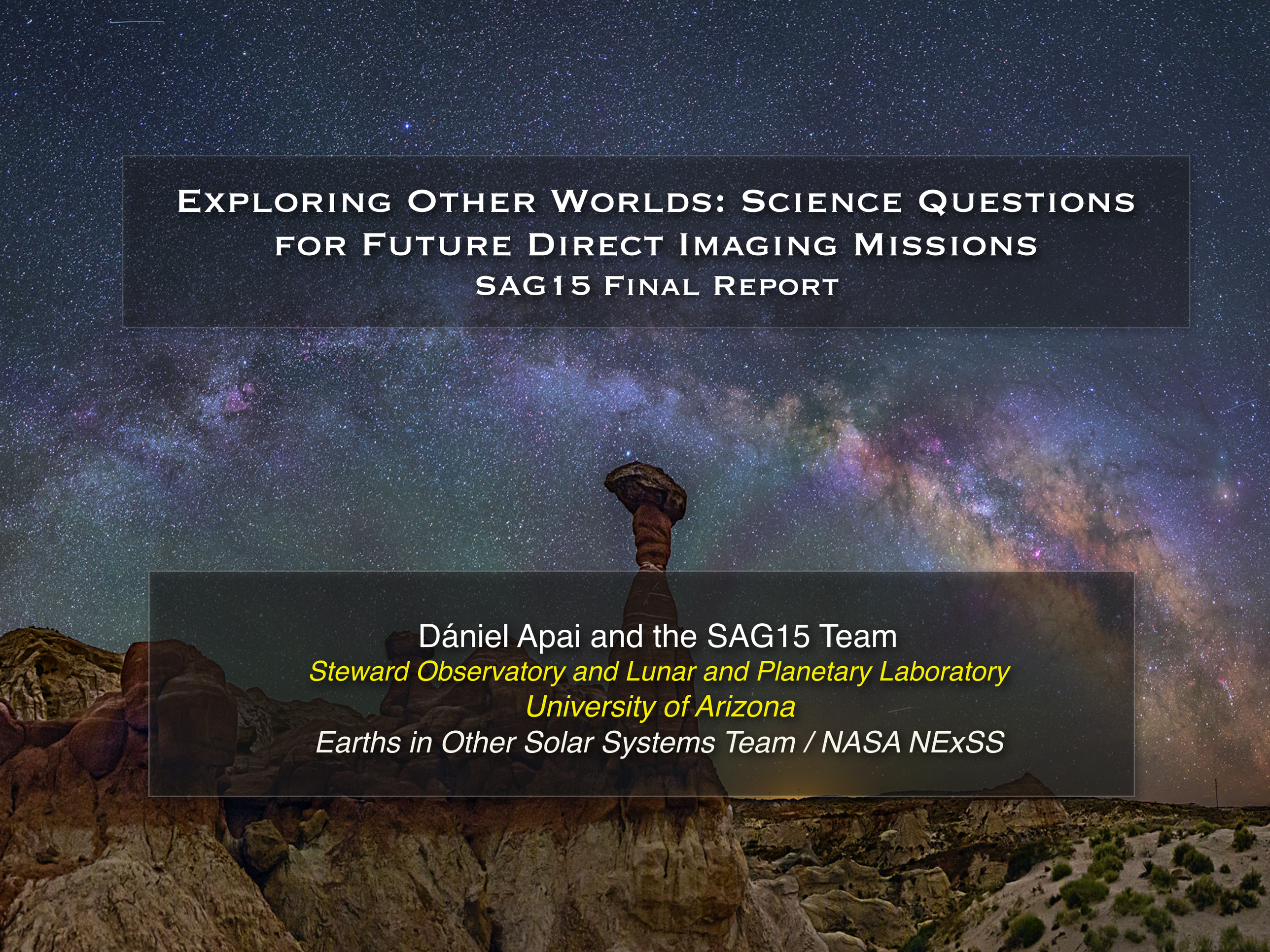
Exploring Other Worlds: Science Questions for Future Direct Imaging Missions

SAG15 Final Report



Dániel Apai and the SAG15 Team

Steward Observatory and Lunar and Planetary Laboratory

University of Arizona

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 (~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

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Approved in October 2015
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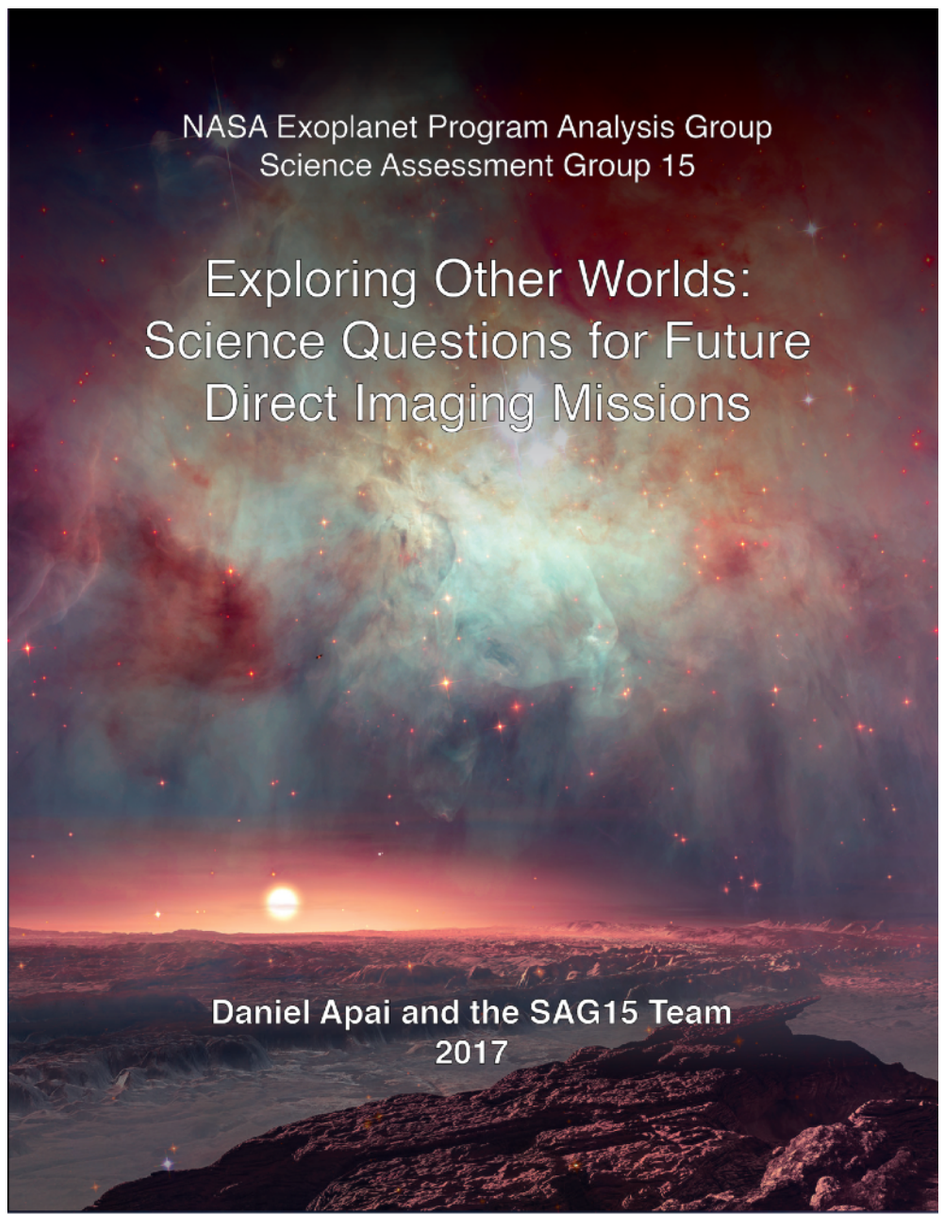
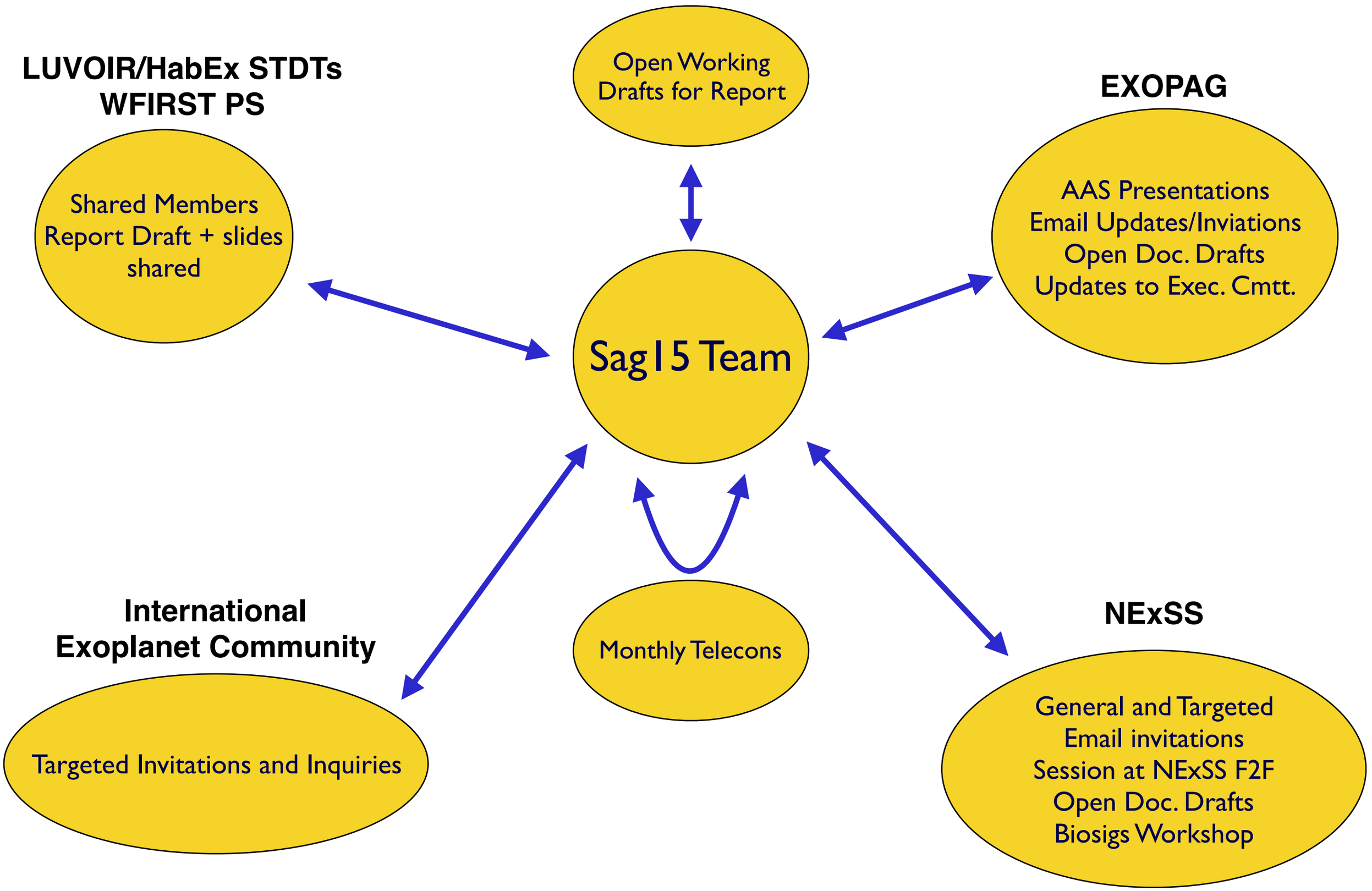
Status: Completed, ready for submission to EXOPAG

1) Collaborated on 31 incremental drafts, 11 telecons
2) Scope slightly extended
3) "Advanced draft" circulated in Oct 2016
4) "Near-final draft" circulated May 2017
5) Final version: 99 pages, 275 references

Next step: Summary version for submission to peer-reviewed journal (Nature Astronomy?)



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 progess
- Emails sent to the NExSS group and EXOPAG groups

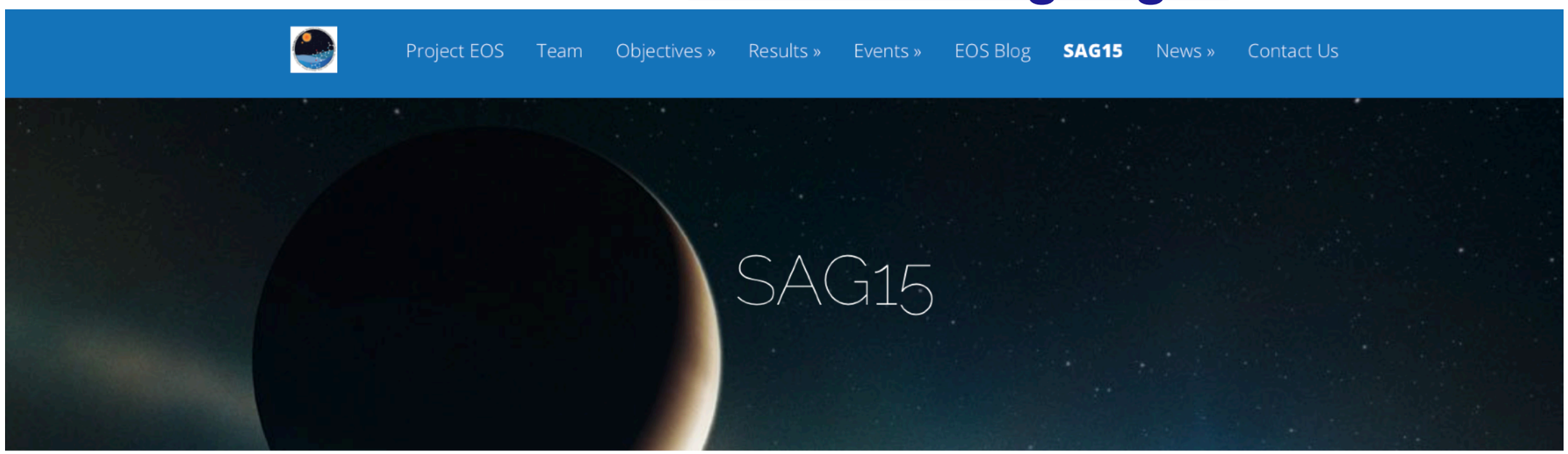
Status updates provided to the EXOPAG community at every AAS meeting during the project:
- Presentation/hackathlon session during the NExSS Face-to-Face meeting in May 2016
- Representatives of the LUVOIR and HabEx STDTs on the SAG15 team and attended telecons
- The up-to-date version of the SAG15 report 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 hackathlon 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 Near-final draft was circulated in May 2017 in the SAG15 group.

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.

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.

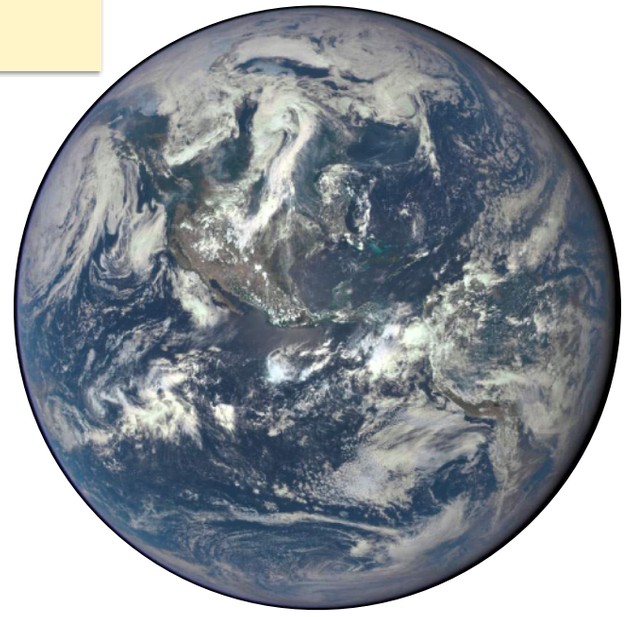
If you would like to contribute to SAG15 or have comments/questions on the draft report, please, email to Daniel Apai (apai@arizona.edu).

Overview of the Science Questions identified in SAG15

SAG15 Report: SAG15 Report, June 18, 2017

Content and Organization of the Report

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



Observables

Required
Data Type

Science Questions and Required Data for Direct Imaging Exoplanet Missions

	Science Questions	Targets	Data Type and Quality
Planetary Sys. Properties	A1 Planetary System Diversity	**Statistical Studies of Planetary Systems**	1) Multi-epoch Imaging: Planetary Orbits 2) Phot/Spec/RV/Astrom: Planet Masses
Planetary Sys. Properties	A2 Planetsimal Belts, Exo-Zodi Disks, Formation of Planetary Systems?	**Statistical Studies of Planetary Systems**	1) O/IR Imaging: Locations of Dust Belts 2) Planet masses and orbits (RV, Astrom.)
Planet Properties	B1 Rotation and Obliquitiy	**Studies of Individual Planets**	1) Time-Resolved Phot/Spec 2) High-Res Spec. for Rotational Period 3) Lightcurves at Multiple Orb. Phases: Obliquity
Planet Properties	B2 Which Rocky Planets have Surface Liquid Water?	**Studies of Individual Planets**	1) Time-Resolved Obs: Ocean Glint 2) Rotational Mapping: Oceans 3) Water Line Spectroscopy
Planet Properties	B3 Aerosols and Composition in Giant Planets	**Studies of Individual Planets**	1) Low-res., broad range spectroscopy 2) Time-resolved Phot. for Cloud Mapping 3) Optical/Near-IR Colors
Planet Properties	B4 Terrestrial Planets Atmospheric Composition	**Studies of Individual Planets**	1) Low-res., broad range spectroscopy 2) Optical/Near-IR colors 3) Planet masses and orbits
Planetary Processes	C1 What Processes/Properties Influence Atmospheric Circulation?	**Statistical Studies of Groups of Planets**	1) Multi-epoch, moderate to high-res. NIR spectroscopy
Planetary Processes	C2 Key evolutionary pathways for rocky planets?	**Statistical Studies of Groups of Planets**	1) Atmospheric Characterization (B4) 2) Planet Mass
Planetary Processes	C3 Geological Activity/Interior Processes	**Statistical Studies of Groups of Planets**	1) Atmospheric Characterization (B4) AND 2) Surface mapping (B2) 3) Planet Mass (RV or astrom.)

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EXOPAG/SAG15 Team and Daniel Apai / Univ. Arizona

Science Questions and Required Data for Direct Imaging Exoplanet Missions

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

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EXOPAG/SAG15 Team and Daniel Apai / Univ. Arizona

Summary

- SAG15 report completed, available from website
- A refereed/shorter overview version planned

- Thanks to main contributors:
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