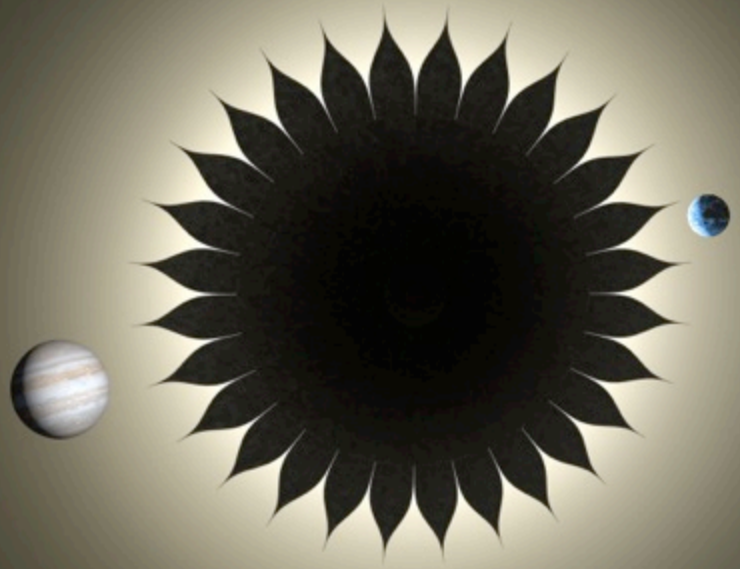
Jet Propulsion Laboratory
California Institute of Technology



Northrop Grumman's
Search for Life Workshop
March 29, 2016

Starshade Technology for Direct Imaging

Dr. Nick Siegler
Program Chief Technologist
Exoplanet Exploration Program
JPL/Caltech

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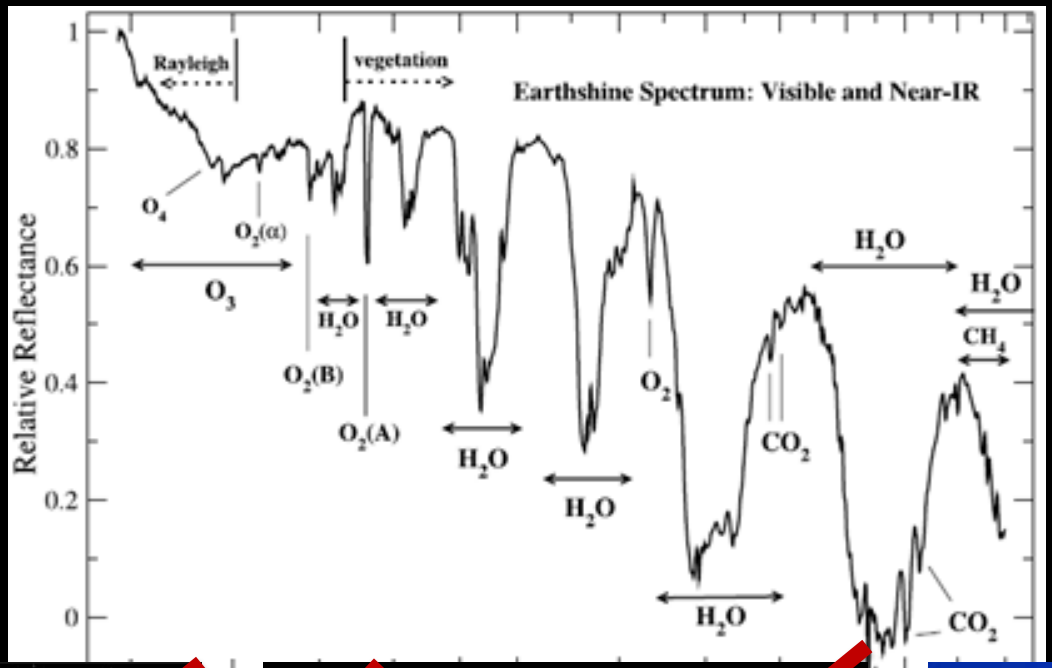
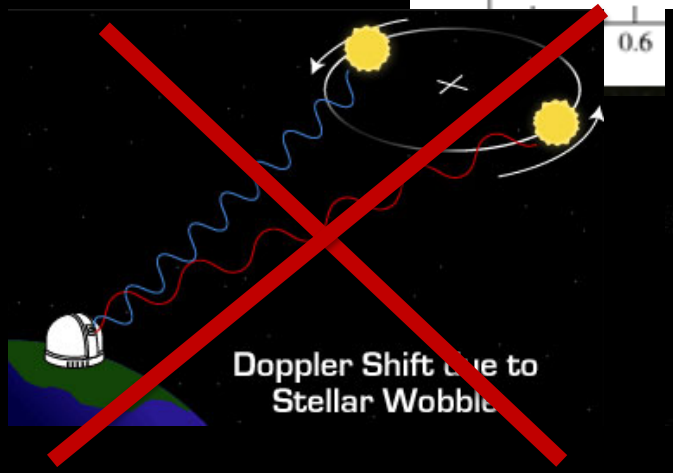
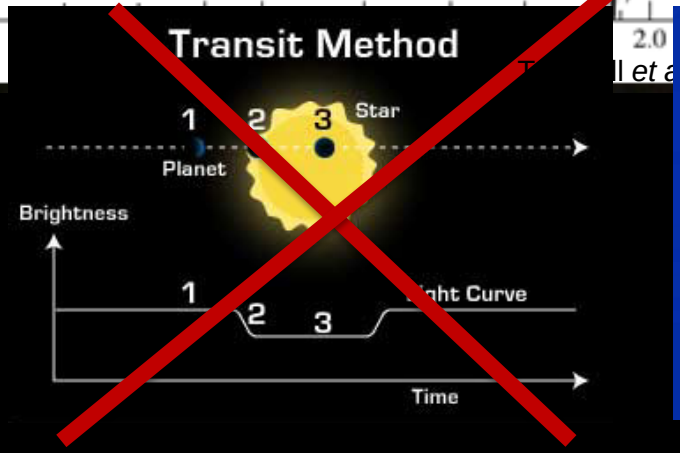
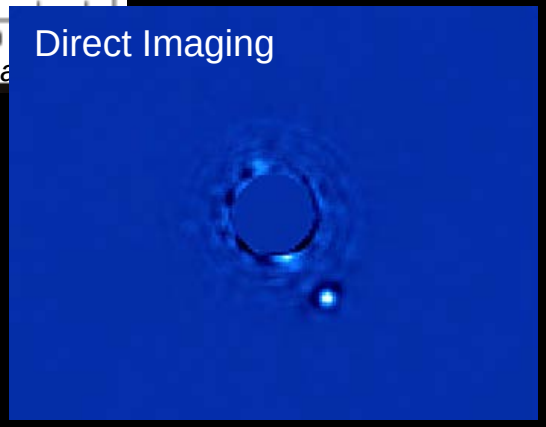

Earthshine Spectrum: Visible and Near-IR
Relative Reflectance
Rayleigh
vegetation
O_4
$O_2(\alpha)$
O_3
H_2O
$O_2(B)$
$O_2(A)$
O_2
CO_2
CH_4
0.6
2.0

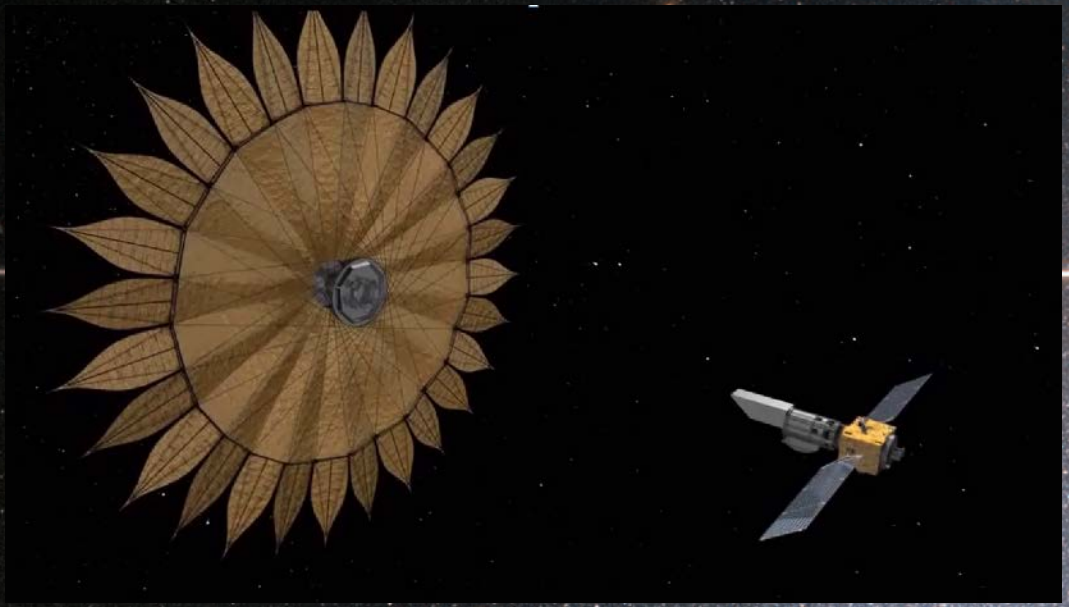

Doppler Shift due to
Stellar Wobble

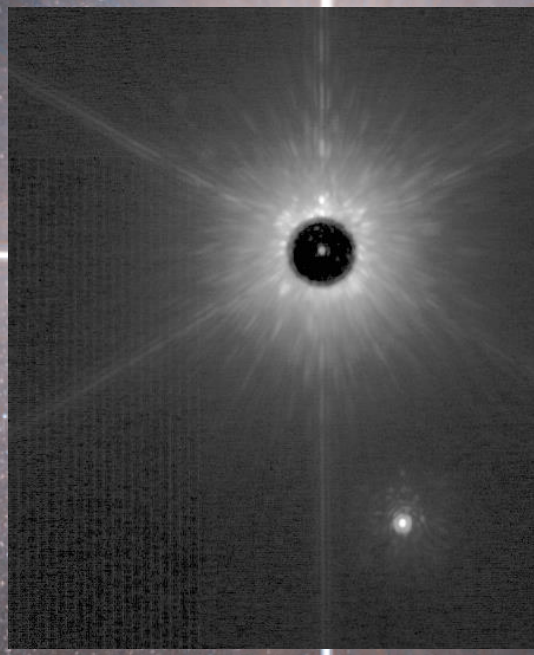

Transit Method
Star
Planet
Brightness
Light Curve
Time


Direct Imaging

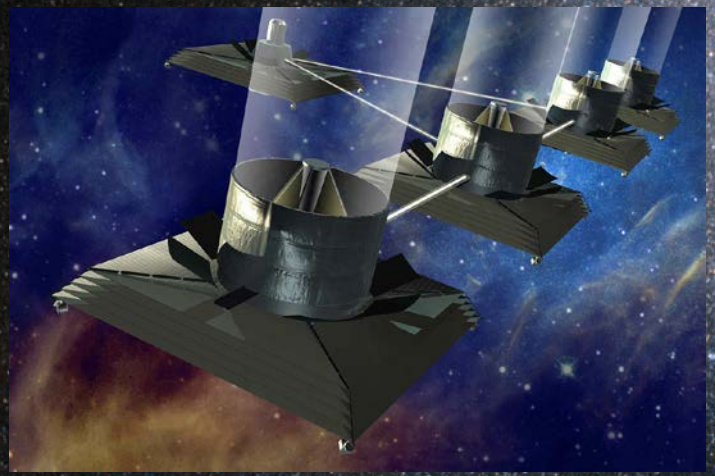
Only Three Starlight Suppression Approaches

External Occulters (Starshades)

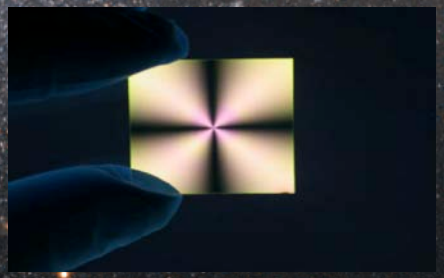


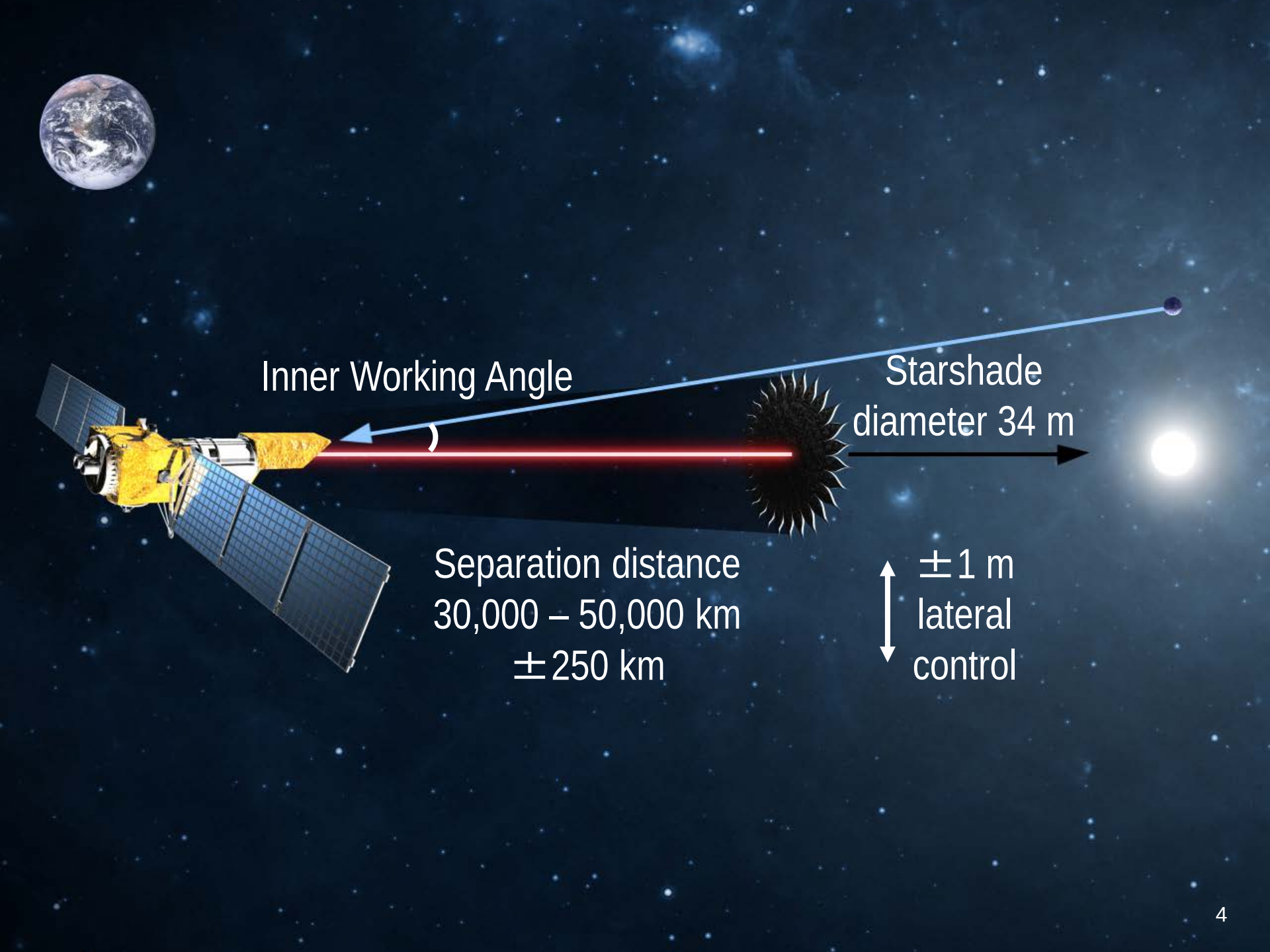


Nulling Interferometry

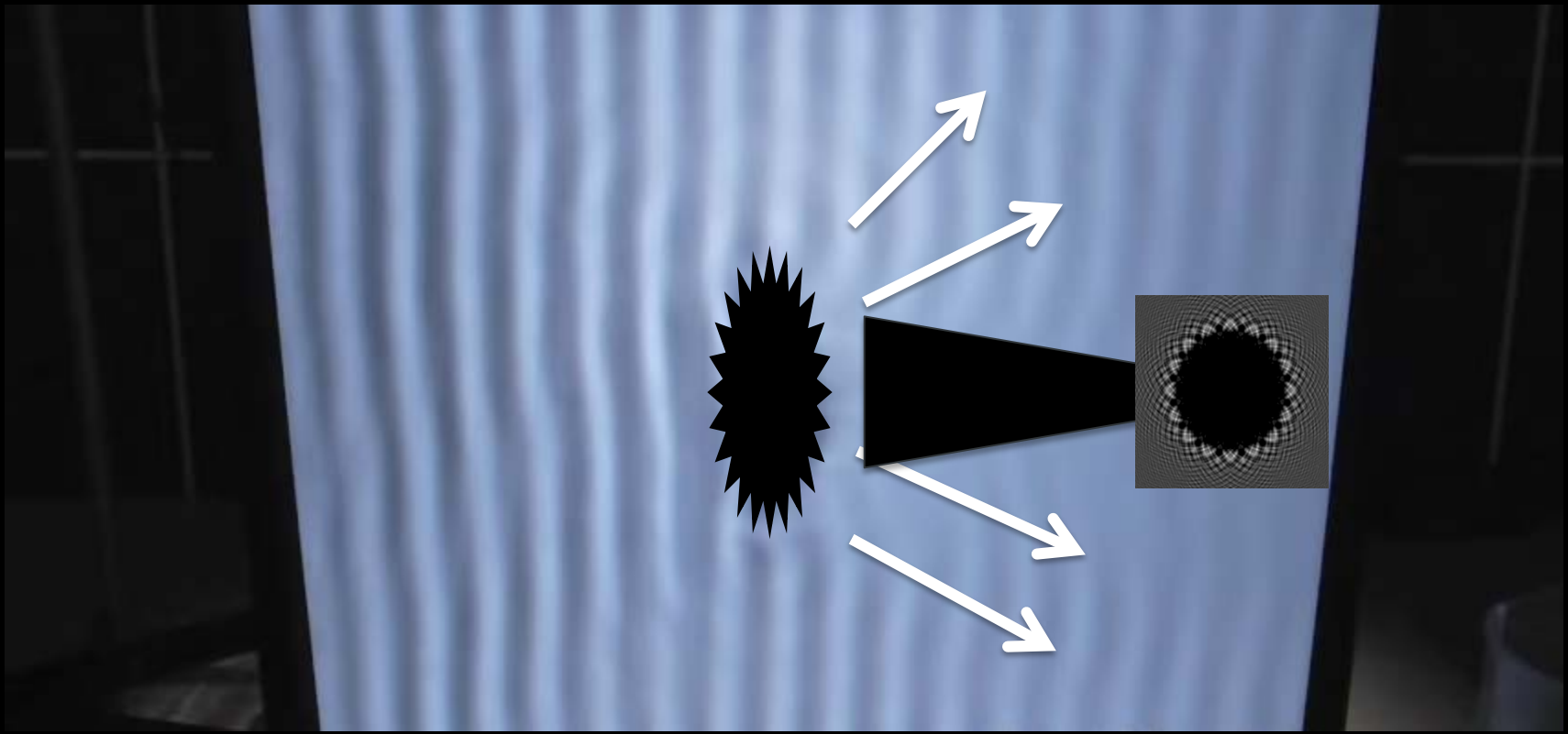


Internal Occulters (Coronagraphs)

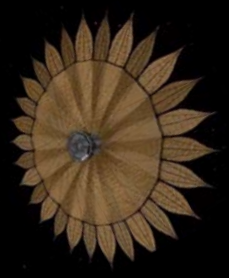



Inner Working Angle
Starshade
diameter 34 m
Separation distance
30,000 – 50,000 km
±250 km
±1 m
lateral
control

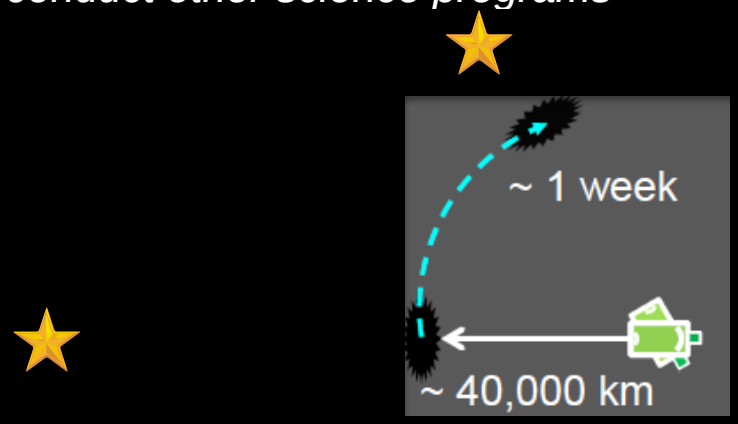
Welcome to the World of Diffraction



Key Challenges of the Starshade



- Relatively long times between observations
  - Slewing the starshade between targets may take ~1-2 weeks
    - *Can conduct other science programs*



- Limited number of Starshade movements
  - Due to limited propellant
    - *SEP could mitigate*

- Full-scale end-to-end system optical testing on the ground not possible; same for formation flying
  - Must rely on sub-scale lab and field optical tests along with high-fidelity validated optical, mechanical, thermal models

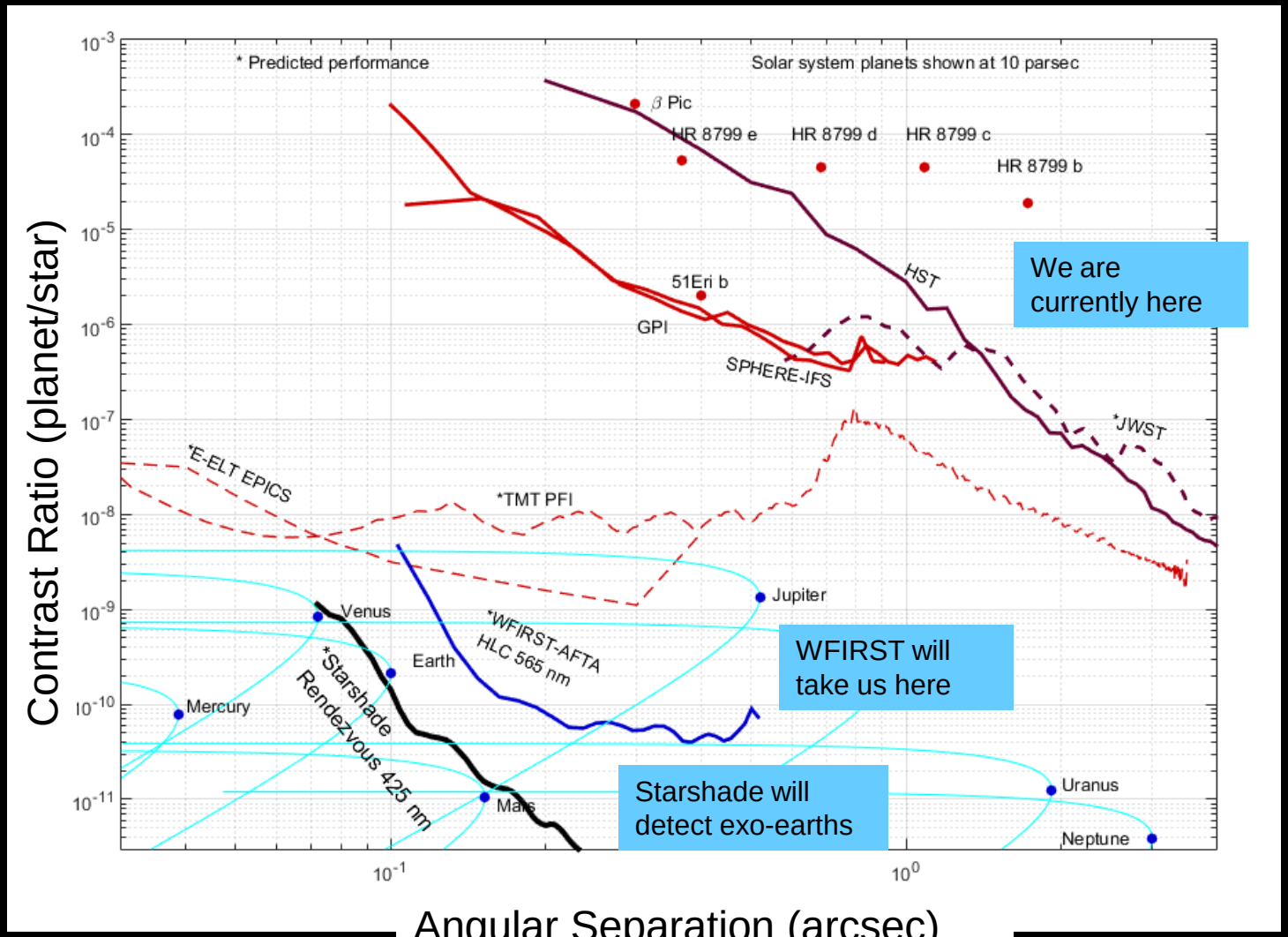
Key Benefits of the Starshade

- **By suppressing the starlight <u>before</u> the it enters the telescope, the starshade:**
  - *reduces sensitivity to scattering within the telescope*
  - *reduces the pointing and thermal stability requirements on the telescope*
  - *eliminates the need for wavefront sensing and control instrumentation*
  - *enables high throughput reducing science integration time*
  - *hence, will not drive the requirements of the telescope*

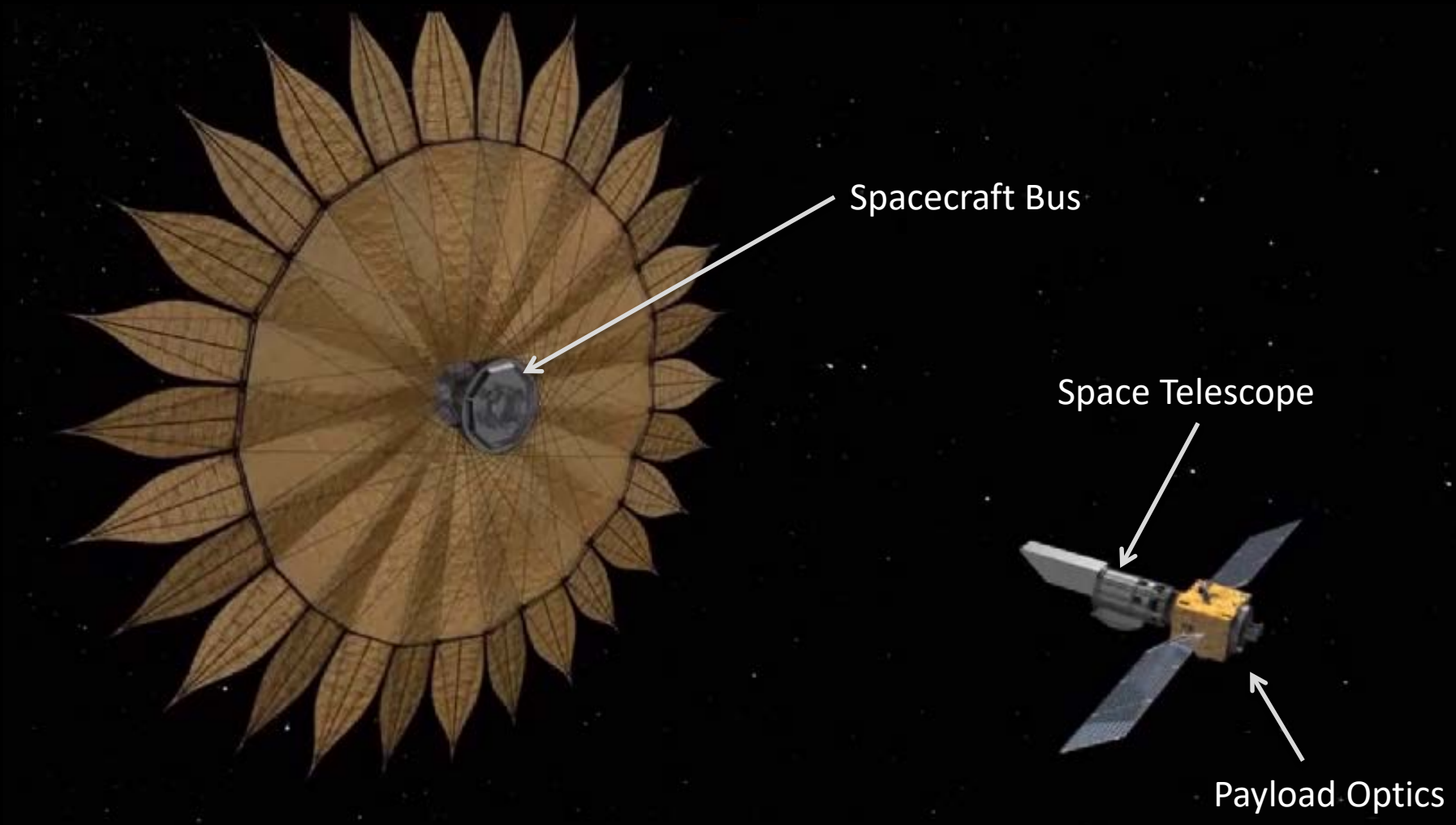
- **Starshade can reach 10^{-10} contrast requirements with < 100 mas resolution with any starshade-ready telescope**
  - *conventional on-axis or segmented telescopes are fine*

- **Inner working angle and starlight suppression is largely independent of the size of the telescope.**
  - *Rocky planets in the HZ can be imaged with smaller telescopes (i.e. WFIRST)*

Contrast Ratio versus Angular Separation



What's not hard…

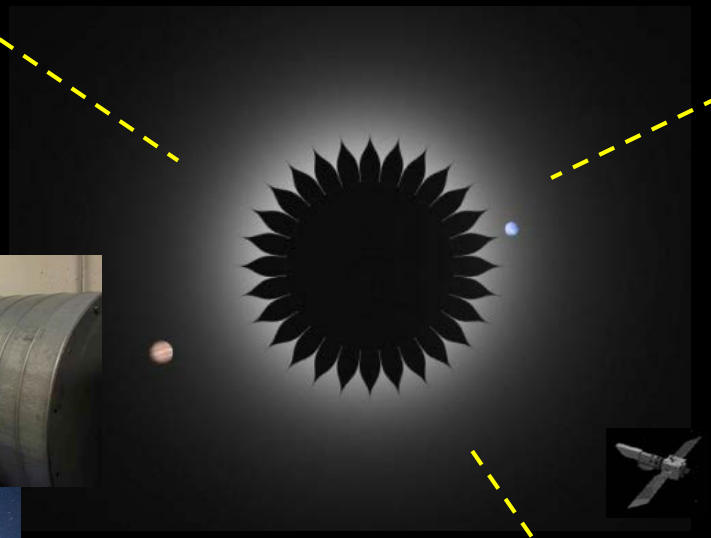


Key Technology Areas for a Starshade

Starlight Suppression

Controlling scattered and diffracted light

Demonstrating optical performance and validating optical model

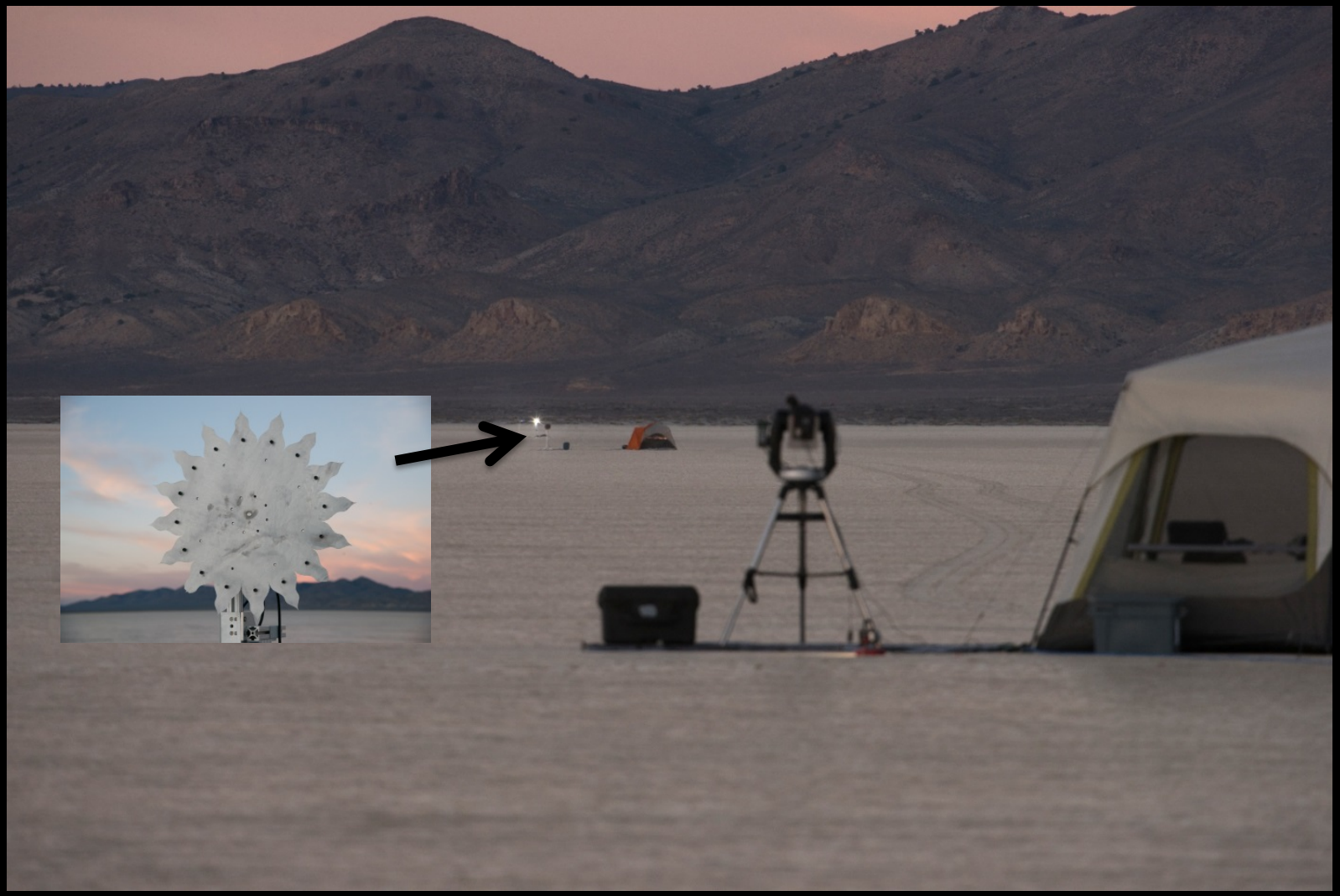


Formation Sensing and Control

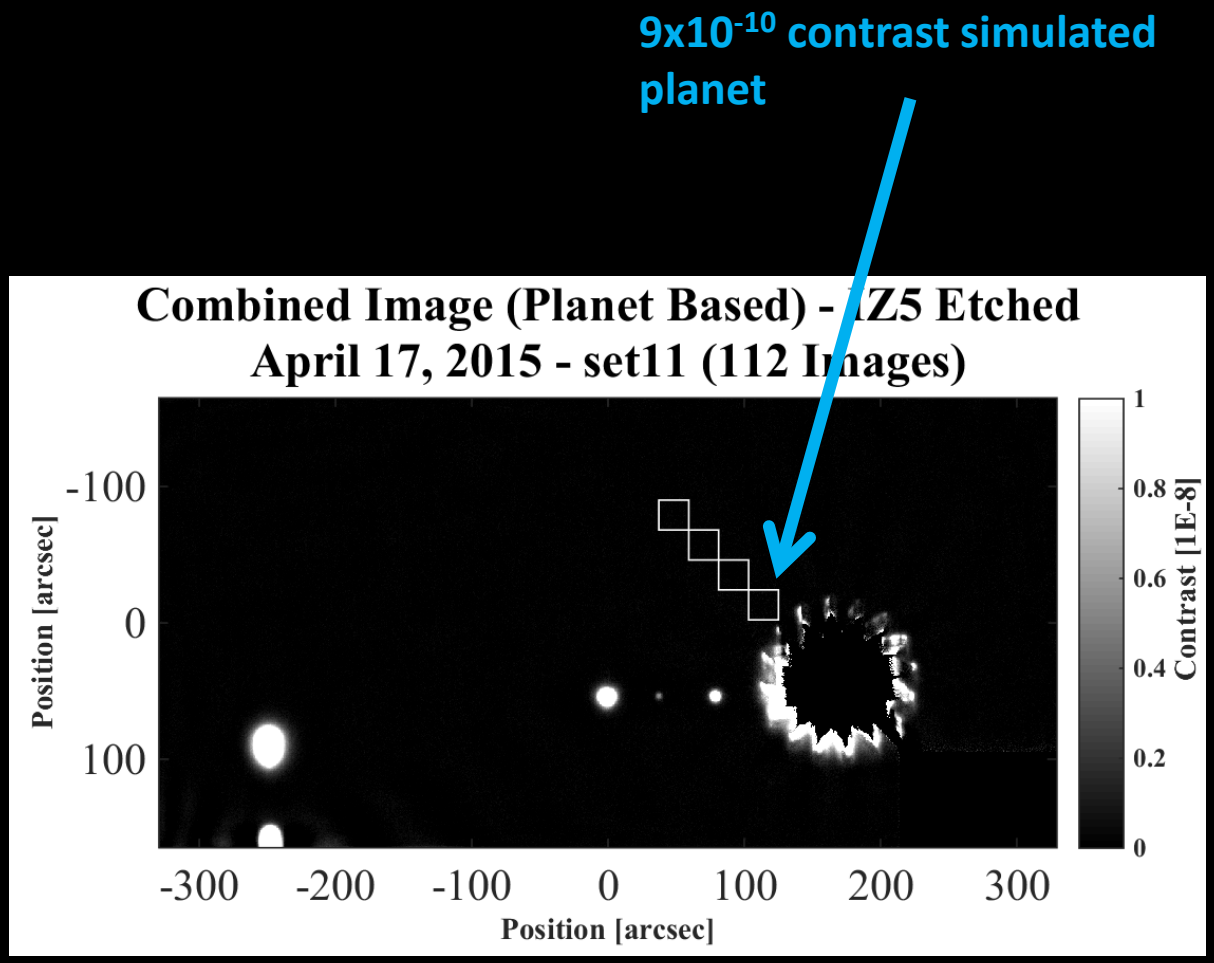
Precision Deployment and Shape Stability

Desert Field Optical Demonstrations

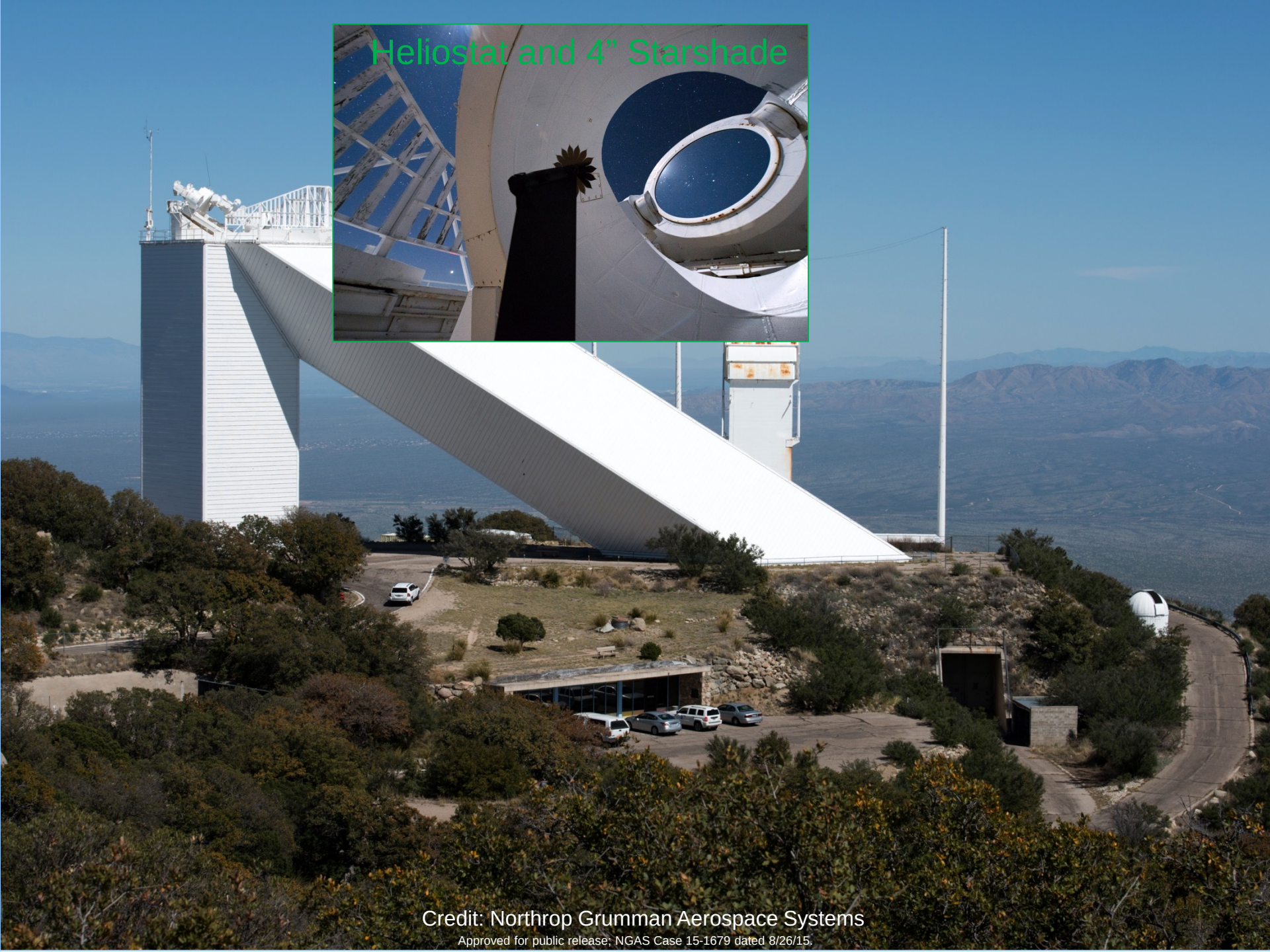
(PI Tiffany Glassman/NGAS)



Credit: PI Tiffany Glassman (Northrop Grumman Aerospace Systems)



Credit: PI Tiffany Glassman (Northrop Grumman Aerospace Systems)

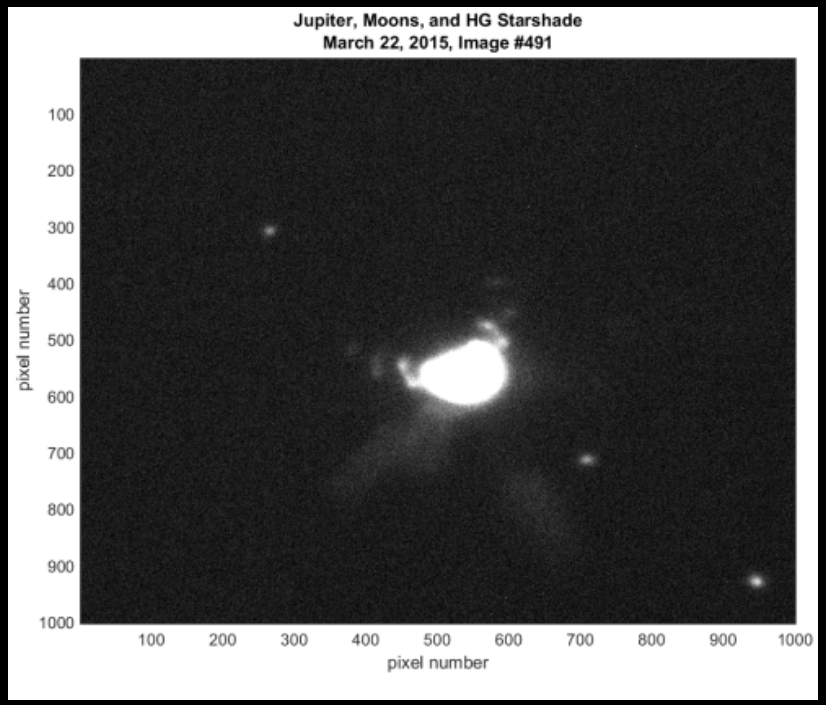


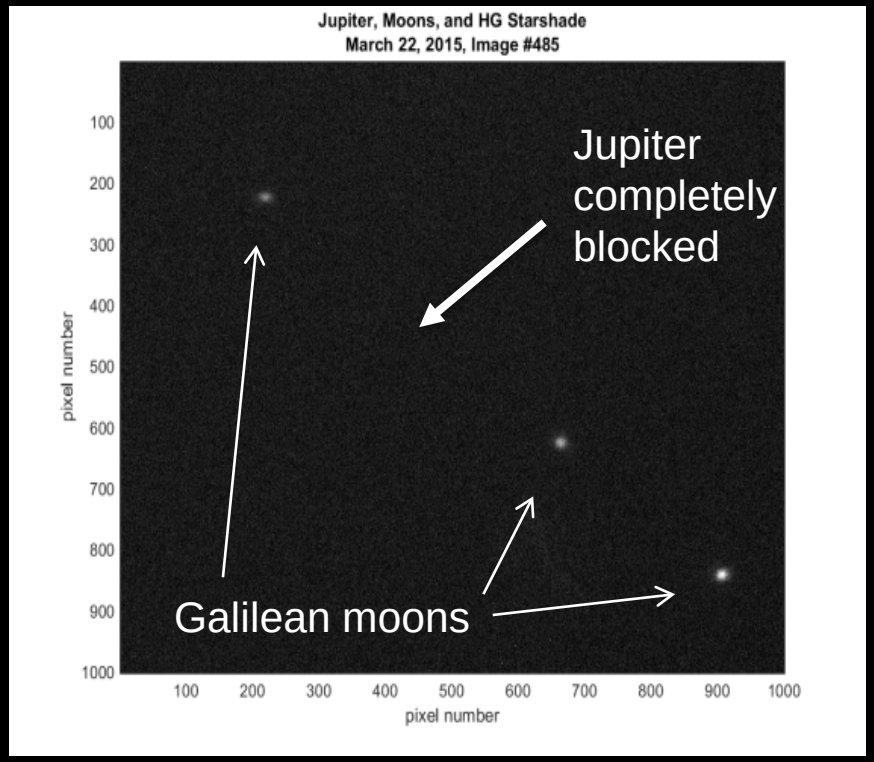
Credit: Northrop Grumman Aerospace Systems

Approved for public release; NGAS Case 15-1679 dated 8/26/15.

Optical Demonstrations at McMath-Pierce Solar Telescope

(PI Steve Warwick/NGAS)

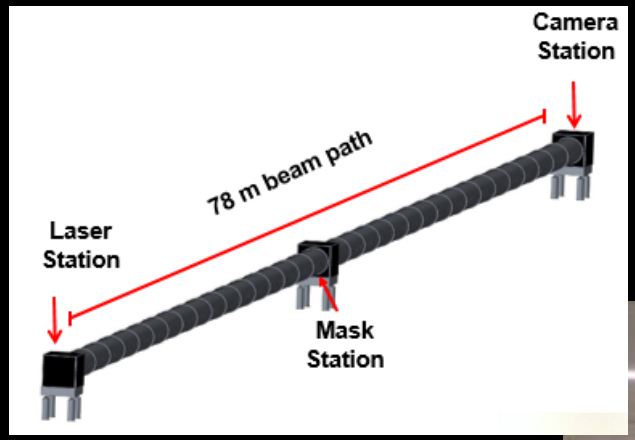


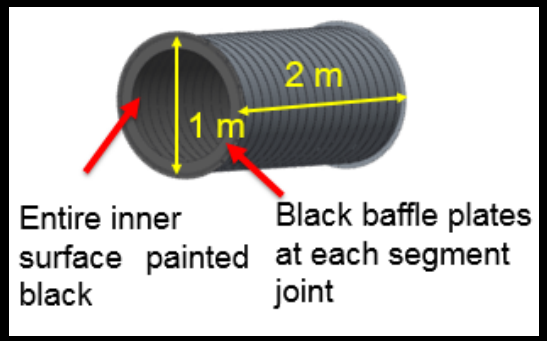


Credit: Northrop Grumman Aerospace Systems

Optical Demonstration at Princeton University

(PI Jeremy Kasdin)





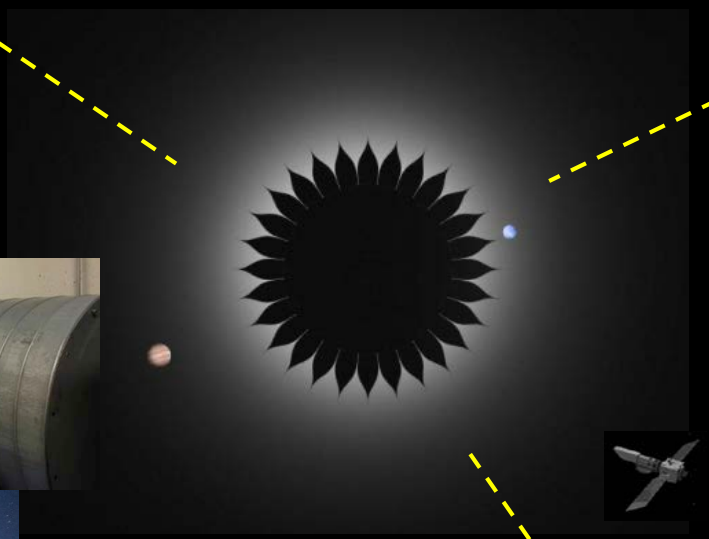
Credit: Princeton University

Key Technology Areas for a Starshade

Starlight Suppression

Controlling scattered and diffracted light

Demonstrating optical performance and validating optical model



Formation Sensing and Control

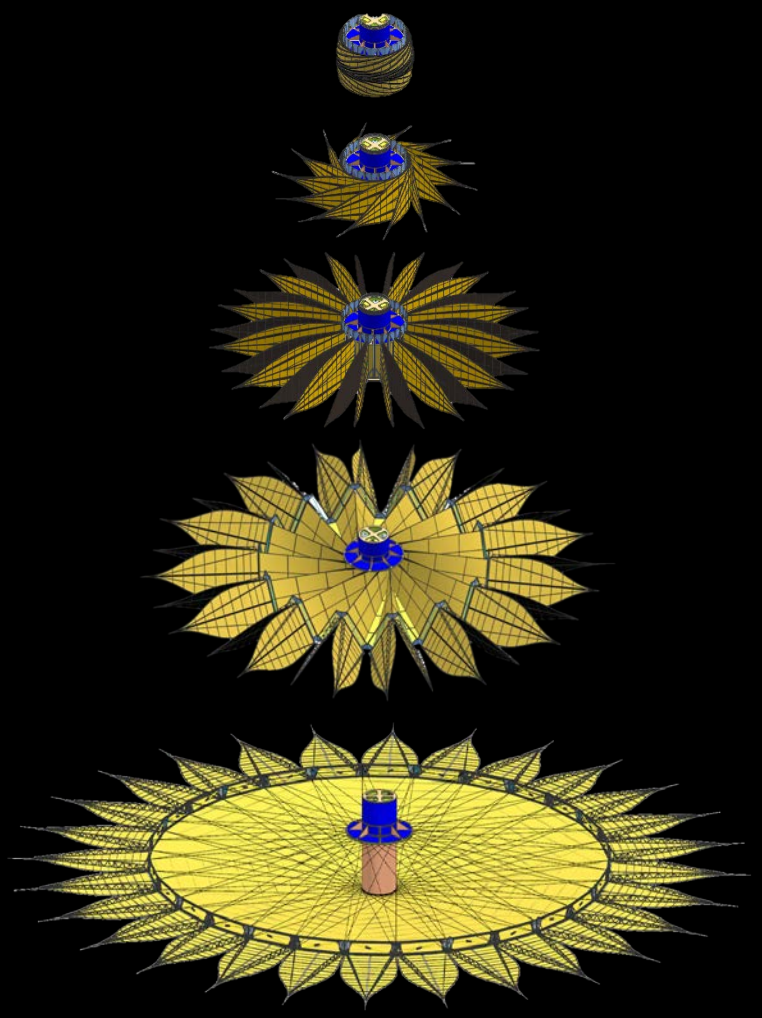
Precision Deployment and Shape Stability

Blocking on-coming starlight and maintaining overall shape

Positioning the petal to high precision; highly stable structure

Fabricating the petal to high precision

Different Deployment Architectures



Exo-S (JPL) starshade deployment concept

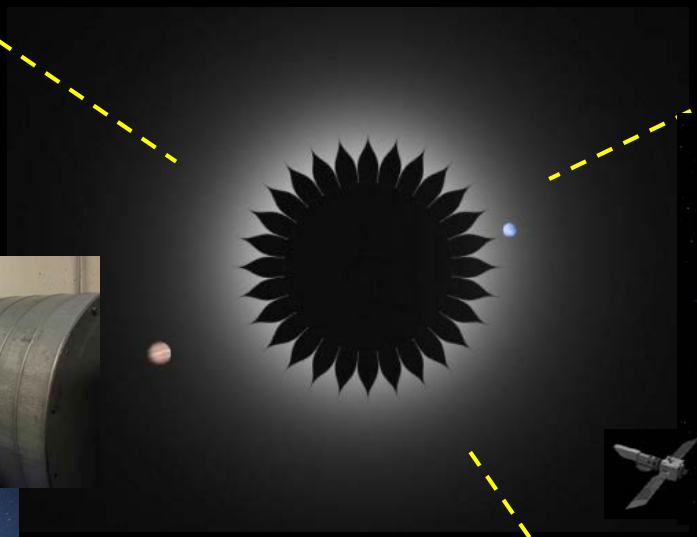
NGAS starshade deployment concept

Key Technology Areas for a Starshade

Starlight Suppression

Controlling scattered and diffracted light (S-1)

Demonstrating optical performance and validating optical model (S-2)



Formation Sensing and Control

Maintaining lateral offset requirement between the spacecrafts

Precision Deployment and Shape Stability

Blocking on-coming starlight and maintaining overall shape

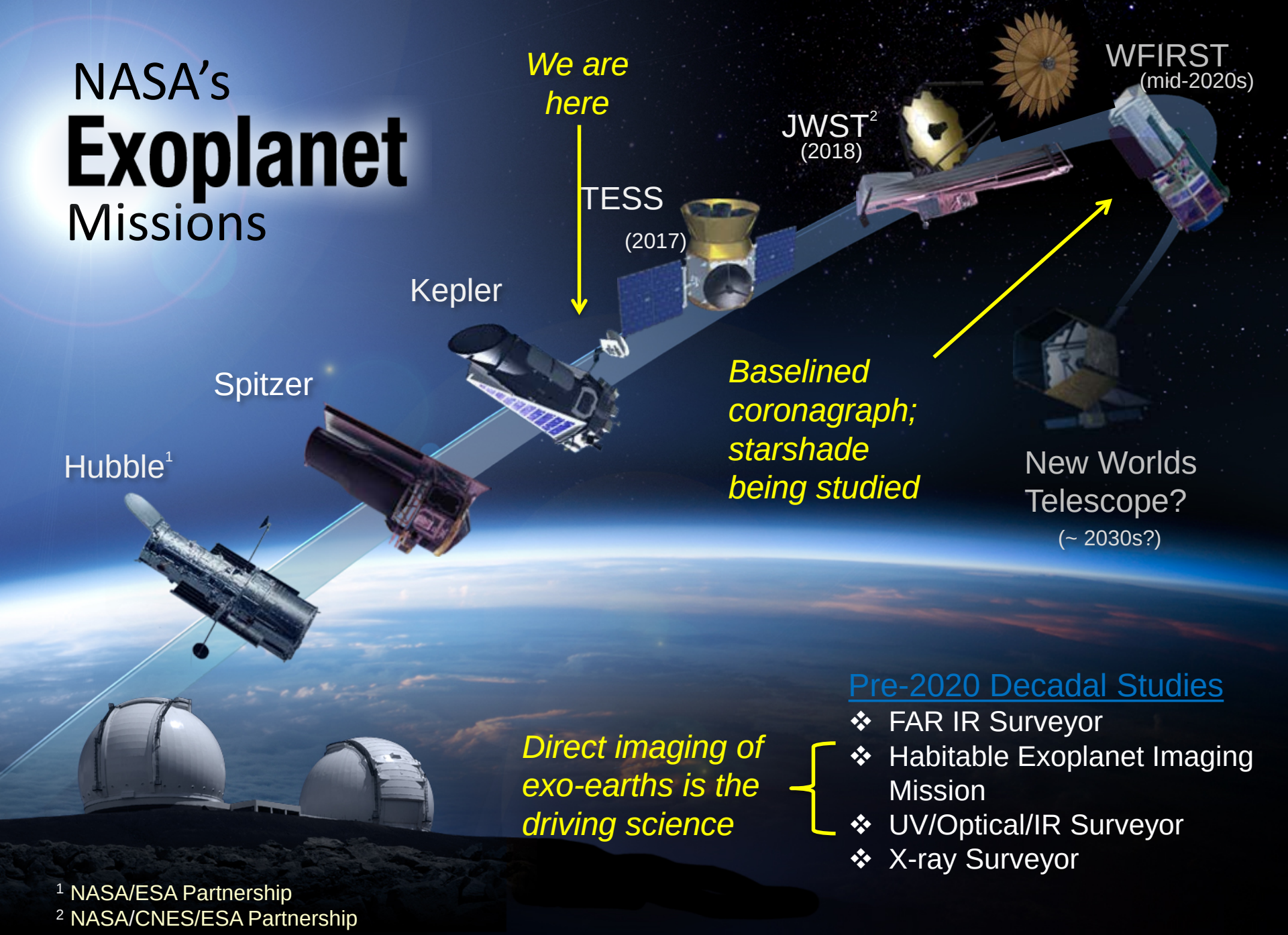
Positioning the petal to high precision; highly stable structure

Fabricating the petal to high precision

- Starshade Readiness Working Group began in January 2016
  - *Objective: Develop and deliver to NASA a recommendation for a plan to validate starshade technology to TRL6/7 that is both necessary and sufficient prior to building and flying a WFIRST starshade for science*
  - *Various options are being considered along with the parameters of the decision matrix*

- Starshade Technology Project to be created in April 2016
  - *Objective: Advance the technology development of starshades from TRL-3 to TRL-5*
  - *ExEP will manage the activities out of JPL*
  - *Initial reference mission will be WFIRST Rendezvous*
  - *Intention is to conduct architectural trades in FY16-17 and involve academia, industry, and other NASA centers*

NASA's Exoplanet Missions



Direct imaging of exo-earths is the driving science

Pre-2020 Decadal Studies

- FAR IR Surveyor
- Habitable Exoplanet Imaging Mission
- UV/Optical/IR Surveyor
- X-ray Surveyor

[1] NASA/ESA Partnership
[2] NASA/CNES/ESA Partnership

Acknowledgements

This work was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration

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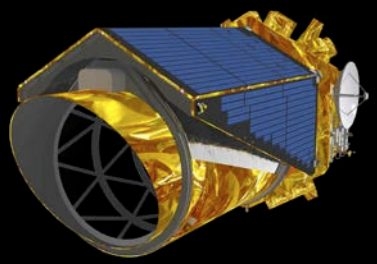
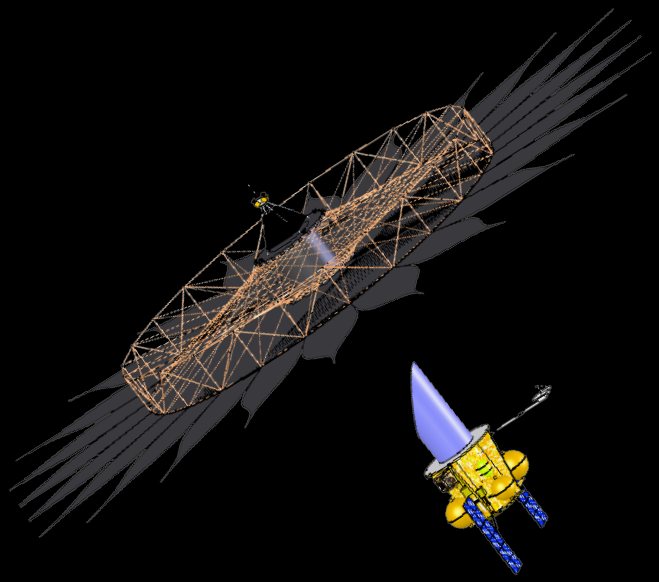
Government sponsorship acknowledged

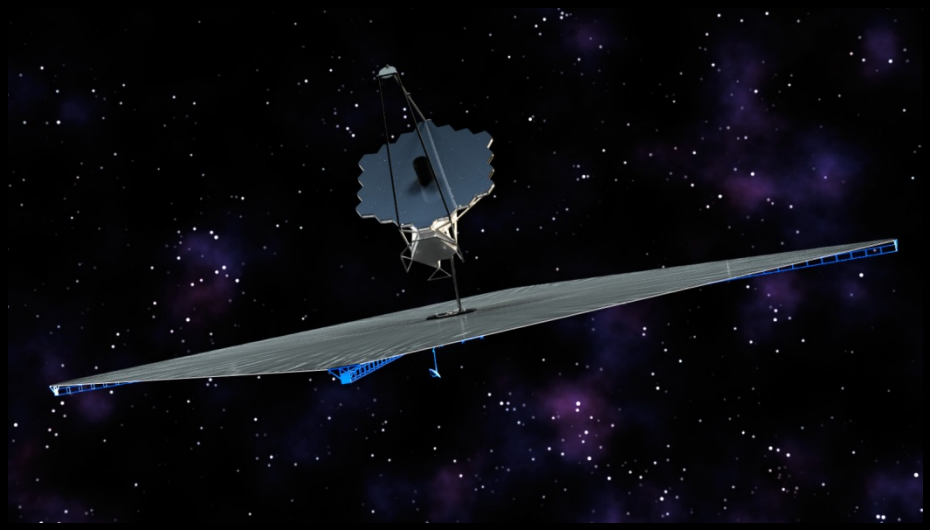




Backup Slides

We have a coronagraph, why do we need a starshade?

- Next generation coronagraphs may likely need to work with telescopes that are on-axis and segmented, with apertures > 8 m.



- Will require new solutions for:
  1. additional diffraction effects to reach 10^{-10} contrast – 10x better than WFIRST
  2. telescope jitter stability ~ 10-100x better than WFIRST
  3. wavefront sensing and control ~ 10-100x better than WFIRST