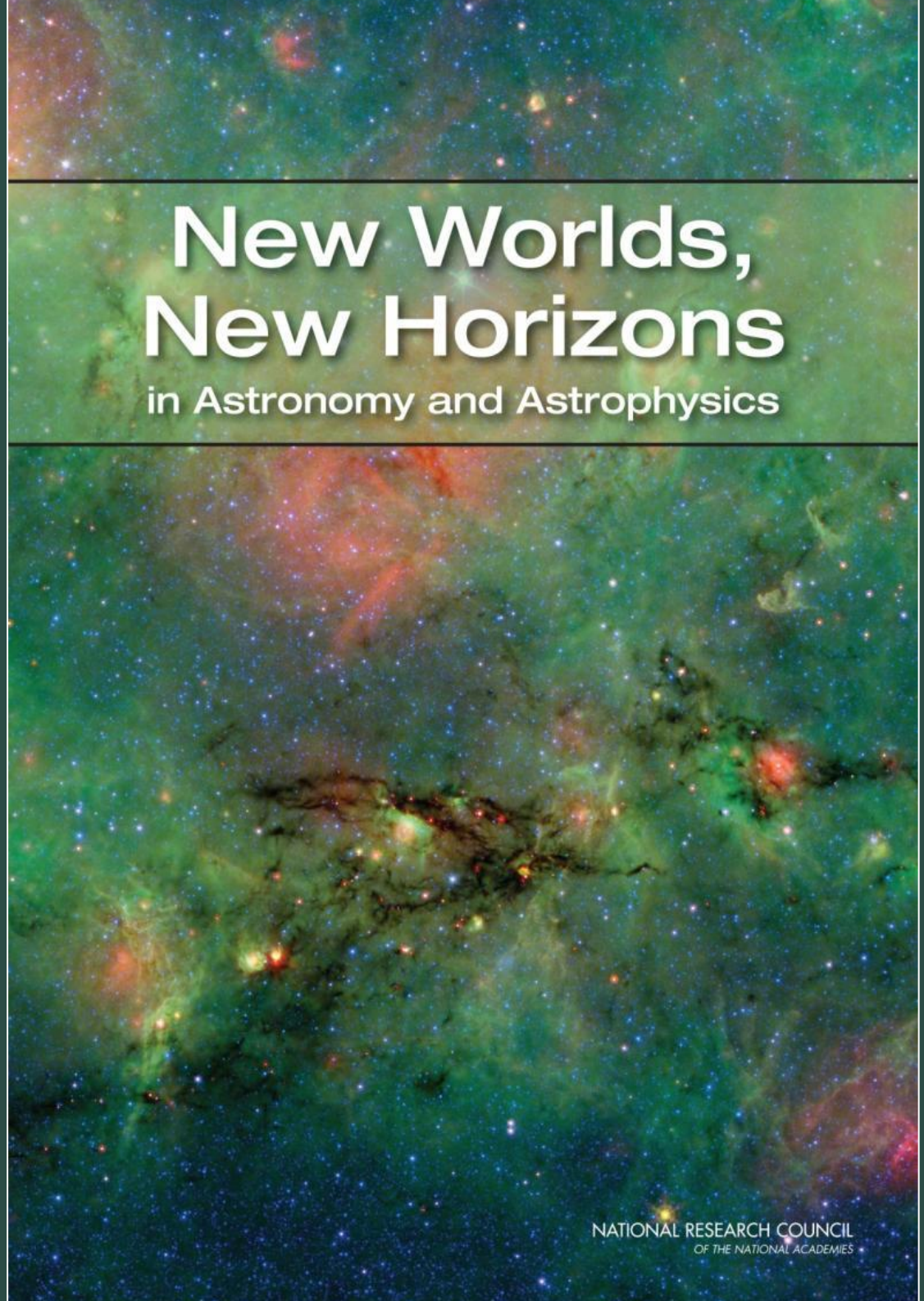
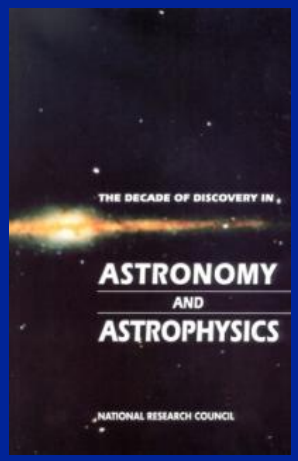
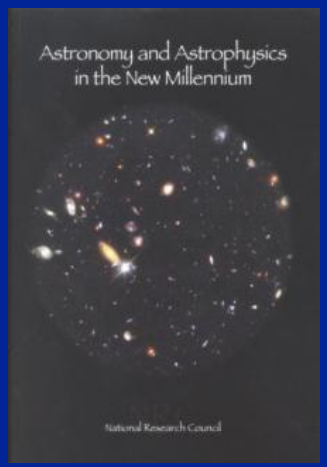

New Worlds,
New Horizons
in Astronomy and Astrophysics
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Decadal Surveys

- Roughly every decade since the 1960s there has been a survey of astronomy and astrophysics in the United States.
- Goals: A community-composed strategic plan for the next decade; a recommended prioritized program of science; and preparation for the following decade.
- Managed independent from the funding agencies by the NRC.
- Sponsored by the relevant government science agencies: DOE, NASA, NSF.
- Recently a new survey was conducted for the period 2011-2021.



U.S. Decadal Surveys

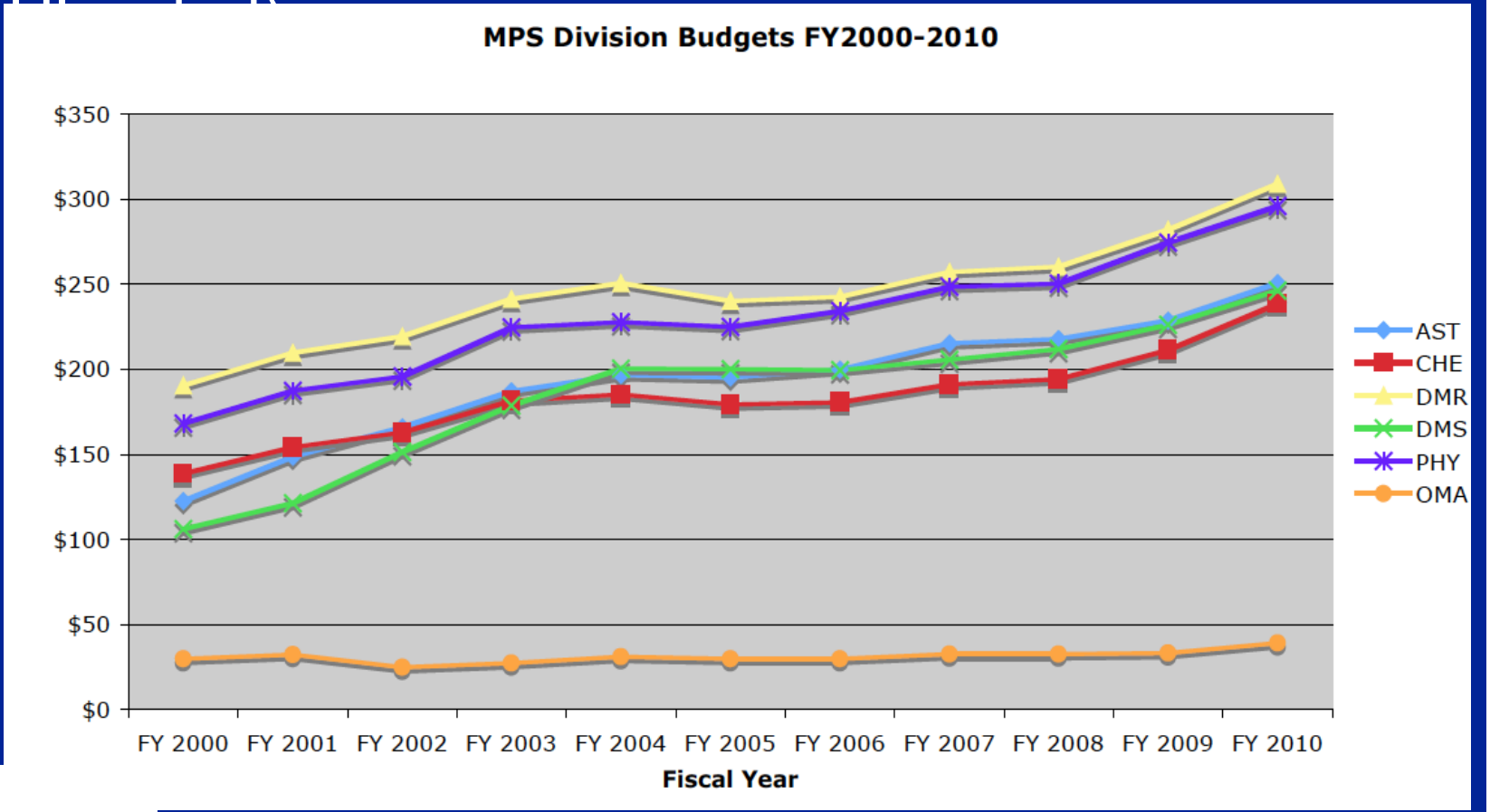


- 1964: Ground-based Astronomy: A Ten Year Program (Whitford)
- 1972: Astronomy and Astrophysics for the 1970s (Greenstein)
- 1982: Astronomy and Astrophysics for the 1980s (Field)
- 1991: The Decade of Discovery in Astronomy and Astrophysics (Bahcall)
- 2001: Astronomy and Astrophysics in the New Millennium (McKee-Taylor)
- 2010: New Worlds, New Horizons in Astronomy and Astrophysics (Blandford)

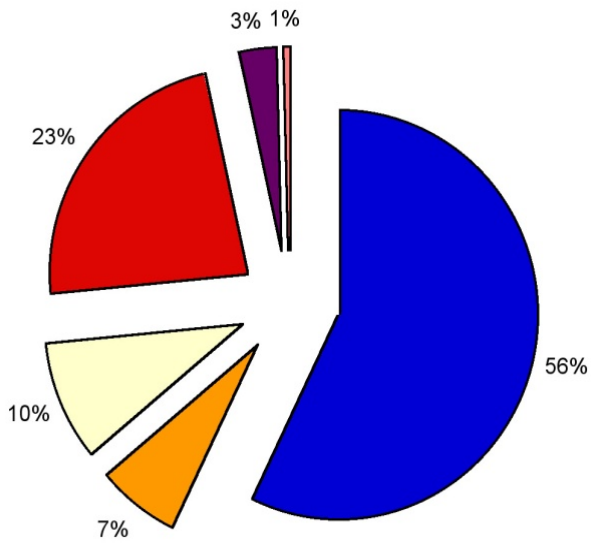
Recent Major Activities of the Agencies

- NSF
  - ALMA construction finished in 2012 (operations costs ramp-up)
  - ATST construction start in 2011; completion ~2017
  - EVLA upgrade completion 2012
  - Other AANM priorities TSIP, CARMA, VERITAS, SPT completed
  - Priorities GSMT, LSST, SKA, FASR not started
  - Evolution in VLBA, Arecibo, Gemini, NOAO recommended
  - ~55% of AST budget to run facilities and ~25% to individual investigators
- NASA
  - JWST schedule/cost unknown
  - Fermi and SDO launched
  - DDAA priority SIM not started
  - AANM priorities Con-X, LISA, EXIST, ARISE not started
  - AANM recommended tech dev for TPF halted and SAFIR not realized
  - Explorer program slowed
  - Imminent ramp-down of the “great observatories” program
- DOE
  - Fermi partnership a success

(This material courtesy of Jim



AST FY2009 $228m



- Facilities
- Future facilities
- Instrumentation
- Individual investigator
- Miscellaneous (STC etc.)
- Operations

FY11 request ~$250M
FY12 request ~$249M

New for this Survey

- Consideration of the key science themes was done by groups separate from those considering projects. The science deliberations came first.
- Projects recommended by earlier Surveys but not completed were assumed to be part of the process unless they were already well underway. There were no “grandfathered” projects.
- Medium and large recommended activities were subject to an independent risk assessment and cost appraisal.
- The recommended program was designed to fit within plausible (*at the time*) agency-specific budget profiles.
- Increased consideration of international and private collaboration.
- DOE joined NASA and NSF in providing funding for the execution of the Survey.

Task and Charge

Negotiated by NRC with Agencies

- The Committee on Astro2010 will survey the field of space- and ground-based astronomy and astrophysics, recommending priorities for the most important scientific and technical activities of the decade 2010-2020. The principal goals of the study will be to carry out an assessment of activities in astronomy and astrophysics, including both new and previously identified concepts, and to prepare a concise report that will be addressed to the agencies supporting the field, the Congressional committees with jurisdiction over those agencies, the scientific community, and the public.

Scope

- NASA, NSF, DOE
- Remote observing of cosmos, theory, physics, computation and simulation, laboratory astrophysics, solar astronomy (excluding space missions), and technology development
- Activities and infrastructure (broadly defined)
- Balance
- Partnerships: international, private, state …..

Challenges linked to S&T: US national

- economic recovery & growth: S&T as drivers (infotech, biotech, nanotech, greentech...?)
- health care: better outcomes for all at lower cost
- energy: reduced oil imports, reduced conventional & climate-altering pollution
- other resources & environment: water, land use, biodiversity, toxics, climate-change adaptation
- national & homeland security: scientific intelligence, cyber- & power-grid security, maintaining safety/reliability of shrinking nuclear stockpile without nuclear testing

Challenges linked to S&T: Global

- deploying S&T to help with poverty eradication and development
- combating preventable and pandemic disease
- transforming the global energy system and land-use practices to avoid catastrophic climate change
- maintaining the ecological integrity and productivity of the oceans
- reducing risks from nuclear & biological weapons

Science and Technology on the President's Mind

(left-side material from John Holdren)

Budget Priorities:

- Jobs, economy
- Health care
- Renewable energy
- Climate research
- Homeland security
- STEM education

NOTE: Astronomy is not generally viewed as part of the nation's agenda.

President Obama in October 2009

"So there are a lot of mysteries left and there are a lot of problems for you students to solve. And I want to be a President who makes sure you have the teachers and the tools that you need to solve them……..we'll move American students to the top of the pack in math and in science over the next decade, and guarantee that America will lead the world in discovery in this new century."

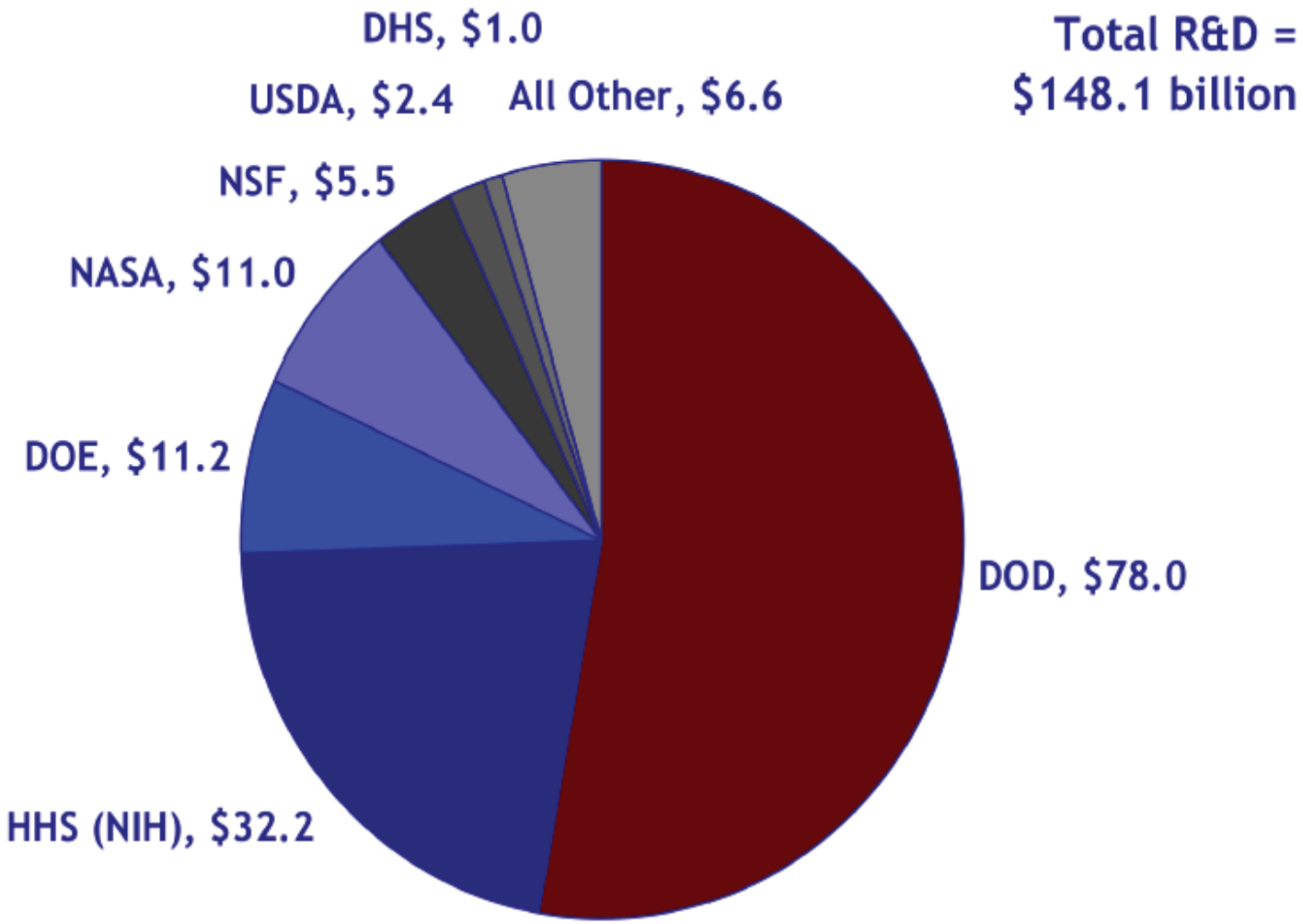
"At such a difficult moment, there are those who say we can't afford to invest in science, that it's a luxury at a moment defined by necessities. I could not disagree more. Science is more essential for our prosperity, our security, and our health, and our way of life than it has ever been."

"We need to ensure that we are encouraging the next generation of discoveries -- and the next generation of discoverers…..That's why my administration has set this goal: by investing in education, funding basic and applied research, and spurring private innovation, we will devote 3 percent of our gross domestic product to research and development. That's more than at any point in recent history.

Context

Total R&D by Agency, FY 2011

budget authority in billions of dollars

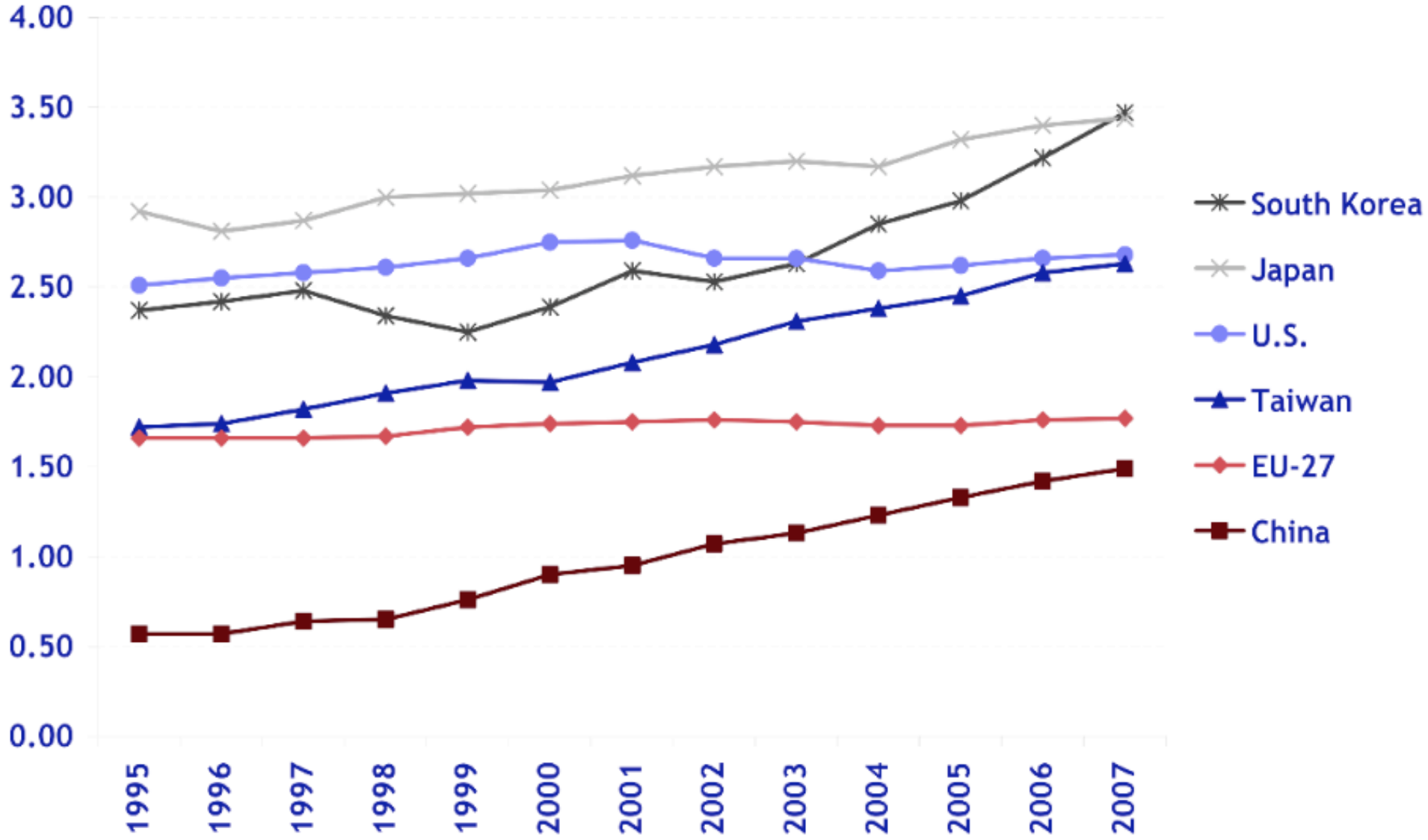


Total R&D = $148.1 billion

Source: OMB R&D budget data, agency budget justifications, and other agency documents.
R&D includes conduct of R&D and R&D facilities.

National R&D Investment

percent of GDP



Source: OECD, Main Science and Technology Indicators, May 2009.

Science and Technology in Congress

Late last year, the bill to reauthorize the expired America COMPETES Act appeared to be going nowhere. It finally passed in late December and in early January, President Obama signed H.R. 5116 into law.

Holdren: "COMPETES keeps America on a path of leadership in an ever more competitive world. It authorizes the continued growth of the budgets of three key agencies that are incubating and generating the breakthroughs of tomorrow -- the Department of Energy's Office of Science, the laboratories of the National Institute of Standards and Technology, and the National Science Foundation. COMPETES also bolsters this Administration's already groundbreaking activities to enhance STEM education -- to raise American students from the middle to the top of the pack and to make sure we are training the next generation of innovative thinkers and doers."

Congress This Year

"My Committee has been working diligently to go line-by-line in every agency budget to find and cut unnecessary spending to reduce our deficit and help our economy thrive…...the CR can and will reach a total of $100 billion in cuts compared to the President's request immediately -- fully meeting the goal outlined in the Republican 'Pledge to America' in one fell swoop. Our intent is to make deep but manageable cuts in nearly every area of government, leaving no stone unturned and allowing no agency or program to be held sacred. I have instructed my committee to include these deeper cuts, and we are continuing to work to complete this critical legislation." – House Appropriations Committee Chairman Harold Rogers

"*Democrats believe we must reduce the deficit and cut spending, but not at the expense of the investments that will pay off tomorrow with an educated workforce, cutting edge research that keeps our economy the world's leader, and a strong infrastructure*." – Democratic Whip Steny Hoyer

Astro2010 Startup (late 2008)

Charge led to

- Establishment of Committee and Panels
- Significant community engagement
- Science First approach
- Independent analysis of risk, technical readiness, schedule, and life cycle costs.
- Attentive to program possibilities under different budgetary scenarios

Astro2010 Committee

Roger Blandford, Chair, Stanford University
Lynne Hillenbrand, Executive Officer, California Institute of Technology

Subcommittee on Science

Martha P. Haynes, Vice Chair – Science Frontiers, Cornell University
Lars Bildsten, University of California, Santa Barbara
John E. Carlstrom, The University of Chicago
Fiona A. Harrison, California Institute of Technology
Timothy M. Heckman, Johns Hopkins University
Jonathan I. Lunine, University of Rome Tor Vergata
Juri Toomre, University of Colorado at Boulder
Scott D. Tremaine, Institute for Advanced Study

Subcommittee on State of the Profession

John P. Huchra, Vice Chair – State of the Profession, Harvard-University
Debra M. Elmegreen, Vassar College
Joshua Frieman, Fermi National Accelerator Laboratory
Robert C. Kennicutt, Jr., University of Cambridge
Dan McCammon, University of Wisconsin-Madison
Neil de Grasse Tyson, American Museum of Natural History

Subcommittee on Programs

Marcia J. Rieke, Vice Chair – Program Prioritization, University of Arizona
Steven J. Battel, Battel Engineering
Claire E. Max, University of California, Santa Cruz
Steven M. Ritz, University of California, Santa Cruz
Michael S. Turner, The University of Chicago
Paul Adrian Vanden Bout, National Radio Astronomy Observatory
A. Thomas Young, Lockheed Martin Corporation [Retired]

Community Input

An unprecedented response

- 324 Science White Papers (a unique snapshot of the field)
- 69 State Of The Profession Position Papers
- 70 White Paper on Technology Development, Theory, Computation, and Laboratory Astrophysics
- 108 Community Responses to a Request for Information on Research Activity Proposals
- Email Inputs to the Committee
- Community-organized Town Halls

Astro2010 Survey Approach

The three pillars of the survey

- **Astro2010: Science Frontiers**
- **Astro2010: State of the Profession / Infrastructure**
- **Astro2010: Activity Program Prioritization**

Report Contents

- Executive Summary
- Chapter 1: 2020 Vision (Overview)
- Chapter 2: On the Threshold (Science)
- Chapter 3: Partnership in Astronomy and Astrophysics
- Chapter 4: Astronomy in Society
- Chapter 5: Sustaining the Core Research Program
- Chapter 6: Preparing for Tomorrow
- Chapter 7: Realizing the Opportunities (Decade Program)
- Appendixes:
    - Science Frontiers
    - Program Prioritization
    - Cost, Risk, and Technical Evaluation Process
    - Mid-Scale Projects

Science Frontier Panels

Planetary Systems and Star Formation (PSF) - Lee Hartmann

- **Solar system bodies (other than the Sun) and extrasolar planets, debris disks, exobiology, formation of individual stars, protostellar and protoplanetary disks, molecular clouds and the cold ISM, dust, and astrochemistry.**

Stars and Stellar Evolution (SSE) - Roger Chevalier

- **The Sun as a star, stellar astrophysics, structure and evolution of single and multiple stars, compact objects, supernovae, gamma-ray bursts and solar neutrinos. Extreme physics on stellar scales.**

The Galactic Neighborhood (GAN) - Mike Shull

- **Structure and properties of nearby galaxies including the Milky Way and their stellar populations, interstellar media, star clusters. Evolution of stellar populations.**

Galaxies across Cosmic Time (GCT) - Meg Urry

- **Formation and evolution of galaxies and galaxy clusters, active galactic nuclei and QSOs, mergers, star formation rate, gas accretion, global properties of galaxies and galaxy clusters, supermassive black holes.**

Cosmology and Fundamental Physics (CFP) - David Spergel

- **Early universe, microwave background, reionization and galaxy formation up to virialization of protogalaxies. Large scale structure, intergalactic medium, determination of cosmological parameters, dark matter, dark energy. High energy physics using astronomical messengers, tests of gravity, physical constants as determined astronomically.**

Infrastructure Study Groups

Computation, Simulation, & Data Handling (CDH) – Robert Hanisch & Lars Hernquist

- Computational resources and support for analysis and archiving of astronomical data; resources and support available for astrophysical and cosmological simulation; major challenges and changes in computing environments and software; expected availability of computing capability over the next decade.

Demographics (DEM) – James Ulvestad

- Numbers of astronomers and astrophysicists working in different environments and subfields; diversity, geography and student populations; breakdown of resource allocation by field, discipline and cost category where possible; subscription rates for programs; publication rates.

Facilities, Funding and Programs (FFP) – J. Craig Wheeler

- List major operational public and private facilities, their capabilities, ages, and proposal pressure; budgets for all agency programs; infrastructure issues such as support for laboratory astrophysics and technology development and theory.

International and Private Partnerships (IPP) – Robert Dickman

- Lessons learned; scope and current status of relevant major projects in development; summarize lessons learned to promote successful collaborations.

Education & Public Outreach (EPO) – Lucy Fortson & Chris Impey

- Public communication programs; astronomy in K-12 and college education; professional education for astronomers, journalists and science policy experts.

Astronomy & Public Policy (APP) – Daniel Lester

- Benefits to the nation that accrue from federal investment; contributions made to important research of societal importance; current structure of committees and reporting lines that are used to provide advice to the federal government.

Conclusions and Recommendations

Astronomers

- There is a widely-acknowledged urgency for increasing “STEM” education, and astronomy has a role to play
- Astronomy research provides technological “spin-offs” of benefit to the nation.
- Astronomy research and astronomers’ skills are well matched to many scientific and technical issues of strong current national importance.
- RECOMMENDATION: The astronomical community should encourage and support astronomers’ commitment to serve in science service/policy positions, on a rotator, fellowship, or permanent basis, at the relevant funding agencies—NSF, NASA, DOE—in Congress, at the Office of Management and Budget, or at the Office of Science and Technology Policy.

Astronomers

- Minorities and women are under-represented in astronomy compared with the general population, and efforts to increase their numbers and percentages must be continued.
- There is much concern among early career astronomers as to their long term professional career opportunities
- There is corresponding uncertainty in the number and range of opportunities over the coming decade.
- An astronomical education is demonstrably a gateway to success in many other careers
- RECOMMENDATION: The American Astronomical Society and the American Physical Society, alongside the nation's astronomy and astrophysics departments, should make both undergraduate and graduate students aware of the wide variety of rewarding career opportunities enabled by their education, and be supportive of students' career decisions that go beyond academia. These groups should work with the federal agencies to gather and disseminate demographic data on astronomers in the workforce to inform students' career decisions.

Theory, Computation

- Many theoretical and computational investigations have become too large for individual investigator grants.
- **RECOMMENDATION**: A new program of Research Networks in Theoretical and Computational Astrophysics should be funded by DOE, NASA, and NSF. The program would support research in six to eight focus areas that cover major theoretical questions raised by the survey Science Frontier Panels.

Computation, Data

- The relative importance of data management in major observational facilities is growing and it must be included from the start in proposing major new activities
- **RECOMMENDATION**: Proposals for new major ground-based facilities and instruments with significant federal funding should be required as a matter of agency policy to include a plan and if necessary a budget for ensuring appropriate data acquisition, processing, archiving, and public access after a suitable proprietary period.

- There is a related need, particularly at ground-based facilities, for the efficient and selective curation of astronomical data that will allow the full scientific benefit to be harvested from these facilities
- RECOMMENDATION: NSF, NASA, and DOE should plan for effective long-term curation of, and access to, large astronomical data sets after completion of the missions or projects that produced these data, given the likely future scientific benefit of the data. NASA currently supports widely used curated data archives, and similar data curation models could be adopted by NSF and DOE.

Laboratory Astrophysics

- There is a growing need for laboratory astrophysics investigations across a broad suite of proposed new activities and increased funds will be needed to support existing programs and grow appropriate new programs

- RECOMMENDATION: NASA and NSF support for laboratory astrophysics under the Astronomy and Physics Research and Analysis and the Astronomy and Astrophysics Research Grants programs, respectively, should continue at current or higher levels over the coming decade because these programs are vital for optimizing the scientific return from current and planned facilities. Missions and facilities, including DOE projects, that will require significant amounts of new laboratory data to reach their science goals should include within their program budgets adequate funding for the necessary experimental and theoretical investigations.

International Matters

- Astronomy is more collaborative, international and interdisciplinary than ever. Most major facilities and spacecraft are multi-national and/or public/private

- Principle of open skies is compatible with maximizing scientific output

- RECOMMENDATION: U.S. investors in astronomy and astrophysics, both public and private, should consider a wide range of approaches to realize participation in international projects and to provide access for the U.S. astronomy and astrophysics community to a larger suite of facilities than can be supported within the United States. The long-term goal should be to maximize the scientific output from major astronomical facilities throughout the world, a goal that is best achieved through opening access to all astronomers.

International Matters

- Globalization of astronomy mandates streamlined strategic planning
- The practical step is to formalize the coordination and sharing of regional strategic plans at the highest level
- RECOMMENDATION: Approximately every 5 years the international science community should come together in a forum to share scientific directions and strategic plans, and to look for opportunities for further collaboration and cooperation, especially on large projects.

Stewardship of the Survey

- Several recommendations in this report are conditional upon technical developments, outcomes of scientific observing programs and decisions taken by international and private partners over the next five years.

- It is imperative that the agencies receive the best independent strategic advice in a timely manner to assess progress toward the recommended goals and to make deferred choices

- RECOMMENDATION: NASA, NSF, and DOE should on a regular basis request advice from an independent standing committee constituted to monitor progress toward reaching the goals recommended in the decadal survey of astronomy and astrophysics, and to provide strategic advice to the agencies over the decade of implementation. Such a Decadal Survey Implementation Advisory Committee (DSIAC) should be charged to produce annual reports to the agencies, the Office of Management and Budget, and the Office of Science and Technology Policy, as well as a mid-decade review of the progress made. The implementation advisory committee should be independent of the agencies and the agency advisory committees in its membership, management, and operation.

Developing a Program for a Decade and Beyond

Optimizing the Recommended Program

- Prioritizing based on science objectives
- Building upon existing astronomical enterprise
- Considering that started projects from previous decadal surveys have schedule slips and cost escalations
- Evaluating cost risk and technical readiness
- Maximizing scientific return under highly constrained budget guidelines
- Choosing most urgently needed activities from long list of compelling ideas and concepts
- Considering international and private partnerships

Balancing the Program

- Large *and* small/medium activities
- Existing *and* new facilities
- Known science objectives *and* discovery space
- Promise *vs.* risk
- Ground *and* Space
- 2020 *and* 2030

Program Prioritization Panels

Radio, Millimeter and Submillimeter from the Ground (RMS) - Neal Evans

- Observatories and telescopes that observe primarily in these wavebands

Optical and Infrared Astronomy from the Ground (OIR) - Pat Osmer

- Observatories and telescopes that observe primarily in these wavebands

Electromagnetic Observations from Space (EOS) - Alan Dressler

- All space-based astronomical projects observing the electromagnetic spectrum.

Particle Astrophysics and Gravitation (PAG) - Jackie Hewitt

- All projects exploring areas at the interface of physics and astronomy such as gravitational radiation, TeV gamma-ray astronomy, and free-flying space missions testing fundamental gravitational physics.

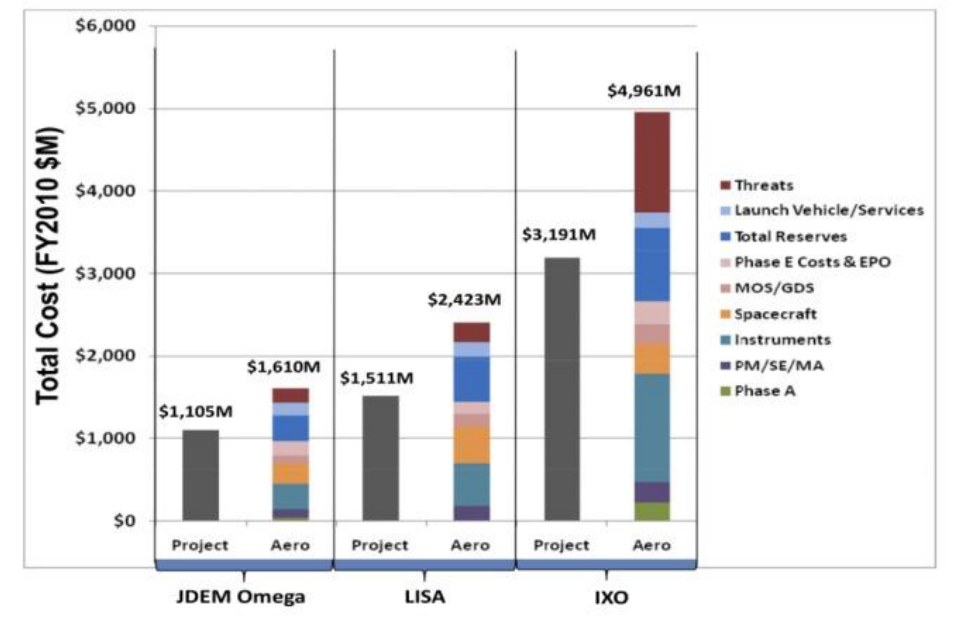
Cost, Risk, and Technical Evaluation

- Is:
  - Based on detailed project input
  - Application of uniform and historical data-informed risk analysis
  - Independent appraisal of project budget, schedule and technical risk
  - Considerate of a wide range of maturity in the concepts with respect to total life cycle, including “pre-Phase A” and designed to be fair and neutral
  - Projection through the decade considering potential cost/schedule growth
  - Probabilistic assessment of required reserves and identification of cost/ schedule liens and threats
  - Generation of a 70% confidence cost appraisal
  - Input to the committee and program prioritization panels

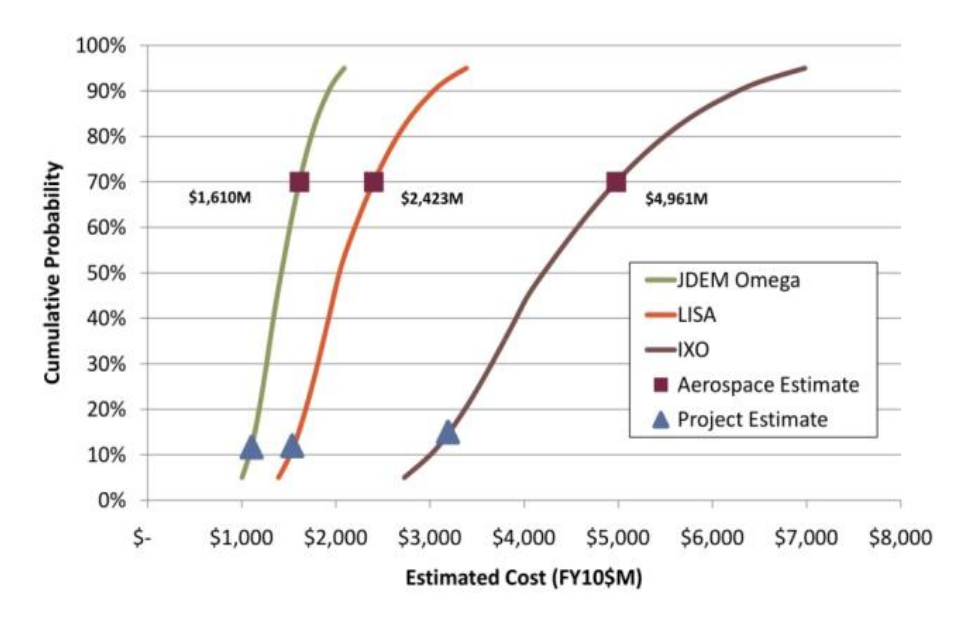
- Is Not:
  - A bottoms-up costing exercise
  - A traditional non-advocate ICE (Independent Cost Evaluation) or TMC (Technical, Management, Cost) process which generally occur later in project lifecycles.

Cost, Risk, and Technical Evaluation

- Early call for Notices of Intent followed by open Request for Information
  - Activities selected by PPPs and committee for a 2nd Request for Information



- Subset selected by PPPs and committee for CATE review
  - Independent cost appraisals
  - Evaluations of technical readiness schedule and risk assessment



Recommended Program

- Space and Ground Activities
- Cost/Size Scales
  - Large, Medium: prioritized
  - Small: unprioritized
- Scientific and Programmatic Synergies

Large Scale Space Program - Prioritized

1. Wide Field InfraRed Survey Telescope (WFIRST)
2. Explorer Program Augmentation
3. Laser Interferometer Space Antenna (LISA)
4. International X-ray Observatory (IXO)

Large Scale Space Program - Prioritized

1. Wide Field InfraRed Survey Telescope (WFIRST)
   - *dark energy, exoplanet statistics, general surveys*
2. Explorer Program Augmentation
   - *versatile, rapid, targeted, competed space science*
3. Laser Interferometer Space Antenna (LISA)
   - *black holes, ultracompact objects, general relativity*
4. International X-ray Observatory (IXO)
   - *galaxy clusters, intergalactic medium, black hole accretion disks*

Medium-Scale Space Program - Prioritized

1. New Worlds Technology Development Program

2. Inflation Technology Development Program

Large-scale Ground-based Program - Prioritized

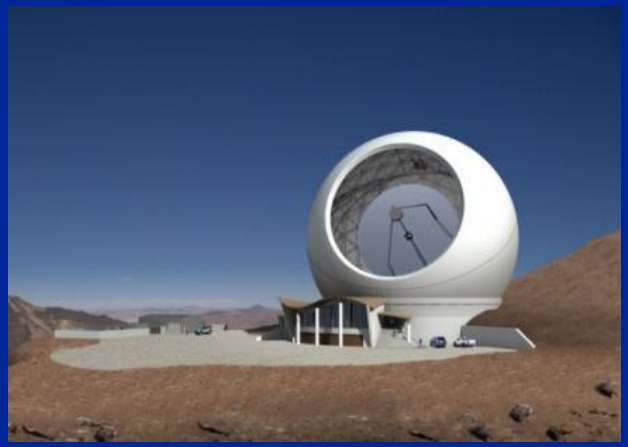
1. Large Synoptic Survey Telescope (LSST)
2. Mid-Scale Innovations Program
3. Giant Segmented Mirror Telescope (GSMT)
4. Atmospheric Cerenkov Telescope Array (ACTA)

Large-scale Ground-based Program - Prioritized

1. Large Synoptic Survey Telescope (LSST)
   - *variable optical universe, dark energy, dark matter, solar system, solar neighborhood, transient objects*
2. Mid-Scale Innovations Program
   - *competed program in $4-135M funding gap*
3. Giant Segmented Mirror Telescope (GSMT)
   - *transformational optical/infrared facility for broad science*
4. Atmospheric Cerenkov Telescope Array (ACTA)
   - *black holes, snr, dark matter, pulsars, binary stars*

Medium-scale Ground-based Program

1. Cerro Chajnantor Atacama Telescope (CCAT)



CCAT

- Kick-off example of Mid Scale Innovations Program
- 25m wide-field submillimeter survey telescope in Chile
- Work in conjunction with ALMA
- **RECOMMEND NSF to be one-third partner**
- Total appraised cost $140M; annual operations $11M
- Needs immediate start to be ready for ALMA
- Estimated completion date 2020; Medium risk

Small-scale Program (Ground and Space – not prioritized)

Program Augmentation	Agency
Advanced Technologies and Instrumentation	NSF
Astronomy and Astrophysics Grants (including Lab. Astro.)	NSF
Astrophysics Theory Program	NASA
Intermediate Technology Development	NASA
Laboratory Astrophysics	NASA
Sub-orbital Program	NASA
Telescope System Instrument Program	NSF

New Initiatives	Agency
Development of future UV-optical space capability	NASA
Leadership in Gemini international partnership (increment)	NSF
Participation in JAXA's SPICA mission	NASA
Theory and Computation Networks	NASA, NSF, DOE

Small-scale Investments

- Target work-force development
  (TSIP, Sub-orbital, AAG, ATP)
- Address changing role of computation and theory
  (TCN)
- Support current/upcoming facilities
  (Gemini, Lab Astro, TCN)
- Develop technology for future
  (NSF ATI, NASA Tech. Dev.)

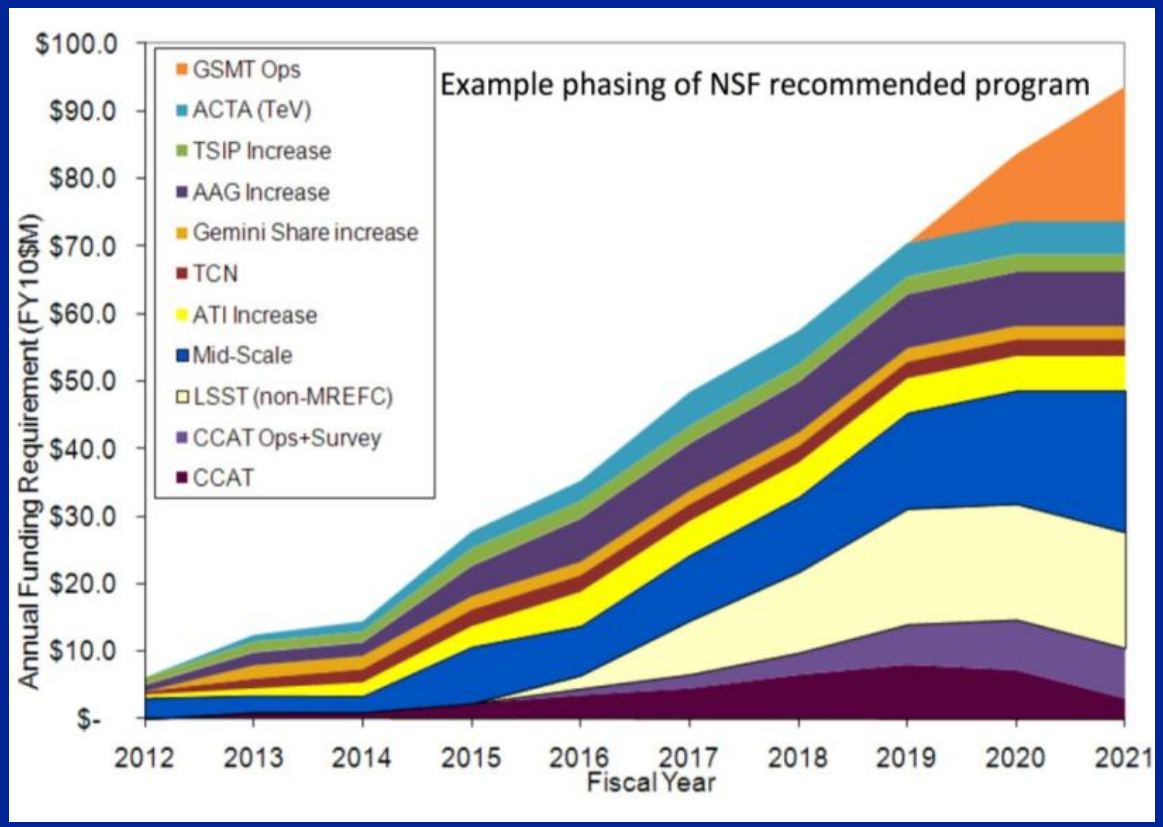
Agency-specific Recommendations

Budgetary Context

- Agency Guidelines
  - NSF and DOE – constant budgets in fixed dollars ($FY2010)
  - NASA – constant real year dollars (declining budget in $FY2010)
- Survey Budgets (the optimistic scenario)
  - NSF and DOE – “doubling” = 4% per year growth in $FY2010
  - NASA – constant in $FY2010 dollars
- Notional “sand charts”
  - Exhibit possible spending profiles consistent with committee budgets and the recommended program, i.e. phasing
  - Allowed the committee to examine possible programmatic scenarios
  - Provide advice in less optimistic budget scenarios

NSF

- Program dependent upon MREFC
  - early entry of LSST
  - followed by GSMT



- In event NSF budget is as projected by agency, there can be no new starts without closure of major facilities following senior review
- If moderate budget increase
  - First priority is small program (including time-critical Gemini augmentation), Mid-scale Innovations program, and starting LSST operations.
  - Second priority is GSMT operations, and starting ACTA

AST Senior Review

- Pressure on the NSF-AST budget necessitates balancing the cost of operating new facilities such as ALMA, ATST, LSST, GSMT against the support of still very productive existing facilities

- RECOMMENDATION: NSF-Astronomy should complete its next senior review before the mid-decade independent review that is recommended elsewhere in this report, so as to determine which, if any, facilities NSF-AST should cease to support in order to release funds for (1) the construction and ongoing operation of new telescopes and instruments, and (2) the science analysis needed to capitalize on the results from existing and future facilities.

NOAO and Gemini

- The Gemini telescopes are now poised to start delivering the level of scientific accomplishment from the U.S. community that they were built to enable.
- The withdrawal of the U.K. from the Gemini partnership will likely require an immediate increase in support for Gemini
- This transition provides an ideal opportunity for an in-depth examination of the way that Gemini is managed and operated
- RECOMMENDATION: To exploit the opportunity for improved partnership between federal, private, and international components of the optical and infrared system, NSF should explore the feasibility of restructuring the management and operations of Gemini and acquiring an increased share of the observing time. It should consider consolidating the National Optical Astronomy Observatory and Gemini under a single operational structure, both to maximize cost-effectiveness and to be more responsive to the needs of the U.S. astronomical community.
- It is expected that Gemini will be considered by the next Senior Review

Solar Astronomy

- The onset of the ATST era and the growing importance of understanding solar –terrestrial relationships prompts a serious re-examination of the manner in which ground-based solar astronomy is organized and managed by the NSF

- RECOMMENDATION: The NSF should work with the solar, heliospheric, stellar, planetary, and geospace communities to determine the best route to an effective and balanced ground-based solar astronomy program that maintains multidisciplinary ties. Such coordination will be essential in developing funding models for the long-term operation of major solar facilities such as the Advanced Technology Solar Telescope and Frequency-Agile Solar Radiotelescope, and in the development of next-generation instrumentation for them along with the funding of associated theory, modeling, and simulation science.

Radio Astronomy & SKA

- The future opportunities, worldwide, in radio-millimeter-submillimeter astronomy are considerable, but U.S. participation in projects such as the Square Kilometer Array is possible only if there is either a significant increase in NSF-AST funding or continuing closure of additional unique and highly productive facilities.

- Square Kilometer Array (SKA) is a major international collaboration which has very strong scientific support within the U.S. However, no conceivable NSF budget will allow a significant U.S. participation this decade. Consequently, it is recommended that SKA precursors be supported and SKA be re-examined by the next decadal survey.

Summary

- This is an extraordinary time in the study of the cosmos, but also a time of serious constraints on federal discretionary budgets.
- The recommended program is science-driven and will enable progress across a large swath of research and open up more discovery space.
- A balanced program should be maintained throughout the decade. Effective international, public-private and inter-agency collaboration is required for success of the program.
- A serious effort has been made to appraise activity cost, risk and technical readiness.
- Mid-decade decisions should be made based on recommendations from an independent, strategic advisory committee.
- Astro2010 has had unprecedented involvement and support by the astronomical community and immense effort by the committee, panels and consultants, as well as the strong cooperation of the agencies and professional societies.

Reports available at www.nationalacademies.org/astro2010

FY 12 Request

NASA Astrophysics

- Down 3% overall relative to FY10.
- JWST separated out and remaining but astrophysics portion up 6%.
- Compare to other SMD divisions earth sciences (up 25%), planetary (up 13%) and heliophysics (up 2%) and NASA as a whole (flat).

NSF Astronomy

- Up 1.4%.
- Compare to 6% for MPS and 13% for NSF as a whole.

DOE Office of Science

- Up 9%.

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