THE OHIO STATE UNIVERSITY

College of Arts and Sciences

Department of Astronomy

4005 McPherson Laboratory
140 West 18th Avenue
Columbus, OH 43210-1173

614-292-1912 Phone
614-292-2928 Fax

gaudi@astronomy.osu.edu

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Dr. Bradley Peterson
Chair, NASA Advisory Council Science Committee
The Ohio State University

Dear Brad,

The NASA Advisory Council's Astrophysics Subcommittee (APS) met at NASA Headquarters on March 15 and 16, 2016. The following members of the APS were present: Marshall (Mark) Bautz, Alan Boss, Patricia Boyd, Joel Bregman (APS Vice-Chair), Neil Cornish, Mark Devlin, Brenda Dingus, Giovanni Fazio, Scott Gaudi (APS Chair), Jason Kalirai, Paul Scowen, and Yun Wang. Paul Hertz (Director, NASA Astrophysics Division) and Hashima Hasan (APS Executive Secretary) were also in attendance. Natalie Batalha and James (Jamie) J. Bock attended remotely both days, and Patricia Boyd attended remotely on the second day. APS member Beth Willman and Rachel Somerville were unable to attend.

Dr. Gaudi kicked off the meeting by reminding the committee members that the APS is a Federal Advisory Committee Act (FACA) committee, and reminded them of the FACA rules. He then welcomed the new APS members, Dr. Mark Devlin and Dr. Brenda Dingus.

Dr. Paul Hertz presented an update on the Astrophysics Division (APD) activities. He first shared a few recent science highlights. He then summarized the APD budget situation. Dr. Hertz reported that the FY16 appropriation and FY17 President's budget request provide funding for NASA astrophysics to continue its programs, missions, budgets, and supporting research and technology. The total APD funding remains at $1.35B. This fully funds continued James Webb Space Telescope development, and directs the APS to begin formulation (i.e., initiate a new start) for the Wide Field Infrared Survey Telescope. He reported that all of APD's currently operating missions are going well, and continue to generate important and compelling science results. SOFIA is in its 5-year prime operations, the ESA Lisa pathfinder was successfully launched on December 3, 2015, and the Japan Aerospace Exploration Agency's (JAXA) Hitomi mission (previously Astro-H) was successfully launched on February 17, 2016. Finally, missions under development continue to progress well, including NICER (launch 2017), ISS-CREAM (launch 2017), TESS (launch 2017), JWST (launch 2018), ESA's Euclid (launch 2020), and WFIRST (launch mid-2020s).

Dr. Hertz also reported on NASA activities with regards to missions in pre-formulation, including Athena, ESA's L3 gravitational wave observatory, and the Explorer line, which includes a SMEX mission to be down-selected from three candidates in 2016, and MIDEX and MoO mission AOs to be released in late 2016. Dr. Hertz noted that the Explorer Program budget is sufficient to select and execute both one MIDEX and one MoO in the 2010 decade.

The Senior Review of ongoing missions is in progress, with reports due by April 2016 and APD response in May or June 2016. The NRC Mid Decade Review (with NSF and DOE) continues, with the final report expected in May 2016.

APD is initiating the large mission Science and Technology Definition Team (STDT) concept studies as input for the 2020 Decadal Survey. As recommended by the three Program Analysis Groups (PAGs), the four missions to be studied are the Far-IR Surveyor, the Habitable Exoplanet Imaging Mission, the Large UV/Optical/IR Surveyor, and the X-Ray Surveyor. The STDTs are

charged to develop the science cases, flow these science cases into mission parameters, develop and vet technology gap lists, and direct trade studies of cost versus capability.

Drs. James Bock (Caltech), Alan Boss (Carnegie DTM), and Paul Scowen (ASU) presented summaries of the PAGs' reports responding to Dr. Hertz's charge regarding probe-class missions. Dr. Hertz suggested two potential options: (1) Issue a solicitation through ROSES for Astrophysics Probe mission concept study proposals, with the expectation that roughly 10 will be selected for one-year roughly $100K studies. The Decadal Survey would have the option of asking NASA to conduct further one-year studies at a higher level for ~3 mission concepts. (2) Do nothing and let the community self-organize. Dr. Hertz's charge also allowed for other, unspecified options.

- The PAGs issued a joint statement in response to this charge: "The COPAG, ExoPAG, and PhysPAG all agree that NASA should support the development of a probe class of competed missions for the Decadal survey. **All three PAGs strongly support the first option proposed by Paul Hertz in his formal charge to the PAGs of January 14, 2016.** Based on the input the three communities have received, there exists a wide range of community science goals that are both consistent with current National Academy priorities and that can be enabled with medium-class missions. The three PAGs also note that the work of preparing high quality white paper proposals to the 2020 Decadal Survey, for missions of this class, cannot be performed absent funding. In particular, all three PAGs agree that competed NASA HQ funds should allow at least 10 concepts for probe-class missions to be studied in some depth. **However, the main concern associated with this first option is that limiting the funds available for each concept study to ~$100K will likely severely limit the veracity of the CATE analyses at this early phase**, even though funds would be provided for more detailed CATE analyses when requested at a later phase by the Decadal Survey committee. **We recommend that APD consider apportioning sufficient funds to carry out multiple CATE analyses that would apply to the general category of probe missions in advance of the Decadal Survey.**
- Dr. Scowen then summarized the findings specific to the Cosmic Origins PAG (COPAG) report. The COPAG issued a call for 2-page white papers. They received a total of 16 such papers. These white papers spanned a broad range of science, implementations, technologies, and risk. This broad range of input was taken to demonstrate that the community is interested in a wide range of science and technological implementations that a Probe-class mission could enable.
- Dr. Boss then summarized the findings specific to the Exoplanet PAG (ExoPAG) report. The ExoPAG drew heavily on previous discussions stemming from the large mission charge, which resulted in a broad pre-existing consensus on the need for a probe-class line, and for several specific probe missions. Three primary missions concepts were discussed: a starshade for WFIRST, a transit characterization mission, and an astrometry mission.
- Dr. Bock then summarized the findings specific to the Physics of the Cosmos PAG (PhysPAG) report. The PhysPAG got an early start in this process: they heard reports on possible probe missions during the July 15 HEAD meeting in Chicago. The PhysPAG finds broad and enthusiastic support in the PCOS community for furthering the development of probe-class missions. The PhysPAG issued a call for white papers and received 14 papers, also covering a wide range of capabilities, technologies, wavelengths, instruments, and costs. The PhysPAG noted that the Inflation Probe is unique in that it was recommended by the 2010 Decadal Survey. The PhysPAG suggested several possible ways of ameliorating the concern about the possibility that the probe mission studies will have insufficient funding for a realistic CATE analysis.

The APS would like to thank Dr. Hertz for providing the community with the opportunity to provide input regarding probe-class missions and thus provide a chance to prepare for the next decadal survey in a fair, structured manner. APS accepts the reports from the three PAGs as

input to Dr. Hertz's charge regarding probe-class missions, and commends them for their efforts in responding to this charge. **The APS agrees that a probe-class mission line should be considered by the Decadal Survey. The APS concurs with the recommendation of all three PAGs to support the first option proposed by Dr. Hertz, namely to issue a solicitation through ROSES for Astrophysics Probe mission concept study proposals, with the expectation that roughly 10 will be selected for one-year studies supported at the level of roughly $100K each. The Decadal Survey would have the option of asking NASA to conduct further one-year studies at a higher level for roughly 3 mission concepts.**

The APS also heard updates from all three PAGs regarding activities not related to Paul Hertz's charge:

- Dr. Paul Scowen (ASU) presented the status of various COPAG activities. Nine Study Analysis Groups (SAGs) have completed their work, delivered reports, and have been closed. One new SAG is being considered and is going through definition. The main topic of this new SAG would be synergies between JWST and the rest of the COR portfolio. Dr. Scowen described the activities of the three active Science Interest Groups (the Far-IR Science and Technology, UV-Visible Science and Technology, and Cosmic Dawn SIGs), with reports to follow. The COPAG is planning for future workshops, a COPAG meeting at the summer AAS meeting in San Diego, and a meeting concurrent with the summer SPIE meeting in Edinburgh, Scotland.
- Dr. Alan Boss (Carnegie DTM) updated the status of the ExoPAG. The ExoPAG accepted a plan for its explicit involvement in the annual Technology Gap List evaluation, managed by the Exoplanet Exploration Program (ExEP) at JPL. Dr. Boss summarized the progress of the three active SAGs (12, 13, 14, and 15). **The ExoPAG requested and received APS approval to initiate a new SAG #16: Biosignatures, to be chaired by Drs. Shawn Domagal-Goldman (NASA GSFC), Nancy Kiang (NASA GISS), and Niki Parenteau (SETI Institute).** The next ExoPAG meeting will be held prior to the AAS summer on June 11-12, 2016 in San Diego, CA.
- Dr. James Bock (Caltech) reported on the activities of the PhysPAG. The PhysPAG is preparing a PCOS mini-symposium at the American Physical Society meeting in Salt Lake City in April 2016. Dr. Bock also summarized the activities of the active Science Interest Groups (the Inflation SIG, the Gravitational Wave SIG, X-Ray SIG, Gamma-Ray SIG, the Cosmic Ray SIG, and the Cosmic Structure SIG).

The APS recommended close coordination between the four large mission STDTs, and the various SAGs that deal with topics of relevance to the science and technology drivers of these four missions under study.

Dr. Neil Gehrels (NASA GSFC) summarized the current status of the Wide Field Infrared Survey Telescope (WFIRST), the number one recommendation for a large space mission by the 2010 Decadal Survey. Dr. Gehrels summarized the expected science capabilities of WFIRST, enabled by two instruments. The Wide-Field Instrument would enable two of the primary directed science objectives: the study of the cosmological evolution of dark matter and dark energy via the measurement of weak lensing of galaxies, baryon acoustic oscillations, and supernovae, and completing the census of exoplanets begun by Kepler by performing a microlensing survey for planets toward the Galactic bulge. A second coronagraph instrument would enable the detection and characterization of several dozen Super-Earth to Jupiter-sized planets, as well as the characterization of many debris disks. Finally, both instruments would enable a wide range of Guest Observer Science, which would comprise 25% of the total observing time. Dr. Kevin Grady (NASA GSFC) summarized the progress toward achieving the technological requirements of the mission, including maturing the technologies associated with the two main instruments. Finally, he summarized the projected development schedule and life cycle costs of the mission,

The APS heard from three presentations related to gravitational wave (GW) science. Dr. Neil Cornish lead off with a report on the first observational run of Advanced Laser Interferometer

Gravitational Observatory (aLIGO), highlighting the historic first direct detection of GWs, in this case from a binary black hole system. The prospects for finding electromagnetic counterparts to GW events was discussed, including issues such as the latency of alerts, and the sky localization possible with the expanded network of GW detectors that will become available in the next few years. A major concern is the potential lack of wide field gamma ray and x-ray telescopes during the prime aLIGO operations in the early 2020s with Fermi, Swift and INTEGRAL reaching the end of their operations. An interesting synergy was pointed out between ground based and space based GW detectors as black hole binaries of the type detected by aLIGO would be detectable by a LISA-type space detector several years before they merge and are detected on the ground.

Dr. Ira Thorpe followed with an update on the LISA Pathfinder mission, which was launched December 2nd 2015 and began science operations on March 1, 2016. Following a description of the mission, Dr. Thorpe reported that the early results are very promising, showing performance consistent with pre-launch estimates; coming very close to the original LISA requirements. The success of the LISA Pathfinder mission was called out as a key decision point in the 2010 New Worlds New Horizons decadal survey for NASA participating in a space GW mission.

Dr. David Shoemaker gave the final GW-related presentation with a report on the L3 Study Team – the recently selected US science team charged with identifying technologies that NASA could contribute to a ESA-led space-based GW mission that addresses the goals of the L3 "Gravitational Universe" science theme in the ESA's Cosmic Visions program (i.e., the eLISA Mission), and to prepare the science case and implementation options for the 2020 decadal survey. One concern is that the current plan for the study does not include any meetings with the European eLISA consortium prior to submitting a report on the first phase of the study in September 2016.

Dr. Linda Sparke provided a summary of the Astrophysics Division's portion of the NASA Earth and Space Science Fellowship (NESSF) program. She reported that roughly 1% of the FY15 Astrophysics research and analysis budget supported the NESSF program. This currently allows for the selection of 9-10 new fellows per year, for an average of 24 fellows being funded through the program each year. Although the program formally can fund students in both masters and doctoral degrees programs, in practice all of the awards are to students in doctoral programs. She noted that a successful NESSF award requires relevance to a primary NASA science objective. From 2008-2015, there were 75 awards, but during this time, the total number of submitted proposals has doubled. This implies that the current success rate has dropped to less than 1 in 10 proposals awarded. Dr. Sparke then discussed the demographics of selected proposals, noting that they were broad and not necessarily localized to particular geographic locations or institutions. Awardees of the NESSF program generally achieved promising future trajectories, with 43 acquiring their PhD, 32 still in grad school, 23 currently in postdoctoral positions, 6 in faculty positions, and 14 in positions outside of the field of astronomy. Although NASA has not done a longitudinal study of the overall success rates of NESSF awardees compared to their peers, Dr. Sparke noted that a similar study of National Science Foundation Graduate Research Fellowship Program (GRFP) fellows noted a small-to-medium impact on the success of GRFP Fellows as compared to a comparison sample of "honorable mention" GRFP proposers. Given that the "honorable mention" sample is likely enriched with respect to the median population of proposers, this would suggest that the NSFG Fellowship program does indeed foster improved occupational outcomes for graduate students. The APS discussed possible methods of altering the NESSF program such that it would have a similar impact as the GRFP, including changing the requirement that the NESSF proposals have relevance to a particular NASA objective, increasing the funding to the program, and restricting the graduate students that are able to apply to the program to those within three years of starting graduate school. The APS also discussed the possible benefits and drawbacks of eliminating the program entirely. Ultimately, after some discussion, **the APS recommended that the NESSF program institute a requirement that only applications from students within three years of starting their graduate studies be accepted.**

Dr. Martin Still reviewed the Exoplanet Research Program (XRP), and in particular addressed three primary questions. First, he addressed the question of why the Origins of Solar Systems (OSS) ROSES element was rebranded as the XRP. This was as part of the redesign of the Planetary Sciences Division to more effectively manage their R&A portfolio. There was no impact upon the Astrophysics administration of the program. Second, he addressed the question of how the XRP is responding to the evolving needs in exoplanet research. The primary methods are by constantly monitoring the state of the field and the portfolios of other funding entities, and balancing the program with NASA Astrophysics' strategic needs. Finally, Dr. Still addressed the question of whether there has been a shift in grants for exoplanet research as compared to planet and star formation research (e.g., disk chemistry). Dr. Still indicated that there was no evidence for a shift within the OSS/XRP program.

Dr. Richard Kelley provided an update of Astro-H/Hitomi. Dr. Kelley reported that the launch was completely successful, with an essentially prefect orbital insertion. The telescope is mostly deployed. The main science goals of Hitomi are the study of the structure and evolution of the Universe, and the study of matter in extreme environments. Hitomi has four telescopes: the NASA-provided Soft X-Ray Telescope Imager (SXT-I), the NASA-provided Soft X-ray Telescope Spectrometer (SXT-S), and the Hard X-ray Telescope (HXTs). These feed four instruments, including the NASA-provided Soft X-ray Spectrometer (SXS), the Soft X-Ray Imager (SXI), the Hard X-ray Imager (HXI), and the Soft Gamma Detector (SGD). Three of the four instruments (SXS, SXI, and HXI) are currently working, with the SGD to be powered up during the week of March 21. Dr. Robert Petre discussed the Guest Observer Program. In Cycle 1, 75% percent of the time is GO time, 15% is Science Working Group Time, and 10% is Observatory Time. The national time allocations are 56% to Japan including 10% for ESA and 44% to the US. All non-US and non-ESA proposals count against the Japanese time. The projected lifetime is at least three years.

The APS received a detailed report from Dr. Philip Stahl on lightweight optics in the optical and IR. The presentation was very informative. The purpose of the presentation was to help the APS understand the technology readiness level and cost of optics designed for use at wavelengths from the optical to the IR. This multi-dimensional problem is a function of the wavelength, the size, the geometry (monolithic or segmented), and the operating temperature. Many of the conclusions are obvious, such as bigger telescopes are more expensive and shorter wavelengths are more difficult (and costly) to achieve. However, there were a number of issues that will come in to play for future missions. In particular, Dr. Stahl asserted that an IR mirror would cost roughly the same as a UV mirror of similar size due to the low operating temperature of the IR mirror. He also indicated that a segmented mirror would be more expensive than a monolithic mirror of similar size due to the cost of engineering the back up structure. Dr. Stahl was adamant that the infrastructure that was developed for previous missions could not be simply transferred to a new mission. For example, the tooling for producing JWST panels is, "gone." He noted that the timescale for developing the technology is 10 years (HST and JWST). The best way to get this done is to have a down select from multiple vendors. Finally, Dr. Stahl presented a number of new materials that were under investigation for next generation mirrors. These could help with thermal stability and cost.

Dr. William Zhang provided a presentation on the status of technology developments on lightweight X-ray optics. Dr. Zhang discussed the various approaches to produce high angular resolution optics that would be suitable for use in a mission such as X-Ray Surveyor or in smaller missions, such as Explorers or Probes. One promising approach involves stiff mirrors produced from single crystal silicon, where arcsecond resolution should be realized in the next few years. Other parallel approaches use slumped glass mirrors, with active adjustments to produce high-quality optical surfaces.

The APS also heard reports from the Study Scientists of the four large missions chosen for Science and Technology Definition Team (STDT) studies in preparation for the next decadal survey. These reports discussed potential science applications, and the overall goals of and timeline for the STDT studies, including deriving science requirements, defining measurement

requirements, evaluating technological readiness, choose architecture and made design trades, and estimate costs.

- Dr David Leisawitz (NASA GSFC) presented the report for the Far-IR Surveyor. The Far-IR Study will be led by the GSFC, and Asantha Cooray (UC Irvine) and Margaret Meixner (STScI) have been chosen as the Community Chairs.
- Dr. Bertrand Mennesson (NASA JPL) presented the report for the Habitable Exoplanet Imaging Mission, or HabEx. The HabEx study will be led by the JPL, and Sara Seager (MIT) and Scott Gaudi (Ohio State) have been chosen as the Community Chairs.
- Dr. Aki Roberge (NASA GSFC) presented the report for the Large UV/Optical/IR Surveyor, or LUVOIR. The LUVOIR study will be led by the GSFC, and Debra Fischer (Yale) and Brad Peterson (Ohio State) have been chosen as the Community Chairs.
- Dr. Jessica Gaskin (NASA MSFC) presented the report for the X-ray Surveyor. The X-ray Surveyor study will be led by the MSFC and the Smithsonian Astrophysical Observatory, and Feryal Ozel (Arizona) and Alexey Vikhlinin (SAO) have been chosen as Community Chairs.

The APS would like to thank Drs. Gaskin, Leisawitz, Mennesson, and Roberge for their presentations, and we look forward to hearing updates on the progress of these STDTs as they proceed with their studies.

Finally, Drs. Hertz and Gaudi again welcomed Drs. Mark Devlin and Brenda Dingus to the APS, and thanked Drs. Bregman and Fazio for their outstanding service on the APS.

Requests for presentations at the next meeting:

1. The APS requests an update at the next meeting on the science being carried out by APD balloon and sub-orbital program.
2. The APS requests presentations on the activities of a subset of the SMD Science Education Cooperative Agreement Notice (CAN) Awards.
3. The APS requests an update on the activities of the four large mission Science and Technology Definition Teams during the fall 2006 APS meeting.

Major conclusion and recommendations:

1. The APS agrees that a probe-class mission line should be considered by the Decadal Survey. The APS concurs with all three PAGs to support the first option proposed by Paul Hertz, namely to issue a solicitation through ROSES for Astrophysics Probe mission concept study proposals, with the expectation that roughly 10 will be selected for one-year studies supported at the level of roughly $100K each. The Decadal Survey would have the option of asking NASA to conduct further one-year studies at a higher level for roughly 3 mission concepts. The APS would like to thank Dr. Hertz for providing the community with the opportunity to provide input to community regarding probe-class missions and thus provide a chance to prepare for the next decadal survey in a fair, structured manner.

2. The APS approved a request by the ExoPAG to initiate a new SAG #16: Biosignatures, to be chaired by Drs. Shawn Domagal-Goldman (NASA GSFC), Nancy Kiang (NASA GISS), and Niki Parenteau (SETI Institute).

3. The APS recommends that the NASA Earth and Space Science Fellowship (NESSF) application requirements be changed to only allow applications from graduate students in their third year of graduate school or less.

Sincerely,

THE OHIO STATE UNIVERSITY

Scott Gaudi
APS Chair
The Ohio State University

Joel Bregman
APS Vice-Chair
University of Michigan