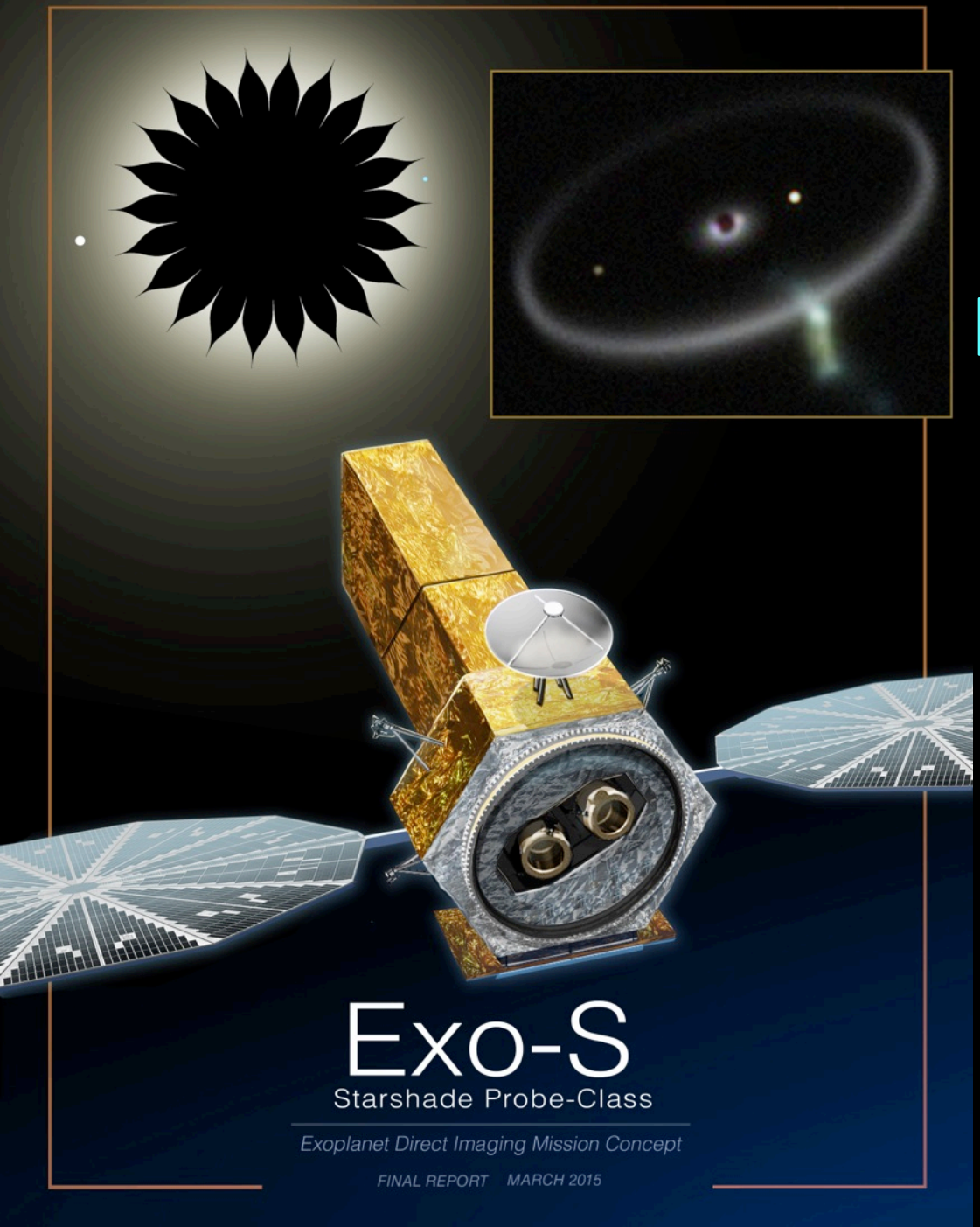

SCIENTIFIC OPPORTUNITIES FOR A STARSHADE WORKING WITH A 2.4 M TELESCOPE AT L2

Aki Roberge

NASA GSFC

Exoplanet Exploration Program

CL#15-1113

Jet Propulsion Laboratory, California Institute of Technology

NASA's recent Exoplanet Probe studies

- The discovery of exoEarths, via a space-based direct imaging mission, is a long-term priority for US astrophysics
- Two studies of "probe sized" exoplanet direct imaging missions: one coronagraph (Exo-C), one starshade (Exo-S)
  - Total mission cost targeted at $1B (FY15 dollars)
  - New start in 2017
  - Compelling science must be beyond the expected ground capability at the time of mission
- Studies also intended as a design input to the exoplanet community to help formulate ideas for the next Decadal Survey in 2020

Exo-S Team Members

STDT

- **S. Seager, Chair (MIT)**
- M. Thomson (NASA-JPL)
- M. Turnbull (GSI)
- W. Sparks (STScI)
- S. Shaklan (NASA-JPL)
- A. Roberge (NASA-GSFC)
- M. Kuchner (NASA-GSFC)
- N. J. Kasdin (Princeton)
- S. Domagal-Goldman (NASA- GSFC)
- W. Cash (Colorado)

JPL Design Team

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- C. Heneghan
- S. Martin
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- R. Trabert
- D. Webb
- E. Cady
- R. Baran
- P. Zarifian
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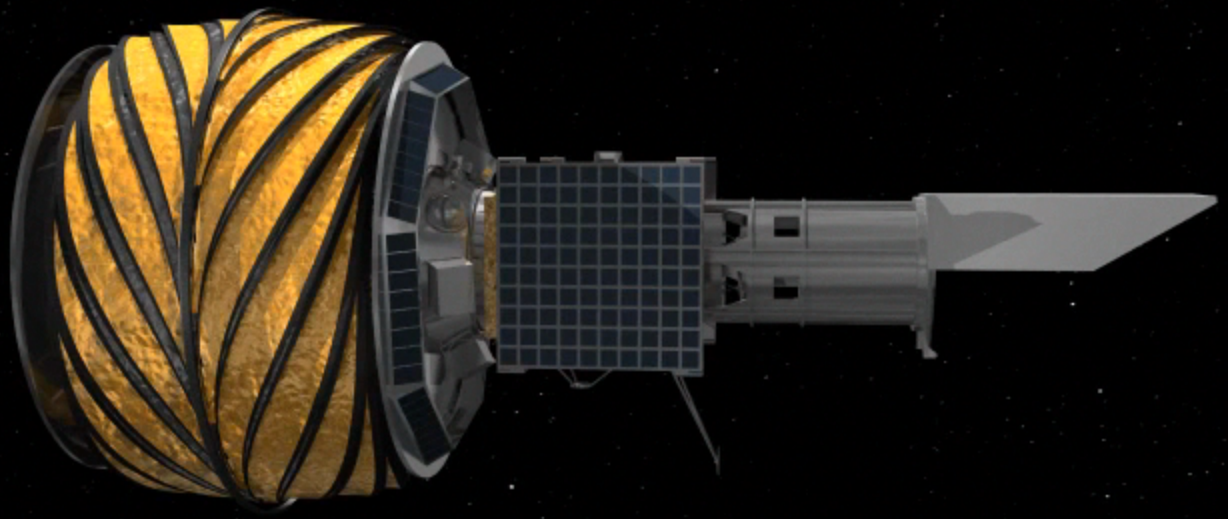
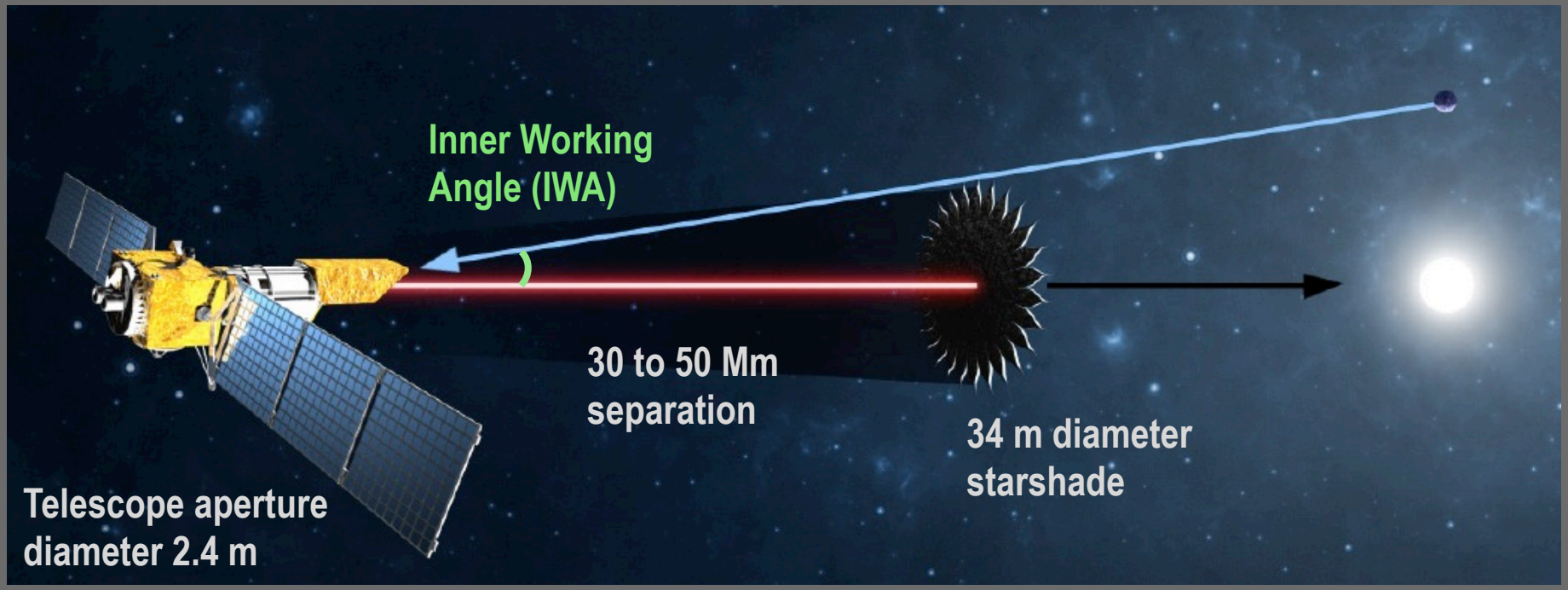
- B. Hirsch



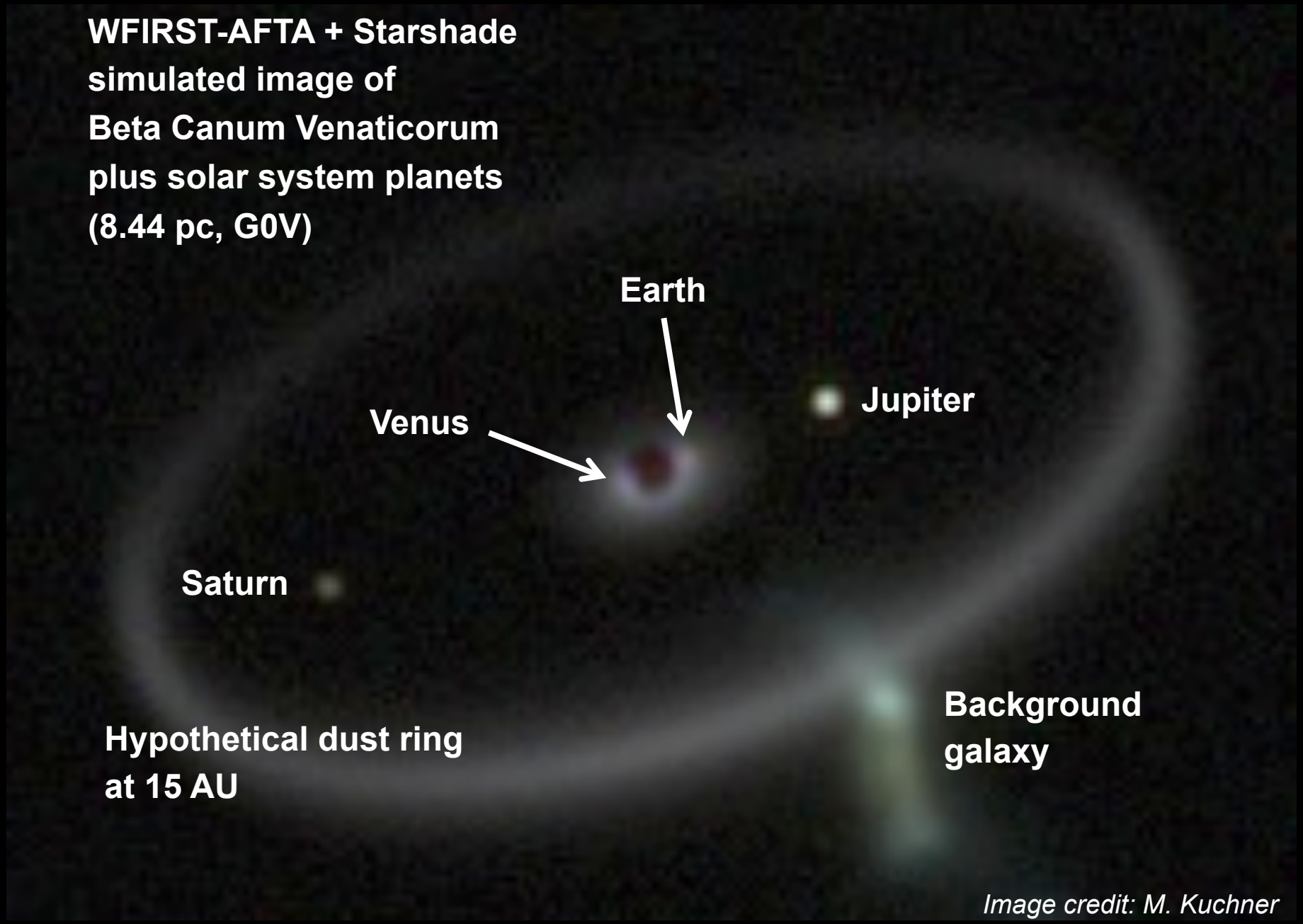
Starshade Basics



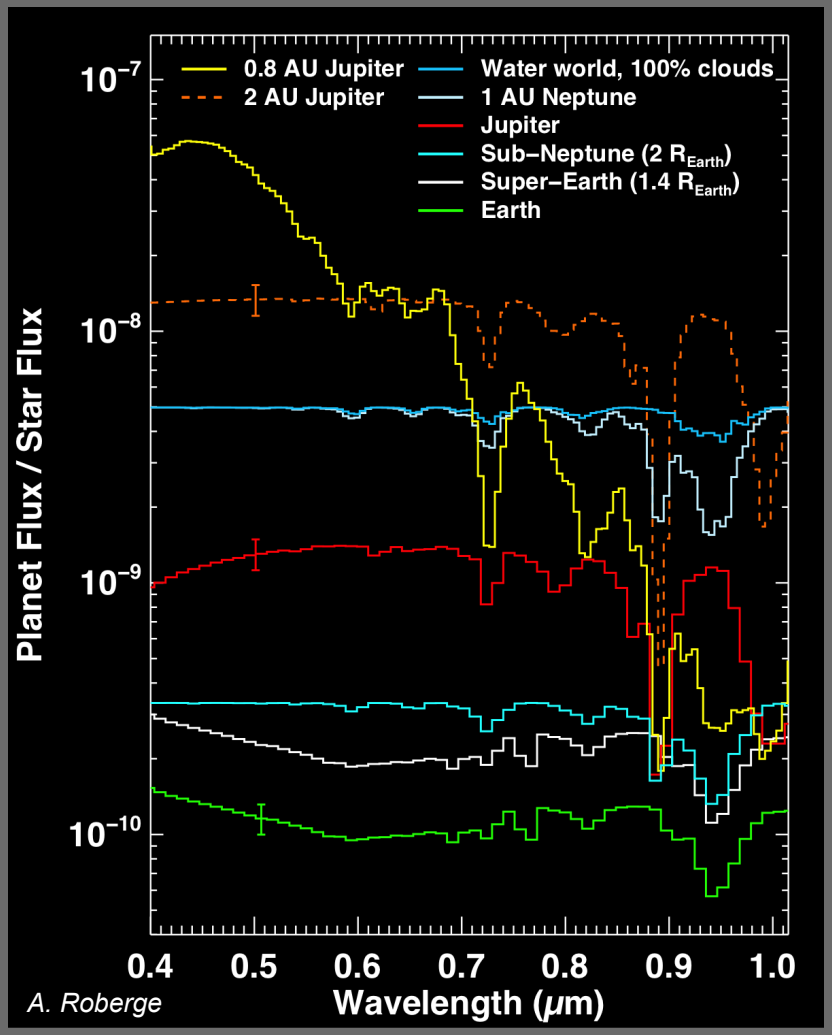
- Contrast and IWA decoupled from telescope aperture size
- No outer working angle
- High throughput, broad wavelength bandpass
- High quality telescope not required
  - Wavefront correction unnecessary
- Retargeting requires long starshade slews (days to weeks)

Two Cost Constrained Exo-S Concepts

- Exo-S Dedicated Co-Launched Mission
  - Starshade and telescope launch together to conserve cost
  - Telescope: low-cost commercial Earth observer, 1.1 m diameter aperture
  - Starshade: 30 m diameter
- Exo-S Rendezvous Mission
  - Starshade launches for a rendezvous with an existing telescope
  - Telescope: WFIRST/AFTA 2.4 m is adopted
  - Starshade: 34 m diameter
  - Orbit: Earth-Sun L2 (assumption for the purposes of the Exo-S study)
  - Three year Class C mission
  - Minimal impact to current mission design
    - No stringent requirements are imposed on the WFIRST/AFTA spacecraft
    - No new instrument, only modification to the existing coronagraph


WFIRST-AFTA + Starshade
simulated image of
Beta Canum Venaticorum
plus solar system planets
(8.44 pc, G0V)
Earth
Jupiter
Venus
Saturn
Hypothetical dust ring
at 15 AU
Background
galaxy
Image credit: M. Kuchner

Exo-S Science Goals



Simulated R=70 planet spectra for the 2.4-m mission, with three representative 10% error bars.

1.1-m mission cannot reach R=70 on small planets.

1. Discover new exoplanets from giants down to Earth size
2. Characterize new planets with R=10 to 70 optical spectra
3. Characterize known giant planets with R=70 spectra and constrain masses
4. Study planetary systems including circumstellar dust
   - Locate dust parent bodies
   - Evidence of unseen planets
   - Exozodi assessment for future missions

Key Capabilities

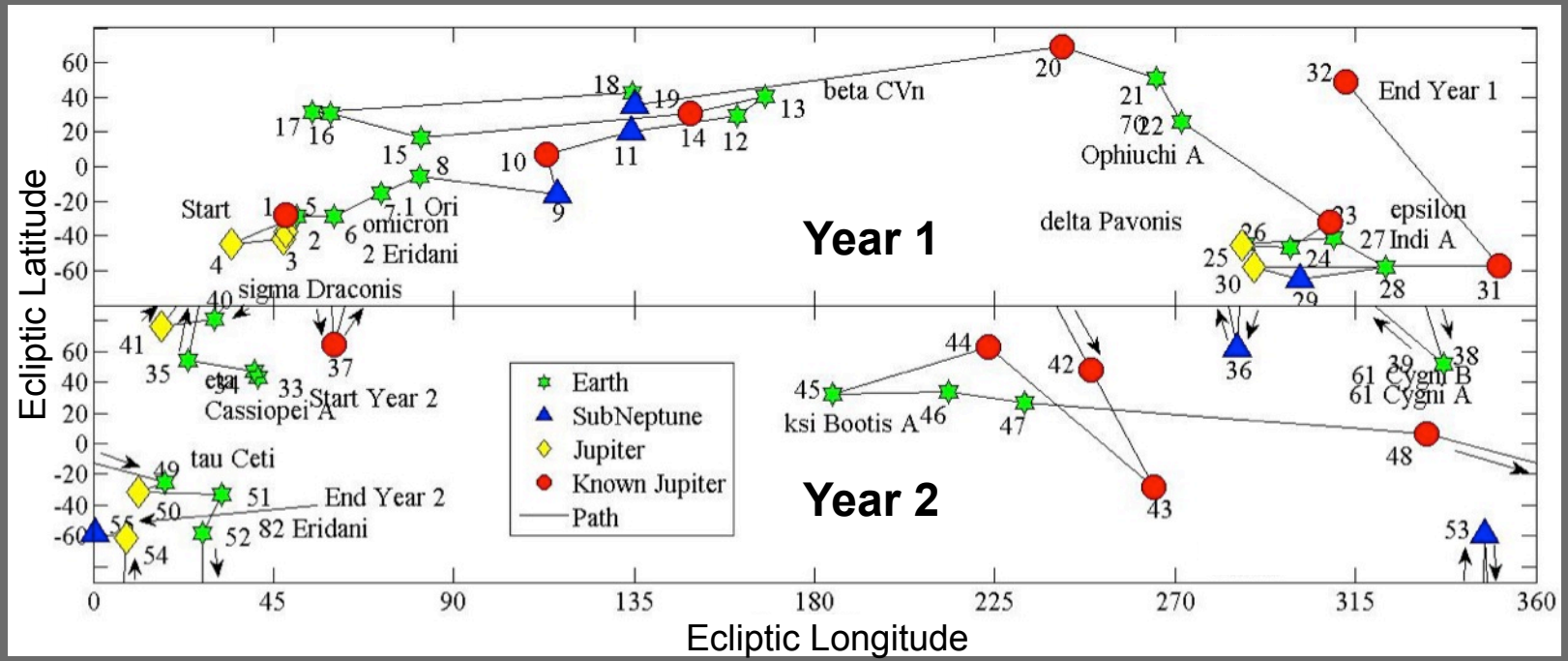
Wide-Field Imager, Integral Field Spectrograph, Guide Camera

Already part of WFIRST coronagraph

- Contrast at inner working angle = 1 x 10^{-10}
- Total throughput = 28% (imager), 22% (IFS)
- Field-of-view = 10 arcsec (imager), 2 arcsec (IFS)

Observing Sequence

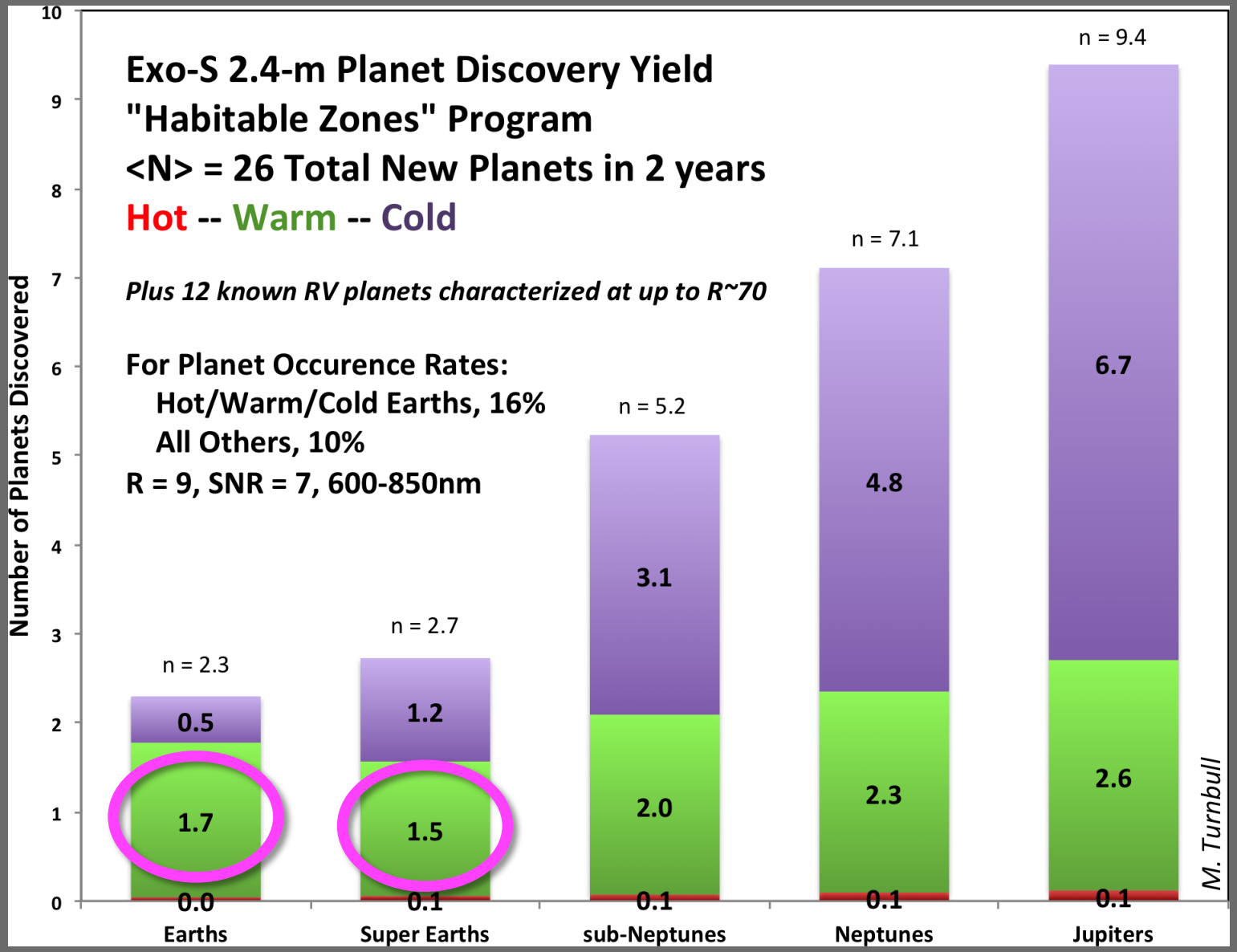
1. Schedule known giant planet observations
2. Fill gaps on sky with highest priority blind search target (Earths)
3. Repeat with lower priority targets (sub-Neptunes & Jupiters) until fuel or time limit (2 years) reached



55 stars visited. Uses ~ 9% of total WFIRST time.

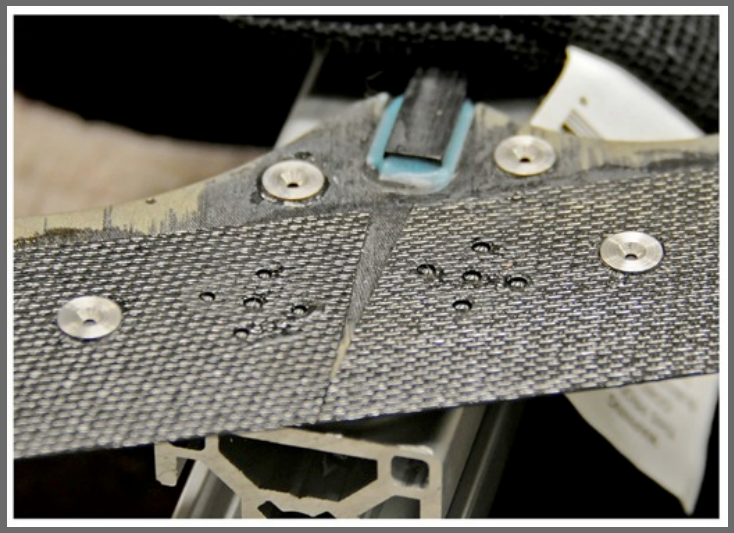
12 known giant planets. Blind search targets: 28 Earths, 7 sub-Neptunes, 8 Jupiters

Expected Yield By Planet Type & Temperature



Technical challenges

- Precise edge profile (~ 50 μm tolerance) required over large structure
- Knife-edge to prevent sunlight scattering into telescope
- On-orbit deployment of large structure



NASA / JPL / Princeton

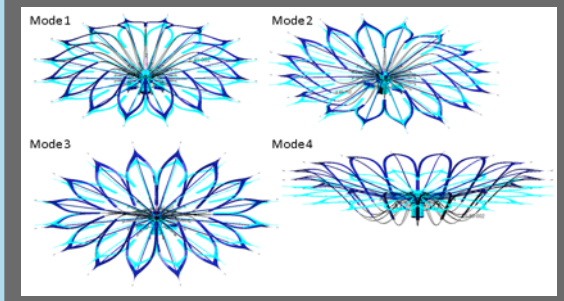
- Precise alignment between starshade and telescope needed (± 1 meter tolerance). Soft requirement
- Full-scale end-to-end system test on the ground not possible

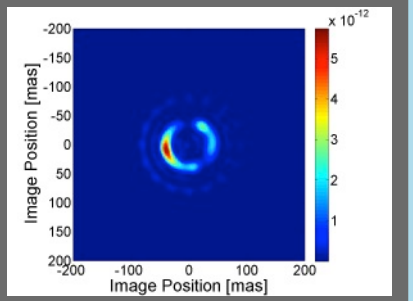
Contrast demonstrations

Caveat : lab & field demonstrations not completely accurate

Optical models with distortions
monochromatic: 10^{-12}

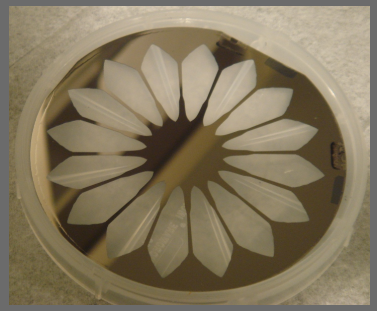
Credit: S. Shaklan (JPL)

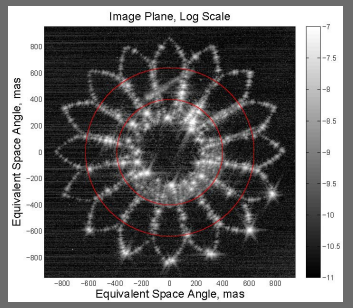




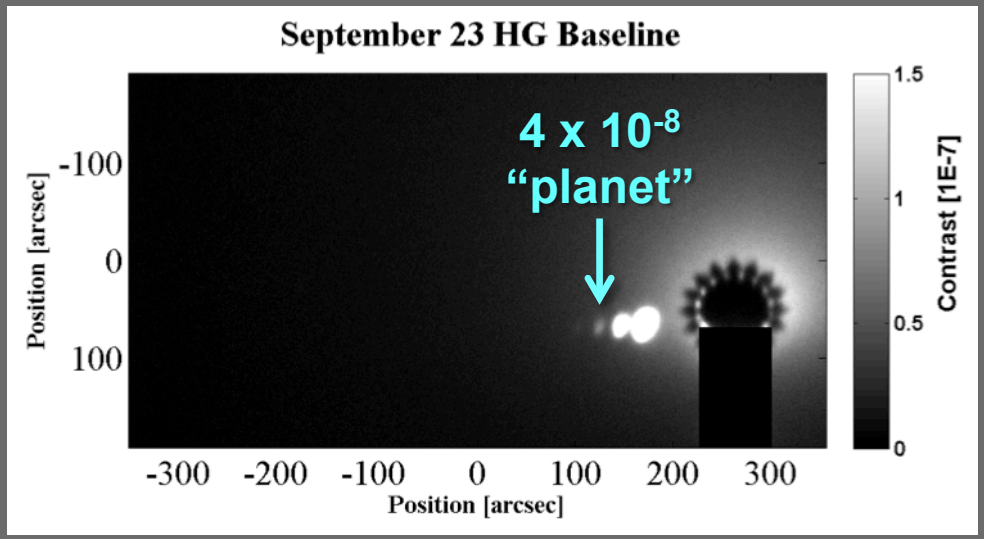
0.1% scale lab testing
monochromatic: 10^{-10}

Credit: J. Kasdin (Princeton)



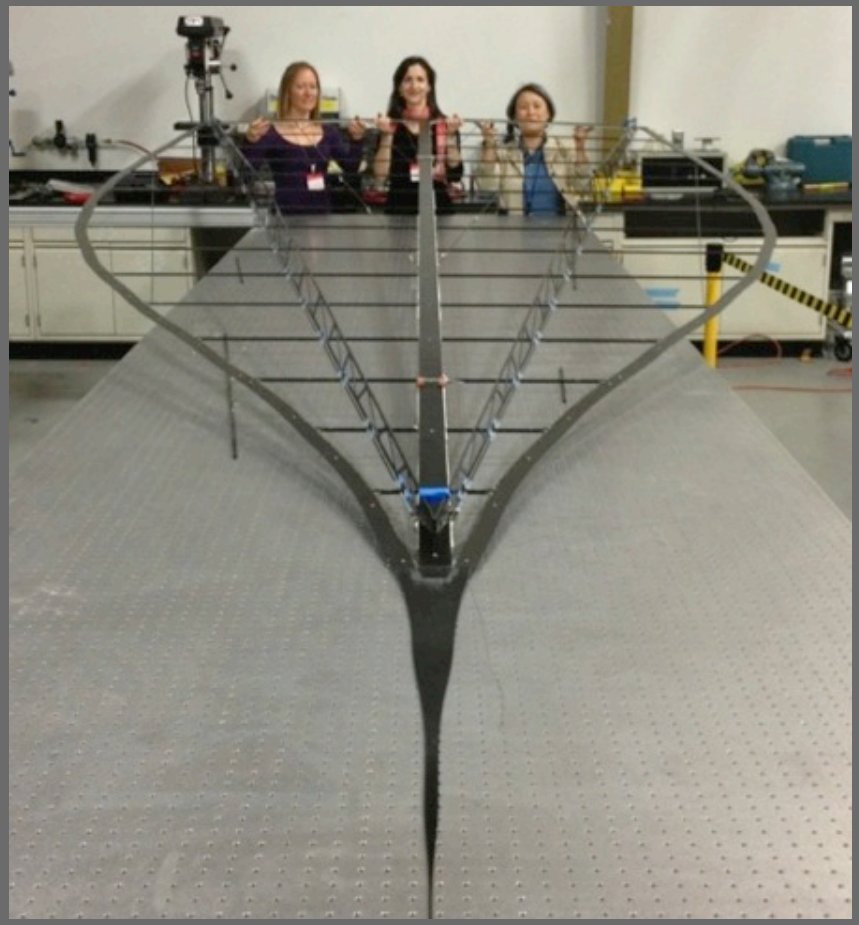


~ 1% scale field testing
50% bandpass: 10^{-8}



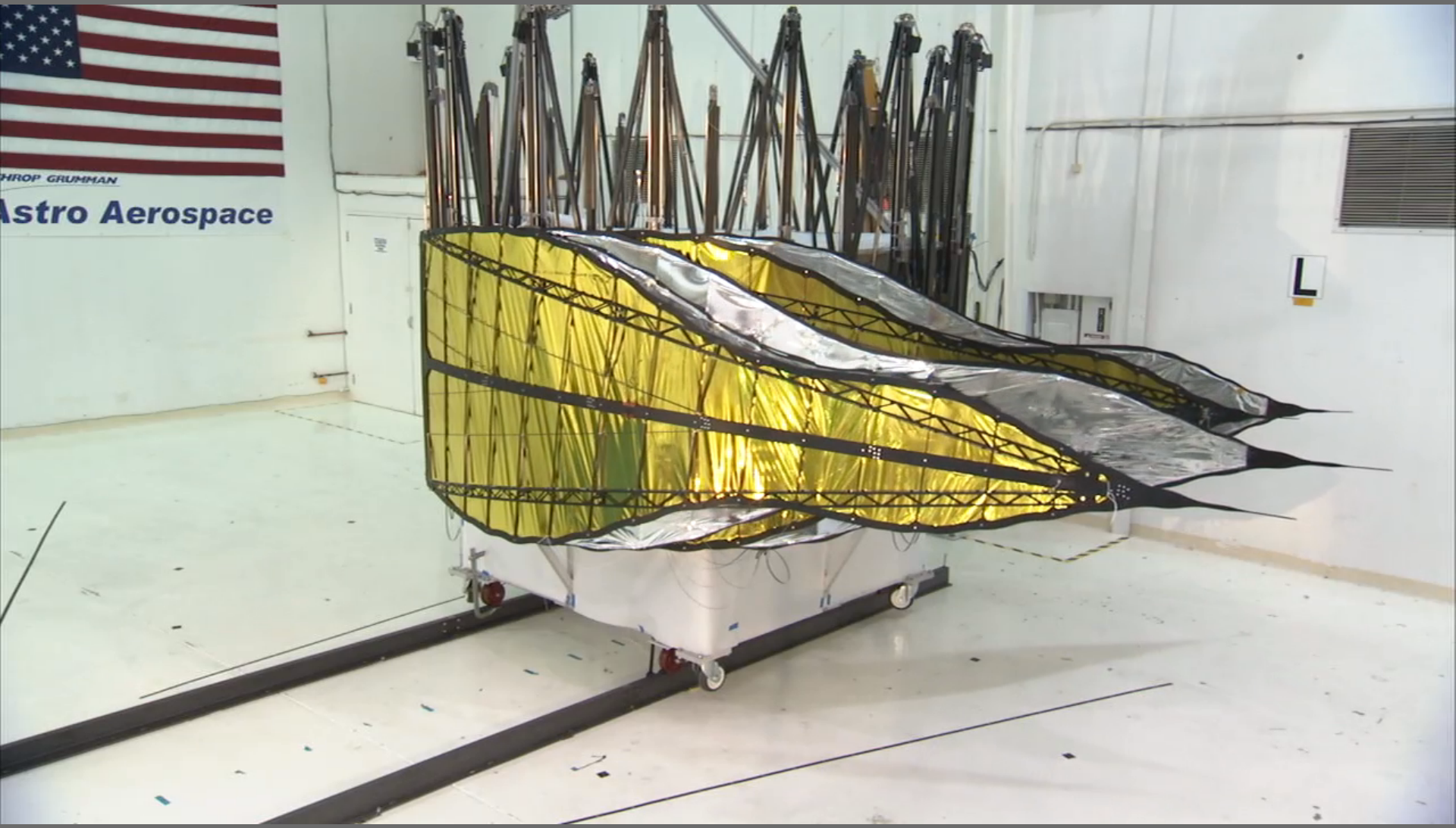
Precision petal manufacturing

Full-scale petal with edge profile for contrast < 10^{-10}



Development of knife-edge to control edge scatter underway

Deployment demonstration



Cost Estimates

- Cost and technology readiness analysis by Exo-S Team, JPL Team X, and Aerospace Corporation
- Estimated 2.4-m mission Phase A – F cost: $627M
  - Includes launch and modifications to WFIRST
- Aerospace Corp. raised no issues with technology schedule
  - To reach TRL-5 by 2017 for 5 key technology gaps

The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and Caltech.

Take-Away Message

WFIRST-AFTA can be leveraged for a unique and timely opportunity

- Mission with 34-m starshade can access exoEarths in the habitable zone for up to 50 unique target stars
- JPL now studying enhanced design with 40-meter starshade
- Minimal modification to WFIRST needed for starshade readiness
- Starshade technology is on track for new start by 2018, but not fully funded