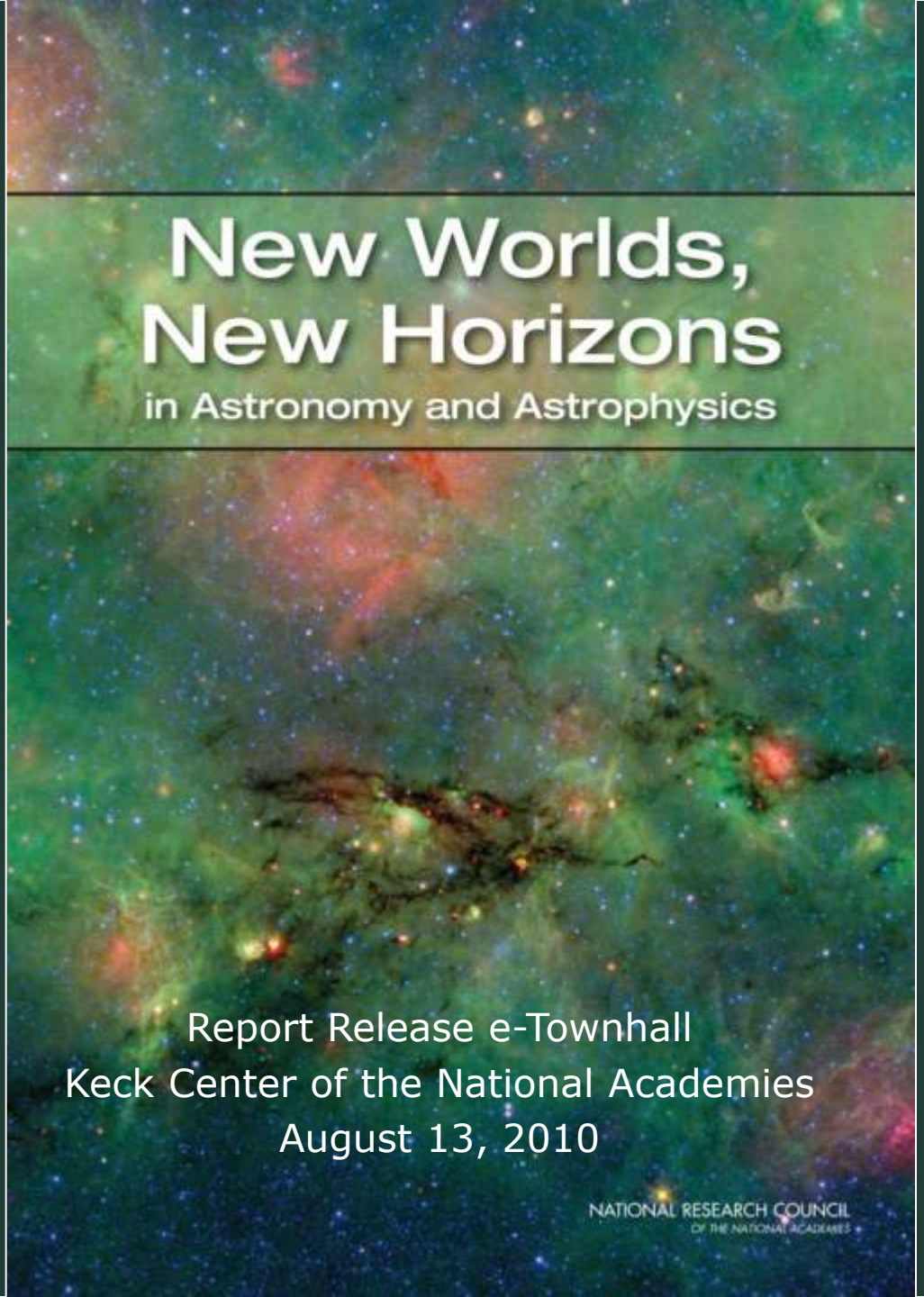
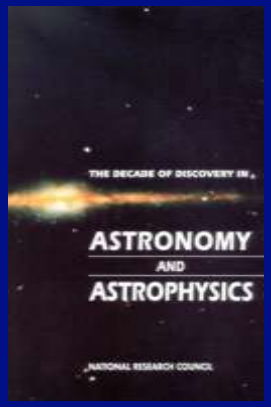

New Worlds,
New Horizons
in Astronomy and Astrophysics
Report Release e-Townhall
Keck Center of the National Academies
August 13, 2010
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES



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

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

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

Charge led to

- Significant community engagement
- Science First
- Independent analysis of risk, technical readiness, schedule, and life cycle costs.
- Recommended program under different budgetary scenarios
- Consideration of unstarted projects from previous surveys - no “grandfathering”

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

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)**

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?

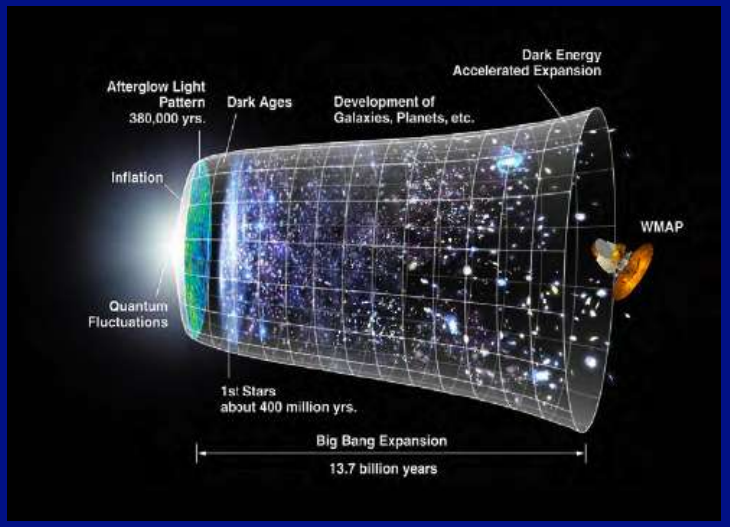
Science Objectives

- 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

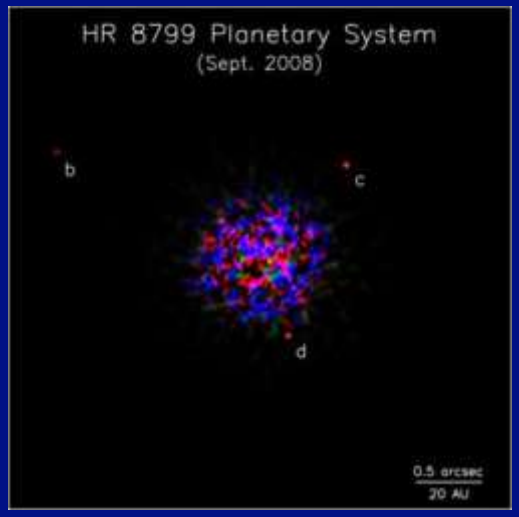
Searching for the first stars, galaxies, and black holes



- 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

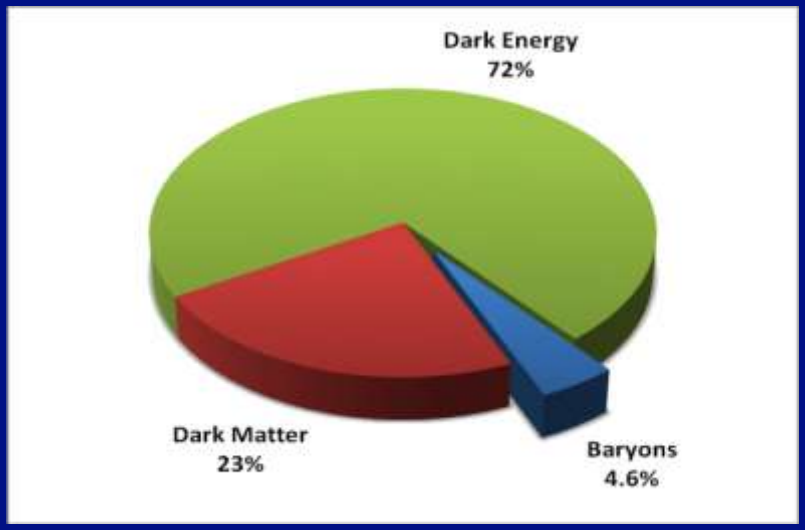
Seeking nearby, habitable planets



- 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

Developing a Program for a Decade and Beyond

Optimizing the Recommended Program

- Prioritizing based on science objectives
- Building upon existing astronomical enterprise
- 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

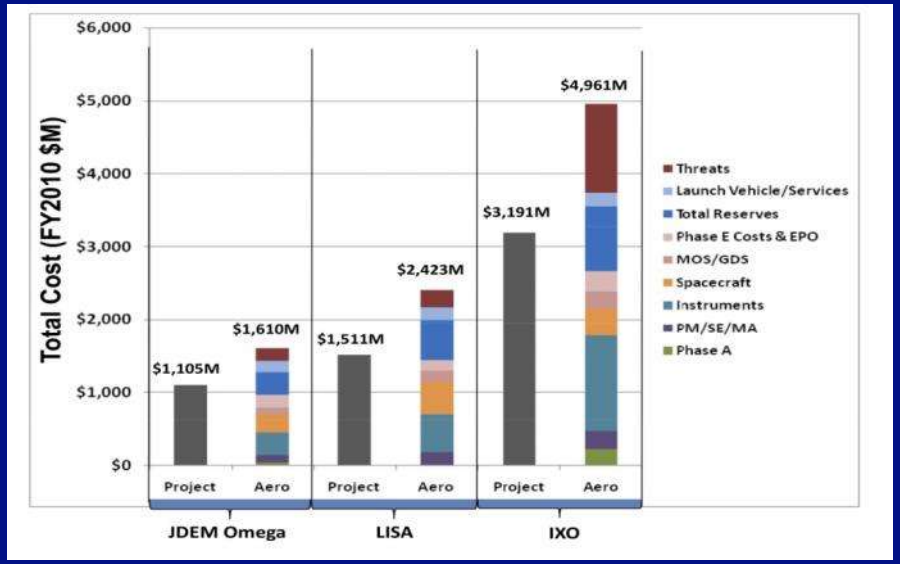
- Large *and* small/medium activities
- Existing *and* new facilities
- Known science objectives *and* discovery space
- Promise *vs.* risk
- Ground *and* Space
- 2020 *and* 2030

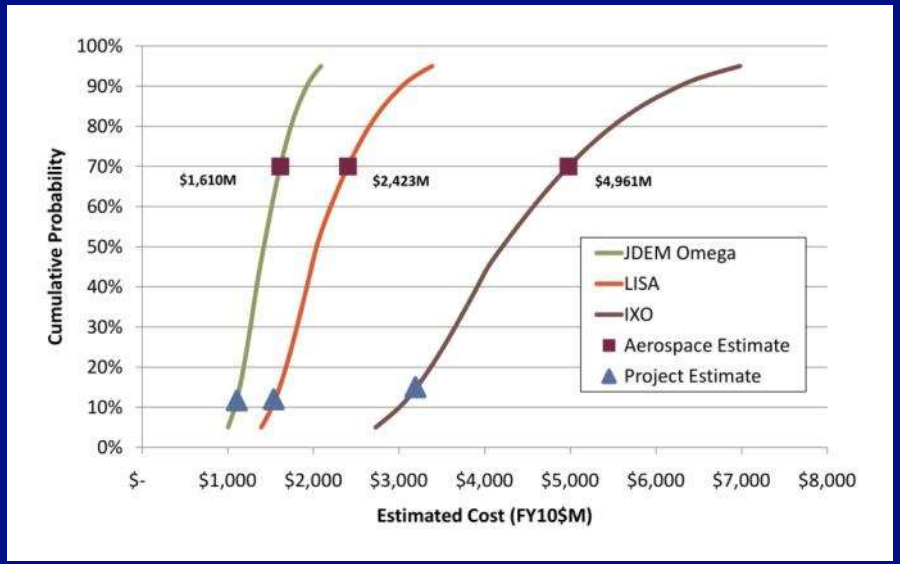
Program Prioritization Panels

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

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





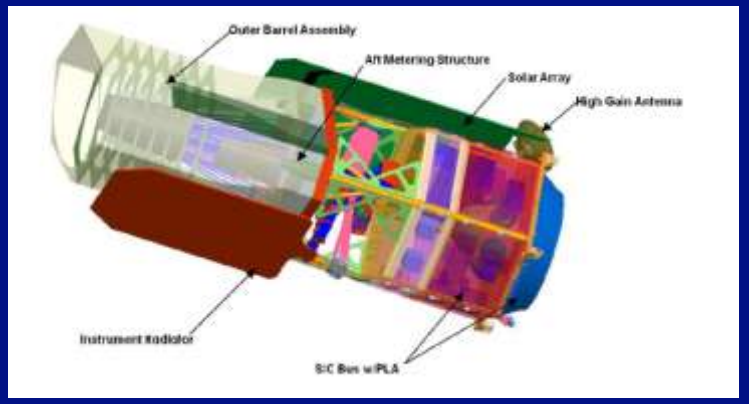
Recommended Program

- 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)

WFIRST - Science



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

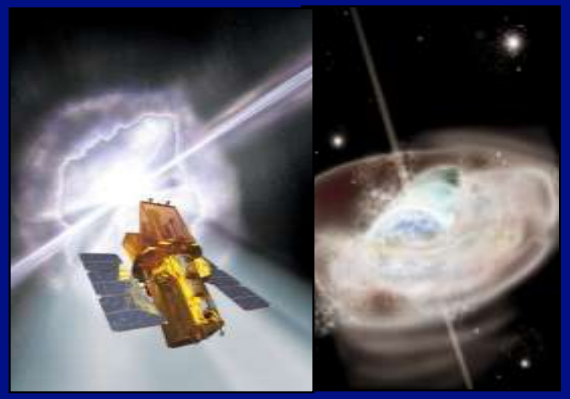
- Dark energy (part of a coherent ground-space strategy):
  - Baryon acoustic oscillations
  - Distant supernovae
  - Weak lensing
- Exoplanet statistics
  - Gravitational microlensing
- Guest investigator mode enabling survey investigations

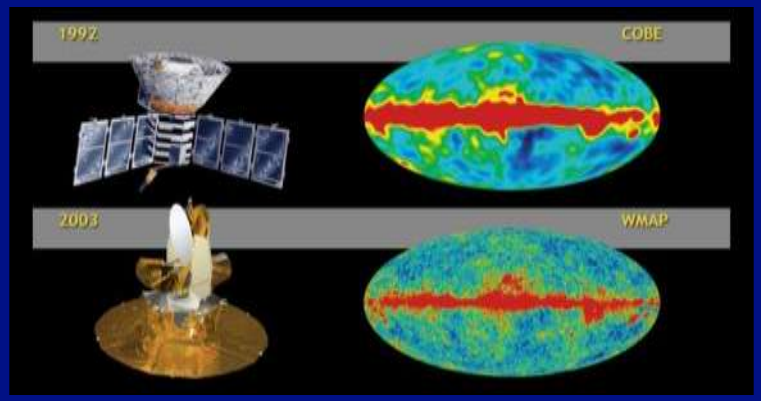
WFIRST – Program Details

- Several RFI concepts for dark energy, IR survey, or exoplanet science promoted similar telescope designs
- All 3 WFIRST science goals are possible employing JDEM-Omega hardware:
  - 1.5m; 144MPx HgCdTe detectors, 200mas, grism; L2
- Start 2013, launch 2020; total appraised cost $1.6B, Medium/Low risk
- Possible collaboration with ESA but U.S. should negotiate with a view to playing a leading role
  - Euclid competing for M-class mission (with PLATO, Solar Probe)
- Key element of the ground & space programs in both dark energy and exoplanets

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





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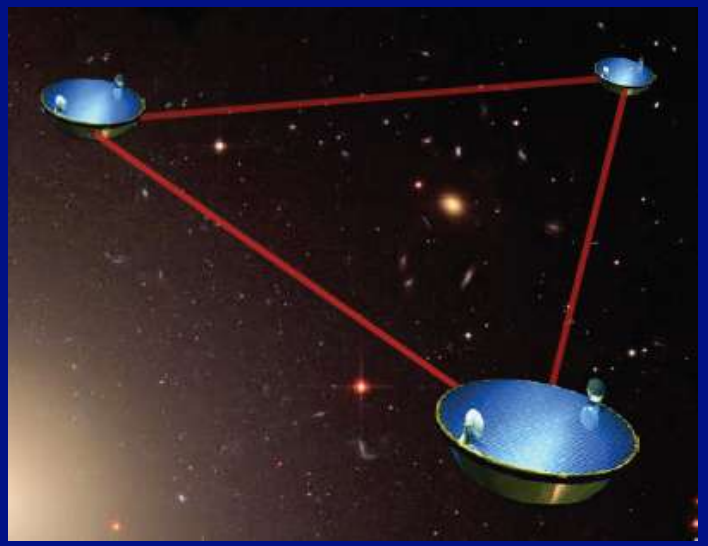
Explorer Augmentation – Program Details

- In past, program reduced to pay for costs of major NASA activities
- **RECOMMEND Restoration of Explorer line to enable astrophysics launch rates originally envisaged**
- Proposed increase from $40M to $100M per year for astrophysics missions -- Low risk
- Support two new MidScale (MIDEX), two new Small (SMEX) Explorers, and at least four Missions of Opportunity (MoO) over decade
- Essential to maintaining breadth and vitality of space astrophysics program

LISA - Science

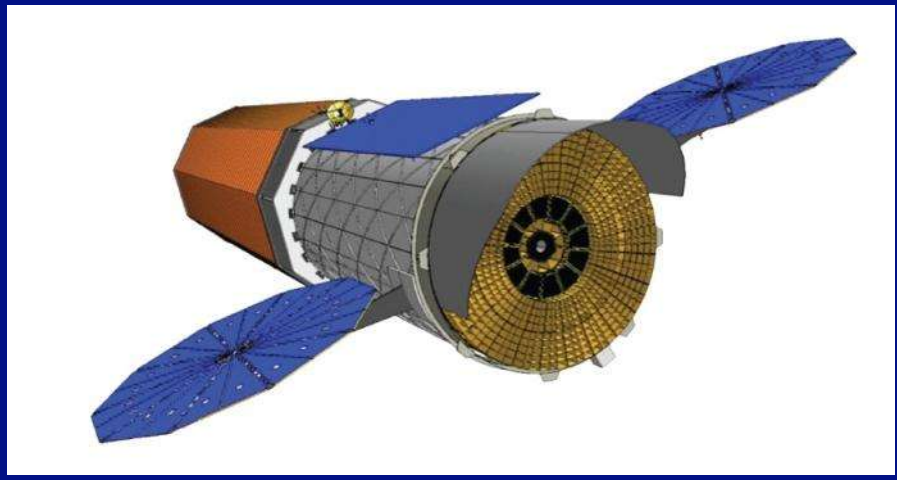


- Exploiting a new field of astronomy using long wavelength gravitational radiation – ripples in spacetime – to observe:
  - Inspirals and mergers of binary black holes to cosmological distances, back to Cosmic Dawn; measure black hole masses, spins
  - Large numbers of ultra-compact binary stars in our galaxy
- Precision tests of general relativity
- Possible detection of spacetime ripples from the very early universe
- The unexpected

LISA – Program Details

- Three spacecraft 5 million km apart in Earth-trailing orbit
- ESA-NASA partnership:
  - Candidate for ESA L-class launch (with IXO, Laplace)
  - LISA Pathfinder mission scheduled for 2012
- Recommendation conditional on success of Pathfinder and selection by ESA as first L-class mission, in which case risk is Medium
- **RECOMMEND U.S. share of 50%**
- Total appraised mission cost $2.4B
- Projected 2016 start and ~2025 launch

IXO – Science



- Large area, high spectral resolution x-ray observatory to explore hottest regions in the universe
- Clusters of galaxies, intergalactic medium, black hole accretion disks
- IXO would revolutionize X-ray astronomy and address many high priority science objectives in the spirit of Chandra and XMM-Newton

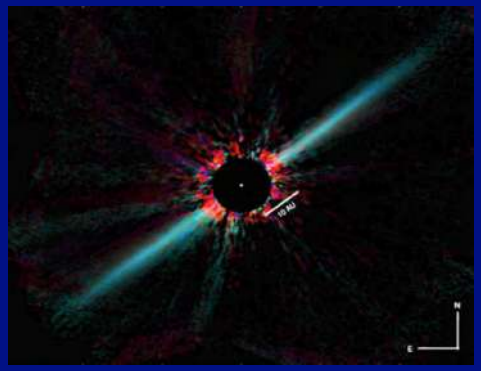
IXO – Program Details

- $3m^2$ aperture, 5 arcsec imaging, microcalorimeter spectrometer
- More ambitious successor to Constellation-X (AANM rec.)
- Joint with ESA, JAXA:
  - Candidate for ESA L-class mission (with LISA, Laplace)
  - Proposed U.S share 50%
  - Current mission appraised at $5.0B, total; Medium-High risk
- If space recommendations 1-3 go ahead, unless there is a substantial budget increase there will be funds only for technology development this decade aimed at reducing the mission cost and risk for next decade
- **RECOMMEND $180M for the decade**

Medium-Scale Space Program - Prioritized

1. New Worlds Technology Development Program

2. Inflation Technology Development Program



New Worlds Technology Development Program

- To achieve New Worlds objective – studying nearby, habitable exoplanets - need preliminary observations before choosing a flagship mission:
  - Planetary demography over wide range of conditions:
    - Kepler, WFIRST, integrated ground-based program
  - Measurement of zodiacal light:
    - Ground-based telescopes.
    - Sub-orbital and explorer mission opportunities.
- In parallel, need technology development for competing approaches to make informed choice in second half of decade
- **RECOMMEND $100-200M over decade**
- Planned integrated ground-space exoplanet 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**

Mid-Scale Innovations Program - Details

- **RECOMMEND annual proposals for:**
  - **Conceptual and preliminary design activities**
  - **Detailed design and construction**
- ~7 projects funded over decade
  - Possible exemplars include: BigBOSS, CMB, ExoPlanet initiatives, FASR, HAWC, HERA, Adaptive Optics, NanoGRAV
- Funding increase from ~$18M currently to competed $40M per year

GSMT - Overview

- Will transform a broad range of science including stellar astronomy, exoplanets, black holes:
  - Complements JWST, ALMA, LSST
  - High spatial resolution; high sensitivity spectroscopy
- Top ground-based recommendation in AANM
- Now two U.S. projects for 30m class optical-infrared telescopes under development:
  - Giant Magellan Telescope in Chile
  - Thirty Meter Telescope in Hawaii
- [Also ESO's E-ELT in Chile]

GSMT - Details

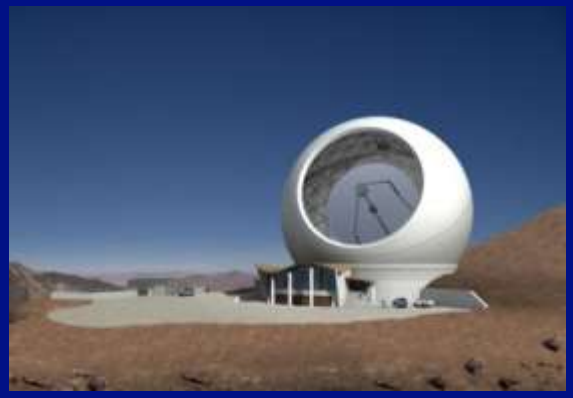
- GMT and TMT have each garnered private and international funding and made significant technical progress
- **RECOMMEND NSF choose one of the two U.S. projects and invest in a quarter share through some combination of construction, operations and instrumentation to provide access to the entire U.S. community**
- Total appraised cost of projects $1.1-1.4B
- Project estimate of total annual running costs $36M (GMT) and $55M (TMT)
- Expect science in mid 2020's; risk Medium to Medium-High
- LSST to be ahead of GSMT in MREFC queue

ACTA - Overview

- Recent coming of age of TeV astronomy, e.g. VERITAS
- Large facility would provide order-of-magnitude leap in capability for studying black holes, supernova remnants, dark matter, pulsars, and binary stars
- Two projects, the European Cherenkov Telescope Array (CTA) and the U.S. Advanced Gamma-ray Imaging System (AGIS) proposed
- AGIS cost estimate: $400M. Technical risk: medium-low
- **RECOMMEND AGIS team should collaborate as a minor partner with European CTA team, with budget of ~ $100M over decade, shared among NSF-Physics, NSF-Astronomy, and DOE**

Medium-scale Ground-based Program

1. Cerro Chajnantor Atacama Telescope (CCAT)



CCAT

- Kick-off example of Mid-Scale Innovations Program
- 25m wide-field submillimeter telescope in Chile
- Work as survey facility 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.)

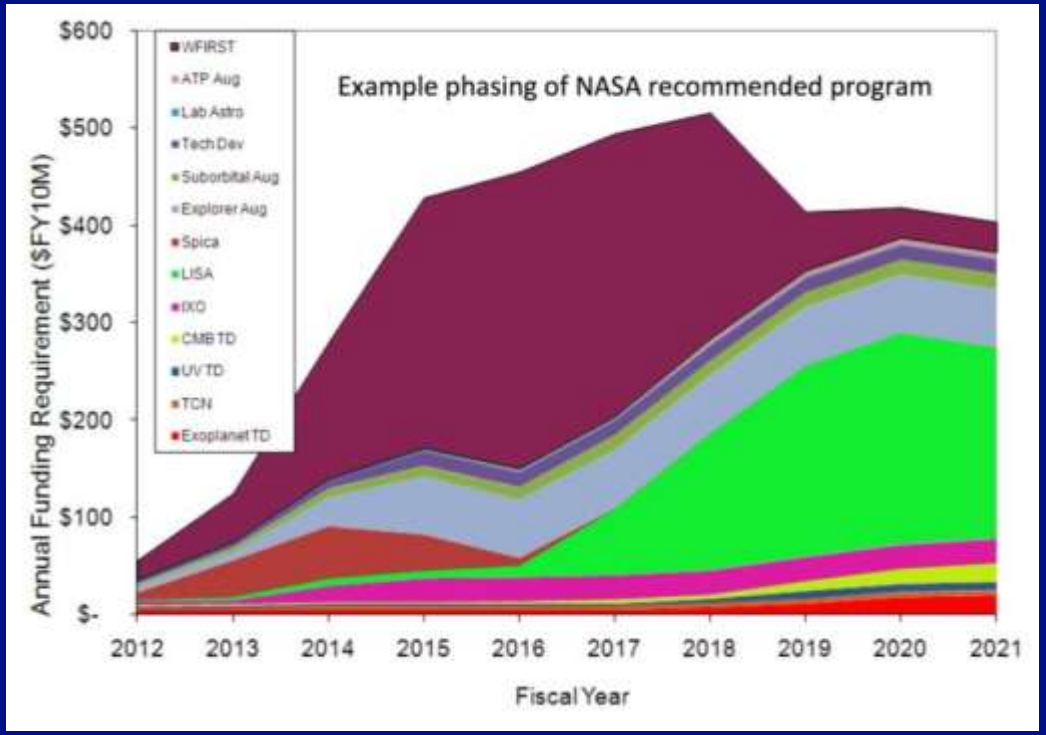
Agency-specific Recommendations

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

NASA

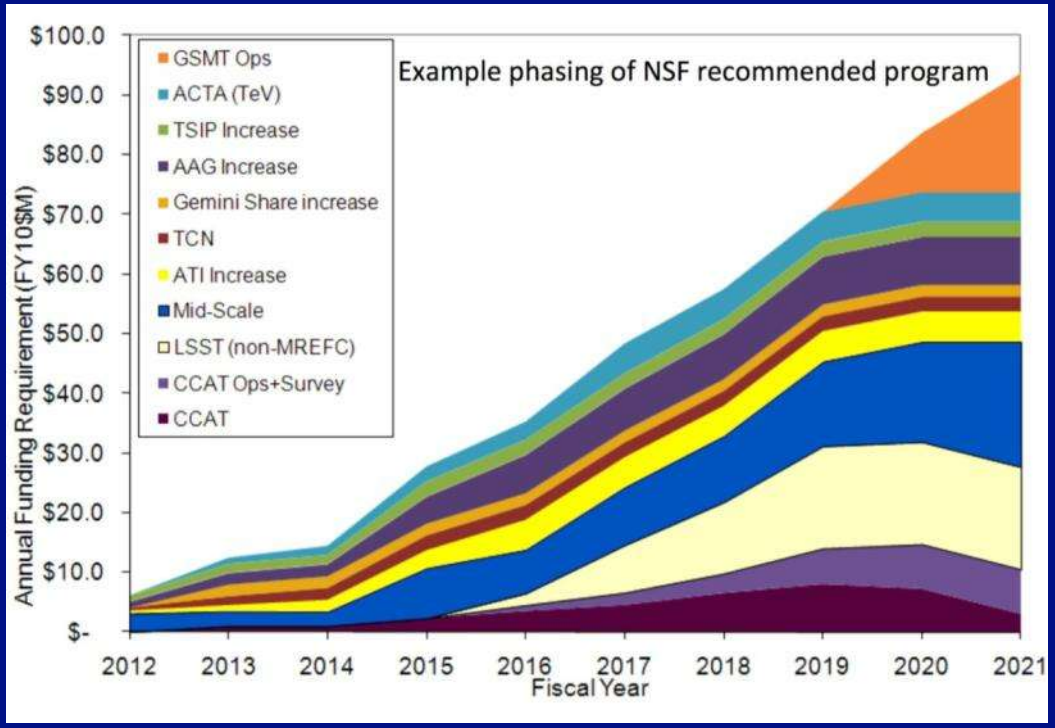
- Expectation under survey's budget scenario:
  - launch WFIRST
  - augment Explorers
  - start LISA
  - timely contribution to SPICA
  - advance
    - IXO
    - Exoplanet and Inflation technology development
- Details depend upon ESA negotiations and decisions



- If budgets are lower, SPICA contribution dropped and
  - First priority: WFIRST, Explorer augmentation and small program
  - Second priority: New Worlds (Exoplanet) Technology Development, LISA and IXO Technology Development
  - Third priority: Inflation Technology Development

NSF

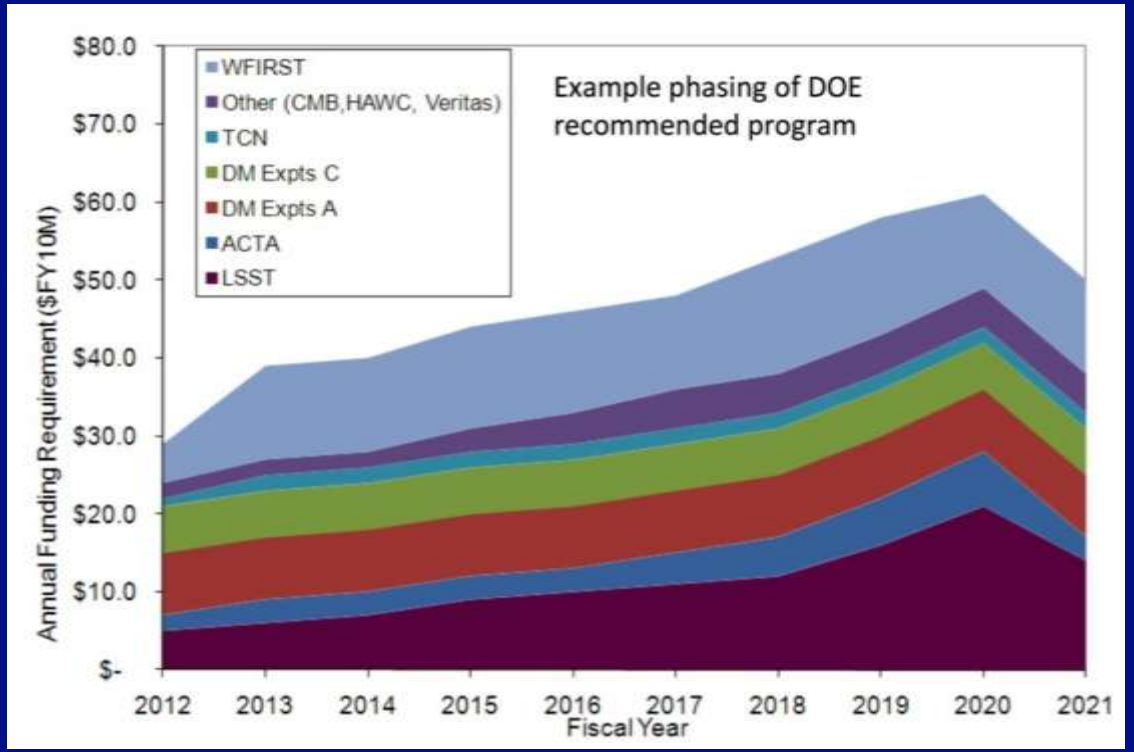
- Program dependent upon MREFC
  - early entry of LSST
  - followed by GSMT



- 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

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:
- Stewardship of the Survey:
- Benefits to the Nation:
- Astronomers:
- Computation and Data:
- Laboratory Astrophysics:
- NSF/AST Senior Review:
- NOAO and Gemini:
- Solar Astronomy:
- Radio Astronomy:

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

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.

Questions for the Q&A may be sent to webcast@nas.edu.

Report is available at www.nationalacademies.org/astro2010