New Worlds, New Horizons
in Astronomy and Astrophysics
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
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 .....

New Worlds, New Horizons in Astronomy and Astrophysics
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
Approach

The three pillars of the survey

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

Some features of Astro2010

- Started with the science
- Solicited and received unprecedented community buy in to process
- Includes unstarted projects from previous surveys
- Improved assessment of technical readiness and risk, and cost drivers
- Changing economic political background and increased international and private collaboration
Optimizing the Recommended Program

• Other important factors
  – International and private partnerships
  – NSF/MREFC funding process is paced
  – Senior Review actions can enable new initiatives
  – Started projects from previous decadal surveys have schedule slips and cost escalations
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)
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
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
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 2\textsuperscript{nd} Request for Information

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

• Key element of the ground & space programs in both dark energy and exoplanets
WFIRST – Program Details

- Discussions between NASA/DOE and ESA about mounting a joint mission could be a positive development if it leads to timely execution of a program that fully supports all of the key science goals of WFIRST (planet microlensing, dark energy science, general investigations) and leads to savings overall.

- It is expected that the United States will play a leading role in this top-priority mission
  - Euclid competing for M-class mission (with PLATO, Solar Probe)
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
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
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
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 0.3-1\mu m
• 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
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]
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
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.)
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
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)
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.