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

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 …..

Astro2010 Committee

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Michael S. Turner, The University of Chicago
Paul Adrian Vanden Bout, National Radio Astronomy Observatory
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Astro2010

Charge led to

- Significant community engagement

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

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- Science First

Science Frontier Panels

- **Planetary Systems and Star Formation (PSF)**
- **Stars and Stellar Evolution (SSE)**
- **The Galactic Neighborhood (GAN)**
- **Galaxies across Cosmic Time (GCT)**
- **Cosmology and Fundamental Physics (CFP)**

The Science Frontier
discovery areas and principal questions

Discovery areas:

- Identification and characterization of nearby habitable exoplanets
- Gravitational wave astronomy
- Time-domain astronomy
- Astrometry
- The epoch of reionization

Questions:

- How did the universe begin?
- What were the first objects to light up the universe and when did they do it?
- How do cosmic structures form and evolve?
- What are the connections between dark and luminous matter?
- What is the fossil record of galaxy assembly and evolution from the first stars to the present?
- How do stars and black holes form?
- How do circumstellar disks evolve and form planetary systems?
- How do baryons cycle in and out of galaxies and what do they do while they are there?
- What are the flows of matter and energy in the circumgalactic medium?
- What controls the mass-energy-chemical cycles within galaxies?
- How do black holes work and influence their surroundings?
- How do rotation and magnetic fields affect stars?
- How do massive stars end their lives?
- What are the progenitors of Type Ia supernovae and how do they explode?
- How diverse are planetary systems and can we identify the telltale signs of life on an exoplanet?
- Why is the universe accelerating?
- What is dark matter?
- What are the properties of the neutrinos?
- What controls the masses, spins and radii of compact stellar remnants?

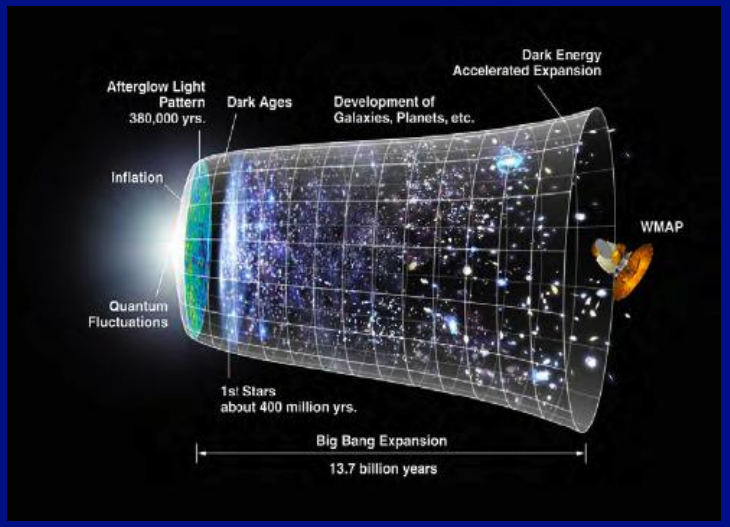
Science Objectives

- Building on the science priorities identified by the survey, the recommended program is organized by three science objectives that represent its scope:
  - Cosmic Dawn
  - New Worlds
  - Physics of the Universe

- Success in attaining these science goals will enable progress on a much broader front
- Also foster unanticipated discoveries

Cosmic Dawn

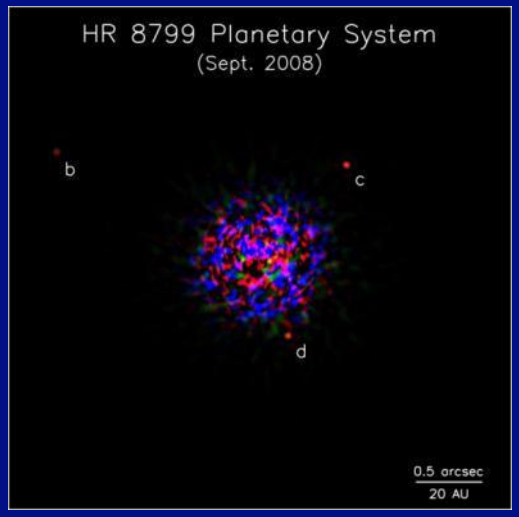
Searching for the first stars, galaxies, and black holes



- We have learned much about the history of the universe, from the Big Bang to today
- A great mystery now confronts us: when and how the first galaxies formed and the earliest stars started to shine - our cosmic dawn
- JWST, ALMA and radio telescopes already under construction will help point the way
- Approaches:
  - Locating “reionization” – finding the epoch ~0.5 billion years, when light from the first stars split interstellar hydrogen atoms into protons and electrons
  - “Cosmic paleontology” – finding the rare stars with the lowest concentrations of heavy elements

New Worlds

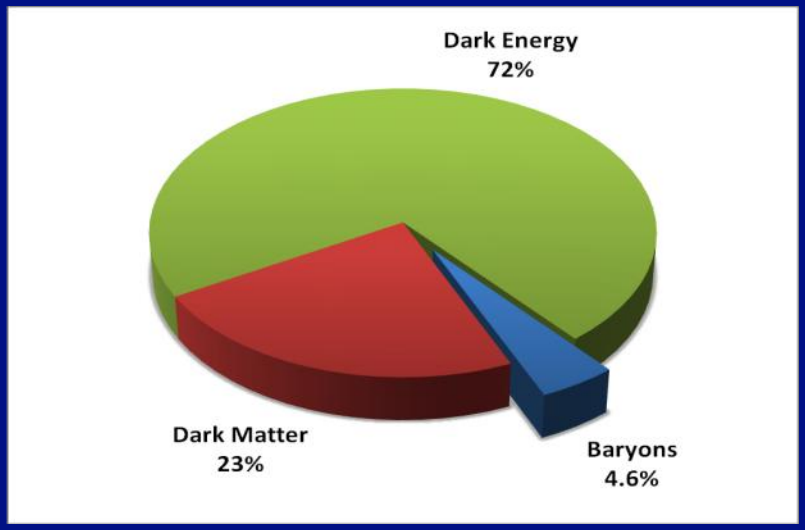
Seeking nearby, habitable planets



- Nearly 500 extrasolar planets now detected - extraordinarily rapid progress
  - Huge range of properties exhibited, surprisingly different from those in our own solar system
  - Many ongoing approaches seek new “Earths” – potentially habitable rocky planets with liquid water and oxygen
  - New techniques being developed
- Kepler data adds over 300 "candidates" to the list, including many less than twice the size of Earth
- Next great step forward: understand frequency of different types of planets and lay scientific and technical groundwork to inform future strategies for detailed study of nearby Earth-like planets

Physics of the Universe

Understanding Scientific Principles



- Determine properties of dark energy, responsible for perplexing acceleration of present-day universe
- Reveal nature of mysterious dark matter, likely composed of new types of elementary particles
- Explore epoch of inflation, earliest instants when seeds of structure in the universe were sown
- Test Einstein's general theory of relativity in new important ways by observing black hole systems and detecting mergers

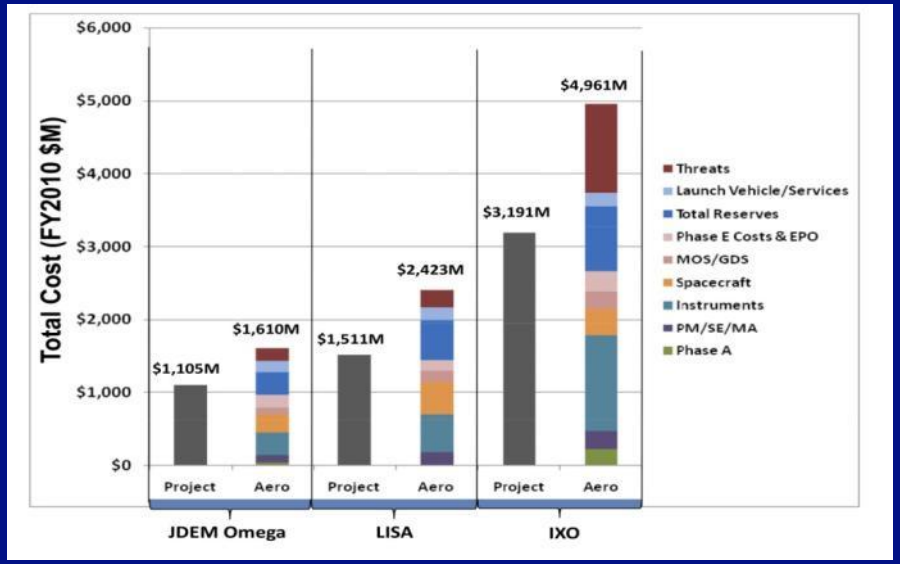
Astro2010

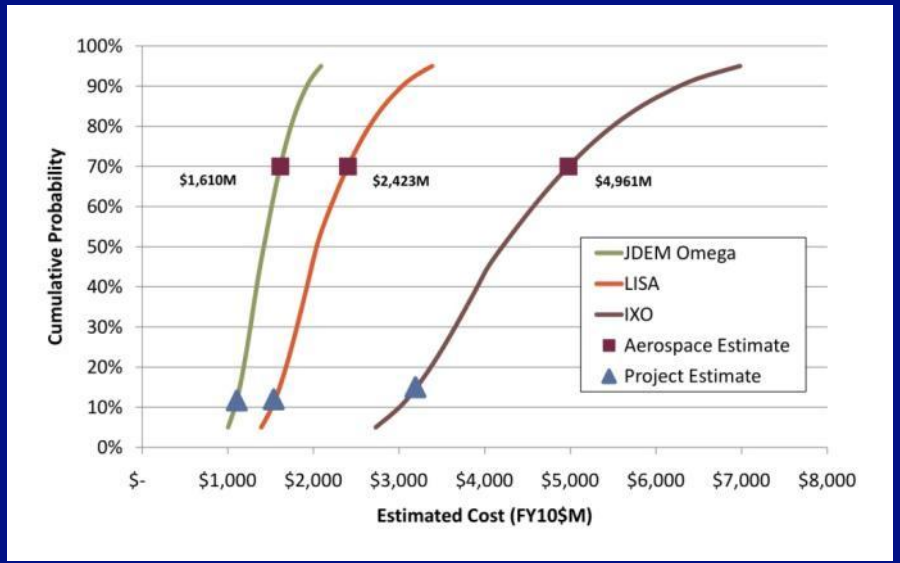
Charge led to

- Significant community engagement
- Science First
- Independent analysis of risk, technical readiness, schedule, and life cycle costs.

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





Program Prioritization Panels

- **Radio, Millimeter and Submillimeter from the Ground (RMS)**
- **Optical and Infrared Astronomy from the Ground (OIR)**
- **Electromagnetic Observations from Space (EOS)**
- **Particle Astrophysics and Gravitation (PAG)**

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

Large Scale Space Program - Prioritized

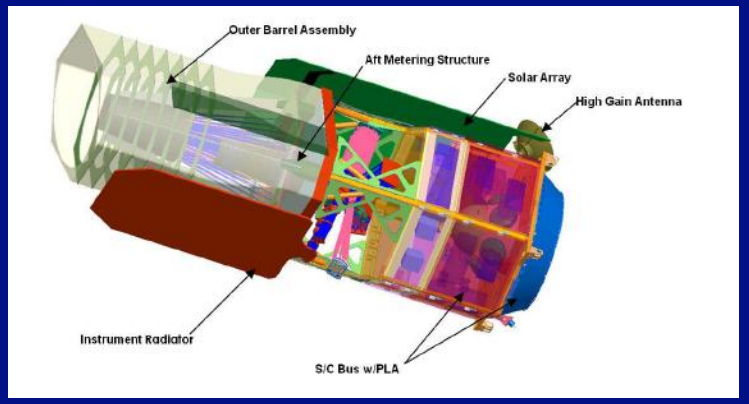
1. Wide Field InfraRed Survey Telescope (WFIRST)

1. Explorer Program Augmentation

2. Laser Interferometer Space Antenna (LISA)

3. International X-ray Observatory (IXO)

WFIRST - Science

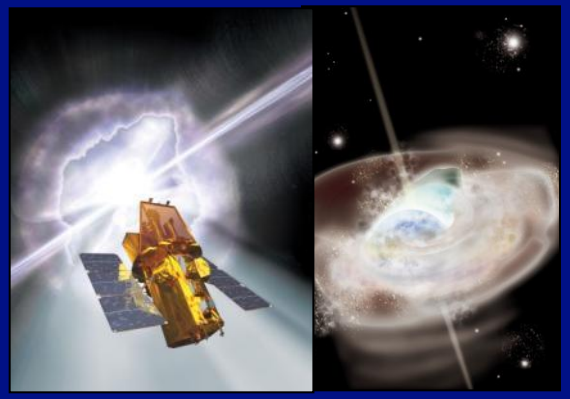


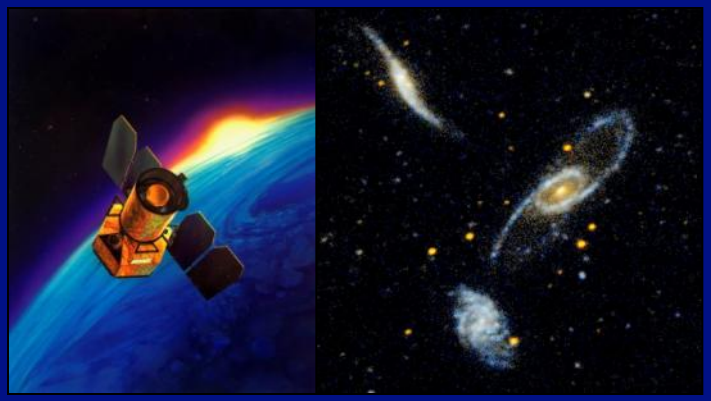
Near infrared wide-field telescope with a *set* of key science objectives:

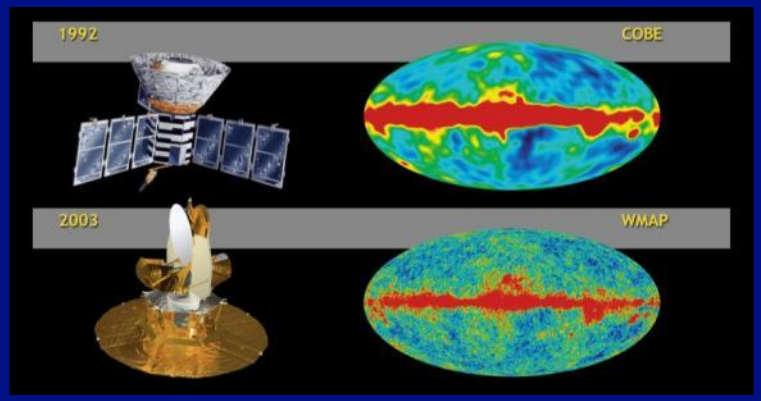
- Dark energy (part of a coherent ground-space strategy):
  - Baryon acoustic oscillations
  - Distant supernovae
  - Weak lensing
- Exoplanet statistics
  - Gravitational microlensing
- Guest investigator mode enabling survey investigations

Explorer Program - Science

- Rapid, targeted, competed investigations
- Versatile program delivers high scientific return
- WMAP, Swift, GALEX, WISE… are extraordinarily successful past examples
- NuSTAR, GEMS, Astro-H very promising







Medium-Scale Space Program - Prioritized

1. New Worlds Technology Development Program

2. Inflation Technology Development Program

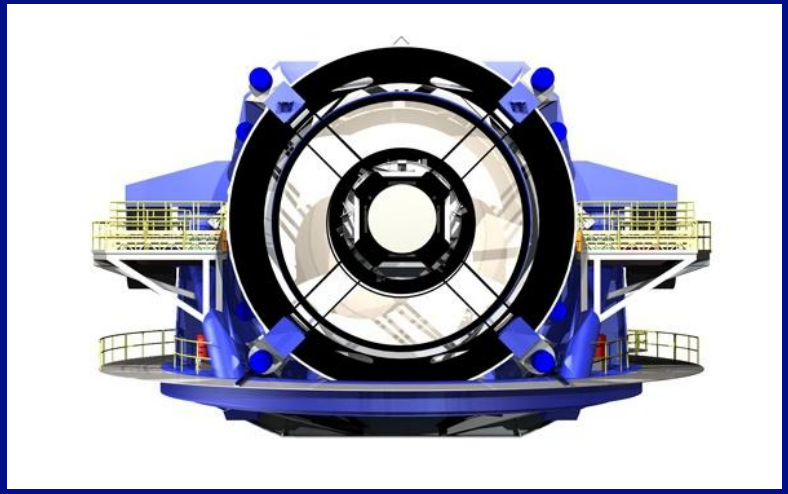
Inflation Technology Development Program

- Ground-based microwave background telescopes seek "B-mode polarization," sensitive signature of processes from epoch of inflation, thought to have occurred during earliest moments of the universe
- If signal is seen from ground then space-based mission with at least ten times greater sensitivity is warranted and associated technology development is needed
- **RECOMMEND $60-200M over decade, conditional on signal detection**

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)

LSST- Science



- Efficient, deep optical survey telescope
- Will transform observation of the variable universe and address broad questions:
  - Dark energy using gravitational lensing and supernovae
  - Dark matter
  - Near-Earth, Kuiper-belt objects
  - Solar neighborhood
  - Transient phenomena
    - Gamma-ray bursts, Variable stars, Supernovae…
- Publicly accessible archive – >100 Pbyte

LSST – Program Details

- 8.4 m diameter telescope located in Chile
- 3.5 degree field of view -- Observe half sky every four days using six filters from 0.3-1μm
- NSF-DOE partnership with private and international contributions
- Total appraised cost $465M; Annual operation $42M
- Medium/Low risk excepting data management and archive software
- **RECOMMEND entry into MREFC line as soon as possible**
- Ten year lifetime, followed by Senior Review

Mid-Scale Innovations Program – Overview

- Large number of exciting and viable projects addressing survey goals are in ~$10-$100M range
- **RECOMMEND creation of competed program at NSF that will meet this need, like NASA Explorer program**

Medium-scale Ground-based Program

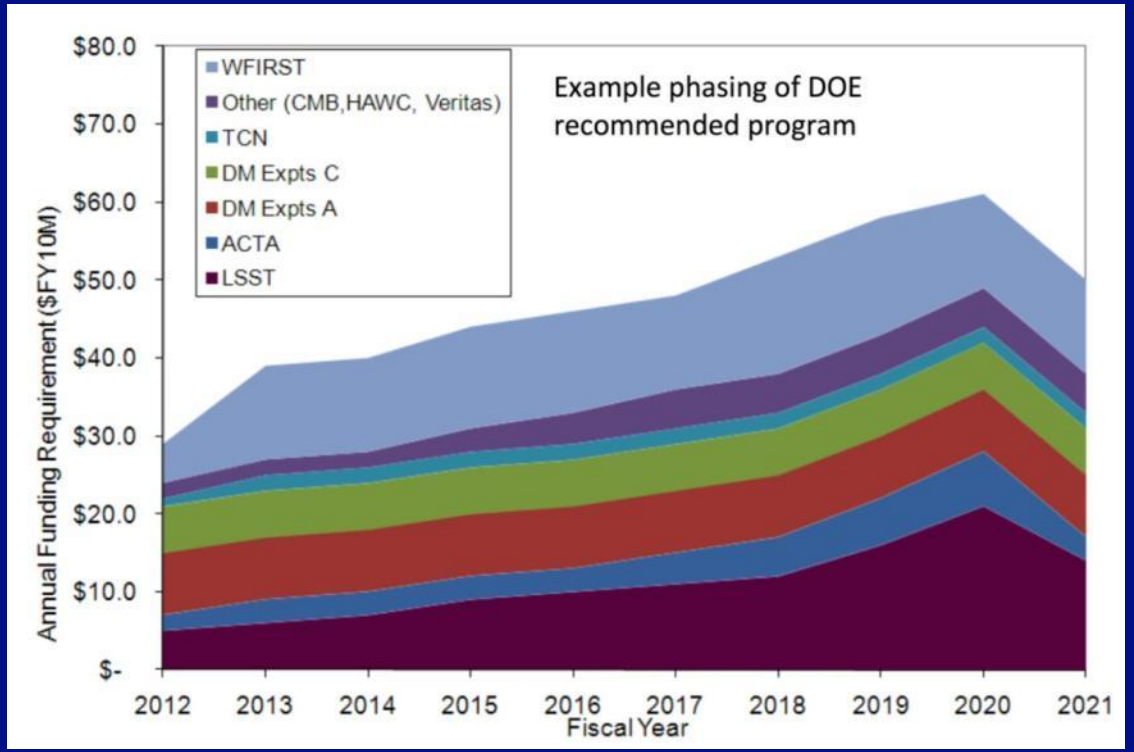
1. Cerro Chajnantor Atacama Telescope (CCAT)

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

DOE

- Survey's budget scenario allows investment in
  - LSST
  - WFIRST
  - other PASAG recommendations.



- In lower budget scenarios, DOE participation in LSST is recommended ahead of WFIRST as contribution relatively larger and technical role relatively more critical

- Small-scale program and ACTA have lower priority

Other Recommendations & Conclusions

- International Matters: collaboration, coordination; open skies
- Stewardship of the Survey: independent, strategic advisory group
- Benefits to the Nation: STEM literacy; technology spin-offs; citizen science
- Astronomers: career mentoring; demographics; public policy
- Computation and Data: archive and curate data
- Laboratory Astrophysics: support at current or higher levels
- NSF/AST Senior Review: conduct early in decade
- NOAO and Gemini: explore management and operations consolidation
- Solar Astronomy: maintain multidisciplinary ties
- Radio Astronomy: SKA pathfinder opportunities

Infrastructure Study Groups

- **Computation, Simulation, & Data Handling (CDH)**
- **Demographics (DEM)**
- **Facilities, Funding and Programs (FFP)**
- **International and Private Partnerships (IPP)**
- **Education & Public Outreach (EPO)**
- **Astronomy & Public Policy (APP)**

Computation and 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.

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.

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.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NRC Panel on Implementing NWNH

- Commissioned by OSTP
- Implement Astro2010 in effective and timely manner
  - Changes in NASA budgetary outlook
  - Status of NASA's implementatino of WFIRST
  - Status of ESA-Euclid including partnership
  - Synergies and complementarities
- Outline pros and cons
- Workshop 7 Nov
- Letter report ~ 5 Dec