ExEP Technology Updates
Since Last ExoPAG

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Exoplanet Exploration Program
Jet Propulsion Laboratory/California Institute of Technology

ExoPAG 18
29 July 2018
Active TDEMS

- **Vortex Coronagraphy**
  - TDEM-14 PI Gene Serabyn charge-4 vortex tests in HCIT.
  - Achieved $2 \times 10^{-9}$ contrast in monochromatic light (milestone is to get to $1 \times 10^{-9}$ contrast at 10% bandwidth)
  - Demonstration used for the first time within the HCIT a MEMS deformable mirror
  - $2 \times 10^{-9}$ contrast is a world contrast record using a MEMS DM

- **Polarization Effects in Coronagraphy**
  - TDEM-15 Jim Breckinridge team performed an independent polarization ray-trace of the HabEx optics (4 m aperture).
  - Showed good agreement with the HabEx team’s calculations: no show-stoppers from polarization aberrations from the primary optics
  - The work highlights the importance of setting requirements on the spatial uniformity of the coatings on the large optics (see Breckinridge et al and Davis et al Austin SPIE papers for details).
Active TDEMS (cont’d)

• **MEMS Deformable Mirrors (DMs)**
  - TDEM-10 PI Paul Bierden (Boston Micromachines) will have ten MEMS deformable mirrors dynamically tested at GSFC in mid-Aug
  - The DMs will return to JPL for post environment testing scheduled in September
  - SBIR is producing a 50x50 DM

• **ExoTAC approved the test plans and milestones for the three TDEM-16 awards:**
  - PI Rus Belikov: PIAACMC
  - PI John Trauger: Super Lyot Coronagraph
  - PI Rus Belikov: Multi-star wavefront control
Segmented Mirror Technology Program

- Telescope apertures will continue to get larger and structural and wavefront error stability will be challenging when working with coronagraphs.

- Industry awards created to address system-level design and modeling challenges for achieving picometer-level wavefront error stability in a segmented UV/V/NIR space telescope.

- Managed by PCOS/COR

Ultra-Stable Large Telescope Research and Analysis (ULTRA),
PI Scott Knight (Ball Aerospace)

System-Level Segmented Telescope Design
PI Larry Dewell (Lockheed Martin)
Starshade Technology Development

- Trade study completed
  - Wrapped-petal architecture selected for further development

- Technology Development Plan being advanced to close the three technology gaps.
  - Review of milestones by ExoTAC in August
  - Delivery of Plan for NASA HQ approval in September

- Thanks John Ziemer!

- Welcome Kendra Short and Phil Willems
Segmented Coronagraph Design and Analysis

• **Purpose:** Ensure there is at least one coronagraph architecture that can meet the contrast requirements of future large segmented space telescopes to directly image and characterize exo-Earths.

• **Promising designs delivered** of the APLC (STScI/GSFC) and Vortex (Caltech/JPL) teams; HLC catching up, PIAACMC and VNC struggling to meet metrics.

• **Lessons learned (See Austin SPIE papers for details)**
  – Big dropoff in throughput seen when secondary obscuration exceeds 30% of the primary mirror diameter
  – Maximize inscribed diameter of the primary mirror
  – Segmentation gaps are not a major problem (if small)

• **Next steps**
  – Test new apodization masks in testbeds (not yet vacuum)
  – Test the robustness of the designs to wavefront errors and tolerancing: Do these coronagraphs put constraints on the telescopes that are unrealistic?

• **Public release of FALCO code** (joint deformable mirror / apodizing mask optimizer); A.J. Riggs (JPL) is the lead.
**Decadal Survey Testbed**
Advancing the next generation of coronagraphs

- **Purpose:**
  - Develop a testbed that is sufficiently low noise to demonstrate next-generation coronagraphs reach $10^{-10}$ contrast
  - To be made available to community

- **Currently in Phase I:**
  - Commissioning with a clear aperture plus Hybrid Lyot
  - **Plan is to reach a new contrast record by the end of this CY ($\leq 10^{-10}$)**

- **Phase II in CY19:**
  - Add a segmented/obscured mask to simulate (in a static environment) the segmentation pattern of a large space telescope mirror

- **Status Briefing to be scheduled in October with WFIRST, HabEx, and LUVOIR teams**
Inputs to National Academies Committees


• Briefed the NAS Exoplanet Science Strategy committee at their Irvine meeting on April 20, 2018 on “Exoplanet Technology Gaps” https://exoplanets.nasa.gov/internal_resources/893/
New Technology Selection and Prioritization Process

- NASA HQ directed the three APD Program Offices (ExEP, PCOS, COR) to develop a plan for closer coordination of the technology prioritization processes.

- Concerns from the community:
  - Potential stove piping
  - Differences in the way technologies were prioritized
  - Different schedules
  - Duplication of technology gaps

- Brendan Crill and Nick Siegler worked with Thai Pham and Opher Ganel of PCOS/COR.

- The plan was approved by Paul Hertz in June; Program Office technologists are now implementing the plan.
New Technology Selection and Prioritization Process Highlights

• The prioritized technology gap lists will be updated every two years instead of annually.
  – Next update will be in calendar year 2019.
  – SAT/TDEM proposal cycle is unchanged, pending funding.
  – December amendments to the SAT will continue.

• Program Offices will share a common schedule and jointly solicit new technology gaps from the community.

• There will be no duplication of technology gaps.
  – Each gap will be evaluated and facilitated by only one Program Office.
  – Any new technology gaps will be evaluated and facilitated by the Program Office with the most suitable expertise.

• The Program Offices will use same prioritization criteria and scoring.

• Resulting lists will be merged into a single prioritized APD technology list.

• An executive summary-level document: *Astrophysics Biennial Technology Report* will be released to support the work
  – ExEP’s Technology Plan Appendix will continue annual publication.
in-Space Assembled Telescope (iSAT) Study

- Chartered by NASA SMD and APD to answer the question:

  *When is it worth assembling telescopes in space rather than building them on the Earth and deploying them autonomously from individual launch vehicles?*

- Study leads Nick Sigler (JPL), Harley Thronson (GSFC), Rudra Mukherjee (JPL)

- Final deliverable is a White Paper to the Decadal Survey Committee in Spring 2019

- **Activity 1a: Modularizing a 20 m space telescope**
  - Workshop held at Caltech June 5-7

- **Activity 1b: Assembling and testing the 20 m modularized telescope in space**
  - Robotics, orbit, launch vehicle, assembly platform
  - Workshop scheduled for October 2-4 at LaRC
Technology Colloquium Series Continues

- Stability of Mid-Infrared Detectors for Future Space-based Transit Spectroscopy Measurements (C. McMurtry, Rochester)

- Cost Drivers for Traditional Space Telescope Missions (H. Phil Stahl, NASA/MSFC, K. Warfield, NASA/JPL)

https://exoplanets.nasa.gov/exep/technology/tech_colloquium/
Talk slides and recordings available
ADDITIONAL SLIDES
Flow Diagram of Coordinated Prioritization and Reporting Cycle

1. Joint PCOS/COR/ExEP Coordination Planning with HQ Concurrence
   - Present – Dec 2018

2. POs Communicate New Integrated Process to their Respective PAGs
   - Jul 2018 and Jan 2019

3. Joint Solicitation for Community Technology Gap Inputs
   - Jan 2019

4. Community/STDTs Submit Gap Inputs
   - Jan – May 2019

5. POs Collect and Divide Gaps Among Three POs for Prioritization
   - Jun 2019

6. PAGs/Peer Review Panel review (non-STDT) Gaps for Their Respective POs
   - Jun – Jul 2019

7. POs with TMB/TAC Independently Prioritize Their Respective Gaps
   - Jul – Aug 2019

8. POs Jointly Combine the Three Prioritized Gap Lists by Scores
   - Aug 2019

9. Include Integrated Gap Prioritization List in ABTR
   - Sep 2019

10. APD Publishes/Releases ABTR
    - Oct 2019
Exoplanet Exploration Program

**TECHNOLOGY**

- Angular Resolution: Interferometry
- Angular Resolution and Collecting Area: Large Space Telescopes
- Contrast Stability: Ultrastable Structures
- Detection Sensitivity: Advanced Detectors
- Starlight Suppression: Starshades
- Starlight Suppression: Coronagraphs

**MISSIONS**

- Hubble
- TESS
- Spitzer
- Kepler
- JWST
- WFIRST
- Starshade
- Rendezvous
- LUVOIR
- OST
- HabEx
- Exo-Earth Interferometer

**SCIENCE**

- Today
- 2020s
  - Exoplanet Abundance
  - Exoplanetary Atmospheres
  - Hot Jupiters
  - Nearest Transiting Planets
  - Atmospheric Chemistry
- 2025s
  - Direct Imaging
  - Exozodiacal Dust
  - Exoplanet Diversity
- 2030s
  - Habitable Exo-Earth Discovery
- 2035 and beyond
  - Exo-Earth Biosignatures
  - Habitable Exo-Earth Abundance
  - M-Dwarf Rocky Planet Biosignatures
  - Cool Gas Giants
  - Life Verification

Possible Pending Decadal Survey

Version 2018_03_07, NASA ExEP
ExEP’s Technology Focus

The driving ExEP science goals are to:
1. Discover planets around other stars
2. Characterize their properties
3. Identify candidates that could harbor life

As recommended in the 2010 Astrophysics Decadal Survey and planned in NASA’s Astrophysics Implementation Plan, the ExEP develops technologies that will enable the direct imaging and characterization of exoplanets in the habitable zone of Sun-like stars.
Exoplanet Exploration Program

ExEP Technology List

- 24 technologies currently tracked

- Technology List posted here: https://exoplanets.nasa.gov/exep/technology/gap-lists/

- More detail coming soon in the Technology Plan Appendix
Exoplanet Exploration Program

2018 Technology Selection and Prioritization Process Results

• In the 2017 Technology Plan Appendix, we had 18 items on the prioritized Technology List and 4 on the Watch List

• This summer, we received 37 technology inputs from the community
  – 14 from LUVOIR STDT
  – 15 from HabEx STDT
  – 4 from OST STDT
  – 2 from community at large
  – 2 redirected from COR

• Results:
  – None were rejected
  – 32 were consolidated into existing technologies already on the List
  – 5 new additions to the Technology List
  – 2 from Watch List upgraded to the Technology List
  – 0 additions to the Watch List
  – 1 listed technology was broken down into 3 finer component/subsystem technologies

• There are now 24 technologies on the 2018 prioritized list and 2 on the Watch List https://exoplanets.nasa.gov/exep/technology/gap-lists/
## 2018 ExEP Prioritized Technology List

<table>
<thead>
<tr>
<th>Tech. ID</th>
<th>Technology Title</th>
<th>Impact</th>
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<th>2018 Score</th>
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**Carried over from 2017**

**New to list in 2018**
# Investments in ExEP Technologies

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V-NIR Coronagraph/Telescope Technology Gaps

Contrast

CG-2: Coronagraph Architecture
CG-3: Deformable Mirrors
CG-4: Data Post-Processing

Angular Resolution

CG-1: Large Monolith Mirrors
CG-1: Segmented Mirrors

Contrast Stability

CG-5: Wavefront Sensing and Control
CG-6: Mirror Segment Phasing
CG-7: Telescope Vibration Sensing and Control or Reduction

Detection Sensitivity

Ultra-low Noise Visible (CG-8) and Infrared (CG-9) Detectors
Starshade Technology Gaps

Starlight Suppression

S-1: Controlling Scattered Sunlight

S-2: Starlight Suppression and Model Validation

S-3: Lateral Formation Sensing

Deployment Accuracy and Shape Stability

S-4: Petal Shape And Stability

S-5: Petal Positioning Accuracy and Opaque Structure
Mid-IR Coronagraph/Telescope Technology Gaps

Contrast

CG-15: Mid-IR Coronagraph Optics and Architecture

CG-16: Cryogenic Deformable Mirror

Angular Resolution

CG-14: Mid-IR Large Aperture Telescopes

Detection Sensitivity

CG-13: Low-Noise Mid-IR Detectors
Other Technology Gaps

UV Contrast

CG-10 UV/V/NIR Mirror Coatings

UV Detection Sensitivity

CG-12: Ultra-low Noise UV Detectors

Stellar Reflex Motion Sensitivity

M-1: Ground-based Ultra-high Precision Radial Velocity

Transit Spectroscopy Sensitivity

M-2: Laser Frequency Combs for Space-based EPRV

M-3: Astrometry

M-4: Ultra-stable Mid-IR Detectors for Transit Spectroscopy