Summary of ExoPAG's Activities in Response to Paul's Charge

Joint Session of the Program Analysis Group
XXIX IAU General Assembly
August 7, 2015

Scott Gaudi
(SIG#1 Chair)

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 has been working to respond to Paul's charge under the auspices of this SIG.

ExoPAG 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 to 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 near the end of the decade in advance of the next decadal survey.

Goal of SIG#1.

- Maximize the the opportunities for exoplanets in the next 10–20 years via consensus building and strategic planning.
- Specific goals:
  - The SIG identifies a holistic, broad, unified, and coherent plan for exoplanet exploration, focusing on areas where NASA can contribute.
  - Recommendation includes Science (“why”), Measurements (“what”), and Missions/Ground Instruments/ Programmatics (“How”)
  - Enthusiastically supported by the ExoPAG, NASA Centers, astronomical community.
  - (Response to Paul Hertz’s charge by October 2015)
  - SIG1 preliminary report completed by end of 2015 (?).

Timeline/Meetings for SIG #1

- 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.
- February 2015: First dedicated SIG #1 Meeting
- June 2, 2015: ExoPAG Virtual Meeting #1
- June 13-14, 2015: ExoPAG #12 (Chicago) – ExoPAG
- July 14, 2015 – ExoPAG Virtual Meeting #2
- August 18, 2015 – ExoPAG Virtual Meeting #3

Inputs to date.

- Talks, brainstorming, and discussion at ExoPAGs 9, 10, 11, 12, one stand-alone meeting, and two virtual meetings.
- NASA Astrophysics Roadmap.
- Solicited (and unsolicited) input from a several dozen members of the community.
- COPAG White Papers
- COPAG, PhysPAG, and SIG Meetings.

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?

Exoplanet Exploration: ExoPAG Input into the 2020 Decadal Survey and Large Mission Studies

ExoPAG Input into the 2020 Decadal Survey and Large Mission Studies

Virtual Meetings | Face-to-Face Meetings | Science Division Documents | Supporting Documents | Links

Paul Hertz (NASA Astrophysics Division Director) has charged the three Astrophysics Program Analysis Groups (PAGs) with reviewing a small set of candidate large mission concepts, and suggesting addition, subtraction, and other useful summary. The results of this review will be reported at the NASA Advisory Council Subcommittee meeting in October in the form of a report. This page provides information on the charge and the ExoPAG's plans for responding to this charge and creating this report.

The ExoPAG will respond to this charge in the context of its Science Interest Group #1 activities, as described in the following charter:

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

The ExoPAG is soliciting input from the community through three primary methods:

- Direct input to the SIG #1 chair Scott Gaudi: gaudi.1@osu.edu.
- Virtual Meetings
- Face-to-Face Meetings

The COPAG is also soliciting white papers and are happy to receive white papers from the ExoPAG community: http://cor.gsfc.nasa.gov/copag/rfi/

NASA's Charge to the PAGs.

"I am charging the Astrophysics PAGs to solicit community input for the purpose of commenting on the small set [of large mission concepts to study], including adding or subtracting large mission concepts."

Detailed Charge, Part 1.

1. Each PAG, under the leadership of its Executive Committee, shall broadly solicit the astronomy and astrophysics community for input to the report in an open and inclusive manner.
   - To accomplish this, each PAG is empowered to envision and use its own process.
2. Each PAG will consider what set of mission concepts should be studied to advance astrophysics as a whole; there is no desire for mission concepts to be identified as "belonging" to a specific Program or PAG.
   - Each PAG shall keep the number of large mission concepts in the set as small as possible.
   - Each PAG is specifically charged to consider modifications and subtractions from the small set, and not just additions.
3. Each PAG shall produce a report, where it shall comment on all large mission concepts in its small set of large missions, including those in the initial small set and those added or subtracted.
   - The PAGs may choose to work together and submit coordinated or joint reports.
   - Where there is existing analysis to support it, PAGs are encouraged to comment on the cost range anticipated large mission concepts (>$1B? Maximum?)

Detailed Charge, Part 2.

4. Each PAG may choose to have a face-to-face meeting or workshop I in developing its report; said meeting may be scheduled in proximity to an existing community meeting or conference.
5. Although there is no page limit for the report, each PAG shall strive to be succinct.
6. Each PAG shall submit its report in writing no later than two weeks prior to the Fall 2015 meeting of the NAC Astrophysics Subcommittee (meeting schedule not yet known).

What is *not* in our charge.

1. Detailed science goals or requirements.
2. Detailed architectures or technology requirements.
3. Advocacy or Advice (rather: “Analysis”)
4. Prioritization of the suggested missions.
5. “Ownership” of any mission concept by any individual PAGs
6. Don’t attempt to prepopulate the STDTs (Note: these are likely to be competitively selected).

Timeline for Charge & STDTs.

- 2015:
  - Identify a small set of candidate large missions to study
  - PAG reports due by October 8, 2015 (Two weeks before APS meeting).
- 2016–2019:
  - Initiate studies.
  - Conduct studies.
  - Identify technology requirements
  - Deliver results to decadal survey.

Charge of the STDTs.

- Define science objectives and a strawman payload concept.
- Identify technology development requirements
- Develop a design reference mission.
- Conduct a cost assessment, with the possibility of iteration.
- Goal: *to maximize the potential of* ***all*** *of these missions.*

Initial list of missions.

Taken from NASA Roadmap (Surveyors) and Decadal Survey (HabEx)

- Far IR Surveyor
- Habitable-Exoplanet Imaging Mission
- UV/Optical/IR Surveyor
- X-ray Surveyor

Far-IR Surveyor

- Wavelength coverage: 25–500 μm in 6–8 log-spaced bands with R~500
- Monolithic telescope – diameter ~ 5 m.
- Telescope actively cooled to < 4 K, instruments cooled to <100 mK.
- Field of View = 1 deg at 500 μm
- Mission: 5 years + at Earth–Sun L2
- High-resolution (heterodyne) spectroscopy also compelling, possibly for warm phase.

Habitable-Exoplanet Imaging Mission

- Aperture: <~8m likely
  - Monolithic or segmented primary
- Two primary science goals:
  - Direct imaging of Earthlike planets.
  - Cosmic origins science enabled by UV capabilities.
  - Architecture optimized for exoplanet direct imaging, cosmic origins is also considered baseline science.
- ExoEarth detection and characterization:
  - Needs $\sim 10^{-10}$ contrast
  - Coronagraph and/or starshade
  - Camera
    - Optical and near-IR wavelength sensitivity for planet characterization
    - IFU, R>70 spectrum of 30 mag exoplanet
    - 1" FOV
- Cosmic Origins Science
  - UV-capable telescope/instrument suite: properties and wavelength range to be determined.
  - Would also enable constraints on the high-energy radiation environment of planets.
- Potential for an instrument for spectroscopic characterization of transiting planets.
- Orbit: L2 or Earth-trailing likely.

Large UVOIR Surveyor

- Aperture: ~8-16m likely
  - Likely segmented, obscured primary.
- Two primary science goals:
  - Direct imaging of Earthlike planets.
  - Broad range of cosmic origins science
- Cosmic Origins Science
  - HST-like wavelength sensitivity (FUV to Near-IR)
  - Suite of imagers/spectrographs, to be determined.
- ExoEarth detection and characterization:
  - Needs ~10^{-10} contrast
  - Coronagraph (likely), perhaps with a starshade
  - Camera
    - Optical and near-IR for planet characterization.
    - IFU, R>70 spectrum of 30 mag exoplanet
    - 1” FOV
- Orbit: L2 likely

X-ray Surveyor

- Effective area ~3 m^2
- Sub-arcsecond angular resolution
- High-resolution spectroscopy (R ~ few x 10^3) over broad band via micro-calorimeter & grating spectrometer instrumentals
- FOV $\gtrsim$ 5'
- Energy range ~0.1–10 keV

Topics of Discussion.

- Joint PAG Reports?
  - Joint summary.
  - Joint table.
- Should we add any missions?
- Should we subtract/merge any missions?
- Should we study the full range of exoplanet direct imaging architectures?
- How should we organize the STDTs for these missions?
- What non-exoplanet science can be done with smaller apertures (e.g., for HabEx)?
- What roles do the Far-IR and X-ray Surveyors play in exoplanet science?
- What do we say about probes?

ExoPAG Points of Consensus.

1. There was a general support for WFIRST with a coronagraph **and** a starshade.
2. 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.
3. There was a general consensus that there should be a common executive summary with the other PAG reports. It was agreed that the executive summary should include: a statement that we support these four missions being studied, a recommendation for probe studies, and suggestions for how STDTs should be organized (provided that the other PAGs are in agreement on these points).
4. There was a general consensus that a common table describing the nominal parameters of the four missions should be included in the PAG reports. These parameters are to be determined in future discussions with the ExoPAG and other PAGs.
5. There was a general consensus that we should neither add nor subtract from the four proposed mission concepts (HabEx, LUVOIR, X-ray Surveyor, and Far-IR Surveyor).

ExoPAG Points of Consensus, cont.

6. With regards to organization of the HabEx and LUVOIR STDTs, there was a general consensus on the following points:
   - There should be two separate science teams and two separate engineering and technology teams.
   - The science teams should have significant overlap (common members), and should include significant representation from the planetary science community.
   - We should express the following concerns in the report:
     - Exoplanets may get marginalized in the LUVOIR STDT if their representation is too small.
     - The general astronomical community may get fractured if the representation of disciplines is very different between the two STDTs.
   - Thus the members of the science teams should be carefully chosen to ameliorate these concerns.
   - The teams should meet periodically, including the kickoff meeting.
   - There should be a small, independent and unbiased team that is tasked to evaluate the science yield and technical readiness of both mission designs in a consistent and transparent manner.

ExoPAG Points of Consensus, cont.

7. There was a general consensus that probe-class (<~$1B) missions should be studied in advance of the next decadal survey, and that the following missions should be presented in the report as examples of possibly compelling probe-class missions.
   - A starshade for WFIRST-AFTA.
   - A transit characterization mission.
   - An astrometry mission.

ExoPAG Report to Paul Hertz Regarding Large Mission Concepts to Study for the 2020 Decadal Survey

August xx, 2015

Authors

Joint PAG Executive Summary

This is a joint summary of the reports from the three Astrophysics Program Analysis Groups (PAGs) in response to the charge given to the PAG Executive Committees by the Astrophysics Division Director, Paul Hertz, in the white paper "Planning for the 2020 Decadal Survey", issued January 4, 2015. This joint executive summary is common to all three PAG reports, and contains points of consensus across all three PAGs, achieved through extensive discussion and vetting within and between our respective communities. Additional information and findings specific to the individual PAG activities related to this charge are reported separately in the remainder of the individual reports. These additional findings are not necessarily in contradiction to material in the other reports, but rather generally focus on findings specific to the individual PAGs. We also present a table common to all three PAG reports that includes the range of nominal mission parameters and architectures for the missions suggested for further study

The PAGs concur that all four large mission concepts identified in the white paper as candidates for mission concept maturation prior to the 2020 Decadal Survey should be studied in detail. These include the Far-IR Surveyor, the Habitable-Exoplanet Imaging Mission, the UV/Optical/IR Surveyor, and the X-ray Surveyor. Other flagship mission concepts were considered, but none achieved sufficiently broad community support to be elevated to the level of these four primary candidate missions.

This finding is predicated upon assumptions outlined in the white paper and subsequent charge, namely that 1) major development of future large flagship missions under consideration are to follow the implementation phases of JWST and WFIRST; 2) NASA will partner with the European Space Agency on its L3 Gravitational Wave Surveyor, participate in preparatory studies leading to this observatory, and conduct the necessary technology development and other activities leading to the L3 mission, including preparations that will be needed for the 2020 decadal review; and 3) that the Inflation Probe be classified as a probe-class mission to be developed according to the technology and mission planning recommendations in the 2010 Decadal Survey report. The PhysPAG sought input on the mission size category for this mission and finds that it is appropriately classified as a Probe-class mission. If these key assumptions were to change, this PAG finding would need to be re-evaluated in light of the changes.

The PAGs find that there is strong community support for the second phase of this activity - maturation of the four proposed mission concept studies. The PAGs believe that these concept studies should be conducted by highly qualified scientists and technical experts assigned to the respective Science and Technology Definition Teams (STDTs). The PAGs find that the community is concerned about the composition of these STDTs and that there is strong consensus that all of the STDTs contain broad and interdisciplinary representation of the science community, and the most qualified technical experts. The PAGs also find that the community expects cross-STDT cooperation and exchange of information whenever possible to facilitate the sharing of expertise, especially in the case of the UVOIR Surveyor and the Habitable-Exoplanet

Imaging Mission, which share some science goals and technological needs. The PAGs concur that a free and open process should be used to competitively select the STDTs.

Finally, the PAGs find that there is community support for a line of Probe-class missions within the Astrophysics mission portfolio. The PAGs discussed different ways probe concept studies could be developed by NASA prior to the decadal review, and were in agreement that the probe category be developed for the 2020 Decadal Survey process. The PAGs would be willing to collect further input on probe missions from the community as a following strategic planning charge if asked to do so by the Astrophysics Director.

Far-IR Surveyor	Habitable-Exoplanet Imaging Mission	UV/Optical/IR Surveyor	X-ray Surveyor
• Wavelength coverage: 25-500 μm in 6-8 log-spaced bands with R~500 • Monolithic telescope – diameter ~ 5 m. • Telescope actively cooled to < 4 K, instruments cooled to <100 mK. • Field of View = 1 deg at 500 μm • Mission: 5 years + at Earth-Sun L2 • High-resolution (heterodyne) spectroscopy also compelling, possibly for warm phase.	• Aperture: <~8m likely • Monolithic or segmented primary • Two primary science goals: • Direct imaging of Earthlike planets. • Cosmic origins science enabled by UV capabilities. • Architecture optimized for exoplanet direct imaging, cosmic origins is also considered baseline science. • ExoEarth detection and characterization: • Needs ~10^{-10} contrast • Coronagraph and/or starshade • Camera • Optical and near-IR wavelength sensitivity for planet characterization • IFU, R>70 spectrum of 30 mag exoplanet • 1″ FOV • Cosmic Origins Science • UV-capable telescope/instrument suite: properties and wavelength range to be determined. • Would also enable constraints on the high-energy radiation environment of planets. • Potential for an instrument for spectroscopic characterization of transiting planets. • Orbit: L2 or Earth-trailing likely.	• Aperture: ~8-16m likely • Likely segmented, obscured primary. • Two primary science goals: • Direct imaging of Earthlike planets. • Broad range of cosmic origins science • Cosmic Origins Science • HST-like wavelength sensitivity (FUV to Near-IR) • Suite of imagers/spectrographs, properties to be determined. • ExoEarth detection and characterization: • Needs ~10^{-10} contrast • Coronagraph (likely), perhaps with a starshade • Camera • Optical and near-IR for planet characterization. • IFU, R>70 spectrum of 30 mag exoplanet • 1" FOV • Orbit: L2 likely	• Effective area ~3 m2 • Sub-arcsecond angular resolution • High-resolution spectroscopy (R ~ few x 103) over broad band via micro-calorimeter & grating spectrometer instruments • FOV ≥ 5′ • Energy range ~0.1-10 keV

Table 1: Notional Mission Parameters. These are the notional parameters of the four missions, developed through coordinated disucssions with and between the three PAGs. We emphasize that these parameters are notional: they are not meant to provide definitive or restrictive specifications for range of possible range of architectures to be studied by the STDTs. We encourage the STDT to consider architectures and parameters outside of those indicated here, in order to explore the full range of science goals, and maximize the science achievable by these mission for a given cost, schedule, and technological readiness.