ExoPAG Study Analysis Group (SAG) 16 Proposal

The future of exoplanet observations will begin a shift from the physical and astronomical characterization of planet size and orbital properties towards the characterization of planet chemical composition, habitability, and inhabitance. We are proposing a SAG to explore the last of these issues, focused on biosignatures. Due to the interdisciplinary nature of biosignature research, it is paramount that the astrobiology and exoplanet communities come together for this effort. This SAG will bring these groups together, in the pursuit of three goals: 1) review the existing state of biosignature science, 2) develop a plan for uncovering novel biosignatures, and 3) list the features of existing biosignatures as an input to mission development and planning activities. In order to most comprehensively achieve these goals, we will organize a workshop to bring together scientists across disciplines, collect notes from that activity to draft a report, and then circulate that report to the community to obtain feedback for a final report. This process will engage a broad range of experts from the NASA Astrobiology Institute (NAI), the Nexus for Exoplanet System Science (NExSS), NASA's Exoplanet Exploration Program (ExEP), and the community served by the ExoPlanet Assessment Group (ExoPAG) and planetary AGs.

Science Goals

We seek to answer 3 broad questions:

1) What are known remotely-observable biosignatures, the processes that produce them, and their known non-biological sources?
2) How can we identify additional biosignatures, and a more comprehensive framework for biosignature assessment?
3) What are the requirements for detecting these biosignatures to different levels of confidence?

1) What is our current strategy for remotely observable biosignatures?

While the community is generally familiar with the classes of biosignatures as outlined in the Astrobiology Roadmap 2008, and their context within a planet's evolutionary path in the NASA Astrobiology Strategy 2015, there remain challenges to constraining and detecting currently known biosignatures. Recent findings have been uncovering potential false positives, and there are always new lessons from the ongoing search for habitable environments and life on Solar System worlds. This will cover the lessons learned from considering Earth as an exoplanet, and from the search for *in situ* biosignatures in the rock records of Earth and Mars. The related discussions will focus on how to discriminate between living planets and "imposter planets" that exhibit some signs of life despite not having a biosphere. Such strategies may lead to a requirement to understand of fundamental biological, geological, and astrophysical processes in order to interpret any biosignature, and the need for cross-disciplinary information exchange.

2) How can we develop a comprehensive framework(s) for biosignature assessment?

The field requires a comprehensive framework for biosignature assessment, that can be extrapolated to a wide diversity of planets and planetary environments beyond Earth.

Biosignature research could be advanced, for example, by an overarching theory for the processes that comprise or control the generation of a remotely-observable biosignature, from the molecular to the environmental and planetary level. Advancing beyond lists of features associated with Earth life, the theory could be generalized to incorporate environmental forcings that will be encountered on other planets, including climate, resources for life, planet composition, and stellar radiation regimes. Multiple groups have started thinking along these lines, e.g., in terms of the level of disequilibrium in the atmosphere (Lovelock, *Nature*, 1965; Krissansen-Totton, et al., *Astrobiology*, 2015), identifying all the gases potentially producible by life (Seager, et al., *Astrobiology*, 2012), the ways that a particular environment may foster/hinder the production/accumulation of a biogenic gas (Segura et al., *Astrobiology*, 2005), or how biological energy needs dictate outputs (Hoehler, *Astrobiology*, 2007). This session will provide review of fundamental processes underlying different types of biosignatures, and the observable consequences of those processes. The ensuing discussions we have on this topic will outline these frameworks, and how to integrate them to produce novel biosignatures and the technologies/instruments needed to detect them.

3) Implications of Remotely Observable Biosignatures for Future Observations and Mission Capabilities

The upcoming suite of flagship-level telescopes -- from JWST to WFIRST to direct imaging missions that will be studied in advance of the 2020 Decadal Survey -- all have some aspect of exoplanet spectroscopy. As a consequence, the science community needs to be prepared to leverage spectroscopic observations to recognize signs of life. The next decade of flagship missions -- for example, the HabEx and LUVOIR missions NASA -- also have the ability to design their missions and instrumentation “from the ground up” with biosignatures in mind. Therefore, one goal of this workshop will be to find a consensus on the level of agreement on “target evaluation tiers” that could drawn from a future life detection observation, and the observations needed for each. In the breakout session, we will ask each breakout group to fill out a rubric that details what type of measurement(s) would be needed to make each of the statements with varying levels of confidence. For example, one set of evaluation tiers (not necessarily the ones we will use in the workshop) could be:

A. We detected preliminary signs of life on an exoplanet.
B. Everything in A., and we also rigorously searched for yet found no evidence of non-biological explanations for this signal.
C. Everything in A. and B., and we also identified secondary lines of evidence to support the conclusion of biological activity.

Workshop

The workshop will take place over three days, with each day focusing on a different science goal. We will leverage the existence of NExSS and the NAI to ensure participation from a broad range of research perspectives. The workshop format will be comprised 3 days of talks, poster sessions, and breakout discussion sessions at a venue that is well-suited to group discussion and that can enable online participation for those that cannot attend in person. We anticipate

30-50 in-person participants, plus many online participants. There will be no simultaneous sessions, but all participants will follow the same schedule. On each of the three days of the workshop, we will use a similar schedule to foster conversations on each of our science goals (see above). The context for each discussion will be presented with overview talks - on past/current biosignature work (day 1), on frameworks that could move the field forward (day 2), and on future mission and instrument goals (day 3). On each day, we will break into discussion groups, with each group discussing identical key questions (TBD by Science Organizing Committee) related to that day's science goal. After a break, the larger group will reconvene and share the answers for each question from the breakout groups. Each day will close with a review of the areas of consensus and disagreement on the questions discussed that day, and a preview of the following days' activities and the drafting of a SAG report.

Workshop Outputs and SAG Report

The outputs from the workshop will be used to draft a SAG report and a corresponding peer-reviewed paper that includes: 1) a summary of currently-known (and published) biosignatures, as well as the wavelength ranges and resolutions needed to observe them; 2) a plan to expand this list with a comprehensive framework(s) for biosignatures in the context of alien planetary environments; and 3) a list of the observations required to make a biosignature assessment to different levels of confidence, with consensus noted where it appears. The report will be circulated to the broader community via email distribution lists, an online discussion, and in-person commenting periods at major meetings. Additionally, this workshop, the SAG report, and the commenting process will help forge a community of biologists, planetary scientists, astronomers, and instrument/mission scientists and engineers, to ensure future progress on biosignatures is incorporated into mission development and management.

Schedule

Our preliminary schedule is to host the workshop in June-July of 2016. We will immediately work on the top-level products from the workshop (for example, PowerPoint slides), so they can be used to solicit community feedback and deliver outputs to the 2020 flagship STDTs as soon as possible. These top-level products will form the core of the SAG report, which we will draft and circulate to the community by October 2016. We will obtain feedback on the draft at DPS (Oct. 2016), AGU (Dec. 2016), and AAS (Jan. 2017), and a dedicated virtual presentation (Nov. 2016). We will then finalize the report by March 2017.

Participation

This SAG effort is being jointly led by Shawn Domagal-Goldman, Nancy Kiang, and Niki Parenteau. Their role will be to facilitate a broader science organizing committee's planning of the workshop and a writing committee's drafting of the SAG report. The workshop and report drafting will be made open to everyone in the community via online tools. The SAG leads are currently soliciting and recruiting members for the workshop science organizing committee, and the writing committee will be recruited during and immediately after the workshop.