Preparing for the 2020 Decadal Survey:

Summary of the ExoPAG's Response to Paul Hertz's Charge Regarding Large Missions

APS Meeting

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ExoPAG SIG#1 Chair

Paul’s Charge.

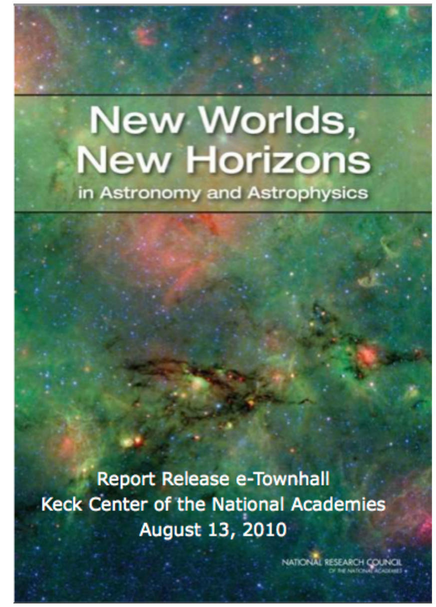
“I am charging the Astrophysics PAGs to solicit community input for the purpose of commenting on the small set [of large mission concepts to study], including adding or subtracting large mission concepts.”

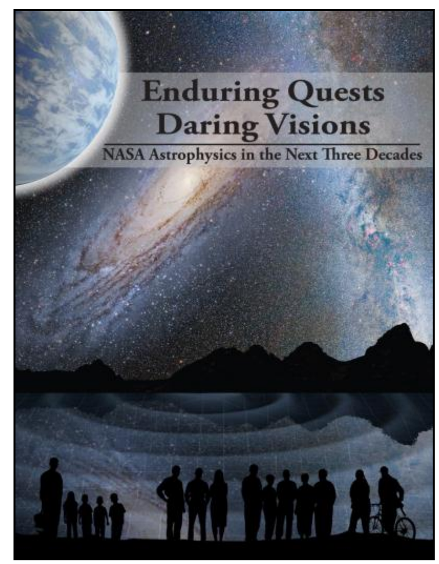
– Paul Hertz, January 4, 2015

Initial list of four missions.

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

- **FAR IR Surveyor** – The Astrophysics Visionary Roadmap identifies a Far IR Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.
- **Habitable-Exoplanet Imaging Mission (HabEx)**– The 2010 Decadal Survey recommends that a habitable-exoplanet imaging mission be studied in time for consideration by the 2020 Decadal Survey.
- **UV/Optical/IR Surveyor** –The Astrophysics Visionary Roadmap identifies a UV/Optical/IR Surveyor as contributing through improvements in sensitivity, spectroscopy, high contrast imaging, astrometry, angular resolution and/or wavelength coverage. The 2010 Decadal Survey recommends that NASA prepare for a UV mission to be considered by the 2020 Decadal Survey.
- **X-ray Surveyor** – The Astrophysics Visionary Roadmap identifies an X-ray Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.





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.

Focusing on the charge.

- Since January 2015, SIG#1 has focused on responding to Paul's charge.
- PAGs immediately agreed to coordinate:
  - EC members from all three PAGs met at STScI in April.
  - Agreed to have a joint executive summary, ~~table of notional mission parameters.~~
  - Substantial interaction and coordination, some contentious issues, but agreement on the primary conclusions.

Primary ExoPAG Sources of Input.

- 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.

Many meetings and telecons.

- January 2014: Initial discussion of SIG#1 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 10 2015: COPAG Virtual Town Hall
- March 19 2015: Joint PAG EC meeting.
- April 11-14 2015, Am. Phys. Soc. (Baltimore) - PhysPAG
- June 2, 2015: ExoPAG Virtual Meeting #1
- June 3-5 201: Far-IR Workshop - COPAG
- June 13-14 2015: ExoPAG #12 - ExoPAG
- June 25-26 2015: UV/Vis SIG Meeting, Greenbelt, MD - COPAG
- July 1 2015: panel discussion during the HEAD meeting - PhysPAG
- July 3 2015: joint PAG EC Chair telecon
- July 13 2015: joint PAG EC Chair telecon with Paul Hertz
- July 14 2015 - ExoPAG Virtual Meeting #2
- August 7 2015 - Joint PAG Splinter Session at IAU
- August 18 2015 - ExoPAG Virtual Meeting #3
- August 20 2015 - COPAG Virtual Town Hall
- August 31 2015, - Joint PAG Session at AIAA Meeting
- Now - September 18: Finalizing the report
- October 1 2015: Deliver report to APS
- October 22+23 2015: APS Meeting, Washington, DC

Joint PAG Points of Consensus.

- **The PAGs concur that all four large mission concepts should be studied.**
- This finding is predicated upon the assumptions outlined in the white paper and subsequent charge (e.g., the 2010 Decadal Survey priorities are realized).
- The PAGs find that there is strong community support for the maturation of the four mission concepts via science and technology definition teams (STDTs). There is strong consensus that all of the STDTs contain broad and interdisciplinary representation of the science community.
- The PAGs find that there is broad community support for a line of probe-class missions within the Astrophysics mission portfolio.

ExoPAG/COPAG Discussions.

Some vigorous but productive discussions amongst various ExoPAG and COPAG members:

The COPAG and ExoPAG concur that, in order to ensure broad support for the HabEx and LUVOIR missions within both the exoplanet and cosmic origins communities, significant science capabilities in both topical areas must be baselined for these missions.

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.

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

Exoplanet Exploration Program Analysis Group (ExoPAG) Report to Paul Hertz Regarding Large Mission Concepts to Study for the 2020 Decadal Survey - Draft 9/2/2015

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/

Notional Mission Science Goals, Measurement Requirements, and Architectures.

- Initially developed during joint EC meeting at STScI.
- Developed in further meetings.
- Notional!!!!! (Did I mention notional?)

“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 STDTs 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 missions given constraints on the cost, schedule, and technological readiness.”

Far-IR Surveyor.

Science Goals:

- History of energy release in galaxies: formation of stars, and growth of black holes.
- Rise of the first heavy elements from primordial gas.
- **Formation of planetary systems and habitable planets, study debris disks.**

Measurement Requirements:

- Spectral-line sensitivity better than 10^{-20} Wm^{-2} in the 25-500 micron band. (5 sigma, 1h)
- Imaging spectroscopy at R~500 over tens of square degrees.
- R~10,000 imaging spectroscopy of in thousands of z<1 galaxies and protoplanetary disks.
- High-spectral-resolution capabilities desired for Galactic star-forming systems and the Galactic Center.

Architecture and Orbit:

- Complete spectroscopic coverage at R~500 from 25-500 um.
- Monolithic telescope cooled to <4 K, diameter ~5 m.
- Field of View = 1 deg at 500 μm
- R~10,000 mode via etalon insert.
- Background limited detector arrays with few x 10^5 pixels, likely at T<0.1 K.
- Mission: 5 years+ in L2 halo orbit.
- High-resolution (heterodyne) spectroscopy under study, possibly for warm phase.

Habitable-Exoplanet Imaging Mission.

Science Goals:

- **Directly image Earthlike planets, and search for potential habitability.**
- **Place the Solar System in the context of a diverse set of exoplanets.**
- **Study and characterize protoplanetary disks.**
- Cosmic origins science enabled by UV capabilities; considered baseline science.

Measurement Requirements:

- Exo-Earth Detection:
  - $\sim 10^{-10}$ contrast
  - Coronagraph and/or starshade
  - Optical and near-IR camera for planet detection and 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.
  - Enable constraints on the high-energy radiation environment of planets.
- Possible instrument for spectroscopic characterization of transiting planets.

Architecture and Orbit:

- Aperture: <~8m likely
- Monolithic or segmented primary
- Optimized for exoplanet direct imaging
- L2 or Earth-trailing likely.

(Large) UV/Optical/IR Surveyor.

Science Goals:

- **Directly image many Earthlike planets, and detect biosignatures if present.**
- **Place the Solar System in the context of a diverse set of exoplanets.**
- **Study and characterize protoplanetary disks.**
- Broad range of cosmic origins science

Measurement Requirements:

- Exo-Earth Detection:
  - $\sim 10^{-10}$ contrast
  - Coronagraph (likely), perhaps with a starshade.
  - Optical and near-IR camera for planet detection and characterization.
  - IFU, R>70 spectrum of 30 mag exoplanet.
  - 1” FOV
- Cosmic Origins Science:
  - HST-like wavelength sensitivity (FUV to Near-IR)
  - Suite of imagers & spectrographs, properties to be determined
- Possible instrument for spectroscopic characterization of transiting planets.

Architecture and Orbit:

- Aperture: ~8-16m likely
- Likely segmented, obscured primary
- Orbit: L2 likely

X-Ray Surveyor.

Science Goals:

- Origin and growth of the first supermassive black holes
- Co-evolution of black holes, galaxies & cosmic structure
- Physics of accretion, particle acceleration and cosmic plasmas
- **Characterizing the high-energy radiation environment of newly discovered exoplanetary systems.**

Measurement Requirements:

- Chandra-like (0.5”) angular resolution
- Detection sensitivity ~ 3 x 10^{-19} erg cm^{-2} s^{-1}
- Spectral resolving power: R>3000 @ 1 keV; R~1200 @ 6 keV

Architecture and Orbit:

- Eff. area ~3 m^2
- Sub-arcsecond angular resolution
- High-resolution spectroscopy (R ~ few x 10^3) over broad band via micro-calorimeter & grating spectrometer instruments
- FOV $\gtrsim$ 5’
- Energy range ~0.1-10 keV
- Orbit: L2 likely

What’s the difference between LUVOIR and HabEx?

- In some sense, nothing – can be seen as a continuum of missions.
- But, there are two natural break points around 8m
  - Largest monolithic aperture to fit in currently-available launch vehicles is ~8m.
  - OIR science is much less compelling below <~8m.
- HabEx – a more focused observatory:
  - Primary driver to search for habitability for a handful of Earthlike planets.
  - Significant new capabilities for a subset of COR science (UV).
- LUVOIR – a general purpose facility (like HST):
  - One primary driver to search for habitability on a large number of systems, and detect biosignatures (if present) on a small number of habitable systems.
  - Dramatically improved science capabilities covering nearly the full COR portfolio (UVOIR)
  - Serviceable.
- LUVOIR would almost certainly be more capable is essentially every respect
  - The ExoPAG favors this implementation, *if* it is feasible given the constraints.

Exoplanet Exploration Program Analysis Group (ExoPAG) Report to Paul Hertz Regarding Large Mission Concepts to Study for the 2020 Decadal Survey

October 6, 2015

Joint PAG Executive Summary:

The PAGs Concur That All Four Mission Concepts Should Be Studied.

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[1] "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.

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 the James Webb Space Telescope (JWST) and the Wide-Field InfraRed Survey Telescope (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[2]. The Physics of the Cosmos PAG (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 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. 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 Division mission portfolio. 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 Division Director.

Far-IR Surveyor	Habitable-Exoplanet Imaging Mission	Large UV/Optical/IR Surveyor	X-ray Surveyor
Primary science goals: • History of energy release in galaxies: formation of stars, and growth of black holes. • Rise of the first heavy elements from primordial gas. • Formation of planetary systems and habitable planets. Measurement Requirements: • Spectral-line sensitivity better than 10^{-21} W m^{-2} in the 25-500 μm band. (5 sigma, 1h) • Imaging spectroscopy at R~500 over tens of square degrees. • R~10,000 imaging spectroscopy of in thousands of z~1 galaxies and protoplanetary disks • High-spectral-resolution capabilities desired for Galactic star-forming systems and the Galactic Center. Architecture and Orbit • Complete spectroscopic coverage at R~500 from 25-500 μm. • Monolithic telescope cooled to ~4 K, diameter ~5 m. • Field of View = 1 deg at 500 μm • R~10,000 mode via etalon insert. • Background limited detector arrays with few x 10^4 pixels, likely at T~0.1 K. • Mission 5 years+ in L2 halo orbit. • High-resolution (heterodyne) spectroscopy under study, possibly for warm phase.	Primary science goals: • Direct imaging of Earth analogs, search for potential habitability. • Cosmic origins science capabilities considered baseline. Measurement Requirements: ExoEarth detection and characterization requirements: • ~10^{-10} contrast • Coronagraph and/or starshade. • Optical and near-IR camera for planet detection and characterization • IFU, R~70 spectrum of 30 mag exoplanet • 1" radius FOV Cosmic Origins Science requirements: • UV-capable telescope/instrument suite; properties and wavelength range to be determined. • Enable constraints on the high-energy radiation environment of planets. Possible instrument for spectroscopic characterization of transiting planets Architecture and Orbit • Aperture: ~-8m likely • Monolithic or segmented primary • Optimized for exoplanet direct imaging. • Orbit: L2 or Earth-trailing likely.	Primary science goals: • Direct imaging of Earth analogs, search for biosignatures. • Broad range of cosmic origins science Measurement Requirements: Cosmic Origins Science requirements: • HST-like wavelength sensitivity (FUV to Near IR) • Suite of imagers/spectrographs, properties to be determined. ExoEarth detection and characterization requirements: • ~10^{-10} contrast • Coronagraph (likely), perhaps with a starshade. • Optical and near-IR camera for planet detection and characterization. • IFU, R~70 spectrum of 30 mag exoplanet • 1" radius FOV • Possible instrument for spectroscopic characterization of transiting planets. Architecture and Orbit • Aperture: ~8-16m likely • Likely segmented, obscured primary. • Orbit: L2 likely	Primary science goals: • Origin and growth of the first supermassive black holes. • Co-evolution of black holes, galaxies, and cosmic structure. • Physics of accretion, particle acceleration, and cosmic plasmas. Measurement Requirements: • Chandra-like (0.5") angular resolution • Detection sensitivity ~ 3 x 10^{-19} erg cm^{-2} s^{-1} • Spectral resolving power: R~3000 @ 1 keV; R~1200 @ 6 keV. Architecture and Orbit • 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 instruments • FOV ≥ 5' • Energy range ~0.1-10 keV. • Orbit: L2 likely

Table 1: Notional Mission Parameters. These are the notional parameters of the four missions, developed through coordinated discussions 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 STDTs 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 missions given constraints on the cost, schedule, and technological readiness. Note by "Earth analogs" above we mean, very roughly, terrestrial (i.e., primarily rocky) planets with thin atmospheres in the habitable zones of their parent star

1. Introduction to the Charge

2. Potential Exoplanet Science Applications of the Four Proposed Missions

2.1 The Far-IR Surveyor

2.2 The Habitable-Exoplanet Imaging Mission (HabEx)

2.2 The Large UV/Optical/IR Surveyor

2.4 The X-Ray Surveyor

3. Other Flagship Missions Considered: A Terrestrial Planet Interferometer

4. Characterization of Transiting Planets: Prospects for LUVOIR, HabEx, and a Probe-Class Mission

5. Probe-class Missions

5.1 Starshade for WFIRST-AFTA

5.2 Transit Characterization Mission

5.3 Astrometry Mission

6. Concerns Regarding the Structure and Charge of the STDTs

6.1 Concerns Specific to the HabEx and LUVOIR Missions

6.1.1 The Need for Astrobiological and Biosignature Standards

6.1.2 Topical Representation on, and Coordination between, LUVOIR and HabEx STDTs

6.1.3 Standards Definition and Evaluation Teams

6.2 General Concerns

6.2.1 Costing

6.2.1 International Representation

6.2.3 Representation From Scientists in "Soft Money" Positions

7. Conclusions and Summary

Acknowledgements

Appendix A: Processes and procedures used to solicit and incorporate community response

Appendix B: Points of Consensus Achieved During ExoPAG 12

Acknowledgements.

We would like to thank:

- Everyone who contributed to this report.
- Paul Hertz:
  - For giving us the opportunity to provide input.
- Ken Sembach and Jamie Bock:
  - For their help with coordinating the process of gathering community input, and forging a consensus amongst the three PAGs.