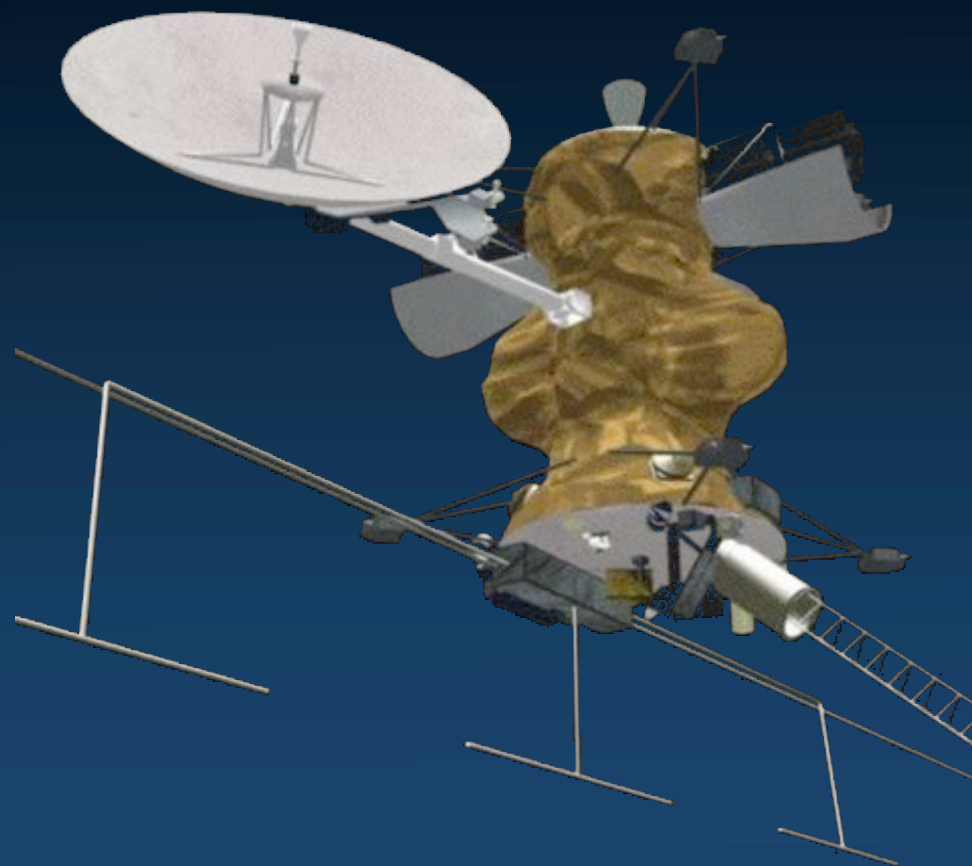


Artist's Rendering

- Thermal
  – Instruments provide own heating/cooling
  – Passive thermal control preferred
  – Power for thermal comes out of 71 W average
- Radiation
  – Shielding mass comes out of 165 kg allocation
  – Most hardware will require more than 2.54 mm (100 mils) of shielding
- Planetary Protection
  – Instruments must be sterilized

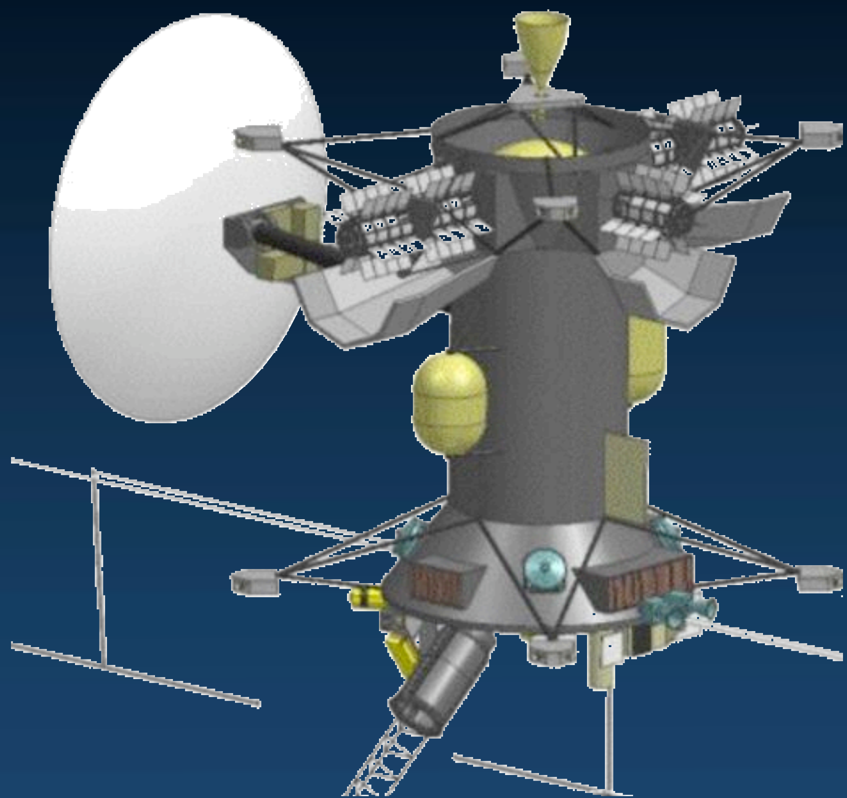
JEO Spacecraft Key Technical Drivers

- Venus fly-by
- Radiation
- Planetary Protection
- Nadir Pointed Instrument Deck
- Real-time Science during Europa orbit
- 17 GB storage for Jovian tour
- 1 GB storage for Europa science



Artist's Rendering

JEO Flight System

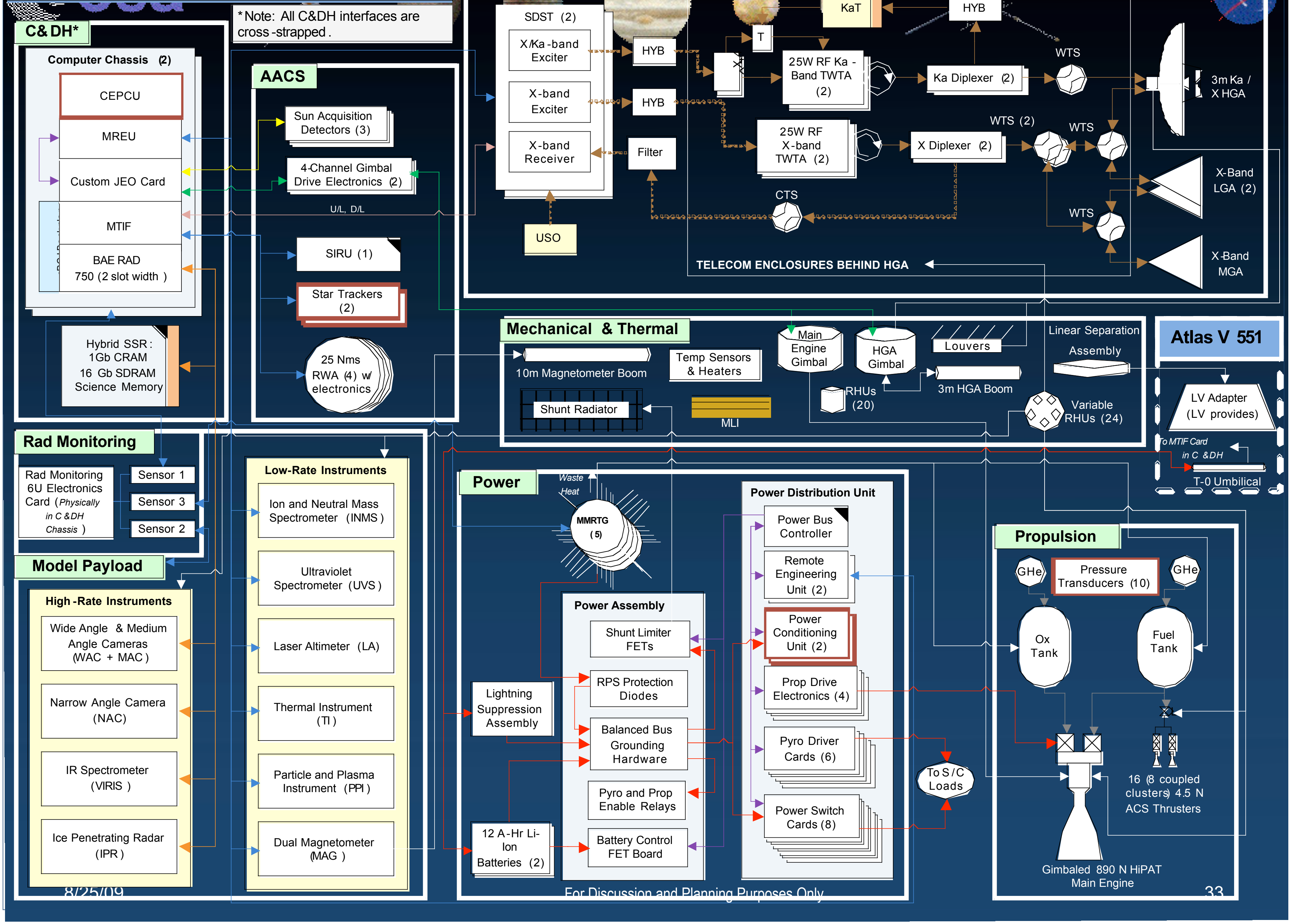


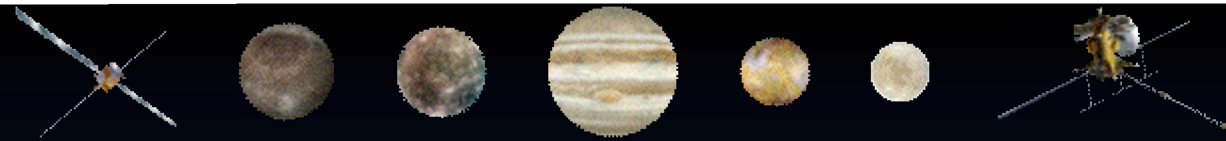
Artist's Rendering

- Three-axis stabilized with instrument deck for nadir pointing
- Articulated HGA for simultaneous downlink during science observations
- Data rate of 150 kbps to DSN 34m antenna on Ka-band
- Performs 2260 m/s ΔV with 2646 kg of propellant
- Five MMRTGs provide 540 W (EOM) with batteries for peak modes
- Rad hardened electronics with shielding to survive 2.9 Mrad (behind 100 mil Al) environment
- 9 year lifetime
- Healthy mass and power margins (43%, >33% respectively)

Back Up

JEO Flight System Block Diagram





Mass Summary

JEO Baseline Mass Equipment List			
	Flight System Mass, kg		
	CBE	Cont.	CBE+Cont.
Payload	163	30%	211
Model Payload	106	30%	137
Payload Radiation Shielding	57	30%	74
Spacecraft	1208	24%	1498
Power (w/o RPSs)	55	30%	72
C&DH	34	17%	40
Telecom	56	27%	70
Structures & Mechanisms	320	31%	420
Thermal	68	30%	88
Propulsion	157	28%	201
AACS	69	33%	91
Cabling	83	30%	108
Radiation Monitoring System	8	30%	10
RPS System	226	0%	226
Spacecraft Radiation Shielding	132	30%	172
Flight System Total Dry	1371	25%	1709
Additional System Margin to achieve study req.			226
Flight System Total Dry with Required Margin			1935
Propellant			2646
Flight System Total Wet			4581
LV Adapter with required margin			123
Flight System Launch Mass Wet			4704
Atlas V 551 Capability for 2020 VEEGA			5040
Additional Margin			336
System Margin (33% required per study guidelines)			43%

Payload and Shielding

5 MMRTGs

S/C Radiation Shielding for 2.9 Mrad

Delta V of 2260 m/s

Very Healthy Margins

Calculating Dry Mass Margin per Study Guidelines:

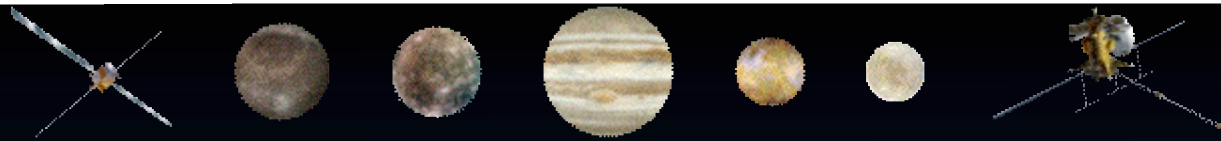
Dry Mass Allocation (MPRV)
= LV Capability – Prop – *RTG Mass**
= 5040 – 2646 – 226 = 2168 kg

Dry Mass CBE (PRV)
= S/C CBE + LV Adapt – *RTG Mass**
= 1371 + 82 – 266 = 1227

Dry Mass Margin
= (MPRV – PRV)/MPRV
= (2168 – 1227)/2168 = **43%**

**Note: The MMRTG mass is considered a Not-To-Exceed Mass, and is therefore excluded from the margin calculations, per HQ direction.*

JEO's design is robust to future changes due to large mass margins



Power Summary

JEO Power Profile (W)				Europa Orbit	
	Launch	Tour Fly-By	Safe	On-Orbit Science with Telecom	On-Orbit Science no Telecom
	3 hr	2 hr	24 hr	83 min	55 min
Payload	0	42	0	71	71
Model Payload	0	42*	0	71*	71*
Spacecraft	162	263	217	277	207
Power Electronics Standby Power	10	10	10	10	10
C&DH	52	52	52	52	52
Telecom	0	82	58	82	30
Structures & Mechanisms	13	0	0	15	0
Thermal	12	23	23	23	23
Propulsion	27	1	25	1	1
AACS	44	90	44	90	86
Cabling - Losses Tracked Below	0	0	0	0	0
Radiation Monitoring System	4	4	4	4	4
Flight System Total Without Losses (CBE)	162	305	217	348	278
Power Losses	11	21	15	24	19
Flight System Total With Losses (CBE)	172	325	232	372	296
System-Level Radiation Load	9	16	12	19	15
Additional System Margin to achieve study req.	89	168	120	192	153
Flight System Total Power Demand with Required Margin	270	510	363	583	464
5 MMRTG Capability	625	545	540	540	540
Additional Power Available	355	35	177	-43	76

Orbital payload power is the average over the two-orbit science scenario and reflects a duty cycle on each of the instruments.

Flyby payload power represents the average during the 2 hr surrounding closest approach

Power losses are 7% for wire, switching, and conversion losses. Battery recharge losses are tracked separately in scenario model.

Radiation load of 5% of CBE is derived from Galileo experience

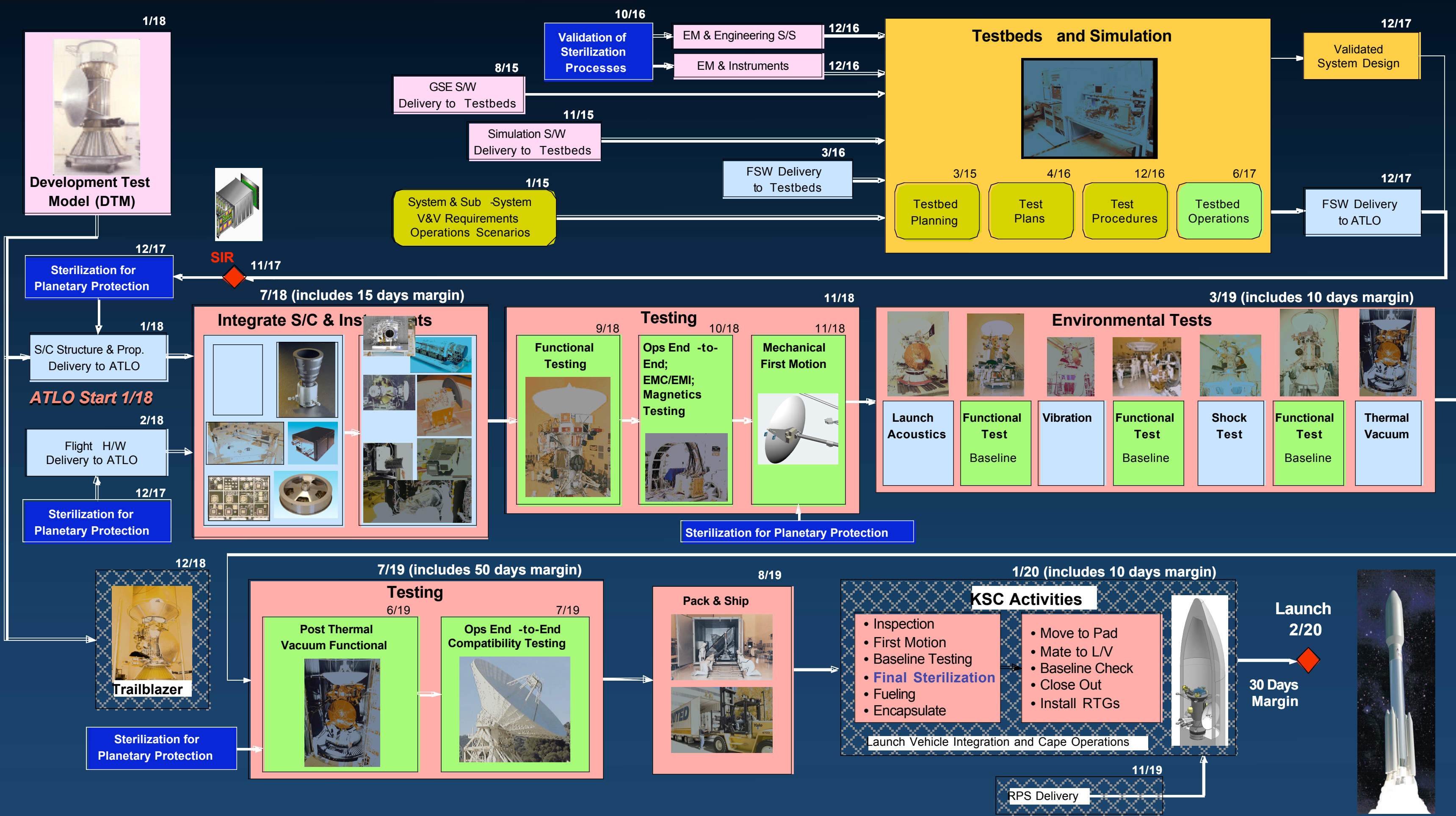
49% added to power load CBE to ensure required 33% margin is achieved

5 MMRTGs produce 540W at the end of 9.1yrs

A negative value indicates battery usage is required in this mode. Battery DOD in this scenario is 6%.

Significant power margins exist with 5 MMRTGs with only minimal use of batteries

Integration and Test



Thoughtfully planned I&T program with considerations for Europa environment and planetary protection requirements