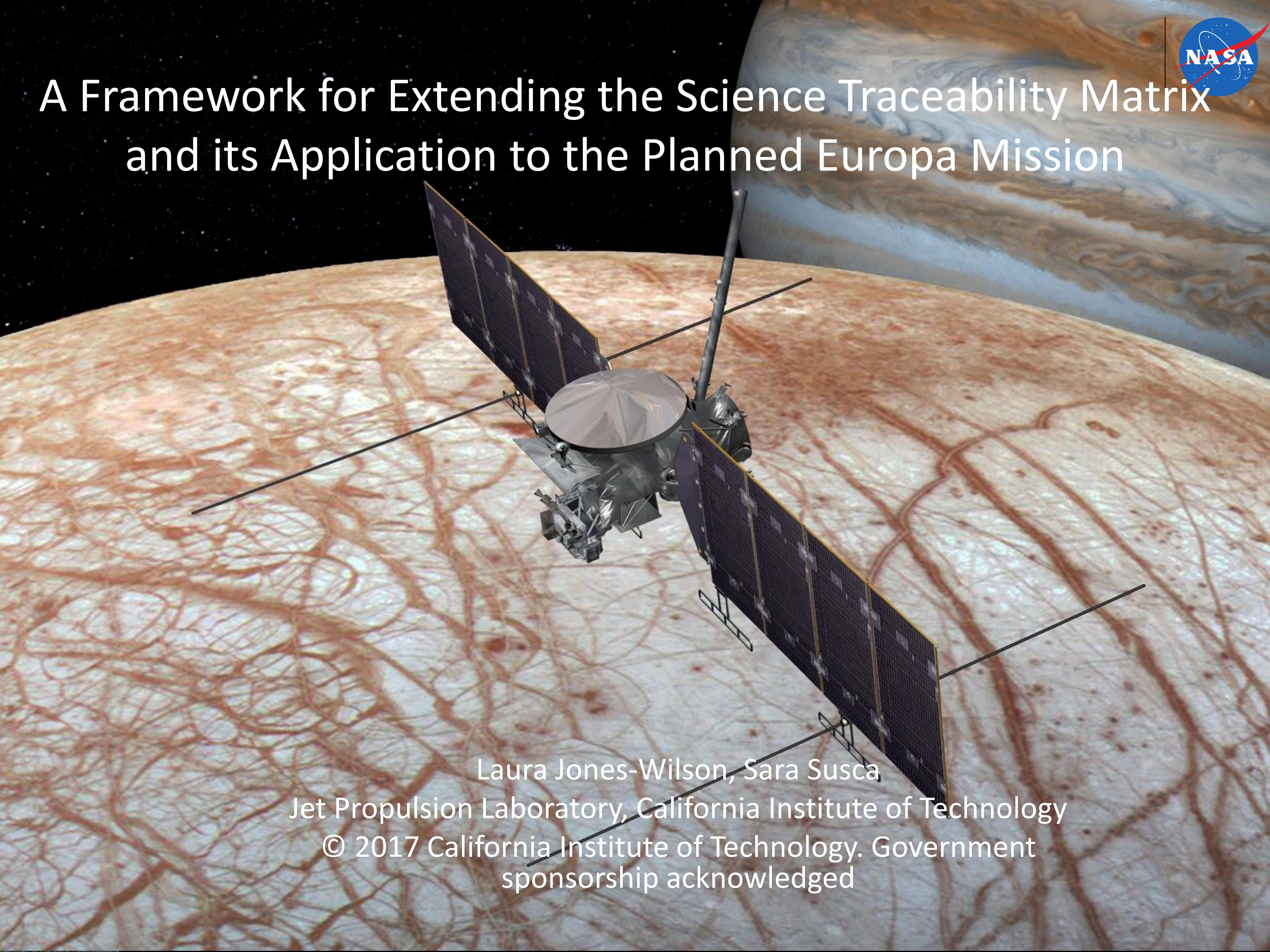
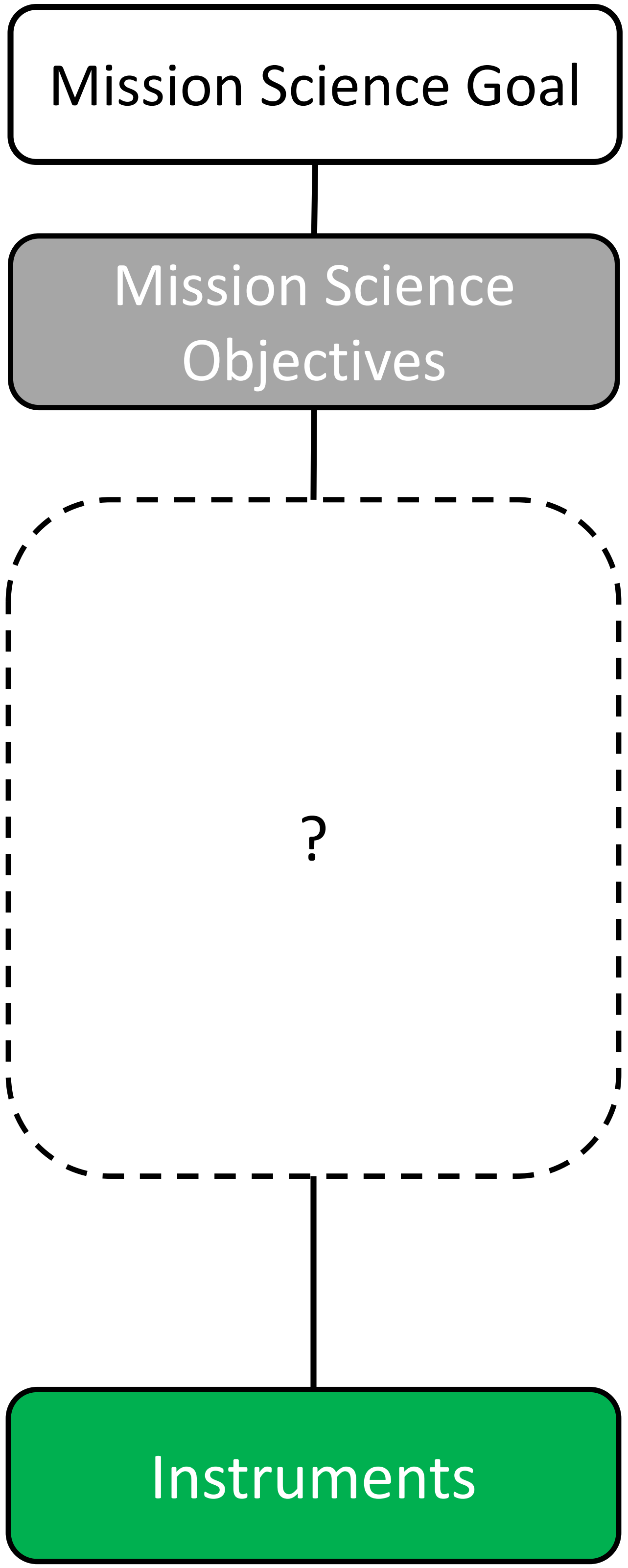


A Framework for Extending the Science Traceability Matrix and its Application to the Planned Europa Mission

Laura Jones-Wilson, Sara Susca
Jet Propulsion Laboratory, California Institute of Technology

Problem Statement



Negotiated with NASA HQ

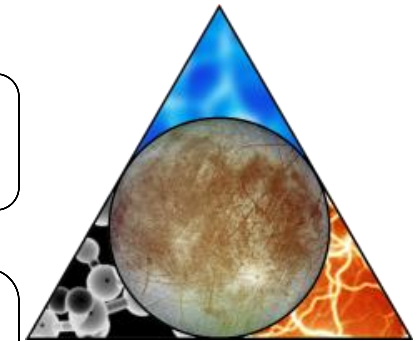
Not clear guidance from NASA Engineering Handbook nor IEEE SE standards on how to break down the mission objectives into science requirements.

Selected by NASA HQ

The Europa Mission

Mission Science Goal

Explore Europa to Investigate its Habitability



Mission Science Objectives

Constrain the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to +/-50%.

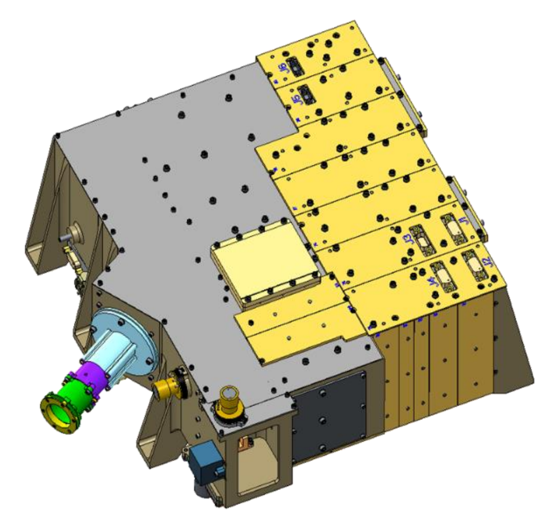
?

- NASA has selected 10 instruments (9 investigations).
- Need to establish a common language to facilitate communications between instruments team and project is key.

Instruments

Europa Instruments:

1. EIS NAC
2. EIS WAC
3. E-THEMIS
4. Europa-UVS
5. ICEMAG
6. MASPEX
7. MISE
8. PIMS
9. REASON
10. SUDA



Science Traceability Matrix

Science Objectives	Measurement Objectives	Measurement Requirements	Instruments	Instrument Requirements	Data Products
Science Objective 1	Measurement Objective 3	• Requirement 1 • Requirement 2	Inst 1	• Requirement A • Requirement B	DP 1
Science Objective 2	Measurement Objective 1	• Requirement 3 • Requirement 4 • Requirement 5 • Requirement 6	Inst 2, 3	• Requirement C • Requirement D	DP 2,3
	Measurement Objective 2	• Requirement 1 • Requirement 4 • Requirement 7	Inst 1,3	• Requirement E • Requirement F • Requirement G	DP 4,5,6
	Measurement Objective 3	• Requirement 1 • Requirement 8	Inst 4	• Requirement H	DP 7
	Measurement Objective 4	• Requirement 9	Inst 2,4	• Requirement I	DP 8, 9

- STAF extends STM by
  - Defining a formal taxonomy that can be understood by scientists and engineers
  - Expanding on the categories and organization of items within the “column space” of the USTM, which supports cross-checking and completeness evaluations across requirements
  - Limiting the relationships formally codified in the framework to those that are strong enough to be captured as requirements

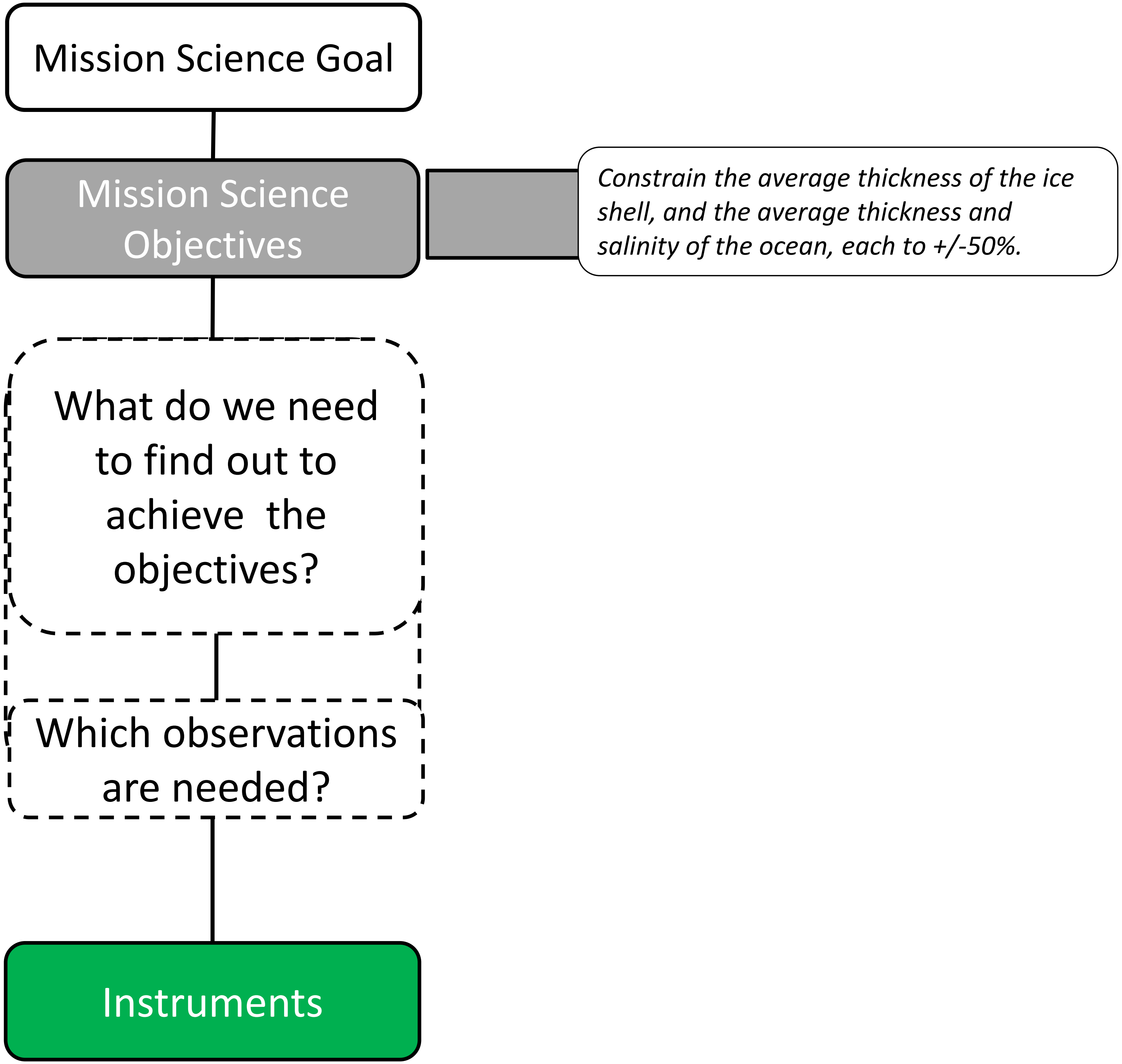
Science Traceability and Alignment Framework

- STAF is divided in
  - Project domain P-STAF ← This presentation
  - Measurement domain M-STAF ← Next presentation
- STAF guarantees
  - Traceability ← This presentation
  - Completeness
  - Consistency across instruments

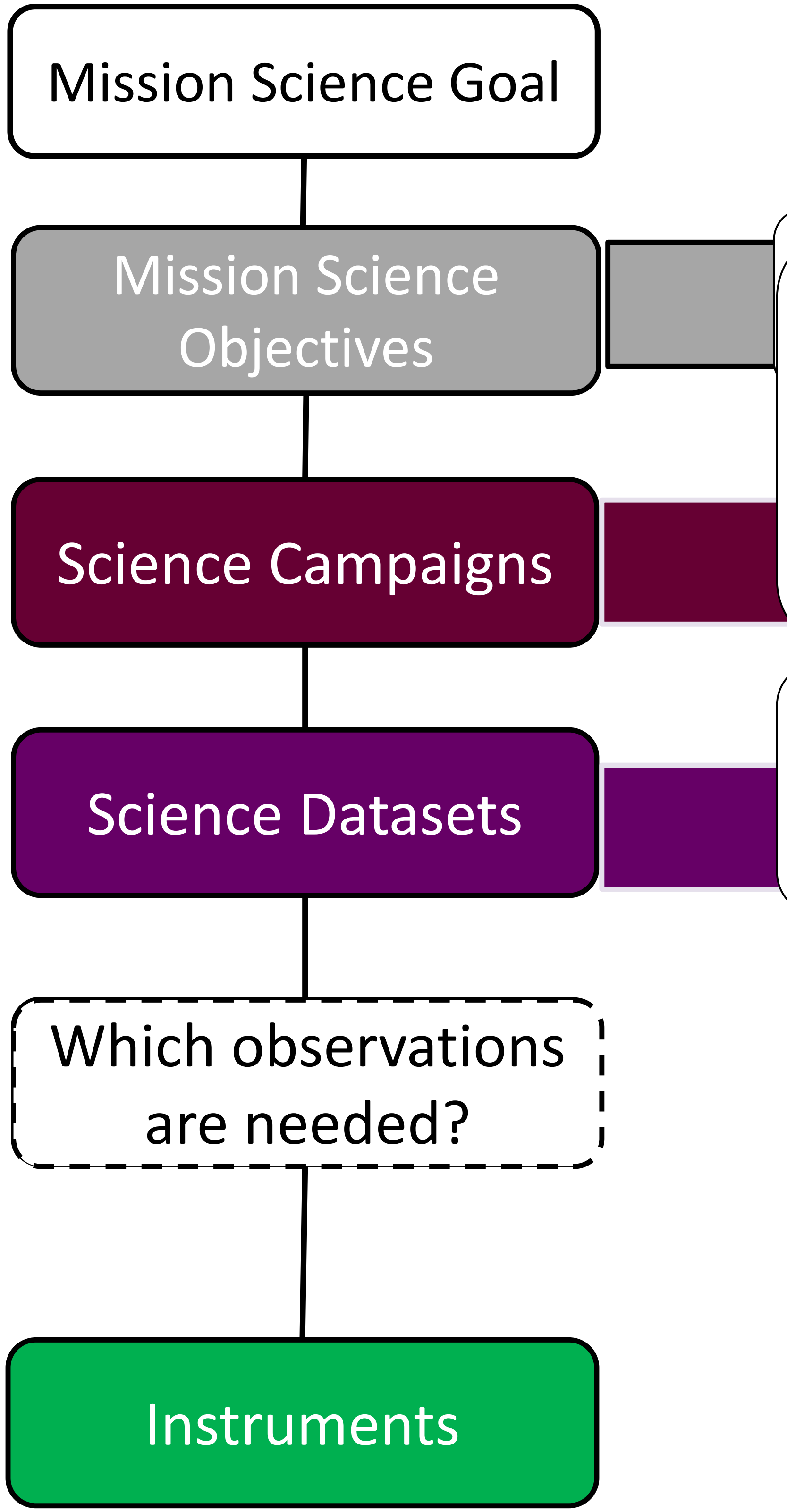
  (Completeness, Consistency across instruments) ← Next presentation
- STAF provides efficiency in
  - Tour analysis
  - Mission robustness analysis

  (Tour analysis, Mission robustness analysis) ← Next presentation

STAF Taxonomy



STAF Taxonomy



The Science Themes are developed by the Project Science Group (PSG), the Science Team management, and the individual investigation teams in order to make meaningful distinctions in the science being requested in the mission science objectives/L1 requirements.

Example: **Ocean Properties**

If an instrument contributes to a Science Campaign it will have a corresponding Science Dataset

Example: Ocean Properties **Plasma Dataset**

STAF Taxonomy

Mission Science Goal

Constrain the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to +/-50%.

Mission Science Objectives

Science Campaigns

The Science Themes are developed by the Project Science Group (PSG), the Science Team management, and the individual investigation teams in order to make meaningful distinctions in the science being requested in the mission science objectives/L1 requirements.

Example: **Ocean Properties**

Science Datasets

If an instrument contributes to a Science Campaign it will have a corresponding Science Dataset

Example: Ocean Properties **Plasma Dataset**

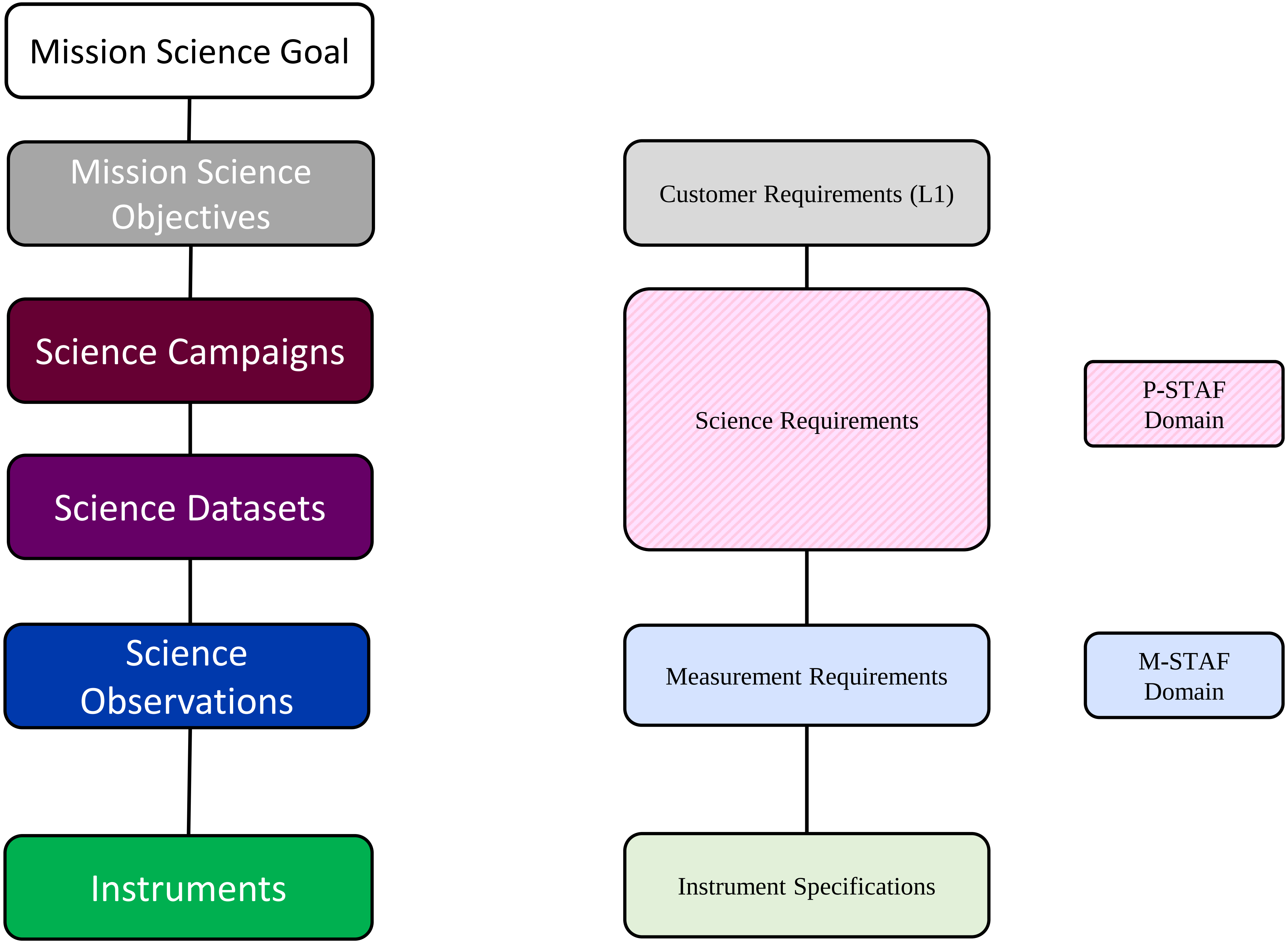
Science Observations

Observations of the particular instrument that feed into a Science Dataset

Example: **Ions Observations**

Instruments

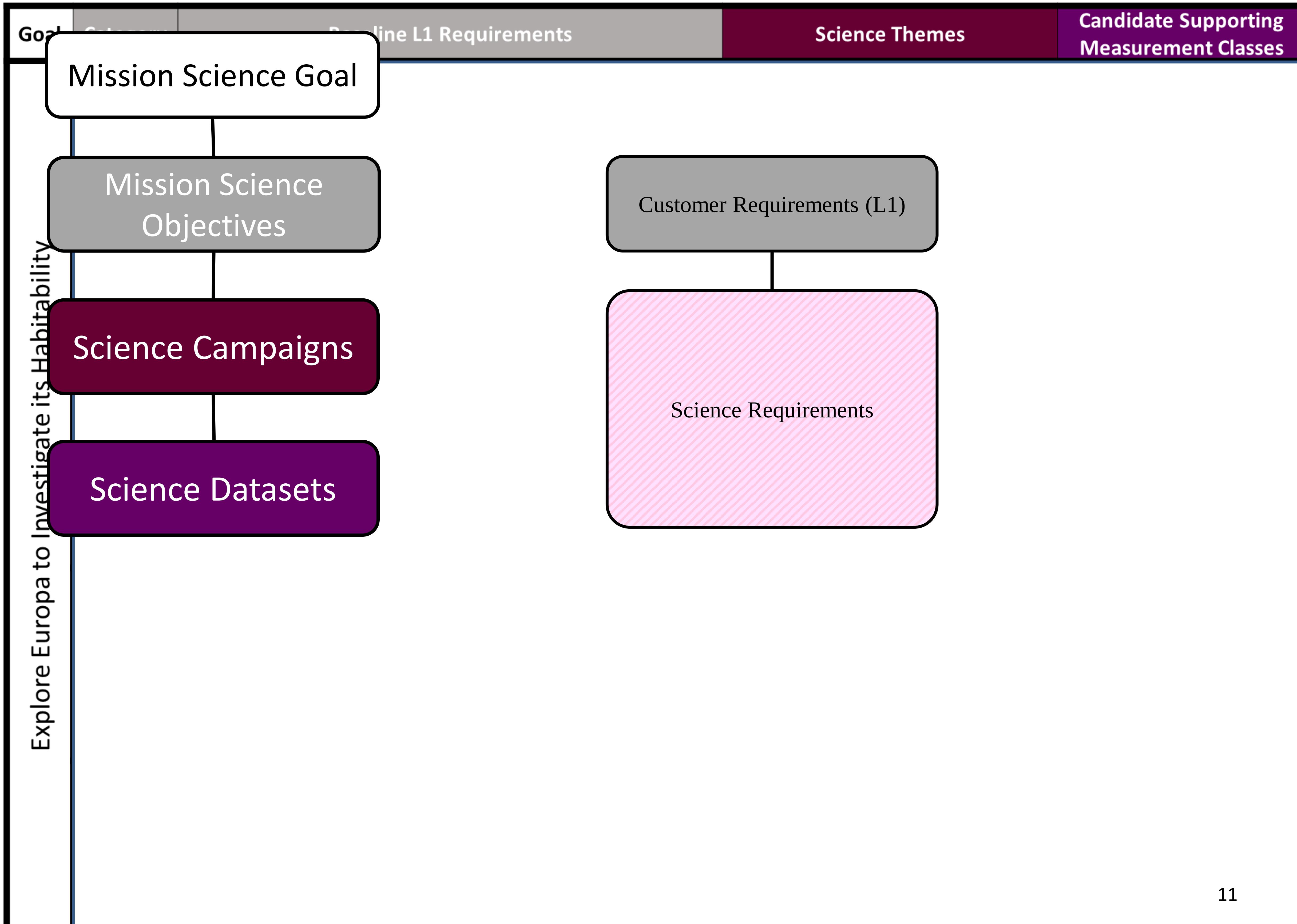
STAF and the Science Requirements Flowdown



Science Requirements

- Science requirements can constrain
  - Science Campaigns or
  - Science Datasets or
  - … No science requirements

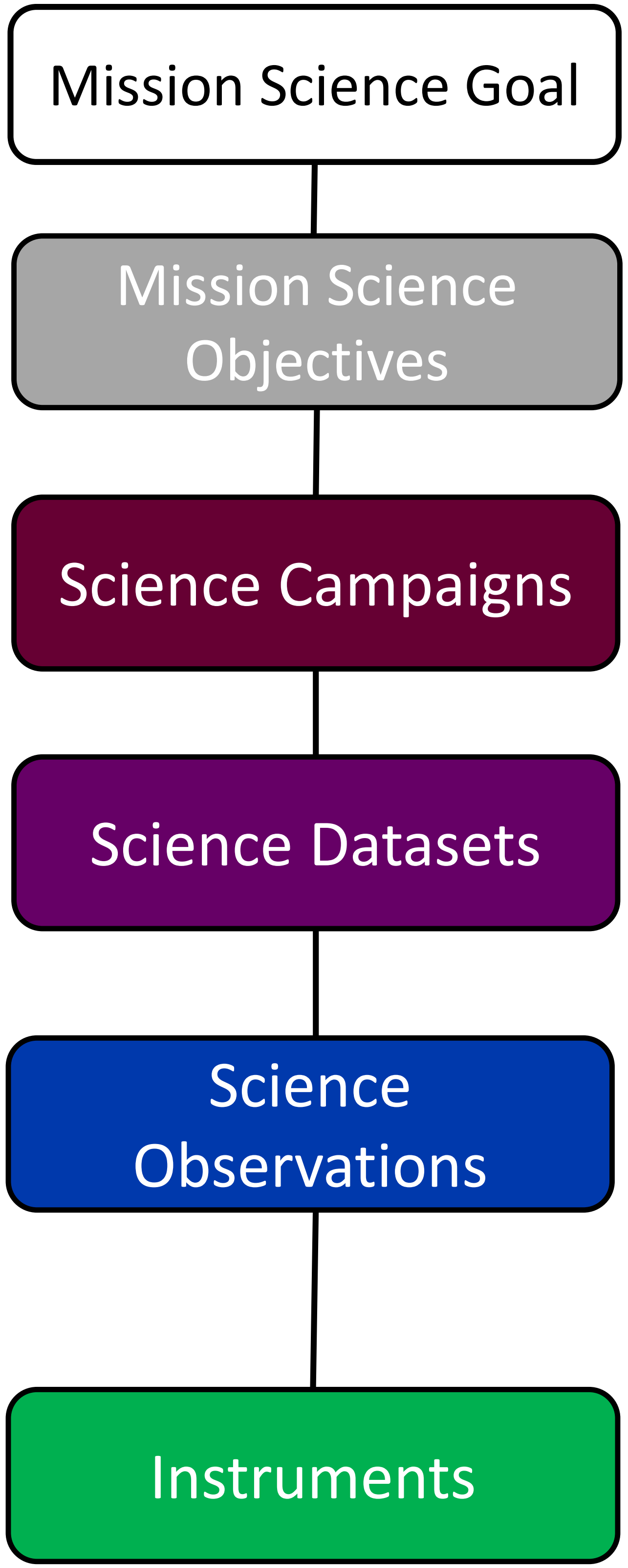
P-STAF: Linking L1s to the Science Datasets

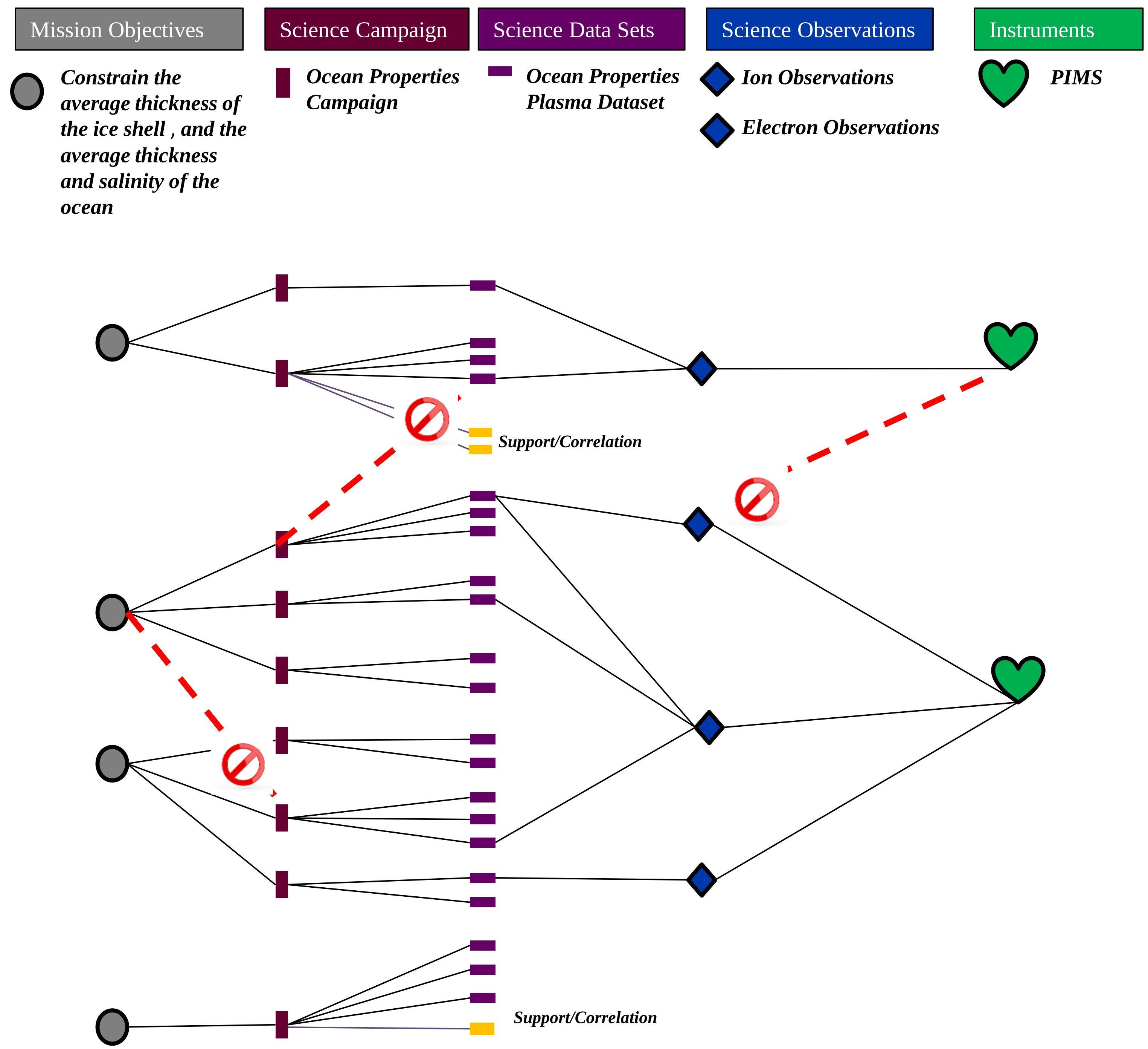


P-STAF Matrix and Traceability

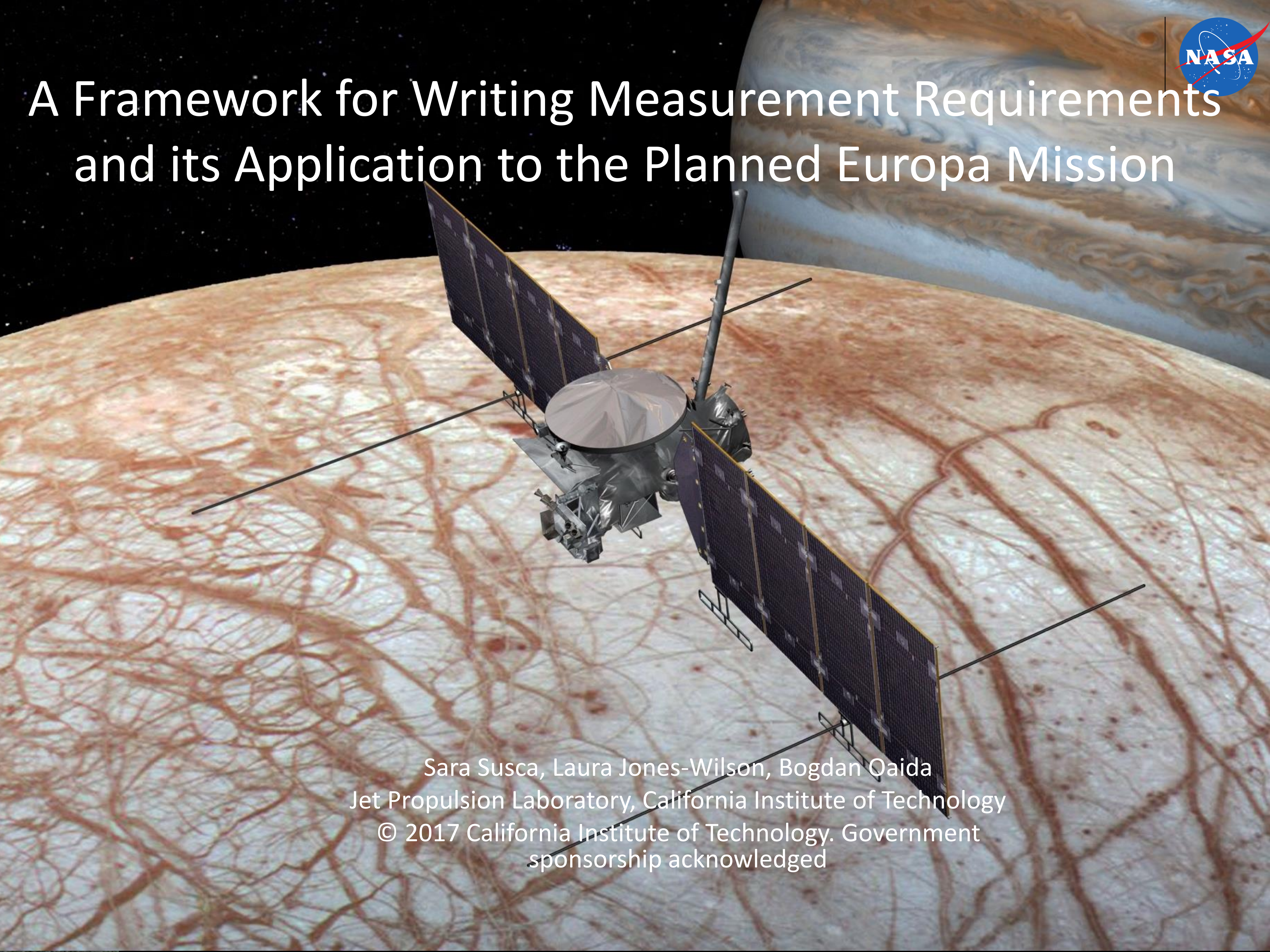
Goal	Category	Baseline L1 Requirements	Science Campaigns	Candidate Supporting Measurement Classes
Explore Europa to Investigate its Habitability	Ice Shell & Ocean	Map the vertical subsurface structure beneath ≥50 globally distributed landforms to ≥3 km depth[, to understand the distribution of subsurface water and processes of surface-ice-ocean exchange].	Deep Subsurface Exchange	Radar (with Visible Support)
			Shallow Subsurface Exchange	Radar (with Visible Support), Thermal
		Constrain the average thickness of the ice shell, and the average thickness and salinity of the ocean, each to +/-50%.	Ice Shell Properties	Gravity (with Visible and Radar Support), Magnetic, Plasma, Radar (with Visible Support), Visible
			Ocean Properties	Gravity (with Visible and Radar Support), Magnetic, Plasma, Visible
	Composition	Create a compositional map at ≤10 km spatial scale, covering ≥70% of the surface[, to identify the composition and distribution of surface materials].	Global-Scale Compositional Surface Mapping	Infrared, IMS, Ultraviolet, Visible
		Characterize the composition of ≥50 globally distributed landforms, at ≤300 m spatial scale[, to identify non-ice surface constituents including any carbon-containing compounds].	Landform Composition	IMS, Infrared, NMS, Radar (with Visible support), Ultraviolet, Visible
		Characterize the composition and sources of volatiles, particulates, and plasma, with sensitivity sufficient to identify the signatures of non-ice materials including any carbon-containing compounds, in globally distributed ions of the atmosphere and local space environment.	Atmospheric Composition	IMS, NMS, Magnetic, Plasma, Radar, Ultraviolet
			Space Environment Composition	IMS, NMS, Magnetic, Plasma, Ultraviolet
	Geology	Produce a controlled photomosaic map of ≥80% of the surface at ≤100-m spatial scale[, to map the global distribution and relationships of geologic landforms].	Global-Scale Surface Mapping	Thermal, Visible
		Characterize the surface at ≤25-m spatial scale, and measure topography at ≤15-m vertical precision, across ≥50 globally distributed landforms[, to identify their morphology and diversity].	Landform Geology	Radar (with Visible support), Thermal, Visible
		Characterize the surface at ~1-m scale to determine surface properties, for ≥40 sites each ≥2 km x 4 km.	Local-Scale Surface Properties	Infrared, Radar, Thermal, Visible
	Recent Activity	Search for and characterize any current activity, notably plumes and thermal anomalies, in regions that are globally distributed.	Active Plume Search	Thermal, Ultraviolet, Visible
			Inferred Plume Evidence	IMS, Infrared, Magnetic, NMS, Plasma, Radar Thermal, Visible
			Surface Thermal Anomaly Search	Infrared, Thermal
			Surface Activity Evidence	Infrared, NMS, Thermal, Visible

Creating an Analyzable Network



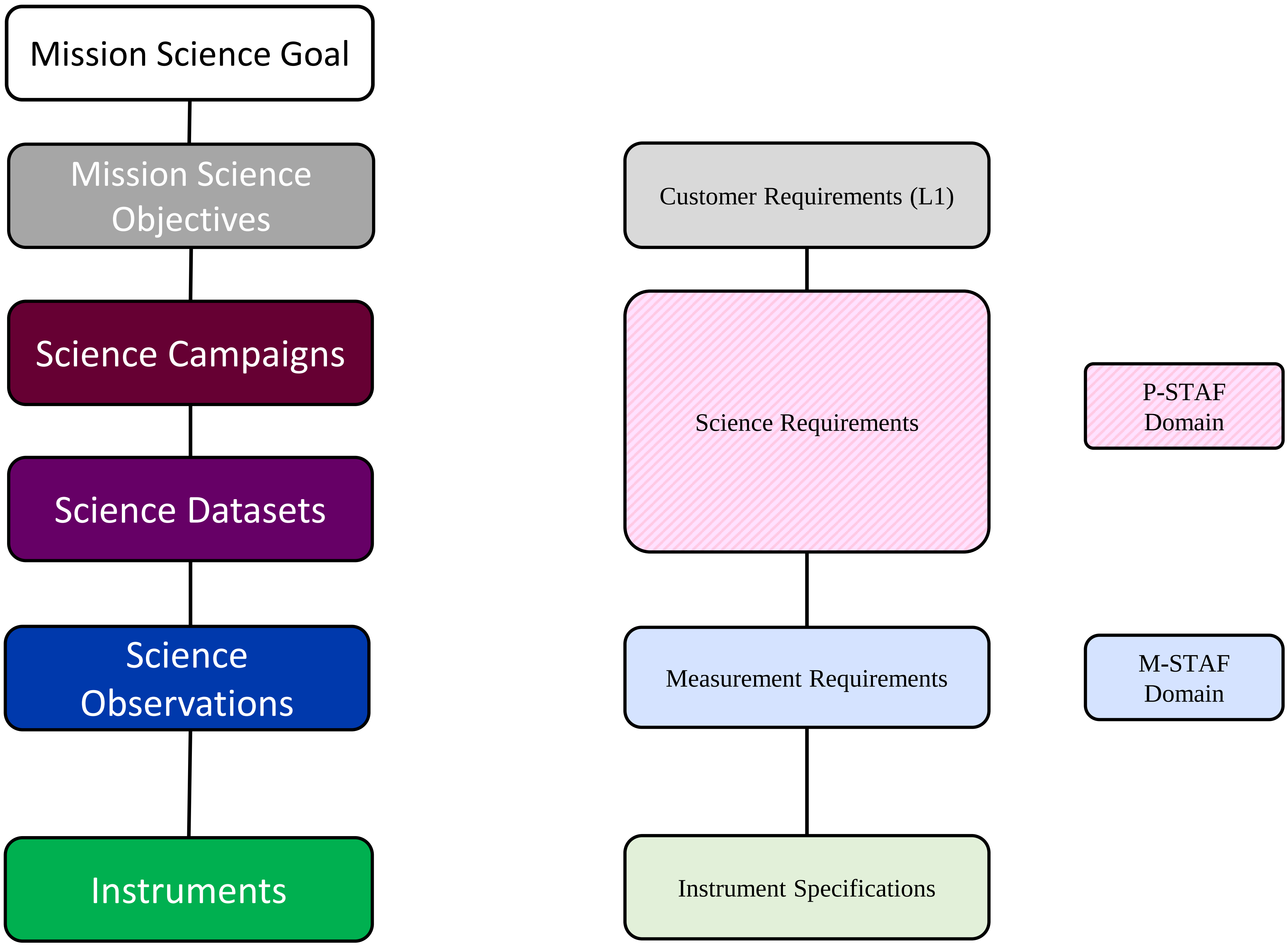


A Framework for Writing Measurement Requirements and its Application to the Planned Europa Mission



Sara Susca, Laura Jones-Wilson, Bogdan Oaida
Jet Propulsion Laboratory, California Institute of Technology

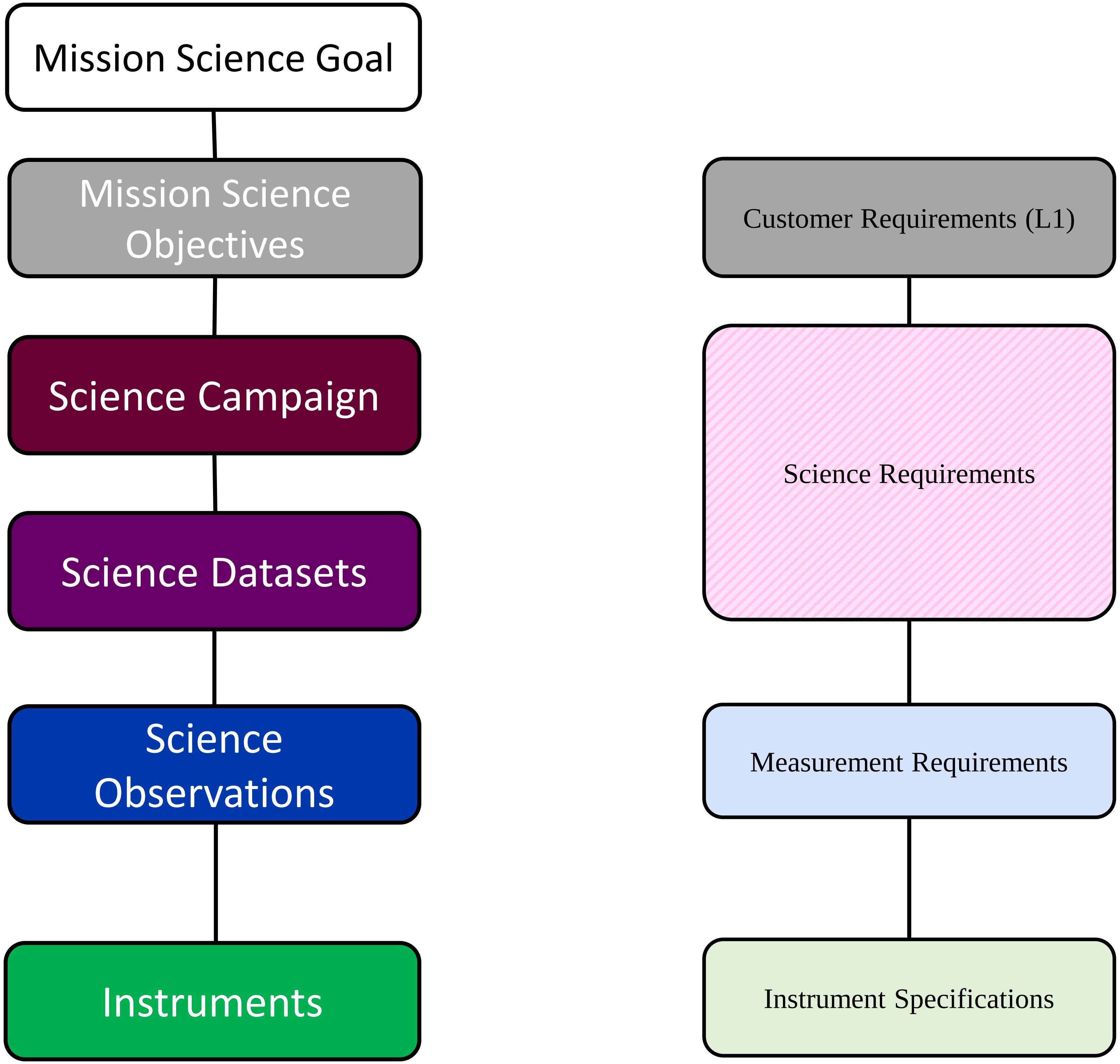
From P-STAF to M-STAF



From P-STAF to M-STAF

- P-STAF:
  - Specifies which Instruments Science Datasets contributes to which L1 via and Science Campaign
- M-STAF:
  - Constrains the Observations that each Instruments has to perform to generate a valid Science Dataset

M-STAF: Linking Science Datasets to Measurement Requirements



M-STAF: Linking Science Datasets to Measurement Requirements

Science Dataset		Science Observation			Measurement Requirements							
Science Theme	Meas. Class	Technique	Conditions		Spatial Coverage and Distribution	Temporal Coverage and Distribution	Diversity and Special Case	Internal Correlations	Measurement Quality			
			Cond. A	Cond. B					Qual. A	Qual. B	Qual. C	Qual. D

Science Campaign

Science Datasets

Science Observations

Measurement Requirements

M-STAF Matrix: Completeness and Consistency

<table>
<tr><th colspan="15">Instrument Name</th></tr>
<tr><th colspan="3">Science Dataset</th><th colspan="3">Science Observation</th><th colspan="9">Measurement Requirements</th></tr>
<tr><th colspan="2" rowspan="2">Science Theme</th><th rowspan="2">Meas. Class</th><th rowspan="2">Technique</th><th colspan="2">Conditions</th><th rowspan="2">Spatial Coverage and Distribution</th><th rowspan="2">Temporal Coverage and Distribution</th><th rowspan="2">Diversity and Special Case</th><th rowspan="2">Internal Correlations</th><th colspan="4">Measurement Quality</th></tr>
<tr><th>Cond. A</th><th>Cond. B</th><th>Qual. A</th><th>Qual. B</th><th>Qual. C</th><th>Qual. D</th></tr>
<tr><td colspan="3" rowspan="4">Science Dataset 1</td><td>Tech. A</td><td rowspan="7">REQ.003</td><td>REQ.001</td><td rowspan="4">REQ.025</td><td></td><td>REQ.09</td><td>REQ.11</td><td rowspan="7">REQ.10</td><td>REQ.06</td><td>REQ.13, REQ.14</td><td></td></tr>
<tr><td>Tech. B</td><td>REQ.001</td><td rowspan="2"></td><td rowspan="2">REQ.12</td><td>REQ.16</td><td>REQ.15</td><td></td><td></td></tr>
<tr><td>Tech. C</td><td></td><td>REQ.22</td><td></td><td>REQ.027</td><td></td></tr>
<tr><td>Tech. D</td><td></td><td></td><td rowspan="3">REQ.18</td><td>REQ.19</td><td>REQ.031</td><td>REQ.028</td><td></td></tr>
<tr><td colspan="3">Science Dataset 2</td><td>Tech. B</td><td>REQ.001</td><td>REQ.025</td><td>REQ.20</td><td></td><td></td><td></td><td>REQ.026</td></tr>
<tr><td rowspan="2">Science Dataset 3</td><td rowspan="2">Science Dataset 4</td><td rowspan="2">Science Dataset 5</td><td>Tech. A</td><td>REQ.001</td><td rowspan="2">REQ.025</td><td>REQ.21, REQ.24</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tech. E</td><td></td><td>REQ.17</td><td>REQ.033</td><td>REQ.11</td><td>REQ.032</td><td>REQ.029, REQ.030</td><td></td></tr>
</table>

Measurement Requirements

Missing
Not Applicable
Needs Clarification

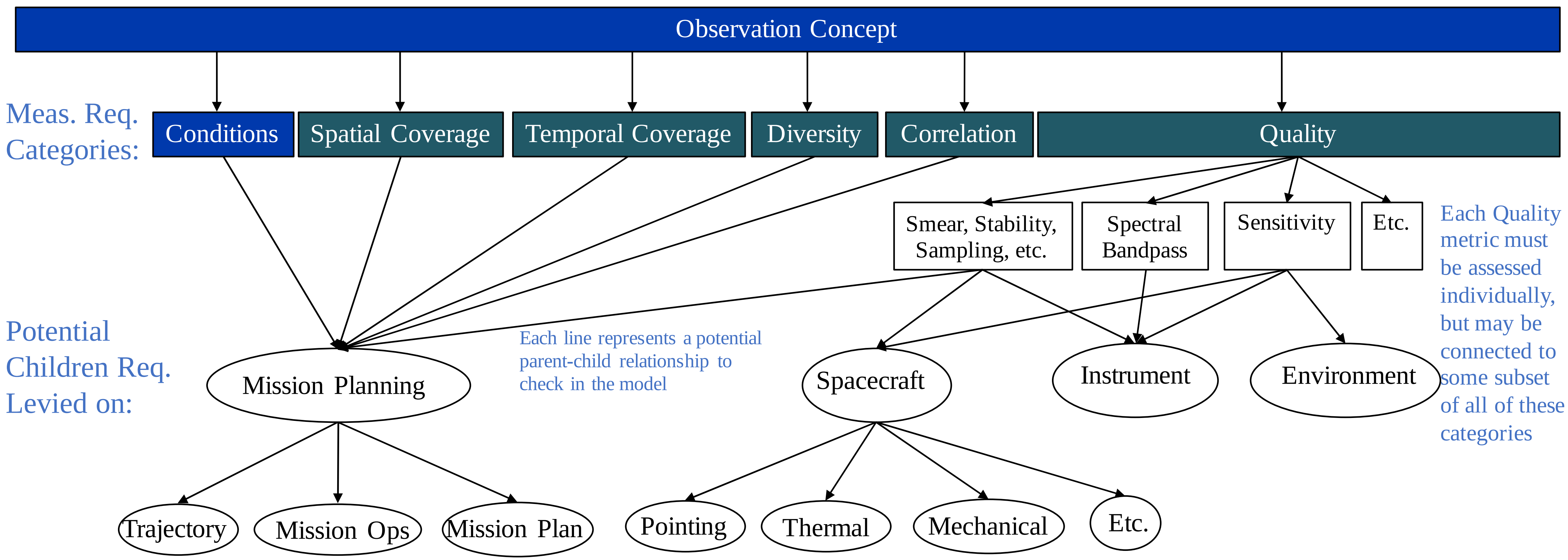
Europa-UVS

Science Dataset		Science Observation				Measurement Requirements								
			Conditions							Measurement Quality				
Science Campaign	Meas. Class	Technique	Europa Solar Phase Angle	Jupiter Solar Phase Angle	Altitude @ Meas.	Spatial Coverage and Distribution	Temporal Coverage and Distribution	Diversity and Special Case	Internal Correlations	Spectral Bandpass and Resolution	Spatial Resolution at Altitude	Scale Height Resolution	Sensitivity	Sampling
Global-Scale Compositional Surface Mapping	Ultraviolet	Nadir Stares	Day < 90 deg (UVS.026)		< 30,000 km (UVS.036)	70% of surface (UVS.001)	Acquisition over duration of nadir subphase (UVS.018)			<=6 nm btwn at least 150-180 nm ; <=25 nm btwn at least 105-180 nm (UVS.003: UVS.004)	<= 30 km per pixel @30,000 km (UVS.002)		TBR SNR >= 3 per spatial resolution element given a Lyman-alpha albedo of 1% at	Capable of Nyquist sampling (UVS.033)
		Scans	Day < 90 deg (UVS.026)		< 30,000 km (UVS.037)									
		Nadir Stares	Night >= 90 deg (UVS.027)		< 36,000 km (UVS.038)	10% of surface across >= 5 representative regions (UVS.009)	Acquisition over duration of nadir subphase (UVS.018)				<= 100 km per pixel @ 36,000 km (UVS.008)		TBR SNR >= 3 per spatial resolution element given a Lyman-alpha albedo of 1% at 2 deg phase (UVS.034)	
		Scans	Night >= 90 deg (UVS.027)		< 30,000 km (UVS.037)									
Landform Composition	Ultraviolet	Nadir Stares	Day < 90 deg (UVS.026)		< 360 km (UVS.039)	>= 30 representative landforms in >= 11 Europa Panels (UVS.011)		>=1 image with Europa latitude @ CA > 45 deg (UVS.012)		<= 6 nm btwn at least 150-180 nm ; <= 25 nm btwn at least 105-180 nm (UVS.003: UVS.004)	<= 1 km per pixel @ 360 km (UVS.010)		TBR SNR >= 3 per spatial resolution element given a Lyman-alpha albedo of 1% at 2 deg phase (UVS.034)	Capable of Nyquist sampling (UVS.033)
Atmospheric Composition / Space Environment Composition	Ultraviolet	Nadir Stares			< 390,000 km (UVS.030)	1 image in each Europa Panel and each local solar time bin (UVS.017)	>= 1 image in each combo of Europa Panel and local solar time bin; acquisition over duration of nadir subphase (UVS.017; UVS.018)			<= 2 nm btwn at least 60-180 nm (UVS.005)	TBR [30] km per pixel @ TBR [30,000] km (UVS.024)			Capable of Nyquist sampling (UVS.033)
		Scans			< 390,000 km (UVS.030)	>= 6 per flyby, distributed evenly on inbound and outbound (UVS.019)	<= 2 hours apart, distributed over >= 6 hours; distributed over >= TBR [18] months (UVS.021, UVS.031)				TBR [500] km per pixel @ TBR [165,000] km (UVS.023)		TBR SNR >= 3 per spatial resolution element given an emission brightness of 0.1 Rayleighs near 130 nm (UVS.035)	
		Stellar Occ				>= TBR [100] with at least 1 in every Europa Panel (UVS.014)						<= 50 km (UVS.013)		Continuous sampling from 400 km to Europa surface
		Solar Occ				>= 1 (UVS.015)								
		Jupiter Transit		< 120 deg (UVS.029)	< 350,000 km (UVS.028)	>= 10 (UVS.016)								
		Neutral Cloud and Torus Stare			>= 500,000 km (UVS.032)	>= 1 per orbit for >= 20 orbits (UVS.022)								
		Nadir Stares			< 390,000 km (UVS.030)	1 image in each Europa Panel and each local solar time bin	>= 1 image in each combo of Europa Panel and local solar time bin; acquisition over duration of nadir				TBR [30] km per pixel @ TBR [30,000] km (UVS.024)			

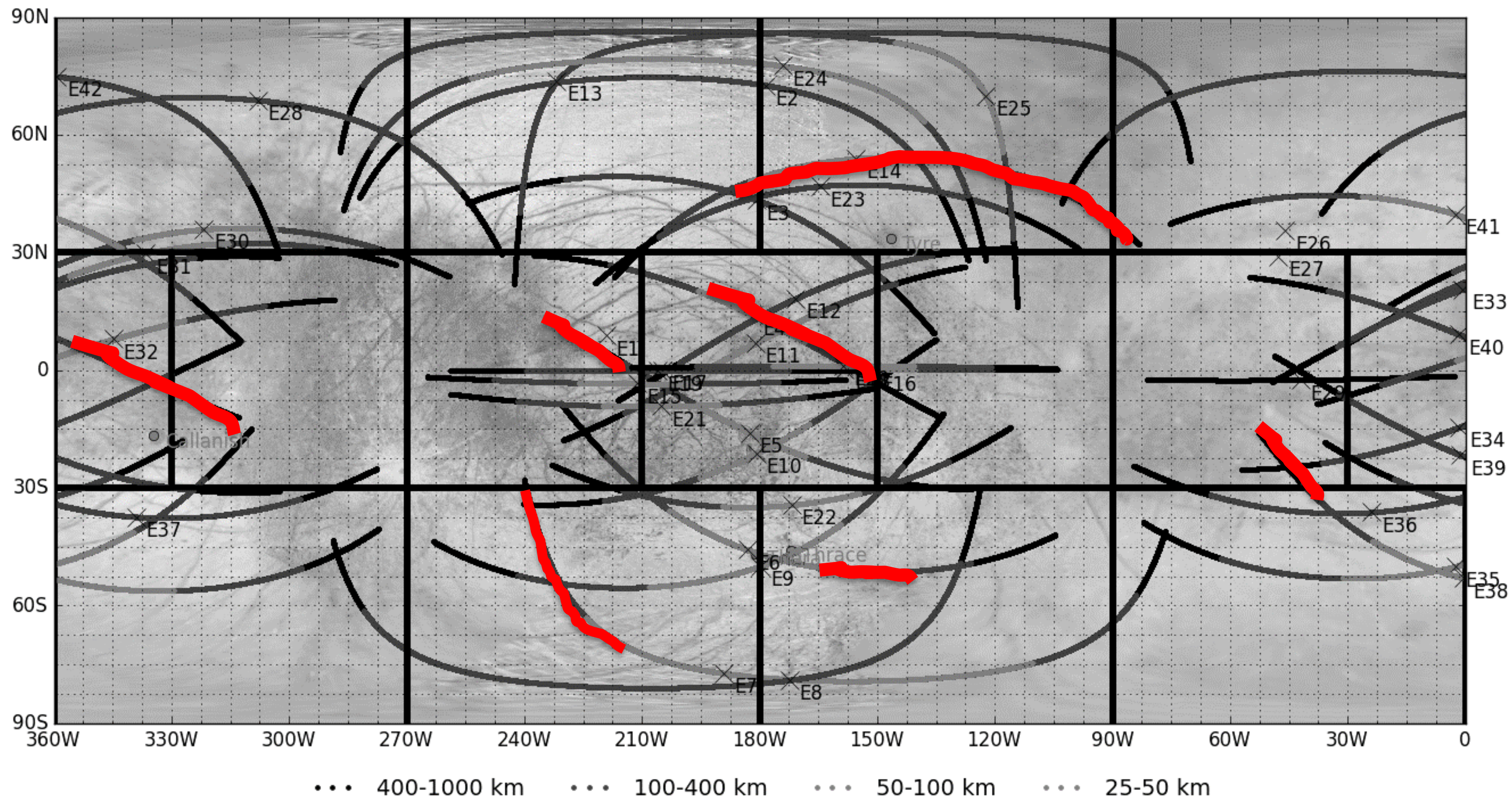
Requirements Templates

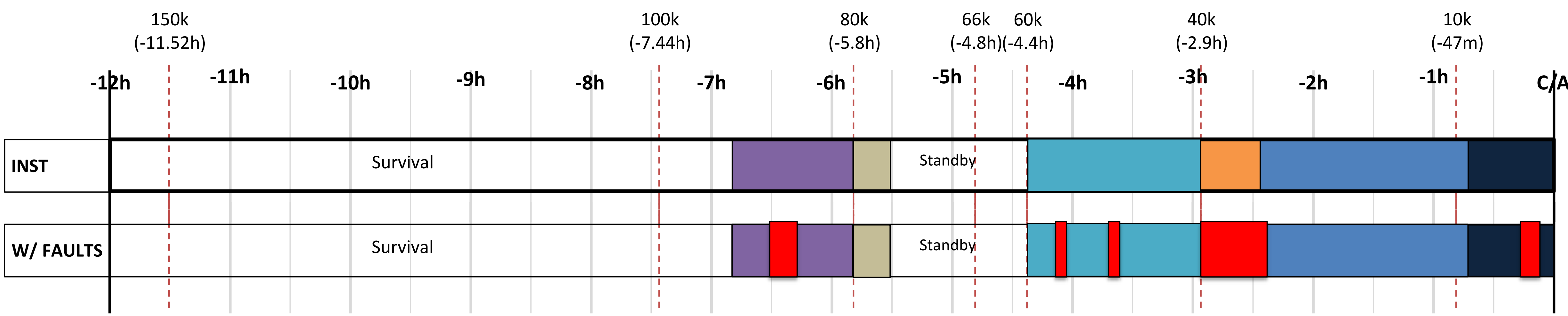
- *Condition Requirement Template*
  - For the [*Science Dataset(s)*], the [*Science Observation*] shall occur when the [**Condition** Type] is... [**Condition** Value].
  - For all ***ultraviolet datasets*****,** all ***dayside nadir stares*** shall occur when the ***Europa solar phase angle*** is less than ***90 degrees***. (UVS.026)
- *Measurement Quality Requirement Template*
  - For the [*Science Dataset(s)*], the [Measurement Quality Type] for the [*Science Observations*] shall... [Quality Value].
  - For all ***plasma datasets***, the ***sampling frequency*** of the ***ions and electrons*** observations in the ***ionospheric mode*** shall be ***greater than or equal to 1 Hz***. (PIM.016)

M-STAF and MBSE



Tour Analysis and Mission Robustness





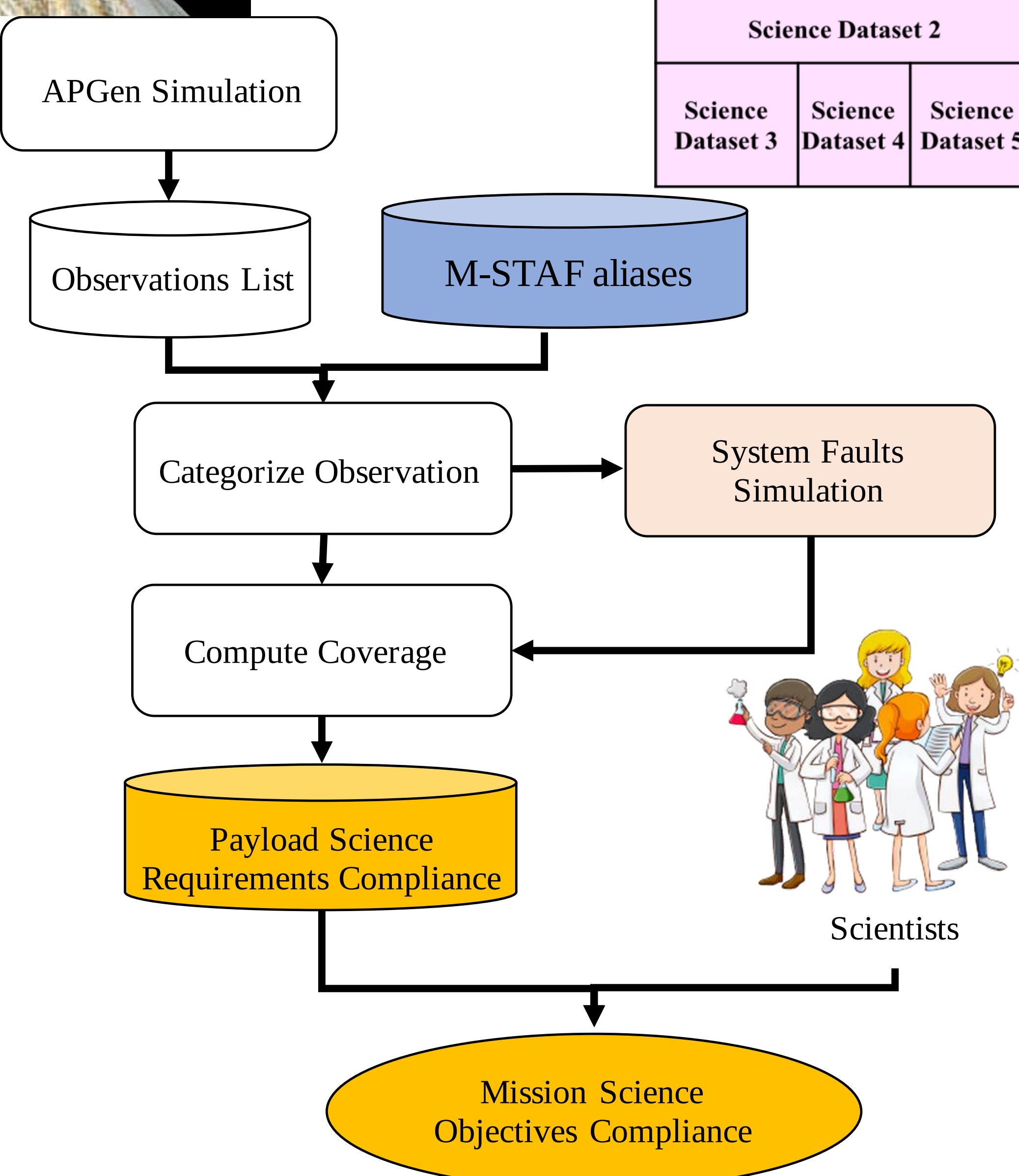
Tour Analysis and Mission Robustness

Dataset_1.Technique.Condition_1.Condition_2 } M-STAF Alias

Science Dataset		Science Observation			Measurement Requirements				Observation-Level Compliance	Science Dataset-Level Compliance
Science Campaign	Meas. Class	Technique	Conditions: Cond. A	Conditions: Cond. B	Spatial Coverage and Distribution	Temporal Coverage and Distribution	Diversity and Special Case	Internal Correlations		
Science Dataset 1		Tech. A	REQ.003	REQ.001						
		Tech. B		REQ.001						
		Tech. C								
		Tech. D								
Science Dataset 2		Tech. B		REQ.001						
Science Dataset 3 / Science Dataset 4 / Science Dataset 5		Tech. A		REQ.001						
		Tech. E								

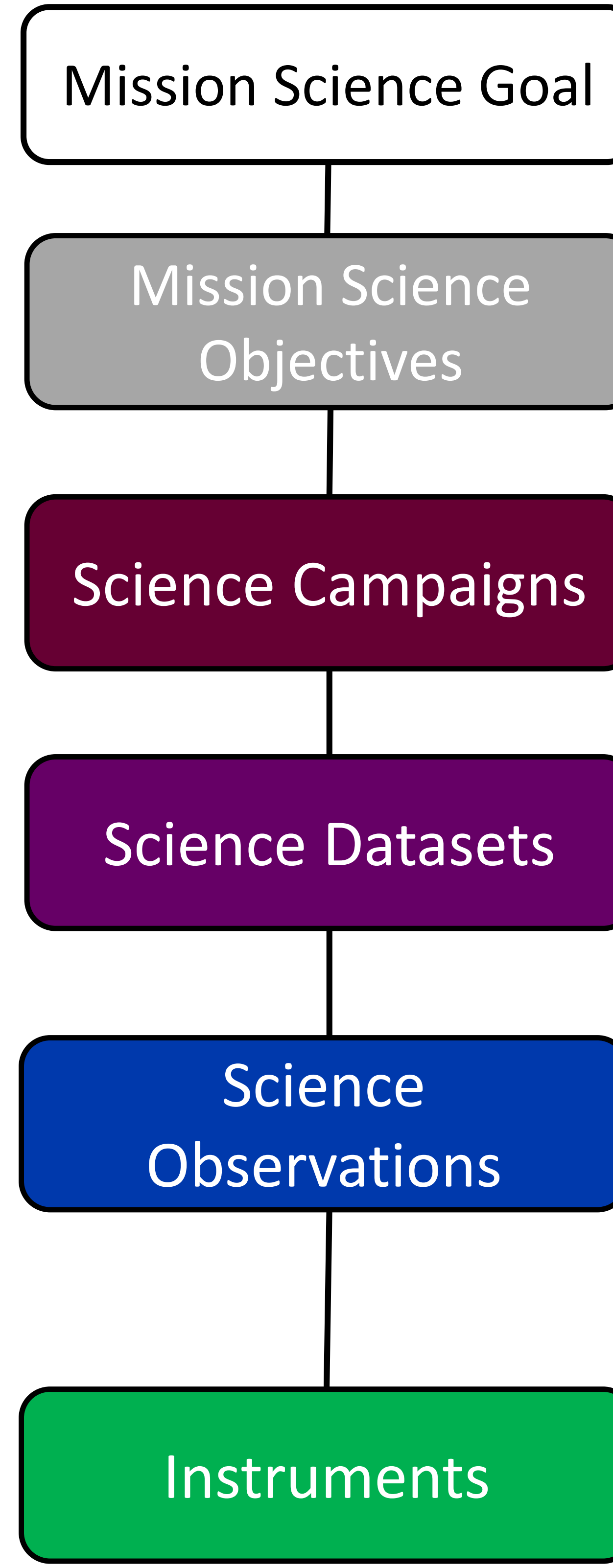
Requirement Satisfied

Requirement NOT Satisfied



Conclusions

- STAF is divided in
  - Project domain P-STAF
  - Measurement domain M-STAF
- STAF guarantees
  - Traceability
  - Completeness
  - Consistency across instruments
- STAF provides efficiency in
  - Tour analysis
  - Mission robustness analysis



Questions?

EXTRA material

STAF Taxonomy in a Nutshell

Mission Science Goal

Mission Science Objectives

Science Campaigns

[Science Scale] + [Science Target] + [Purpose/Objective]

e.g. Global-Scale Surface Composition

Science Datasets

[Science Theme] + [Measurement Class]

e.g. Global-Scale Surface Composition Ultraviolet Dataset

Science Observations

[Condition] + [Measurement Technique]

e.g. Dayside surface aurora/airglow observations

Stellar Occultations

Instruments