



**Jet Propulsion
Laboratory**
California Institute of
Technology

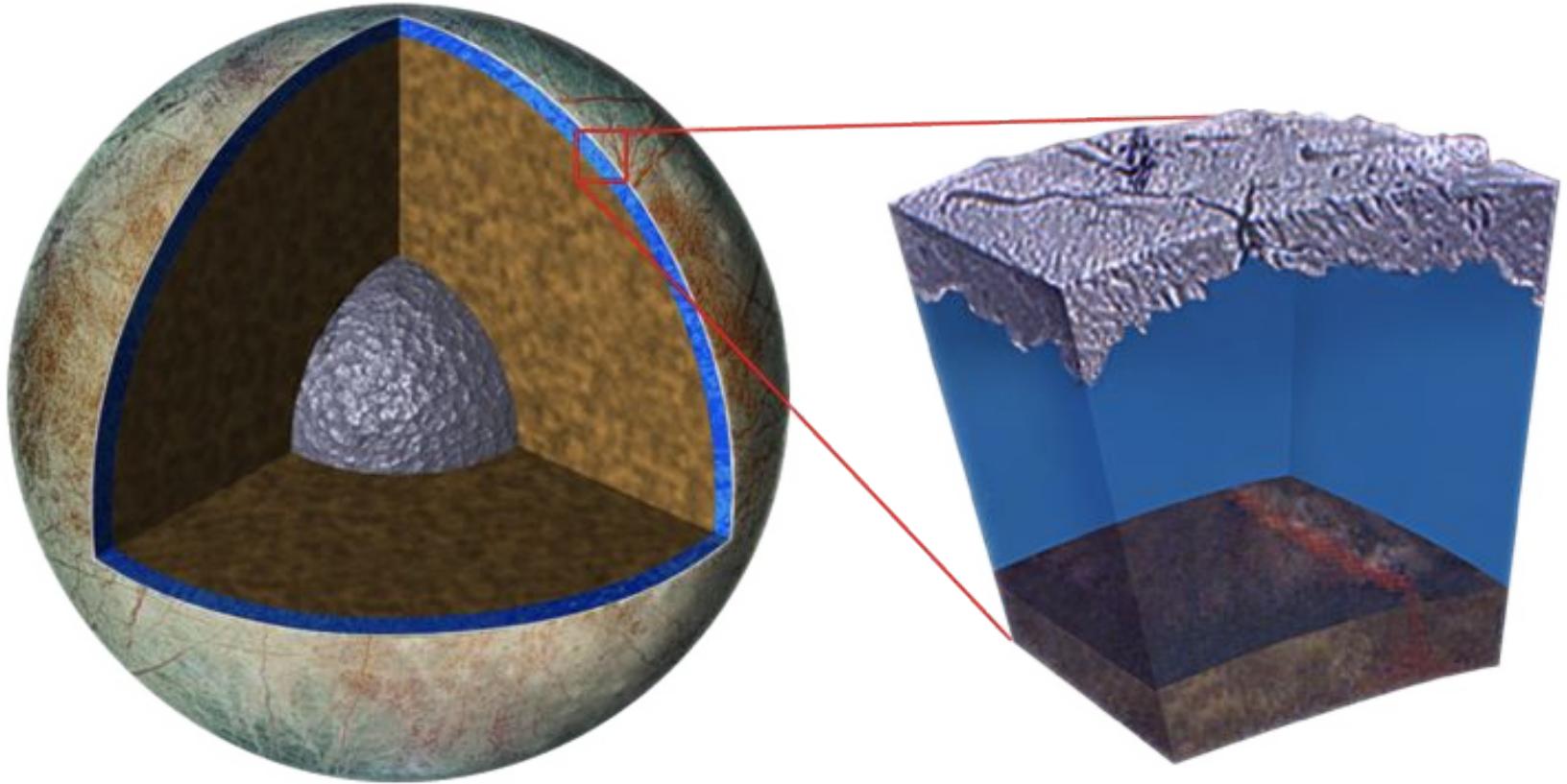


Model-based Systems Engineering Mission Formulation on the Europa Clipper Pre-Project

Alek Kerzhner
Europa MSET Team Lead

Brian Cooke
Europa Project System Engineer
NASA -JPL / California Institute of Technology

The Ocean That Beckons



*"Europa, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers **one of the most promising extraterrestrial habitable environments**, and a plausible model for habitable environments beyond our solar system"*

"Visions and Voyages", 2011 Planetary Decadal Survey

Europa: Ingredients for Life?



Water:

- Probable saltwater ocean, indicated by surface geology and magnetic field
- Possible lakes within the ice shell, produced by local melting

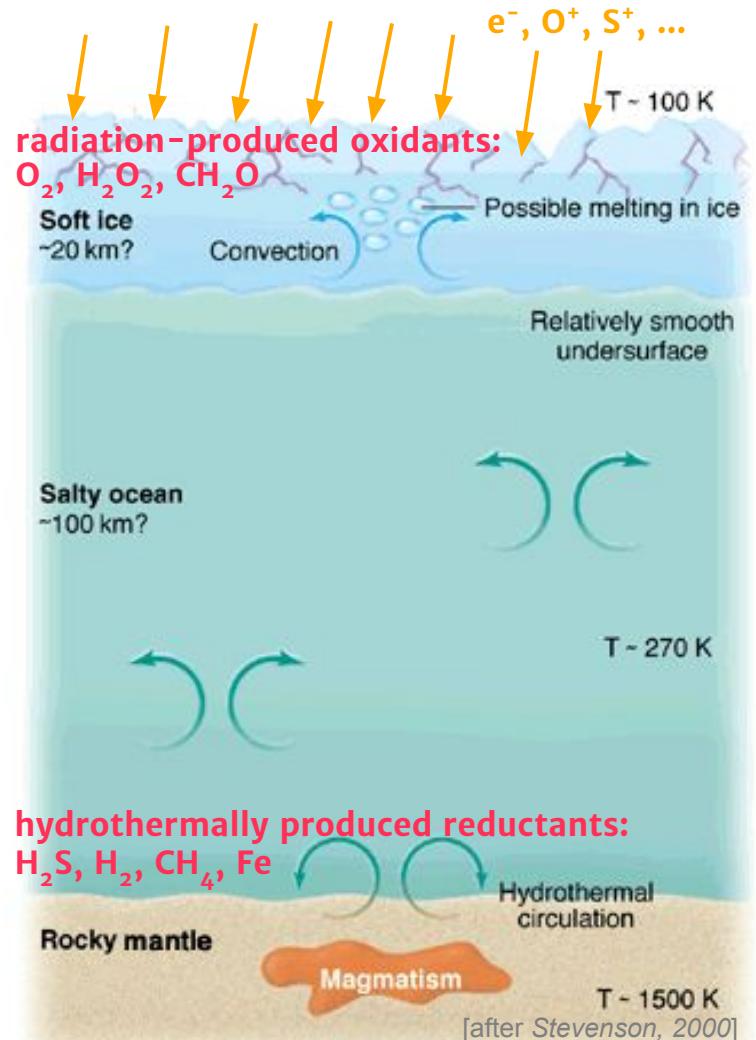
Chemistry:

- Ocean in direct contact with mantle rock, promoting chemical leaching
- Dark red surface materials contain salts, probably from the ocean

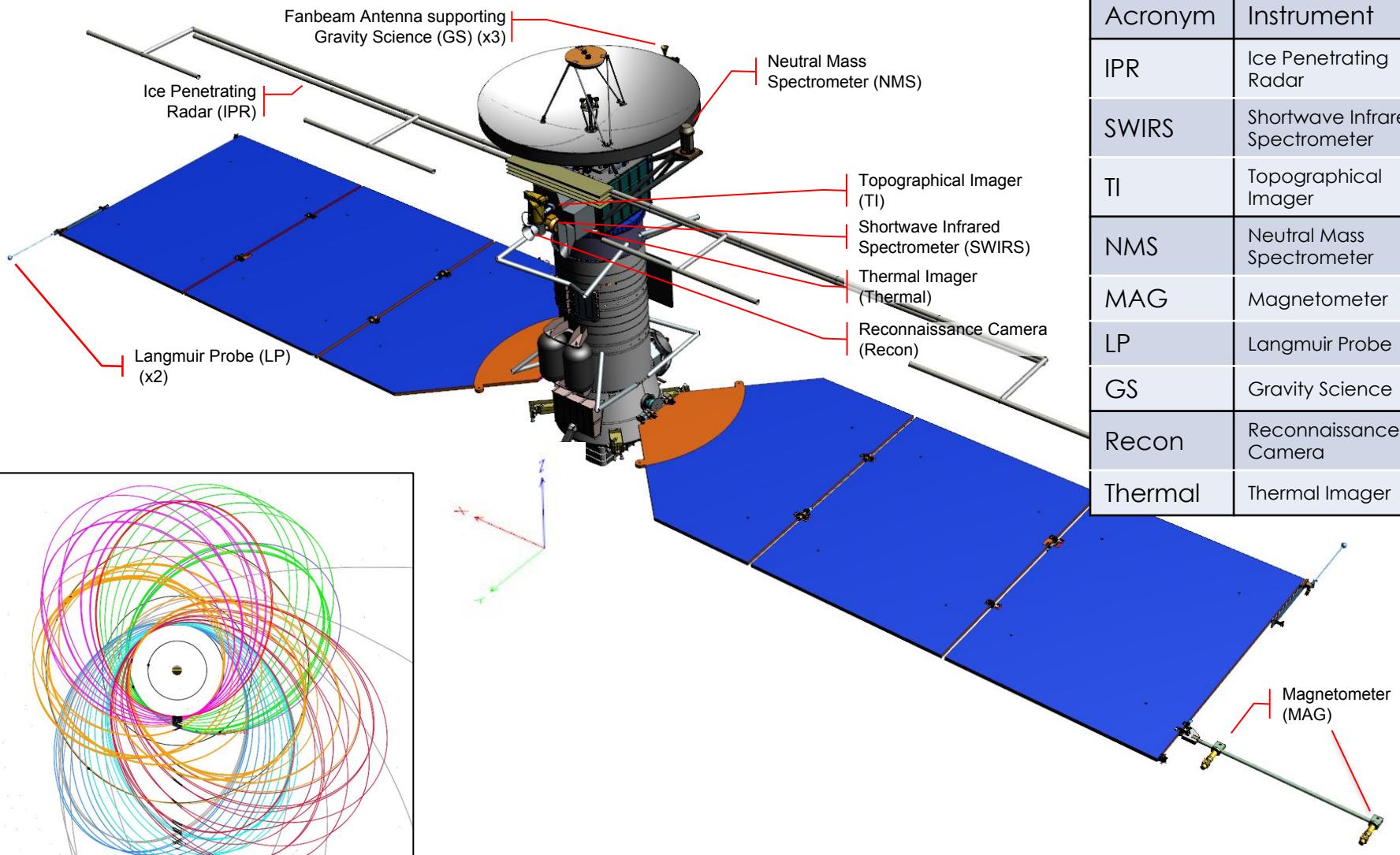
Energy:

- Chemical energy could sustain life
 - Surface irradiation creates oxidants
 - Mantle tidal heating could create reductants
- Geological activity would “stir the pot”

The Europa Clipper would test habitability hypotheses



Europa Clipper Mission Concept Overview





Laboratory

California Institute of
Technology



MBSE ON EUROPA

What is MBSE?

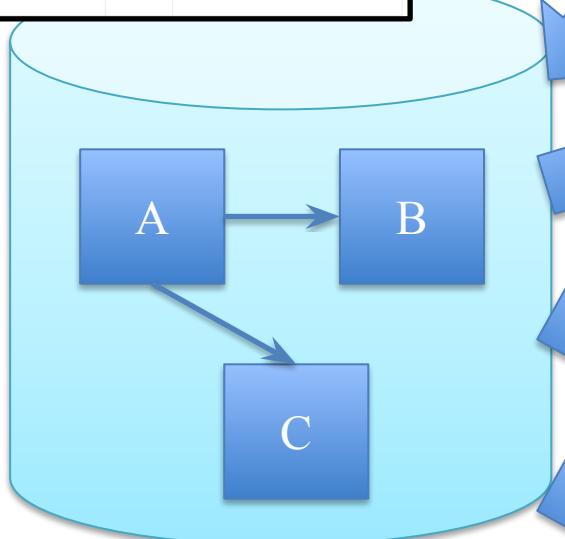
“Structural” Validation

Results for Rule: hasConstrainedElement

Alert: CONSTRAINED ELEMENT must have at least one constrained element
 Description: Constraints that constrain anything other than ONE constrained element will FAIL this rule.
 Applies To: ConstraintBlock
 Total Elements Evaluated: 31

VIOLATORS: 14 | PASSED: 1 | SKIPPED: 0 | SKIPPED (N/A): 16 |

Afid	Name of Validated Element	Validation Result	Model ID
CT100.897	Duration Between Off-Sun Turns in Inner Cruise	FAILED	_P6tXV0wEeOA16G4SXuN9A
CT100.894	Temperature Limits during Faults in Adverse Environments	FAILED	_P8zmOwEeOA16G4SXuN9A
CT100.900	Supplementary Heater Power on Off Hardware	FAILED	_Xb1FOuwEeOA16G4SXuN9A
CT100.895	Temperature Limits during Faults with Abnormal Power Dissipations	FAILED	_P5JJ0wEeOA16G4SXuN9A

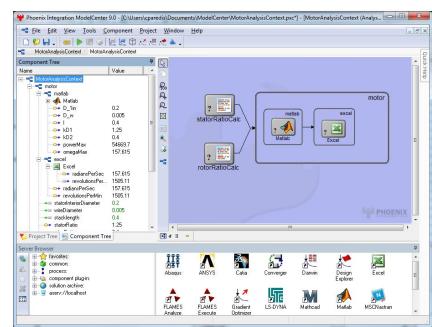
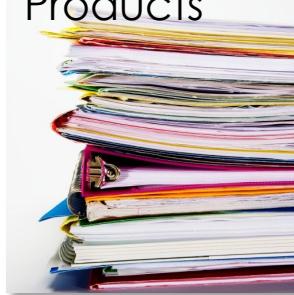


Repository



(Interactive)
Views

Gate
Products



Analyses

Performance
Validation

What problems does MBSE try to address?

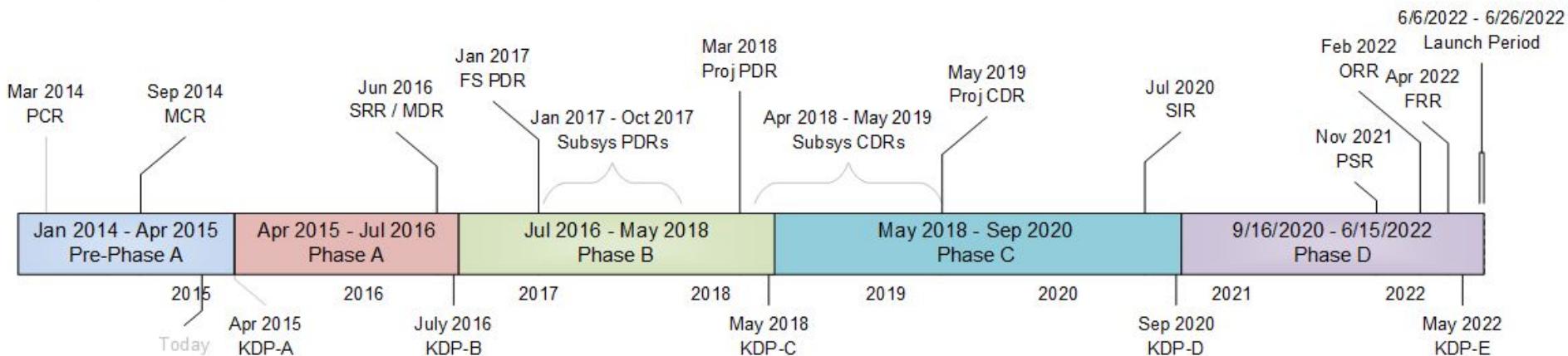


- Gaps and issues in project design because of implicit assumptions
- Inconsistency between information sources (project documents, etc.):
 - Disconnected tools with their own data store: inconsistent or incorrect analysis results
- Communicating and maintaining current project baseline
- Common changes need to be made separately to all information sources
 - Bigger issue when you have multiple variants
 - Bigger issue when you have a large # of information sources
- Tracking changes to the project baseline over time

Europa Clipper Project Schedule

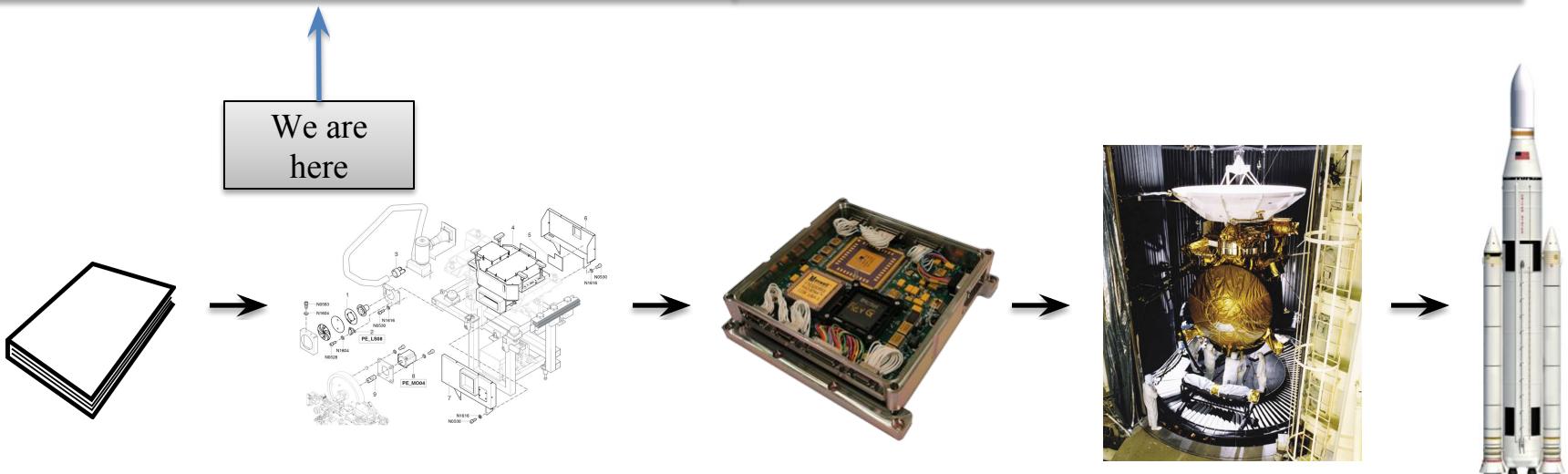


Europa Project Timeline – 2022 SLS Launch

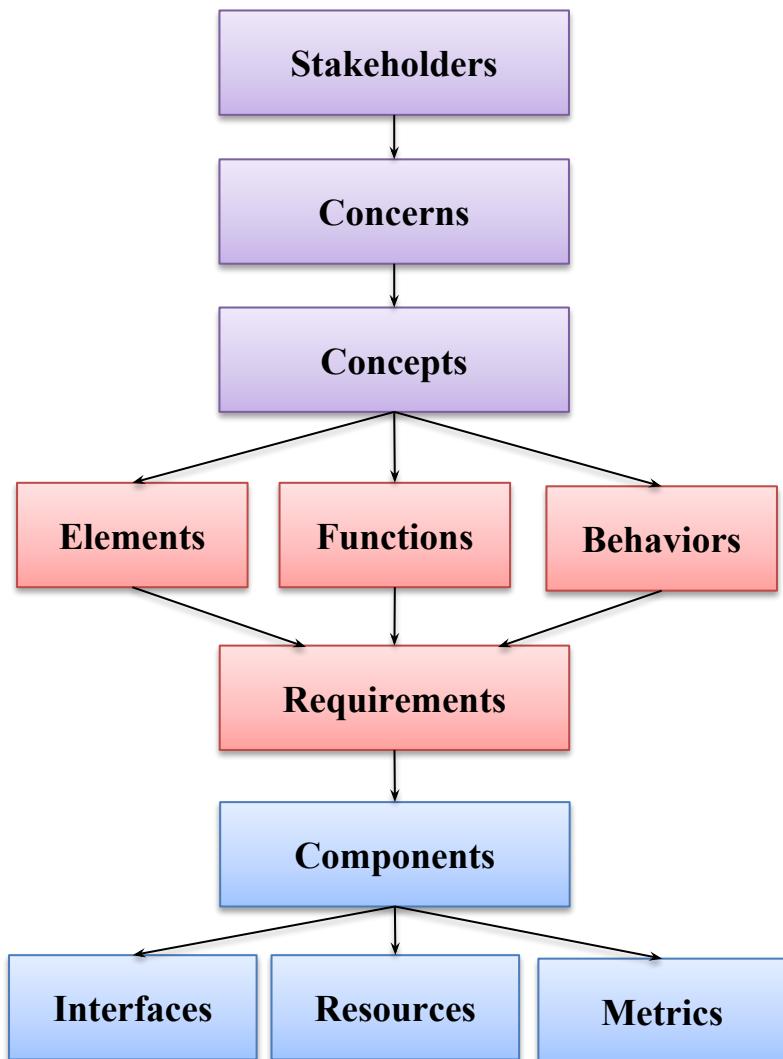


Formulation

Implementation

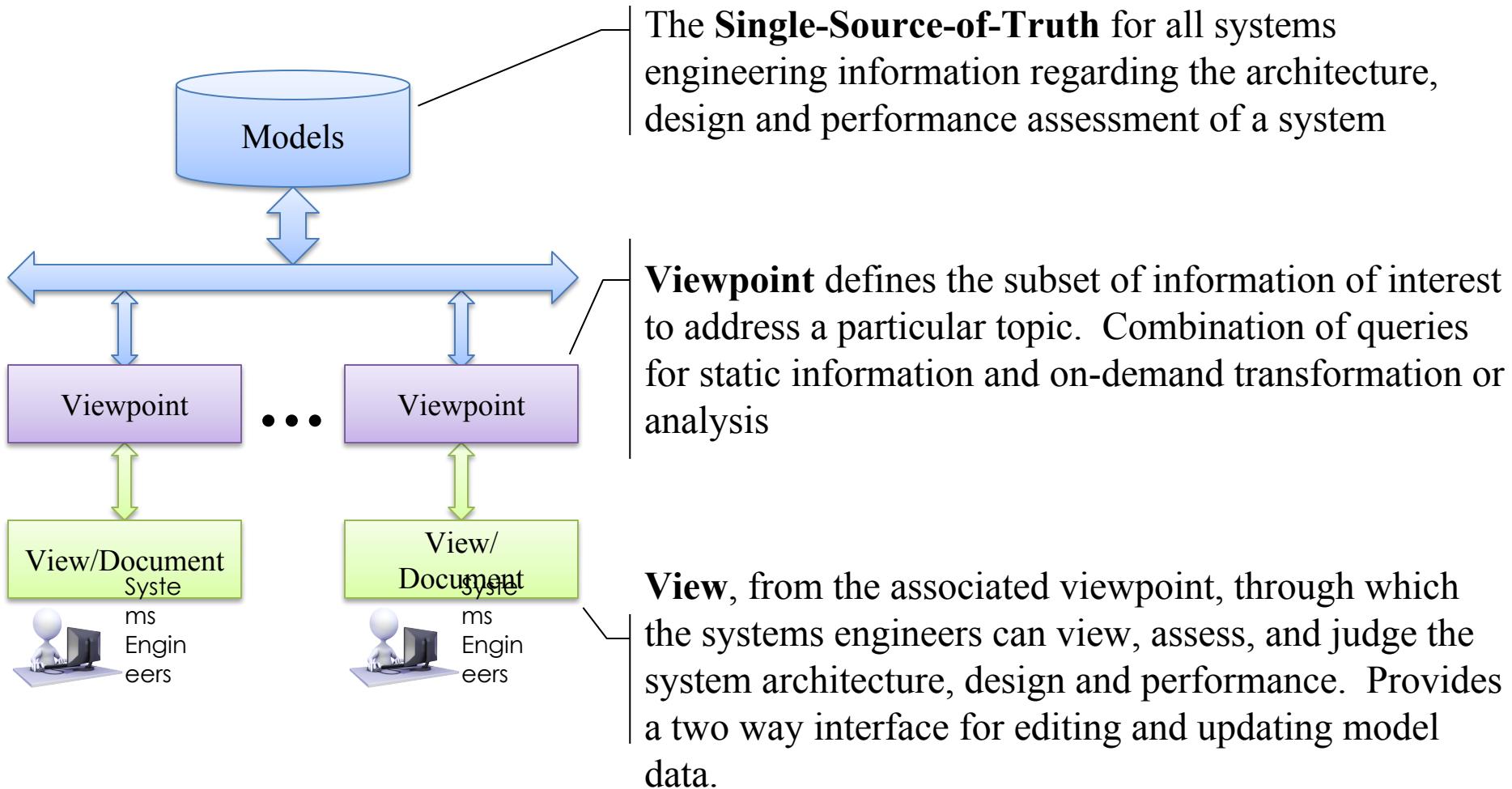


Model-Based System Engineering Approach



- Define formal semantics for technical information
- Construct patterns defining allowable element relationships and facilitating auditing and completeness checking
- Ensure consistency across all generated products through single-source-of-truth enforcement
- Make best use of modern information infrastructure to track details and calculate metrics; freeing engineers to consider design alternatives

Modeling & Analysis Framework



Unique Europa challenges:

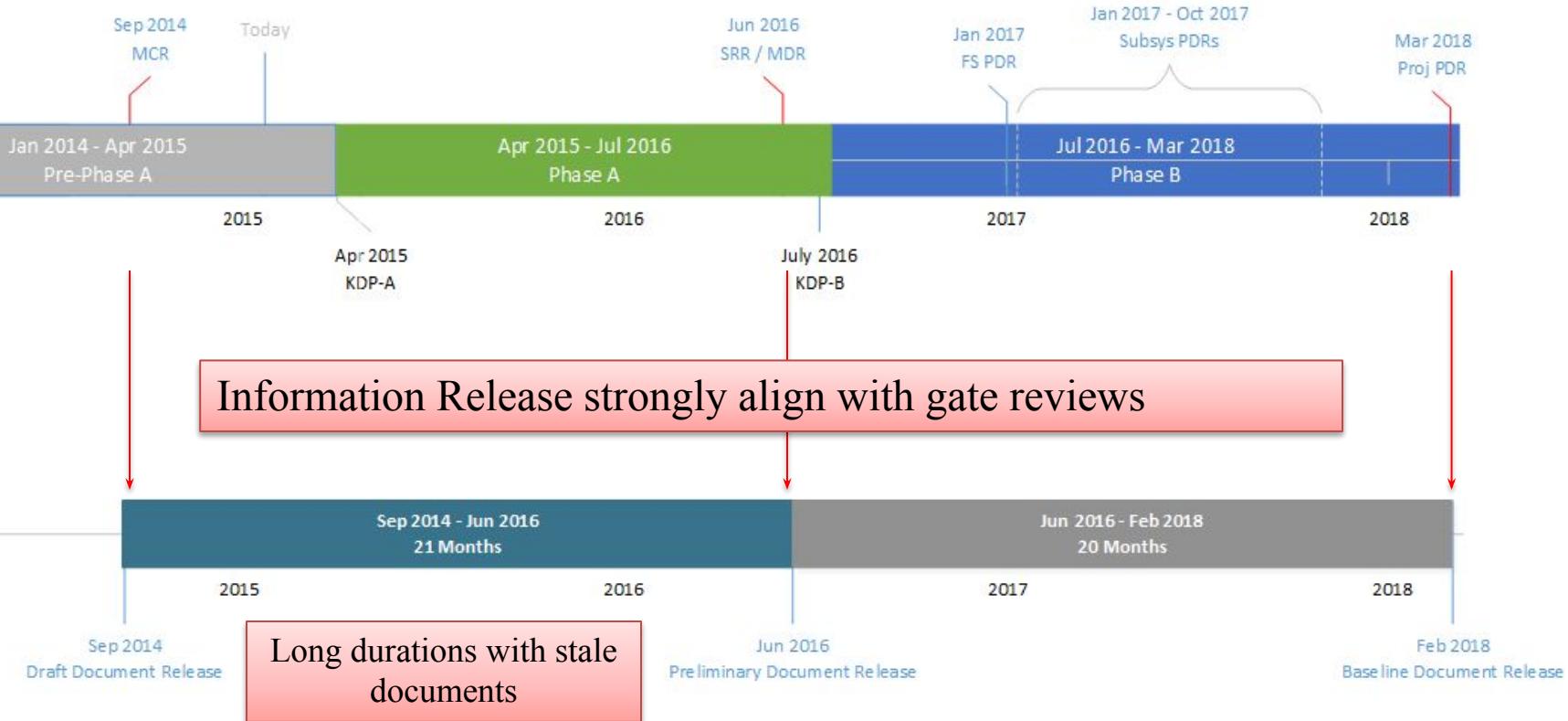


- **Scope:** trying to capture information from across the project, content from >40 people who need to interact with the environment in some way. 10-15 people working in MagicDraw.
- **Tooling:** being developed as approach is applied. Tools such as EMS, View Editor, etc.
- **Architecture Framework:** endeavoring on a different approach to architecting and requirements development.



Typical Information Release Cadence

Project Timeline (typical):

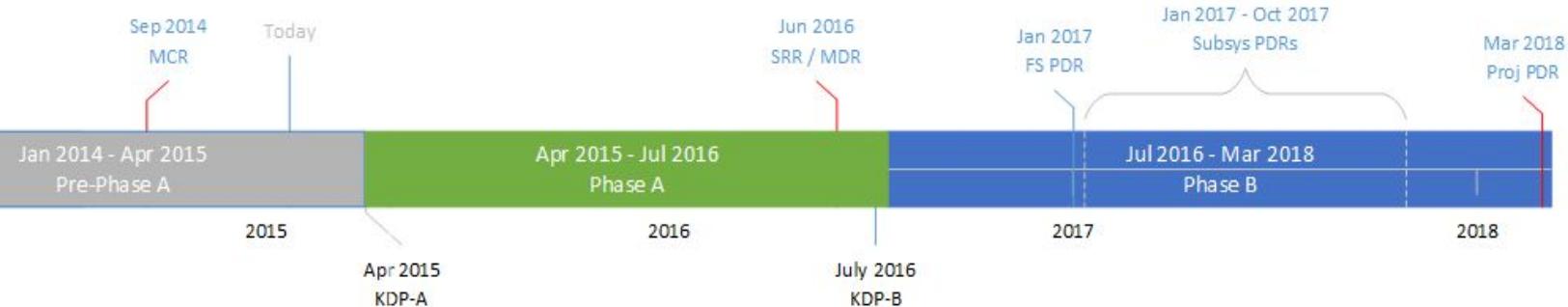


Project personnel relied upon to know what information is reliable and what is in the (long) process of being changed

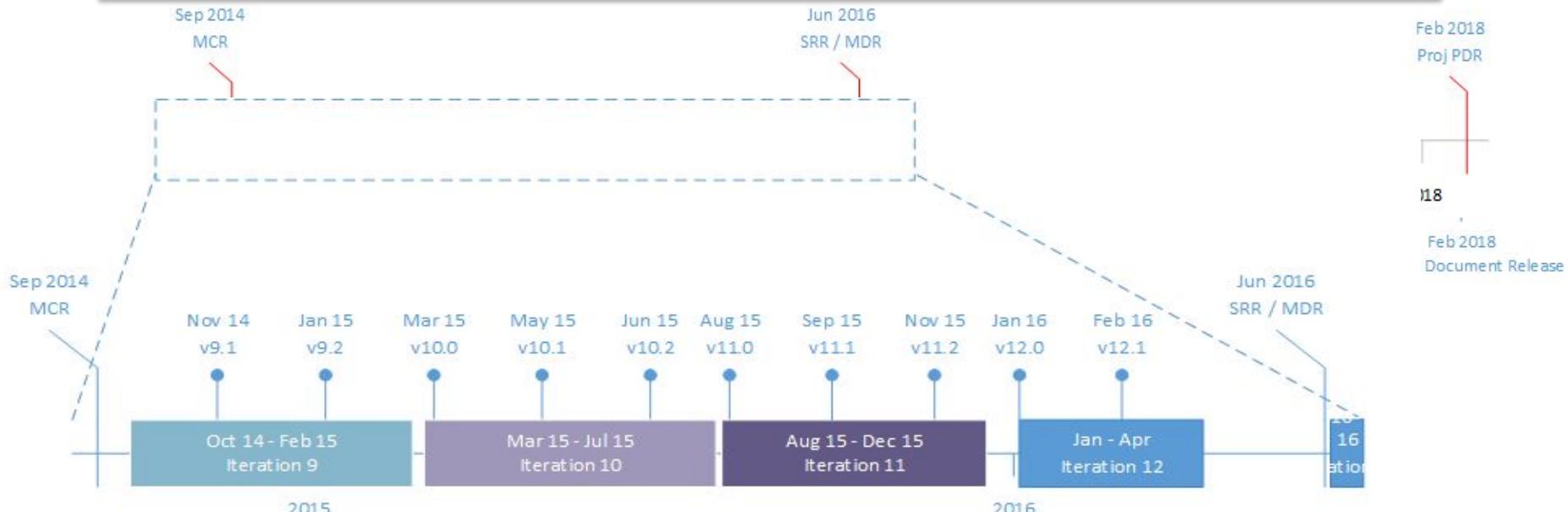
MBSE Enhanced Information Release Cadence



Project Timeline (typical):



Iterative approach sets regular release cadence; independent of review schedule



Increments set much shorter duration between change request and updated documentation



Requirements

Requirements Document (SRRD) Go To Europa Documents Europa Dashboard Other Sites ▾

2 SRRD Requirement Totals

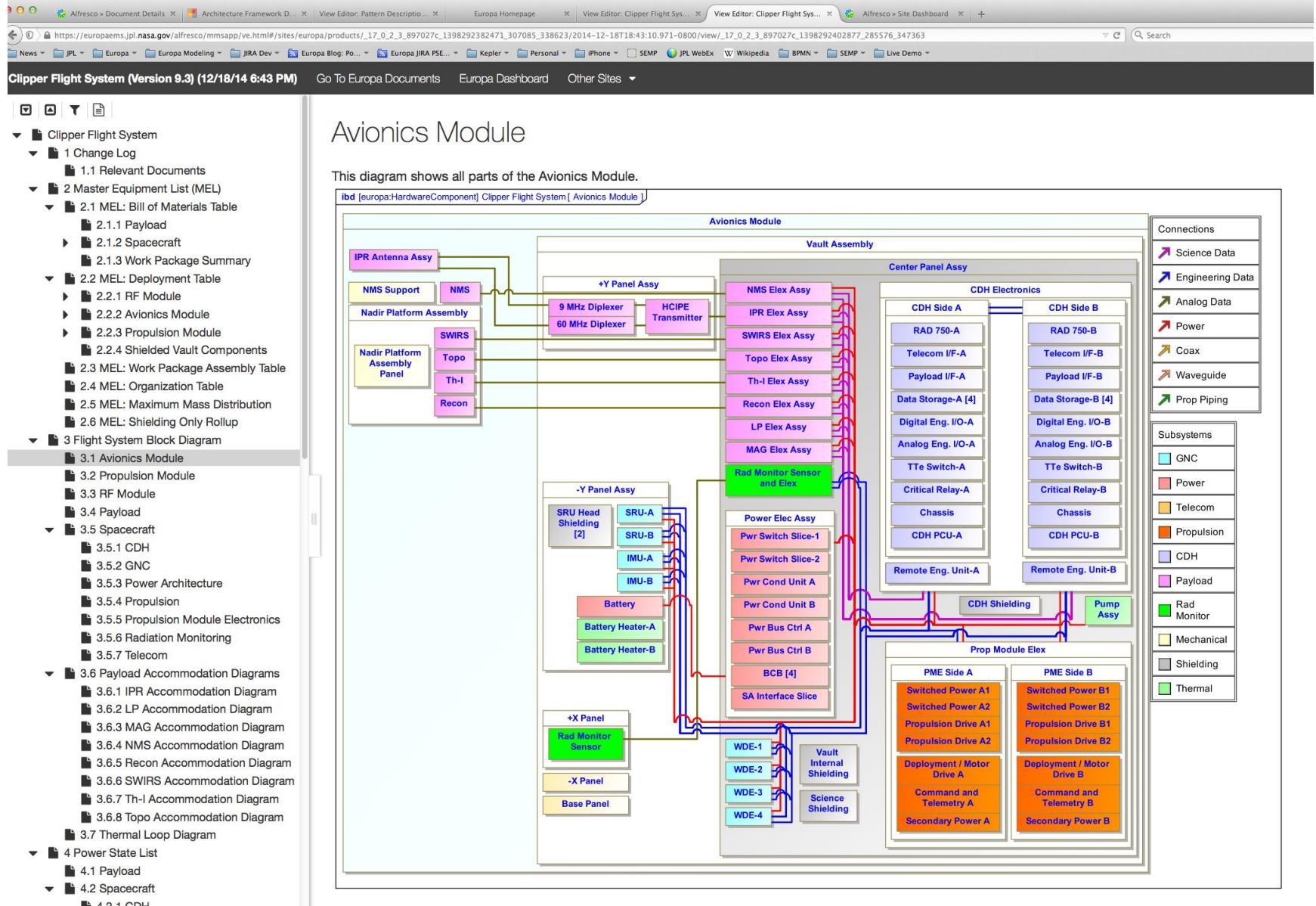
Requirement Totals (by package)	
	Number of Requirements
Recon L2 Requirements	8
Science L2 Requirements	13
Total Requirements	
Total	21

3 Science Requirements

The Science Requirements are written based on the investigations and measurements identified in the Science Traceability Matrix. They generally flow down to other Science Requirements from the Observation Requirements.

ID	Name	Text
SR.1	Shallow water characterization	The shallow subsurface data set shall characterize water or brine within 3 km depth, on a horizontal scale \leq 10 km, in regions that are globally distributed across at least 70% of the surface.
SR.2	Search for ice-ocean interface	The deep subsurface data set shall search for an ice-ocean interface extending from 1 km to 30 km depth, in regions that are globally distributed across at least 70% of the surface.
SR.3	Heat flow variations	The deep subsurface data set shall permit identification and mapping of subsurface thermal horizons extending from 1 km depth, in regions that are globally distributed across at least 70% of the surface.
SR.4	Gravitational tides	The gravity science data set shall characterize the amplitude and phase of Europa's gravitational tides to recover the k2 tide amplitude at Europa's orbital frequency to \leq 0.05 absolute accuracy.
SR.5	Europa's magnetic induction response	The magnetic induction data set shall measure Europa's magnetic induction response to Jupiter's magnetic field with sensitivity of \leq 1 nT and \leq 1 nT accuracy.
SR.6	Global scale composition and chemistry	The global-scale surface composition data set shall characterize the global-scale composition and chemistry by mapping at a spatial resolution of \leq 10 km covering \geq 70% of Europa's surface.

Block Diagrams



Instrument Overview



Alfresco » Document Details × Architecture Framework D... × View Editor: Pattern Descriptio... × Europa Homepage × View Editor: Europa Clipper Ex... × View Editor: Europa Organizati... × View Editor: Clipper Flight Sys... × View Editor: Clipper Flight Sys... × All
https://europaems.jpl.nasa.gov/alfresco/mmsapp/ve.html#/sites/europa/products/_17_0_2_3_897027c_1398292382472_719225_338625/2014-12-18T18:49:48.533-0800/all#_17_0_2_3_897027c_1398292404816_995547_347845
JPL Europa Europa Modeling JIRA Dev Europa Blog: Po... Europa JIRA PSE... Kepler Personal iPhone SEMP JPL WebEx W Wikipedia BPMN SEMP Live Demo

Clipper Executive Summary (Version 9.3) (12/18/14 6:49 PM) Go To Europa Documents Europa Dashboard Other Sites



Europa Clipper Executive Summary

1 Europa Clipper Mission

- 1.1 Mission Scenarios
- 1.2 Trajectory Information
- 1.3 Mission Timeline

2 Clipper Flight System Design

- 2.1 Flight System Margins
 - 2.1.1 Mass Margin
 - 2.1.2 Power Margins
 - 2.1.3 Data Margins
 - 2.1.4 Tank Volume Margins

2.2 Payload at a glance

- 2.2.1 Overview of Instruments
- 2.2.2 Mass Breakdown
- 2.2.3 Power Breakdown

2.3 Spacecraft at a glance

- 2.3.1 Mass Breakdown
- 2.3.2 Power Breakdown

3 Ground System Design

4 Europa Clipper Project

2.2.1 Overview of Instruments

- Ice Penetrating Radar

Dual-frequency sounder (60 MHz with 10 MHz bandwidth (shallow) and 9 MHz with 1 MHz bandwidth (deep)) with surface altimetry capability. Deployed dipole antenna array on 15-m boom, including four 2.5-m dipole elements. Transmitters and matching network located at base of antenna; receivers, digital electronics, and power supply housed remotely in radiation-shielded science electronics box. FOV ~12° cross-track. The altitude constraint is < 1,000 km.

Payload Overview

Total Mass (inc. shield) [kg]	Operating Power [W]	Raw Instantaneous Data rate [Mb/s]	Altitude Constraints	Number of Boards included
36.7	57.0	24.6 (processed)	< 1,000 km	8

- Langmuir Probe

LP comprises a dual-sensor system with 5-cm diameter spheres mounted on 1-m long booms. The LP sensors measure the local plasma temperature, and flow; electric field vectors (from near DC to 3 MHz); electron temperature; and ion currents. The sensors measure over a solid angle. Pre-amps must be located <3 m from each sensor. If possible, the two sensors should be mounted such that at least one is also free of any S/C plasma wake with a 15° clearance buffer. The sampling rate is 1 Hz. S/C EMI/EMC cleanliness comparable to that of Juno and Cassini is required.

Payload Overview

Total Mass (inc. shield) [kg]	Operating Power [W]	Raw Instantaneous Data rate [Mb/s]	Altitude Constraints	Number of Boards included
4.3	2.8	.002	n/a	2

- Magnetometer

MAG comprises a dual-sensor 3-axis fluxgate magnetometer system. Its sensitivity is 0.1 nT over an intensity range of at least ± 1024 nT. The maximum sampling rate is 32 Hz; sampling resolution is 0.01 nT. S/C EMI/EMC cleanliness comparable to that of Juno and Cassini is required.

Payload Overview

Total Mass (inc. shield) [kg]	Operating Power [W]	Raw Instantaneous Data rate [Mb/s]	Altitude Constraints	Number of Boards included
2.72	4.45	.004	n/a	1

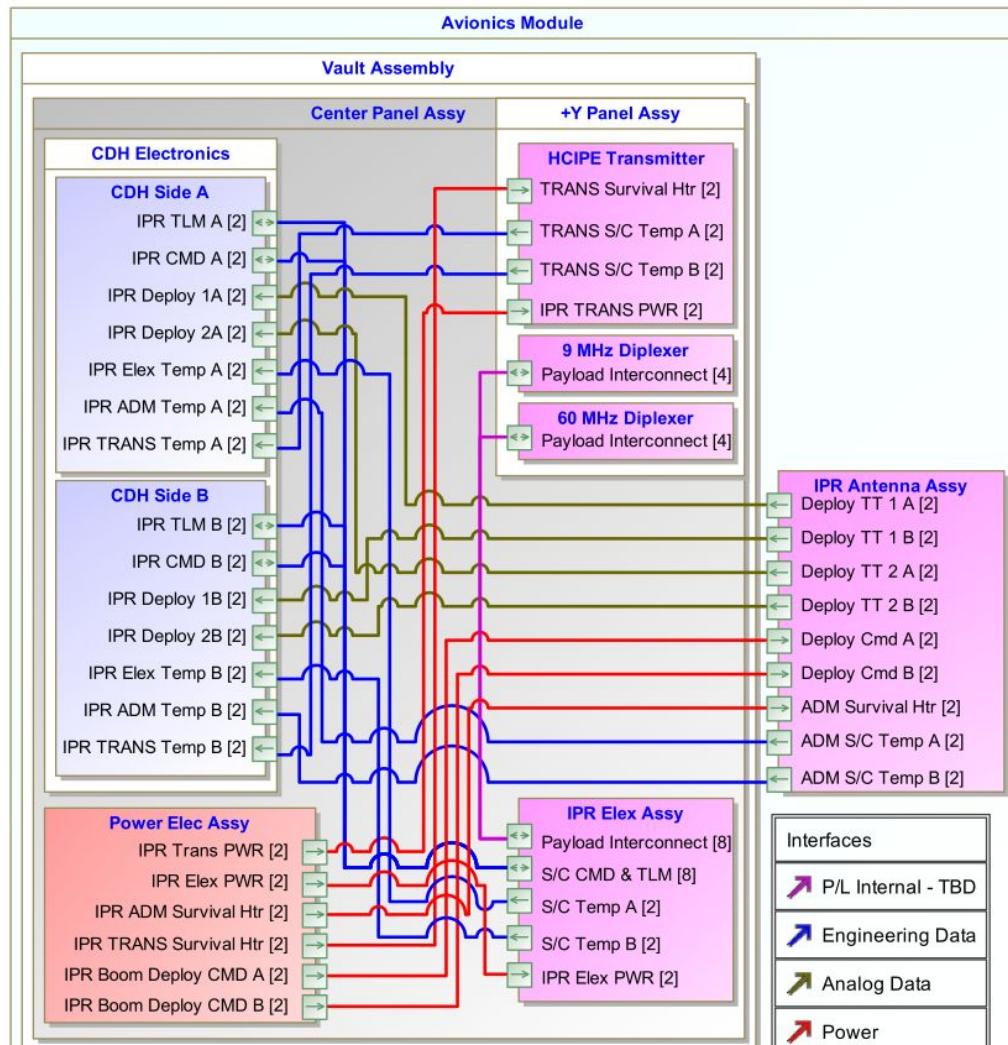
Instrument Accommodations



Subsystem View: Payload

- 1 Summary
- 2 Block Diagram
 - 2.1 IPR Accommodation Diagram
 - 2.2 LP Accommodation Diagram
 - 2.3 MAG Accommodation Diagram
 - 2.4 NMS Accommodation Diagram
 - 2.5 Recon Accommodation Diagram
 - 2.6 SWIRS Accommodation Diagram
 - 2.7 Th-I Accommodation Diagram
 - 2.8 Topo Accommodation Diagram
- 3 Mass Equipment List (MEL)
- 4 Power Equipment List (PEL)
- 5 Subsystem Power Scenarios
- 6 Thermal Equipment List (TEL)
- 7 Card Margins
 - 7.1 List of Cards in Boxes
- 8 Volume and Area

IPR Accommodation Diagram



Value Proposition – A Look Back



- On Europa (Out of 3 ✓'s) :
 - Model repository can act as a single source of truth (✓)
 - By providing a structured and interconnected representation, consistency can be maintained (½)
 - Capturing information in a structured way can reduce implicit assumptions (✓)
 - Validation of model structure can identify gaps and inconsistencies (✓)
 - Common changes can be made in one place and propagated to various products via automated transformations (½)
 - The impact of changes can be identified by tracing relationships (¼)
 - System level analyses can utilize the model to produce consistent results (✓ ½)

Conclusion



- Europa Clipper has embraced MBSE as core to our formulation effort
- Product development and SE process improvement starting to be realized with much more to come
- Shift from document-based to model-based culture is slow but progressing
- Effort needs to be considered in staffing, resources, and schedule

MBSE is ready to support flagship class mission formulation