Jet Propulsion Laboratory
California Institute of Technology

American Astronomical Society Meeting
Exoplanet Exploration Program Update Splinter Session
Seattle WA, January 10, 2019

NASA Exoplanet Exploration Program Technology

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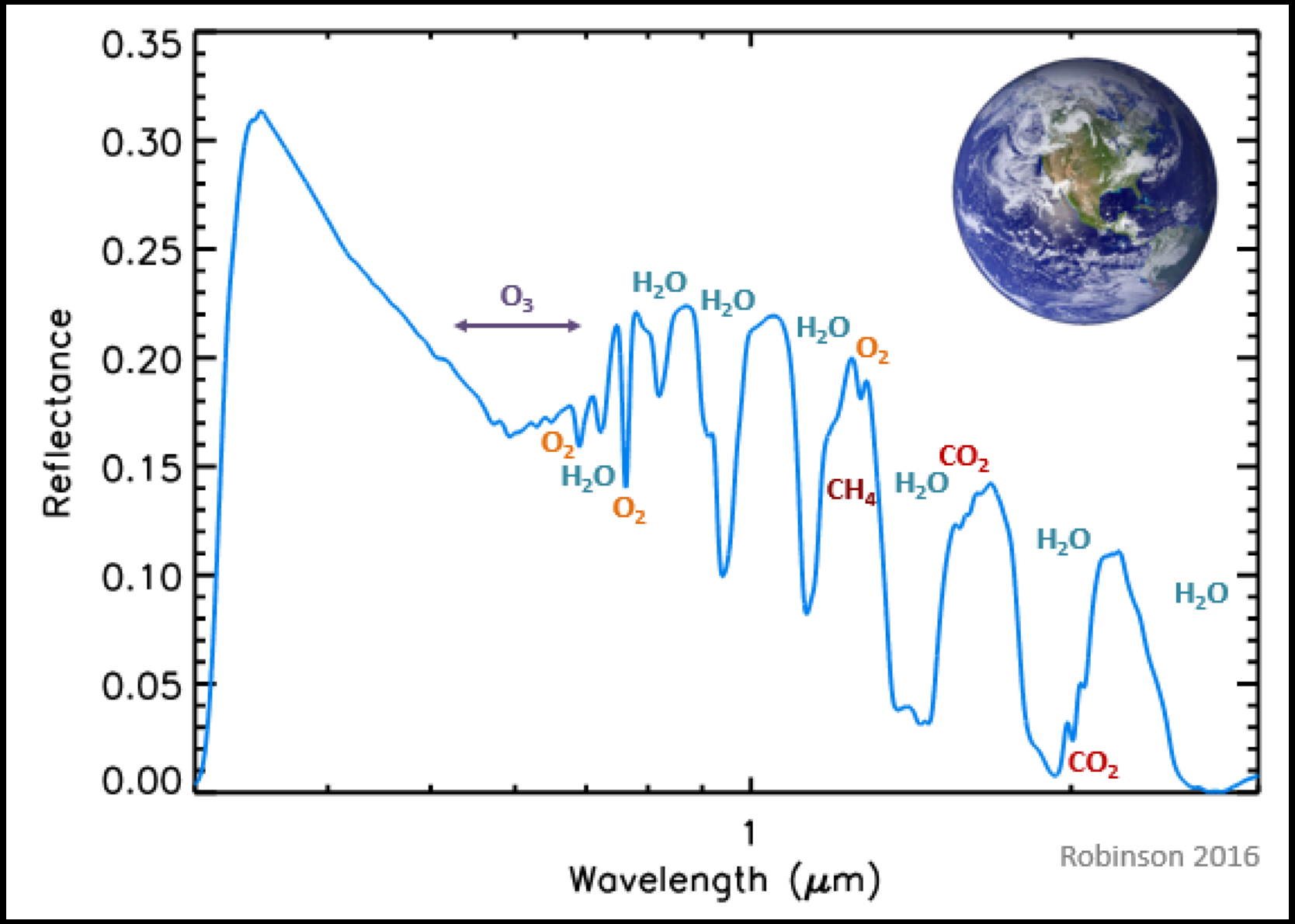
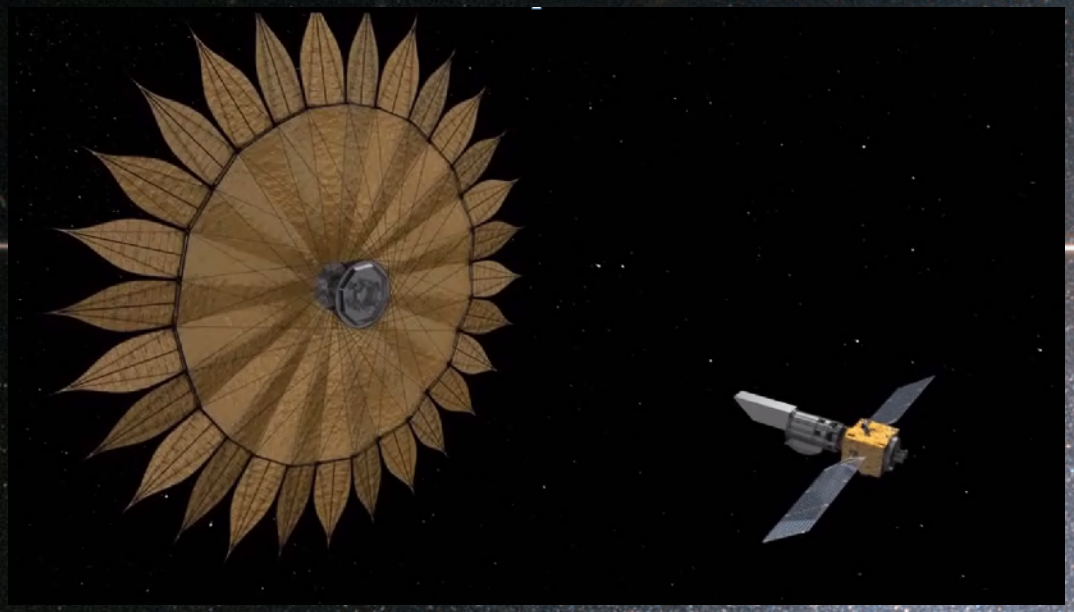
The Evidence for Life on Exoplanets

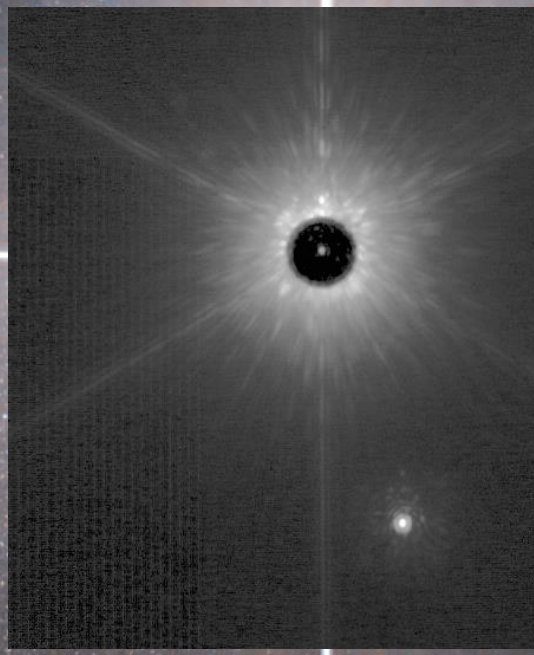
--reflected light spectroscopy



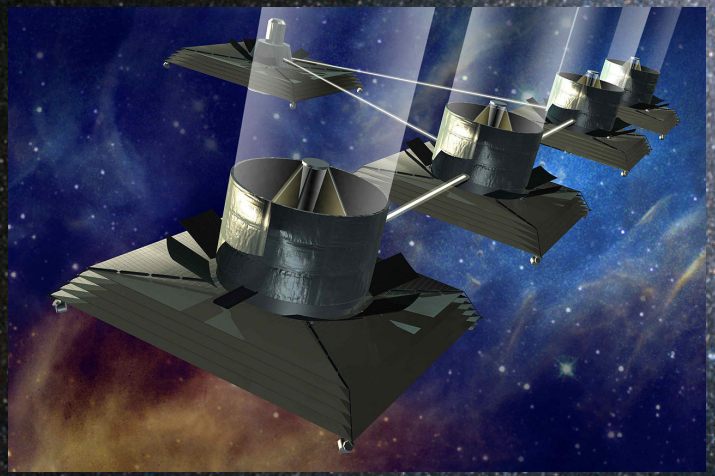
Starlight Suppression is the Key Technology in the Search for Life on Earth-Size Exoplanets

External Occulters (Starshades)

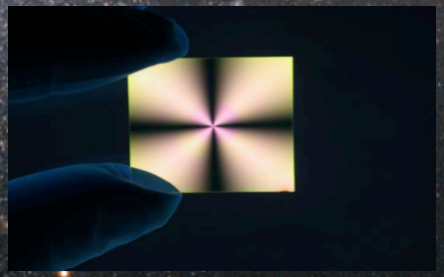




Nulling Interferometry



Internal Occulters (Coronagraphs)



2010 Decadal Survey Recommendation

Medium-scale

TABLE ES.4 Space: Recommended Activities—Medium-Scale (Priority Order)

Recommendation	Science	Appraisal of Costs[a]
1. New Worlds Technology Development Program	Preparation for a planet-imaging mission beyond 2020, including precursor science activities	$100M to $200M
2. Inflation Probe Technology Development Program	Cosmic microwave background (CMB)/ inflation technology development and preparation for a possible mission beyond 2020	$60M to $200M

"…high-priority science areas for which mid-term investments are needed beginning early in the decade, including development of a variety of technologies for exoplanet imaging, such as coronagraphs, interferometers, and starshades, leading to possible late-decade down-selecting."

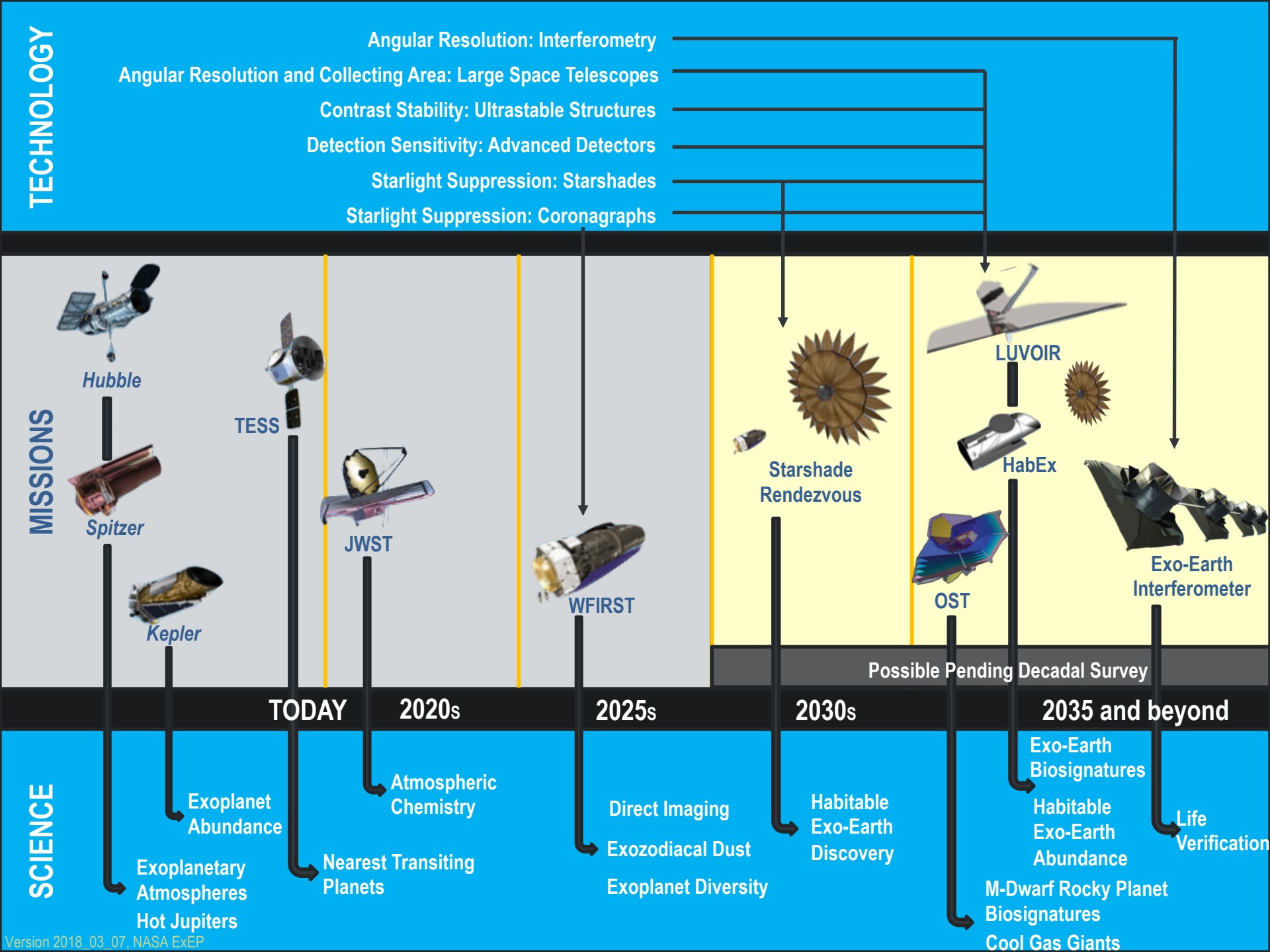
Exoplanet Science Strategy

Released by National Academies in September 2018

David Charbonneau (Harvard) Scott Gaudi (Ohio State University)

Featured 7 recommendations, including:

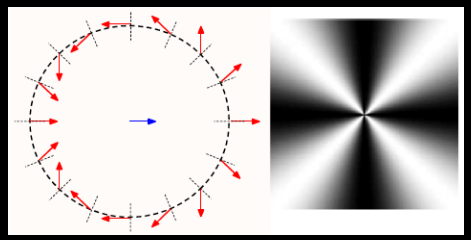
Recommendation: NASA should lead a large strategic direct imaging mission capable of measuring the reflected-light spectra of temperate terrestrial planets orbiting Sun-like stars.



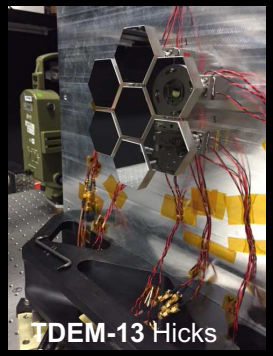
Version 2018_03_07, NASA ExEP

NASA TDEM Awards

- Annually competed awards solicited to meet NASA's priorities
- Active awards are advancing exoplanet direct-imaging technology and yields
- Coronagraphy
  - Vector Vortex (PI Serabyn/NASA-JPL)
  - Visible Nulling Coronagraph (PI Hicks/NASA-GSFC)
  - Deformable mirrors (PI Bierden/BMC, PI Helmbrecht/Iris AO)
  - Polarization (PI Breckenridge/UA)
  - Lyot Coronagraph (PI Trauger/NASA-JPL)
  - Phase-Induced Amplitude Apodization-Complex Mask Coronagraph (PI Belikov/NASA-Ames)
  - Apodized Pupil Lyot Coronagraph (PI Soummer/STScI)
  - Wavefront control techniques (PI Guyon/UA)
- Starshade
  - Re-directed to starshade technology activity

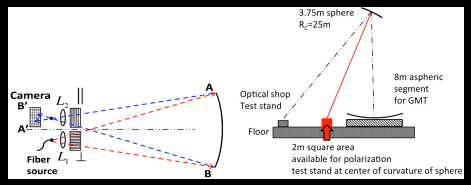


TDEM-14 Serabyn

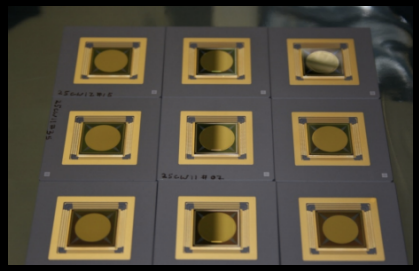


TDEM-13 Hicks

TDEM-17 Soummer



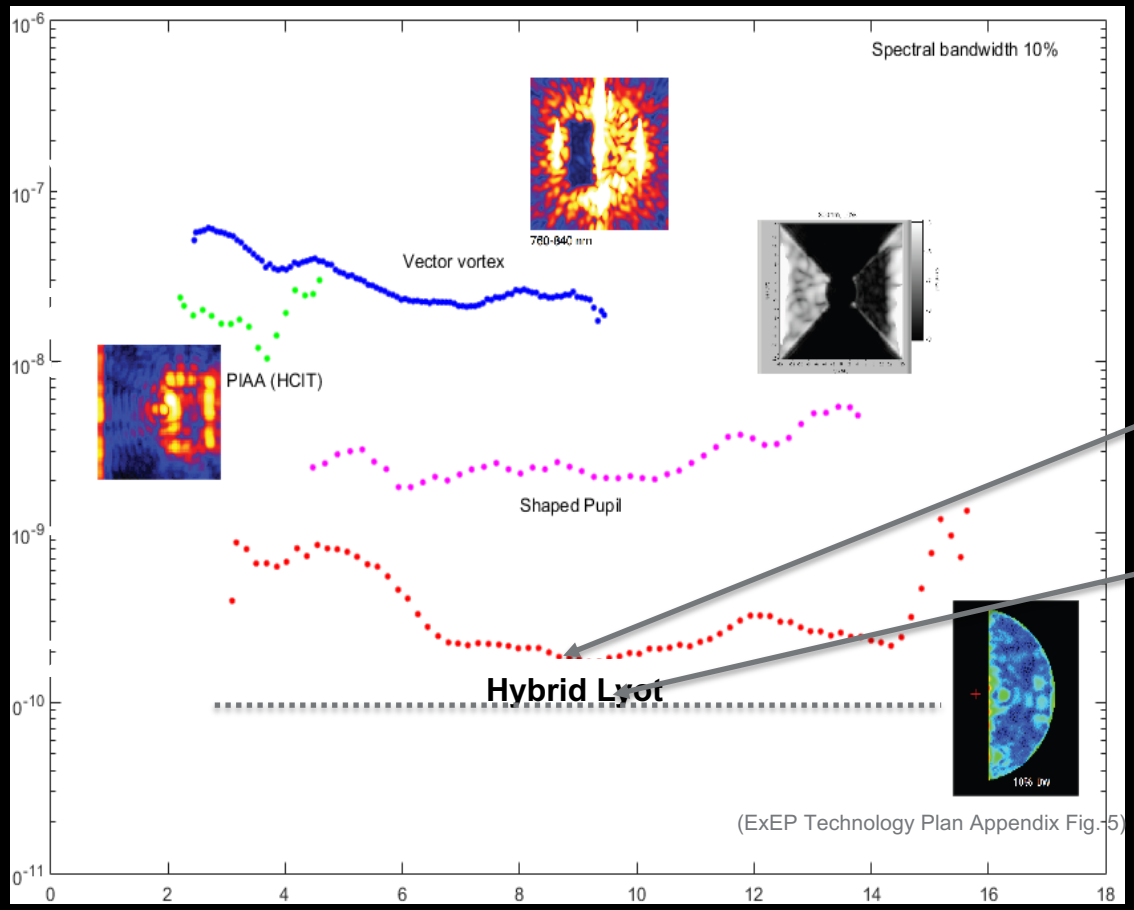
TDEM-15 Breckinridge

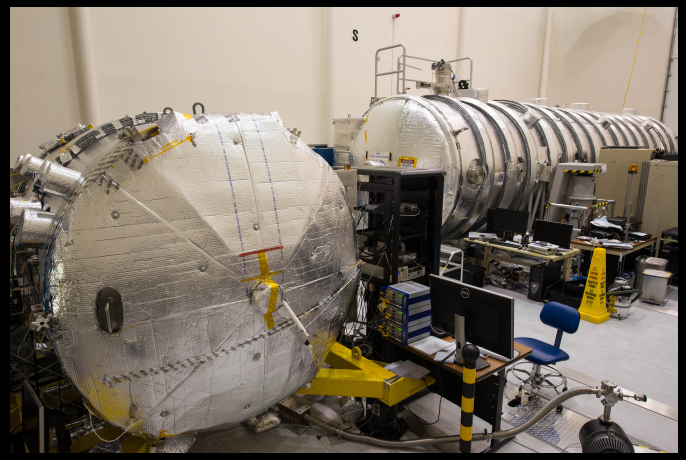


TDEM-10 Bierden

High-Contrast Imaging Testbed (HCIT)

Decadal Survey Testbed





Current best contrast demonstration with 10% band (Trauger (JPL)

<u>Decadal Survey Testbed</u>

Being commissioned with a Lyot coronagraph

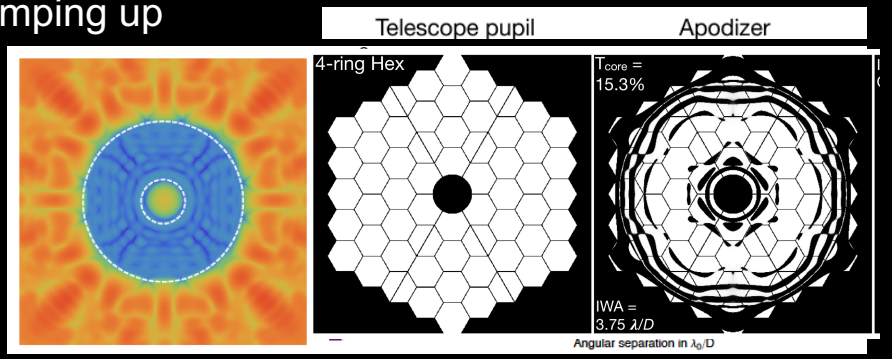
Phase I: meet 10^{-10} contrast with 10% band and a clear aperture in 2018

Phase II: replace clear pupil with a segmented/obscured (static) aperture in 2019

Phase III: replace static aperture with a dynamic segmented/obscured telescope simulator in 2020

Segmented Coronagraph Design & Analysis (SCDA) Study

- ExEP-led study to evaluate coronagraph designs for a segmented/obscured telescope
  - Stuart Shaklan (JPL) is Study Lead, five teams
  - 12 m class on-axis telescopes with central obscurations
  - Finite star size
  - Compared to clear apertures
- APLC design so far most successful
  - APLC: Apodized Pupil Lyot Coronagraph is being developed at the STSCI (Soummer)
  - APLC robustness against design tolerances and segment phasing errors being evaluated
  - Vector Vortex being optimized for finite star size and on-axis secondary
  - PIAACMC considered for longer-wavelength use
  - VNC experiencing challenges; HLC ramping up

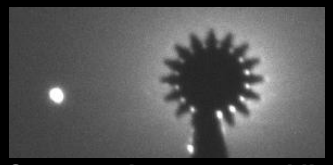


Starshade Technologies

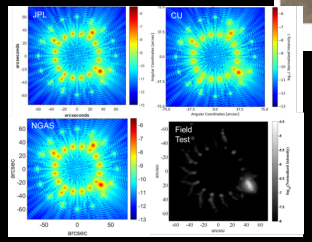
Maturing to TRL 5

(see P. Willems talk, Wednesday a.m.)

Starlight Suppression

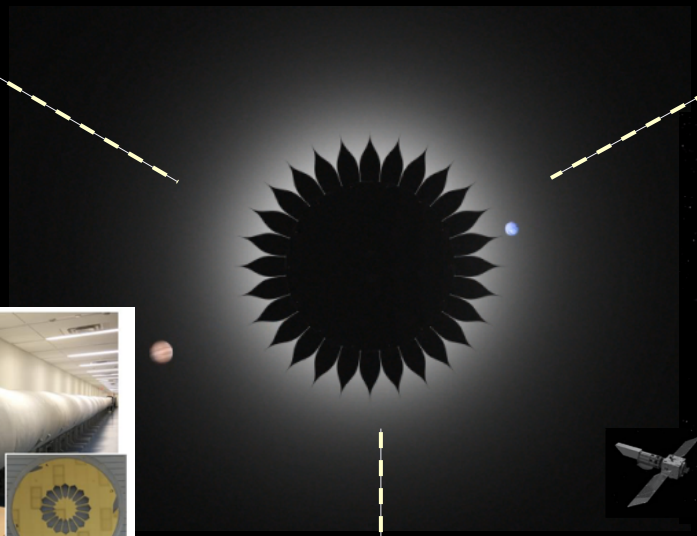


Suppressing scattered light off petal edges from off-axis Sunlight

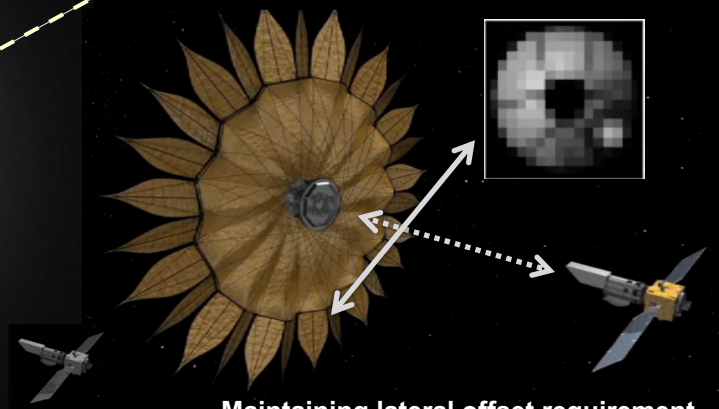


Model Validation & suppressing diffracted light from on-axis starlight

(see A. Harness talk, Wedesday a.m.)

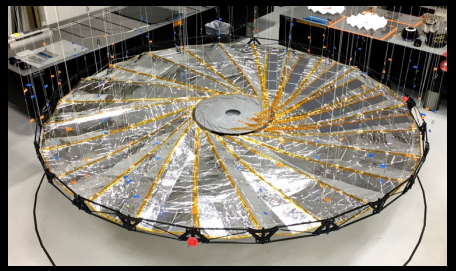


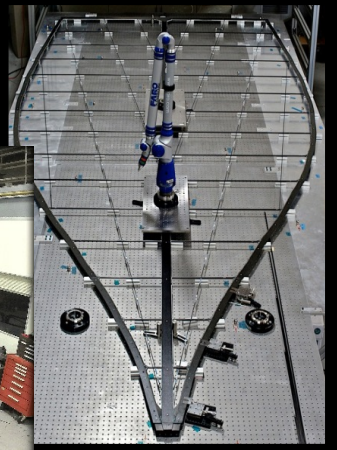
Formation Sensing



Maintaining lateral offset requirement between the spacecraft

Deployment Accuracy and Shape Stability





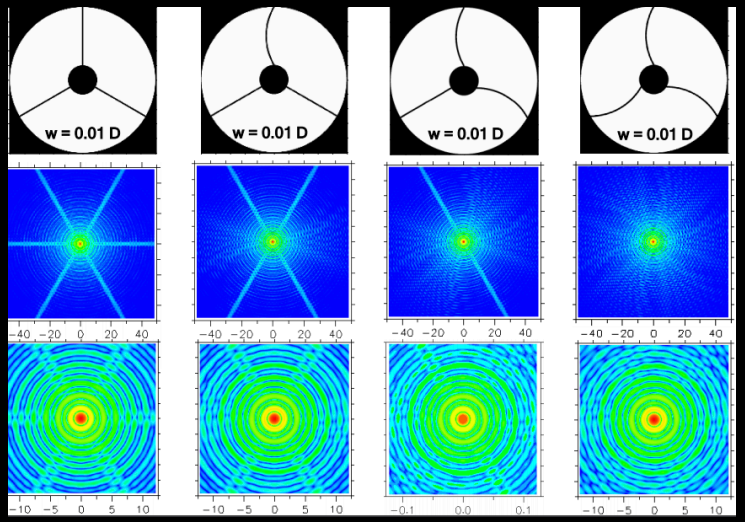
Fabricating the petals to high accuracy

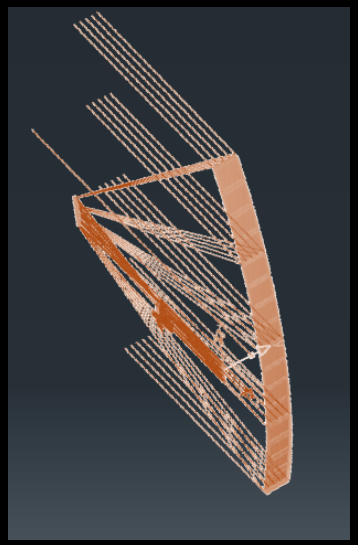
(see Tendeg talks, Wedesday a.m.)

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

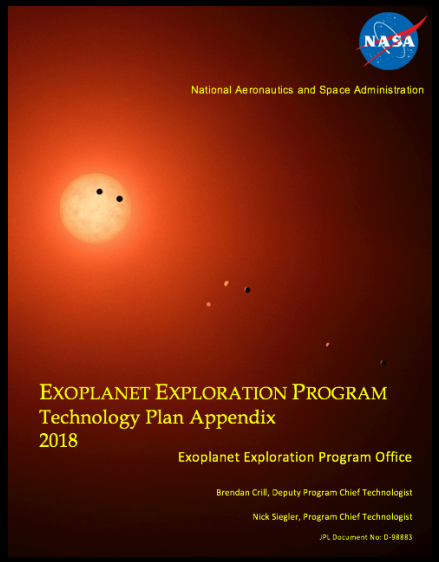
ExEP Technology Colloquium Series

- Recordings and slides available here: https://exoplanets.nasa.gov/exep/technology/tech_colloquium/
- Recent topics: Linear aperture telescope for the mid-IR,



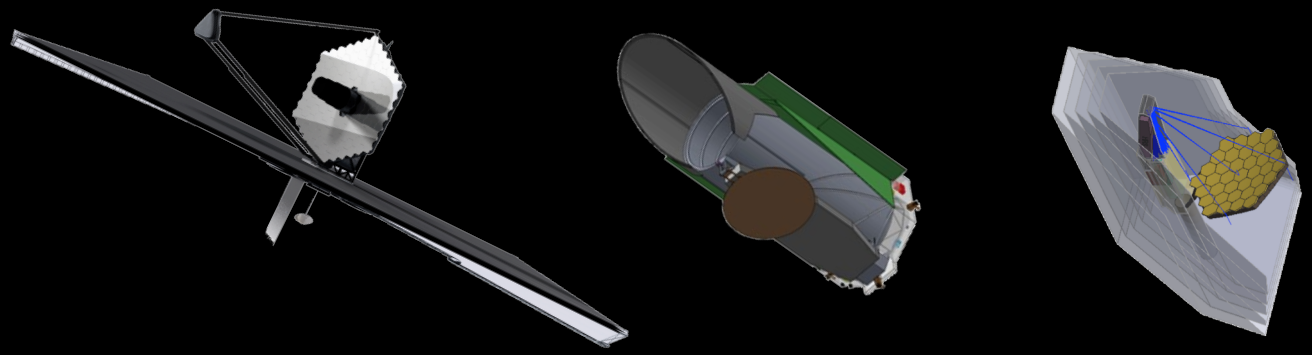


Towards an exo-Earth imaging and characterization mission



ExEP Technology Plan Appendix (2018): updated annually

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



- Large mission STDT interim reports (March 2018) final reports (2019)
- 2020 Decadal Survey final report (December 2020)
  - will set the nation's science priorities, including recommendations for NASA astrophysics missions and their technology needs

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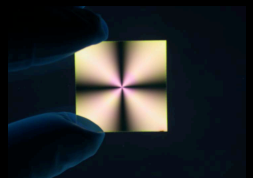
Please visit the NASA ExEP website for more details:

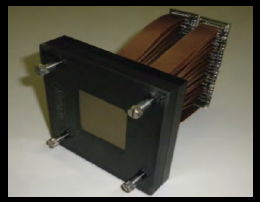
https://exoplanets.nasa.gov/exep/

V-NIR Coronagraph/Telescope Technology Gaps

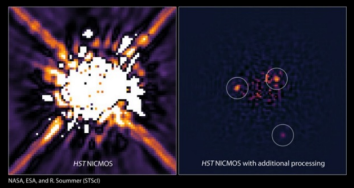
Contrast



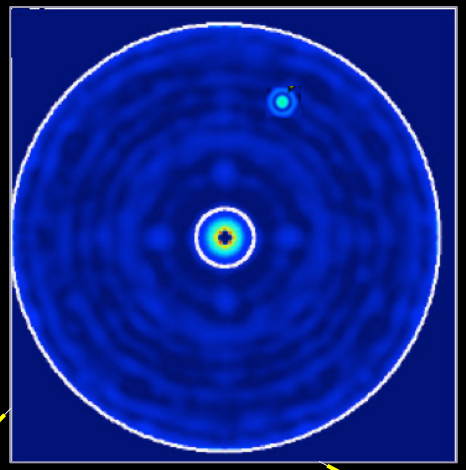
CG-2: Coronagraph Demonstrations and Modeling



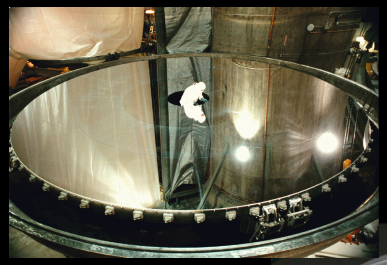
CG-3: Deformable mirrors



CG-4: Data post-processing



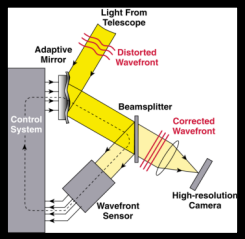
Angular Resolution



CG-1: Large monolith mirrors

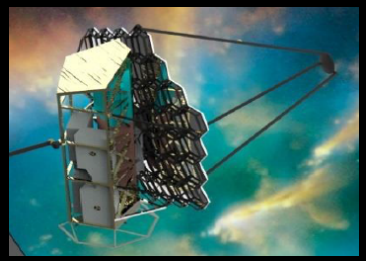
CG-1: Segmented mirrors

Contrast Stability



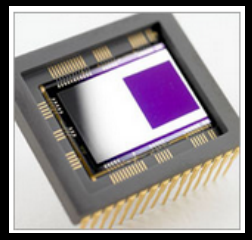
CG-5: Wavefront sensing and control

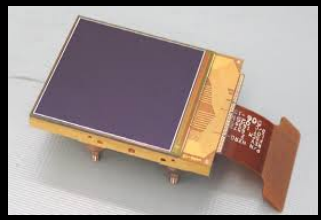
CG-6: Segment phasing and rigid body sensing and control



CG-7: Telescope vibration sensing and control or reduction

Detection Sensitivity

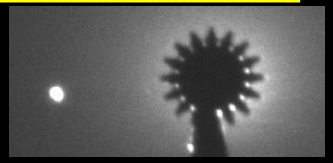




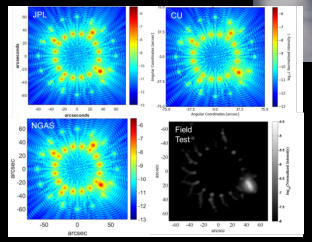
Ultra-low noise visible (CG-8) and infrared (CG-9) detectors

Starshade Technology Gaps

Contrast (Starlight Suppression)

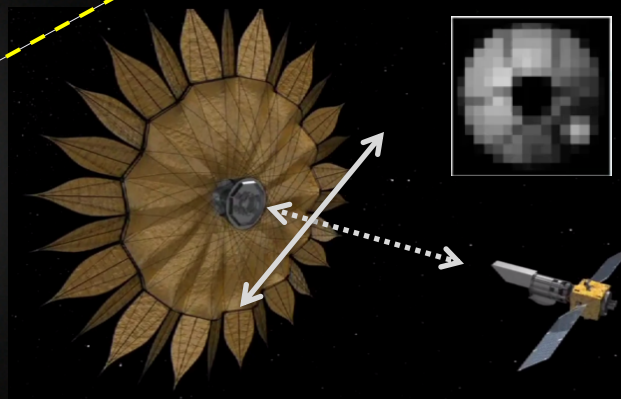


S-1: Controlling Scattered Sunlight



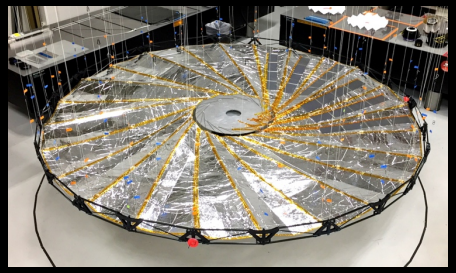
S-2: Starlight Suppression and Model Validation

Contrast Stability (Formation Sensing)

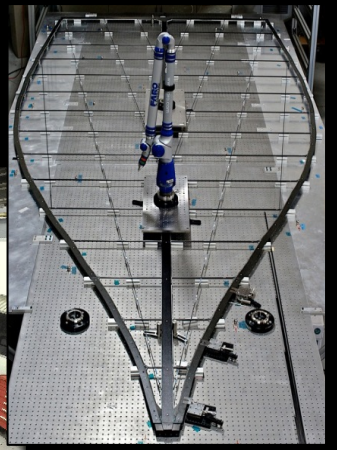


S-3: Lateral Formation Sensing

Deployment Accuracy and Shape Stability



S-5: Petal Positioning Accuracy and Opaque Structure

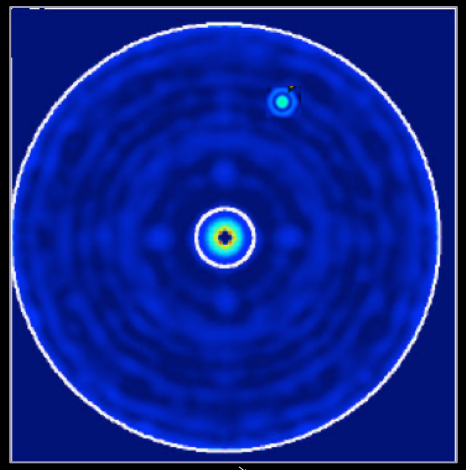


S-4: Petal Shape And Stability

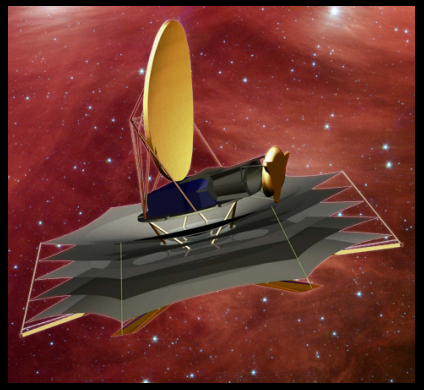
Mid-IR Coronagraph/Telescope Technology Gaps

Contrast

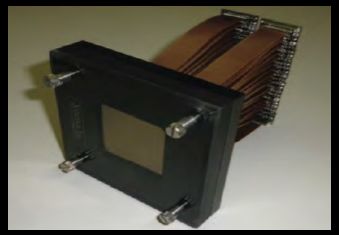
CG-15: Mid Infrared Coronagraph Optics and Architecture



Angular Resolution

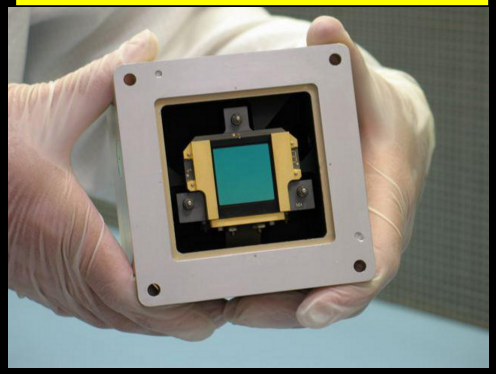


CG-14: Mid-IR Large Aperture Telescopes



CG-16: Cryogenic Deformable Mirror

Detection Sensitivity

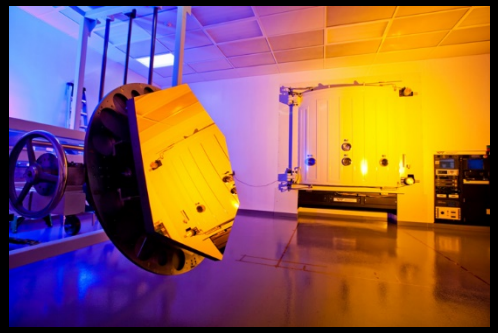


CG-13: Low noise Mid-IR detectors

M-4: Ultra-stable Mid-IR detectors for transit spectroscopy

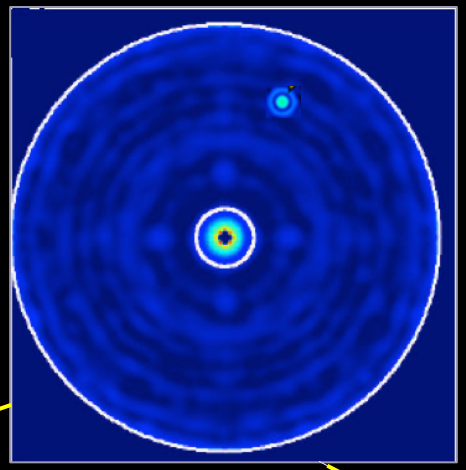
Other Technology Gaps

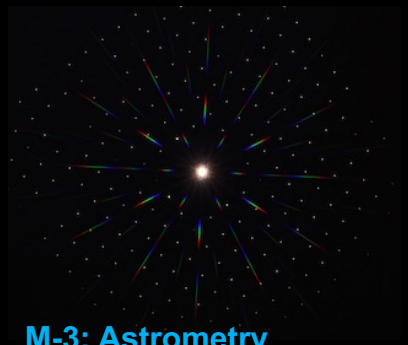
UV Contrast



CG-10 UV/V/NIR mirror coatings

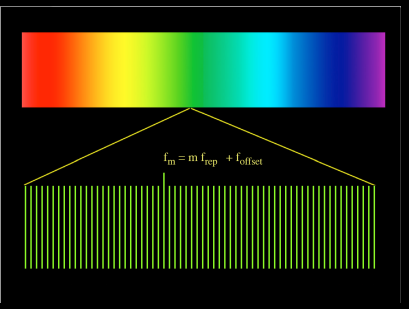
Tangential Stellar Motion Sensitivity



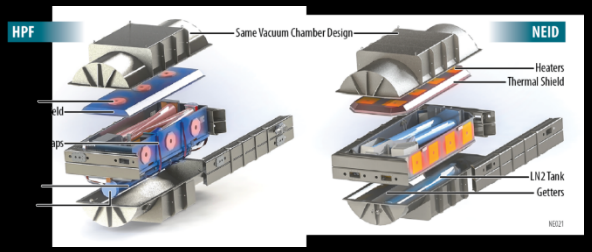


M-3: Astrometry

Radial Stellar Motion Sensitivity

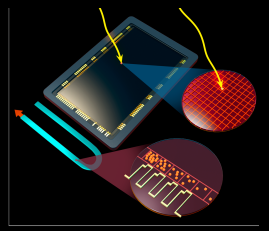


-2: Laser Frequency Combs for Space-based EPRV



M-1: Ground-based Ultra-high precision Radial Velociity

UV Detection Sensitivity



CG-12: Ultra-low noise UV detectors