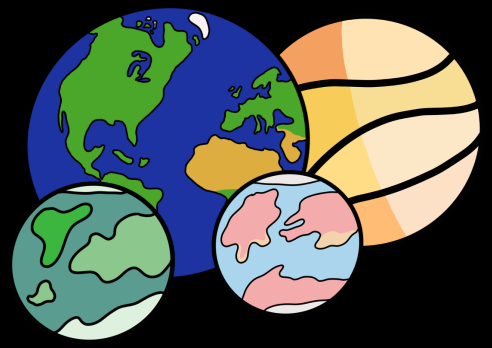
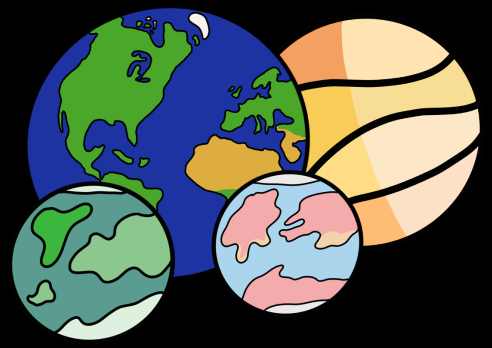


SIG 3 ExoSS Synergies

Victoria Meadows (UW/NExSS/ExoPAG), Kathy Mandt (JHU/APL/OPAG)

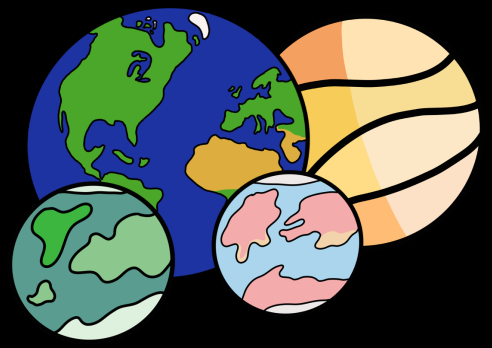
Presentation by L. Mayorga (JHU/APL)



SIG 3 ExoSS Overview

- **Chairs:**
  - Victoria Meadows (UW/NExSS/ExoPAG)
  - Kathy Mandt (JHU/APL/OPAG)
- **Founding Members:**

Giada Arney (GSFC/VExAG EC, ExoPAG)
Chuanfei Dong (Princeton)
Tony Del Genio (GISS/retired)
Shawn Domagal-Goldman (GSFC)
Noam Izenberg (JHUAPL, VExAG Deputy Chair)
Stephen Kane (UCR, VExAG, ExoPAG)
Tiffany Kataria (JPL/Caltech, ExoPAG EC)
Mark Marley (Ames)
Niki Parenteau (Ames)
Abi Rymer (JHUAPL, OPAG EC)
Karl Stapelfeldt (JPL)

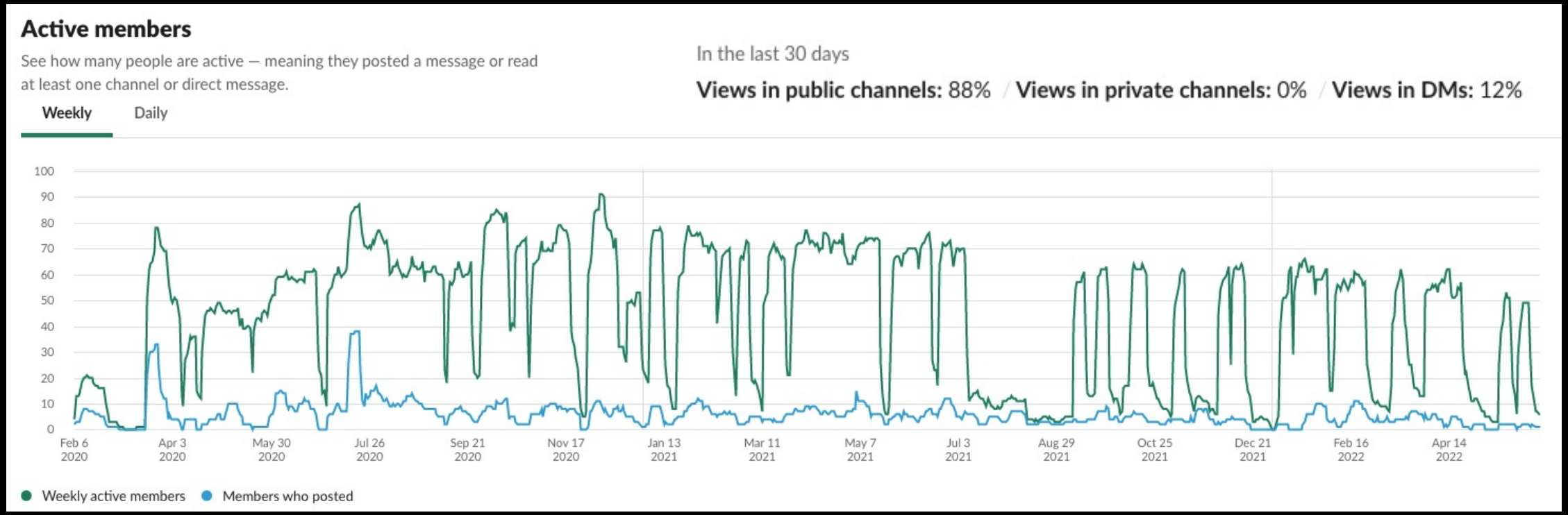


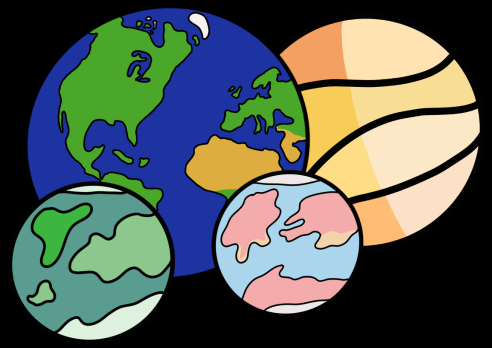
SIG 3 ExoSS Overview

- **Goal:** *To provide a forum for interaction between the Solar System and exoplanet communities on topics of mutual interest, and to work to identify ways in which NASA and the scientific community could enhance these interactions.*
- SIG3 is a mechanism to continue the community dialog started with the cross-P/AG organized Exoplanets in our Backyard Conference (Feb 5-7, 2020, Houston).
  - Findings: https://www.hou.usra.edu/meetings/exoplanets2020/EioB-Findings.pdf
- SIG3 approved on March 26, 2020. Held its inaugural meeting on July 14.
- SIG3 is now open to all interested scientific community members (please contact meadows@uw.edu or Kathleen.Mandt@jhuapl.edu to join)

SIG 3 ExoSS Activities

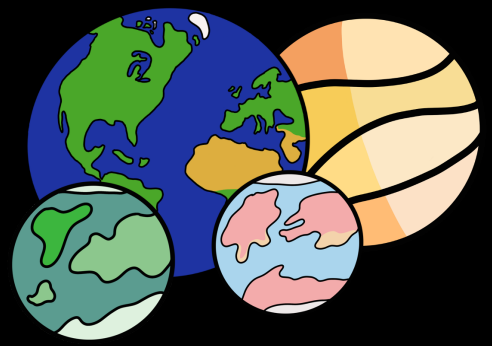
- ExoSS Slack Channel
  - news updates, paper-sharing, collaborations, all are welcome!
  - 193 members (If you would like to join: meadows@uw.edu or slack link at the end)



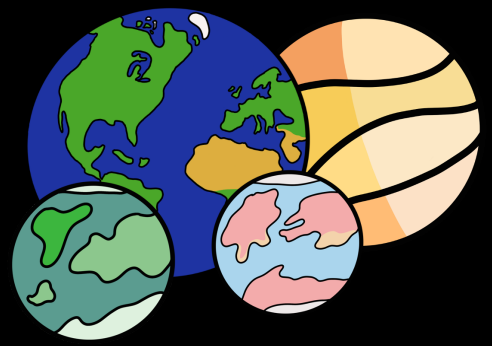


SIG 3 ExoSS Activities

- Gathering community input on key ExoSS synergies: https://tinyurl.com/yxbnyfwu
  - This document started as notes from the unconference session at EioB and is now being used as a resource for new initiatives.
- Promoted community-led Planetary Decadal activities:
  - List of lists - https://bit.ly/3fu6ang



Exoplanets in our Backyard



Exoplanets in our Backyard 1.5

- EioB 1.5 organized and held at 2020 Winter AGU.
- This session focused on lab/field/Solar System observations and what they could bring to exoplanetary science (and vice versa!)
- 40 participants

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

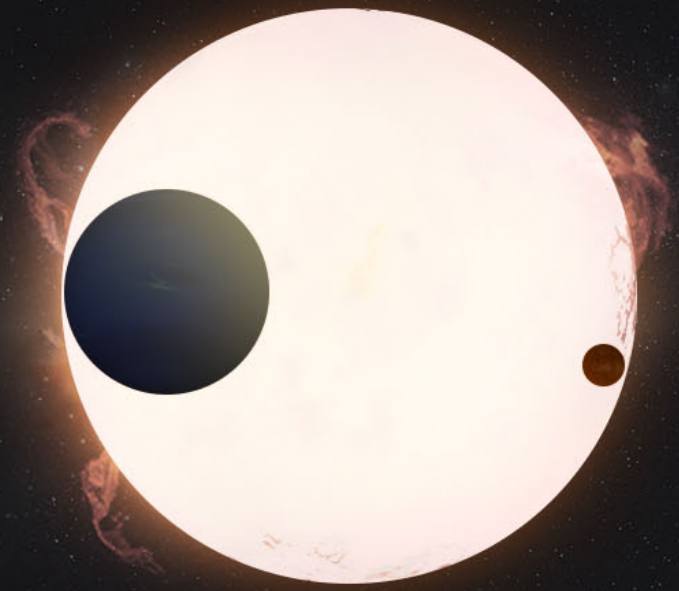
INV14 Exoplanets in Our Backyard 1.5

Exoplanets in Our Backyard (EioB) was a workshop hosted by the Venus Exploration Analysis Group (VEXAG), the Outer Planets Assessment Group (OPAG), and the Exoplanet Exploration Program Analysis Group (ExoPAG) to examine and discuss exoplanet-solar system synergies on planetary properties, formation, evolution, and habitability. The workshop aimed to foster and build new collaborations among scientists in the solar system and exoplanet communities and to help guide the direction of future exploration and observations of worlds in the solar system and beyond. The EioB workshop held February 5-7, 2020 at LPI in Houston was small (110 participant) two-and-a-half day meeting. The meeting was extremely successful and we are looking to carry forward the momentum we created. While we are planning for an "EioB II" workshop for 2022 we wanted to bring the concepts and interactions of our meeting to the even more diverse and multidisciplinary environment of AGU. "**Exoplanets In Our Backyard 1.5**" is intended to increase both reach and collaboration across communities. This half-day Innovative Session will use the successful and well-received format we used in the original workshop.

Exoplanets in Our Backyard 2

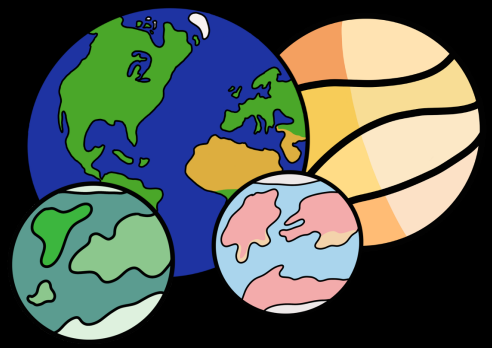
Nov 2–4
2022 Pasadena, California/Virtual

A joint Assessment Group meeting by VEXAG, OPAG, ExoPAG, MEPAG, and MExAG



Conveners: Ravi Kopparapu and Stephen Kane
Abstracts: August 19, 2022

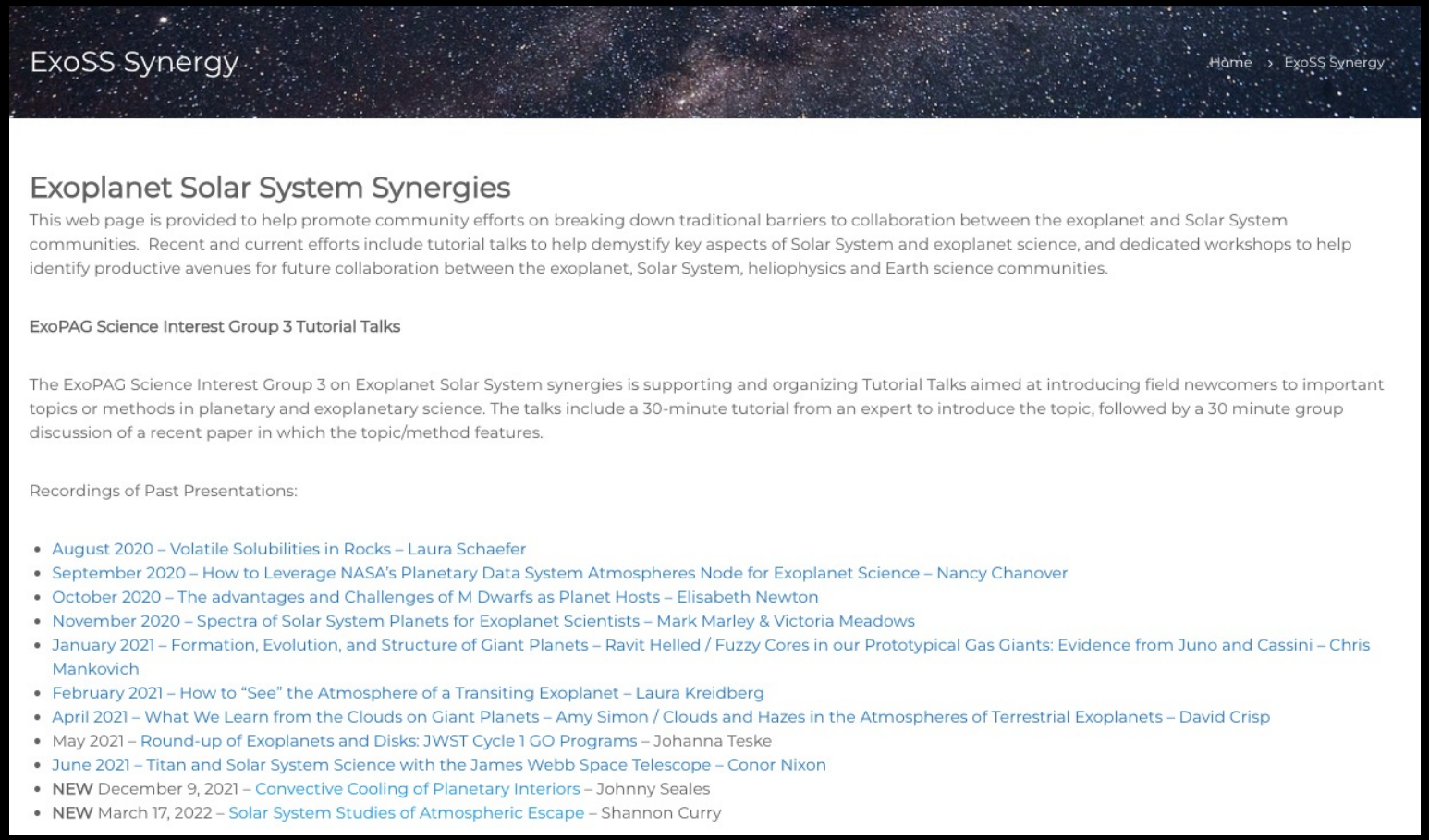
https://www.hou.usra.edu/meetings/exoplanets2022/



SIG 3 ExoSS Activities

- Input to ExoPAG Science Gap List (also input to VEXAG GOI by SIG3 members)
- Helped coordinate speakers for the ExoPAG23 ExoSS Science Symposium

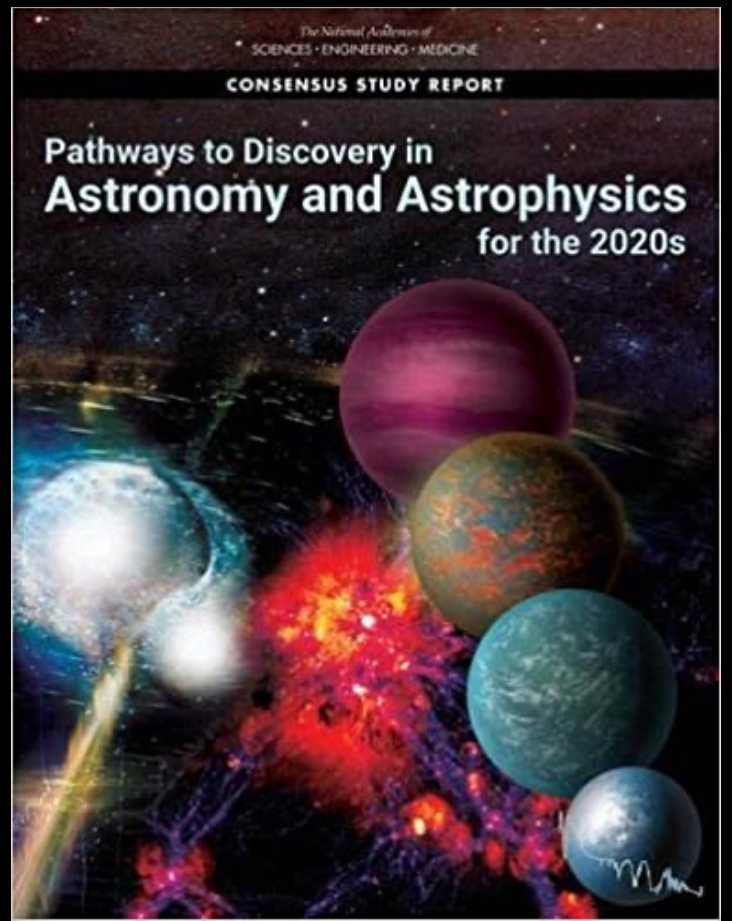
SIG3 ExoSS Tutorial Talks



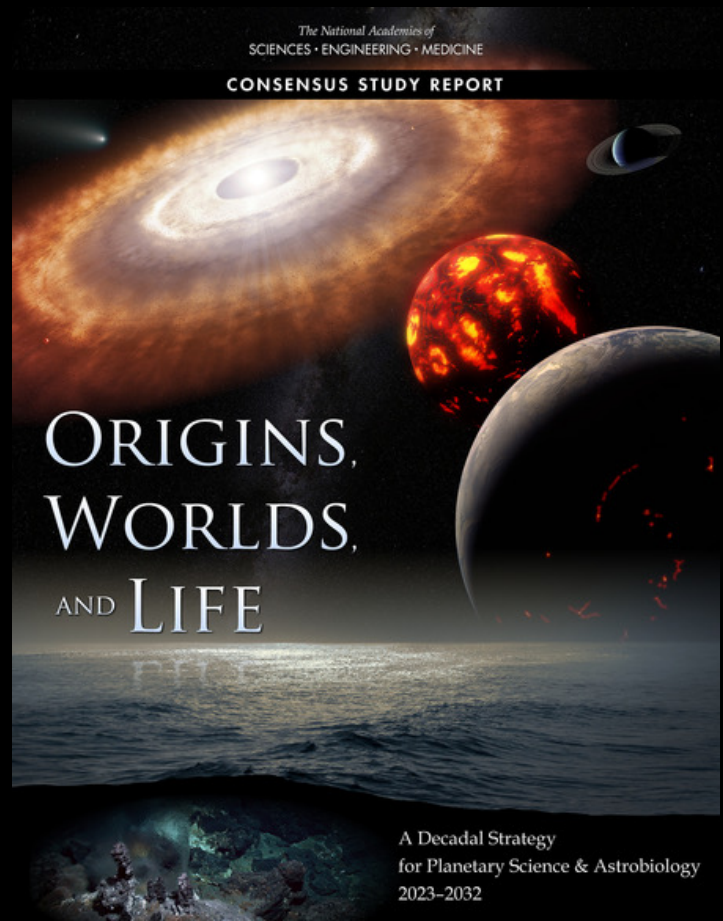
- Initiated monthly SIG3 Tutorial/Journal Club to explain key concepts within our different scientific communities
- All talks recorded and available here: https://nexss.info/exoss-synergy/
- Organized by: Laura Schaefer, Vikki Meadows, Kathy Mandt, and Mark Marley

Decadal Synergies

Astrophysics



Planetary



Exoplanet/Solar System Synergy, Decadal Edition

The National Academies of SCIENCES · ENGINEERING · MEDICINE

CONSENSUS STUDY REPORT

Pathways to Discovery in **Astronomy and Astrophysics** for the 2020s

Steering Committee "friends of exoplanets": Jonathan Fortney, Bruce MacIntosh, Keivan Stassun, Rachel Osten

Panel on Exoplanets, Astrobiology, and the Solar System

The Panel on Exoplanets, Astrobiology, and the Solar System will identify and articulate the scientific themes that will define the frontier in research of exoplanets, astrobiology, and the solar system in the 2022-2032 decade. Its scope will include the detection, demographics, and physical characteristics of exoplanets, solar system observations relevant to Astro2020, astrobiology, stellar phenomena and activity that impact detectability and characterization of exoplanets, and effects of stellar activity on the evolution and habitability of planets. The panel will consider as inputs the congressionally mandated reports *Exoplanet Science Strategy* and *An Astrobiology Strategy for the Search for Life in the Universe.*

EASS Panel Members: Victoria Meadows, David Brain, Ian Crossfield, Courtney Dressing, Jonathan Fortney, Tiffany Kataria, Kathy Mandt, Mark Marley, Britney Schmidt, Chris Stark.

And THIS panel was informed by white papers, and the 2018 Exoplanet (Charbonneau, Gaudi) and Astrobiology (Sherwood-Lollar) Strategies….

The National Academies of SCIENCES · ENGINEERING · MEDICINE

15

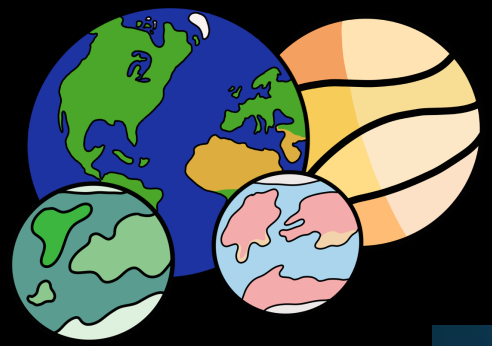
Question 12: Exoplanets

What does our planetary system and its circumplanetary systems of satellites and rings reveal about other planetary systems, and what can disks and exoplanets orbiting other stars teach us about the solar system?

You can learn more about the opportunities for comparative planetology at the Planetary Decadal Town Hall tonight at 7pm!

Strategic Research for Q12.6

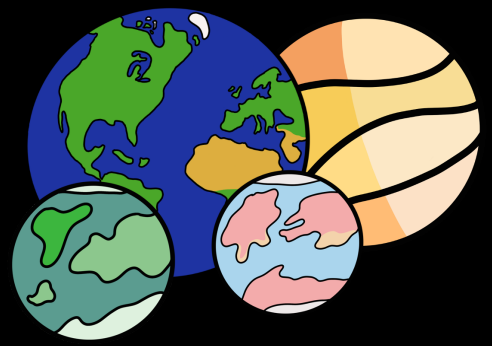
- **Characterize the atmospheres of solid-body exoplanets** by conducting transit spectroscopy, high-dispersion spectroscopy and thermal phase curve observations and compare them with atmospheres of solid bodies in the solar system.
- **Determine past atmospheric mass and composition in the solar system** by measuring and/or collecting noble gas abundance and isotopic fractionation from solid- body atmospheres within the solar system (i.e., Venus, Mars, Titan).
- **Determine the properties of the atmospheres of terrestrial planets (Earth, Venus, Mars) that would be observable on exoplanets to build a foundation for atmospheric characterization of analogue exoplanets** through coordinating in situ/remote sensing measurements and theoretical studies of wind velocities, radiative balance, cloud dynamics, and atmospheric compositing as function of orbital phase, local time, and solar conditions.
- **Determine the connection between exoplanet observables and atmospheric properties and dynamics by conducting theoretical and modeling studies to include:** simulations (1D and 3D) with hazes and clouds; radiative-microphysical feedbacks; volatile transfer between atmospheres and surfaces; and interactions with the solar wind including the influence of magnetic fields on atmospheric escape processes.
- **Determine key radiative properties, gas absorption and other quantities of interest to understand feedbacks on planetary atmospheres for the solar system and exoplanets** through targeted laboratory studies, including of atmospheres with different primary constituents (e.g., N_2, CO_2, and CH_4) and temperatures.



Highlights on the Planetary Decadal

Decadal Process

- > 500 white papers received (summer 2020)
- 153 Panel and 23 steering group meetings (fall 2020 to fall 2021)
  - > 300 presentations by external speakers in open sessions
- Key Milestones:
  - Review of white papers and Planetary Mission Concept Study reports (Fall 2020)
  - Identification of priority science questions (Fall 2020)
  - Definition of 9 additional mission concepts & new study completion (Fall 2020 – Winter 2021)
  - Prioritization of mission concepts for TRACE (Spring 2021)
  - Prioritizations and high-level recommendations (Summer – Fall 2021)
  - Draft report to Academies and external review (November – December 2021)
  - Response to 23 external reviews and final report approval (January – March 2022)



Themes	Priority Science Question Topic and Scope
A) Origins	**Q1. Evolution of the protoplanetary disk** What were the initial conditions in the Solar System? What processes led to the production of planetary building blocks, and what was the nature and evolution of these materials?
	Q2. Accretion in the outer solar system How and when did the giant planets and their satellite systems originate, and did their orbits migrate early in their history? How and when did dwarf planets and cometary bodies orbiting beyond the giant planets form, and how were they affected by the early evolution of the solar system?
	Q3. Origin of Earth and inner solar system bodies How and when did the terrestrial planets, their moons, and the asteroids accrete, and what processes determined their initial properties? To what extent were outer Solar System materials incorporated?
B) Worlds & Processes	**Q4. Impacts and dynamics** How has the population of Solar System bodies changed through time, and how has bombardment varied across the Solar System? How have collisions affected the evolution of planetary bodies?
	Q5. Solid body interiors and surfaces How do the interiors of solid bodies evolve, and how is this evolution recorded in a body's physical and chemical properties? How are solid surfaces shaped by subsurface, surface, and external processes?
	Q6. Solid body atmospheres, exospheres, magnetospheres, and climate evolution What establishes the properties and dynamics of solid body atmospheres and exospheres, and what governs material loss to space and exchange between the atmosphere and the surface and interior? Why did planetary climates evolve to their current varied states?
	Q7. Giant planet structure and evolution What processes influence the structure, evolution, and dynamics of giant planet interiors, atmospheres, and magnetospheres?
	Q8. Circumplanetary systems What processes and interactions establish the diverse properties of satellite and ring systems, and how do these systems interact with the host planet and the external environment?
C) Life & Habitability	**Q9. Insights from Terrestrial Life** What conditions and processes led to the emergence and evolution of life on Earth, what is the range of possible metabolisms in the surface, subsurface and/or atmosphere, and how can this inform our understanding of the likelihood of life elsewhere?
	Q10. Dynamic Habitability Where in the solar system do potentially habitable environments exist, what processes led to their formation, and how do planetary environments and habitable conditions co-evolve over time?
	Q11. Search for life elsewhere Is there evidence of past or present life in the solar system beyond Earth and how do we detect it?
All Themes	**Q12. Exoplanets** What does our planetary system and its circumplanetary systems of satellites and rings reveal about exoplanetary systems, and what can circumstellar disks and exoplanetary systems teach us about the solar system?

Planetary Decadal

- Long (781 pages)
- How to read table

TABLE 1.2 A Guide to Reading This Report

Topic	Primary Discussion	Additional Discussion	Recommendations
Issues Related to Nine Priority Topics Identified in the Statement of Task			
1. Overview of planetary science, astrobiology, and planetary defense	Chapter 1	n/a	n/a
2. Broad survey of the current state of knowledge	Chapter 2	n/a	n/a
3a. Compelling questions, goals and challenges for planetary science	Chapters 3 to 11	n/a	n/a
3b. Ditto astrobiology	Chapters 3 and 12-14	Chapter 22	n/a
3b. Ditto planetary defense;	Chapter 18	Chapter 22	Chapter 18 and 22
4a. Recommended research traceable to objectives and goals	Chapters 4 to 15	Chapter 22	n/a
4b. Recommended missions traceable to objectives and goals	Chapter 22	Appendix C	Chapter 22
5a. Comprehensive research strategy for planetary science, astrobiology and planetary defense	Chapter 22	n/a	Chapter 22
5b. Timing, cost, risk, and technical readiness of recommended missions	Chapter 22	Appendix C	n/a
6. Decision rules	Chapter 22	n/a	Chapter 22
7a. Human Exploration	Chapter 19	Chapter 22	Chapters 19 and 22
7b. International Cooperation	Chapter 1	n/a	n/a
8. Intra- and inter-agency collaboration	Chapters 1 and 19-21	Chapter 22	Chapters 19 and 22
9. State of the Profession	Chapter 16	Chapter 22	Chapters 16 and 22
Other Topics Discussed in the Report			
Apophis 2029 encounter	Chapter 18	n/a	n/a
Arecibo	Chapter 18	Chapter 22	Chapters 18 and 22
Artemis Program	Chapter 19	Chapter 22	Chapters 19 and 22
Budgetary projections	Chapter 22	n/a	n/a
Deep Space Network	Chapter 19	n/a	n/a
Discovery program	Chapter 22	n/a	Chapter 22
Europa Clipper	Chapter 22	n/a	n/a
Ground- and space-based telescopes	Chapter 20	Chapter 18 and Appendix E	n/a
International Mars Ice Mapper	Chapter 22	Chapter 19	Chapter 22
Launch vehicles	Chapter 20	Chapter 22	Chapter 22
Lunar Exploration and Discovery Program	Chapter 22	Chapter 19	Chapter 22
Mars Exploration Program	Chapter 22	n/a	Chapter 22
Mars Sample Return	Chapter 22	n/a	Chapter 22
Mission studies, PMCS and SDT	Appendix C	Appendix D	n/a
Mission studies, future	Chapter 23	Chapter 22	n/a
Mission studies, decadal survey	Appendix C	Appendices D and E	n/a
New Frontiers program	Chapter 22	n/a	Chapter 22
NSF facilities and programs	Chapter 20	Chapter 1	n/a
Planetary Data System	Chapter 17	n/a	Chapter 17
Planetary radar facilities	Chapter 18	Chapter 22	Chapters 18 and 22
Plutonium-238	Chapter 20	Chapter 22	Chapters 20 and 22
Research and Analysis Programs	Chapter 17	Chapter 22	Chapters 17 and 22
Sample receiving and curation facilities	Chapter 20	Chapter 22	Chapter 22
SIMPLEx program	Chapter 22	n/a	Chapter 22
Technology development	Chapter 21	Chapter 22	Chapters 21 and 22
Technical risk and cost evaluation	Appendix C	Chapter 22	n/a
White papers received	Appendix B	n/a	n/a

Highest priority new flagship: Uranus Orbiter and Probe

- In situ probe & multi-year orbital tour: atmosphere, interiors, magnetosphere, rings, and satellites
- First dedicated study of class of planets that may be most common in the universe
- Technically ready to start now
- Launch on Falcon Heavy Expendable

  → **Optimal launch in 2031-2032 with Jupiter gravity assist to shorten cruise to 12 to 13 yrs**

  - Flexible launch opportunities through 2038 with increased ~ 15 yr cruise and inner solar system gravity assists
- Strong international interest & potential for partnership (e.g., 2021 report of ESA's Voyage 2050 Senior Committee)

Science Question Chapter Format

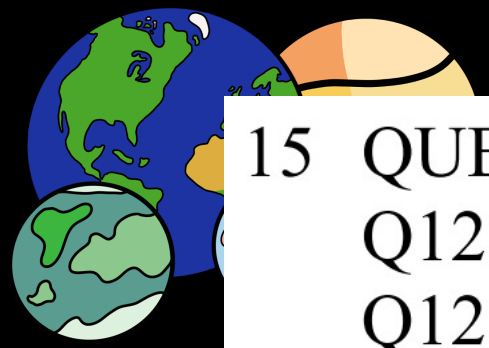
Q2: Accretion in the Outer Solar System ← Priority Science Question Topic

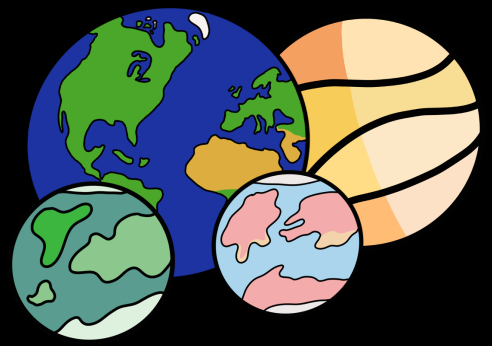
Q2.1 How did the giant planets form? ← Most important sub-questions

Q2.1a. What is the formation mechanism of gas giant planets? What were the accretion rates of solids (planetesimals/pebbles) and gas during the formation process? How long did it take?
Q2.1b. How did Uranus and Neptune form and what prevented them from becoming gas giants?
Q2.1c. What were the primordial internal structures of giant planets?
……

Strategic Research Q2.1: ← Strategic research needed to address each main sub-question

- **Determine the atmospheric composition of Saturn, Uranus, and Neptune** via in situ sampling of noble gas, elemental, and isotopic abundances, and remote sensing by spacecraft and ground/space-based telescopes.
- **Determine the bulk composition and internal structure of Uranus and Neptune** via gravity, magnetic field, and atmospheric profile measurements by spacecraft, as well as Doppler seismology.
- **Constrain physical properties and boundary conditions (i.e., tropospheric temperatures, shapes, rotation rates) for structure models of Uranus and Neptune** via gravity, magnetic field, and atmospheric profile measurements by spacecraft, remote sensing by spacecraft and ground/space-based telescopes.
- ……





Supporting Activities for Question 12

- Observations of solar system planets and moons through transit spectroscopy and direct-imaging as analogs to exoplanet observations, including hemispherically averaged fluxes as a function of orbital phase and time; observations of particle and gas opacity in the giant planets and Venus as a function of phase angle to help determine the dependence of reflectivity and scattering on particles and clouds in exoplanet atmospheres; and ultraviolet-near-infrared-scattered light observations from the poles of the giant planets for comparison with future direct imaging of giant exoplanets.
- A census of protoplanetary disks, young planets, and mature planetary systems across a wide range of planet-star separations to determine how the initial composition and conditions in a protoplanetary disk influence the diversity of resulting planets.
- Improved spatial resolution of telescopic techniques to determine variations in the structure and composition of circumstellar disks, as well as the next-generation telescopes recommended by NASEM (2021) that will allow for observations of circumplanetary disks, detection of exomoons and ring systems, and characterization of exoplanets around sun-like stars.
- Laboratory studies to understand the relationship between the bulk composition of a planet and its atmosphere, and to determine the optical properties of clouds and hazes relevant to exoplanet atmospheres.
- Increased interactions between the astronomy and planetary science and astrobiology communities (supported under, e.g., NASA's Planetary Science and Astrophysics divisions) are needed to maximize advances in exoplanetary science and to address the questions identified in this chapter. This point was emphasized in multiple white papers received by the committee.

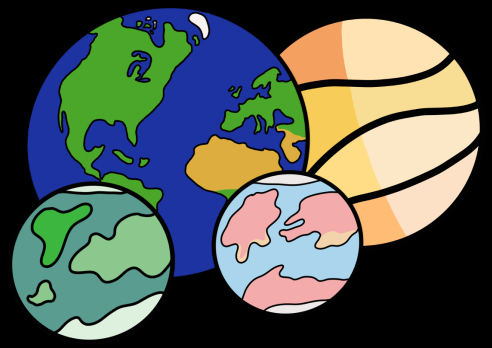
2022 Planetary Mission Senior Review (PMSR22)

Missions reviewed: InSight, LRO, Mars Odyssey, MAVEN, MRO, MSL, New Horizons, and OSIRIS-REx (APEX).

- 2022 NASA Response to the Senior Review
- 2022 Final Report Package
- 2022 Call for Proposals
- 2022 Terms of Reference

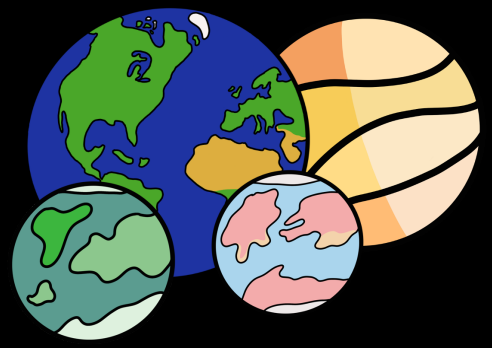
Occurred prior to the decadal release!

https://science.nasa.gov/solar-system/documents/senior-review



OSIRIS-APEX – Excellent/Very Good

- OSIRIS-APEX (APophis EXplorer) is arguably the most imaginative extended mission proposal of recent PMSRs, and the Review Chairs agree with the Panel scores. After the OREx Sample Return Capsule is released to Earth's surface in 2023, the spacecraft will divert into an orbit around the Sun with remaining potential to observe other Near-Earth Objects (NEOs).
- Earth observations may even provide an opportunity for the Exoplanet community to collect data to improve their habitable world search models, however critical details of imaging "Earth as-an-analog" requires greater engagement with the exoplanet community to confirm viability.



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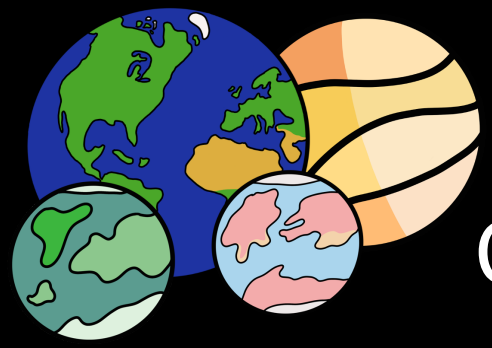


OSIRIS - APEX Observing Plan

To observe Earth as an exoplanet analog during cruise. This goal involves repeated imaging of Earth at various wavelengths and phase angles, to expand understanding of observable discriminants for habitable environments.

Science Goals:

- Measure Earth's reflectivity throughout a continuous 24-h period over phase angles between 30 and 90°.
- Repeat the measurements during multiple Earth seasons.

Instruments:

- OCAMS
- OVIRS
- OTES

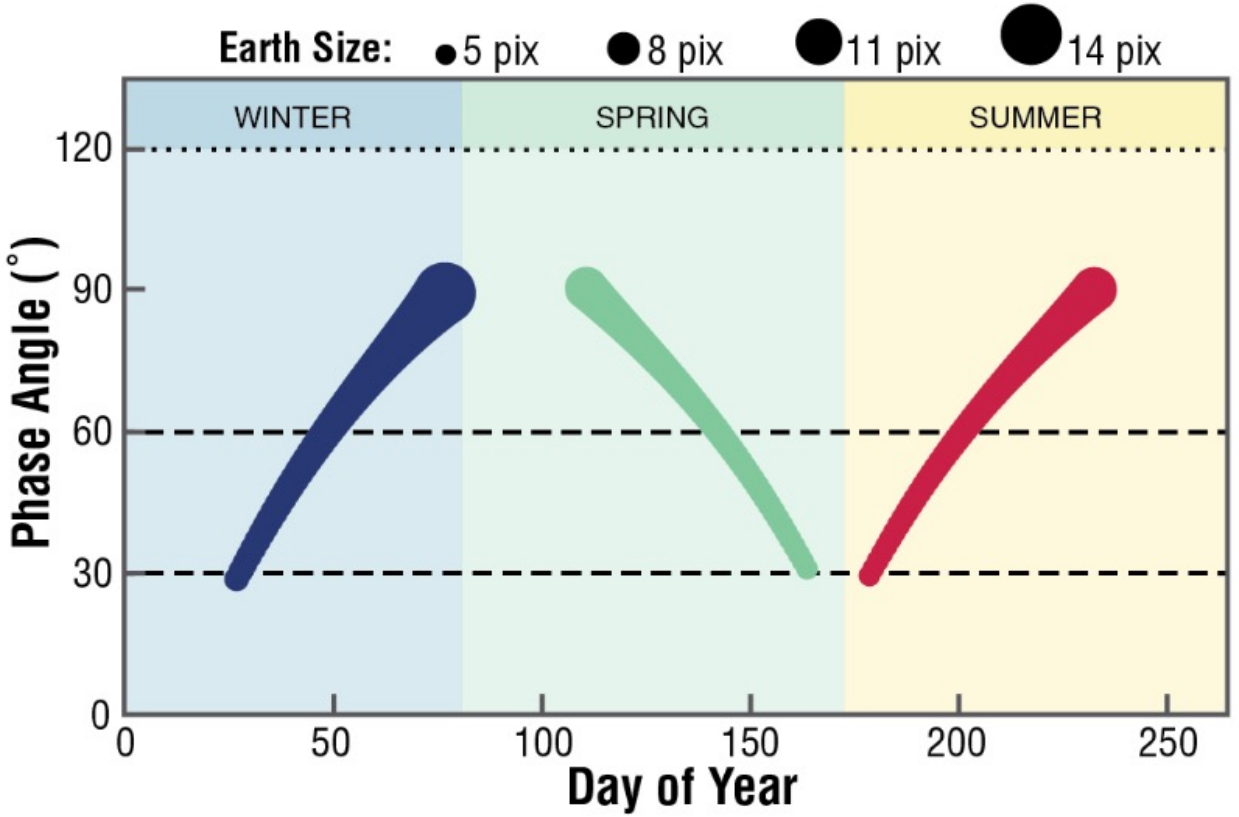
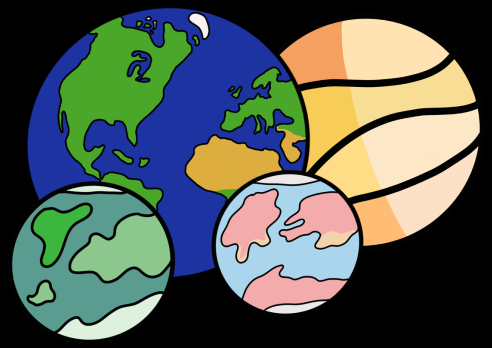


Figure D-7 *Earth phase angles observed by* ***APEX****. During the cruise to Apophis, three EGA flybys present opportunities to image Earth in reflected light as an exoplanet analog and assess Earth's rotational and seasonal variability. The points are colored-coded by EGA (2025:blue, 2027:green, and 2029:red) and sized by the apparent pixel size of Earth in MapCam images.*



How Can I Participate with SIG3?

- Get on the mailing list (email meadows@uw.edu)
- SIG3 tutorial recordings are here:
  - https://nexss.info/exoss-synergy/
- Exoplanets in our Backyard 2.0!
- Join the slack!
  - https://join.slack.com/t/exoss2/shared_invite/zt-1aa91dkp3-tlkfPRqF8K_xjRxIrGmB9A
  - (link good for 30 days)