EPFL

EPIC Mission : Europa Probe for Interior Structure Characterization

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Ecole polytechnique fédérale de Lausanne

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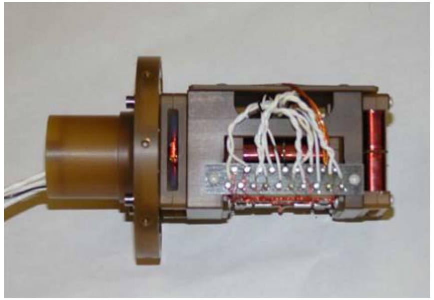
Mission definition

- **Mission statement** : orbit around Europa to characterize its interior structure
- **Launch window** : August 2029 on a mother spacecraft
- **Mission duration** : 6 months in orbit
- **Customers** : NASA and ESA
- **Mission class** : M-class (<100M USD)
- **Financial partners** : US government and ESA's member states
- **Constraints :** low mass, shielding
- **Heritage** : Messenger, New Horizons, Cassini, current missions (Juice and Europa Clipper)
- **Novelty** : compute magnetic and gravity fields at synodic (Jupiter's rotation) and orbital (Europa's orbit) periods

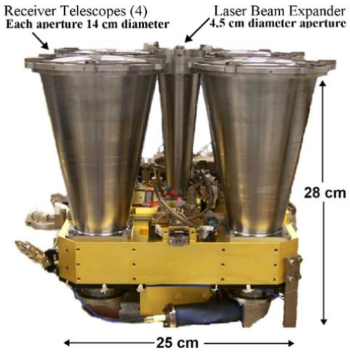
Science objectives

- **Main goal** : characterize the interior structure of Europa
  - existence of liquid water subsurface ocean
  - composition (salinity, conductivity) and depth of this ocean
- **Investigations** :
  - Europa’s magnetic induction response
  - amplitude and phase of gravitational tides
  - amplitude and phase of topographic tides
  - Europa’s rotation state

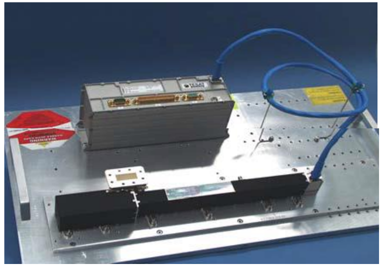
Payload



Dual 3-axis Fluxgate Magnetometer Sensor (MESSENGER)



Laser Altimeter (MESSENGER)

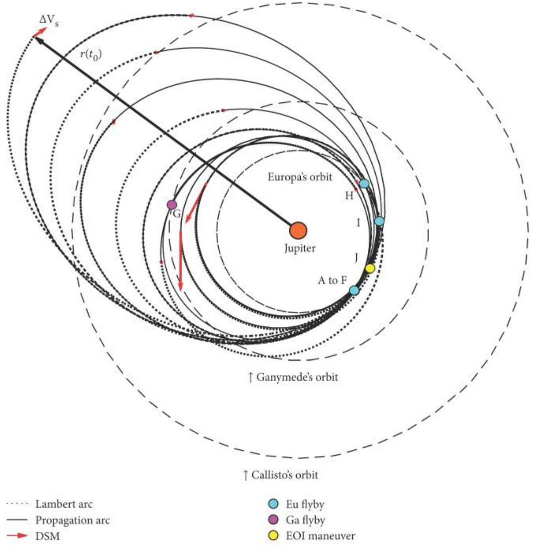


Radio Science Subsystem (IRIS V2 Transponder, Juno)

Langmuir Probe (Cassini)

Mapping Camera (MESSENGER, New Horizons)

Transit and Orbit



Phase	Subphase	DV [m/s]	Start-end
Interplanetary	Launch	/	10 Oct. 2024 – 11 Ap. 2030 (5.5 years)
	Cruise	0	
	Jupiter orbit insert.	/	
Jovian tour	Released by Clipper	0	11 Ap.2030 – 1 Nov. 2030 (130 days)
	Pre-insertion	159	
	Europa orbit insert.	716	
Europa orbit	/	43	1 Nov. 2030 – 1 May 2031 (6 mo.)
End of life	/	0	/

Orbital element	Value
Semi-major axis [km]	1810.8
Eccentricity	<0.00001
Inclination [°]	98.184
Right ascension of ascending node [°]	90
Argument of perigee [°]	15
True anomaly [°]	Varying

Orbital period [hours]	2.37
Altitude [km]	250
Coverage	Near-global coverage
Eclipse	2.85 hours every 85 hours

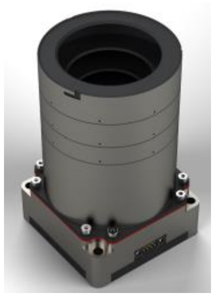
Orbit characteristics

Other subsystems

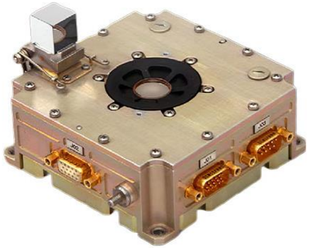
- **Telecommunications :**
  - Communicate through mother spacecraft HGA
  - 1 conical horn HGA, 2 LGA, 1 transponder
  - X-band
  - Downlink margin : 12,9 dB
- **Command and Data Handling :**
  - Assume no mapping camera
  - RAD750 radiation-hardened with 512 Mbits of storage, up to 266 MIPS @200MHz
  - Data budget : 77 Mbits/orbit
  - SpaceWire network (highly fault-tolerant, low complexity in the wiring)

Other subsystems (cont.)

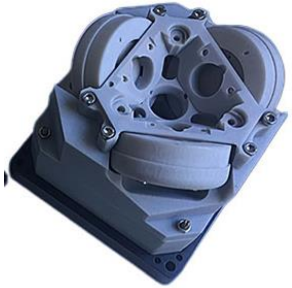
- **Attitude Determination and Control:**
  - Determination :
    - 2 Star Trackers STAR-T3
    - 2 Smart Sun Sensors
    - 1 Astrix NS three-axis Fiber Optic Gyroscope
  - Control :
    - three-axis-stabilized, sun-pointing reference
    - 4 Reaction Wheels RW3-1.0 (sized to perform a maneuver of 180° in less than 120s)
    - 12x 1N B1-thrusters for desaturation



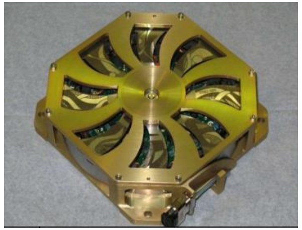
Star Tracker



Sun Sensor



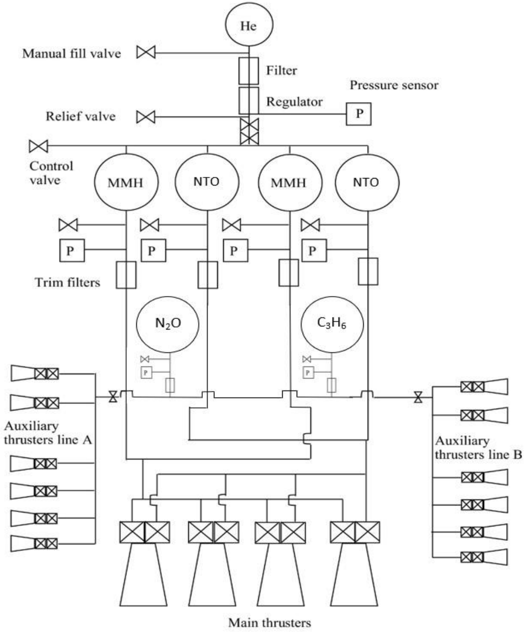
Fiber Optic Gyroscope



Reaction Wheel

Other subsystems (cont.)

- **Propulsion system :**
  - DV budget : 997 m/s
  - Primary propulsion :
    - Liquid bipropellant (MMH/NTO)
    - 4x 22N R-6F thrusters
  - Secondary propulsion :
    - Liquid bipropellant (N2O/C3H6)
    - 12x 1N B1 thrusters
  - Total propellant mass : 95 kg



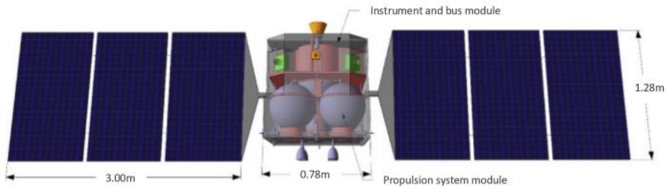
Other subsystems (cont.)

- **Electrical power :**
  - Daylight/Eclipse power demand : 90 W
  - Peak power : 135 W
  - Solar panels : 7,7 m² with GaAs cells
  - Battery : Li-ion, capacity 380 Wh
  - Architecture : Direct Energy Transfer with switching mode (3,3V; 5V; 28V)
- **Thermal system :**
  - Minimal temperature : -9,5°C, max : 12,5°C
  - Combination of gold multi-layer insulation blankets with black paint

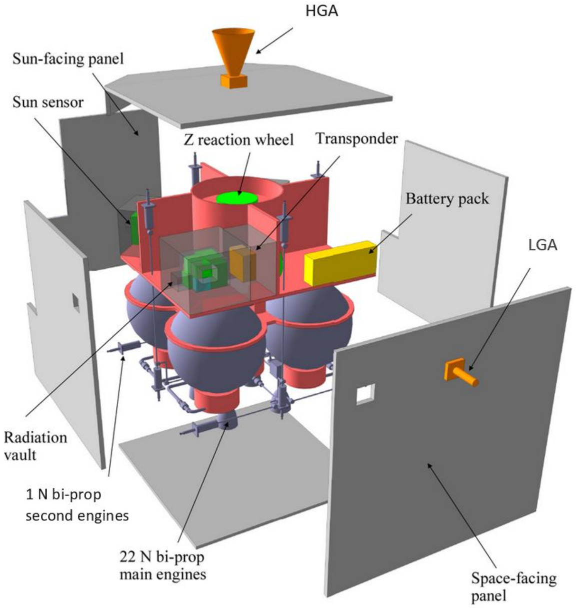
Subsystem/Component	Pre-EOI Mode	EOI Mode	Orbit (Sun, no ISL) Mode	Orbit (Sun, ISL) Mode	Orbit (Eclipse, no ISL) Mode	Orbit (Eclipse, ISL) Mode	Safe Mode
Payload	0	0	21.3	21.3	21.3	21.3	0
Attitude and Orbit Control System							
- Star Tracker	2	2	2	2	2	2	2
- Sun Sensor	0.7	0.7	0.7	0.7	0.7	0.7	0.7
- Gyroscope	7	7	7	7	7	7	7
- Reaction Wheel	0	0	15.01	15.01	15.01	15.01	0
Communication system							
- Solid State Power Amplifier	20	0	0	20	0	20	20
- Transponder	1	0	0	1	0	1	1
Thermal Control System	3	3	3	3	3	3	3
Propulsion System	25	100	2	2	2	2	2
On-Board Data Handling	10	10	10	10	10	10	10
TOTAL	68.7	122.7	61.01	82.01	61.01	82.01	45.7
Margin	10	10	10	10	10	10	10
TOTAL	75.57	134.97	67.11	90.21	67.11	90.21	50.27

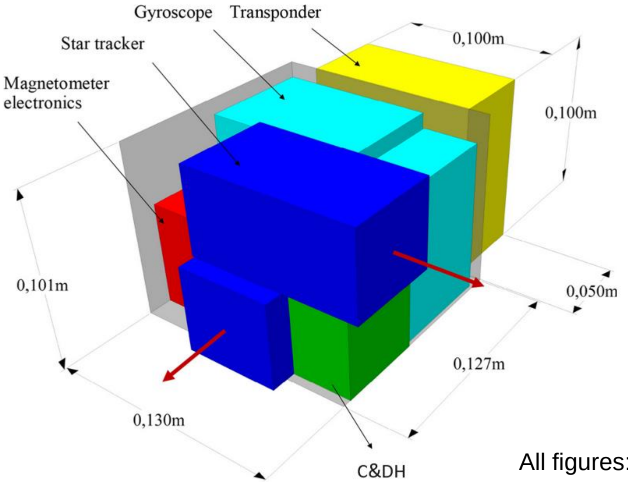
Power budget

Structure and Configuration



- **Design :** central structural support with 6 shear panels, aluminium
- **Shielding box :** aluminium, 5 cm thick (75 krad)

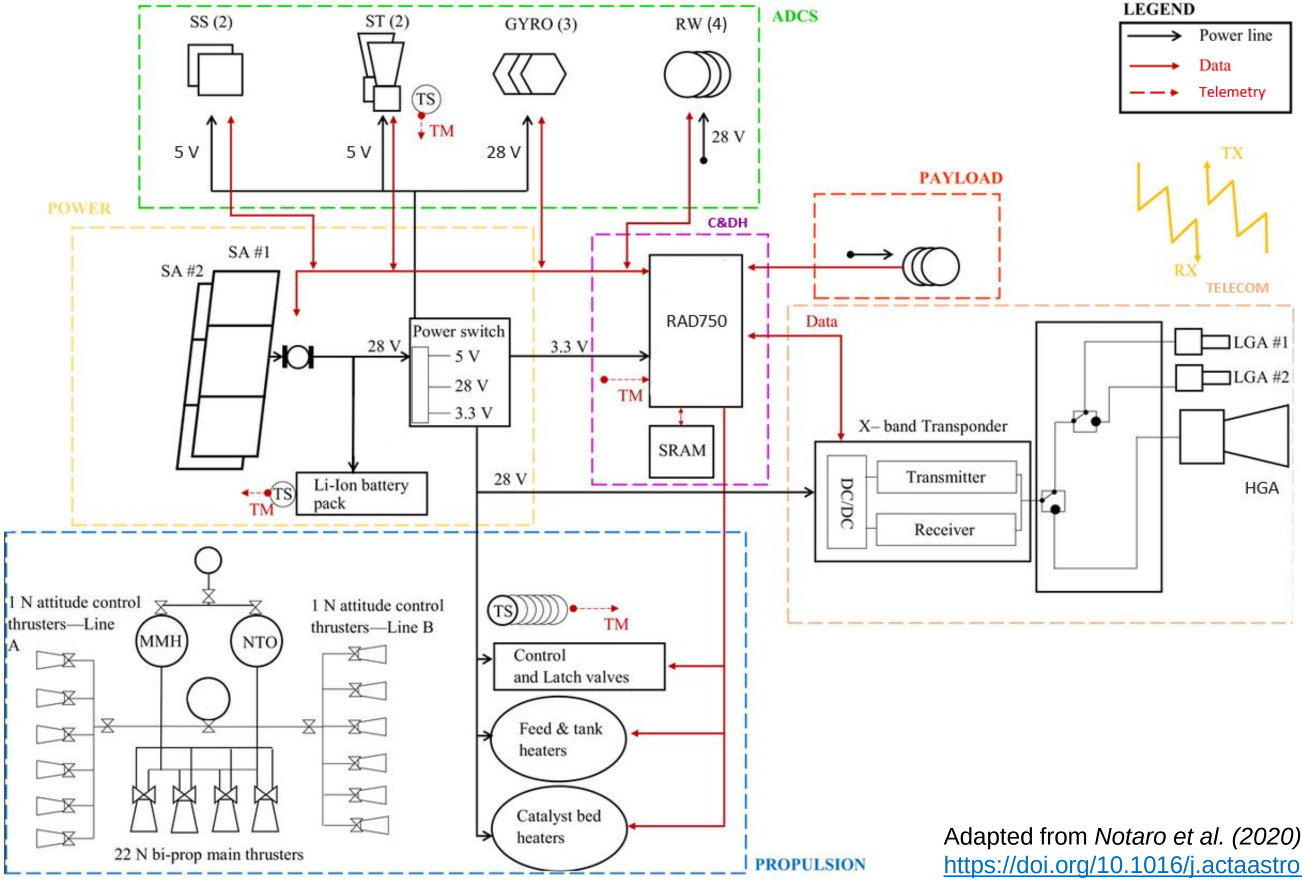




Shielding box

All figures:
Notaro et al. (2020)
https://doi.org/10.1016/j.actaastro.2019.10.017

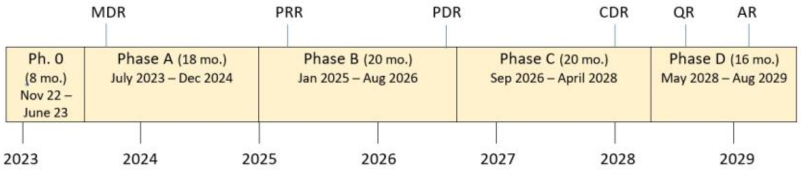
Functional block diagram



Adapted from *Notaro et al. (2020)*
https://doi.org/10.1016/j.actaastro.2019.10.017

Conclusion

- **Mass budget :** 371,2 kg
- **Can decrease with :**
  - More precise margins
  - Development of lighter technologies



Subsystem/component	Quantity	Unit mass [kg]	Current best estimate mass [kg]	Predicted mass [kg]
Propulsion (dry)				**29.88**
- Tanks	1	/	16.01 (TBC)	20.81
- Main engines	4	0.965	3.86	5.02
- Secondary engines	12	0.26	3.12	4.05
Attitude and Orbit Control System				**7.85**
- Sun sensor	2	0.33	0.66	0.85
- Star Tracker	2	0.35	0.70	0.91
- Gyroscope	1	0.80	0.80	1.04
- Reaction wheel	4	0.97	3.88	5.04
Electrical Power System				**34.36**
- Solar panels	1	22.56	22.56	29.33
- Li-ion battery	1	2.91	2.91	3.78
- Power Control and Distribution Unit	1	0.96	0.96	1.25
Thermal Control System				**0.65**
- Multi-Layer Insulation	1	0.50	0.50	0.65
On-Board Data Handling				**29.51**
- CPU and Static Random Access Memory	1	10.00	10.00	13.00
Payload			12.70	**16.51**
Structure				**120.96**
- Aluminium structure	1	51.98	51.98	67.57
- Radiation shielding	1	41.07	41.07	53.39
Telecommunications				**7.67**
- Medium Gain Antenna	1	3.00	3.00	3.90
- Low gain antenna	2	0.30	0.60	0.78
- Transponder	1	1.20	1.20	1.56
- Solid State Power Amplifier	1	1.10	1.10	1.43
TOTAL DRY mass				**247.40**
Propellant			95.23	**123.79**
TOTAL WET mass				**371.20**

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Science objectives and payload

Objective	Investigation	Measurement and requirements	Instrument
Characterize Europa's interior structure (existence and composition of potential liquid water subsurface ocean)	Determine Europa's magnetic induction response	Measure magnetic field components at synodic (11.1 h) and orbital (Jupiter rotation time scale, 85 h) periods	Magnetometer (MAG)
		Measure plasma density/temperature/flow around Europa to characterize the magnetic field induced by plasma currents and finally subtract it from magnetic field computed by MAG	Langmuir Probe (LP)
	Determine amplitude and phase of gravitational tides	Measure static gravity field and time-varying, degree-2 part of the gravity field at synodic period to estimate the Love number k_2 with an absolute accuracy lower than 0.0001	Radio Subsystem (RS)
		Determine spacecraft altitude with 1-m accuracy	Laser Altimeter (LA)
	Determine amplitude and phase of topographic tides	Measure topographical differences with a vertical 1-m accuracy to estimate the Love number h_2	Laser Altimeter (LA)
		Measure spacecraft velocity to determine its position with 1-m accuracy	Radio Subsystem (RS)
	Determine Europa's rotation state	Determine the mean spin pole direction by combining data from altimetry and imaging	Laser Altimeter (LA) Mapping Camera (MC)
		Determine the nutation and libration amplitudes	Laser Altimeter (LA)

Telecommunication system

- **Communication window :** 10 hours, every day
- **Data transmitted :** 770 Mbits per day

UL frequency [GHz]	8.424
UL data rate [kbits/s]	1 (emergency mode : 10 bps)
DL frequency [GHz]	7.170
DL data rate [kbits/s]	21.6 (emergency mode : 10 bps)
Modulation	Binary Phase-Shift Keying (BPSK)
Protocols	From CCSDS standards, such as - CCSDS TM Synchronization and Channel Coding : Turbo 1/6 Coding - CCSDS Radio Frequency and Modulation Systems
Linked receiver/transmitter	Europa Clipper HGA (no direct ground station on Earth)
Link margin [dB]	12.9
Hardware configuration	- Uplink/Downlink : X-band - HGA, 2 LGA, 1 transponder - Solid State Power Amplifier (SSPA)
HGA design	- conical horn - gain : 24 dBi - diameter : 0.3 m - output power : 2 W - mass : 3 kg
SSPA design	- power consumption : 20 W - mass : 1.1 kg

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Link budget

Parameter	Symb.	Unit	Value	Justification
Antenna			HGA	Gt > 20 dB
Frequency band			X-band	f = 7.17 GHz
DL Frequency	f	GHz	7.17	given by Europa Clipper HGA uplink
Wavelength	λ	m	0.042	c = f λ with c the speed of light, c = $3*10^8$ m/s
Range	R	m	10^9	highest distance with Europa Clipper [13]
Spacecraft				
Tx Antenna type			conic horn	same performances as a parabolic dish (gain, bandwidth, good directivity), easier to construct
Tx Antenna diameter	D	m	0.3	not too high to fit the spacecraft size, but enough to have a margin > 10 dB
Tx Antenna efficiency	ε	-	0.55 (TBC)	typical space antenna
Tx Half power beamwidth	c	°	10.8	θ = λ / (D sqrt(ε)) * 180/π
Tx Antenna gain	Gt	dBi	24.5	Gt = ε (πD/λ)^2
Tx Power output	Pt	W	2	not too small to have a margin > 10
Tx Circuit losses	Lt	dB	-1 (TBC)	estimated
EIRP (Effective Isotropic Radiated Power)	EIRP	dB W	26.5	EIRP = Gt + Pt|dB + Lt
Downlink path				
Free space path losses	Ls	dB	-229.5	Ls = [λ / (4πR)]^2
Tx Antenna pointing losses	Ltp	dB	-3 (TBC)	estimated
Rx Antenna pointing losses	Lrp	dB	-1 (TBC)	estimated
Polarization factor losses	Lp	dB	0	assume that circular polarizations are used in both antennas
Isotropic signal at mother spacecraft	Pr	dB W	-207.1	Pr = EIRP + Ls + Ltp + La + Lrp + Lp
Mother spacecraft				
Rx Antenna diameter		m	3	given by Europa Clipper HGA diameter
Rx Figure of merit	Gr/T	dB/K	30 (TBC)	estimated
Rx circuit losses	Lr	dB	-1 (TBC)	estimated
Signal-to-noise density ratio	S/N0	dB Hz	50.5	S/N0 = Pr + Lr + Gr/Ts – k|dB with k the Boltzmann constant, k = $1.38*10^{-23}$ J/K
Link performances				
Modulation			BPSK	very robust
Coding			rate 1/6 turbo	- chosen to obtain the lowest ratio Es/N0_r (see Annexe 8), to enable the highest margin - with an information block length of 3568 bits
Required bit error rate	BER	-	10^{-5}	requirement
Duration of transmission	t	hours	10	estimated
Storage	s	Mbits	770	computed in Section 10
Bit rate	r	kbps	21.6	r = s/t
Bandwidth	B	kHz	21.6	B = r when using BPSK
Achieved Es/N0	Es/N0_a	dB	7.2	Es/N0 = S/N0 - B|dB
Required Es/N0	Es/N0_r	dB	-7.7 (TBC)	given by BER and coding (see Annexe 8)
Implementation losses	Li	dB	-2 (TBC)	estimated
Link margin	M	dB	12.9	M = Es/N0_a - Es/N0_r + Li

Electrical power system

- **Solar panels :**

$$P_{sun} = \frac{k}{\eta_{cell}} \frac{\frac{P_d T_d}{\eta_d} + \frac{P_e T_e}{\eta_e}}{T_d}$$

$$P_{sun}/60 = 7.69 \text{ m}^2$$

- **Battery :**

$$C = \frac{P_e T_e}{(DoD)\eta}$$

Reaction wheels

- Find T_max for which the reaction wheel can perform a maneuver of 180° in less than 120 s

$$t_{\text{slew}} = \sqrt{4\frac{\theta_{\text{slew}} I_{sat}}{T_{max}}}$$

$$I_{sat} = \frac{m}{12}\left(s_1^2 + s_2^2\right)$$

Propellant mass

$$m_{prop} = m_f \left[\exp\left(\frac{\Delta v}{g_0 Isp} \right) \right]$$

- m_f : the dry mass (with margin, $m_f = 247.40$ kg);
- g_0 : the gravitational constant (9.80665 m/s^2);
- Isp : the specific impulse (285 s for the main engines and 305 s for the secondary system);
- Δv : the velocity increase of the vehicle (using a 10% margin, $\Delta v = 175$ m/s for pre-insertion phase, $\Delta v = 800$ m/s the Europa orbit insertion, and $\Delta v = 50$ m/s for the attitude control once in orbit, with corrections to do just after the orbit insertion).

Thermal system : heat balance equation

$$Q_{rad} = Q_s + Q_{a,jup} + Q_{a,eur} + Q_{ir,jup} + Q_{ir,eur} + Q_{int}$$

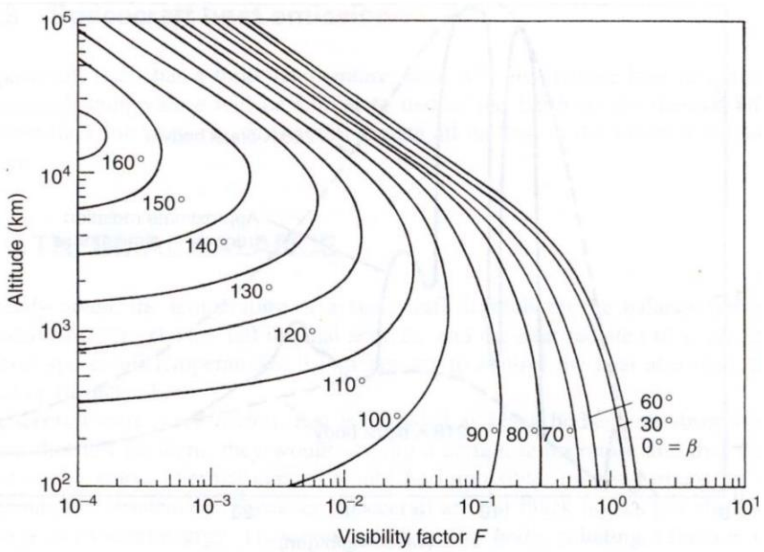
- solar radiation $Q_s = \alpha A J_s$;
- albedo radiation from Jupiter $Q_{a,jup} = \alpha A J_{a,jup}$;
- albedo radiation from Europa $Q_{a,eur} = \alpha A J_{a,eur}$;
- infrared radiation from Jupiter $Q_{ir,jup} = \alpha A J_{ir,jup}$;
- infrared radiation from Europa $Q_{ir,eur} = \alpha A J_{ir,eur}$;
- dissipated heat inside the spacecraft $Q_{int} = 67.1$ W during no-ISL Modes, and $Q_{int} = 90.2$ W during ISL Modes (cf. power budget in Section 8);
- heat radiated to space $Q_{rad} = \sigma \epsilon A_{rad} T^4$.

$$\alpha = 0.35 \text{ and } \epsilon = 0.05$$

- $a_{eur} = 0.64$: the albedo from Europa [4];
- $F_{jup} = 10^{-3}$: the visibility factor on Jupiter. We assume this value because EPIC is more than 10^5 km far away from Jupiter (cf. Annexe 5);
- $F_{eur} = 10^{-1}$: the visibility factor on Europa. As EPIC has a dawn-dusk Sun-synchroneous orbit, we have $\beta = 90°$, at an altitude of 250 km, hence $F_{eur} = 10^{-1}$ (cf. Annexe 5);
- α : the solar absorptance;
- ϵ : the infrared emittance;
- $\sigma = 5.67 \cdot 10^{-8}$ W/m^2/K^4 : the Stefan-Boltzmann constant;
- A : the surface area exposed to the radiation. We assume that each radiation will hit the panel area of $A = 0.9 \cdot 0.9$ m^2 (with margin);
- A_{rad} : the surface area which is radiating, hence $A_{rad} = 6 \cdot 0.9 \cdot 0.9$ (with margin);
- $P_{aurora} = 50 \cdot 10^12$ W : the emitted power in the infrared band during aurorae on Jupiter (which are permanent and give most of the infrared power from the planet [33]);
- $d = 664862$ km : the distance between EPIC and Jupiter (approximated to the distance between Europa and Jupiter);
- $J_s = 60$ W/m^2 : the solar radiation at 5.2 AU (visible);
- $J_{a,jup} = a_{jup} F_{jup} J_s$: the albedo radiation from Jupiter (visible);
- $J_{a,eur} = a_{eur} F_{eur} J_s$: the albedo radiation from Europa (visible);
- $J_{ir,jup} = \frac{P_{aurora}}{4\pi d^2}$: the infrared radiation from Jupiter;
- $J_{ir,eur} = 1$: the infrared radiation from Europa, estimated at 1 since it is not expected that Europa emits a lot of heat power;
- T : the temperature at which there is a thermic equilibrium between the absorbed heat and the radiated heat.

Albedo and visibility factor

Planet	Solar radiation intensity, J_s (percentage of solar intensity at 1 AU)	Planetary albedo, a
Mercury	667	0.06–0.10
Venus	191	0.60–0.76
Earth	100	0.31–0.39
Moon	100	0.07
Mars	43.1	0.15
Jupiter	3.69	0.41–0.52
Saturn	1.10	0.42–0.76
Uranus	0.27	0.45–0.66
Neptune	0.11	0.35–0.62
Pluto	0.064	0.16–0.40



Speaker

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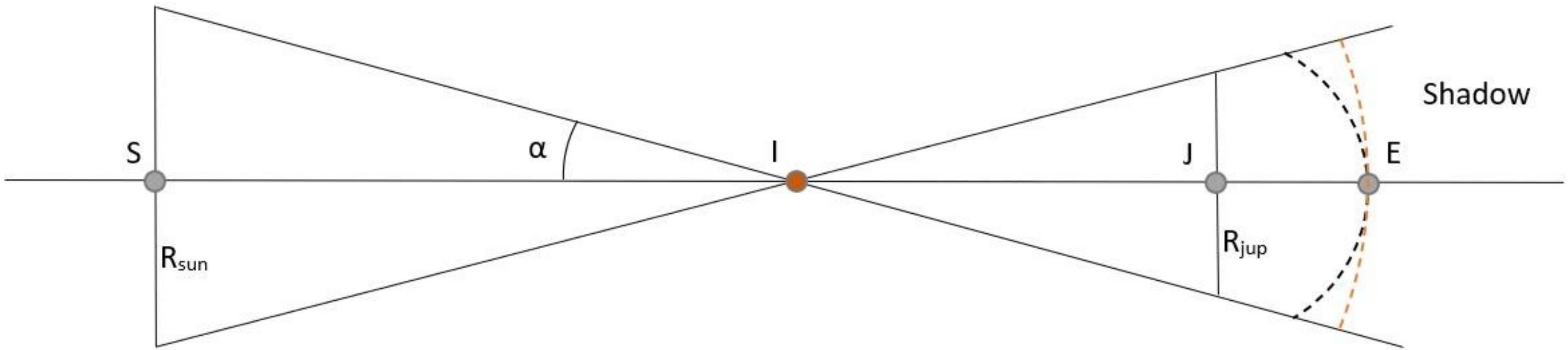
Eclipse duration

$$\frac{R_{sun}}{|SI|} = \frac{R_{jup}}{|SJ| - |SI|} \implies |SI| = \frac{R_{sun}|SJ|}{R_{jup} + R_{sun}}$$



$$d = \frac{|EI|2\alpha}{v_{Europa}} = \frac{(|SJ|+|JE|-|SI|)2\alpha}{v_{Europa}} = 2.85 \text{ hours}$$