Jet Propulsion Laboratory
California Institute of Technology

The NASA Exoplanet Exploration Program

Dr. Karl Stapelfeldt, Program Chief Scientist
Jet Propulsion Laboratory, California Institute of Technology

August 11, 2017
Sagan Summer School
Pasadena, CA

Discovery of Trappist-1 system had big public impact

"All the News That's Fit to Print"

The New York Times

Late Edition

Today, patchy morning fog, partly sunny, warm, high 64. Tonight, mostly cloudy, mild, low 52. Tomorrow, clouds and sunshine, showers, high 66. Weather map is on Page B9.

VOL. CLXVI ... No. 57,517 © 2017 The New York Times Company NEW YORK, THURSDAY, FEBRUARY 23, 2017 $2.50

A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water. JPL-CALTECH/NASA

TRUMP RESCINDS OBAMA DIRECTIVE ON BATHROOM USE

ENTERING CULTURE WARS

Question of Transgender Rights Splits DeVos and Sessions

This article is by Jeremy W. Peters, Jo Becker and Julie Hirschfeld Davis.

WASHINGTON — President Trump on Wednesday rescinded protections for transgender students that had allowed them to use bathrooms corresponding with their gender identity, overruling his own education secretary and placing his administration firmly in the middle of the culture wars that many Republicans have tried to leave behind.

In a joint letter, the top civil rights officials from the Justice Department and the Education Department rejected the Obama administration's position that nondiscrimination laws require schools to allow transgender students to use the bathrooms of their choice.

That directive, they said, was improperly and arbitrarily devised, "without due regard for the primary role of the states and lo-

Circling a Star Not Far Away, 7 Shots at Life

By KENNETH CHANG

Uber's Culture Of Gutsiness Under Review

By MIKE ISAAC

Migrants Hide, Fearing Capture on 'Any Corner'

By VIVIAN YEE

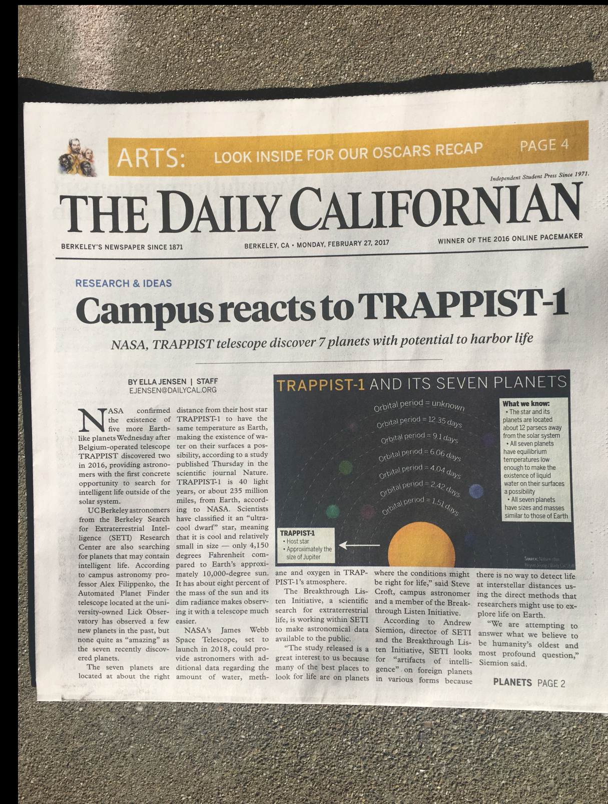
No going to church, no going to the store. No doctor's appointments for some, no school for others. No driving, period — not

duras.

If deportation has always been a threat on paper for the 11 million people living in the country illegally, it rarely imperiled those who did not commit serious crimes. But with the Trump ad-

IMMIGRATION A police department worries a crackdown will harm work to fight gangs. PAGE A11

MEXICO The secretary of state pays a visit at a time of rising



ARTS: LOOK INSIDE FOR OUR OSCARS RECAP PAGE 4

THE DAILY CALIFORNIAN

Independent Student Press Since 1971

BERKELEY'S NEWSPAPER SINCE 1871 BERKELEY, CA • MONDAY, FEBRUARY 27, 2017 WINNER OF THE 2016 ONLINE PACEMAKER

RESEARCH & IDEAS

Campus reacts to TRAPPIST-1

NASA, TRAPPIST telescope discover 7 planets with potential to harbor life

BY ELLA JENSEN | STAFF
EJENSEN@DAILYCAL.ORG

NASA confirmed the existence of five more Earth-like planets Wednesday after Belgium-operated telescope TRAPPIST discovered two in 2016, providing astronomers with the first concrete opportunity to search for intelligent life outside of the solar system.

UC Berkeley astronomers from the Berkeley Search for Extraterrestrial Intelligence (SETI) Research Center are also searching for planets that may contain intelligent life. According to campus astronomy professor Alex Filippenko, the Automated Planet Finder telescope located at the university-owned Lick Observatory has observed a few new planets in the past, but none quite as "amazing" as the seven recently discovered planets.

The seven planets are located at about the right distance from their host star TRAPPIST-1 to have the same temperature as Earth, making the existence of water on their surfaces a possibility, according to a study published Thursday in the scientific journal Nature. TRAPPIST-1 is 40 light years, or about 235 million miles, from Earth, according to NASA. Scientists have classified it an "ultra-cool dwarf" star, meaning that it is cool and relatively small in size — only 4,150 degrees Fahrenheit compared to Earth's approximately 10,000-degree sun. It has about eight percent of the mass of the sun and its dim radiance makes observing it with a telescope much easier.

NASA's James Webb Space Telescope, set to launch in 2018, could provide astronomers with additional data regarding the amount of water, methane and oxygen in TRAPPIST-1's atmosphere.

The Breakthrough Listen Initiative, a scientific search for extraterrestrial life, is working within SETI to make astronomical data available to the public.

"The study released is a great interest to us because many of the best places to look for life are on planets where the conditions might be right for life," said Steve Croft, campus astronomer and a member of the Breakthrough Listen Initiative.

According to Andrew Siemion, director of SETI and the Breakthrough Listen Initiative, SETI looks for "artifacts of intelligence" on foreign planets in various forms because there is no way to detect life at interstellar distances using the direct methods that researchers might use to explore life on Earth.

"We are attempting to answer what we believe to be humanity's oldest and most profound question," Siemion said.

PLANETS PAGE 2

7 Earth-sized exoplanets, at least 3 of which lie in the habitable zone where liquid water is possible, were found by the transit method orbiting an ultra-cool dwarf star. Mass ratios ~3×10^{-5} of the central star

Trappist-1 Discovery

The Richest Set of Earth-sized Planets Ever Found

Exoplanet Program supported the PI Michael Gillon, the Spitzer Project, & NASA HQ to develop materials for the public release. Set up dedicated site https://exoplanets.nasa.gov/trappist1/ with original stories, image & video gallery, virtual reality views, & the travel poster at left

Fictional headline by Nick Siegler

"All the News That's Fit to Print"

The New York Times

LATE CITY EDITION

10 CENTS

VOL. CXVIII . No. 40,721

NEW YORK, MONDAY, JULY 21, 1969

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.

APOLLO CONTROL: The next major stay-no stay ... That is at 21 minutes 26 sec-

We are not alone!

By JOHN NOBLE WILFORD

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 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 current means to detect a habitable planet in this system today

The case of 40 Eridani A

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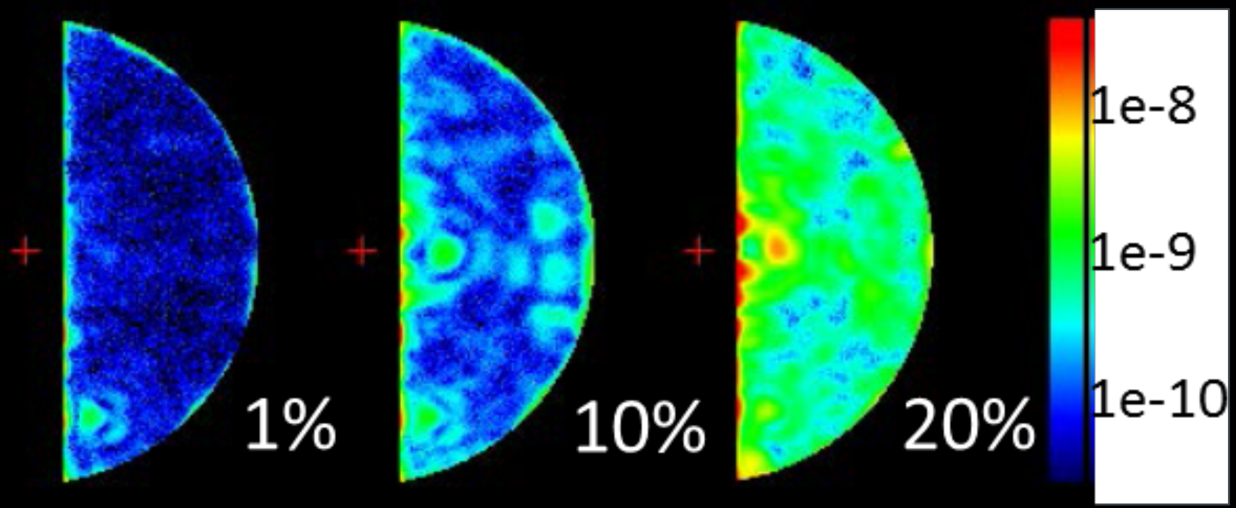
  - Won't lens background stars (galactic latitude -38°)

    Mass ratio ~$5x10^{-6}$ to the star
- 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).
- <u>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</u>



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

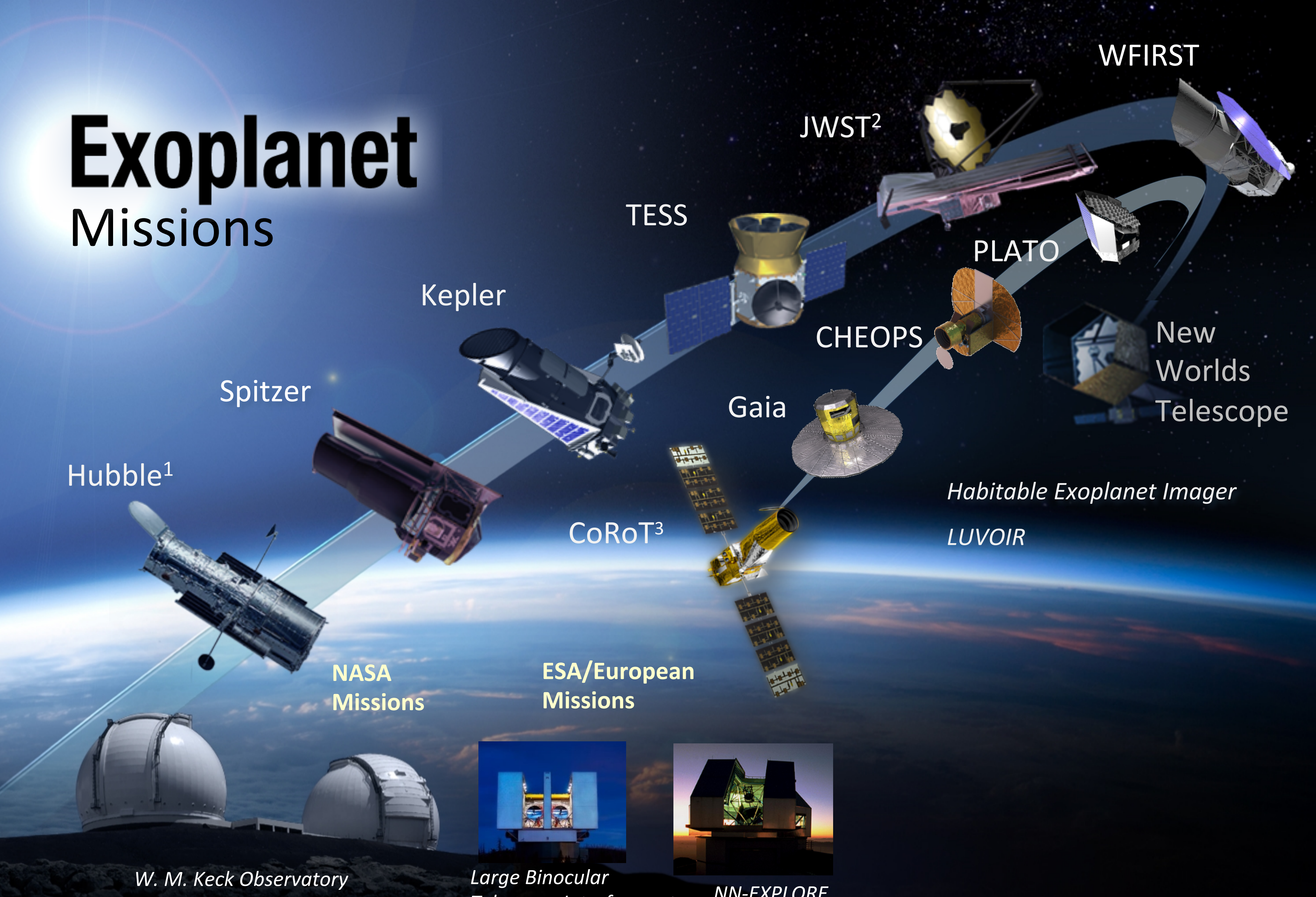
Part of the NASA Astrophysics Division, Science Mission Directorate

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



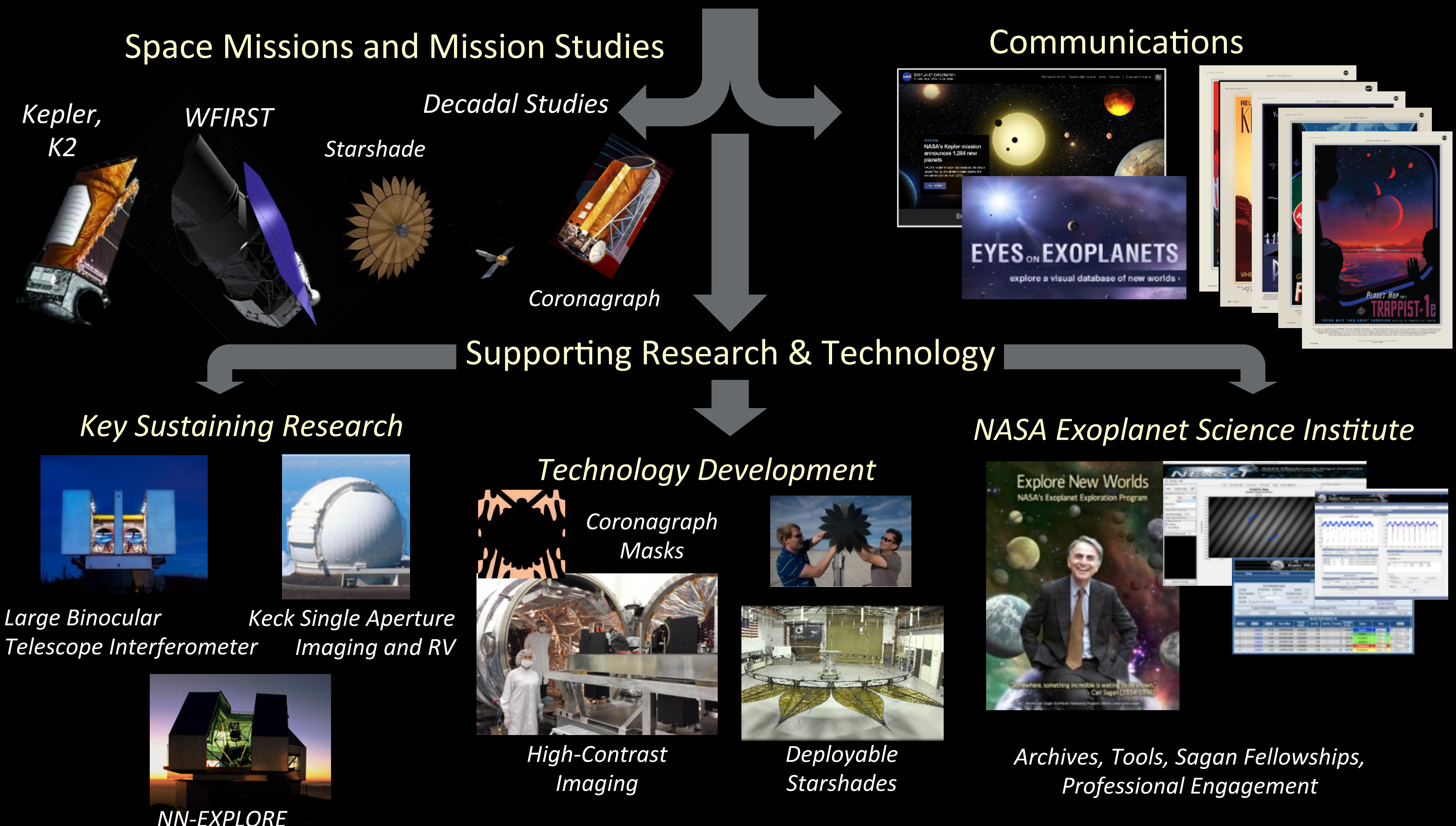
[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA

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 3/18 launch)
- JWST (NASA HQ & STScI; in development for 10/18 launch)

NASA Exoplanet Exploration Program



https://exoplanets.nasa.gov

Kepler Close-Out

Transits – mission concluding

Delivering Kepler's Legacy. 4496 exoplanet candidates, 2337 confirmed

- Kepler SOC9.3 Final Catalog and Occurrence Rate data has been delivered and is live at the NExScI Data Archive.

- Kepler closeout and final data processing continues steadily within overall schedule margin. Prime mission ends Sep 30 2017

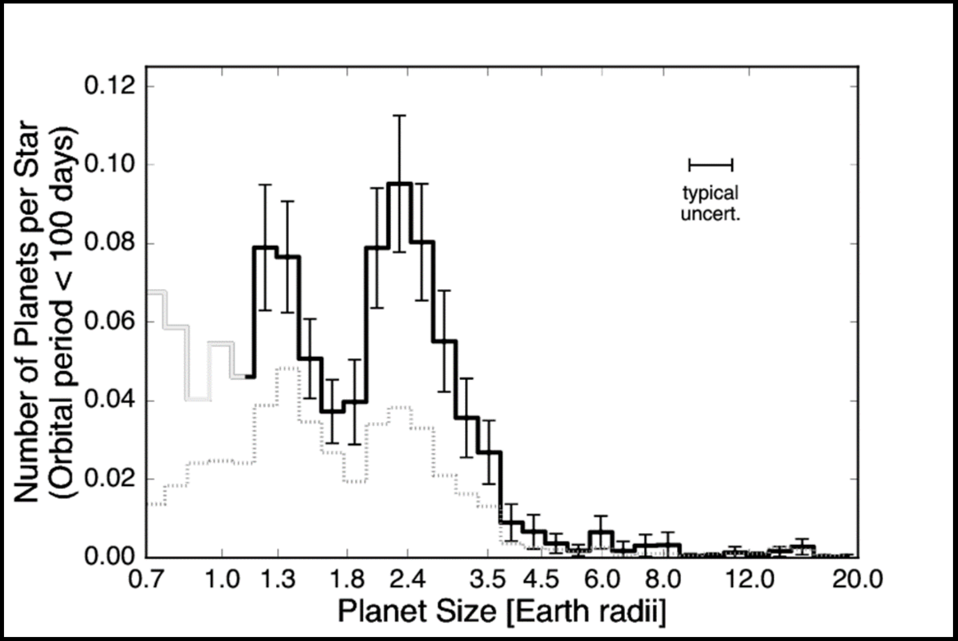
Credit: NASA/ARC

Key Kepler result this year

Transits – mission concluding

- A gap in the size distribution of small planets has been reported by B.J. Fulton and collaborators. The gap emerged when Petigura et al. derived more accurate stellar radii for more than 1000 Kepler planet host stars using Keck observations. The two peaks correspond to rocky planets and planet with significant gaseous envelopes. This is a fundamental discovery in planetary physics.

arXiv:1703.10375, arXiv:1703.10400

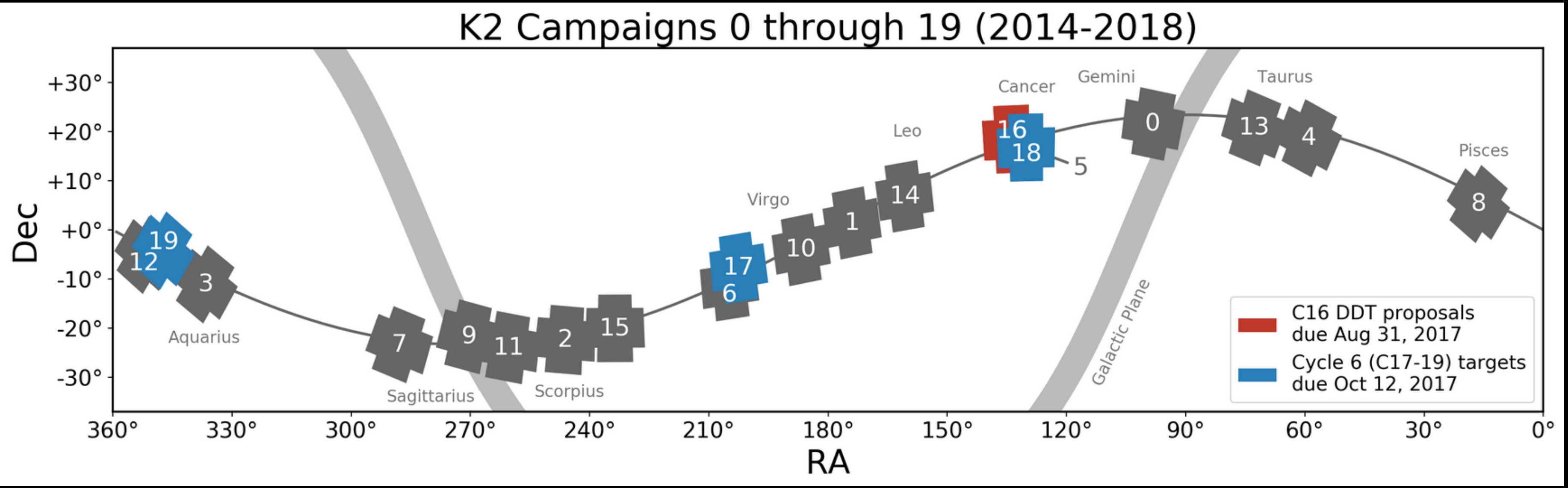


Kepler / K2

Transits – mission operating

Extending Kepler to the Ecliptic. 521 exoplanet candidates, 157 confirmed

Campaign 9 provided the first large space-based microlensing survey



Recently completed Campaign 14 (Leo); now in Campaign 15 (Scorpius)

Upcoming:

- Changed the position of the field for Campaign 16 – Kepler will observe in the forward-facing direction; emphasis on supernova science
- Campaign 17, 18, 19 fields have now been selected through March 2019 (?)

https://exoplanets.nasa.gov/k2

NASA Exoplanet Science Institute

NExScI
NASA Exoplanet Science Institute
California Institute of Technology

- Exoplanet Archive:
  - Planet tables
  - Light curves
  - Analysis tools
  - Regularly updated

- Exoplanet Follow-up Observing Program
  data-sharing infrastructure for community followup of Kepler, K2, and TESS

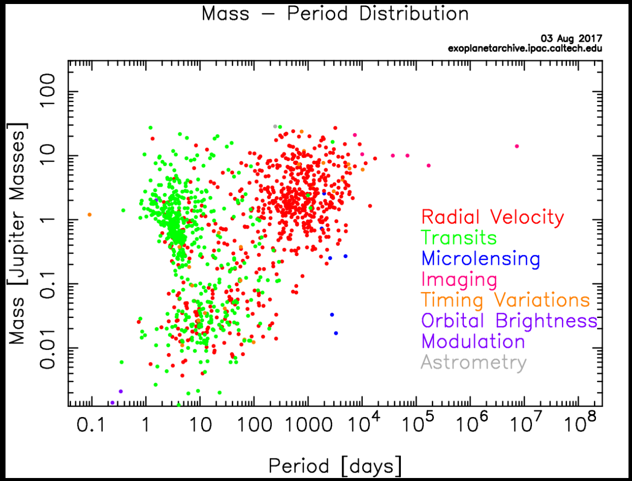
- Sagan Summer Schools

- Sagan Fellowship Program
  (new role working with STScI)

In the HZ

Confirmed

Candidates



Three 2017 Sagan Fellows Selected

Training the next generation of exoplanet scientists

Raphaëlle Haywood
Harvard
Breaking the Ultimate Barrier to Characterizing Other Earths

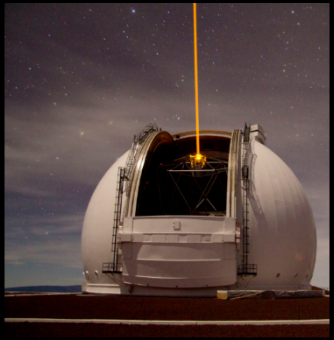
Ben Pope
NYU
Finding Planets Around Naked-Eye Stars

Andrew Vanderburg,
University of Texas, Austin
The Galactic Distribution of Exoplanets

Operating

Ground-Based Support for Space Missions

I. The twin 10m Keck telecopes at Mauna Kea, Hawaii



- NExScI administers NASA's 1/6 share
- Key Projects and smaller general observer Investigations
- Proposals for 2018A due on 9/14

Operating

Ground-Based Support for Space Missions

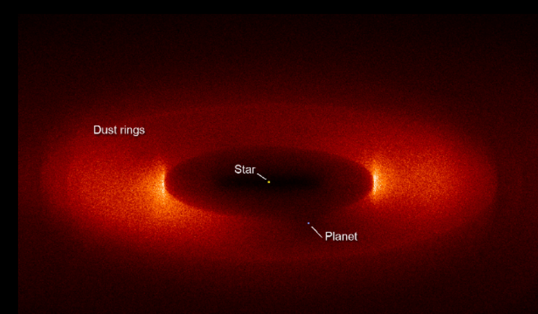
II. Large Binocular Telescope Interferometer, Mt. Graham Arizona,

Credit: ESO/Y. Beletsky

- Measuring HZ exozodiacal dust at 10 μm to inform designs of future missions
- Measurement precision: ~12 zodi one star one sigma
- Progress:
  - 26 stars observed
  - Mostly upper limits so far
- 35-star survey should be achieved this fall
- Project scheduled to complete in 2018

Phil Hinz, PI

The University of Arizona



Credit: NASA/GSFC

RV - Building

NN·EXPLORE

Partnership for Exoplanet Discovery and Characterization

NASA NSF

- 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

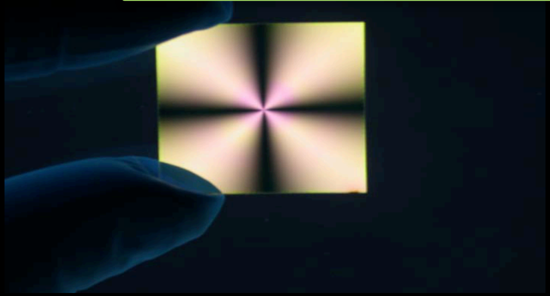
Coronagraph Technology Gap List

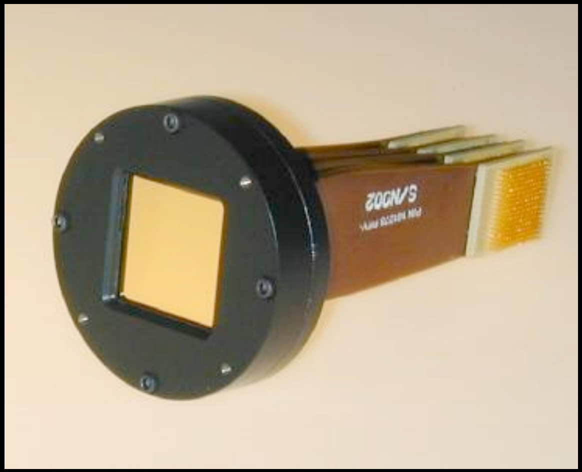
Table A.3 Coronagraph Technology Gap List.

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.

Future imaging mission technology





Coronagraph Technology Gaps

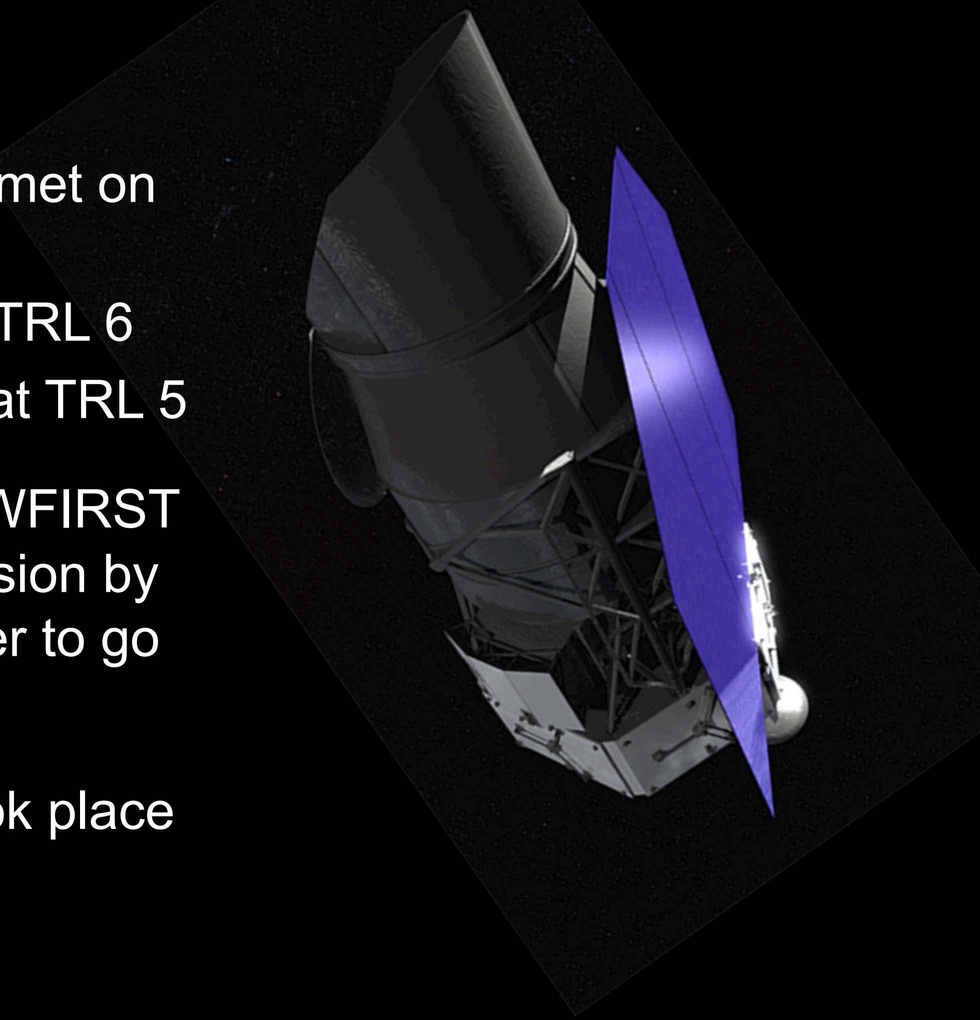
http://exoplanets.nasa.gov/exep/technology/

Mission in Formulation

Wide Field Infrared Survey Telescope (WFIRST)

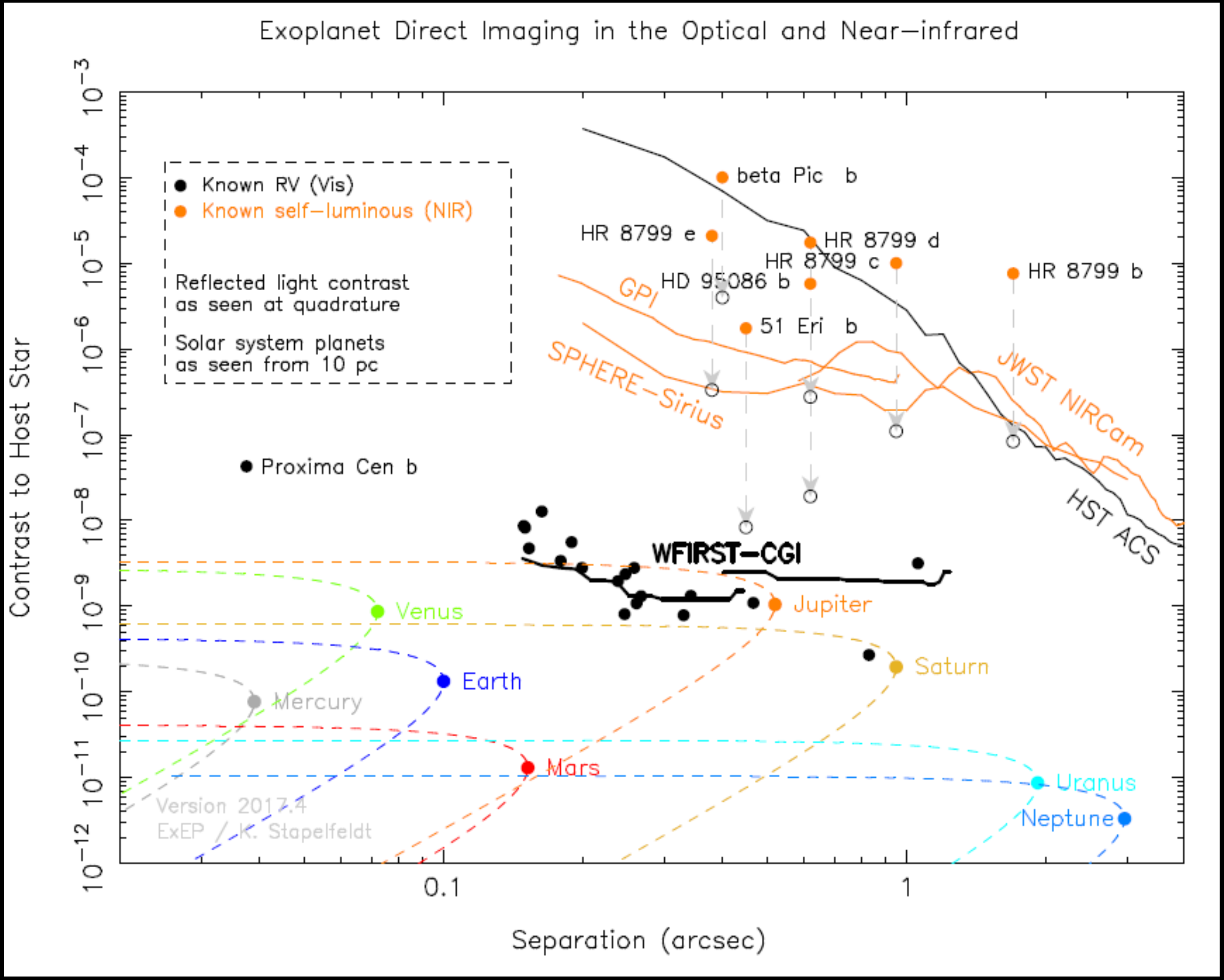
Dark Energy, Microlensing, Coronagraphy, and Infrared Surveys …

- WFIRST in Project Phase A
- All technology milestones were met on time
  - Five for IR Detector, now at TRL 6
  - Nine for Coronagraph, now at TRL 5
- Actively studying how to make WFIRST starshade-ready, to enable decision by 2020 Decadal survey on whether to go forward with this option
- Independent external review took place this week !



Credit: NASA/GSFC

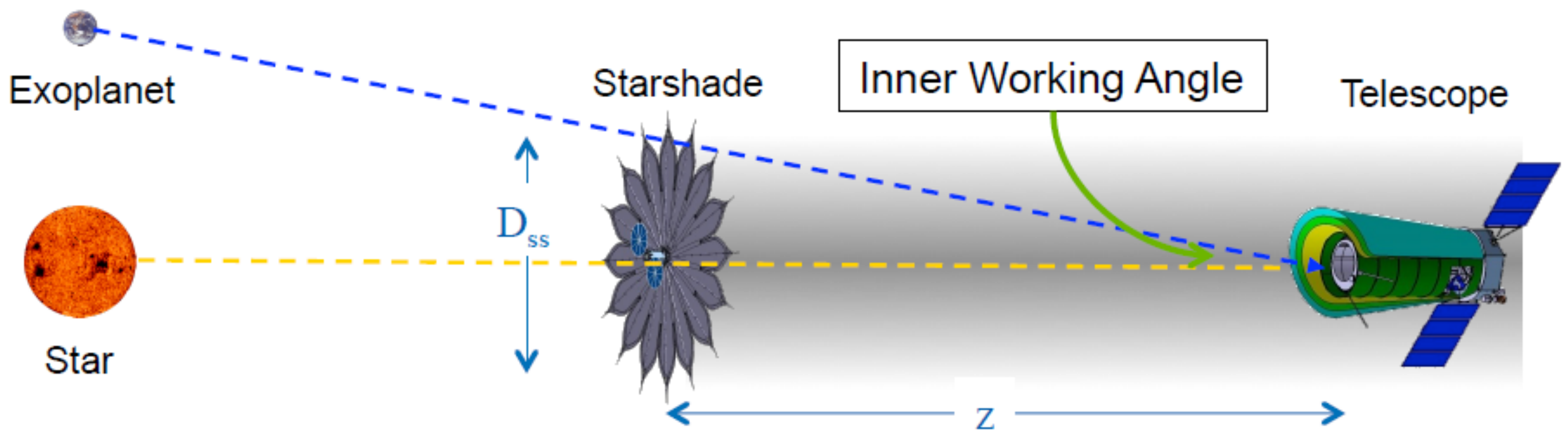
WFIRST coronagraph:
A milestone on the way to exo-Earth contrasts



STARSHADE

Future mission concept

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

Future mission technology

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 an 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 ≤ 3×10^{-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

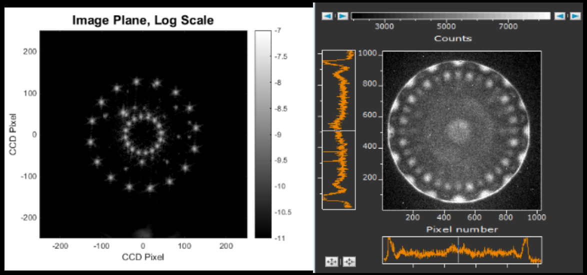
Tech development project

Starshade Technology Development "S5"

- Focused effort to ready starshade technology by 2020 – enable a WFIRST starshade option
- Held two workshops on scattered sunlight from edges and the mechanical architecture trade space
  - Per plan, one more workshop to go on starlight suppression demonstration
  - Adding a new workshop on petal shape and science return
- Key Technology Achievements
  - Demonstrated starlight suppression modeling agreement within 10%
  - Princeton starlight suppression demonstration currently at $10^{-7.5}$ (mask limits)
  - Demonstrated half-scale deployment of inner disk optical shield

Starshade Workshops

Contrast at higher Fresnel number, exposure time: 100s



Suppression at flight Fresnel n umber, exposure time: 3000s

Inner optical shield deployment tests

Decadal Flagship Mission Studies

Future mission concepts

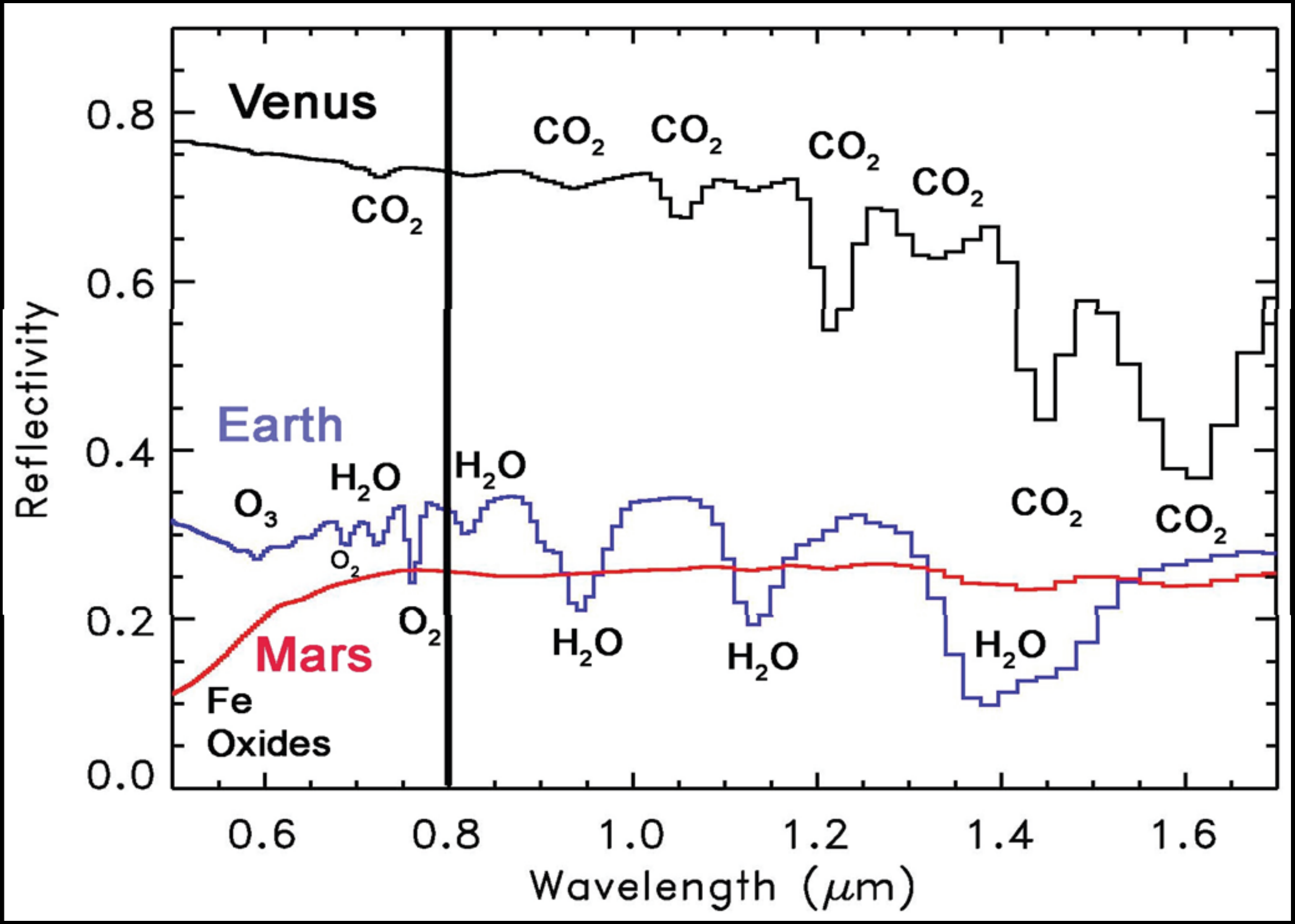
Possible New Worlds Exoplanet Telescopes

(for 2020 Decadal Survey; mid 2030s launch; work outside ExEP)

- Origins Space Telescope: Large mid/far-infrared mission
  - Primary exoplanet science case is transit spectroscopy to follow build on JWST results
- Large Ultra-Violet Optical InfraRed Telescope (LUVOIR)
  - Coronagraphic imaging with deployed/segmented primary mirror
  - Large apertures & exoplanet survey sample
  - equal weighting to exoplanets & general astrophysics
  - 5 instruments: coronagraph, UV spectrometer, general astrophysics camera, optical/NIR spectrograph, UV polarimeter (CNES)
- Habitable Exoplanet Mission (HabEx)
  - Coronagraph & starshade imaging with monolithic, off-axis telescope
  - Smaller apertures & exoplanet survey samples
  - 3 instruments: coronagraph, UV spectrometer & general astrophysics camera

HabEx & LUVOIR's prime goal: spectra of rocky exoplanets

FROM TPF-C STDT report

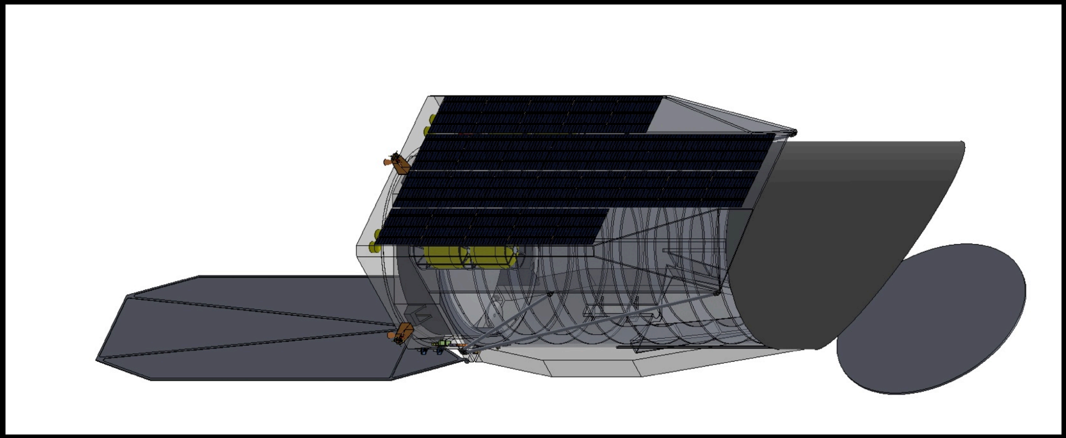


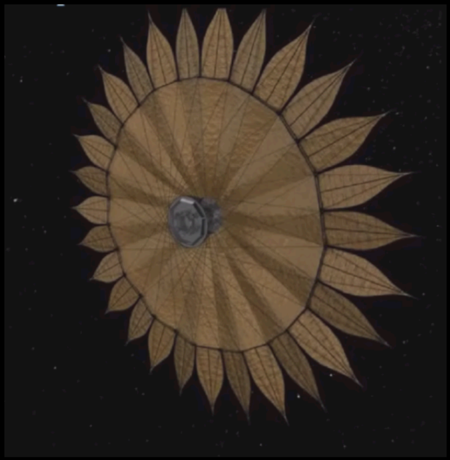
Two studies: Habitable Exoplanet Mission (HabEx) and Large UltraViolet Optical near-IR (LUVOIR) surveyor

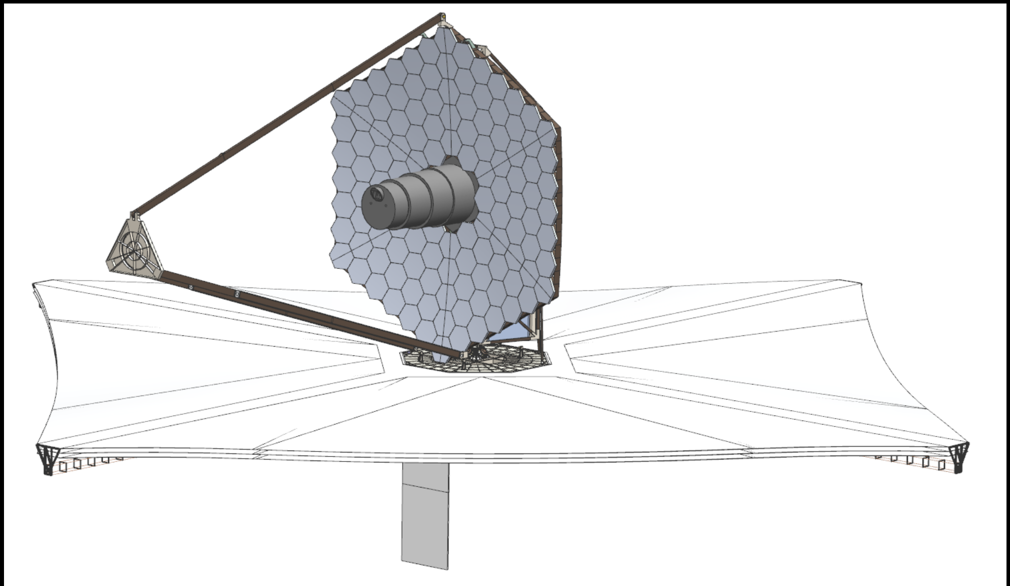
- Both have goal of studying Earthlike planets in reflected light, visible & near-infrared. They differ in levels of ambition
  - HabEx to "search for" signs of habitability and biosignatures. ~50 HZs ?
  - LUVOIR to "constrain the frequency of" habitability and biosignatures = larger statistical survey of exoEarths, larger aperture. ~300 HZs ?
- HabEx to focus on exoplanets, "best effort" only on general astrophysics. Apertures 4, 6.5? m. Study led by JPL.
- LUVOIR gives equal priority to exoplanets and general astrophysics. Would be HST-like, expansive vision. Apertures 15, 9 m. Study led by NASA Goddard.
- They are likely to differ in cost and technical readiness
- Interim reports late 2017; final reports early 2019

Progress in HabEx and LUVOIR designs

(work outside of ExEP; both teams gave input on their tech priorities)







Above: HabEx 4m monolith telescope with lateral optical bench, solar pressure paddle & 72 m starshade.

Right: LUVOIR 15m segmented telescope, 6 ring hex, deployed 70 m sunshade.

Steps that will enable direct imaging and spectra of habitable exoplanets

- Understand the frequency of HZ rocky planets
- Measure the astronomical backgrounds
- Make precursor and follow-up observations to measure exoplanet masses and orbits, where possible
- Measure host star properties that affect habitability
- Develop our understanding of exoplanet atmospheres, biosignatures, and biosignature false positives
- Ready the starlight suppression technology
- Close in on the mission architecture

Important NASA Exoplanet websites and dates

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

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

3rd Workshop on Extreme Precision Radial Velocities

State College PA, August 14-17 (next week)

Know Thy Star, Know Thy Planet – Oct 9-12 2017, Pasadena

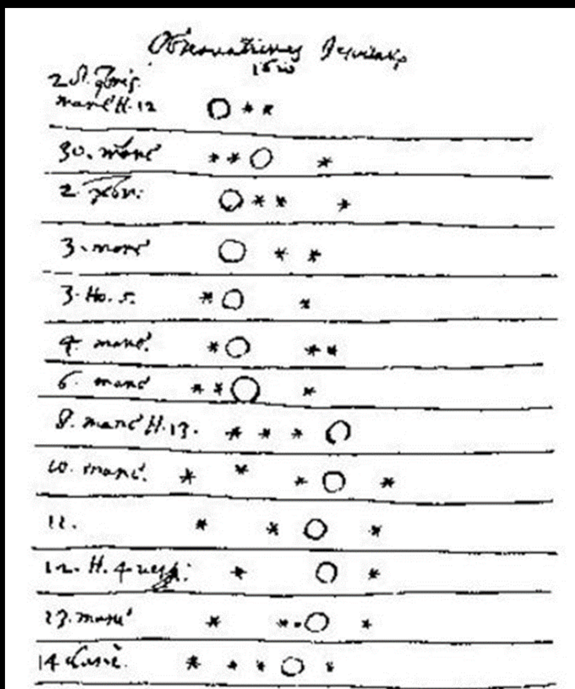
NExSS Workshop "Habitable Worlds 2017"

– Laramie WY, November 13-17

ExoPAG 17 meeting at winter AAS: Jan 7-8, Washington DC

A historical progression

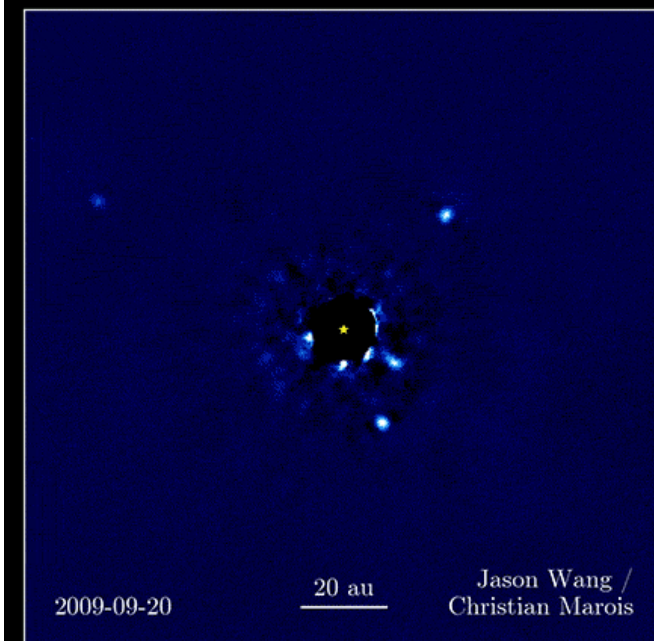
1610



Galileo discovers Jovian satellite system

2008

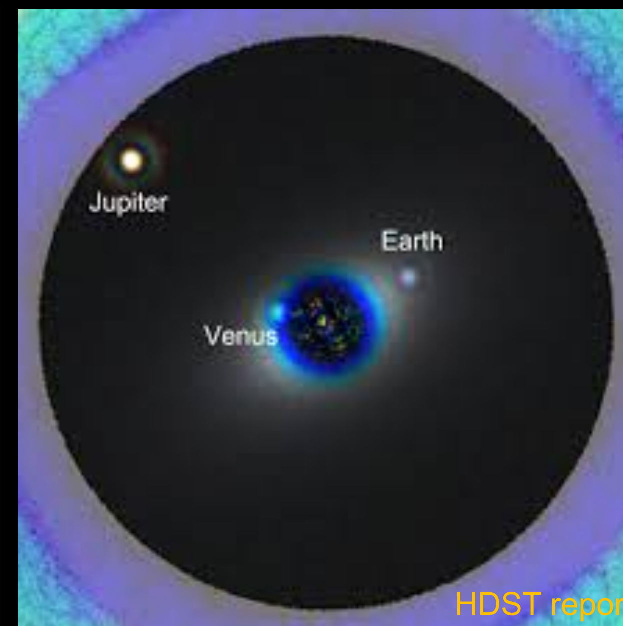
2009-2016



Marois et al. discover HR 8799 planetary system

Eight years of orbital motion

2035 ?



Future space telescopes confirm first habitable exoplanet

Jet Propulsion Laboratory
California Institute of Technology

ExEP is a Program Office within the NASA Astrophysics Division