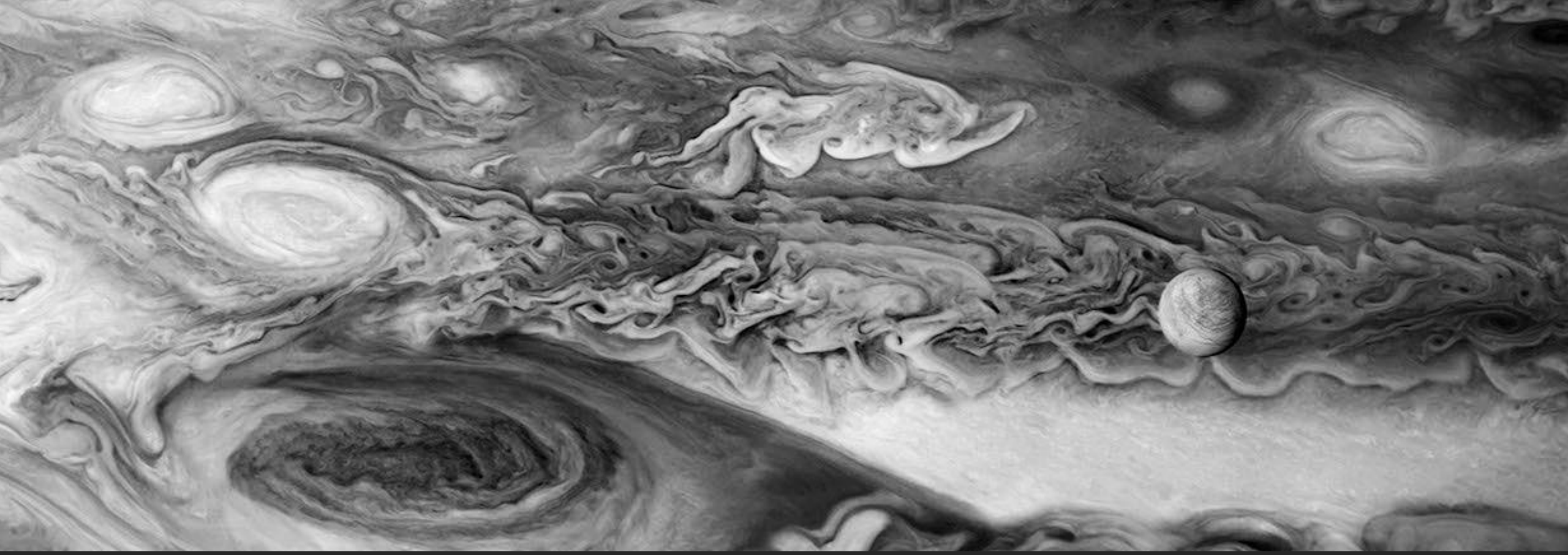

Assessing the Science Robustness of the Europa Clipper Mission: Science Sensitivity Model

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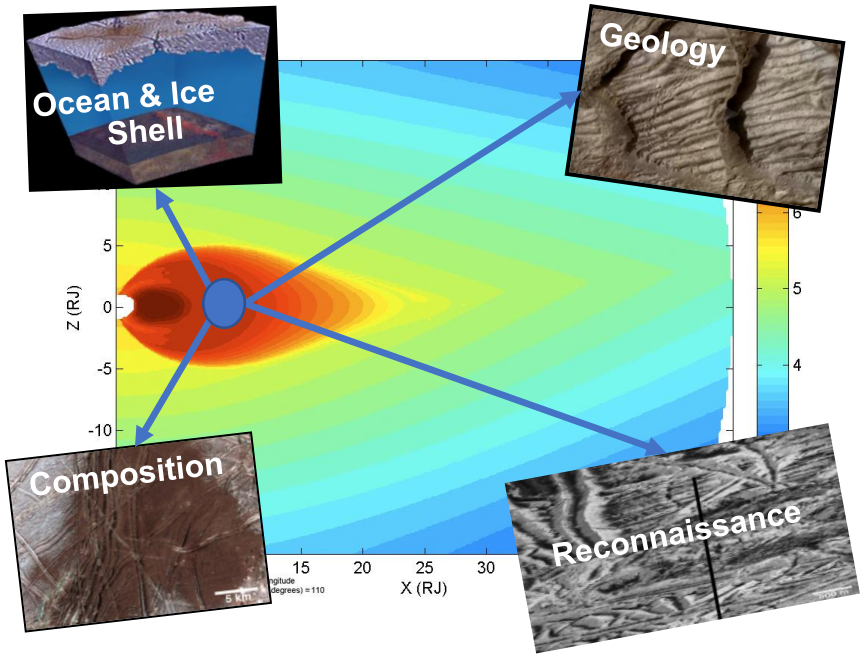
March 8, 2018

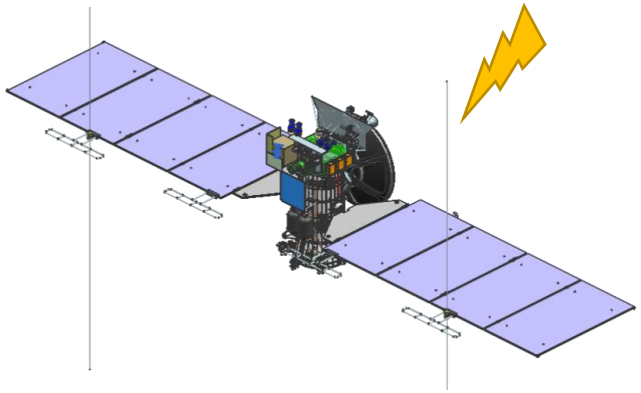
EUROPA CLIPPER

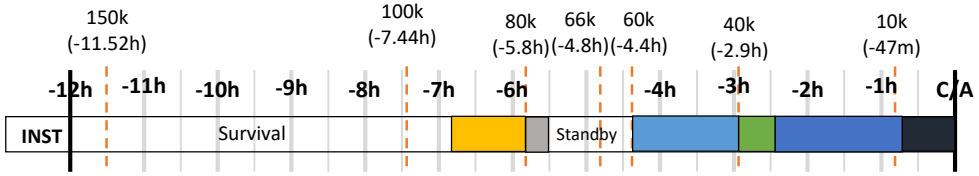
Science Robustness Motivation

- Europa Clipper's enabling strategy is to dip into Europa's intense radiation, collect the bulk of its science data, and get out



- Due to the uncertainty in the radiation environment, disruptions to planned activity are expected
  - A robust Flight System and Mission Plan are required to return sufficient science data



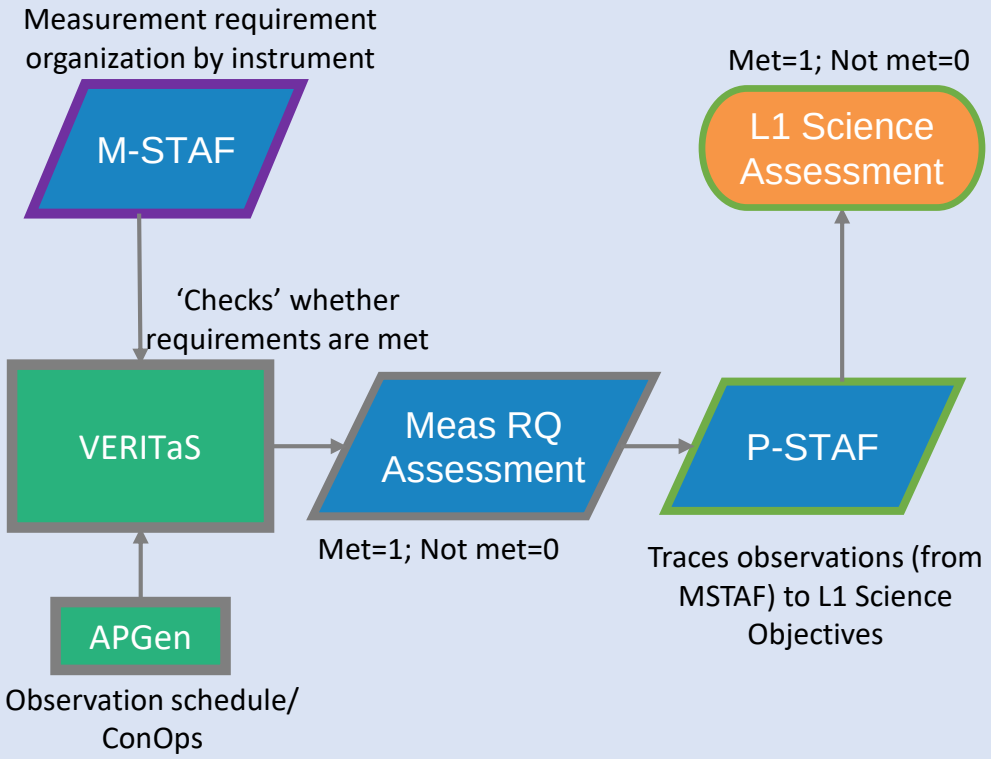


A comprehensive suite of tools is needed to inform robustness conversations

Assessment Tool Suite Overview

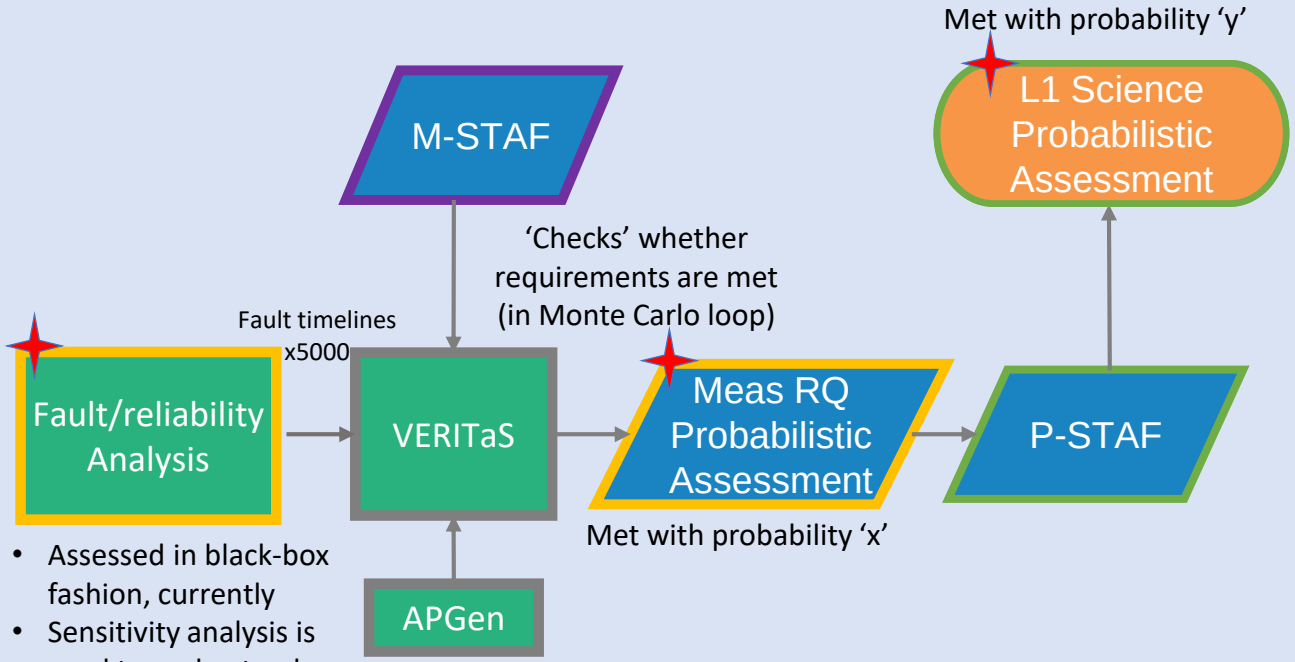
Nominal Scenario:

Objective: deterministically assess candidate tours against Measurement Requirements and L1 Science Objectives



Robustness Scenario: Science Sensitivity Model

Objective: probabilistically assess achievement of Measurement Requirements and L1 Science Objectives; use results to ensure a robustness in the Flight/Mission System design



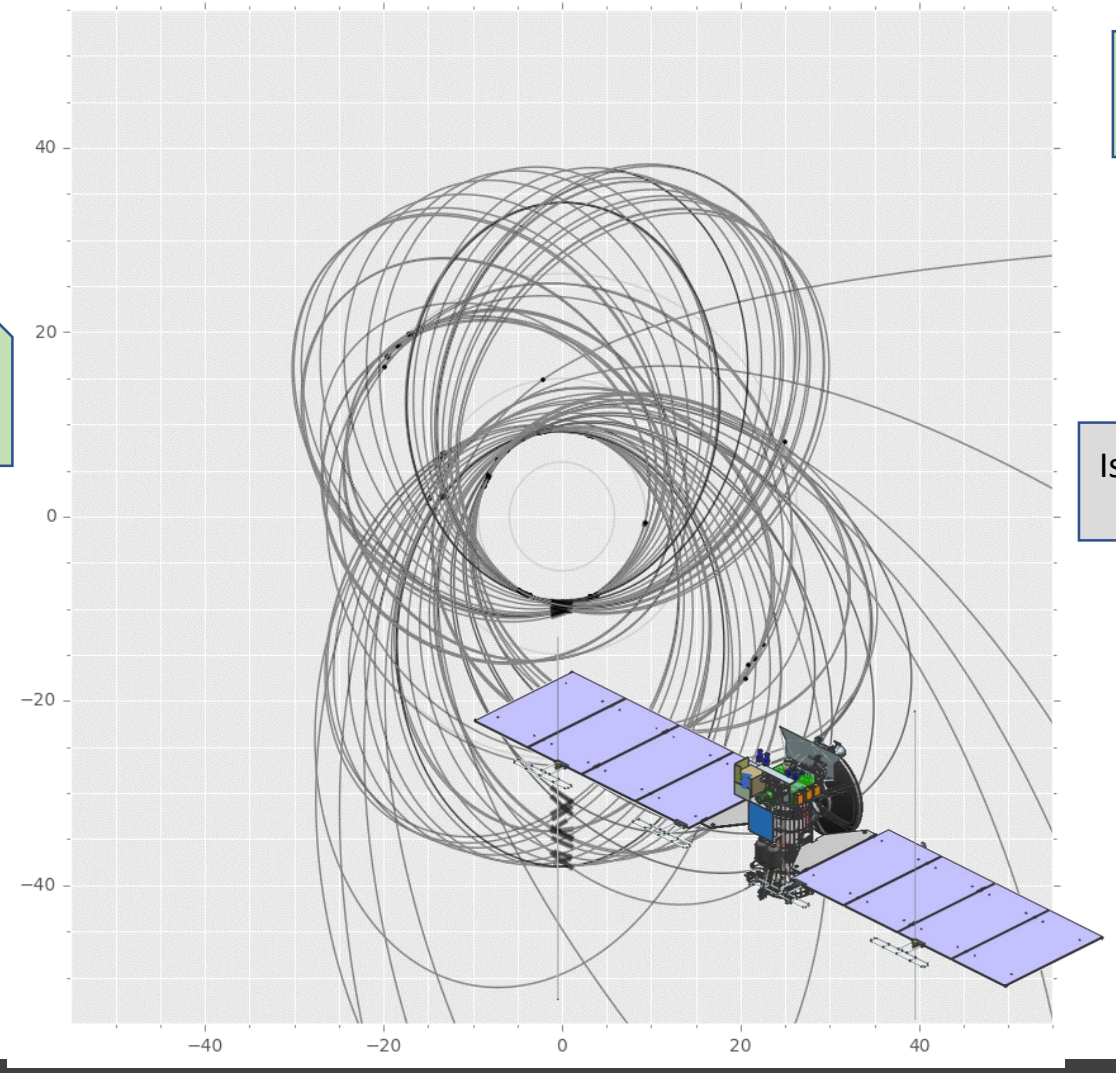
Robustness Architecture Capability Examples

We know when each L1 RQ is met. When satisfied, can we turn off the associated instruments to save power, etc?

Can the current mission/flight system design meet L1 science RQs with high probability?

Does each instrument, s/c need the capability to recover during a flyby? If so, how quickly?

Is there a piece of hardware susceptible to radiation that could cause science loss?



Is a particular measurement RQ driving L1 results?

If something goes wrong, the tour can be replanned to target specific science

Is more margin needed in the tour to meet L1 science RQs?

If the tour needs to be longer, the solar arrays need to be larger; more shielding, propellant is needed

Mission Related

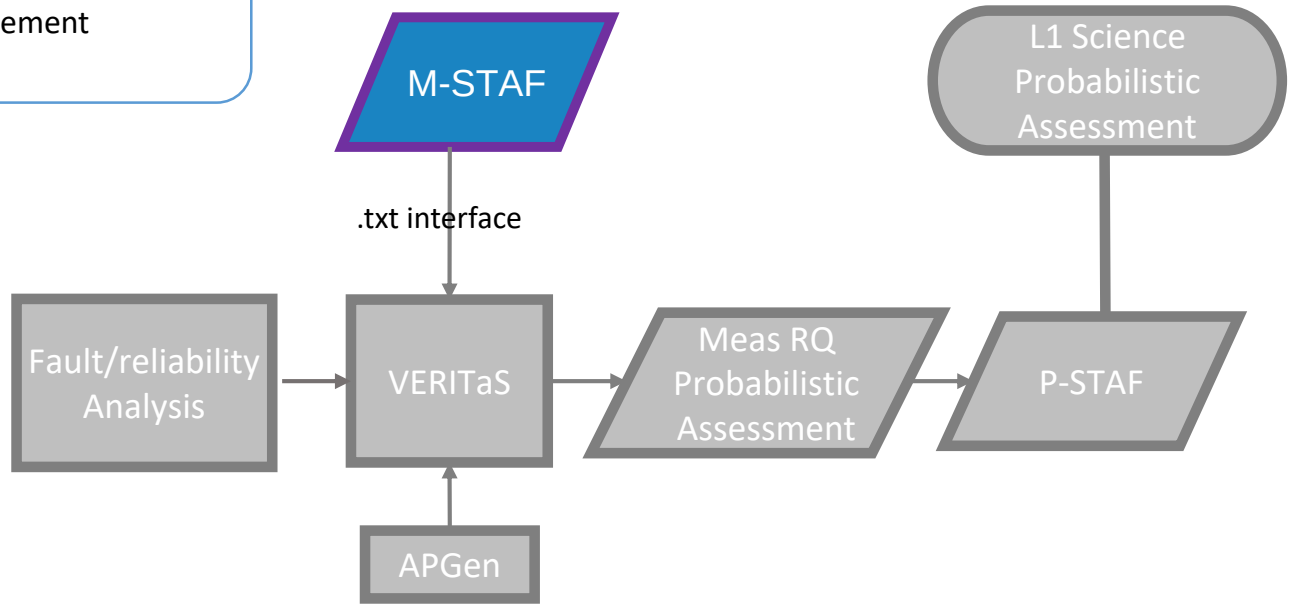
Science Related

Flight System Related

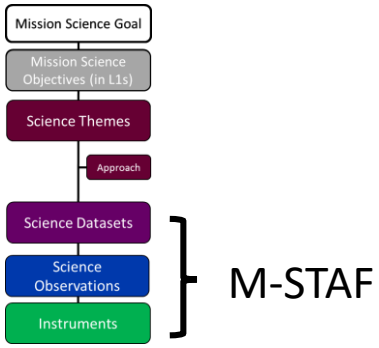
Science Sensitivity Model

M-STAF benefits

- Provide structure for science traceability and science validation
- Ensure consistent and complete measurement requirements
- Support verification of measurement requirements



M-STAF Matrices



Mission Science Goal

Mission Science Objectives (in L1s)

Science Themes

Approach

Science Datasets

Science Observations

Instruments

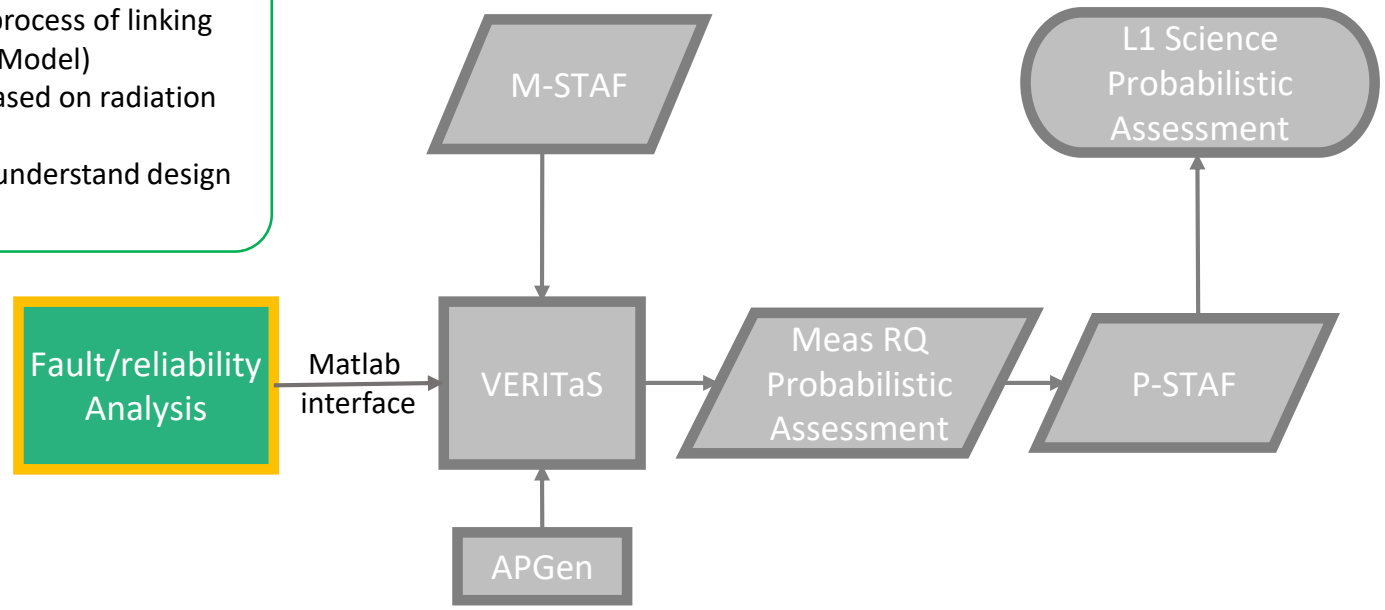
Instrument Name										
Observation		Measurement Requirements								
Conditions						Measurement Quality				
Cond. A	Cond. B	Spatial Coverage and Distribution	Temporal Coverage and Distribution	Diversity and Special Case	Internal Correlations	Qual. A	Qual. B	Qual. C	Qual. D	
REQ.003	REQ.001	REQ.025		REQ.09	REQ.11	REQ.10	REQ.06	REQ.13, REQ.14		
	REQ.001			REQ.12	REQ.16		REQ.15			
					REQ.22			REQ.027		
					REQ.19		REQ.031	REQ.028		
	REQ.001	REQ.025	REQ.20	REQ.18					REQ.026	
	REQ.001	REQ.025	REQ.21, REQ.24							
			REQ.17	REQ.033	REQ.11		REQ.032	REQ.029, REQ.030		

Measurement Requirements

Science Sensitivity Model

Reliability Analysis

- Currently assessed in black-box fashion based on historical data (but in the process of linking to the Europa Clipper System Model)
- Time-dependent fault rates based on radiation environment
- Sensitivity analysis is used to understand design “needs”

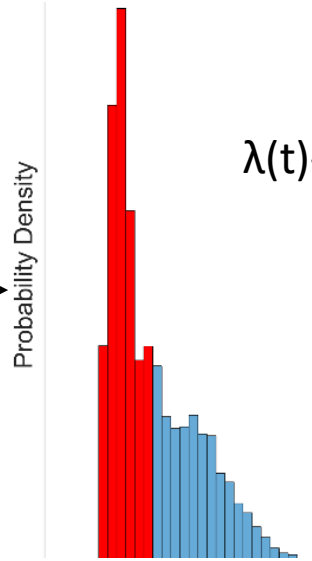


Current Reliability Analysis

Historical spacecraft/instrument anomaly data analysis (s/c safing & SEE, instruments)

Probabilistic Scaling
- Heritage, duty cycle, environment

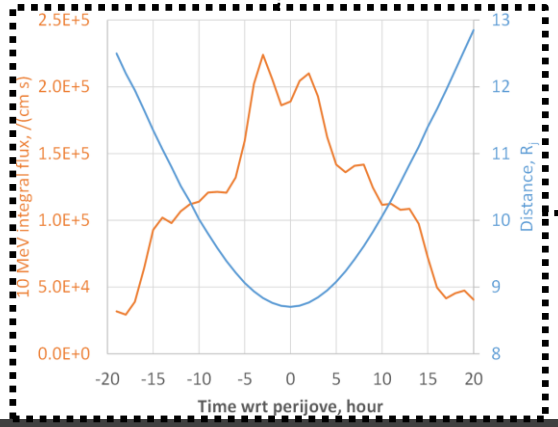
Historical Spacecraft/Instrument Fault Rate distribution
(with time dependencies based on radiation)



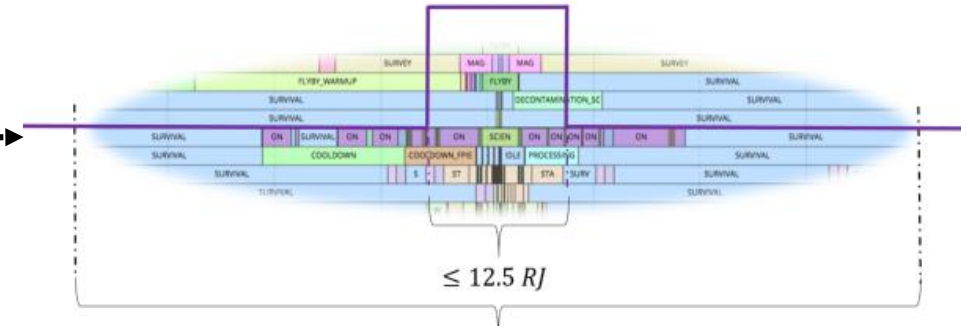
λ(t)- fault rate

Fault timelines passed to VERITaS

Proton Environment

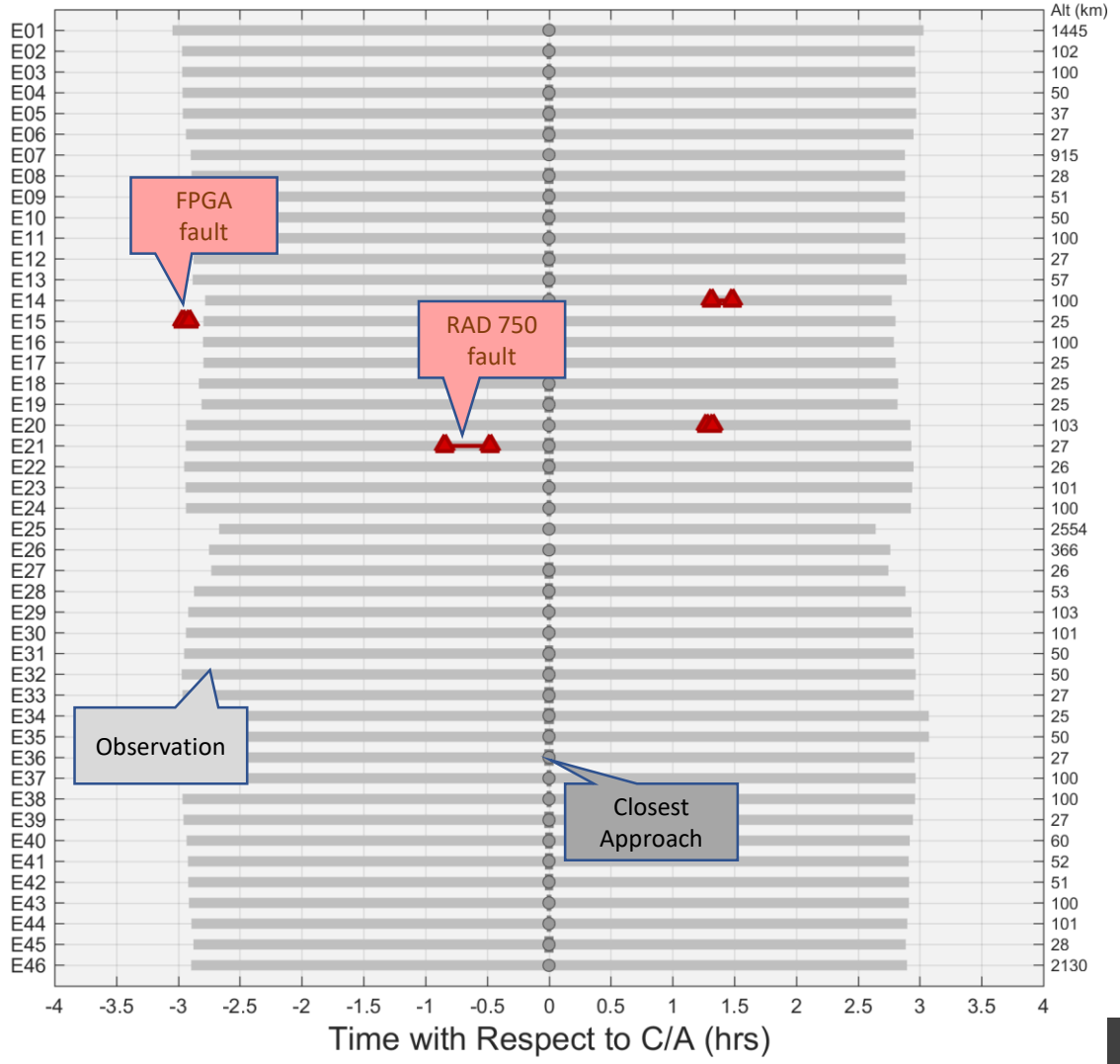


time dependencies based on radiation

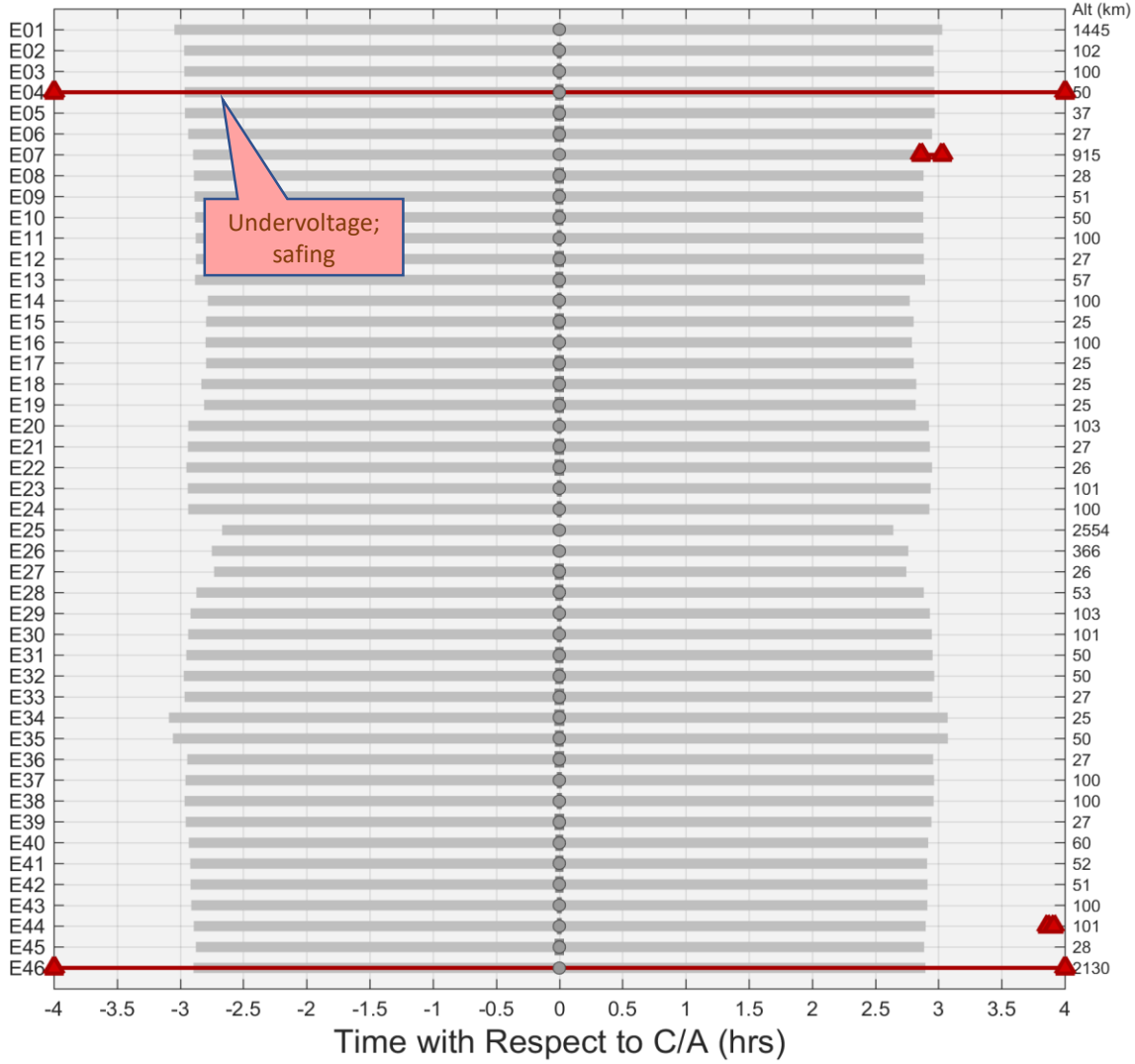


Fault timelines Generation Examples

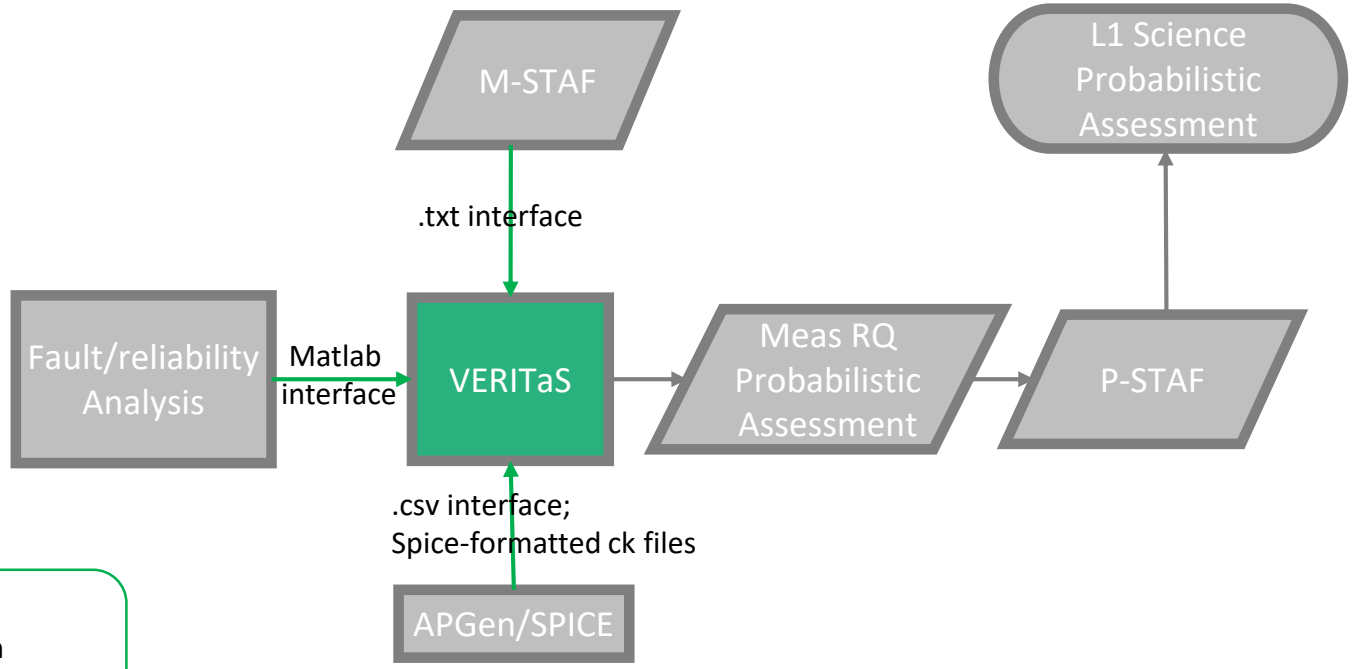
Example Timeline 1



Example Timeline 2



Science Sensitivity Model



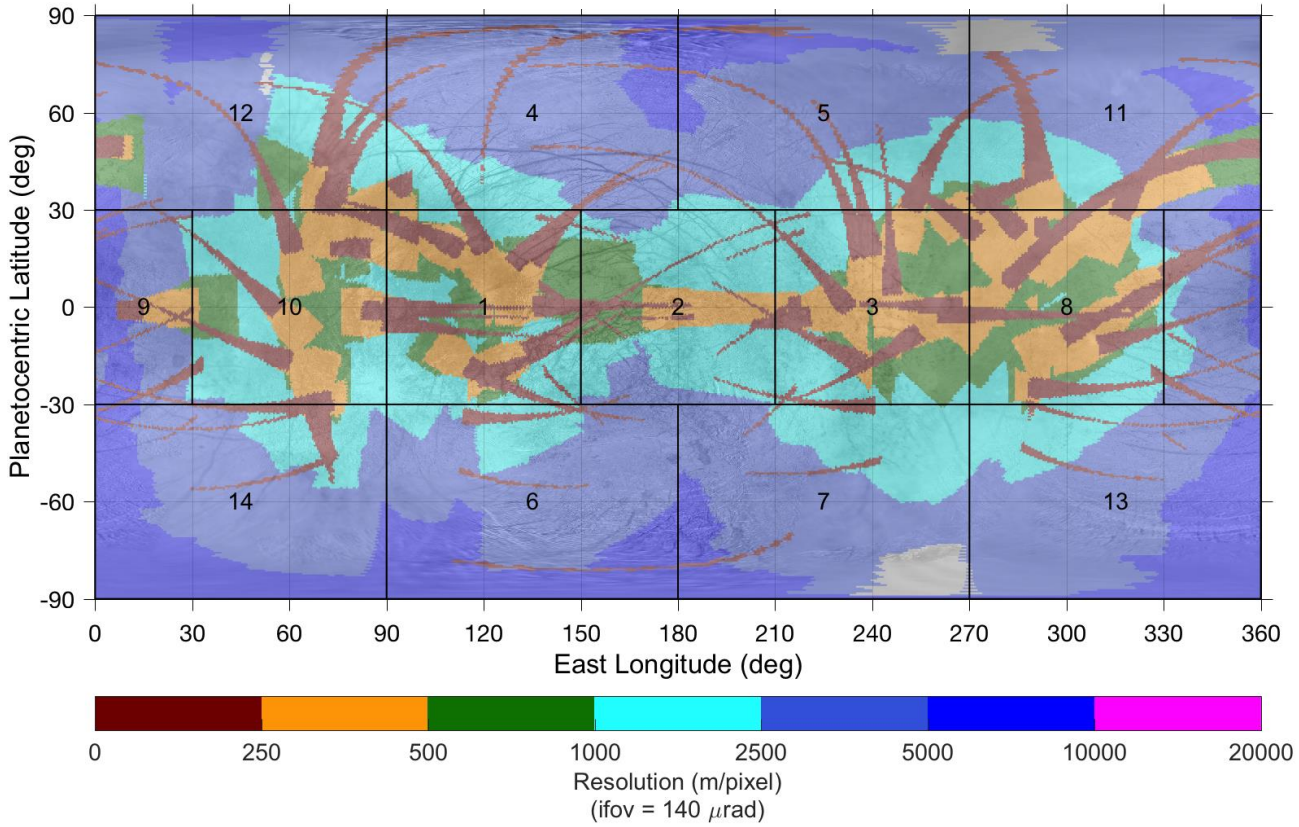
VERITaS benefits

- Clarify key interfaces between science and mission design
- Evaluate candidate tours efficiently
- Systematically verify mission design measurement requirements
- Run a multitude of what-if scenarios

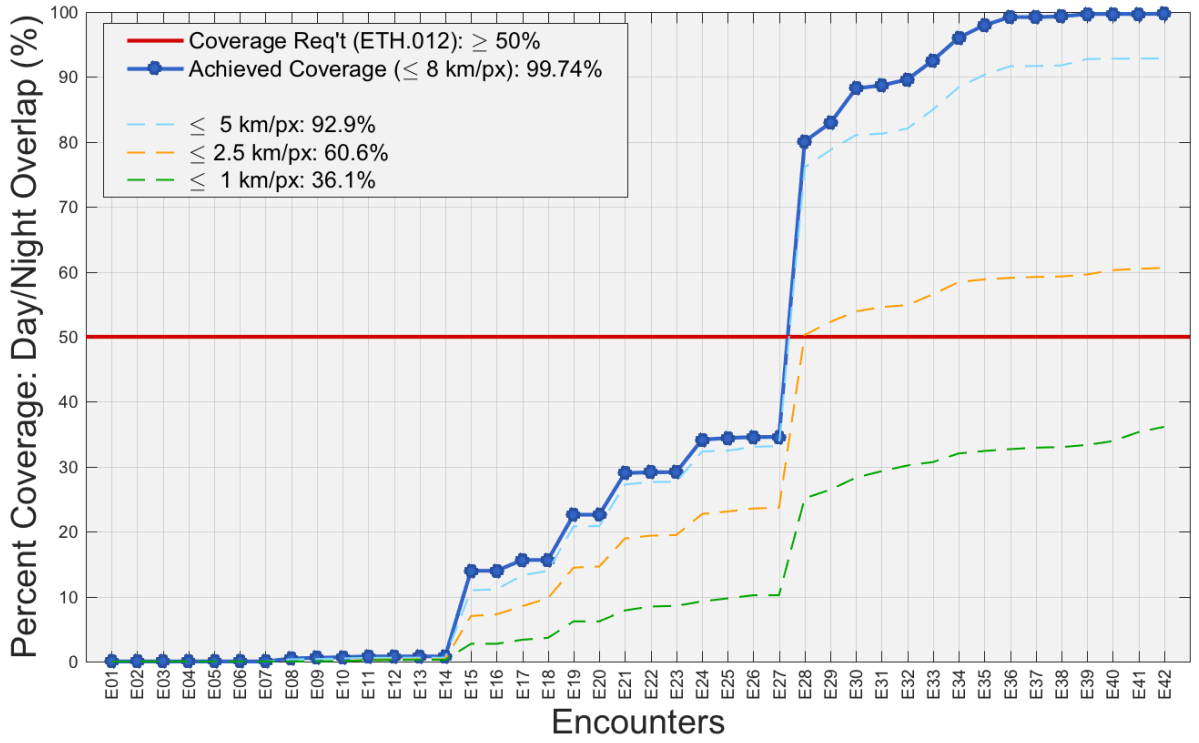
VERITaS: Example Req’ts

REQ.012

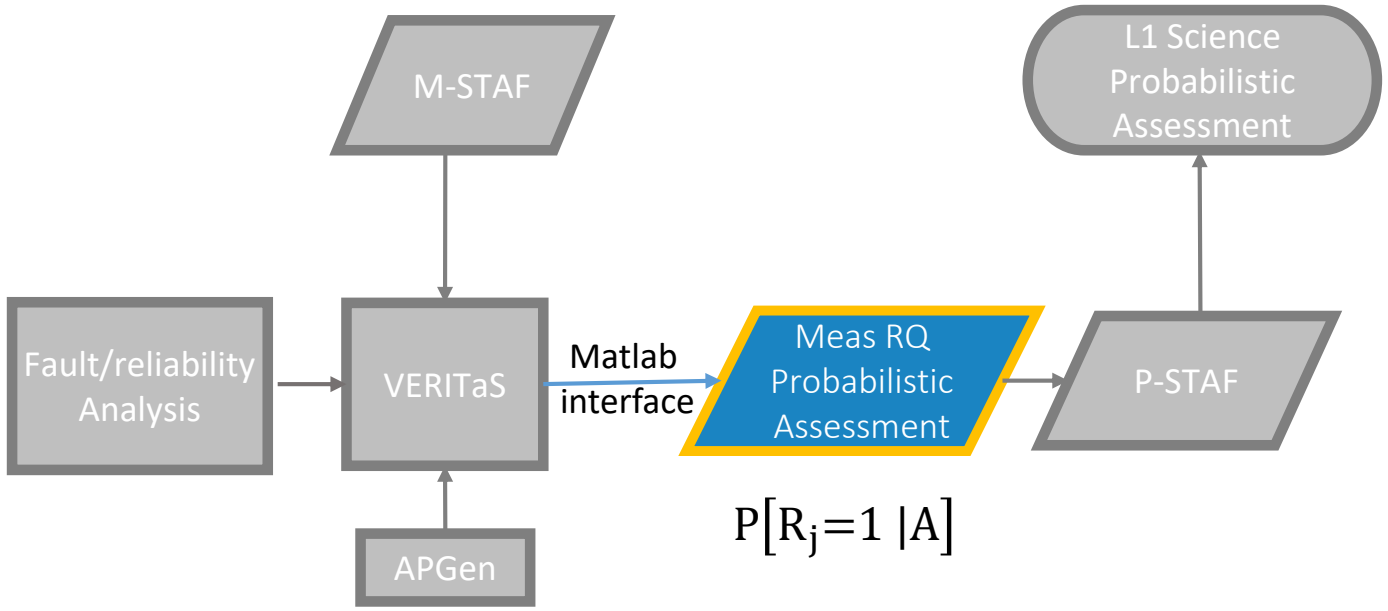
E-THEMIS - Coverage Map
Stare + Scan Techniques



Percent Coverage Buildup Throughout Mission



Science Sensitivity Model



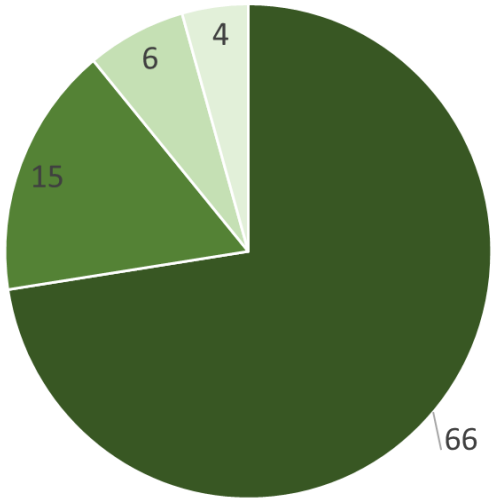
Probabilistic Assessment

- Identify and manage key system sensitivities
- Inform requirement development
- Assess design risk w.r.t meeting science objectives

Robustness Assessment: Measurement RQs

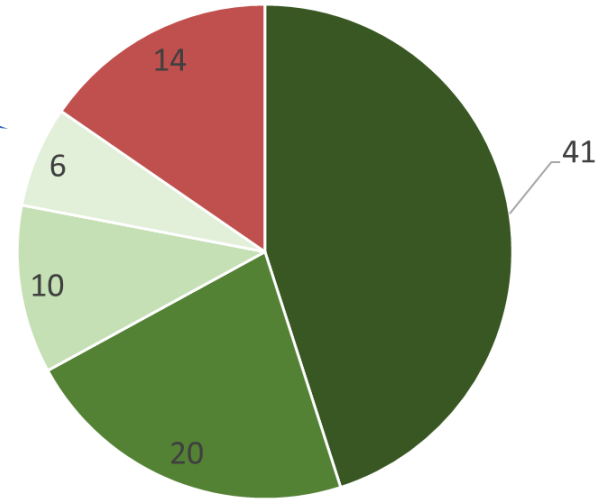
Current Design Recovery: Low Fault Rate (Measurement Requirement Count)

Low fault rate= higher probability of meeting meeting RQs



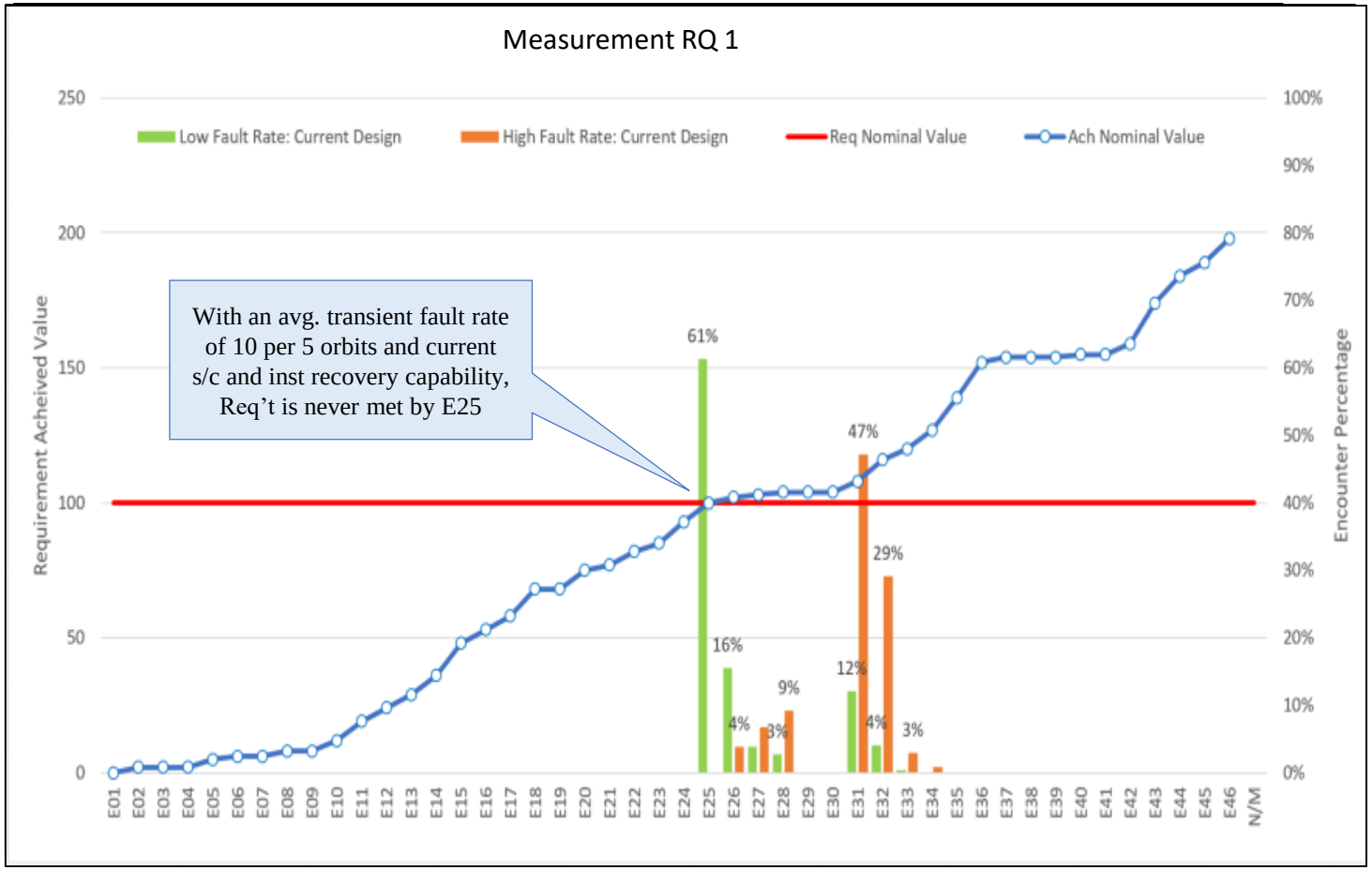
Current Design Recovery: High Fault Rate (Measurement Requirement Count)

High fault rate= lower probability of meeting RQs



P(75%-100%) P(50%-75%) P(25%-50%) P(>0%-25%) Never Met

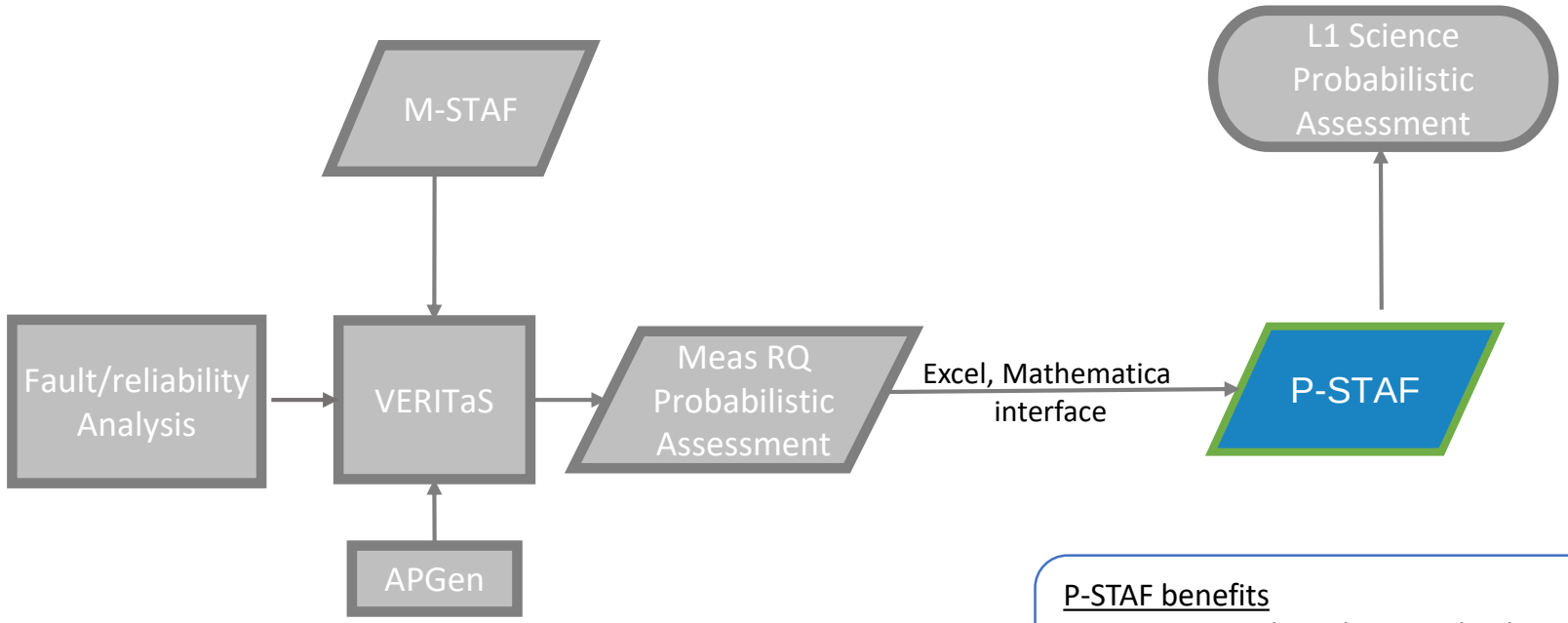
Robustness Assessment: Measurement RQs



How sensitive are Measurement RQs to fault rate?

Is a particular Measurement RQ driving tour duration?

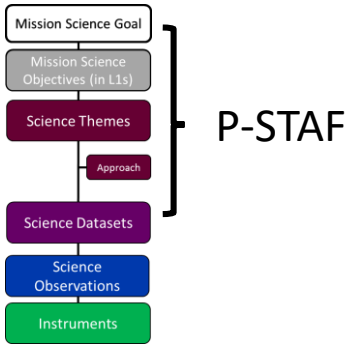
Science Sensitivity Model



P-STAF benefits

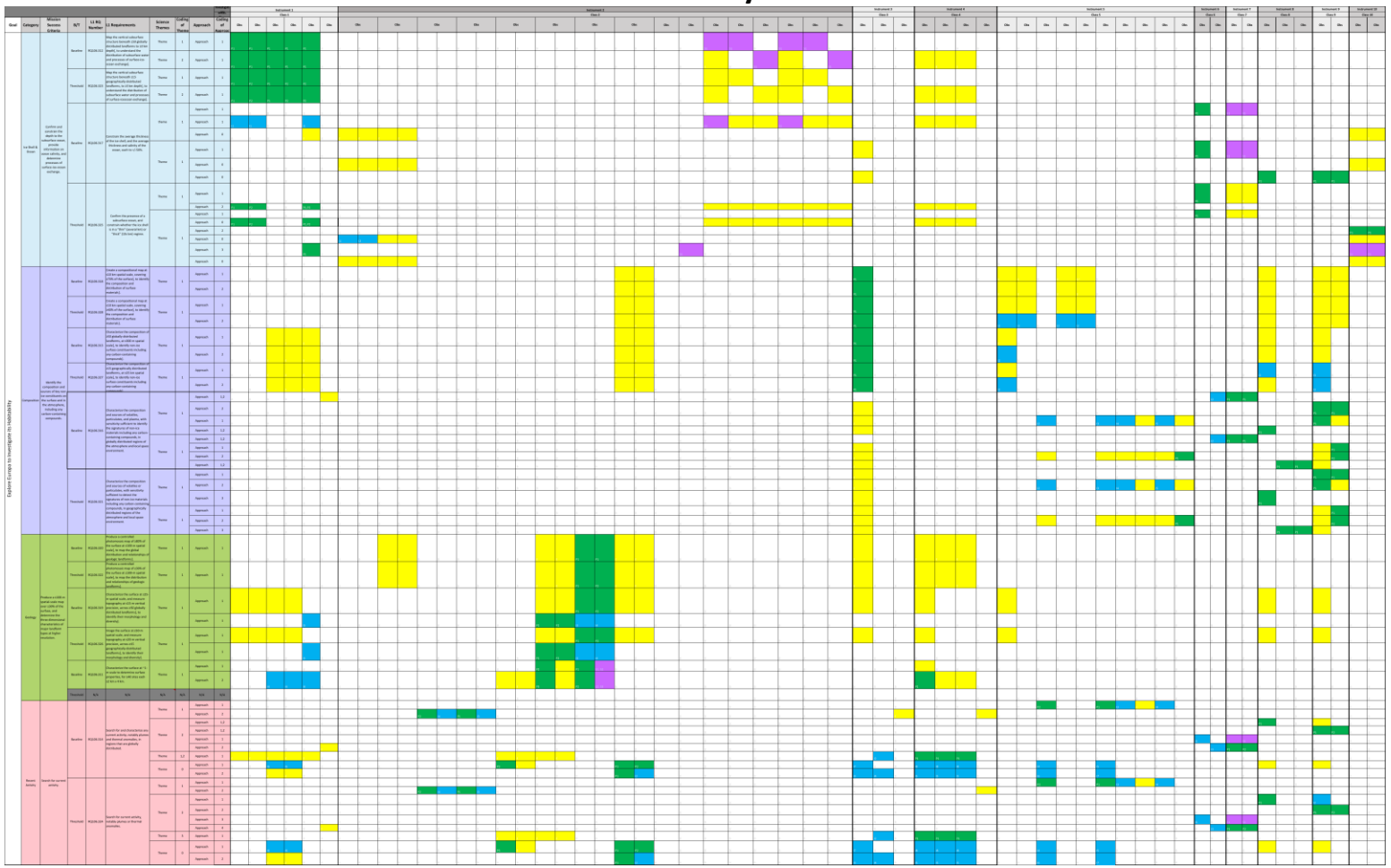
- Quantitatively evaluate payload robustness
- Understand science synergies
- Assess impact to science when inst requirements are not met
- Inform trade studies

P-STAF Matrix



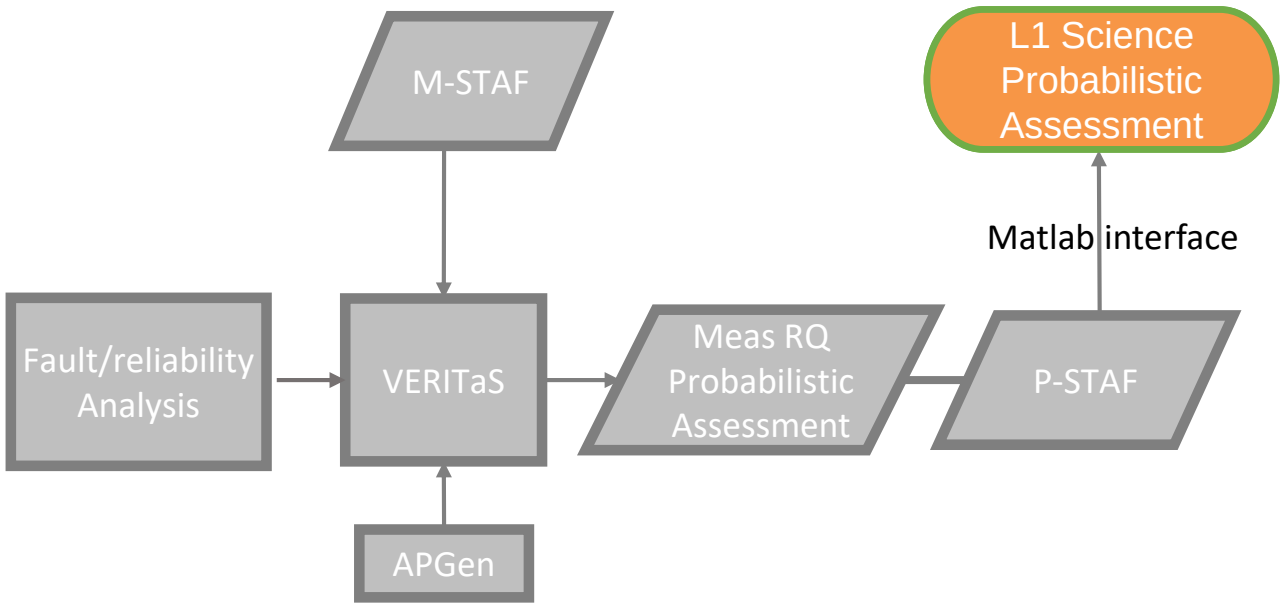
Science Observations by Measurement Class

Mission Goal, L1 Req., Science Theme, Approach



P	**Primary:** Most robust way to meet science
I	**Independent** Less robust way to meet science
S	**Supporting** Necessary context for another instrument
E	**Enhancing** Contributes but cannot answer main science questions

Science Sensitivity Model

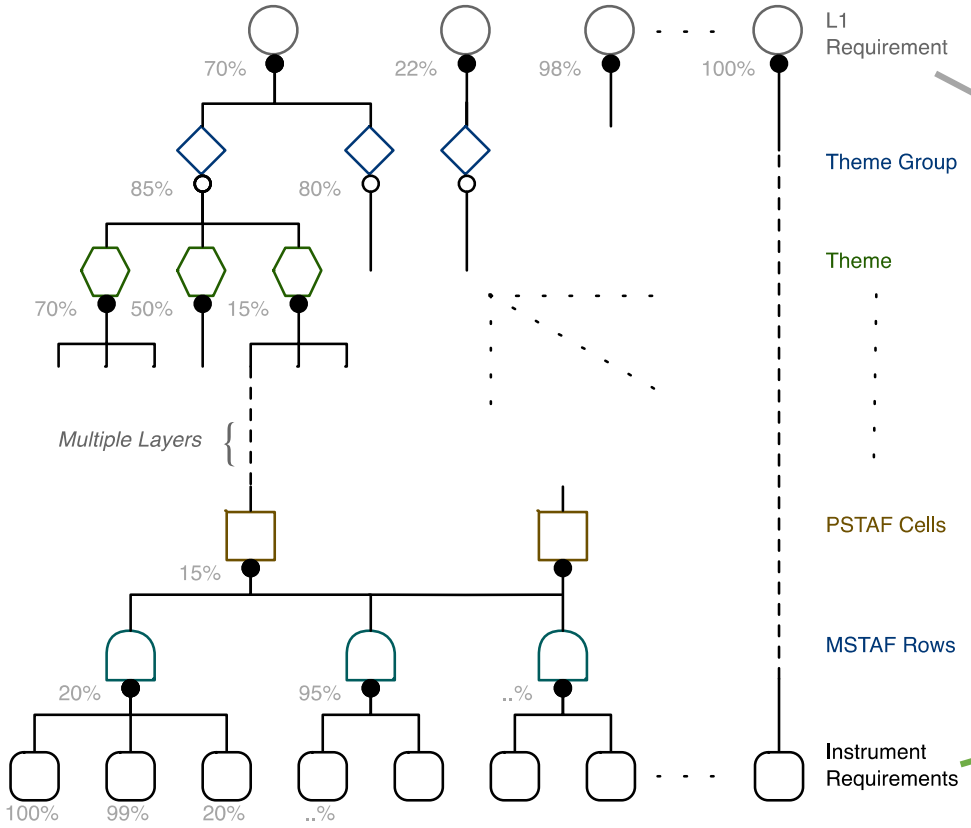


$$\mathrm{P}\left[\bigcap_{i=1}^{9} L_i = 1 \mid A\right] > 0.95$$

Project Requirement: the set of L1 Baseline RQs must be met with >95% probability

L1 Science Probabilistic Assessment

Calculate ***probability each level of tree is met*** and the distribution of **when it is met**

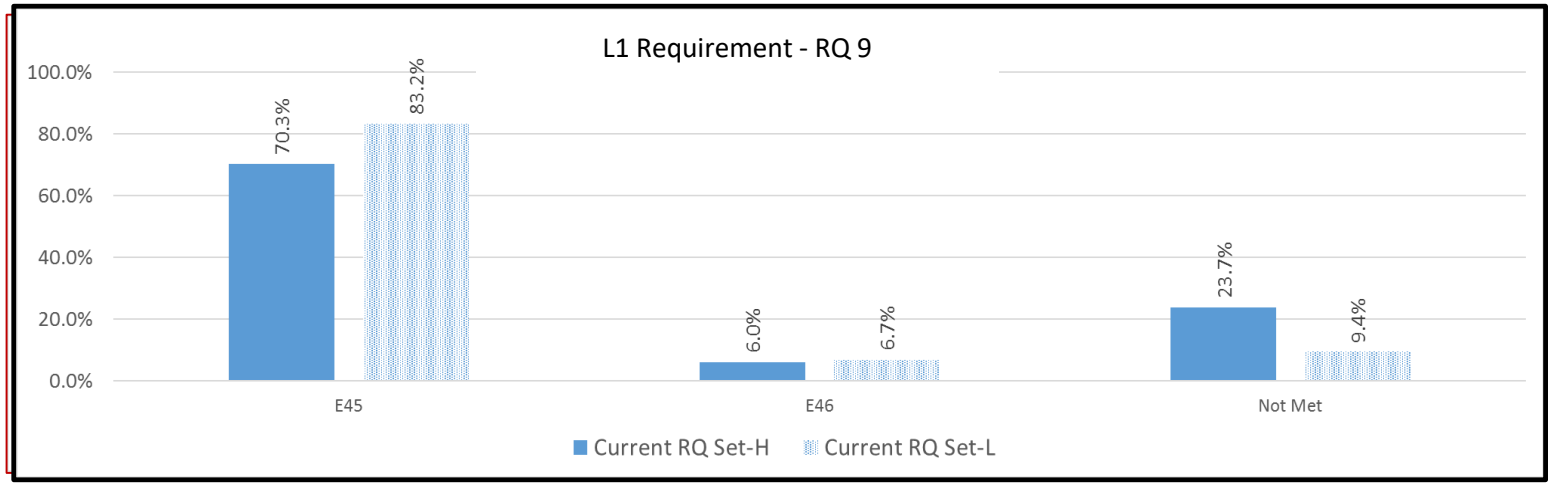


P-STAF / M-STAF Graph Representation

L1 Req't	Probability	Earliest Encounter	Latest Encounter	Latest Encounter If Met	Most Common Encounter
RQ 1	70.00%	E40	N/M	E43	E40
RQ 2	22.00%	E45	N/M	E45	E45
RQ 3	98.00%	E26	N/M	E27	E26
RQ 4	98.00%	E26	N/M	E27	E26
RQ 5	100.00%	N/A	N/A	N/A	N/A
…	…	…	…	…	…

Measurement Req't	Probability	Earliest Encounter	Latest Encounter	Latest Encounter If Met	Most Common Encounter
MsRQ 1	100.00%	E25	E32	E32	E25
MsRQ 2	84.74%	E39	N/M	E45	E39
MsRQ 3	100.00%	E35	E39	E39	E35
MsRQ 4	84.74%	E39	N/M	E45	E39
…	…	…	…	…	…

L1 Science Probabilistic Assessment



Current S/C & instrument recovery times + high fault rates = **~51%** chance of never meeting this L1 RQ

L**ower** S/C & instrument recovery time + high fault rates = ~ **24%** chance of never meeting this L1 RQ

Can the current mission/flight system design meet L1 science RQs with high probability?

Is a particular measurement RQ driving L1 results? Is there science margin in this RQ?

Is more margin needed in the tour to meet L1 science RQs? Should flybys be added to the tour?

Does each instrument, s/c need the capability to recover during a flyby? If so, how quickly?

We know when each L1 RQ is met. When satisfied, can we turn off the associated instruments to save power, etc?