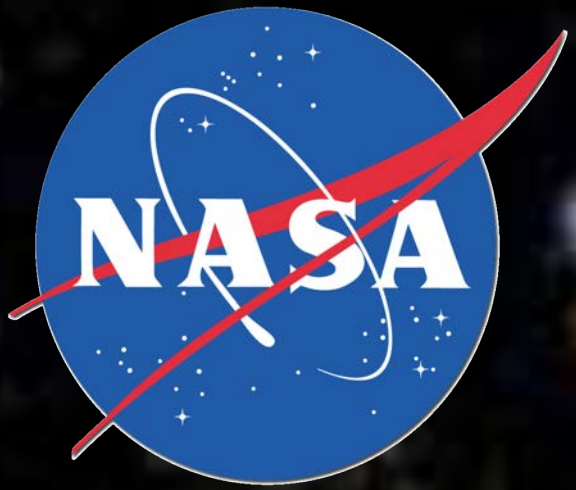


# NEXSS/NAI JOINT ExoPAG SAG 16 REPORT ON REMOTE BIOSIGNATURES FOR EXOPLANETS



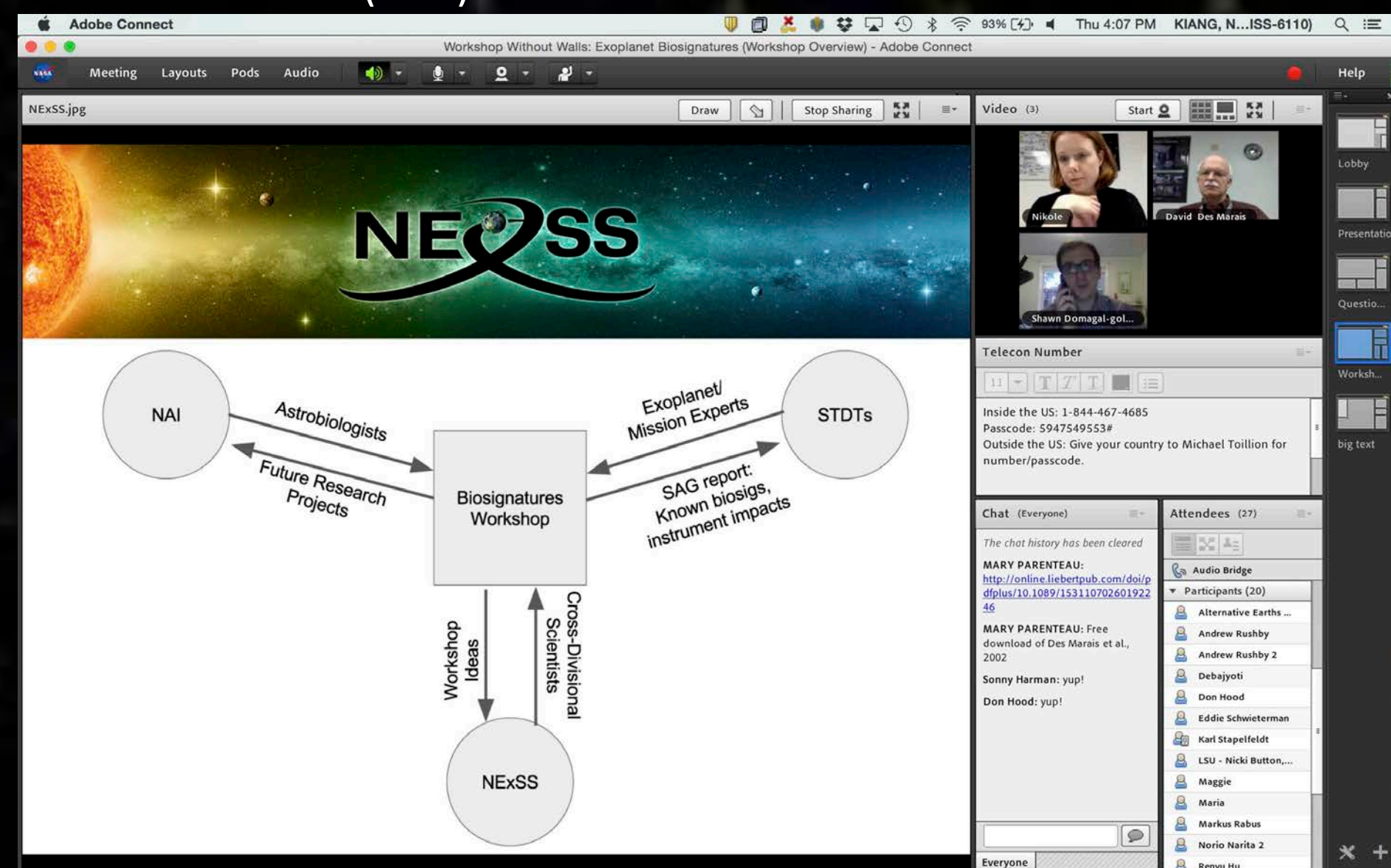
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<http://nexss.info/community/workshops/exoplanet-biosignatures-workshop>



## Exoplanet Biosignatures Workshop

The search for life beyond our Solar System motivates future exoplanet missions to observe for biosignatures with global, potentially detectable, impacts on a planet. Biosignatures occur in an environmental context in which geological, atmospheric, stellar processes and interactions, and evolutionary history may work to enhance, suppress or mimic these biosignatures. Thus biosignature science is inherently interdisciplinary. Its advance is necessary to inform the design of the next flagship missions that will obtain spectra of habitable extrasolar planets.

NASA's Nexus for Exoplanet System Science and the NASA Astrobiology Institute held a joint Exoplanet Biosignatures Workshop-Without-Walls in June-July 2016, which brought together the astrobiology, exoplanet, and mission concept communities to review, discuss, debate, and advance the science of biosignatures. A broad range of experts were engaged, merging the interdisciplinary reaches of NEXSS, the NAI, NASA's Exoplanet Exploration Program (ExEP), and international partners, such as the European Astrobiology Network Association (EANA) and Japan's Earth Life Science Institute (ELSI).



The workshop focused around three goals:

1. State of the Science Review: What are known remotely-observable biosignatures, the processes that produce them, and their known non-biological sources?
2. Advancing the Science of Biosignatures: How can we develop a more comprehensive conceptual framework for identifying additional biosignatures and their possible abiotic mimics?
3. Confidence Standards for Biosignature Observation and Interpretation: What paradigm informed by both scientists and technologists could establish confidence standards for biosignature detection?

To ensure accessibility for contribution by as many of the international community as possible, workshop activities included 6 online videoconference sessions for interactive review of the State of the Science preliminary to an in-person meeting in Seattle, WA, including remote dial-in. Participants spanned astronomy, planetary science, Earth sciences, heliophysics, biology, instrument/mission development, and engineering from around the world.

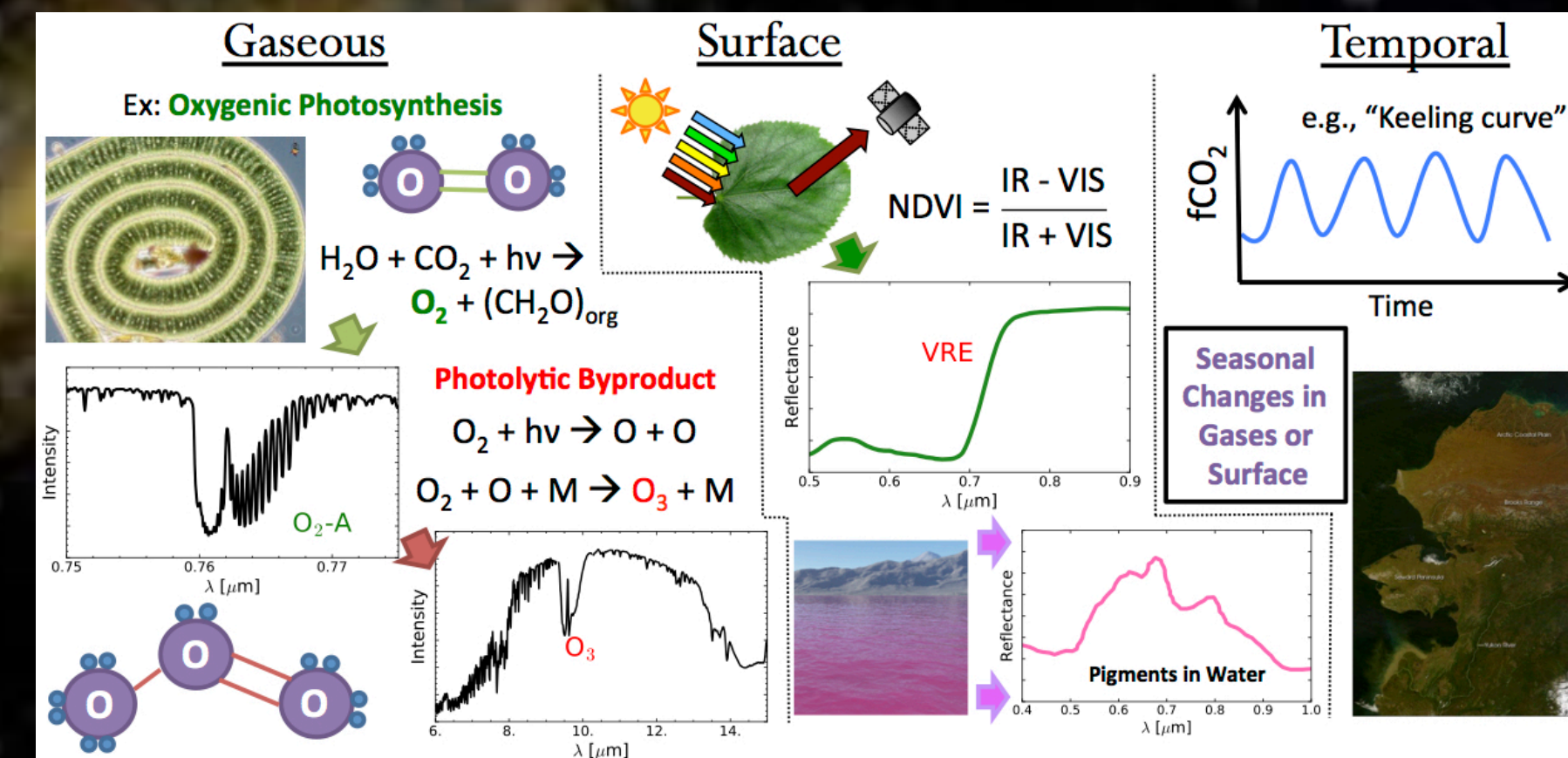
All talks and Seattle sessions may be streamed online at the workshop website above.

The workshop activities have culminated in five review papers on the science and technology of remote searches for signs of life on exoplanets. Broad participation was solicited for these papers, which will serve as an interdisciplinary, educational, state of the art reference for use across a wide community. Community comments are invited in May 2017 at: [nexss.info](http://nexss.info).

## Exoplanet Biosignatures: A Review of Remotely Detectable Signs of Life

Contact: Edward Schwieterman, edward.schwieterman@ucr.edu

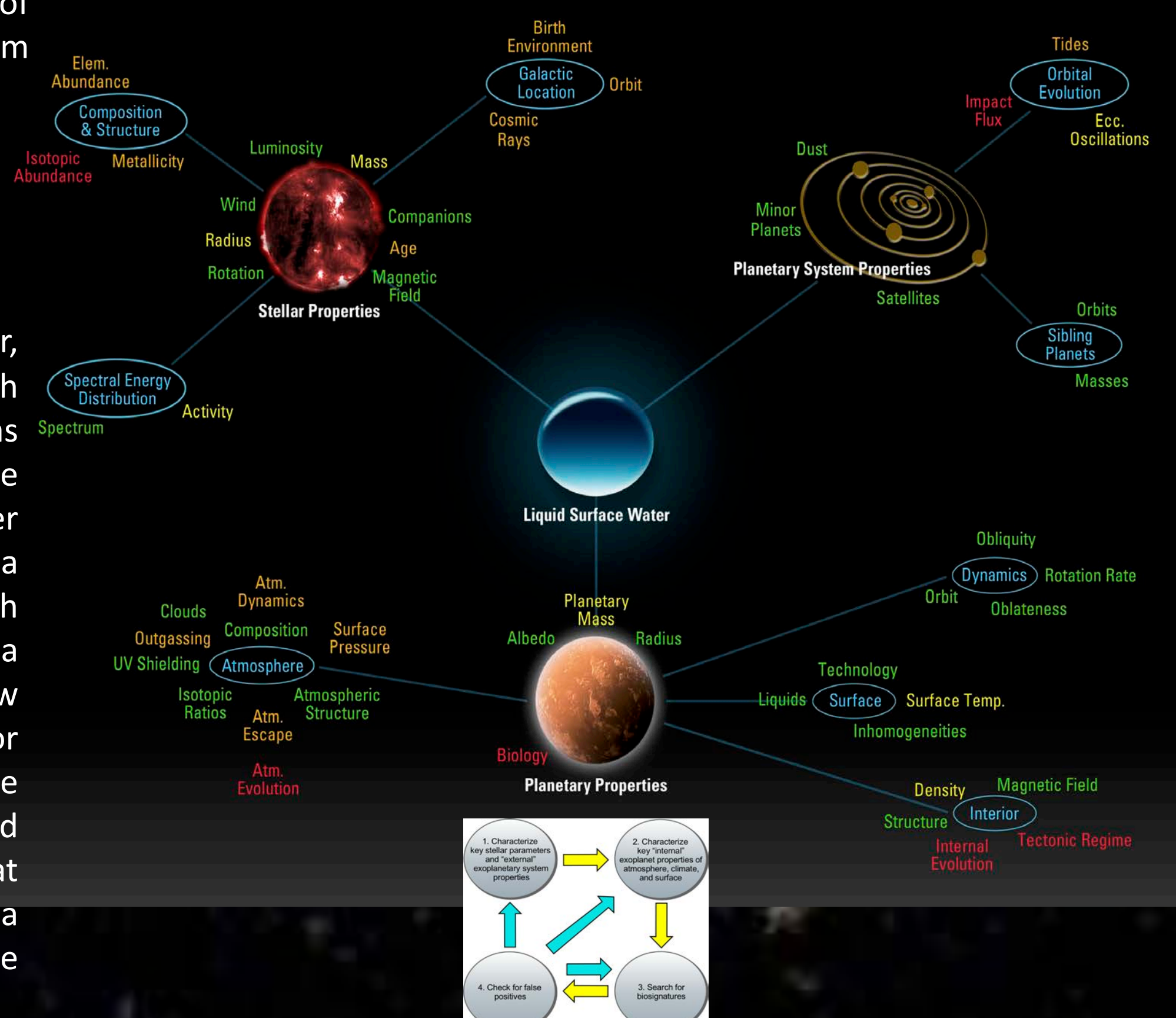
This paper provides an in-depth review of current understanding of potential exoplanet biosignatures including gaseous, surface, and temporal biosignatures. We focus particularly on advances made since the review by Des Marais et al. (2002). This paper does not propose new biosignatures strategies, but reviews currently existing literature to provide a foundation for a path forward. We survey some biogenic spectral features that are well-known in the specialist literature but not yet robustly vetted in the context of exoplanet biosignatures. We also briefly review advances in assessing biosignature plausibility, including novel methods of determining chemical disequilibrium and the minimum biomass required for a given atmospheric signature.



## Exoplanet Biosignatures: Understanding Oxygen as a Biosignature in the Context of Its Environment

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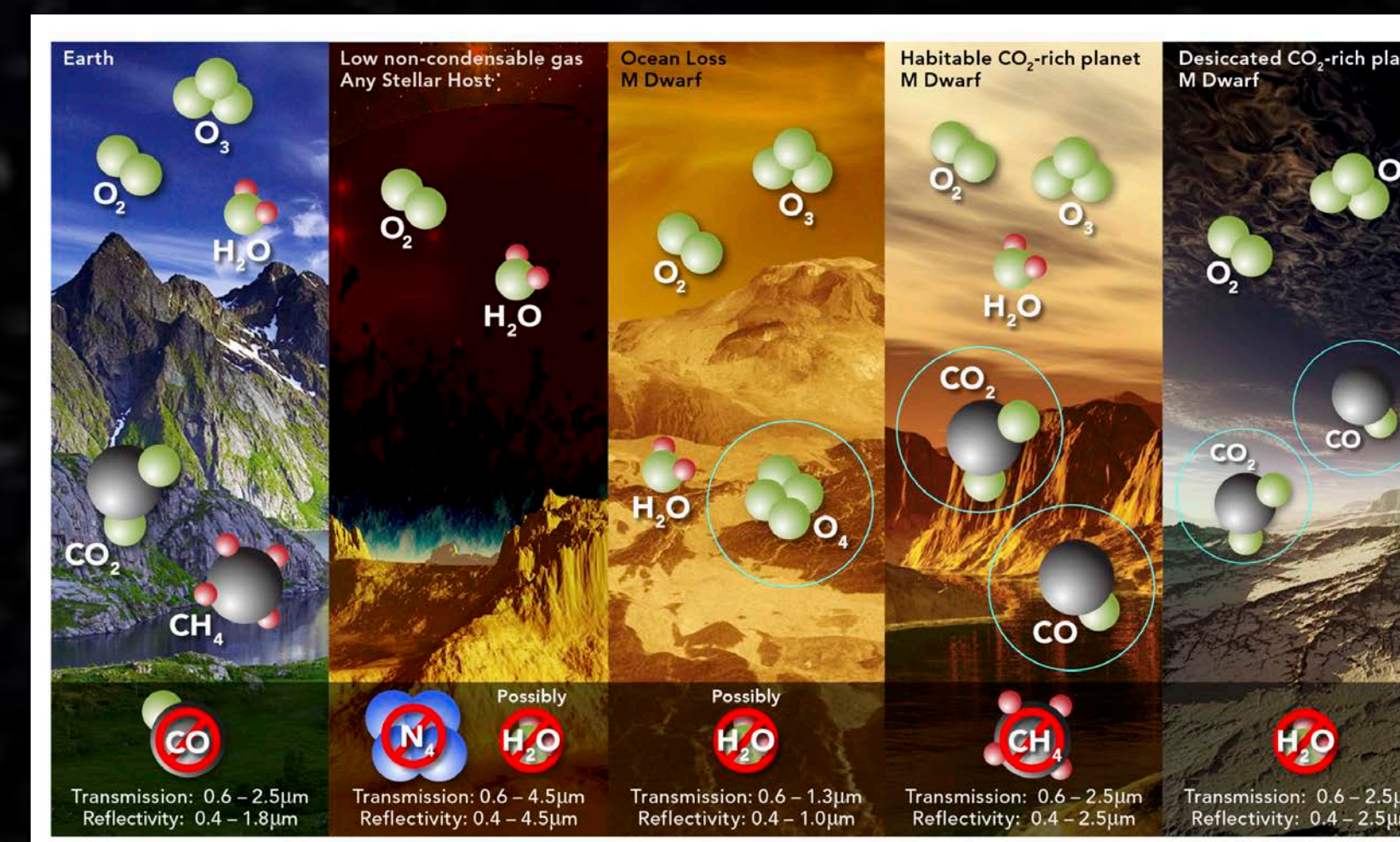
O<sub>2</sub> remains our most robust biosignature. However, possibilities for false negatives exist, as on the early Earth when accumulation of biogenic O<sub>2</sub> in the atmosphere was delayed by at least a billion years. Possibilities for false positives also have been uncovered through computer modeling of mechanisms for abundant O<sub>2</sub> in the absence of a biosphere. We review past and current biosignature research to detail the story of O<sub>2</sub> as a specific example of how life is a function of and modifies its planetary environment, and how we would use remote-sensing observations to search for biosignatures in the near term. In addition, we describe current knowledge of specific photometric, spectroscopic and time-dependent observations of environmental context that could be made by future observatories to identify O<sub>2</sub> as a biosignature, and discriminate it from potential false positives.



## Exoplanet Biosignatures: A Framework for Their Assessment

Contact: David Catling, dcatling@uw.edu

We present a general scheme for observing potential exoplanet biosignatures and gaining and expressing confidence levels for positive detection of signs of life. An appropriate framework uses models with data (in the form of exoplanetary system properties and spectral or photometric data) to find the Bayesian likelihoods of those data occurring if the exoplanet has or does not have life. The latter includes the case of false positives, i.e., where abiotic sources mimic biosignatures. Prior knowledge (including all factors that influence habitability and previous exoplanet observations) would be combined with the likelihoods to arrive at the probability of life existing on a given exoplanet given the observations.



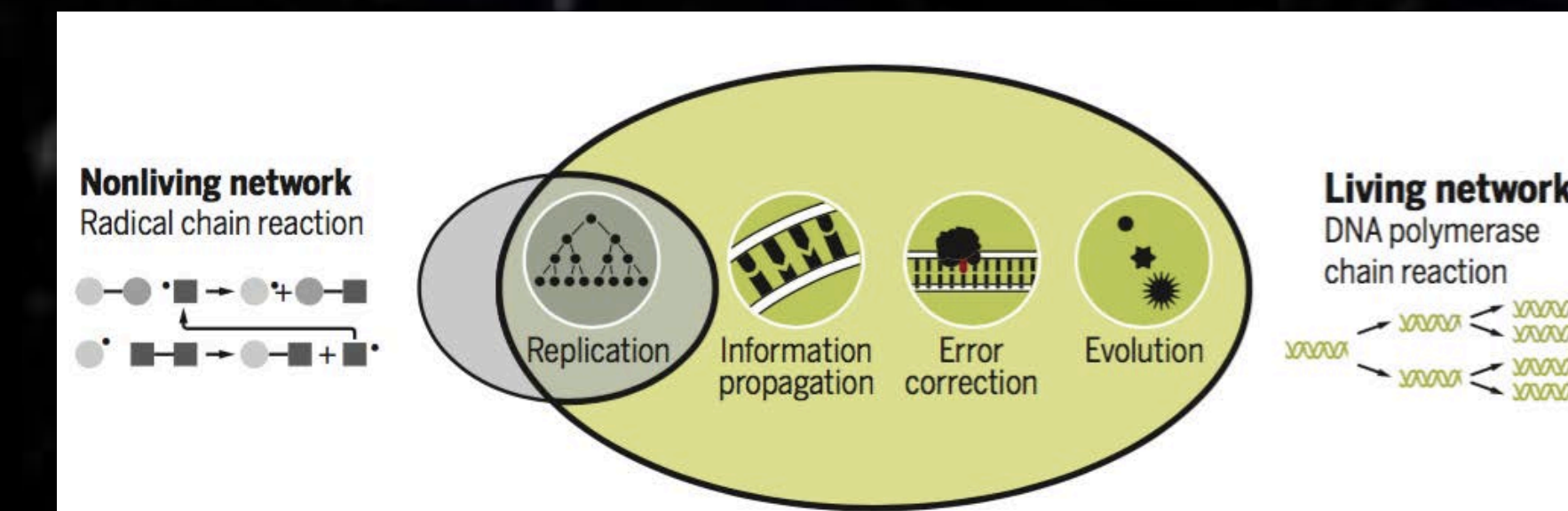
## Acknowledgments:

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## Exoplanet Biosignatures: Future Directions

Contact: Sara Walker, sara.i.walker@asu.edu

We summarize novel concepts about planetary biosignatures that are just emerging in the literature, addressing the importance of environmental context and biology that may be very different from Earth. Topics include evaluating: the evolutionary trajectory of coupled systems to identify high- vs. low-probability outcomes; classification of biosignatures from process-based, multi-disciplinary perspectives; laboratory and theoretical validation outside of Earth-like conditions. We summarize the debates over these novel ideas, proposals from the community for developing them further, and consider modeling of observational discriminatory power, and set the stage for future instrument development requirements.



## Exoplanet Biosignatures: Observational Prospects

Contact: Yuka Fujii, yuka.fujii.ebihara@gmail.com

We provide an overview of the observational prospects for biosignature detection and general characterization of temperate Earth-size planets. We summarize what kind of key planetary properties may become observable as the new facilities come on line, reviewing the planned space-based and ground-based projects as well as the methodologies these projects will employ. We distinguish reasonable expectations for the first constraints on spectroscopic features of atmospheres (and perhaps surfaces) of transiting and non-transiting planets obtainable before 2030, versus more detailed scrutinies and/or larger surveys to address statistical questions such as the occurrence rate of habitable environments, to be planned beyond 2030. The broad outlook which this paper presents is useful in developing the methodologies to assess the possibility of biospheres based on what we can observe.

