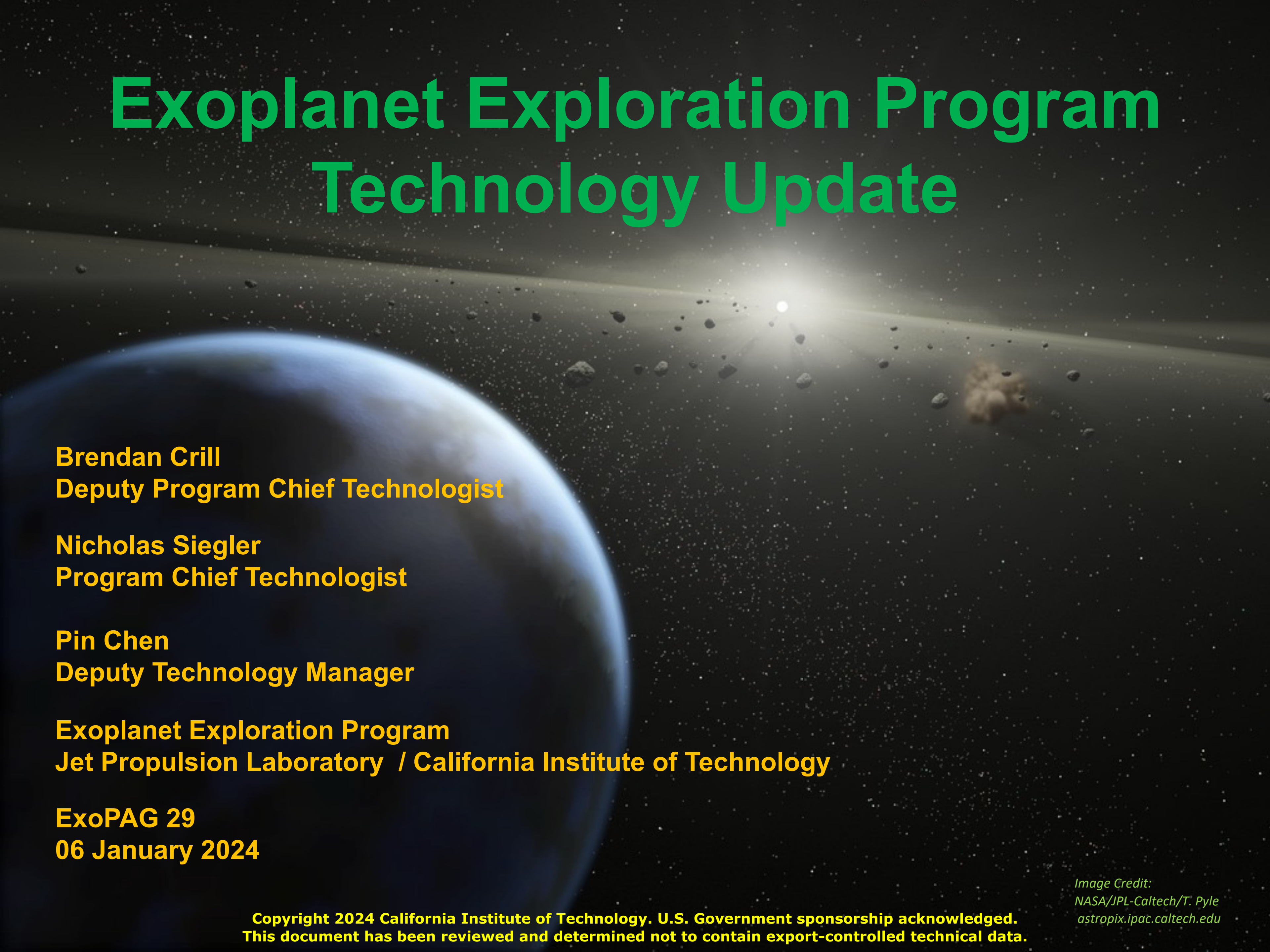

Exoplanet Exploration Program Technology Update

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Exoplanet Exploration Program
Jet Propulsion Laboratory / California Institute of Technology

ExoPAG 29
06 January 2024

Image Credit:
NASA/JPL-Caltech/T. Pyle
astropix.ipac.caltech.edu

ExEP Develops Technology for Future Exoplanet Missions

Since we last met:

Five ExEP technology initiatives all launched (some completed):

1. **Coronagraph Technology Roadmap**
   Creating a comprehensive plan to mature coronagraph technology

2. **Deformable Mirror Technology Roadmap**
   Created draft requirements, shared with vendors

3. **Coronagraph Design Survey**
   Investigating 17 coronagraph designs: traditional to immature to emerging

4. **Segmented Optical Telescope Assembly Simulator**
   Demonstrated a segmented pupil phase mask

5. **Starlight Suppression Technology Workshop**
   Held in August 2023 in Pasadena; all talks posted online including pedagogical talks on coronagraph, starshade, and terrestrial exoplanet direct imaging science

2024 Update to Astrophysics Technology Gap List

- **The Astrophysics Division maintains a prioritized Technology Gap List**
  - A technology gap is the difference between a capability needed to enable a future mission and the current state-of-the-art

- **Program Office technologists jointly carry out a biennial Technology Gap List Process – last update in 2022**

  - **Identify Technology Gaps** applicable to Astrophysics strategic objectives based on 2020 Decadal Survey: Habitable Worlds Observatory is highest priority

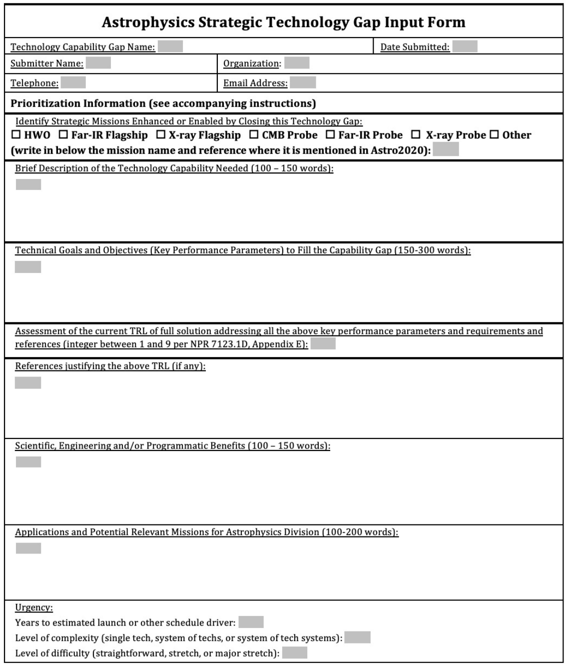
  - **Rank Technology Gaps** to prioritize them for investment

  - **Inform the community** (particularly SAT proposers) of NASA's technology needs

- **Published in the NASA Astrophysics Biennial Technology Report**

Submit Candidate Technology Gaps

- **You can help with the Technology Gap List update!**
  - We rely on the science/technology community to help identify missing capabilities needed to enable future NASA missions
- **Please review current Gap List**
- **Submit Candidate Technology Gaps**
  - Anyone can submit candidate gaps via a Technology Gap Submission Form available via ExEP/PhysCOS/COR websites
- **Submission deadline for this cycle is <u>June 3, 2024</u>**
- **New prioritized Gap List to be published in ~September 2024**



Astrophysics Strategic Technology Gap Input Form

Technology Capability Gap Name:	Date Submitted:
Submitter Name:	Organization:
Telephone:	Email Address:

Prioritization Information (see accompanying instructions)

Identify Strategic Missions Enhanced or Enabled by Closing this Technology Gap:
☐ **HWO** ☐ **Far-IR Flagship** ☐ **X-ray Flagship** ☐ **CMB Probe** ☐ **Far-IR Probe** ☐ **X-ray Probe** ☐ **Other (write in below the mission name and reference where it is mentioned in Astro2020):**

Brief Description of the Technology Capability Needed (100 – 150 words):

Technical Goals and Objectives (Key Performance Parameters) to Fill the Capability Gap (150-300 words):

Assessment of the current TRL of full solution addressing all the above key performance parameters and requirements and references (integer between 1 and 9 per NPR 7123.1D, Appendix E):

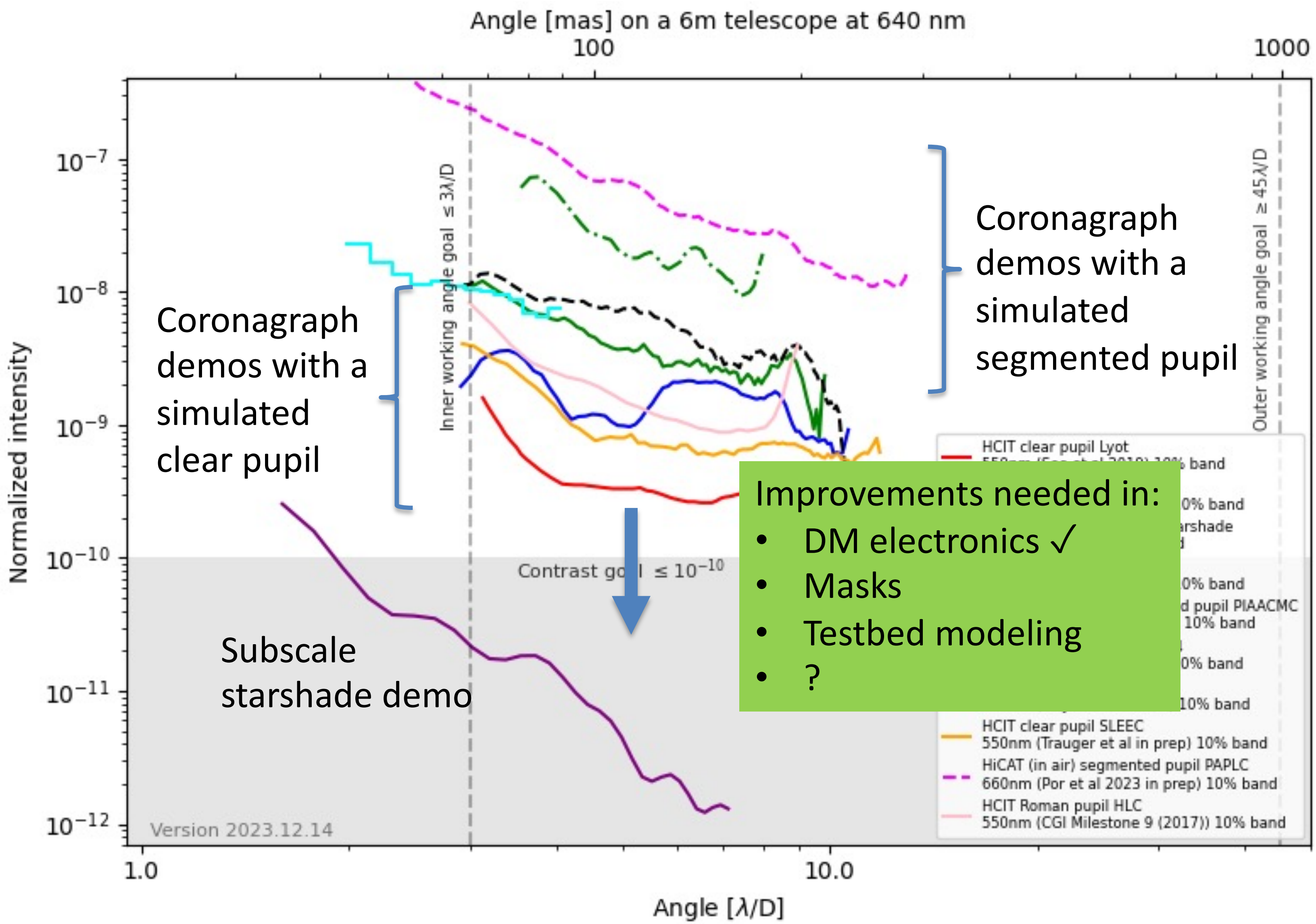
References justifying the above TRL (if any):

Scientific, Engineering and/or Programmatic Benefits (100 – 150 words):

Applications and Potential Relevant Missions for Astrophysics Division (100-200 words):

Urgency:
Years to estimated launch or other schedule driver:
Level of complexity (single tech, system of techs, or system of tech systems):
Level of difficulty (straightforward, stretch, or major stretch):

Recent Starlight Suppression Lab Demos (10% science bandwidth)

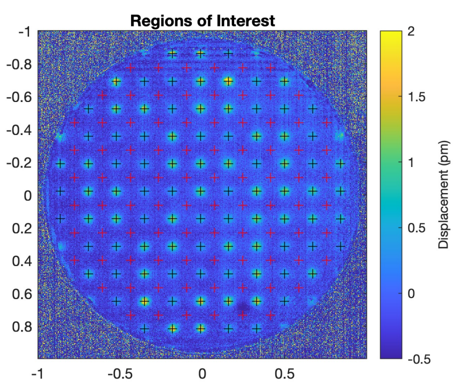


Vacuum Coronagraph Testbed Updates

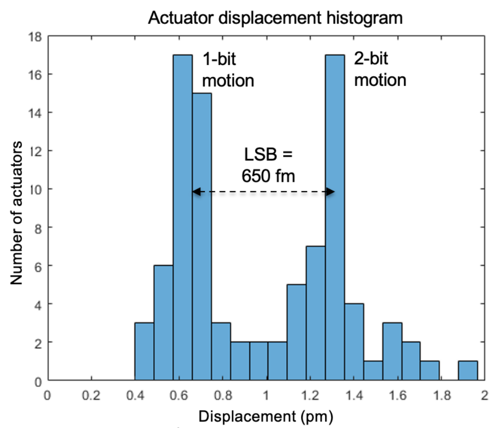
Available to SAT Proposers!

High Resolution Deformable Mirror Drive Electronics

- 20-bit resolution
- Measured 0.65 pm optical resolution
- Stability better than 1pm/hr



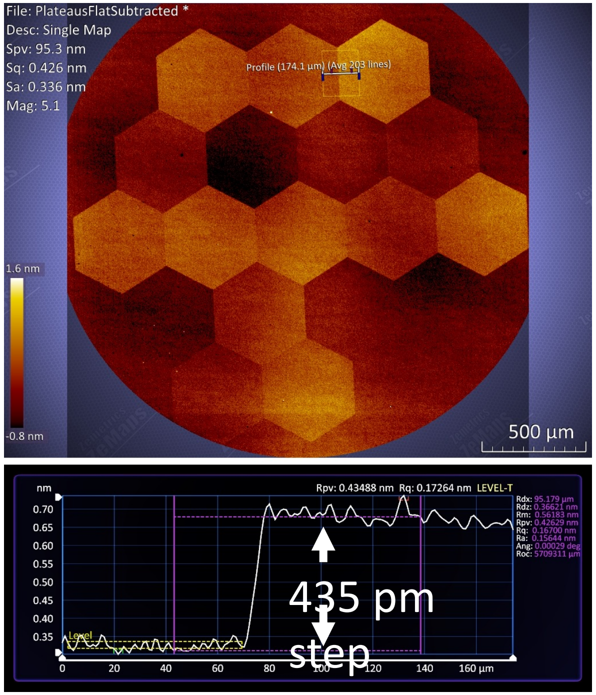
Wavefront showing 1 pm pokes



Histogram showing resolution 1 and 2-bit pokes

Segmented Pupil Phase Mask

- Enabling simulated segmented mirror coronagraph demos



Optical path difference error measured across two segmented hexagons from Prototype 1 (2.5 mm); Step size differences are produced through multiple overlapping rounds of photolithography and e-beam deposition.
(image credit: Dr Dan Shanks, JPL)

Six new exoplanet SAT-2022s awarded

- **Starshade:**
  - Starshade Petal Fabrication and Accuracy Demonstration at Full-Scale for IROUV Great Observatory
    PI: Arya (Stanford)
- **Coronagraphy:**
  - A Low-order Hardware Implementation for Sensing and Control in Exoplanet Imaging
    PI: Trauger (JPL)
  - Laboratory Demonstrations of High Contrast with Black Silicon Masks
    PI: Riggs (JPL)
  - Robust Deep Contrast Imaging with Self-Calibrating Coronagraph Systems
    PI: Guyon (Arizona)
- **Low-vibration propulsion:**
  - Colloid Thruster Life Testing and Modeling
    PI: Marese-Reading (JPL)
- **Segmented telescope:**
  - Demonstration of Advanced Wavefront Control for Segmented Aperture Telescopes
    PI: Tesch (JPL)
- **And other detector awards relevant to exoplanet technology (managed by PhysCOS/COR program office)**
  - Four megapixel sensor for ultra-low-background shortwave infrared astronomy PI: Bottom (Hawaii)
  - Characterizing Single-photon-sensing CMOS image sensors for NASA missions PI: Figer (RIT)

Starshade

- **Work continues in FY24 to close remaining technology gap: Deployment Accuracy and Shape Stability**

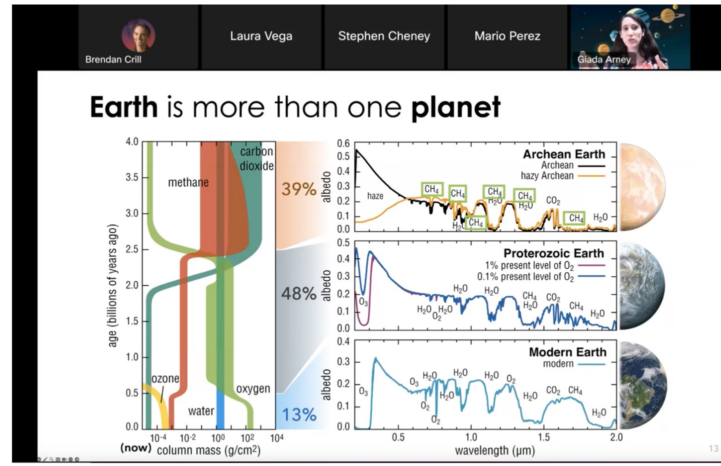
- **Assessment, by an external board, of starshade optical and formation flying technology maturity for HWO posted on starshade website**
  - Conclusion: The two technologies are low risk for a HWO starshade

- **An SAT-2022 award "Starshade Petal Fabrication and Accuracy Demonstration at Full-Scale for IROUV Great Observatory" (PI Manan Arya, Stanford) continues the funding in FY25**

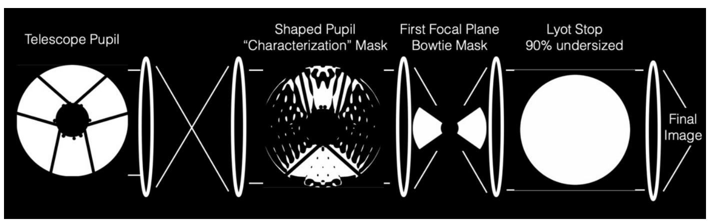
https://exoplanets.nasa.gov/exep/technology/starshade/

Exoplanet Exploration Technology Colloquium Series

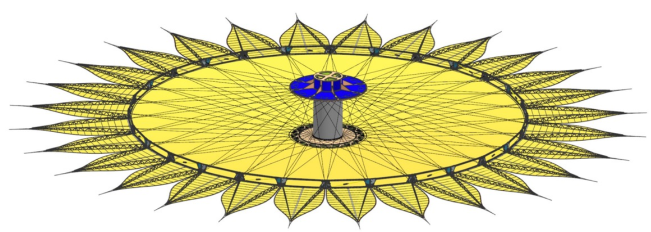
- ***Terrestrial Exoplanets 101***
  Giada Arney (NASA/GSFC)



- ***Coronagraphy 101***
  Jeremy Kasdin (Princeton)



- ***Starshades 101***
  Jeremy Kasdin (Princeton)



- **Recordings and slides available:**
  - https://exoplanets.nasa.gov/exep/technology/tech_colloquium/

How you can be involved

- **Propose to NASA programs to help develop technology:**
  - Strategic Astrophysics Technology (SAT)
  - Astrophysics Research and Analysis (APRA)
  - Nancy Grace Roman Technology Fellowships [proposals Due Jan 31, 2024]

- **Participate in the 2024 Technology Gap List process**

- **Tune in to the ExEP Technology Colloquium Series**
  - or propose a talk!

- **Participate in the ExEP technology initiatives**

BACKUP

2022 Astrophysics Technology Gaps

Tier 1 Technology Gaps

- Advanced Cryocoolers
- Coronagraph Contrast and Efficiency
- Coronagraph Stability
- Cryogenic Readouts for Large-Format Far-IR Detectors
- Heterodyne Far-IR Detector Systems
- High-Performance, Sub-Kelvin Coolers
- High-Reflectivity Broadband Far-UV-to-Near-IR Mirror Coatings
- High-Resolution, Large-Area, Lightweight X-ray Optics
- High-Throughput Bandpass Selection for UV/VIS
- High-Throughput, Large-Format Object Selection Technologies for Multi-Object and Integral Field Spectroscopy
- Large Cryogenic Optics for the Mid IR to Far IR
- Large-Format, High-Resolution Focal Plane Arrays
- Large-Format, Low-Darkrate, High-Efficiency, Photon-Counting, Solar-blind, Far- and Near-UV Detectors
- Large-Format, Low-Noise and Ultralow-Noise Far-IR Direct Detectors
- Long-Wavelength-Blocking Filters for X-ray Micro-Calorimeters
- Low-Stress, High-Stability, X-ray Reflective Coatings
- Mirror Technologies for High Angular Resolution (UV/Vis/Near IR)
- Stellar Reflex Motion Sensitivity – Astrometry
- Stellar Reflex Motion Sensitivity – Extreme Precision Radial Velocity
- Vis/Near-IR Detection Sensitivity

Tier 2 Technology Gaps

- Broadband X-ray Detectors
- Compact, Integrated Spectrometers for 100 to 1000 µm
- Far-IR Imaging Interferometer for High-Resolution Spectroscopy
- Far-IR Spatio-Spectral Interferometry
- Fast, Low-Noise, Megapixel X-ray Imaging Arrays with Moderate Spectral Resolution
- High-Efficiency X-ray Grating Arrays for High-Resolution Spectroscopy
- High-Resolution, Direct-Detection Spectrometers for Far-IR Wavelengths
- Improving the Calibration of Far-IR Heterodyne Measurements
- Large-Aperture Deployable Antennas for Far-IR/THz/sub-mm Astronomy for Frequencies over 100 GHz
- Large-Format, High-Spectral-Resolution, Small-Pixel X-ray Focal-Plane Arrays
- Polarization-Preserving Millimeter-Wave Optical Elements
- Precision Timing for Space-Based Astrophysics
- Rapid Readout Electronics for X-ray Detectors
- Starshade Deployment and Shape Stability
- Starshade Starlight Suppression and Model Validation
- UV Detection Sensitivity

Tier 3 Technology Gaps

- Advancement of X-ray Polarimeter Sensitivity
- Detection Stability in Mid-IR
- Far-UV Imaging Bandpass Filters
- High-Efficiency Far-UV Mirror
- High-Efficiency, Low-Scatter, High- and Low-Ruling-Density, High- and Low-Blazed-Angle UV Gratings
- High-Quantum-Efficiency, Solar-Blind, Broadband Near-UV Detector
- Photon-Counting, Large-Format UV Detectors
- Short-Wave UV Coatings
- Warm Readout Electronics for Large-Format Far-IR Detectors

Tier 4 Technology Gaps

- Advanced Millimeter-Wave Focal-Plane Arrays for CMB Polarimetry
- Improving the Photometric and Spectro-Photometric Precision of Time-Domain and Time-Series Measurements
- UV/Opt/Near-IR Tunable Narrow-Band Imaging Capability
- Very-Wide-Field Focusing Instrument for Time-Domain X-ray Astronomy

Tier 5 Technology Gaps

- Complex Ultra-Stable Structures for Future Gravitational-Wave Missions
- Disturbance Reduction for Gravitational-Wave Missions
- Gravitational Reference Sensor
- High-Performance Spectral Dispersion Component/Device
- High-Power, High-Stability Laser for Gravitational-Wave Missions
- Laser Phase Measurement Chain for a Decihertz Gravitational-Wave Mission
- Micro-Newton Thrusters for Gravitational Wave-Missions
- Stable Telescopes for Gravitational Wave-Missions

The 10 ExEP Technology Gaps

Where to find the Gap List

ExEP
NASA EXOPLANET EXPLORATION PROGRAM

https://apd440.gsfc.nasa.gov/tech_gap_priorities.html

ASTROPHYSICS TECHNOLOGY DEVELOPMENT

Overview | Technology | Outreach

Astrophysics Program Offices

2022 Astrophysics Strategic Technology Gaps

TECHNOLOGY GAPS: OVERVIEW / TECH GAP PRIORITIES / PRIORITIZATION PROCESS / TECH GAP DESCRIPTIONS

Gap Name	Description	Current SOA	TRL	Performance Goals and Objectives	Scientific, Engineering and/or Programmatic Benefits	Applications and Potential Relevant Missions	Urgency
Coronagraph Stability	The capability to maintain the deep starlight suppression provided by a coronagraph for a time period long enough to detect light from an exo-Earth.	RST CGI demonstrated ~10^{-8} contrast in a simulated dynamic environment using LOWFS (which obtained 12 pm focus sensitivity) SIM and non-NASA work has demonstrated nm accuracy and stability with laser metrology Capacitive gap sensors demonstrated at 10 pm 80 dB vibration isolation demonstrated Gaia cold gas microthrusters and LISA pathfinder colloidal microthrusters can reduce vibrations	3	Contrast stability on time scales needed for spectral measurements (possibly as long as days). Achieving this stability requires an integrated approach to the coronagraph and telescope, possibly including wavefront sense/control, metrology and correction of mirror segment phasing, vibration isolation/reduction This stability is likely to require wavefront error stability at the level of 10-100 pm per control step (of order 10 minutes). Sub-gaps that could partially or fully close this gap: - Ultra-stable Telescope - Integrated Modeling of Telescope/Coronagraph system - Disturbance Reduction and	This gap is likely to be closed by a combination of many factors in a coronagraph/observatory system, including active wavefront control at the coronagraph level, thermal control, active and passive ultra-stable structures, and disturbance isolation/ reduction. Integrated modeling for tracability to flight environments is likely to be a key capability to close this gap.	IR/O/UV Great Observatory; or any other coronagraph-based exoplanet direct-imaging mission.	Demonstration of feability and as much risk reduction as possible prior to mission formulation. TRL 6 in the mid-to-late 2020's.

Click on the tiers for details