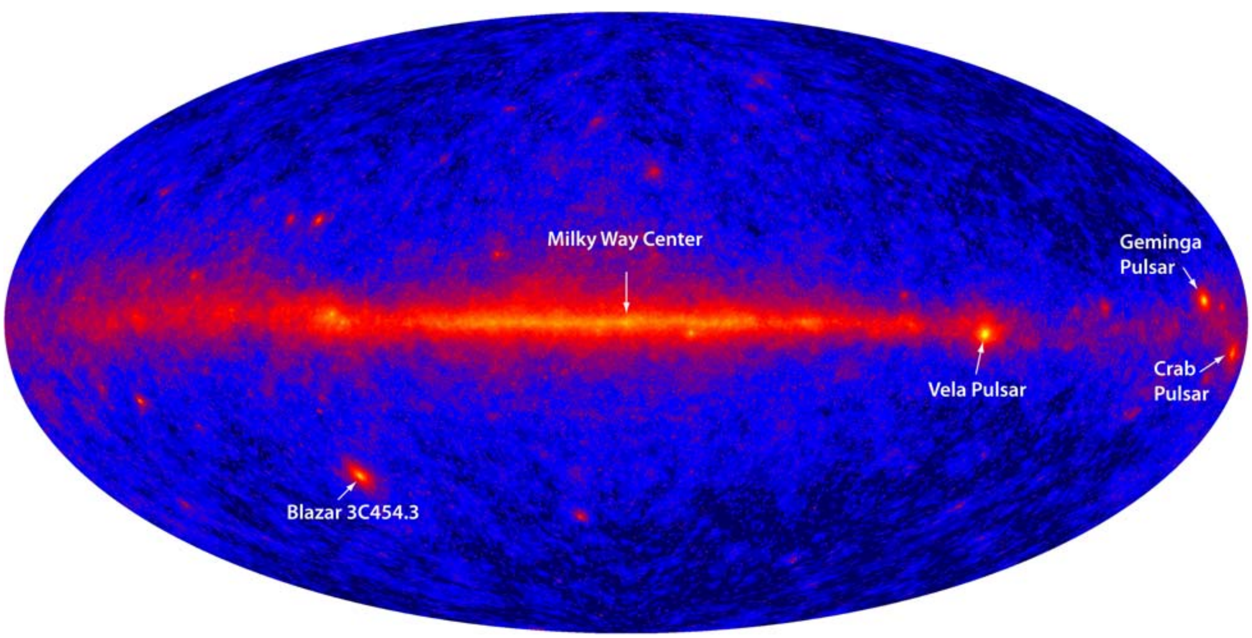
Report of the Astronomy and Astrophysics Advisory Committee (AAAC)

March 15, 2009



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THE OBSERVATORIES

March 15, 2009

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Arlington, VA 22230

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Washington, DC 20546-0001

Dr. Steven Chu, Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

The Honorable Bart Gordon, Chairman
Committee on Science and Technology
House of Representatives
Washington, DC 20515

The Honorable John D. Rockefeller, IV, Chairman
Committee on Commerce, Science and Transportation
United States Senate
Washington, DC 20510

The Honorable Ted Kennedy, Chairman
Committee on Health, Education, Labor and Pensions
United States Senate
Washington, DC 20510

Dear Dr. Bement, Dr. Scolese, Secretary Chu, Chairman Gordon, Chairman Rockefeller, and Chairman Kennedy:

I am pleased to transmit to you the annual report of the Astronomy and Astrophysics Advisory Committee for 2008–2009.

The Astronomy and Astrophysics Advisory Committee was established under the National Science Foundation Authorization Act of 2002 Public Law 107-368 to:

The Observatories
of the Carnegie Institution

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(1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy;
(2) assess, and make recommendations regarding, the status of the activities of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy as they relate to the recommendations contained in the National Research Council's 2001 report entitled Astronomy and Astrophysics in the New Millennium, and the recommendations contained in subsequent National Research Council reports of a similar nature;
(3) not later than March 15 of each year, transmit a report to the Director, the Administrator of the National Aeronautics and Space Administration, the Secretary of Energy and the Committee on Science of the House of Representatives, the Committee on Commerce, Science, and Transportation of the Senate, and the Committee on Health, Education, Labor, and Pensions of the Senate on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

The attached document is the sixth such report. The executive summary is followed by the report, with recommendations for NSF, NASA and DOE regarding their support of the nation's astronomy and astrophysics research enterprise.

I would be glad to provide you with a personal briefing if you so desire.

Sincerely yours, on behalf of the Committee,

Wendy Freedman

Wendy L. Freedman
Chair, Astronomy and Astrophysics Advisory Committee

cc: Representative Ralph Hall, Ranking Member, Committee on Science and Technology, House of Representatives
Senator Kay Bailey Hutchison, Ranking Member, Committee on Commerce, Science and Transportation, United States Senate
Senator Michael Enzi, Ranking Member, Committee on Health, Education, Labor and Pensions, United States Senate
Senator Barbara Mikulski, Chairwoman, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate
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Dr. Kathleen Turner, Program Manager, Office of High Energy Physics, U.S. Department of Energy
Dr. Charles Elachi, Director, NASA Jet Propulsion Laboratory
Dr. Robert D. Strain, Director, NASA Goddard Space Flight Center
Mr. Chuck Atkins, Chief of Staff, Committee on Science and Technology, House of Representatives
Ms. Janet Poppleton, Ranking Chief of Staff, Committee on Science and Technology, House of Representatives

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Dr. Scott Dodelson, Fermi National Accelerator Laboratory
Dr. Wendy Freedman (Chair), Observatories of the Carnegie Institution of Washington
Dr. Kim Griest, University of California, San Diego
Dr. Jacqueline Hewitt, Massachusetts Institute of Technology
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ANNUAL REPORT

ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE (AAAC)

MARCH 2008 — MARCH 2009

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EXECUTIVE SUMMARY

Exciting developments in astronomy: such as the discovery of extrasolar planets, the anticipation of finding planets capable of harboring life, and the discovery of the mysterious and dominant dark energy that is causing the expansion of the Universe to accelerate, all continue to excite the human imagination and fuel new technologies to increase further scientific discovery. In this, the Annual Report of the Astronomy and Astrophysics Advisory Committee (AAAC), we provide an overview of the astronomy and astrophysics field since the time of the last National Research Council (NRC) decadal survey process, and discuss the status of the prioritized projects in that report. This review is intended as a summary precursor to the Astro2010 Decadal Survey, now underway, which will provide definitive community consensus on these efforts. We also provide an assessment of the interagency cooperation for collaborative projects involving the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). We note where the successes of the past decade have come, and where challenges remain. Finally, we highlight some of the areas where astronomy has benefited our nation, beyond scientific discovery alone.

In contrast to previous decades, few of the major initiatives called for in the most recent Decadal Survey have reached maturity; some have not yet even started. The astronomy and astrophysics community has begun its 2010 decadal survey process, with a report planned for summer 2010. Most of the programs from the last decadal survey will need to be re-prioritized. We discuss here some steps that could be taken in anticipation of the new 2010 report, so that the highest-priority recommendations can be implemented successfully and efficiently.

We are pleased to report that interagency collaboration has grown considerably in this decade, and that the scientific opportunities are driving the field toward further cooperation. Significant challenges remain, however, in bridging the cultural differences and interests of the agencies.

FINDINGS AND RECOMMENDATIONS

Findings:

1) **Inter-agency cooperation amongst DOE, NASA and NSF is healthy on many levels: from scientist to scientist, at the programmatic level, in the sharing of skills, and for small and large facilities. It has led to an increasingly dynamic scientific discipline. Challenges in implementation, particularly of the largest facilities and projects, still remain.**

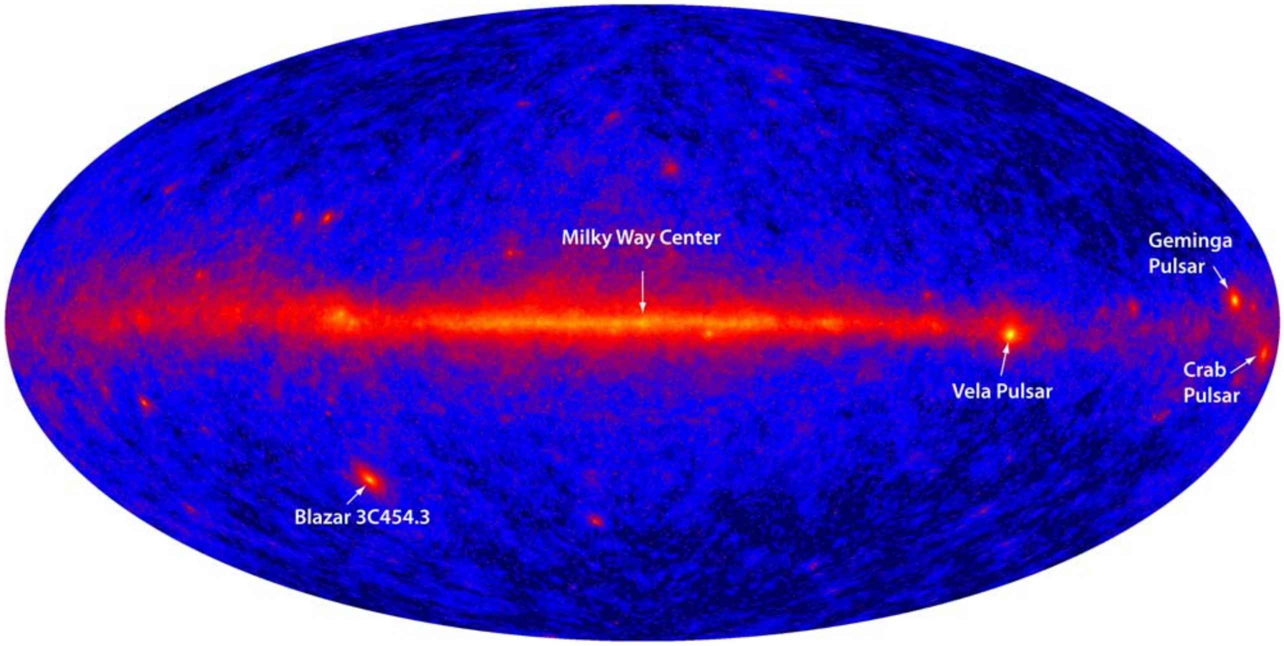
2) **A disappointingly small number of initiatives called for in the 2000 National Academy of Sciences Decadal Survey have come to fruition.**

Recommendations:

1) In the interest of astronomical research, agencies should be encouraged to continue coordinating activities *where the science or technology demands it*, and furthermore, to map out more clearly the scientific and technological complementarities that might be the basis for future missions/projects. We emphasize coordination, which may, but not necessarily, take the form of joint projects. Taking advantage of unique skill sets amongst agencies and throughout the world, coordinated access to northern and southern hemispheres of the sky, ground and space access – all are important aspects of a vigorous scientific program.

2) Robust cost estimates, including full life-cycle costs and external analyses of the budgets, as well as strategic planning for large facilities are a necessity, and should be an integral part of any prioritization and implementation process.

3) Assessment of the cooperation within projects involving federal plus international and private partners is now needed, in addition to that of inter-agency projects. Some of these projects have started since the time the AAAC was chartered.



NASA's newest space observatory, the Fermi Gamma-ray Space Telescope, began its mission on 11 June 2008 to explore the Universe in high-energy gamma rays. Shown here is the telescope's first all-sky image, revealing the glowing gas of the Milky Way, blinking pulsars, and a blazing galaxy billions of light years away. The image shows a band of gas and dust in the plane of the Milky Way, lit up in gamma rays by cosmic ray collisions. The famous Crab Nebula and Vela pulsars, fast-spinning neutron stars originally discovered by their radio emissions, also shine brightly. Scientists expect Fermi will discover many new pulsars in our own Galactic backyard, reveal powerful processes near supermassive black holes at the cores of thousands of active galaxies and enable a search for signs of new physical laws. Fermi is an inter-agency NASA-DOE partnership. Image: NASA/DOE/ International LAT Team.

I. SCIENCE OVERVIEW

Astronomy and astrophysics is a curiosity-driven endeavor to understand the Universe in which we live. Astronomy is mankind's oldest science and remains a universal quest worldwide. This year, 2009, is the International Year of Astronomy, celebrating the 400th anniversary since Galileo focused his first telescope on the sky. Today, Earth-based and space-based telescopes return new views of planets, stars, and galaxies at a dizzying pace. The rate of astronomical discoveries has never been greater, and the opportunities for fundamental discoveries are as great as any time since Galileo first turned his optic tube toward the heavens. Just in the last decade, there have been a remarkable number of astronomical advances that will shape astronomical investigations in the next decade.

While it is not possible in this report to discuss all of the progress in a decade rich in astronomical discoveries, it is illustrative to highlight two. We mean to convey the excitement astronomers feel at the potential for discoveries. We also comment on the recent growth of collaborative research in the field, which is crossing traditional disciplinary lines.

The Sombrero is one of the largest galaxies in the nearby Virgo cluster of galaxies, about 28 million light years from Earth. This Great Observatories view was made using NASA's Chandra X-ray Observatory, Hubble Space Telescope and Spitzer Space Telescope. The main figure shows the combined image, while the three inset images show the separate observatory views. The Chandra observations show that diffuse X-ray emission extends over 60,000 light years from the center of the Sombrero. (The galaxy itself spans 50,000 light years across.) Scientists think this extended X-ray glow may be the result of a wind from the galaxy, primarily being driven by supernovae that have exploded within its bulge and disk. The Hubble optical image (green) shows a bulge of starlight partially blocked by a rim of dust, as this spiral galaxy is observed edge on. That same rim of dust appears bright in Spitzer's infrared image, which also reveals Sombrero's central bulge of stars. Credit: X-ray: NASA/UMass/Q.D.Wang et al.; Optical: NASA/STScI/AURA/Hubble Heritage; Infrared: NASA/JPL-Caltech/Univ. AZ/R.Kennicutt/SINGS Team.

Dark Energy

The most fundamental feature of our modern cosmology is the expansion of the Universe since its creation in the Big Bang nearly 14 billion years ago. Although "predicted" by Einstein's 1915 theory of gravity, the expansion was not discovered until 1929 in the famous study of galaxy motions by Edwin Hubble.

For seventy years, astronomers measured the expansion velocity of the nearby universe with increasing accuracy, culminating in the Hubble Space Telescope Key Project's determination of the present expansion speed (roughly five million miles-per-hour over distances of 100-million light-years) to an accuracy of 10%.

At the end of the 1990s, using exploding stars equal in brilliance to billions of our own Sun, astronomers were able to look out into space, hence back in time, and measure the expansion velocity of the Universe billions of years ago. The remarkable, and largely unanticipated, discovery is that the universe today is expanding faster than it was then: the universe appears to be undergoing a second, recent spurt of growth! This was a total surprise because scientists expected the pull of gravity would continually slow the expansion from the initial Big Bang. The simplest explanation for this “accelerating universe” is that empty space is infused with a new, anti-gravity-like type of mass-energy, known as dark energy.

This dark energy, unveiled by astronomical observations, appears to be the dominant component of the physical Universe. And as yet, there is no compelling theoretical explanation for its existence or amount. The discovery of dark energy followed the discovery by astronomers with their telescopes, of the next most dominant and totally mysterious, component of the Universe: dark matter. Using a NASA telescope in space that measured miniscule ripples of temperature variations from the heat of the initial Big Bang, astronomers conclude that the ordinary matter and energy of which we are familiar and composed of constitutes a mere 4% of the Universe. Most scientists believe that nothing short of a revolution in our understanding of the fundamental laws of Nature will be required to explain the remaining 96% of our Universe. As Richard Feynmann said, “nature uses the longest threads to weave her tapestry.” Dark energy and Dark Matter are threads that connect the inner-space of the quantum and high-energy physics to the outer-space of the cosmos and astronomy.

In the ten years since the discovery of dark energy, we have measured the acceleration of the universe with increasing accuracy. In 2007, the AAAC’s Dark Energy Task Force[1] recommended a diverse program of Earth-based facilities and space-based missions to tackle this mystery. In the decade ahead we expect that increasingly accurate measurements will be able to discern between different ideas for the nature of dark energy and shed light on the behavior of fundamental forces and/or gravity.

Extrasolar Planets

Twenty years ago, we had no evidence of a single planet encircling another star. Today, we know of more than 300. Planets are small, dim bodies that orbit big, bright stars. That extrasolar planets exist at all is powerful evidence that the same processes which formed the Solar System acted around other stars. The pace of discovery increases as new telescopes take on the challenge of finding planets with ever decreasing mass and size.

Most of the extrasolar planetary systems discovered so far are not like our Solar System. These planets orbit at vastly different distances from the Sun: Uranus is nearly 50 times as far away as Mercury. They can be rocky and covered with liquid water as is the Earth, lifeless dry balls of rock like Mercury or massive balls of gas like Jupiter. This rich variation inspires us to study how our system came to be. Copernicus provided the evidence that the Earth was not the center of the Solar System. Today’s telescopes seek to find if other stars harbor planetary systems like ours.

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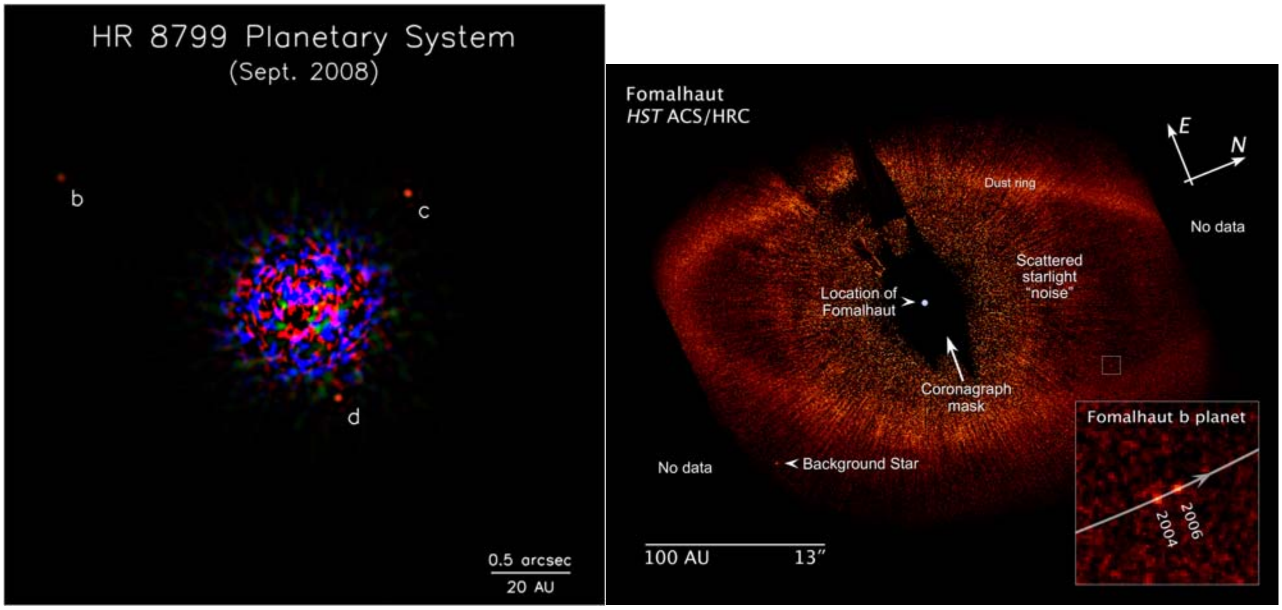
[1] Dark Energy Task Force report, www.nsf.gov/mps/ast/aaac/dark_energy_task_force/report/detf_final_report.pdf



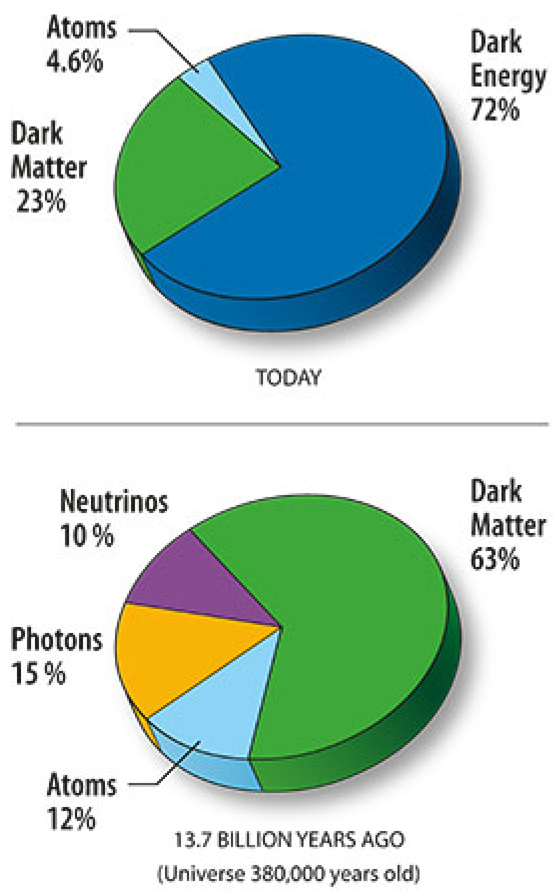
Direct images of exoplanets around two solar-type stars. (Left) The Gemini and Keck Telescopes with adaptive optics systems were used to correct for image-blurring atmospheric turbulence to find 3 planets around the star HR8799. Image credit: National Research Council of Canada. (Right) The Hubble Space Telescope's Advanced Camera for Surveys discovered a planet orbiting the nearby star Fomalhaut. Like many stars, Fomalhaut is surrounded by a dusty debris disk from which the newly discovered planet most likely formed. Fomalhaut's planet is measured to weigh 3 Jupiter masses, orbiting at a distance of around 115 AU from the star. There is evidence for Saturn-like rings around the planet as well. Image credit: P. Kalas, UC Berkeley.

Current techniques have partially revealed the richness of extrasolar planets, including gas giants closer to their stars than Mercury is to the Sun and planets that venture in close and then far from their stars.

Astronomers seek to refine their detection methods and develop new ways of measuring the frequency of planets and their mass, sizes and compositions. In 2008, the AAAC's Exoplanet Task Force[2] recommended a 15 year plan toward an ultimate, achievable, goal of knowing how common planets of the mass and size of Earth are and whether they harbor liquid water and life.

In the last year, astronomers have found planets of mass 4 to 5 times the mass of the Earth. They have also measured the composition of the atmospheres of gas giant planets and found that the constituents common in our Solar System appear in others as well. Cameras on the ground and in space have taken pictures of extrasolar giant planets. These exciting discoveries set the stage for the search for habitable planets around other stars. Astronomers look forward to results from NASA's Kepler mission, launched March 6, as this report was being prepared. Kepler's main goal is to discover Earth-size planets outside our Solar System with conditions hospitable for life. It will also reveal how common rocky planets like Earth are.

[2] Extrasolar Planet Task Force report, www.nsf.gov/mps/ast/aaac/exoplanet_task_force/reports/exoptf_final_report.pdf



Data from NASA's WMAP satellite reveals that the Universe's contents include 4.6% atoms, the building blocks of stars and planets. Dark matter comprises 23% of the universe. This matter, different from atoms, does not emit or absorb light. It has only been detected indirectly by its gravity. 72% of the universe is composed of "dark energy" that acts as a sort of an anti-gravity. This energy, distinct from dark matter, is responsible for the present-day acceleration of the universal expansion. WMAP data is accurate to two digits, so the total of these numbers is not 100%. This reflects the current limits of WMAP's ability to define Dark Matter and Dark Energy. Credit: NASA / WMAP Science Team

The Nature of Astronomical Research

Astronomers are unique among scientists in being able to peer directly into the past. Because of the finite speed of light, telescopes can be used as time machines to detect directly the birth and growth of the cosmos as far back as 14 billion years ago when the Universe started. Astronomers gather light to understand the creation and evolution of the universe, galaxies, black holes, stars, and planets. These data are interpreted using the laws of physics and computer simulations to gain a deeper understanding of the processes that govern the evolution of the universe and its diverse constituents

Astronomers study the Universe, Nature's laboratory. The early moments of the hot big bang involved energies in excess of the energies of the most powerful terrestrial accelerators. The Universe is also a laboratory in which to study rare processes like those involving neutrinos. This also illustrates the inner-space/outer-space connection: in order to understand astrophysical processes in extreme environments astrophysicists require the detailed knowledge from particle accelerators, and high-energy physicists can explore their discipline in Nature's laboratory.

As exemplified by some of the highlights above, our field is exploding – in scope, in new areas of intensive research, in data, in the need for more diverse instruments and telescopes, in the use of new technology, in new concepts and directions, in theoretical simulations and understanding. This fertile growth is leading to connections of our discoveries with other areas of science, especially related to particle physics, atmospheric physics, planetary geology, and biology. Much of the excitement of astronomy comes from the resonances among researchers in these different scientific disciplines. Supporting this interdisciplinary research often requires resources that are presently resident in different federal funding agents, each with their own missions, administrative and decision making traditions, and funding mechanisms.

These exciting discoveries have been possible in large part due to major technological advances and increases in the diversity and power of major facilities. As part of this changing landscape of more expensive major facilities, the sources of funding have also diversified to include combining private sources of funds, multiple federal agencies that support astronomical sciences (especially NSF, NASA, and DOE), and many more international sources, at both institutional to national levels.

As a result of this scientific resonance and technology diversity, astronomy projects are now commonly multi-institutional – crossing even international borders. One of the major changes over the past decade is the emergence of DOE-HEP support for astrophysics, a trend driven by this exciting new science at the interface of astronomy and physics. The synergistic combination of large survey projects, which map the universe from the largest scales to the orbits of Earth-crossing asteroids, and a mix of large-aperture follow-up and multi-wavelength facilities have become an increasingly important aspect of astronomical research. These collaborations offer many opportunities for exciting scientific discovery, as well as operational challenges, as we discuss in our report.

II. THE ROLE OF THE AAAC AND ITS RELATION TO THE DECADAL SURVEY

The AAAC was established in response to a 2002 study by the National Academy of Science (NAS) Committee on the Organization and Management of Research in Astronomy and Astrophysics (COMRAA). The COMRAA report, *U.S. Astronomy and Astrophysics: Managing an Integrated Program*[3], recommended the establishment of an advisory committee to address the growing need for collaboration among the agencies involved in supporting astronomy and astrophysics: the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the U.S. Department of Energy (DOE). The charter for the AAAC is included in Appendix A of this report. There are two roles for the AAAC:

1) to assess and make recommendations regarding the coordination of astronomy and astrophysics programs across DOE, NASA and NSF agency boundaries and

2) to assess and make recommendations regarding the status of activities contained in the astronomy decadal survey report.

[3] http://www.nap.edu/catalog.php?record_id=10190

The AAAC report is transmitted annually by March 15 of each year. There have been five previous reports from the AAAC[4]. We refer readers who are new to the subjects discussed here to these previous, comprehensive reports for contextual background material. We also refer readers to the 2001 NRC decadal survey report, *Astronomy and Astrophysics in the New Millennium* [5] (hereafter, the AANM 2001 report).

The National Research Council (NRC) decadal surveys have proven to be a very successful mechanism for prioritizing and making recommendations for new initiatives in astronomy. They involve significant input from the astronomical community resulting in a consensus report, and they provide advice for federal agency planning for new investments in the field.

At the time of writing this AAAC report, the new decadal survey (Astro2010) has just commenced. The AAAC and decadal surveys are complementary activities, and with Astro2010 underway, it is useful to look at the role of the AAAC. While the survey is being conducted, the NRC's astronomy advisory committee, the Committee on Astronomy and Astrophysics (CAA), steps down. Thus, the AAAC becomes the only body looking at the full scope of on-going astronomy activities. The Astro2010 Survey will take 18 months to produce, and the AAAC fulfills the need for continuing high-level oversight of major astronomy activities during this period. Because the ongoing decadal survey is comprehensive with regard to updating community goals for science, and reaches for broad community consensus in this regard, this AAAC report is intended as a precursor to that, considering current activities in the context of the previous decadal report.

Over the period 2005 to 2008, the AAAC set up four Task Forces to evaluate future research programs in the areas of the cosmic microwave background, dark energy, dark matter and extrasolar planets. These studies involved significant community input by an expert group of astronomers and astrophysicists in each of these fields. The reports were written under FACA guidelines. We plan to assess the impact of these reports at our October 2009 meeting.

As required in the charter, the AAAC held four meetings from March 2008 to March 2009. Face-to-face meetings were held at the NSF on May 9, 2008,[6] October 14, 15, 2008 and February 18, 19, 2009. A telephone conference was held to review a draft of this report on March 5, 2009. The AAAC meeting agendas and minutes, as well as reports, can be found at http://www.nsf.gov/mps/ast/aaac.jsp .

This current report looks first at the projects that were prioritized in the AANM 2001 report, and second at the current projects being coordinated jointly amongst the DOE, NASA, NSF, international and privately-funded projects.

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[4] http://www.nsf.gov/mps/ast/aaac.jsp

[5] http://www.nap.edu/openbook.php?isbn=0309070317

[6] The AAAC was chaired by Professor Garth Illingworth until June 30, 2008.

III. PROGRESS ON PROJECTS FROM THE LAST DECADAL SURVEY (AANM 2001)

The table below reproduces Table ES.1 from the 2001 AANM report, which is a ranked list of both ground- and space-based initiatives of major to moderate scale.

TABLE ES.1 Prioritized Initiatives (Combined Ground and Space) and Estimated Federal Costs for the Decade 2000 to 2010[a,b]

Initiative	Cost[c] ($M)
Major Initiatives	
Next Generation Space Telescope (NGST)[d]	1,000
Giant Segmented Mirror Telescope (GSMT)[d]	350
Constellation-X Observatory (Con-X)	800
Expanded Very Large Array (EVLA)[d]	140
Large-aperture Synoptic Survey Telescope (LSST)	170
Terrestrial Planet Finder (TPF)[e]	200
Single Aperture Far Infrared (SAFIR) Observatory[e]	100
Subtotal for major initiatives	2,760
Moderate Initiatives	
Telescope System Instrumentation Program (TSIP)	50
Gamma-ray Large Area Space Telescope (GLAST)[d]	300
Laser Interferometer Space Antenna (LISA)[d]	250
Advanced Solar Telescope (AST)[d]	60
Square Kilometer Array (SKA) technology development	22
Solar Dynamics Observatory (SDO)	300
Combined Array for Research in Millimeter-wave Astronomy (CARMA)[d]	11
Energetic X-ray Imaging Survey Telescope (EXIST)	150
Very Energetic Radiation Imaging Telescope Array System (VERITAS)	35
Advanced Radio Interferometry between Space and Earth (ARISE)	350
Frequency Agile Solar Radio telescope (FASR)	26
South Pole Submillimeter-wave Telescope (SPST)	50
Subtotal for moderate initiatives	1,604
Small Initiatives	
National Virtual Observatory (NVO)	60
Other small initiatives[f]	246
Subtotal for small initiatives	306
DECADE TOTAL	4,670

[a]Cost estimates for ground-based capital projects include technology development plus funds for operations, new instrumentation, and facility grants for 5 years.
[b]Cost estimates for space-based projects exclude technology development.
[c]Best available estimated costs to U.S. government agencies in millions of FY2000 dollars and rounded. Full costs are given for all initiatives except TPF and the SAFIR Observatory.
[d]Cost estimate for this initiative assumes significant additional funding to be provided by international or private partner; see *Astronomy and Astrophysics in the New Millennium: Panel Reports* (NRC, 2001) for details.
[e]These missions could start at the turn of the decade. The committee attributes $200 million of the $1,700 million total estimated cost of TPF to the current decade and $100 million of the $600 million total estimated cost of the SAFIR Observatory to the current decade.
[f]See Chapter 1 for details.

We briefly describe each of these projects and report on their current status. Subsequently, we make some general comments on the overall status of the implementation of the survey report, with some recommendations for implementing the new Astro2010 recommendations.

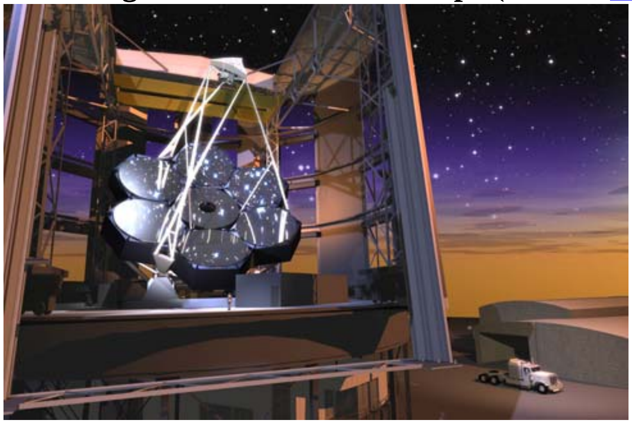
AANM 2001 Major Initiatives:

Next Generation Space Telescope (NGST; http://www.jwst.nasa.gov/)

The Next Generation Space Telescope (now the James Webb Space Telescope) is a 6.5 meter near infrared telescope with instruments permitting spectroscopy and imaging. Its sensitivity in these wavelength ranges provides capabilities to characterize the physical and chemical conditions in young solar systems, to study the assembly of galaxies and to identify the first stars that formed in the universe.

The project is currently in implementation, and has passed its major non-advocate review. Launch is expected in June 2013. The project has been delayed about 5 years compared to AANM 2001 expectations.

Giant Segmented Mirror Telescope (GSMT; http://www.gmto.org/, http://www.tmt.org/)



The Giant Segmented Mirror Telescope was envisaged as a 20 to 30 meter aperture ground-based telescope operating with adaptive optics and laser guide stars in the optical and near infrared wavelength regions. As presently conceived, a GSMT can study the first stars and active galactic nuclei (AGN), study the assembly of galaxies, can characterize the history of chemical evolution and star formation in nearby galaxies and is a powerful tool to detect other solar systems.

There are two teams with conceptual designs led by private groups with some public investment in technology development. There has been significant private and international investment.

Progress has been much slower than envisaged by AANM 2001, incommensurate with its first-ranked position.

Constellation X (Con-X, now IXO; (http://ixo.gsfc.nasa.gov/)

Originally conceived as a multiple satellite set of X-ray telescopes, primarily for spectroscopy, the concept has been replaced by the International X-ray Observatory, which is comprised of a single satellite, a project in collaboration with Europe and Japan. IXO can obtain spectra and images of objects emitting X-rays at much greater sensitivity than any of the current generation of X-ray telescopes. IXO will characterize the masses and spins of accreting black holes, and study the formation and evolution of clusters of galaxies.

Con-X has received technical development funding only. This project has been significantly slowed by limited funding. It is now waiting for prioritization by Astro2010.

Expanded Very Large Array (EVLA; http://www.ao c.nrao.edu/evla/)

Phase 1 of The Expanded Very Large Array is a project to upgrade the VLA's radio receivers, correlator, fiber-optic data transmission lines and upgrading electronics., and is currently under construction. Phase 2 of The Expanded Very large Array was reviewed and not funded.

Large – aperture Synoptic Survey Telescope (LSST; http://www.lsst.org/lsst)

The LSST is a 6-meter effective aperture wide-field telescope with imaging sensors and a data system designed to survey a large part of the sky repeatedly. The LSST has great power to identify small bodies in the solar system, to detect enormous numbers of supernovae at moderate distances, and to measure the weak lensing of very distant objects by ones at intermediate distance.

The project has passed its conceptual design review within NSF. DOE and NSF have supported design and development at roughly 10% of the total of the currently estimated construction costs. The project has also benefited from substantial private investment.

Terrestrial Planet Finder (TPF; http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm)

TPF is a mission concept for a single or multiple aperture very high resolution telescope to search for earthlike planets and evidence of life. TPF was recommended for funding that would prepare the mission for start at the end of the decade.

There has been considerable funding for technology development. There is no current plan for implementation.

Single Aperture Far Infrared Observatory (SAFIR; http://safir.jpl.nasa.gov/)

SAFIR is a cooled telescope about 8 meters in aperture capable of observing the universe at long infrared wavelengths with great sensitivity to forming stars and to galaxies at high redshift. SAFIR funding was recommended that would prepare the mission for start at the end of the decade.

There has been a small amount of funding for technology development. There is no current plan for implementation.

AANM 2001 Moderate Initiatives:

Telescope System Instrumentation Program (TSIP; http://www.noao.edu/system/tsip/)

TSIP provides funding for the development of new instrumentation and to otherwise enhance the scientific capability of private telescopes. In exchange telescope time is provided for use by the community.

Although funding has been less than recommended, the program is widely seen as a success both in supporting users and in developing instrumentation on large telescopes.

Gamma-ray Large Area Space Telescope (GLAST; http://www.nasa.gov/mission_pages/GLAST/main/index.html)

GLAST, now the Fermi Gamma-ray Space Telescope, is a large imaging gamma-ray detector with spectroscopic capabilities. The telescope is able to study gamma-ray bursts and other gamma ray sources.

The telescope has been launched, is gathering data, and is widely seen as a great success.

Laser Interferometer Space Antenna (LISA; http://lisa.nasa.gov/)

LISA is a group of 3 small satellites with test masses linked by laser interferometers. It can detect and study very long gravitational waves emitted by merging massive black holes over the history of galaxy formation and precisely measure the infall of compact objects into black holes in nearby galaxies.

LISA has been in phase A since 2004. The LISA Pathfinder has been funded primarily by ESA. It is delayed by limited funding and is awaiting reprioritization by Astro2010.

Advanced Technology Solar Telescope (ATST; http://atst.nso.edu/)

ATST (formerly AST) will be a world-class 4-meter telescope which exploits adaptive optics to obtain very high resolution images of the Sun. ATST will study the solar atmosphere where magnetic activities manifest themselves as sun-spots and other changing phenomena that can affect life on Earth.

It has been approved by NSB for inclusion in a future Major Research Equipment and Facilities Construction (MREFC) budget request at the NSF Director's discretion.

Square Kilometer Array (SKA; http://www.skatelescope.org/)

The SKA will be an interferometric array of individual antenna stations, with a total collecting area of a square kilometer. The very long wavelength radiation detected by these antennae will enable progress in five key science areas: planet formation, probing the Dark Ages, the origin and evolution of Cosmic Magnetism, strong field tests of gravity using pulsars and black holes, and a number of cosmological puzzles such as dark energy and galaxy evolution.

Several configurations are under consideration, but technology development is currently funded at a somewhat lower level than recommended. SKA will involve international collaboration. Two potential sites are under consideration, one in South Africa and the other in Australia.

Solar Dynamics Observatory (SDO; http://sdo.gsfc.nasa.gov/)

SDO is a suite of three instruments designed to help us understand the Sun's influence on Earth and Near-Earth space by studying the solar atmosphere on small scales of space and time and in many wavelengths simultaneously.

SDO is planned to launch shortly on an Atlas V rocket.

Combined Array for Research in Millimeter-wave Astronomy (CARMA; http://www.mmarray.org/)

CARMA is an array of six 10-meter, nine 6-meter, and eight 3.5 meter antennae that are used in combination to image the astronomical Universe at millimeter wavelengths. This array will detect radiation from the dawn of time which carries unique information about the structure and evolution of the universe. Galaxies, stars, and planets are born from cold gas and dust that hide them from view but will be revealed by CARMA.

The 10- and 6- meter telescopes began science operations in 2007, and the 3.5-meter telescopes were added in 2008.

Energetic X-ray Imaging Survey Telescope (EXIST; http://exist.gsfc.nasa.gov/)

EXIST is a proposed hard X-ray imaging all-sky deep survey. It will measure X-rays that emanate from many sources, including supermassive black holes in the centers of galaxies, stellar mass black holes, neutron stars, embedded supernovae in our galaxy, and the mysterious distant sources of gamma-ray bursts of radiation. EXIST's repeated surveys of the entire sky in the hard x-ray region will complement those by LSST at optical wavelengths.

Although there is currently no line for EXIST, it is a candidate to be the Black Hole Finder Probe.

Very Energetic Radiation Imaging Telescope Array System (VERITAS; http://veritas.sao.arizona.edu/)

VERITAS is an array of four 12 meter telescopes for gamma ray astronomy. The array complements the GLAST/Fermi satellite due to its sensitivity to higher energy radiation and ability to observe sources for long periods of time. It therefore studies the cosmic sources of relativistic particles such as supermassive black holes, gamma ray bursts, pulsars, and supernova remnants. VERITAS will also search for signs of the products of dark matter particles annihilating in the cosmos.

VERITAS opened in 2007 and all four telescopes are currently operational.

Advanced Radio Interferometry between Space and Earth (ARISE)

A proposed orbital radio telescope that is no longer under consideration.

Frequency Agile Solar Radiotelescope (FASR; http://www.fasr.org/)

FASR is an array of 75 antennae which measure radio waves from the Sun over a wide range of frequencies. These measurements will bring information about the heating of the corona, the nature and evolution of coronal magnetic fields, the structure of the solar atmosphere, and the origin of the solar wind. FASR is now under consideration for funding under atmospheric sciences in NSF.

Design and development was funded.

South Pole Sub-Millimeter Telescope (SPST; http://pole.uchicago.edu/)

SPST is a 10-meter telescope sensitive to radiation at sub-millimeter wavelengths. Its large size enables it to observe the cosmic microwave background with unprecedented resolution.

SPST saw first light in 2007, reported its first results in 2008, and continues to operate successfully at the South Pole.

AANM 2001 Small Initiatives:

National Virtual Observatory (NVO; http://www.us-vo.org/)

The NVO (now the Virtual Astronomical Observatory, VOA) is the US-based project that is collaborating with the International Virtual Observatory Alliance (IVOA) to make it possible for astronomical researchers to find, retrieve, and analyze astronomical data from ground- and space-based telescopes worldwide.

The previous Decadal Survey ranked Virtual Observatory as the highest priority for small projects, and its design and development has been funded for this fiscal year. Progress has been slower than anticipated.

Existing and Carry-over Projects from the 1990 Decadal Survey[7]

Hubble Space Telescope (HST; http://hubblesite.org/)

HST is a 2.4-meter reflecting telescope, which was deployed in low-Earth orbit (600 kilometers) by the crew of the space shuttle Discovery (STS-31) in 1990.

With 3 servicing missions, it continues to inspire generations of people around the world and has forever altered our knowledge of the Universe. One measure of this success is the more than 3500 scientific publications devoted to findings by HST.

Spitzer (formerly SIRTF; http://www.spitzer.caltech.edu/)

Spitzer is the largest infrared telescope (0.85-meter) ever launched into space.

Launched in 2003, Spitzer is still operating, producing important results on the origin and composition of planets, star formation and death, and distant galaxies.

Stratospheric Observatory for Infrared Astronomy (SOFIA; http://www.sofia.usra.edu/)

SOFIA is a 2.5-meter telescope carried aboard a Boeing 747-SP aircraft that will study the universe in the infrared spectrum.

Its first science flight is anticipated in 2009. Although recommended in both the 1990 and 2001 Decadal Surveys, progress has been slower than expected.

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[7] p. 109, AANM 2001

Space Interferometry Mission (SIM; http://planetquest.jpl.nasa.gov/SIM/)

SIM is a proposed space-based 6-meter baseline optical interferometer operating in the visible waveband. It will determine the positions and distances of stars several hundred times more accurately than any previous program. This accuracy will allow SIM to determine the distances to stars throughout the galaxy and to probe nearby stars for Earth-sized planets.

SIM was originally anticipated to be launched in 2006. A de-scoped project (SIM-lite) is to be reviewed by 2010 Panel.

Discussion:

There have been some remarkable successes over the past decade. For example, Fermi (formerly GLAST) has recently been launched and is making new discoveries, Kepler has just been launched, JWST is under construction, the first phase of the expansion of the VLA was funded, and the TSIP program has led to new instrumentation and public access to otherwise privately-funded telescopes. Of the previous existing and carryover projects, HST continues to make fundamental discoveries, the radio array, ALMA, is under construction in Chile, and Spitzer (formerly SIRTF) has made unanticipated discoveries in the mid-infrared sky. A new concept for a NASA/DOE Joint Dark Energy Mission (JDEM) has been developed in response to the excitement over the discovery of dark energy. This mission was not yet developed enough to be ranked in the previous 2001 AANM survey, but its progress is a tribute to a system flexible enough to allow for new initiatives. Clearly, the field remains vibrant.

The first-ranked space mission, JWST, is making very good progress. Yet, it is also the case that most of the highly prioritized programs from the 2001 AANM report have received very little federal funding over the past decade. Funding for Con X and LISA and SIM (formerly AIM in the 1990 decadal survey report) has been lower than envisaged, and these missions will require re-prioritizing, in the Astro2010 survey. For the ground, the situation is even worse. The first-ranked ground-based facility, GSMT, the 30-meter class optical telescope has received only a small (few-percent) share of the recommended NSF funding, and the third-ranked LSST, has also had comparably limited support. The moderate-sized solar telescope, ATST is approved for construction funding, with final design review pending. The top-ranked major ground-based projects have not received federal support commensurate with their rankings and the history of previous decadal reports.

Most of the highly prioritized programs from the 2001 AANM report have received little federal funding over the past decade. The reasons are complex, but large astronomical projects have grown increasingly expensive. A lesson from the 2000-2010 decade is the necessity of robust cost estimates for large projects (including full life-cycle costs and external analyses of the budgets). The AAAC was very pleased to hear about NSF's strategic planning process for large facilities, both Foundation-wide and within MPS.

The reasons for this small success rate are complex, and it is beyond the scope of this report to discuss all of them. However, large astronomical projects have grown increasingly expensive, and accomplishing many large projects within a single decade is not feasible within current budgets.

Cost growth of projects has been a major factor in what could be carried out in the current decade. In the case of NASA, the funding outlined in the 2001 AANM report ($4.67B) corresponds roughly with the investment over the last decade. This allowed funding for JWST as the first-ranked project, and much lower than anticipated funding left over for other missions. In the case of NSF, less than one half of the requested funding (about $1B was requested) was allocated to development of the recommended 2001 AANM facilities.

A lesson from the 2000-2010 decade is the necessity of robust cost estimates (including full life-cycle costs and external analyses of the budgets). The Astro2010 process already includes within it a requirement for outside assessment of the cost estimates for projects. To quote from its charge, Astro2010 "will assess various sources of risk, and it will develop its own estimate of the costs of the activity with help from an independent contractor with expertise in this area… the committee is expected to consider and make recommendations relating to the allocation of future budgets and address choices which may be faced, given a range of budget scenarios." Given the backlog of projects from the 2001 AANM survey, hard choices will need to be made.

The AAAC was very pleased to hear about NSF's strategic planning process for large facilities, both Foundation-wide and within Mathematical and Physical Sciences (MPS). The MREFC account has been an important source of funding for construction of astronomical observatories including ALMA, and is anticipated to begin funding ATST shortly. As facilities get larger, however, pre-construction planning becomes more expensive and important to generating reliable construction cost estimates and to buying down construction risk. In addition, operating costs of facilities are also rising, and improved mechanisms for dealing with full life-cycle costs are necessary. Planning of MREFC funding will be useful within NSF and also for defining the gates for interagency projects involving NSF. The AAAC views such strategic planning for facility investments as essential.

IV. INTERAGENCY, INTERNATIONAL, PUBLIC-PRIVATE PARTNERSHIPS

Some facilities and missions have reached a sufficiently large scale that their construction cannot be carried out by a single agency, or in some cases, a single country. Larger partnerships and collaborations are required, some international in scope, others inter-agency, and yet others involving broader agency and/or international partnerships with universities. There is no "one size fits all" blueprint for agreements. Every agency has its own set of requirements, the funding proposal solicitations and review mechanisms are different, as are the timescales for funding.

Before making recommendations for streamlining the process for inter-agency collaboration, it is helpful to understand the ways in which each of the agencies work. Each agency brings with it some unique and important differences, and with these differences come advantages in working jointly, as well as challenges in implementation.

AGENCY PROCESSES

1. DOE

The mission of the High Energy Physics (HEP) program is to understand how our universe works at its most fundamental level. To enable these discoveries, HEP supports theoretical and experimental research in both elementary particle physics and fundamental accelerator science and other supporting technologies. DOE and its national laboratories actively seek external input using a variety of advisory bodies for community input. This includes National Academy of Science studies as well as program advice from two federal advisory panels: the High Energy Physics Advisory Panel (HEPAP) and the Astronomy and Astrophysics Advisory Committee (AAAC), and their directed Subpanels and Task Forces. The HEP program office reviews and provides oversight for its research program, operating facilities and projects under construction through peer review.

2. NASA

The science program of NASA's Astrophysics Division is determined by the science community through decadal surveys, advisory committees, and agency planning activities that incorporate community input. NASA has two standing advisory committees, the AAAC, and the NASA Advisory Committee (NAC), both FACA committees. NASA strives to maintain a mission portfolio that is balanced between large (observatory class), medium, and small (PI-led) missions. In addition, a competitive research and analysis effort ensures that current data are fully exploited and that fertile ideas that could inform future space missions are nourished.

3. NSF

The NSF is proposal-driven and responds to proposals from individual investigators and projects. It strives to maintain a balance amongst individual research grants, operation of existing facilities and construction of new facilities. NSF receives advice from two FACA committees: the AAAC and the Mathematical and Physical Sciences Advisory Committee (MPSAC), in addition to review panels, while considering the priorities put forth by the Decadal Survey and other NAS reports.

In the next section we list the relevant inter-agency projects.

V. INTERAGENCY PROJECTS (See Appendix B for a complete list)

Many of the most profound and exciting science questions have little regard to discipline or agency boundaries. The agencies have embraced the strategic importance of many highly recommended instruments/facilities that span these boundaries and built them into their funding profiles, as we describe below. The community recognizes and applauds this responsiveness. Compared to the situation in the last decade, there is a healthy, vibrant interagency cooperation in ongoing projects, projects in construction, and projects in development. A complete list of the relevant projects is provided in Appendix B.

Here, we illustrate some joint projects and make some general observations.

LARGE NEW JOINT PROJECTS:

DOE and NASA: JDEM and Fermi

JDEM is a space mission to measure the characteristics of dark energy, to determine if the equation of state of dark energy is constant over cosmic time and if its behavior is consistent with that of Einstein's Cosmological Constant.

NASA and DOE are currently collaborating on two major missions: JDEM, which is under study, and Fermi, which is operational. In these missions the efforts of the two agencies have been deeply interconnected, as both sides produce hardware and software that must be integrated into a single mission. A major challenge that has had to be overcome is the difference in culture between the two agencies. NASA and DOE have differing experience sets with hardware development, testing, and integration. With regard to the severe demands for missions in space, NASA oversight in these areas remains essential. Another challenge is the difficulty in establishing the cost and schedule baseline of a space project and the need to accommodate an evolving cost estimate during formulation. The cost commitment for a NASA space project is not set until Confirmation, which is considerably later than the CD1 milestone for DOE. With time these differences are being ameliorated, but the differences are real, and the challenges significant. The great success of Fermi is indicative of how well NASA and DOE can work together. The recent interest on the part of the European Space Agency (ESA) in partnering with the U.S. on a dark energy cosmology mission is an interesting.and potentially very positive new development.

DOE and NSF: LSST

LSST is a six-meter effective aperture, wide field camera and telescope, repeatedly surveying the sky for investigations of, among others, (1) the nature of dark energy, (2) the structure of our galaxy, (3) discovery of new types of transient events, and (4) census of near-Earth asteroids.

DOE Office of Science and NSF Astronomy Division are both currently contributing R&D funds and anticipate jointly funding construction.

NSF and University/International Partners:

GSMT is the umbrella name for two projects: the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT). The GSMT is complementary to the LSST, and will be critical for spectroscopic follow-up of targets found by LSST, as well as JWST, JDEM, ALMA, SKA, IXO, and other planned and ongoing facilities. Its key science programs are in the areas of extrasolar planet studies, early galaxy formation, and the characterization of dark matter and dark energy.

NSF is currently contributing modest funding for adaptive optics, laser, and other technology development. About a dozen private U.S. institutions, and several countries are contributing funding to these projects.

The history of astronomy clearly demonstrates the remarkably productive synergy between surveys of the sky, combined with telescopes of larger aperture that provide the capability for detailed study and follow up. This synergy will continue with LSST/GSMT.

MEDIUM-SCALE NEW PROJECTS:

DOE and NSF: DES

DES involves a new camera for CTIO's Blanco telescope, which is part of NSF-funded NOAO. Together, these will provide very wide field images of the southern sky in order to investigate the nature of the dark energy.

The DOE Office of Science and NSF Astronomy Division are cooperating on DES. DOE is responsible for the camera (DECam). NSF is responsible for the data management system and upgrades to the telescope facility. DES passed DOE CD3b and under construction.

SMALL-SCALE PROJECTS:

NASA and NSF: South Pole Balloon Program and VAO

An example of a successful smaller cooperative project involves NSF Polar Programs and NASA's Antarctic balloon program. In this case NSF has been providing infrastructural and operational support for NASA's astronomical balloon missions, quite separate from the construction, flight, and science operations of the balloon payloads, which are supported by NASA. NASA is also participating with NSF Astronomy in developing a Virtual Astronomical Observatory. At a less formal level, between program scientists at NASA, NSF and DOE, beneficial exchanges take place regularly to coordinate, when appropriate, research and analysis program efforts.

Discussion

A strong conclusion of this report is that inter-agency cooperation amongst DOE, NASA and NSF has increased significantly in this decade. This is a very positive development. These agencies have vastly different cultures, procedures, funding streams, constituencies, and ways of evaluating (and soliciting) proposals. At the start of this decade, it was not obvious how, in practice, actually to cooperate. Last decade, inter-agency collaboration was almost unheard of; this decade an increasing amount of the science is heading in that direction. We commend the agencies for this impressive progress in this regard, and for mutually supporting a common scientific enterprise. In particular, there are many productive interactions at the scientist-to-scientist level (e.g., theory, instrumentation, software), in which we heard many examples of almost seamless interaction, facilitated by the program directors from the respective agencies.

Collaborative projects appear to work best when one agency is dominant and can lead the effort. Roughly equally-split partnerships may stall as each agency waits for the other(s) to commit funding, and the processes for allocating funding differ substantially. In this regard, JDEM still faces challenges integrating the different cultures and constituencies of NASA and the DOE (and now possibly also ESA).

The next generation of missions and facilities will require increasing levels of adaptability and flexibility. To date, collaborative projects appear to work best when one agency is dominant and can lead the effort. That is, roughly equally-split partnerships may stall as each agency waits for the other(s) to commit funding, and the processes for allocating funding differ substantially. In this regard, JDEM still faces challenges integrating the different cultures and constituencies of NASA and the DOE (and now possibly also ESA).

We draw attention here to an issue that will need increasing attention in the coming decade. The scientific questions at the interface of astronomy and physics are leading to larger collaborations, and the scale of the largest astronomical facilities is now such that not only interagency, but also international partnerships are becoming more common. Moreover, astronomy (on the ground) is unique (and fortunate) amongst the sciences in the support that it receives from private institutions and donors. These projects have also become international in scope. In the past two decades, less than one third of the investment in new ground-based (6 to 10-meter) optical telescopes came from the NSF. This trend is continuing with the development of the next generation of large telescopes. As yet, there is no clear path to the highest priority projects, as ranked in AANM 2001.

The AAAC is chartered to assess the interaction amongst the DOE, NASA and the NSF. However, there are now interaction issues requiring some attention beyond these agencies alone, which have started since the time the AAAC was chartered. No committee is currently monitoring the health of the expanded, overall landscape, including agency-international and

There are now interaction issues requiring some attention beyond the agencies within the AAAC's current purview. No committee is currently monitoring the health of the expanded, overall landscape, including agency-international and agency-private-institution partnerships. The coordination of these projects with the agencies could also benefit from advice and assessment by the AAAC.

agency-private-institution partnerships. These additional partnerships present many of the same coordination challenges that interagency collaborations faced a decade ago, and could also benefit from assessment by the AAAC. Finding a way to address these additional interfaces in collaboration with the agencies remains a serious challenge.

A remaining, unaddressed question is the overall strategy for missions and facilities, independent of agency. For example, what is the best mix of interagency support for projects such as LSST, JDEM, GSMT? Should these be coordinated to optimize the best science? What is the best timescale for proceeding? What is the best mix of agency support and participation? What is the best slate of projects (ground and space)? These are difficult questions, and they generally have not been addressed in the decadal survey process or by any other committee.

Astro2010 will set the scientific priorities for the upcoming decade. The federal agencies will then face the task of implementing these priorities. Anticipating the Astro2010 list of recommendations, it is useful to ask what can be done to be ready to advance these projects.

VI. ASTRONOMY AND NATIONAL NEEDS

While this is a time of great opportunity in astronomy and astrophysics, it is also a period of great national needs in other areas.

Why, in a time of severe economic challenges should the federal government invest in astronomy? This question is relevant of course to all fields of science, but we focus here specifically on astronomy. As we look back over the last decade of federal support for astronomy, what has been the return to the taxpayer?

The success of projects endorsed by the decadal survey process, both new and ongoing, reflects both formal scientific progress as well as other benefits to the nation that were, in many respects, anticipated in the 2001 AANM survey. Since that decadal survey we have seen heightened concern, on a national front, about the scientific and technological literacy of the American public, and realization of the extent to which that literacy bears on our quality of life and competitiveness. The 2007 NRC report *"Rising Above the Gathering Storm"*[8] articulated this need quantitatively and prophetically, and was followed by a White House initiative that justified budget increases for science, technology, and science education – the "American Competitiveness Initiative". This initiative was reflected in the congressional "America COMPETES Act," a strongly endorsed bipartisan authorization of such increases that was signed by the President. Although not addressed specifically in these White House and congressional efforts, astronomy research, education, and public outreach, as recommended in our decadal surveys, led to agency investments that both anticipated these efforts and were responsive to them. Significant benefits also come from the engagement of the American public in science and technology, and the pride that the American public takes in our accomplishments.

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[8] http://www.nap.edu/openbook.php?isbn=0309100399

The astronomy community recognizes the importance of our work to national competitiveness, through developing skill sets in areas as diverse as optical systems and detection technology, image processing, and atmospheric radiative balance. But the work that we do also results in new perspectives on the universe in which we live that stretch the imagination, and excite curiosity about scientific exploration in this country. A great nation should be capable of offering such new perspectives, and at least through the close attention given to it by the press, taxpayers see value from their investment in this work. The fostering of such curiosity serves an important national need, spurring the innovation on which much of our economic heritage is founded. Recent public data bases generated from astronomical facilities are bringing research into the high-school and undergraduate curriculum, stimulating broad interest in science in our youth and stimulating creative thinking in new ways. In this way, we believe that our work over the last decade, as mapped out by our previous decadal surveys, serves the nation in ways that go well beyond basic scientific research.

The 2001 decadal survey posited four overriding goals that address benefits to the nation. We believe that through careful agency investment, these goals have been met in a compelling way.

1. To disseminate astronomical discoveries widely, and thus bring the excitement inherent in science to the American public.

2. To use the excitement that astronomy engenders to increase public understanding of science and scientific methods and to make clear that science is a pathway to discovery, not just a collection of facts. This must be done at both the K-12 level and the undergraduate level.

3. To capitalize on the close involvement of astronomy with technology and instrumentation to contribute to training the technical work force.

4. To prepare future generations of professionals who will sustain U.S. preeminence in astronomy and will contribute to a scientifically literate nation.

VII. ACKNOWLEDGEMENTS

We thank the many agency staff involved for their participation in the AAAC meetings, contributions to discussions, and the provision of materials in response to our questions. We appreciate their willingness to discuss a wide range of complex issues, and to work collaboratively with each other in preparing for the meetings. Wise insight has been offered by staff at OMB and OSTP, and the House Science Committee. We also appreciate the willingness of several leaders in our field to comment on a draft version of this report.

APPENDIX A: AAAC CHARTER

As established in SEC. 23 of P.L. 107-368 (the National Science Foundation Authorization Act of 2002) and amended by SEC. 5 of P.L. 108-423 (the Department of Energy High-End Computing Revitalization Act of 2004):

ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE

(a) Establishment.—The Foundation, the National Aeronautics and Space Administration, and the Department of Energy shall jointly establish an Astronomy and Astrophysics Advisory Committee (in this section referred to as the "Advisory Committee").
(b) Duties.—The Advisory Committee shall—

(1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the Foundation, the National Aeronautics and Space Administration, and the Department of Energy;

(2) assess, and make recommendations regarding, the status of the activities of the Foundation, the National Aeronautics and Space Administration, and the Department of Energy as they relate to the recommendations contained in the National Research Council's 2001 report entitled "Astronomy and Astrophysics in the New Millennium", and the recommendations contained in subsequent National Research Council reports of a similar nature; and

(3) not later than March 15 of each year, transmit a report to the Director, the Administrator of the National Aeronautics and Space Administration, the Secretary of Energy, the Committee on Science of the House of Representatives, the Committee on Commerce, Science, and Transportation of the Senate, and the Committee on Health, Education, Labor, and Pensions of the Senate on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

(c) Membership.—The Advisory Committee shall consist of 13 members, none of whom shall be a Federal employee, including—

(1) 4 members selected by the Director;

(2) 4 members selected by the Administrator of the National Aeronautics and Space Administration;

(3) 3 members selected by the Secretary of Energy; and

(4) 2 members selected by the Director of the Office of Science and Technology Policy.

(d) Selection Process.—Initial selections under subsection (c) shall be made within 3 months after the date of the enactment of this Act. Vacancies shall be filled in the same manner as provided in subsection (c).
(e) Chairperson.—The Advisory Committee shall select a chairperson from among its members.

(f) Coordination.—The Advisory Committee shall coordinate with other Federal advisory committees that advise Federal agencies that engage in related research activities.
(g) Compensation.—The members of the Advisory Committee shall serve without compensation, but shall receive travel expenses, including per diem in lieu of subsistence, in accordance with sections 5702 and 5703 of title 5, United States Code.
(h) Meetings.—The Advisory Committee shall convene, in person or by electronic means, at least 4 times a year.
(i) Quorum.—A majority of the members serving on the Advisory Committee shall constitute a quorum for purposes of conducting the business of the Advisory Committee.
(j) Duration.—Section 14 of the Federal Advisory Committee Act shall not apply to the Advisory Committee.

APPENDIX B: LIST OF CURRENT INTERAGENCY (NSF/NASA/DOE) PROJECTS

JDEM (Joint Dark Energy Mission):

A NASA/DOE collaborative mission to measure the characteristics of dark energy, to determine if the equation of state of dark energy is constant over cosmic time and if its behavior is consistent with that of Einstein's Cosmological Constant. The European Space Agency also has expressed interest in joining.

Status: about to start Phase A

Fermi Gamma-ray Space Telescope (FGST); previously GLAST

DOE and NASA partner on the Large Area Telescope (LAT), the primary instrument on the NASA FGST mission. The LAT will do a full-sky map of the gamma-ray sky from energies of approximately 20 to 300 GeV.

Status: taking data

LSST (Large Synoptic Survey Telescope):

A six-meter effective aperture, wide field camera and telescope, repeatedly surveying the sky for investigations of, among others, (1) the nature of dark energy, (2) the structure of our galaxy, (3) transient events, and a complete survey of the solar system. Partnership is NSF/AST and DOE/HEP along with substantial private and foreign investment.

Status: proposed; has been through an NSF Conceptual Design Review

DES (Dark Energy Survey):

A new camera for CTIO's Blanco telescope will provide very wide field images of parts of the southern sky in order to investigate the nature of the dark energy. Partnership is DOE/HEP and NSF/AST, along with foreign and private contributions. DOE is responsible for the camera (DECam). NSF is responsible for the data management system and upgrades to the telescope facility.

Status: passed DOE CD3b and under construction

BOSS/SDSS-III (Baryon Oscillation Spectroscopic Survey/Sloan Digital Sky Survey-III):

The SDSS-III project includes several new surveys of astronomical phenomena, one of which is BOSS, a deep and wide redshift survey to use baryon acoustic waves generated in the early universe to study the nature of dark energy. Partnership is NSF/AST and DOE/HEP, with Sloan Foundation and partner investments

Status: finishing detector upgrade and commissioning

VERITAS (Very Energetic Radiation Imaging Telescope Array System)**:**

An array of four 12-meter diameter light collectors that detect very high energy gamma rays as witnessed by Cherenkov radiation resulting from air showers in the upper atmosphere. The gamma rays are produced in the most energetic environments in the universe: supernova remnants and active galactic nuclei and quasars. Partnership is NSF/AST, NSF/PHY, and DOE/HEP.

Status: taking data

Pierre Auger Cosmic Ray Observatory:

Partnership is DOE/HEP, NSF/PHY, NSF/AST and approximately 20 foreign countries. The purpose is the study of the flux, arrival direction and other properties of the highest energy particles in nature. The observatory has 1600 water surface Cherenkov detectors and 24 fluorescence telescopes over a 3000 square kilometer area in Argentina.

Status: taking data

CDMS and CDMS-II (Cryogenic Dark Matter Search):

Direct detection of Weakly Interacting Massive Particles (WIMPs) with solid state detectors in the Soudan mine in Minnesota. NSF/PHY and DOE/HEP: small initial involvement of NSF/AST.

Status: taking data

Large Underground Xenon (LUX):

Experiment for the direct detection of WIMP dark matter. The detector is a 300 kg, liquid-gas Xenon Time Projection Chamber at the Sanford Deep Underground Laboratory at the Homestake Mine, South Dakota. Partnership between NSF/PHY and DOE/HEP.

Status: detector being assembled above ground while waiting to get into the SUSEL mine.

COUPP (Chicagoland Observatory for Underground Particle Physics):

Heavy liquid bubble chamber experiment in the underground MINOS near detector hall at Fermilab for WIMP dark matter direct detection. Partnership between NSF/PHY and DOE/HEP.

Status: a 4kg chamber is taking data and a 60kg chamber is being commissioned

VAO (Virtual Astronomical Observatory):

A project that will provide a common interface to the digital archives of ground- and space-based observatories, allowing researchers both to use and to add value to the data sets via web-based services. This is the US project affiliated with the International Virtual Observatory Alliance. Partnership is NSF/AST and NASA/Astrophysics.

Status: awardee selected, funding will start after detailed negotiations are concluded.

POLARBeaR (POLARization of the Background Radiation):

Project to study the polarization of the CMB from Chile. Supported by NSF/AST and involving collaborators and small contributions-in-kind from DOE's LBNL.

Status: under construction

NASA ballooning;

Includes SPIDR (Spectrometry and Photometry of the Intergalactic mediums' Diffuse Radiation), TIGER (Trans Iron Galactic Element Recorder) - direction of arrival and the energy of cosmic rays that had atoms with weights near that of iron, ANITA (Antarctic Impulsive Transient Antenna) used up to a quarter of the Antarctic ice sheet as a neutrino detector, ANITA-II, CREAM and Super Pressure Balloon. The capability for flight of NASA's high-altitude, long-duration balloon payloads in the Antarctic.

Status: access to the Antarctic is provided by the infrastructure and operations support of NSF/OPP.

Astronomy and Astrophysics Decadal Survey:

The community-based evaluation of the state of the fields of Astronomy and Astrophysics, carried out by the National Research Council and funded by NSF/AST, NASA/Astrophysics, and DOE/HEP. This is the sixth such survey that provides prioritization for new astronomy initiatives and large projects for the decade 2011-2020.

Status: underway.

Planetary Science Decadal Survey:

The community-based study to develop a comprehensive science and mission strategy for space- and ground-based planetary science.

Status: carried out by the National Research Council and funded by NSF/AST & NASA/Planetary Science.

NRC study of Near Earth Object Surveys and Hazard Mitigation Strategies:

An NRC conducted study of options for detecting potentially hazardous asteroids and comets larger than 140 meters in diameter, and mitigating their potential collisions with the earth.

Status: the study was commissioned by NASA/Planetary Science and NSF/AST.

APPENDIX C:

ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE MEMBERS

Bruce Balick, University of Washington

Scott Dodelson, Fermi National Accelerator Laboratory

Wendy Freedman, (Chair) Observatories of the Carnegie Institution of Washington

Kim Griest, University of California, San Diego

Jacqueline Hewitt, Massachusetts Institute of Technology

Rocky Kolb, (Vice-chair) University of Chicago

David Koo, University of California, Santa Cruz

Daniel Lester, University of Texas at Austin

Doug Richstone, University of Michigan

Marcia Rieke, University of Arizona

Keivan G. Stassun, Vanderbilt University

Christopher Stubbs, Harvard University

Alycia Weinberger, DTM, Carnegie Institution of Washington