Starshade Rendezvous Probe Study
AAS Update
January 9, 2018

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Study lead: Andrew Gray (JPL)

Team Membership

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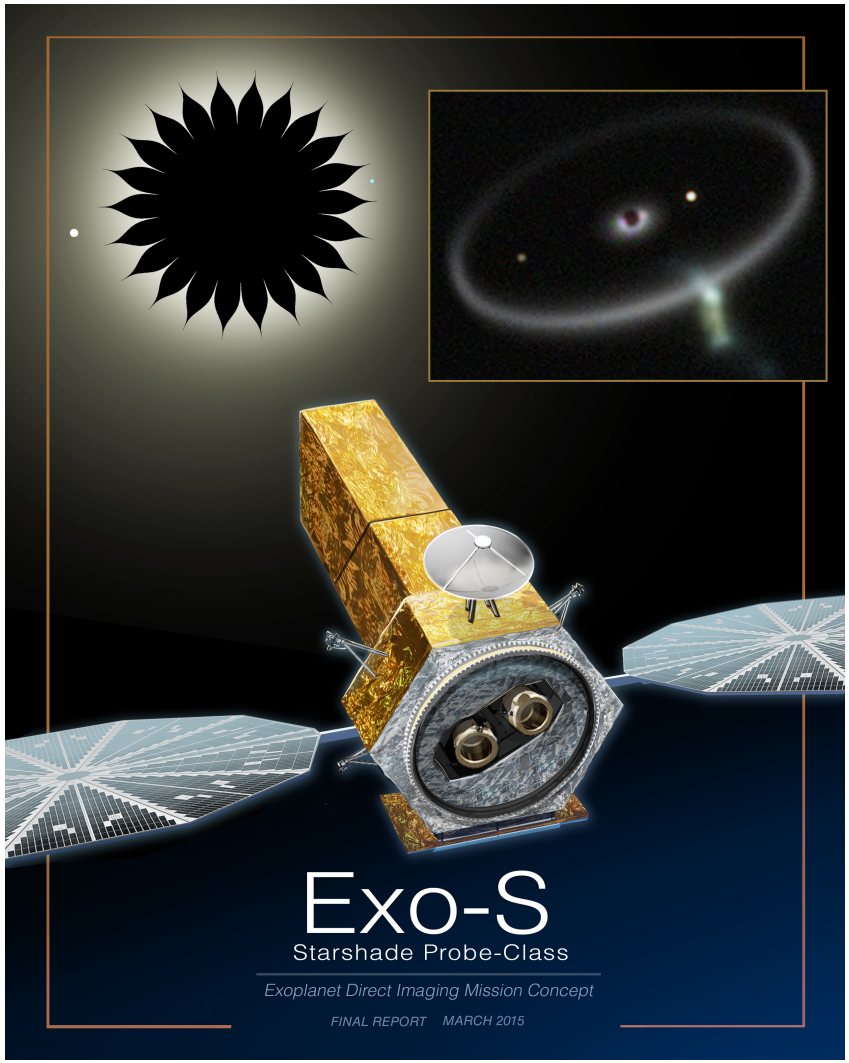
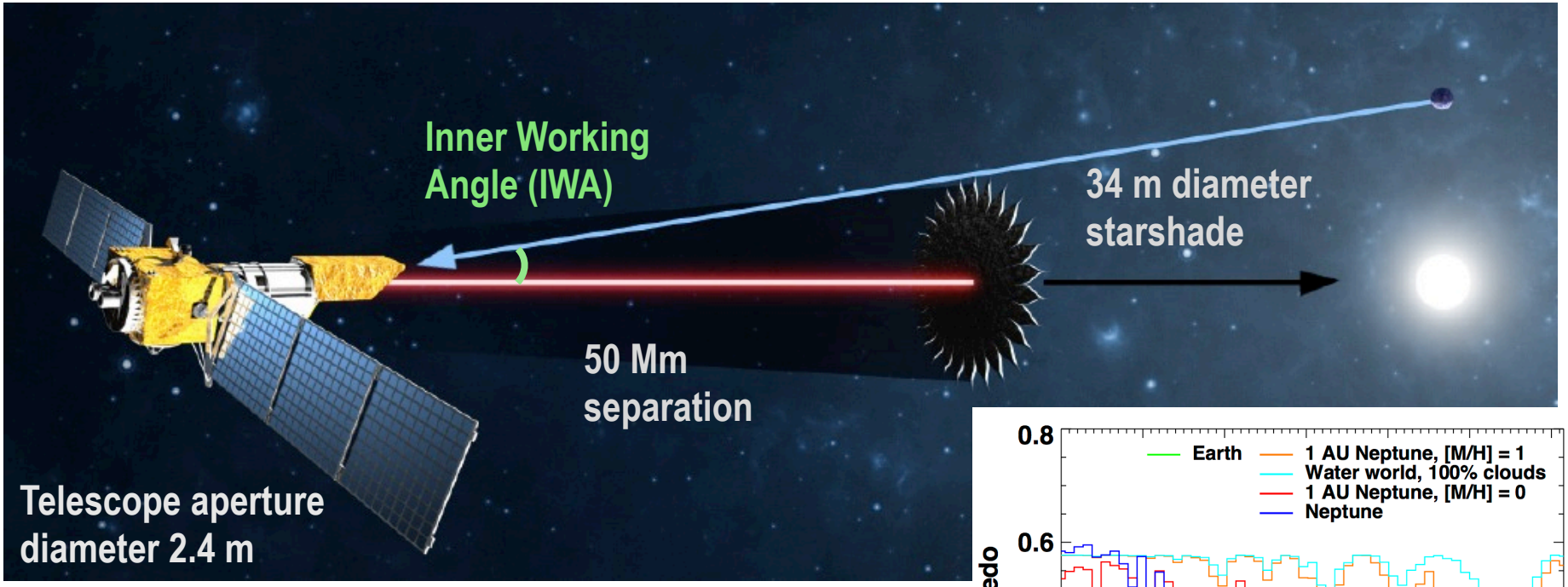
Dmitry Savransky	Cornell University
Chris Stark	StScI
John Ziemer	JPL

Introduction

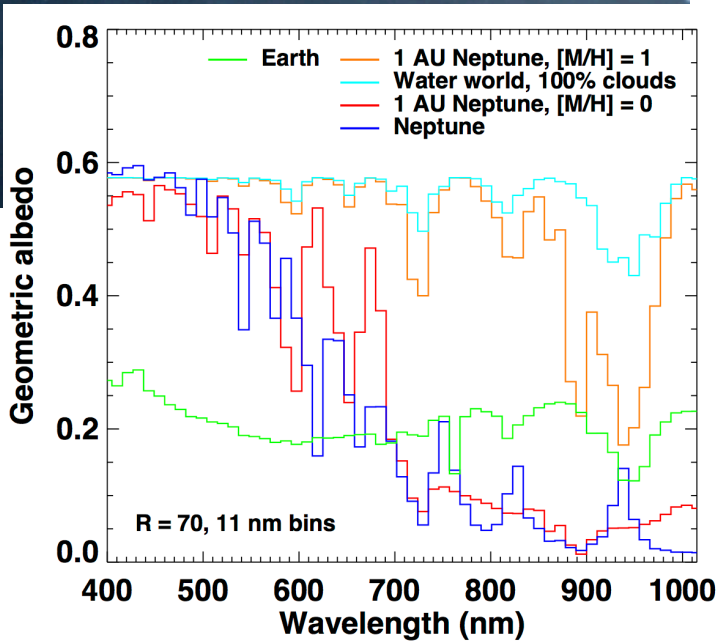
- **Starshade History (1960-2013)**
  - Proposed by L. Spitzer in 1962
  - Revisited each decade, including a revitalization by W. Cash in 2000s
- **Probe Study (2013-2015)**
  - Directed by NASA HQ to develop a mission concept under $1B, with other programmatic constraints
  - The Probe Study two concepts
    - The Dedicated Mission", a 30 m Starshade and 1.1 m telescope co-launches
    - **The Rendezvous Mission, 34 m Starshade launches and meets up with WFIRST**
- **Other Studies (2015-present)**
  - Extended Probe Study (2015)
  - Starshade Readiness WG (2016)
  - HabEx Flagship Study (present)



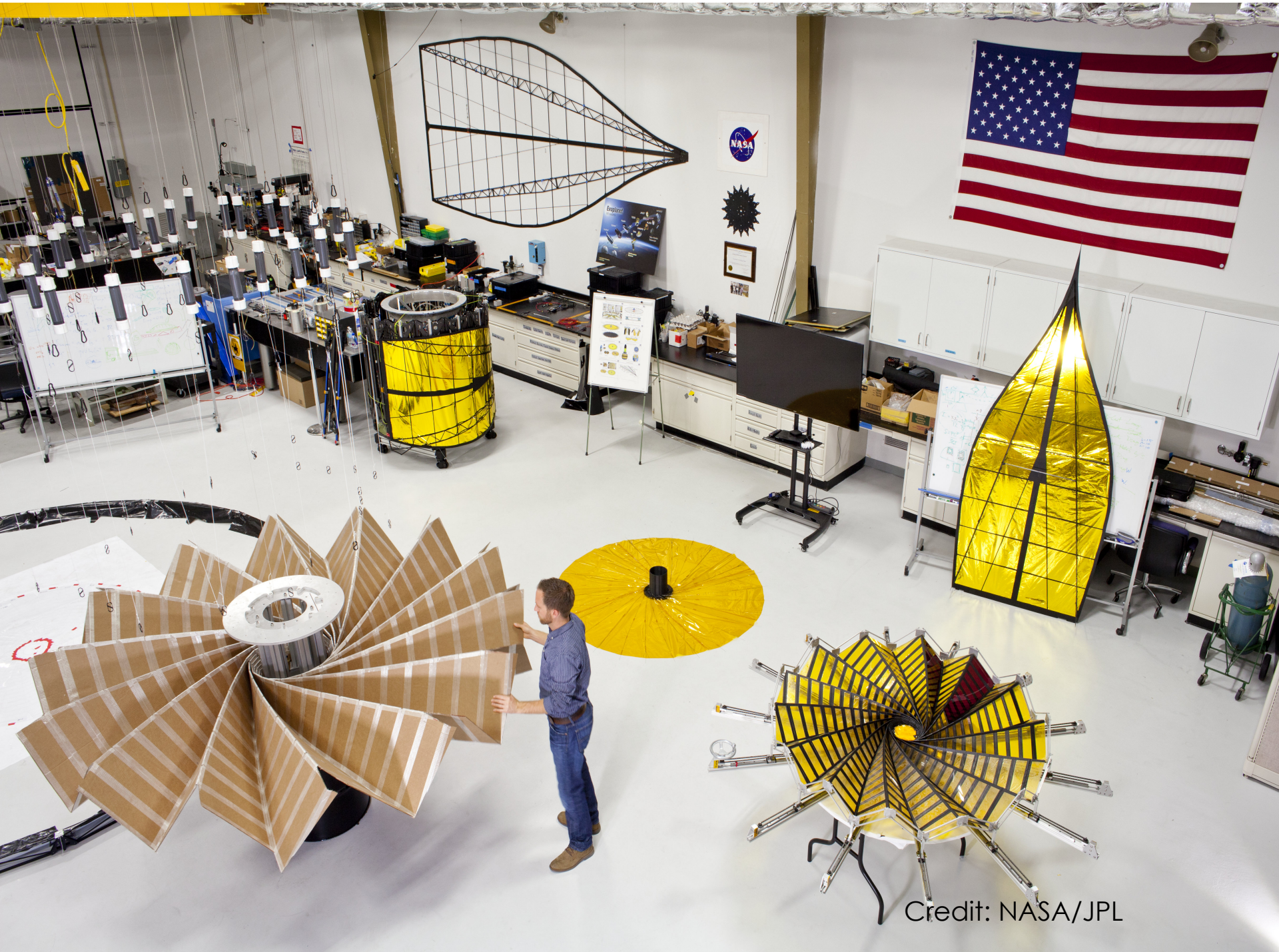
Starshade Rendezvous Basics

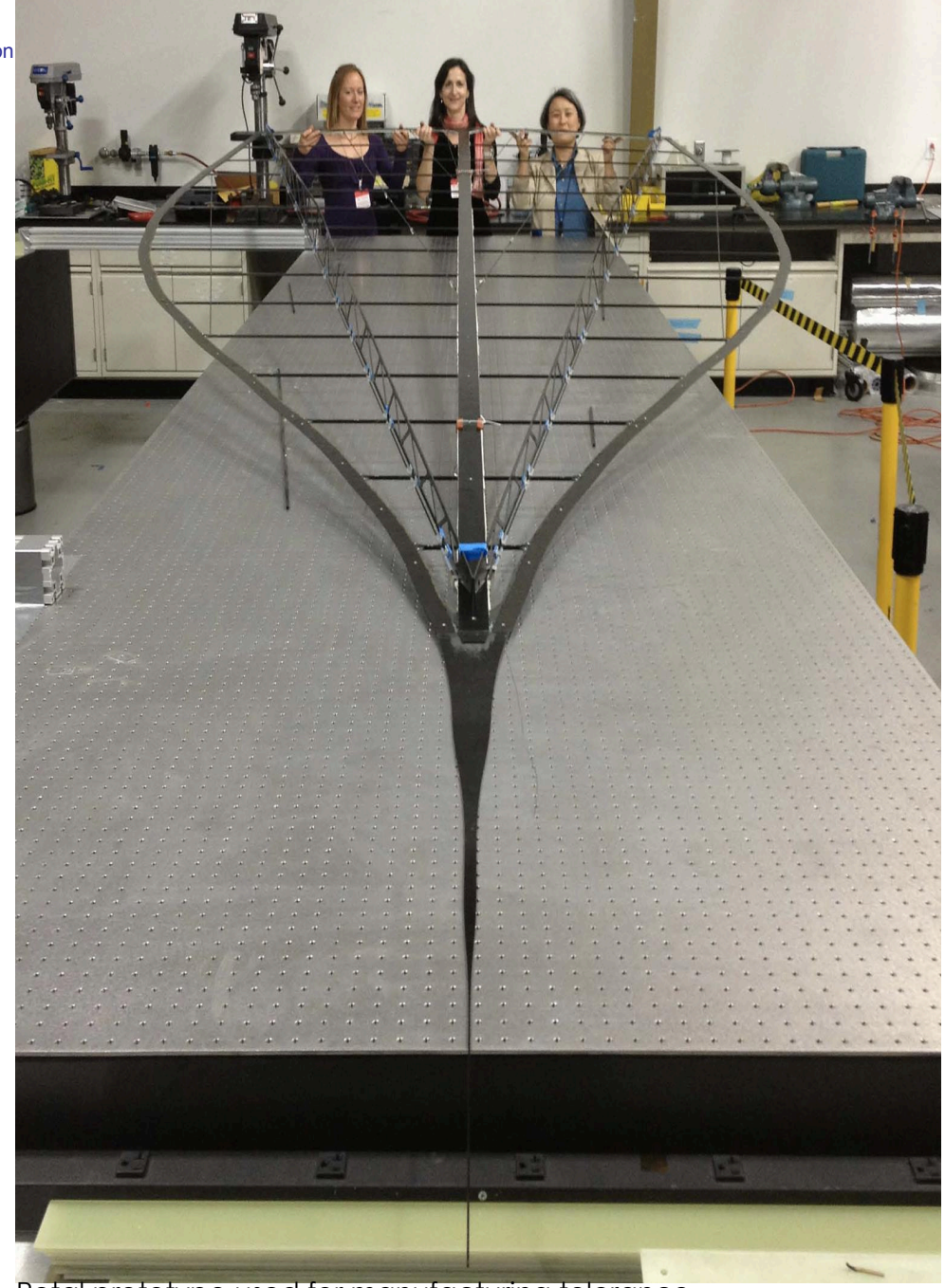


- Contrast and IWA largely decoupled from telescope aperture size
- Outerworking angle limited only by detector
- High throughput, broad wavelength bandpass
- High quality telescope not required means wavefront correction unnecessary
- Retargeting requires long starshade slews (days to weeks)



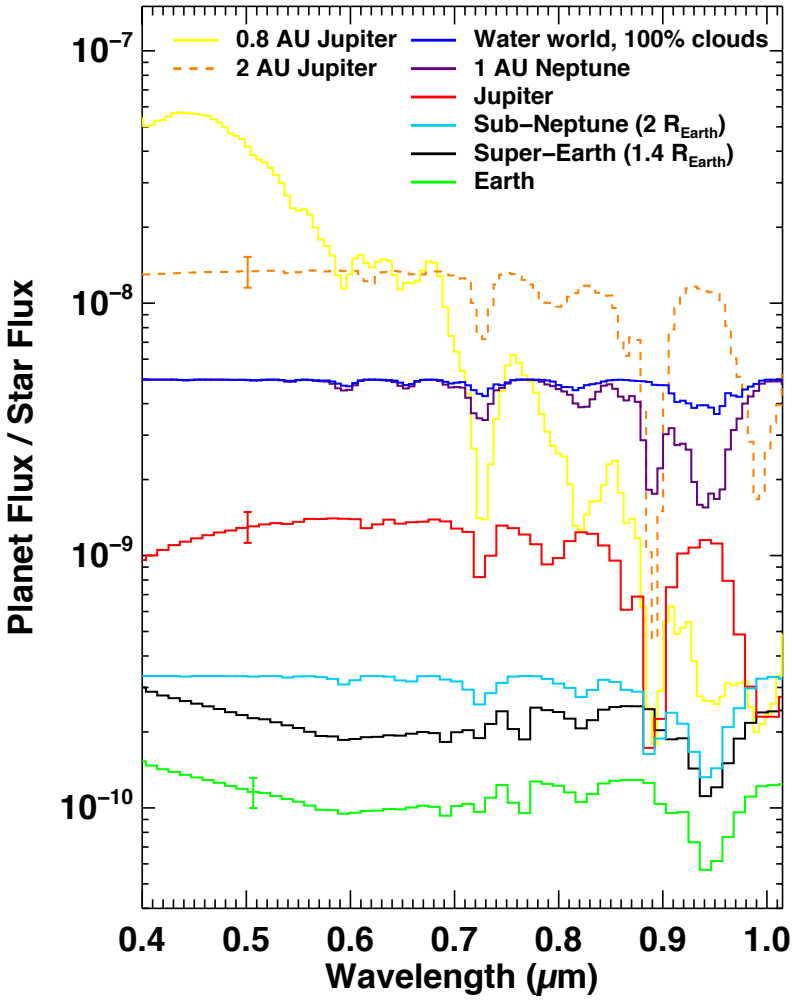
Simulated reflected light spectra of exoplanets convolved to *R*=70


NASA
Credit: NASA/JPL



Petal prototype used for manufacturing tolerance verification tests. Credit: NASA/JPL

Exo-S Science Goals



Simulated spectra for the Rendezvous mission, with three representative 10% error bars for SNR=10.

Parameters	Observing Bands		
	Blue	Green	Red
Bandpass (nm)	425-602	600-850	706-1000
IWA (mas)	70	100	118
Separation (Mm)	50	35	30

1) Discover new exoplanets from giant planet down to Earth size
2) Characterize new planets by spectra (*R*=10 to 70)
3) Characterize known giant planets by spectra (*R*=70) and constrain masses
4) Study planetary systems including circumstellar dust in the context of known planets

A DRM "proof of concept" shows feasbility

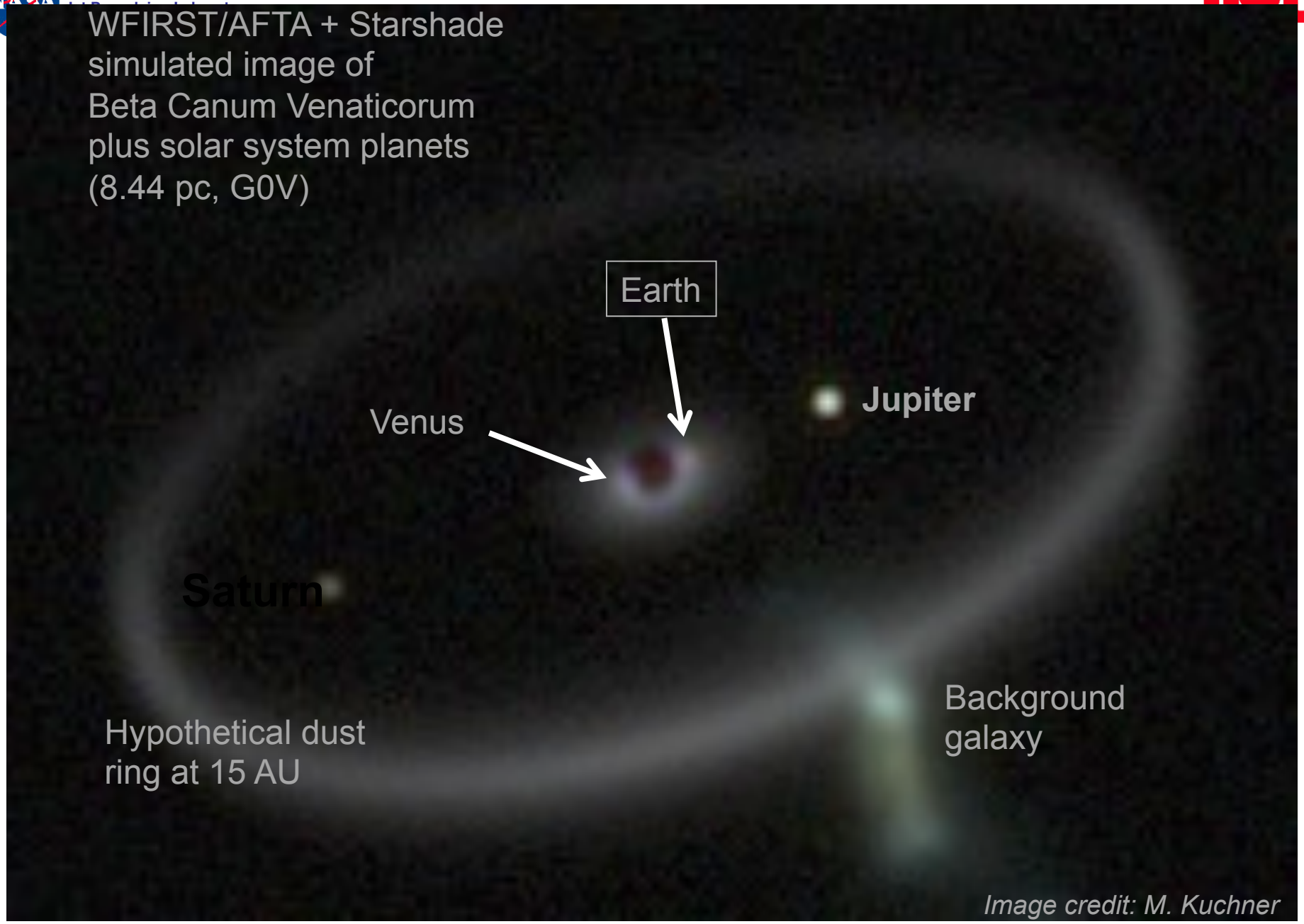
Study Goals: Update the previously completed Starshade Rendezvous concept study

- **Science and Observing Strategy**
  - New scientific vision: “Deep Dive” direct imaging exploration of planetary systems orbiting the nearest sun-like stars in a search for Earth-like planets
  - Assess the full science potential of each system including the diversity of planets and locations of dust/asteroid belts
  - (Incorporate findings from the WFIRST SITs for complementarity with CGI science)

WFIRST/AFTA + Starshade simulated image of Beta Canum Venaticorum 8.44 pc, G05 plus solar system planets. Image credit: M. Kuchner

- **Update EXO-S Study with advances in S-5 Technology Project and W-First Accommodation Study**

- **JPL and GSFC are internally investing in additional maturation**
  - Increase maturity of the study report and engineering concept definition


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

Starshade Rendezvous Probe

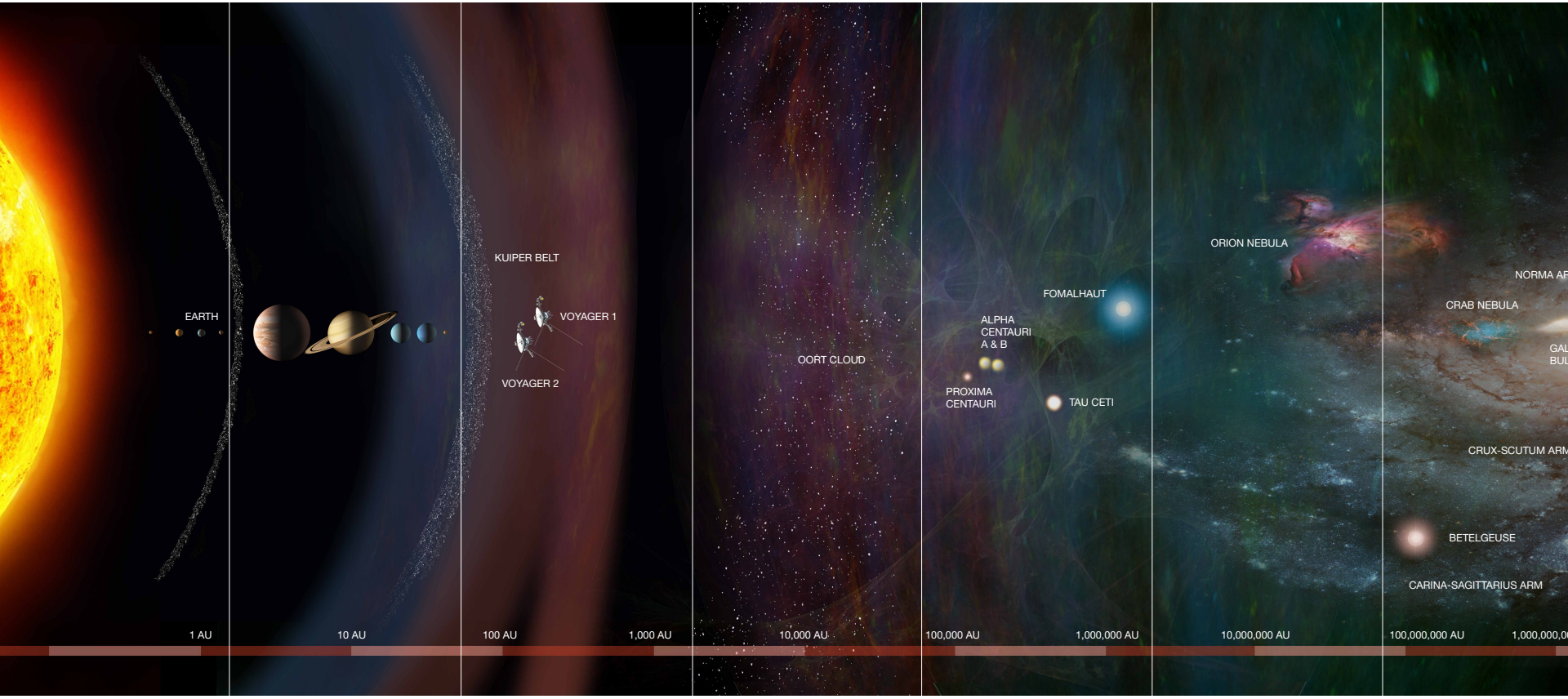


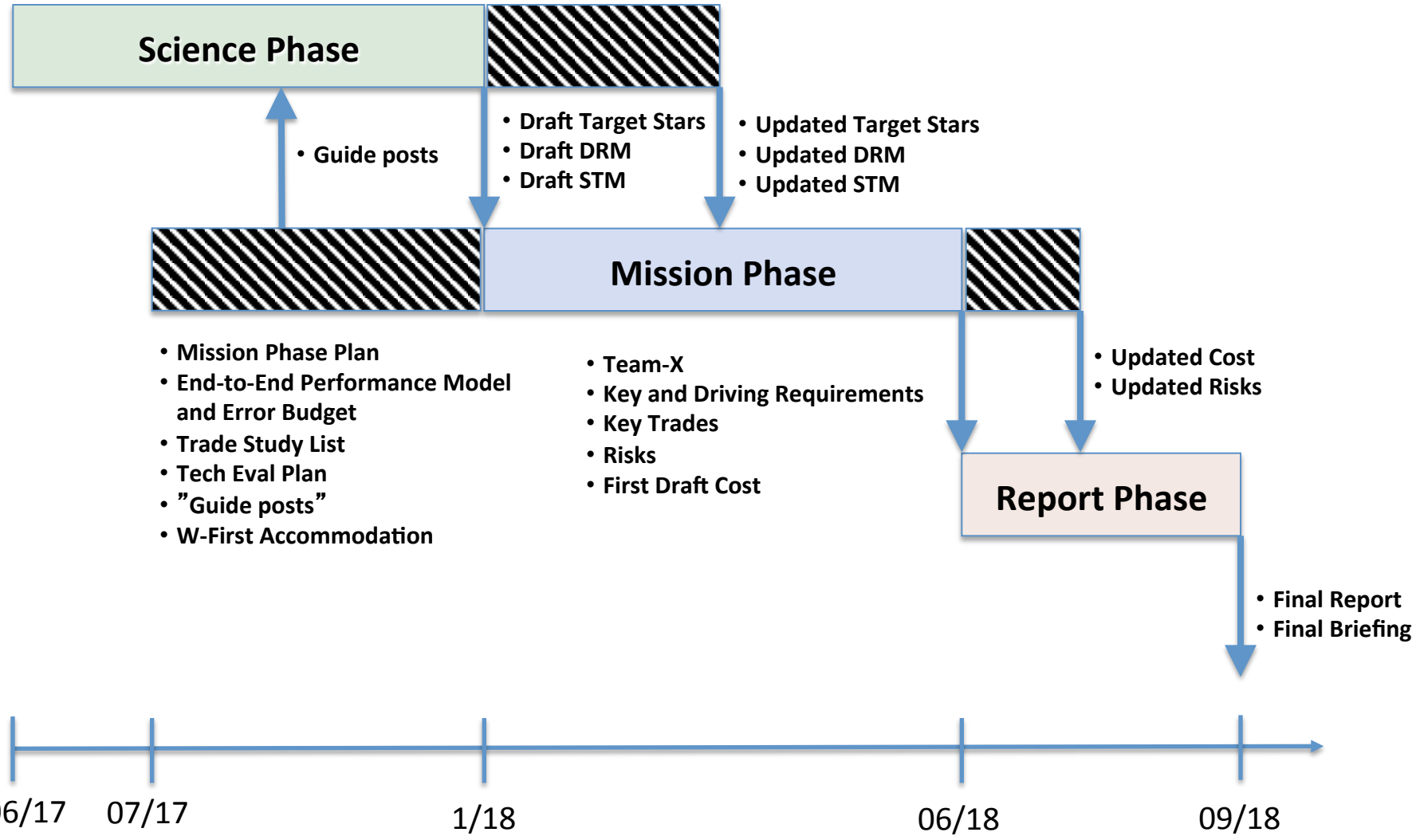
Image credit: JPL

Key Science Activities

Milestone	Date	Location
Study Kick-off	07-20-17	Telecon
Science Working Meeting	08-02/03-17	Pasadena, CA
Science Meeting: **Giant Planet Metallicity**	10-12/13-17	Newark, NJ
Science Meeting: **Biosignature Gases**	10-31-17	Pasadena, CA
Science Meeting: **Identifying Water**	12-08-17	Cambridge, MA
Science Meeting: **Dust Disks**	01-12-18	National Harbor, MD
Science Meeting: **Science Traceability Matrix**	03-??-18	Pasadena, CA

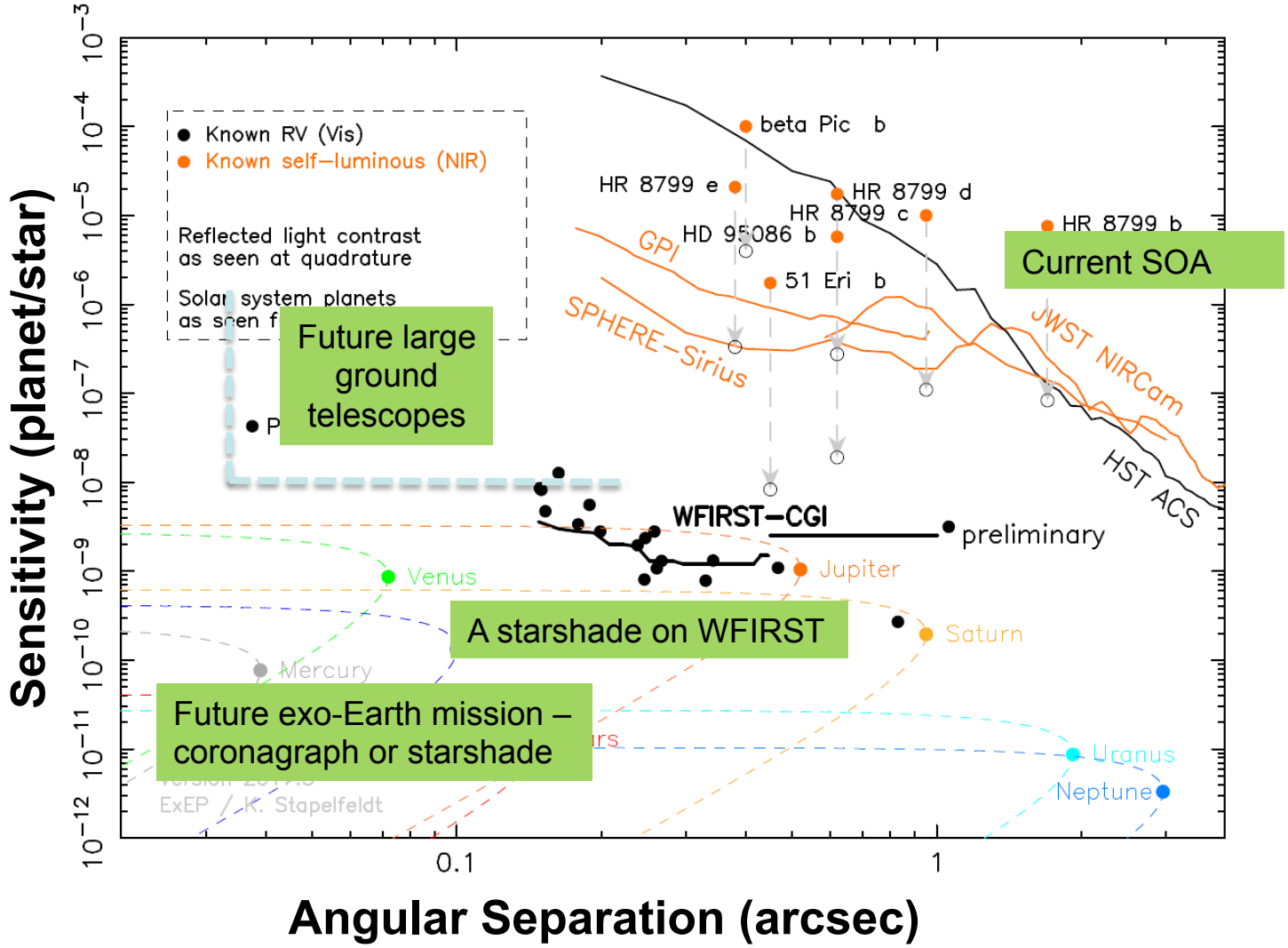
- Weekly science telecons
- Mission phase is ramping up

Study Top Level Schedule

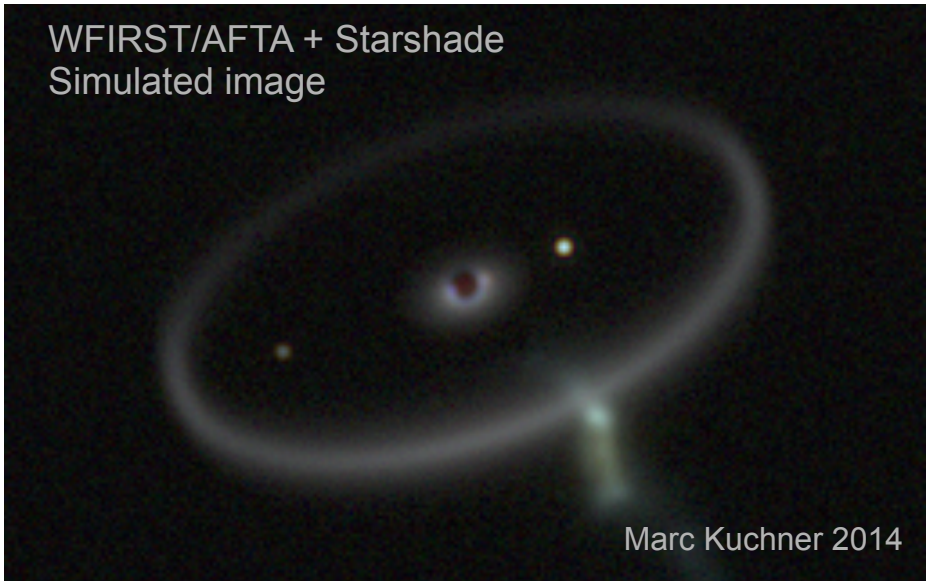


Starlight Suppression

State of Art vs Needs



Exo-S Summary

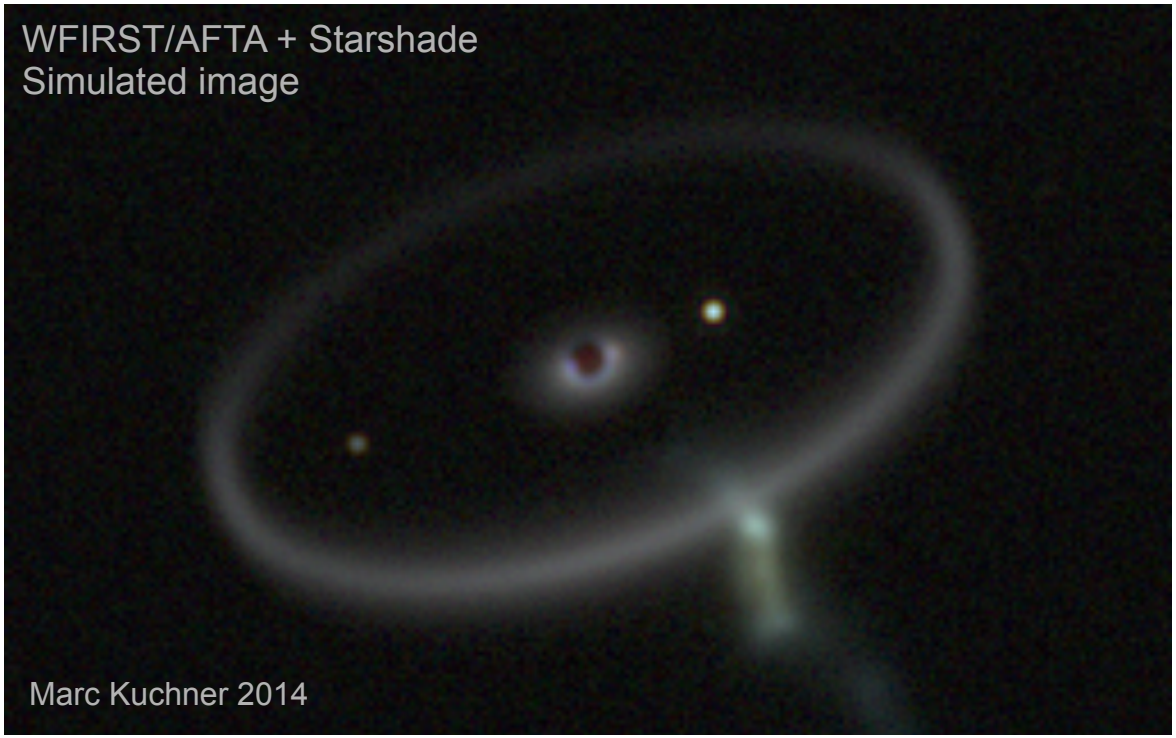


WFIRST/AFTA can be made starshade ready with minimal modification to instrumentation and spacecraft

- Contrast and IWA accomplished by the starshade and not the telescope
- A compelling, flexible scientific program
  - Emphasis can be placed on discovery of exoEarths, or on characterization of larger planets.
- Starshade design and requirements
  - Design has been optimized for IWA and limiting sensitivity as well as engineering constraints
  - Tolerances of petal shape and deployment positions are typically in the range of 10s to 100s of microns
  - Several key starshade requirements have already been demonstrated

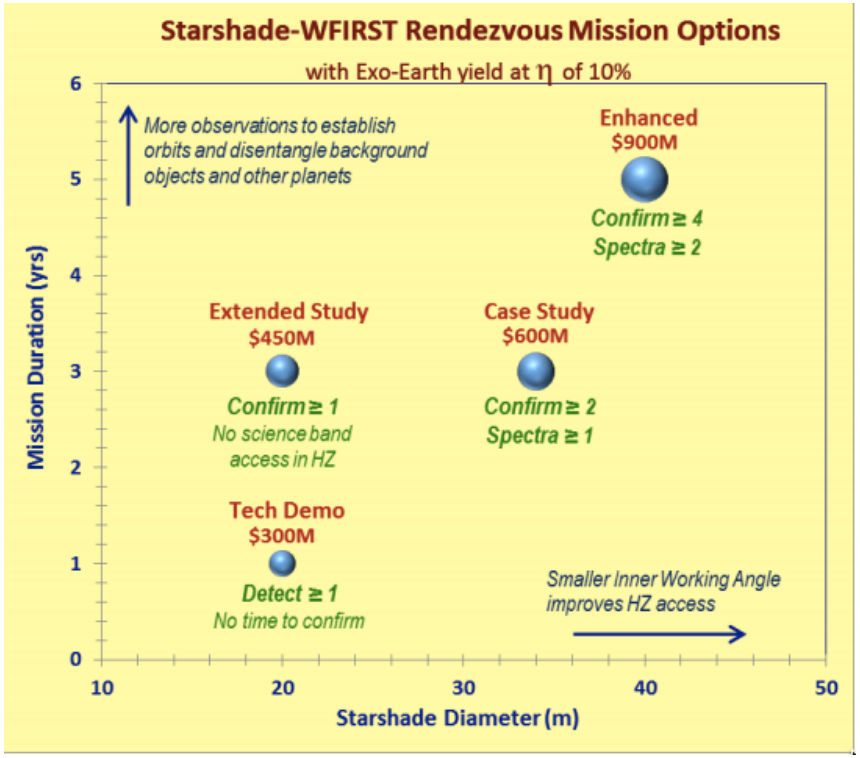
Exo-S Summary

- WFIRST/AFTA can be leveraged for a unique and timely opportunity
  - The Starshade Rendezvous Mission can access up to 50 target stars for exoEarths in the HZ
  - WFIRST/AFTA starshade readiness requires minimal modification
  - Starshade technology is on track for TRL 5 by 2017 for a new start by 2018
  - Rendezvous Mission cost estimate $627 M



Introduction: History

- **Extended Probe Study (2015)**
  - Designs outside of the Probe-class
  - 20 m Starshade https://exoplanets.nasa.gov/internal_resources/225/
- **SSWG (2016)**
  - Starshade Readiness Working Group
  - Goal: recommendation for a plan to validate starshade technology
  - Conclusion: no space-based technology demonstration needed
  - https://exoplanets.nasa.gov/exep/studies/sswg/
- **Note: Exo-S Probe Update (2017)**
  - Report changes since Exo-S report (science cases, yields, technical readiness, costs)
  - No Rendezvous, focused on stand-alone Dedicated Mission two spacecraft co-launch
  - E. Mamajek, lead



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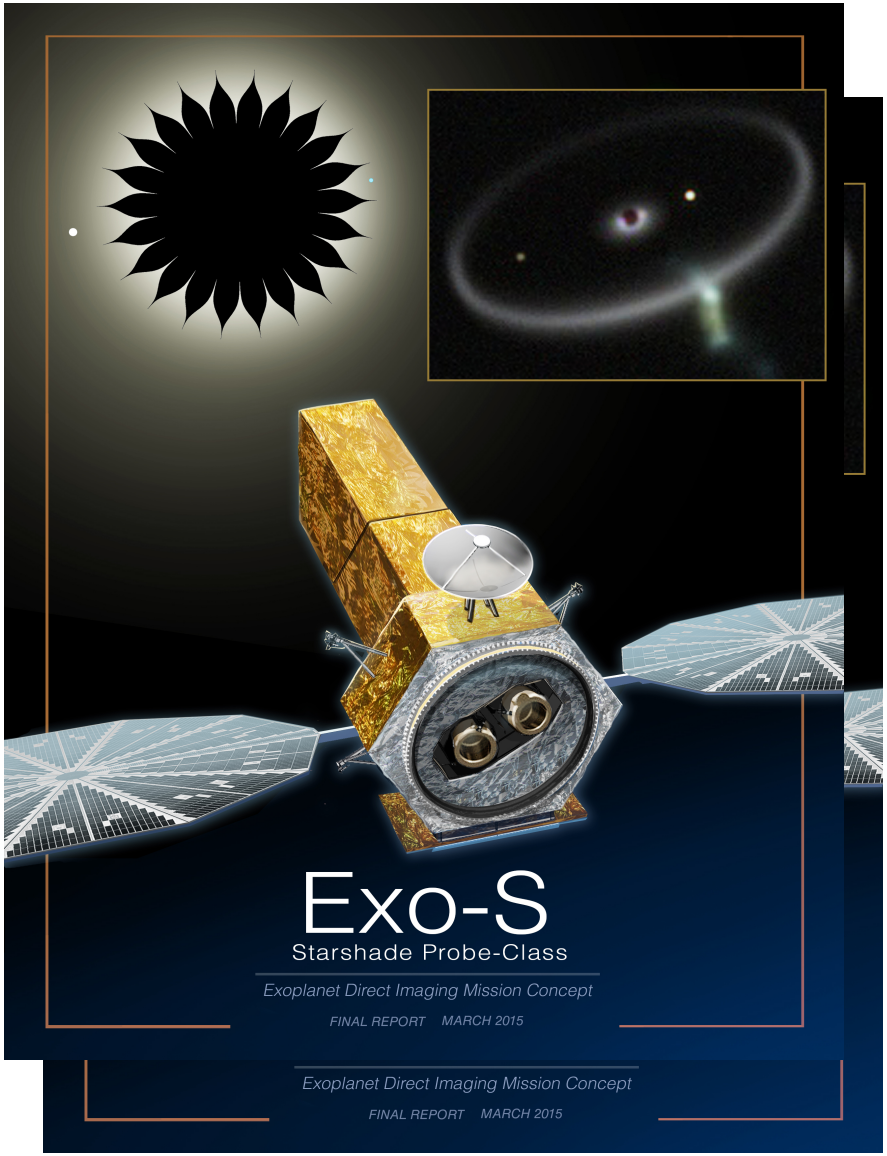
  - The Probe Study two concepts
    - The Dedicated Mission", a 30 m Starshade and 1.1 m telescope co-launches
    - The Rendezvous Mission, 34 m Starshade launches and meets up with WFIRST
  - Science case included
    - Search for new exoplanets from giant down to Earth-size
    - Spectra of known giant exoplanets
    - Circumstellar disks
    - DRM was intended as a sample observation strategy



Starshade Science Bands

λ (nm)	BW	Δλ	λ_{min} (nm)	λ_{max} (nm)
488.5	26.0%	127	425	552
707.5	26.1%	185	615	800
728	19.8%	144	656	800
884.5	26.1%	231	769	1000
910	19.8%	180	820	1000

Key Capabilities

Instruments: Wide-Field Imager, Integral Field Spectrograph, Guide Camera

Case Study	Parameters	Observing Bands		
		Blue	Green	Red
Rendezvous Mission	Bandpass (nm)	425-602	600-850	706-1000
20m inner disk	IWA (mas)	70	100	118
28 7m petals	Separation (Mm)	50	35	30
Dedicated Mission	Bandpass (nm)	400-647	510-825	618-1000
16m inner disk	IWA (mas)	80	100	124
22 7m petals	Separation (Mm)	39	30	25

FoV (arcsec)	
Imager	IFS
10	2
60	3

Throughput	
Imager	IFS
28%	22%
51%	42%

Contrast at inner working angle consistent w/ error budget

- Dedicated: 5×10^{-10}
- Rendezvous: 1×10^{-10}

Design Reference Mission Strategies

- **Planet detection**
  - Green band observation with IFS
  - Divided into 3 channels for multi-color imaging
  - SNR = 4 per channel
- **Planet characterization**
  - SNR = 10, R=10 to 70 per spectral resolution element
- **If dust level high, obtain wide-field image then move on**

Three target prioritization strategies studied

Study Case	Theme	Mission	Propulsion	Defining Characteristic
Case 1	"Earths in HZ"	1.1 m Dedicated	SEP	Efficient observations based on Stellar Luminosity
Case 2	"Maximum Planet Diversity"	1.1 m Dedicated	SEP	Observe all stars to limiting sensitivity limΔmag=26 (contrast of 4e-11)
Case 3	"Earths in HZ"	2.4 m Rendezvous	Bi-prop	Efficient observations based on Stellar Luminosity

Key Capabilities

Instruments: Wide-Field Imager, Integral Field Spectrograph, Guide Camera

Parameters	Observing Bands		
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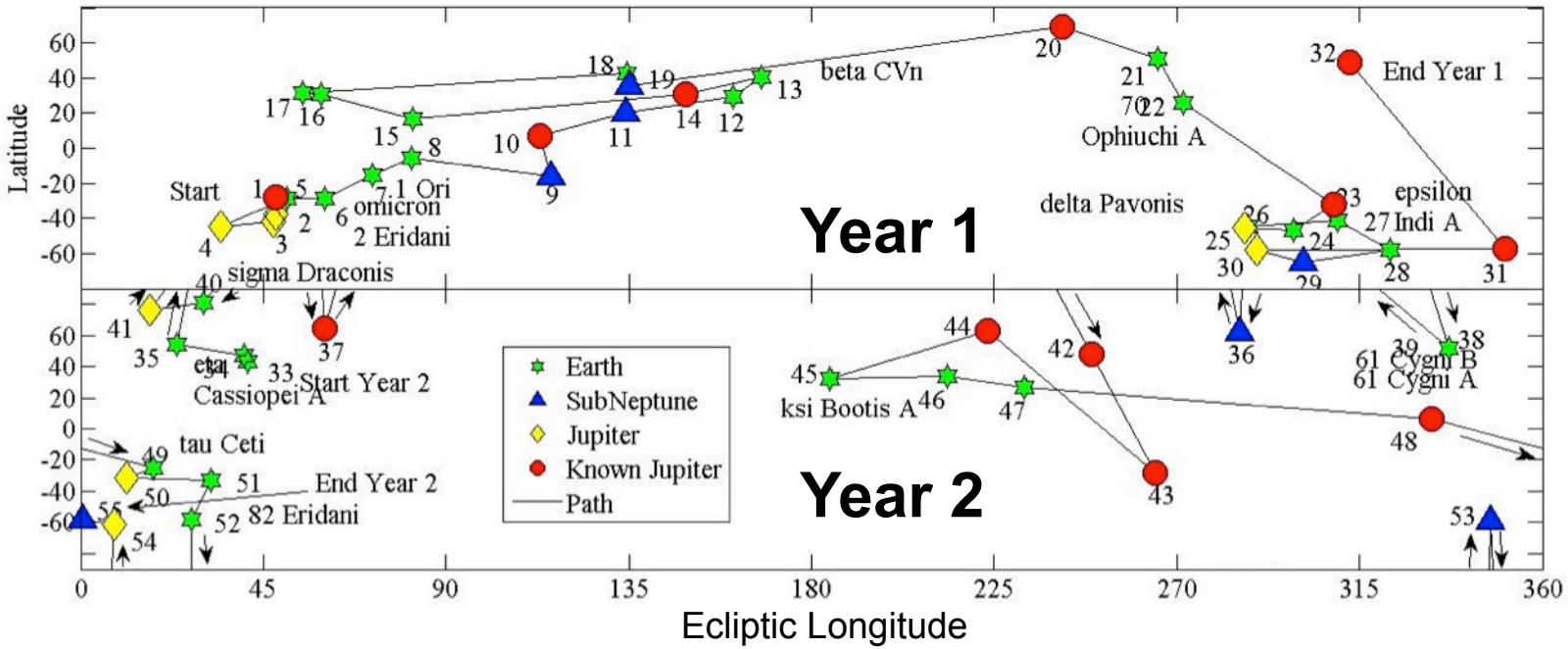
FoV (arcsec)	
Imager	IFS
10	2

Throughput	
Imager	IFS
28%	22%

Contrast at inner working angle consistent with error budget 1×10^{-10}

Observing Sequence

1. Schedule known giant planet observations
2. Fill in gaps on sky with highest priority blind search target
3. Repeat with lower priority targets until fuel or time limit reached
4. Reserve 3rd year for follow-up / additional characterization revisits



Two-year sequence, 55 stars visited

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