The Future of NASA’s Exoplanet Exploration Program

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The Exoplanet Exploration Program: Exploring New Worlds

Exploring How the Universe Works
Discovering and Characterizing Exoplanets
Searching for Signs of Life in the Galaxy

Space Missions and Mission Studies

- **Kepler**
- **AFTA**
- **Probe-Scale:** External Occulter (Starshade)

Public Engagement

- **Kepler Probe-Scale:**
- **Archives, Tools & Professional Education**

Supporting Research & Technology

- **Key Sustaining Research**
  - Keck Single Aperture Imaging and RV
  - Large Binocular Telescope Interferometer

Technology Development

- **Technology Development**
  - High Contrast Imaging
  - Deployable Star Shades
  - NASA Exoplanet Science Institute
Exoplanet Missions

- JWST
- TESS
- Kepler
- Spitzer
- Hubble
- Ground-based Observatories

Books:
- 2001 Decadal Survey
- New Worlds, New Horizons in Astronomy and Astrophysics
- 2010 Decadal Survey
The Search for Life in the Universe Requires $\eta_{\text{Earth}}$

Complete the census
- Kepler (warm planets)
- WFIRST microlensing (cool planets)

Find nearby transiting planets
- TESS

Characterize super-earth/mini-Neptunes
- JWST

Imaging and Spectroscopy of planets
- WFIRST-AFTA coronagraph
  - Jupiters, Neptunes, Super-Earths
- New Worlds Mission (‘Earth 2.0’)

η Earth
Kepler Mission

- Kepler Mission ended in May 2013 after a second reaction wheel failed
- Analysis of Kepler data continue
- Data from Quarter 0-17 (May 2009 – May 2013) are archived

April 17: Kepler team announced discovery of Kepler-186f, the first nearly Earth-sized planet located in the habitable zone of an M1 dwarf

February 26: announced Kepler confirms the existence of 715 new exoplanets using “verification by multiplicity”
Kepler’s ‘Second Light’ – the Proposed K-2 Mission

- A series of engineering demonstrations of 2-wheel performance on the spacecraft were performed in 2013
- With only two reaction wheels, operations are possible only in certain orientations (balancing solar pressure)
- Photometry possible at reduced precision (~60 ppm in 6 hours on V-12 G-star)
- In Feb 2104 a second detector module failed (40 of the original 44 operational)
- A Call for White Papers resulted in 42 submitted papers covering exoplanets, asteroseismology, open cluster studies, NEOs, and more.
- Kepler Project received permission in Dec 2013 to submit a proposal to the 2014 Astrophysics Senior Review of Operating Missions
  - Under review: Hubble, Chandra, Fermi, NuSTAR, Spitzer, Suzaku, Swift, XMM-Newton, and WISE
- If approved, K-2 will observe a series of ecliptic plane fields
**Mission PI:** George Ricker, MIT

**Selection occurred April 5, 2013**

**SRR held February 2014**

**Development progressing on plan**

**Tentative launch date August 2017**

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**Mission:** All-Sky, two-year photometric exoplanet mapping mission.

**Instruments:** Four WFOV CCD cameras with overlapping FOV of 23x90deg. Passively-cooled 600-1000nm 4096x4096 pixel FPA

**Science goal:** Identify transiting planets around the brightest stars in the sky

- Planets with periods up to 1 month in the ecliptic (~HZ for M stars)
- Can find up to 1 year orbits in continuous viewing zones at ecliptic poles

A subset of the resulting planets will have their atmospheres characterized by:

- JWST
- Extremely Large Telescopes (ELTs)
- Future Exoplanet Explorers, Probes, and Large Missions
Large Binocular Telescope Interferometer (LBTI)  
University of Arizona

Commissioning Status:
• All subsystems finalized and demonstrated on-sky
• Achieved closed-loop nulls on the sky (in Dec 2013)

Science Capabilities:
• LBTI will enable characterization of exo-solar planetary systems
• Survey 50 nearby stars for exozodiacal dust, at levels of 3-6 times (1σ) the dust in our own planetary system
2.4m aperture on-axis obscured telescope, 270K
28.5 degree inclination geosynchronous orbit, Atlas V 541 launch vehicle
Two-channel widefield instrument with IFU channel 0.6 to 2.0 µm for Dark Energy, NIR Surveys, and Exoplanet Microlensing
FPA: 6x3 4k x 4k HgCdTe detectors, 0.76 to 2.0 µm
Coronagraph instrument for Exoplanet Direct Imaging and Characterization
Mission life 6 years with coronagraph

Science Definition Team (SDT):
- SDT Interim Report due in May 2014
- SDT Final Report due in Jan 2015

WFIRST final report May 23, 2013
http://wfirst.gsfc.nasa.gov/
Exoplanet detection by AFTA Microlensing

- Search field towards galactic bulge
- Sensitive to ~3000 bound planets
- Sensitive to hundreds of unbound, free-floating planets to ~Mars mass
- Complements the census begun by Kepler
Sensitivity of AFTA Coronagraph for Imaging Exoplanets

- Model planets are shown:
  - Gas giants: red, yellow
  - Ice giants: blue-green
  - Terrestrial: blue

- Measurement goal is to measure the brightness of reflected light of each planet, across the spectrum.

- Science goal is to determine atmospheric gases, clouds, clues regarding origin & evolution of planet, and history of planet system.

- Debris Disks (exozodiacal dust)
- Characterize the spectra of over a dozen radial velocity planets
- Discover and characterize up to a dozen more ice and gas giants
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation
- Respond to Decadal Survey to mature coronagraph technologies, leading to first images of a nearby Earth
Several Potential Technologies for High-Contrast Imaging

**Primary Approach**
(combined on filter wheel)

- Hybrid Lyot Coronagraph
- Shaped Pupil

**Back-up approach**

- PIAA-CMC (Phase-Induced Amplitude Apodization Complex Mask Coronagraph)

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Downselection in Jan 2014

- TRL-5 at start of Phase A (Oct 2016)
- TRL-6 at PDR (Oct 2018)
Exoplanet Probe Studies

• In 2013 NASA began studies for two ‘probe-scale’ exoplanet missions
  – For consideration by 2020 Decadal Survey
  – To guide technology investment for remainder of decade
  – Candidate for 2017 new start if AFTA cannot be started this decade
• Two Science and Technology Definition Teams (STDTs) selected
  – Exo-C: Probe coronagraph
  – Exo-S: Probe starshade (external occulter)
• Success criteria include:
  – Compelling science, viable technology, $1B life cycle cost
• Both teams have written Interim Reports (May 2014)
• Final Mission Concept Reports due in January 2015
• Independent cost estimates due in February 2015
# STDT Membership

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Starshade Deployment

at Northrop Grumman's Goleta Facility
Program objective: three compelling and viable mission concept reports by Jan 2015 with independent cost estimates by Feb 2015
ExEP: Recent Progress and a Look Ahead

Great Progress!

- Significant recent scientific discoveries:
  - Kepler current totals: confirmed (964), candidates (3845)
  - Kepler-186f: rocky planet in Habitable Zone of an M star
- Kepler demonstrated two-wheel science observations
- LBTI: reached sensitivity of 36x Solar System zodi level
- Downselected coronagraph technologies for AFTA
- Delivered 3 interim reports: AFTA and two Probes
- Technology: steady progress in high-contrast imaging, starshade deployment demonstrations

Looking Ahead:

- LBTI: final steps to commissioning
- WFIRST-AFTA: technology progress, final report and costs
- Probe studies: final reports and independent costs
- Sagan Summer Workshop “Imaging Planets & Disks”
- Exoplanet Program Analysis Group very active
‘Eyes on Exoplanets’: Interactive Tour

- All 3,600 candidate systems shown in FOV
- Each confirmed planet can be visited
- Continuously updated as planets are confirmed

http://eyes.jpl.nasa.gov/exoplanets
For more information on NASA exoplanet missions:

http://exep.jpl.nasa.gov

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