Minutes of the Meeting of the
Astronomy and Astrophysics Advisory Committee
28-29 January 2016
National Science Foundation, Arlington, VA

Members attending:

James Buckley
Craig Hogan
David Hogg (Telecon)
Klaus Honscheid
Buell Jannuzi
Rachel Mandelbaum
Lisa Kaltenegger (Telecon)
Angela Olinto (Chair)
William Smith (Vice Chair)
Angela Speck
Suzanne Staggs (Telecon)
Jean Turner (Telecon)
Martin White

Agency personnel:

James Ulvestad, NSF-AST
Chris Davis, NSF-AST
Elizabeth Pentecost, NSF-AST
Philip Puxley, NSF-AST
Richard Barvainis, NSF-AST
Patricia Knezek, NSF-AST
Diana Phan, NSF-AST
Thomas Wilson, NSF-AST
David Boboltz, NSF-AST
Ralph Gaume, NSF-AST
Nigel Sharp, NSF-AST
Ed Ajhar, NSF-AST
Mangala Sharma, NSF-AST
Randy Phelps, NSF-OIA
Ivy Kupec, NSF-OLPA
Vladimir Papitashvili, NSF-PLR`
James Whitmore, NSF-PHY
Jean Cottam, NSF-PHY
Vyacheslav Lukin, NSF-PHY
Paul Hertz, NASA
Hashima Hasan, NASA
Wilton Sanders, NASA
Ann Hornschemeier Cardiff, NASA
Rita Sambruna, NASA
Michael Garcia, NASA
Dominic Benford, NASA
Linda Sparke, NASA
Thomas Griffin, NASA-GSFC
Kathleen Turner, DOE
Eric Linder, DOE
Michael Salamon, DOE
Glen Crawford, DOE
Anwar Bhatti, DOE

Others:

Amaya Moro Martin, STSci
Paola Castano, Smithsonian NASM
Priscilla Cushman, U. of Minnesota
Makenzie Lystrop, Ball Aerospace
Heidi Hammel, AURA
Scott Dodelson, Fermilab
John Carlstrom, Univ. of Chicago
Pete Roming, SWRI
Heather Bloemhard, AAS
David Lang, NRC
Alberto Conti, Northrup Grumman
Joseph Pesce, GMU/CU
Roeland Van Der Marel, STScI
Monty Di Biasi, SWRI
Dana Lehr, AURA
Karin Hilser, USRA
Jacqueline Hewitt, MIT
John O'Meara, St. Michael's College
Jason Rhodes, JPL
Martin Still
Mitch Ambrose
David Trilling
Marcia Smith
Jeff Foust
Ted Oded Avraham

MEETING CONVENED 9:00 AM, 28 January 2016

The Chair called the meeting to order. Introductions were done.

The minutes from the 12-13 November 2015 meeting were approved by the Committee.

Elizabeth Pentecost, the AAAC Recording Secretary, reviewed the list of identified Conflicts of Interest (COIs) for the AAAC. There were several additions to Dr. Stagg's list.

Christopher Scolese, Goddard Space Flight Center Director, welcomed the Committee to GSFC. The Chair thanked him and NASA for hosting the meeting at GSFC.

James Ulvestad presented an update on AST activities. There have been some outstanding science opportunities in the Division, namely science results from ALMA, EVLA, the Dark Energy Camera, and Gemini Planet Imager. DKIST and LSST are being constructed and will offer science opportunities in the next few years. AST has made more than 100 research awards per year in its investigator award program. Partnerships with DOE and NASA have strengthened NSF spent over $100 million on construction n of AST facilities in FY 2015. Data-enabled science continued to grow in importance. The community continues to make progress at the science frontiers.

AST has several rotator openings under the Intergovernmental Personnel Act (IPA). These are typically for 2-3 years at NSF, while maintaining employment status at their home institution. The IPAs being a different and important university perspective to the federal government and can help translate federal requirements to the scientific community. As a default, IPAs return to their home institutions, some come back to the federal government or leverage their experience for other positions. At present, AST has only two IPAs on staff are recruiting for several more.

AST conducted three major competitions for the management of its major facilities. The NOAO competition concluded and AURA was selected for a new 5-year cooperative agreement that began October 1, 2015. The NRAO just concluded and AUI was selected for a new 10-year cooperative agreement that will begin on October 1, 2016. The Gemini competition is nearing completion for a 6-year cooperative agreement to begin January 1, 2017. There was a non-competitive 10-year award made to AURA for the management of NSO (including DKIST) that will run through September 30, 2024.

Ulvestad provided some science and programmatic results. The Dark Energy Camera on the CTIO 4-m Blanco telescope revealed "new" galaxies in the Fornax cluster. This is a possible solution to the "missing" dwarf galaxies predicted by cosmological simulations. Excellent construction progress has been made on the Daniel K. Inouye Solar Telescope. There were some delays due to poor weather in Hawai'i; it is scheduled for completion in 2019. The data rate for DKIST will be equal to that of LSST. The LSST construction award was made in August 2014 with a strong NSF/DOE partnership in construction and operations. The NRC committee studied the OIR system in the LSST era.

The Omnibus funding bill for FY2016 was passed in December. The President's Budget Request for AST in FY2016 was $246.5 million, a $2.4 million increase over FY2015 and essentially equal to the AST budget in FY2010. NSF's current plan for FY2016 has been submitted to Congress, awaiting approval. The FY2017 PBR will be out on February 2019 and will contain the FY2016 estimated budget. The Facility fraction of the AST budget was 63%-65% in the late 1990s, decreased to 53% in 2008, and then rose back to around 60% in the FY2016 request.

James Ulvestad provided an update on the Portfolio Review and Divestment activities. In 2012, the Portfolio Review report recommended significant facility divestment to enable support of *NWNH* priorities. The Committee was charged to recommend a balanced program, in realistic funding scenarios. There was a need to retain balance between community research tools (large and mid-scale facilities) and direct research funding (mid-scale experiments and individual investigator awards) in order to best sustain the astronomical enterprise. Process toward divestment has been slower than anticipated. NSF (through a contractor) is currently concluding engineering studies and baseline environmental surveys for a number of telescopes and observatories recommended for divestment. Results of these studies will inform more detailed assessments. Most divestments are not clean 100% divestments, but are evolutionary changes to new partnership arrangements. To date, most capabilities have remained available for science in some form. The Portfolio review identified facilities recommended for divestment from the AST budget, or for future consideration. NSF, through a contractor, is currently concluding engineering studies and baseline environmental surveys for a number of telescopes and observatories with the goal of identifying key issues, costing different alternatives, and providing NSF information to assess the viability of those options. Alternatives include but are not limited to new partnership arrangements, conversion to new missions for the facilities including scope reductions, mothballing, and decommissioning. Real progress has been made on partnerships, with ongoing negotiations in many cases. After receiving the engineering reports in FY2016, NSF will identify viable options for the different facilities and telescopes. Following conclusion of the formal alternative considerations, NSF will select a preferred alternative for each facility and then seek to execute that alternative.

The Mayall telescope is slated for a DOE-supplied Dark Energy Spectroscopic Instrument (DESI). NSF is providing bridge funding in FY2016 and FY2017, with a combination of DESI targeting survey and open access. DOE will take over the majority of ops funding in FY2018, leading to the DESI prime mission and full DOE funding in FY2019. A small amount of community time may be available after FY2018. NSF is continuing to fund NOAO's share of WIYN operations, currently being used for exoplanet research with existing instrumentation. NASA is providing funds for the development of an Extreme Precision Doppler Spectrometer (EPDS), aiming for installation on WIYN in FY2018-2019. A Caltech-led consortium is operating the 2.1-m telescope for 2016-2018.

Engineering studies are underway for both the Green Bank Telescope (GBT) and the Very Large Baseline Array (VLBA). GBT and VLBA were not included in the recent NRAO management competition, and will be separated from NRAO after September 30, 2016. The VLBA funding partnership includes the U.S. Naval Observatory (USNO) partnership for measurement of the Earth-orientation parameters and maintenance of the celestial reference frame. GBT funding partnerships include the Breakthrough Prize Foundation usage for Search for Extraterrestrial Intelligence; there is also NANOGrav and West Virginia University. There are ongoing discussions for other partnerships.

An engineering study is underway for Sacramento Peak. New Mexico State University is taking the lead in forming a consortium that will operate the Dunn Solar Telescope as a university-led facility rather than a national observatory. If the partnership is successful, it would result in DST access for some portion of the solar physics community, a training ground for the scientific community for DKIST, and possibly a site for further development of future DKIST instrumentation. NSF would partner with the consortium.

Most of the funding for Arecibo Observatory (AO) is received from NSF/MPS/AST, NSF GEO/AGS (Atmospheric and Geospace Sciences), and NASA's Planetary Science Division. The AST Portfolio Committee recommended that AST's involvement in AO be reevaluated later in the current decade. AGS is currently conducting a portfolio review of its research investments; a report is expected in early 2016. NSF issued a Dear Colleague Letter (DCL) in October 2015 requesting viable concepts for future Arecibo operations; an analysis of the responses is underway. The DCL response, the completion of the AGS review, the completion of the baseline engineering/environmental study, discussions with NASA, and the results of the NRC mid-decadal review all will be used by NSF in deciding on the next step for Arecibo.

Excellent progress has been made on the Portfolio recommendations but AST will not be able to save all the funds recommended by the Portfolio Review Committee. Savings so far total ~$10-15 million. Portfolio Review recommendations totaled around $37 million, not including the downward ramps that were already in progress for EVLA and Arecibo. Reaching savings in the $25-30 million range will be very difficult. Flat budgets into the LSST era will cause substantial portfolio damage unless more divestment occurs.

Klaus Honscheid confirmed with Ulvestad that the budget for the Facilities does not include any support for the scientists analyzing data produced by the facilities. Ulvestad indicated that was correct. For instance, for LSST, funding is provided for telescope operations, delivering data products, and providing some support for users to query the system and get data products out but does not include funding for developing their own algorithms or own science; the same is true for ALMA. Honscheid further asked Ulvestad why ALMA was so expensive. Ulvestad replied that 66 dishes, high elevation (5000 meters), remote site, high personnel costs, power costs, are just a few of the reasons associated with running ALMA in a difficult environment. The new ALMA cooperative agreement starts October 1 and runs for 10 years.

Paul Hertz presented the NASA update, including some programmatic and science highlights. Using WISE and Spitzer data, scientists found rapidly moving stars within our galaxy, more than what was predicted and most of them are giant stars; the bow shocks are caused by moving through the interstellar medium. Kepler has been collecting light curves of around 150,000 stars that let scientists do interesting asteroseismology. In over 60% of the stars studied, scientists were able to detect the presence of strong magnetic fields in the interiors of the stars through oscillations that manifest as variations of the light curves.

The FY2016 budget request provides funding for NASA astrophysics to continue its programs, missions, and projects as planned. The total funding is flat at ~$1.3 billion through FY2020. JWST is fully funded and remains on plan for an October 2018 launch. The budget funds a new start for WFIRST, with a start of formulation planned for February 2016; this will require some adjustments to the FY2016 plans in response to appropriation levels. The operating missions continue to generate important and compelling science results, and new missions are under development for the future. An update to the Astrophysics Implementation Plan was released in December 2014. The NRC mid-decade review is underway and a report is expected in May 2016. NASA is initiating large mission concept studies as input to the 2020 Decadal Survey.

Hertz provided an update on several flight missions. The LISA Pathfinder, an ESA mission with NASA collaboration, was launched on December 3, 2015. SOFIA is in its 5-year prime operations as of May 2014. The HAWC+ 2nd generation instrument is to begin commissioning in Spring 2016; 3rd generation instrument concept studies have been selected. Missions on track for launch include JAXA's ASTRO-H (2016), NICER (Neutron Star Interior Composition Explorer; 2016), CREAM (Cosmic Ray Energetics and Mass; 2017, TESS (Transiting Exoplanet Survey Satellite, 2017), JWST (2018), ESA's Euclid (2020). Five SMEX (Small Explorer) and Mission of Opportunity concept studies were selected for an early 2017 downselect with a MIDEX Announcement of Opportunity in 2016. NASA is joining ESA's Athena X-ray observatory and ESA's L3 gravitational wave observatory.

The FY2016 appropriation provides $90 million for WFIRST and directs NASA to start formulation. The budget provides full funding for SOFIA operations ($85M), and places SOFIA into the 2018 Astrophysics Senior review; full funding for continued Hubble operations ($98M); $37M for Science Mission Directorate (SMD) education activities. All of this requires a reduction of $36M in the rest of the Astrophysics portfolio.

The R&A funding continues to grow; there has been a post *NWNH* growth of 22% (FY2011 to FY2016). There may be some adjustments made in FY2016 in response to the appropriation levels. For proposal selections in 2015, 100% of the 2015 selections were announced within 155 days; the R&A selection rate was 24% and the Guest Observer selection rate was 28%. Several proposal opportunities are expected in

2016 including those in the ROSES program, and the Guest Observer programs for ROSES and the missions such as Chandra, Hubble, SOFIA, Spitzer, and XMM-Newton.

JWST remains on schedule and within budget for a launch in October 2018. Pre-formulation for WFIRST using the Astrophysics Focused Telescope Assets (AFTA) is well underway. Planning for the Key Decision Point A (KDP-A) is scheduled for February, with an official start of the formulation phase that is supported by a FY2016 appropriation. The LISA Pathfinder mission was launched December 3; the test masses will be released in February with science operations to start in March. NASA intends to partner with ESA on the ESA-led Large 3 (L3) gravitational wave mission with a launch in 2034. NASA is forming an L3 Study Team drawing membership from members of the US astrophysics community. A Dear Colleague Letter was released in December and members are to be announced in late January. NASA is also involved in the ESA-led Athena mission, to be launched in 2028; NASA will provide the sensor array for the X-ray Integral Field Unit (calorimeter), and possibly other contributions.

William Smith asked what the earliest possible launch date for WFIRST was and Hertz replied 2024 but that would require over-guides from what is in the planning budget. The launch date that is consistent with the planning budget is around 2025. It will overlap with Euclid survey and will overlap with LSST. WFIRST will identify many objects that would benefit from JWST follow-up.

The Mid-term Review is underway. NASA is preparing for the next decadal survey by initiating community-led studies of four large mission concepts. NASA is asking for applications for membership on the four large mission concept Science and Technology Definition Teams.

Kathy Turner gave an update on DOE activities. The FY 2016 HEP budget was on December 16. The Office of Science approved budget was $5,350.2M. The PBR for HEP for FY2016 is $795 million, an increase of ~4%. The FY 2016 President's Budget Request is $119.325 million for the Cosmic Frontier. Even though the FY 2016 approved budget of $122.750M is more than the requested amount, due to the budget guidance HEP received and other constraints, the research budget is still planned at the Continuing Resolution (few % reduced) levels. The Cosmic Frontier MIE (Major Item of Equipment) projects funded in FY 2016 include the LSST camera, the Dark Energy Spectroscopic Instrument (DESI), LZ (Lux-Zeplin at Homestake Mine), and SuperCDMS-SNOLAB. There are small fabrication projects that include the Axion Dark Matter eXperiment Generation 2 (ADMX-G2), a set of five mini experiments to search for axions, and an upgrade of the CMB camera on the South Pole Telescope, to greatly increase sensitivity.

Each project or experiment provides a summary-level data plan to HEP and this is used in referencing in research proposals and is also used to check against the *AAAC Principles for Access in Astrophysics*. There are currently fourteen operating experiments; there are plans to reduce the number to nine by the end of FY 2017. For dark matter detection, there is suite of Generation 1 experiments. In the area of cosmic-ray and gamma-ray, DOE is supporting the Instrument Science Ops Center at SLAC for the NASA-Fermi mission, and is involved in Veritas, Auger, AMS, and HAWC.

Since the P5 report, HEP laboratories are redirecting their programs to align with the P5 priorities. HEP has started Cosmic Visions groups in Dark Matter, Dark Energy and CMB are planning to coordinate the HEP community to support R&D efforts. Community groups will collect and coordinate HEP community status and HEP funded efforts for research and development, planning, studies, and options for future datasets, experiments, and projects.

HEP supports teams and collaborations of scientists with the necessary expertise and responsibilities to take experiments through all phases, from R&D, fabrication, operations, and data analysis. Science planning is expected throughout all phases to end up with coordinated data analysis. Funding for theory, simulations, and computational efforts are in direct support of the experiments.

James Buckley commented that some proportion of the theory program needs to be supported by all of these missions in order to realize the scientific return of the missions. He noted that there is a certain proportion of bright time operations that will be supported by DOE for DESI. Turner commented there is a certain fraction of the bright time that the DESI does not need and that time may be offered to the community but is under discussion by the collaboration.

Klaus Honscheid commented that it is very important to include the tools, the algorithms, and the software in discussing research and development. Turner commented that the research program supports these.

There was no presentation from the NSF Physics Division because Denise Caldwell was unable to attend the meeting. Jean Cottam commented that NSF-Physics coordinates and collaborates within NSF (AST) as well as with the agencies, specifically DOE/HEP. AST and the Physics Division coordinate activities and co-fund proposals that are of mutual interest to both divisions.

John Carlstrom, University of Chicago, gave an update on the CMB Stage 4 Collaboration. The Stage 4 CMB experiment is a next generation ground-based program building on the CMB stage 2 and 3 projects to pursue inflation, neutrino properties, dark energy, and new discoveries. It is a science driven program combining the deep CMB experience of the university groups with the expertise and resources at the national laboratories. It is a multi-agency effort between NSF and DOE, and will be complementary with balloon and space-based instruments. It is US-led with international partners expected. The path forward is clear and the required technologies are in the pipeline; the next steps are to scale to O (500,000) detectors spanning 30-300 GHz using multiple telescopes and sites. The CMB gains the science community access to energy scales of order 10^{16} GeV through precision temperature and ultra-sensitive polarization measurements of the primary CMB anisotropy, through precision measurement of CMB power spectrum to fine angular scales, and eventually through spectral distortions and recombination lines; through measurement of polarization on large angular scales and through measurements of the diffuse kinematic SZ effect on small angular scales; through structure formation through lensing of the CMB and kinematic SZ effect and through measurement of the evolution of Galaxy Clusters through the thermal SZ effect. Polarization is being done with large aperture CMB telescopes such as the 2.5 Huan Tran Telescope, the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT); polarization with small aperture CMB telescopes such as BICEP 2 & 3, Spider balloon experiments, and a large angular scale experiment in Chile. There are also balloon experiments and proposed satellite experiments. The scale of the CMB-4 experiments exceeds the capabilities of the university CMB groups; a partnership of the CMB community and the DOE labs would be needed. CMB-S4 would greatly enhance DES, DESI and LSST science by overlapping the sky coverage. NSF and DOE activities would need to be carefully coordinated for CMB-S4. The CMB-S4 will be a great leap for CMB measurements, cosmology, and astrophysics. With the next generation CMB measurements, scientists will be searching for inflationary gravitational waves and rigorously testing single field slow roll inflation, determining the neutrino masses, mapping the universe in momentum, investigating dark energy, testing general relativity and more.

Lindley Johnson and Thomas Statler have a presentation on studying the use of LSST for Near-Earth Object (NEO) detection and tracking. NASA has formed the Planetary Defense Coordination Office to coordinate planetary defense related activities across NASA, and coordinate both US interagency and international efforts and projects to address and plan response to the asteroid impact hazard. The missions of the Office is to lead national and international efforts to detect any potential for significant impact of planet Earth by natural objects, appraise the range of potential effects by any possible impact, and develop strategies to mitigate impact effects on human welfare. NEO detection, tracking, and research was one of the seven explicitly stated purposes of NASA stated in the NASA Authorization Act of 2005. The program began with NASA's commitment to the House Committee on Science in May 1998 to find at least 90% of 1km and larger NEOs. It is not the goal of the survey program to achieve 90% completion of its near-Earth object catalogue within 15 years. As of December 2015, there were 13,514 near-Earth asteroids discovered under this program, 1,649 of which were deemed potentially hazardous asteroids (come within 5 million miles of Earth orbit). NASA's NEO search program consists of the use of several platforms including Pan-STARRS, the NEO-WISE satellite, the Catalina Sky Survey, and the LINEAR/SST. The traditional-design optical telescopes like Gemini, Keck, Subaru, VLT, Hubble, and Spitzer are not the instruments of choice; the NEO surveys must be deep and wide (i.e., Pan-STARRS and LSST), and there must be multiple detections to complete discovery and determine orbit.

LSST will detect and recognize objects in single images that are not already-know sources, link detections in multiple images and establish that they constitute a single moving object rather than an unrelated event, and obtain enough positional measurements to determine and orbit which must be accurate enough to guarantee later re-observation. Once built and commissioned, LSST may prove to be a highly effective NEO discovery engine and an excellent instrument for NEO follow-up and tracing. NASA needs a better assessment of LSST's capabilities for NEOs and has commissioned a quasi-independent study of LSST NEO capabilities. The study is a single, coordinated effort involving the LSST project with a team knowledgeable on NEO surveys (JPL and IPAC) and will evaluate effects of false positives, detection thresholds, and alternative cadences. A study plan was drafted and reviewed. Work is in progress and a report is to be reviewed and delivered to NSF and NASA by September 2016.

Jacqueline Hewitt, Chair of the NRC Mid-Decade Review Committee, provided an update on the Astro2010 *NWNH* Midterm Assessment. The Committee was given four tasks:(1) describe the most significant scientific discoveries, technical advances, and relevant programmatic changes in astronomy and astrophysics over the years since the publication of the decadal survey; (2) assess how well the Agencies' programs address the strategies, goals, and priorities outlined in the 2010 decadal survey and other relevant NRC reports; (3) assess the progress toward realizing these strategies, goals, and priorities; and, (4) in the context of strategic advice provided for the Agencies' programs by Federal Advisory Committees, and in the context of mid-decade contingencies described in the decadal survey, recommend any actions that could be taken to maximize the science return of the Agencies' programs. The review will not revisit or alter the scientific priorities or mission recommendations provided in the decadal survey and related NRC reports but may provide guidance on implementation of the recommended science and activities portfolio and on other potential activities in preparation for the next decadal survey. There have been three Committee meetings with time set aside for public comment; there was a splinter session at the January AAS meeting and an open letter to the community was distributed by the AAS. The three Agencies have made presentations to the Committee as well as presentations given by OSTP, ESA, JAXA (Japan Space Agency), TMT, GMT, LSST, and CTA. The Committee has observed that the landscape is more complicated than expected and there are many unresolved issues that may need more detailed study. The report is expected to be released in May.

Craig Hogan asked who is going to advise the agencies about writing their charge and charter for the next decadal survey, about designing the next phase of community advice, is it the AAAC, the mid-decade committee? Hewitt indicated that this has been part of the discussions in the mid-decade committee and the committee does have some thoughts on how the process might be changed (what things worked and did not work well before).

James Ulvestad commented that the Mid-Decade report comes out too late for the next AAAC annual report but March 2017 is about the time to for the AAAC to recommend what the next decadal survey should look like because by March 2018 the Academy will be far enough along in the survey; it works out well for what the Mid-decade review committee will say and how the AAAC can incorporate their thoughts into the 2017 report.

The Chair invited Hewitt to give a presentation at the June AAAC telecon after the report has been released.

The Committee spent some time discussing report writing and planning for the annual report.

The Committee scheduled the Fall 2016 meeting for October 27-28, 2016 at NSF.

MEETING ADJOURNED AT 5:00 PM, 28 January 2016
MEETING RECONVENED AT 9:00 AM, 29 January 2016

Steven Kahn, LSST Director, gave a presentation on LSST/Euclid/WFIRST Synergies. All three programs are wide, deep imaging survey missions operating in the optical/IR.

The Committee spent time discussing the annual report that is due on March 15, 2016. The Chair made writing assignments for the different sections of the report. There will be further discussion of the annual report at the February teleconference. While all three are motivated, in part, to address cosmological questions, such as the nature of dark energy, the data they provide will also enable a wide variety of other investigations in astronomy and solar system science. The designs of the three missions are also complementary in interesting ways. LSST will provide a large number of seeing-limited optical band observations of half the sky, which will go deep, and enable time-domain studies on a wide range of timescales; Euclid will provide visible band and IR imaging at higher spatial resolution over a comparable region of sky, but with many fewer visits, and at much shallower depth; WFIRST will cover a smaller region of sky in the IR band at the highest spatial resolution, at comparable depth to LSST. Euclid and WFIRST both also provide spectroscopic surveys in the NIR. A synergistic approach to the analysis of data from all three missions is clearly in the interest of extracting the optimal scientific return. However, since these are separate facilities, funded by different agencies, it will take some effort to make this work.

Over a decade of operations the LSST survey will acquire, process, and make available a collection of over 5 million images and catalogs with more than 37 billion objects and 7 trillion sources. Tens of billions of time-domain events will be detect and alerted on in real-time. The LSST will enable a wide variety of complementary scientific investigations, utilizing a common database and alert stream. These range from searches for small bodies in the Solar System to precision astrometry of the outer regions of the Galaxy to systematic monitoring for transient phenomena in the optical sky. LSST will also provide crucial constraints on our understanding of the nature of dark energy and dark matter. Euclid is an ESA-led wide-field deep survey mission with support from NASA; NASA is responsible for the sensor chip systems for the Near Infrared Spectrometer and Photometer instrument on Euclid. The survey results will be released in stages with US members of the Euclid Consortium having immediate access to all data. WFIRST, the highest ranked NWNH large space mission will determine the nature of the dark energy that is driving the current accelerating expansion of the universe, perform statistical census of planetary systems through microlensing survey, survey the NIR sky, and provide the community with a wide field telescope for pointed wide observations. WFIRST will give Hubble-quality and depth imaging over thousands of square degrees.

LSST, Euclid, and WFIRST are highly complementary. LSST and Euclid will cover large fractions of the sky, but at different depth, with different spatial resolution, and in different wavelength bands. WFIRST will get to comparable depth to the full LSST, but in the near infrared, with much high spatial resolution, but over a more limited region of the sky. The biggest advantage of combining data will come from significant reduction in systematic errors, affecting each of the various different cosmological probes, that builds on the differences in characteristics. For the ultimate weak lensing and large-scale structure measurements, a combination of LSST + Euclid/WFIRST is essential to provide the multiband photometry necessary to improve photometric redshifts, in particular to narrow the error distribution and suppress catastrophic errors. In addition, shear comparisons over limited regions of sky between the higher spatial resolution images obtained by Euclid and WFIRST can help to calibrate both multiplicative and additive errors in the LSST shear determinations. Finally, the higher resolution imaging provided by the space missions will aid in galaxy de-blending in the LSST image analyses.

There are significant systematic effects that will be encountered if we simply combine catalogued fluxes determined separately by each of the missions. The way to avoid this problem is to re-reduce all of the pixel-level data jointly, using the same apertures, centroids, etc. There are other benefits to joint pixel-level processing, e.g. using the higher resolution space-based images to de-blend the LSST images, using the IR colors of stars together with LSST data for astronomical investigations, etc. A joint analysis of LSST data together with Euclid and WFIRST data is outside the scope of the current LSST Project; this applies to both figuring out how to do it, and implementing it in operations. It is also outside the scope of the NASA-supported US effort on Euclid, and the anticipated NASA-supported data processing effort for WFIRST. All three agencies expressed interest in convening a meeting on the topic; a meeting was held last June with a representative from each project attending plus those from the three agencies, NSF, NASA, and DOE. A tri-agency, three-project working group has been established to look at the joint pixel level processing. Cooperation with Euclid requires special consideration, since, at present, most Euclid Consortium members will not have access to LSST data, and most Americans will not have access to Euclid data during the proprietary periods. Draft agreements between the Euclid Consortium, the LSST Project, and the LSST Dark Energy Science Collaboration (DESC) have been generated on both sides of the Atlantic, but, to date, none has been found acceptable to all sides. A Euclid/LSST discussion group is being reformed to try to work this, first by cooperatively developing the science case, and then an implementation plan. While there is strong overlap in the science planned for the three separate facilities, their designs are highly complementary. A combined analysis of the data from all three will provide a significant enhancement in scientific return.

David Hogg asked whether the three groups were going to release the raw data (at the pixel level) for an outsider to perform the combined analyses. Kahn indicated that for LSST, the raw images along with the software that is used at every stage of process will be released for anyone with access to LSST data (Americans, Chileans, and scientists who have agreements with LSST). The Euclid raw data may be released but neither Kahn nor Jason Rhodes (JPL) knew for sure. The LSST data will be made public to the world two years after each release; the proprietary period is two years after the release of each annual release which includes access to the raw data. Dominic Benford (NASA) indicated that the raw data (L1B calibrated frames) for WFIRST would likely be made available on short timescales (i.e., a week post downlink) publically through the archives. David Hogg asked a further question,

William Smith asked if the timing of the data sets matter too much to the joint analysis; LSST and WFIRST will roughly overlap but Euclid will have had five years of data and two more years left in their mission. Kahn replied that current launch date for Euclid is 2020, LSST will be commissioning then, but the camera will have been delivered and after some tuning period, real imaging on the sky will have started; part of the commissioning plan is do mini-surveys of the sky in the operations mode in order to understand how LSST is doing it. One of the ideas being discussed is LSST selectively observing the Euclid fields that were coming up early to provide that data; it could be part of an agreement to tailor the observing strategy for LSST to ensure Euclid gets the data it needs. The launch date for WFIRST is not decided and LSST will have been in operations for a while; LSST will get to the depth requirements needed before WFIRST exploitation. Euclid needs the photometric redshifts in order to publish cosmological analyses; Euclid steps through the sky and gets to the depth they are going to achieve and then moves on to the next past of the sky, LSST systematically covers the whole sky and keeps coming back. It would take some coordination to ensure that the right data to enable certain scientific analysis by certain date, which would have to part of the agreement. Jason Rhodes indicated that Euclid will use DES data in the south and in the north, a combination of data from different telescopes such CFHT, Subaru, William Herschel telescope, and others; the plan is to get the full 15,000 square degree Euclid survey covered either before launch or in the early 2020s. The LSST data will be better and deeper and it is the preferred solution scientifically and programmatically, but it is not required on a timescale that will be problematic; timescales for LSST and Euclid can be coordinated.

Buell Jannuzi asked why the joint analysis of the data had to come at a time while all three of the missions were in their commissioning phase. Kahn replied that if they were to do the joint processing (LSST processing stream), the most cost effective way to do that is to do it together; it is also good while the LSST project is putting together its data management system to incorporate this joint processing now rather than retrofit later; it is a diversion and will cost some money but it is not an enormous diversion assuming all three projects work together.

The Committee spent time the remaining time discussing the annual report that is due on March 15, 2016. The Chair made additional writing assignments for the different sections of the report. There will be further discussion of the annual report at the February telecon meeting.

MEETING ADJOURNED AT 11:00 PM, 29 January 2016