Exoplanet Exploration Program Update

Gary Blackwood, Program Manager
Karl Stapelfeldt, Program Chief Scientist
Jet Propulsion Laboratory

June 11, 2016
Exoplanet Exploration Program Analysis Group Meeting (ExoPAG 14)
San Diego, CA
NASA Exoplanet Exploration Program
NASA Astrophysics Division, Science Mission Directorate

Purpose described in 2014 NASA Science Plan

1. Discover planets around other stars
2. Characterize their properties
3. Identify candidates that could harbor life

The Search for Exoplanets is…
The Search for Life in our Galaxy

ExEP serves the science community and NASA APD by Implementing NASA’s space science vision for exoplanets

http://exep.jpl.nasa.gov
NASA Exoplanet Exploration Program

Space Missions and Mission Studies
- Kepler, K2
- WFIRST
- Starshade
- Decadal Studies
- Coronagraph

Supporting Research & Technology
- Key Sustaining Research
  - Large Binocular Telescope Interferometer
  - Keck Single Aperture Imaging and RV
- Technology Development
  - Coronagraph Masks
  - High-Contrast Imaging
  - Deployable Starshades

Public Communications
- NASA Exoplanet Science Institute
- Archives, Tools, Sagan Fellowships, Professional Engagement
- EYES OF EXOPLANETS

http://exep.jpl.nasa.gov
Kepler Close Out
Delivering Kepler’s Legacy

• Kepler closeout and final data processing continues steadily within overall schedule margin
  – SOC 9.3 Q0-Q17 Short Cadence Light Curves Delivered to MAST (June 2016, imminent)
  – Documentation Completeness Review (Oct 2016)
  – SOC 9.3 Final Occurrence Rate Products (April 2017)
**Kepler K2**
Extending Kepler to the Ecliptic

- Since last ExoPAG:
  - Data released through Campaign 7 (Campaign 8 imminent)
- High-value exoplanets: small, rocky, nearby (46 pc), orbiting bright stars.
- Spacecraft fully operational after suspension of operations April 8-22 (SEU requiring resets of onboard systems)
- Campaign 9 (Microlensing) was slightly truncated, first 28 days of data are on the ground. NASA funding UKIRT time.
- **K2 does much more than exoplanets** - example: shock breakout seen in supernova lightcurve (Garnavich et al. 2016)

[https://exep.jpl.nasa.gov/k2/](https://exep.jpl.nasa.gov/k2/)
Progress towards 2010 Decadal Survey Priorities

Program Updates

Preparations for 2020 Decadal Survey
Welcome Kendra Short

Deputy Program Manager

Exoplanet Exploration
Progress towards 2010 Decadal Survey Priorities

Program Updates

Preparations for 2020 Decadal Survey
WFIRST
The Fate of the Universe, and Our Place in It

- WFIRST entered Formulation Phase: NASA Key Decision Point (KDP)-A 2/17
- Formulation Science Working Group and Science Investigation Teams underway
- Wide Field Instrument Industry Concept Study Underway: Ball Aerospace and Lockheed Martin ATC
- 6/9 –Project received APD direction to incorporate starshade compatibility into Phase A DRM – for SMD decision following SRR/MDR Spring 2017
Technology - Coronagraph

All prior WFIRST technology milestones met on schedule

PISCES Integral Field Spectrograph hardware delivered by GSFC to HCIT

- First demonstration of ultra-high contrast spectroscopy for characterization of exoplanets and image speckles
- Setup and initial testing this summer
- New PI Avi Mandell

Key upcoming milestones by 9/30/16:

- Read noise of EMCCD detector+readout
- First lab demo of PIAACMC coronagraph
- Demonstrate $10^{-8}$ raw contrast in 10% band in a simulated dynamic environment
Exo-S Extended Probe Study completed
(Seager et al.)

- Options for follow-on missions with WFIRST, with operations at the Earth-Sun L2 point.
- Petal optimization for detection in blue band could improve Tech Demo and Extended Study IWA

<table>
<thead>
<tr>
<th>Mission Option Characteristics</th>
<th>Performance Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Option</strong></td>
<td><strong>Starshade Size</strong></td>
</tr>
<tr>
<td>Exo-S Tech Demo</td>
<td>20 m</td>
</tr>
<tr>
<td>Exo-S Extended Study</td>
<td>20 m</td>
</tr>
<tr>
<td>Exo-S Case Study</td>
<td>34 m</td>
</tr>
<tr>
<td>Exo-S Enhanced</td>
<td>40 m</td>
</tr>
</tbody>
</table>

Exo-S ES compared to Exo-S CS

- **Discovery**: Stars that could be searched have the same quality images as before. Fewer targets with desirable IWA
- **Characterization by spectra**: only blue band is accessible for exoEarths
- **Background discrimination**: lack of colors at small IWA hurts for background contamination

<table>
<thead>
<tr>
<th>Version</th>
<th>Parameters</th>
<th>Observing Bands</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Study</td>
<td>Bandpass (nm)</td>
<td>425-602</td>
<td>600-850</td>
<td>706-1000</td>
<td></td>
</tr>
<tr>
<td>20m inner disk</td>
<td>IWA (mas)</td>
<td>70</td>
<td>100</td>
<td>118</td>
<td></td>
</tr>
<tr>
<td>28 7m petals</td>
<td>Separation (Mm)</td>
<td>50</td>
<td>35</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Extended study</td>
<td>Bandpass (nm)</td>
<td>425-565</td>
<td>600-800</td>
<td>750-1000</td>
<td></td>
</tr>
<tr>
<td>10m inner disk</td>
<td>IWA (mas)</td>
<td>100</td>
<td>140</td>
<td>176</td>
<td></td>
</tr>
<tr>
<td>28 5m petals</td>
<td>Separation (Mm)</td>
<td>20.5</td>
<td>15</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>
Exo-C Extended Probe Study Completed  
(Cahoy et al.)

- Exo-C ES report captures the science capability of a 2.4-m aperture space telescope designed specifically for exoplanet direct imaging.
- Highlights technology development needs beyond WFIRST:
  - 4k x 4k radiation-tolerant EMCCD detectors
  - 96 x 96 actuator deformable mirrors
  - Refinement and validation of contrast stability models to $10^{-11}$
- Considered possible secondary payloads.
  - NIR coronagraph, Transit Spectrometer, NIRSpec “Lite”
• Motivation
  – 2010 Decadal Survey calls for precise ground-based spectrometer for exoplanet discovery and characterization
  – Follow-up & precursor science for current missions (K2, TESS, JWST, WFIRST)
  – Observations inform design/operation of future missions

• Scope:
  – Extreme precision radial velocity spectrometer (<0.5 m/s) for WIYN telescope contract is out
    • Penn State NEID proposal selected in March (see Chad Bender’s talk tomorrow)
    • Instrument to be commissioned by July 2019
  – Ongoing Guest Observer program using NOAO share of telescope time for exoplanet research
Strategic Astrophysics Technology - TDEM

Reports for completed and active TDEMs: http://exep.jpl.nasa.gov/technology/
Reviewed and approved by ExoTAC, Alan Boss (chair)

• Active TDEMs
  – 2010
    • (Bierden) Environmental Testing of MEMs DMs
    • (Helmbrecht) Environmental Testing of MEMs DMs
  – 2012
    • (Kasdin) Optical and Mechanical Verification of External Occulter
  – 2013
    • (Bendek) Enhanced Direct Imaging with Astrometric Mass
    • (Cash) Development of Formation Flying Sensors
    • (Bolcar) Segmented Aperture Nulling Coronagraph
  – 2014
    • (Bolcar) Next Generation Visible Nulling
    • (Serabyn) Broadband Vector Vortex Coronagraph
ExEP Technology Gap Lists

Starshade Technology Gap List

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Description</th>
<th>Current</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>Central Edge Scattered Light</td>
<td>Limit edge-scattered light with optical quality edges that ensure high-contrast bending angles</td>
<td>Edge ratios &lt; 0.01 μm</td>
<td>Optical path edges manufactured of high surface strength material with edge ratio 0.1 mm and reflectivity ≤ 5%</td>
</tr>
</tbody>
</table>

Coronagraph Technology Gap List

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Description</th>
<th>Current</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1</td>
<td>Speckle Suppression Optics</td>
<td>Reduce speckle suppression</td>
<td>5× in dynamic range</td>
<td>&lt; 10% suppression</td>
</tr>
<tr>
<td>C-2</td>
<td>Low Order Wavefront Sensing &amp; Control</td>
<td>Sensing and control</td>
<td>0.1 μm rms</td>
<td>0.01 μm rms</td>
</tr>
<tr>
<td>C-3</td>
<td>Large Format Correlated Pixel Stacks</td>
<td>Prediction of the best spatial resolution</td>
<td>0.1 μm rms</td>
<td>0.01 μm rms</td>
</tr>
<tr>
<td>C-4</td>
<td>Efficient Contrast Strategies</td>
<td>Optimize contrast optimization</td>
<td>10^6 to 10^7 contrast</td>
<td>10^8 to 10^9 contrast</td>
</tr>
<tr>
<td>C-5</td>
<td>Post-Data Processing</td>
<td>Optimize data processing</td>
<td>&lt; 10%</td>
<td>&lt; 1%</td>
</tr>
</tbody>
</table>

http://exep.jpl.nasa.gov/technology/
Strategic Astrophysics Technology - TDEM
Advancing Technology Readiness towards next Decadal Survey

• Sunday 9 am talk from Nick Siegler on how ExEP technology needs are identified and prioritized

Dr. Nick Siegler
Chief Technologist
Exoplanet Exploration
Progress towards 2010 Decadal Survey Priorities

Program Updates

Preparations for 2020 Decadal Survey
High Contrast Imaging with Segmented Apertures
ExEP-sponsored workshop held at JPL, May 5-6 2016

SOC Chair Olivier Guyon

• Considered challenges posed by obscured & segmented apertures to coronagraphy and wavefront control

• Topics covered included
  – Segmented telescopes in development
  – Options for segmentation
  – Contrast dependence on segment misalignments (top left, Stahl & Stahl)
  – Coronagraph performance as a function of IWA and degree of segmentation (Zimmerman et al., lower left)

• 25 presentations available to review at https://exep.jpl.nasa.gov/hcisa/
Sagan Programs Update

- Next Sagan Summer School
  July 18-22 2016 in Pasadena
  “Is there a planet in my data?”

- Six new 2016 Sagan Fellows selected
New Public Website: NASA Exoplanet Exploration

exoplanets.jpl.nasa.gov

Replaces planetquest.jpl.nasa.gov
New content, compatibility with mobile devices, some features of “eyes on exoplanets” incorporated
Progress towards 2010 Decadal Survey Priorities

Program Updates

Preparations for 2020 Decadal Survey
Large Binocular Telescope Interferometer
Measures exozodiacal dust in habitable zones

- Results of HOSTS survey to inform next decadal survey on direct exoplanet imaging: *Survey deliveries planned for Sept 2016 and Sept 2017*
- Demonstrated 12-15 zodi sensitivity for a solar twin at 10 pc at May 2015, <6 zodi single star sensitivity planned for April 2016 Science Operations Review
- HOSTS survey interrupted by glycol leak in secondary mirror, repairs complete January 2016
- No HOSTS science performed since last year – unable to complete (in-guide) the 32 star survey. Total of one HOSTS star thus far
- APD has a decision to make: Convene July 12 Continuation/Cancellation review at NASA HQs
Decadal Flagship Mission Studies

• Support science planning and yield estimates
  – Exoplanet Standard Definitions and Evaluation Team
  – See Rhonda Morgan’s talk tomorrow

• Incorporate any mission concept’s exoplanet technology requirements in Program Technology Gap list
  – Include telescope stability and detectors which apply to all architectures. See Nick Siegler’s talk on Sunday

• High Contrast Imaging technology initiatives:
  – Segmented Coronagraph Design & Analysis: program-funded study to evaluate coronagraph designs suitable to segmented apertures. See Stuart Shaklan’s talk tomorrow.
The Starshade Readiness Working Group (SSWG)
http://exep.jpl.nasa.gov/sswg/

- Require a risk reduction plan for technology validation of starshades to enable starshade flight science missions to be considered in 2020 Decadal Survey
- Will answer these questions and deliver recommendation:
  - How to go from TRL 5 to ~TRL6,7
  - Do we need a tech demo, and if so, what is it?
- Adopted the Exo-S probe “Starshade Rendezvous” as representative motivation of technology requirements
- Chairs: G. Blackwood (ExEP/JPL), S. Seager (MIT)
- Status:
  - Consensus reached on musts, wants; options defined, technical vetting underway.
The Starshade Technology Project

- Purpose: achieve TRL5 by ~Decadal 2020
- Directed funding and reprogramming of competed funds
- March 23: APD Instructions to begin Planning Phase

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Description</th>
<th>Responsible Authority</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Review</td>
<td>Confirm updated reference mission is complete enough to begin tech development plan</td>
<td>Starsshade Technology Project</td>
<td>May 2017</td>
</tr>
<tr>
<td>Technology Development Project Plan Review</td>
<td>Confirm technology development plan is complete and forms a good baseline to complete the planning of the implementation phase</td>
<td>Exoplanet Program Office</td>
<td>Jul 2017</td>
</tr>
<tr>
<td>Internal Planning Stage Review</td>
<td>Ensure Planning Stage Plan is robust</td>
<td>JPL Director-for 7X</td>
<td>Aug 2017</td>
</tr>
<tr>
<td>Baseline TRL-5 Development Plan</td>
<td>Authorize start of Planning Stage Phase</td>
<td>SMD Astrophysics Division</td>
<td>Sep 2017</td>
</tr>
</tbody>
</table>

- Intent is broad institutional participation and funding
- Next step: Open workshop for work prioritization (Sept)
Acknowledgements

• This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration. © 2016 All rights reserved.

• Work was also carried out at NASA’s:
  • Goddard Space Flight Center
  • Ames Research Center

• Work was carried out as well under contracts with the National Aeronautics and Space Administration and:
  • Princeton University
  • University of Arizona
  • Northrop Grumman Aerospace Systems
  • National Optical Astronomy Observatory (NOAO)
  • Massachusetts Institute of Technology
  • Pennsylvania State University