Exploring Europa with an RPS-Powered Spacecraft

Results of the Europa Explorer mission concept study

IEEE Aerospace Conference

March 6, 2006
Big Sky, Montana

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Context

- JPL conducted two Europa orbiter concept studies in 2005.
  - Europa Geophysical Explorer (EGE)
  - Europa Explorer (EE)

- EGE was studied in the Summer of 2005
  - Was a 45 day study requested by NASA HQ.
  - The IEEE paper is based on the results of this study.

- Subsequently, JPL continued to investigate issues and details to refine the mission concept in the EE study. Major areas re-assessed:
  - Radiation predictions and mitigations including shield masses
  - Science Data Return approaches

- Though the EE Study was more detailed and reached a modified design point, it re-affirmed all the conclusions reached during the EGE Study

This presentation focuses on the results of the more recent and detailed EE study

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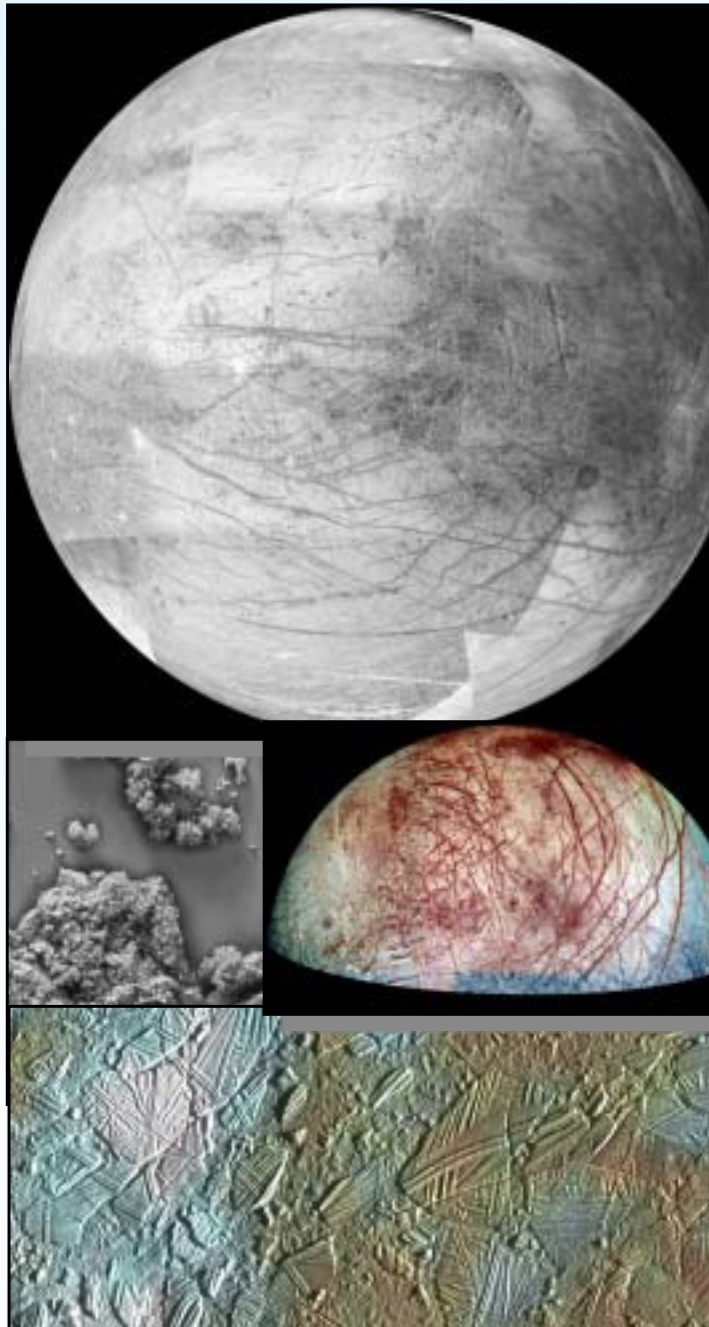
EE Study Objectives

- The Strategic Road Map for Solar System Exploration recommended in May 2005 that NASA implement a Europa orbiter as a Flagship mission early in the next decade.

- This supported the recommendations of the Solar System Decadal Survey and the priorities of the Outer Planets Assessment Group (OPAG).



Why do this Study Now? What has Changed?

The next step in Europa exploration, the EE concept study builds upon previous Europa Orbiter concepts:

- ✓ **Earth Gravity Assists (EGA) are on the table (direction from NASA)**
- ✓ Result in a dramatic increase in delivered mass
  - The somewhat longer flight time is deemed acceptable
- ✓ **Better understanding of the radiation environment**
  - Radiation modeling from Galileo data indicates a smaller total radiation dose
- ✓ **Advances in radiation-hardened components and subsystems**
  - Results from considerable investments from X-2000 and JIMO
- ✓ **Developments in radioisotope power systems (RPS)**
  - Technology development for the MMRTG

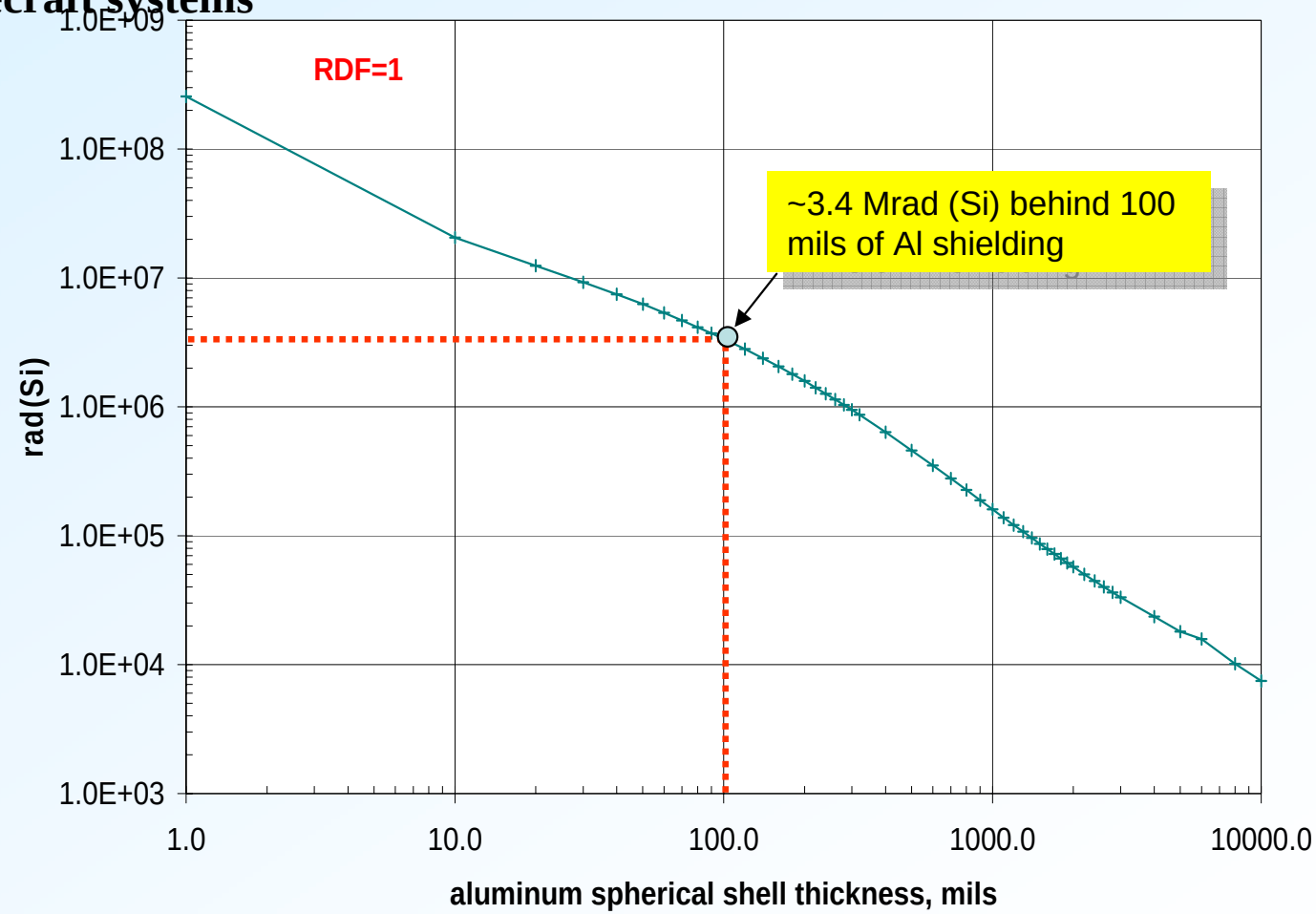
Level 1 EE Mission Requirements

- **The mission concepts shall support a science-mission duration of at least 90 days in Europa orbit**
- **The mission concepts shall feature a high-inclination orbit at Europa***
- **The mission concepts shall be designed to launch in 2015**
- **The mission concepts shall consider a trajectory design that employs gravity assists, including around Earth***
  - The trade studies shall include the two basic trajectory types that use gravity assists:
    - VEEGA
    - ΔV-EGA
- **The mission concepts shall consider a Delta IV-H or Atlas V launch vehicle***
- **The mission concepts shall use chemical propulsion***
- **The trade studies shall consider the following RPSs:**
  - MMRTG
  - GPHS-RTG
- **The trade studies shall consider the options for a "bolt-on" lander***
  - The studies must assess which mission options permit a "bolt-on," capable, lander payload

(* Based on requirements defined by Curt Niebur, NASA HQ for the Summer EGE study)

EE Radiation Environment

- **The total mission dose would be ~3.4 Mrad behind 100 mils of aluminum, based on the current Galileo Interim Radiation Electron (GIRE) model results**
- **Tour dose would be ~1.2 Mrad, and Europa orbit dose (90d) would be ~2.2 Mrad behind 100 mils of Al.**
- **Even using hardened parts, radiation vaults would be required for certain critical spacecraft systems**



Reference Case Parameters

Launch date: June 2015

Trajectory: VEEGA (C_3~14 km^2/s^2)

Launch vehicle: Delta IV-H (4050H)

Injected mass capability: ~7230 kg

Max available S/C dry mass: ~3250 kg

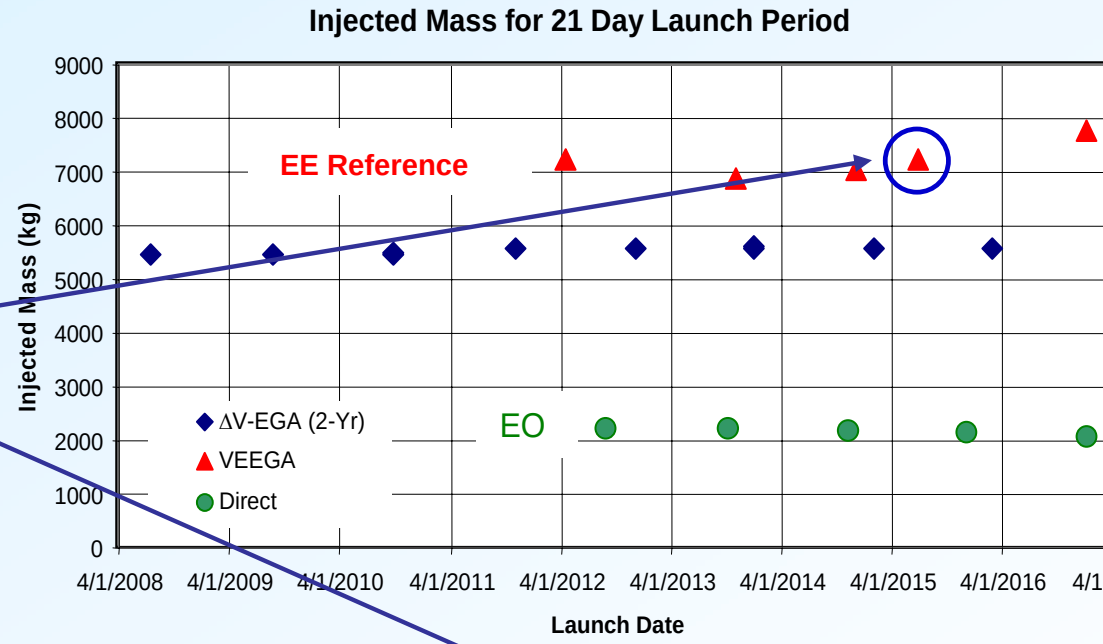
- Is the most conservative mass value between 2012 and 2017

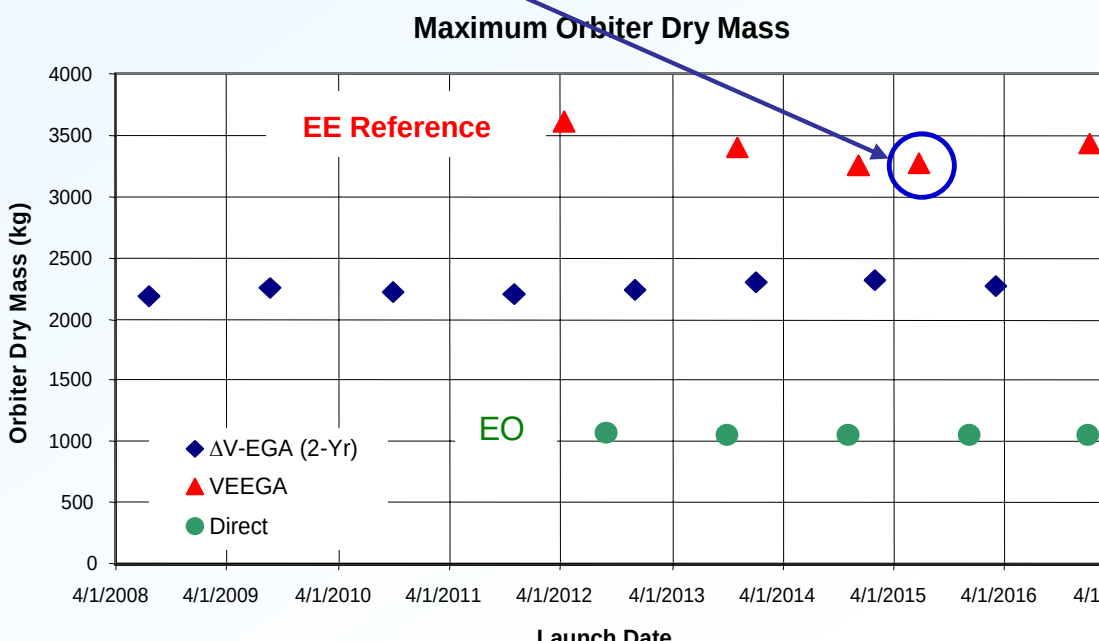
Total time to Europa: ~8 years

- To Jupiter: 6.4 years
- Jupiter Tour: ~1.5 years

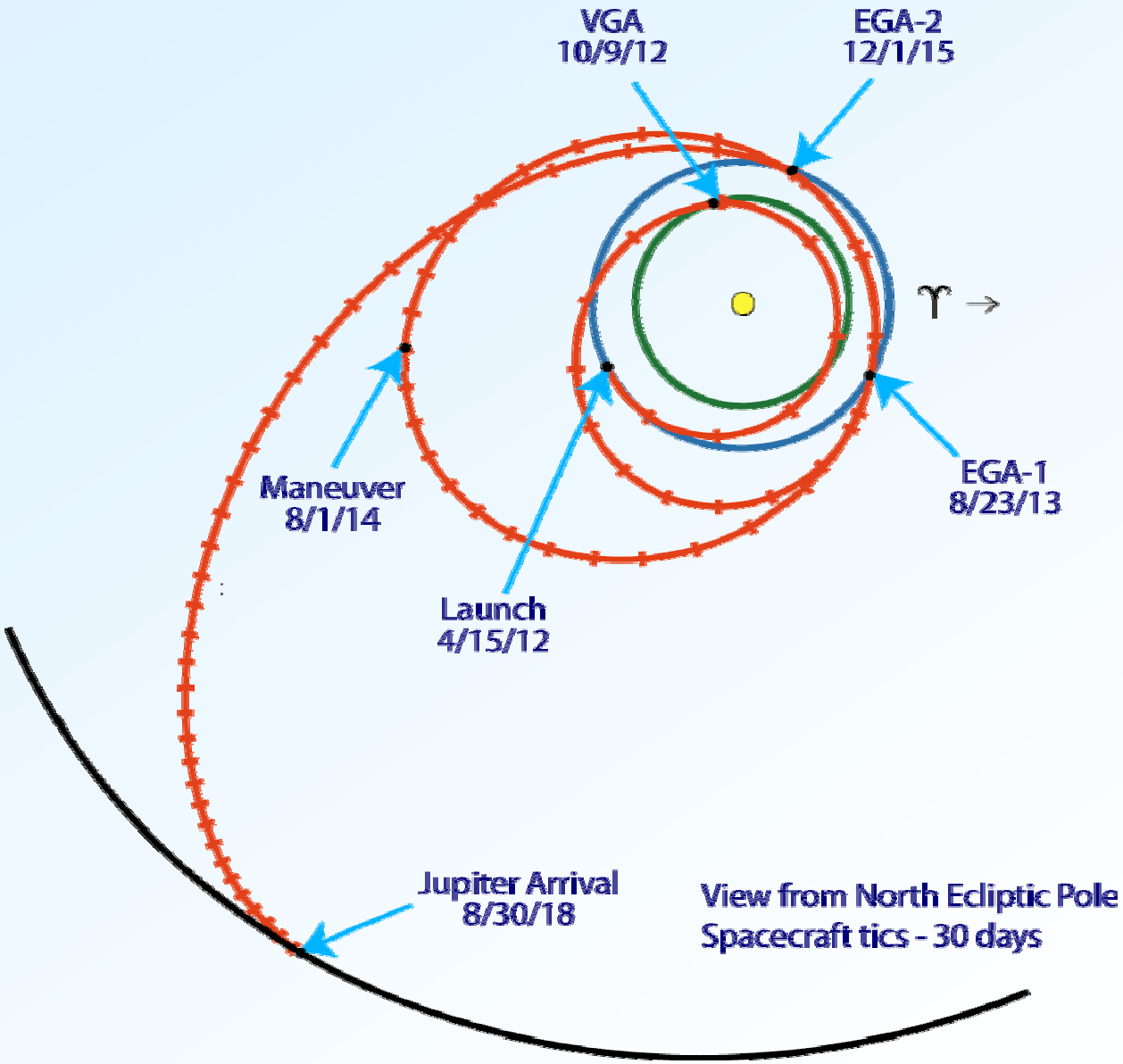
If an earlier or later launch date was selected, the maximum delivered dry mass would increase (for the time periods studied).

he ΔV-EGA trajectories shown at right have a ~2-year Earth-turn period, with the Earth flyby occurring during the inbound g of the Earth return transfer orbit. A similar ΔV-EGA ajectory (not shown), where the Earth flyby occurs during the utbound leg of the transfer orbit, goes through a perihelion of 0.9 AU, has a roughly comparable injected mass and orbiter y mass capability, and launches ~2 months earlier than the bound case

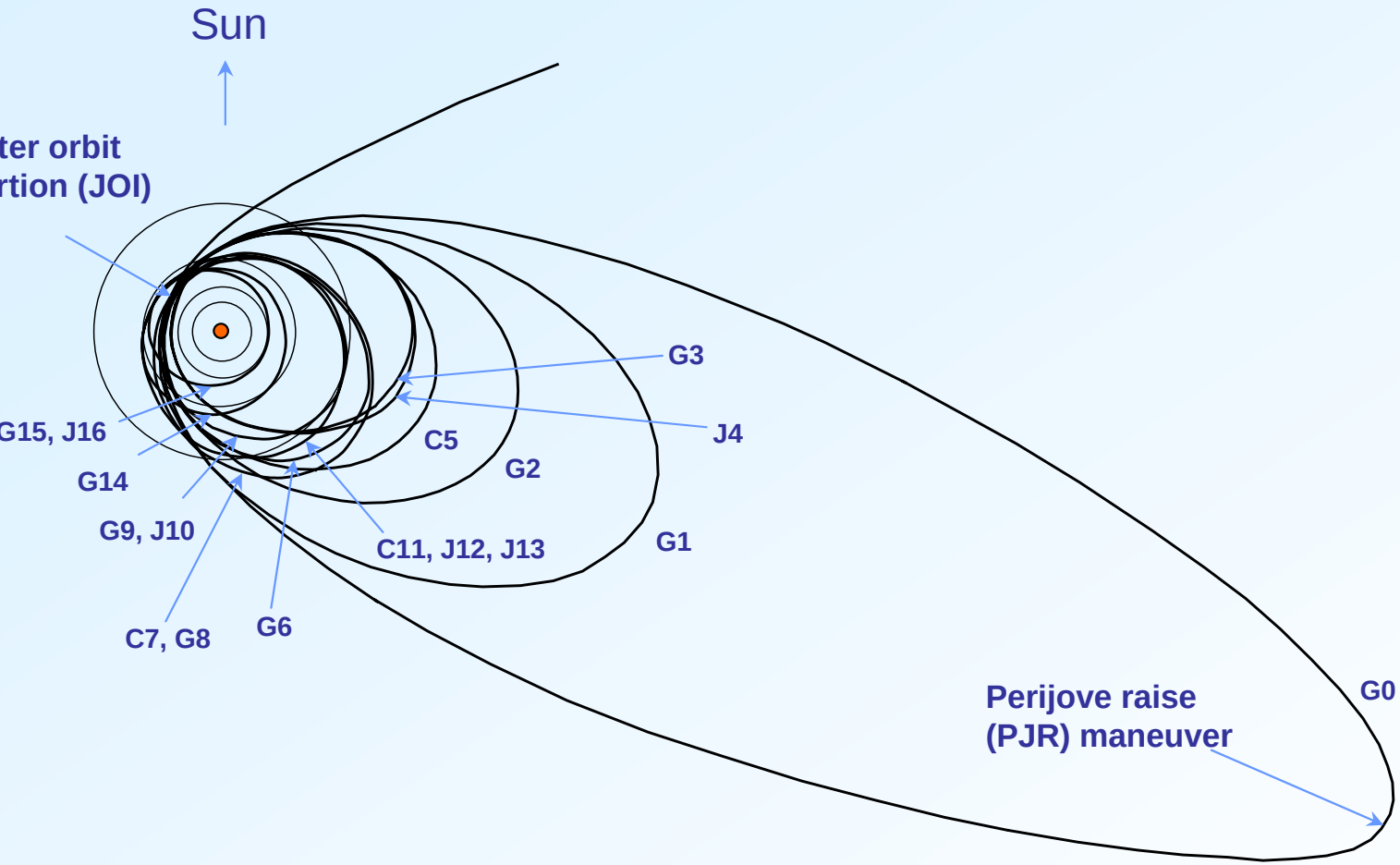




Representative VEEGA Trajectory



Representative Jovian Tour



un–Jupiter Fixed View

J = Jupiter
C = Callisto
G = Ganymede

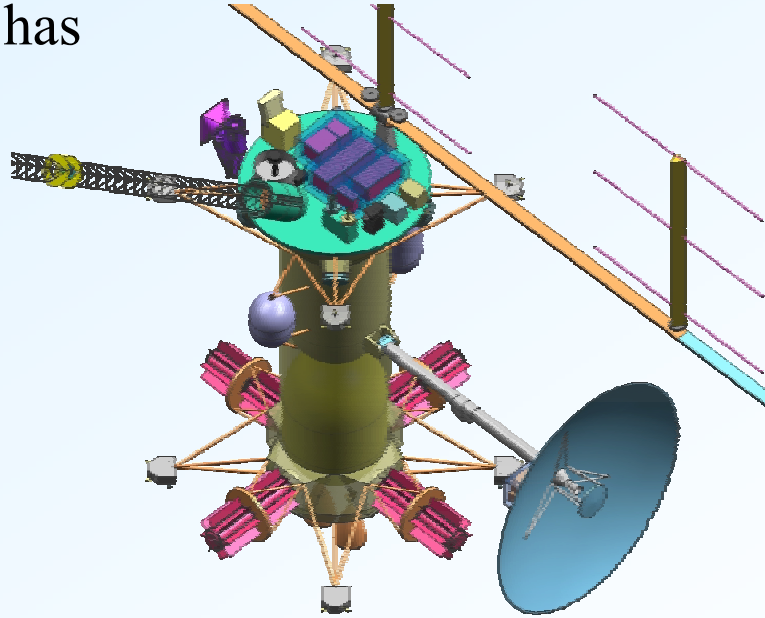
Encounter	Days Since Las Encounter
G1	—
G2	50
C3	34
G4	40
G5	21
C6	9
J7	
G8	39
J9	
G10	21
G11	7
J12	
E13	9
J14	
G15	13
J16	
E17	8
J18	
J19	
E20	14
J21	
J22	
J23	
J24	
J25	
EOI	23

Strawman Instrument Suite

Instrument	Mass (kg) (CBE)	Power (W), Day/Night	Approximate Dimensions (cm)	Field of View (deg)
Wide-angle Camera (WAC)	3	3/1	15x5x5 (optics) 5x15x20 (electronics)	59 x 59
Medium-angle Camera (MAC) (2 sensors)	10	10/1	15x10x5 (optics) 5x15x20 (electronics)	7 x 0.1
IR Mapping Spectrometer (IMS)	12	15/1	37x39x83 (optics) 20x25x13 (electronics)	34 x 0.1
Laser Altimeter (LA)	12	21/21	75x60x60	0.05 x 0.05
Ice Penetrating Radar (IPR)	30	61/5	20x30x20 (electronics) + 30-m dipole + 10-m x 2.6 m Yagi (65x25x25 stowed)	
Thermal Imager (TI)	11	1/14	29x37x55	17 x 0.2
Magnetometer (MAG)	2	1/1	2x2x2 (2) + 10-m? boom	
Ion and Neutral Mass Spectrometer (INMS)	10	28/28	19x23x32	
MeV Ion Spectrometer (MIS)	10	10/10	20x27x36	
KeV Ion Spectrometer (KIS)	7	11/11	20x27x36	
TOTAL ALL INSTRUMENTS	107	161/93		
TOTAL ALL INSTRUMENTS + 43% contingency	153	230/133		
Additional radiation shielding	20			
Avg daylight power use, W		111		
Avg nighttime power use, W		88		
Orbital average with assumed duty cycles without contingency		99		

EE Reference Mission Capability

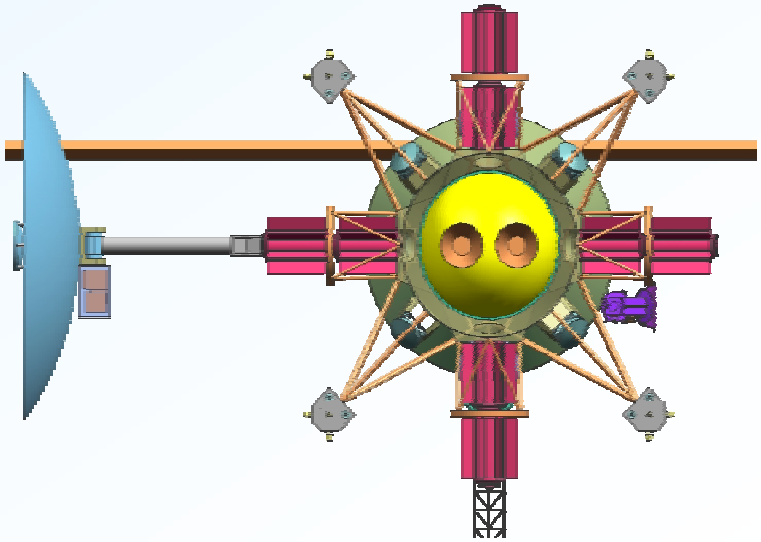
The reference Europa Explorer mission concept has the following capabilities:



- Launch mass capability: 7230 kg
- Spacecraft wet mass: 6888 kg
- Spacecraft dry mass: 2608 kg
- Power available (EOM): 823 W
- Number of MMRTGs: Eight
- Data rate (@5.5 AU): 400 kb/s

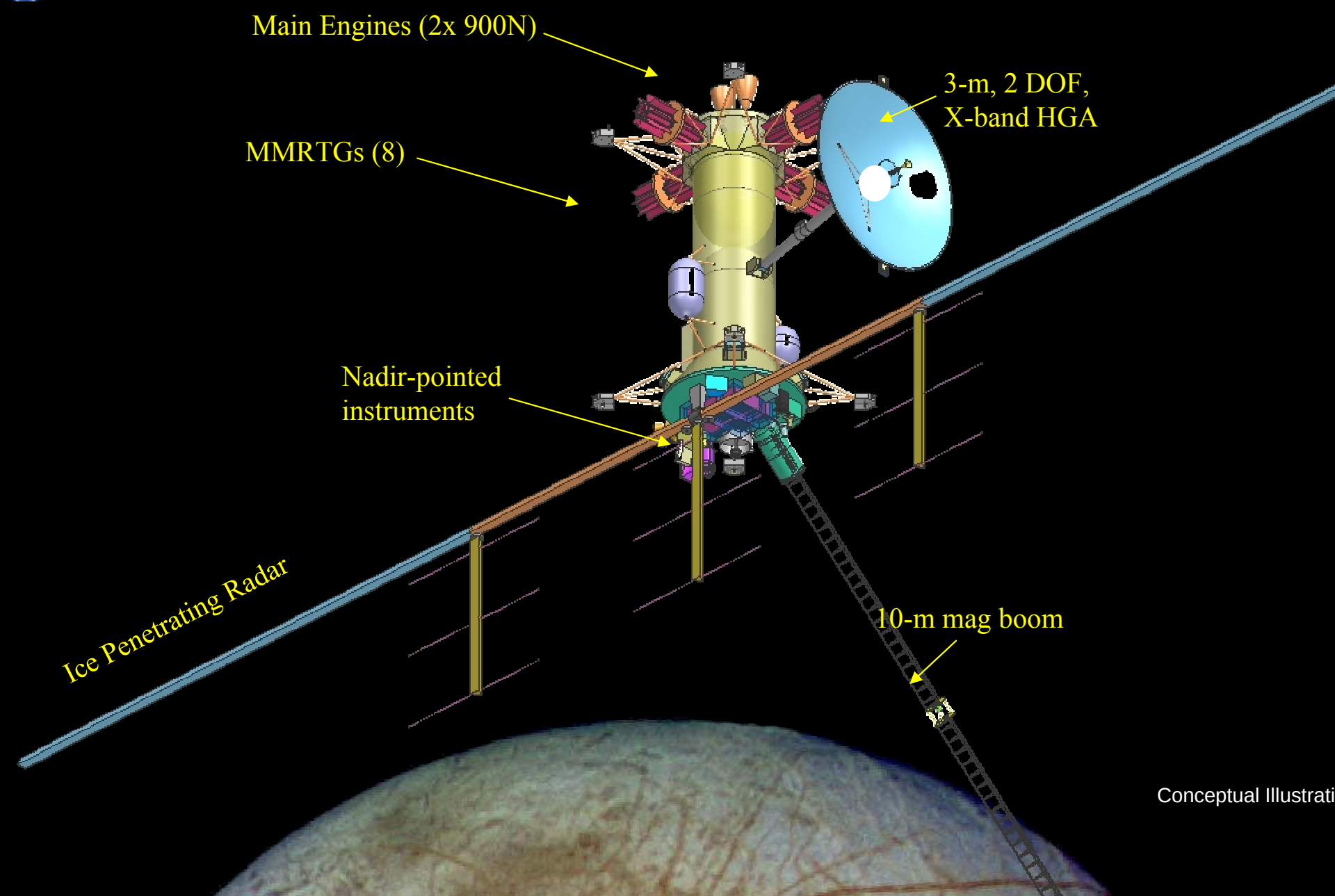
This leaves an additional 342 kg of unallocated mass that may be used for greater spacecraft margin and/or mission enhancements.

- **Unallocated EE mass: 342 kg**



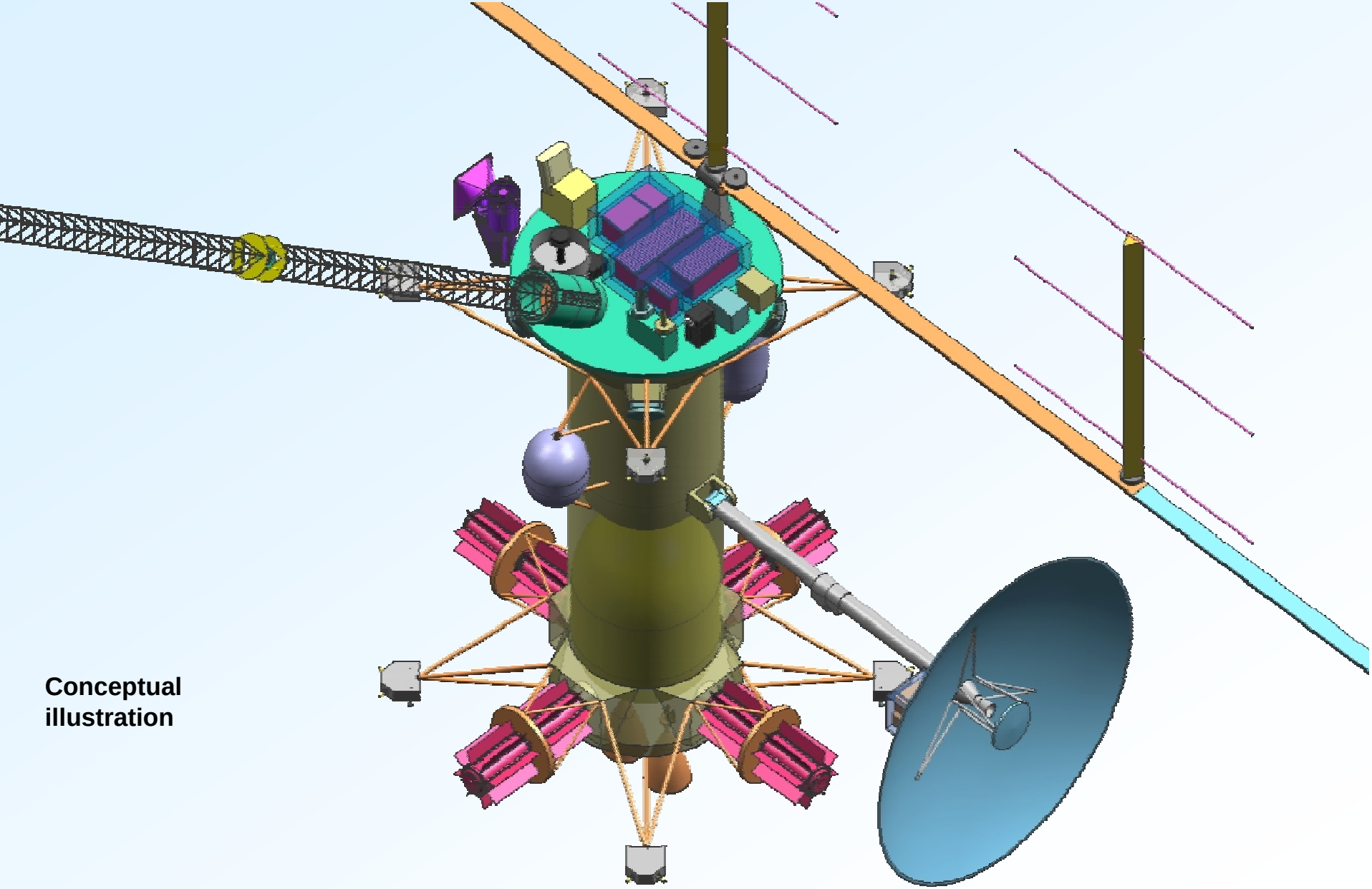
Conceptual Illustrations

Spacecraft Configuration



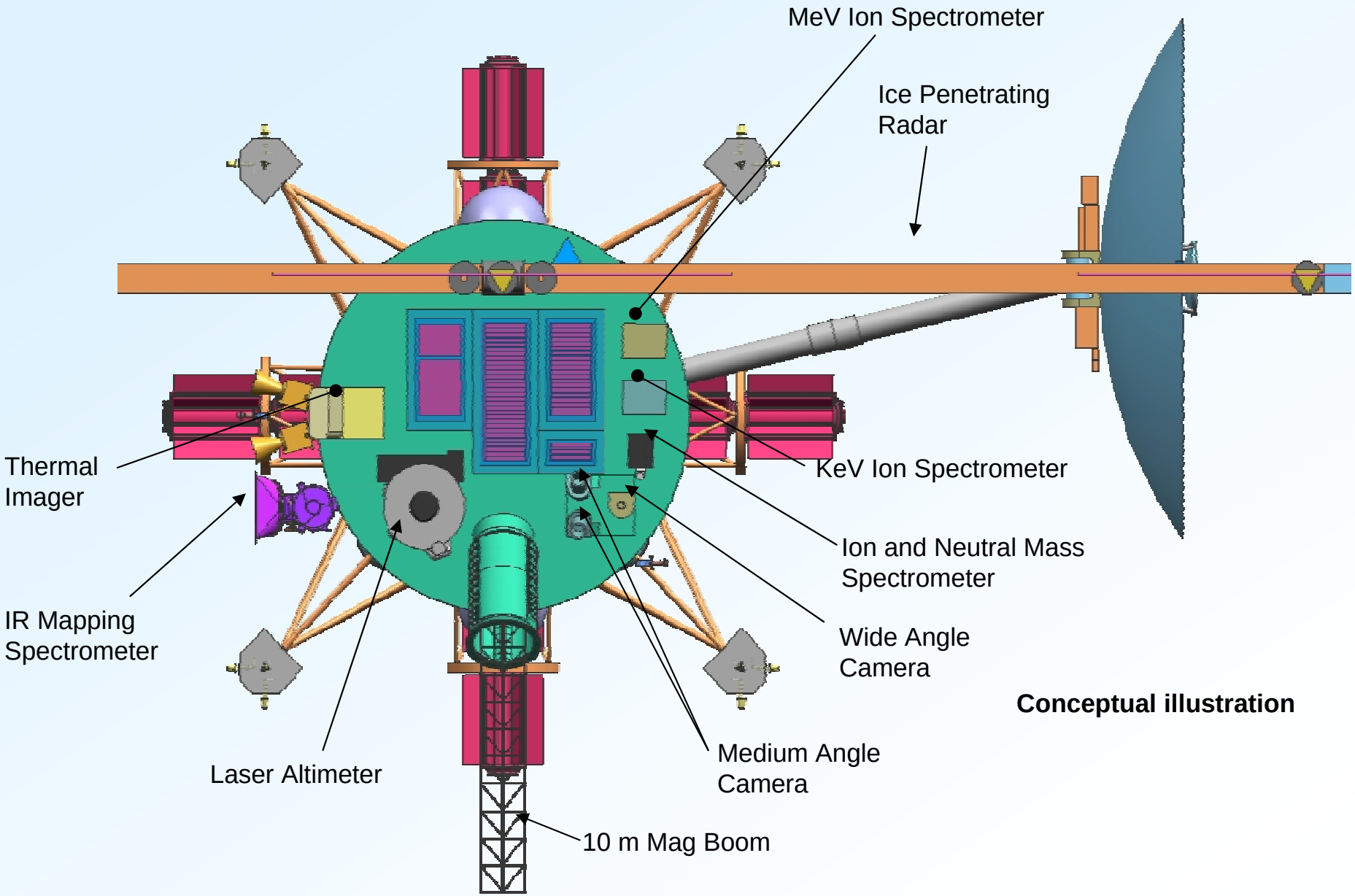
Conceptual Illustrati

Spacecraft Configuration



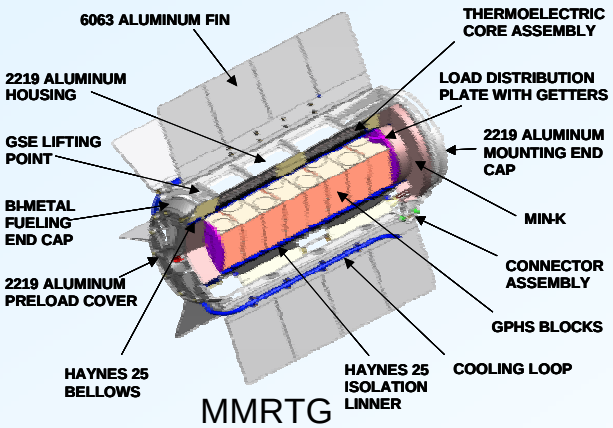
Conceptual illustration

Science Instrument View



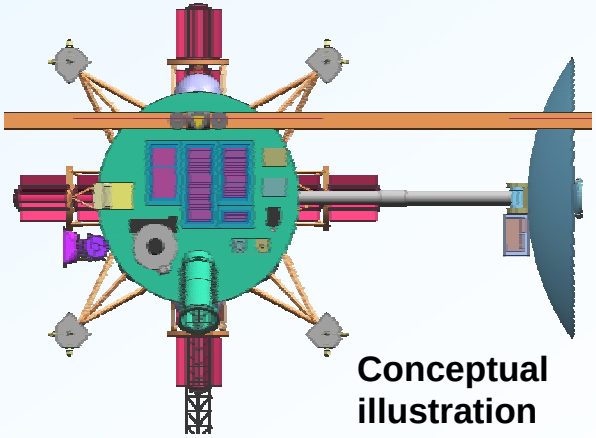
Spacecraft Functional Description (1 of 2)

- General
  - 3-axis stabilized
  - MMRTG powered, with battery
  - 10 body-fixed instruments
  - Deployed appendages: HGA, MAG, IPR antenna array



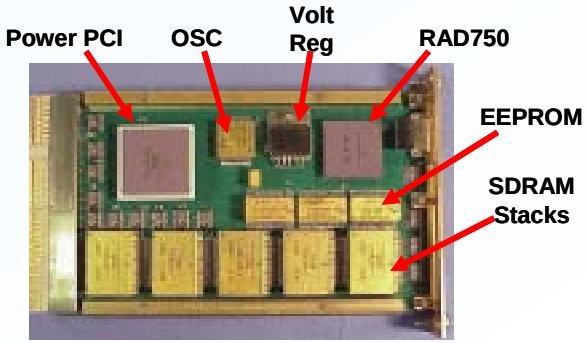
MMRTG

- Communications
  - X-band; 50 W(RF); gimbaled 3m HGA
  - Ka up/down for science; 3.5 W transmitter



2-DO
3-m H

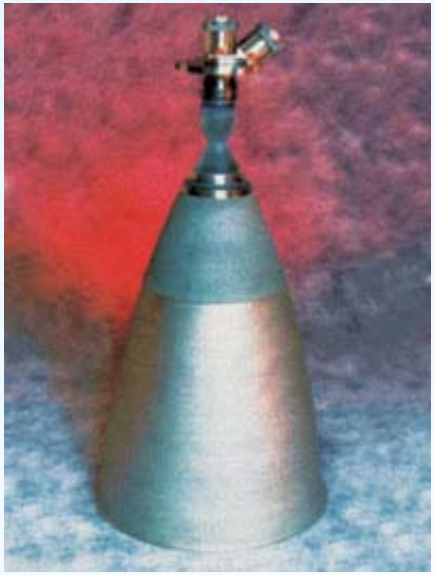
- Data Handling
  - RAD750 processors
  - 1553 bus + LVDS interfaces
  - Separate science computer and mass memory
  - Small mass memories: 0.5 – 0.75 Gbit



RAD750 Processor

Spacecraft Functional Description (2 of 2)

- Attitude and Propulsion
  - Reaction wheels
  - Star sensor/IRU/sun sensors
  - 900 N bipropellant main engine
  - 4.5 and 32.5 N monoprop thrusters
  - Translational thrusting in 6 directions



Notional bi-prop thruster

- Thermal Control, using:
  - RTG waste heat
  - 140 Radioisotope Heater Units (RHUs)
    - 120 used on Galileo
    - 117 used on Cassini
    - 8 used on each MER rover
  - Electrical heaters, blankets, louvers, etc.

Radioisotope Heater Unit (RHU)

Telecommunications and Data Volume

The limited mission duration (90d at Europa) and the high instrument data rates drive the reqt for a high-performance telecom system.

An articulating (2-DOF) 3m diameter X-band high-gain antenna (HGA) is used with redundant 50-W (RF) amplifiers.

Would concurrently gather and downlink data during communications periods.

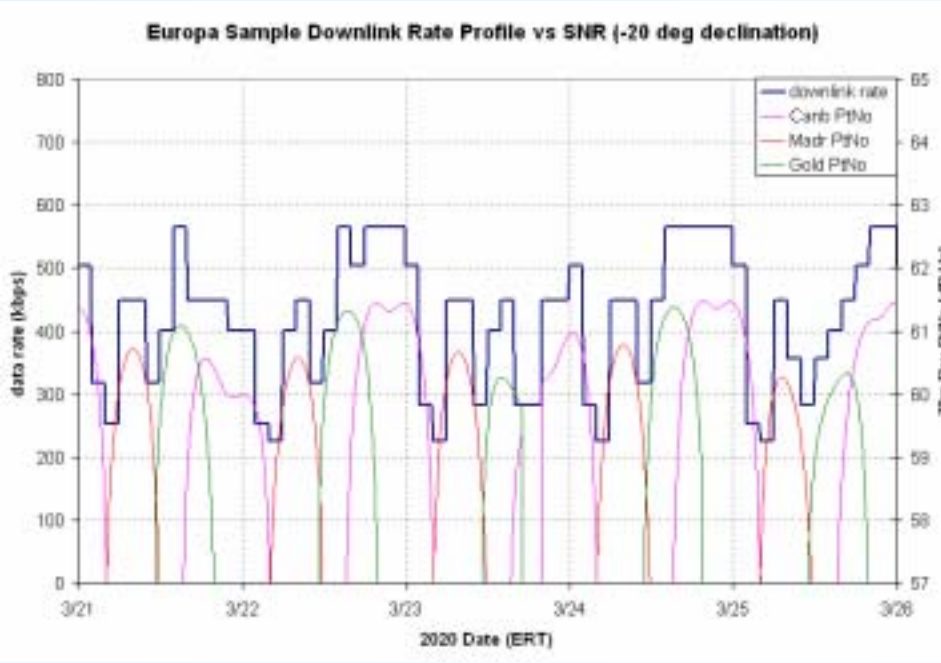
Average mission downlink rate would be 530 kb/s using 70-m DSN antennas (or equivalent).

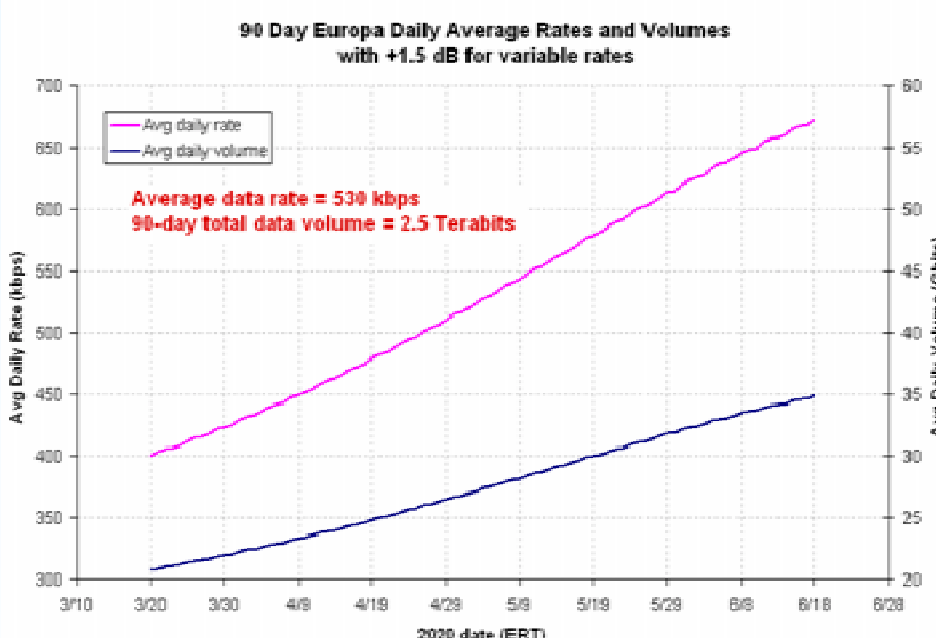
Would use orbit-optimized data rates to maximize downlink data volume.

Europa orbit period is 2.05 hours (at 100 km altitude assumed for EE). Corresponds to:

- Comm w/ Earth: 63% of orbit (77 min)
- No comm: 37% or orbit (46 min)

90 day total data volume would be ~2.5 Tbits





Propulsion: ΔV and Propellant Usage

Activity	Delta V (m/s)	Prop Mass (kg)	Description
Launch Injection Correction	30	67	Corrects S/C insertion errors from LV. Assumes that 90 kg stays behind with launch vehicle (i.e., fopr LV adapter - conservative assumption used for estimating fuel mass).
Earth Biasing	50	110	Total set of correction maneuvers to target S/C to proper Earth flyby trajectories for both Earth flybys. May be integrated with other TCMs or performed on their own.
DSMs	215	454	Course correction DV during Cruise phase. Assumes most conservative case in 21d launch period centered around June 23, 2015.
Interplanetary TCMs	20	59	Comprised of many small statistical burns (total ~20 m/s).
JOI DV (with Ganymede GA)	1081	1855	Jupiter Orbit Insertion. One long propulsive maneuver.
Cleanup Maneuvers	25	36	Covers JOI, PJR, and EOI.
PJR	70	99	PeriJove Raise. One short propulsive maneuver.
Tour TCMs	150	205	Propulsive events reqt to perform tour. Assumes ballistic trajectory (minimal/no deterministic DV), and 3 maneuvers per flyby event (~10 m/s per flyby event, ~12-13 flybys total) - Includes statistical components (primarily) and deterministic components (
Endgame	300	382	Occurs after last Ganymede encounter - Assumed to be two maneuvers for this case (180 m/s and 120 m/s, respectively) - Could be more for other endgame architectures.
EOI	477	538	Propulsive event that brings Orbiter into initial 200 km altitude Europa orbit - includes gravity losses (27 m/s) for EOI.
Europa Altitude Change	40	41.6	Science orbit defined at 100 km circular, 70-110o inclination
Orbital Maintenance	50	74	Due to orbital instability - Occurs over duration of the science mission while in the science orbit.
Uncertainties - Biprop	50	50	Allocated Delta V for uncertainties in mission design (i.e., flyby architecture, timing to EOI, inclination changes, etc.) that would use the bi-prop system (>5 m/s). This is a WAG.
Uncertainties - Monoprop	50	71	Allocated Delta V for uncertainties in mission design (i.e., flyby architecture, timing to EOI, inclination changes, etc.) that would use the mono-prop system (≤5 m/s). This is a WAG.
Pressurant and Holdup	N/A	61	Pressurant and unusable propellant.
Residual Propellant	N/A	20	For Non Delta-V Propulsive Events (RW Desats, etc.)
Total	**2608**	**4123**	

Power and Mass Estimates

EE Power Estimates

Subsystem	Europa Explorer	
	Comm. Mode	Non-Comm. Mode
Payload	**106.25**	**88**
Instruments	106.25	88
Bus	**465**	**350**
AACS	94.2	90.2
CDH	137	137
Power	47.9	47.9
Propulsion	13	13
Structures and Mechanisms	11	0
Cabling	20.0	15.3
Telecom	123.8	28.3
Thermal	18	18
Total Power Level (CBE), W	**571**	**438**
Contingency%	**43%**	
Total Power Level w/ Contingency, W	**817**	**626**
Orbit Period, hrs	2.05	
Mode Duration per Orbit, hrs	1.29	0.76
Average Total Power Used per Orbit, W	**746**	
Total MMRTG Power Output at EOM, W	**823**	
Minimum usable MMRTG power, W	**70.6 ***	

* Additional available power beyond required 746 W

EE Mass Estimates

Subsystem	EE Mass, kg		
	CBE	Contingency	CBE + Contingency
Payload	**107**	**43%**	**153**
Instruments	107	43%	153
Bus	**1550**	**24%**	**1928**
AACS	36	38%	49
CDH	43	33%	58
Power (w/o RPSs)	58	43%	83
RPS Generators	353	2%	360
RPS Adapters and Struts	36	31%	47
Cabling	128	30%	166
Propulsion	221	30%	287
Structures & Mechanisms	542	30%	704
LV Adapter (S/C Side)	8	33%	10
Telecom	56	30%	73
Thermal	70	29%	90
Radiation Shielding	**165**	**41%**	**233**
System Margin (Separated Mass)	-	**16%**	**294**
Spacecraft Total Dry (e.g., Separated Dry)	**1822.2**	**43%**	**2608**
Propellant	4123		4123
Spacecraft Total Wet (e.g., Separated Wet)	**5945**		**6731**
LV Adapter (LV Side)	110	30%	143
System Margin (LV Adapter on LV Side)		13%	14
Launch Mass Wet	**6055**		**6888**

EE Special Cases and Trades

EE Special Case Studies

Three special cases are presented here for the EE concept study:

Case	S/C Dry Mass (w/ Cont.), kg	Launch Mass Wet (w/ Cont.) kg	C3, km2/s2	LV Injected Mass Capability, kg	Unallocated Mass, kg	Delta from Reference, kg	Assumptions
Reference	2608	6888	14.14	7230	342		Delta IV-H, VEEGA, 8 MMRTGs
3 GPHS-RTGs	2314	6565	14.14	7180	615	273	Delta IV-H, VEEGA, 3 GPHS-RTGs and use of acoustic blankets (that reduce injected mass capability by 50 kg.)
DeltaV-EGA	2373	5809	26.94	5580	-229	-571	Delta IV-H, DeltaV-EGA, 8 MMRTGs
Altas V-551	2275	5227	14.14	4920	-307	-649	Atlas V-551, VEEGA, 8 MMRTGs

- **The use of GPHS-RTGs would increase the unallocated mass to ~615 kg.**
  - **Is due to the higher specific power of the GPHS-RTGs compared with the reference MMRTGs.**
- **Implementing a ΔV-EGA trajectory would result in a negative mass margin.**
  - **Results from the higher launch energy requirement (C3) of the ΔV-EGA trajectory vs. VEEGA.**
- **Using an Atlas V-551 LV would result in a negative mass margin.**
  - **Is due to the lower injected mass capability of the Atlas V-551 vs. the Delta IV-H.**

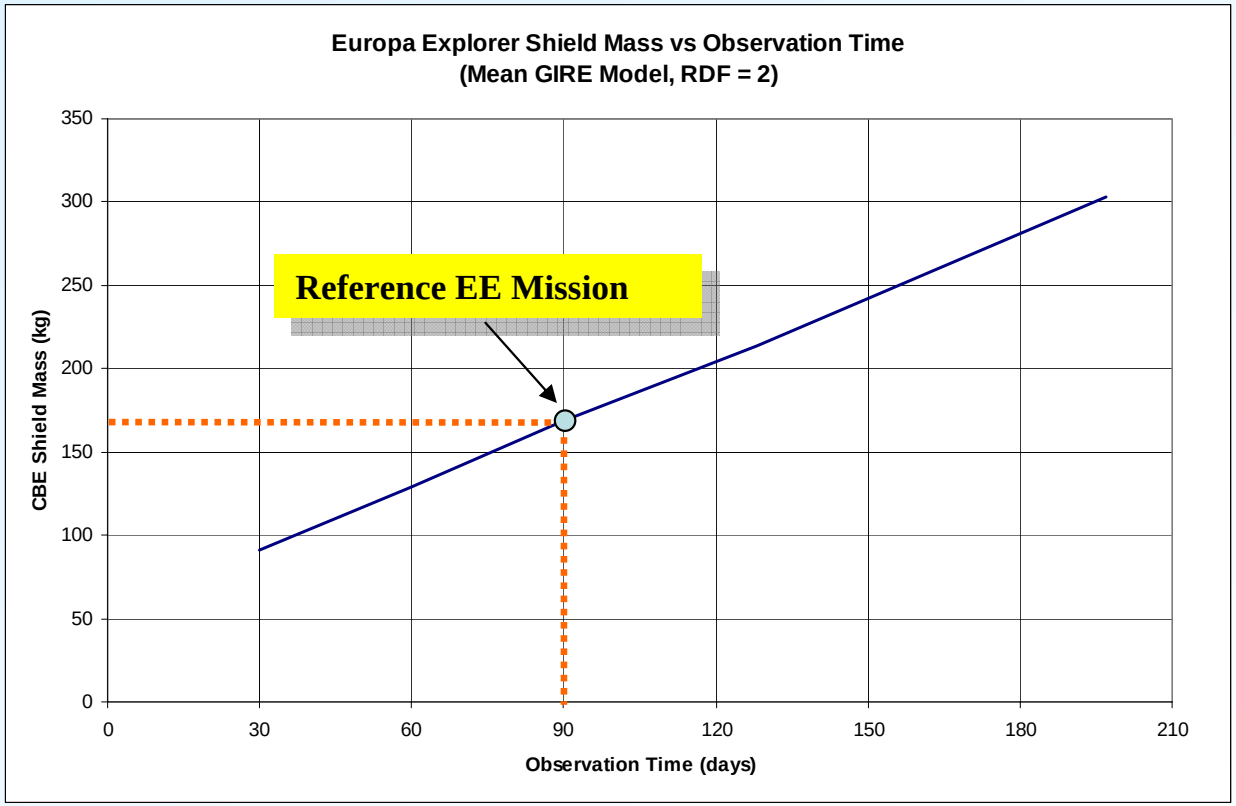
EE Trade Study: Mission Duration at Europa

Shielding mass estimates were made for mission durations ranging from 30 to 200 days (See plot).

The orbiter would experience ~1.2 Mrad (behind 100 mils Al) during the ~1.5 yr Jovian tour.

Each month at Europa would expose the spacecraft to ~720 krad (behind 100 mils of Al).

Shielding mass is approximately linear with observation time.



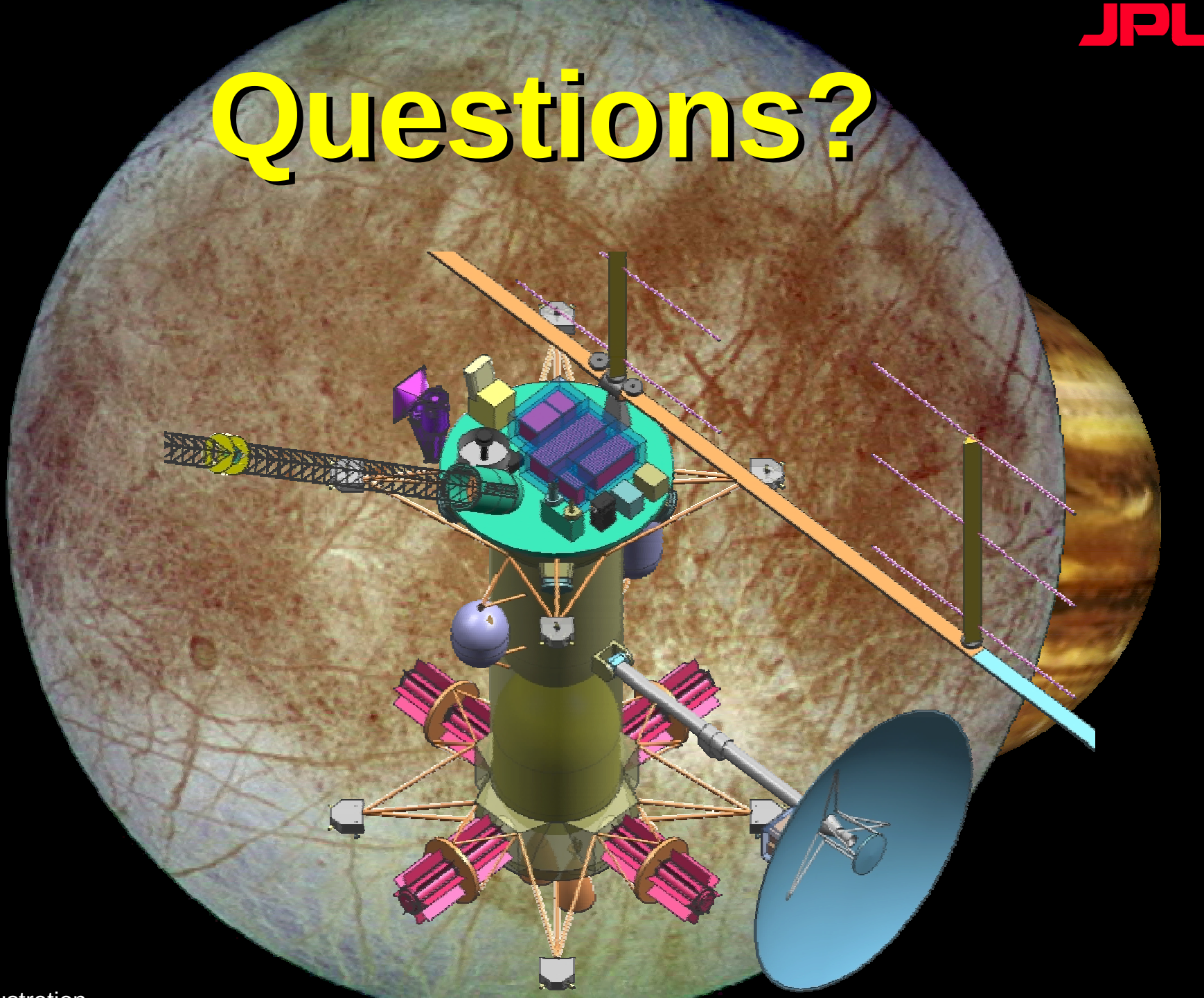
Would require ~165 kg (CBE) of shielding for the reference 90d orbital mission.

Would need ~40 kg (CBE) more shielding for each additional month in Europa orbit.

Summary

- The Europa Explorer would be fully operational in Europa orbit for at least 90
  - Is likely to continue observations for up to a year in Europa orbit.
- EE would produce 1000 times more close-up observations of Europa as the Galileo mission performed in six years of flybys.
- EE would carry 200 kg of instruments (including shielding and contingency).
  - Includes 10 instruments such as a hi-res imaging system, ice penetrating radar to search for subsurface liquid water, and a Ka-band transceiver for gravity science.
- EE would return at least 21 Gbits of Europa data per Earth day.
  - In just 90 days, the spacecraft would return 250x as much Europa data as Galileo, and more data than Cassini returns from Saturn in three years.
- EE would have ~340 kg of unallocated mass that could be used for additional margin, an enhanced science payload, and/or a Europa lander.
- No new technology development would be required for the EE spacecraft.
  - The Europe Explorer would use existing technology.

Questions?



Conceptual Illustration

Backup Material

Comparison of EE and EGE Concepts

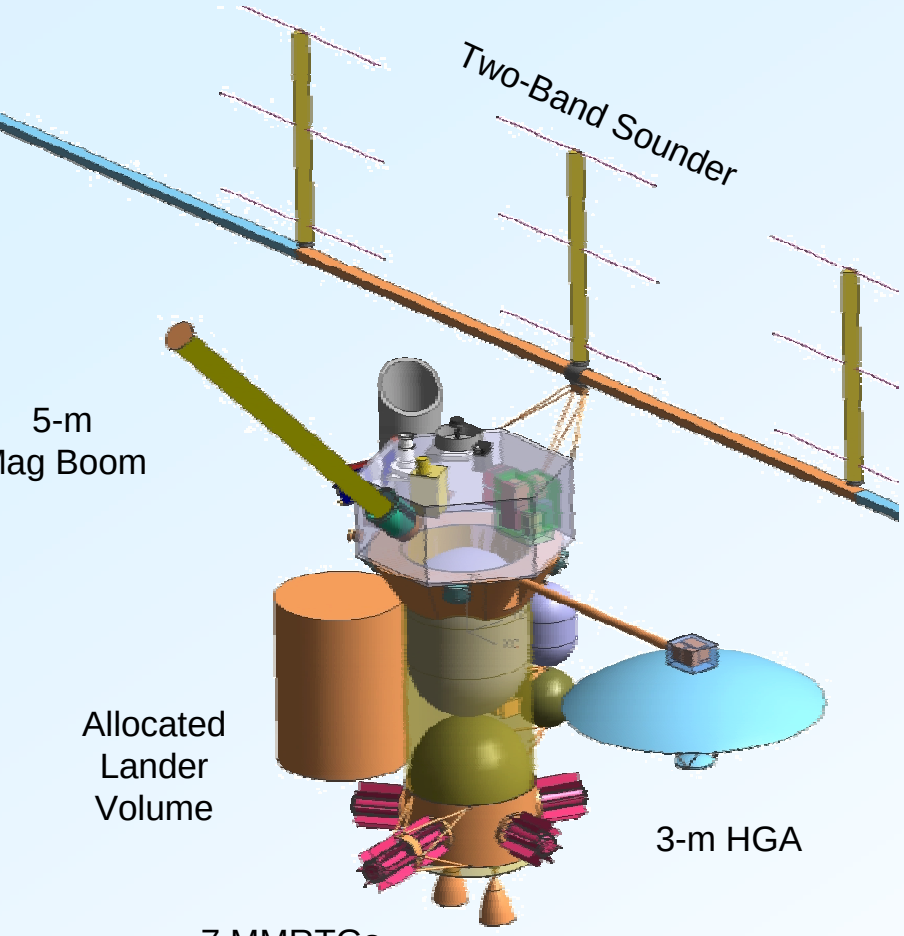
Key Differences between EGE and EE Studies

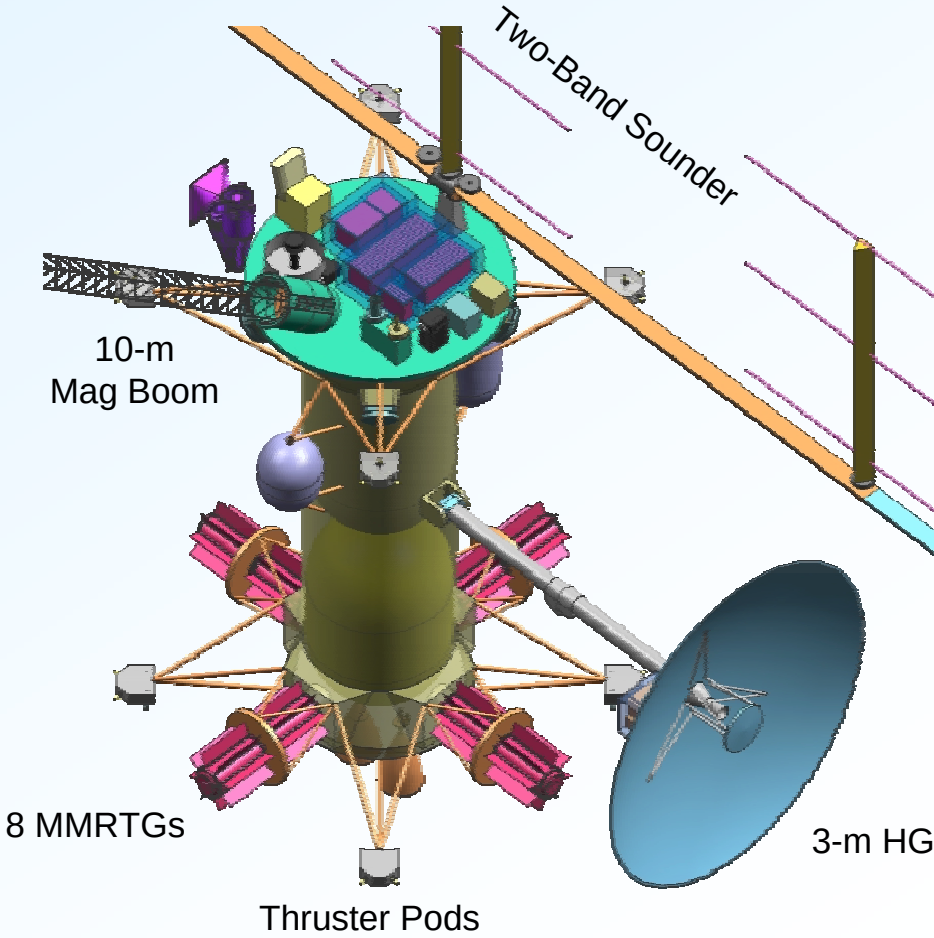
Parameter	Europa Geophysical Explorer (EGE) - 2005	Europa Explorer (EE) - 2005-2006
Prime Mission Duration*, days	30	90
Orbit	100 km circular, 80° inclination	100 km nearly circular, inclination between 70° and 110°
Wet Mass, kg	6374 (w/ full LV allocation)	6888 (w/ full LV allocation)
Dry Mass, kg	2404 (w/ full LV allocation)	2608 (w/ full LV allocation)
Number of Instruments	9	10
Payload Complement	Radar sounder, Laser Altimeter, WAC, VIS/NIR HiRes, VIS-MWIR Spec, INMS, keV Ion Spectrometer, MeV Ion Spectrometer, Magnetometer	Radar sounder, Laser Altimeter, WAC, MAC, IR Mass Spec, INMS, keV Ion Spectrometer, MeV Ion Spectrometer, Magnetometer, Thermal Imager
RPS	7 MMRTGs	8 MMRTGs
Telecom Antenna for Science D/L	3-m, 2-axes articulated, Ka-band	3-m, 2-axes articulated, X-band
Downlink Rate	~340 kbps (~5.2 AU)	~400 kbps (~5.5 AU)
Returned Data Volume in Prime Mission, Gb	529	2900
Data Storage	18 Gbits	750 Mb (Science SSR) 500 Mb (Flight SSR)
Predicted Radiation Environment	1.8 Mrad (behind 100 mils Al)	3.4 Mrad (behind 100 mils Al)
Shielding Mass, kg	195	233
Unallocated Available Mass, kg	856	342

* Prime mission is defined to start upon reaching Europa orbit, and does not include the ~1.5 year Jovian tour duration (common to both the EGE and EE studies) where scientific observations and measurements would be made of targets of opportunity. Additionally, the mission would be expected to last longer than the 30 days (EGE) and 90 days (EE) specified above.

Spacecraft Configurations

EGE Configuration



Conceptual Illustrations

EE Configuration