Exoplanet Exploration Program Technology Update

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Technology Activities

Technology Gaps

Strategic Astrophysics Technology Grants
- Coronagraph architectures: modeling and demonstrations
- Wavefront control
- Extreme Precision Radial Velocity
- Detectors

Ultra-Stable Coronagraph Testbeds

Deformable Mirror Survey

Extreme Precision Radial Velocity

Starshade Technology Development

Segmented Coronagraph Design & Analysis Study

Roman/CGI

Zernike Wavefront Sensor

Coronagraph architectures: modeling and demonstrations

Wavefront control

Extreme Precision Radial Velocity

Detectors
Strategic Astrophysics Technology (1/2)

- 4 coronagraph masks/architectures
  - Vortex Coronagraph (Serabyn/NASA-JPL)
  - Phase Induced Amplitude Apodization Complex Mask Coronagraph (Belikov/NASA-ARC)
  - Apodized Pupil Lyot Coronagraph (Soummer/STScI)
  - Super-Lyot Coronagraph (Trauger/NASA-JPL)

- 4 wavefront-control techniques
  - Single mode fiber and optimization for spectroscopy (Mawet/Caltech)
  - Multi-star wavefront control demos (Belikov/NASA-ARC)
  - WFC using light outside the dark field (Guyon/UA)
  - MEMS deformable mirrors (Bierden/BMC)

- Polarization & Coronagraphy (Breckinridge/UA)
Detectors

- Vis-band rad-hard photon-counting detectors (Rauscher/NASA-GSFC)
- Ultra-stable mid-IR detector array (Staguhn/JHU)

Extreme Precision Radial Velocity

- Micro-resonator optical etalon for radial velocity measurements (Leifer/NASA-JPL)

https://exoplanets.nasa.gov/exep/technology/TDEM-awards/
Decadal Survey Testbed (DST)

- Coronagraph testbed specifically designed for opto-mechanical stability permitting demonstration of $10^{-10}$ contrast

- Zernike wavefront sensor commissioned in DST, achieving picometer sensitivity, and available to investigators

- Segmented pupil (static) will commence later in 2020, targeting large space telescope concepts; also installing EMCCD
Segmented Coronagraph Design & Analysis

- **2020 Objectives:**
  - Investigate sensitivity of science yield to telescope aberrations/instabilities
  - Investigate how coronagraph requirements drive telescope requirements

- **Year-to-Date Accomplishments**
  - Produced end-to-end propagation model
  - Incorporated quasi-static and dynamic telescope aberrations

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**Quasi-Static Segment Deformations (Coyle, East)**

**Snapshots of Dynamic Wavefront Errors (Chopra, Dewell, Nordt)**

**Preliminary Contrast Result, APLC w/ Angular Differential Imaging (Ruane, JPL)**
Deformable Mirror Survey

• Have we identified all candidate deformable mirrors that might be suitable for a future exoplanet direct imaging mission?

• A 1-year survey to assemble a Subject-Matter Expert team, define requirements, perform a global fact-finding effort, and write a report.

• Identify novel wavefront control technologies that could mature rapidly.

• Current Status: Defined requirements with Subject Matter Experts, fact finding ongoing with vendors.

• Report to be made public at the end of the year
Extreme Precision Radial Velocity

- Extreme Precision Radial Velocity Initiative Plan delivered to NASA and NSF in March 2020

- See upcoming talk by Scott Gaudi and Jenn Burt for the details!
Exoplanet Exploration Technology Colloquium Series

• Telescope Stability + Coronagraph modeling

• Workshop on Advanced Wavefront Sensing for Coronagraphy

• Update on Starshade Technology Development

• Recordings and slides available here:
  – https://exoplanets.nasa.gov/exep/technology/tech_colloquium/
The Three Starshade Technology Gaps

(1) Starlight Suppression
- Suppressing scattered light off petal edges from off-axis sunlight (S-1)
- Suppressing diffracted light from on-axis starlight and optical modeling (S-2)

(2) Formation Sensing
- Sensing the lateral offset between the spacecraft (S-3)
- Fabricating the petals to high accuracy (S-4)

(3) Deployment Accuracy and Shape Stability
- Positioning the petals to high accuracy, blocking on-axis starlight, maintaining overall shape on a highly stable structure (S-5)

https://exoplanets.nasa.gov/exep/technology/starshade/
Starlight Suppression and Edge Scatter

- Validate models of starshade performance
- Princeton testbed has been used to demonstrate starlight suppression to < 10^{-10} over a 10% band of sub-scale starshade
- Last step: measure deliberately misshapen subscale starshades and compare with model predictions
Starlight Suppression and Edge Scatter

- Demonstrated starshade optical edge limits Solar scatter performance to lobe dimmer than mag 25 and maintains performance after thermal cycling
Shape Accuracy: Critical Features demonstrated

- Starshade Petal System successfully demonstrated to maintain prelaunch shape within +/- 70 µm after deploy and thermal cycles
Full Scale Inner Disk

- Integrated solar cells
- Gravity offloading

(a) Deployed
(b) Stowed
Shape Accuracy: Critical Features demonstrated

- Full Scale Prototype Tested

- Inner disk deployment dimensional stability with thermal cycles and storage successfully demonstrated to +/- 300 µm
Starshade Shape Stability: critical components demonstrated

- On-orbit thermal stability on-orbit of petal critical dimensions demonstrated to +/- 80 µm through measurement and models.
Starshade Shape Stability: critical components demonstrated

- Thermal stability on-orbit of critical parts of inner disk demonstrated to +/- 200 μm
Starshade Technology Gaps Scorecard

https://exoplanets.nasa.gov/exep/technology/starshade/

(1) Starlight Suppression

Suppressing diffracted light from on-axis starlight and optical modeling (S-2)

Suppressing scattered light off petal edges from off-axis sunlight (S-1)

(2) Formation Sensing

Sensing the lateral offset between the spacecraft (S-3)

(3) Deployment Accuracy and Shape Stability

Positioning the petals to high accuracy, blocking on-axis starlight, maintaining overall shape on a highly stable structure (S-5)

Fabricating the petals to high accuracy (S-4)

One milestone remaining!

Remaining accuracy and stability milestones complete by 2023
Looking ahead..

- **SAT Results coming:**
  - Final Reports on Polarization, MEMS DMs
  - Lab Coronagraph demonstrations of PIAACMC, Vortex, HLC
  - Further upgrades to DST – segmented pupil, EMCCD

- **Starshade work continues:** subscale optical demos, deployment shape and stability demos

- **Segmented Coronagraph Design and Analysis:** telescope tolerancing results

- **Roman/CGI:** Zernike Wavefront Sensor and Multi-Star Wavefront Control masks in spare slots

- **Extreme Precision Radial Velocity solicitation coming in August**

- **Astro2020 coming 2021**
Want to get involved?

- Please contact me
- In July or August 2020, I plan to offer a 1-hour ExEP Technology Primer briefing: a deeper dive into our technology activities
  
  - Look for an email on ExoPAGannounce
BACKUP
Starshade Technology Activity (S5)
Technology Milestones Scorecard

Starlight Suppression
- Complete 2020:
  - Contrast NB 1A
  - Contrast BB 1B
  - Modeling 2
- Complete 2023:
  - Milestone Completed
  - Report under Review

Scattered Sunlight
- Edges 3
- Sensing 4

Formation Flying
- Critical Features
- All Features

Shape Accuracy
- Petal 5A
- Truss Bay 7A
- Inner Disk 7C

Shape Stability
- Petal 6A
- Inner Disk 8A

from Phil Willems
Technology Gap List

- **Astrophysics Technology Gap List**
  - Technology gaps for all three NASA Astrophysics Division (APD)’s programs
  - Database of technology activities:
    - [http://astrostrategictech.us/](http://astrostrategictech.us/)
    - Update coming in 2021, post-decadal

- **Exoplanet Technology Gap List**
  - Subset of APD gap list corresponding to exoplanet science:
    - [https://exoplanets.nasa.gov/exep/technology/gap-lists/](https://exoplanets.nasa.gov/exep/technology/gap-lists/)
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
Other Technology Gaps

UV Contrast

UV Detection Sensitivity

UV Contrast

CG-10 UV/V/NIR Mirror Coatings

Stellar Reflex Motion Sensitivity

CG-12: Ultra-low Noise UV Detectors

Transit Spectroscopy Sensitivity

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

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

M-3: Astrometry

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