JUICE
Jupiter Icy Moons Explorer

CaC Lessons Learned
Space Cost Engineering conference - SCE2022

Manuela Baroni, JUICE AIT & Launcher Interface Engineer, , ESA / ESTEC
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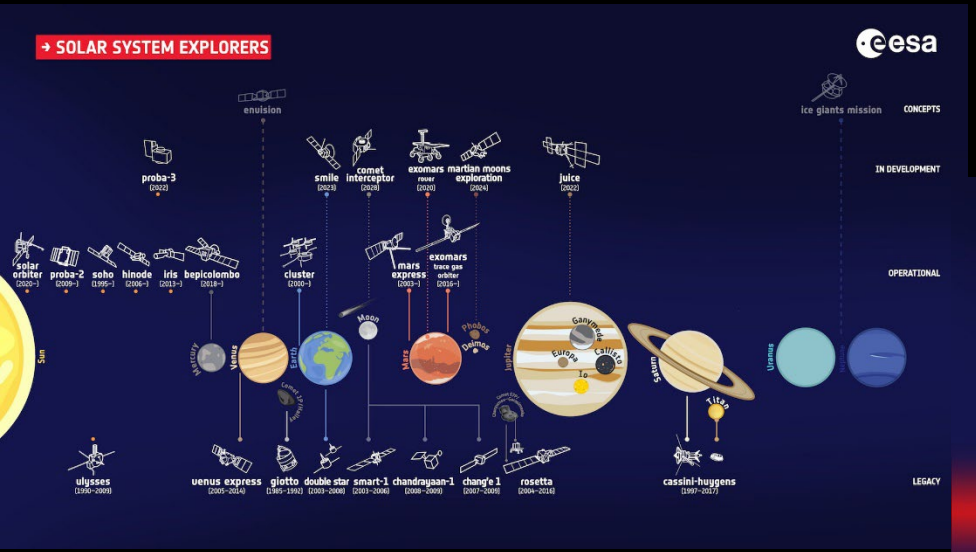
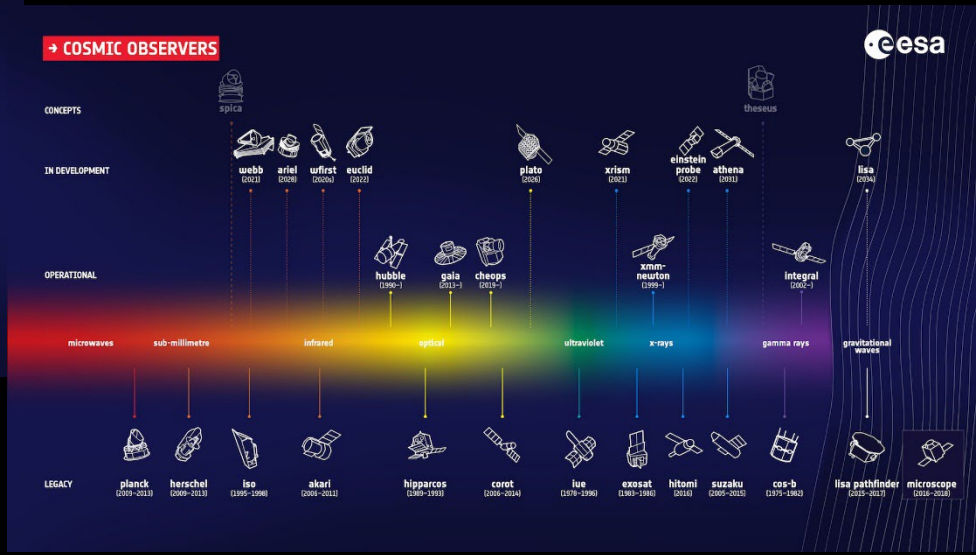
Content

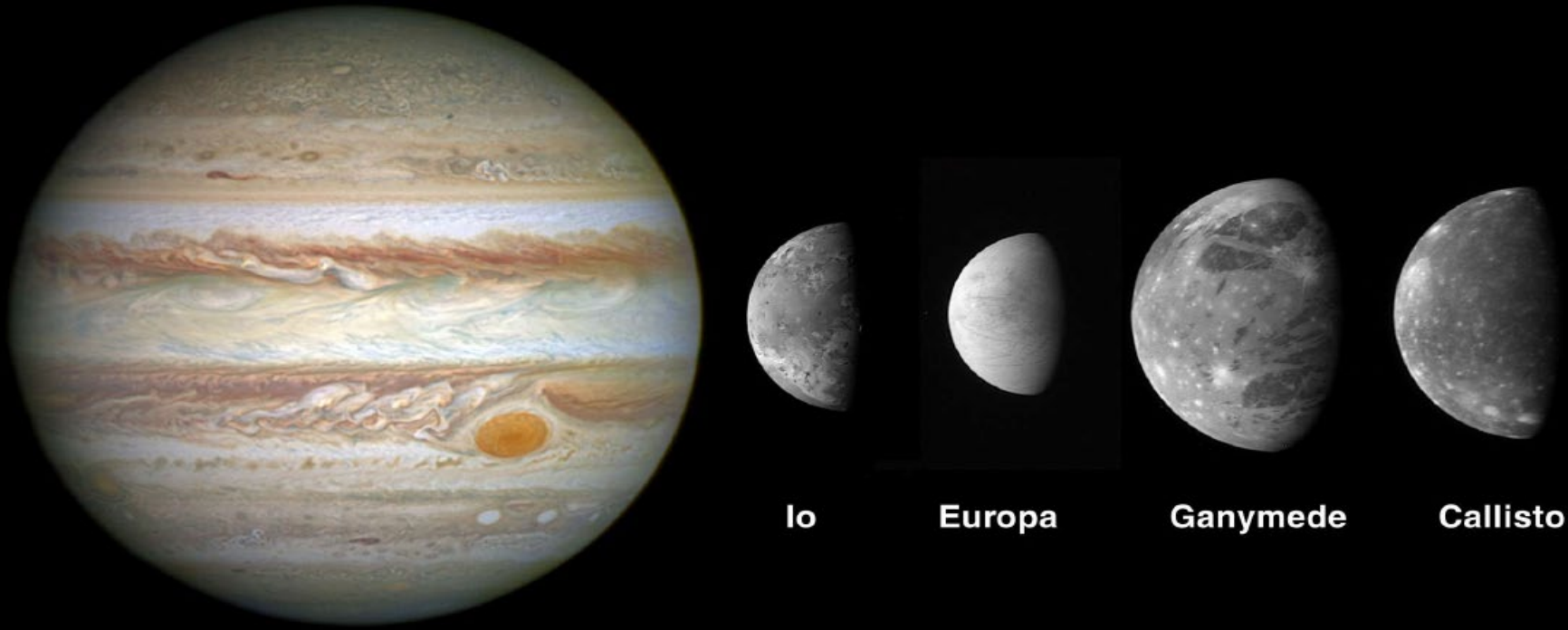
- JUICE background and current status
- Areas underestimated by Industry & ESA
- Schedule and Financial margins management
- Improvement of estimates in early phases
- Cost & schedule control during implementation

Solar System and Astrophysics Fleet





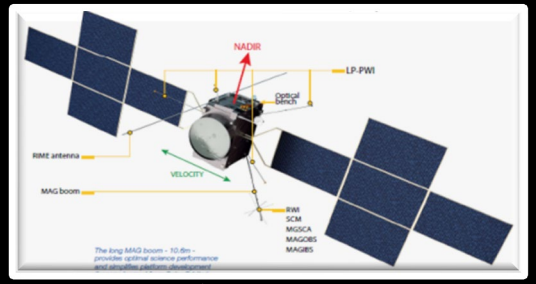
Cosmic Vision programme



“What are the conditions for planet formation and the emergence of life?”

“How does the Solar System work?”

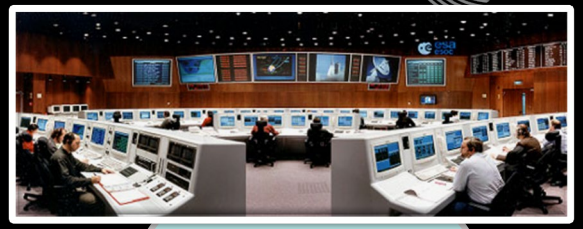
Elements of the JUICE mission



Spacecraft:
Airbus D&S SAS

Launcher:
Ariane 5
ECA

Ground Stations:
- ✓ **Cebreros**
- ✓ **New Norcia**
- ✓ **Malargue**



Mission Operation Centre (MOC)
ESOC

Science Operation Centre (SOC)
ESAC

European Scientific Community

Overall Mission Profile

Launch	**April 2023**
Interplanetary transfer	**≅ 8 years**
Jupiter orbit insertion	**July 2031**
2 Europa flybys	**July 2032**
Jupiter high-latitude phase	**Aug 2032-Aug 2033**
Transfer to Ganymede	**Nov 2033-Nov 2034**
Ganymede orbit insertion	**December 2034**
Ganymede elliptical orbit/5000 km circular orbit	**Dec 2034/May 2035**
Ganymede 500 km Circular Orbit	**May/Sept 2035**
End of mission	**Sep 2035**

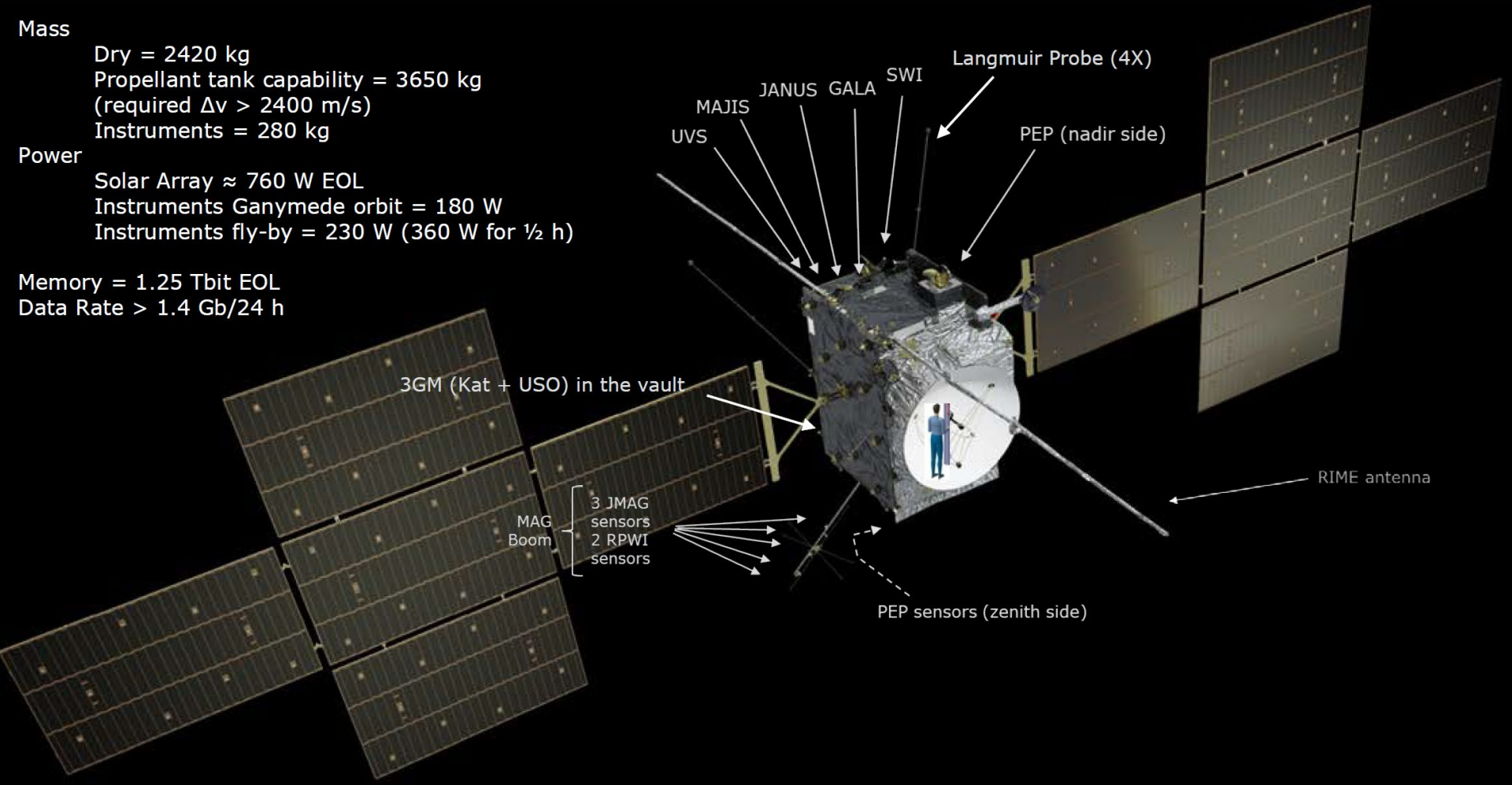
Mass

Dry = 2420 kg
Propellant tank capability = 3650 kg
(required Δv > 2400 m/s)
Instruments = 280 kg

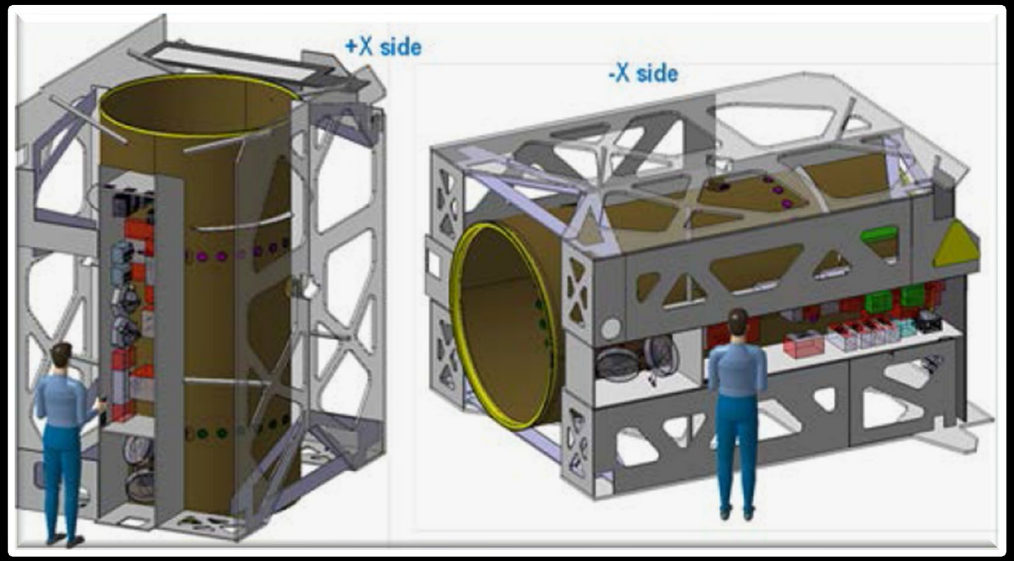
Power

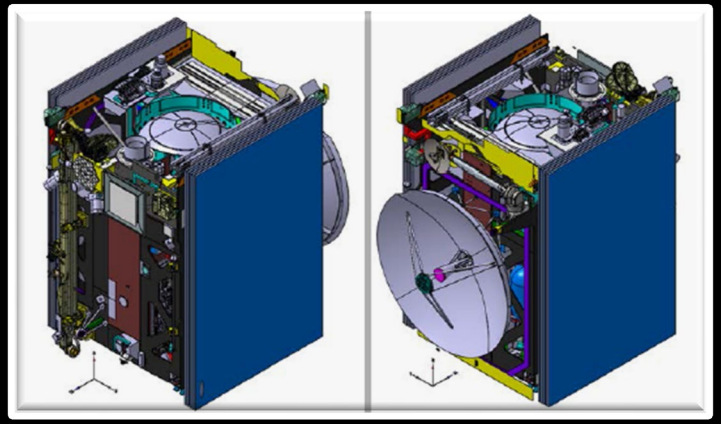
Solar Array ≈ 760 W EOL
Instruments Ganymede orbit = 180 W
Instruments fly-by = 230 W (360 W for ½ h)

Memory = 1.25 Tbit EOL
Data Rate > 1.4 Gb/24 h



Spacecraft configuration





Challenges

Technical:

Instruments and s/c

Radiations

Thermal

Mass

Power

EMC

Operationals:

Navigation

Planetary protection

Power and data volume for the instruments

Programmatics:

Launcher
COVID-19
Transportation

Human challenges

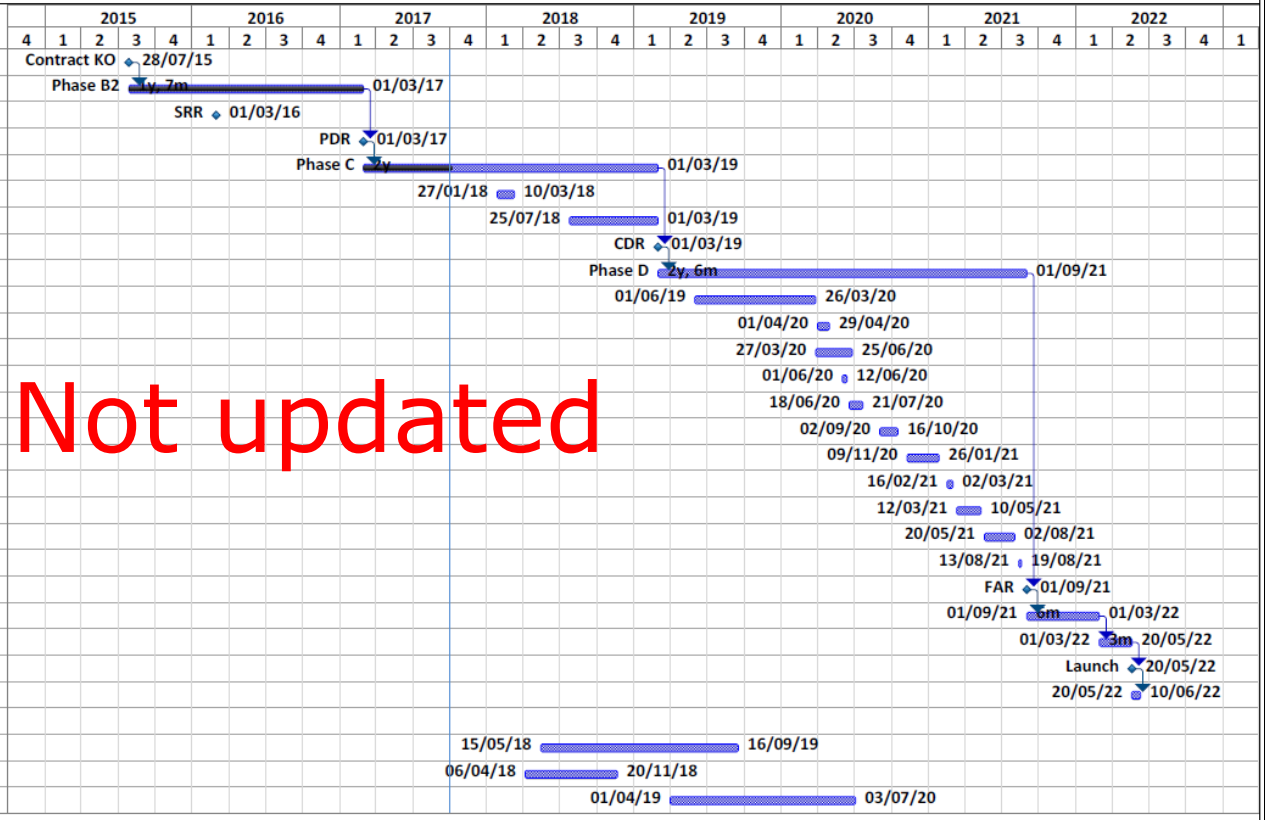
Master Schedule

Status Date: 30 September 2017

JUICE Project Reference Master Schedule

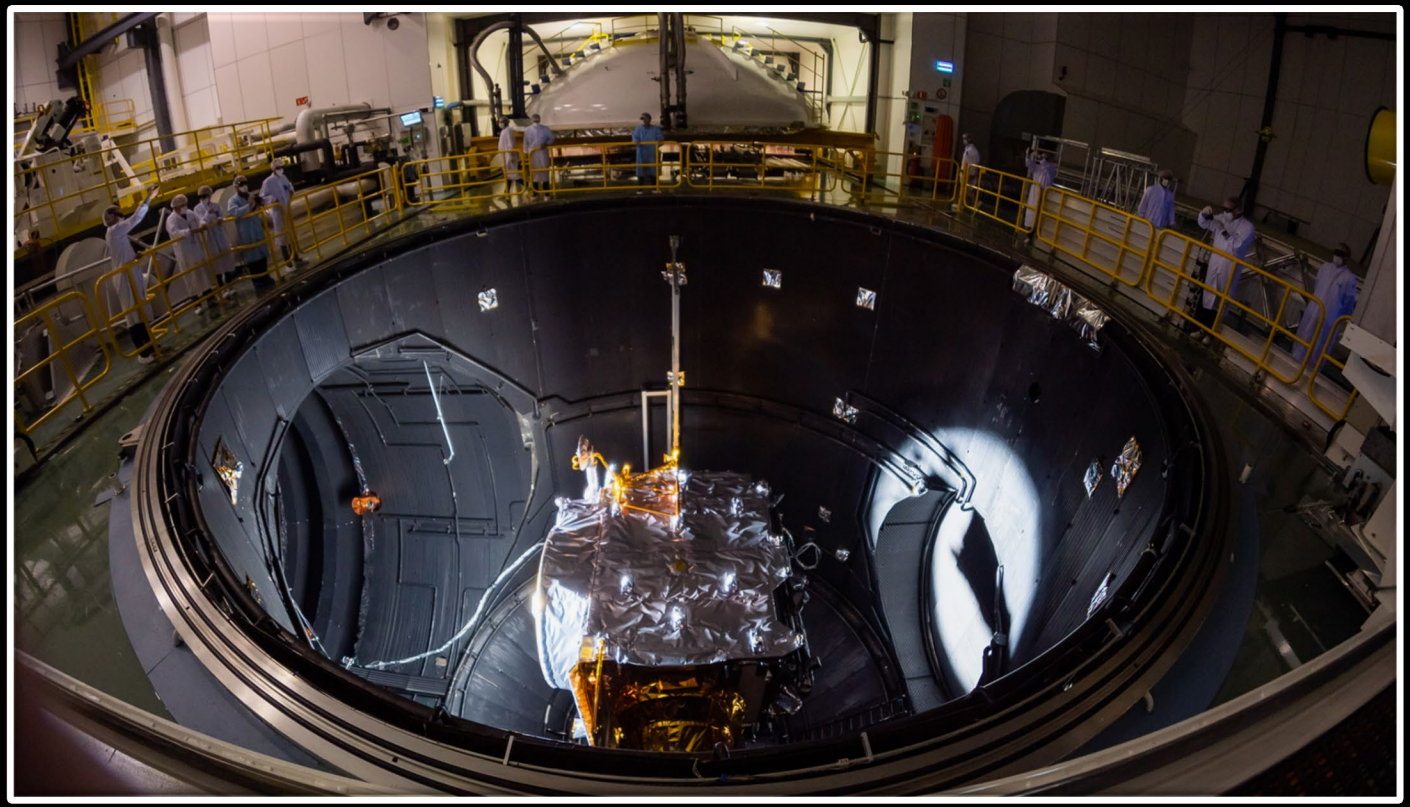
Rev 21

ID	Task Name
1	Contract KO
2	Phase B2
3	SRR
4	PDR
5	Phase C
6	Spacecraft TDM Thermal Balance Test
7	Instrument EM integration and test
8	CDR
9	Phase D
10	Instrument FM Integration
11	Instrument Functional Tests
12	Spacecraft Functional Tests
13	Conducted EMC Test
14	TB/TV Test
15	Magnetic/ Radiated EMC Tests
16	Functional/ Performances/ Physical properties Tests
17	Solar Array integration and deployment
18	Vibration/Acoustic
19	Final Tests
20	S/C preparation for shipment
21	FAR
22	Margin
23	Launch Campaign
24	Launch
25	Launch Window
26	
27	Instrument STM delivery
28	Instrument EM delivery
29	Instrument FM delivery

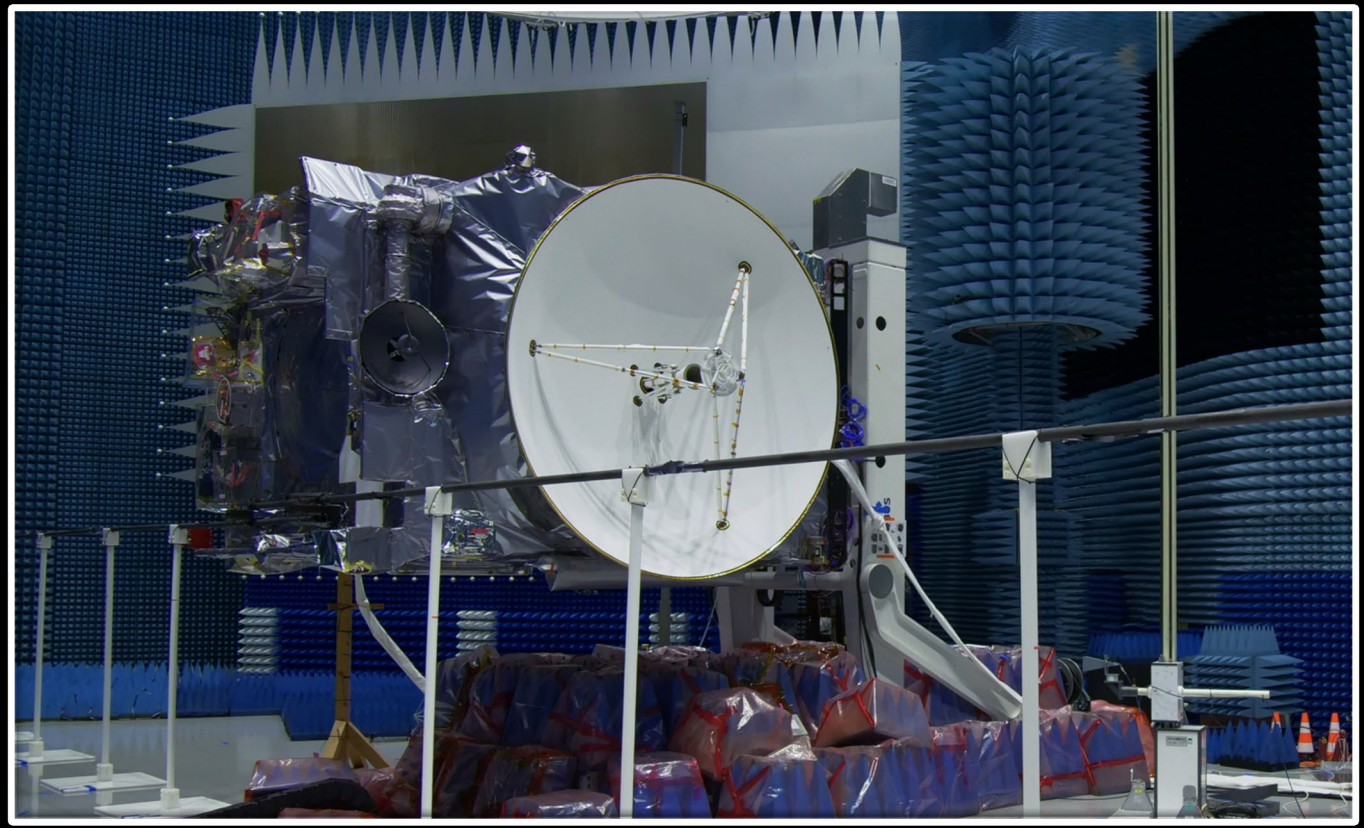


Not updated

JUICE in Summer 2021
@ ESTEC, TB/TV test campaign in the LSS



JUICE in spring 2022
@ Airbus Toulouse, EMC test campaign



JUICE in summer 2022,
@ Airbus Toulouse, Mechanical & Acoustic test campaign

JUICE in August 2022,
@ Airbus Toulouse, Magnetic test campaign

JUICE Financial overview

- In 2014 the JUICE mission was adopted by SPC, with a CaC for launch in 2022
- The CaC included a Project Level contingency of about 16%
- SC Development Prime contract structure:
  - Core Team
  - Subcontractors consortium (in Best Practices), “Lean Prime” with Subsystems
  - Management Reserve, under ESA control (to cover: consortium build up underestimations, additional activities / manpower, Class B CCNs, schedule delays)
  - Risk Sharing Schemes
  - Phase E1 financial provision
- Scientific instruments delivered as CFIs (not direct ESA or Prime contract)

JUICE Financial overview: evolution

- The CaC remained stable until 2021, when launch got delayed from 2022 to 2023 due to:
  - COVID-19 Pandemic impacts
  - Scientific instruments delays (CFIs)
- Overall CaC increase: about 4%
- SC Development contract
  - Core Team ➔ + 40% (additional activities, teams strengthening, schedule delay…)
  - Subcontractors consortium ➔ + 15% (mainly Class B changes, Industrial Consortium overrun at Price Conversion was minor for JUICE)
    - Above covered by the Management Reserve (increased with conditions / incentives)
  - Class A CCNs: + 30 % of contract value (70% of which Instruments driven)
  - Phase E1 financial provision ➔ final price almost doubled (mainly due to transport)
- Scientific instruments exceptional support ➔ 5% CaC

Schedule / Financial increase drivers (1/2)

Typical areas/items/activities underestimated by Industry & ESA

- Industrial manpower underestimation @ proposal:
  - During development (Payload, Engineering, Subsystems and 3rd tier Subs management, AIT)
  - No manpower planned during schedule margin
- General attempts to make price competitive
- Additional Industrial / Prime activities & schedule elongations due to Instruments (e.g. I/F changes, tests, debugging…) until the end of AIT phase (CCNs A due to PL > 70% of the total Class A CCNs)
- CPPA (Coordinated Parts Procurement Agent) – components
- Changes on industrial consortium due to geo dis constraints
- Unknown space environments for Scientific missions
- Underestimation of TRL level, e.g. rarely a “re-flight” is a rebuild, adaptations could be major
- Some Technology Preparatory activities not concluded at Phase B2 KO phase, and taken over within the industrial Development contract
- Underestimation of Co-Engineering phases duration
- Phase E1 “Financial Provision”

- Risks of moderate / high probability and moderate impact

Schedule / Financial increase drivers (2/2)

Unforeseen events with significant cost impacts

- Issue external to Project
- Covid pandemic
- War & Geo political panorama
- Political/ programmatics imposed priorities
- Launchers availability
- Components shortage
- SCI programme – level constraints, e.g. cash disbursement
- Escalations (for FPV contracts, also FFPs)

- Generally Low probability – High Impact risks or “unknown unknowns”

Schedule Margins

- Schedule driven by launch window ➔ + 1 year due to fixed windows, although a reasonable margin was initially included
- Schedule margins:
  - Should be visibly and savvily allocated, and tracked
  - Minor allocation during design & procurement phase, to keep the pressure and avoid shrinking the AIT phase beyond feasibility
  - Reasonable and justified during development phase (e.g. until CDR), again keeping pressure
  - Short intervals margins during AIV / AIT phase, to allow flexibility, AIT flow reshuffling, extra activities etc. without eroding the final contingency
  - A major margin before FAR

- A Must: every announced delay shall come with a recovery plan
- Limiting schedule delays ➔ costs overruns are naturally reduced

Financial Margins

- Two main reserves:
  - A financial Contingency at Project level, to cover additional internal ESA costs, Class A CCNs, any other overrun / extra costs / risk mitigations actions
  - An Industrial Management Reserve under ESA control (under the Prime contract + MR at Subsystem level) to cover:
    - Risk mitigation actions / materialised risks impacts
    - Additional manpower, e.g. reinforcement of teams (engineering, AIT…), shift / weekend work, schedule delays
    - Additional activities, e.g. investigations, tests, additional models, HW, GSE, SW versions, integration & test lines
    - Activities for the whole schedule margin contingency (e.g. industrial “marching army”)
    - Class B CCNs (changes Prime vs Subs)
    - Industrial Consortium overrun at Price Conversion
    - The idea is for the Prime PM to have enough “freedom” to find solutions and invest without impacting the schedule
    - Partially released as incentives upon technical achievements, providing to the Prime PM “leverage” vis-a-vis their management to “buy” priorities e.g. from the supply chain, access to internal facilities, to get valuable manpower
- Management reserves should be sized based on Risk Register and the remainder cross checked with the updated RR throughout the development phase
- Structured incentives scheme, mainly based on technical achievement (see above)

Early Estimates improvement

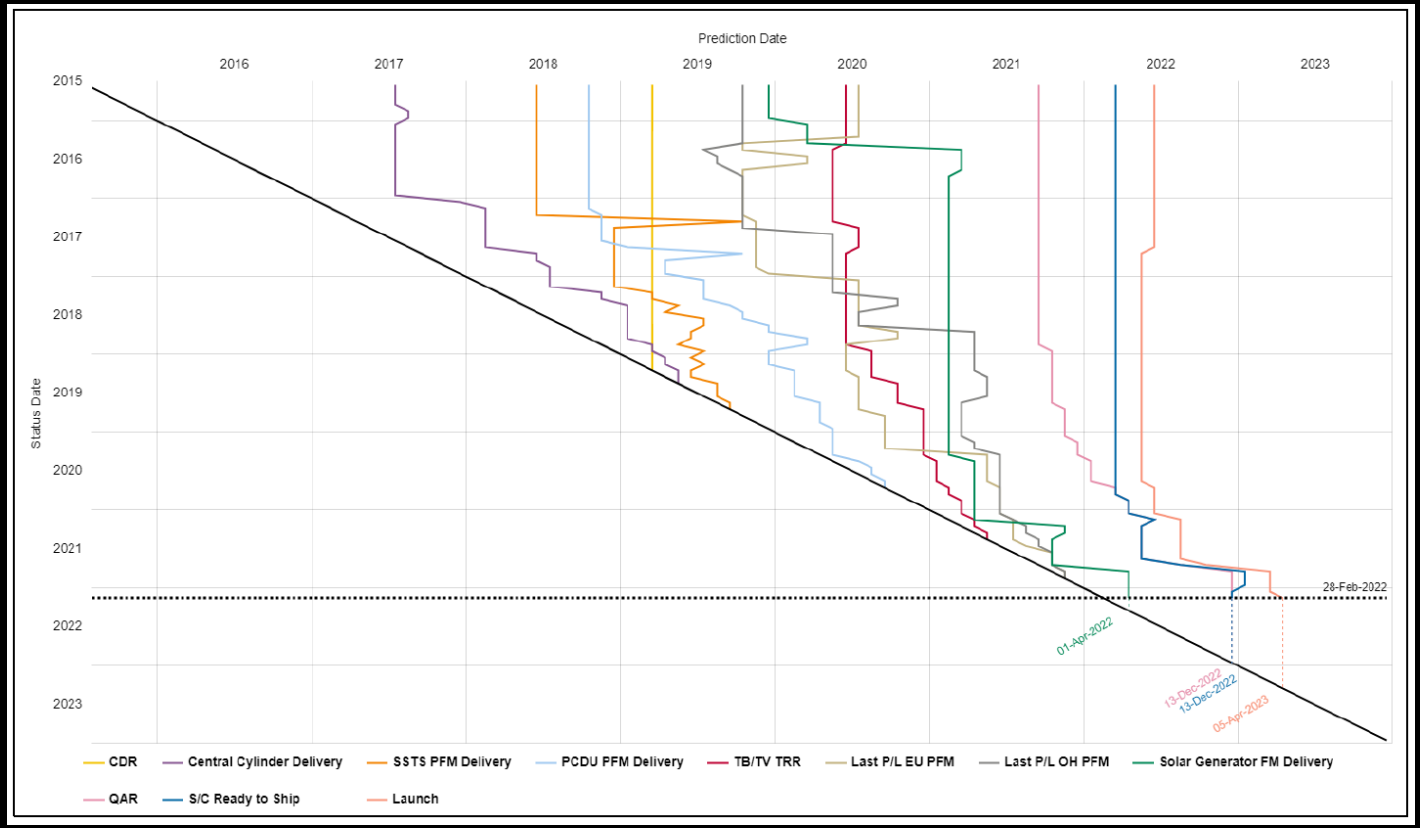
- Benchmarks:
  - Costs of Units/ Equipment, as well as Primes from As-Run project, and not from proposals, deltas can be major
  - ESA and Industry manpower profile from “as run” (e.g. no dip between CDR / FAR and Launch Campaign, consider AIT phase in double shift)
  - Schedule of missions / project phases / instruments benchmarks from “as-run”, and not proposals
  - An As-Run costs unified repository is currently not available, a schedule repository is in the making
- Analysis of companies performances via the “SET” tool, to understand experience, issues and trends
- Improvement of Risk Register content of the early phases (e.g. including programmatic risks) to set aside suitable contingencies and possibly reserve “Programme- Level” contingencies (e.g. for low probability – high impact risks)
- Challenge of the declared TRL level, increase contingency allocations for low TRLs (high probability – TBD impact risks)
- The CaC from TEC-SYC to be developed together with, or at least reviewed by, experienced Controllers from the Project Development Phase
- Schedule preparation shall be driven by technical analysis and not by higher-level programmatic constraints
- The master schedule shall be developed by Schedule officers with project experience
- To develop an analysis to track initial declared TRLs level vs. final cost increase / development time, to be used as benchmark (tool not existing, as far as I know)
- In reviews include a major umber of experts from Projects in development, beside TEC experts.
- Watch out for… the conspiracy of optimism !

Cost & schedule control during implementation

- Mind set, making “On Cost, On Time and On Quality” a priority
- Each and every announced delay shall come with recovery action throughout the consortium and the Instruments’: cost control is also achieved via schedule control !
- “Pro-Active” controlling by the Project Control Team, beside mere accountancy
- Systematic and deep Schedule & Margins management (e.g. schedule trendcharts, financial contingencies trendcharts, KPIs, e.g. Project contingencies, Management Reserves depletions, other reserves…), schedule training of Subs and Payload teams
- Financial support to CFIs, e.g.:
  - CPPA, other procurements to give schedule insights and take over some level of control (e.g. test campaign in Estec)
  - Common HW development , e.g. SC Interface, Simulators
  - In situ personnel
- Increase management / invest resources to lower performers Subs
- Continuous exchange throughout the consortium (e.g. yearly industry days to keep all up to speed – status, drivers…), open and systematic discussion with Prime
- Flexible AIT schedule, that allows continuous reshuffling and parallelisation – requires creativity and thinking out of the box, also challenging the *“status quo”*
- Initial Management Reserve based on solid and extended risk register
- Solid and extended Incentive scheme throughout the consortium (e.g. “bonus / malus” schemes, that get applied !)

Annex 4

Milestones Trend Chart : Spacecraft



Contingency Trend Chart