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Teleconference

MEETING MINUTES

Feryal Özel 12/17/2018

Feryal Ozel, Chair

12/11/12

Hashima Hasan, Executive Secretary

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Introduction and Announcements

Dr. Hashima Hasan, Executive Secretary of NASA's Astrophysics Advisory Committee (APAC), opened the meeting by welcoming the Committee members. She then reviewed the Federal Advisory Committee Act (FACA) rules. Members were appointed by the Science Mission Directorate (SMD) Associate Administrator due to their subject matter expertise, and are subject to government rules pertaining to Special Government Employees (SGEs).

Dr. Hasan explained that a number of APAC members had conflicts of interest (COIs) with specific topics on the agenda. These included Drs. Patricia Boyd and Marshall Bautz on the Transiting Exoplanet Survey Satellite (TESS), and all but four Committee members on the Wide Field InfraRed Space Telescope (WFIRST). The four unconflicted members were Drs. Brenda Dingus, John Conklin, Kelly Holley-Bockelmann, and Charles Woodward. Dr. Hasan added that Dr. Woodward was a new member of APAC, and welcomed him. She then took roll of APAC members.

Dr. Feryal Ozel, APAC Chair, welcomed the Committee members, and briefly reviewed the agenda.

Astrophysics Division Update

Dr. Hertz welcomed the APAC members. The Astrophysics Division (APD) continues implementing the recommendations of the 2010 Decadal Survey (DS), while seeking to answer key questions about the origins of the universe, its various features, and life beyond Earth. APD has seen some staff changes since the last APAC meeting. Mr. Jeff Volosin is now the Acting Deputy Director, Ms. Jackie Townsend is the interim Astrophysics Strategic Missions Program Manager, and Dr. Eric Smith is the Chief Scientist for the Astrophysics Division. Among changes within SMD, Mr. Steve Clarke is the Deputy Associate Administrator of Exploration.

Dr. Hertz next reviewed some NASA science highlights and noted that NASA is celebrating its 60th anniversary. The Agency's highest priority is now the lunar exploration campaign. A graphic showed the plan for orbital and landed missions, some of which are in development. The Orion spacecraft is moving toward a 2020 launch. NASA's Lunar Gateway will go into a lunar orbit and operate as a science station, among other functions. The first Gateway element should launch around 2022, and full assembly is planned for around 2026. The International Space Station (ISS) will continue to operate, though U.S. involvement will change. Small commercial lunar landers could launch as early as 2019. NASA has received proposals from companies willing to take NASA payloads to the moon. The first set of payloads will be off-the-shelf or existing payloads. There has already been a Research Opportunities in Space and Earth Sciences (ROSES) call for this effort, and such calls are likely to be annual. The expectation is for mid-sized robotic landers to launch around 2022 and for an advanced exploration lander to go up in the late 2020s – the latter will be human tended, and will serve as a precursor to human exploration of Mars.

It was important to note that none of the missions on that particular slide are funded by APD. Science payloads selected by SMD will be funded by SMD. The Planetary Science Division (PSD) is seeking payloads in a call that is open to astrophysics payloads, and later calls will include astrophysics. The 2019 Mission of Opportunity (MoO) call for proposals from APD will solicit astrophysics payloads that could go on the Gateway, and those will be funded by APD. Unlike ISS, the Gateway will not be permanently tended, though it will permanently host both interior and exterior payloads. It will have a 6-day,

elliptical lunar orbit that will facilitate communications and enable launches to multiple destinations. The European Space Agency (ESA) is among the international partners.

In discussing accomplishments and activities since the last APAC meeting, Dr. Hertz noted that the balloon campaign at Fort Sumner was shortened due to a launch vehicle failure, which has led to an inspection of all balloon launch vehicles. The Euclid sensor chip electronics recovery plan was approved, and NASA plans to deliver all of the new-design flight units within about a year. The first of two Stratospheric Observatory for Infrared Astronomy (SOFIA) reviews has begun. The Imaging X-ray Polarimetry Explorer (IXPE) is about to enter Phase C. Fuel depletion will force Kepler to complete its mission in calendar year 2018. The National Science Foundation (NSF) has delayed the Antarctic balloon campaign due to bad weather. The 2020 DS will begin soon and the next Astrophysics Senior Review (SR) will begin early next year. Also, in early 2019 will be the release of the Small Explorer (SMEX) and MoO Announcement of Opportunity (AO).

The Fiscal Year 2019 (FY19) budget is still awaiting Congressional action. In the meantime, NASA is operating under a Continuing Resolution (CR). WFIRST will continue to execute the plan approved at Key Decision Point-B (KDP-B) while awaiting the FY19 appropriation. The Medium Class Explorer (MIDEX) downselect and the SMEX AO are still on track. Plans for the James Webb Space Telescope's (JWST's) increased budget requirements will be submitted as part of the FY20 budget request. The FY19 budget was submitted prior to the revised JWST budget needs becoming apparent, and additional funding is not needed until FY20 and FY21. JWST will still be in development then, which will call for more funds than anticipated. Dr. Hertz showed the FY19 budget chart from the previous meeting, which included Congressional markups and the sand chart with WFIRST funding deleted. Neither chart had changed.

Dr. Hertz next did a quick review of the four elements of APD's Research and Analysis (R&A) program. The teleconference was to include a presentation on the NASA Earth and Space Science Fellowships (NESSFs) as background for an in-depth discussion at APAC's spring 2019 meeting. Dr. Hertz asked that if Committee members wanted more information, they identify it for APD. There were no changes in plans for R&A. However, starting in FY19, the Division will have an additional $5 million allocated for cubesats, and APD planned to select at least one new cubesat every year. R&A proposal pressure had not changed since the previous meeting.

Internal Scientist Funding Model

APAC had requested an update on the Internal Scientist Funding Model (ISFM). Dr. Hertz showed a chart with the NASA Center (i.e. excluding JPL) directed work packages that had been approved for the first 2 years. Many of the funded projects build on work previously done through ROSES and peer-reviewed research. The total funding comes to about 8 percent of the R&A budget and less than 30 percent of the Strategic Astrophysics Technology (SAT) budget. These are below the percentages that go to the NASA centers without the ISFM. The centers receive roughly 20 percent or more of the ROSES budget, which is remaining stable while the share going to the rest of the community is increasing. This shows that ISFM does not affect the community's competitive R&A programs.

Dr. Bautz thought that some of the amounts seemed larger than expected for the Astrophysics Research and Analysis (APRA) and SAT programs. He asked if these were for multiple programs, which Dr. Hertz confirmed. Some centers had multiple, related investigations, so APD bundled them. Dr. Ozel asked if other proposals were influenced by the presence of the directed funding. Dr. Hertz explained that APD does not instruct the peer review panels to look at this, and only tells them what has been approved across both ISFM and R&A. The reviewers need to know about redundancy, so this is normal practice.

He said that he would verify this, but as the selecting official, he believed there had been no impact. In many cases, the directed work is unique and should be done at NASA centers anyway.

APD has no quantitative limit on the split between civil servants, contractors, and other collaborators in these projects. The Jet Propulsion Lab (JPL) is included in the sandcharts shown, which needs to be corrected since JPL as a NASA FFRDC is not part of and does not benefit from the ISFM. There are two steps in the review process for the directed work packages. First, centers present a short description of a work package, which they discuss with Headquarters. Such work must be substantial, strategic, forward-leaning, and innovative, while also being the kind of work best done at a center. The second step is for APD to request a full description for peer review, and this description is subject to a mail-in review by external reviewers. The first discussion more or less selects the work, and the peer review provides checks on the decision and optimization. Renewals will work the same way. There is also a review halfway through the project. Dr. Hertz presented data showing the fraction of funds going to the community. The number of proposals coming from the centers has gone down, which was one of the ISFM goals.

R&A Myths

Dr. Hertz sought to dispel two myths about R&A. The first myth is that expensive proposals are less likely to be funded. Data analysis for the Astrophysics Data Analysis Program (ADAP) from 2010 to 2018, normalized for inflation, shows that to not be true. There is no reduction in the selection rate for expensive proposals and no bias favoring inexpensive ones. The second myth concerned the high-risk/high-impact survey of peer reviewers, which the National Academy of Sciences (NAS) recommended. Following reviews, APD asked the reviewers if they thought the proposals were high risk and high impact. The data indicate that 35 percent of high risk/high impact proposals were selected for funding, although only 24 percent of all proposals were selected. There appears to be no correlation on risk, and panelists are highly motivated by high-impact proposals. Dr. Bautz said that the community needs to know this, and suggested that the Program Analysis Groups (PAGs) might be vehicles to communicate the survey results. Dr. Hertz agreed, adding that it will be discussed in the astrophysics townhall at the January meeting of the American Astronomical Society (AAS) in Seattle.

Mission Status

APD has seven missions in development. TESS began collecting data on Sector 4 that weekend. The team is now putting pixel data into alerts; the quick alert system will enable rapid follow-up while objects are in night-time sky. The TESS operations team is working towards steady-state data delivery. On JWST, the increase in development costs is $805 million through commissioning, and another $490 million will be needed in FY20-21 for development. The anticipated cost growth is likely to affect other science missions. NASA continues to participate in Congressional hearings on JWST, along with briefings in public and staff sessions. The Webb Internal Review Board (IRB) will meet later in the year to review the replan, the progress toward it, and the NASA response to IRB recommendations.

At the previous meeting, APAC sought more information on WFIRST, which was to be presented later in the meeting. NASA continues to make progress during Phase B, the preliminary design phase. In May, the team incorporated the WFIRST Independent External Technical/Management/Cost Review (WIETR) recommendations. To meet the $3.2 billion budget goal, NASA needs the planned budget profile, as any deviation from that budget will increase costs. The team completed system requirements reviews for all primary mission elements and is putting in place the contracts for the wide field instrument, infrared detectors, and telescope.

For Explorers, APD is maintaining the plan for four AOs per decade: two for Medium Class Explorers (MIDEXes) and two for SMEXes. The 2016 MIDEX is in competitive Phase A, while the 2019 SMEX AO will be out in the spring. For the Draft 2019 SMEX AO, there is a cost cap of $195 million, and NASA can provide a launch for a $50 million charge against that cap. MoOs have a $75 million cost cap for small complete or partner missions, and a $35 million cap for suborbital and smallsats. For smallsats proposed to go onto an Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) ring, NASA will identify a launch opportunity as part of the SMD rideshare program. These smallsats must do no harm and cannot drive the payload. The division with the secondary payload will pay for integration onto the primary mission. APD is seeking compelling science in the smallsat proposals. The Division sent out a Request for Information (RFI), receiving 55 responsive proposals. APD also received 38 proposals for smallsat mission concept studies, and selected 9 in advance of the 2019 SMEX/MoO AO.

Dr. Paul Scowen observed that while NASA will provide a launch for a $50 million charge, some launch vehicles are more expensive than that, and some are less. Dr. Hertz replied that NASA puts out a call for proposals for launch vehicles once a mission is selected, choosing one at KDP-C. It is not possible to know the costs at the time of the call for proposals. There are providers of small launch vehicles that can meet SMEX requirements and that are coming on as NASA options. There are also potential proposers who want to get their SMEXes into space without NASA managing them, and those PIs can now buy a launch vehicle as long as they manage it.

APD currently has 12 operating missions. The Hubble Space Telescope (HST) lost gyro 2 on October 5; gyro 2 had been troubled for about a year and was similar to previous gyro failures. HST has six gyros and uses three for the most efficient science operations. The remaining three gyros all have enhanced leads. As it is the leads that failed on the others, the mission team expects those with enhanced leads to have a longer mean time to failure. Gyro 3 had been in reserve, but it exhibited anomalous behavior. An anomaly review board recommended that the team test and make changes to the gyro 3 controls; this resulted in the bias rates being brought into the usable range. The team is now testing for stability and determining whether this can be maintained. If the tests are successful, HST will return to operations in three-gyro mode. HST can operate in one-gyro mode. What is lost in one-gyro mode is the amount of sky that is accessible, but quality science is still possible. The plan is to go into one-gyro mode when the next gyro is lost, holding the other in reserve. In this plan, HST should operate well into 2020s.

Coincidentally, the Chandra mission also lost a gyro, on October 10, and went into safe mode. This was the first of the mission's four gyros to be lost; it needs two. After testing, the team decided on the best two to return to use. The mission was to resume science mode shortly. These gyros are completely different from those on HST.

The Kepler mission team recently completed the download of campaign 19 data. The pressure on the fuel tank thrusters is dropping, and the mission is close to running out of fuel. However, the team began campaign 20 on October 14, with the intent of downloading as much of that data as possible. Downloading data requires a lot of fuel.

SOFIA's 5-year prime mission will end late in FY19, which would normally put it into the SR process, as statutorily required. However, the 2018 consolidated appropriations act forbade NASA from including SOFIA in the 2019 SR. It is appropriate and timely to review the project, so NASA is now reviewing the maintenance and operations paradigm to ensure efficiency and effectiveness in executing the science program. NASA will seek more science flight hours per dollar from the mission. In 2019, NASA will review SOFIA's science progress and prospects, along with the plans for the extended mission, to ensure that

SOFIA will be scientifically productive and relevant. In response to the reviews, NASA will not consider closeout or cancellation of SOFIA.

The SOFIA reviews will go to Dr. Hertz, but the 2019 SR results will be delivered to APAC. Dr. Hertz presented the SR timeline. There will be three panels: one for HST, one for Chandra, and one for six additional missions. He was in the process of appointing the SR members. After all three panels meet, they will report to the SR Subcommittee which will report to APAC, which will then make recommendations to NASA.

DS Planning

The upcoming DS must be ambitious, and it should recommend missions that are as compelling and paradigm-shifting as what has come from earlier DSes. These documents largely govern what the Division does. APD has initiated studies for 4 flagship and 10 probe mission concepts to help facilitate the DS committee's deliberations and inform the 2020 DS. APD asked the NAS Committee on Astronomy and Astrophysics (CAA) how NASA might best prepare for the 2020 DS. The response noted science traceability matrices; descope options; risk assessments; a common format for the four large missions; optimized designs for the probes (the timeline does not permit this); an open call for concepts beyond NASA-funded ideas; and, guidance on costs and budget profiles.

The Large Mission Concept Independent Assessment Team (LCIT) will conduct a technical, risk, and cost assessment of the four large-scale mission concept studies, providing the Science and Technology Definition Teams (STDTs) with feedback. Each mission team is doing its own cost estimate, and the LCIT will assess the credibility of the proposed cost estimates. This is appropriate for pre-Phase A mission concepts, as it is a credibility assessment. The DS panel will also do assessments in order to make recommendations and set priorities.

The probe concept studies are led by Principal Investigators (PIs), and the teams develop the concepts with a lower level of detail and definition than do the STDTs. Each probe concept team has access to a design run at the Goddard Space Flight Center (GSFC) or JPL. Many evolved their designs from there. When the teams submit their reports later this year, there will be independent cost assessments from GSFC and JPL. APD is also assembling a Probes Concept Assessment Team (PCAT) of subject matter experts who will assess the cost estimates of the costing offices, design labs, and studies. These assessment efforts will provide NASA HQ with confidence in the science, technical, cost, and risk conclusions to be presented to the DS. He is putting scientists on the assessment teams to ensure that the mission being costed is responsive to the science objectives.

Both NSF and NASA have approved DS funding, which will go to NAS at end of the month. The Department of Energy (DOE) is providing 10 percent of the funding, but NAS can start with 70 percent of the total and therefore does not need the DOE funds in hand in order to begin work. A CAA meeting was to take place the next week to discuss this, with a Space Studies Board meeting in the Spring to look at science using the resources and capabilities from the lunar exploration campaign. The statement of task calls on the DS to provide an overview of the state of astronomy and science; identify the most compelling science challenges; develop a comprehensive and balanced research strategy; use and recommend decision rules; and conduct and publish an assessment of the state of the profession.

APAC Recommendations

In response to recommendations APAC made at the previous meeting, this meeting was to have presentations on: JWST, to include a lessons learned report; WFIRST demonstration requirements; plans

for review of SOFIA; NESSF; and ISFM. APD was still working on responses to recommendations having to do with future High End Computing (HEC) work; ways to address SMD divisional barriers; and an update on SMD's tracking of the career paths of successful PIs.

NASA Earth and Space Science Fellows Program

Dr. Stefan Immler described the NESSF program, which offers research grants for future NASA investigators. There is a governmentwide effort to consolidate fellowship programs, but SMD has determined that it has no programs meeting the reporting criteria and therefore NESSF should not be part of this effort. NESSF gives an award to the selected students' university, while also providing training in proposal writing and NASA review procedures. APD has chosen to keep its NESSF selections at a specific rate, and so awards 6 to 10 new graduate fellowships in astrophysics each year. At the same time, APD supports graduate students through its R&A programs and suborbital programs.

SMD proposal data show that Earth Science Division (ESD) receives and funds a much larger number of proposals than do the other three divisions. But while PSD and APD receive comparable numbers of proposals, APD funds significantly fewer, closer to the rate of the Heliophysics Division (HPD), which receives fewer proposals but funds a greater percentage of them. In addition, APD's award rate is essentially flat, currently at 5 percent. The awards are for up to 3 years, at $45,000 per year. The Division supports many more graduate students through its Guest Observer (GO) and R&A programs.

APD is supporting 24 NESSF students at $45,000 per year, for a cost of about $1.1 million annually. Data on students supported through GO programs is incomplete, but factoring in R&A data, Dr. Immler determined that APD spends about $29 million per year supporting almost 600 students. For comparison purposes, he showed limited data from non-NASA programs, which were not specific to astrophysics.

When asked about the differences in NESSF acceptance rates between APD and PSD, given the similar proposal rates, Dr. Immler said that he did not have information on how other divisions manage their awards. Dr. Hertz said that APD could provide specific data if APAC made a request. ESD, which has an R&A budget six times that of APD's, has chosen to support a larger number of graduate students. A request was made to determine the fraction of NESSF awards to students under advisors who win as PIs. Dr. Hertz confirmed that the decision was made in past to put more funds into R&A and APRA. APAC was free to advise on that. There are mechanisms in place to ensure that APD's NESSF students do not have other awards. An APD intern studied where NESSF awardees went with their careers, and APD can share that report, though Dr. Hertz was not sure that the study was comprehensive. Dr. Immler added that the study showed that all of the awardees became successful, whether inside or outside the profession.

Discussion

Dr. Ozel noted that APAC would like a sense of the funding as a fraction of the other divisions' budgets, and would also like to know if NESSF students' advisors have other NASA R&A funding, as well as what happens next in their careers. Dr. Hertz explained that the limited approach to NESSF funding grew from the decision to get the most relevant science out of R&A funds, which APD determined meant investment in R&A, as it also supports graduate students. The Division holds that the approach maximizes the results and impact of R&A funds.

Dr. Dingus observed that with such a low acceptance rate, it is hard to do the right thing. She asked if the AO could be made more targeted. For example, the fellowships might focus on applicants whose

advisors have no other NASA funding, or first-time applicants only. It was suggested that APD identify a sector that might not have this opportunity otherwise. Dr. Ozel thought this might be a topic for the more in-depth discussion planned for APAC's next meeting. It might be helpful to determine whether the groups that have NASA funding are more successful. Dr. Scowen pointed out that APAC's predecessor, the Astrophysics Subcommittee (APS), discussed this in 2016. He offered to forward that information to APAC members.

In discussing other items, Dr. Leonidas Moustakas said it was interesting to see the breadth of programs focused on lunar discovery. He wondered about the APD strategy in this area, as it is a fairly new element. He thought they should be ready to take advantage of this opportunity and not be left behind. Dr. Hertz said that the statement of task for the DS includes asking the panels to consider ISS, the Gateway, and other Agency priorities that APD can leverage. At the moment, there are no high-level recommendations to do astrophysics on or near the moon. Therefore, he is treating it as an opportunity, which will be explicit in the next AO. APD will let merit determine selections, as always. In addition, while the competition for astrophysics on the landers will go through PSD, it will also be open, and APD will ensure that the right peer reviewers are involved in the panels. There have been workshops dealing with science enabled by this initiative. One such workshop, held in Denver in 2017, included a session on astrophysics. There has never been a prior call for missions that go to the moon in APD's strategic documents.

The Gateway opportunity does not open up a new funding wedge, but will be absorbed into current programs. This is how APD deals with ISS. Although NASA may stop funding 100 percent of ISS in 2024, the Station will continue, most likely with NASA involvement, which means that APD will take proposals that involve ISS beyond 2024. Mr. Clarke will facilitate the SMD aspects of lunar-based science. As yet, there are no prescribed processes, nor have there been any astrophysics proposals in that area.

Dr. Scowen explained that he attended a meeting with the Human Exploration and Operations Committee (HEOC). They are very interested in an open dialogue on the opportunities for science on the Gateway. Dr. Hertz said that that is the case within SMD as well. The Gateway developers have provided models so that SMD can see the viewing possibilities. Dr. Scowen noted that there was discussion of varying orbits and of contamination that might affect astrophysics. Assembly of telescopes in space might be affected, for example. Dr. Hertz said that in-space assembly is being studied so that NASA can determine how to identify the point at which in-space assembly becomes attractive. The output of that study will help the DS committee get perspective on in-space assembly and the timeframe. It is not yet certain that the Gateway will have assembly capabilities. It will have an airlock, habitation capabilities, and external connections.

Dr. Ozel asked if APAC should be thinking about anything else in preparing for the Gateway. Dr. Hertz replied that members of the community with ideas on this are already attending the workshops and other opportunities for involvement, which APD advertises. He would take APAC advice on how to spread the word, however, and Dr. Ozel asked the members to keep talking to the community about possibilities and directions. Dr. Moustakas asked whether there are guidelines for the STDTs on how to address any LCIT assessments of unrealistic costs. Dr. Hertz said that the LCIT will go back to the teams and discuss differences of opinion, at which point the STDTs will decide what to do.

Webb Telescope Update

Dr. Smith provided an update on JWST. Northrop Grumman (Northrop) has completely reassembled the spacecraft element. The Northrop clean room still has the telescope. The spacecraft element is about to

undergo a vibration test. This is the same test that uncovered the fastener issue earlier in 2018. If this test succeeds, the program will return to the normal flow. The spacecraft thermal vacuum test is different from the cryogenic test for the telescope in that it does not require the spacecraft element to reach cryogenic temperatures like the science payload. Dr. Smith showed a graphic of the schedule, pointing out the circles indicating months of schedule reserve. There is also launch reserve, and NASA HQ holds 4 months of funded schedule reserve, assuming a launch in March of 2021.

Work on the ground system is going well at the Space Telescope Science Institute (STScI), which is conducting rehearsals. Dr. Smith noted the remaining integration and testing (I&T) activities. Some science payload work is contingent on the spacecraft element testing. There will be a full deployment of the spacecraft element with acoustics and vibration testing. The team has been implementing the IRB's 32 recommendations and will meet with the board later in the year. There was also a teleconference with the General Accounting Office (GAO) annual audit team. The spacecraft element has returned to environmental testing and will go through thermal vacuum testing in early 2019. The Optical Telescope element/Integrated Science (OTIS) completed additional warm functional tests.

Current technical issues include maintaining schedule performance; depressurization at fairing jettison; and an OTIS Problem Failure Report (PFR). The fairing depressurization arose when it was noted that residual air trapped in the folded sunshield membrane may cause an overstress condition at the time of fairing separation. The team has validated the capability of the membrane material and investigated further. The fairings have vents to release air, and the team is fixing them to ensure that they latch and stay open. Regarding the OTIS PFR, final modifications and modeling of the primary mirror segment assembly must wait for the spacecraft to leave the clean room, which will happen in January. The Near InfraRed Camera (NIRCam) pupil wheel failure review board is wrapping up to determine if there has been a degradation of the bond wire connection. Dr. Smith can report back to APAC at the next meeting.

At the previous APAC meeting, the Committee asked for a plan to identify and minimize the science impacts of a delayed launch. Dr. Smith said that the largest impact is likely to be decreased overlap with a fully operational HST and Chandra. However, JWST will have overlap with Euclid, TESS and WFIRST and the coming generation of very large ground-based telescopes. The Guaranteed Time Observing (GTO) and Early Release Science (ERS) programs are largely unaffected. The Exoplanet Program Analysis Group (ExoPAG) is studying how the delay affects that community. JWST will do the best science whenever it is launched. The run-up to the call for proposals has led to some lessons learned to apply in the future.

Another APAC recommendation was to obtain lessons learned. The JWST team was already doing this in collaboration with SMD and GSFC. Responses from queries of NASA and Northrop are being organized to provide general lessons for the Agency's large programs, along with specific lessons for JWST. Both SMD and the Human Exploration and Operations Mission Directorate (HEOMD) are looking at how to apply these. Dr. Smith was unable to share these lessons with APAC at the moment, as they had not yet been approved by the Agency.

Dr. Hertz explained that what APAC was calling "flagship missions" are referred to as "large, strategic missions" within NASA. Dr. Ozel said that APAC can use that term from now on. Dr. Hertz said that NASA has increased the budgeted costs of JWST operations to accommodate inflation. Also, in exchange for spending 2.5 more years in development, the Agency is budgeting 2.5 more years of prime mission operations at the back end. If JWST were to pass SR, APD would spend that money anyway, so the additional costs show up 10+ years after launch.

Dr. Scowen asked how they will be able to tell that the environmental tests will succeed without breaking something. Dr. Smith explained that there will be a final system test so that everything is deployed once again. However, there will not be an additional fully deployed thermal vac test, as there is no chamber big enough. Dr. Ozel asked about possible overlap with TESS. Dr. Smith replied that, assuming TESS goes through SR, it will operate at the same time as JWST, which would match the operational lifetime that existed had JWST launched as originally planned. The mission will still be in sync with some portion of the TESS operational lifetime. Regarding the cryovac test, the actual test took 1 month, with cool-down and warm-up each taking an additional month. However, the cooldown and warmup are not needed for the spacecraft element.

Dr. Woodward noted that ERS programs are often led by early career individuals without permanent positions. He asked how those teams will maintain cohesiveness going forward. Dr. Smith replied that STScI will fund the activities so that some of those plans can continue. What it means for their later careers is something to consider. Dr. Laura Brenneman asked about the timing for the release of the lessons learned document. Dr. Smith said that it should be available by the next APAC meeting.

Discussion

The Committee had previously considered having a survey to identify areas of interdivisional science and proposals, determine whether investigators have obtained funding, and learn if there are areas they want to expand into but do not because it is unclear where to go. Dr. Ozel said it would also be helpful to know which other SMD divisions held the most interest for astrophysicists, and whether proposers feel the current system supports interdivisional research. Her concern was whether this survey might be too similar to the previous one, but she believed there was still uncertainty in this area, and that this topic might have been overshadowed by other survey questions. Dr. Moustakas agreed that the focus of the High-Impact/High-Reward survey diluted the questions on interdivisional work. He felt that the effectiveness of cross-divisional research opportunities still warranted exploration.

Dr. Victoria Meadows added that the previous survey did not go out to the ExoPAG community. They are very cross-divisional and she would like them to be able to weigh in. She also wanted to know whether people feel stymied by not knowing what box to put things in. Dr. Ozel noted that they might also feel that they have a research home and it has not been a problem. Either way, it would be good to know. Dr. Scowen pointed out that there were only 59 respondents to the first survey. He also thought there might have been some distraction, as the emphasis was different. That survey did provide some good anecdotal information, which was instructive, but he did not feel it was complete. Dr. Meadows wondered if anyone has steered research away from the interdivisional aspect. Dr. Ozel thought that was a good question.

Dr. Scowen saw no reason not to conduct this survey. Dr. Ozel said that she would send out a preliminary list of questions for edits, and Drs. Moustakas and Meadows could develop the draft. The goal is to have it in time for the spring meeting. She asked if APAC was allowed to have a shared site for documents. Dr. Hasan replied that APAC members are allowed to exchange materials among themselves, but any conclusions or advice must be developed in a public meeting.

SOFIA Review Update

Dr. Kartik Sheth presented an update on the two SOFIA reviews: the SOFIA Operations and Maintenance Efficiency Review (SOMER) and the SOFIA 5-Year Flagship Mission Review (S5YFMR). SOFIA's 5-year prime mission will be completed at the end of FY19. The mission would normally go into SR, but the 2018 Consolidated Appropriations Act forbade NASA from including SOFIA in the 2019 SR. Therefore,

SOMER will review maintenance and operations to ensure efficiency, and S5YFMR will look at science progress and prospects. These reviews will be used in planning but will not consider options for closeout or cancellation of SOFIA.

SOMER will look at the mission's aircraft, operations, and maintenance, and will examine alternative operations and maintenance models that might enable more flights and/or reduce overall program costs. This review will include everything except science operations and management. In addition, SOMER will study and recommend strategies and procedures to achieve more flights for minimum cost; for each model, provide specific numbers of personnel needed according to skill sets; consider the sustainability of each model over the next 5-15 years; and recommend changes to staffing, culture, and environment to improve efficiency. SOMER recently held its first meeting, with the goal of having a draft report in early 2019, and the project response and final report in February. The panel now has a good sense of the baseline and possibilities.

S5YRMR will evaluate SOFIA's continuing relevance to NASA's strategic plan, the mission's performance and ability to execute its performance plan, the scientific merit, the science per dollar, and optimization options. The review panel will include astrophysics community members, mission operations experts, and a few SOMER members. It will also use the SOMER report as an input. The draft Terms of Reference (TOR) will be sent to APAC and other groups in early November. The panel is likely to meet in mid-February, with a report in late March and a proposed optimization plan in May. Dr. Ozel said that APAC must meet publicly in order to respond but did not have another meeting planned for some time. Therefore, she wondered how APAC might provide input on the draft TOR. Dr. Hertz said that APAC members can give feedback as individuals. Dr. Sheth said that a concern is overload for potential panelists, as the SR and other projects will have meetings during the same time period.

Dr. Scowen noted that maintenance and repair of the telescope can be a factor in SOFIA's operations, since the mission is inoperable then. Dr. Sheth said that telescope / observatory operations will be conducted during the S5YFMR. He also noted that the telescope belongs to the German Aerospace Center (DLR), and the SOMER will look at the maintenance periods and get feedback about the time required for telescope repair / maintenance. There is not anything major that needs to be done on the telescope. Dr. Bautz asked if NASA operated any analogous facilities. Dr. Sheth replied that ESD's airborne science program has four aircraft, and those PIs are given specific times. The reviews will do a comparison. Some people with airborne science experience are on the SOMER panel.

Dr. Sheth said that this is a great opportunity to examine and scrub the entire operation going forward. Dr. Ozel replied that that is the hope of APAC, that the mission gets feedback to help boost its operations. Dr. Bautz noted that the Chandra and HST teams exchange insights, which could be valuable. Dr. Sheth added that while some upcoming maintenance activities are mandated, SOMER feels SOFIA should be able to do significantly more flights.

WFIRST Requirements

Because Dr. Ozel had a COI, along with all but four APAC members, Dr. Holley-Bockelmann chaired this portion of the meeting. Dr. Jeff Kruk explained that he was providing excerpts of the system requirements review conducted earlier in 2018. He began with a schematic flow-down of the requirements for Levels 1 through 3. That flow-down has been completed, some of it early. There are six Level 1 science objectives, which address the Near InfraRed (NIR) survey, expansion and growth of the universe, an exoplanet survey, and archival and guest observer access to the data. Most of the technology demonstration objectives relate to the coronagraph. Dr. Kruk showed how the objectives

flowed into science requirements, data records, data processing, ground system/operations, and flight hardware.

The coronagraph demonstration will test the unusual lenslet array. There is also a need for a zero-read noise detector, and there will be autonomous low-order and high-order wavefront sensing and control. Dr. Woodward was concerned about the Technology Readiness Levels (TRLs). Dr. Kruk explained that aside from the deformable mirrors, everything is at TRL 6. The interconnects on the deformable mirrors should be dealt with in a year or so. He used the high-latitude survey to show the flow from a science objective. To measure matter distribution to a redshift of two, the team defines the data needed, and what observation requirements will provide those data. In looking at the next level of detail, the team identifies what is needed for that measurement. There are some constraints, and some of the information for photometric redshift training and calibration already exists, as in the Euclid program. But for WFIRST, the limiting magnitude will be much fainter, requiring an ongoing effort to reach the desired depth. Another example flow was the weak lensing requirements summary. The object is to measure correlations, so the challenge is understanding the point spread function over the field.

The team has tried to gather all of the key requirements into groups they can use as they flow down, then breaking the requirements out by which aspect of the mission they affect. Some elements are more universal, such as survey speed, while others are more specific. A table gathers these parameters. Everything is documented, and there are traceability matrices that flow throughout. Dr. Kruk described how the process works; he spends hours each week meeting with the engineers, for example. There are processes for requesting changes, etc.

Dr. Woodward asked about the balance with the coronagraph and other science drivers. Dr. Kruk explained that the team has been instructed that the coronagraph cannot drive the rest of the observatory, but they can still have discussions. The coronagraph's throughput was improved without driving the rest of the satellite, for example. He is confident that mission creep is unlikely. The team does often ask for more, and the managers usually tell them no. However, even with constraints, the team can achieve good performance. The technology demonstration plan is solid. There are two architectures: a shaped pupil mode and a hybrid Lyot mode, and the team plans to demonstrate imaging with both architectures, and spectroscopy with two filters in the shaped pupil mode. He does not expect a change to the baseline. There is some I&T time that depends on the number of modes. A graphic showed what has been done with coronagraphs already, as well as what has been shown in the lab. The general observer and archival research objectives do not impose unique requirements on the observatory.

Dr. Kruk next presented the detailed mission requirements, which also illustrate the flows. The data volume is particularly high for APD, but ESD does this often. Instead of using the Deep Space Network (DSN), WFIRST will send communications through the ground station facility in White Sands, NM, and other ground stations.

Public Comment Period

The public was provided an opportunity for comment, but no one came forward.

Wrap Up for Day 1

The meeting was adjourned for the day at 4:27 p.m.

Tuesday, October 23

Opening Remarks

Dr. Hasan opened the second day of the meeting and reviewed the FACA requirements. COIs included Drs. Bautz and Boyd on TESS. After taking roll, Dr. Hasan determined that the meeting had a quorum.

Dr. Ozel welcomed the meeting participants and noted that there would be some changes in the agenda.

TESS Science Results

Dr. George Ricker, TESS PI, explained that the mission's commissioning had been successful and that science data were coming in. TESS will search for transiting exoplanets by monitoring the brightness of hundreds of thousands of stars, and will provide images for every object in every observed field at a 30-minute cadence. Ultimately, the mission will deliver photometric data for many millions of stars and galaxies. Ground analysis and follow-up will identify and confirm the presence of transiting planets, and determine their mass. Dr. Ricker described the differences between Kepler and TESS, and listed the advantages of the TESS high orbit, which has a larger than expected signal-to-noise improvement. The resonant orbit is close to perfect.

The mission's orbit stability should be greater than 25 years, and ample propellant is available for operations through at least 2038. In addition, the photometric precision and field of view have been better than the requirements. There was an "accidental discovery" towards the end of commissioning, involving a number of solar system objects that were serendipitously observed. A video showed a comet tail and reflected light from Mars, as well as many asteroids. Commissioning was completed on July 24, and the science survey began the next day, starting with the southern hemisphere. Dr. Ricker showed the instrument orientation and the views from the four cameras, as well as a plot of the camera views. TESS began by looking at exoplanets from previous surveys, which were readily detected at high signal-to-noise ratios.

There is some overlap in the Fields of View (FOVs) for TESS sectors 1-4. Observations of sectors 1-3 were completed, and sector 4 had observations had just begun. A first light image from sector 1, one of about 1,200 images, contained about 10 million stars and 1 million galaxies. There is some scattered light from Earth and the moon, which was always anticipated and which can be addressed with observational planning.

The mission team has commenced searches for new exoplanets. Dr. Ricker reviewed the small-planet search strategy and the initial processing of transit-like signals. The Science Processing Operations Center (SPOC) at Ames Research Center (ARC) at Ames is the pipeline of record. Students, postdocs, and staff from MIT and Harvard Smithsonian have been busy examining images. TESS Objects of Interest (TOI) alerts from the Quick Look Pipeline (QLP) at MIT has enabled rapid follow-up for planet candidates and began in September for sector 1. TOIs include planet candidates, eclipsing binaries, stellar variability, and other data. Deliveries to the Mikulski Archive for Space Telescopes (MAST) began about 2 months earlier than planned. Dr. Ricker used the example of Pi Mensae, a very bright star being validated as a planet candidate host, to illustrate the kind of work that can result from TESS observations. A giant planet was known to be orbiting Pi Mensae in a 6-year orbit, and a second "Super Earth" planet (Pi Mensae c) has been discovered by TESS in the same system. The light curves from the Quick-Look Pipeline (QLP) and SPOC for the newly-discovered TESS planet matched quite well, and more

work is being done to establish the planet's properties. Another TESS discovery is LHS 3844b, a planet that orbits an M dwarf star in an ultra-short period. Ninety percent of the sky has not yet been surveyed by TESS or Kepler.

Beyond exoplanet discovery and characterization, the camera's sensitivity is quite good, even better than expected. About 300 million stars and galaxies are accessible to TESS. Dr. Ricker showed a graph of TESS and depth, with peak luminosity on the y axis and characteristic timescale on the x axis. This graph illustrates the power of TESS to complement ground-based supernovae surveys by providing pre-discovery observations.

The team is already thinking about how the prime mission can feed into an extended mission through FY24, along with new initiatives through 2028. The ESA/Swiss CHaracterising ExOPlanet Satellite (CHEOPS) baseline mission will launch next year and overlap nicely. Coordination will also be possible with JWST, LIGO, the Large Synoptic Survey Telescope (LSST), and possibly even the PLAnetary Transits and Oscillations of stars (PLATO) mission if TESS is extended by a third SR. The team anticipates being able to move to shorter duration Full-Frame Images (FFIs) in extended mission, to provide added sensitivity and finer time resolution for 1-2 orders of magnitude more astronomical objects.

Regarding the mission duration to 2038, TESS is extremely unlikely to be limited by consumables, as it only requres hydrazine for angular momentum management, and the remaining supply could last about 300 years. There is no indication of other limitations to the mission's lifetime. It is in a very benign orbit regarding radiation damage, so that is not an issue, and there are no moving parts at all in the science instruments. The oversized solar panels are rotated very infrequently, especially compared to other missions. Nor are there filter wheels on TESS. Essentially, deployment and mechanical issues ended at launch.

For ground-based facility coordination, the mission established a team to provide resources to carry out minimum characterization and follow-up imaging. The team is funded by the primary mission and international partner contributions. Data are being deposited for coordination and examination, and others astronomers are being invited to contribute. A number of ground-based facilities are coming online. NASA has funded a new ground-based spectrograph that will come online to support TESS next year, and there will be two new European spectrographs coming online as well. The team is extremely happy with NASA's support, which has included lessons learned from Kepler.

ExoPAG/PhysPAG/COPAG Updates

ExoPAG

Dr. Meadows provided an update on ExoPAG activities. The Executive Committee membership had not changed since the summer. The PAG closed out Study Analysis Group (SAG) 16 and was seeking to close SAG17. SAG19 in ongoing and will complete its work in 2019. At the previous meeting, ExoPAG initiated Science Interest Group (SIG) 2, and was now proposing to initiate SAG20, to study the impact the JWST delay might have on exoplanet science, and any mitigation concepts.

Recent activities included the ExoPAG 18 meeting shortly after the last APAC meeting. This meeting was held at the Cool Stars 20 convention in Boston, and had 140 attendees. ExoPAG is planning its next meeting for the AAS in Seattle. That will have a mini science symposium on characterization of nearby planetary systems, and a showcase for exoplanet inputs to the DS. ExoPAG developed a Google spreadsheet for community members to note which white papers they plan or want to do for the DS.

The report for SAG17, on community resources needed for K2/TESS planetary candidate confirmation, was presented at the July ExoPAG meeting and is now on the website. The report confirmed the need for ground-based observations and the funds to support such work. ExoPAG was now requesting that APAC close out SAG17. SIG2, on exoplanet demographics, is still recruiting members. This SIG will augment Kepler-centric demographics to provide comparisons for mission concepts. As noted, the proposed SAG20 will seek to understand the impacts the JWST delay might have on exoplanet science, and outline a strategy for mitigation of adverse effects and enhancement of the science return. This will involve an online community survey, a report, and analysis. ExoPAG will ensure that the SAG20 members consult with STScI.

APD's Exoplanet Exploration (EXEP) Program helps draft, fund, and manage the student travel scholarships to events, but ExoPAG selects the students. The PAG negotiated this with the Program.

Dr. Ozel asked if there were any objections to closing out SAG17. No APAC members objected, so she took that as approval. She then asked if there were objections to SAG20. Again, there were none, so that was assumed to be unanimous consent.

PhysPAG

Dr. Conklin presented the Physics of the Cosmos PAG (PhysPAG) objectives, noting that while the Executive Committee membership has not changed, three members were about to roll off and the PAG was seeking candidates for those seats. The Multi Messenger Astrophysics SAG (MMA SAG) is PhysPAG's only active SAG at this time. The SAG is studying existing and planned observatories, how they align with APD priorities, and the technical drivers. The SAG is community-driven and open to all; the Cosmic Origins PAG (COPAG) is also involved. The work is not necessarily specific to gravitational waves, but instead considers any combination of messengers. There are four teams organized around astrophysical sources, comprising people interested in the same sources but observing via different messengers. Each team has one or two leads, and they all feature regular telecons. The SAG will document its findings in one or more publicly available white papers, but these will not advocate for a particular mission. Dr. Conklin listed the white papers in progress; there will be at least nine.

Dr. Conklin next presented PhysPAG highlights and updates. The Great Observatories SAG originated in COPAG but has strong PhysPAG community interest. PhysPAG is essentially its SIGs, and these address gravitational waves, cosmic structure, cosmic radiation, x-rays, gamma rays, and inflation probes. Dr. Conklin listed the SIG activities. He also noted recent and upcoming meetings and teleconferences. Much activity is planned for the January AAS meeting in Seattle and the April APS meeting in Denver. PhysPAG requested no actions from APAC.

COPAG

Dr. Scowen cited the members of the Executive Committee who are rotating off, with new members nominated to fill those slots. He then noted COPAG activities since July. The PAG is very involved in the STDTs. SAG10, on Great Observatories, has begun work. There are also three open SIGs and a Technology Interest Group (TIG). COPAG has started preparing for the DS and is coordinating efforts without influencing the focus and direction of those efforts. There is also a "Slack workspace open to all astronomers to discuss white paper inputs. So far, there are more than 30 science topics and more than 400 members.

COPAG is considering changing the Far InfraRed SIG (FIR SIG) to the InfraRed SIG in order to broaden its focus. FIR SIG's recent activities include a newsletter and ongoing webinar series, coordination of white papers with the Origins Space Telescope (OST) STDT, review of a journal article, and preparations for the January AAS. SIG2, on UV science, is seeking up to 10 white papers for the DS and identifying topics. SIG3, to address the cosmic dawn, was created a couple of years ago and is now dormant. There has been no activity since April and COPAG wondered how to shut it down. SIGs do not have a deliverable. SAG10 is active, with a number of teleconferences, many members, and five working groups that are preparing white papers, among other things. There is good cross-pollination with PhysPAG's MMA SAG. The TIG has been dormant since July, as the technology gap assessments are now bi-annual. However, discussion with talked to APD's Dr. Thai Pham has helped COPAG better understand their role, so the TIG will resume activities.

Dr. Hertz explained that the process for closing out a SIG is the same as for creating one: APAC votes on a PAG recommendation to close it out, and APAC recommends that Dr. Hertz do so.

Discussion

Dr. Scowen said that the PAGs wanted to discuss the capacity of the SIGs and SAGs to self-organize to write white papers. Dr. Hertz replied that NASA's advisory structure, involving advisory committees, PAGs, etc., is set up to advise NASA. That information ends up in the public domain. It is not their purpose to provide advice to the DS. However, it is also within the mandate for these groups to serve the community by helping organize community responses to the DS. A rule of thumb is that individuals can write white papers, but they cannot do so as a PAG or SAG. He advised using care with that. He also rescinded a previous statement that they could not help organize white papers. He committed to making a formal policy statement to share with the community, for which he would seek input from the chairs of the PAG Executive Committees in the name of clarity and focus. He made it clear that when a group submits to the DS, they should not identify themselves as a SAG or SIG. Instead, they should identify themselves as individuals and invite people to work on the papers as individuals. While they could point to published studies and reports, they could not stamp things as being from a PAG or a PAG subgroup. In addition, since the MMA SAG was ahead of the timeline for which it was approved, it should enable people to get together to write, but not present to the DS as a SAG, PAG, APAC, or NASA.

Dr. Meadows said that the community sees the PAGs as community organizations, while Dr. Hertz sees them as an extension of NASA. Dr. Hertz pointed out that the PAGs were called together by NASA to provide NASA with analysis, which is stated explicitly in the PAG charters. Dr. Meadows maintained that there was a need to discuss the dual role of the PAGs as community organizations. Dr. Hertz replied that support for the community is not the same as advocating to the DS, and that was what he wanted to make clear.

Dr. Holley-Bockelmann said that there are reports given to APAC, which are then given to the DS. Dr. Hertz explained that any member of the community can write a report to the DS and say "here's a SAG report you might find interesting." Dr. Meadows noted that they have to list sources and authors of reports, and it seems difficult to say that it is not an ExoPAG product. She asked if they are allowed to retain the product's identity as an ExoPAG report. Dr. Hertz said he was not ready to answer that right away, as it would require some thought first.

Dr. Conklin said that another issue is that the process is for SAGs to submit reports to APAC, where they are approved and then become publicly available. However, there are no APAC meetings planned before the DS papers are due. Dr. Hertz said that the people writing the report can submit directly to the DS

without saying it is a product of the SAG. APAC can also have a telecon if necessary. Dr. Scowen said that while he understood how this needs to be done, the MMA SAG and SAG10 were specifically set up to deliver reports in mid-2019. The root of the problem is that the DS had declared an early window for inputs. The community was concerned, but the NAS response was that they want the papers ready for when the DS committee is announced so they can sort them into appropriate panels. However, there is little information on how the DS will do its work, and the submissions are due the week after AAS, which is not a terribly coherent window. Dr. Hertz noted that CAA was having an open session the next week; Dr. Scowen said that COPAG would try to send some people.

Dr. Meadows was trying to understand why this is different from PSD, which allowed its Analysis Groups (AGs) to submit papers. When Dr. Hertz said that the PSD AGs are not linked to NASA in the same way as the astrophysics PAGs, she disagreed and said she would check on it. The AGs write consensus documents. She thought it was important to have groups that represent the community rather than just assertive individuals. Dr. Hertz replied that it was not clear how this policy inhibits anyone from submitting. Dr. Meadows held that sometimes it is important to have a community strategy, identify the gaps, and encourage the community to put things forward. She wanted a cohesive and comprehensive response. If ExoPAG could not coordinate such a response, it was not clear what organizations could. She added that PhysPAG and COPAG would have even more difficulty with this.

Dr. Hertz said that while it would be great to have scientists recommend a high-level strategy and priorities, it would make him uncomfortable to have that coming from the PAGs. Enabling the community by calling meetings and letting them self-organize is fine. It is when the PAGs might try to create a strategy that required prioritization that he becomes uncomfortable. They can submit that to him, but not to the DS. It would also be fine to have the community talk about gaps, but not the prioritization. Dr. Ozel added that they could not be sure that a PAG paper represents a community, rather than just a portion of that community. The minute they present something on behalf of the entire PAG, it becomes problematic. Dr. Meadows took the point as being fair. She would like to provide the community with opportunities for discussion. Dr. Hertz said that she could also send the DS a list of the reports done. That would not constitute an advocacy document.

He said that he had the action to write a short policy and FAQs to send to the Executive Committee chairs for their input, and asked Dr. Ozel to include this in the meeting letter.

NAS Report on Exoplanet Science Strategy

Dr. David Charbonneau explained that he and Dr. Scott Gaudi co-chaired this effort. The kickoff meeting was in March, and public release of the report was in September. The statement of task called on the committee to survey the status of the field of exoplanet science; recommend an exoplanet science strategy; discuss which goals of the strategy could be addressed under current DS priorities; and identify opportunities for coordination.

The first science goal was to identify the key science questions, which led to three findings: that the current knowledge of demographics and characteristics is incomplete; that such an understanding requires a census; and that the results of such a census will provide fundamental new knowledge. Goal 2 was to identify and make distinctions among the properties and signatures of exoplanet environments, leading the committee to find that such work would require a multiparameter, holistic approach, and that there is a need for a comprehensive framework in assessing biosignatures.

Drs. Charbonneau and Gaudi then reviewed the recommendations. First is that a space-based exoplanet imaging mission is needed to measure reflected light spectra of temperate terrestrial planets orbiting sun-like stars. The next recommendation is for NSF to invest in both the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT), and their exoplanet instrumentation, in order to provide all-sky access to the U.S. science community. While directed to NSF, this recommendation is of enormous importance to NASA due to its impact.

Dr. Gaudi noted that WFIRST will provide critical exoplanet data and pave the way for a direct imaging mission. Therefore, the report recommends that NASA launch WFIRST to conduct its microlensing survey of distant planets and to demonstrate coronagraphic spectroscopy on exoplanet targets. Dr. Charbonneau said that improving the precision of radial velocity measurements will support exoplanet missions, which led to the recommendation that NASA and NSF establish a strategic initiative in Extremely Precise Radial Velocities (EPRVs), to develop methods and facilities to measure the masses of temperate terrestrial planets orbiting sun-like stars. They should do this together because of their complementarity of expertise and specialties.

Dr. Gaudi said that JWST could survey exoplanet atmospheres and guide future observing strategies. Therefore, NASA should create a mechanism for community-driven legacy surveys of exoplanet atmospheres early in the mission. Another recommendation was to build on the Nexus for Exoplanet System Science (NExSS) to support a cross-divisional exoplanet research coordination network to include additional membership opportunities via dedicated proposal calls for interdisciplinary research. In addition, NASA should support a robust individual investigator program that includes grants for theoretical, lab, and ground-based telescopic investigations in order to realize the full scientific yield of exoplanet missions.

Dr. Charbonneau said that in addition to the seven recommendations, the Committee endorses the IA2015 recommendation to provide full opportunities to a more diverse and broader community. This should be addressed through the DS in the form of actionable recommendations supporting and expanding diversity of the community and the elimination of harassment, bias, and discrimination. Dr. Gaudi gave the strategic timeline of near-term (<5 years), medium-term (5-15 years), and long-term (15-20 years) activities. A long-term activity, the space-based direct imaging mission, is the only new activity listed.

Dr. Ozel noted that at the July meeting, APAC recommended a more coordinated effort between NSF and NASA in order to get the best results from ground-based radio-velocity observations. It seemed that this report made a similar recommendation, and she thanked them for raising the issue. Dr. Conklin noted that this was not a recommendation for NSF and NASA to jointly support large, ground-based telescopes. Dr. Charbonneau acknowledged that NASA is primarily engaged in space-based activities, and there are recommendations for NASA. The large, ground-based telescopes would never be built just for exoplanets, but rather for the general astronomy that NSF funds. Dr. Gaudi added that the committee wants both agencies to play to their strengths. Dr. Moustakas observed that this report synthesizes a large number of white papers. He wondered if anything might be missing. Dr. Charbonneau replied that these are the big items that need to be acted upon, but there are other activities discussed in the report. Dr. Gaudi agreed, adding that the report does not include priorities or preferences.

Public Comment Period

The meeting was opened to the public for comment. Dr. Terri Brandt of the Physics of the Cosmos (PCOS) office at GSFC thanked Dr. Meadows for mentioning concerns about the community. She explained that her group is working hard to ensure that they are including and empowering everyone so that all voices can be heard and included. They reach out, but some people choose not to participate, or prefer to work on their own as individuals. The PAGs are not the only means through which people talk to each other.

Dr. Ozel thanked Dr. Brandt for her comments, and said that she knows Dr. Brandt has been working hard to include diverse voices. She is more concerned that if a white paper come from a PAG and is submitted to represent it, the level of scrutiny is much higher than if the PAG just organized the community. There are different viewpoints, interests, and goals. The issue is labeling things as coming from PAGs. Dr. Meadows said that ExoPAG should consist of the entire community that is willing to interact. It is a different perception.

NAS Report on Astrobiology Science Strategy

Dr. Barbara Sherwood Lollar said that this report had been released 2 weeks prior to the APAC meeting. She was the committee chair, and two APAC members – Dr. Meadows and Dr. Alan Boss – were also on the committee. She presented the authorization language and shows statement of task from NAS. The committee was to build on what has happened since 2015; identify key questions, discoveries, and technology challenges; determine the most promising key research goals, and discuss which of the key goals could be addressed by U.S. and international organizations. There was significant coordination with the Exoplanet Science Strategy committee, and it was helpful to have Dr. Meadows.

The committee started with a January meeting and released its report on Oct. 10. It received 52 white papers as inputs. There were 9 recommendations and 25 findings, from which key messages emerged. The first was to "go broad," which encompassed four recommendations focusing on the need to think outside the box without attempting to do everything. The second was "go deep," for a broader perspective that includes subsurface environments as targets in the search for life. Third was "go high-contrast," as direct imaging missions will enable remote characterization of exoplanet atmospheres.

Cross-divisional collaborations are essential to advance this field. In the area of "go broad," there are changes in the understanding of habitability and its parameters. Habitability and emergency of life are not necessarily the same thing. Habitability is on a continuum defined by multiple evolving parameters, which creates an area in which various communities of study can come together. NASA and other agencies should catalyze research focused on dynamic habitability, with interdisciplinary collaboration.

Another recommendation is that NASA programs and missions reflect a dedicated focus on the research and exploration of subsurface habitability. Dr. Boss, explicitly commenting as a participant in this study rather than an APAC member, described the findings on exploring the habitability of exoplanets. Once JWST launches, there will be data on the atmospheres of terrestrial exoplanets orbiting M dwarfs, and investigators need to understand both the planets and their stars. There is a need to inform target selection and exploration in the context of a solar and planetary system's characteristics. In enabling technologies and approaches, NASA should implement high-contrast starlight suppression technologies in near-term space- and ground-based direct imaging missions.

Dr. Lollar said that in the systematic re-evaluation of biosignatures, the committee recommends that NASA direct community focus to address important gaps in understanding the environmental contexts

of abiotic phenomena that mimic biosignatures. Another recommendation is that NASA support research on novel and/or agnostic biosignatures in order to develop more sophisticated frameworks for considering the potential of non-terran life. There were two recommendations addressing frameworks for assessment of biosignatures. First, NASA should support expanding biosignature research to address gaps in understanding biosignature preservation and the breadth of both false positives and false negatives. NASA should also support the community in developing a comprehensive framework for assessment to guide testing and evaluation of *in situ* and remote biosignatures. The final recommendation in this area is to develop frameworks for assessment in order to provide guidance and support decision-making.

On the topic of enabling technologies, there is a recommendation that NASA accelerate the development and validation of these technologies. Dr. Boss noted the committee was charged with looking at partnerships. There are many opportunities to share the costs – for example, some philanthropic organizations are interested in biosignatures. NASA should seek new mechanisms to reduce the barriers to collaboration with private and philanthropic entities, as well as with international space agencies.

Dr. Bautz asked if there were any examples of the Federal government collaborating with philanthropic organizations. Dr. Lollar replied that the report includes some examples, such as the National Institutes of Health (NIH), which has a foundation. Dr. Boss added that there are pros and cons, noting that philanthropists sometimes try to direct funds to their interests rather than support the most active needs.

Integrated Technology Prioritization Process

Dr. Brendan Crill described APD's new process for acting on technology gaps. The APD technology development strategy aims to mature technologies for future strategic missions, and so has solicited and prioritized technology gaps, mainly via the PAGs. APD program offices include PCOS, Cosmic Origins (COR), and EXEP. Dr. Hertz sought improved coordination and streamlining among the program offices. The following changes have been approved for implementation: joint solicitation of technology gaps from the community; coordinated prioritization of the technology gaps; and joint reporting on the technology gaps. These will begin in 2019 and will occur every 2 years rather than annually. The program offices will assign the gaps to the individual programs, and will generate a joint publication, the Astrophysics Biennial Technology Report (ABTR), replacing the Program Annual Technology Reports (PATRs).

The details are still being worked out, but the program office technologists have communicated the new processes to the PAGs. In January, they will jointly solicit community technology gap inputs, due by June. At that point, the technologists and chief scientists of the three program offices will jointly decide which program should carry which gaps. Each office will then set priorities using existing processes. They are now developing criteria; each gap list will go into one of four priority tiers before being merged for a joint APD technology gap list. The program office technologists will create the ABTR, which will be similar to an executive summary, no more than 20 pages. The SAT proposal call will be integrated into this without changing its solicitation cycle. The integrated, uniform practices will create synergy, streamline processes, increase transparency, and reduce effort.

Dr. Scowen asked about how the program offices would ensure balance among the three areas with an integrated SAT call. Dr. Crill said that this will be done at HQ. Dr. Ozel said that this is a step in the right

direction, but APAC will probably want to hear back on how the integration is going and how the balance is among the program subject matter. Dr. Crill said that he will be glad to come back.

Mission Cost Caps

Dr. Ozel explained that APAC requested this presentation in order to decide whether to pursue the topic further at future meetings. Dr. Michael New, SMD Deputy Associate Administrator for Research, defined "Explorer class" as MIDEX, SMEX, and ESD's Earth Venture Missions (EVM). For his presentation, he used cost caps from publicly available AOs, subtracted the assigned cost of the launch vehicles, and adjusted for inflation. The raw data show the year the cost cap was established. A graphic representation of SMEX cost caps from 2007 through 2016 indicates that the cap for those missions is close to flat. Dr. Hertz reminded APAC that the upcoming SMEX AO will have a cap of $145 million without the launch vehicles. There were some gaps in the MIDEX AOs.

Dr. Bautz observed that even without inflation, the way missions need to be built changes over time, which accounts for some increase. Dr. Hertz explained that the data were corrected for inflation. Data from before 2003 would not be comparable due to changes in accounting procedures. Dr. Ozel added that the way things are done also changes over time, and building missions is becoming more expensive, even adjusting for inflation. Dr. Bautz said that there are also improvements in capabilities. Dr. New asked about the breadth of proposals. It is possible that they are stronger, which is something to think about.

Dr. Ozel thought it would be interesting to see where proposals come in vis-a-vis the cost cap. Dr. New replied that in running three Discovery AOs, he found only a single proposal was not at the cost cap. Dr. Hertz said that that was his experience as well. He asked the CAA about whether SMEXes still made sense. It was determined that there is a lot of good science that can be conducted within the cost caps. He could provide the data if it were requested. Dr. Ozel wondered what other data might be helpful, as Dr. New's data were good. She would look at the CAA report. She also observed that it was not clear that they were at the right price point to pursue exciting science in different mission categories, noting that there is some wonderful cubesat science being done. Nor was it clear how a reallocation of resources might extend science dollars. Dr. Bautz was concerned about what was not being funded.

Dr. New asked for more specificity regarding their cost cap questions and the hypothesis they were forming. Was it that if the h-index is falling over time, it shows that the cost cap is an issue? Dr. Ozel thought it might be dangerous to draw conclusions. Dr. Scowen said the h-index would need to span the life of a mission. Dr. New explained that these data are not comparable across disciplines, and chasing these metrics could be a red herring. They could ask whether, in the astronomy proposals responding to the last three SMEX calls, they were getting a broad range of proposals focused on the important areas SMD wants to see. Discovery was devolving into a small bodies program before SMD adjusted it. The key is to ensure that high-potential missions are proposed. No analysis exists as to why rejected proposals were not accepted. Dr. Bautz asked if there are kinds of astrophysics that cannot be done in an Explorer. Dr. Hertz replied that if APAC wants this analysis, they have to ask a direct question. The CAA report covered a lot of these things, so APAC might want to look at it first.

Dr. Ozel wondered how they might be able to know if they get to a point where the mission cost caps no longer allow novel science to be performed, and asked what to look for. Dr. Bautz suggested that that was something to discuss in greater depth. Investigators aspire to do more and more, which raises the price. It is important that there are multiple price points.

Discussion, Recommendations, Actions

Dr. Ozel led the discussion on the APAC meeting report letter to Dr. Hertz. She reminded APAC members that they could use the Google Drive folder on the cross-divisional survey. She asked that they determine if they needed more data on NESSF. Dr. Conklin wanted to discuss the relationship among PAGs, SIGs, SAGs, and the DS, and whether APAC wanted to review the papers to allow them to become inputs. He noted that there would not be another APAC meeting before the DS deadline for inputs. If the reports from the SAGs are completed and made publicly available, the missing step is APAC acceptance and closing the SAG.

Dr. Scowen said that the larger issue is with the SIGs, which are more community-based and -driven. Those groups will write white papers that do not require PAG endorsement. Dr. Hertz explained that the SIGs, whose membership is the entire community, will coordinate the writing of white papers by members of the community for inputs to the DS. However, since they were not formed in response to a request for analysis, they can submit as members of the community. SAGs are different, as they were chartered and must go up through the PAGs to APAC. Dr. Ozel reiterated the distinction: a group charged with a particular task must report back formally. A white paper from an interest group organized for the community is different.

Regarding data from NESSF, Dr. Conklin noted that APAC had discussed whether the applicants had advisors who were funded separately through R&A. There was also a request for the APD intern's study on where NESSF recipients end up in their careers. Dr. Ozel said that the balance was the concern, as the success rate is only 5 percent. When the rate is so low, the distinctions are hard to make and an element of randomness is introduced. There was also the question about whether the outcome warranted the administrative burden. APAC was gathering information to determine whether APD should revise the funding numbers, do away with NESSF, or keep it as is. Dr. Hertz explained that APD is not allowed to collect gender and race information. The cost of administering NESSF is relatively low. It does take time for the peer review, but that is virtual, requiring no travel funds. Therefore, most of the costs are from program administration. APD uses graduate students and postdocs as peer reviewers for NESSF, which is a training opportunity.

Dr. Hertz asked that APAC summarize the findings and recommendations that would be in their letter to him. Dr. Ozel confirmed that APAC planned to solicit information from the PAGs about cross-divisional research. She had the impression that this is being discussed in multiple areas, so they should determine if there are other needs. Regarding NESSF, the letter to Dr. Hertz would include any additional inputs APAC members sought. For SOFIA, Dr. Ozel noted that individual APAC members can weigh in on the TOR as individuals, as there was no time to do it as a committee. APAC also requested formal guidance from Dr. Hertz regarding PAG input to the DS. The Committee approved closeout of SAG17 and initiation of SAG20. In answer to a question, Dr. Scowen explained that the cosmic dawn SIG would be closing due to lack of interest by the COPAG membership. The Executive Committee would discuss it again, and possibly request closeout at the next APAC meeting.

From the two NAS reports, on exoplanet science strategy and astrobiology, APAC heard of the need for a large mission and for coordination with NSF. In addition, the astrobiology report touched on interdivisional science, so the letter would refer to APAC's efforts to poll the community in order to ensure that APD is sufficiently responsive.

APAC would like updates in the next couple of years about the integrated technology prioritization effort, particularly in terms of implementation and programmatic balance. This should enable efficiency

and promote a global view. Dr. Scowen noted the need to ensure that the balance remains the same and that this does not disadvantage a group. Dr. Hertz explained that APD has evolved its investment portfolio for mid-TRL development. Much of the funding under what was considered SAT has a shrinking competed element, while the directed part grows. Examples are the starshade and coronagraph. The Division is trying to follow the current DS; SAT will get a complete reset with the new DS. Dr. Hertz said that he could give a detailed accounting of where APD thinks it is going so that APAC has data as a basis for any recommendation. Dr. Ozel agreed to ask for a detailed presentation on where APD is with mid-TRL development in the SAT development program. In the meantime, APAC members will read the CAA report to determine if they can bring something new to the table and, if so, whether this calls for new information from NASA.

Dr. Ozel observed that, in his presentation, Dr. Hertz addressed two myths. Dr. Scowen suggested stating that APAC remains concerned about the impact JWST has on other science missions. Dr. Hertz said that when the next budget request comes out, in February, they will be able to see what the Administration is proposing. The initial Congressional reaction will be available in the summer. Dr. Ozel noted that Dr. Hertz presented responses to APAC's requests from the July meeting.

Brief to Division Director

As the previous discussion had served as a briefing, Dr. Hertz thanked Dr. Ozel for her leadership, and thanked everyone else for their engagement, active contributions, and time.

Adjourn

The meeting was adjourned at 4:42 p.m.

Appendix A
Participants

Committee members
Feryal Ozel, University of Arizona, *Chair, Astrophysics Advisory Committee*
Marshall (Mark) Bautz, Massachusetts Institute of Technology
Alan Boss, Carnegie Institution of Science
Patricia Boyd, Goddard Space Flight Center
Laura Brenneman, Harvard-Smithsonian Center for Astrophysics
John Conklin, University of Florida
Asantha Cooray, University of California, Irvine
Brenda Dingus, Los Alamos National Laboratory
Debra Fischer, Yale University
Kelly Holley-Bockelmann, Vanderbilt University
William C. Jones, Princeton University (via teleconference)
Victoria Meadows, University of Washington
Leonidas Moustakas, NASA JPL
Paul Scowen, Arizona State University
Charles Woodward, University of Minnesota

NASA attendees
Paul Hertz, NASA HQ, *Director, Astrophysics Division*
Dominic Benford, NASA HQ
Shahid Habib, NASA HQ
Hashima Hasan, NASA HQ, *Executive Secretary, APAC*
Stefan Immler, NASA HQ
Jeff Kruk, NASA GSFC
Matt Myers, NASA
Michael New, NASA HQ
Mathew Riggs, NASA HQ
Kartik Sheth, NASA HQ
Martin Shil, NASA
Eric Smith, NASA HQ
Eric Tollestrup, NASA HQ

Non-NASA attendees
Francesco Bordi, Aerospace
Elizabeth Sheley, ElectroSoft

Webex/Telecon
Louis Barbier, NASA
Betriusha Bella, Virgin Orbit
Dominic Benford, NASA
Terri Brandt, GSFC
John Callous, JPL
Victoria Colta Cortez, Space Agency
Brendan Crill, JPL

Patti Daws, NASA
Nicole Delcortez, Space Agency
Monty DiBiasi, Didiasi Associates
Shawn Domagal-Goldman, NASA
Jeff Foust, Space News
Margaret Frerking, JPL
David Gaba, Stanford University
Mike Garcia, NASA
Johnathan Gardner, GSFC
Michael Henry, NASA
Christopher Hirata, Ohio State University
Grace Hu, OMB
Jason Kalirai, STScI
John Karcz, NASA
David Ladler
Jeanette Le, NASA
Sara Lipscey, Ball Aerospace
Jim Lochner, USRA
Eric Mamajek, JPL
Rachel O'Connor, Ball Aerospace
John O'Meara, St. Michael's College
Joel Parriott, AAS
Nicole Pelfrey, NASA Marshall
Mario Perez, NASA
Thai Pham, NASA
Jeremy Rehm, Nature
George Ricker, MIT
Aki Roberge, NASA GSFC
Misteen Ronwalan, NASA Ames
John Rummel, CTI
Rita Sambruna, NASA
Kevin Schmadel, USRA
Nick Siegler, JPL
Kendra Short, JPL
David Ciardi, CalTech
Marcia Smith, SpacePolicyOnline
Karl Stapelfeldt, JPL
Azita Valinia, NASA GSFC
Nicholas White, USRA
Phil Willems, JPL
Harold Yorke, USRA
Eddie Zavala, NASA

Appendix B
Astrophysics Advisory Committee Members

Feryal Ozel, APAC Chair
University of Arizona

Hashima Hasan, Executive Secretary
Astrophysics Division
Science Mission Directorate
NASA Headquarters

Marshall (Mark) Bautz
Massachusetts Institute of Technology

Alan Boss
Carnegie Institution of Science

Patricia Boyd
Goddard Space Flight Center

Laura Brenneman
Harvard-Smithsonian Center for Astrophysics

John Conklin
University of Florida

Asantha Cooray
University of California, Irvine

Brenda Dingus
Los Alamos National Laboratory

Debra Fischer
Yale University

Kelly Holley-Bockelmann
Vanderbilt University

William Jones
Princeton University

Victoria Meadows
University of Washington

Leonidas Moustakas
Jet Propulsion Lab

Paul Scowen
Arizona State University

Beth Willman
University of Arizona

Charles Woodward
University of Minnesota

Appendix C
Presentations

1. *Astrophysics Division Update*, Paul Hertz
2. *NASA Earth and Space Science Fellows Program,* Stefan Immler
3. *Webb Telescope Update,* Eric Smith
4. *SOFIA Reviews,* Kartik Sheth
5. *WFIRST Requirements*, Jeff Kruk
6. *TESS Science Requirements,* George Ricker
7. *ExoPAG Report*, Victoria Meadows
8. *PhysPAG Report*, John Conklin
9. *COPAG Report,* Paul Scowen
10. *Mission Cost Caps,* Michael New
11. *NAS Report on Exoplanet Science Strategy,* Scott Gaudi/David Charbonneau
12. *NAS Report on Astrobiology Science Strategy,* Barbara Sherwood Lollar
13. *Integrated Technology Prioritization Process,* Brendan Crill

Appendix D
Agenda

Astrophysics Advisory Committee
October 22-23, 2018
Teleconference

Monday, October 22, 2018

11:00 a.m.	Introduction and Announcements	Hashima Hasan/Feryal Ozel
11:10 a.m.	Astrophysics Division Update	Paul Hertz
1:10 p.m.	NASA Earth and Space Science Fellows Program	Stefan Immler
1:30 p.m.	Discussion	APAC members
2:00 p.m.	Break	
2:15 p.m.	Webb Telescope Update	Eric Smith
3:15 p.m.	SOFIA Review Update	Kartik Sheth
3:45 p.m.	WFIRST Requirements	Jeff Kruk
4:15 p.m.	Public Comment Period	
4:20 p.m.	Discussion	APAC Members
5:00 p.m.	Wrap up for Day 1	Feryal Ozel

Tuesday, October 23, 2018

11:00 a.m.	Opening Remarks	Feryal Ozel
11:10 a.m.	TESS Science Results	George Ricker
11:55 p.m.	ExoPAG/PhysPAG/COPAG Updates	Vikki Meadows/John Conklin/Paul Scowen
12:55 p.m.	Mission Cost Caps	Michael New
1:25 p.m.	NAS Report on Exoplanet Science Strategy	Scott Gaudi/David Charbonneau
1:55 p.m.	Public Comment Period	
2:00 p.m.	Break	
2:30 p.m.	NAS Report on Astrobiology Science Strategy	Barbara Sherwood Lollar
3:00 p.m.	Integrated Technology Prioritization Process	Thai Pham/Brendan Crill
3:30 p.m.	Discussion, Recommendations, Actions	APAC members
4:45 p.m.	Brief to Division Director	Feryal Ozel
5:00 p.m.	Adjourn	