A night sky photograph of the Milky Way galaxy, showing a dense band of stars and colorful nebulae. The galaxy is viewed from a low angle, arching across the sky. In the foreground, a desert landscape is visible with a prominent, tall, thin rock formation (a hoodoo) in the center. The sky is dark, and the stars are bright, creating a striking contrast.

SAG 15 PROGRESS REPORT

SCIENCE QUESTIONS FOR DIRECT IMAGING MISSIONS

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Earths in Other Solar Systems Team / NASA NExSS



SAG15 Charge

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

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?

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 ($\sim 2,000$ K). For each question we will study and describe the type and quality of the data required to answer it.



SAG15 Charge

What is not included:

- 1) Biosignatures (but habitable planets are!)
- 2) Evaluation of instrument capabilities or advocacy for mission architectures





Uses of the Report

- 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.



1. The SAG15 Team and Contributors

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Status and Milestones

Approved in October 2015

Initial SAG 15 Team Assembled Dec 2015

Process, timeline, and publications identified

Status:

- 1) Collaborated on 24 incremental drafts, 11 telecons
- 2) “Advanced draft” was circulated Oct 2015
- 3) Scope slightly extended
- 4) Publication-quality report about 93% ready, 80 pages long
- 5) Work still ongoing on two incomplete topics

2017

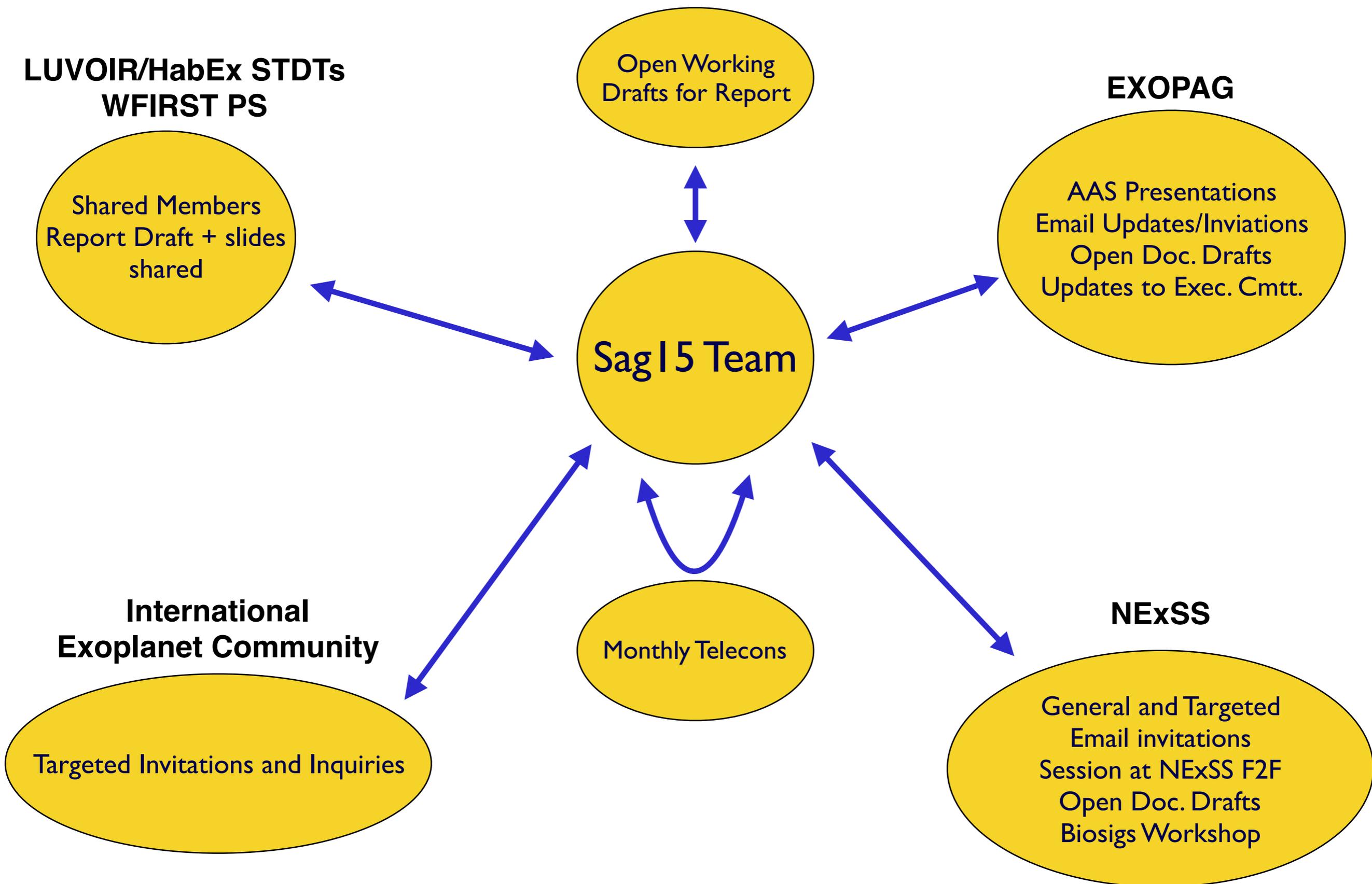
Feb 15: Final draft version of the report circulated

April 1: Short review summarizing report

April 15: Submission of the report to EXOPAG and APS



Community Involvement





Community Involvement

Throughout the project the SAG15 team has provided **up-to-date information on the report's status** and next steps to different constituents (EXOPAG, EXOPAG EC, NExSS, exoplanet community, STDTs) via the following channels:

- SAG15 website always containing the up-to-date report draft and links to all relevant documents
- Monthly telecons open to anyone in the exoplanet community
- Minutes of most telecons were circulated on the SAG15 mailing list to keep all members abreast of the progress
- Emails sent to the NExSS group and EXOPAG groups

Status updates provided to the EXOPAG community at every AAS meeting during the project:

- Presentation/hackathon session during the NExSS Face-to-Face meeting in May 2016
- Representatives of the LUVOIR and HabEx STDTs on the SAG15 team and attended telecons
- The up-to-date version of the SAG15 report was shared with the LUVOIR STDT

Soliciting Input:

- Presentations at the EXOPAG/AAS meetings
- Presentations to the NExSS community
- Emails sent to the NExSS group and EXOPAG groups
- Targeted emails soliciting input from scientists with required expertise
- Input collected from the NExSS Biosignatures and SAG16 workshop
- Input collected from hackathon session at NExSS Face-to-Face meeting (25 participants)
- Representatives of the LUVOIR and HabEx STDTs on the SAG15 team, attended telecons, and provided updates on progress
- ESA/Gaia Mission
- ESO/ELT Project

The **advanced draft of the report** was circulated in Oct 2016 in the EXOPAG, NExSS communities and sent to topical experts

SAG15 Website: The SAG15 website (<http://eos-nexus.org/sag15/>) was established right after the approval of SAG15 by the Astrophysics Subcommittee. The website contains links to the SAG15 report draft, providing step-by-step overview on the evolution of the report as well as a copy of the up-to-date report.



Content and Organization of the Report

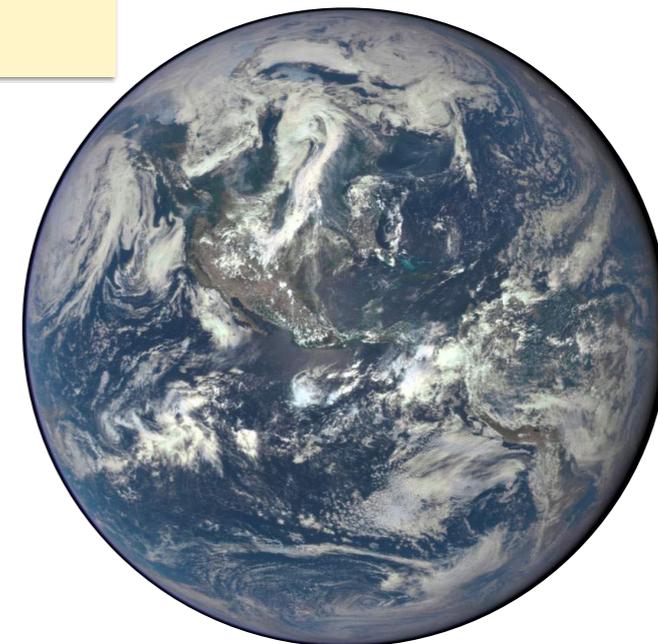
High-level Science Questions
(Overview, State-of-the-Art,
Constraint Types, Next Decades)



Observables

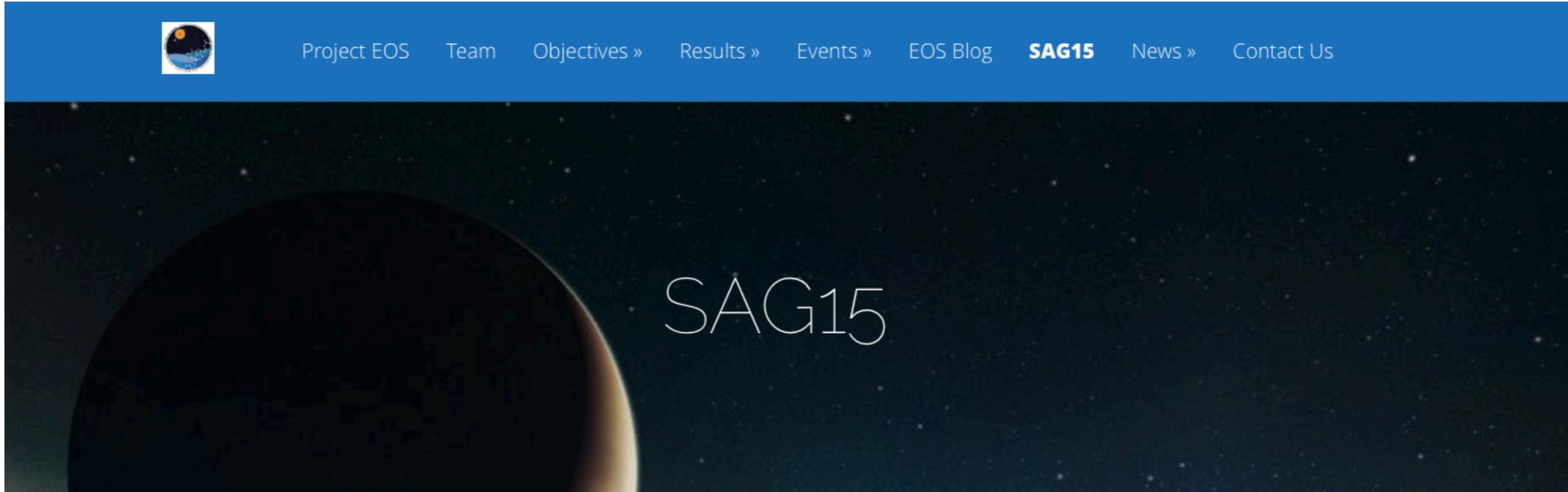


Required Data Type/
Quality





Website: eos-nexus.org/sag15



This page provides status reports and documents in support of the development of the [EXOPAG](#) Study Analysis Group 15: Science Goals from Direct Imaging Missions.

The SAG15 study is led by [Daniel Apai](#) (University of Arizona). The SAG15 team is charged with studying high-level science questions that can be answered by direct imaging studies of exoplanets and identifying the type and quality of data these studies require. The SAG15 study does not focus on any particular telescope architecture or observational method, but on the fundamental science questions.

This page provides a summary of the SAG15 study and status updates. The SAG15 study is voluntary and open to all members of the exoplanet, EXOPAG, NExSS communities.

If you would like to contribute to SAG15 or have comments/questions on the draft report, please, email to Daniel Apai (apai@arizona.edu).

SAG15 Report Drafts:

[SAG15 Report Draft, 2nd December 15, 2016](#)

[SAG15 Report Draft, December 15, 2016](#)

[SAG15 Draft Report, December 14, 2016](#)

[SAG15 Draft Report, November 15](#)

Science Questions and Data Requirements for Direct Imaging Exoplanet Missions

	Science Questions	Targets	Data Type and Quality
Planetary System Properties	A1 Planetary System Diversity <i>What is the Diversity of Exoplanetary Architectures?</i>	Statistical Studies of Planetary Systems	1) Multi-epoch Imaging: Planetary Orbits 2) Phot/Spec/RV/Astrom: Planet Masses
	A2 Planetsimal Belts and Exo-Zodi Disks <i>What are the properties of planetesimal belts and exo-zodiacal disks and how do they probe the formation and dynamical evolution of planetary systems?</i>		1) O/IR Imaging: Locations of Dust Belts 2) Planet masses and orbits (RV, Astrom.)
Planet Properties	B1 Rotation and Obliquity <i>How do rotational periods and obliquity vary with orbital elements and planet mass/type?</i>	Studies of Individual Planets	1) Time-Resolved Phot/Spec 2) High-Res Spec. for Rotational Period 3) Light curves at Multiple Orb. Phases: Obliquity
	B2 Rocky Planets with Liquid Water <i>Which rocky planets have liquid water on their surfaces?</i>		1) Time-Resolved Obs: Ocean Glint 2) Rotational Mapping: Oceans 3) Water Line Spectroscopy
	B3 Aeorols and Composition in Giant Planets <i>What are the origins and composition of clouds and hazes in ice/gas giants and how do these vary with system parameters?</i>		1) Low-res., broad range spectroscopy 2) Time-resolved Photometry for Cloud Mapping 3) Optical/Near-IR Colors
	B4 Terrestrial Planets Atmospheric Composition <i>How do photochemistry, transport chemistry, surface chemistry, and mantle outgassing affect the composition and chemical processes in terrestrial planet atmospheres?</i>		1) Low-res., broad range spectroscopy 2) Optical/Near-IR colors 3) Planet masses and orbits
Planetary Processes	C1 Atmospheric Circulation <i>What processes/properties set the modes of atmospheric circulation and heat transport in exoplanets and how do these vary with system parameters?</i>	Statistical Studies of Groups of Planets	1) Multi-epoch, moderate to high-res. NIR spectroscopy
	C2 Rocky Planet Evolution <i>What are the key evolutionary pathways for rocky planets?</i>		1) Atmospheric Characterization (B4)
	C3 Geological Activity <i>What types/which planets are geological active, have interior processes, and/or continent-forming or resurfacing processes?</i>		1) Atmospheric Characterization (B4) AND 2) Surface mapping (B2) 3) Planet Mass (RV or astrom.)



Join us!

We need further help with completing our answer to:

- 1) What quality data are needed for the science questions?
- 2) How large samples are needed for the science questions?



Summary

- SAG15 on track, close to completion in Spring 2017
- A refereed version and/or a shorter overview version planned
- Would like to contribute? Please contact me: apai@arizona.edu

