EXOPAG SAG15 Draft Report

Exploring Other Worlds: Observational Constraints and Science Questions for Direct Imaging Exoplanet Missions

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Abstract

SAG15 Charter

Future direct imaging missions may allow observations of flux density as a function of wavelength, polarization, time (orbital and rotational phases) for a broad variety of exoplanets ranging from rocky sub-earths through super-earths and neptunes to giant planets. With the daunting challenges to directly imaging exoplanets, most of the community's attention is currently focused on *how* to reach the goal of exploring habitable planets or, more specifically, how to search for biosignatures.

Arguably, however, most of the exoplanet science from direct imaging missions will not come from biosignature searches in habitable earth-like planets, but from the studies of a much larger number of planets *outside* the habitable zone or from planets within the habitable zone that do not display biosignatures. These two groups of planets will provide an essential context for interpreting detections of possible biosignatures in habitable zone earth-sized planets.

However, while many of the broader science goals of exoplanet characterization are recognized, there has been no systematic assessment of the following two questions:
1) What are the most important science questions in exoplanet characterization *apart* from biosignature searches?
2) What type of data (spectra, polarization, photometry) with what quality (resolution, signal-to-noise, cadence) is required to answer these science questions?

We propose to form SAG15 to identify the key questions in exoplanet characterization and determine what observational data obtainable from direct imaging missions is necessary and sufficient to answer these.

The report developed by this SAG will explore high-level science questions on exoplanets ranging from gas giant planets through ice giants to rocky and sub-earth planets, and — in temperatures — from cold (~200 K) to hot (~2,000 K). For each question we will study and describe the type and quality of the data required to answer it.

For example, the SAG15 could evaluate what observational data (minimum sample size, spectral resolution, wavelength coverage, and signal-to-noise) is required to test that different formation pathways in giant planets lead to different abundances (e.g. C/O ratios). Or the SAG15 could evaluate what photometric accuracy, bands, and cadence is required to identify continents and oceans in a habitable zone Earth-sized or a super-earths planet. As another example, the SAG15 could evaluate what reflected light data is *required* to constrain the fundamental parameters of planets, e.g. size (distinguishing earth-sized planets from super-earths), temperature (cold/warm/hot), composition (rocky, icy, gaseous), etc.

SAG15 will not attempt to evaluate exoplanet detectability or specific instrument or mission capabilities; instead, it will focus on evaluating the *diagnostic power* of different measurements on key exoplanet science questions, simply adopting resolution, signal-to-noise, cadence, wavelength coverage as parameters along which the diagnostic power of the data will be studied. Decoupling instrumental capabilities from science goals allows this community-based effort to explore the science goals for exoplanet characterization in an unbiased manner and in a depth beyond what is possible in a typical STDT.

We envision the SAG report to be important for multiple exoplanet sub-communities and specifically foresee the following uses:
1) Future STD teams will be able to easily connect observational requirements to missions to fundamental science goals;
2) By providing an overview of the key science questions on exoplanets and how they could be answered, it may motivate new, dedicated mission proposals;
3) By providing a single, unified source of requirements on exoplanet data in advance of the Decadal Survey, the science yield of various missions designs can be evaluated realistically, with the same set of assumptions.

Our goal is to carry out this SAG study by building on both the EXOPAG and NExSS communities.

We aim to complete a report by Spring 2017 and submit it to a refereed journal, although this timeline can be adjusted to maximize the impact of the SAG15 study for the ongoing and near-future STDTs and other mission planning processes.

Synergy with a potential future SAG proposed by Shawn Domagal-Goldman: While the SAG proposed here will include studies of habitable zone rocky planets, it will focus on planets without significant biological processes. A future SAG may be proposed by Shawn Domagal-Goldman to explore biosignatures; if such a SAG is proposed, we envision a close collaboration on these complementary, but distinct problems.

Introduction

Science Questions Potential Answerable by Direct Imaging Missions

This section aims to identify the high-level science questions that a direct imaging mission may answer through exoplanet characterization. The current content is a placeholder, both in terms of the information and in terms of the formatting.

<u>Questions suggested:</u>
Shawn Domagal-Goldman: *"How do we define meaningful categories for planets"?*
Maggie Turnbull: *"How strongly do stellar properties influence the properties of the planets and planetary systems and habitability?"*
Nick Cowan: *Diversity of the planetary evolutionary process and what are the key factors influencing it? As an example, what differences led to present-day Venus and Earth?*

Summary of science questions for different types of individual planets.					
	Gas Giant	Ice Giant	Super-Earth	Earth	Sub-Earth
Hot					
Warm					
Cold					

Summary of science questions for populations of planets, i.e. questions that are comparative or statistical in nature.					
	Gas Giant	Ice Giant	Super-Earth	Earth	Sub-Earth
Hot					
Warm					
Cold					

Detailed discussion of high-level science questions.

Potentially Observable Quantities from Imaging Missions

The aim of this section is to identify potentially observable quantities from imaging missions, i.e. direct observables. For each science question from the previous section we identified direct observables that are required for answering the question.

<table>
<tr><th colspan="6">Summary of observables for different types of individual planets.</th></tr>
<tr><td></td><td>Gas Giants</td><td>Ice Giants</td><td>Super-Earths</td><td>Earths</td><td>Sub-Earths</td></tr>
<tr><td>Hot (>600 K)</td><td colspan="4">Size. Orbit. Gas-phase abundances. Cloud and haze coverage (lon/lat/alt). Cloud evolution. Rotational period. Albedo. Presence of giant satellites.</td><td></td></tr>
<tr><td>Warm (400-600K)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cold (<400 K)</td><td></td><td></td><td></td><td></td><td></td></tr>
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Data Type and Data Quality Required

Table below is a placeholder.

Summary of observables and the required data type and data quality					
	Gas Giants	**Ice Giant**	**Super-Earth**	**Earth**	**Sub-Earth**
Absorption feature depth					
Light curve					
Albedo					
Rotation Period	NIR Photometry, Cadence XX/hr, SNR20				
NIR Colors					

References

Initially, the references will be collected through a myADS public library:
http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?library&libname=SAG15&libid=4fde410a6e

Please, send ADS links to all relevant references to apai@arizona.edu