

National Aeronautics and
Space Administration



EXPLORESCIENCE

Writing Level 1 Requirements

APEX Phase A Kick-off Meeting

Dr. Jared Leisner
Heliophysics Division
Science Mission Directorate

Level 1 and 2 Requirements

- Level 1 and 2 requirements are defined in the APEX C&R [C&R §E.1]
 - Level 1 requirements define the key scientific determinations and/or results that would represent completion of the investigation science objectives.
 - Level 2 requirements define the first level of project-specific mission implementation requirements (e.g., measurements).
- Level 1 and 2 requirements are addressed in Factor B-8 [Req. CS-21]
 - Evaluators will be instructed to use the standards written in the C&R
 - Evaluators will have access to this presentation
- Example of Level 1 requirements are posted in the Program Library
 - TESS
 - Look to the key scientific determinations/results in the rationales, those are the real Level 1 requirements.

Goals and Objectives

- Projects are formulated starting with Goals and Objectives
 - *Goal*: A broad scientific effort that is part of a larger strategy to address a program's objectives. An investigation will make progress towards the project's Goals.
 - *Objective*: A focused scientific effort that is part of a larger strategy to address a project Goal. An Objective must be achieved by an investigation.
- Can think of putting an Objective into one of three rough categories (*my terms*):
 - Characterization: You know enough to design a mission to study a system at a high-level.
 - Voyager characterized Jupiter's atmospheric winds (number of bands, speed of each band).
 - Hypothesis-testing: You have specific hypotheses that a mission can be designed to resolve.
 - GEP [decadal survey concept] would determine whether feedback from buried accreting black holes could have caused the decline of luminosity density from star formation in the last half of the Universe's history. *[quote from concept study]*
 - Analytic: You have specific knowledge gaps about an understood (to some level) system that a mission can be designed to fill.
 - THEMIS determined the relative timing of substorm onset in the auroral zone and in the magnetotail.

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 - *Goal*: A broad scientific effort that is part of a larger strategy to address a program's objectives. An investigation will make progress towards the project's Goals. Uses progress-based verbs like "understand"
 - *Objective*: A focused scientific effort that is part of a larger strategy to address a project Goal. An Objective must be achieved by an investigation. Uses completion-based verbs like "determine"
- Can think of putting an Objective into one of three rough categories (*my terms*):
 - Characterization: You know enough to design a mission to study a system at a high-level.
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Requirement Levels

Requirements Level	Mission Level
Level 1	Program
Level 2	Project
Level 3	Instrument, Mission System
Level 4	Subsystems

These are requirements, so they flow up and down:

- Level N Requirement(s) decompose down to Level (N+1) Requirements
- Level N Requirements deliver a product up Level (N-1) Requirement(s)

These are requirements, so they must be validated and verified [NASA Sys. Eng. Hdbk]:

- Validate: The product would complete the intended purpose in the intended environment.
- Verify: The product met each “shall” statement as proven through performance of a test, analysis, inspection, and/or demonstration.

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These are require

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As there is no higher level, Level 1 Requirements can only deliver a product to the program (to NASA). And the product promised to NASA is *completion of the Science Objectives*.

Therefore, Level 1 Requirements are the scientific determinations and/or results that represent completion of each Science Objective.

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These are requirements, so they flow up and down:

- Level 1 Requirement(s) decompose down to **mission measurement capabilities**
- Level 1 Requirements **represent completion of the Science Objectives**

These are requirements, so they must be validated and verified [NASA Sys. Eng. Hdbk]:

- Validate: The investigation would complete **its Science Objectives during prime science operations.**
- Verify: The investigation **completed its Science Objectives** as proven through performance of a test, analysis, inspection, and/or demonstration.

Requirement Levels

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Remember that Level 2 Reqs must be met through prime science ops!

Therefore, validation and verification of the Level Reqs must use the full mission data set.

These are requirements, so they flow up and down:

- Level 1 Requirement(s) decompose down to **mission measurement**
- Level 1 Requirements **represent completion of the Science Objectives**

These are requirements, so they must be validated and verified [NASA Sys. Eng. Hdbk]:

- Validate: The investigation would complete **its Science Objectives during prime science operations**.
- Verify: The investigation **completed its Science Objectives** as proven through performance of a test, analysis, inspection, and/or demonstration.

The link between Level 1 and Level 2 is the research plan.

Requirement Levels

Requirements Level	Mission Level
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Level 1 Requirements are the scientific determinations and/or results that are necessary for completion of each Science Objective.

- They are agnostic to mission implementation details, but mission implementation details flow up to them.

Example: The [project name] shall determine the average time for [auroral emission] to maximize after the impact of [solar wind structure] with an accuracy of X minutes ([confidence level]).

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Combines multiple measurements for each event!

Example: The [project name] shall determine the average time for [auroral emission] to maximize after the impact of [solar wind structure] with an accuracy of X minutes ([confidence level]).

Multiple events required!

Writing Level 1 Requirements

- How do I determine my Level 1 Requirements?
 - Assume the mission data sets are completed and already archived.
 - Imagine the research paper(s) that uses the archived data sets to complete the Science Objectives. What do the key figures, tables, etc. show? The key scientific determinations and/or results.
 - If a science requirement can't be displayed like that, there might be challenges for validation/verification.
 - A result could reduce to another result, and thus the second does not need to be a requirement.
 - Once they are drafted, they can flow down into Level 2 and lower requirements.
 - Define the trade within and between systems (for example, a Level 1 requirement's accuracy can bound measurement number, cadence, accuracy, and precision)
- A science team will do so much research that quantifying it all will be extremely cumbersome.
 - Level 1 Requirements do not quantify *all* science results to be completed. They quantify the science results that are the main tent poles for the Science Objectives (validation, verification) and that drive mission implementation requirements (flowdown/decomposition).
- My mission data will enable more science than we anticipate right now.
 - NASA expects that. Since you can't anticipate it, it can't be a project requirement. Therefore, it can't be in your Level 1 Requirements.

The background of the slide is a cosmic image featuring a dark blue and black space filled with numerous stars of varying brightness. In the upper right, there is a prominent blue nebula with wispy, ethereal structures. The lower portion of the image transitions into a warm, golden-yellow glow, suggesting a distant star or a different nebula. The overall effect is a sense of vastness and celestial wonder.

Requirement MadLibs!

Level 1 Requirements

- Level 1 Mad Libs: The investigation shall [quantitative scientific-result verb] [aspect of the physical system] [prepositional phrase] [verification parameter(s)].
- Quantitative scientific-result verb
 - All requirements must lead to a pre-registered, quantified scientific result.
 - “Intent-based” verbs are precluded: “study”, “investigate”, “perform”, “survey”, “search”
 - “Result-based” verbs are required: “determine”, “map”
- Aspect of the physical system
- Verification parameter(s)

Level 1 Requirements

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- Quantitative scientific-result verb
- Aspect of the physical system
 - Science Objectives require results about the physical system. (Not just measurements.)
 - Written to be agnostic of the research plan that accomplishes them.
 - The aspects are varied and depend on the particulars of a mission.
 - Because these Level 1s are shown to be met at the end of the mission, they are aggregates. For dynamic systems, time-separated events, etc., Level 1s target characteristics of a statistical distribution (e.g. average, 80th percentile).
 - Ex: rise time of a specific signal after a particular event (e.g. auroral radio emission after CIR impacting the magnetosphere), fraction of a specific energy input partitioned into a specific output (e.g. electron heating in a solar coronal event)
- Verification parameter(s)

Level 1 Requirements

- Level 1 Mad Libs: The investigation shall [quantitative scientific-result verb] [aspect of the physical system] [prepositional phrase] [verification parameter(s)].
- Quantitative scientific-result verb
- Aspect of the physical system
- Verification parameter(s)
 - The robustness of the results that the project must achieve.
 - Origin of flow down into implementation requirements.
 - Needs to be sufficient to deliver compelling science for NASA's investment. Should not be the best that the implementation can do.
 - Examples: accuracy (space, time, fraction, etc.), confidence level, coverage ("80% of the surface of Planet Acme", "75% of the total energy")
- Many Objectives have more than one Level 1 Requirement. The exact form of the L1s depends on the project-specific Objectives.

Level 1 Requirements

- Level 1 Mad Libs: The investigation shall [quantitative scientific-result verb] [aspect of the physical system] [prepositional phrase] [verification parameter(s)].
- Level 1s can be imagined as coming in one of two forms:
 - Test: The “aspect of the physical system” is a test whether some specific observable configuration of the physical system is fulfilled. Hypothesis- or search-based Objectives may be able to use one or more test requirements.
 - The investigation shall determine whether the abundance of Element X in Astrophysical Structure Y increases with radial distance to a 90% confidence interval.
 - The investigation shall determine whether the average magnetopause reconnection rate increases with Earth’s tilt towards the Sun to a 95% confidence interval.
 - Task: The “aspect of the physical system” is a required analysis task to draw scientific conclusions about the physical system. All Objectives can use one or more task requirements.
 - The investigation shall determine Planet Acme’s internal magnetic field to degree 2 and order 2 with 10% accuracy.
 - The investigation shall determine the average Auroral Emission X rise time after the impact of Solar Wind Structure Y with an accuracy of 5 minutes.
 - The investigation shall determine the absolute age for Planet Acme’s geologic units larger than X by Y km with an accuracy of 5 minutes for at least 80% of the surface.

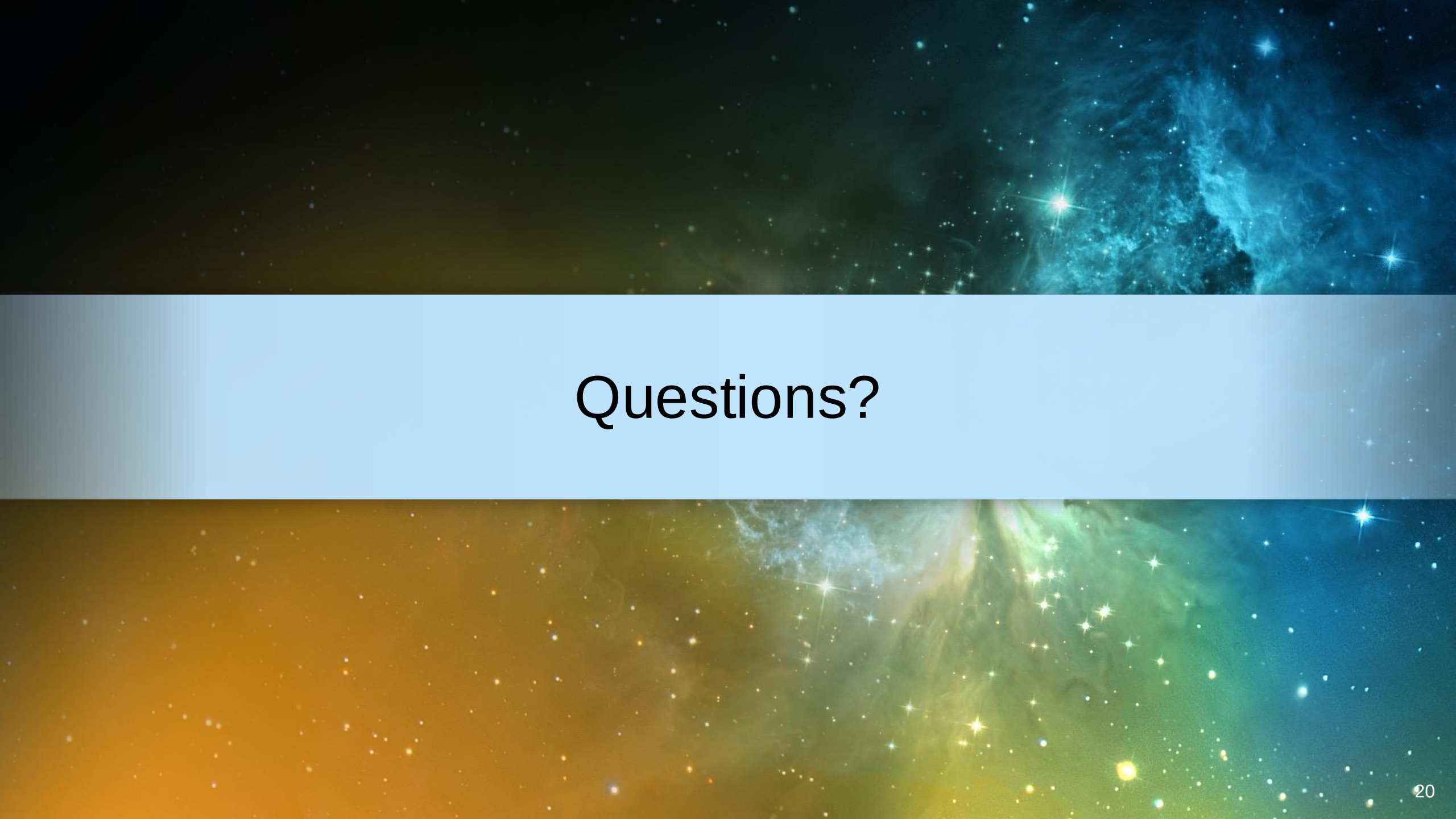
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Note: All of these Level 1s require multiple measurements. There are no measurement-specific parameters (e.g., precision, integration time, time between observations).

Level 2 Requirements

- Level 2 Mad Libs: The mission shall [quantitative measurement verb] [parameter of the physical system] [prepositional phrase] [verification parameter(s)].
- Level 2 Requirements are the first level of implementation-specific requirements in a mission design.
 - Level 2s describe the data-product requirements for executing the research plan necessary for completing the Level 1s.
 - Level 2s are not the actual observation made by the instrumentation. (For some observables, however, they may be very close. For instance, the vector magnetic field.)
 - Level 2s are still based in the physical system.
- Level 2s have a variability between implementation centers, between projects, and between individuals in leadership positions.
 - Main point is that the Level 1s are based in scientific results and the Level 2s have clear traceability down from the Level 1s.

The background of the slide is a composite of two cosmic images. The top half features a dark space with a prominent blue and cyan nebula on the right side, with several bright stars visible. The bottom half shows a vast field of stars against a warm, orange and yellow nebula. A horizontal light blue band separates the two images, serving as a background for the text.

Questions?