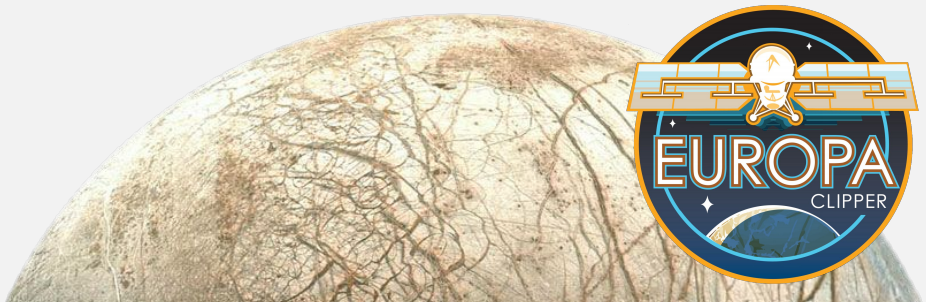
Jet Propulsion Laboratory
California Institute of Technology



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

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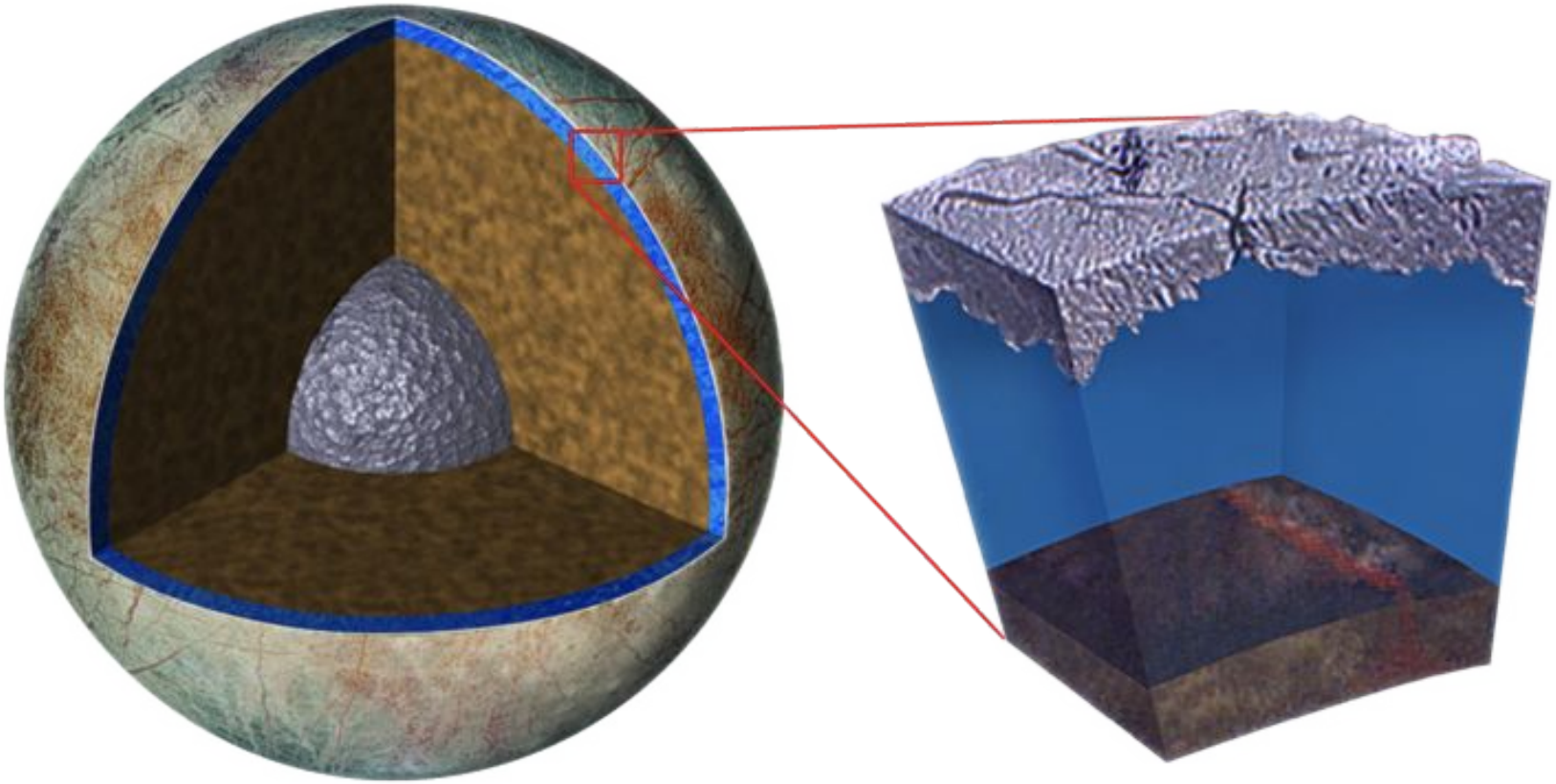
Europa MSET Team Lead

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

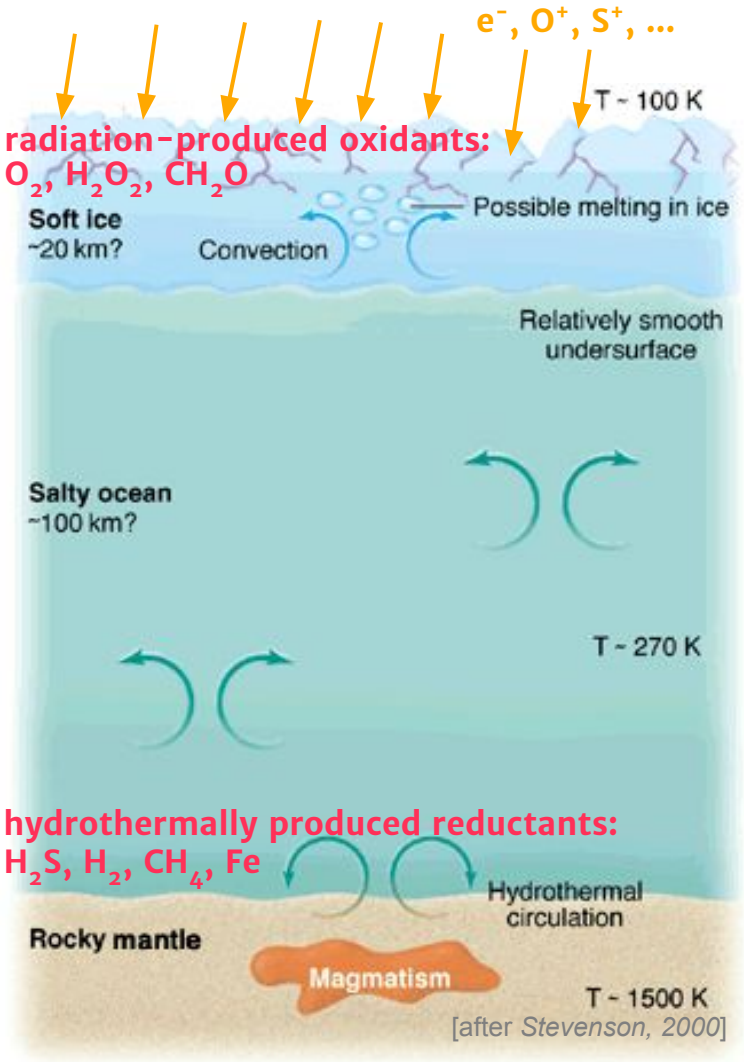
Chemistry:

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

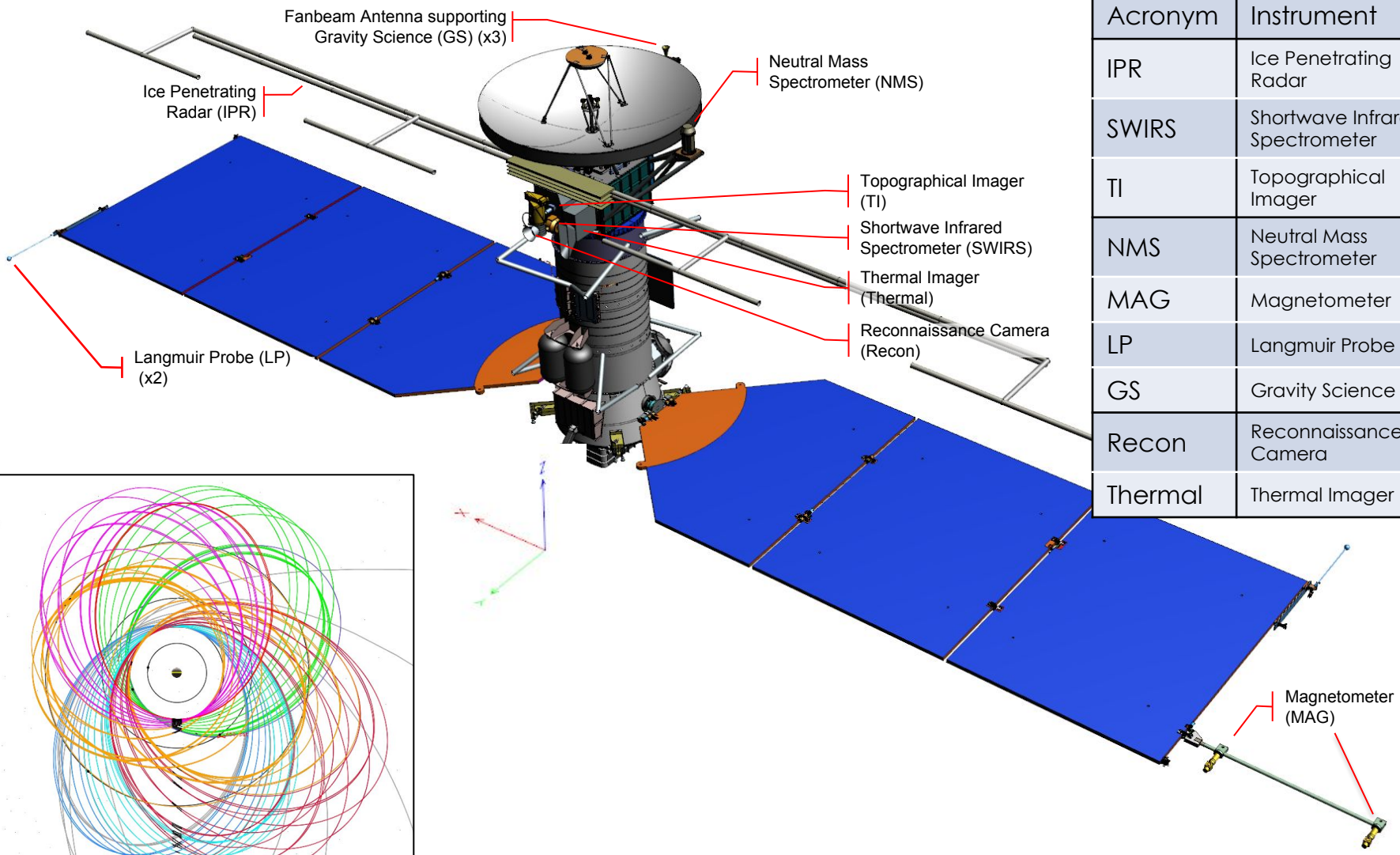
Energy:

- 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



Model Payload	
Acronym	Instrument
IPR	Ice Penetrating Radar
SWIRS	Shortwave Infrared Spectrometer
TI	Topographical Imager
NMS	Neutral Mass Spectrometer
MAG	Magnetometer
LP	Langmuir Probe
GS	Gravity Science
Recon	Reconnaissance Camera
Thermal	Thermal Imager

MBSE ON EUROPA

What is MBSE?

"Structural" Validation

Results for Rule: hasConstrainedElement

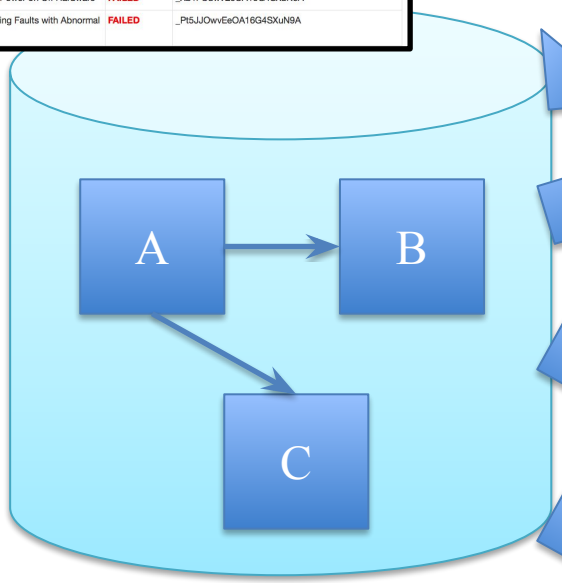
Alert: CONSTRAINED ELEMENT: must have at least one constrained element
Description: Constraints that constrain anything other than ONE constrained element will FAIL this rule.
Applies To: ConstraintBlock
Total Elements Evaluated: 31

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

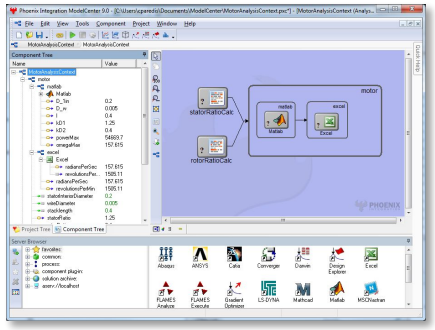
Afid	Name of Validated Element	Validation Result	Model ID
CT100.897	Duration Between Off-Sun Turns in Inner Cruise	FAILED	_Pt6XVOwvEeOA16G4SXuN9A
CT100.894	Temperature Limits during Faults in Adverse Environments	FAILED	_Pt8zmOwvEeOA16G4SXuN9A
CT100.900	Supplementary Heater Power on Off Hardware	FAILED	_Xb1FOuwvEeOA16G4SXuN9A
CT100.895	Temperature Limits during Faults with Abnormal Power Dissipations	FAILED	_Pt5JJOwvEeOA16G4SXuN9A

(Interactive) Views

Gate Products



Repository



Analyses

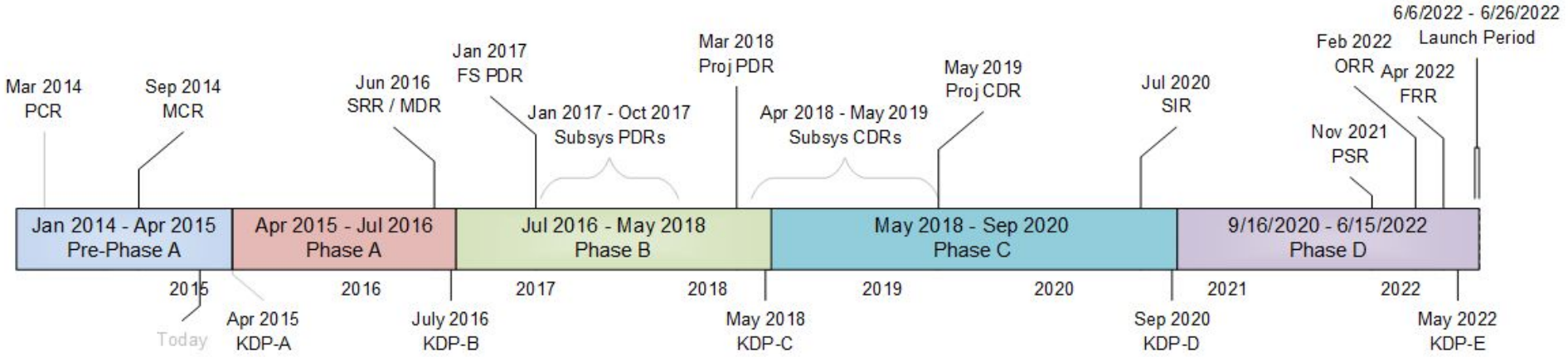
Performance Validation

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

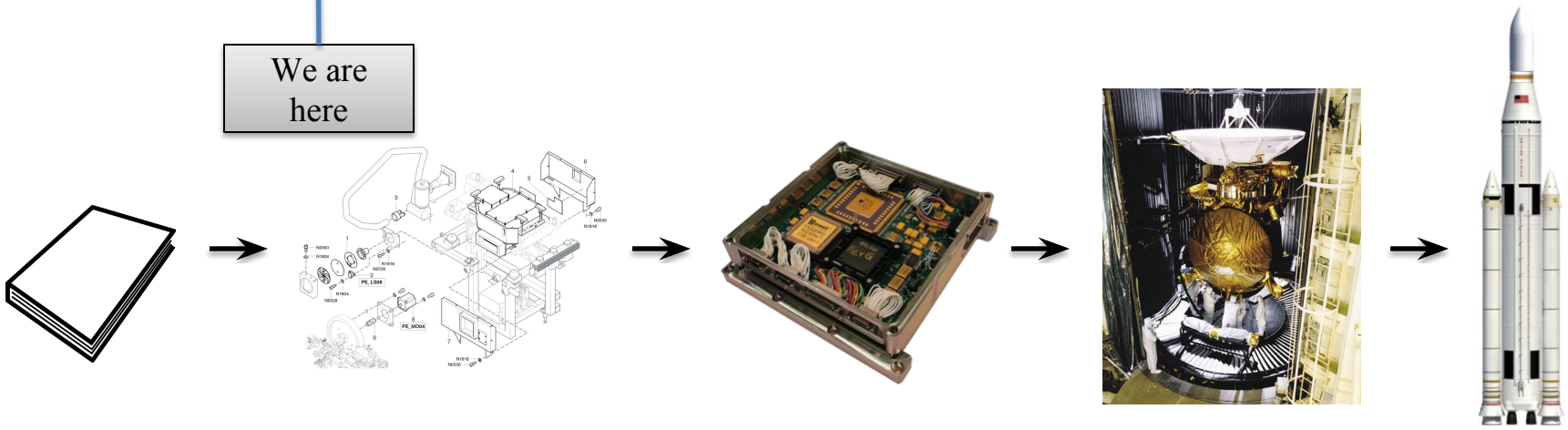
Europa Clipper Project Schedule

Europa Project Timeline – 2022 SLS Launch

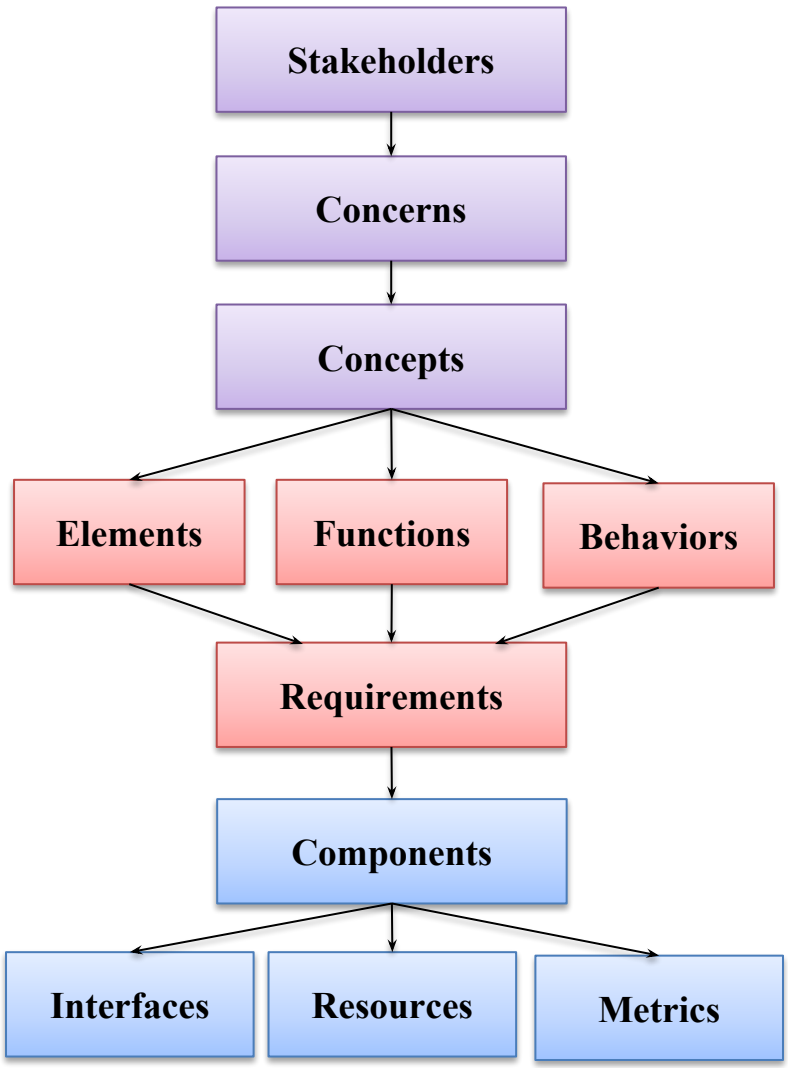


Formulation | **Implementation**

We are here

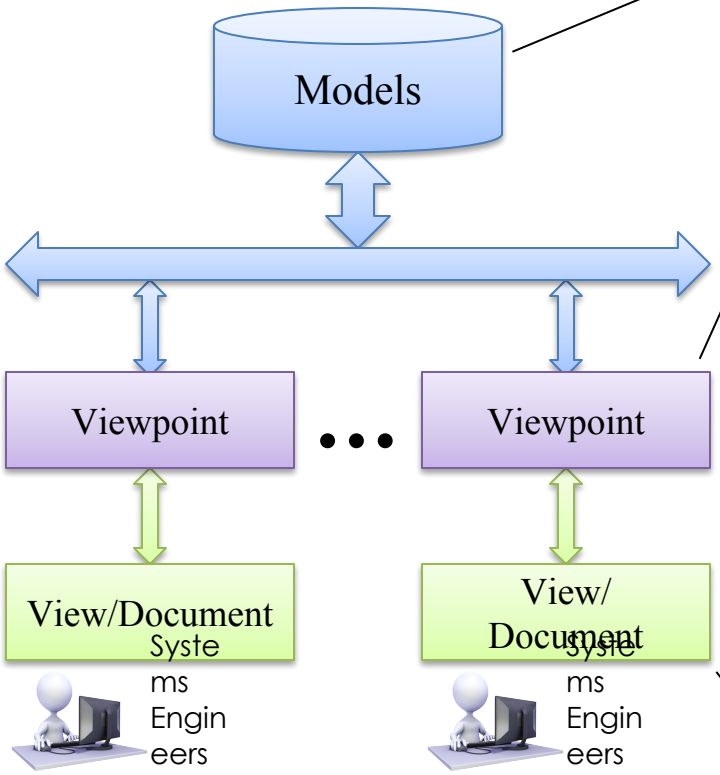


Model-Based System Engineering Approach



- 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



The **Single-Source-of-Truth** for all systems engineering information regarding the architecture, design and performance assessment of a system

Viewpoint defines the subset of information of interest to address a particular topic. Combination of queries for static information and on-demand transformation or analysis

View, from the associated viewpoint, through which the systems engineers can view, assess, and judge the system architecture, design and performance. Provides a two way interface for editing and updating model data.

Unique Europa challenges:

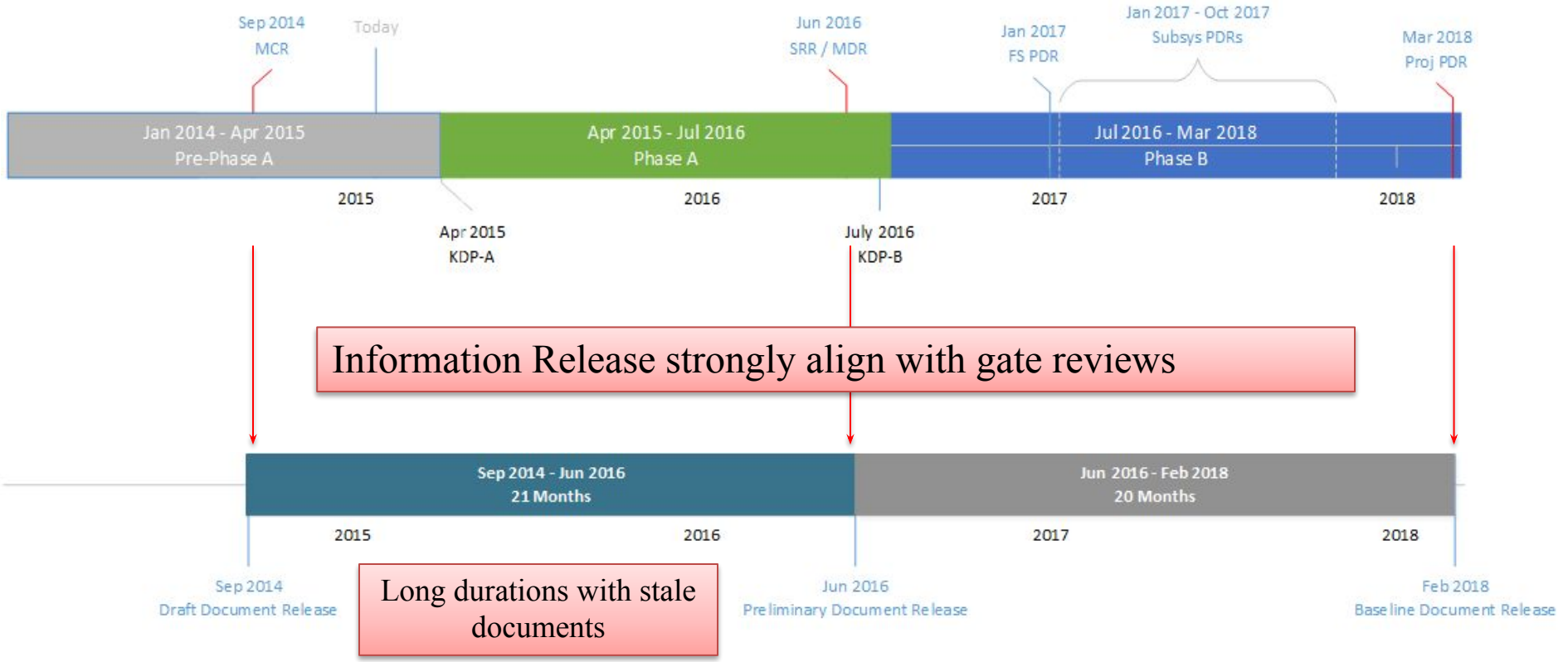
- **Scope**: trying to capture information from across the project, content from >40 people who need to interact with the environment in some way. 10-15 people working in MagicDraw.

- **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

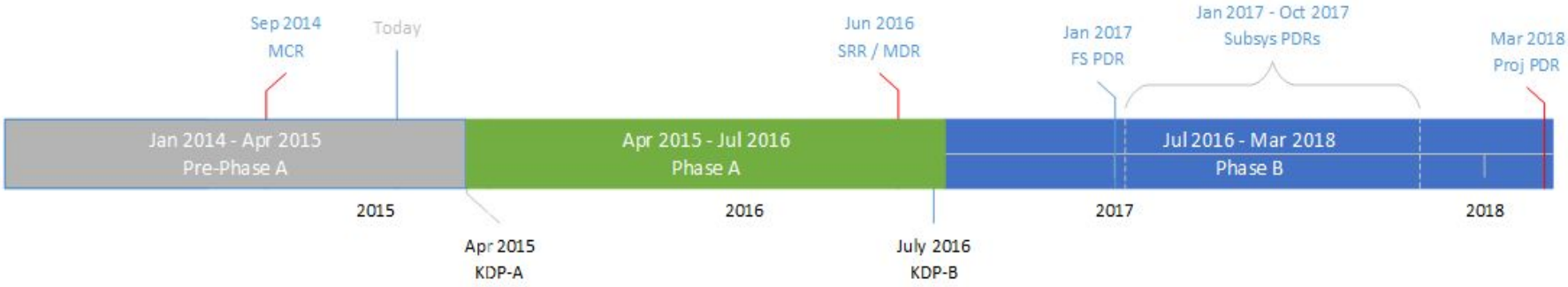
Project Timeline (typical):



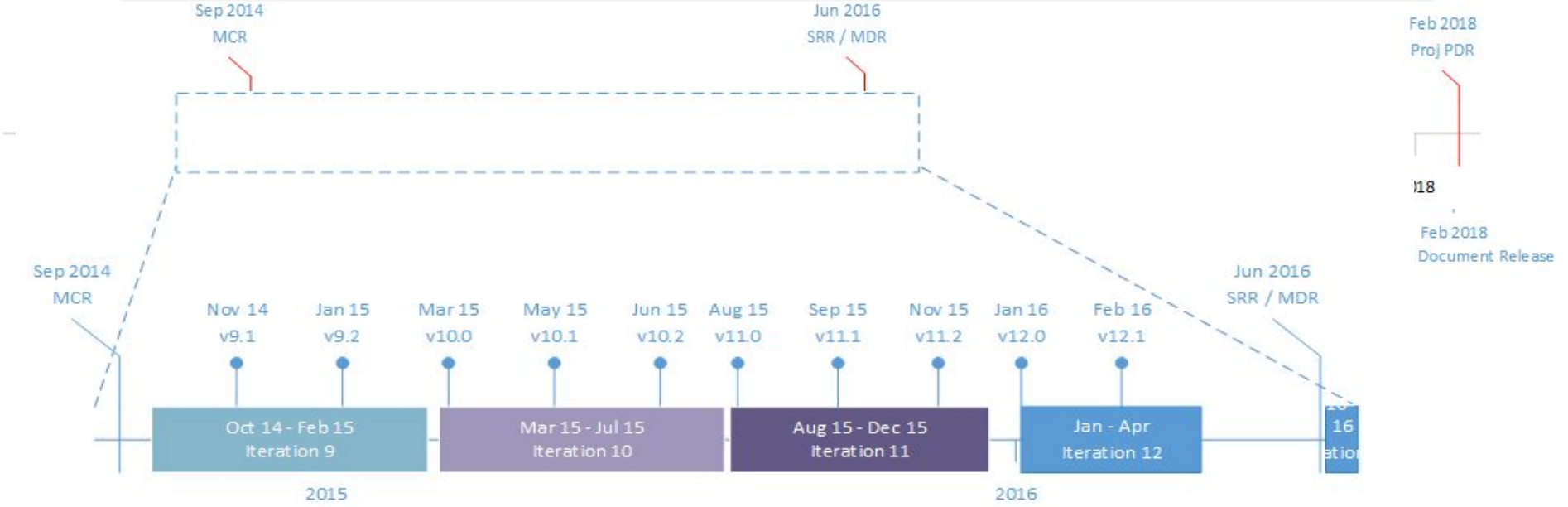
Project personnel relied upon to know what information is reliable and what is in the (long) process of being changed

MBSE Enhanced Information Release Cadence

Project Timeline (typical):

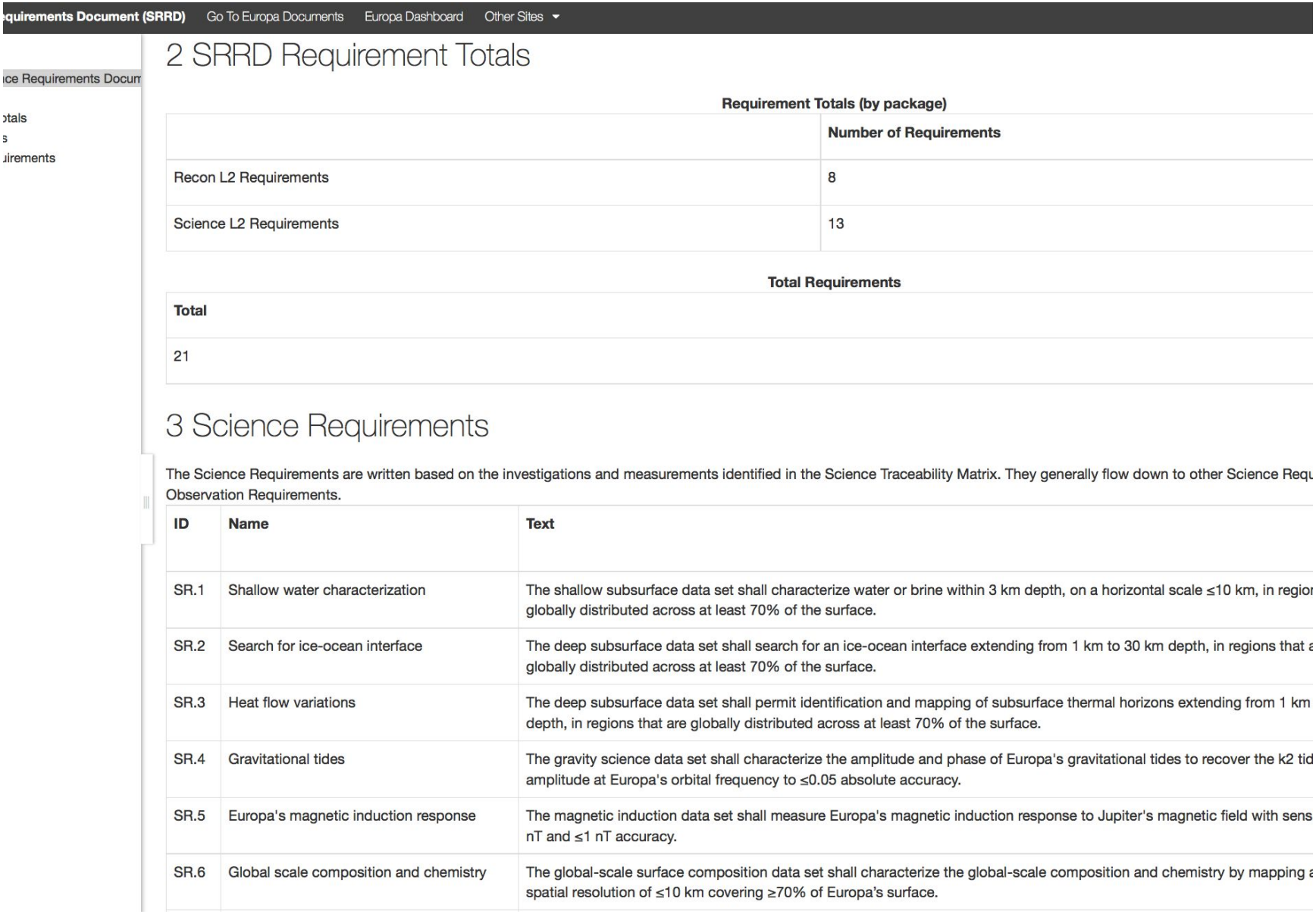


Iterative approach sets regular release cadence; independent of review schedule



Increments set much shorter duration between change request and updated documentation

Requirements



quirements Document (SRRD) | Go To Europa Documents | Europa Dashboard | Other Sites

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2 SRRD Requirement Totals

Requirement Totals (by package)

	Number of Requirements
Recon L2 Requirements	8
Science L2 Requirements	13

Total Requirements

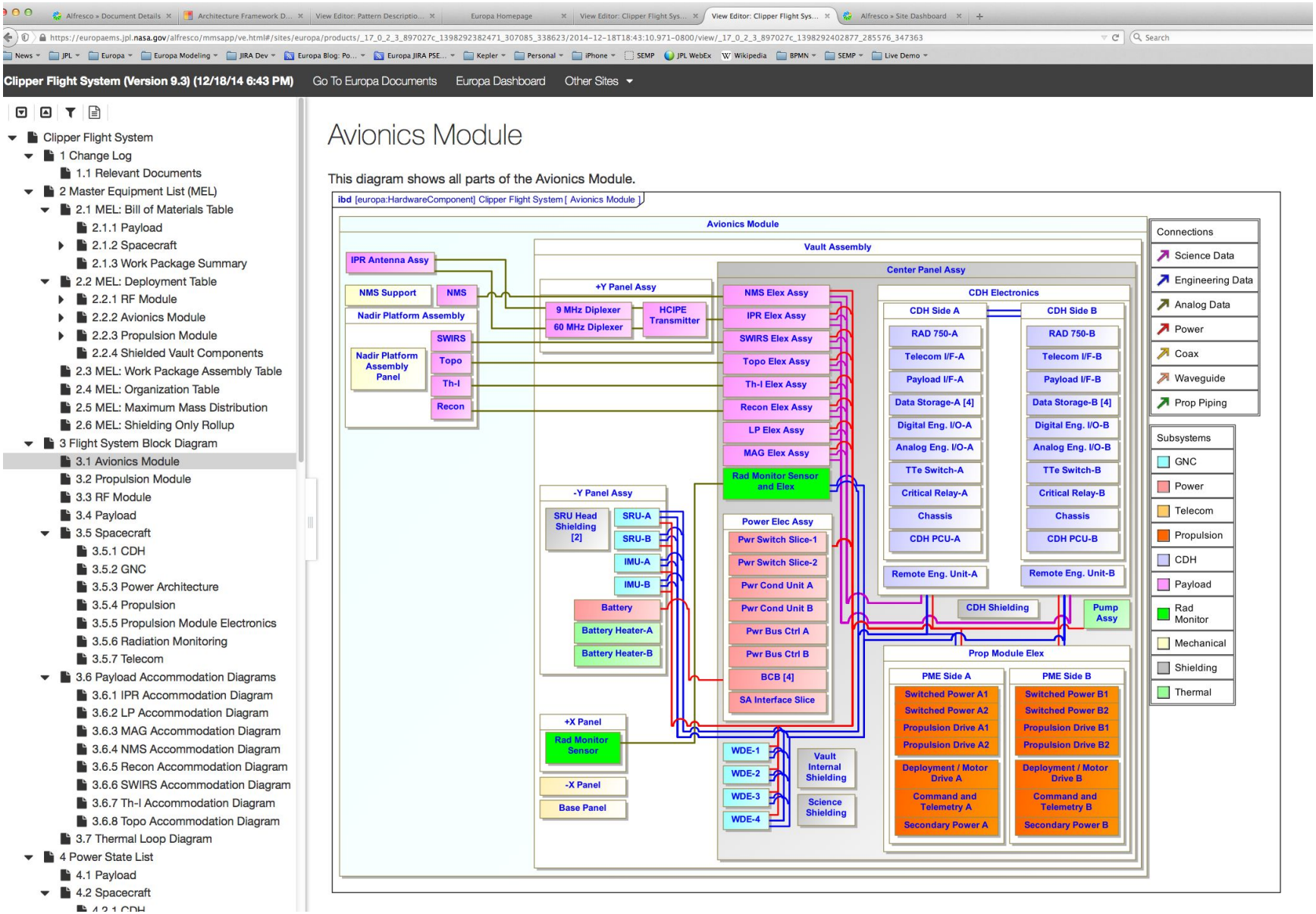
Total
21

3 Science Requirements

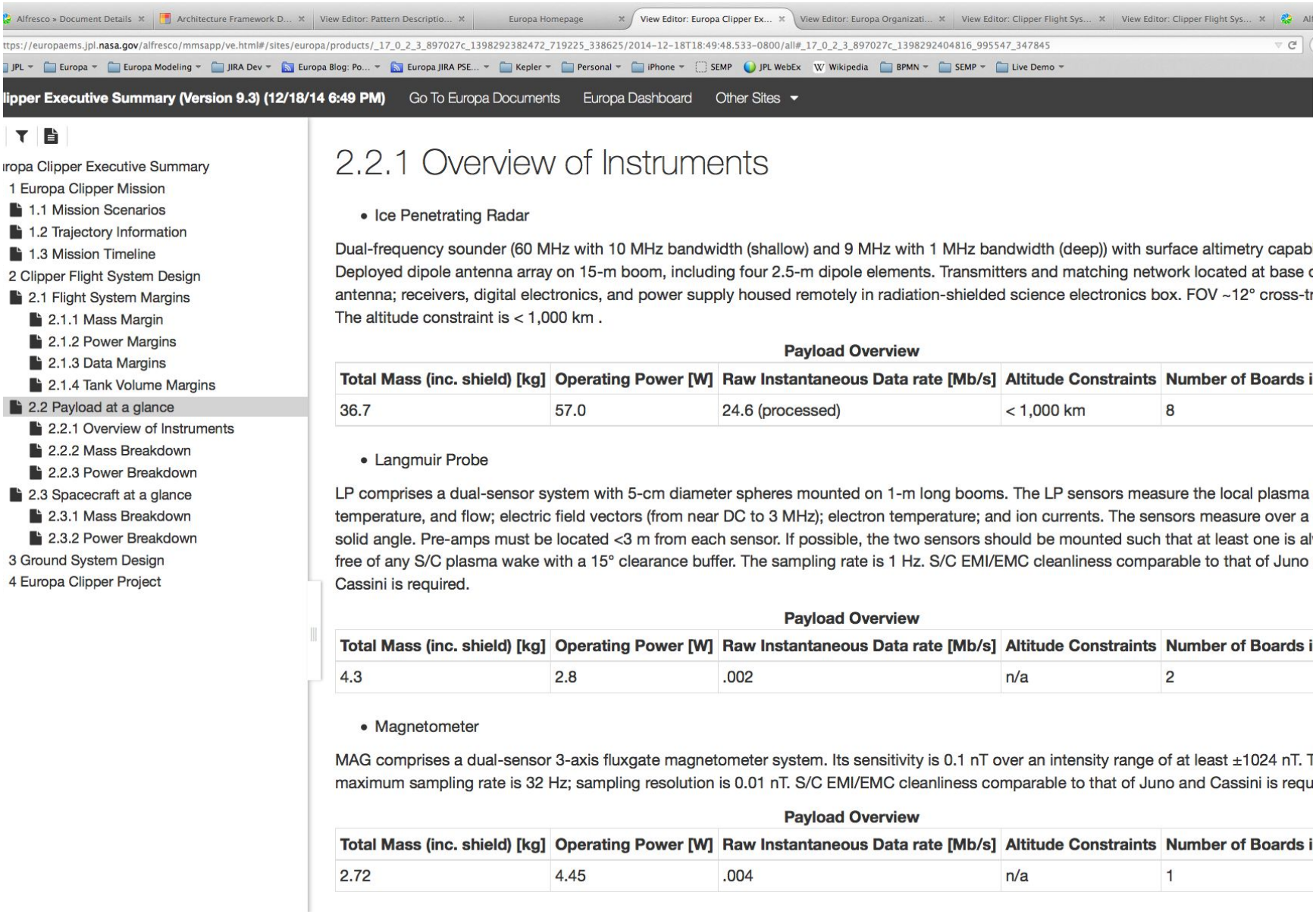
The Science Requirements are written based on the investigations and measurements identified in the Science Traceability Matrix. They generally flow down to other Science Requ
Observation Requirements.

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 ≤10 km, in regio 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 a 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 tid amplitude at Europa's orbital frequency to ≤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 sens nT and ≤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 a spatial resolution of ≤10 km covering ≥70% of Europa's surface.

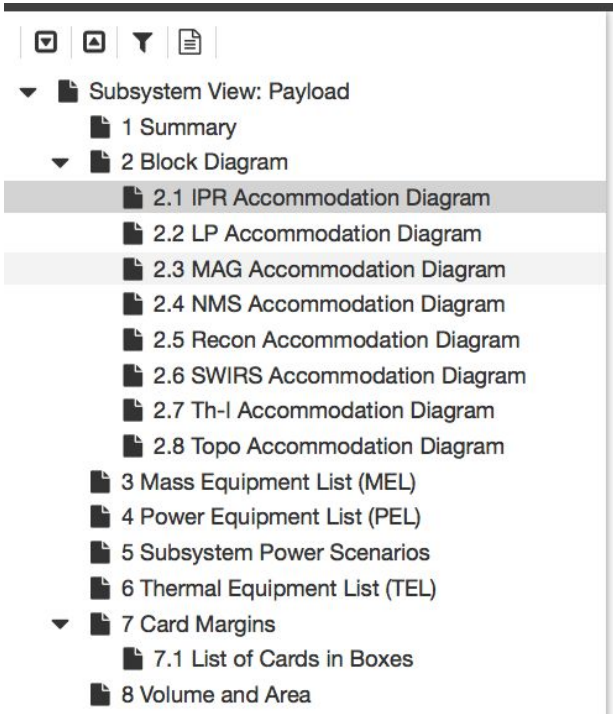
Block Diagrams



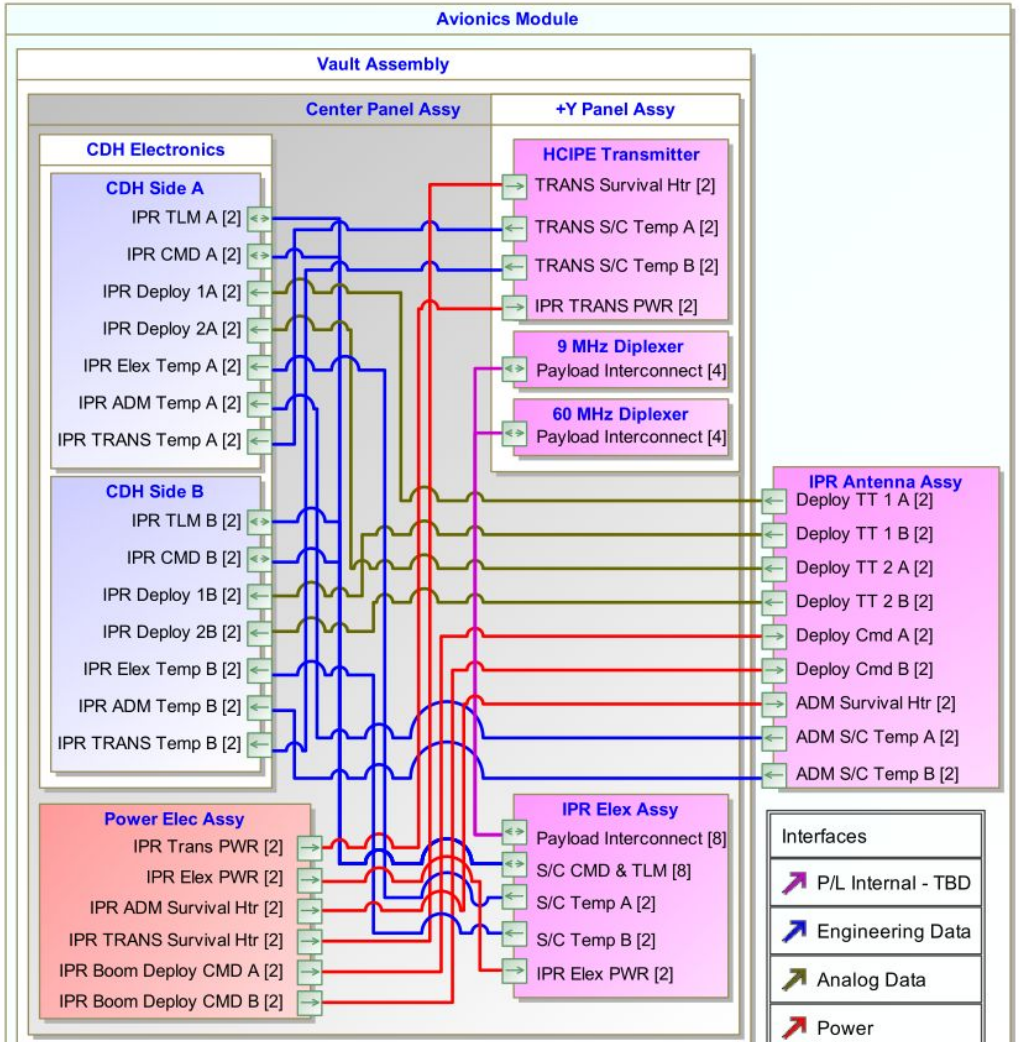
Instrument Overview



Instrument Accommodations



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