Exoplanet Program Analysis Group Report.

Astrophysics Subcommittee Meeting
March 17, 2015

Scott Gaudi
(Outgoing ExoPAG EC Chair)

Current EC Membership.

Rus Belikov	NASA Ames
Nick Cowan	Amherst College
Jonathan Fortney	U.C. Santa Cruz
Scott Gaudi (*Chair)*	Ohio State
Dave Latham	SAO
Amy Lo	Northrop Grumman
Peter Plavchan	Missouri State U.
Gene Serabyn	JPL
Remi Soummer	Space Telescope Sci. Inst.
Maggie Turnbull	Global Science Institute
Lucianne Walkowicz	Adler Planetarium
Doug Hudgins (*Ex officio)*	NASA Headquarters
Wes Traub (*Ex officio)*	JPL

Future EC Membership.

Alan Boss (Chair)	Carnegie DMT
Rus Belikov	NASA Ames
Nick Cowan	Amherst College
Amy Lo	Northrop Grumman
Peter Plavchan	Missouri State U.
Gene Serabyn	JPL
Maggie Turnbull	Global Science Institute
Lucianne Walkowicz	Adler Planetarium
Martin Still (*Ex officio)*	NASA Headquarters

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Three new EC members
New ExEP Program Chief Scientist (Ex officio)

ExoPAG Meta-goal:

Develop a holistic, broad, unified, and coherent exoplanet plan for the next decade, with community consensus, focusing on areas where NASA can contribute.

Methods & Activities.

- Solicit community input through ExoPAG meetings.
- Identify questions and inquiry areas.
- If needed, form Study Analysis Groups (SAGs) or Science Interest Groups (SIGs) to address these questions in depth.
  - Chaired by EC members (generally), but comprised of community members.
- Deliver conclusions and community input to NASA through the Astrophysics Subcommittee (APS) of the NASA Advisory Council (NAC).
  - Includes final reports from SAGs.

ExoPAG 6, 7, 8, 9, 10, 11.

- Since June 2012:
  - ExoPAG 6: October 13-14, 2012, Reno, NV
  - ExoPAG 7: January 5+6, 2013, Long Beach, CA
  - ExoPAG 8: October 5+6, 2013, Denver, CO
  - ExoPAG 9: January 4+5, 2014, Washington, DC
  - ExoPAG 10: June 6, 2014, Boston, MA
  - ExoPAG 11: January 3+4, 2015, Seattle, WA

- Primary topics/questions addressed:
  - What is the landscape of current and future missions?
  - What are the radial velocity requirements to support NASA's goals and current and future missions?
  - What do we need to characterize exoplanets and their host stars?
  - Progress toward a high-contrast imager in space.
  - What do we need to do to prepare for WFIRST-AFTA exoplanet surveys?
  - What do we need to do to ensure a robust measurement of η_{Earth}?
  - What is the potential of JWST to characterize transiting planets?
  - "What Do We Need to Know About Exoplanet Host Stars?"

- (most) Talks available online:

  http://exep.jpl.nasa.gov/exopag/exopag#/agenda/

ExoPAG 11.

- Closed out two SAGs.
- Introduce potential new topics for study through SAGs.
- Mini-Workshop on “What Do We Need to Know About Exoplanet Host Stars?”
- Joint COPAG/ExoPAG Meeting.
- Started planning for the next decadal!
  - Started the SIG1 discussion.
  - Discussed the Hertz charge to PAGs.

What we've learned.

- Continued investment in extracting science from Kepler is both worthwhile and critical.
- The telescope time needed for precision RVs to support NASA missions (Kepler, K2, TESS, WFIRST-AFTA, future flagship mission) will far exceed available resources.
- The frequency of habitable planets is not one number; need to specify distribution functions and/or agree upon a fiducial definition for a habitable planet.
- Need to determine overlap of RV surveys and ground-based direct imaging surveys with potential future direct imaging (space) missions.
- Need to determine what is needed to characterize exoplanets; need to figure out whether or not JWST can characterize habitable planets.
- Need to identify the future roles of astrometry and interferometry.

Completed SAGs.

SAG1: Debris Disks & Exozodiacal Dust – Aki Roberge

- Report completed; paper published in PASP, 2012, 124, 799–808

SAG2: Potential for Exoplanet Science Measurements from Solar System Probes – Dave Bennett and Dan Coulter

- Completed, no report. Topic explored in detail at Kavli Institute workshop, Santa Barbara CA, May 2010

SAG5: Exoplanet Flagship Requirements and Characteristics– Charley Noecker, Tom Greene

- Final report complete, approved by APS, arXiv:1303.6707

SAG11: Preparing for the WFIRST microlensing survey (Jennifer Yee, Chair)

- Final report complete, approved by APS, arXiv:1409.2759

Active SAGs.

- **SAG8: Requirements and Limits of Future Precision Radial Velocity Measurements** (Dave Latham, Peter Plavchan, co-Chairs)
  - Final oral report at ExoPAG 11.
  - Circulate written report to the community early February.
- SAG9: Exoplanet Probe to Medium Scale Direct-Imaging Mission Requirements and Characteristics (Rémi Soummer, Chair)
  - Scope revised, final report this year.
- **SAG10: Characterizing the Climate of Transiting Planets with JWST and Beyond** (Nick Cowan, Chair)
  - Final oral report at ExoPAG 11.
  - Written report circulated, will be submitted to arXiv, APS in the next few months.
- SAG12: Scientific Potential of High-Precision Astrometry for Exoplanet Detection and Characterization (Eduardo Bendek, Chair)
  - Kick off discussion at ExoPAG 11.

SIG #1: Toward a Near-Term Exoplanet Community Plan.

The goal of this Science Interest Group is to begin the process of developing a holistic, broad, unified, and coherent plan for exoplanet exploration, focusing on areas where NASA can contribute. To accomplish this goal, the SIG will work with the ExoPAG to collect community input on the objectives and priorities for the study of exoplanets. Using this input, it will attempt develop a near term (5-10 year) plan for exoplanets, based on the broadest possible community consensus. The results of this effort will serve as input to more formal strategic planning activities that we expect will be initiated after the mid-decadal review, in advance of the next decadal survey.

Introductions at ExoPAG 8+9, sessions at ExoPAG 10 + 11, one stand alone meeting (February 10+12, 2015).

Characterizing Transiting Planet Atmospheres through 2025

N.B. Cowan, T. Greene et al. (ExoPAG SAG-10)

- JWST will characterize the atmospheres of dozens of short-period planets with transits, eclipses & phases
  - A dedicated survey mission is necessary to obtain transit spectra for the hundreds-thousand of bright TESS hot Jupiters and warm sub-Neptunes
- JWST will provide tantalizing constraints on a few HZ rocky planets transiting M-Dwarfs
  - Future flagship missions must be able to constrain the habitability of these worlds

Summary of PRV support for NASA mission science objectives

Mission	Target identification for mission science yield optimization	Follow-up validation & characterization of low mass transiting exoplanets	Exoplanet mass & orbit determination
Kepler		✓	✓
TESS	✓	✓	✓
JWST	✓	✓	✓
AFTA/Coronagraph/ probe direct imaging	✓		✓
Future Flagship direct imaging	✓		✓

SAG 8 Conclusions

P. Plavchan, D. Latham. (ExoPAG SAG-8)

- The demands on telescope time for NASA mission support, especially for systems of small planets, will exceed the number of nights available using instruments now in operation by a factor of at least several for TESS alone.
- A **~50 cm/s visible spectrographs on 4-meter class telescope** offers the capability for the identification of Neptune-mass and larger exoplanets for Exo-C/S direct imaging.
- Additionally**, a ~5 cm/s visible spectrograph capability on a 10-m class telescope** could enable the detection of Earth analogs for a future flagship direct imaging mission.
- Minimum survey durations of ~15 years will be necessary (either due to orbital period or photons), requiring a **long-term survey commitment and investment** for both the survey and follow-up of candidate exoplanets.
- Stellar jitter is a limiting factor in RV surveys today, but a number of approaches show promise, including increased wavelength coverage, increased spectral resolution, increased cadence, and simultaneous photometric monitoring.

Recent and Upcoming Developments.

1. WFIRST-AFTA moving full steam ahead, with coronagraph baselined, final report complete.
2. Science and Technology Definition Teams final reports complete.
3. Kepler reaches end of its primary mission; future: primary mission closeout + K2.
4. Gaia, JWST, TESS, CHEOPS, PLATO are here or imminent.
5. NSF/NASA Radial Velocity Initiative.
6. Mid-decadal and next Decadal Review.
7. Hertz “Large Mission” charge.

ExoPAG's Response to Paul's "Large Mission" Charge.

- The ExoPAG had already initiated the process of building consensus for an "Exoplanet Roadmap" through the SIG #1 activities.
- The ExoPAG will respond to Paul's charge under the auspices of this SIG.

Inputs to date.

- Talks, brainstorming, and discussion at ExoPAGs 8, 9, 10, 11, and stand-alone meeting.
- NASA Astrophysics Roadmap.
- Solicited (and unsolicited) input from a several dozen members of the community.

SIG #1 Meeting
Collated Suggestions

Suggestions
how: can we construct candidate list for target list (from RV, or do we need astrometry)
how: dedicated precision radial velocity instrument on 10m-class telescope
how: false positives (strategy for screening)
how: high-resolution UV spectrograph instrument with capabilities much greater than HST.
how: Optical and IR spectroscopic instruments on Spitzer, JWST, and future large space missions
how: probability of a rocky planet in HZ actually being habitable (define as potentially habitable)
how: TPF-I as a capstone mission
how: transit characterization mission
how: understand the astrophysical limits of precision radial velocity, high resolution, large aperture, optical + near-IR
how: unresolved Doppler shift spectra?
how: what are the true capabilities for ground-based VLTs for direct imaging?
how: what is Eta_Earth? Or at least assume for mission designs
how: what will ELTs do for HZ earths orbiting M stars?
how: yield goal (how many stars do we need to look at)
how: 2015 is too early to be presuming anything about mission size, narrow down after considering all of the options
how: a large ($8B-$10B) mission will be dead on arrival for 2020-2030, due to "JWST hangover", need to consider alternatives
how: a mission must do direct spectroscopy of earth analogs to be relevant when launched, need to start now for US leadership role
how: boost R&A grants by a factor of ~3
how: bring in planetary scientists
how: Can we sell a mission that doesn't look for and characterize Earth-like planets?
how: consider aperture as metric for comparison with other science
how: convince the entire community (get observing time)
how: dedicated exoplanet Explorer ($300-$400M) program every few years, allows one to be nimble
how: develop a consensus program with a modest flagship plus modest “Probe” class options
how: develop a menu of options of increasing costs and capabilities: occulter for WFIRST/AFTA -> 4-m class -> 12-16-m class.
how: direct imaging mission: go as big as possible, without creating a budget crises (starving R&A)
how: direct imaging mission: where to set the bar for the minimum justifiable science, is that affordable?
how: discuss with COPAG
how: don't put all our eggs in the "spectra of Earth-twin" to sell a mission
how: don’t constrain the budget too much early on (let the science lead, then marshal resources to that goal)
how: even a dedicated mission can be tuned to various science programs, and incorporate other science goals
how: exoplanet community must unite behind WFIRST-AFTA + coronagraph
how: Far IR surveyor, LUVOIR surveyor, Habitable Exo-planet Imaging Mission, X-ray surveyor
how: go for big goal, or make sure you also harvest all of the low hanging fruit (how do you prioritize)
how: how do we allocate observing time between science objectives?
how: how do we not become a non-fractured community?
how: how to avoid mission creep (assess needs)
how: how to get mission selected (engage entire community early on)

SIG #1 Meeting
Collated Suggestions

how: large DI mission questions: launch vehicle? UV+coronagraph compatibility? Starshade viable, and demonstrable?
how: major missions: have to demonstrate that they are capable of a broad range of science
how: make sure the dedicated technology advances other (broader) science
how: maximize probability of actually flying a mission
how: national or agency priority (get buy in from entire agency)
how: need an intermediate mission category ($500M - $1B), enable an image-based astrometry or transit spectroscopy mission?
how: not realistic to do spectroscopy of exo-Earths using an internal coronagraph
how: probes are cost-capped, not science constrained
how: put all of our eggs in one basket for a large flagship mission, or study more affordable 2-4m missions
how: serving the entire community, time needs, yield goal
how: support theoretical models on planet formations, atmospheres, climate, bio-signatures, etc.
how: technology for 10^-10 contrast imaging with segmented apertures appears unlikely to be ready in time for Astro2020
how: viability: technology, multiple communities, other science mission can do
how: what missions do we recommend for technology development
how: when is the next flagship mission?
what: K2,TESS, PLATO, GAIA: precision radial velocity follow-up
what: earth analogs: R=100 spectroscopy, 30 magnitude objects, 0.2” from a 5th magnitude star.
what: find Rosette stone planets that tie together the different characterization techniques
what: fundamental parameters of the star (ages)
what: get orbits of the planet (eccentricity), ensure they stay in HZ, etc.
what: host star parallaxes, astroseismology
what: how much risk do we accept when searching for habitable planets
what: is Kepler + WFIRST a good enough survey, or do we need an other mission?
what: look at planets that are not habitable (is the census from WFIRST and Kepler enough)
what: mass loss rates from exoplanet host stars
what: Measure compositions of exoplanet atmospheres, build robust codes to understand the physical and chemical processes
what: measurements of the UV, extreme-UV, and X-ray
what: need spectra of stars (UV), for stellar environment
what: need UV measurements of planetary systems
what: planet formation imager? Mid- to far-IR for young systems
what: precision RV census and masses of planets orbiting the closes FGKM stars for potential HZ targets for DI mission
what: tie habitable planets to those with direct imaging (M-dwarfs); be smart about what has been done from transit searches
what: to understand climate, need mid IR (to confirm habitability and surface temperature)
what: wavelengths do we absolutely have to have, for habitability, and what Resolution
why: Are specific exoplanets habitable?
why: are we alone?
why: characterize exoplanets and solar system planets: interiors, compositions, radii, bulk metallicity, P-T profile, magnetic fields
why: characterizing systems (not just a single planet), Exo-Zodi, dynamics, disks, holistic understanding of the full planetary system
why: comparative planetology

SIG #1 Meeting
Collated Suggestions

why: demographic measurements of planets, host stars and host environments
why: Eta_* other planet types (not just Earths) (Hot Earth, super-Earth, etc.) Get also from WFRIST and Kepler
why: Exo-planet science also doesn't end with a single spectra of an Earth-twin
why: go smaller and smaller, ultimately characterize, biology
why: how do exoplanets form?
why: how do planet system form? (formation and evolution, this is part of cosmic origins)
why: how does planet atmosphere depend on star, formation, evolution
why: language: use broader language than Earth-twin, or planet. Use planetary system, characterize Earth-like planets, etc.
why: leverage from diversity (need to characterize more than just a bunch of Earths)
why: properties of host stars: demographics, masses, radii, ages
why: put Earth in context, not just search for Earth-twin
why: search for habitable conditions is primary, and actually finding Earth-like comes after
why: synergy with planetary science
why: understand all planets as a species
why: understand atmosphere is important to understand habitability (chemistry and processes)
why: understand habitability planets as a system (geology, integration of the entire planet)
why: understanding exoplanets in general in order to inform our understanding of habitable zone planets
why: what are exoplanets like?
why: what are the architectures of multi-planet systems?
why: what are the demographics of moons, belts, cometary systems, and protoplanetary debris disks?
why: what are the environments of planets in the universe and over cosmic time?
why: what happens to habitable planet when star goes off main sequence
why: what is habitability mean (not just Earth-like), what are the implications for bio-signatures
why: what planets are out there?
why: where is the closest habitable, earthlike zone planet?

SIG #1 Stand-alone Meeting

- February 10+11, 2015 at JPL.
- Roughly 45 people attended in person and remotely.
- Talks, break-out sessions, brainstorming and group discussions.
- Afternoon of February 11 devoted to Paul's charge.
- Consensus building.
  - Start the process of developing a consensus on Whys and Whats.
- Define path forward.
  - Identify questions and topics for future discussions.

Takeaways.

1. There was a general consensus that a broad range of apertures and architectures for direct imaging missions should be studied, encompassing both the nominal concepts of the HabEx and LUVOIR missions.

2. There were discussions about how the STDT or STDTs that study these direct imaging missions should be organized. There was a diversity of opinions as to whether there should be completely separate teams for HabEx and LUVOIR (including separate science and design teams), or a joint science team with two design teams, or one science and one design team.

3. There was discussion about whether we should attempt to prioritize the various direct imaging mission concepts, or whether we are even capable prioritizing those missions.

Notional Timeline.

- January 2014: Initial discussion at ExoPAG 9.
- March 2014: APS approves SIG #1.
- June 2014: Brainstorming session at ExoPAG 10.
- January 2015: Brainstorming session at ExoPAG 11, Paul's charge.
- February 2015: First dedicated SIG #1 Meeting, brainstorming & consensus building.
- March 2015: Joint PAG EC meeting.
- April–May 2015: SIG #1 telecons.
- June 2015: Consensus building at ExoPAG 12.
- July–September 2015: Telecons, stand-along meeting (?), writing, circulating, finalizing report(s?).
- October 2015: Deliver Hertz report to APS.
- November–December 2015: Circulate and finalize SIG #1 report.
- January 2016: Deliver final SIG #1 report at ExoPAG 13.

Future.

- ExoPAG12:
  - Hilton Chicago,
  - June 13+14, 2015
  - Weekend before AbSciCon
- SIG #1/Hertz Charge activities
  - I will stay on the ExoPAG as an Ex Officio member to guide the SIG #1/PH Charge activities through completion.
  - Virtual meetings
  - ExoPAG 12
  - Stand alone meeting (?)
- Let us know if you have input, or would like to contribute to these efforts!
- Email me: gaudi@astronomy.ohio-state.edu
- More information on website, including email list:

http://exep.jpl.nasa.gov/exopag/