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.

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

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This paper provides an in-depth review of current understanding of potential exoplanet biosignatures including gases, surface features, and observable biosignatures. The paper particularly advances much since the review by Des Marais et al. (2002). This paper does not propose new biosignatures but rather reviews the current literature to provide a foundation for a path forward. We discuss 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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O₂ remains our most robust biosignature, however, possibilities for false negatives exist, as on the early Earth when accumulation of biogenic O₂ 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 O₂ in the absence of a biosphere. We review past and current biosignature research to detail the story of O₂ 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, spectrophotometric, and time-dependent observations of environmental context that could be made by future observatories to identify O₂ as a biosignature, and discriminate it from potential false positives.

Exoplanet Biosignatures: A Framework for Their Assessment

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We present a general scheme for observing potential exoplanet biosignatures and gauging and expressing confidence levels for positive detection of life on exoplanets. An appropriate framework uses models with data (in the form of exoplanet syntheses and atmospheric 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. This knowledge (including all factors that influence habitability and previous exoplanet observations) would be combined with the likelihood to arrive at the probability of life existing on a given exoplanet given the observations.

Exoplanet Biosignatures: Observational Prospects

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

We provide an overview of the observational prospects for biosignature detection and general characterization of temperate Earth-like 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 methodological approaches these projects will employ. We discuss reasonable expectations for the first constraints on spectroscopic features of atmospheres (and perhaps surfaces) of transiting and non-transiting exoplanets. We summarize what kind of novel concepts about planetary biosignatures could be made by future observatories to identify O₂ as a biosignature, and discriminate it from potential false positives.

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-/low-probability outcomes; classification of biosignatures from terrestrial, 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.