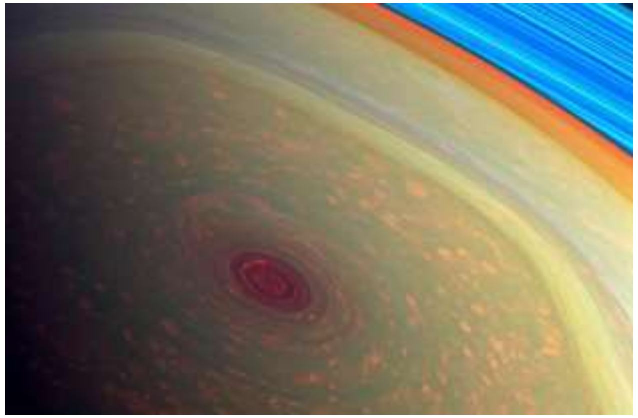
National Aeronautics and Space Administration

SCIENCE

Astrobiology Update

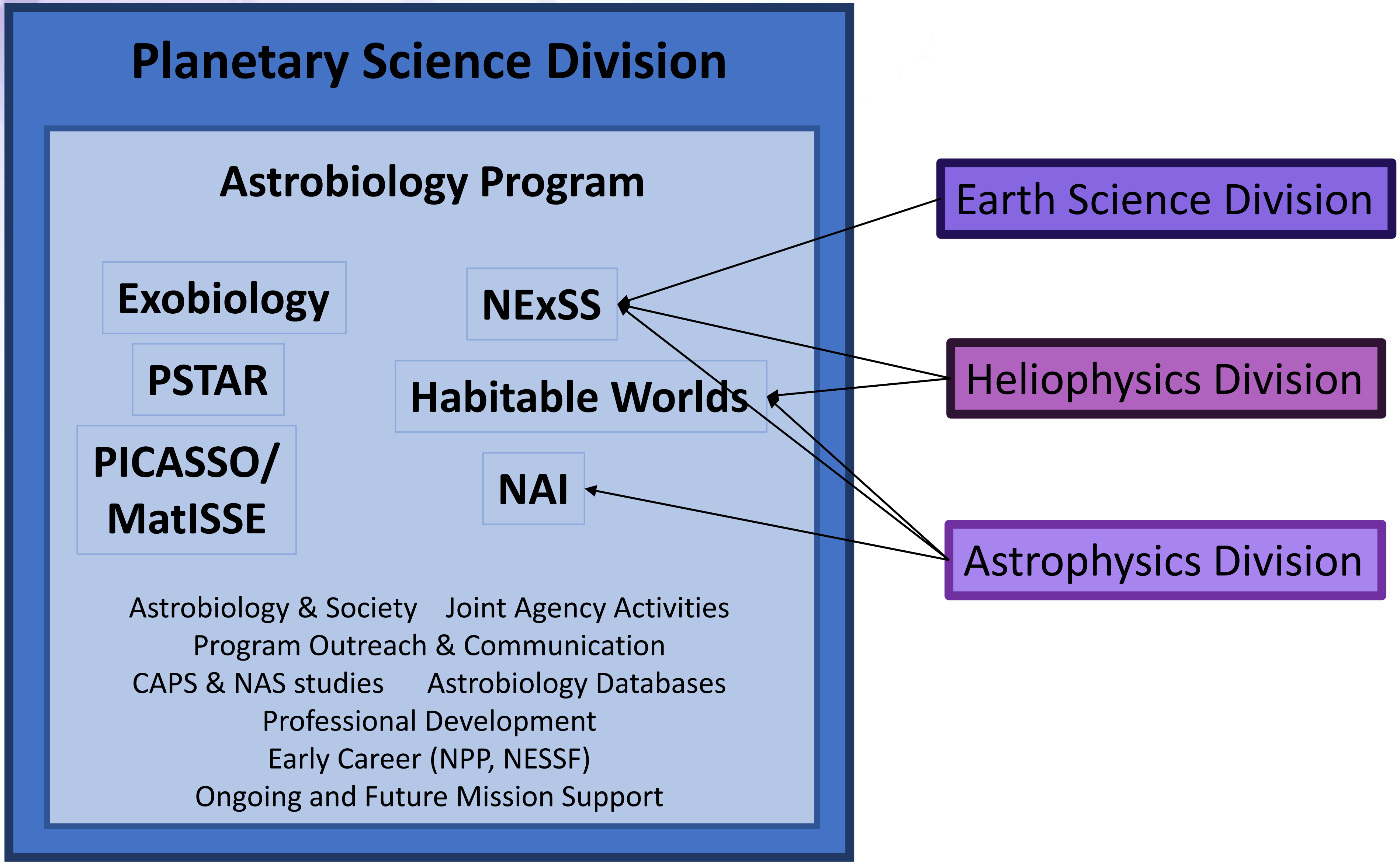
MEETING OF THE COMMITTEE ON ASTROBIOLOGY AND PLANETARY SCIENCE

Mary Voytek

Senior Scientist Astrobiology
Planetary Science Division

September 11, 2018

MISSION: To advance foundational, interdisciplinary research in order to enable NASA's missions to search for life in the Universe.



C.5 EXOBIOLOGY

NOTICE: This program element no longer uses the two-step proposal submission process common in Appendix C. Instead, a Notice of Intent (NOI) is requested in place of a Step-1 proposal.

2.2 Program Exclusions

- Research aimed at investigating the habitability of planetary bodies in our Solar System other than Earth or in other planetary systems should be submitted to the Habitable Worlds program (E.4).
- Proposals focused on the formation and stability of habitable planets and the formation of complex organic molecules in space and their delivery to planetary surfaces should be submitted to the Emerging Worlds program (C.2).
- Proposals aimed at the identification and characterization of radio signals from extrasolar planets that may harbor intelligent life are not solicited at this time.

2.11 Antarctica

- The Exobiology Program is no longer accepting proposals for work in Antarctica.

C.14 Planetary Science and Technology Through Analog Research

3.2 Restriction on Funding for Mission-Related Activities

- Unless otherwise specified in the program element, proposals containing work for a mission team member, or for a worker who will directly collaborate with a mission team, **may not request funding that is intended to help the mission meet its science requirements or achieve mission success.** These proposals may also not request funding for work that is close in scope to a mission's funded activities.
- This restriction applies regardless of the mission team-member's or collaborator's role on the proposal (e.g., PI, Co-I, collaborator, postdoc, student) or role on the mission. It applies when the mission is in phases A through F, unless otherwise specified in the program element.
- If a proposal includes workers on, or collaborating with, a mission team and contains work that is relevant to that mission, it must demonstrate how the tasks to be funded by the proposal do not violate this restriction. This demonstration should be included in the proposal's Budget Justification section and does not count against the page limit of the Scientific/Technical/Management section.

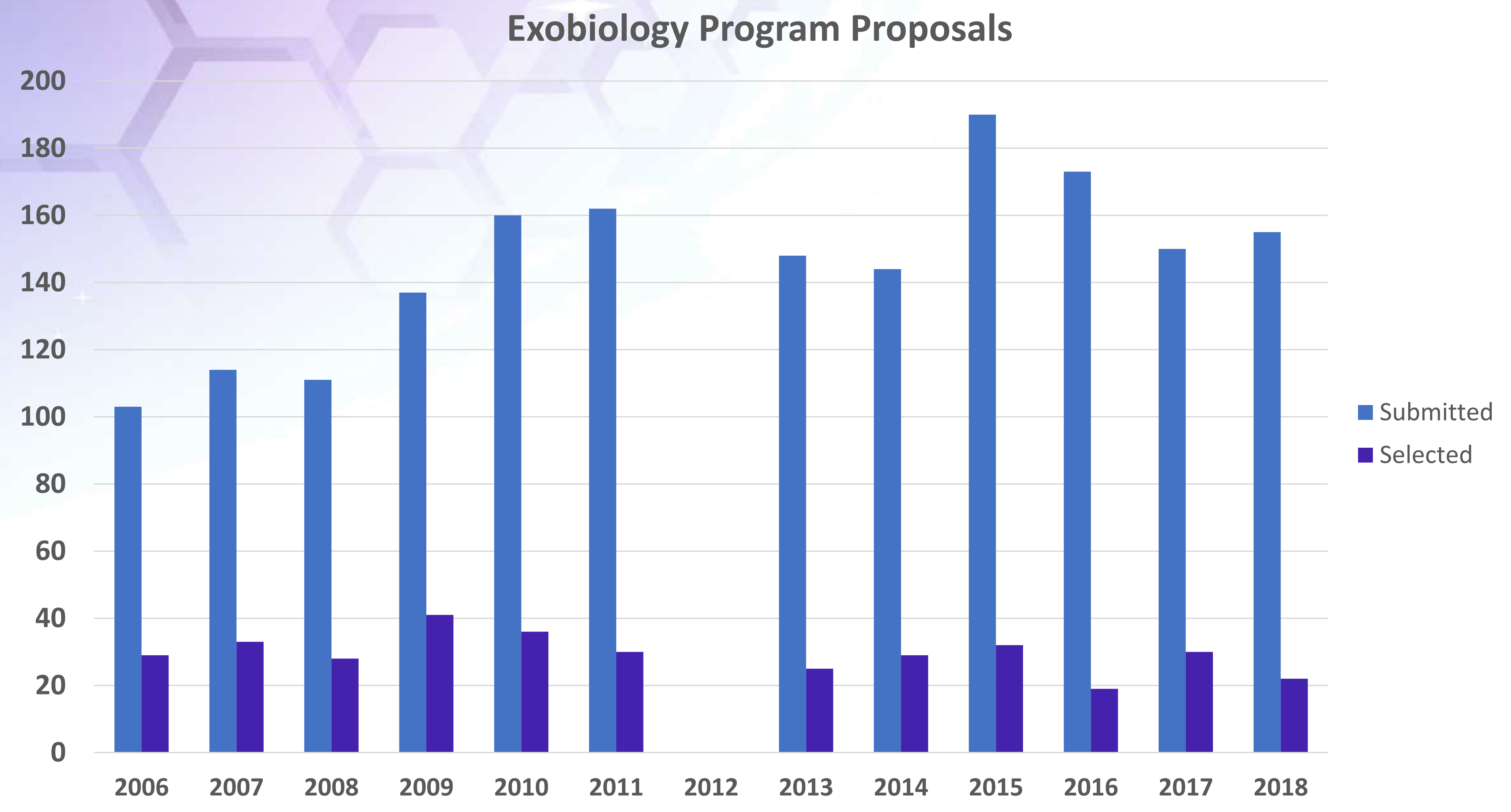
E.4 Habitable Worlds

- NASA's Habitable Worlds Program includes elements of the Astrobiology Program, the Mars Exploration Program, the Outer Planets Program (all in the Planetary Science Division), Exoplanet research in the **Astrophysics Division**, and Living With a Star in the **Heliophysics Division**.

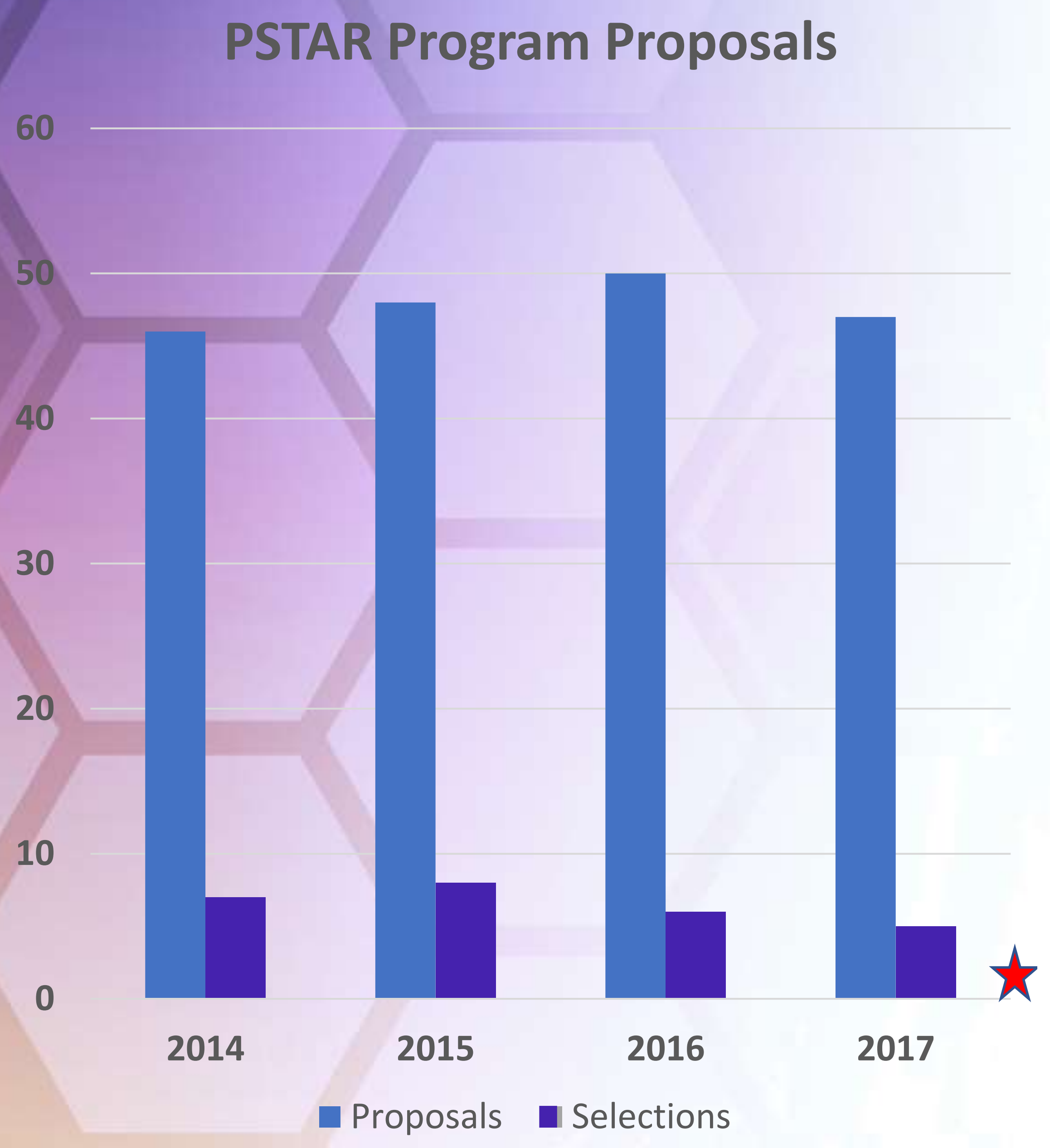
• Mars - the astrobiological potential of past or present environments on or in the Martian surface or subsurface.
• Icy Worlds - the astrobiological potential of icy worlds in the outer solar system, including Europa, Ganymede, Enceladus, and Titan.
• Habitable Exoplanets and/or their moons - A potentially habitable exoplanet implies a planet with conditions roughly comparable to those of Earth (i.e., an Earth analog) and thus potentially favorable to the presence of life.

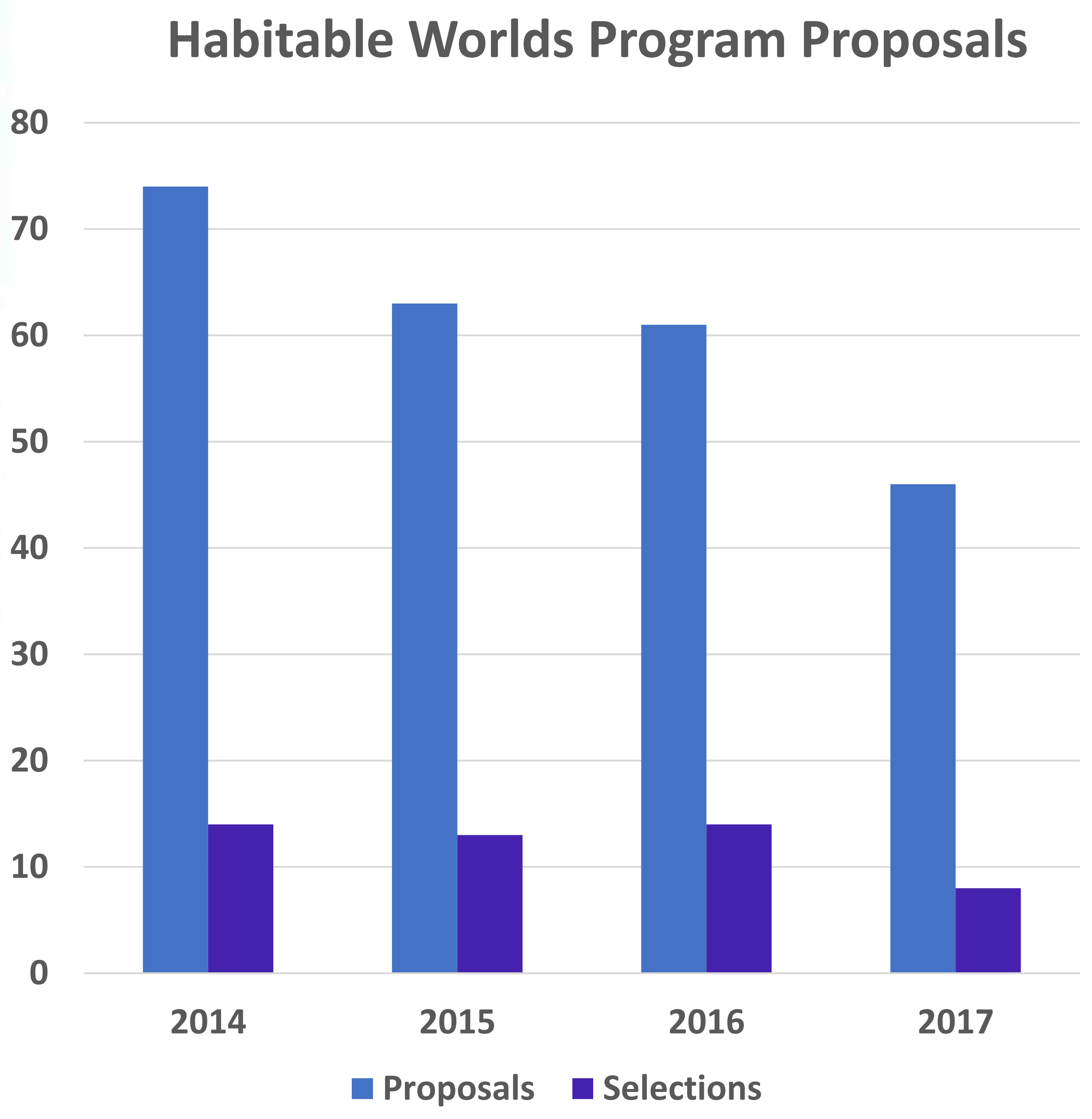
2.6 Nexus of Exoplanet System Science

Although Habitable Worlds solicits proposals aimed at habitability of any planet, including those within the solar system, PIs of proposals selected for funding from this program element that cover a research topic related to the habitability of, or search for life on, exoplanets specifically **can elect** to be part of the Nexus of Exoplanet System Science (NExSS). **Relevance to NExSS is not an evaluation criterion** for proposals to this program element. Eligibility for participation in **NExSS does not indicate that additional funding** will be provided; NExSS is a research coordination network that brings together scientists from many disciplines that study planets beyond our Solar System. For more information see https://nexss.info/.



Exobiology Program Proposals
200
180
160
140
120
100
80
60
40
20
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Submitted
Selected


PSTAR Program Proposals
60
50
40
30
20
10
0
2014
2015
2016
2017
Proposals
Selections

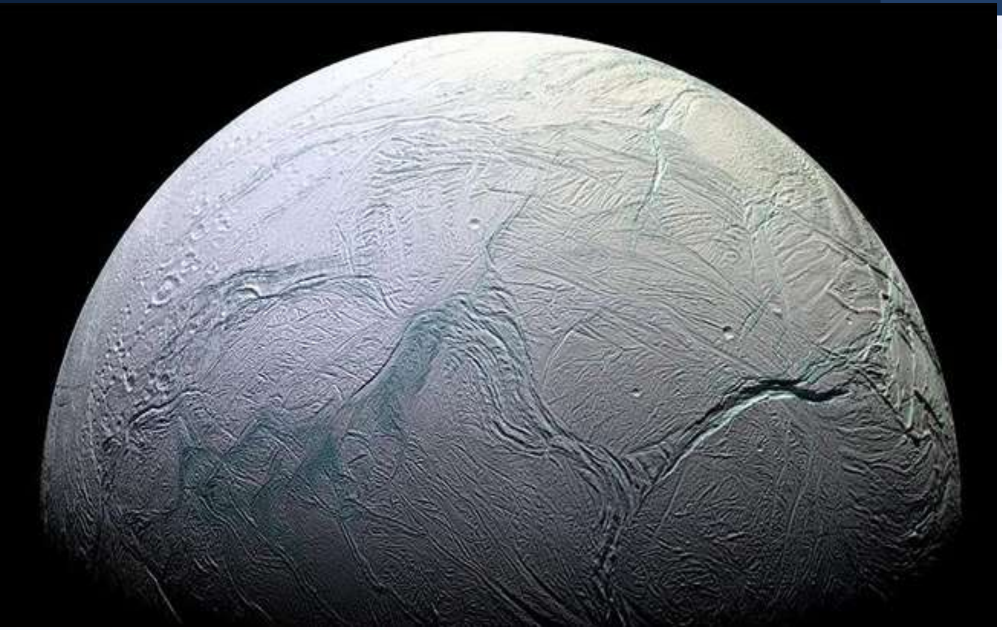

Habitable Worlds Program Proposals
80
70
60
50
40
30
20
10
0
2014
2015
2016
2017
Proposals
Selections

Planetary Science Analog Research team assists observation of Hawai'i Eruptions

NASA-funded analog research groups studying volcanic terrains are assisting the USGS and Department of the Interior in observations of the current eruption in Hawai'i. The BASALT (Biologic Analog Science Associated with Lava Terrains) research program investigates terrestrial volcanic terrains and their habitability as analog environments for Mars, under simulated mission constraints to evaluate concepts of operations (ConOps) and capabilities for the joint human and robotic exploration of Mars and the Moon.

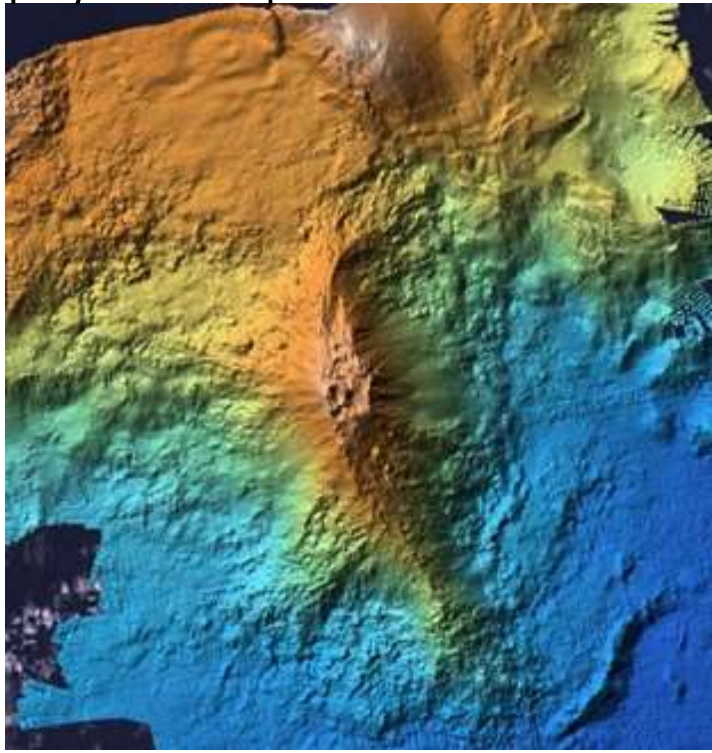
A communications network system for streaming data from the field to remote stations was developed. Hardware integration knowledge from these deployments allowed the BASALT team to implement a solution for the USGS to see live streaming data from aerial video monitoring equipment (above).

Testing Telepresence for Ocean Worlds



As part of a NASA/NOAA partnership, scientists are gaining experience with "telepresence" and exploring ocean floor hydrothermal systems that may be similar to environments on ocean worlds in our Solar System.

- SUBSEA (Systematic Underwater Biogeochemical Science and Exploration Analog) scientists aboard the Exploration Vehicle Nautilus have deployed two remotely operated vehicles, Hercules and Argus, to the Lō`ihi seamount, an underwater volcano 22 miles southeast of the Big Island of Hawaii, and treat them as if they were deployed on as part of a mission to explore other worlds.



- The Lō`ihi seamount (right) contains an extensive network of hydrothermal vents, where hot, mineral-rich water comes out of the seafloor. Such locations are rich in biodiversity, ranging from clouds of bacteria to giant clams and tubeworms.
- The inspiration for SUBSEA comes in large part from the findings of Cassini, which orbited Saturn from 2004 to 2017, particularly after analyzing jets of water erupting from Enceladus's south pole, confirmed the suspected presence of hydrothermal water rock interactions and revealed that Enceladus's ocean contains organic compounds.
- Testing operations of remotely controlled robots, where there may be time-lags or other problems is the first step in understanding how humans explorers and robots may work together in future exploration of the solar system.

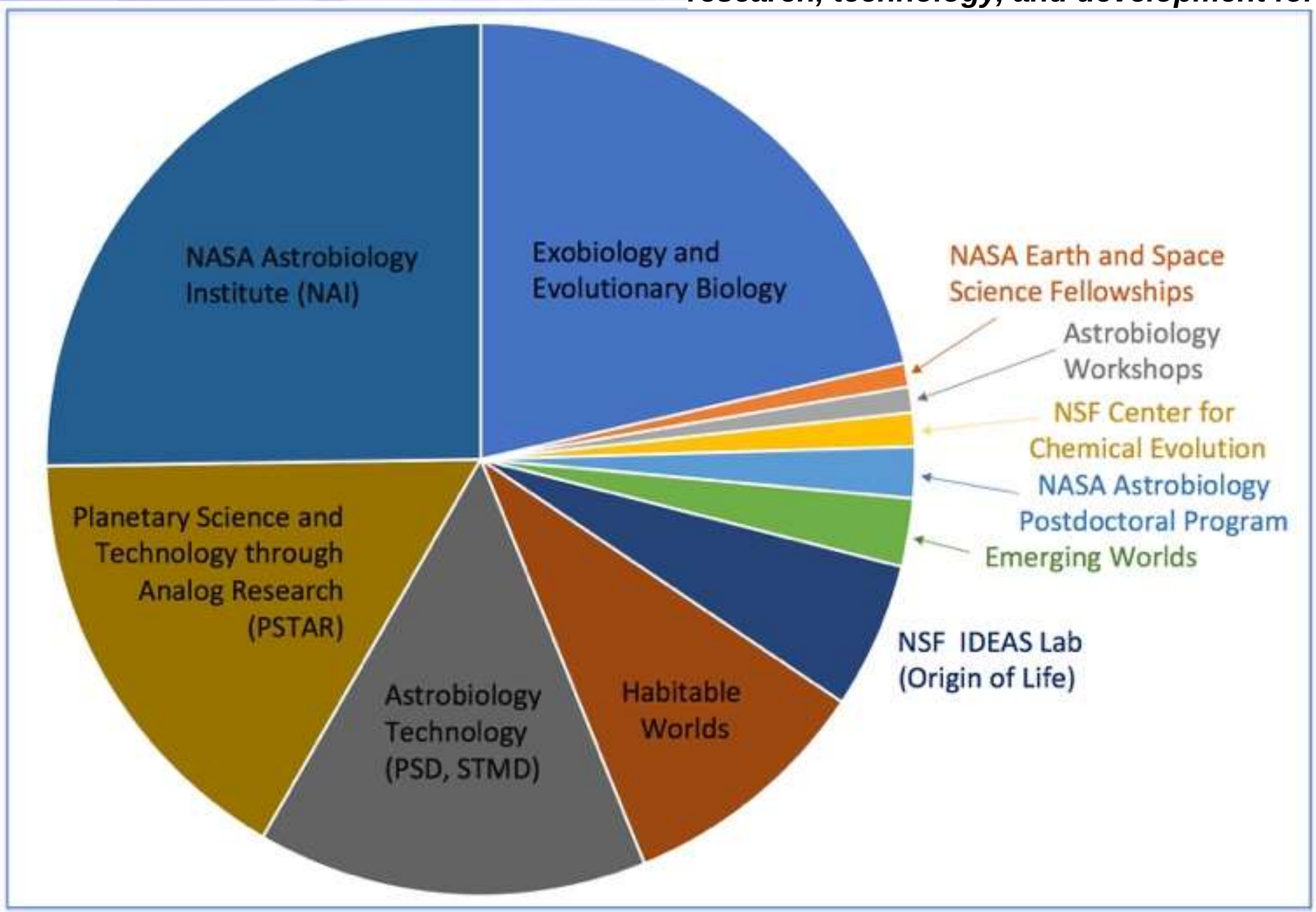
New NAI Teams

PI: Falkowski
Rutgers University
ENIGMA: Evolution of Nanomachines In Geospheres and Microbial Ancestors. The results of the ENIGMA research program will help answer a central question in astrobiology: ***How did proteins evolve to become the catalysts of life on Earth?***

PI: Freeman
Penn State Univ
The Astrobiology Center for Isotopologue Research (ACIR) brings together an international team of top scientists and their cutting-edge observational and computational tools in order to find out: ***to what degree do the abundance and positions of isotopes within molecules explicitly reveal the origins and history of organic compounds?***

PI: Lopes
Jet Propulsion Lab
Habitability of Hydrocarbon Worlds: Titan and Beyond. The goal is to address a key question in astrobiology of the solar system: ***What habitable environments exist on Titan and what resulting potential biosignatures should we look for***

Typical annual allocations of astrobiology funds support basic research, technology, and development for off-world exploration.




NFoLD
Network FOr Life Detection

How can we leverage interdisciplinary thinking to build robust life detection strategies and instrumentation?

- NASA has been at the forefront of life detection efforts since the Viking missions.
- Life detection has been a fundamental part of the NASA Astrobiology program since its inception.
- The challenges of the life detection problem are reflected in both the successes and failures of major NASA-funded efforts, including the Viking missions, the ALH84001 Martian meteor, and the putative identification of arsenic-based life in Mono Lake.
- Life detection is a challenging mission that requires multidisciplinary thinking and expertise; this problem is ideal for a *Research Coordination Network (RCN)*.
- NfoLD builds on the success of the NExSS RCN and is aimed at encouraging and sustaining interdisciplinary, cross-cutting research in life detection.

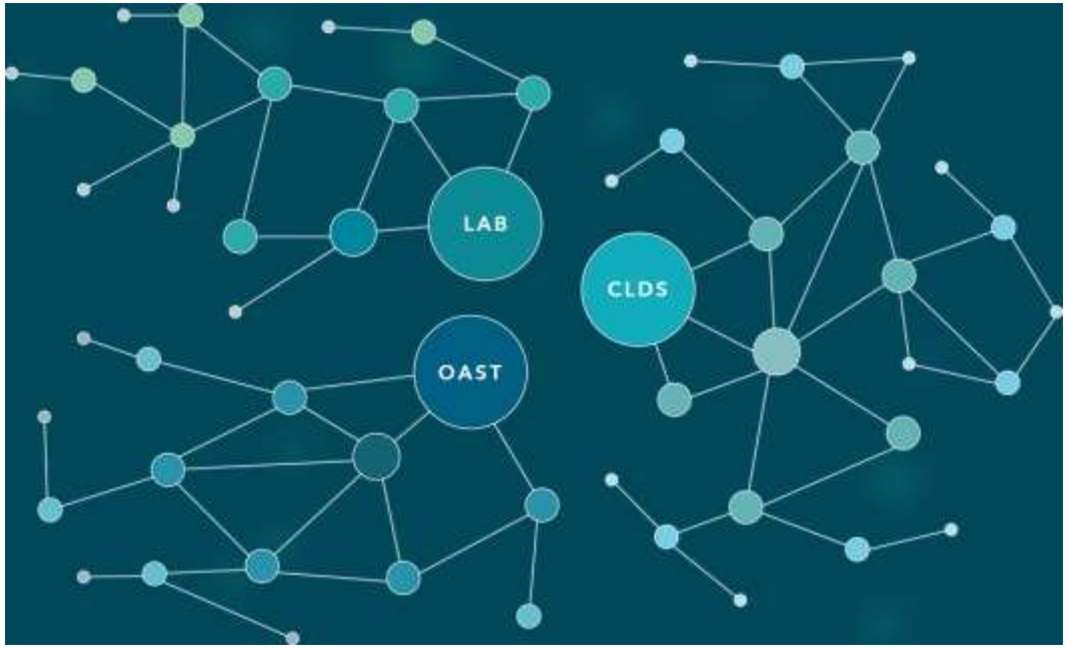
Objectives of NfoLD

- Collaborate to investigate life detection strategies, including **biosignature creation and preservation**
- Facilitate work between scientists and engineers to **develop technologies and tools** to look for extraterrestial life
- Actively and inclusively engage the scientific community to foster collaboration on projects
- Cultivate interdisciplinary and multi-organizational initiatives
- **Organize a reference sample set**
- Coordinate **community engagement with the ladder of life detection**, including incorporating the ideas of agnostic biosignatures and combining different features of assessment and confidence work with missions during the design phase to incorporate realistic life detection goals and objectives
- Promote **cross-cutting train**ing and educational activities

Initial effort

- NfoLD will gather investigators of multiple backgrounds and perspectives, beginning with core teams based at NASA Ames Research Center (CLDS), Georgetown University (LAB), and the Georgia Institute of Technology (OAST).

- The consortium is expanding to include new partners among NASA-funded research groups, thereby extending its expertise and capabilities.



NfoID team members by discipline

	Habitability	Microbiology/Geobiology	Early Evolution	Genomic/ Bioinformatics	Microbial Physiology	Biochemistry	Prebiotic Chemistry	Organic Geochemistry	Isotopic Chemistry	Biogeochemistry	Environmental Chemistry /Mineralogy	Thermodynamics	Geology	Sedimentology	Morphology	Geophysics	Polar Studies	Oceanography	Planetary Science	Instrument Developers	Technology	Complex Systems Theory/ Machine Learning	Modeling	Minimal Life Theory
Exoplanet	3	1	1	1	1	1	1	2	1	2	1	2	1	0	2	0	1	1	1	2	1	0	1	0
Mars	3	3	0	2	3	1	2	6	2	3	4	2	3	1	2	0	2	1	4	4	1	1	2	1
Earth	6	4	1	2	3	2	3	9	2	6	7	3	4	3	2	2	6	2	4	3	4	1	3	1
Icy/Ocean Worlds	5	3	0	2	2	2	2	12	2	4	5	2	2	1	1	2	6	2	4	9	5	1	3	1
Mission Participant	2	1	0	0	0	0	0	4	1	0	2	1	3	0	0	1	1	2	2	4	2	0	0	0

NfoLD Measures of Success

- Investigators carry out and propose interdisciplinary research through new collaborations
- Identify new targeted technologies needed not yet reported elsewhere
- Influence Decadal Surveys for both Planetary Science and Astronomy and Astrophysics
- Enhance international engagement
- Improve diversity of the life detection community, particularly among early career scientists

Participation by Centers

- There would be two ways center personnel would be included
  - The new internal scientist funding model
    - We have already added 2
    - SEEC from GSFC joined NExSS
    - CLDS at Ames was the seed for the Center For Life Detection
  - Successful recipients from the relevant ROSES calls from all 4 divisions.

NASA FDL

ASTROBIOLOGY

Google Cloud

What is the Frontier Development Lab (FDL)?

FDL is an applied artificial intelligence research accelerator established to maximize new **AI technologies** and capacities emerging in academia and the private sector and apply them to **challenges in the space sciences**.

Commercial, international and academic partners, such as Nvidia, Intel, IBM and Lockheed Martin, ESA, SpaceResources Luxembourg, USC MASCLE, Kx and Miso Technologies providee capital, expertise and vast GPU compute resources necessary for rapid experimentation and iteration in data intensive areas.

FDL is an eight week activity hosted by the SETI Institute in Mountain View, California

ASTROBIOLOGY CHALLENGE 1:

UNDERSTANDING WHAT IS UNIVERSALLY POSSIBLE FOR LIFE

- Can we anticipate exotic metabolic pathways using unsupervised (non-human bias) Machine Learning approaches with a view to determining the chemistry of a biosphere - and ultimately ecological signatures that may suggest life, but 'not as we know it'?

ASTROBIOLOGY CHALLENGE 2:

FROM BIOHINTS TO CONFIRMED EVIDENCE OF LIFE ON EXOPLANETS WITHIN GIVEN ENVIRONMENTAL SUBSTRATES

- Extraterrestrial environments may have coevolved a broad range of alternative life processes markedly different to those we observe on Earth. Can we deploy AI techniques to generate an extended parameter space for possible metabolisms based on given (observed) environmental conditions and substrates? AKA "biohints"

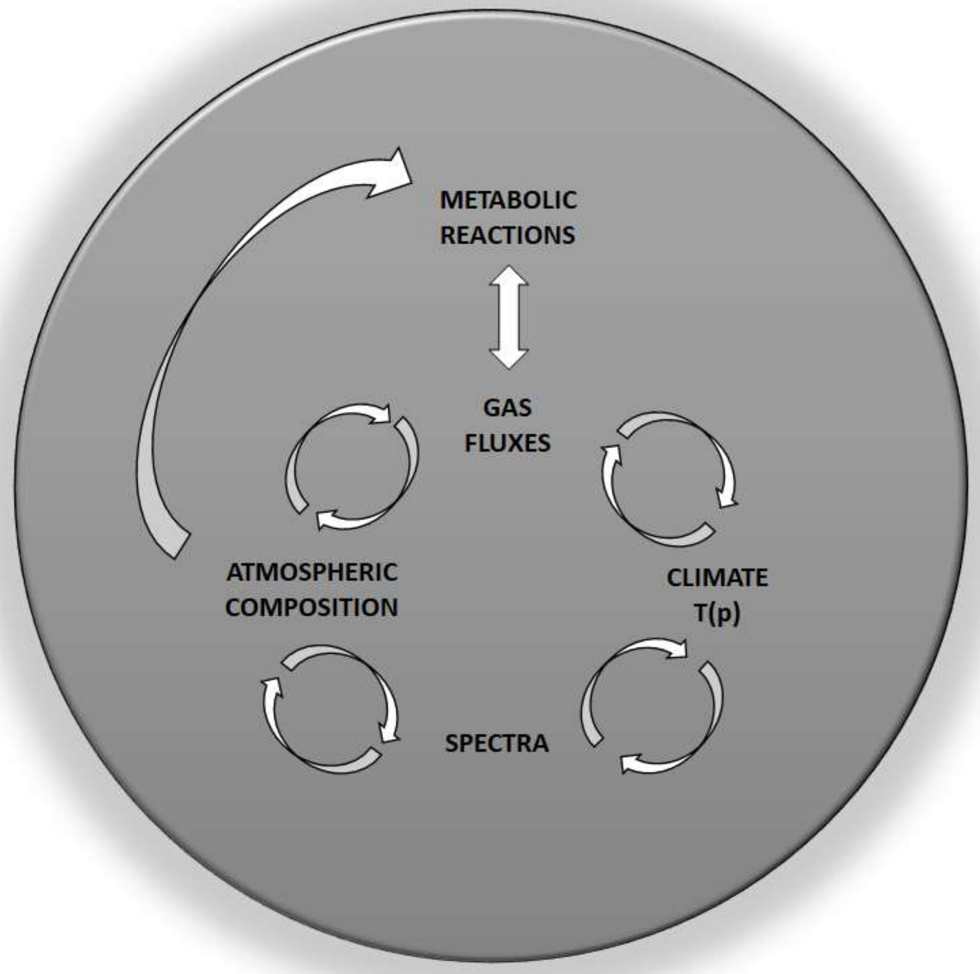
NASA Frontier Development Lab Final Technical Presentation

Team: **Astrobiology Team 2**

Authors: Himes, Michael, University of Central Florida, O'Beirne, Molly, University of Pittsburgh, Soboczenski, Frank, King's College London, Zorzan, Simone, Luxembourg Institute of Science and Technology, Baydin, Atılım Güneş, University of Oxford, Cobb, Adam, University of Oxford, Arney, Giada, NASA Astrobiology Institute & NASA Goddard Space Flight Center, Domagal-Goldman, Shawn, NASA Astrobiology Institute & NASA Goddard Space Flight Center, Angerhausen, Daniel, Universität Bern

Introduction

- Planetary spectra are a product of the pressure-temperature profile and atmospheric composition
- Atmospheric composition is influenced by geological and biological processes
- Biological activity may be able to be determined based on the inferred atmospheric composition
- If biology is present, we can potentially determine the metabolisms occurring on the planet



Abstract

Characterization of exoplanet atmospheres is done via inverse modeling techniques (“retrievals”). These involve computationally-expensive and time-consuming algorithms, usually in a Bayesian framework, that produce many forward models of varying atmospheric structure and composition, compare the spectra in the bandpasses corresponding to observations, and find a best-fit model with associated uncertainties in each model parameter.

Accurate constraints on parameters require spectroscopic observations spanning a broad wavelength range. Presently, such techniques can be reasonably applied to only a small subset of the total number of observed exoplanets due to limited observations. Currently, two ML retrieval algorithms, HELA and ExoGAN, exist, but they are limited in scope as they only apply to hot Jupiters with less than a handful of molecular species.

To date, characterization of rocky/terrestrial exoplanetary atmospheres has not been possible due to the sensitivity limits of existing telescopes. This class of exoplanets is particularly intriguing as it offers the best opportunity to remotely detect life via biosignatures, e.g. combinations of molecules indicative of life.

The detection of such biosignatures are driving future telescope designs such as LUVOIR and HabEx to enable the inference of whether or not biological processes are necessary to explain the deduced atmospheric characteristics.

The first ML retrieval algorithm for rocky/terrestrial exoplanets using a convolutional neural network trained on 100,000 synthetic planets covering a range of 28 stellar and planetary parameters.

Data Description

- Generated **3 million** synthetic planetary spectra using Planetary Spectrum Generator (PSG) and Google Cloud compute resources
- Spectra cover large range of 28 stellar and planetary parameters
  - F, G, K, M stars
  - Distance to system
  - Planetary radius, mass, surface pressure
  - T(p) profile
  - 12 molecules: H_2O, CO, CO_2, CH_4, C_2H_6, O_2, O_3, N_2, N_2O, NO_2, NH_3, SO_2

Tools, Compute, Software Environment

- **Python**
- **ML frameworks:** PyTorch**,** Tensorflow, Keras, scikit-learn
- **Planetary Spectrum Generator**
- **Docker**
- **Google Cloud** (~2000 VM instances (CPUs) and ~27 GPUs)

Results

- pypsg
  - Python interface for PSG
  - https://gitlab.com/frontierdevelopmentlab/astrobiology/pypsg
- INARA: Intelligent exoplaNet Atmospheric RetrievAl
  - Spawns PSG instances, generates data, trains ML models
  - https://gitlab.com/frontierdevelopmentlab/astrobiology/inara
- Dataset of generated planets
  - 3+ million planetary models
  - Will be hosted somewhere? Link will be available at the INARA repo


The National Academies of SCIENCES ENGINEERING MEDICINE
Exoplanet Science Strategy
Download the report at nap.edu/25187
#ExoplanetScience
Questions?: exoplanets@nas.edu

Goal 1 is to understand the formation and evolution of planetary systems as products of the process of star formation, and characterize and explain the diversity of planetary system architectures, planetary compositions, and planetary environments produced by these processes. This leads to three scientific findings that will guide an implementation strategy:

> **Finding:** Current knowledge of the demographics and characteristics of planets and their systems is substantially incomplete. Advancing an understanding of the formation and evolution of planets requires two surveys: First, it requires a survey for planets where the census is most incomplete, which includes the parameter space occupied by most planets of the Solar System. Second, it requires the characterization of the atmospheres and bulk compositions of planets spanning a broad range of masses and orbits.

> **Finding:** An understanding of planet formation requires a census of protoplanetary disks, young planets, and mature planetary systems across a wide range of planet-star separations.

> **Finding:** Characterizing the masses, radii, and atmospheres of a large number of exoplanets with a range of physical and orbital parameters for a diverse set of parent stars will yield fundamentally new insights into the formation and evolution of planets and the physics and chemistry of planetary environments.

Goal 2 is to learn enough about the properties of exoplanets to identify potentially habitable environments and their frequency, and connect these environments to the planetary systems in which they reside. Furthermore, scientists need to distinguish between the signatures of life and those of nonbiological processes, and search for signatures of life on worlds orbiting other stars. This goal, in turn, leads to two guiding scientific findings:

> **Finding:** The concept of the habitable zone has provided a first-order technique for identifying exoplanets that may be able to harbor life. A multiparameter holistic approach to studying exoplanet habitability, using both theory and observation, is ultimately required for target selection for biosignature searches.
>
> **Finding:** Inferring the presence of life on an exoplanet from remote sensing of a biosignature will require a comprehensive framework for assessing biosignatures. Such a framework would need to consider the context of the stellar and planetary environment, and include an understanding of false negatives, false positives, and their observational discriminants.

Recommendation: Building on the NExSS model, NASA should support a cross-divisional exoplanet research coordination network that includes additional membership opportunities via dedicated proposal calls for interdisciplinary research. (Chapter 4)

This workshop has four main goals:

Define the current state of the technosignature field. What experiments have occurred? What is the state-of-the-art for technosignature detection? What limits do we currently have on technosignatures?

Understand the advances coming near-term in the technosignature field. What assets are in place that can be applied to the search for technosignatures? What planned and funded projects will advance the state-of-the-art in future years, and what is the nature of that advancement?

Understand the future potential of the technosignature field. What new surveys, new instruments, technology development, new data-mining algorithms, new theory and modeling, etc., would be important for future advances in the field?

What role can NASA partnerships with the private sector and philanthropic organizations play in advancing our understanding of the technosignatures field?

Questions???

AbSciCon 2019

Seattle, Washington