**Jet Propulsion Laboratory**
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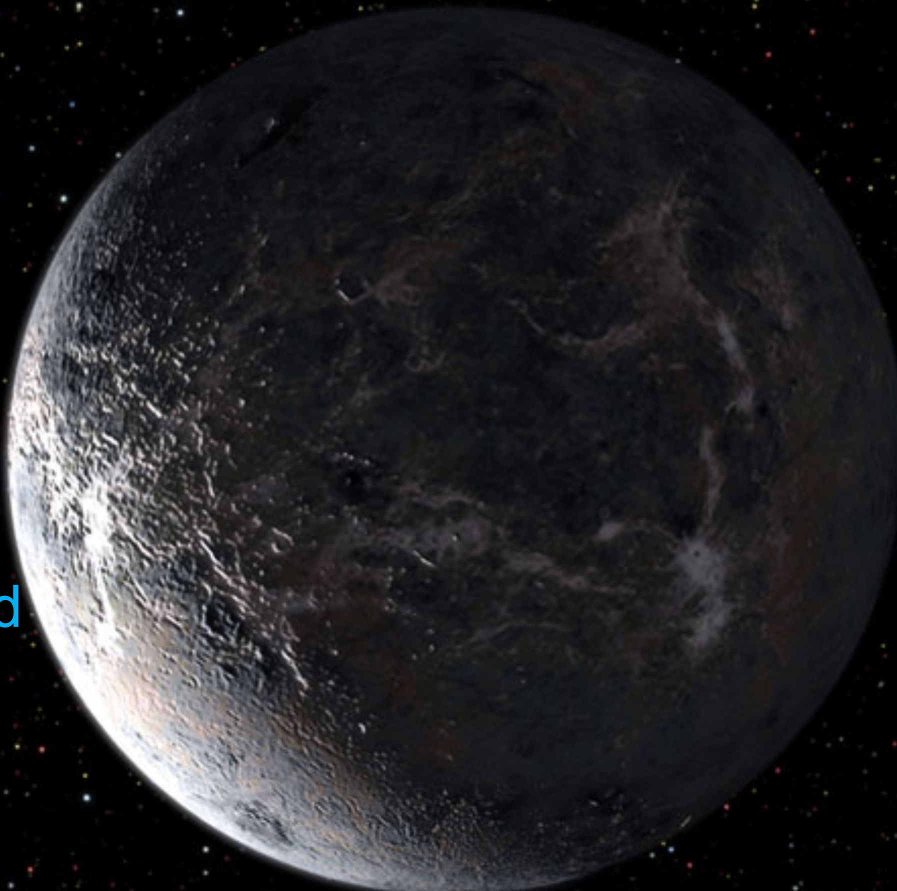

**Workshop on Technology for Direct Detection and Characterization of Exoplanets April 11, 2018**

# Exoplanet Exploration Program Technology:

## Decadal Survey Testbed, Segmented Coronagraph Design and Analysis, Mission Roadmap

Brendan Crill
Deputy Program Chief Technologist

Nick Siegler
Program Chief Technologist

NASA Exoplanet Exploration Program
Jet Propulsion Laboratory – California Institute of Technology

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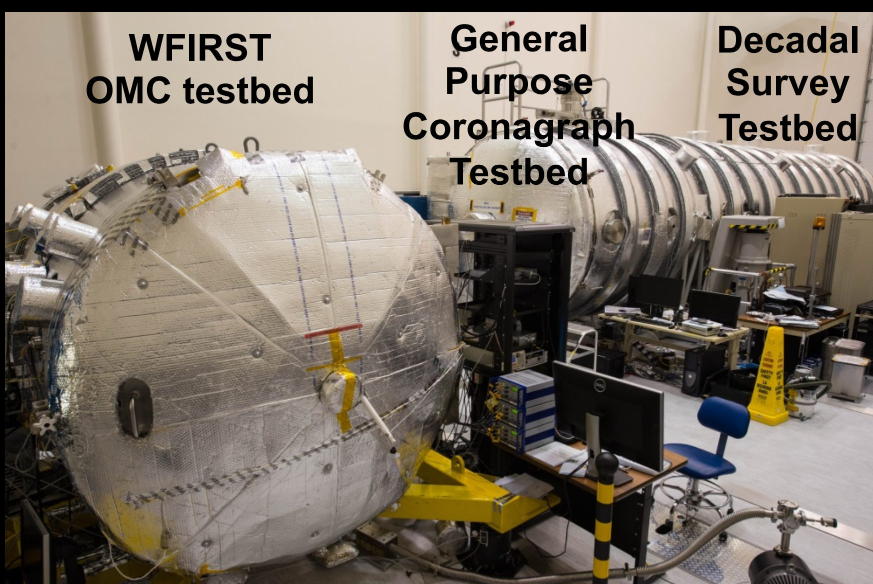
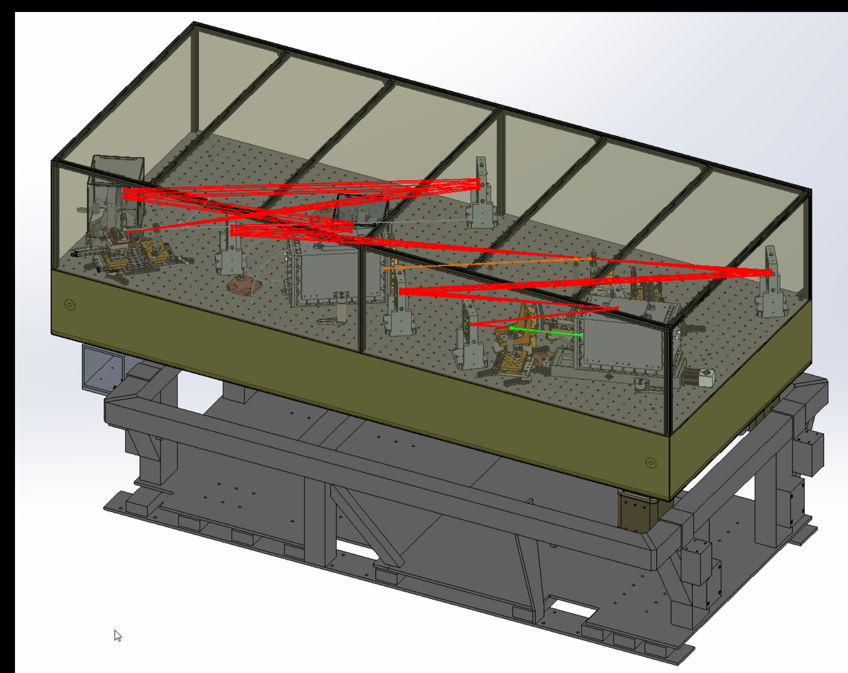
# The Decadal Survey Testbed

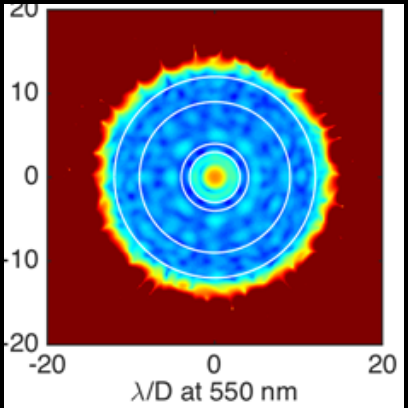
- New coronagraph vacuum testbed facility to be commissioned in the large High Contrast Imaging Testbed 40’ chamber this year
- Aim to achieve $1 \times 10^{-10}$ contrast levels



# Unique features of the DST

- Simple optical layout, minimize number of reflections
- Low CTE carbon composite bench
- 16-zone thermal control (including DM), MLI shrouds
- Well-characterized DM
- Jitter reduction: vacuum-compatible isolation stages
- LOWFS/C with DM mounted on a fast piezo tip-tilt stage

# Decadal Survey Testbed plans

**Phase I - Commissioning (clear, unobscured pupil; static demonstration)**

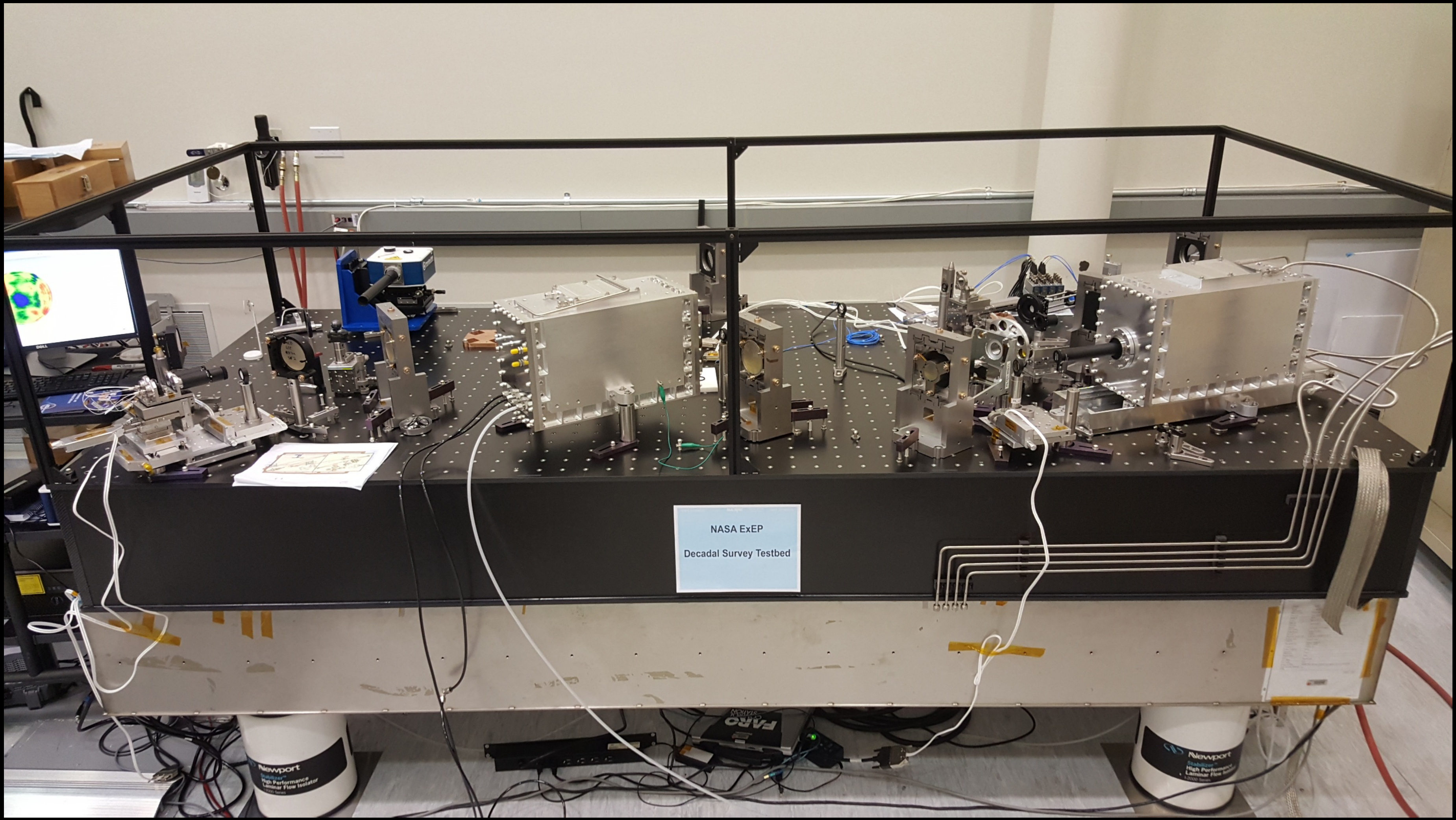
- Using a Hybrid Lyot Coronagraph architecture with an unmasked circular pupil, demonstrate a 360º annular dark hole from 3 to 9 λ/D in a 10% bandpass centered at 550 nm with mean contrast ≤ $10^{-10}$.

**Phase II – Segmented Telescope (segmented, obscured pupil; static demonstration)**

- Using a TBD coronagraph, add a TBD segmented pupil mask and demonstrate a 360º annular dark hole from 3 to 9 λ/D in a 10% bandpass centered at 550 nm with mean contrast ≤ 5e-10 (TBR).

**Phase III – Segmented Telescope (segmented, obscured pupil, dynamic demonstration)**

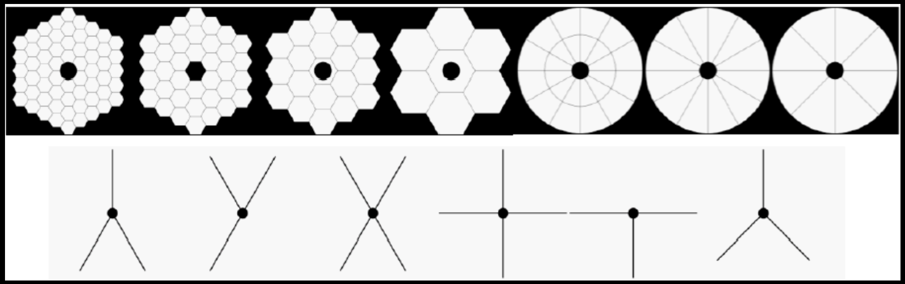
- Same as Phase II but now with a segmented telescope simulator and a disturbance source




DST first light by next month:
DM installed this summer

# Segmented Coronagraph Design and Analysis (SCDA) study

- SCDA study is evaluating coronagraph designs for future large on-axis, segmented space telescopes



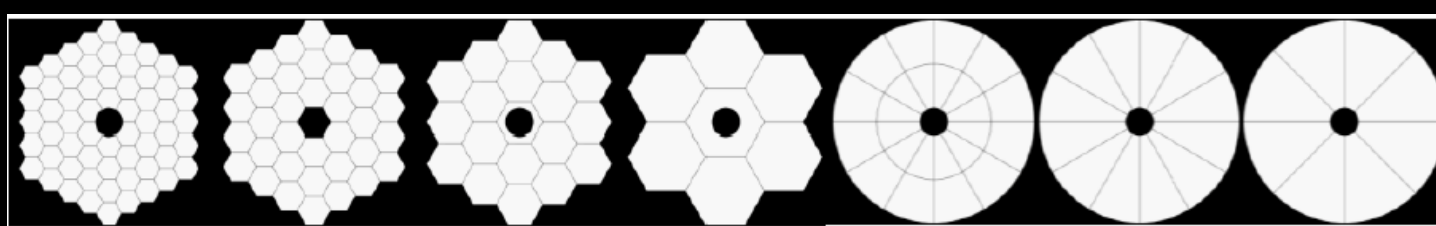
- Groups at Arizona, Ames, GSFC, STScI, JPL, Caltech, are designing coronagraphs to achieve $10^{-10}$ contrast -> maximize scientific yield
- Evaluate designs against a common set of metrics (such as robustness, manufacturability, does coronagraph place unrealistic demands on telescope)
- APLC design so far is the most successful architecture, though obtaining excellent throughput and IWA is still a challenge
- Apodized vortex designs for centrally obscured pupils are sensitive to stellar diameter
- PIAACMC design can be used for longer wavelengths (where stellar size is less of a problem)

# Lessons from SCDA

**Study of relative merits of possible segment configurations**
**see 2016 report by Feinberg et al. on ExEP website**

Table 1 Relative challenges of designs under consideration. Green to red designates least to most challenging. No absolute scale of difficulty is implied, and the relative challenge scale of each row may be different.

| | APERTURES | | | | | | |
|---|---|---|---|---|---|---|---|
| | 4 ring | 3 ring | 2 ring | 1 ring | Keystone 24 | Pie wedge 12 | Pie wedge 8 |
| **Segment Shape** | Hex | Hex | Hex | Hex | Keystone | Pie wedge | Pie wedge |
| **Max Segm. Dimension** | 1.54 m | 1.98 m | 2.77 m | 4.62 m | 2.5 m x 3.14 m | 5 m x 3.14 m | 5 m x 4.71 m |
| **Segments** | Green | Yellow | Orange | Red | Orange | Red | Red |
| **Backplane** | Green | Green | Orange | Red | Orange | Orange | Red |
| **Stability** | Green | Yellow | Yellow | Red | Yellow | Red | Red |
| **Launch Configuration** | Yellow | Green | Orange | Red | Orange | Red | Red |
| **SM Support** | Green | Green | Green | Yellow | Orange | Red | Red |
| **Overall Ranking** | Green | Yellow | Orange | Red | Orange | Red | Red |



# Lessons from SCDA

**Pupil obscuration from secondary mirror + supports is extremely important for determining coronagraph throughput**

**For example APLC designs see a large performance dropoff when secondary mirror diameter exceeds ~30%  of the primary mirror diameter**

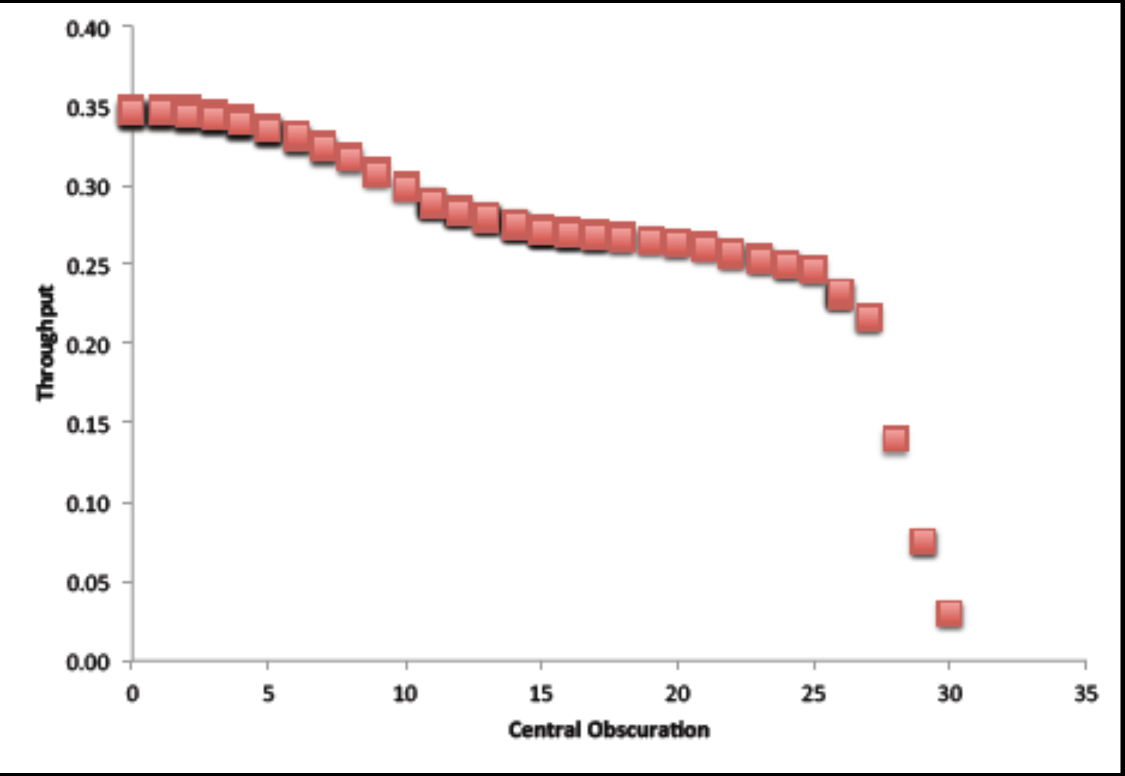
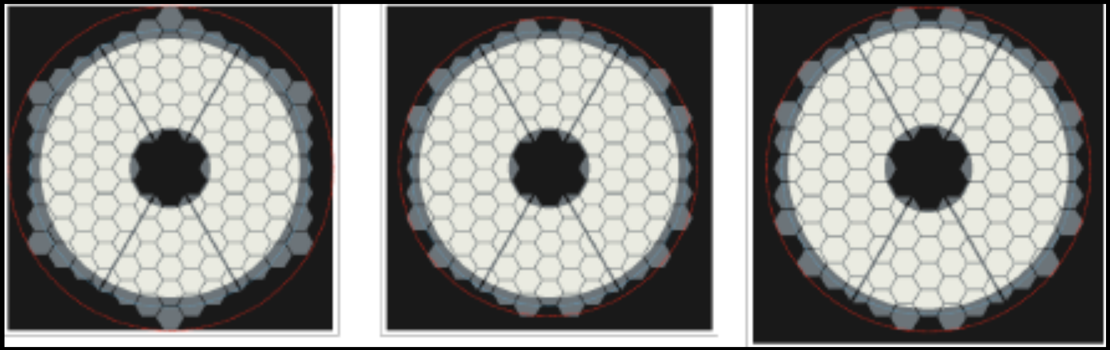



Figure courtesy of K. St Laurent

# Lessons from SCDA

**Inscribed diameter of primary mirror matters more than circumscribed diameter**

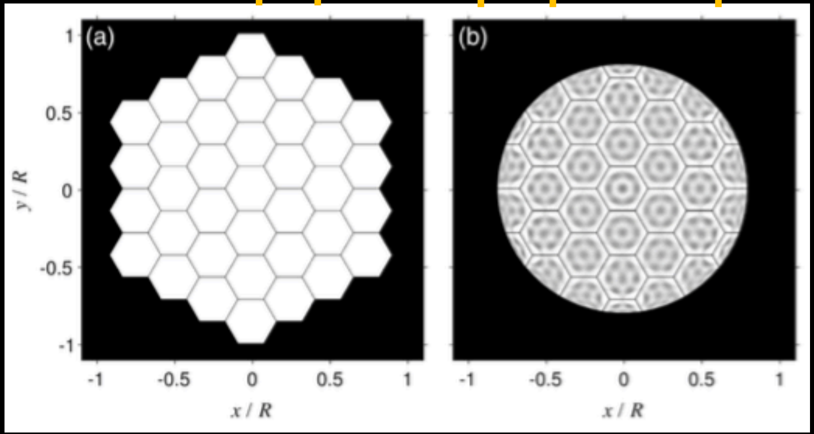
Coronagraph throughput increasing



From Soummer et al (2017) SCDA report

**If segment gaps are small, segmentation itself doesn't matter much**

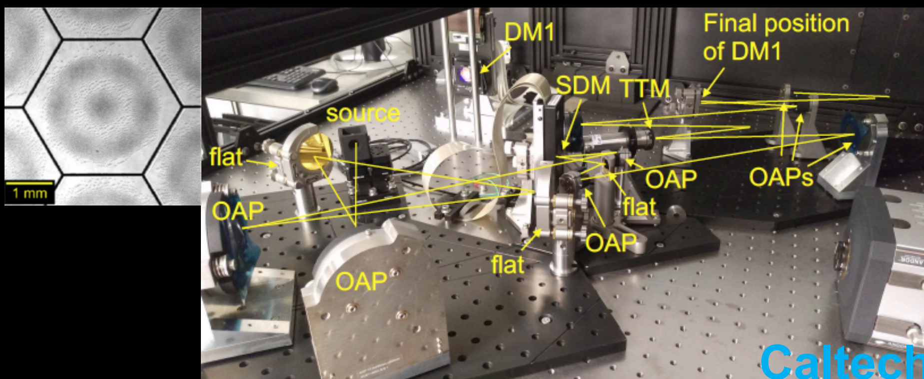
Entrance pupil    Pupil-plane apodizer

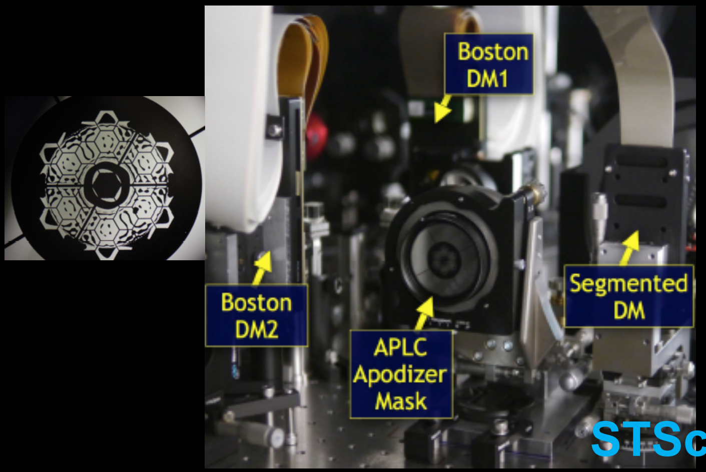



From Ruane et al JATIS (2018)

# SCDA next steps

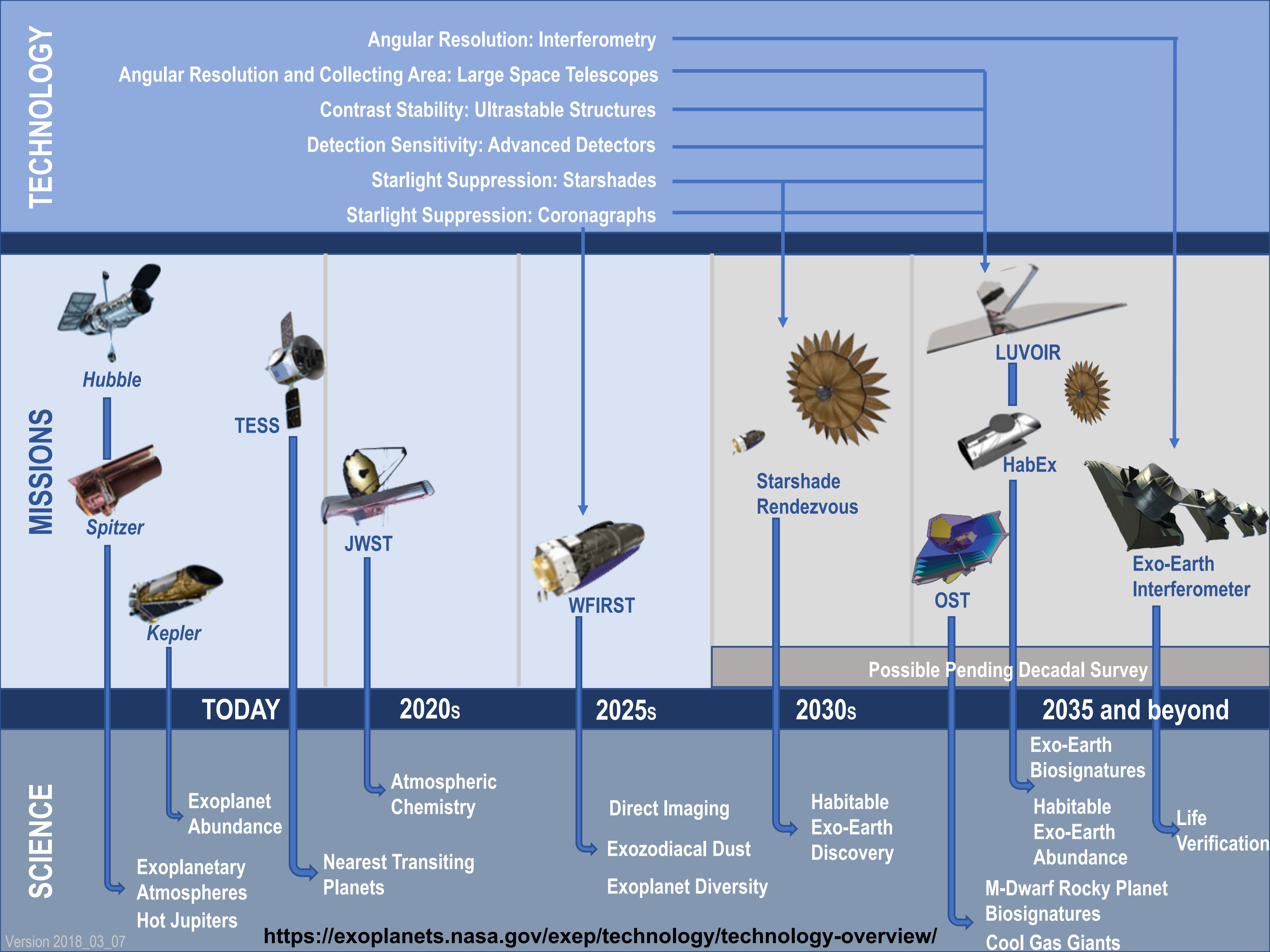
- Lab tests of masks underway




- Robustness metrics for wavefront errors are being developed and designs will be evaluated against them
- FALCO (joint DM / apodizer optimizer) code public release imminent
- Designs to be tested within same PROPER software framework

- Many results to be presented at Austin SPIE: joint SCDA paper planned for this fall



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
Exo-Earth Biosignatures
Habitable Exo-Earth Abundance
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