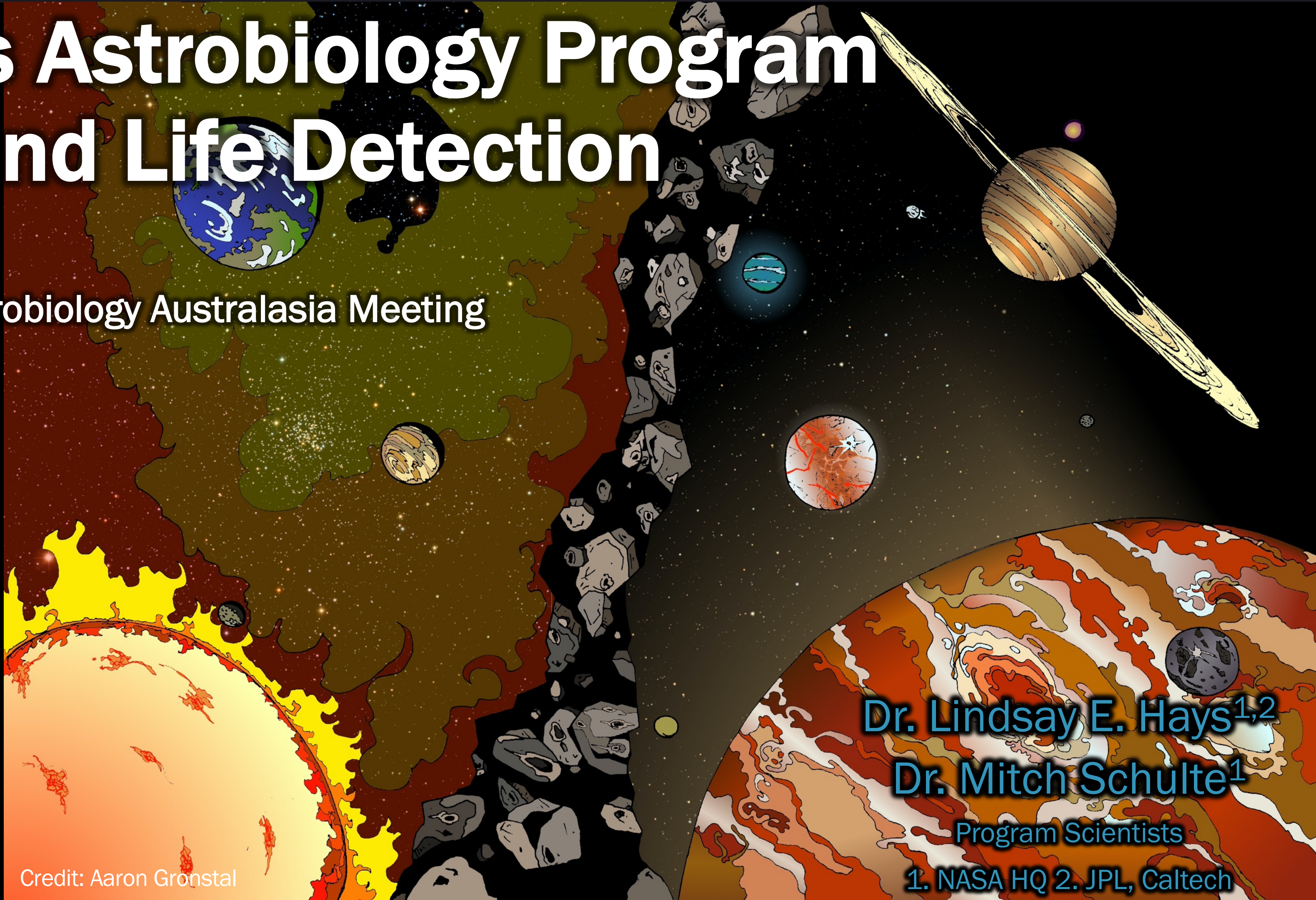
NASA's Astrobiology Program and Life Detection



2018 Astrobiology Australasia Meeting

Credit: Aaron Gronstal

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Program Scientists
1. NASA HQ 2. JPL, Caltech

Astrobiology at NASA

(1963-present)

Interdisciplinary study of life in the context of the Universe, focusing on three fundamental questions:

1. How does life begin and evolve?
2. Does life exist elsewhere in the Universe?
3. What is the future for life on Earth and beyond?

National Aeronautics and Space Act

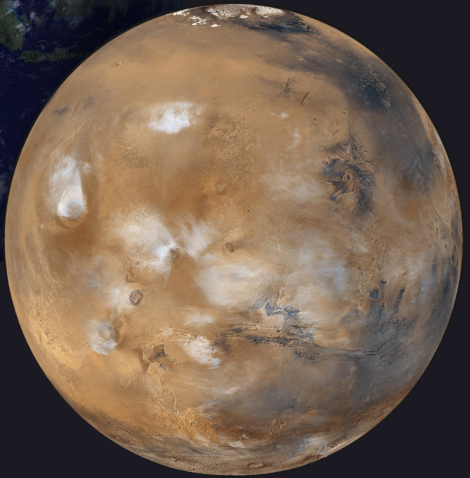
20102. Congressional declaration of policy and purpose

Objectives of Aeronautical and Space Activities.—The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more of the following objectives:

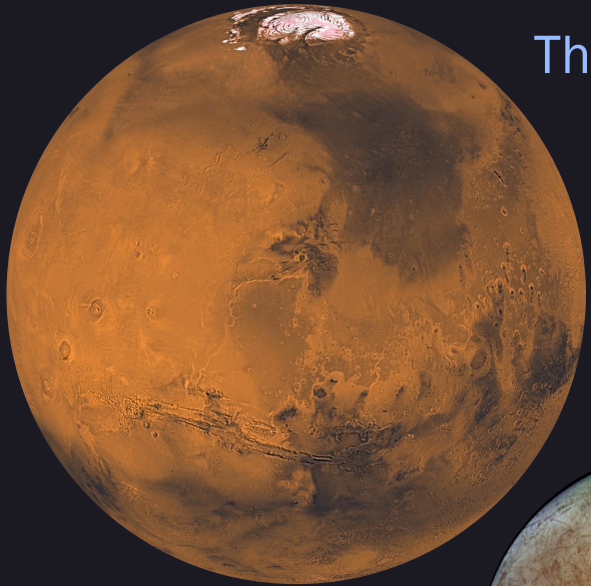
1. The expansion of human knowledge of the Earth and of phenomena in the atmosphere and space.
2. The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles.
3. The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space.
4. The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes.
5. The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere.
6. The making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency.
7. Cooperation by the United States with other nations and groups of nations in work done pursuant to this chapter and in the peaceful application of the results thereof.
8. The most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment.
9. The preservation of the United States preeminent position in aeronautics and space through research and technology development related to associated manufacturing processes.
10. **The search for life's origin, evolution, distribution, and future in the universe.**

What can we learn about searching for life, by studying the Earth?

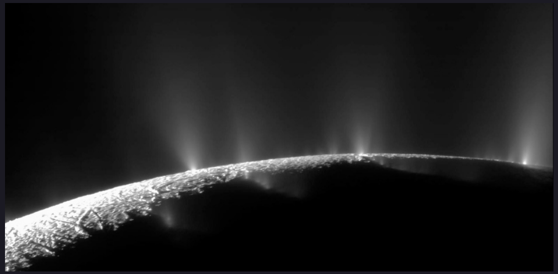
1. Life is tough (extremophiles)
2. Life is tenacious (long survival times)
3. When conditions get tough, life moves inside the rocks!
4. Life is metabolically diverse (it eats anything, it breathes anything!!)

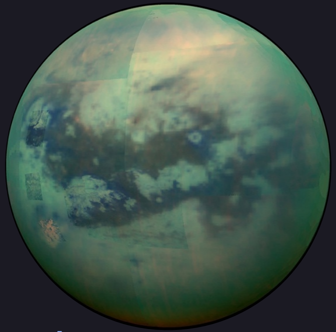


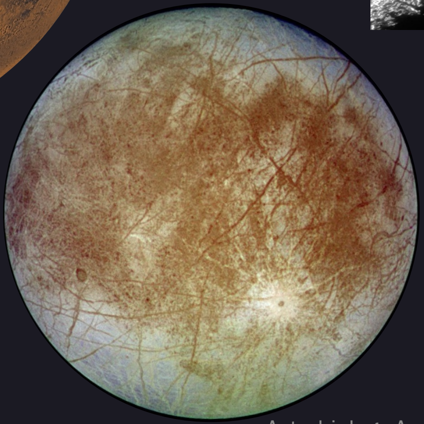
Planetary Environments are Diverse



The unaltered surfaces of most planets are cold, and by being cold, are dry



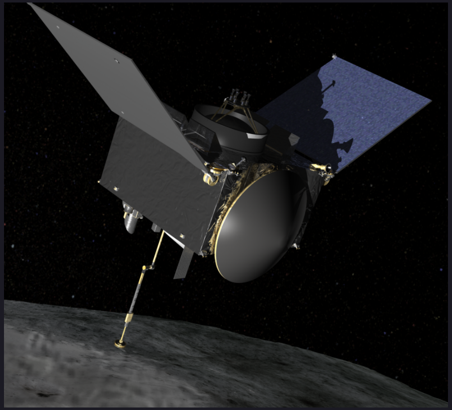




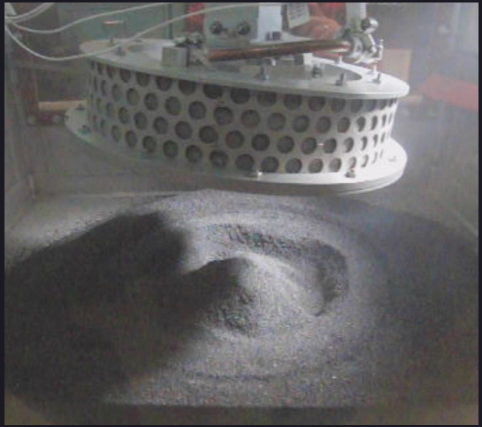
Interior environments may be more similar to Earth:

- possible subsurface oceans, both hot and cold
- subsurface rock, similar (?) to inhabited Earth rocks

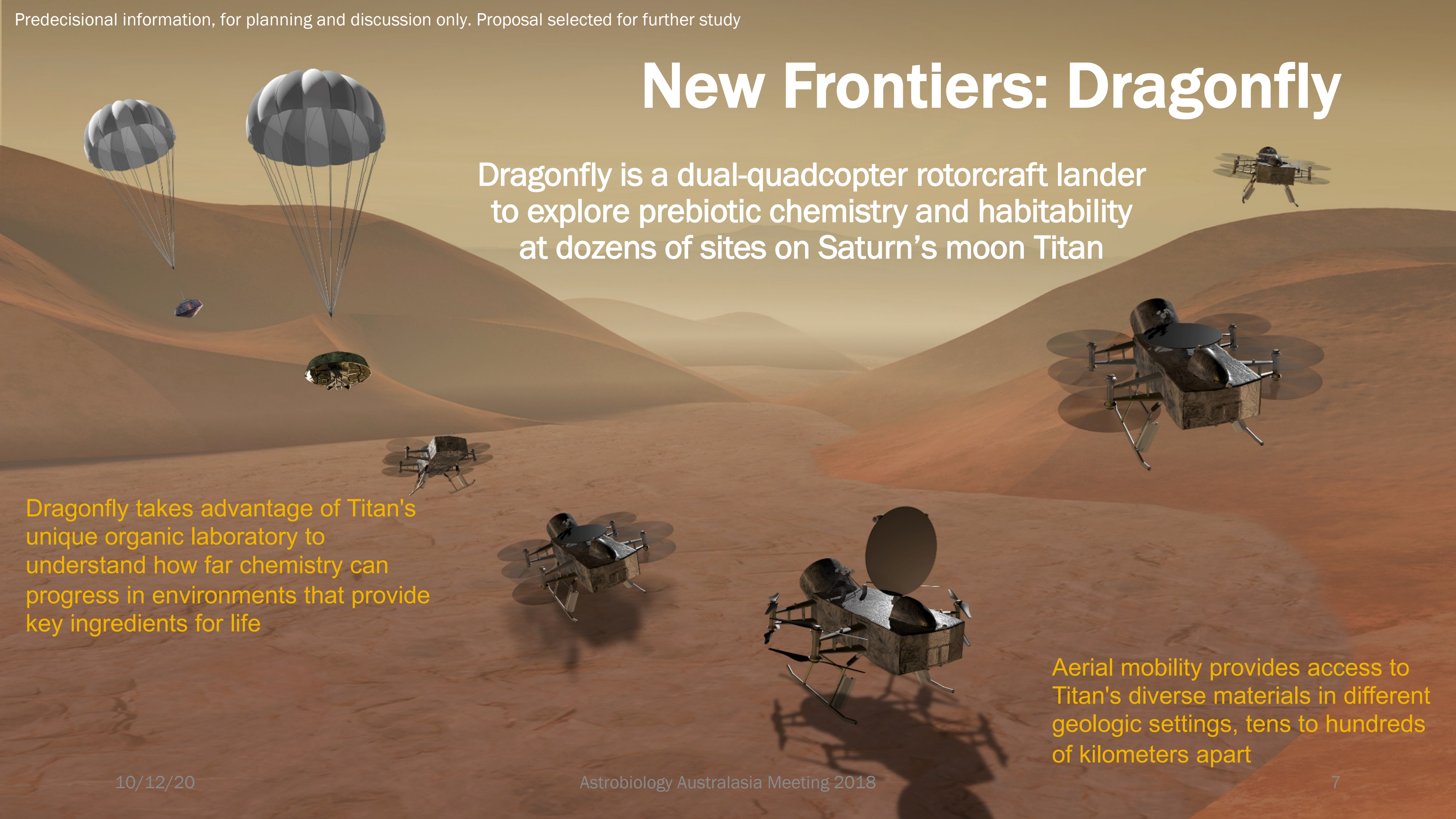
New Frontiers: OSIRIS-REx:



- Origins
  Return and analyze a sample of pristine carbonaceous asteroid regolith
- Spectral Interpretation
  Provide ground truth for telescopic data of the entire asteroid population
- Resource Identification
  Map the chemistry and mineralogy of a primitive carbonaceous asteroid
- Security
  Measure the Yarkovsky effect on a potentially hazardous asteroid
- Regolith Explorer
  Document the regolith at the sampling site at scales down to the sub-cm



New Frontiers: Dragonfly

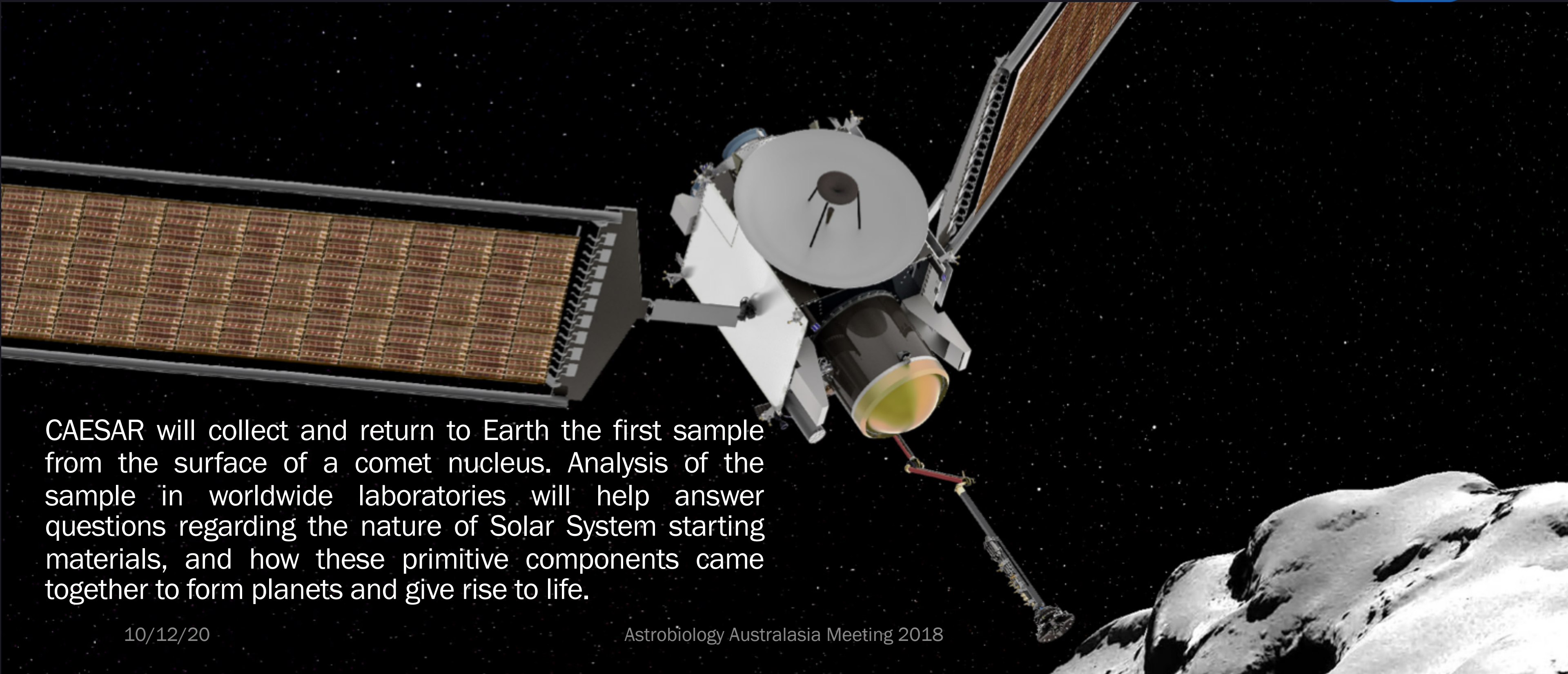


Dragonfly is a dual-quadcopter rotorcraft lander to explore prebiotic chemistry and habitability at dozens of sites on Saturn's moon Titan

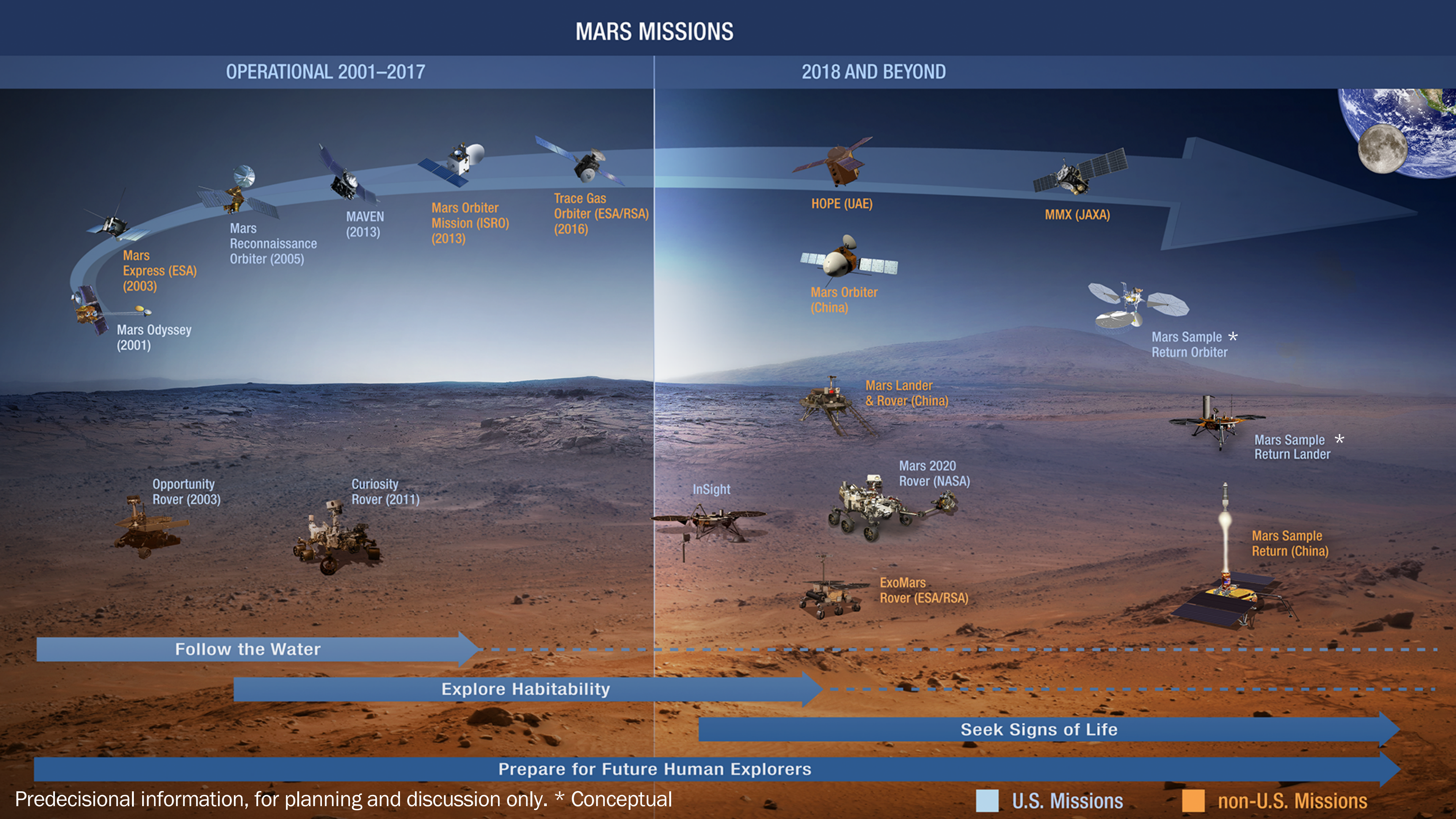
Dragonfly takes advantage of Titan's unique organic laboratory to understand how far chemistry can progress in environments that provide key ingredients for life

Aerial mobility provides access to Titan's diverse materials in different geologic settings, tens to hundreds of kilometers apart

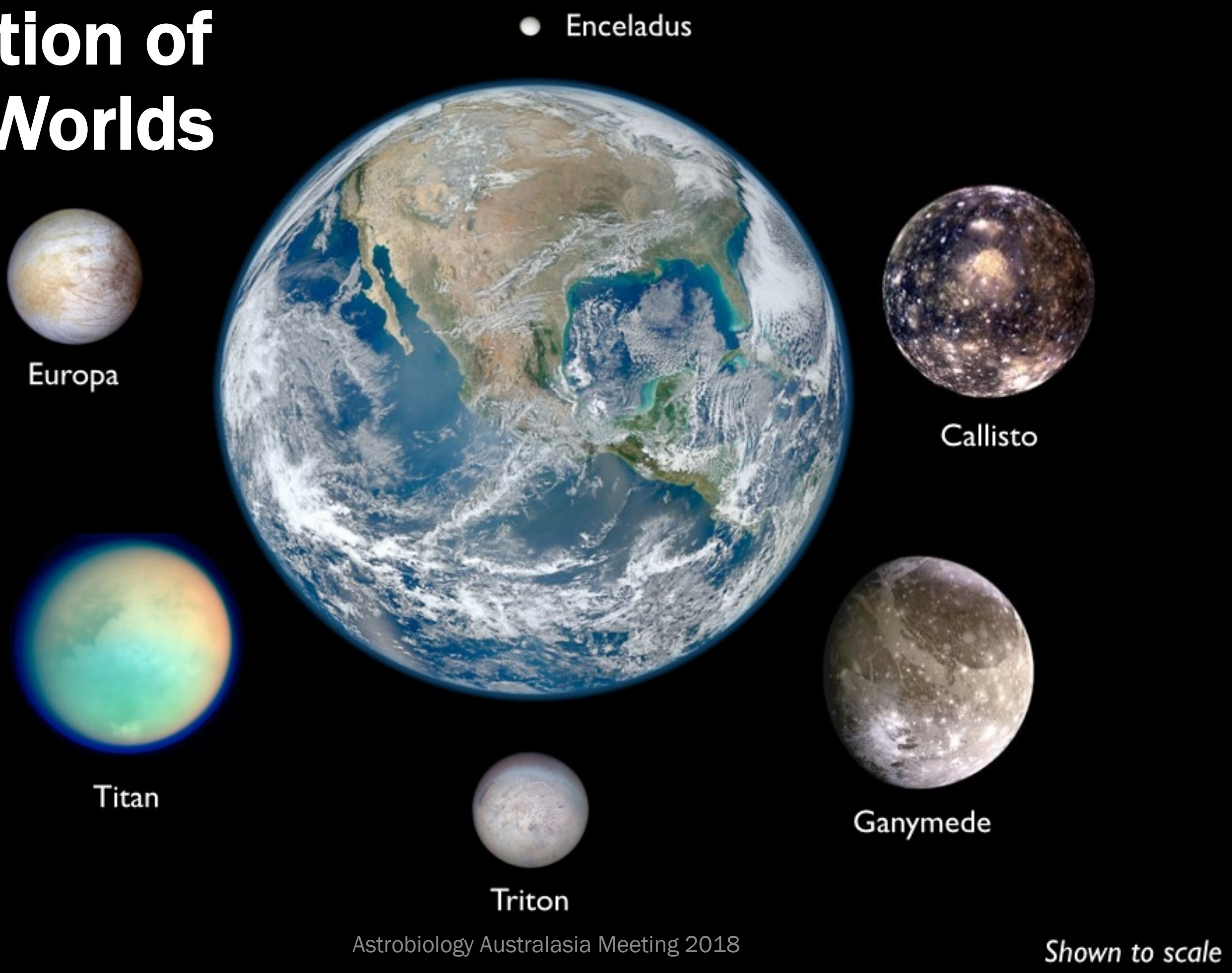
New Frontiers: Comet Astrobiology Exploration Sample Return (CAESAR)



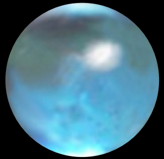
CAESAR will collect and return to Earth the first sample from the surface of a comet nucleus. Analysis of the sample in worldwide laboratories will help answer questions regarding the nature of Solar System starting materials, and how these primitive components came together to form planets and give rise to life.


MARS MISSIONS
OPERATIONAL 2001–2017
2018 AND BEYOND
Mars Odyssey (2001)
Mars Express (ESA) (2003)
Mars Reconnaissance Orbiter (2005)
MAVEN (2013)
Mars Orbiter Mission (ISRO) (2013)
Trace Gas Orbiter (ESA/RSA) (2016)
HOPE (UAE)
MMX (JAXA)
Mars Orbiter (China)
Mars Sample Return Orbiter *
Mars Lander & Rover (China)
Mars Sample Return Lander *
Opportunity Rover (2003)
Curiosity Rover (2011)
InSight
Mars 2020 Rover (NASA)
Mars Sample Return (China)
ExoMars Rover (ESA/RSA)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers
Predecisional information, for planning and discussion only. * Conceptual
U.S. Missions
non-U.S. Missions

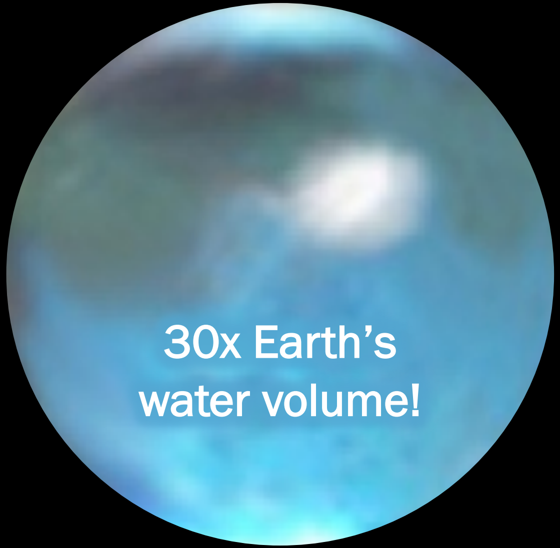
Exploration of Ocean Worlds



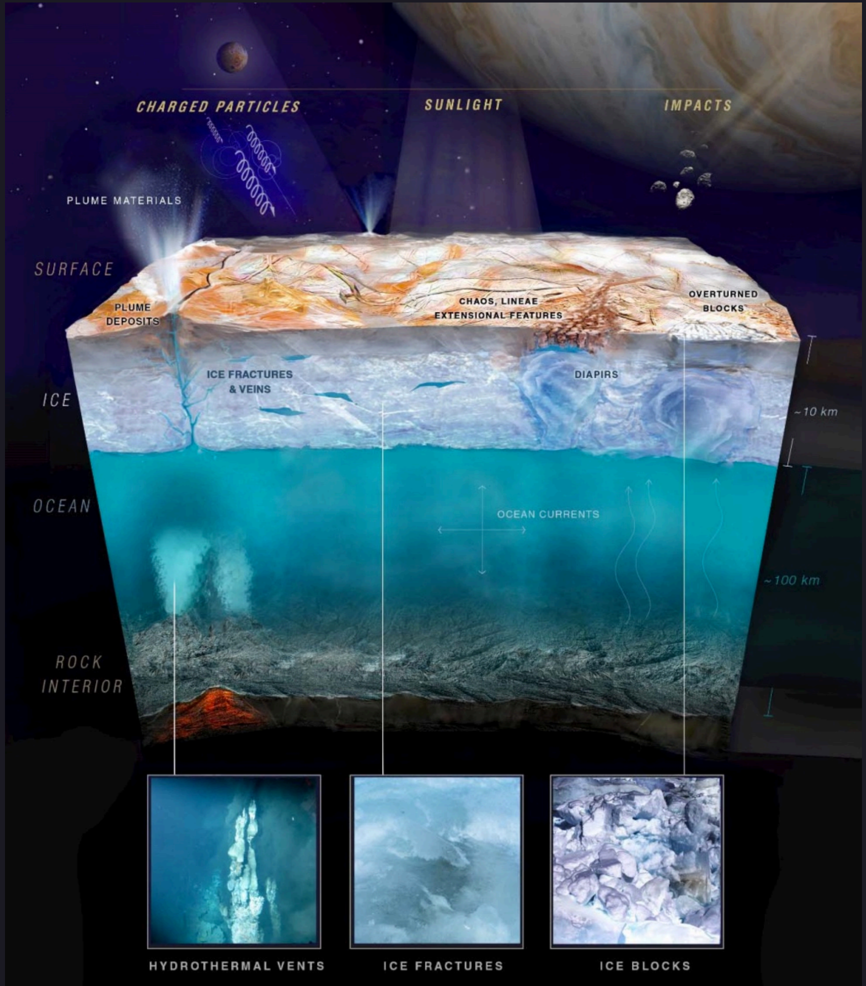
Exploration of Ocean Worlds



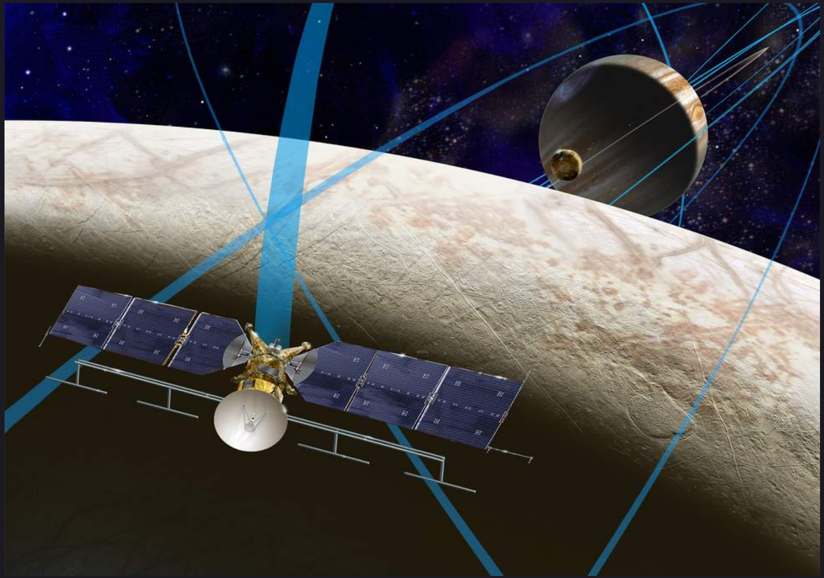
Earth

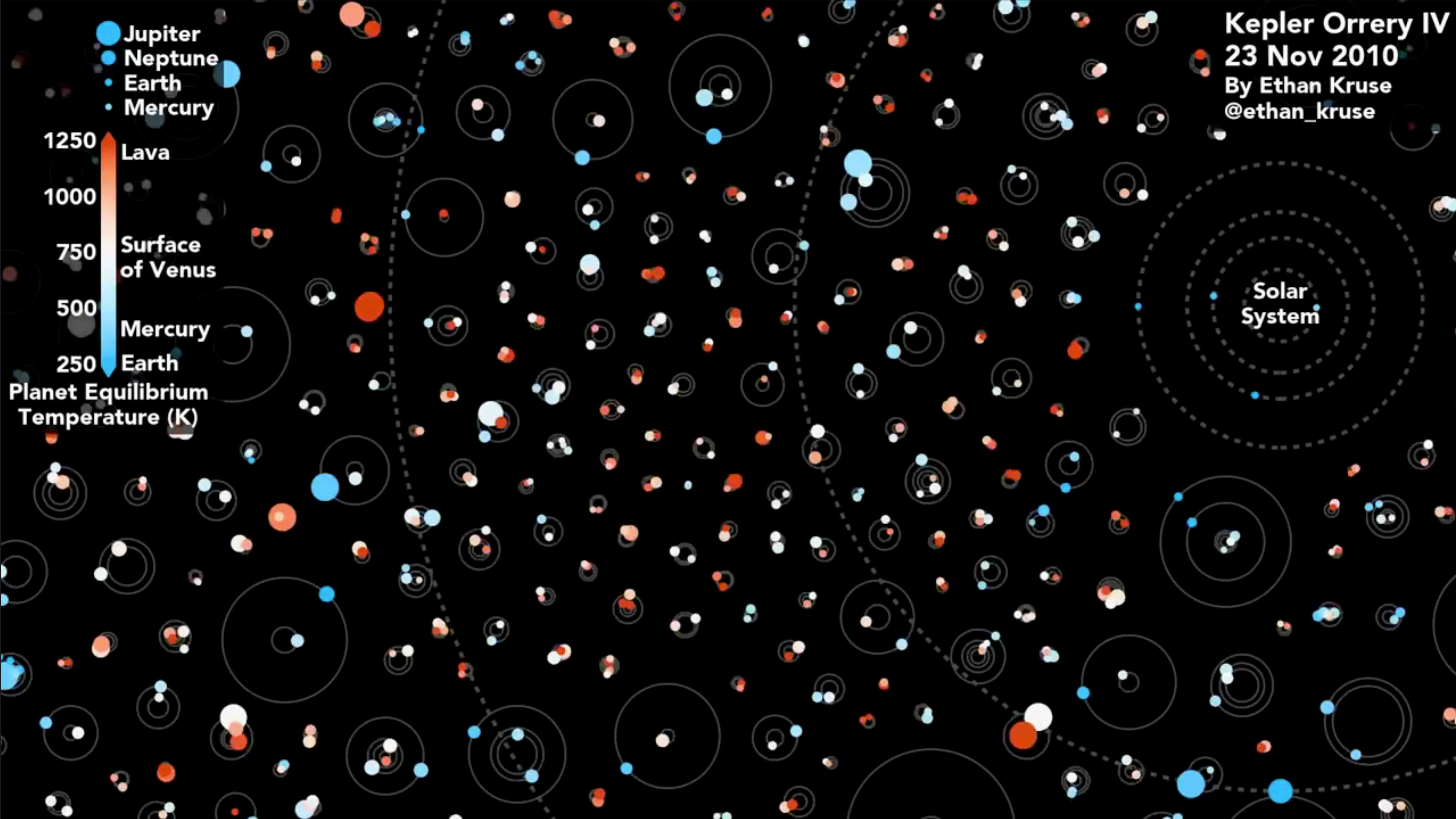


Ice-covered moons



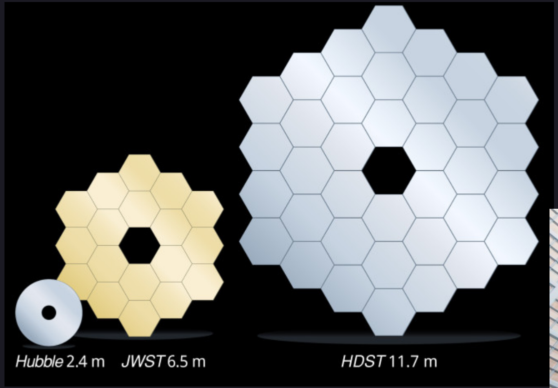
Europa
Focus of Future Astrobiological Study

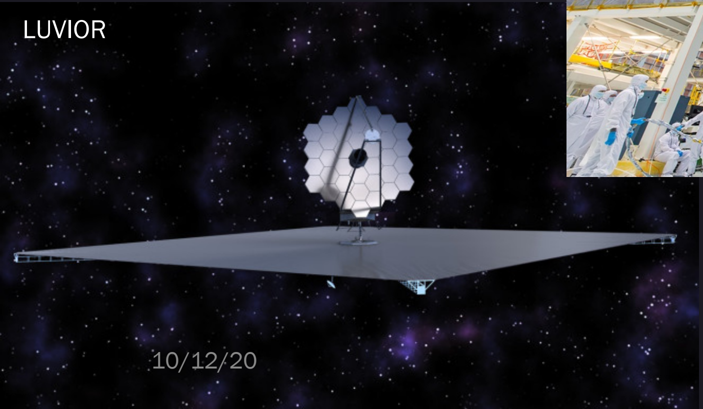


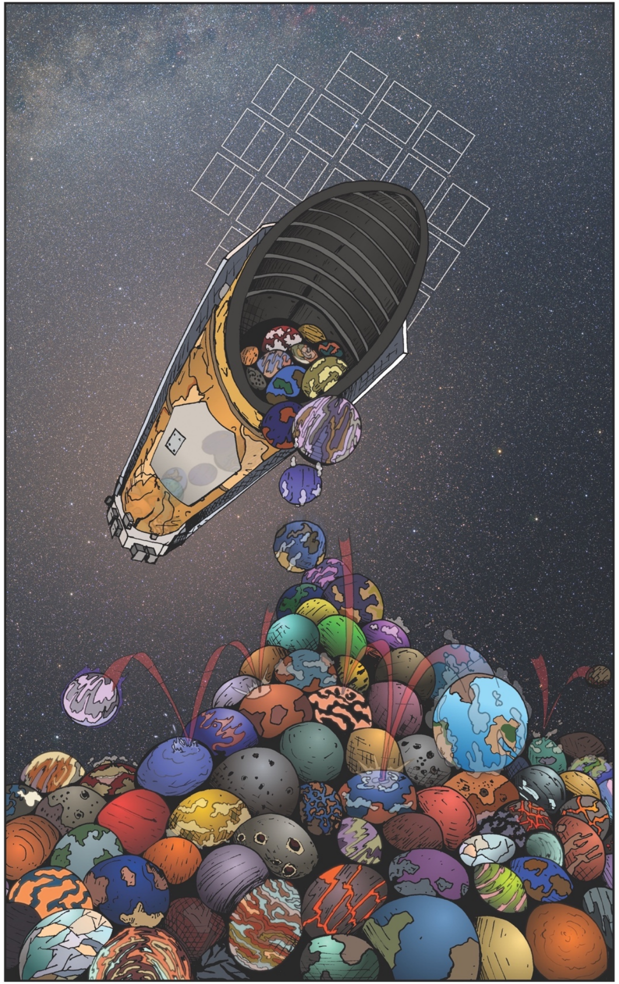


Jupiter
Neptune
Earth
Mercury
1250
1000
750
500
250
Lava
Surface of Venus
Mercury
Earth
Planet Equilibrium Temperature (K)
Kepler Orrery IV
23 Nov 2010
By Ethan Kruse
@ethan_kruse
Solar System

Exoplanets: Next Generation Space Telescopes







Credit: Aaron Gronstal

Ladder of Life detection

Category	Criteria	Why?	Test	Explanation	Examples / Notes
Instrumental criteria	Sensitive	Avoid false negatives	Positive controls	Signal for feature of life selectively quantified above instrumental limit of quantitation, within response time and dynamic range	Encompasses all quantitative measures of instrumental performance (Armbruster & Pry 2008)
Instrumental criteria	Contamination-free	Avoid false positives	Test #1: Neg. controls	Signal for feature of life not selectively detected (below instrumental LoD) in abiotic samples	"Below LoD" implies signal indistinguishable from noise given instrument sensitivity and stability (Armbruster & Pry 2008)
			Test #2: Blanks	Distinguish indigenous signals from contamination signals arising from:	• Hardware • Other samples (cross-contamination)
Instrumental criteria	Repeatable	Avoid fluke	≥Triplicate	$N \geq 3$ measurements is the typical burden of proof in microbiology and chemistry, also depends on other factors (Table 2)	*N* measurements per sample, for as many samples as needed to capture the heterogeneity of the setting
Contextual criteria	Detectable	Avoid false negatives	Positive controls	Physical, chemical, or geological conditions in the sample's current environment do not prevent the measurement from being made	• Reaction of organics with oxidant upon heating • Ionization suppression by salts • Some antibody methods in "sticky" briny liquid
Contextual criteria	Survivable	Avoid false negatives	$\tau_{residence} > N^{*}\tau_{degradation}$	Physical, chemical, or geological conditions in the suite of environments encountered by the sample between its synthesis and its measurement have not destroyed targeted signs of life	• Photo-destruction of biosignature gases • Radiolysis of organics • Racemization Test from Hoehler (2017); N~1 to a few units
Contextual criteria	Reliable	Avoid false positives	Measure [bio]≠[abio]	Propensity to be produced by life and distinguished from abiotic backgrounds from any of the environments encountered by the sample between its synthesis and its measurement	$\frac{[bio]}{[bio]+[abio]} >$ instrument precision
Contextual criteria	Compatible	Consistent with what we know of life	Within bounds of NRC (2007)	The feature must not be excessively different from what is known of life on Earth (specificity vs. genericity). Limits can be pushed within bounds.	• Organic molecules, carbon-based (this would include e.g. proposed "arseno-DNA" (Wolfe-Simon et al., 2011)). • Temperature not too high. Prions survive combustion at 600°C (Brown et al. 2004).
	Last-resort hypothesis	Precludes abiotic origin	Decision rules (Table 3)	The measurement, either alone or taken together with sufficient complementary measurements, precludes an abiotic origin with sufficiently little ambiguity.	Not just an appeal to authority (Sagan et al., 1993), as this criterion has been informally adopted by the astrobiology community as a standard.

Neveu et al. (2018), *Astrobiology*

	RUNG Roughly, subjectively ordered by (top to bottom): 1. decreasing strength of evidence for life 2. increasing ease of measurement	FEATURE Listed in no specific order within a given rung	MEASUREMENT TARGET		LIKELIHOOD ... that the feature would be a biosignature, given the criteria to the right	INSTRUMENTAL CRITERIA Quantifiable Detectability	INSTRUMENTAL CRITERIA Contamination-free Likelihood of false positive	INSTRUMENTAL CRITERIA Repeatable	CONTEXTUAL CRITERIA Detectable Detectability	CONTEXTUAL CRITERIA Survivable Likelihood of false negative	CONTEXTUAL CRITERIA Reliable Ambiguity of feature	CONTEXTUAL CRITERIA Compatible Specificity to Earth life	CONTEXTUAL CRITERIA Last-resort Ambiguity of interpretation
LIFE	Darwinian evolution	Changes in inheritable traits in response to selective pressures	Not practical under mission constraints	• In situ • Sample return	No	-	-	Number of replicates depends on: • Characteristics of the instrument, • Heterogeneity of the sample, • Likelihood of systematic errors, • Required values of the relevant statistical parameters, • Value and cost of information.	-	N/A (extant)	-	-	-
LIFE	Growth & Reproduction	Concurrent life stages or identifiable reproductive form, motility	Cell(-like?) structures in multiple stages	• In situ • Sample return	Low	Hard	Low		Med (don't identify stages, timing off, sample size low)	High?	Ambiguous. What is a cell? What morphological differences exist?	Earth	Med / High
LIFE	Metabolism	Major element or isotope fractionations indicative of metabolism	Deviation from abiotic fractionation controlled by thermodynamic equilibrium and/or kinetics	• Remote sensing • In situ • Sample return	Low / Med	Easy	High		Medium	High	Hinges on understanding of context	Earth?	Low
LIFE	Metabolism	Response to substrate addition	Waste output (compound, heat)	• In situ • Sample return	Low / Med	Easy	Low		High	N/A (extant)	Hinges on understanding of context	Earth	Medium
LIFE	Metabolism	Co-located reductant and oxidant	Deviation from abiotic distribution controlled by thermodynamic equilibrium and/or kinetics	• Remote sensing • In situ • Sample return	Med / High	Med (linked to specificity of instrument)	Low / Med		Med / High	High	Mixed reactions, large inventory of chemistries	Generic	Low / Med
LIFE	Molecules & Structures Conferring Function	Polymers that support information storage and transfer for terran life (DNA, RNA)	Abundance	• In situ • Sample return	Low	Hard (instrument specificity must be high); RNA hard to measure on Earth	DNA: high; RNA: low (reactive)		Low (technology limited, only terran); RNA highly reactive	Low (hydrolysis in water)	Reliable	Earth	Negligible
LIFE	Molecules & Structures Conferring Function	Structural preferences in organic molecules (non-random and enhancing function)	Polymer with repeating charge	• In situ • Sample return	Low / Med	Need a lot of material and overprinting must be discernable	Low		Med / High	Low (hydrolysis in water, diagenesis)	How much preference needed to detect?	Generic	Low
LIFE	Molecules & Structures Conferring Function	Structural preferences in organic molecules (non-random and enhancing function)	Enantiomeric excess > 20% in multiple amino acid types	• In situ • Sample return	High	How much excess necessary?	Low		Low	Medium	Mixed sample both processes present	Generic	Low
LIFE	Molecules & Structures Conferring Function	Pigments as evidence of non-random chemistries (e.g. specific pathways)	Spectral feature and/ or color, otherwise see "structural preferences"	• Remote sensing • In situ • Sample return	Low / Med	Easy (fluorescence)	Low		Low (limitation of what we are looking for)	Low (diagenesis)	How to define pigment as we don't know it?	Earth (can one abstract?)	Very low
SUSPICIOUS BIOMATERIALS	Potential biomolecule components	Organics not found abiotically (e.g. hopanes, ATP, histidine)	Presence	• In situ • Sample return	Medium	Easy if enough material	Low		High	High	Low	Earth?	High
SUSPICIOUS BIOMATERIALS	Potential biomolecule components	Complex organics (e.g. nucleic acid oligomers, peptides, PAH)	Presence	• Remote sensing (PAH) • In situ • Sample return	High	Easy if enough material	Low		High	Medium	Abiotic production known	Generic	Med / High
SUSPICIOUS BIOMATERIALS	Potential biomolecule components	Monomeric units of biopolymers (nucleobases, amino acids, lipids for compartmentalization)	Presence	• Remote sensing • In situ • Sample return	Med / High	Limit of detection, need a lot of material	High		High	Med (diagenesis)	Abiotic pathways known	Generic	Medium
SUSPICIOUS BIOMATERIALS	Potential metabolic byproducts	Distribution of metals e.g. V in oil or Fe, Ni, Mo/W, Co, S, Se, P	Presence	• In situ • Sample return	Medium	Easy except background issue	Low		High	High	Background known	Generic	Medium
SUSPICIOUS BIOMATERIALS	Potential metabolic byproducts	Patterns of complexity (organics)	Deviation from equilibrium (P(Poisson distribution of pathway complexity) < 0.01?) or abiotic kinetic distribution	• In situ • Sample return	High	Background issue, material limited	Low		High	Medium?	Limited documentation of abiotic vs. biotic differences	Generic	Medium
SUSPICIOUS BIOMATERIALS	Biofabrics	Textures	Biologically mediated morphologies, preferably with co-located composition	• In situ • Sample return	Medium	Medium	Low		Medium	High?	Highly ambiguous	Earth	High
	Habitability	Liquid water, building blocks, energy source, gradients	Redox, temperature, pH, energy, disequilibria										

Neveu et al. (2018), *Astrobiology*

Ladder of Life Detection Next Steps:

- The **Center for Life Detection Science** (CLDS) is an Ames-Goddard collaboration developed to support NASA's emerging life detection objectives.
- The initial objective of the CLDS is to develop a web-based platform in which to compile, organize, and curate a "living" repository of information and community dialog relating to life detection science.

Stakeholders:

1. Life Detection Science Community
2. Mission/Instrument Community
3. NASA Headquarters

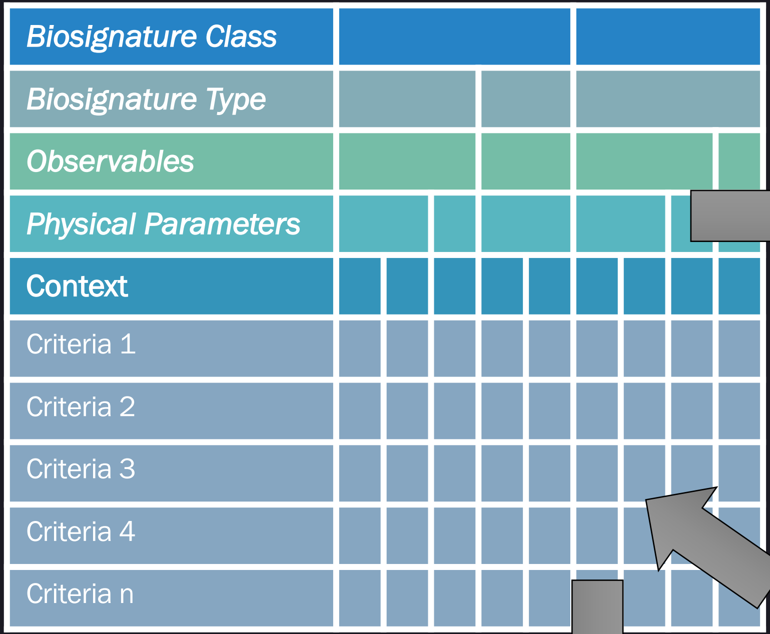
1. Comparison Matrix

Currently in development, the CM will be a dynamic, filterable table used to compare multiple features at a highly distilled level.

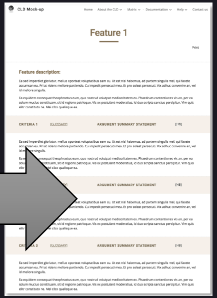
Search

Apply Filters:

- ❑ Biosignature Class
- ❑ Biosignature Type
- ❑ Observables
- ❑ Physical Parameters
- ❑ Environments:
  - ❑ Context 1
  - ❑ Context 2
  - ❑ Context 3
  - ❑ Context n



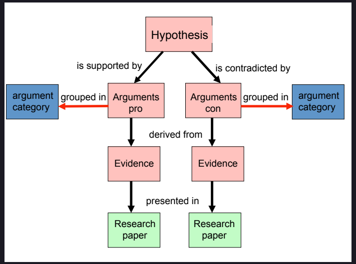
2. Feature Summary



Narrative document that conveys background relevant to **a given feature** and discusses individual criteria at an expanded level of detail.

3. Knowledge Base

Organizes **published papers** and ongoing community dialog according to its bearing on a specific criterion for **a specific feature in and specific environment.** Based on the preexisting **"Hypothesis Browser"** platform, a community based system for indexing and organizing scientific papers based on hypotheses that they support or contradict.



4. Instrument Forum

Per Feature:

	Instrument	Measurement	Capabilities during ideal operation	Potential sources of noise	Methods of overcoming noise	Influence of processing (environment)	Maturity (maturation milestone achieved)
Lab based	Instrument A						
	Instrument B						
	Instrument n						
In-situ/heritage	Instrument A						
	Instrument B						
	Instrument n						

Any Questions?