Study Analysis Group 15
Exoplanet Exploration Program Analysis Group

Science Questions for Direct Imaging Missions

DRAFT

Contact: Daniel Apai (apai@arizona.edu)

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Alan Boss, Carnegie DTM
James Breckenridge, Caltech
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SAG15 Website: http://eos-nexus.org/sag15

Introduction

This report presents organized input from the international exoplanet community on science questions that can be answered by direct imaging missions.

For each science question we also explore the types and quality of datasets that are either required to answer the question or greatly enhance the quality of the answer. We also highlight questions that require or benefit from complementary (non-direct imaging) observations.

In preparing the report no specific mission architecture or requirements were assumed or advocated for; however, where obvious connections to planned or possible future mission existed there were identified. The report does not include discussion of biosignatures or planets transformed by life; but it does include discussion of the characterization of habitable zone earth-sized planets.

Overview of science questions

Science Questions on Exoplanetary System Architectures & Population	Importance
A1. What is the diversity of planetary architectures? Are there typical classes/ types of planetary architectures?	
What are the distributions and properties of planetesimal belts and eco-zodiacal disks in exoplanetary systems and what can these tell about the formation and dynamical evolution of the planetary systems?	
A3. Are there natural classes of exoplanets and if so, what are these?	
A4. How Common are Planetary Architectures resembling the Solar System?	

Science Questions on Exoplanet Properties	Importance
B1. How do rotation periods and obliquity vary with orbital elements and planet mass/type?	
B2. Which rocky planets have liquid water on their surfaces?	
B3. What are the origins and composition of clouds and hazes in ice/gas giants and how do these vary with system parameters?	
B4. Which planets have large continents and oceans?	
B5. How do photochemistry, transport chemistry, surface chemistry, and mantle outgassing effect the composition and chemical processes in terrestrial planet atmospheres (both habitable and non-habitable)?	

Science Questions of Evolution and Processes that Change Exoplanets	Importance
C1. What processes/properties set the modes of atmospheric circulation and heat transport in exoplanets and how do these vary with system parameters?	
C2. What are the Key Evolutionary Pathways for Rocky Planets?	
C3. What types/which planets have active geological activity, interior processes, and /or continent-forming/resurfacing processes?	

Discussion of Science Questions

The following sections provide a preliminary discussion of possible science questions for direct imaging missions. The questions are organized in three categories: Questions in Category A focus on the statistical assessment of the properties of exoplanetary systems. Questions in Category B focus on the understanding of specific exoplanets. Questions in Category C focus on understanding the details and importance of key processes by establishing causal relations between present-day properties and processes.

A1. What is the diversity of planetary architectures? Are there typical classes/types of planetary architectures?

Our current picture of planetary system architectures builds on five sources: 1) Solar System; 2) Data from transiting exoplanets, primarily Kepler, which probes the inner planetary systems (typically up to periods of approximately 1 year); 3) radial velocity surveys, which provide data on planets with masses typically larger than those accessible to Kepler observations, but some of which cover multi-year periods; 4) microlensing surveys, which are also sensitive to small rocky planets at intermediate periods, but provide a yet limited statistics; 5) direct imaging surveys: capable of probing giant exoplanets at semi-major axes of 8 au or longer.

Based on the extrapolation of the close-in exoplanet population detected by Kepler we do not yet have an efficient method to detect most of the planets (at intermediate to large periods, with masses comparable to Earth).

A direct imaging mission could provide a powerful tool to survey planets at intermediate orbits (~1 to 30 au), establish their orbits or constrain their orbital parameters, and measure or deduce their masses or sizes.

Comments from Telecon 2:
SDG: There will be an upcoming white paper by Debra Fischer and colleagues on high-precision RV measurements that will be very relevant for this question.
SDG: Rather than identifying a complete understanding of planetary architectures (which may be impossible to achieve), we may want to identify specific hypotheses that should be tested. For example, a hypothesis on the transition between rocky planets and gas giants could have specific, testable predictions.

Data Required: *Optical or infrared imaging to identify the presence and location of planets in each system. Multi-epoch imaging (or complementary radial velocity or astrometry) is required to constrain orbital parameters.*

Questions to SAG15: *1) How many epochs are required to establish orbital parameters?*
2) To what accuracy should the orbital parameters be measured to?

3) What sample size (number of systems imaged) would be a) minimum required, or be b) optimally suited for answering this question?

Complementary Non-Imaging Data:

1) Radial velocity: Constraints from radial velocity measurements can greatly reduce the number of direct imaging epochs required to establish the orbital elements of the planets. These measurements can also constrain or determine the mass of the target planets.
2) Astrometry: Constraints from radial velocity measurements can greatly reduce the number of direct imaging epochs required to establish the orbital elements of the planets. These measurements can also constrain or determine the mass of the target planets.
3) Ground-based adaptive optics imaging: These observations may be capable of discovering giant exoplanets and providing positions at additional epochs.

A2. What are the distributions and properties of planetesimal belts and eco-zodiacal disks in exoplanetary systems and what can these tell about the formation and dynamical evolution of the planetary systems?

Direct imaging missions will likely provide spatially resolved images of exo-zodi disks, possibly composed of narrow and/or extended dust belts. In these belts dust is produced by minor body collisions and the dust belts are dynamically sculpted by the gravitational influence of the planets in the systems, grain-grain collisions, as well as radiation pressure from the stars.

Currently, detailed simulations of debris disk structures and disk-planet interactions provide predictions for the expected disk structures. In a large set of disks complex structures have been observed which have been explained via the influence of yet unseen planets; in a very small set of systems disks and planets have been observed together, providing an opportunity to study disk-planet interactions and to validate models.

<u>Questions to SAG15:</u>

1) What are the most compelling science questions to be answered through observations of dust belts / exozodiacal disk structures?
2) To what extent could the dust belt structures be used to: a) deduce the presence of lower-mass planets; b) provide constraints on the mass and eccentricity of the directly imaged planets in the system; or c) constrain the dynamical evolution of given planetary systems, i.e., through constraining possible migration histories?

A3. Are there natural classes of exoplanets and if so, what are these?

For centuries the planets in the Solar System provided a basic template for planet classification, based on their mass distribution and composition ("rocky planets", "gas giants", "ice giants", "dwarf planets"). In the Solar System the mass/composition based classification also correlates with an alternative location-based definition and agrees with differences in the expected formation pathways (i.e., accretion of rock/iron; gas accretion to a rocky/icy core; gas-limited accretion to a rocky/icy core).

However, the diversity of exoplanets discovered revealed a greater diversity of exoplanets, including an apparently continuous planetary mass distribution, presence of planets of different sizes/compositions at very different orbits, and possibly multiple very different formation and evolutionary pathways.

Publications converged to ad hoc planet categories and adjectives (e.g., *by mass:* sub-earths, earths, super-earths, mini-neptunes, neptunes, saturns, jupiters, super-jupiter; *by temperature:* cold, warm, hot; *by formation*: exoplanet, planetary-mass companion, brown dwarf, ejected planet).

Planet formation and evolution pathways may lead to continuous spectra in planet mass, composition, temperature, and formation/evolution, in which case it is of limited use (or may be misleading) to distinguish different categories of exoplanets. On the other hand it is also possible or even likely that in a multi-dimensional space of planet properties strong clustering is present, providing natural new categories for planets.

Identifying the natural categories of planets can enhance the effectiveness of studies (by comparing similar objects).

Imaging Data Requirements:

Complementary Non-Imaging Data:

1) Radial velocity / Astrometry: Required for mass determination.
2) Transits: Statistics on short-period planets not accessible to direct imaging.

Comments on Telecon 2:

SDG: We should also consider that, given also complementary measurements, which dimensions of the description of planetary architectures are important and which are not probed sufficiently by existing/future measurements, i.e., prioritize dimensions that are important and unexplored.

SK: We should consider dynamical constraints, such as mean-motion resonances, on the N-dim parameter space, as the dynamical information can be important for understanding the systems.

SK: A related question: are compact planetary systems extremely common? There are some biases and intriguing trends in the existing transit-based data that could be verified with direct imaging.

A4. How Common are Planetary Architectures resembling the Solar System?

Needs more discussion:
The Solar System may in many ways differ from typical planetary systems. Which parameters are relevant for this question?

Comments from Telecon 2:
SK? : Jupiter analogs are becoming detectable and this question (at least frequency of Sun-Jupiter pairs) will be answered relatively soon.
DA: There are many parameters that could be used to determine the similarity of a given planetary system and the Solar System; not clear which are more important than others for our purposes and how to weight them.
Consensus: We will need to better define this question.

Summary of discussion in Telecon 3 (see Telecon 3 Minutes on SAG15 website for more details):
Question was rephrased as "How Common Are Planetary Architectures resembling the Solar System"?

Very important constraints will be placed on this question by Kepler, K2, RV surveys, GAIA, ALMA, LBTI, and WFIRST-Microlensing. However, each of these will be sensitive to only certain types of planets in certain systems, i.e., not clear that the science question above can be fully addressed by combining heterogeneous constraints from different missions.

A careful discussion is required to evaluate the whether this question will/should be important for a future large direct imaging mission and if so, what will be the available complementary data.

Complementary Observations: Kepler, K2, RV surveys, ALMA, LBTI, GAIA, and WFIRST-Microlensing

Type of Data from Direct Imaging Mission:

Category B: Questions on Exoplanet Properties

B1. How do rotational periods and obliquity vary with orbital elements and planet mass/type?

Contributors: Daniel Apai

Rotational periods are important parameters of planets as they constrain: 1) atmospheric dynamics; 2) diurnal surface temperature variations; 3) formation and angular evolution; 4) dynamo-generated magnetic field. Furthermore, trends between rotation period and planet mass/type may place important constraints on models of planet formation/evolution.

For potentially habitable planets rotation rates are an important parameter in climate models. and they Current calculations assume a rotational rate that matches Earth's rate.

Current status and methods: As of now rotation periods for exoplanets have been determined through three different methods:

a) *Orbital period measurement* for very short-period gaseous planets in spin-orbit resonance (1:1, tidally locked). Orbital/rotational phase curves in thermal emission and in reflected light verified the synchronous rotation for a handful of hot jupiters (e.g., Knutson et al. 2007,).

b) *Absorption line width measurements* for directly imaged giant exoplanets (Beta Pictoris b: Snellen et al. 2014). Similar studies for rotational line broadening have been carried out successfully for brown dwarfs (e.g.,).

c) *Rotational photometric/spectroscopic modulations* in hemisphere-integrated light for directly imaged exoplanets (Fig. B1.2, Zhou et al. 2016) and planetary-mass brown dwarfs (Biller et al. 2015). Observations of brown dwarfs (planetary mass and more massive), good analogs for directly imaged exoplanets. These observations showed that low-level (~1%) rotational modulations in thermal emission are common (e.g., Buenzli et al. 2014; Metchev et al. 2015), and can be used to measure or constrain rotational periods (e.g., Artigau et al. 2009, Radigan et al. 2012, Apai et al. 2013). Reflected-light observations of Solar System giant planets demonstrated that rotation periods can be measured (e.g., Jupiter: Karalidi et al. 2015; Neptune: Simon et al. 2016).

The latter two techniques may be both applicable for exoplanets directly imaged with next-generation space telescopes. While method b requires high spectral resolution and provides Doppler information, method c requires only high signal-to-noise time-resolved photometry and not strongly wavelength-dependent.

Earth observations: In addition, to exoplanet observations, considerable effort was put into exploring time-revolved observations of Earth, as exoplanet analog. The

[… 1-2 paragraph high-level summary of Earth or simulated Earth observations focusing on rotation period / obliquity determination…]

Other Solar System planet observations: Neptune (Simon et al. 2016), Jupiter (Karalidi et al. 2015).

Science cases and Considerations for different planet types:

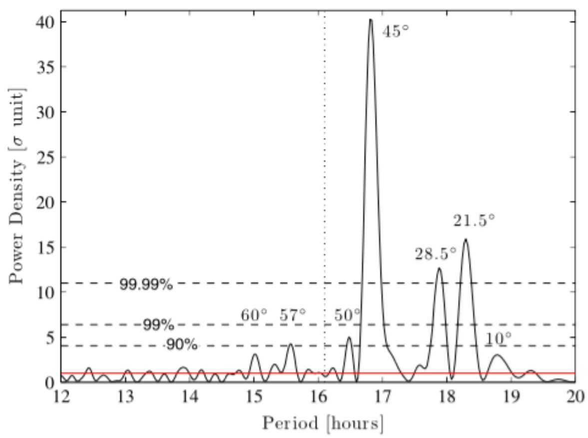

Figure XX: Whitened power spectrum from 50-day-long Kepler monitoring of hemisphere-integrated reflected light Neptune, with the most significant peak corresponding to the rotation period. Numbers above some peaks indicate the latitudes on Neptune corresponding to that rotation period based on the zonal velocities. From Simon et al. (2016).

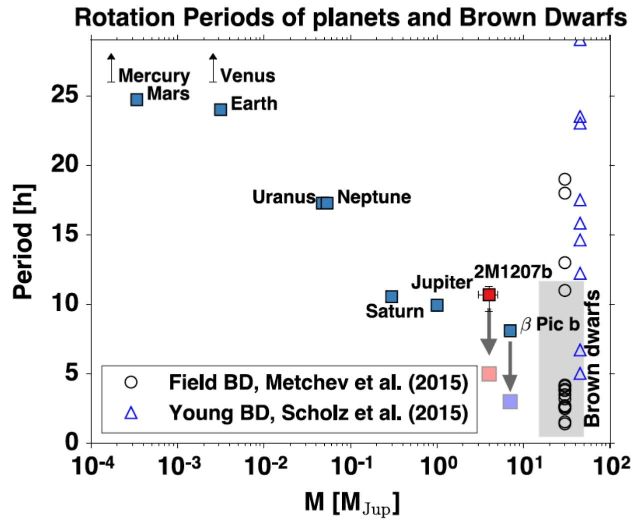

Figure XX: Rotation periods provide insights into the properties and formation of planets. A comparison of Solar System planets, directly imaged exoplanets, and brown dwarfs reveals a characteristic mass-dependent rotation rate for massive planets. The arrows shows the expected spin-up due to gravitational contraction. From Zhou et al. (2016).

Gas and Ice Giant Exoplanets: Non-axisymmetrically distributed condensate clouds and hazes (photochemical or other origin) will introduce rotational modulations, both in reflected and in scattered light (e.g., Simon et al. 2016). In addition, polarimetric modulations introduced by light scattering on heterogeneously distributed dust/haze grains may also be detectable. The rotation periods of gas/ice giants may be useful for constraining their formation/evolution; but no detailed models exists yet to evaluate this possibility(?).

Atmosphere-less Rocky Planets ("Super-Mars"): Rocky planets with very thin or no atmosphere may exists, perhaps as a result of extensive atmospheric loss due to evaporation (Hot Super-Mars), stellar wind stripping, or impact stripping. At pressures lower than water's triple point (6 mbar) liquid water is not stable., even if the planet is otherwise Earth-sized and it is in the habitable zone. For these planets establishing rotational periods may provide insights into the mechanism that led to the complete atmospheric loss.

While atmosphere-less rocky planets would not be suitable for direct measurements of their rotational periods through method *b* (absorption line width measurements), significant features at the rocky surface would introduced photometric rotational modulations that would be suitable for characterization through method *c*.

Habitable Planets (Earth-sized or Super-Earths): Rotation periods are important for climate and atmospheric circulation models of habitable planets; for constraining diurnal temperature modulations; and for constraining current and past magnetic field strengths and, indirectly, constraining the atmospheric loss that may have occurred on these planets.

Ongoing observations by the Earth-observing EPIC camera (Kane et al.) will provide an important demonstration of the technique.

Hazy Atmospheres: Planets with thick haze layer will pose a challenge for rotational signal using methods b and c. Because haze particles —by definition — are small (~0.01 μm), their residence time in the atmosphere will be much longer than the rotational period (t_{res} >> P), which will result in featureless haze layers. As haze particles can be generated at smaller pressure levels and will settle down much slower than larger particles produces by condensation, the featureless haze layers — if optically thick — will mask any heterogenous condensate cloud structure as well as any surface structures. Similarly, optically thick haze layers may cover or weaken the rotationally broadened line profiles in the atmospheres, also limiting the use of Doppler techniques. Therefore, planets enshrouded in thick haze layers are not well suited for rotational studies.

Obliquity for Earth-like planets and for planets with quasi-permanent non-axisymmetric features: The obliquity of habitable planets has a major impact on the seasonal and diurnal temperature variations and on their climate in general. Obliquity is much more difficult to determine than the directly observable rotational rate. However, simulated observations demonstrate that it is possible to determine this quantity from high signal-to-noise reflected light lightcurves obtained at multiple orbital phases.

Obliquity for gas giants: For gas giants (with well-constrained radius) combining the rotational period determined from rotational modulations with radial velocity information (line broadening due to rotation) allows constraining or deriving the inclination of the planet (e.g., Allers et al. 2016).

Complementary Observations: No complementary observations are required for science results from rotational period measurements, but observations constraining the planetary orbits may be combined with the obliquity and rotational period to constrain the formation history of low-mass planets. Planet mass measurements from radial velocity or astrometry, or gravitational interactions between the planets, can be combined with rotational periods to determine the angular momenta of the giant planets, which may be useful for constraining their accretion history.

Data Required:

Open Questions to SAG15:

1) *How important are rotation periods for different types of planets?*
2) *To what accuracy should rotation periods be determined?*
3) *Connection between planet formation/evolution and angular momentum*
4) *Connection between rotation period - magnetic field - stellar wind: implications for atmospheric loss for habitable planets*

B2. Which rocky planets have liquid water on their surfaces? Which planets have continents and oceans?

Water is not a biosignature itself, but the presence of liquid water is required for life as we know it. And life as we know it is probably the only kind of life that we may be able to identify remotely. Liquid water is not the only factor required for planetary habitability, but it is arguably the most important one.

The presence of liquid surface water may be constrained through different measurements, including atmospheric spectroscopy; rotational phase mapping; presence of clouds composed of liquid water droplets.

Liquid water is a “habitability signature”. Establishing which habitable zone planets have liquid water on their surfaces provides an important context for EXOPAG SAG16, which focuses on biosignatures, but will rely on SAG15 for habitability signatures and characterization of habitable planets.

Comments from SAG15 Team / Telecon 2:
From Jim Kasting:
The key question for me concerns the availability of liquid water on the surfaces of rocky planets orbiting other stars. Water is not a biosignature itself, but the presence of liquid water is required for life as we know it. And life as we know it is probably the only kind of life that we may be able to identify remotely. Liquid water is not the only factor required for planetary habitability, but it is arguably the most important one.

Related observables: 1) orbital distance. It is critical to determine the semi-major axes of rocky exoplanets because this plays a key role in determining whether they can support liquid water on their surfaces. Note that this likely requires multiple revisits to each planetary system of interest. On TPF-C, we assumed 5-6 revisits per system. 2) Gaseous CO_2 and H_2O. Both of these gases are potentially observable at near-IR wavelengths. CO_2 is even easier to observe in the thermal-IR, but that requires a different kind of direct imaging mission.

Other comments:
Consensus: Important question.
Multiple people: Presence of water may be constrained through measurements other than atmospheric spectroscopy; rotational phase mapping, for example, could be important.
RK: Determining P-T profile and presence of water clouds would also be important/ useful.
SDG: This question connects well to SAG16, where we study biosignatures. Liquid water on the planetary surface is a habitability signature, which is not studied in SAG16; SAG16 will rely on SAG15 for this context.

Analysis of simulated eco-earth observations was used to demonstrate that rotational phase mapping (time-resolved observations of hemisphere-integrated reflected light from the planet) can reveal the types and distribution of surfaces. Equipped with additional data on the color/spectra of the features and the physical conditions on the planetary surface may be used to identify surface features as oceans and continents.

Questions to SAG15:

B3. What are the origins and composition of clouds and hazes in ice/gas giants and how do these vary with system parameters??

All Solar System planets with an atmosphere harbor cloud and/or haze layers. Clouds and hazes influence the pressure-temperature structure of the atmosphere, its emission and transmission spectrum, the albedo of the planets. Clouds and hazes may also used as tracer to characterize atmospheric dynamics (circulation, mixing, turbulence).

Presence of haze or cloud layers may also mask the presence of specific atmospheric absorbers even if present at large abundances at pressures higher than the particle layer.

Exoplanets are expected to harbor a large variety of condensates and haze-forming particles that may be important and/or observable with future direct imaging missions.

Understanding the composition of cloud- and haze-forming particles is an important step in developing physical/chemical models for exoplanets.

Questions to SAG15:
1) What data can constrain particle size distribution, pressure levels, composition?
2) What fundamental parameters (composition, temperature, surface gravity?) are expected to have significant impact on cloud/haze formation and properties?

Notes: Question revised in Telecon 3. Additional, related question (B5) added.

[B4 was merged with B2]

B5. How do photochemistry, transport chemistry, surface chemistry, and mantle outgassing effect the composition and chemical processes in terrestrial planet atmospheres (both habitable and non-habitable)?

Answering this question will also provide a context for interpreting biosignatures in habitable planets discussed in SAG16.

Question added in Telecon 3.

<u>Question to SAG16:</u>
1) What planetary constraints are important for the interpretation of biosignatures?

Category C Questions: Processes

C1. What processes/properties set the modes of atmospheric circulation and heat transport in exoplanets and how do these vary with system parameters?

Atmospheric circulation plays a key role in redistribution energy in exoplanets' atmospheres. Depending on wind speed, rotational velocity, insolation, latent heat released during condensation, and other system parameters a range of atmospheric circulation regimes are expected on planets that can be studied with direct imaging missions.

For potentially habitable exoplanets atmospheric circulation will determine the day-night heat differential and the equator-pole temperature difference. Understanding the presence and size of Hadley cells can also provide important insights into how water vapor (or other condensibles) may be distributed in habitable planets.

Understanding atmospheric circulation in habitable exoplanets is an important component in establishing a correct climate model for them.

As of now, atmospheric circulation has been probed in the Solar System planets and a small sample of hot jupiters and brown dwarfs. Lower-mass exoplanets remain unexplored.

Using time-resolved observations and rotational phase mapping techniques atmospheric circulation may be constrained.

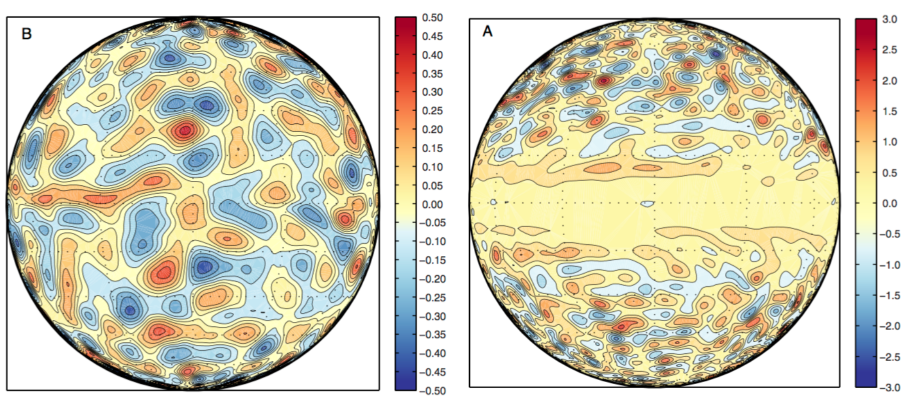

Fig C1.1 Depending on the relative importance of rotational speed, wind speed, and vertical heat transport, simple models predict two different regimes of circulation for giant planets: vortex-dominated (left) and jet-dominated (right). From Zhang & Showman (2014).

Questions to SAG15:

1) To what level can the atmospheric circulation be constrained for different types of planets?
2) What hypotheses / toy circulation models should be tested for gas giants?
3) What hypotheses / toy circulation models should be tested for habitable super-earths / earths?
4) What data type and cadence is required or best suited for characterizing circulation?

C2. What are the key evolutionary pathways for rocky planets and what first-order processes dominate these?

From Nick Cowan: WHY DO PLANETS TURN OUT THE WAY THEY DO? In other words, which aspects of planet formation (mass, spin, composition) impact which aspects of planetary atmospheres and climate? This is a classic nature vs nurture problem. Maybe the most important determinant of a planet's evolution is the final major impact, or its star's UV flux, or maybe it is the planet's volatile content... or maybe it is first-order stochastic with only second-order correlations to the factors above. Another way to think about the effect of nurture is the extent to which planets exhibit hysteresis. If Earth and Venus traded locations, would the new cooler Venus end up looking more Earth-like in the long run, and vice versa.
Stephen Kane: The evolution is perhaps understood as "Atmospheric evolution”. However, there are lot of important differences between Earth and Venus beyond their location in the Solar System: their rotational periods and magnetic fields are very different.
We should make it clear that the focus is on fundamental, important parameters. We could rephrase the question as “What are the first order effects that determine evolutionary pathways?” Perhaps just irradiation is important, but maybe also composition, etc.

C3. What types/which planets have active geological activity, interior processes, and /or continent-forming/resurfacing processes?

Planetary interior processes and geological activity play an important role in coupling Earth’s atmosphere to its crust and providing a long-term stabilizer for Earth’s climate. Developing reliable climate models to determine the habitability of potentially habitable planets will likely require assumptions on geological activity and the level of coupling between the planet’s crust and atmosphere.

Interior processes are obviously very difficult to probe via low signal-to-noise and spatially unresolved remote sensing.

Possible ideas includes:

1) Detection of atmospheric absorbers that can be attributed to volcanic release, and deducing the level of volcanic activity.
2) Using land-mass distribution to place constraints on continent-forming processes.
3) Other methods?

Data Requirements

This section identifies the type and quality of data ideal or required to answer the individual science questions discussed in Section 2.

Summary of data requirements

Science Questi-ons	Optical			Near-Infrared			Mid-IR		Num. Targets
	Phot.	Spec.	Pol.	Phot.	Spec.	Pol.	Phot.	Spec.	
A1									
A2									
A3									
A5									
B1									
B2									
B3									
B4									
C1									
C2									
C3									
C4									

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.

EXOPAG SAG15 Draft Report – Feb 5, 2016

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.

SAG15 Timeline and Process

This section records the SAG15 timeline and explains how the report was assembled and identifies the methods through which community input was solicited and collected.

SAG15 Website: http://eos-nexus.org/sag15

Telecon 1: December 15, 2016 (Minutes)

Telecon 2: March 2, 2016 (Minutes)

Telecon 3: April 6, 2016 (Minutes)

The minutes, agenda, documents, and slides for each telecon are available at the SAG15 website: http://eos-nexus.org/sag15/