Exoplanet Exploration Program Technology Update

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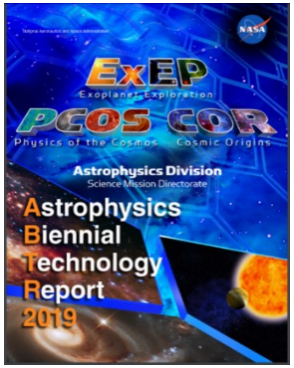
ExoPAG 24
24 June 2021

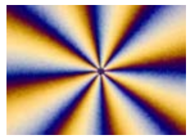
Image Credit:
NASA/Ames/JPL-Caltech/T. Pyle
astropix.ipac.caltech.edu

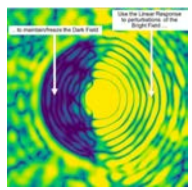
Current Technology Activities

Technology Gaps



Strategic Astrophysics Technology (SAT) Grants

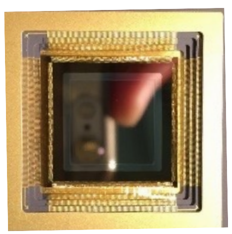




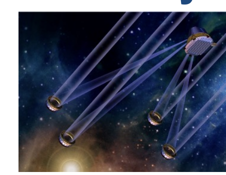
- *Coronagraph architectures: modeling and demonstrations*
- *Wavefront control*
- *Extreme Precision Radial Velocity*
- *Detectors*

Ultra-Stable Coronagraph Testbeds

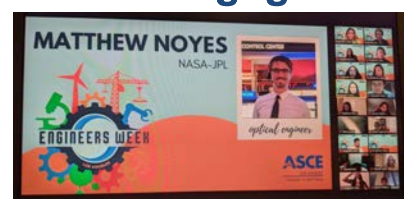
Deformable Mirror Survey



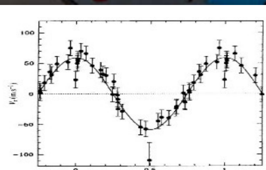
Nulling Interferometry Study



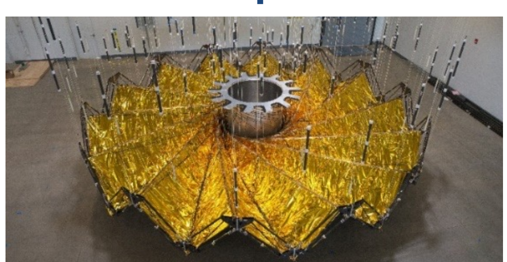
Public Engagement



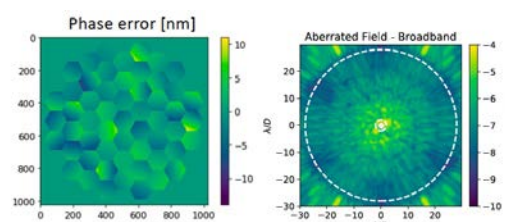
Extreme Precision Radial Velocity



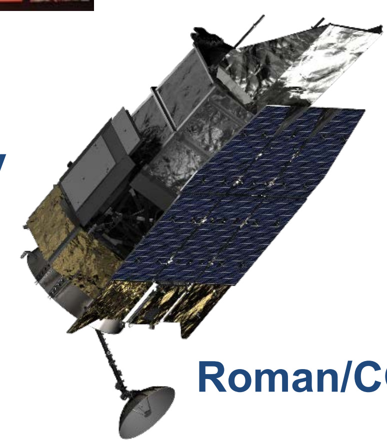
Starshade Technology Development



Segmented Coronagraph Design & Analysis Study



Roman/CGI



10 Currently Active Strategic Astrophysics Technology (SAT) Awards

Coronagraph masks/architectures

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

Wavefront-control techniques

- Single mode fiber and optimization for spectroscopy (Mawet/Caltech)
- Linear Dark Field Control (Guyon/Arizona)
- Multi-star Wavefront Control (Belikov/NASA-ARC)

Detectors

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

Extreme Precision Radial Velocity

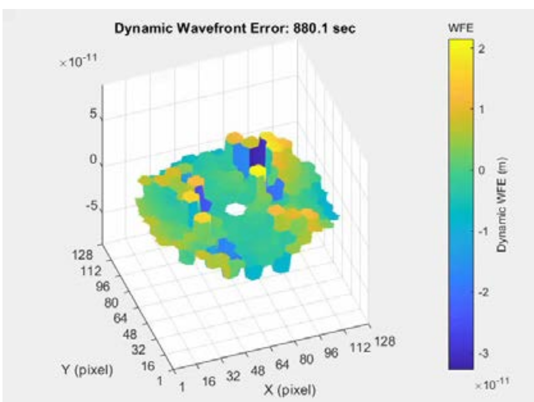
- Micro-resonator optical etalon for radial velocity measurements (Vasisht/NASA-JPL)

Segmented Coronagraph Design & Analysis Study

- **Purpose:**
  - Coronagraph feasibility with segmented-mirror telescope
  - Coronagraph/segmented telescope system feasibility

- **Preliminary end-to-end modeling of telescope dynamics, wavefront control, and coronagraph -> science yield**

- **Close collaboration with Ball and Lockheed telescope modeling**
  - Reconfirmed requirement for ~10 pm WFE stability, per LUVOIR report



RMS Amplitude [pm]	Yield Loss (compared to no aberration)
3	0%
10	2%
100	92%

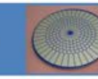
Next Steps:
- Understanding benefits of wavefront control techniques with both natural and laser guide stars
- Study further damping of telescope modes that most impact the science yield
- Pursuing higher fidelity Integrated Telescope-Coronagraph modeling

Deformable Mirror Survey

- Goal: Survey and document viable DM technologies across the world to inform future exoplanet missions of their capabilities and technology readiness
  → Completed in May 2021

Eduardo Bendek (Study Lead)

- Looked at 14 candidates in 6 countries:
  - Xinetics and BMC are currently the best options – ALPAO is a backup candidate
  - New promising technology identified (Microscale, Obsidian, SLM)
- Recommended next steps:
  - Develop high actuator count devices
  - Advance DM electronics and connectorization
  - Develop backup technologies
  - Continue to revise DM survey annually

	BMC 	Xinetics 	ALPAO 	Cilas 
Technology	Electro static force between pin and membrane	Electrostrictive (PMN) material	Electromagnetic	Bimorph piezoelectric actuation
Control type	Voltage	Voltage	Current	Voltage
Membrane contact	None	Yes	None	Yes
Actuator pitch	0.3 - 0.45 mm	1.0 - 2.5 mm	0.8 – 20.6 mm	≥ 2 mm
Actuator stroke	1 to 2 μm	0.5 μm	8 – 25 μm	20 μm (OTOS)
Actuator count	4096 (64x64)	4356 (66x66)	3228 (64 across)	188(OTOS has 63)
Capability	Up to 9216 (96x96)	Up to 9216 (96x96)	Up to 12912 (128 across)	Few hundreds
Actuator resolution	15 pm	20 pm measured	120 pm	~300 pm
Capability	15 pm	8 pm	15 pm	50 pm
Key limitations for flagship mission	Surface Quilting, actuator **count**	Actuator **pitch**, stability	Actuator **pitch**	Actuator **count, pitch** and resolution
Company information	U.S. Based DMs are the main business Independent company	U.S. Based DMs are the main business Parent: Northrop Grumman, strategic business unit	France DMs 70% of $4M revenue Parent: Eveon	France DM's 10% of revenue Ariane group and AREVA

- ***Look for an ExEP Technology Colloquium on this topic coming soon***

Starshade Technology Activity

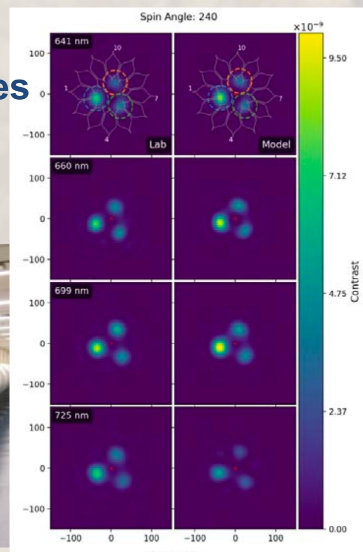
Angelle Tanner, MSU

Starshade Data Challenge launched: all synthetic images released to two challenge teams[1]

Brian Dunn,
Quartus Engineering

Special section on starshades published in April 2021 issue of JATIS[2]

Optical Modeling:
All variant subscale starshades for model validation built and measured at Princeton testbed



Improved error budgeting, Revisiting earlier results:
e.g. petal optical edge bonded joint redesign

Edge before redesign

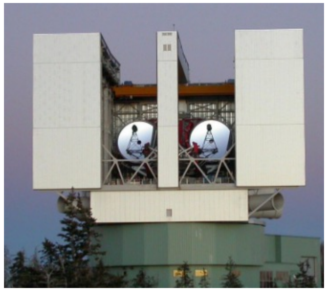
Edge after redesign

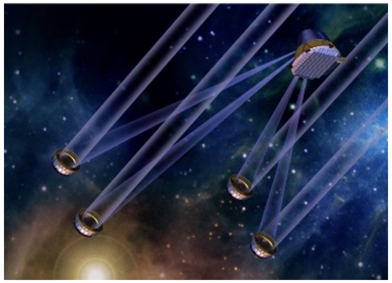
[1] see them for yourself at https://exoplanets.nasa.gov/exep/technology/starshade-data-challenge/

[2] at https://www.spiedigitallibrary.org/journals/Journal-of-Astronomical-Telescopes-Instruments-and-Systems/volume-7/issue-02

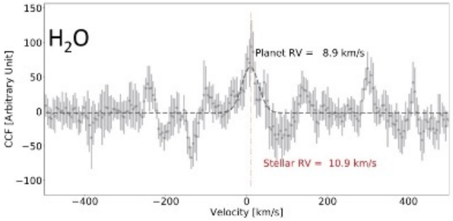
Exoplanet Exploration Technology Colloquium Series

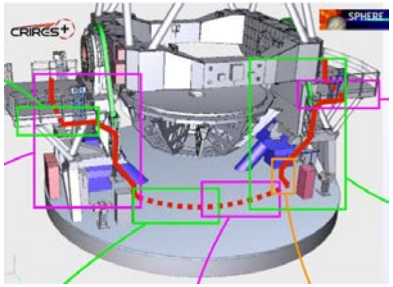
- **The Past, Present, and Future of Nulling Interferometry**
  Gene Serabyn (JPL)





- **Ground-based Coronagraphy plus High-Resolution Spectroscopy**
  Nem Jovanovic (Caltech) and Arthur Vigan (LAM)

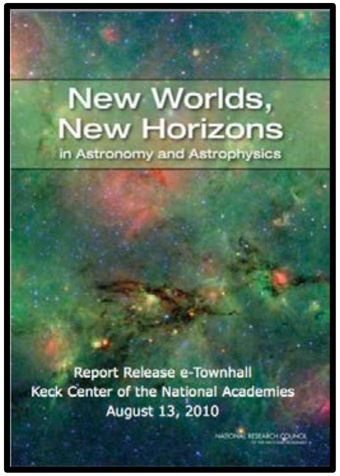




- **Recordings and slides available:**
  - https://exoplanets.nasa.gov/exep/technology/tech_colloquium/

Astro2020 and ExEP Technology

- **ExEP's technology priorities flow from recommendations in the Decadal Survey and NASA's implementation plans**



National Aeronautics and Space Administration

Astrophysics Implementation Plan:
2018 Update

Astrophysics Division
Science Mission Directorate
NASA Headquarters

December 17, 2018

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

Astro2020

?

- **Planning underway to align ExEP (and PCOS/COR, HQ) technology activities with recommendations in the 2020 Decadal Survey**
  - Astrophysics Technology Gap list update to support the SAT 2021 call for proposals
  - Analyses of the decadal survey recommendations
    - "Dot product" assessment of current investments vs. recommendations of Astro2020
    - Input to HQ on competed/directed technology

2021 APD Technology Gap List

ExEP NASA EXOPLANET EXPLORATION PROGRAM

- **Technology Gap List update this year will be responsive to Decadal**
  - Prioritization will be adjusted to reflect mission priorities from Decadal
  - We are prepared to add new technology gaps
- **We are now accepting new technology gaps from the community**
  - Will be considered for prioritization
  - Due date is 3 weeks after release of Decadal Survey report
  - Astrophysics Technology Gap List update schedule is driven by plans for SAT 2021
- **Stay tuned for the SAT 2021 call..**

In 2021, the deadline to submit technology gaps is extended until three weeks after the Astro2020 release date.

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:
☐ **HabEx** ☐ **LUVOIR** ☐ **Lynx** ☐ **Origins** ☐ **IP** ☐ **SOFIA** ☐ **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):

Assessment of the current State-of-the-Art (SOTA) and references justifying full-solution TRL quoted at right (100 – 150 words):

Estimated TRL of full solution addressing all key performance parameters of this gap:

Technical Goals and Objectives (Key Performance Parameters) to Fill the Capability Gap:

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

Applications and Potential Relevant Missions for Astrophysics Division:

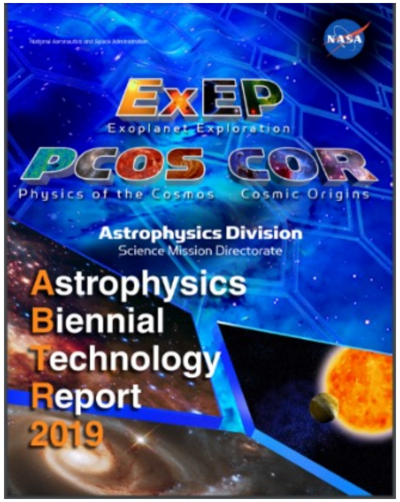
Urgency:
Years to estimated launch or other schedule driver:
Level of complexity (single tech, system of techs, or system of tech systems):
Level of difficulty (straightforward, stretch, or major stretch):

https://exoplanets.nasa.gov/internal_resources/1185

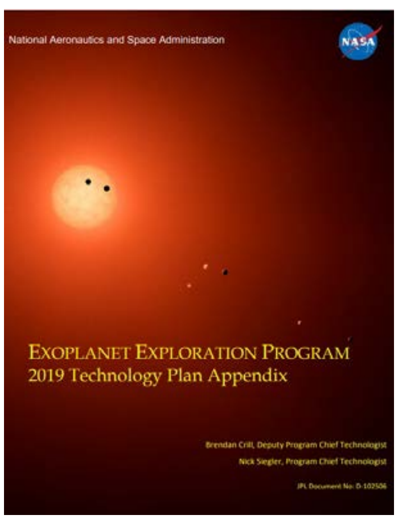

Exoplanet
Missions
NASA
Missions
ESA Partner
Missions
Hubble1
Spitzer
Kepler
TESS
JWST2
Roman
CoRoT3
Gaia
CHEOPS 4
PLATO
ARIEL7 (CASE8)
?
W. M. Keck Observatory
1 NASA/ESA Partnership
2 NASA/ESA/CSA Partnership
3 CNES/ESA
4 ESA/Swiss Space Office
7 ESA
8 NASA

BACKUP

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/
  - 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/

Starshade Technology Activity

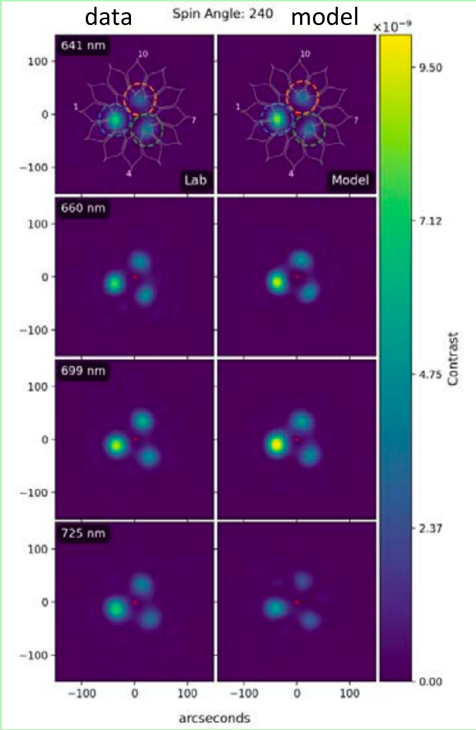
Angelle Tanner, MSU

- Starshade Data Challenge launched, all synthetic images released to two challenge teams[1]
- Special section on starshades published in April 2021 issue of JATIS[2]

Brian Dunn,
Quartus Engineering

- All variant masks for contrast optical model validation built and measured at Princeton testbed

Mixed perturbation mask



- Milestone 6A report on petal thermal deformation revised for final submission to ExoTAC
- Debris disk scattering phase functions added to starshade noise budget
- Secondary solar reflection analysis underway to set requirements on starshade out-of-plane deformations
- Petal optical edge bonded joint re-designed, and shown to survive environmental testing.

Edge before redesign

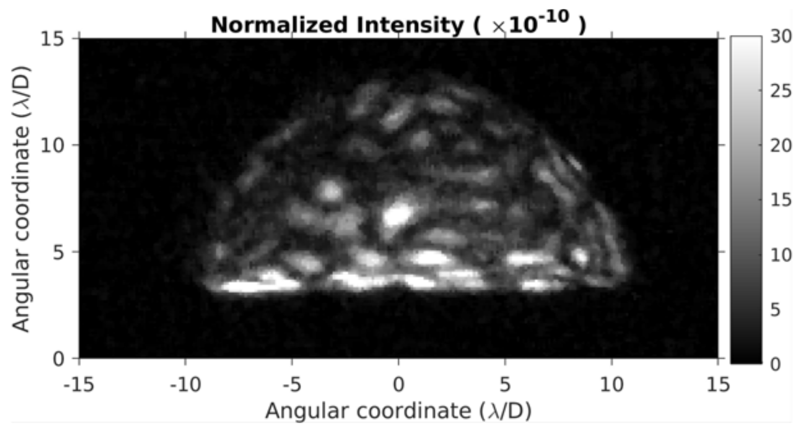
Edge after redesign

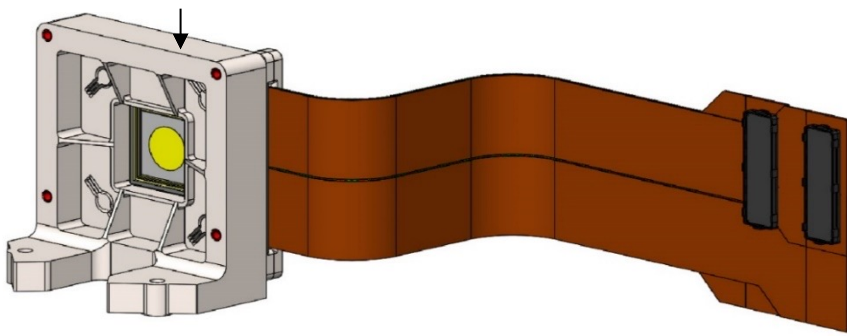
[1] see them for yourself at https://exoplanets.nasa.gov/exep/technology/starshade-data-challenge/

[2] at https://www.spiedigitallibrary.org/journals/Journal-of-Astronomical-Telescopes-Instruments-and-Systems/volume-7/issue-02?SSO=1#SpecialSectiononStarshades

MEMS Deformable Mirrors

- **2000-actuator Deformable Mirror demonstrations in vacuum**
  - MEMS DM narrowband demo in Decadal Survey Testbed contrast 8×10^{-10} from 3.5 to 13.5 λ/D narrowband at 516 nm; 2×10^{-9} 10% band





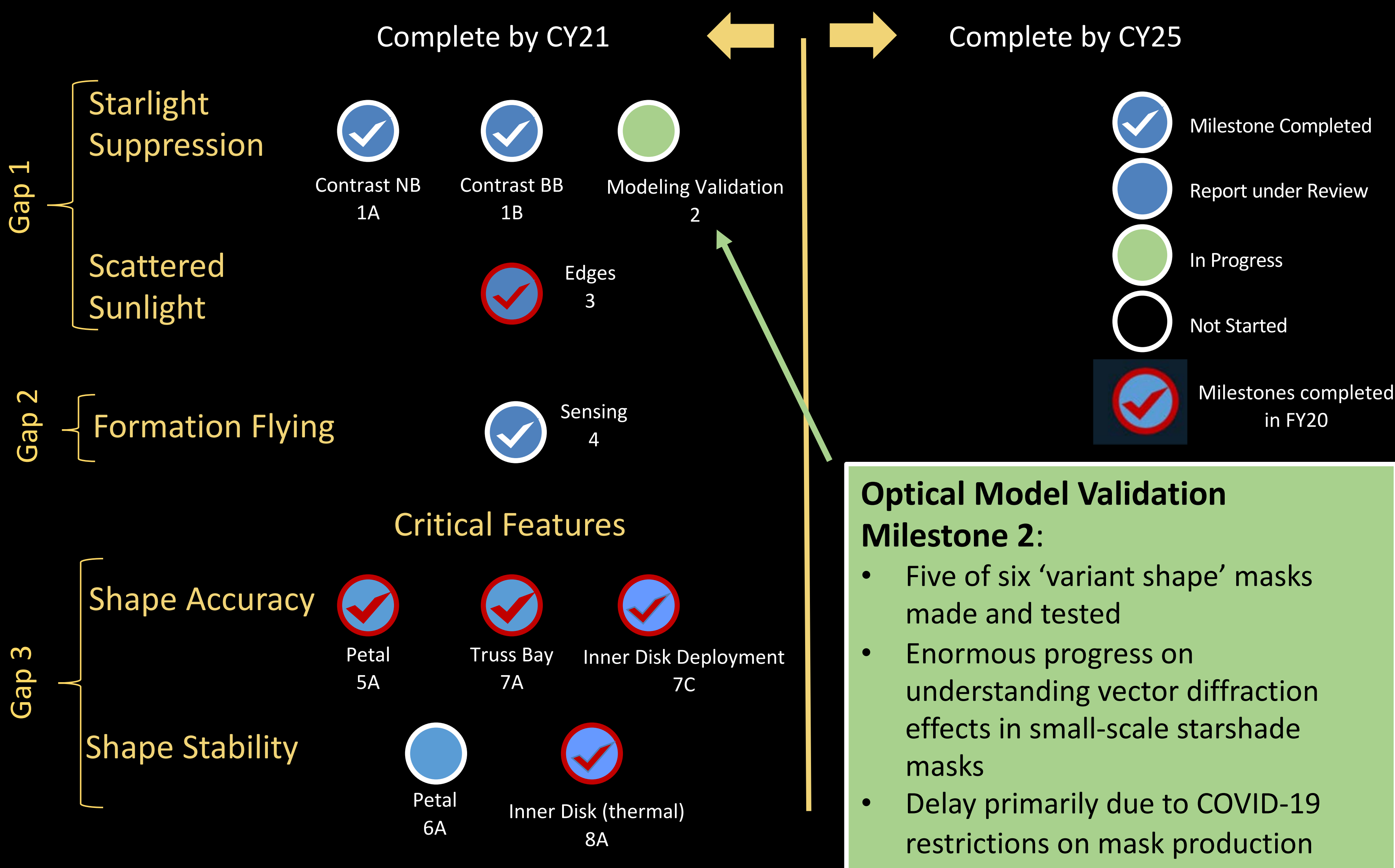
- **Two 2000-actuator MEMS DM's to undergo launch-level vibrations**
  - one not coated (to allow IR microscopy)
  - one coated

- **Pre-test performance characterization underway**

- **Next step: expose devices to random vibe**

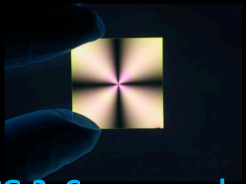
S5: Closing Starshade Technology Gaps

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

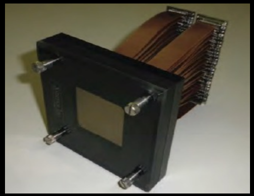


V-NIR Coronagraph/Telescope Technology Gaps

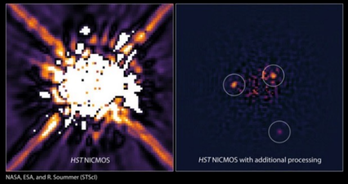
Contrast



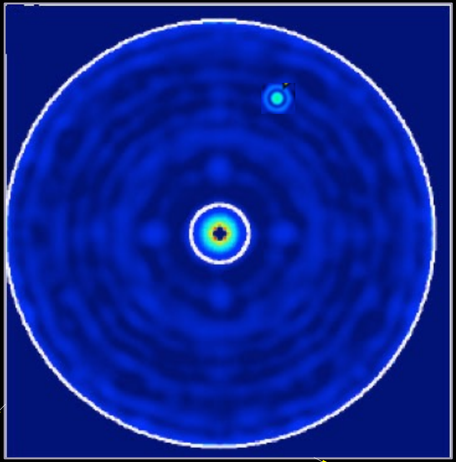
CG-2: Coronagraph Architecture



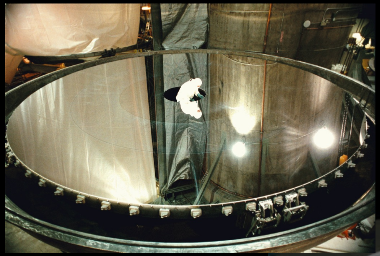
CG-3: Deformable Mirrors



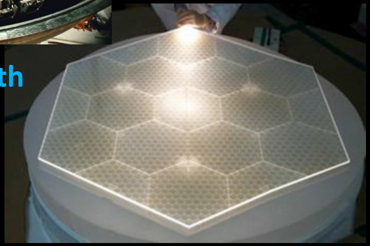
CG-4: Data Post-Processing



Angular Resolution

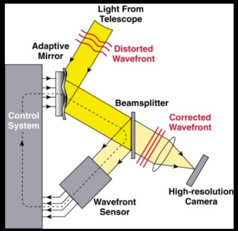


CG-1: Large Monolith Mirrors



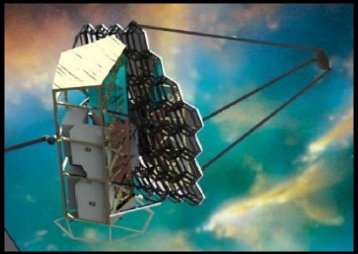
CG-1: Segmented Mirrors

Contrast Stability



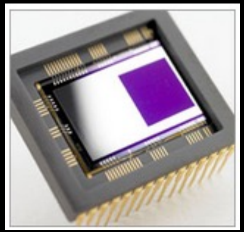
CG-5: Wavefront Sensing and Control

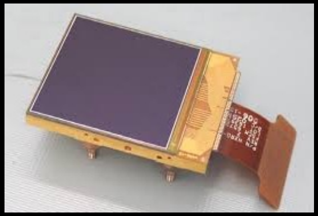
CG-6: Mirror Segment Phasing



CG-7: Telescope Vibration Sensing and Control or Reduction

Detection Sensitivity

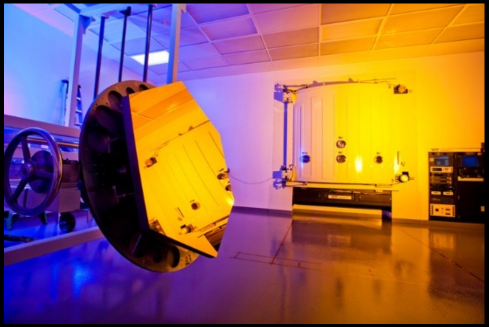




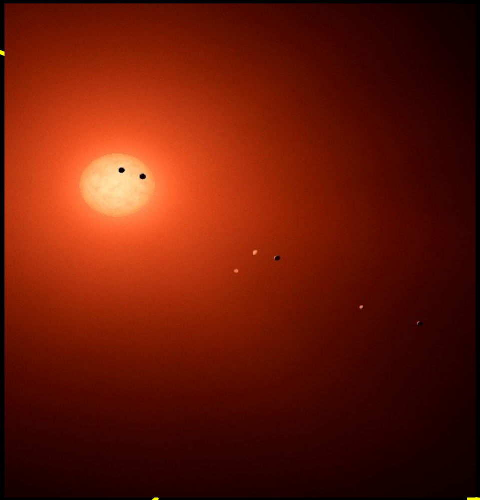
Ultra-low Noise Visible (CG-8) and Infrared (CG-9) Detectors

Other Technology Gaps

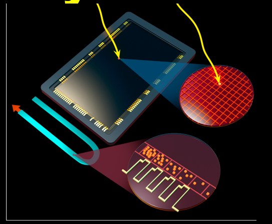
UV Contrast



CG-10 UV/V/NIR Mirror Coatings

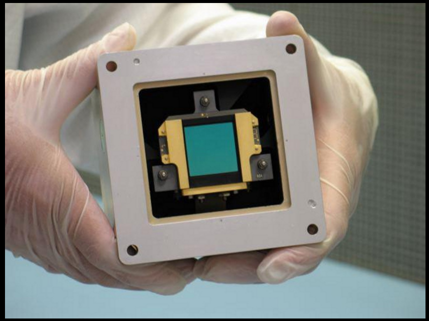


UV Detection Sensitivity



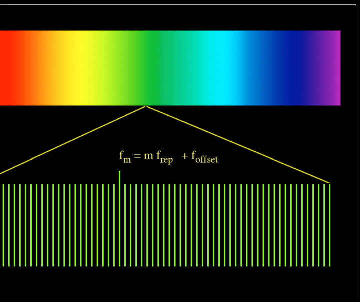
CG-12: Ultra-low Noise UV Detectors

Transit Spectroscopy Sensitivity

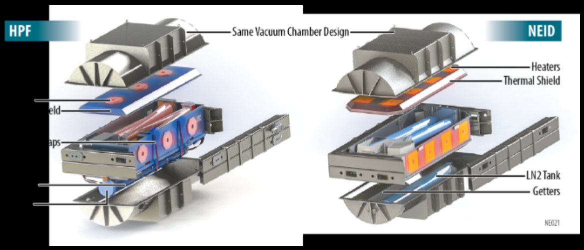


M-4: Ultra-stable Mid-IR Detectors for Transit Spectroscopy

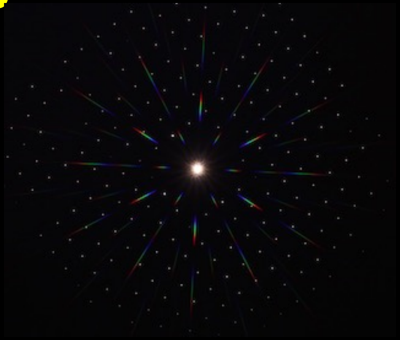
Stellar Reflex Motion Sensitivity



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



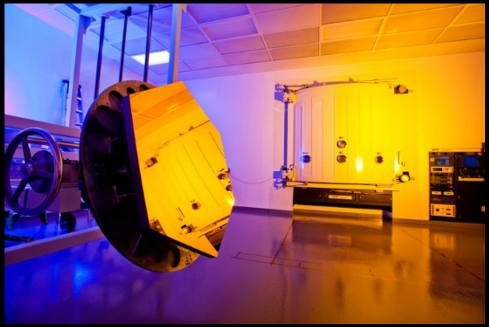
M-1: Ground-based Ultra-high Precision Radial Velocity



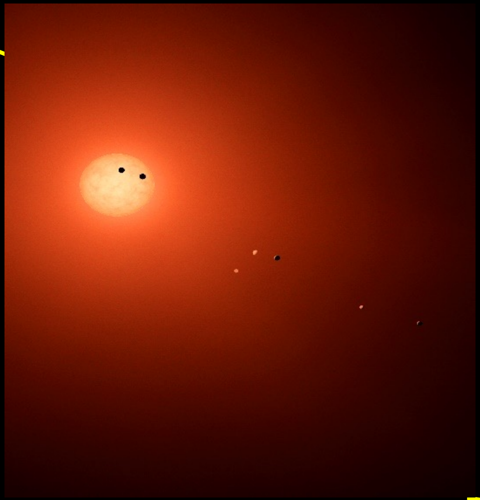
M-3: Astrometry

Mid-IR Technology Gaps

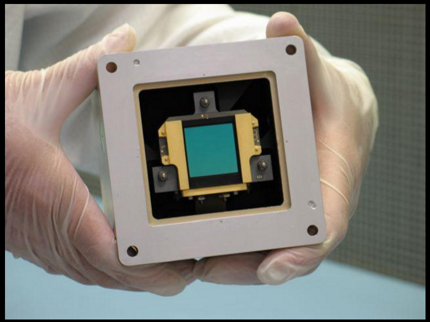
Mid-IR Coronagraph Contrast



CG-10 UV/V/NIR Mirror Coatings



Transit Spectroscopy Sensitivity



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