DARES Focus Area #3

Co-Evolution of Biospheres, Worlds, and Planetary Systems

Primary: Tyler Robinson (UArizona)
Secondary 1: Tanja Bosak (MIT)
Secondary 2: Laurie Barge (JPL)
Secondary 3: Tiffany Kataria (JPL)

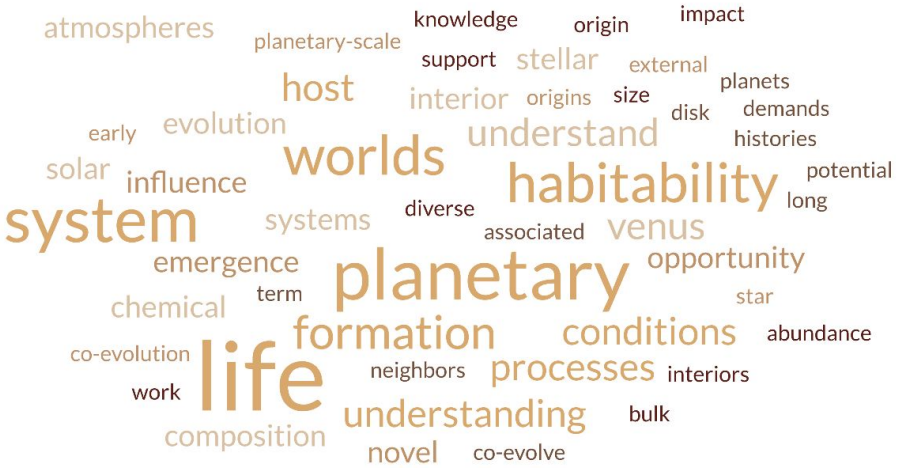
Summary: Understanding habitability as well as origins and signs of life requires a holistic approach to studying worlds — their host star(s), formation, neighbors, histories, interiors, surfaces, atmospheres, and inhabitants.

Image: Google Gemini

Overview

What is this Focus Area about?

1. Habitability and origins of life as trajectories within complex systems.
2. Worlds as coupled to their host systems and hosted biospheres.
3. Planetary context as the stage for abiogenesis and life detection.



Overview

Why is this Focus Area important to NASA Astrobiology?

- **Missions**: Planetary co-evolution is a driving theme for active and near-future solar system missions and exoplanet observations. Future life detection missions/observations must understand environmental context, from host stars to local chemistries.

Overview

Why is this Focus Area important to NASA Astrobiology?

- **Missions**: Planetary co-evolution is a driving theme for active and near-future solar system missions and exoplanet observations. Future life detection missions/observations must understand environmental context, from host stars to local chemistries.

- **Astrobiology Strategy 2015**: Co-evolution of life and its host planet and the context from planetary systems helps answer all three strategic questions: How does life begin and evolve? Does life exist elsewhere? What is the future of life on Earth and beyond?

Overview

Why is this Focus Area important to NASA Astrobiology?

- **Missions**: Planetary co-evolution is a driving theme for active and near-future solar system missions and exoplanet observations. Future life detection missions/observations must understand environmental context, from host stars to local chemistries.

- **Astrobiology Strategy 2015**: Co-evolution of life and its host planet and the context from planetary systems helps answer all three strategic questions: How does life begin and evolve? Does life exist elsewhere? What is the future of life on Earth and beyond?

- **Decadal and Strategy Reports**: Themes of co-evolution of a world with its host star and/or a world with its biosphere appear in all of: Earth, Astro, Helio, and Planetary 2020s Decadals; recent Mars Exploration, Astrobiology, and Exoplanet strategies.

Overview

Key Takeaways

- Co-evolution of Biospheres, Worlds, and Planetary Systems bridges a large number of field-guiding strategies.

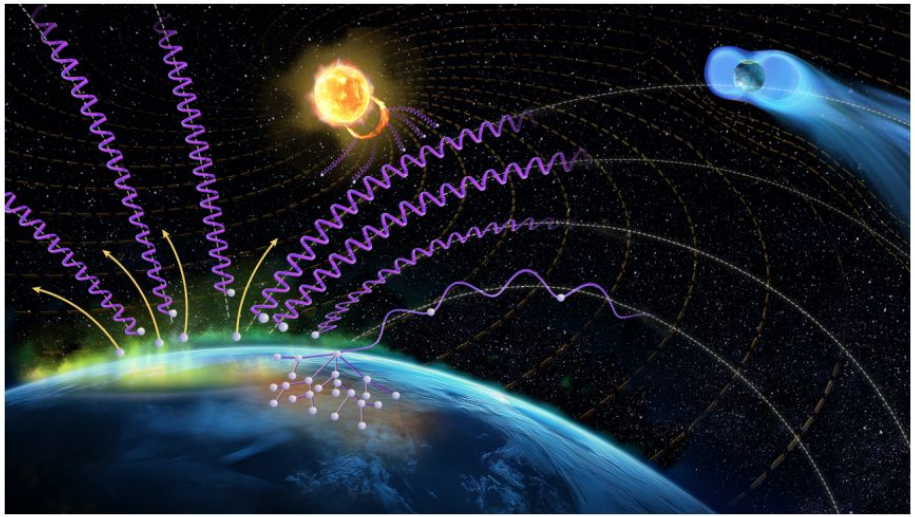
- The theme of co-evolution garners strong community interest through connections to ongoing, unprecedented observations of planetary systems alongside current/near-future missions to understand planetary evolution and prospects for extraterrestrial life.

Image: Beta Pictoris from JWST/MIRI | Credit: NASA/ESA/CSA/STScI/Stark/Lawson/Kammerer/Perrin

Key Findings from RFI Synthesis

Finding 1: Sun and Stars

- Host star(s) – including their formation, evolution, and current activity – are central to planetary and biosphere co-evolution.
- Star-planet interactions drive fundamental processes in atmospheric escape and chemistry.
- The role of host star(s) should be better represented in an updated NASA Astrobiology Strategy.



C. Carter | WP 0083

Key Findings from RFI Synthesis

Finding 1: Sun and Stars

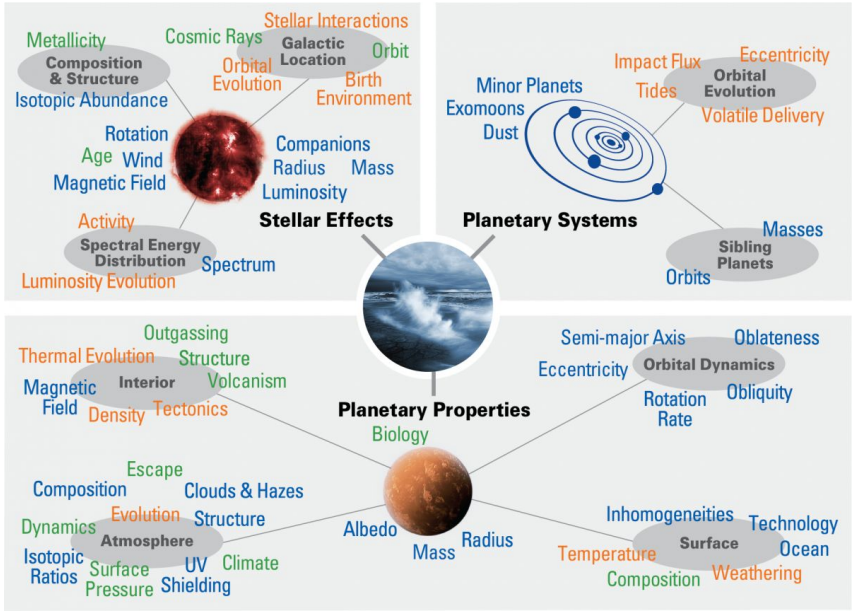
- How have Sun-Earth interactions influenced the long-term habitability and inhabitance of our Earth?
- How can our detailed understanding of the solar wind and Sun-Earth interactions be extended to other star-planet systems?
- What properties of exoplanet host stars should be measured/inferred to best constrain associated models of star-planet interactions?

Note: 2024 Decadal Survey for Solar and Space Physics includes a key Driving Question: “What internal and external characteristics have played a role in creating a space environment conducive to life?”

Key Findings from RFI Synthesis

Finding 2: Emergence and Maintenance of Habitability and Life

- The seeds for habitability and life can be placed early in the evolution of a planetary system.
- Extrinsic forces can act to stabilize or destabilize planetary environments.
- The topic of emergence and maintenance of habitability and life should be broadened to include the roles of host star(s) formation conditions, star and planetary system evolution, and the coupled physical-chemical evolution of planetary interiors.



Meadows & Barnes (2018)

Key Findings from RFI Synthesis

Finding 2: Emergence and Maintenance of Habitability and Life

- What role does the host stellar formation environment and composition play in driving planetary system formation and evolution, and what are the longer-term consequences for planetary habitability?

- How can the observed structure of a planetary system be used to infer past histories of habitability for rocky exoplanets? Or icy moons?

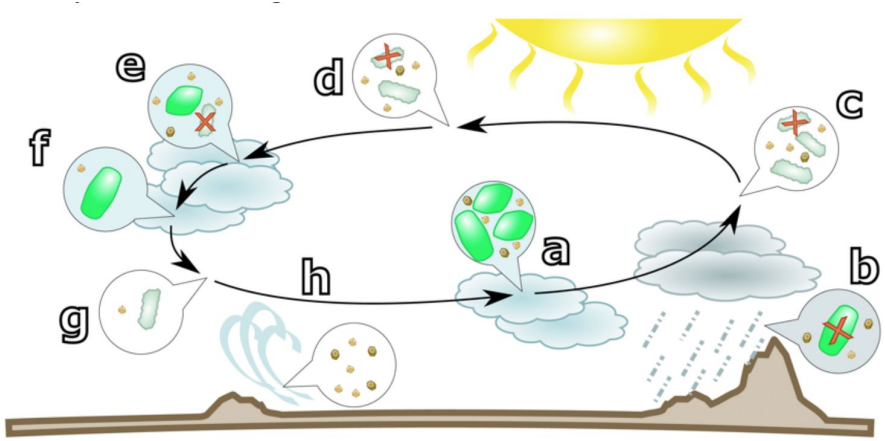
- What role(s) do initial composition, core formation, and coupled interior/surface/atmosphere/biosphere cycling play in the long-term habitability and maintenance of life?

Note: Couples well to the theme of “dynamic habitability” developed in NASEM 2019 Astrobiology Strategy. Additionally, key theme of “agnostic biosignatures” developed in this Strategy does not mean environment-agnostic.

Key Findings from RFI Synthesis

Finding 3: Atmospheres as Windows and Habitats

- Atmospheres are already appreciated for their role in planetary evolution and remote characterization (incl. biosignature detection).
- The astrobiological significance of atmospheres should be expanded to include these being viable locations for life as well as abiogenesis.



Izenberg et al. (WP 0041)

Key Findings from RFI Synthesis

Finding 3: Atmospheres as Windows and Habitats

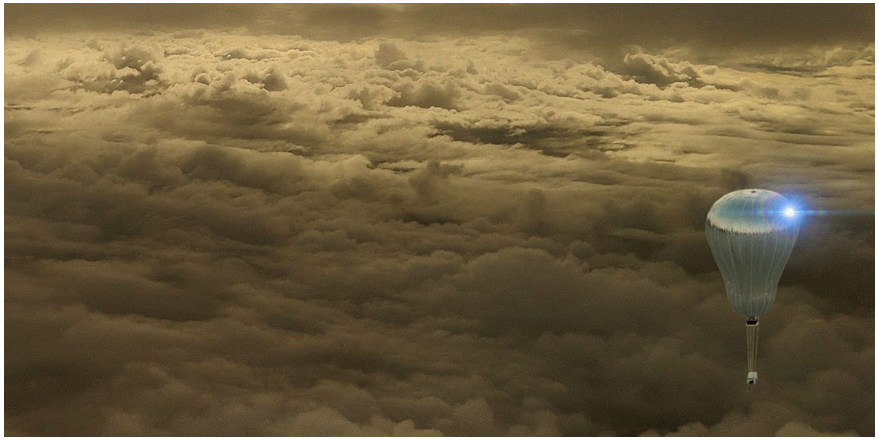
- How could an atmosphere support a sustained biosphere? What metabolisms might this biosphere rely on, and what would be the associated biosignatures?

- Can atmospheres serve as sites for abiogenesis?

Key Findings from RFI Synthesis

Finding 4: Venus as an Astrobiological Laboratory

- The value of Venus should be expanded to include its value as a laboratory for testing ideas in planetary evolution, emergence/maintenance of habitability/life, biosignature detection and vetting, as well as novel chemistries for abiogenesis and life.
- Venus is a target for forthcoming NASA missions and a nearby target for efficient/rapid mission development.



Byrne et al. (WP 0130)

Key Findings from RFI Synthesis

Finding 4: Venus as an Astrobiological Laboratory

- How do we best interpret and verify Venusian atmospheric biosignatures? What lessons can be derived from this process and applied to noisy biosignature detections for exoplanets or other solar system worlds?

- What novel chemistries, origins, and biochemistries might sulfuric acid support as a polar solvent?

- How do we interpret future *in situ* measurements from the Venusian atmosphere for constraints on models for the long-term evolution of habitability and volatile reservoirs?

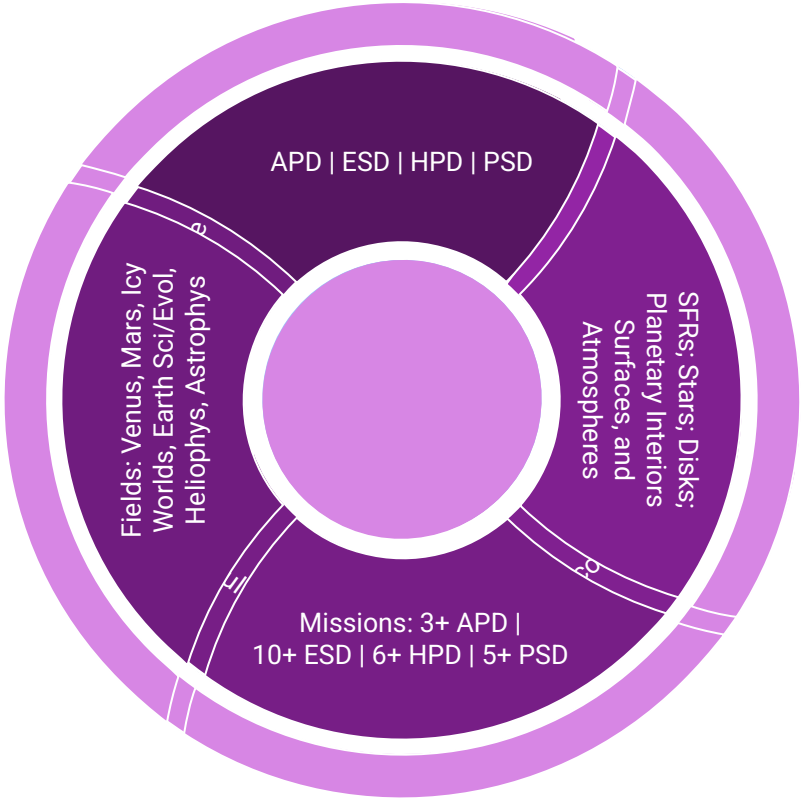
Why this Focus Area now?

	Sun/Stars	Emerge/Maintain	Atmospheres	Venus
Then	Emphasis on evolution of stellar brightness as a key to habitability.	Emphasis on Earth (and Mars) as the laboratory for habitability/life maint.	Recognized role in biogeochem. cycles, evolution, and remote sensing.	Venus as a failure case in habitability.
Now	More-detailed knowledge of solar wind w/applications to other stars. Models and obs. of how stars interact with planetary atmospheres.	New obs. tools for studying planet system form/evol and star-planet co-evol. Emerging opps. to observationally test models of habit/life maintenance.	Increasingly detailed obs. of atmospheres of exoplanets, w/new missions in develop. Growing interest in atmosphere's role as habitat and site for abiogenesis.	VERITAS, DAVINCI Ongoing biosignatures debate. Venus as a dynamic laboratory for studying many aspects of co-evolution.

Focus Area Uncertainties and Discussion Topics

- What research areas within the theme of co-evolution may have been missed because they now have a well-developed literature? (E.g., coupled biogeochemical cycles; geological/geochemical studies of ancient Earth environments)
- Context for biosignatures – or biosignatures demand context?
- Connections to space biology, human spaceflight.

Focus Area Landscape



Focus Area Landscape

- **Earth Science Decadal 2018** | Vision includes:
  - Enable society to thrive amidst Earth's rapid changes.
  - Embrace Earth as integrated system of atmos, ocean, land, ice, and humans.
- **Exoplanet Science Strategy 2018** | Strategic goals emphasize:
  - Formation and evolution of planetary systems.
  - Habitability and life detection.
- **Astrobiology Strategy 2019** | Vision and strategic goals include:
  - Expanding astrobiology to a system science.
  - Understanding dynamic habitability, biosignature science.
- **Astro2020 Decadal Survey** | Scientific themes include:
  - Worlds and Suns in Context - formation/diversity of exoplanet systems.
  - Cosmic Ecosystems - co-evolution of stars, galaxies, and gas.
- **Origins, Worlds, and Life 2023** | Vision emphasizes:
  - Origin and evolution of solar system and life.
- **Mars Exploration Strategy 2024-2044** | Vision emphasizes:
  - Understanding Mars' past, present, and future.
- **2024 Solar and Space Physics Decadal** | A "guiding question" of:
  - What internal/external characteristics have played a role in creating a space environment conducive to life?

Summary

Understanding habitability as well as origins and signs of life requires a holistic approach to studying worlds — their host star(s), formation, neighbors, histories, interiors, surfaces, atmospheres, and inhabitants.

Findings:

1. Sun and Stars
2. Emergence and Maintenance of Habitability and Life
3. Atmospheres as Windows and Habitats
4. Venus as an Astrobiological Laboratory

Co-Evolution of Biospheres, Worlds, and Planetary Systems connects themes of origins and evolution spanning an array of field-guiding strategy documents and NASA missions.