National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

NASA SBIR Topic S2

Proximity Glare Suppression for Astronomical Coronagraphy (S2.01)
Precision Deployable Optical Structures and Metrology (S2.02)

Mirror Tech Days 2018
Raytheon Space Systems, El Segundo, CA

Nov 5, 2018

Stuart Shaklan

Jet Propulsion Laboratory

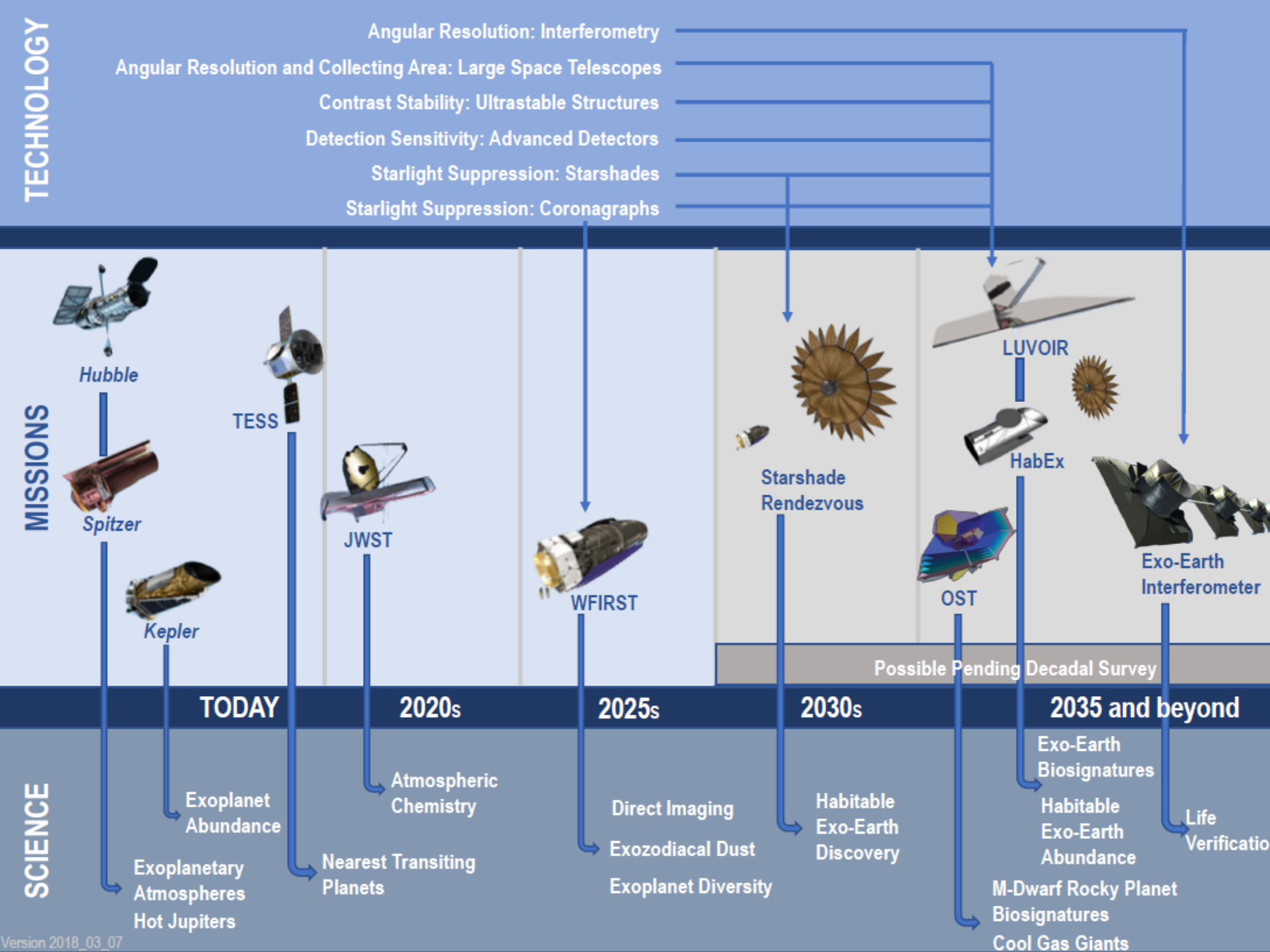
California Institute of Technology

Overview

- High Contrast Imaging
  - Technical challenges in coronagraphs and starshades
- S2.01 Subtopic Proximity Glare Suppression
- S2.02: Precision Deployable Optical Structures and Metrology
- Current Phase I and Phase II Proposals

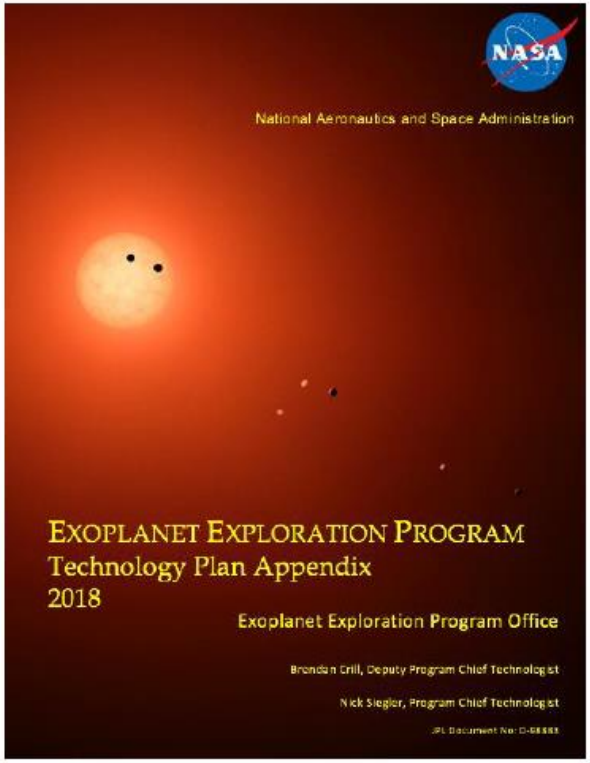
- Where to find information on High Contrast Imaging Technologies and Technology Gaps:

- https://exoplanets.nasa.gov/exep/technology/technology-overview/


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
Spitzer
Kepler
TESS
JWST
WFIRST
Starshade Rendezvous
LUVOIR
HabEx
OST
Exo-Earth Interferometer
Possible Pending Decadal Survey
TODAY
2020s
2025s
2030s
2035 and beyond
SCIENCE
Exoplanetary Atmospheres
Hot Jupiters
Exoplanet Abundance
Nearest Transiting Planets
Atmospheric Chemistry
Direct Imaging
Exozodiacal Dust
Exoplanet Diversity
Habitable Exo-Earth Discovery
M-Dwarf Rocky Planet Biosignatures
Cool Gas Giants
Exo-Earth Biosignatures
Habitable Exo-Earth Abundance
Life Verificatio
Version 2018_03_07

ExEP Technology List

ID	Technology	Technology Gap	Technology Description	Current Capabilities	Needed Capabilities
S-1	**Controlling Scattered Sunlight**	Starshade Contrast	Limit edge-scattered sunlight and diffracted starlight with optical petal edges that also handle stowed bending strain.	Machined graphite edges meet all specs but edge radius (≥ 10 μm); etched metal edges meet all specs but in-plane shape tolerance (Exo-S design).	Integrated petal optical edges maintaining precision in-plane shape requirements after deployment trials and limit solar glint contributing < 10^{-10} contrast at petal edges.



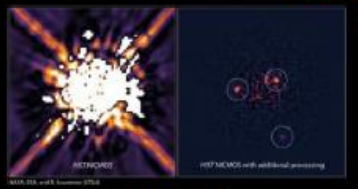
- **14 technology gaps**
- **24 technologies being currently tracked**
- **Technology List posted at:**
  https://exoplanets.nasa.gov/exep/technology/gap-lists/
- **Technology Plan Appendix posted at:**
  https://exoplanets.nasa.gov/exep/technology/technology-overview/

V-NIR Coronagraph/Telescope Technology Gaps

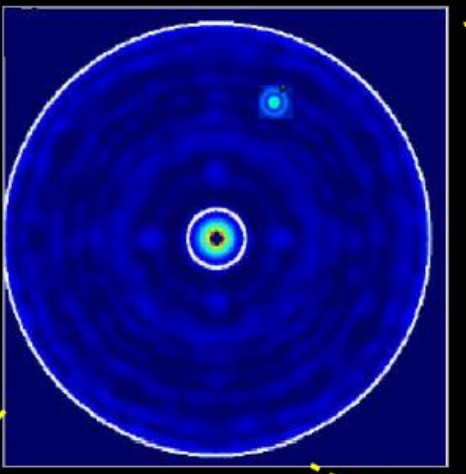
Contrast

CG-2: Coronagraph Architecture

CG-3: Deformable Mirrors

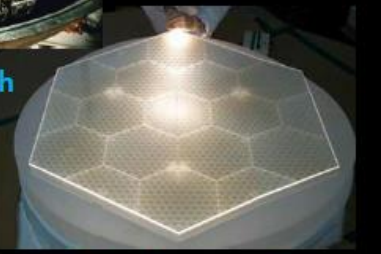


CG-4: Data Post-Processing



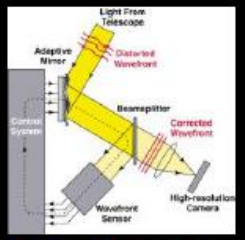
Angular Resolution

CG-1: Large Monolith Mirrors



CG-1: Segmented Mirrors

Contrast Stability

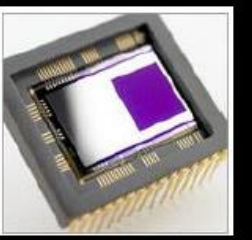


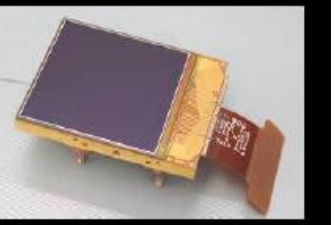
CG-5: Wavefront Sensing and Control

CG-6: Mirror Segment Phasing

CG-7: Telescope Vibration Sensing and Control or Reduction

Detection Sensitivity

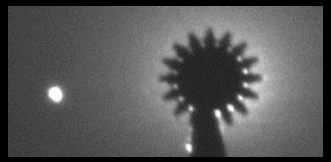


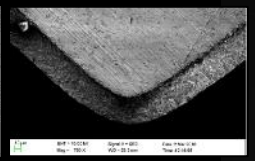


Ultra-low Noise Visible (CG-8) and Infrared (CG-9) Detectors

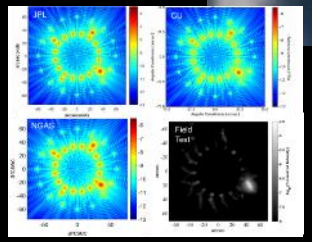
Starshade Technology Gaps as defined by ExEP TGL

(1) Starlight Suppression



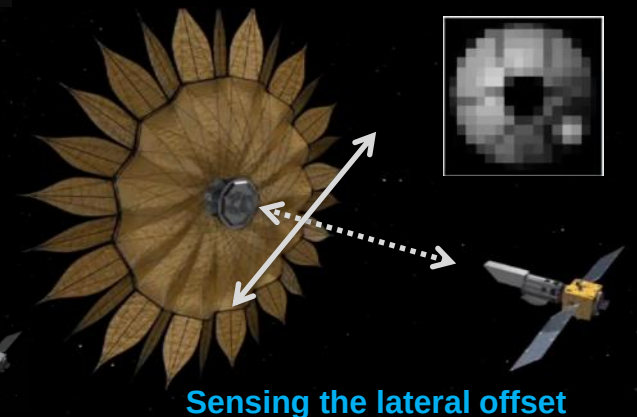


Suppressing scattered light off petal edges from off-axis Sunlight (S-1)



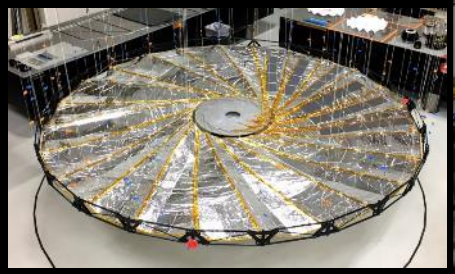
Suppressing diffracted light from on-axis starlight and optical modeling (S-2)

(2) Formation Flying

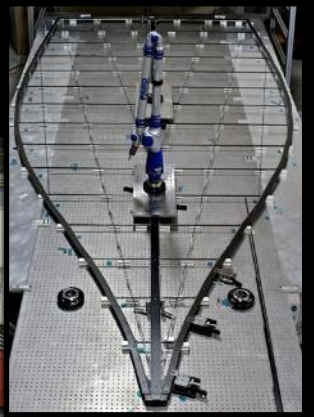


Sensing the lateral offset between the spacecraft (S-3)

(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)

S-# corresponds to ExEP Starshade Technology ID# (http://exoplanets.nasa.gov/exep/technology/gap-lists)

S2.01 Proximity Glare Suppression

Lead Center: JPL, subtopics mgr Stuart Shaklan
Participating Center(s): ARC, GSFC

- This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources.

Starlight Suppression Technologies

- Hybrid metal/dielectric, and polarization apodization masks for diffraction control of phase and amplitude for coronagraph scaled starshade experiments.
- Low-scatter, low-reflectivity, sharp, flexible edges for control of solar scatter in starshades.
- Systems to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of high-dynamic range apodizing masks.
- Methods to distinguish the coherent and incoherent scatter in a broad band speckle field.

S2.01 Cont'd

Wavefront Measurement and Control Technologies

- Small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10,000 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices.
- Multiplexers with ultra-low power dissipation for electrical connection to deformable mirrors.
- Low-order wavefront sensors for measuring wavefront instabilities to enable real-time control and post-processing of aberrations.
- Thermally and mechanically insensitive optical benches and systems.

S2.01 Cont'd

Optical Coating and Measurement Technologies

- Instruments capable of measuring polarization cross-talk and birefringence to parts per million.
- Polarization-insensitive coatings for large optics.
- Methods to measure the spectral reflectivity and polarization uniformity across large optics.
- Methods to apply carbon nanotube coatings on the surfaces of the coronagraphs for broadband suppression from visible to NIR.

Other

- Artificial star and planet point sources, with 1e10 dynamic range and uniform illumination of an f/25 optical system, working in the visible and near infrared.

S2.02 Precision Deployable Optical Structures and Metrology

Lead Center: JPL, subtopic mgr Greg Agnes
Participating Center(s): GSFC, LaRC

- This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost. :“Everything but the shiny stuff.”

Research areas of interest include:

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.

In particular, important subsystem considerations may include:

- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE < 1ppm) for deployable structures.
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

Current Phase I Awards

2018 Program Phase I		Announced May 25, 2018
S2.01	Boston Micromachines Corp.	Primary Tweeters: Segmented micro-mirrors for picometer-scale wavefront compensation in space-based observatories
S2.01	BEAM Engineering for Advanced Measurements	Broadband Vector Vortices for High Contrast Coronagraphy
S2.02	Goodman Technologies, LLC	Near-Zero CTE 3D Printed RoboSiC Deployable Truss Core Structures with Active Precision Adjustment

Current Phase II Awards

2017 Program Phase II		**Announced March 7, 2018**
S2.01	Microscale Inc.	Next-Generation Deformable Mirrors for Astronomical Coronagraphy by Utilizing PMN-PT Single Crystal Stack Actuators in Integration with Driver ASIC
S2.01	Boston Micromachines Corp.	Technology Developmnet for High-Actuator-Count MEMS DM Systems
S2.01	Photonic Cleaning Technologies LLC	Polymer Coating-Based Contaminant Control/Eliination for Exo-S Starshade Probe
S2.01	Lamda Consulting/Advanced Photonics	Proximity Glare Suppression Using Carbon Nanotubes
S2.02	Tendeg LLC	Redundant Starshade Truss Deployment Motor/Cable Assembly
2016 Program Phase II		**Announced March 8, 2017**
S2.01	Tendeg LLC	Robust Optical Edge for a Starshade Petal
S2.02	Tendeg LLC	Solar Array for a Starshade Inner Disk
2015 Phase II E funded in Summer/Fall 2018		
s2.01	Boston Micromachines Corp.	High Actuator Count DM
S2.02	Tendeg LLC	Design, build, and test of a medium Fidelity Petal Launch and Unfurling System

Statistics for 2018

- Phase I: 3 of 7 selected
- Phase II: 5 of 8 Phase I's selected for Phase II