The Coming Decade of Exoplanet Exploration at NASA

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Astro2010 Decadal Survey

- Science themes
  - **Cosmic Dawn** – early universe, first stars and galaxy formation
  - **New Worlds** – search for nearby, habitable, rocky planets with oxygen and liquid water
  - **Physics of the Universe** – understand fundamental physical laws and principles
- New Worlds Science Objectives
  - **Complete the statistical census of exoplanetary system architectures, abundance of Earth-sized planets on large orbits.**
    need an "unbiased" survey of the demographics of exoplanetary systems.
  - **Survey Earth-mass planets/planetary systems Solar neighborhood**
    provide most promising candidates for observations with future direct-detection mission.
  - **Characterize the exozodiacal dust clouds in exoplanetary systems**
    understanding exozodi dust levels and distribution crucial to design of future direct-detection mission and analysis of observations.
- Highest priority Large space mission is Wide Field Infrared Survey Telescope (WFIRST); second Large priority is augmentation to Explorer Program to increase flight rate
- Highest Medium priority is New Worlds Technology Development Program to prepare for a planet-imaging and spectroscopy mission beyond 2020, including precursor science activities.

Astro2010 Decadal Survey

Key *New Worlds* Implementation Recommendations:

- Perform a microlensing exoplanet survey from space using **WFIRST** to characterize in detail the statistical properties of habitable terrestrial planets.
- Improve RV measurements on existing ground-based telescopes to locate the prime targets for hosting habitable, terrestrial planets among our closest stellar neighbors and discover planets as small as 2-3 M_{Earth} as targets for future space-based direct-detection missions.
- Use ground-based telescopes […] or space-based Explorers, to characterize the dust environment around stars like the Sun, so as to gauge the ability of future missions to directly detect Earth-size planets in orbits like that of our own Earth.
- Develop the technology for future space mission to study nearby Earth-like planets.
- Use **JWST** to characterize the atmospheric and/or surface composition of planets down to super-Earth masses orbiting the coolest red stars.

Astro2010 Recommendation L-1: Wide-Field IR Survey Telescope (WFIRST)

WFIRST is the top recommended Astro2010 Large project for a near-IR space observatory to do wide-field imaging and low-resolution spectroscopy

- Designed to conduct cosmic expansion, microlensing exoplanet census, and other galactic and extragalactic large-area surveys, including pointed guest observer programs

Near-term mission concept study (pre-formulation) activities. The WFIRST Science Definition Team has been selected and had their first kick off telecon on Jan 3. The first face-to-face meeting will be in February 2011.

- The SDT preliminary report to be completed by summer 2011; final report by the end of 2012.
- The SDT has been asked to develop a design reference mission (DRM) that meets
  - the science goals stated in New Worlds New Horizons (NWNH) decadal report
  - the launch date envisioned by NWNH (to be launched by 2021)
  - the cost cap established after the FY 2012 President's Budget Request is released in February.
- Two DRMs need to be worked on for the preliminary report due in 2011:
  - One that assumes Euclid is selected by ESA and launches before WFIRST
  - One that outlines a framework for a combined WFIRST/Euclid mission
- The final report due in 2012 will reflect ESA's decision on Euclid

Wide-Field IR Survey Telescope (WFIRST)

Important considerations

The budgetary and science environment in which WFIRST is developed will impact its implementation.

Budget environment:

- Budget profile and schedule for JWST dominate considerations of when WFIRST development may begin
  - Significant funds for the next Astrophysics flagship not available until after JWST launches

Science environment:

- LSST (top Large ground-based priority of Astro2010) and other ground-based telescopes
- Investigations by Hubble, Chandra, Spitzer, JWST, etc.
- Potential Explorer selections
- Potential missions under development by other nations (e.g., Euclid)

Astro2010 Recommendation L-2: Augmentation to Explorer Program

NASA's Explorer Program: Competed, PI-led missions that deliver a high level of scientific return on relatively moderate investments and that provide the capability to respond rapidly to new scientific and technical breakthroughs.

Astro2010 Recommendation: Augment budget to support 2 MIDEX missions (ca. $300M), 2 SMEX missions (ca. $160M), and 4 MoOs (ca. $35M) in coming decade.

For the coming decade, the Explorer program represents the only foreseeable path to a dedicated Exoplanet Exploration mission, and the only path to a space-based platform which could, for example:

- Survey nearby planetary systems and/or their dust environments as emphasized in Astro2010
- Demonstrate key exoplanet measurement technologies upon which a future flagship mission might be based.

Astro2010 Recommendation M-1: New Worlds Technology Development

New Worlds Technology Development Program - a competed program conceived to lay the technical and scientific foundations for a space mission in the 2020 decade capable of imaging and spectroscopy of rocky planets that lie in the habitable zone of their parent stars.

Astro2010 Recommendations:

- Increase of $4M/yr in exoplanet technology development through mid-decade, ramping up rapidly thereafter leading to a mature mission concept for consideration by 2020 Decadal survey; total investment over decade $100M - $200M.
- Development of candidate starlight suppression techniques (coronagraphy, interferometry, star-shades) should continue through mid-decade. If scientific groundwork and design requirements for a direct-detection mission are clear by mid-decade, a technology down-select should be made and subsequent technology investments focused on most promising mission architecture.
- Goal: Mature concept of flagship mission for imaging and spectroscopy of habitable, terrestrial exoplanets for consideration by 2020 Decadal Survey.

New Worlds Technology Development

Existing Astrophysics SR&T programs provide vehicle for implementation

- **Astrophysics Research and Analysis (APRA)—**fundamental research into new technologies, TRL levels 1-3.
- **Technology Development for Exoplanet Missions (TDEM)—**mid-TRL maturation of established technologies, TRL levels 3-6.

Includes **mission-enabling*** ground-based precursor science activities. For example:

- High-precision RV surveys of planetary systems in Solar neighborhood
- Characterization of exozodiacal dust disks (e.g. opacity, distribution, evolution)

** science that advances technologies or informs the design of future NASA flight missions.*

Other Astro2010 Recommendations and Ongoing Activities

Several Small Initiatives recommended by Astro2010 will likely contribute to NASA's Exoplanet Exploration activities:

- Augmentations to NASA's Astrophysics Theory and Laboratory Astrophysics Programs
- Augmentation to Suborbital Program
- Definition of future UV/optical space capability

Key, ongoing activities that will continue in the coming decade:

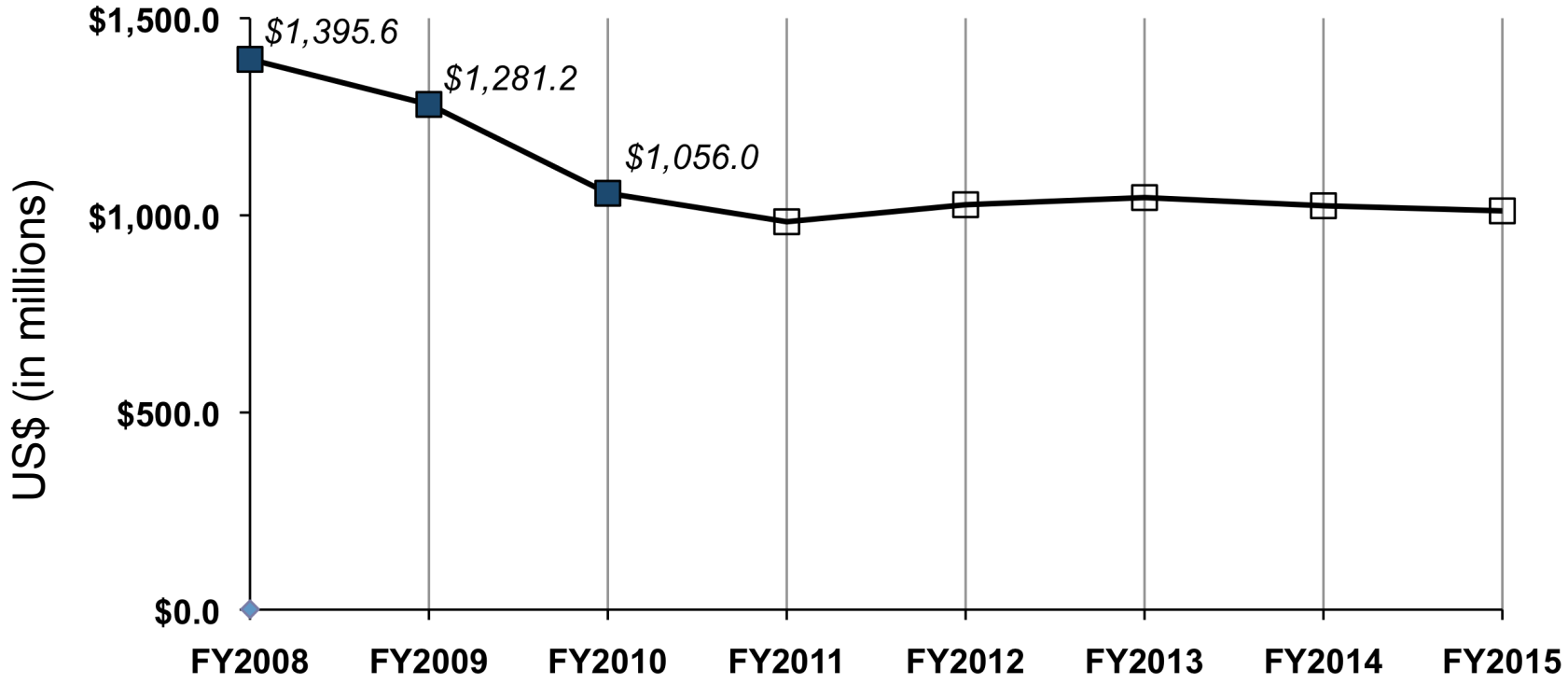
- Continued operation of the *Kepler* mission and support of *Kepler* science.
- Keck/HIRES RV studies and follow-up of *Kepler* observations.
- Characterization of exozodiacal dust with the LBTI.
- Support of fundamental exoplanet research through competitively selected R&A programs (e.g. Astrophysics Data Analysis, Astrophysics Theory, Origins of Solar Systems, Planetary Atmospheres, etc.)

Impacts of Astro2010 – SIM-Lite

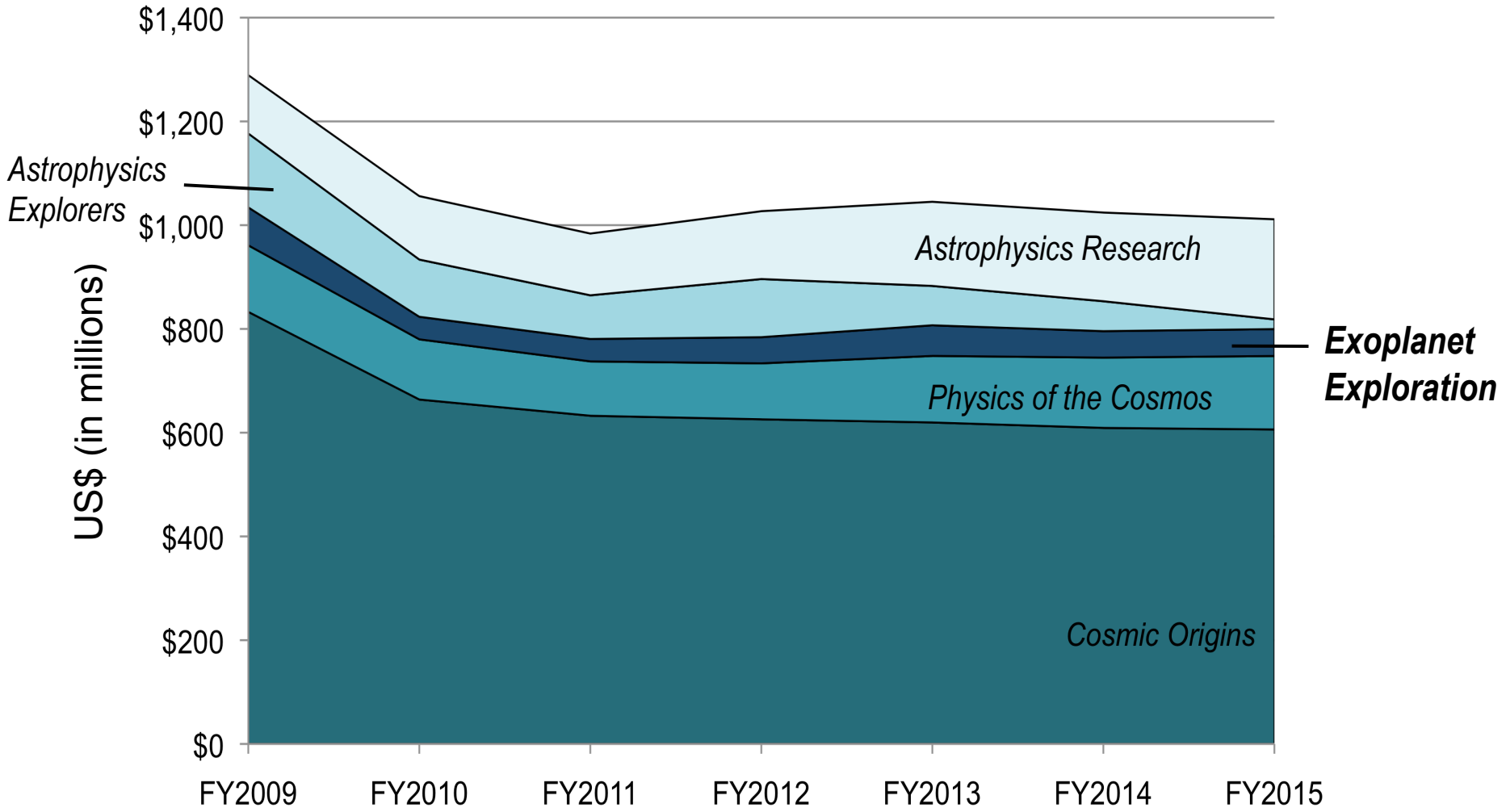
- Decadal Survey did not include SIM-Lite in its recommendations
  - $1.9 billion price tag (per Astro2010 cost estimate) and ca. 8.5 yr time to launch make it uncompetitive in rapidly changing field of exoplanet science.
  - "The role of target-finding for future direct-detection missions, one not universally accepted as essential, can be done at least partially by pushing ground-based radial-velocity capabilities to a challenging but achievable precision below 10 centimeters per second."
- In 24 Sept. 2010 letter, NASA Science Mission Directorate formally discontinued sponsorship of SIM Lite and directed project to discontinue Phase B activities immediately.
  - Project was shut down effective 31 Dec. 2010.
- Closeout activities:
  - Residual SIM hardware will be retained by the NASA Exoplanet Exploration Program (ExEP) for potential future use.
  - SIM technology and design documentation will be archived.
  - SIM personnel moving on to new work.

NASA/Astrophysics Division Budget Profile 2008 - 2015

Projected budget for NASA's Astrophysics Division is essentially flat at around US$1B through the middle of the decade



NASA Astrophysics Division Budget Profile 2009 - 2015



NASA's Exoplanet Exploration Activities in the Coming Decade.

Kepler: Continue to operate and support the science of NASA's first dedicated exoplanet exploration flight mission.

WFIRST: Initiate science definition, requirements development, design engineering activities immediately, with a formal project start as resources permit.

Astrophysics Explorer missions: competed program, exoplanet exploration mission proposals expected to be strong candidates.

New Worlds Technology Development: fundamental technology research and technology maturation leading to the development of a mature, direct-detection mission concept for consideration by the 2020 decadal survey; mission-enabling precursor science.

Fundamental Exoplanet Science: investigations supported through a variety of open, competitive R&A and GO programs.