Jet Propulsion Laboratory
California Institute of Technology

The NASA Exoplanet Exploration Program

Dr. Karl Stapelfeldt, Program Chief Scientist

Dr. Eric Mamajek, Deputy Program Chief Scientist, starting August 29

Jet Propulsion Laboratory, California Institute of Technology

July 22, 2016

Sagan Summer School

Pasadena, CA

"All the News That's Fit to Print"

The New York Times

LATE CITY EDITION

Weather: Rain, warm today; clear tonight. Sunny, pleasant tomorrow. Temp. range: today 85-68; Sunday 71-66. Temp.-Hum. Index yesterday 69. Complete U.S. report on P. 35.

VOL. CXVIII .. No. 40,721

NEW YORK, MONDAY, JULY 21, 1969

10 CENTS

NASA DISCOVERS EVIDENCE OF LIFE ON AN EXOPLANET

Observed gases consistent with life on Earth

Clear signs of biosignatures

EAGLE (the lunar module): Houston, Tranquility Base here. The Eagle has landed.

HOUSTON: Roger, Tranquility, we copy you on the ground. You've got a bunch of guys about to turn blue. We're breathing again. Thanks a lot.

TRANQUILITY BASE: Thank you.

HOUSTON: You're looking good here.

TRANQUILITY BASE: A very smooth touchdown.

HOUSTON: Eagle, you are stay for T1. [The first step in the lunar operation.] Over.

TRANQUILITY BASE: Roger. Stay for T1.

HOUSTON: Roger and we see you venting the ox.

TRANQUILITY BASE: Roger.

COLUMBIA (the command and service module): How do you read me?

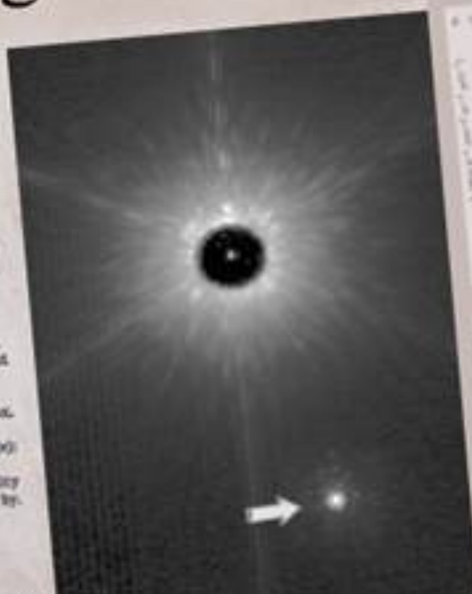
HOUSTON: Columbia, he has landed Tranquility Base. Eagle is at Tranquility. I read you five by. Over.

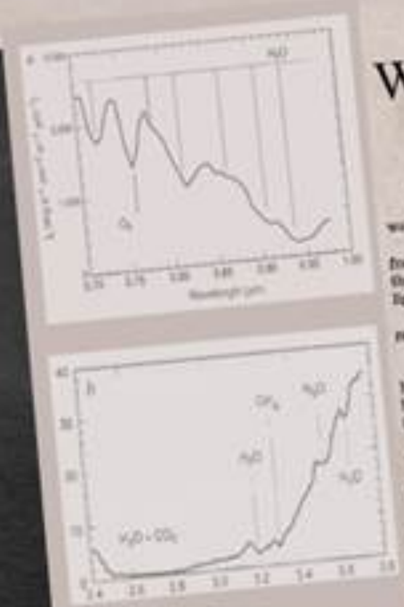
COLUMBIA: Yes, I heard the whole thing.

HOUSTON: Well, it's a good show.

COLUMBIA: Fantastic.

TRANQUILITY BASE: I'll second that.





We are not alone!

By JOHN NOBLE WILFORD

Special to The New York Times

HOUSTON, Monday, July 21—Men have landed and walked on the moon.

Two Americans, astronauts of Apollo 11, steered their fragile four-legged lunar module safely and smoothly to the historic landing yesterday at 4:17:40 P.M., Eastern daylight time.

Neil A. Armstrong, the 38-year-old civilian commander, radioed to earth and the mission control room here: "Houston, Tranquility Base here. The Eagle has landed."

The first men to reach the moon—Mr. Armstrong and his co-pilot, Col. Edwin E. Aldrin Jr. of the Air Force—brought their ship to rest on a level, rock-strewn plain near the southwestern shore of the arid Sea of Tranquility.

About six and a half hours later, Mr. Armstrong opened the landing craft's hatch, stepped slowly down the ladder and declared as he planted the first human footprint on the lunar crust:

"That's one small step for man, one giant leap for mankind."

His first step on the moon came at 10:56:20 P.M., as a television camera outside the craft transmitted his every move to an awed and excited audience of hundreds of millions of people on earth.

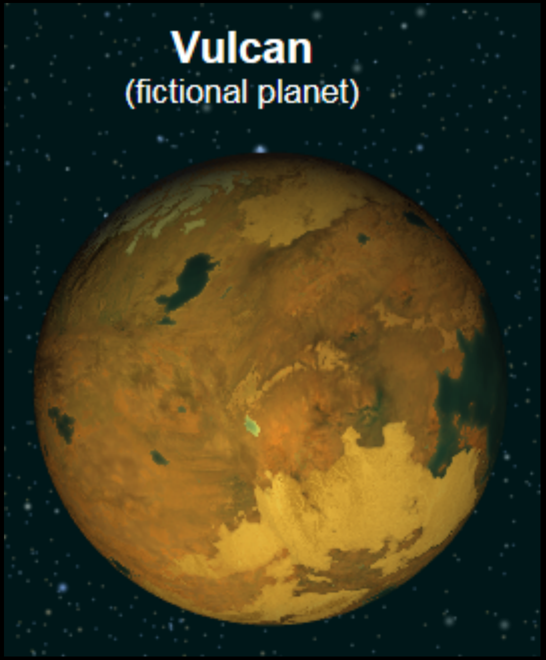
Tentative Steps Test Soil

The case of 40 Eridani A

Constraining the presence of a habitable planet

- Very nearby K0 dwarf star at 5 pc distance; B and C components orbit each other 80″ away
- HZ lies at 0.13″ separation. An earth mass planet there:
  - Would induce 12 cm/sec of stellar reflex motion
  - Has a 0.4% probability of ever transiting
  - Would induce 0.5 μas of stellar astrometric wobble
  - Won't lens background stars (galactic lat. -38°)

- 40 Eri A is the host of Star Trek's fictional planet Vulcan
- There is no medium of instrumentality at our command that can detect at a habitable planet in this system today



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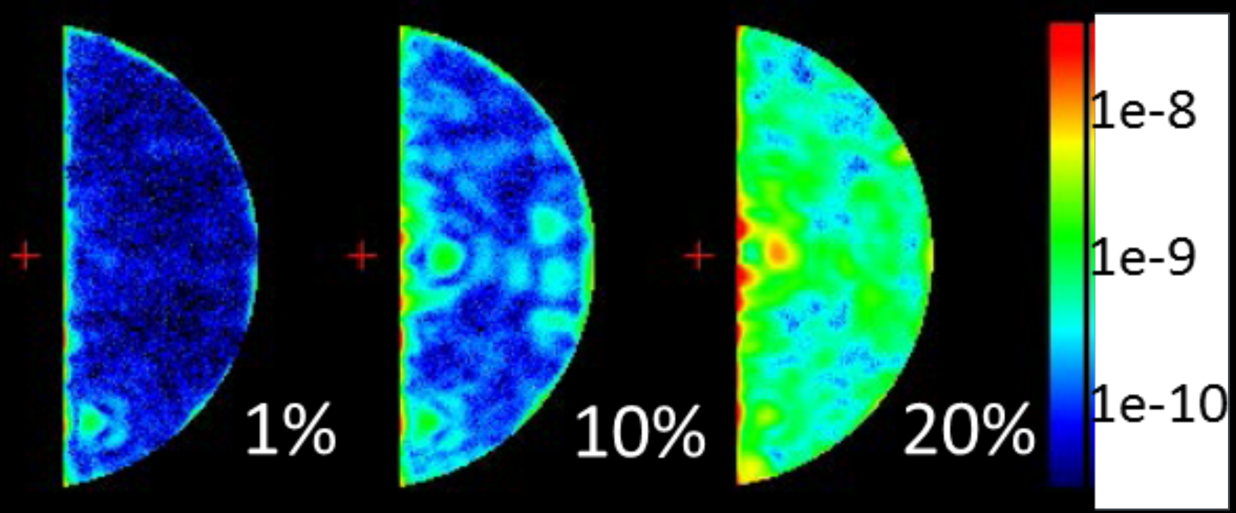
- In direct imaging, an Earth analog here would:
  - Appear at R magnitude 27.6, and with contrast to the star of 3×10^{-10}
  - Be separated from the star by 3 resolution elements as seen by a 3 meter telescope observing in V band
  - Provide photons enabling its discovery *and* spectral measurements of its physical/chemical/biological? conditions

Coronagraph technology today

- Development and laboratory contrast demonstrations have been ongoing for 10+ years, supported by NASA technology investments
- Has already demonstrated 10^{-9} visible contrast with 20% bandwidth at an inner working angle (IWA) of 3 λ/D in the laboratory (Trauger et al. 2012).
- We are within reach of the contrast and bandwidth needed to image a habitable planet around 40 Eri A, if the host telescope is sufficiently stable



Hybrid Lyot coronagraph, lab measurements of contrast versus bandwidth

Progress since this demo:
- Full dark hole created using two deformable mirrors
- Circular masks fabricated
- Mask rebuilt to provide better performance

NASA Exoplanet Exploration Program

Part of the NASA Astrophysics Division, Science Mission Directorate

Purpose described in 2014 NASA Science Plan

1. Discover planets around other stars
2. Characterize their properties
3. Identify candidates that could harbor life

ExEP serves the science community and NASA by implementing NASA's space science vision for exoplanets

http://exoplanets.nasa.gov/exep

Exoplanet research within other NASA Projects & Programs

(General-purpose activities managed outside of ExEP)

- Hubble Space Telescope general observer (STScI)
- Spitzer Space Telescope general observer (SSC/IPAC)
- Research & Analysis grant programs (NASA HQ)
  - Exoplanet Research (XRP), Habitable Worlds, Emerging Worlds
  - NASA Astrobiology Institute
  - Nexus for Exoplanet System Science (NExSS)
- TESS (NASA Explorer Program; in development for 12/17 launch)
- JWST (NASA HQ & STScI; in development for 10/18 launch)

NASA Exoplanet Exploration Program

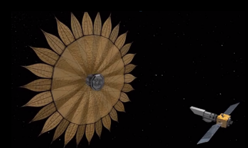
ExEP
ExoPlanet Exploration Program

Space Missions and Mission Studies

Kepler, K2

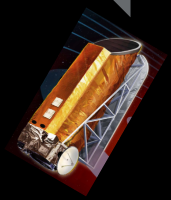
WFIRST

Starshade



Decadal Studies

Coronagraph



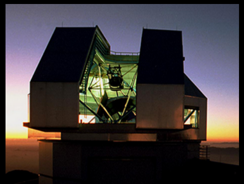
Public Communications

Supporting Research & Technology

Key Sustaining Research

Large Binocular Telescope Interferometer

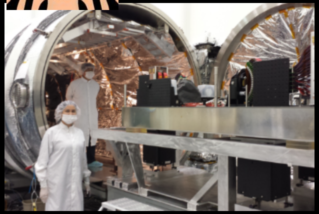
Keck Single Aperture Imaging and RV



NN-EXPLORE

Technology Development

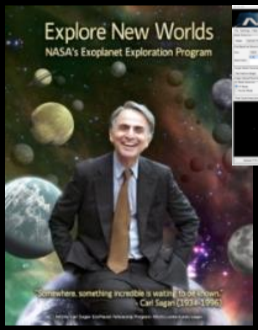
Coronagraph Masks



High-Contrast Imaging

Deployable Starshades

NASA Exoplanet Science Institute



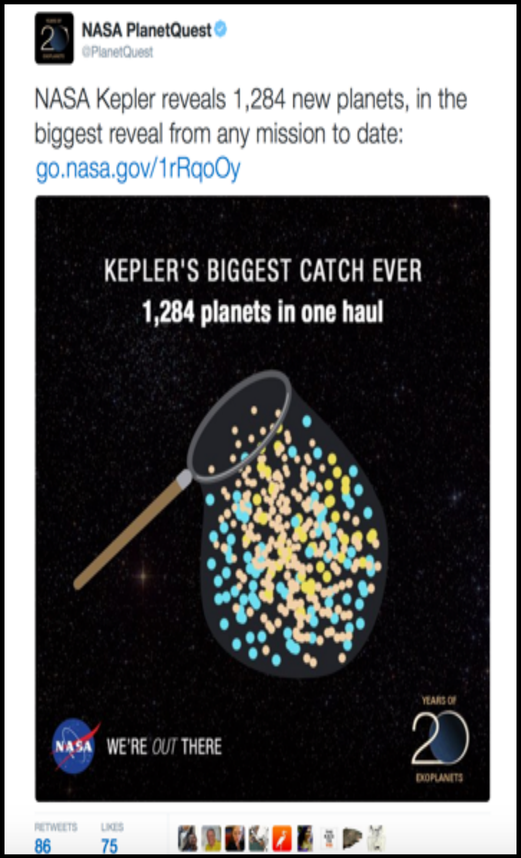
Archives, Tools, Sagan Fellowships, Professional Engagement

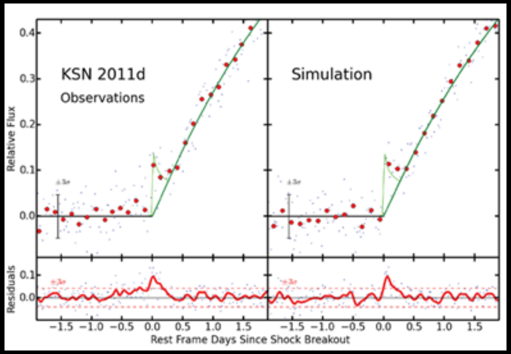
http://exoplanets.nasa.gov

Kepler Close Out

Delivering Kepler's Legacy

- Kepler closeout and final data processing continues steadily within overall schedule margin.
  - SOC 9.3 Q0-Q17 Short Cadence Light Curves delivered to MAST (June 2016)
  - Final Occurrence Rate Products (April 2017)
- Kepler did much more than exoplanets: shock breakout seen in supernova lightcurve (Garnavich et al. 2016)

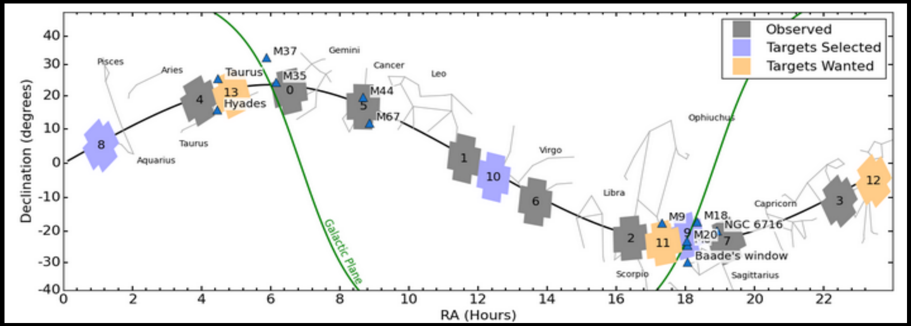




The K2 mission

Extending Kepler to the Ecliptic

Mission extended to 2018



- Data released through Campaign 8 (July 5 2016)
- High-value exoplanets: small, rocky, nearby, orbiting bright stars. Some highlights:
  - 109 confirmed exoplanets in 79 systems; > 500 additional candidates
  - Already several suitable for atmospheric characterization with HST or JWST
- Spacecraft fully operational after suspension of operations April 8-22 (single event upset requiring resets of onboard systems)
- Campaign 9 (Microlensing) completed in early July. Data release expected in September.

Community Support

NASA Exoplanet Science Institute at Caltech campus

Exoplanet Archive

- Planet tables
- Light curves
- Analysis tools
- Regularly updated

Followup Program

- "ExoFOP" data sharing infrastructure for community followup of Kepler, K2, TESS

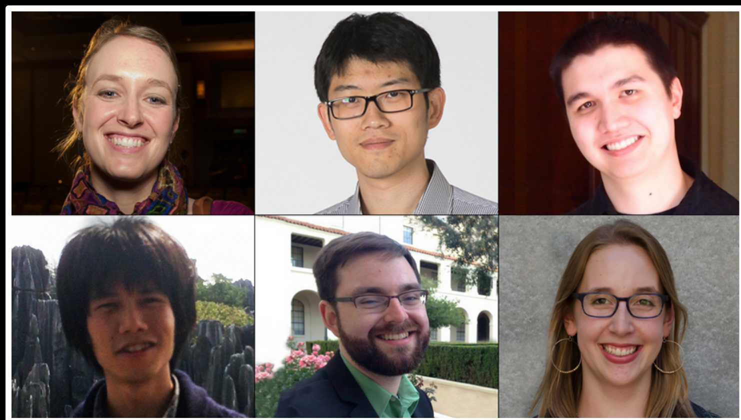
http://exoplanetarchive.ipac.caltech.edu

Sagan Fellowship Program

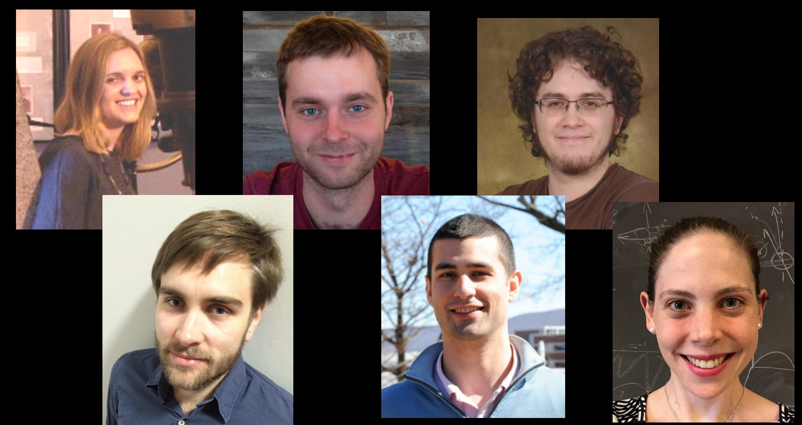
- Six 2016 Sagan Fellows selected

NExSci
NASA Exoplanet Science Institute

2016



2015



2013

2014

NN·EXPLORE

Partnership for Exoplanet Discovery and Characterization

- Motivation
  - 2010 Decadal Survey called for precise ground-based spectrometer for exoplanet discovery and characterization
  - Follow-up & precursor science for current missions (K2, TESS, JWST, WFIRST)
  - Inform design/operation of future missions
- Scope:
  - Extreme precision radial velocity spectrometer (<0.5 m/s) with 40% of time on WIYN telescope
    - Penn State NEID proposal selected in March 2016
    - Instrument to be commissioned spring 2019
    - R= 100,000; 380-930 nm wavelength coverage
  - Ongoing Guest Observer program using NOAO share of telescope time for exoplanet research

NEID

NN-Explore Exoplanet Investigations with Doppler Spectroscopy

PennState

PI: S. Mahadevan

3.5m WIYN Telescope
Kitt Peak National Observatory
Arizona

Technical readiness for direct imaging of habitable exoplanets:

The #1 medium-scale space mission priority of U.S. 2010 Decadal Survey

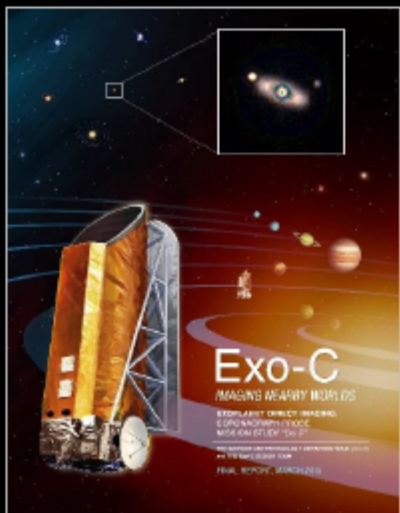
Strategic Astrophysics Technology - TDEM

Technology Development for Exoplanet Missions: http://exoplanets.nasa.gov/exep/technology/

- Active Projects Competitively Selected
  - 2010
    - (Bierden, Helmbrecht) Environmental Testing of Deformable Mirrors
  - 2012
    - (Kasdin) Optical and Mechanical Verification of External Occulter
  - 2013
    - (Bendek) Enhanced Direct Imaging with Astrometric Mass Determination
    - (Cash) Development of Starshade Formation Flying Sensors
    - (Bolcar) Segmented Aperture Interferometric Nulling Testbed
  - 2014
    - (Bolcar) Next Generation Visible Nulling Coronagraph
    - (Serabyn) Broadband Vector Vortex Coronagraph
  - 2015 (this year's) selections are pending

Exoplanet direct imaging probe mission studies

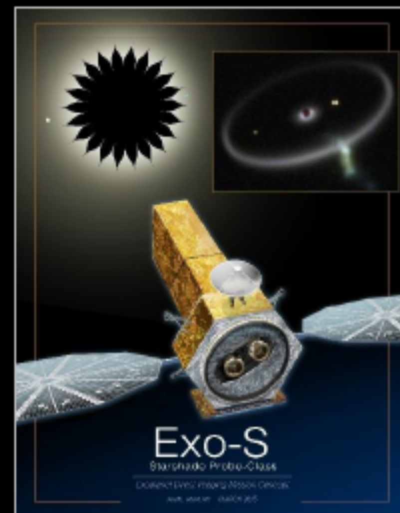
Carried out 2013-2015; directed at cost point < $ 1 B



Exo-C:

Internal Occulter (Coronagraph)

K. Stapelfeldt, STDT Chair, GSFC



Exo-S:

External Occulter (Starshade)

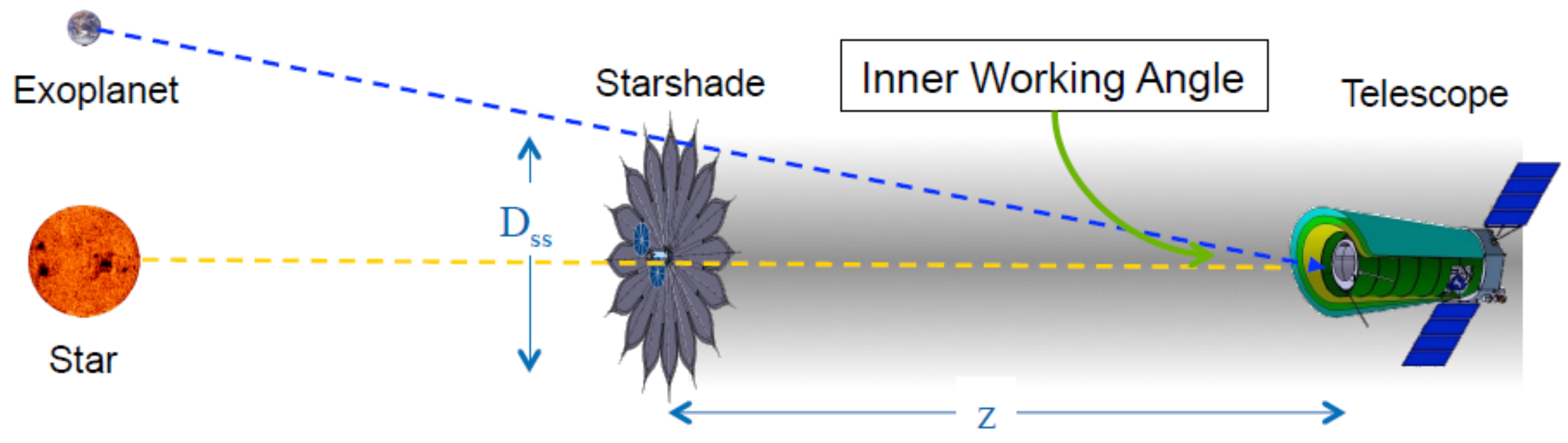
S. Seager, STDT Chair, MIT

- 1.4 m unobscured telescope
- Kepler-like mission in Earth-trailing orbit
- RV planets, dust disks, mini-Neptunes, super-Earths ?

- Studied 2 spacecraft mission and starshade to rendezvous with WFIRST
- RV planet, dust disks, small planets down to Earth analogs in ~2 systems

STARSHADE

for visible wavelengths; active area of NASA study/investment
Does not require high telescope stability. Needs fuel to reposition.
A deployed structure ≥ 30 m diameter, cannot fully test before flight



- Inner Working Angle is the closest separation of Planet and Star that we can expect to see with a given starshade
- For Hypergaussian starshade, this is approximately equivalent to:

$$IWA = \frac{D_{SS}/2}{z}$$

Figure by Steve Warwick, NGST

Starshade Technology Gap List

Table A.4 Starshade Technology Gap List

ID	Title	Description	Current	Required
S-1	Control Edge-Scattered Sunlight	Limit edge-scattered sunlight with optical petal edges that also handle stowed bending strain.	Graphite edges meet all specs except sharpness, with edge radius ≥10 μm.	Optical petal edges manufactured of high flexural strength material with edge radius ≤ 1 μm and reflectivity ≤ 10%.
S-2	Contrast Performance Demonstration a Optical Model Validation	Experimentally validate the equations that predict the contrasts achievable with a starshade.	Experiments have validated optical diffraction models at Fresnel number of ~500 to contrasts of 3×10^{-10} at 632 nm.	Experimentally validate models of starlight suppression to $\leq 3\times10^{-11}$ at Fresnel numbers ≤ 50 over 510-825 nm bandpass.
S-3	Lateral Formation Flying Sensing Accuracy	Demonstrate lateral formation flying sensing accuracy consistent with keeping telescope in starshade's dark shadow.	Centroid accuracy ≥ 1% is common. Simulations have shown that sensing and GN&C is tractable, though sensing demonstration of lateral control has not yet been performed.	Demonstrate sensing lateral errors ≤ 0.20m at scaled flight separations and estimated centroid positions ≤ 0.3% of optical resolution. Control algorithms demonstrated with lateral control errors ≤ 1m.
S-4	Flight-Like Petal Fabrication and Deployment	Demonstrate a high-fidelity, flight-like starshade petal and its unfurling mechanism.	Prototype petal that meets optical edge position tolerances has been demonstrated.	Demonstrate a fully integrated petal, including blankets, edges, and deployment control interfaces. Demonstrate a flight-like unfurling mechanism.
S-5	Inner Disk Deployment	Demonstrate that a starshade can be autonomously deployed to within the budgeted tolerances.	Demonstrated deployment tolerances with 12m heritage Astromesh antenna with four petals, no blankets, no outrigger struts, and no launch restraint.	Demonstrate deployment tolerances with flight-like, minimum half-scale inner disk, with simulated petals, blankets, and interfaces to launch restraint.

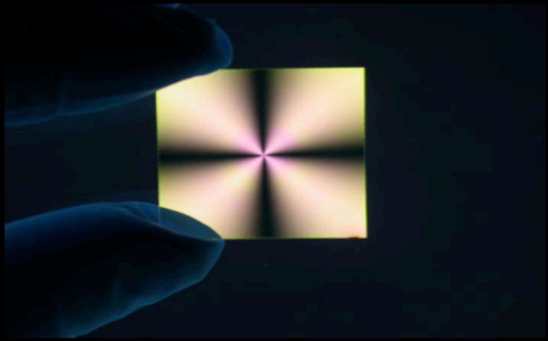
Starshade Technology Gaps

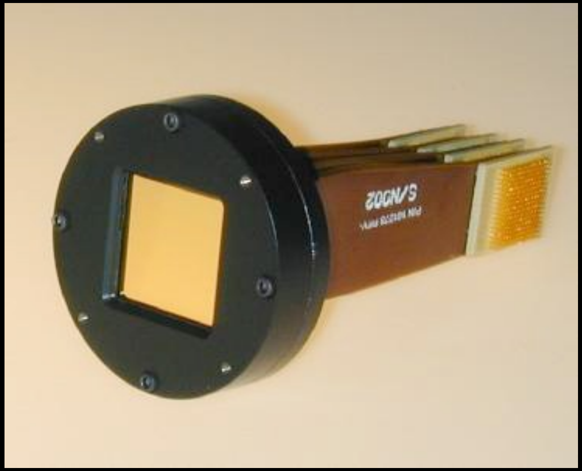
Coronagraph Technology Gap List

Table A.3 Coronagraph Technology Gap List.

ID	Title	Description	Current	Required
C-1	Specialized Coronagraph Optics	Masks, apodizers, or beam-shaping optics to provide starlight suppression and planet detection capability.	A linear mask design has yielded 3.2×10^{-10} mean raw contrast from 3–16 λ/D with 10% bandwidth using an unobscured pupil in a static lab demonstration.	Circularly symmetric masks achieving $\leq 1\times10^{-10}$ contrast with IWA $\leq 3\lambda/D$ and $\geq$ 10% bandwidth on obscured or segmented pupils.
C-2*	Low-Order Wavefront Sensing & Control	Beam jitter and slowly varying large-scale (low-order) optical aberrations may obscure the detection of an exoplanet.	Tip/tilt errors have been sensed and corrected in a stable vacuum environment with a stability of $10^{-3}\,\lambda$ rms at sub-Hz frequencies.	Tip/tilt, focus, astigmatism, and coma sensed and corrected simultaneously to $10^{-4}\,\lambda$ (~10's of pm) rms to maintain raw contrasts of $\leq 1\times10^{-10}$ in a simulated dynamic testing environment.
C-3*	Large-Format Ultra-Low Noise Visible Detectors	Low-noise visible detectors for faint exoplanet characterization with an Integral Field Spectrograph.	Read noise of < 1 e^-/pixel has been demonstrated with EMCCDs in a 1k × 1k format with standard read-out electronics	Read noise < 0.1e^-/pixel in a ≥ 4k × 4k format validated for a space radiation environment and flight-accepted electronics.
C-4*	Large-Format Deformable Mirrors	Maturation of deformable mirror technology toward flight readiness.	Electrostrictive 64x64 DMs have been demonstrated to meet $\leq 10^{-9}$ contrasts in a vacuum environment and 10% bandwidth.	≥ 64x64 DMs with flight-like electronics capable of wavefront correction to $\leq 10^{-10}$ contrasts. Full environmental testing validation.
C-5	Efficient Contrast Convergence	Rate at which wavefront control methods achieve 10^{-10} contrast.	Model and measurement uncertainties limit wavefront control convergence and require many tens to hundreds of iterations to get to 10^{-10} contrast from an arbitrary initial wavefront.	Wavefront control methods that enable convergence to 10^{-10} contrast ratios in fewer iterations (10-20).
C-6*	Post-Data Processing	Techniques are needed to characterize exoplanet spectra from residual speckle noise for typical targets.	Few 100x speckle suppression has been achieved by HST and by ground-based AO telescopes in the NIR and in contrast regimes of 10^{-5} to 10^{-6}, dominated by phase errors.	A 10-fold improvement over the raw contrast of ~10^{-9} in the visible where amplitude errors are expected to no longer be negligible with respect to phase errors.

*Topic being addressed by directed-technology development for the WFIRST/AFTA coronagraph. Consequently, coronagraph technologies that will be substantially advanced under the WFIRST/AFTA technology development are not eligible for TDEMs.





Coronagraph Technology Gaps

http://exoplanets.nasa.gov/exep/technology/

WFIRST: Wide Field Infrared Survey Telescope

Exoplanets and Dark Energy; #1 recommendation of 2010 Decadal Survey

- WFIRST entered Formulation (Phase A) on February 17 2016, launch ~2025
- Coronagraph now part of the baseline mission, will accomplish much of what the Exo-C mission would do at less cost
- Formulation Science Working Group and Science Investigation Teams underway

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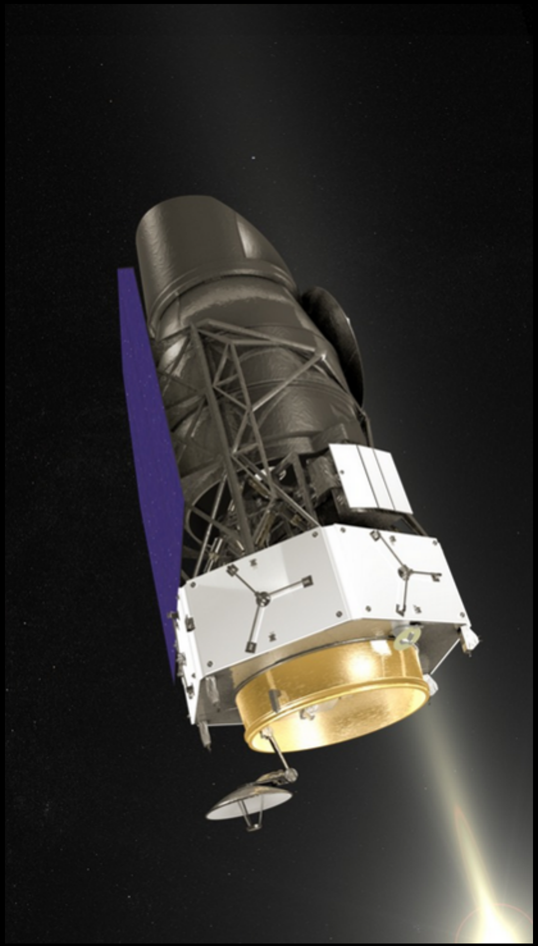
- WFIRST has been directed to study starshade compatibility during Phase A – for a NASA HQ decision in Spring 2017 on whether to build-in this compatibility
- Decision to whether or not to fly a starshade would be made by the 2020 Decadal Survey



See today's talks by Scott Gaudi and Nikole Lewis

Starshade Readiness Working Group (SSWG)

http://exoplanets.nasa.gov/sswg

- Develop a risk reduction strategy for technology validation of starshades to enable starshade flight science missions to be considered in 2020 Decadal Survey
- Will answer these questions and deliver recommendation:
  - How to advance technological readiness of starshade
  - What flight or lab demonstrations would be needed ?
- Adopted the WFIRST “Starshade Rendezvous” as representative motivation of technology requirements
- Chairs: G. Blackwood (ExEP/JPL), S. Seager (MIT)
- Status:
  - Consensus reached on goals: options being developed
  - Kickoff: January 2016, Report to NASA HQ: Fall 2016.

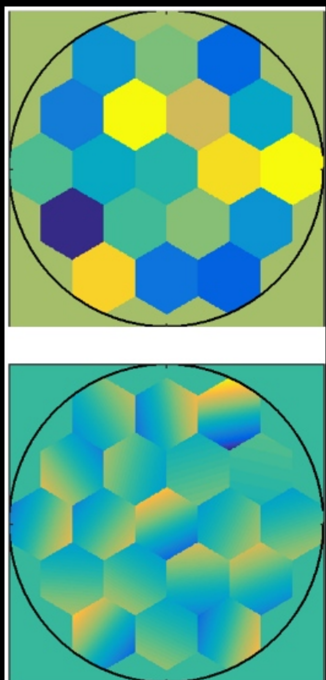
The Starshade Technology Project

- Purpose: Demonstrate technical readiness at the component level by the 2020 U.S. Decadal Survey
- Authorized by NASA HQ this spring. A focusing of community effort to achieve the above goal
- Key issues include
  - Deployment & shape control
  - Control of sunlight scattered off starshade petal edges
  - Precision formation flying to lateral tolerances < 25 cm at ~20,000 km separation from the telescope
- Intent is broad institutional participation and funding
- Open workshop for work prioritization Sept 7-9 2016

High Contrast Imaging with Segmented Apertures

ExEP-sponsored workshop held at JPL, May 5-6 2016

SOC Chair Olivier Guyon



- Considered challenges posed by obscured & segmented apertures to coronagraphy and wavefront control
- Topics covered included
  - Segmented telescopes in development
  - Options for segmentation
  - Contrast dependence on segment misalignments (top left, Stahl & Stahl)
  - Coronagraph performance as a function of IWA and degree of segmentation (Zimmerman et al., lower left)
- 25 presentations available to review at https://exoplanets.nasa.gov/hcisa/

Large Binocular Telescope Interferometer (LBTI)

Measure exozodiacal dust background levels in the HZs of nearby stars

- Inform exoplanet imaging strategy: High exozodi levels would imply that larger apertures would be needed for exoEarth spectroscopy
- Combine beams from two 8.2m telescope shifted by 180° in phase. On-axis starlight nulls out, leaving off-axis dust emission visible in constructive areas of sky null pattern.
- Measurements made at 10 μm wavelength
- Demonstrated 15 zodi sensitivity for star at 10 pc, May 2015. Survey made no progress since then due to telescope, instrument, and weather problems.
- Need better telescope reliability, more observing nights if the 32 star survey is to be completed.
- NASA HQ is now deciding whether/how to continue the LBTI exozodi survey

Phil Hinz, PI

THE UNIVERSITY OF ARIZONA

Defrere et al. 2015, 2016
Kennedy et al. 2015
Weinberger et al. 2015

Decadal Flagship Mission Studies

Capabilities vs. aperture for future space telescopes doing exoplanet imaging characterization: Spectroscopy targets & integration times

- Results below are for 1 solar radiance Earth analogs observed R= 70 and S/N of 10. Number of doable targets drops by half for R= 250.
- Corresponding starshade numbers should be better in the 4 m case, but depend on TBD engineering limits (fuel, launch packaging, etc.)
- N.B. multiply targets numbers by eta_Earth to get planet yield estimate !

Source	Count rate (photons/sec)
HZ Earth analog	0.02
Foreground zodi	0.004
One exozodi	0.007
Residual starlight	0.03
Detector dark current	0.03

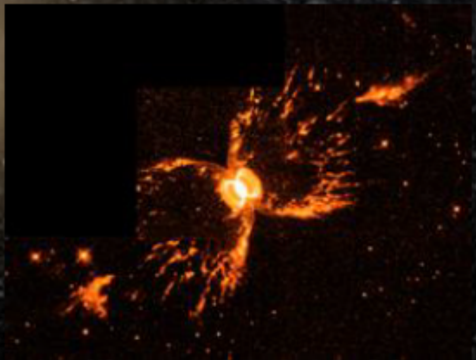
Aperture	4 m	8 m	12 m
Number of targets accessible to coronagraph	17	76	158
Number of the above with full 0.5-1.0 μm spectra	8	42	106
Median integration time (hrs)	251	116	15

Two studies: Habitable Exoplanet Mission (HabEx) and Large UltraViolet Optical near-IR (LUVOIR) surveyor

- Both have goal of studying Earthlike planets in reflected light; they differ in levels of ambition
  - HabEx to "search for" signs of habitability and biosignatures
  - LUVOIR to "constrain the frequency of" habitability and biosignatures = larger statistical survey of exoEarths, larger aperture
- HabEx to focus on exoplanets, "best effort" only on general astrophysics. Perhaps only 2 instruments, like WFIRST. Aperture < ~8 m. Study led by JPL.
- LUVOIR gives equal priority to exoplanets and general astrophysics. Would be HST-like, expansive vision. Aperture 8-12 m. Study led by NASA Goddard.
- They are likely to differ in cost and technical readiness
- Interim reports late 2017; final reports early 2019

HabEx Science Goals and Concept

- Primary Goal Requires a large ultra-stable space telescope with a unique combination of
  - Very high spatial resolution (< 30 mas) and dynamic range (~10^{10})
  - High sensitivity / exquisite detectors in the optical (possibly UV and NIR)
- Such a facility will necessarily also provide exceptional capabilities for
  - Characterizing *full* planetary systems, including rocky planets, "water worlds", gas giants, ice giants, inner and outer dust belts
  - Conducting planet formation and evolution studies
  - Star formation and evolution studies
  - Studying the formation and evolution of galaxies
  - Other general Astrophysics applications



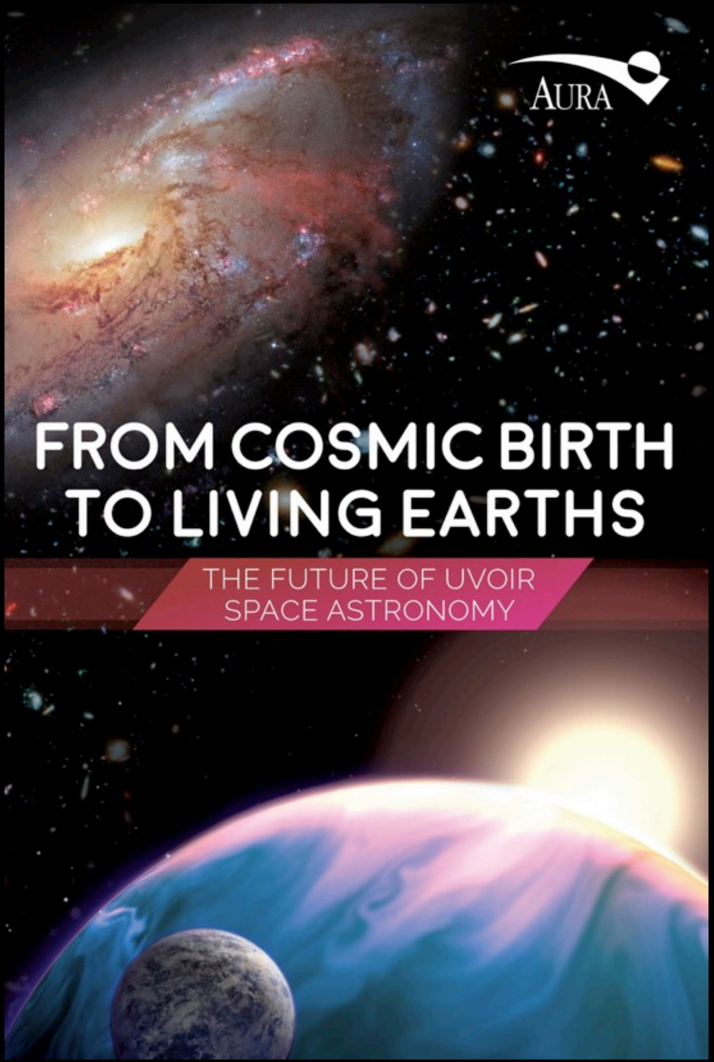
- STDT will direct design team to explore key trades (λ, D, FoV, R)
  - For the primary science goal *and* for non-exoplanet studies (secondary payload(s))

2015 High-Definition Space Telescope Report

"HDST's primary goal is to find and characterize dozens of Earth-like exoplanets."

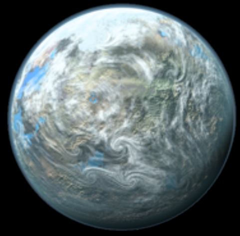
"Major advances in all areas of astrophysics are possible with HDST."

- Other HDST science goals include ...
  - First galaxies, galaxy formation & evolution, star and planet formation in Milky Way, Solar System observations
- LUVOIR ≠≠ HDST



LUVOIR: "Big bang to biosignatures"

- Notional ! – all to be determined by the STDT
- Capabilities



  - FUV to NIR wavelength sensitivity
  - Suite of imagers and spectrographs
  - High-contrast capability (~ 10^{-10})
  - Aperture diameter of order 8 – 16 m
  - Serviceable (astronaut or robot)
  - "Space Observatory for the 21st Century" - decades of science, capability to answer questions we have not yet conceived, instrument upgrades (like *Hubble*)

Important NASA Exoplanet websites and dates

Main Exoplanet Exploration Program website:
http://exoplanets.nasa.gov

Exoplanet science archive:
http://exoplanetarchive.ipac.caltech.edu

WFIRST Project: http://wfirst.gsfc.nasa.gov

HabEx mission study: http://www.jpl.nasa.gov/habex

LUVOIR mission study: http://asd.gsfc.nasa.gov/luvoir

ExoPAG 15 meeting at winter AAS: Jan 2-3, Dallas TX

Microlensing conference February 1-3 2017, Caltech

Kepler and K2 Science Conference IV:
June 19-23 2017, NASA Ames Research Center

WFIRST Community Science Conference:
June 26-30 2017, Space Telescope Science Institute

Jet Propulsion Laboratory
California Institute of Technology

Exoplanet Exploration Program Organization Chart

Astrophysics Division, NASA HQ
Director – Dr. P. Hertz
Deputy Director/Program Director – A. Razzaghi

Exoplanet Prog. Exec. – J. Gagosian
Exoplanet Prog. Sci. – Dr. D. Hudgins

WFIRST Program Executive – J. Gagosian
WFIRST Program Scientist – Dr. D. Benford
Kepler / Closeout Program Exec – K. Chamberlin
Kepler / K2 Program Executive – J. Hayes
Kepler / K2 Program Scientist – Dr. M. Perez
NExScI, Keck, LBTI Prog. Exec. – Dr. M. Perez
NExScI, Keck, LBTI Prog. Sci. – Dr. H. Hasan
NExScI, Keck, LBTI Deputy Prog. Sci – Dr. K. Sheth
NN-EXPLORE Program Exec/Sci.- Dr. D. Hudgins

Astronomy Physics & Space Technology Directorate, JPL
Director for – D. Gallagher
Deputy Director for – Dr. D. Coulter

730
Exoplanet Exploration Program Office
Program Manager – Dr. G. Blackwood
Deputy Program Manager – K. Short
Program Chief Scientist – Dr. K. Stapelfeldt
Program Chief Technologist – Dr. N. Siegler

7301
Program Science Office
Chief Scientist – Dr. K. Stapelfeldt
Deputy Chief Scientist - Vacant
Dr. N. Gautier (326)
Dr. G. Bryden (326)

7303
Program Engineering Office
Program Chief Engineer – K. Warfield
Program Engineer - K. Warfield
Export Tech Lia. – Dr. A. Abramovici (383)
Mission Assurance Manager – J. Mehta

ExoPlanet TAC[1]
Dr. A. Boss
Carnegie Institution

Exoplanet Probe STDT - Starshade[1]
Dr. S. Seager, MIT

7310
Program Business Office
Business Admin. Mgr – R. Lemus (731)
Administrator – O. Pananyan (731)
Project Acquisition Manager – W. Kert (268)
Staff Assistant – K. Miller (731)
Staff Assistant – J. Gregory (731)

Exoplanet Probe Extended Study Office
K. Warfield (312)

Exoplanet Probe STDT - Coronagraph[1]
Dr. K. Cahoy, MIT

7312
Business Operations
Resource Analyst – L. Scott (252)
Project Schedule Analyst – G. Luzwick (252)

Mission Managers
Kepler Mission Mgr – I. Heinrichsen (734)
WFIRST Mission Mgr – I. Heinrichsen (730)

790
NASA Exoplanet Science Institute (Caltech)
Exec. Director –
Dr. C. Beichman (790)
Deputy Director – Dr. R. Akeson
Manager – Dr. D. Imel

Kepler (ARC)
Project Manager (Phase E) – C. Sobeck
Project Scientist (Phase E) – Dr. S. Howell
Mission Scientist – Dr. N. Batalha
Guest Observer Office Dir. – Dr. T. Barclay

733
Program Technology (JPL)
Manager – Dr. N. Siegler, AD (383)

732
LBTI (Univ. of Arizona)
Manager – Dr. P. Willems, AD (383D)
Principal Investigator – Dr. P. Hinz, U of A
Project Scientist – Dr. R. Millan-Gabet, Caltech

WFIRST Project Office (GSFC)
Project Manager – K. Grady
Deputy Project Manager – C. Peddie
Project Scientist – Dr. N. Gehrels

WFIRST Formulation Science Working Group
Project Scientist – Dr. N. Gehrels, GSFC
Dr. D. Spergel[1], Princeton
Dr. J. Kasdin[1], Princeton

Ground Observatories & Suborbital Activity (Caltech)
Manager – Dr. D. Imel
Keck Project Scientist –
Dr. R. Akeson

Starshade Technology Project (JPL)
Manager – TBD

735
NASA-NSF Exoplanet Observational Research
Manager – Dr. P. Willems, AD, JPL (383D)
Pennsylvania State University Team

7302
Program/Project Communications and Public Engagement (JPL)
Manager – M. Greene (183)
Web Manager – R. Jackson
Engagement Specialist – A. Biferno
Writer Editor – P. Brennan
Internet Communications – A. Samuelson

706
WFIRST Project Office (JPL)
Project Manager, P. Barela
Project Scientist: Dr W. Traub
Deputy Proj. Scientist: Dr. J. Rhodes
Telescope – B. Parvin (706)
Coronagraph – Dr. F. Zhao (383)
Technology -
Dr. I. Poberezhskiy (383)
Dr. R. Demers (383)
Science Center –
Dr. R. Cutri (Caltech)

WFIRST TAC[1]
Dr. A. Boss
Carnegie Institution

[1]Reports to NASA HQs APD

April 18, 2016
R. Lemus
NASA Exoplanet Exploration Program

Legend:
Programmatic lines of authority ———
Interface - - - - -