# NASA ADVISORY COUNCIL

# ASTROPHYSICS SUBCOMMITTEE

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## MEETING REPORT

B. Scott Gaudi, Chair

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***Ingenicomm, Inc.***

February 16, 2011

Introduction

Dr. B. Scott Gaudi, Chair of the Astrophysics Subcommittee (APS), opened the meeting, made administrative announcements, advised members of Federal Advisory Committee Act (FACA) rules. He welcomed new members Drs. Mark Devlin and Brenda Dingus, and Drs. Natalie Batalha and James Bock, who joined the meeting on Webex.

Astrophysics Division (APD) Update

Dr. Paul Hertz, Director of the Astrophysics Division (APD), provided a status of division activities, and noted that the confluence of having the James Webb Space Telescope (JWST) approaching its launch, the Wide Field Infrared Survey Telescope (WFIRST) becoming a real mission, and kicking off concept studies for future missions, have brought about an exciting time for the discipline. Recent science items include a highlight from the online visualization tool, "Eyes on Exoplanets," showing the growing impact of the Kepler K2 mission on exoplanet demography. The Hubble Space Telescope observed a brown dwarf with a companion planet of 10 Jupiter masses; a photometric light curve has shown variation, yielding the first exoplanet rotation curve where the planet is not tidally locked to its parent star. Chandra has imaged the first x-ray-discovered active galactic nucleus (AGN) jet. This is a radio-quiet jet that is thought to be indicative of early-universe AGNs. Hubble has also imaged a new record holder for the most distant galaxy with a redshift confirmed spectroscopically.

After the NRC mid-decade review committee reports out in May 2016, NASA will write an update of the Astrophysics (AP) Implementation Plan, to be released by mid-December 2016. AP slides that are relevant to the mid-decade review are now available on the National Research Council (NRC) website.

Dr. Hertz reported that the Fiscal Year 2016 (FY16) budget maintains at $1.35B per year resource for AP, fully supporting JWST in terms of both requested and appropriated dollars. JWST is still on track for an October 2018 launch. The FY16 budget also supports WFIRST, which has just entered phase A (Formulation). The Stratospheric Observatory for Infrared Astronomy (SOFIA) continues to execute its prime mission, with its High-resolution Airborne Wideband Camera plus (HAWC+) second-generation instrument to begin commissioning in Spring 2016. Instrument concept studies have been selected for SOFIA's 3rd generation instrument, and a Senior Review for SOFIA will be held in Spring 2018. The European Space Agency's (ESA) Laser Interferometer Space Antenna (LISA) Pathfinder mission launched successfully in December 2015. APD proposal selections since 2015 have yielded turnarounds at well under 155 days, and Research and Analysis (R&A) and Guest Observer (GO) selections have averaged around 25%. In the Suborbital program, two payloads were taken to Antarctica, GRIPS (a Heliophysics campaign) and the Stratospheric Terahertz Observatory-II (STO-II) (AP). GRIPS was able to launch, but STO-II was not, due to weather delays. STO-II hardware is wintering over and will be in the queue for next year, marking the first time a payload has been overwintered at Antarctica. The Colorado High-resolution Echelle Stellar Spectrograph-2 (CHESS-2) is the most recent rocket launch for APD; two more are scheduled for Fall 2016: Micro-X and Cosmic Infrared Background ExpeRiment-2 (CIBER-2). In the Spring 2016, a superpressure balloon payload will be deployed in New Zealand, the Compton Spectrometer and Imager (COSI). COSI's goal is to obtain tens of days of flight at mid-latitudes. After New Zealand, the Palestine campaign will be undertaken in June, and the Fort Sumner campaign in the Fall.

The Senior Review 2016 main panel convened in February to review six projects. Hubble was reviewed in depth in the first week of March, and will be followed by Chandra. Delivery of the final report is expected in April. The results will be used to inform the budget formulation process, as well as programmatic direction to the projects for the next two years. NASA will publish the full report, and response, in the May/June timeframe.

NASA will release a draft Mid-sized Explorers and Missions of Opportunity (MIDEX and MO) Announcement of Opportunity (AO) in Spring 2016. The Explorers program has doubled the funding and shortened the times for the competitive phase A studies; downselection is targeted for late 2018. Dr. Joel Bregman asked if the two-step process were truly necessary for the MIDEX proposals. Dr. Hertz replied that the Earth Venture (EV) mission classes could be compared to the Small Explorer (SMEX) size and cost cap. He felt there was a slight difference in risk tolerance in the APD Explorer program vs. the EV program. The Earth Science Division (ESD) holds no reserves above cost cap; if the projects overrun they get descoped or cancelled. Dr. Hertz said he would rather pick missions that are likely to stay in the box, and that the second step analysis gives a better understanding of that cost cap. At present, the policy for both APD SMEX and MIDEX AOs is to go for that level of certainty. The next SMEX AO may be a good time, however, to test out a one-step proposal process. Dr. Marshall Bautz asked what fraction of budget typically gets spent in an EV phase A. Dr. Hertz agreed to look up the statistic.

The LISA Pathfinder (LPF) launch went very well, and the mission began science operations in March 2016; an extended mission (EM) is being considered in order to run more aggressive tests that one would not want to run in prime mission. APD began a US L3 study team, whose goal is analyze various options for the US to participate in L3, the future ESA Cosmic Vision gravitational wave mission, and prepare the GW community for the 2020 Decadal. The first meeting of the study team was held in February of this year.

NASA considerations for a space-based gravitational-wave observatory, in light of the recent Laser Interferometer Gravitational-wave Observatory (LIGO) detection of a gravitational wave source, will be guided by the outcomes of the 2020 Decadal Survey. In any case, a US-led mission could not be done before WFIRST. At the time of the next Decadal Survey, the outcome of LPF will have been determined, and more information from continued LIGO results will have been gleaned. NASA has done many concept studies on a US-led LISA, and feels there is no need to do more. At present, the plan is to participate in the ESA-led L3 mission. The Physics of the Cosmos Program Analysis Group (PhysPAG) concurred with progressing the US participation with ESA. Dr. Neil Cornish noted that in the charter for the L3 study allows a look at more options for missions. Dr. Hertz replied that the community is welcome to advocate a US-led LISA, but at the moment NASA will not be starting new studies. Dr. Brenda Dingus asked whether the proposed 2034 launch of L3 could be moved up. Dr. Hertz observed that such an effort would require additional funding beyond planned budgets at both ESA and NASA.

Japan's Astro-H mission was launched on 17 February 2016 and renamed to Hitomi; the commissioning phase is going well. Hitomi contains the NASA-provided soft x-ray spectrometer (SXS). JAXA and NASA are currently working on the call for proposals, and a simultaneous Guest Observer (GO) call in early May is planned in both Japan and the US. Dr. Jason Kalirai commended Dr. Hertz for investing in the science in this way.

APD has six missions in development, all with notional launch dates. The Neutron star Interior Composition Explorer (NICER) experiment is in thermal-vacuum testing at present; its launch has been delayed to ~March 2017 due to the delays in the ISS commercial supply manifest following launch failures in 2014-2015. NICER will be delivered and stored until launch to the International Space Station (ISS). The Transiting Exoplanet Survey Satellite (TESS) mission is in fabrication phase and due to deliver to the Kennedy Space Center (KSC) launch site in Summer 2017. All of JWST's mirrors have been installed, as well as the aft optics assembly. The complete telescope assembly is sitting in the cleanroom at Goddard Space Flight Center. The mission held a successful pre-ship review for the Integrated Science Instrument Module (ISIM), which will be integrated into telescope later this spring. The next major perfomance tests will be performed at Johnson Space Center (JSC). In cryovacuum testing, one slight problem was found with the B-side of a Mid-Infrared Instrument (MIRI) control board, which had been traced to an electronics card, which in turn will be swapped out. Dr. Kalirai confirmed that this repair was indeed successful. The flight cryocooler is now in its final performance testing, which is going well at the Jet Propulsion Laboratory (JPL). There is currently a 7.5-month schedule margin on the critical path. Dr. Kalirai commented that this is the right time for the community to start building its science teams, as JWST research calls are only 1 to 1.5 years away.

While challenges have arisen during the final manufacturing and integration and test (I&T) phases, Dr. Hertz was pleased to say that the assembly of JWST is proceeding as planned, with the mission staying within cost and schedule margins as replanned in 2011, as the JWST program continues to execute to its 2018 launch commitment.

Another mission in formulation, ESA's Euclid, just went through a formal re-plan after a two-year delay in the ESA-managed detector engineering phase, which subsequently led to a NASA overrun in its contribution to the mission. NASA has all contracts in place for detector fabrication and is on track to make its commitment to ESA, with the first flight detectors to be delivered to ESA in March 2017. NASA is also funding a US science team for Euclid.

WFIRST has also begun formulation, and completed its Mission Concept Review in December. APD made 13 selections for the formulation science investigation teams, which are now working with the mission to establish science requirements. Dr. Karilai noted that with growing interest in this mission, the community hopes to make WFIRST and JWST better by trying to sync up timing as much as possible. Dr. Hertz noted that there are two schedules, one of which provides for a 2025 launch within the planned funding. If more funding was provided, WFIRST could launch earlier. APD has establishing a planning profile; the only way to spend more on WFIRST within the notional planning budget is to spend less on something else.

In the FY16 appropriation of $1.35B, $90M is allocated for WFIRST, as well as full funding for SOFIA, full funding for Hubble, and $37M for Science Mission Directorate (SMD) Science, Technology, Engineering and Mathematics (STEM) education activities. While APD received $42M more than planned, it must still find $36M in reductions in the rest of the APD, an effective 7% reduction for the rest of the program (outside of JWST, WFIRST, Hubble and STEM). Changes have been submitted in the Operating Plan, which can only be discussed after Congressional approval. Dr. Hertz discussed the various ways in how budgetary changes are handled between Congress, the Office of Management and Budget (OMB) and NASA, and how Congressional language provides programmatic direction. Congress has appropriated funding, e.g., that accelerates WFIRST. Dr. Kalirai felt that Congress had effectively advanced the mission through its great respect for the Decadal Survey process.

Dr. Hertz reviewed the FY17 budget request, noting that the SMD STEM budget line is arbitrarily bookkept as a project, inside APD; thus he presented totals with and without the STEM numbers. The FY17 budget request including JWST without STEM is $1326M, which compares well with the FY16 appropriation. WFIRST is also funded at $90M for FY17. Overall, FY17 lets APD continue everything. The runout keeps APD at the $1.3B level, while JWST funding runs down and WFIRST ramps up. The estimated cost for WFIRST to launch, based on parametric estimates, in real-year dollars, is $2.3 to 2.7B, with uncertainties dependent on funding profiles and launch vehicle costs. Less the GO program and coronagraph costs, and corrected for inflation, the cost of WFIRST is within 10% of the $1.6B (in $FY10) as estimated by the Decadal Survey. Neither WFIRST nor JWST would be adversely affected by a Continuing Resolution (CR) this year, in Dr. Hertz's opinion. Asked how APD could recapture the $36M shortfall, Dr. Hertz maintained that the outyear planning numbers are sufficient to allow WFIRST to continue to progress. Dr. Batalha asked if there were any great concerns about the shortfall in terms of planning. Dr. Hertz replied that the Senior Review budget for FY17 is substantially low ($37M available in FY17 vs. $62M budgeted in FY16), which will be addressed in the FY17 Operating Plan. It will be a challenge, but APD will work hard to spread the pain, with the guidance of the community. Dr. Bregman complimented Dr. Hertz on his handling of the budget

Dr. Hertz concluded by announcing that Science and Technology Definition Team members have been appointed by NASA to support four mission concepts, which will be presented to the Decadal Survey; planning documents are currently on line. The teams will submit reports by March 2019. The mission concepts are the Far IR Surveyor, Habitable Exoplanet Imaging Mission, the Large UV Optical IR (LUVOIR) Surveyor mission, and X-Ray Surveyor.

<u>ExoPAG report</u>

Dr. Alan Boss provided an update on the Exoplanet Program Analysis Group (ExoPAG). Four members are rotating off, and the PAG is now in the process of selecting three replacements. In response to the Dr. Hertz's charge to the PAGs regarding probe-class missions, , Dr. Boss reported that ExoPAG fully supports this effort. In his charge, Dr. Hertz suggested two 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. Dr. Boss reported that the ExoPAG expressed preference for Option 1, as it ensures that at least 10 probe class concepts will have been studied. Furthermore, ExoPAG finds that the studies should lay out their goals in a white paper format, for ingestion by the Decadal Survey. The PAG's main concern was that $100K per study would not go far enough to include a formal and detailed Cost and Technical Estimate (CATE). ExoPAG also reviewed an annual technology gap list, which included an initial look at coronograph technology gaps for direct imaging of exo-Earths. Overall, seven Study Analysis Groups (SAGS) have completed their work, while others continue. ExoPAG is trying to increase SAG activities, establish monthly missions, and better define completion dates.

SAG-12 was kicked off in January 2015 to study high precision astrometry for exoplanet detection and characterization. SAG-13 is studying exoplanet occurrence rates and distributions, and thus far has converged on a consensus for "standard eta tables," using computation and crowdsourcing methods. Six participant tables have been submitted thus far. SAG-14 is working to characterize stars targeted for NASA exoplanet missions. A primary TESS goal is to discover 50 Earth-sized transiting planets whose masses can be measured by follow-up radial velocity measurements, enough that TESS can deliver the mission requirements. SAG-14 feels it best to pre-select targets spectrographically, at a cost of $2.5M to guarantee viewing time, and may propose this route to NASA. SAG-15 is considering observational constraints for exoplanet discovery. A new SAG-16 has been proposed to answer questions on biosignatures. These are: What are known remotely observable biosignatures, the processes that produce them, and their known nonbiological sources? How can we identify them, and what are the requirements for detecting biosignatures to different levels of confidence? SAG-16 is planning workshops, in tandem with the NASA Astrobiology Institute (NAI) and NASA Nexus for Exoplanet System Science (NExSS), and will report out in one year. Dr. Boss sought APS approval to establish SAG-16.

ExoPAG continues to have monthly telecons and is carrying out the work of the new and active SAGs. An ExoPAG meeting will be held in June 2016 in San Diego, followed by a meeting in January 2017 at a yet to be determined location. Dr. Kalirai asked how some of the Science and Technology Definition Teams (STDTs) might work with the PAGs. Dr. Gaudi noted that Shawn Domagal-Goldman is on the HabEx STDT, and is the deputy science center study scientist for the LUVOIR STDT. Dr. Boss reported that ExoPAG also has ties with the STDTs and will have representatives at future meetings. Dr. Gaudi felt the SAG-16 biosignature effort to be worthwhile, and the APS approved the SAG with a unanimous vote.

PhysPAG

Dr. James Bock reported on the most recent meeting of the Physics of the Cosmos PAG (PhysPAG). Its first finding expressed broad and enthusiastic support for the development of the Probe missions. The PAG has collected wider input and now has 14 white paper concepts on the subject. PhysPAG believes that a scientific niche has been missing in the APD portfolio, noting that NASA missions close in cost to the ESA M-class missions have been successful in carrying out astronomical science (e.g. Fermi, Spitzer, Kepler). White papers include probe ideas to address to address high-energy x-ray and gamma ray astrophysics, death of massive stars, an advanced particle astrophysics telescope, and time-domain spectroscopiy, at costs from $500M to $1.2B, and could be valuable to the Decadal Survey planners.

PhysPAG endorsed Option 1 ($100K, 10 studies) as an initial step, but issued a finding that $100k was not sufficient to allow for the cost fidelity required by the Decadal Survey. Further, PhysPAG found that cost modeling should be done earlier on so as to avoid a disconnect with the Decadal Survey, as had occurred previously. APD should consider developing a second phase of studies to define costs for the general probe missions, to provide this important input. Finding 5 noted that an "Inflation Probe" was originally recommended in the 2010 Decadal Survey and could provide a point of departure. PhysPAG recommended a path forward on cost analysis, i.e. sufficiently fund all 10 studies, select a reduced number for second-phase studies, and cost "exemplar" concepts that are either scientifically defined, or use the Inflation Probe as one "exemplar" concept.

PhysPAG has rolled on two new members. Upcoming events include plans for a mini-symposium at the American Physical Society, in April 2016. PhysPAG's Inflation Probe Science Interest Group (SIG) noted as general interest items, the SMEX mission, SPHEREx, and the US Mission of Opportunity participation in LiteBIRD, have been selected for Phas A study. A Department of Energy (DOE) Stage IV Cosmic Microwave Background (CMB) polarization meeting was held earlier in March. The Gravitational Wave SIG noted that the NASA L3 Study Team has been announced. The X-ray SIG noted that two x-ray polarimetry SMEX concepts, IXPE and PRAXys, have been selected for phase A study. The Gamma Ray SIG is working on a roadmap for input to the 2020 Decadal Survey. The Cosmic Ray SIG noted that the Cosmic Ray Energetics And Mass (CREAM) instrument has completed testing. The Cosmic Ray SIG had a special session at the American Physical Society meeting in Salt Lake City earlier this year. Dr. Bock noted also that there is now a Cosmic Structure SIG.

Dr. Hertz noted that the recent Heliophysics and Planetary Science Decadal Surveys identified which mission concepts should come back with CATEs. He agreed with the concern on the $100k studies, but felt it could be overcome by having the Decadal Survey decide which concepts would eventually receive full cost estimates. The Planetary Decadal Survey did this with Europa, Titan, etc. Dr. Bregman raised the concern of picking winning and losers through this process. Dr. Gaudi supported the notion of the Decadal Survey's directing of CATEs. Dr. Hertz commented that there are multiple concepts as to how the Inflation Probe might be done, and asked whether an STDT would be able to resolve the challenges and come up with a single Design Reference Mission (DRM). Dr. Bock felt that an STDT could at least quantify a DRM. Dr. Devlin agreed.

CoPAG

Dr. Paul Scowen, as the new chair, reported out findings from the Cosmic Origins PAG (CoPAG), which has also welcomed three new members. Dr. Scowen recognized previous chair, Dr. Ken Sembach, for his hard work. Last December, CoPAG initiated two page white papers as part of the Probe response, and received 16 papers, while working with the other PAGs to work on a joint statement. CoPAG echoes the concerns of the other PAGs as to adequacy of funding for the ten studies, and is also concerned that the mission line be openly competed and not restricted. The primary takeaway is that there is high interest in the community for this probe mission class, as it fills scientific gaps. The range of science addressed by the concept papers is wide, and includes massive star evolution and death, reionization in the Dark Ages, galaxy cluster formation and assembly, and THz imaging and study of the earliest stages of molecular gas assembly. Non-cosmic origins science included a hard x-ray monitor of the sky, space-based follow-up on Large Synoptic Survey Telescope (LSST) discoveries, asteroids and Kuiper Belt objects (KBOs), and understanding gamma-ray bursts. The science spanned many wavelengths and included mostly spectrometers. Many concepts had large fields of view (survey instruments, complementary to future missions). Costs ranged from $350M to $2B. Most were NASA Center studies and parametric estimates, with some heritage. New technologies were considered in radio signal processing, electronics, power, data storage, optical coatings, and linear variable filters. Overall, CoPAG concluded that there is a wide range of concepts consistent with Academy goals, but that more funding is needed for high-quality white papers to adequately flesh out mission concepts. The CoPAG endorsed Option 1 as the preferred method for soliciting input on such a mission size to the 2020 Decadal Survey.

Nine CoPAG SAGs have completed their work and delivered reports. CoPAG is considering a new SAG for identifying enabling synergies between JWST and the rest of the Cosmic Origins portfolio. There are currently three active SIGs, which will eventually pass their inputs to the respective Probe STDTs. SIG-1, Far Infrared Science and Technology, held a workshop in June 2015. SIG 2, for UV-Visible Science and Technology, intends to have its report ready for use by the new Large UV/Optical/IR (LUVOIR) and Habitable Exoplanet STDTs. SIG-3, Cosmic Dawn, is studying how to probe cosmic dawn with JWST and other assets, in a multi-wavelength approach, which also represents an excellent means of stimulating cross-PAG engagement. Biweekly telecons continue, while CoPAG plans for next-steps workshops, and the possible formation of a JWST SAG/SIG. Dr. Kalirai commented that there are now more than a dozen papers published each month on JWST impact, and felt that a workshop on synergies would be excellent. LSST also has a close tie to Cosmic Origins science, and perhaps should be included. Dr. Scowen concluded his report, noting that no APS actions were requested.

Discussion

The subcommittee discussed the PAG reports and their joint summary endorsing Option 1. Dr. Hertz reiterated that the intent of the Probe Charge was the first step to flesh out science cases, so as to enable a few concepts to move forward to a CATE. The downselection would entail three mission concepts, which would be subsequently funded as a second step for full CATEs. The committee discussed ways in which to refine their response to the PAG findings, addressing the point of the Decadal Survey "picking winners." Dr. Hertz noted that NASA spent $17M on the previous AP strategic concept studies, and wondered whether it was a worthwhile undertaking. The Decadal Survey only prioritized actual concept studies. Under the current recommendation, Dr. Hertz felt that the 10 concepts would have gone through some peer review and will have received a NASA imprimatur. Dr. Boss noted that the ExoPAGs felt that $100k would at least fund some travel, and could be used intelligently. Dr. Hertz felt that the purpose of the papers is to demonstrate to the Decadal Survey that medium-class missions can deliver valuable science goals, and to lay out some notional architecture so that they can be appropriately costed. Dr. Mark Bautz commented that it costs $1M to figure out a mission costs $1B, and wanted to avoid having the Decadal Survey decide that no medium-class missions are valuable. Dr. Gaudi felt that this concern argued for considering the established "exemplar" concepts. Dr. Hertz said another option would be to identify three mission concepts now and do three real studies. Dr. Kalirai commented that the four flagship concepts now being considered were developed through a year-long roadmapping process, and felt Option 1 would not do the same thing for Probe class concepts. Dr. Gaudi suggested that despite misgivings, that APS should concur, but not necessarily strongly support, the ten studies funded at $100k each. The majority of members agreed.

WFIRST Update

Dr. Neil Gehrels presented the science case for WFIRST, as the mission moves into phase A. A Formulation science team has been selected, and has held one meeting. Phase A will be 18 months long, and its details were presented to the most recent Science Committee meeting, where there was a unanimous vote to move forward to phase A. Supported by Decadal Survey findings, a wide-field near-IR (NIR) telescope will be able to address many areas in dark matter, exoplanets and matters of general astrophysics. The Survey recommended a 1.5m telescope, while NASA was able to acquire a 2.4m telescope, greatly expanding the capabilities of the mission. Compared to Hubble, WFIRST will be able to image over 100X more sky area, and will be able to image exoplanets with $10^{-9}$ contrast (with a coronagraph). WFIRST will be able to see a million galaxies at a time, vs. Hubble, which can image 10,000 galaxies in a Deep Field view. WFIRST promises to discover rare and interesting objects. Ideally, NASA would like to overlap with JWST as much as possible, and to act as a finder scope for targets for JWST to observe. Science objectives of WFIRST are to provide Hubble-quality NIR images of the sky; this is expected to be one of the major legacies of WFIRST. Other goals are to determine the expansion history of universe; complete a statistical census of planetary systems using microlensing; provide the first direct high-contrast images of giant planets, and study debris disks with a coronagraph. Twenty-five percent of WFIRST time (for the first six years) is to be used for a robust GO program. Instrumentation includes the Wide Field Instrument (NIR) and coronagraph (visible). WFIRST will combine techniques to determine the nature of dark energy and the acceleration history of the universe, and will be the only observatory doing such comprehensive observations.

For exoplanets, WFIRST provides a complement to Kepler, TESS and Plato, by providing a microlensing exoplanet survey. This is the only technique that allows discovery of "free-floaters," planets that are not gravitationally bound to a star system. The current guess is that there may be as many free floaters as there are bound planets. Imaging at high contrast will allow direct detection and spectroscopy (characterization) of exoplanets, using a coronagraph to block light from the central star. WFIRST will advance key elements for a future coronagraph to image an exo-Earth, through use of its own coronagraph, wavefront sensing and control, detectors and algorithms. GO science for the first six years of operation will be followed by 100% open competition in the ensuing years. The WFIRST Formulation Science Working Group (FSWG) has been selected, which will be in place for 5 years. It is headed by Dr.

Neil Gehrels, and co-chaired by Drs. David Spergel and Jeremy Kasdin. There are 207 members on the selected WFIRST Science Investigation Teams, and many more community members are involved in the planning process.

Mr. Kevin Grady, Program Manager (PM) for WFIRST, presented the programmatics side of the mission, which has just completed Key Decision Point-A (KDP-A), and its Mission Concept Review (MCR) in December 2015. The coronagraph and IR detectors continue to make excellent progress. The President's Budget Request (PBR) for FY17 has $90M in support for WFIRST from SMD, and $10M from the Science and Technology Mission Directorate (STMD). This recently augmented funding has enabled significant progress in technology maturation, and fidelity in the design reference. An industry request for information (RFI) was issued in July 2015; inputs were received and management was briefed. The Wide Field concept study released an request for proposals (RFP), and awarded Wide Field Optical Mechanical Assembly concept studies to Ball Aerospace and Lockheed Martin.

Key programmatic drivers for the WFIRST mission are documented in the New Worlds New Horizons Decadal Survey science objectives. The entire mission is class B, and the coronagraph is class C (demonstration class). WFIRST will orbit at the Sun-Earth L2 point, and will launch from the Eastern Test Range. The spacecraft and instruments have a modular design in order to facilitate (potential) robotic servicing. International contributions are being considered. WFIRST is part of the Exoplanet Exploration Program. The Wide Field Instrument (WFI) provides imaging to support dark energy and microlensing science, spectroscopic capability, and a guide star for fine pointing. The coronagraph provides high-contrast imaging and integral field spectroscopy in support of exoplanet and debris disk science. The schedule has been designed to both a 2024 and 2025 launch date to meet differing budget profiles; the current mission budget guidelines are constrained in FY18-20. The mission cost was increased to accommodate increased launch vehicle costs, design maturation, increased science team funding, an extended phase A, configuration changes, and Wide Field industry studies. The life cycle cost is now estimated at $2.7 to $3.2B in real year dollars. International contributions are being considered for elements of the WFI, coronagraph and ground system. STMD is providing some funding for coronagraph development in FY16 and FY17, in accordance with some of its own roadmapping goals. A 2024 launch would require on the order of an extra $250M to $300M per year over three years. Asked how tight instrument structural tolerances were (for robotic servicing, Mr. Grady responded that he get that information. Dr. Scowen raised a concern about throwing off beam angles, etc., should servicing be required. Mr. Grady reported that the program was doing a study on the minimum temperature the mirror could tolerate, for IR purposes, given that the mirror was originally a room-temperature design. The project hopes to have an answer by Summer or Fall. The best-case estimate for the moment is 2.4 microns, at a minimum temperature of 260°K (currently held at 280°K). Dr. Kalirai noted that the project was also looking at making the capacity bluer as well, using filters. Dr. Gehrels concluded the briefing by saying there is very strong interest in WFIRST from Europe, Japan, and Canada. NASA is working with these potential partners on possible contributions.

LIGO Science and EM Follow-up

Dr. Cornish reported the 14 September 2015 detection of a gravitational wave source, GW150914, by the Laser Interferometer Gravitational-Wave Observatory (LIGO), providing a brief history of LIGO's origins and the progression of its sensitivity. It is hoped that with a second run later this year, the instrument will get out to 80-120 megaparsecs (Mpc). He reported on 17 days of coincident data from the first run of the instrument, and promised much more data to come. In the GW 150914 second observing run, the 50 detections are expected. LIGO had a 41% coincident duty cycle, and the detection represented three Sun-masses turned into energy in a fraction of a second. The remaining black hole is calculated to be about the size of Montana. The event happened somewhere in the southern hemisphere of the galaxy, between the Large and Small Magellanic clouds. Once four detections have been made, announcements will be made on a general basis.

The research team is currently triangulating the source, and is hoping that the Virgo interferometer will join the effort during the second run, later followed by the Kamioka Gravitational Wave Detector (KAGRA; Japan), the German-UK interferometric detector (GEO) and future LIGO instruments. Electromagnetic counterparts of gravitational wave events include neutron star-neutron star mergers, neutron star-black hole mergers, core collapse supernovae, collapsars/hypernovae, pulsars, low-mass x-ray binaries, or black-hole-black-hole mergers (with some kind of gas inflow). It is hoped that the latency for the second observing run will be around an hour, with a goal of reaching 20-30 seconds by run three. Instruments for following up GW events should provide for good localization, rapid notification, and rapid response. Candidates such as ESA's INTERnational Gamma-Ray Astrophysics Laboratory (INTEGRAL), Swift, Fermi, the future Space-based multi-band astronomical Variable Objects Monitor (SVOM; French) and a Lobster ETA (MIDEX proposal) are being considered. There is concern about a potential gap during prime operations in the period around 2020-25. There is also a "protoproposal" for a Lobster Lite mission under study, as well as cubesats (e.g., a BurstCube for gamma ray burst detection). The Wide Field Imager, Infrared Telescope or Gamma Ray Transient Monitor (all at TRL 6) may be able to fill the gap, as well as a Transient Astrophysics Probe (Super Lobster). Dr. Cornish concluded by commenting that the only sure way to find counterparts to events such as GW150914 is to fly a LISA mission.

LISA Pathfinder Status

Dr. Ira Thorpe provided an update on the LISA Pathfinder mission, a technology demonstrator for a future space-based gravitational wave detector. The mission was designed to essentially allay fears about making measurements of frequencies in the picometer range. It must be noted that the ground-based LIGO makes measurements many orders of magnitude smaller; space makes it easier to make the measurements for gravity waves. LISA Pathfinder is measuring the curvature of space by timing photon travel between freely falling objects. The spacecraft is carrying two test masses, an optical metrology system, a thermal magnetic diagnostic system, NASA-contributed micronewton thrusters (colloidal), and drag-free control laws (test masses). The goal of the mission to obtain a physics-based model for the residual acceleration noise. Now in week three of European operations, the mission will switch to NASA operations in June. The project hopes to release intermediate results in Spring to early Summer 2016. Interested parties can stay up to date at lisapathfinder.org. The subcommittee briefly discussed the value of an extended mission (EM). Dr. Thorpe reported that there is an idea to fly the spacecraft through the MOND bubble (modified Newtonian dynamics). Alternatively, once could do more aggressive instrument work, such as determining what happens when the thruster runs out of gas. An EM would also be an opportunity to investigate caging mechanisms, such as grabbing and release of test masses multiple times to get a probabilistic view.

Public comment period

Dr. Fazio reminded APS that Spitzer Space Telescope made very significant contributions to the discovery of the farthest galaxy ever detected, GN-z11, just 400 million years after the Big Bang.

L3 Study Team Status

Dr. David Shoemaker gave an update on the progress of the L3 study team (L3ST), of which he is Chair. L3 is an ESA gravitational wave mission that represents the third large (L) mission in its Cosmic Vision 2015-2025 Programme. Its notional launch date is 2034. In Fall 2015, APS recommended that an L3 study team be created to enable NASA's eventual contribution to L3 at a cost cap of $150M. The charter of the study directs that a report is to be delivered in September 2016, while during a second phase of the study the Team will provide a report for input into the 2020 Decadal Survey. The Technology Analysis Group (TAG) is assisting the study team with technical analyses. L3ST and TAG together constitute the L3 Study Group. The Study Group began its activities in February 2016 with its first teleconference. A science task force has also been formed to conduct science trade studies to assess the cost to NASA. The final product will be a written report to NASA providing options for possible contributions as a function of mission design. Dr. Shoemaker expected that the report will be useful to the APD director in future negotiations with ESA. A Study Group meeting will be held at the American Physical Society in April. There will be an interim debrief to APD in May 2016, with a final report to be published in September 2016. Dr. Gaudi expressed concern about the health of the community, with a launch 20 years away. Dr. Shoemaker recommended trying to maintain a small continuum of funding from NASA to keep the expertise alive. Dr. Cornish commented that an L3/LISA mission could launch in 10 years if there were sufficient funding. While there were no explicit plans to hold L3 Study group discussions with the Europeans, Dr. Shoemaker agreed that this should happen.

March 16, 2016

Opening Remarks
Dr. Gaudi opened the meeting, reviewed FACA rules, and took the roll.

NESSF
Dr. Linda Sparke presented a briefing on the NASA Earth and Space Science Fellowship, for which funding is allotted under the Astrophysics Research Award (APRA) programs in FY15 for the Astrophysics research proposals. The total funding for the Research Program has been going up: the total was $89M in FY15. NESSF is a small part of the total, about as large as the fundamental physics program. APS had expressed concern over low selection rates in NESSF, and Dr. Sparke provided a response. The purpose of NESSF is to ensure continued training of a highly qualified workforce in disciplines needed to achieve NASA's scientific goals. From 2008 to 2015, NESSF made 75 awards to PhD. students. There are 9-10 new fellows in Astrophysics each year. About a third of the fellows are women, a third of recipients are at private schools, and a third work on technology or suborbital-class payloads. Of the pool of 2007-13 fellows, 43 have completed their doctorates, and 32 are still in their programs. Most of the 43 fellows are still post-docs, 6 are faculty at research institutions, and 8 are in the field of software data outside astronomy. . Looking at institutions that host fellows, some universities (notably the University of Maryland) have more fellows than average, but for any given fellow, the most probable number of other fellows at that institution is zero. The effect of small-number statistics is evident: Columbia University's winners are all women.

To increase selection rates, there are several options. APD can increase funding; it is now spending roughly $720K per year. The cost of selecting 20 new fellows each year would be $1.8M per year. The additional $1M/year is equivalent to two awards in Theory and Computational Astrophysics Networks Program, one fewer rocket payload per three years, or one fewer balloon payload every 4 years. Another option would be to restrict the years in which students can apply: this would eliminate proposals made later in a student's career. This might follow the model of STMD, which awards 4-5 fellowships each year for Astrophysics topics, and requires that students apply during the first 3 years of graduate education. The National Science Foundation (NSF) has a 1-in-7 success rate for its graduate fellowship program across disciplines. NSF pays less than STMD but more than NESSF, and requires an application in or before the second year of graduate school.

It's hard to tell whether the fellowship is helpful to recipients. A study of NSF recipients published in 2014 showed that receiving the fellowship doesn't make PhDs finish faster , compared to those who narrowly missed being selected. Fellows were more likely than average STEM PhD to be employed in higher education. Women, Hispanics and African Americans were more likely to be picked for fellowships from the "maybe" pool. Half of the 2009-11 NSF cohort in engineering and physical science areas felt that fellowships from other sources were more desirable, as they provided more money and more help covering tuition costs. The effects seem to be weak, generally. Dr. Hertz commented that NESSF is an SMD-wide program, thus APD can't change the size of the stipend, but can change the number of fellowships awarded in astrophysics, which is purely a budgetary decision. There would have to be a rebalance of funds to address any changes. DOE fellowships are known to pay well, as are departmental assistantships. Dr. Sparke added that the NSF study indicated that NSF fellows report being somewhat less engaged in their departments than those who just missed a fellowship.. Dr. Kalirai noted that the study by NSF compares students in the upper echelons; the impact is probably larger than evidence suggests. He felt some type of rebalancing might be appropriate. Dr. Dingus suggested funding the grants the professors bring in, rather than funding students through a fellowship, to allow the professor to recruit students best suited to work on the project at hand. . Dr. Devlin also favored funding the task rather than the student; but an advantage of the NESSF is in training students to write proposals. Dr. Bregman felt that (an advising) professor should encourage the student to apply for the grant, to help fund the task. Dr. Gaudi completely disagreed and suggested that rather than having graduate students get absorbed into the research advisor's group, NESSF fellowships should allow graduate students the independence to experience different areas of concentration, as the NSF fellowships do. He cited many graduate students that end up on projects they are not interested in, simply for funding reasons. Dr. Cornish suggested changing the rules to make the fellowship more about the student and less about the project. The cost of proposal review and administering the program is also relatively large,, compared to what it's actually funding. Dr. Hertz reiterated that while a three-year limit to eligibility could be discussed within SMD, a recommendation to change to a student-centric approach should be taken to the Science Committee. Dr. Batalha suggested that NESSF could continue to encourage its awardees to consider NASA's strategic goals, encompassing astrophysics in a larger sense, rather than using awards to support a specific principal investigator. Dr. Bregman felt that graduate students did not possess the vision to create relevant programs and preferred to see the funds funneled more effectively (to professors). Dr. Gaudi felt that this part of the discussion centered on approaches to graduate education, rather than the disposition of NESSF.

Exoplanet Research Program

Dr. Martin Still, a Program Officer for the Exoplanet element of ROSES, presented a briefing on the outcome of the ROSES restructuring, specifically the "re-branding" of Origins of the Solar System (OSS) to the Exoplanets Research Program (XRP), and how XRP has since represented previous categorizations. Specifically, has there been a shift in grants for exoplanet work compared to pre-exoplanet work (debris disk chemistry, star formation)? ROSES has undergone two cycles since the restructuring, and Dr. Still reported on some results.

It is important to note that XRP shares administration with the Planetary Science Division (PSD), thus any changes to the category must be debated bilaterally. The intent of XRP is to study extrasolar planets with broad applications in the areas of composition, dynamics, and energetics of planetary bodies. The previous OSS initiative began in 1986, issuing from a workshop on the Origins of the Solar Systems, several years before the first exoplanet was discovered. OSS was highly successful. Its change to XRP came about to encourage interdisciplinary research, enable PSD strategic decision making, increase flexibility in responding to changing research priorities, reduce overlaps between program elements, make the structure of R&A program more explainable, and to make it easier to compute budgets (OMB, Congress). In the transition from ROSES-13 to ROSES-14, the number of research elements was reduced to represent simpler, tighter categories. OSS became XRP, with overlap with Emerging Worlds (origin of Solar System planets), and Habitable Worlds (life elsewhere). What was previously Planetary Atmospheres now falls under XRP. Of all OSS proposals, 86% went to Emerging Worlds, and 10% to XRP. Most PSD XRP proposals previously fell under Planetary Atmospheres and OSS.

PSD (ground-based and space based), APD (space-based) and NSF (ground-based), all fund exoplanet research. Players in the future of XRP may be Earth Science Division (ESD) (responding to climate change) and the Heliophysics Division (HPD) (space weather and effects on planetary atmospheres). In ROSES 16, it should be noted that Astrophysics XRP does not fund: archive data analysis theoretical investigations, laboratory astrophysics experiments, technology development, guest observations, or simulations of space data; these are funded by other Astrophysics elements such as Astrophysics Research and Analysis (APRA), Astrophysical Data Analysis Program (ADAP), Astrophysics Theory Program (ATP), and the missions. XRP funds everything else, primarily ground-based support of NASA's Astrophysics Space Program. XRP encourages follow-up observations for space-based exoplanet detections, ground-based observations that increase the value of NASA space data (characterization of exoplanet atmospheres); ground-based observations that increase value of future space-based assets (e.g., JWST), and ground-based observations that inform the operations of future space missions (e.g., collecting data that defines WFIRST visits to planetary systems). It is also hoped that the new categorizations will reduce the likelihood of proposers sending the same proposals to both NSF and NASA.

The PSD ROSES-15 Habitable Worlds element has become a cross-divisional element between Planetary and Astrophysics in ROSES-16. New money is not available, but APD will select suitably strategic programs from Habitable Worlds for funding, using XRP resources. Dr. Batalha added that an advantage of this scheme is that it gives the APD other bins to which to propose. Dr. Still addressed the question of whether there had been a shift in the types of proposals since the name change. He noted that the number of proposals is slowly increasing, in parallel with the budget. The selection rate has remained fairly steady over the last 7 years, and there is no long-term trend in the number or ratio of star and planetary-system formation proposals in the OSS/XRP element. Chemistry is generally considered under laboratory astrophysics or Theory, but formation and disks can be considered under XRP. Very few proposals are coming in under this XRP for validation of Kepler and K2 observations. Dr. Still felt that such proposals are going to the mission for the present. Dr. Batalha pointed to some missing topics: exoplanet demographics and occurrence rates. Dr. Still said radial velocities were held in the bulk properties category. As for demographics, XRP is dominated by observations; demographics proposals would fall under detection, or ADAP. Asked whether the funding rate for planetary proposals increasing, Dr. Still noted that PSD has been spending slightly more than APD, but that they tend to spread their money thinly over more proposals. Dr. Gaudi concluded from this observation that some community consternation about monies allotted is largely unfounded. Dr. Batalha wondered whether HPD and ESD were willing to step up to the plate and start contributing to XRP. Dr. Hertz felt that divisional science priorities would determine any decision to contribute to XRP, adding that it would be difficult to argue that funds for climate change are better spent in exoplanet research.

Astro-H/Hitomi Update

Dr. Richard Kelley (online) and Dr. Robert Petre provided an update on the progress of Astro-H, which successfully launched in February under the auspices of a large international collaboration. The newly re-named Hitomi satellite will study the structure and evolution of the universe, matter in extreme environments, black holes, galaxies, heavy elements, and non-thermal processes with soft and hard x-ray telescopes, a soft x-ray spectrometer, and a soft gamma ray detector. The US contributed, in collaboration with JAXA, a dewar/cooling system to the soft x-ray spectrometer (SXS; GSFC), which can run with and without cryogen. NASA also provided mirrors for the SXS and soft x-ray imager (SXI). The SXS launched with 37L (minimum requirement of 33L) of liquid He to provide a normal lifetime of 3 years, after which it will run in cryogen-free mode. The operating temperature is 0.05°K. Operations will be affected as the spacecraft passes over the South Atlantic Anomaly, therefore the instrument will respond periodically to maintain temperature stability. Thus far operations have been meeting temperature requirements. The equilibrium temperature is estimated to be 1.10°K. Once the detector system cools down, it can take data for 48 hours, after which it goes through a 45-minute re-cool cycle, representing very good efficiency. There is very low heat load emanating both from parasitic heat and the operation of the on-board refrigerators. There is actually about a five-year hold time, in terms of liquid He, in total. The mission expects to have about a year of margin, above the three-year lifetime. The in-orbit performance of the dedicated calibration channel has worked well in test-pointing conditions

The optical bench for the hard x-ray imager, which required 22 steps to deploy, has been successfully carried out, and repointed to calibrate as well. The SXI and hard x-ray imager are up and running. The soft gamma ray detector will be powered up the week of 21 March. The SXS aperture door will be opened on 8 April, followed by a calibration period.

Dr. Petre covered aspects of the Guest Observer (GO) program. The US GO program is enabled via the Hitomi Science Enhancement Option. Cycle 1 and subsequent cycles will last one year. For the Cycle 1,, the time division is 75% GO time, 15% Science Working Group (SWG) time, and 10% Observatory time. Fifty-six percent of time is devoted to JAXA, including a 10% share to ESA, and 44% to the US. The announcement for the GO program will be made in May, proposals are due in August, and Cycle 1 observations will begin on 1 December. The merging of conflicting US and Japanese proposals will continue to encourage collaboration. There is no explicit merged proposal time, which allows substantial overlapping observations. The proposal process will be two-step, and once accepted proposers must submit a budget through NSPIRES. There will also be an embedded call for laboratory astrophysics measurements directly related to Hitomi questions. The US GO program will be funded at $5M (by APD) for the first 3 cycles.

Dr. Kelley wrapped up the presentation, noting that the first major opportunity in the US to see spectra from Hitomi will be at the High Energy Astrophysics Division (HEAD) meeting. Dr. Bautz offered his congratulations.

Lightweight Optics: Optical to IR

Dr. H. PhilipStahl presented a status of present-day lightweight optics. Depending on the requirement, lightweight optic TRL varies from 3 to 6. The single most challenging requirement is achieving the picometer wavefront stability needed to detect exoplanets. This challenge is compounded by the desire for large telescopes. The bigger the telescope, the harder it is have a stable structure for wavefront and pointing; e.g., every doubling in aperture diameter also increases the distance between the primary and secondary mirrors and makes the entire system four times less stiff. It will be easier to achieve the required stability if NASA chooses to take advantage of the mass and volume capacity of the planned Space Launch System (SLS) to launch future large-aperture telescopes. Otherwise, NASA will need a long-term, sustained investment to develop either low-mass stable telescopes, or telescopes that can be assembled on orbit. In either event, exoplanet wave-front error (WFE) stability will require technology development. Also, longer wavelength optics are generally less expensive and are easier to manufacture.

The segmented JWST primary mirror defines the current state of the art with a 20 nm rms WFE stable, 6.5m mirror that is at TRL 6. Dr. Stahl averred that a large segmented mirror that possesses picometer WFE stability suitable for detecting exoplanets is presently only a concept. Lessons Learned from JWST have shown that mirror stiffness is essential to withstand launch loads and maintain performance. Mirrors significantly lighter weight than JWST 's optics will need significant engineering to survive (current) launch conditions. JWST achieved a two-fold mirror production schedule and cost reduction compared to the Hubble Space Telescope. Depending on many factors, the state of the art for lightweight mirrors is 40 to 80 kg/m$^2$ (the JWST primary mirror assembly is ~70 kg/m$^2$). Historically, segmented mirrors are used when a monolithic mirror is not practicable. JWST is based on real ground-based telescopes (e.g., Keck), and will be the best segmented telescope ever made. Continuing mirror technology development has reduced areal cost further since JWST. Currently both Corning and Schott can make 4m class substrates.

Technology development takes time and money; it is important to note that Hubble took 27 years, and JWST will take 22 years from start of funded technology development to launch. Both telescopes had the same problems: how to make and test a large stable mass-constrained affordable mirror. And both telescopes developed the same technology solutions, i.e. better materials and better testing tools. For example, Hubble's primary mirror was originally a segmented design, but development of ultralow expansion (ULE) glass enabled a simpler monolithic mirror; and, JWST's segmented primary mirror was enabled by the development of O-30 Beryllium powder. And on both HST and JWST, competition between multiple technology providers was the most important factor in maturing technology rapidly. Finally, systems engineering is absolutely critical to the process by establishing requirements.

Dr. Stahl then reviewed several mirror technology activities which he manages. NASA's Advanced Mirror Technology Development (AMTD) program is working to mature critical technologies. Key AMTD accomplishments include defining, from science requirements, the specification that the telescope must achieve a stability of less than 10 picometers root-mean squared (rms) per 10 minutes, and demonstrating a new process for manufacturing mechanically stiff UVOIR mirrors. Several Small Business Innovation Research (SBIR) funded projects have made advances in large aperture Far-IR telescope, additive manufacturing of aluminum mirrors, developing zero-CTE SiC material for mirrors and structure, and developing a new, SiOC material.

Asked about the use of adaptive optics (AO) to improve mirror performance, Dr. Stahl stated that his personal bias was to do as much as possible passively, and only then resort to AO. A monolithic mirror will probably need AO, but it is likely to be simpler than the AO needed for a segmented mirror.

Lightweight Optics X-ray

Dr. William Zhang presented a briefing on the state of the art in x-ray optics. Three metrics are relevant to progress in this area: angular resolution (point spread function; PSF), mass per unit effective area, and cost per unit effective area. The definition of progress is to perform ten times better in one or more of the metrics. For comparative purposes, missions in operations, such as Chandra, have metrics of 0.5 PSF, 18000 (mass), and $10,000 cost (high). NuStar cost a total of $50M. The International X-ray Observatory (IXO) was cancelled, but its technology is still in hand. Based on glass slumping, IXO technology is mature and is ready for missions requiring 10 PSF. Future missions such as Athena, X-ray Surveyor, and Probes/Explorers, will present further challenges. The specific challenge for X-ray Surveyor will be to make 10m$^2$ of lightweight optics at reasonable cost in reasonable time.

NASA's current lightweight, x-ray optics efforts center on single-crystal Si, which is mass-produced to , to lower cost and production time. A single crystal is polished, sliced into thin sections, and acid-etched to remove polishing damage. The proven concept requires 12 labor hours to make one mirror ($1000 per mirror). The coating is carried out by sputtering iridium on both sides of the mirror to minimize stress, after which the coating is annealed. Each mirror is kinematically supported to minimize distortion. Implementation and testing is under way; initial results are expected by December 2016.

*Status and prospects*
Slumped glass technology is ready for making 10 arc second x-ray telescopes. It is 10 times lighter than XMM-Newton's technology. Single-crystal Si mirrors are currently capable of 2 arc seconds, and with refinement of polishing, will reach one arc second. Diffraction-limited performance is eventually possible with this technology, with proper spacing of segments. Dr. Zhang felt that single-crystal Si was very likely to reach one arc second by 2020, in time to support the X-ray Surveyor mission. Other global efforts in x-ray optics development include Germany and Italy (slumping technology); efforts to improve slumped glass mirrors (piezoelectric, magnetic, differential deposition; 5 efforts in the US). Grinding and polishing thin full shells, and efforts to improve mirror bonding (MIT) are also under way.
Public comment
No comments were noted.

Far IR Surveyor Planning Report
Dr. David Leisawitz, NASA Center Study Scientist, presented a status on the Far Infrared (FIR) Surveyor, a future mission concept derived from the most recent Astrophysics Roadmap. The surveyor will require a large gain in measurement capabilities relative to past missions, with possible gains in sensitivity (potentially several orders of magnitude), spectroscopic capabilitiesand angular resolution sufficient to overcome spatial confusion in deep cosmic surveys, and to resolve protoplanetary disks. The far-infrared region is an information-rich area that is underexploited.. There are many science questions that can be answered with a FIR Surveyor: including how do the conditions for habitability arise in planet formation, what will dust-obscured galaxies reveal about AGNs and galactic evolution, and where are the exoplanets? Where is the water reservoir for planets? The FIR Surveyor will bring both complementary and unique capabilities relative to existing and upcoming facilities, such as ALMA and JWST, including access to water in the FIR, access to the dominant interstellar gas-cooling spectral lines, lines that can describe physical conditions (starburst vs. AGN), and the ability to observe many objects where they are brightest.

The STDT study flow was described as follows: identify visionary science questions as design drivers; derive requirements (sensitivity, angular and spectral resolution), decide what executable means (in terms of TRL); choose a mission architecture; determine technology needs; evaluate trades and engineering design; estimate cost; and present results to the Decadal Survey. In terms of technology, the Surveyor will need low-noise FIR detector arrays and cryocoolers. The telescope and instrumentation needs to be very cold, 4-5°K. New technology needs may be recognized by the STDT, such as large, high thermal conductance mirrors, and advances in interferometry. The call for the STDT had a great turnout. NASA received 90 applications and much international interest. Community chairs are Drs. Asantha Cooray and Margaret Meixner. A kickoff meeting is in the planning stages, scheduled for before the end of March and the first STDT face-to-face meeting will be held around the end of April or early May..

The team is demographically diverse and includes 12 men, 7 women, 4 persons of color, and 6 early-career researchers. STDT members represent in a wide variety of science areas. Near-term study priorities have been agreed upon, and GSFC has been chosen as lead Center. The team is seeking to get a systems engineering understanding in place quickly. The Infrared Processing and Analysis Center (IPAC) will provide the liaison and communication infrastructure for the study, including a public website. Key guiding principles have been established: approach all topics with an open mind, represent the community broadly, have a documented presentation release policy, keep meetings and telecons open to the public. A FIR-SIG is now active and growing. There may be other science and technology working groups associated with the STDT, all of which will enable the sharing of information. An announcement for the first meeting can be found at cor.gsfc.nasa.gov. In response to a question, Dr. Leisawitz thought the team would be able to study only one architecture fully. There are some existing concepts to work with Two major concepts are traceable to presentations made to the 2000 Decadal Survey, and a third concept originated in a FIR community workshop held in 2002. Several concepts were studied by NASA as Vision Missions or Origins Probes in the 2004-05 time frame. The architecture choice for the FIR Surveyor will be based on science drivers identified by the STDT.

Habitable Exoplanet Imaging Mission Concept Study Plan
Dr. Bertrand Mennesson presented the briefing. The primary science goals of this mission are to find habitable, Earth-sized exoplanets via direct detection and spectroscopic analysis of their reflected starlight, understand atmospheres and surface conditions, search for water and biosignatures, and search for signs of life. The overall imaging concept is open. The mission will require a large ultra-stable space telescope with high spatial resolution, sensitivity and dynamic range, with exquisite detectors in the optical (possibly UV and IR) spectrum. The imager should provide the capability for characterizing full planetary systems of rocky planets, water worlds, etc., to help understand the formation and evolution of planets, stars and galaxies. STDT will direct the design team to explore key trades (lambda, field of view, D, R). The concept study must fold in recent advances in knowledge and technology from the Kepler mission, as well as post-processing techniques for Hubble and ground-based observations, and advances in coronagraphs. The study team received 88 applications from high profile-scientists, from which selections were made with an eye to continuity with previous studies, and a good balance of expertise. Drs. Scott Gaudi and Sara Seager are co-chairs of the STDT, which also has *ex officios* representing Germany, Canada and France. A core team is being built, and plans are being made to engage with partners, the LUVOIR team, industry day at JPL, Star Shade Working Group (SSWG), an ExEP-appointed standards definition group, and a segmented aperture design analysis group. A three-year study plan will be delivered in August 2016. Dr. Kalirai said that he was happy to hear that broad community engagement is part of the study philosophy. Dr. Mennesson noted that the latest DRM results support a significant ability for the mission to support non-exoplanet physics.

LUVOIR Planning Report
Dr. Aki Roberge presented a briefing on the Large UV/Optical/IR mission (LUVOIR) concept, a general purpose multi-wavelength observatory with broad science capabilities, or a "super-duper Hubble." Born from the Astrophysics 2013 roadmap, LUVOIR is conceived as a leap forward in the ability to understand cosmic origins, study planet formation in protoplanetary disks, uncover the archaeology of nearby galaxies, search exoplanet atmospheres for signs of habitable conditions and the disequilibrium gases that might be biosignatures, and energize the field of comparative planetology. Sensitivity from far-UV to NIR wavelengths is envisioned, with some suite of imagers and spectrographs, and an aperture diameter in the range 8-16m. The study team received 136 applications, from which 24 voting STDT members were selected, suitably representing a broad range of topics (general astrophysics, exoplanets, Solar System observations, and technologists). Drs. Debra Fischer and Brad Peterson are the chairs of the STDT. The team is composed of 62% men, 38% women, and includes 7 members in early-career phase. The plan is to form Science and Technology Working Groups to capture the community's enthusiasm and help support the STDT. There are several international *ex officio* members of the STDT; Dr. Roberge felt

they should have a more active role than general observers. Asked about LUVOIR's distinction from the Habitable Exoplanet Imager, Dr. Roberge felt LUVOIR was more ambitious, but that the two concepts represent points on a continuum of optical missions. LUVOIR has a mandate to cover a broad range of science and to let all areas drive the mission design.

X-ray Surveyor Mission

Dr. Jessica Gaskin, Study Scientist for the X-Ray Surveyor Mission, presented a briefing. Also arising from the Astrophysics Roadmap (but not limited to/by it), the mission is looking for one to two order-of-magnitude gains in technical capability, to address topics surrounding the origins of the universe, the origin and growth of the first supermassive black holes, and physics of matter in extreme environments (jets and outflows). The mission can carry out deep and wide surveys in conjunction with other wavelengths to further characterize black holes. What turns star formation on and off? How did the universe of galaxies emerge from initial conditions? The surveyor will also look at the physics behind the structure of astronomical objects; supernova remnants; and particle acceleration in pulsar wind nebulae. This will require high- resolution spectroscopy. Ultimately, the STDT will define the key science and the mission concept needed to carry out that science. X-ray is a key waveband to have to solve the puzzle. It is important to note that X-Ray Surveyor not just be complimentary to orbiting observatories, but ground based observatories as well. Several giant ground-based telescopes will be operational at the time X-Ray surveyor comes on line; two of these are the Thirty Meter Telescope (144 times collecting area of Hubble), and the European Extremely Large Telescope. The STDT is chaired by Drs. Alexey Vikhlinin and Feryal Ozel, and overall represents a good cross-section of expertise. The study team had over 70 applicants. *Ex officio* members include Robert Petre (GSFC), and representatives from France, Canada and Germany. The notional management plan includes an emphasis on the relationship with the Smithsonian Astrophysical Observatory; who is partnered on the Study Team with MSFC. An informal mission concept was initiated last year, providing a point of departure for the current STDT, indicating great community interest. Some notional parameters include a 50X-more effective area than Chandra, and initial ideas about optics and instruments, such as multiple focal-plane instruments, a high definition x-ray imager, wide field-of-view imaging, at a cost of $3B. The team is in the process on putting out an RFI to industry to gather information on optics. A kickoff meeting will be scheduled as soon as possible, and a public website established.

Discussion

Dr. Gaudi initiated a discussion on findings, beginning with the issue of NESSF selection rates. While noting varying opinions on ancillary issues, he felt the consensus opinion was that the selection rate is too low. Several responses seemed possible: eliminate the program entirely; change its focus to the graduate student; ask APD to spend more money on it; or limit the number of times that a student can re-propose. Dr. Bregman suggested limiting the number of fellowships at any one time at a particular institution, or limit the years in which the student can propose. Dr. Batalha reiterated support for a student-centric fellowship. Dr. Wang recommended that the student be restricted to making an application within the first three years of graduate school to solve the oversubscription rate. A majority favored adding more money to the program. In addition, APS concurred with the PAGs that the current funding status of the ten studies was acceptable, and agreed that a Probe-class mission line should be considered by the Decadal Survey, with an expectation of three in-depth costing studies to follow the ten funded concept studies.

Future meeting topics were suggested, among them a suborbital/balloon briefing, a science presentation on the suborbital program, a briefing from ExoPAG's Exoplanet SIG-16, and a briefing on short-term

Education efforts in Astrophysics. The next APS meeting was scheduled for 20-21 July. Dr. Gaudi adjourned the meeting at 2:53 pm.

# Appendix A
# Attendees

Subcommittee members
**B. Scott Gaudi, Chair, The Ohio State University**
Joel Bregman, Vice-Chair, University of Michigan
Natalie Batalha, NASA Ames Research Center (Webex)
Marshall Bautz, Massachusetts Institute of Technology
James Bock, California Institute of Technology (Webex)
Alan Boss, Carnegie Institution
Patricia Boyd, NASA Goddard Space Flight Center
Neil J. Cornish, Montana State University
Mark Devlin, University of Pennsylvania
Brenda L. Dingus, Los Alamos National Laboratory
Giovanni Fazio, Harvard-Smithsonian Center for Astrophysics
Jason Kalirai, Space Telescope Science Institute
Paul A. Scowen, Arizona State University
Yun Wang, California Institute of Technology
Beth Willman, LSST/University of Arizona
Hashima Hasan, Executive Secretary, NASA Headquarters

NASA Attendees
Gabriel Adler, NASA HQ
Dominic Benford, NASA HQ
Ann Cardiff, NASA GSFC
Rebecca Doroshenk, NASA HQ
John Gagosian, NASA HQ
Kevin Grady, NASA GSFC
Thomas Haas, NASA HQ
Colleen Hartman, NASA GSFC
Jeffrey Hayes, NASA HQ
Paul Hertz, NASA HQ
Stefan Immler, NASA HQ
W. Vernon Jones, NASA HQ
Jeff Livas, NASA GSFC
Carolyn Mercer, NASA HQ
Susan Neff, NASA GSFC
Mario Perez, NASA HQ
Allyson Reneau, NASA HQ
Bob Petre, NASA GSFC Goddard

Rita Sambruna, NASA HQ
Wilton Sanders, NASA HQ
Kartik Sheth, NASA HQ
Phil Stahl, NASA MSFC
Robin Stebbins, NASA GSFC

Other Attendees
Grace Hu, Office of Management & Budget
Warren Skidmore, Thirty Meter Telescope
Ana Wilson, Ingenicomm
Joan Zimmermann, Ingenicomm

Webex
Mansoor Ahmed, NASA GSFC
Jim Bartoni, NASA
Felicia Chow, NASA
Mark Clampin, NASA GSFC
Julie Crooke, NASA GSFC
John Dyster, Orbital ATK
Dan Evans, NASA HQ
Will Fisher,
Jeff Foust, Space News
Michael Garcia, NASA HQ
Jessica Gaskin, NASA MSFC
Neil Gehrels, NASA GSFC
Thomas Griffin, NASA GSFC
Shahid Habib, NASA HQ
Lewis Kaluzienski, NASA
Jennifer Kearns, NASA HQ
Richard Kelley, NASA GSFC
David Leisawitz, NASA GSFC
Tonya Levins, NASA
James Lochner, USRA
Bertrand Menneson, NASA JPL
Deborah Padgett, NASA GSFC
Peter Pertoni, NASA
Peter Plavchan, Missouri State University
Erin Preston, JAO
Steve Roming, SWRI
Nick Saab, Lewis-Burke Associates
David Shoemaker, MIT
Linda Siobhan-Spark, NASA HQ

Carl Stapelfeldt, NASA JPL
Doug Swartz, NASA MSFC
Harvey Tananbaum, SAO
Pamela Terrell, NASA HQ
Steve Thompson, Millennium Space Systems
Michael Werner, NASA JPL

# Appendix B
# NAC Astrophysics Subcommittee Membership

B. Scott Gaudi, Chair
The Ohio State University

Joel Bregman, Vice-Chair
University of Michigan

Natalie Batalha
NASA Ames Research Center

Marshall Bautz
Massachusetts Institute of Technology

Jamie Bock
California Institute of Technology

Alan Boss
Carnegie Institution

Patricia Boyd
NASA Goddard Space Flight Center

Neil J. Cornish
Montana State University

Mark Devlin
University of Pennsylvania

Brenda L. Dingus
Los Alamos National Laboratory

Giovanni Fazio
Harvard-Smithsonian Center for Astrophysics
Jason Kalirai
Space Telescope Science Institute

Paul A. Scowen
Arizona State University

Rachel Somerville
Rutgers University

Yun Wang
California Institute of Technology

Beth Willman
LSST/University of Arizona

Hashima Hasan
Executive Secretary
NASA Headquarters

# Appendix C
# Presentations

1. Astrophysics Division and Budget Update, *Paul Hertz*
2. Exoplanets Program Analysis Group; *Alan Boss*
3. NASA's Physics of the Cosmos Program Analysis Group; *James Bock*
4. Cosmic Origins Program Analysis Group; *Paul Scowen*
5. WFIRST Status; *Neil Gehrels & Kevin Grady*
6. LIGO report; *Neil Cornish*
7. LISA Pathfinder; *Ira Thorpe*
8. L3 Study Update; *David Shoemaker*
9. NESSF Report; *Linda Sparke*
10. XRP; *Martin Still*
11. Astro-H/Hitomi Status Report; *Richard Kelley*
12. Lightweight Optics: Optical to IR; *H. Philip Stahl*
13. Lightweight X-ray Optics; *William Zhang*
14. Far-IR Surveyor Planning Report; *David Leisawitz*
15. HabEx Imaging Mission; *Bertrand Mennesson*

# Appendix D
# Agenda

Astrophysics Subcommittee

March 15-16, 2016

NASA Headquarters 3H42 (MIC 3)

Time Zone: Eastern

Tuesday March 15

| | | |
|---|---|---|
| 8:30 a.m. | Meeting Room Open | |
| 9:00 a.m. | Introduction and Announcements | Scott Gaudi |
| 9:05 a.m. | Astrophysics Division Update | Paul Hertz |
| 11:00 a.m. | Break | |
| 11:15 a.m. | ExoPAG Report | Alan Boss |
| 11:35 a.m. | PhysPAG Report | James Bock |
| 11:55 a.m. | COPAG Report | Paul Scowen |
| 12:15 p.m. | Lunch | |
| 1:15 p.m. | Discussion of PAG Reports | APS members |
| 1:45 p.m. | WFIRST Update | Neil Gehrels/Kevin Grady |
| 2:15 p.m. | LIGO science & EM Followup | Neil Cornish |
| 3:15 p.m. | Break | |
| 3:30 p.m. | LISA Pathfinder status | Ira Thorpe |
| 3:45 p.m. | L3 Study Team status | David Shoemaker |
| 4:00 p.m. | Public Comment Period | |
| 4:10 p.m. | Discussion | APS Members |
| 5:00 p.m. | Adjourn Day 1 | |

Wednesday March 16

| | | |
|---|---|---|
| 8:30 a.m. | Meeting Room Open | |
| 9:00 a.m. | Opening Remarks | Scott Gaudi |
| 9:10 a.m. | NESSF Update | Linda Sparke |
| 9:40 a.m. | Exoplanet Research Program | Martin Still |
| 10:10 a.m. | Astro H/Hitomi Update | Richard Kelley/Robert Petre |
| 10:40 a.m. | Break | |
| 11:00 a.m. | Lightweight Optics Optical/IR | Philip Stahl |
| 11:15 a.m. | Lightweight Optics X-ray | William Zhang |
| 11:30 a.m | Far-IR Surveyor Planning Report | David Leisawitz |
| 11:45 a.m. | Habitable Exoplanet Imaging Mission Planning Report | Bertrand Mennesson |
| 12:00 p.m. | Public Comment | |
| 12:10 p.m. | Lunch | |
| 1:00 p.m. | Large UV/Optical/IR Surveyor Planning Report | Aki Roberge |
| 1:15 p.m. | X-Ray Surveyor Planning Report | Jessica Gaskin |
| 1:30 p.m. | Discussion | APS members |
| 3:00 p.m. | Recommendations, Actions | Scott Gaudi |
| 3:30 p.m. | Brief to Hertz | Scott Gaudi |
| 4:00 p.m. | Adjourn | |