Jet Propulsion Laboratory
California Institute of Technology

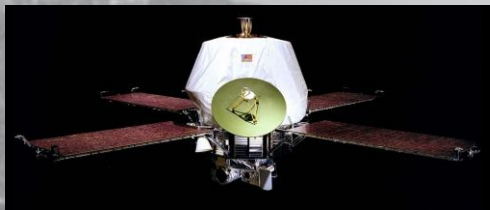
The NASA Exoplanet Exploration Program:

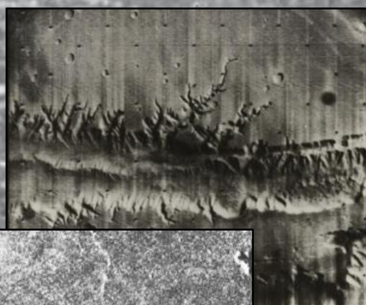
The Search for Exoplanets, Habitability, and Life in our Galaxy

Gary H. Blackwood
Manager, NASA Exoplanet Exploration Program
February 18, 2015

ATLAST Seminar Series
Goddard Space Flight Center

NASA began the exploration of other worlds around our Sun…





THE RECORD, THURSDAY, DECEMBER 5, 1974

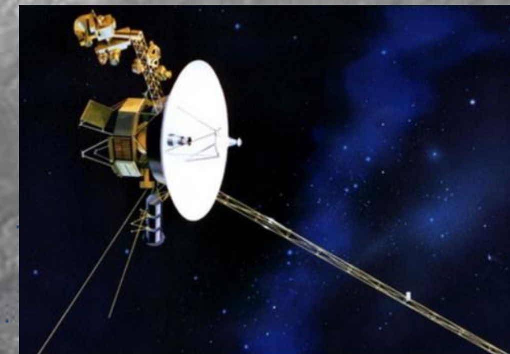
UPI Photo

This is an artist's conception of the Pioneer 11 mission, showing the spacecraft at right of the ringed planet Saturn, and the moon Titan near Saturn's center. Formerly called the Pioneer-Jupiter mission, it has been re-designated the Pioneer-Saturn mission.

Pioneer to chance flight near Saturn

United Press International

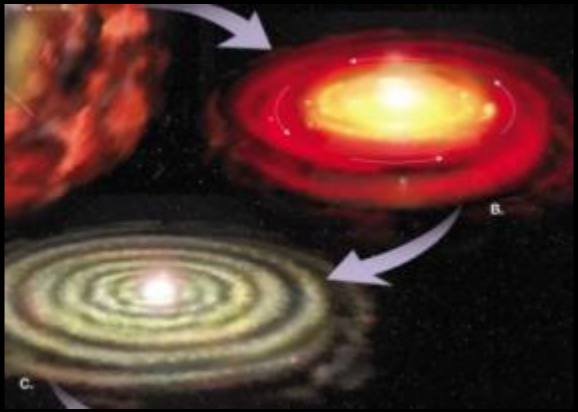
MOUNTAIN VIEW, Calif. — Pioneer 11 will flash between … ard to the 570-pound Pioneer is great because at high speed a single fleck of dust would de- … communications when it makes its critical pass through the rings.



Why Astrophysics?

Astrophysics is humankind's scientific endeavor to understand the universe and our place in it.

1. How did our universe begin and evolve?



2. How did galaxies, stars, and planets come to be?

3. Are We Alone?

Blank slide

Blank slide

Our galaxy is teeming with exoplanets…

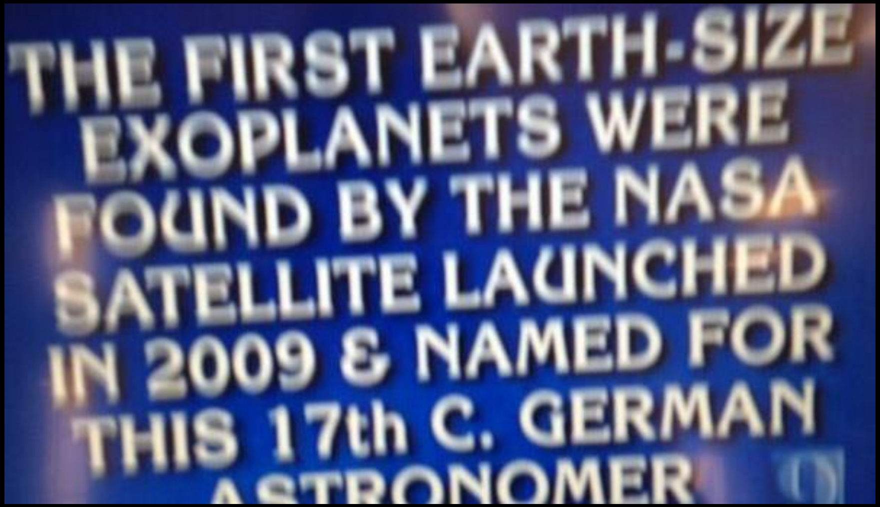
….At least one for every star in the sky

Yet our eyes can see only a few thousand stars….

….of the hundreds of billions within our galaxy alone

Exoplanets for $1000, please!

May 2014

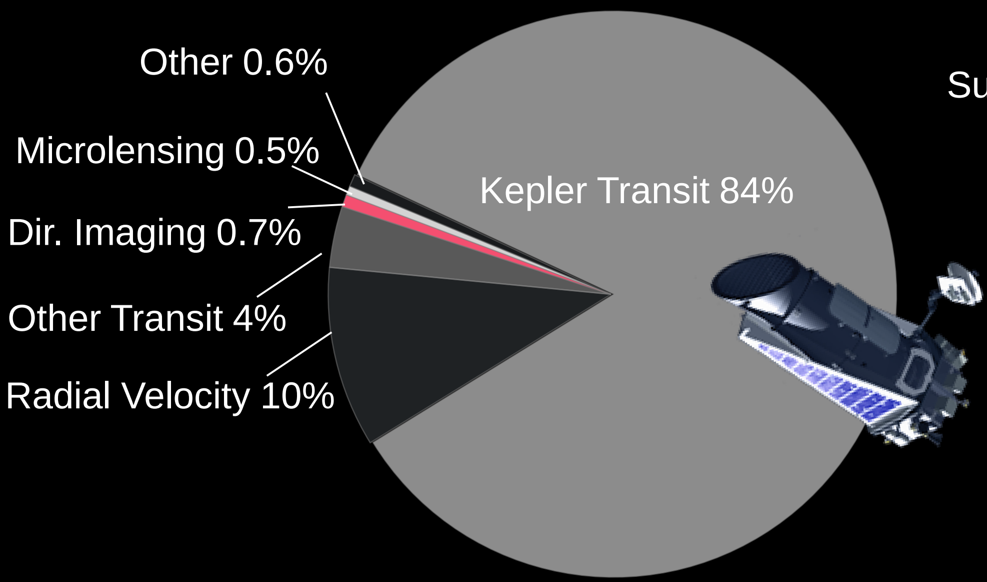


And the Question is: Who is Johannes Kepler?

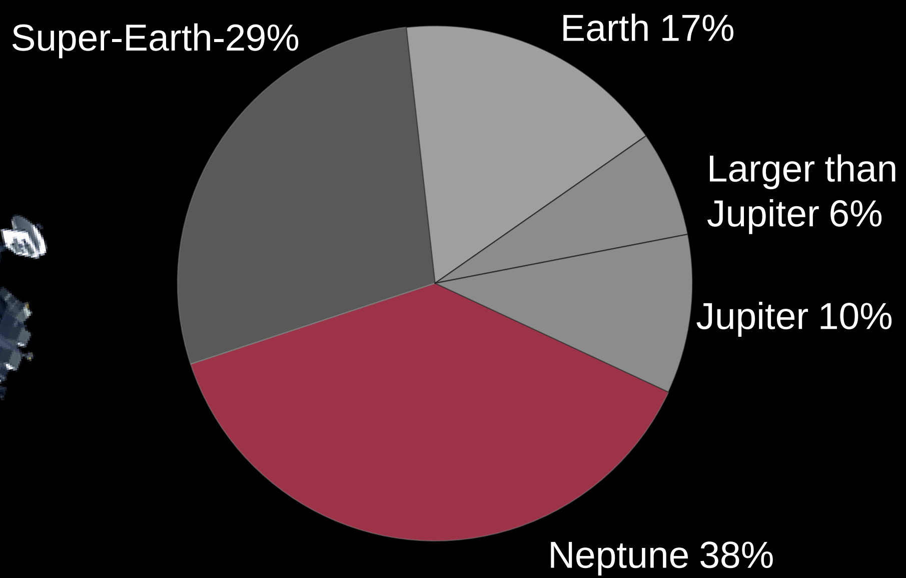
Even with the Kepler Mission,
we have explored only a tiny corner of our galaxy

Thousands of Exoplanets have been discovered. . .

Discovery Method



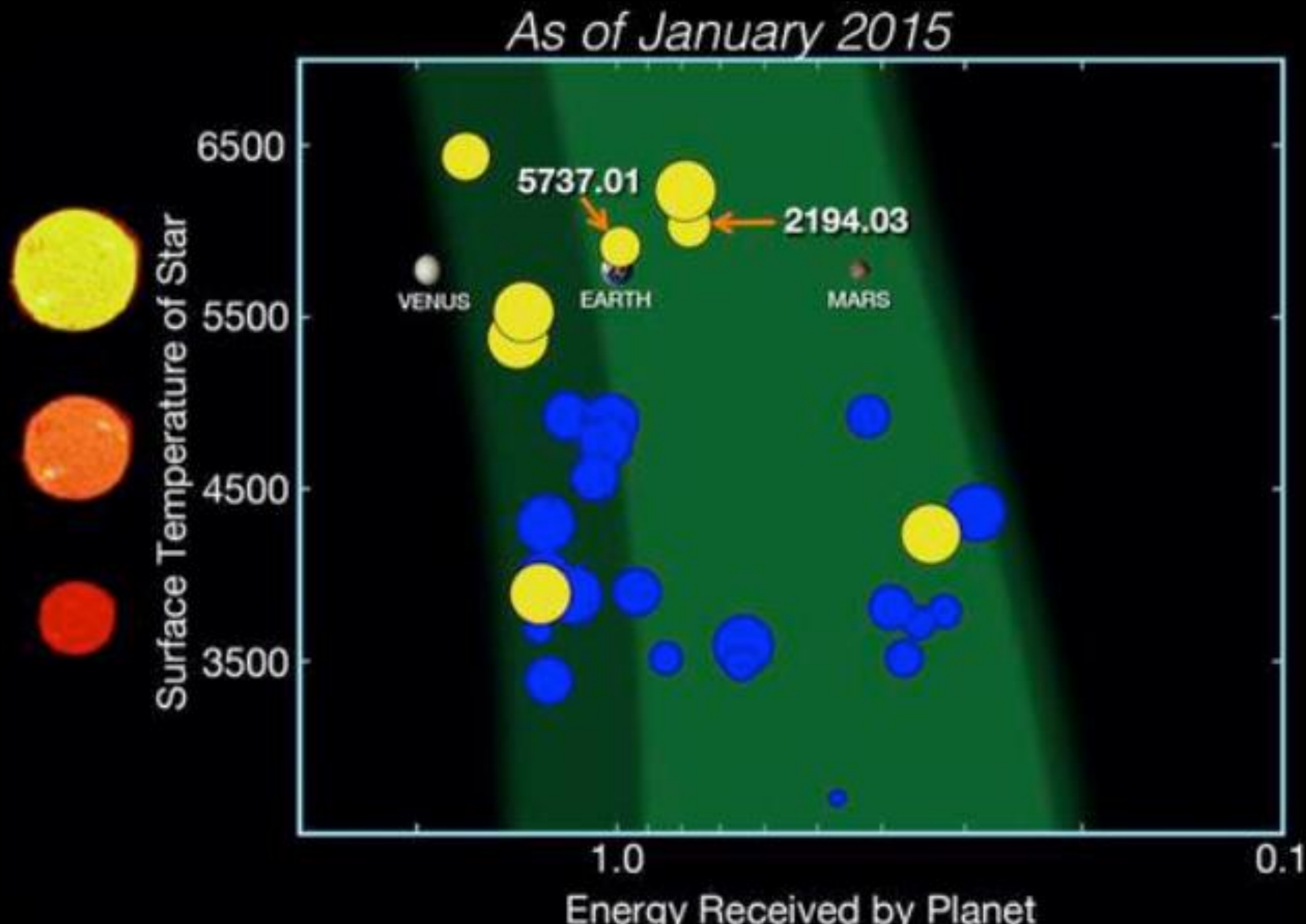
Exoplanets by Size



Total Exoplanets: 5013
(candidate and confirmed)

Ref.: http://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html - Updated 4 November 2014

…and we are particularly interested in those in the *Habitable Zone*

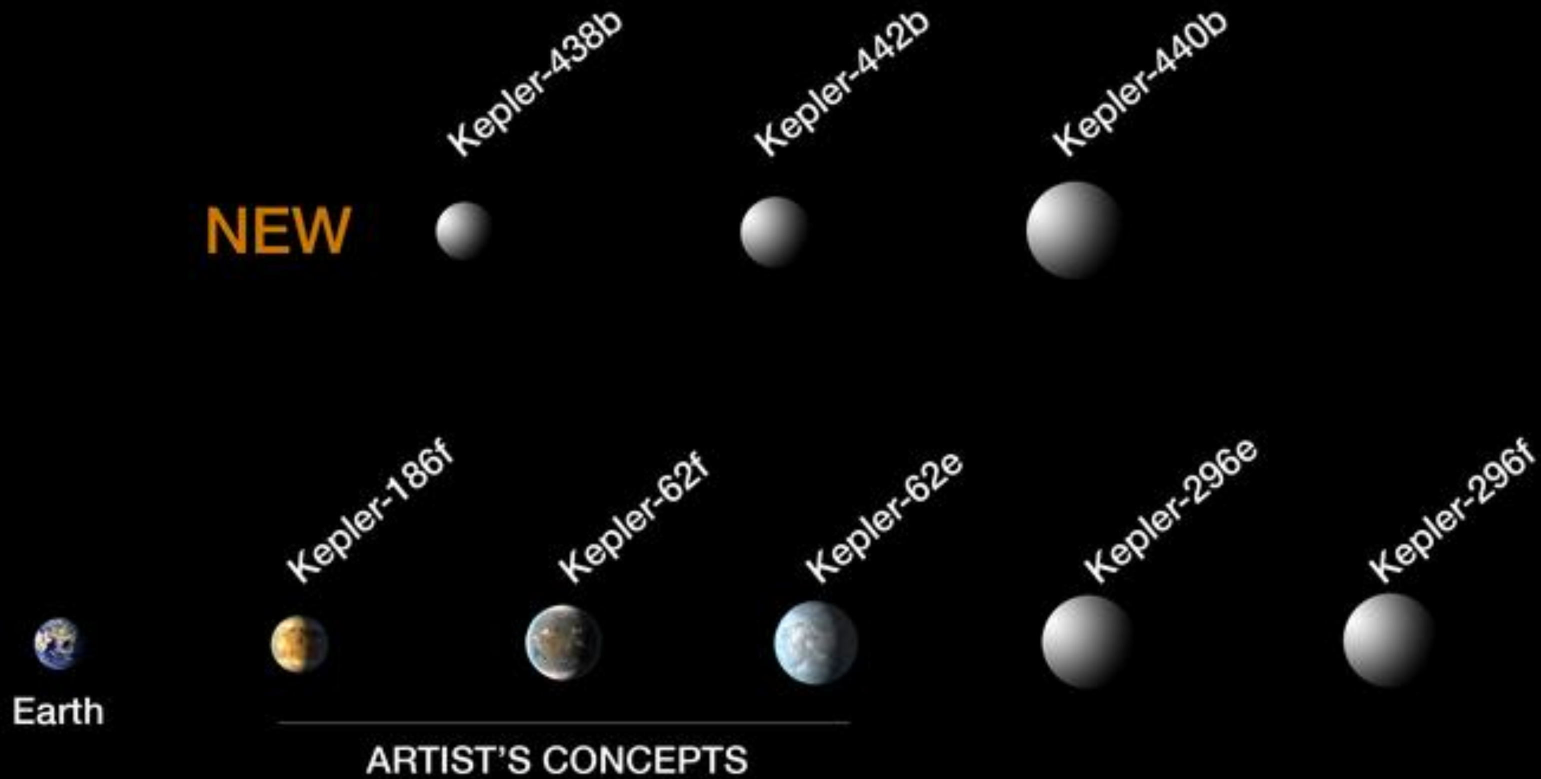


Batalha 2015

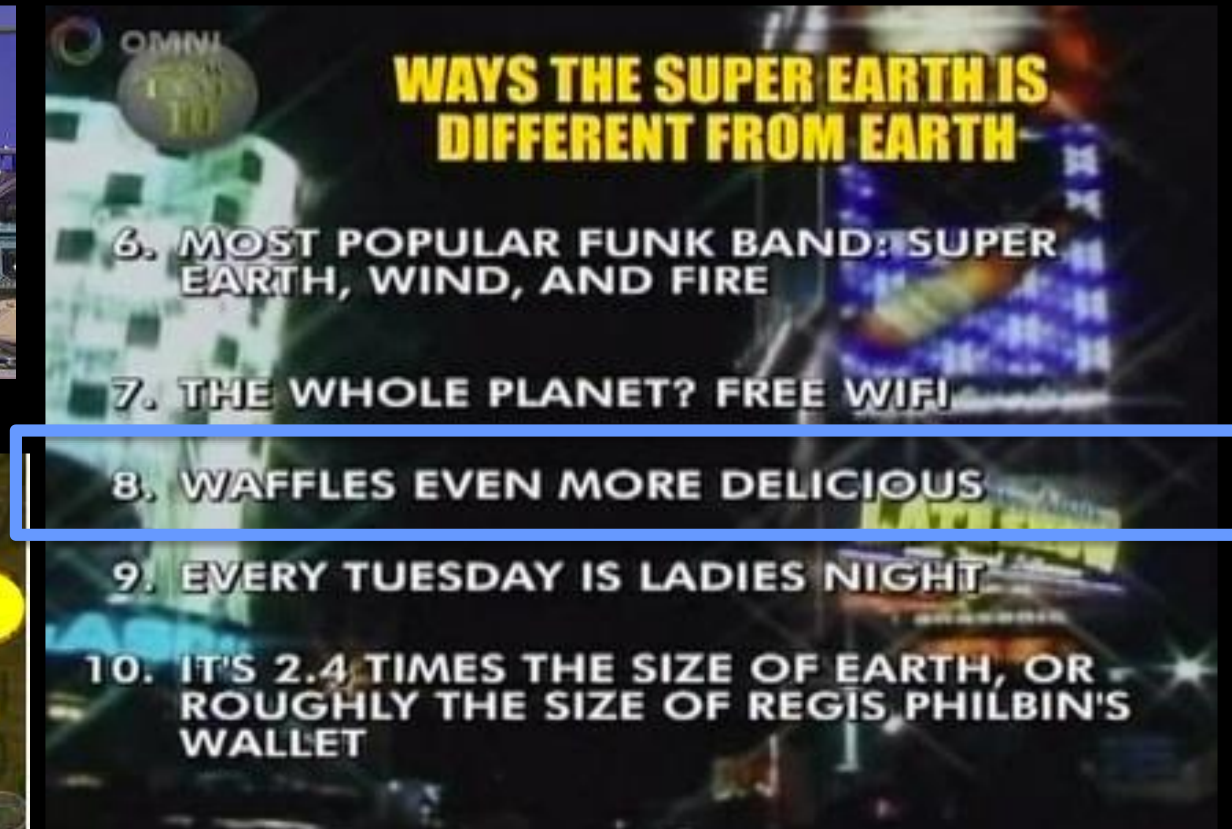
NASA Kepler's Hall of Fame:

Small Habitable Zone Planets

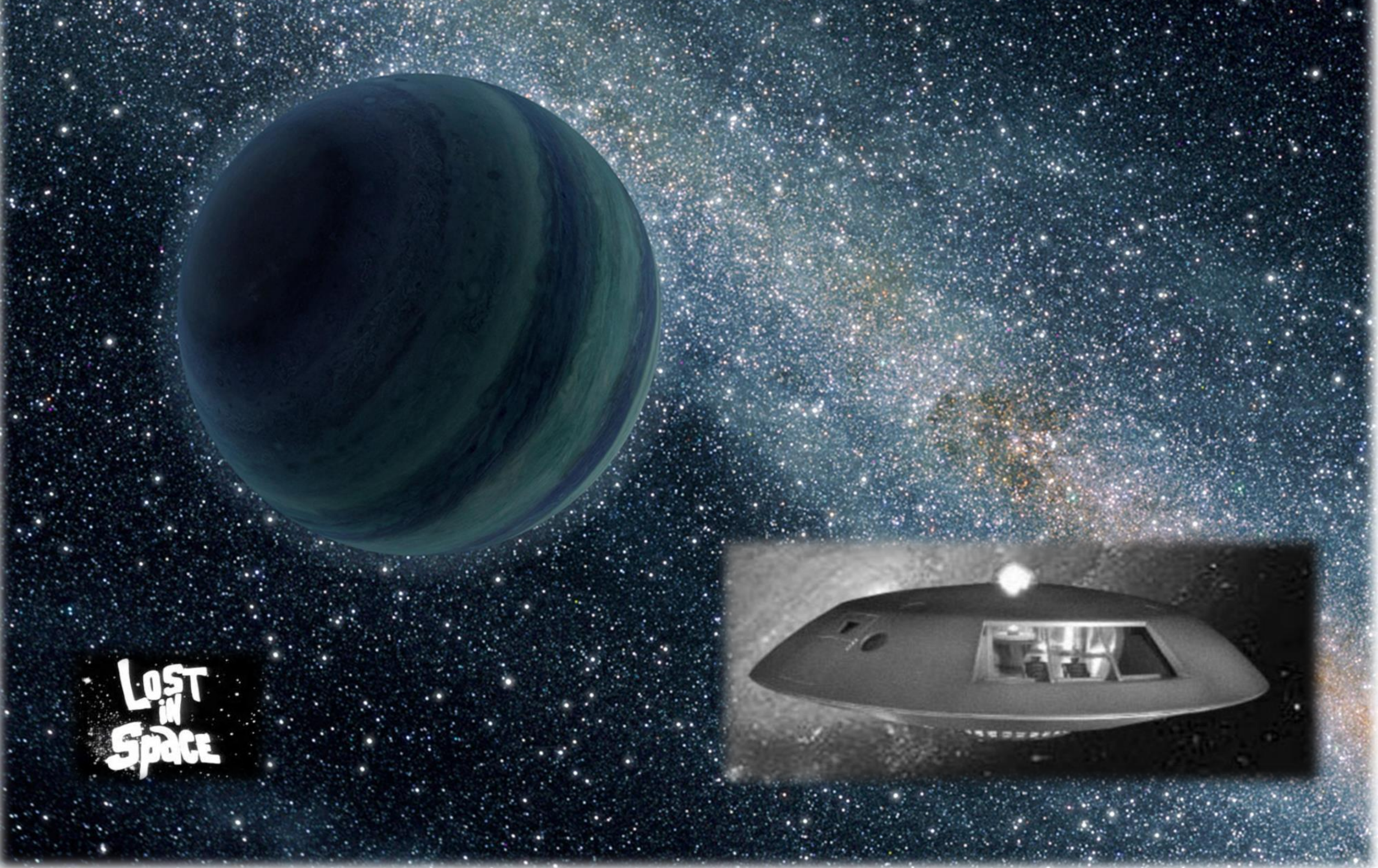
As of January 2015



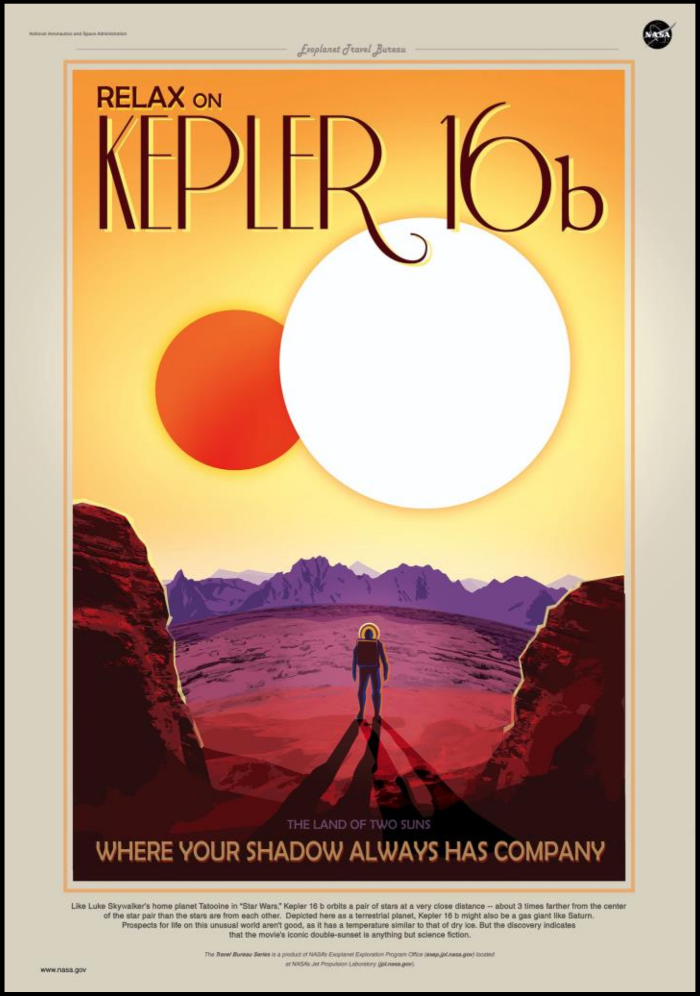
We've discovered an abundance of Super Earths…



…and *Rogue planets* not bound to any star at all!



Where will exploration take us in 100 years?
Introducing the ***Exoplanet Travel Bureau***



Let’s call the ***Exoplanet Travel Bureau***, and book a trip…

Let’s visit *Kepler-186f* !

The Exoplanet Exploration Program

Astrophysics Division: Driving Documents

http://science.nasa.gov/astrophysics/documents

Here's how we are Organized

Within the NASA Science Mission Directorate

Astrophysics Division

Director
Paul Hertz

Deputy Director
Andrea Razzaghi

Program Exec: J. Gagosian
Program Scientist: D. Hudgins

Cross Cutting

Astrophysics Research

Programs / Missions

Exoplanet Exploration
Cosmic Origins
Physics of the Cosmos
Astrophysics Explorers
WFIRST / AFTA

The Exoplanet Program Office is managed by the NASA Jet Propulsion Laboratory for the Astrophysics Division, NASA Science Mission Directorate

What is the Purpose of the Program?

Described in 2014 NASA Science Plan

Exoplanet Exploration Program

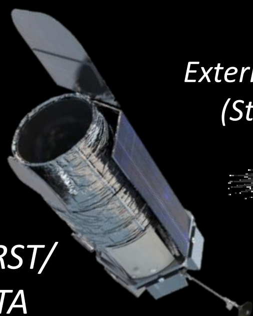
The Exoplanet Exploration Program aims at

1. Discovering planets around other stars
2. Characterizing their properties
3. Identifying candidates that could harbor life

The Exoplanet Exploration Program

Space Missions and Mission Studies

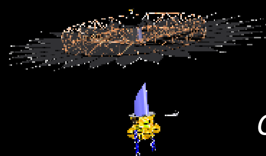
Kepler, K2



WFIRST/ AFTA

Probe-Scale:

External Occulter (Starshade)



Coronagraph

Public Engagement

Supporting Research & Technology

Key Sustaining Research

Large Binocular Telescope Interferometer

Keck Single Aperture Imaging and RV

Extreme Precision Doppler Spectrometer

Technology Development

Coronagraph Masks

High Contrast Imaging

Deployable Star Shades

NASA Exoplanet Science Institute

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 Program Executive – J. Gagosian
Kepler Program Scientist – Dr. D. Wallace
NExScI, Keck, LBTI Prog. Exec. – Dr. M. Perez
NExScI, Keck, LBTI Prog. Sci. – Dr. H. Hasan

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 - Vacant
Program Chief Scientist – Dr. W. Traub (3200)
Program Chief Technologist – Vacant

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

7301
Program Science Office
Scientist - Dr. S. Unwin (312)
AFTA - Dr. D. Stern (326)
AFTA – Dr. G. Bryden (326)

7303
Program Engineering Office
Chief Engineer - Vacant

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

7304
Program Business Office
Manager – Vacant
Resource Analyst – L. Scott (252)
Export Tech Lia. – Dr. A. Abramovici (383)
Administrator – O. Pananyan (720)
Project Schedule Analyst – K. McClane (252)
Staff Assistant – K. Miller (730)
Staff Assistant - M. Rubio (730)

Exoplanet Probe Study Office
K. Warfield (312)

Exoplanet Probe STDT - Coronagraph[1]
Dr. K. Stapelfeldt, GSFC

Mission Managers / Scientists
Kepler Mission Mgr – I. Heinrichsen (734)
Kepler Mission Sci – Dr. N. Gautier (326)
WFIRST Mission Mgr – I. Heinrichsen (730)
WFIRST Mission Sci – Dr. S. Unwin (312)

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

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

Kepler (ARC)
Project Manager (Phase E) – C. Sobeck
Project Scientist (Phase E) – Dr. S. Howell
Science PI – W. Borucki

Extreme Precision Doppler Spectrometer
Manager – Dr. M. Jeganathan (383) (acting)
Proj Scientist – R. Capps (acting)
Concept Team A (TBD)
Concept Team B (TBD)

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

7302
Program Education & Public Outreach (JPL)
EPO Manager – M. Greene (183)
Web Manager – R. Jackson
Web Editor – J. Rodriguez
EPO Coordinator – A. Biferno

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

WFIRST/AFTA Study Office (GSFC)
Study Manager – K. Grady
Study Scientist – Dr. N. Gehrels

WFIRST/AFTA SDT[1]
Prof D. Spergel
Princeton University
Dr. N. Gehrels
GSFC

747
JPL WFIRST/AFTA Project Office
Project Manager, B. Parvin , AD
Project Scientist: Dr W. Traub
Deputy Proj Scientist: Dr. J. Rhodes
Telescope – B. Parvin (747)
Coronagraph – Dr. F. Zhao (383)
Technology – Dr. I. Poberezhskiy (383)
-- Dr. R. Demers (383)
Science Center – Dr. R. Cutri (Caltech)

WFIRST/AFTA TAC
Dr. A. Boss
Carnegie Institute

[1] Reports to HQs APD

The Program relies on the Scientific Community

Active teams and committees:

- ExoTAC (Technology Assessment Committee)
  Chair: A. Boss, Carnegie Institute
- WFIRST/AFTA SDT (Science Definition Team)
  Chairs: D. Spergel, Princeton University
  N. Gehrels, Goddard Space Flight Center
- STDT (Science and Technology Definition Team). Two:
  - Exo-C (Probe Coronagraph) Chair: K. Stapelfelt, GSFC
  - Exo-S (Probe Starshade) Chair: S. Seager, MIT
- ExoPAG (Program Analysis Group)
  EC Chair: S. Gaudi, Ohio State University

Key Exoplanet Science Questions

1. Discovering Planets: How abundant are exoplanets in our Galaxy?
   - Radial Velocity — <1 m/s
   - Transit Photometry — < 10 parts per million

2. Characterizing Planets: What are exoplanets like?
   - Transit Spectroscopy — < 25 parts per million — (large planets)
   - Direct Imaging
     - High Contrast — < 1E-9 — (after post-processing)
     - Small Inner Working Angle — < 500 mas (<200 mas)
     - Spectroscopy — R~40 in visible, near infrared — (water lines)

3. "Pale Blue Dots": Are the planets habitable? Are there signs of life?

Current Exoplanet Science Missions

Kepler Space Telescope

- **PI:** W. Borucki, NASA Ames Research Center
- **Launch Date:** March 6, 2009
- **Science Data Collection through May 2013**
- **Final processing of full data set underway**

Kepler Closeout

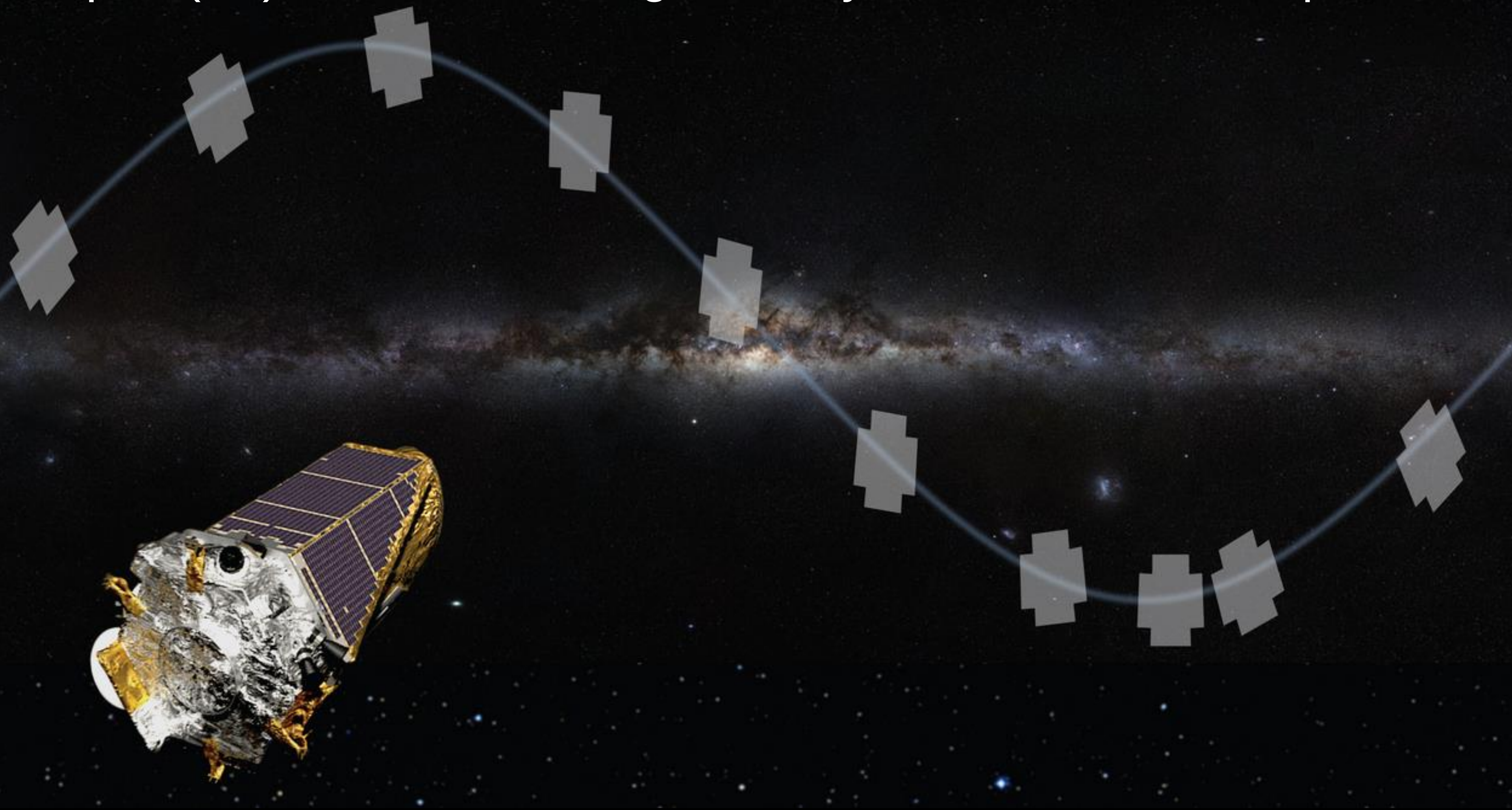
Harvesting the exoplanet yield from the mission

- Already available to Community: Q0-Q16

- Uniform Processing: Q0-Q17 (9.2)
  - Long cadence light curves — Dec 2014
  - Short cadence light curves — Mar 2015
  - Release notes — Jul 2015

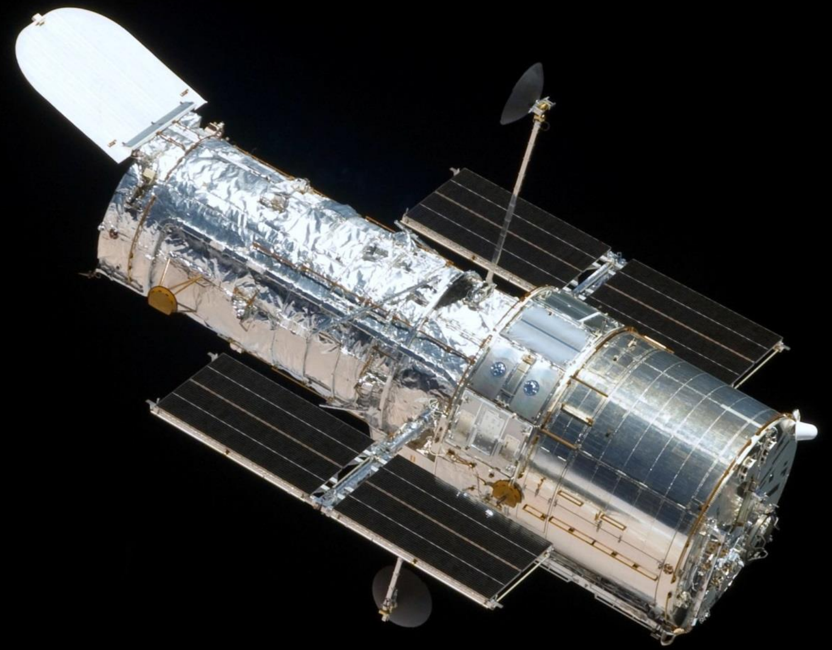
- Final Data processing: Q0-Q17 (9.3)
  - Light curves — Jan 2016
  - Release notes — Aug 2016

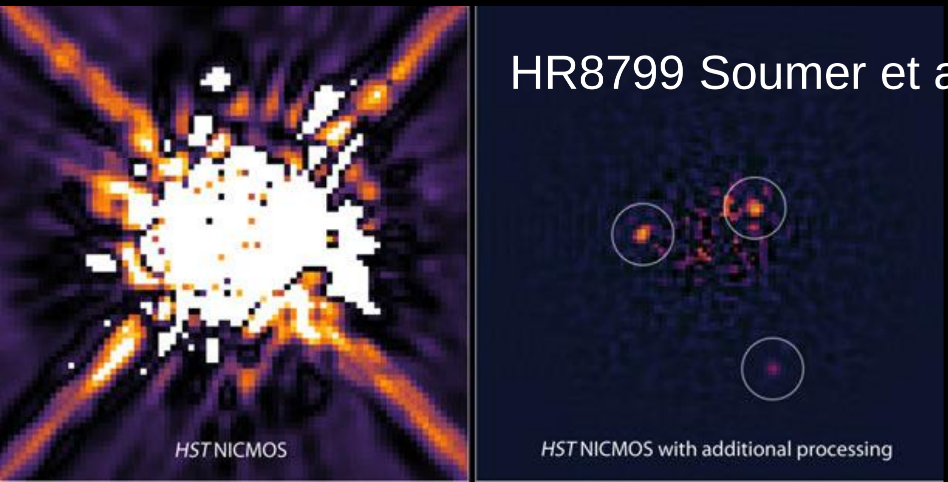
Kepler (K2) is now observing ~80-day windows in the ecliptic



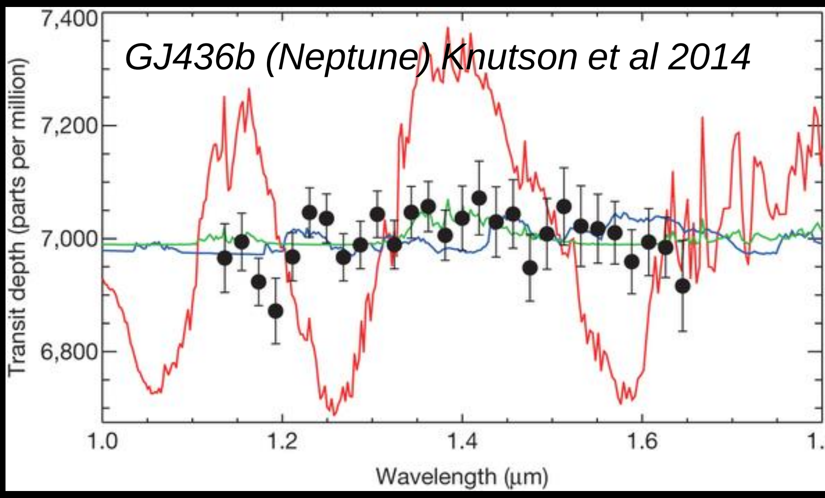
Hubble – an Exoplanet Observatory

Advancing the art of coronagraphy and transit spectroscopy



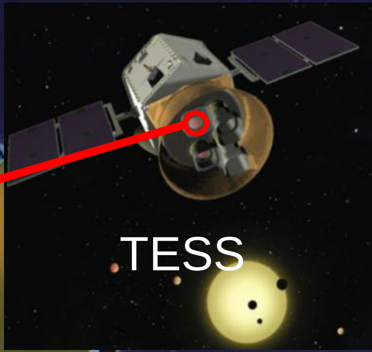


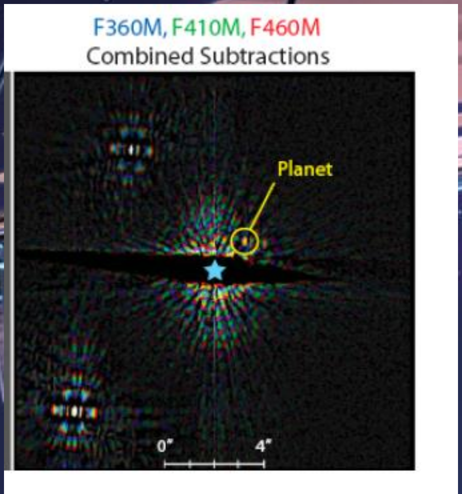
HR8799 Soumer et al



JWST – another Exoplanet Observatory

- Transit spectroscopy and photometry (1-20 μm)
- Coronagraphic imaging at 3-23 μm of planets (young Jupiters to Saturns)
- Spectra of coolest brown dwarfs
(free floating planets)



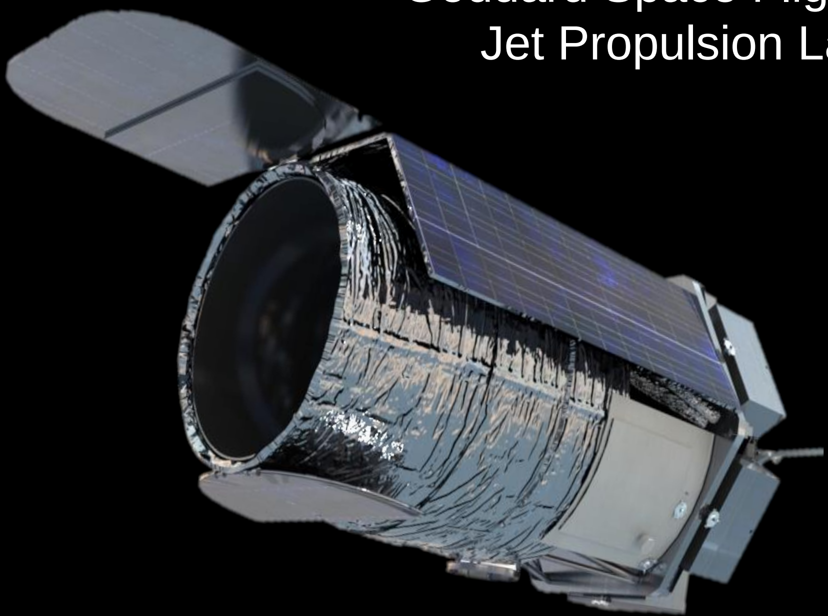


NIRCam Simulation

WFIRST / AFTA

Wide-Field Infrared Survey Telescope (WFIRST)
Astrophysics Focused Telescope Assets (AFTA)

Goddard Space Flight Center
Jet Propulsion Laboratory
STScI
NExScI



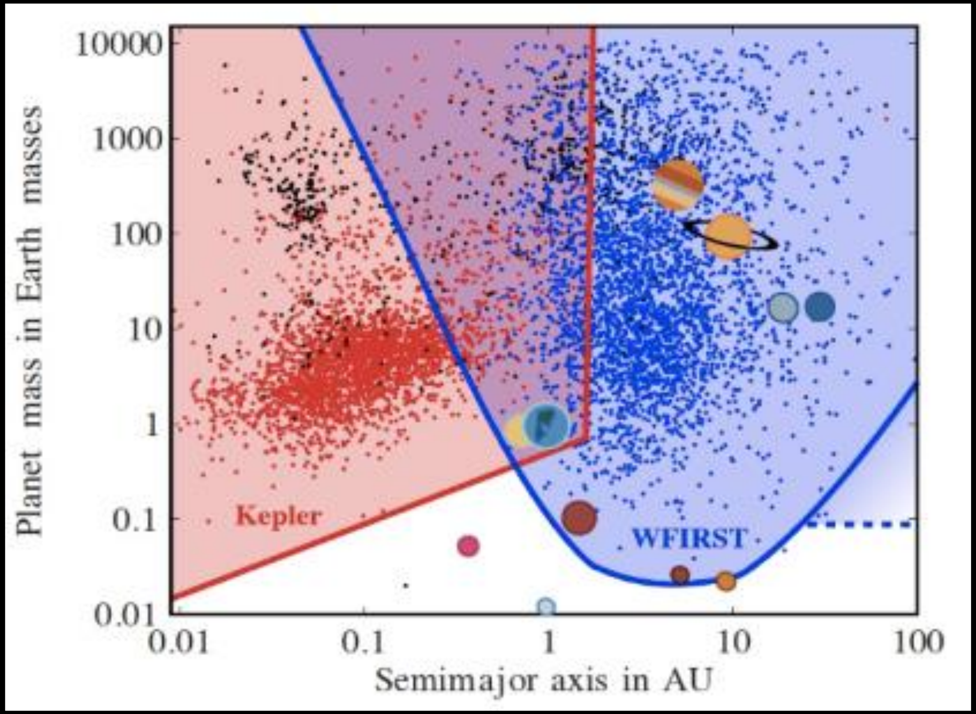
Wide-field Instrument

- H4RG detectors (Qty 18)
- Wavelength: 0.6 to 2.0 micron
- FOV: 0.28 deg^2

Wide-field Instrument Science

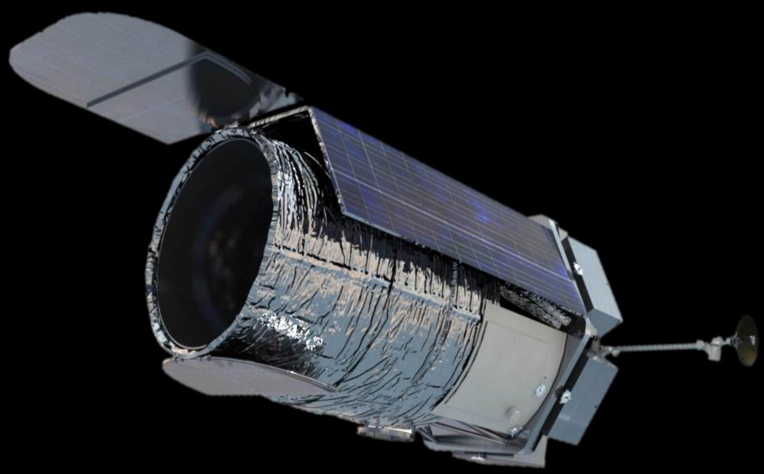
- Dark Energy
- Infrared Survey
- Microlensing survey for exoplanets

WFIRST / AFTA
Microlensing survey completes the census begun by Kepler



But wait, there's more!
the WFIRST / AFTA Coronagraph

Direct Imaging of Exoplanet Nearest Neighbors



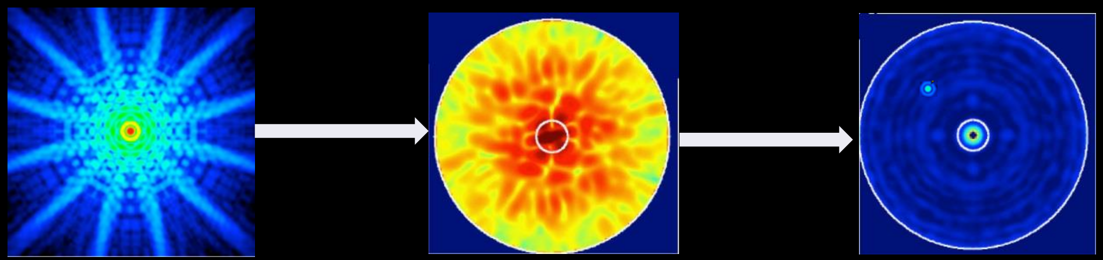
Coronagraph Instrument

- Imaging and spectra channels
- 0.4 – 1 μm bandpass
- ≤ 10^{-9} detection contrast
- 100 mas inner working angle at 0.4 μm
- R ~ 70

Coronagraph Science

- Imaging and spectroscopy of exoplanet atmospheres down to a few Earth masses
- Study populations of debris disks

No Mask — **With Mask** — **With Mask and Deformable Mirrors**



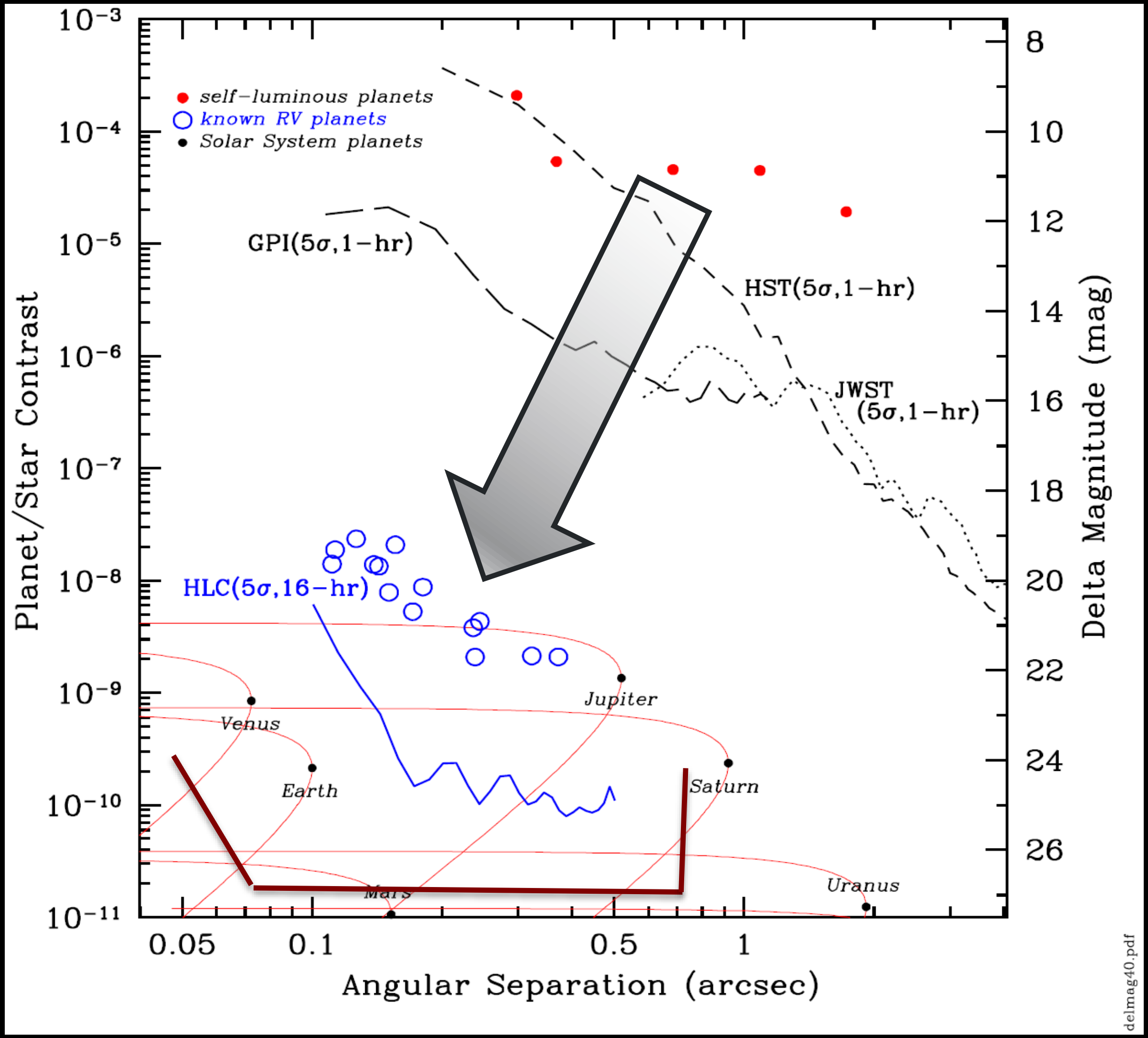
Coronagraph will develop the technologies for a future exo-Earth mission

WFIRST Coronagraph images cool gas and ice giants

GPI

WFIRST

New Worlds Telescope



HST

JWST

W. Traub

WFIRST SDT Final Report

- Final SDT Report Delivered to HQ on 1/30/2015
- Presentation to John Grunsfeld and Paul Hertz 2/13
- Public release afterwards, following incorporation of comments from HQ and presentation.

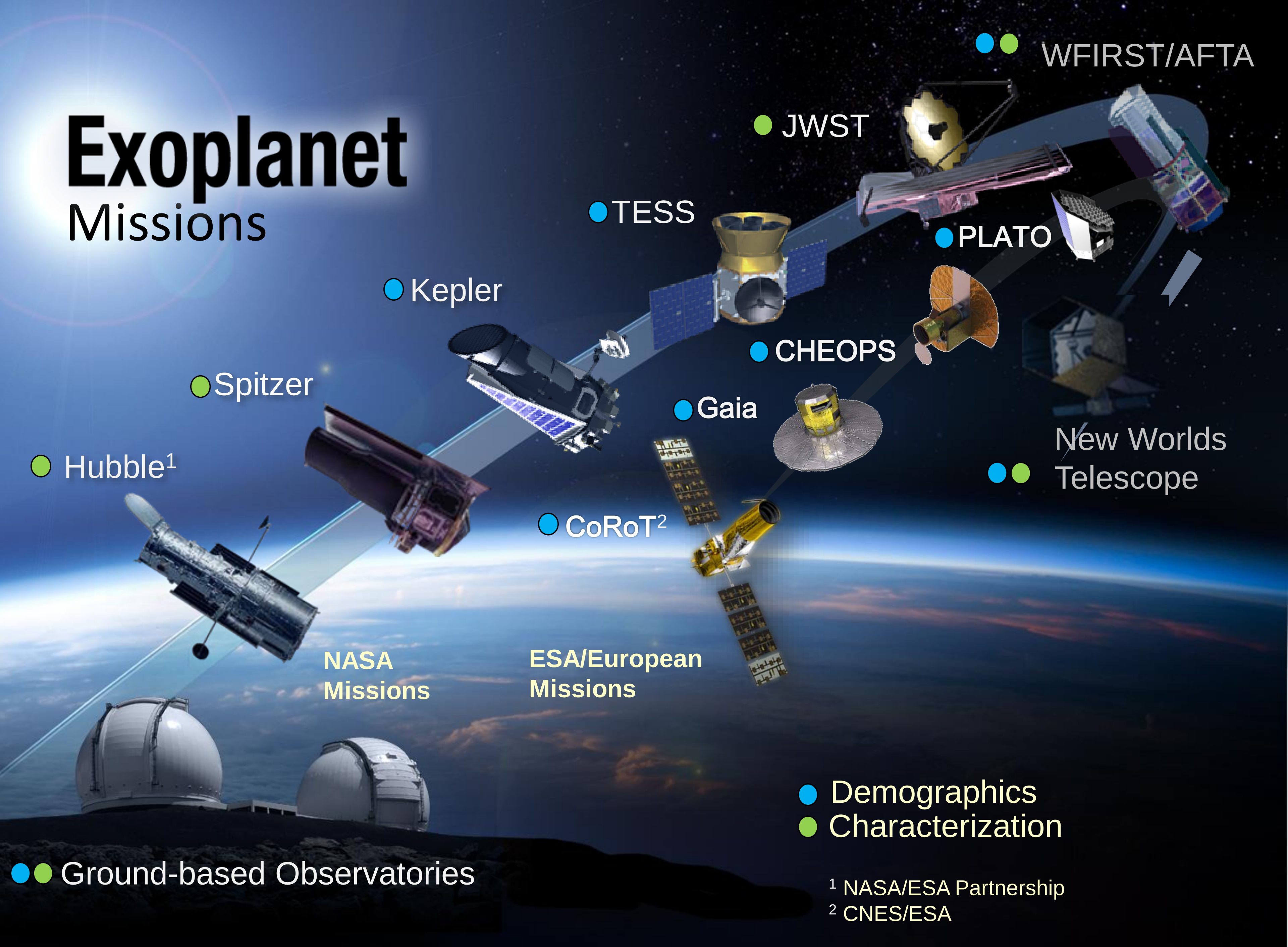
Science Definition Team

D. Spergel[1], N. Gehrels[2]
C. Baltay[3], D. Bennett[4], J. Breckinridge[5], M. Donahue[6], A. Dressler[7], B. S. Gaudi[8], T. Greene[9], O. Guyon[10]
C. Hirata[8], J. Kalirai[11], N. J. Kasdin[1], B. Macintosh[12], W. Moos[13], S. Perlmutter[14], M. Postman[11], B. Rauscher[2]
J. Rhodes[15], Y. Wang[16,17], D. Weinberg[8],

Ex Officio
D. Benford[18], M. Hudson[19], W. -S. Jeong[20], Y. Mellier[21], W. Traub[15], T. Yamada[22]

Consultants
P. Capak[17], J. Colbert[17], D. Masters[17], M. Penny[6], D. Savransky[23], D. Stern[15]

Study Team
R. Barry[2], L. Bartusek[2], K. Carpenter[2], E. Cheng[24], D. Content[2], F. Dekens[15], R. Demers[15], K. Grady[2], C. Jackson[25]
G. Kuan[15], J. Kruk[2], M. Melton[2], B. Nemati[15], B. Parvin[15], I. Poberezhskiy[15], C. Peddie[2], J. Ruffa[2]
J.K. Wallace[15], A. Whipple[24], E. Wollack[2], F. Zhao[15]

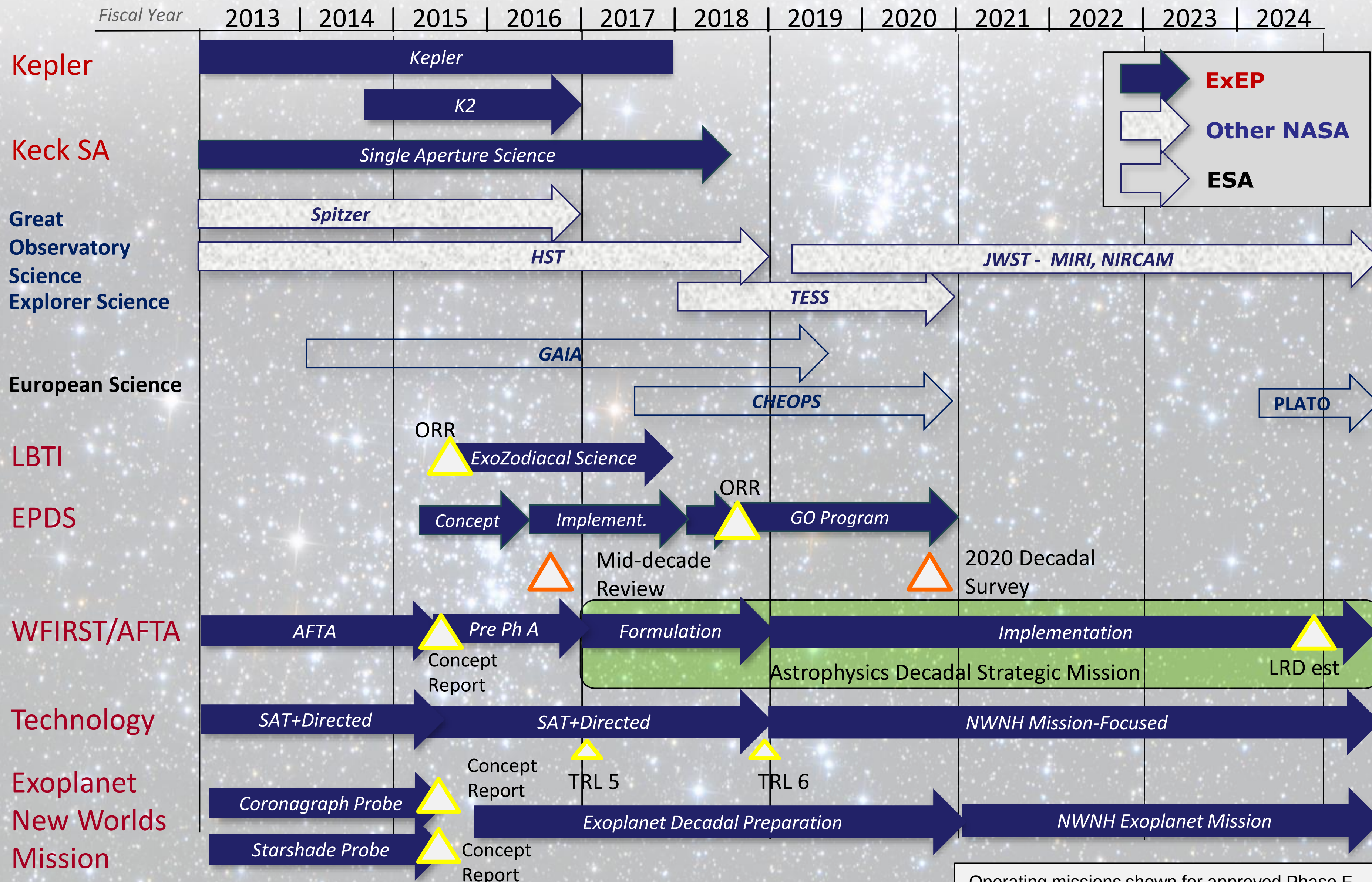


WFIRST/AFTA
JWST
Exoplanet
Missions
TESS
PLATO
Kepler
CHEOPS
Spitzer
Gaia
New Worlds
Telescope
Hubble[1]
CoRoT[2]
NASA
Missions
ESA/European
Missions
Demographics
Characterization
Ground-based Observatories
[1] NASA/ESA Partnership
[2] CNES/ESA

Exoplanet Exploration: A Decade Horizon

NASA and ESA efforts

ExoPlanet Exploration Program




EXOPLANET
Q&Alien
PLANETQUEST

Enabling and Creating the Exo-Future: Science and Mission Studies

Key Exoplanet Science Questions

1. Discovering Planets: How abundant are exoplanets in our Galaxy?
   - Radial Velocity <1 m/s
   - Transit Photometry < 10 parts per million

2. Characterizing Planets: What are the (large) exoplanets like?
   - Transit Spectroscopy < 100 parts per million
   - Direct Imaging
     - High Contrast < 1E-9 (after post-processing)
     - Small Inner Working Angle < 500 mas (<200 mas)
     - Spectroscopy R~40 in visible, near infrared (water lines)

3. “Pale Blue Dots”: Are the planets habitable? Are there signs of life?

Key Exoplanet Science Questions

1. Discovering Planets: How abundant are exoplanets in our Galaxy?

2. Characterizing Planets: What are the (large) exoplanets like?

3. "Pale Blue Dots": Are the planets habitable? Are there signs of life?

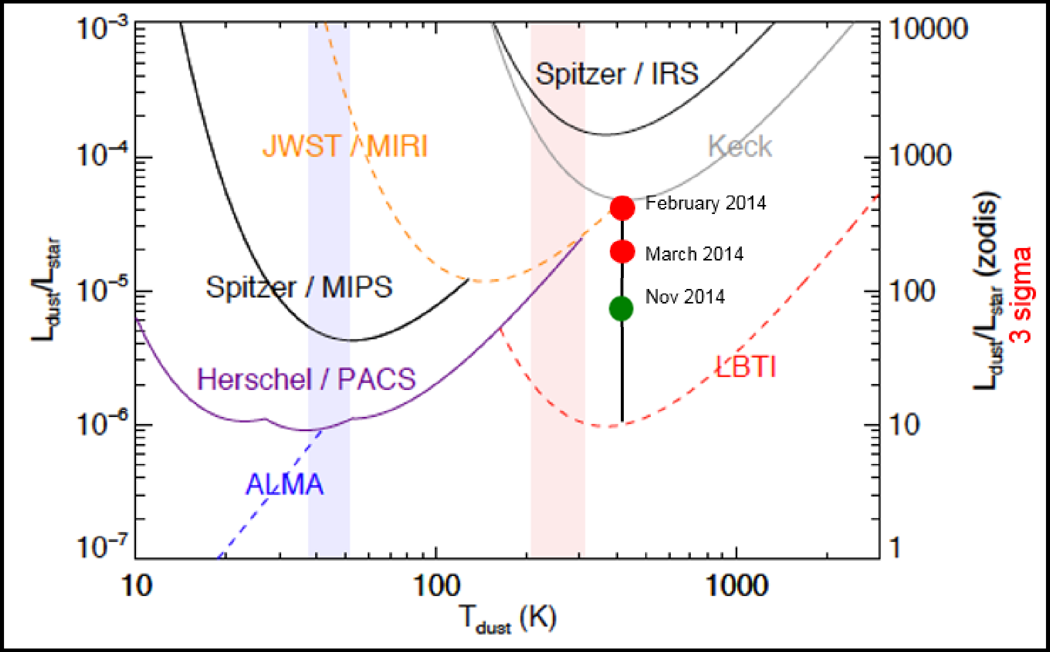
   – Transit Spectroscopy — < 1 part per million
   – Direct Imaging
     - High Contrast — < 1E-10 — (after post-processing)
     - Small Inner Working Angle — < 100 mas (<40mas)
     - Spectroscopy — R~70 in visible, near infrared — (biosignature gases)
     - η_Earth — Quantify, for mission design
     - Exozodiacal Dust — Quantify, for mission design
     - Yield — Ideally: dozens of rocky planets

Large Binocular Telescope Interferometer

Measures exozodiacal dust in habitable zones

University of Arizona
P. Hinz, PI

LBTI Performance

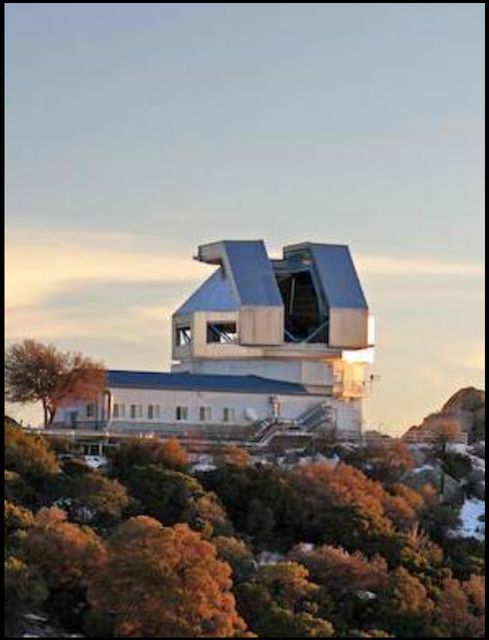


- 24 zodi (one sigma) achieved during November 2014 run
- LBTI will characterize the exo-zodiacal dust emissions of 50 target stars in mid-IR to a level of 3 - 6 zodi (one sigma)

NASA/NSF Partnership for Exoplanet Research

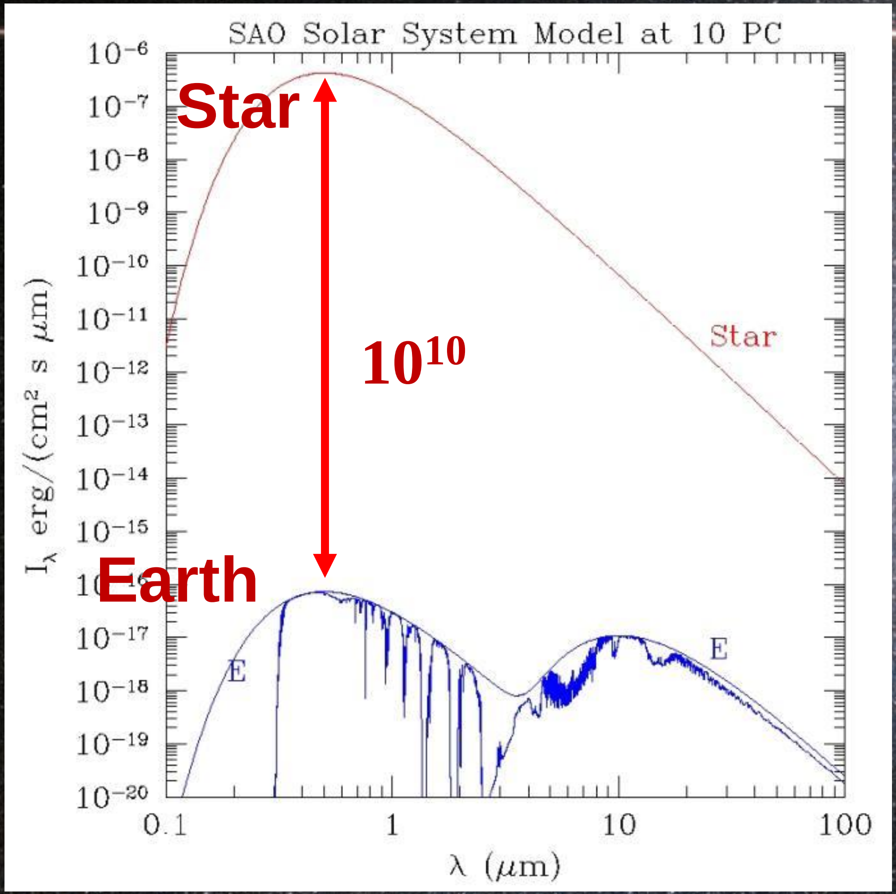
Extreme Precision Doppler Spectrometer

- Scope:
  - Exoplanet-targeted Guest Observer program with existing instrumentation on WIYN using NOAO share (40%) of telescope time
  - Solicitation for facility-class extreme precision radial velocity spectrometer for WIYN telescope (commissioning goal: 2018)
- Motivation
  - Follow-up of current missions (K2, TESS, JWST)
  - Pathfinder observations inform design/operation of future missions
- Timeline:
  - Dec 2014: community announcement
  - Jan 2015: amendment to ROSES 2014 NRA



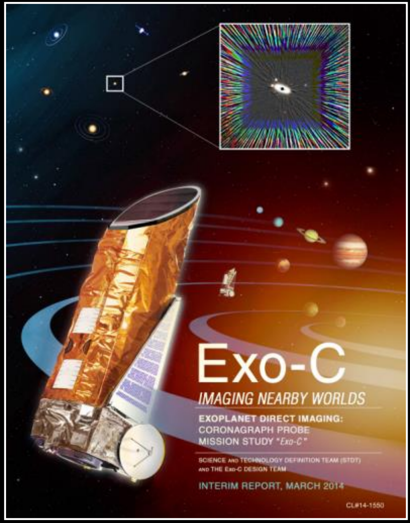
3.5m WIYN Telescope
Kitt Peak National Observatory
Arizona

The Exoplanet Direct-Imaging Challenge



Probe-Scale studies

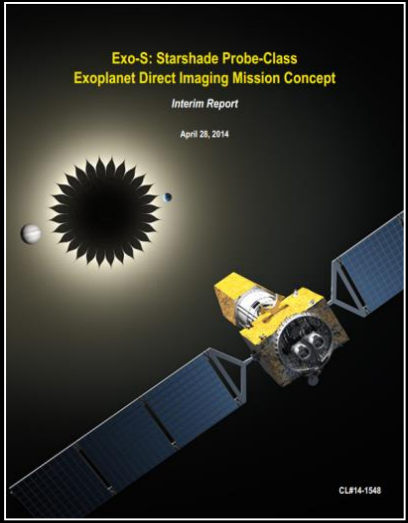
High-Contrast Imaging



Exo-C:

Internal Occulter
(Coronagraph)

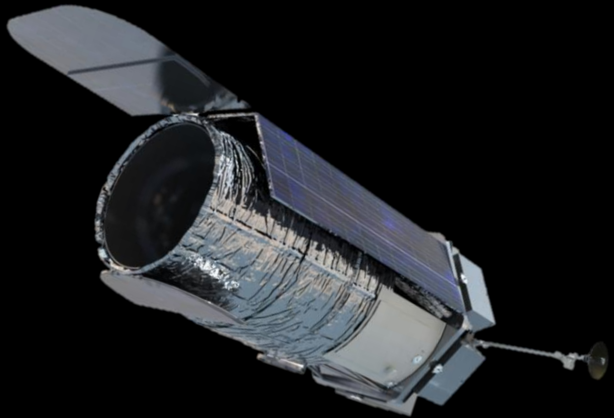
K. Stapelfeldt,
STDT Chair, GSFC

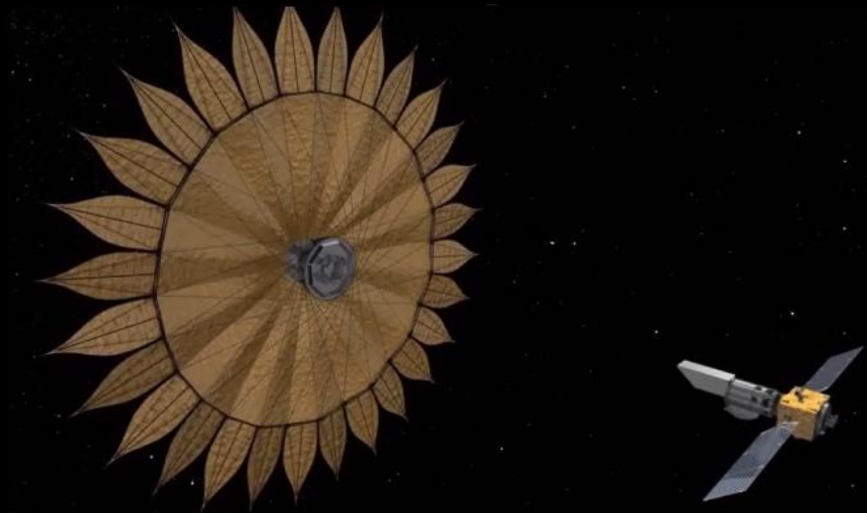


Exo-S:

External Occulter
(Starshade)

S. Seager,
STDT Chair, MIT

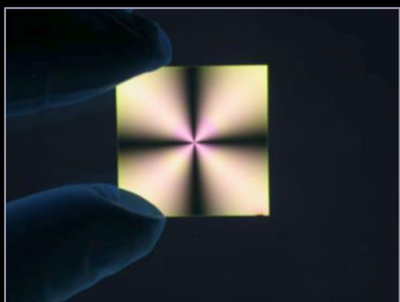




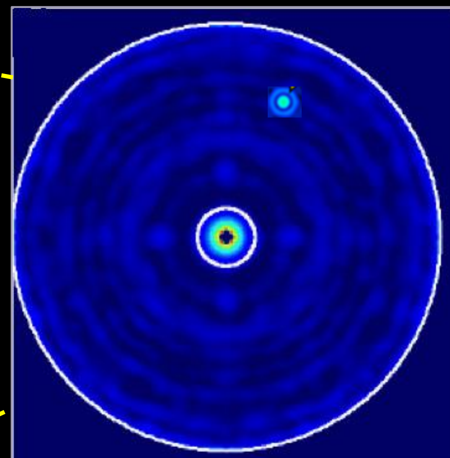
Enabling the Exo-Future: Technology Development

Technology Development for Coronagraphs

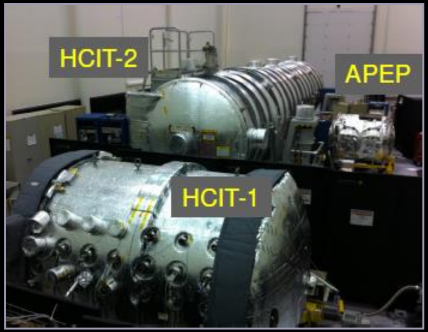
Occulting Masks/
Apodizers



Serabyn – Vector Vortex Mask

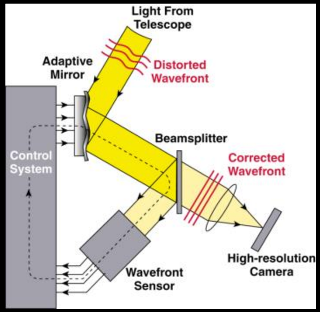


System Demonstration

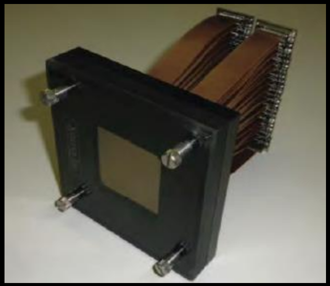


Jet Propulsion Laboratory

Low Order Wavefront
Sensing and Control

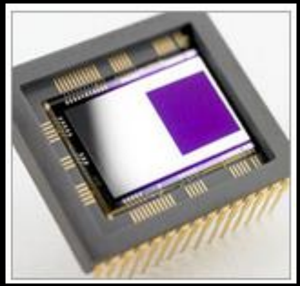


Deformable
Mirrors



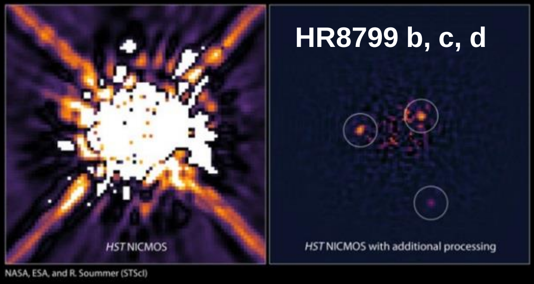
Xinetics

Ultra-Low-Noise
Visible Detectors



e2v Electron Multiplying CCD

Image Post Processing

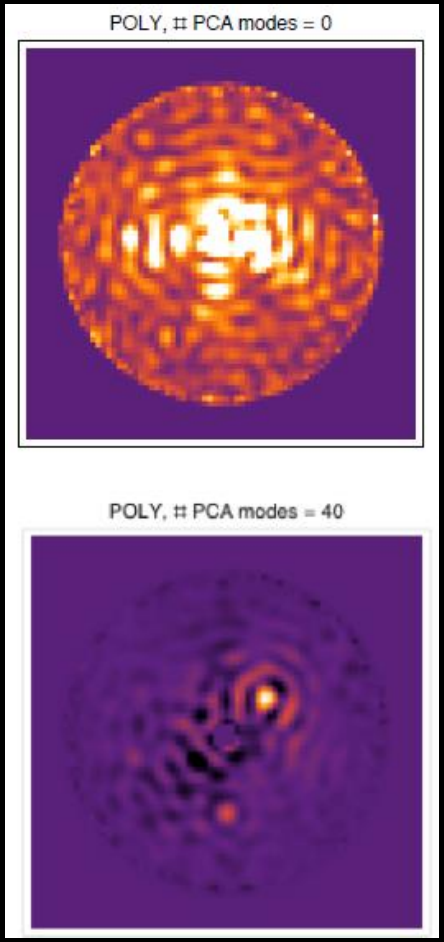


Soummer et al. 2011

Extracting Exoplanets from the Speckles

Effect of post-processing on raw coronagraph images

- JPL-simulated fields from observation sequence of 47 Uma using HLC coronagraph
- Post-processing done at STScI "blindly" using PCA-KLIP algorithm (Soummer et al. 2010)
- Two known planets correctly retrieved



Pueyo, Soummer et al. STScI

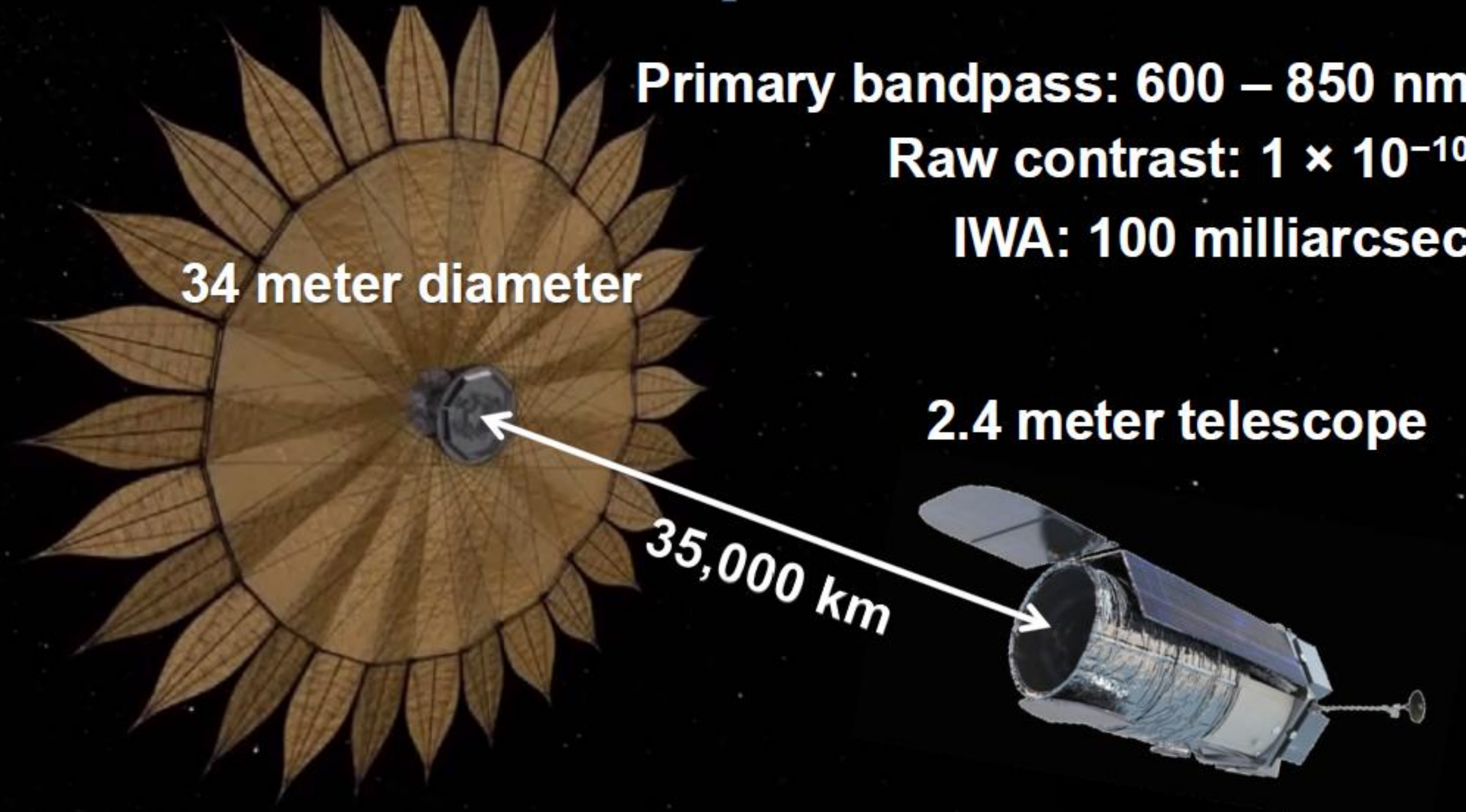
Blank slide

The External Occulter: Starshade

The starshade could launch together with a telescope.
Once in space, it would split off and move into position
to block the starlight.

Starshade Rendezvous

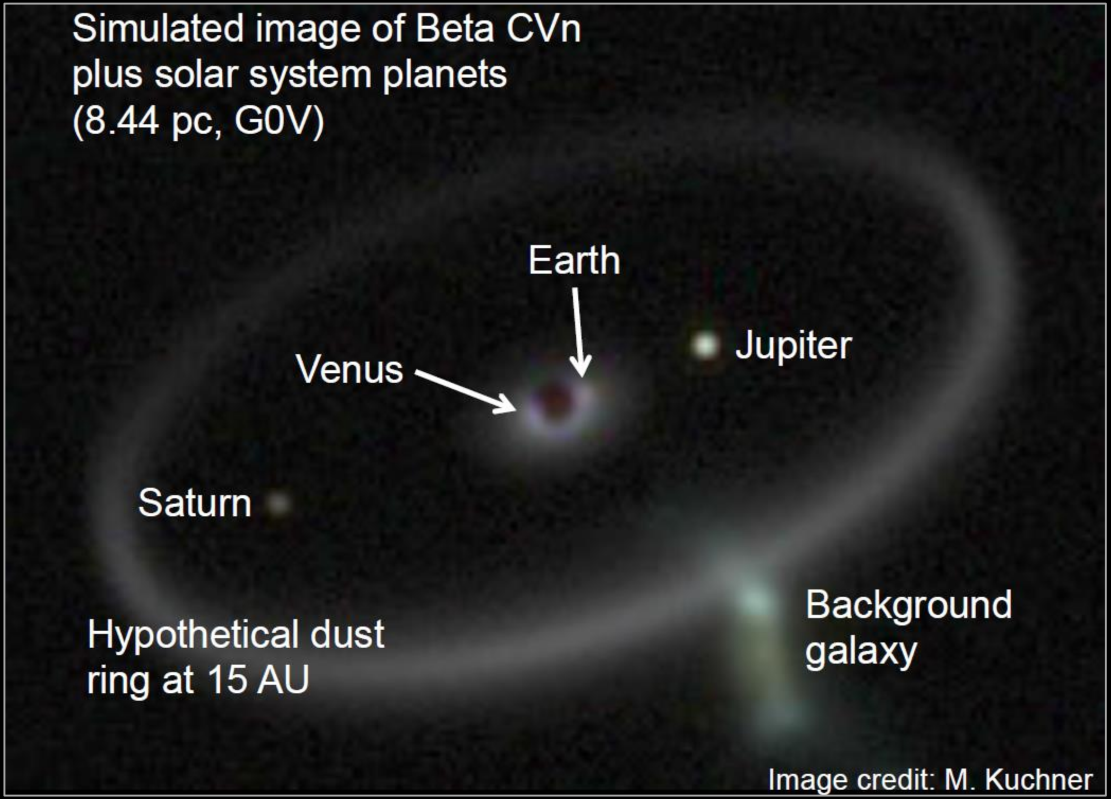
At L2 with WFIRST/AFTA



Starshade Rendezvous

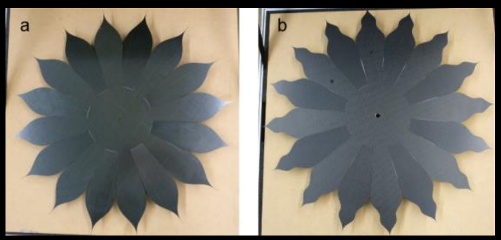
Possible Science

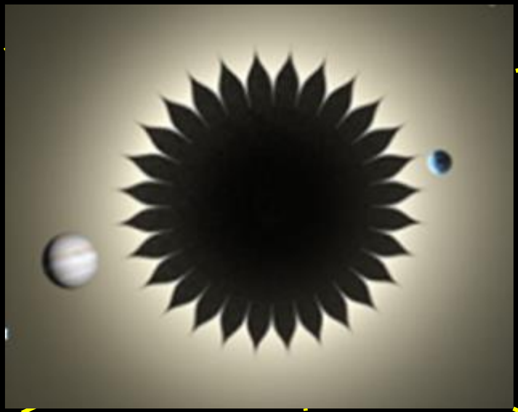
- Observe 52 stars in 2 years
- 13 known exoplanets
- 19 HZ targets. Expect ~ 2 Earths or Super-Earths
- Can detect sub-Neptunes to Jupiters around all HZ targets and 20 additional stars



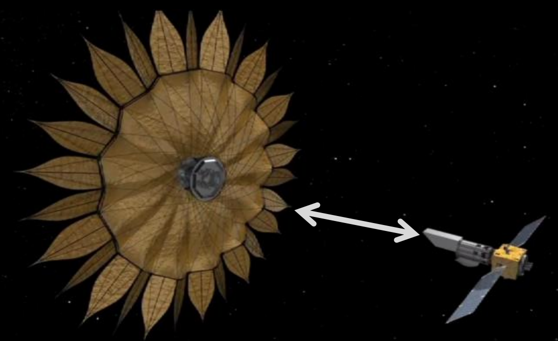
Technology Development for Starshades (External Occulters)

Control of Scattered Light

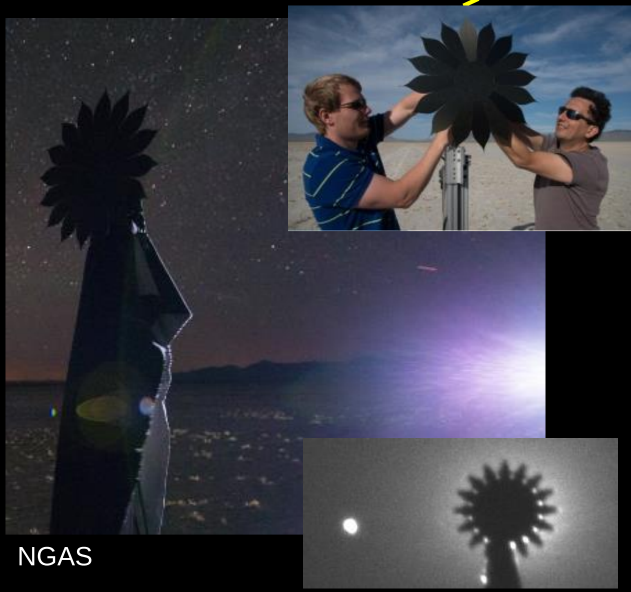




Formation Flying

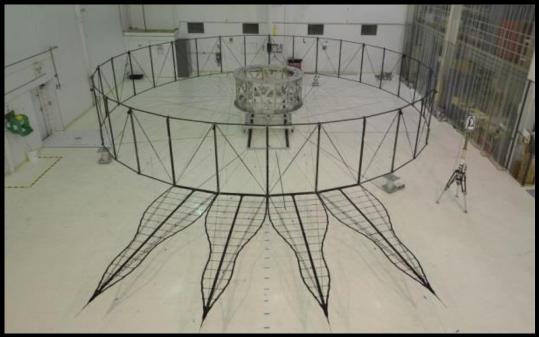


Validation of Optical Models



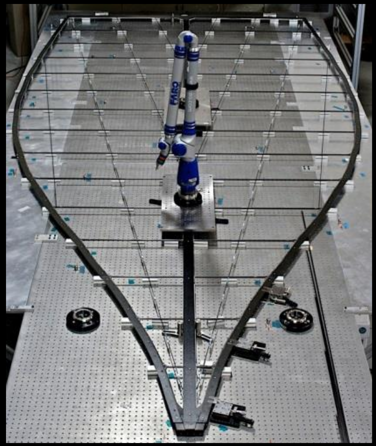
NGAS

Starshade Deployment



NGAS, Princeton, JPL

Petal Prototype



Princeton, JPL

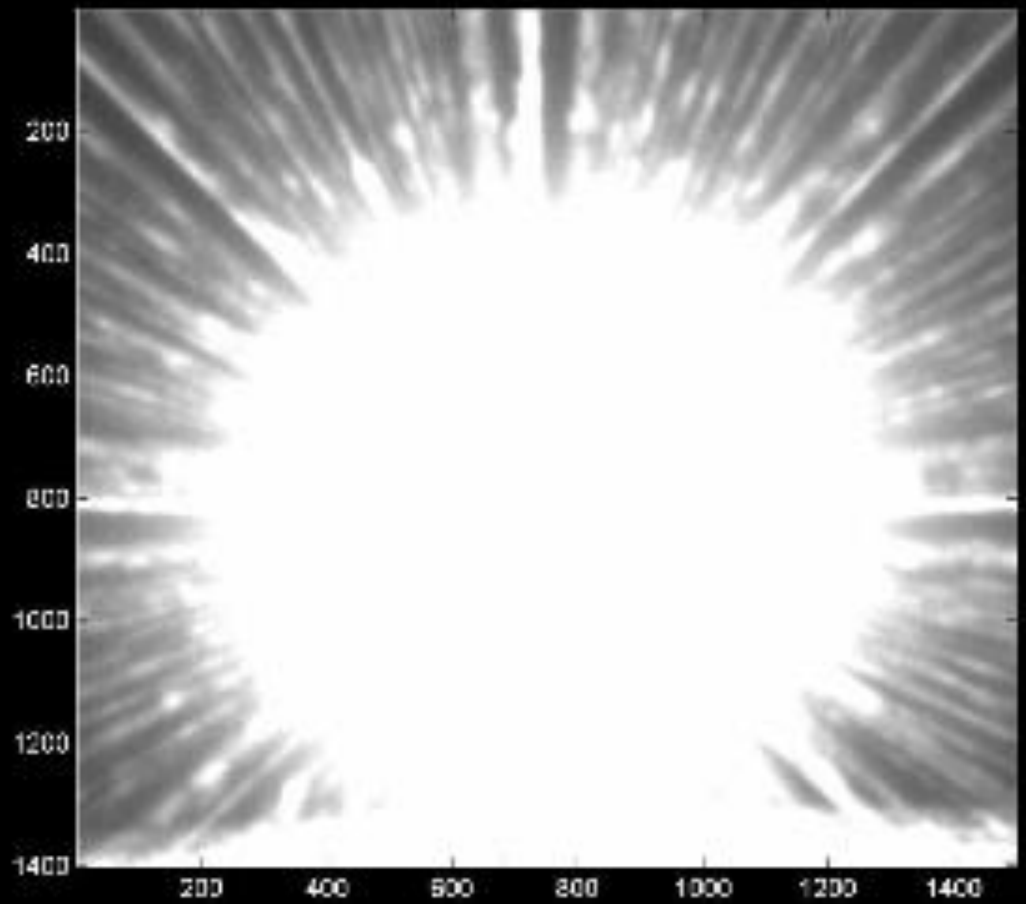
Deployment Testing at Northrop Grumman (Astro-Aerospace)

Demonstration of starshade development model

Desert Testing of Starshades

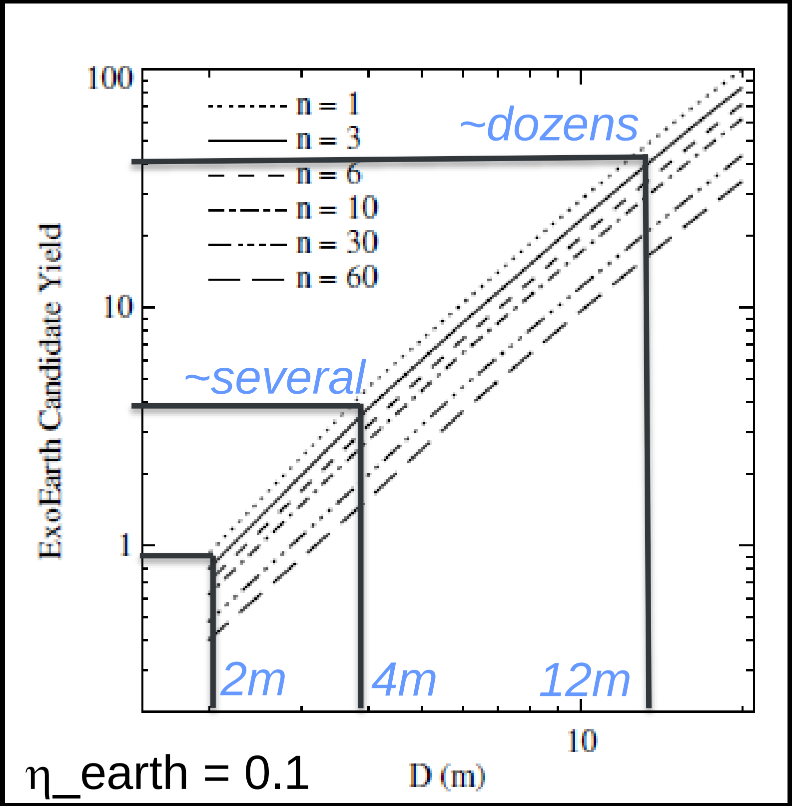
S. Warwick, Northrop Grumman

Desert Testing of Starshades



S. Warwick, Northrop Grumman

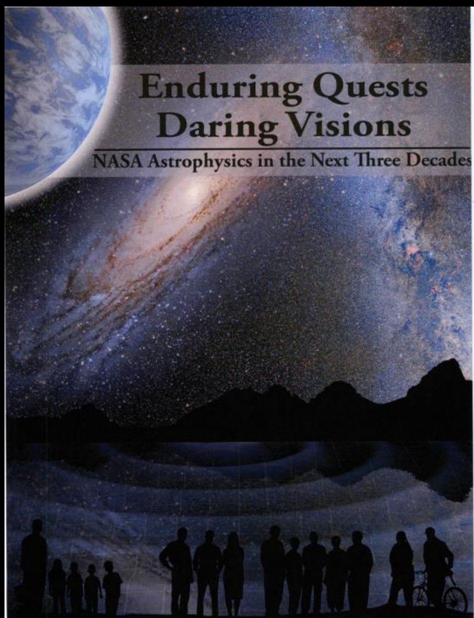
Exo-Earths require large telescopes



Stark et al, 2014
For Coronagraphs

- Yield most sensitive to (in order):
  - Telescope diameter
  - Coronagraph inner working angle
  - Coronagraph contrast
  - Coronagraph noise floor
- Also sensitive to η_earth (strong) and exozodical dust (relatively weak)

Formative Era: Large UV-Optical-IR Telescope



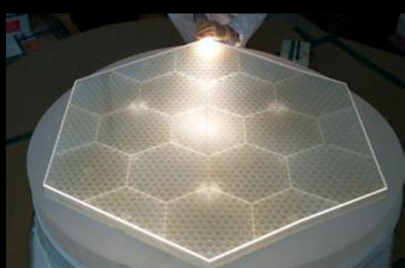
	LUVOIR Surveyor
Formation flying	
Interferometry: precision metrology	
X-ray interferometry	
High-contrast imaging techniques	
Optics deployment and assembly	
Broadband coatings	
X-ray optics	
Large-format detector arrays	
New detector capabilities	
Cryogenics	

Formative Era: Large UV-Optical-IR Telescope (LUVOIR)

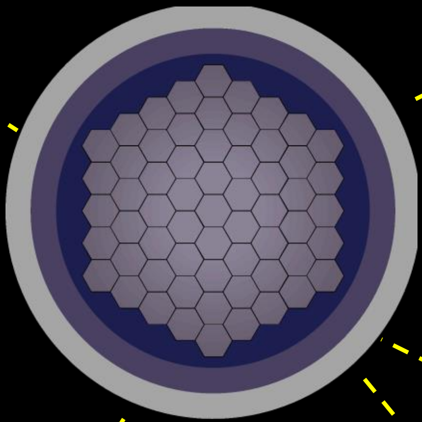
Optics Deployment and Assy

SiC Active Hybrid Mirror, Xinetics

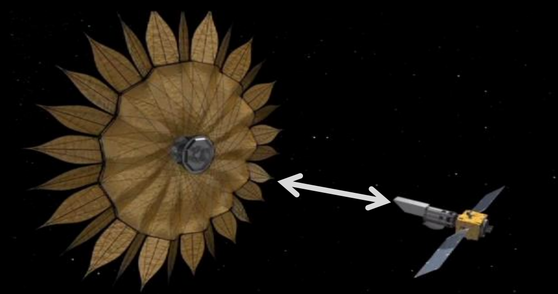
MOIRE, BATC



Lightweight ULE, ITT



Formation Flying

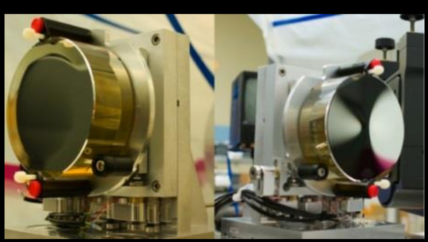


Broadband Mirror Coatings

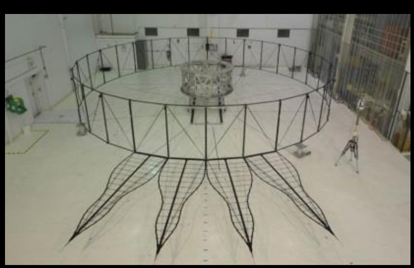
Telescope Mechanical Isolation Systems

Starlight Suppression Systems

Visible Nuller, GSFC



Pupil Mapping, Univ. Arizona



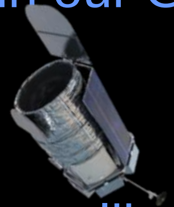
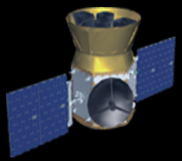
Starshade
NGAS, Princeton, JPL

The Program Address the Key Questions

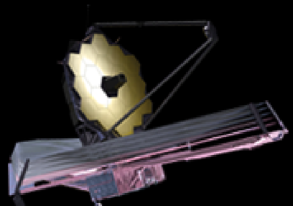
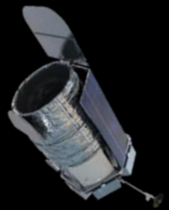
Through Science, Advanced Studies, and Technology Development

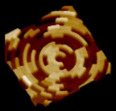
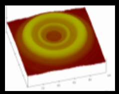
1. Discovering Planets: How abundant are exoplanets in our Galaxy?
   - Radial Velocity
   - Transit Photometry



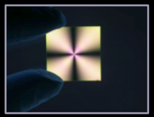
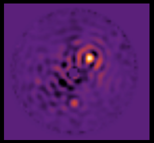




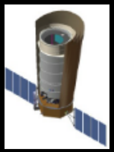
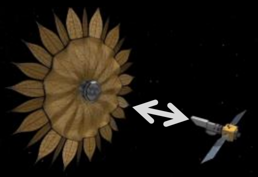
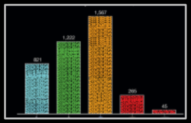
2. Characterizing Planets: What are the (large) exoplanets like?
   - Transit Spectroscopy
   - Direct Imaging

3. "Pale Blue Dots": Are the planets habitable? Are there signs of life?
   - Transit Spectroscopy
   - Direct Imaging
     - High Contrast
     - Small Inner Working Angle
     - Spectroscopy
     - η_Earth
     - Exozodiacal Dust
     - Yield

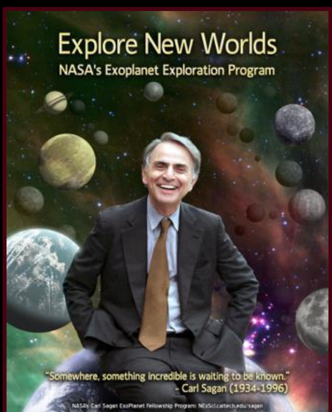





Engaging the Science Community

NASA Exoplanet Science Institute

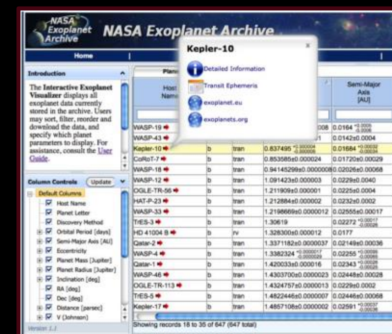
Archives, Tools, and Professional Education

Sagan Fellowships and Workshops



Kepler Community Follow-up Program

Exoplanet Database Science Data Archives



LBTI Project Science

Administers NASA Keck Telescope time

NExScI hosts an archive of all data ever acquired on all Keck Instruments

NExScI provides science center support for the WFIRST Coronagraph

Program Engages the Public

http://exep.jpl.nasa.gov

http://planetquest.jpl.nasa.gov

Ways to Become Involved

ExoPAG (Program Analysis Group)

- Solicits and coordinates community input
- Provides analysis findings through Astrophysics subcommittee of the NASA Advisory Council

ExoPAG Executive Committee members

Scott Gaudi *Chair*	Ohio State University
Rus Belikov	NASA Ames Research CenterÂ
Nick Cowan	Northwestern University
Jonathan Fortney	University of California,Â Santa Cruz
Dave Latham	Harvard Smithsonian Center for Astrophysics
Amy Lo	Northrop Grumman Aerospace Systems
Peter Plavchan	Caltech/NASA Exoplanet Science Institute
Gene Serabyn	Jet Propulsion Laboratory
Remi Soummer	Space Telescope Science Institute
Maggie Turnbull	Global Science Institute
Lucianne Walkowicz	Princeton University

Active Science Analysis Groups

- Precision radial velocity
- Probe/Medium-scale direct imaging mission requirements
- Atmospheres / transit spectroscopy
- High-precision astrometry

Active Science Interest Group

- Toward a Near-Term Exoplanet Community Plan

Preparing for the Next Astrophysics Decadal Survey

Charge from Astrophysics Division Director, Jan 4 2015:

- Part A: Identify a small set (~3-4) of large missions to study
- Part B: Science and Technology Definition Teams conduct studies
  - Supported by engineering design team assigned to NASA Centers

From ADD Charge, Jan 4 2015

Preparing for the 2020 Decadal Survey Large Mission Concepts

The initial short list (in alphabetical order):

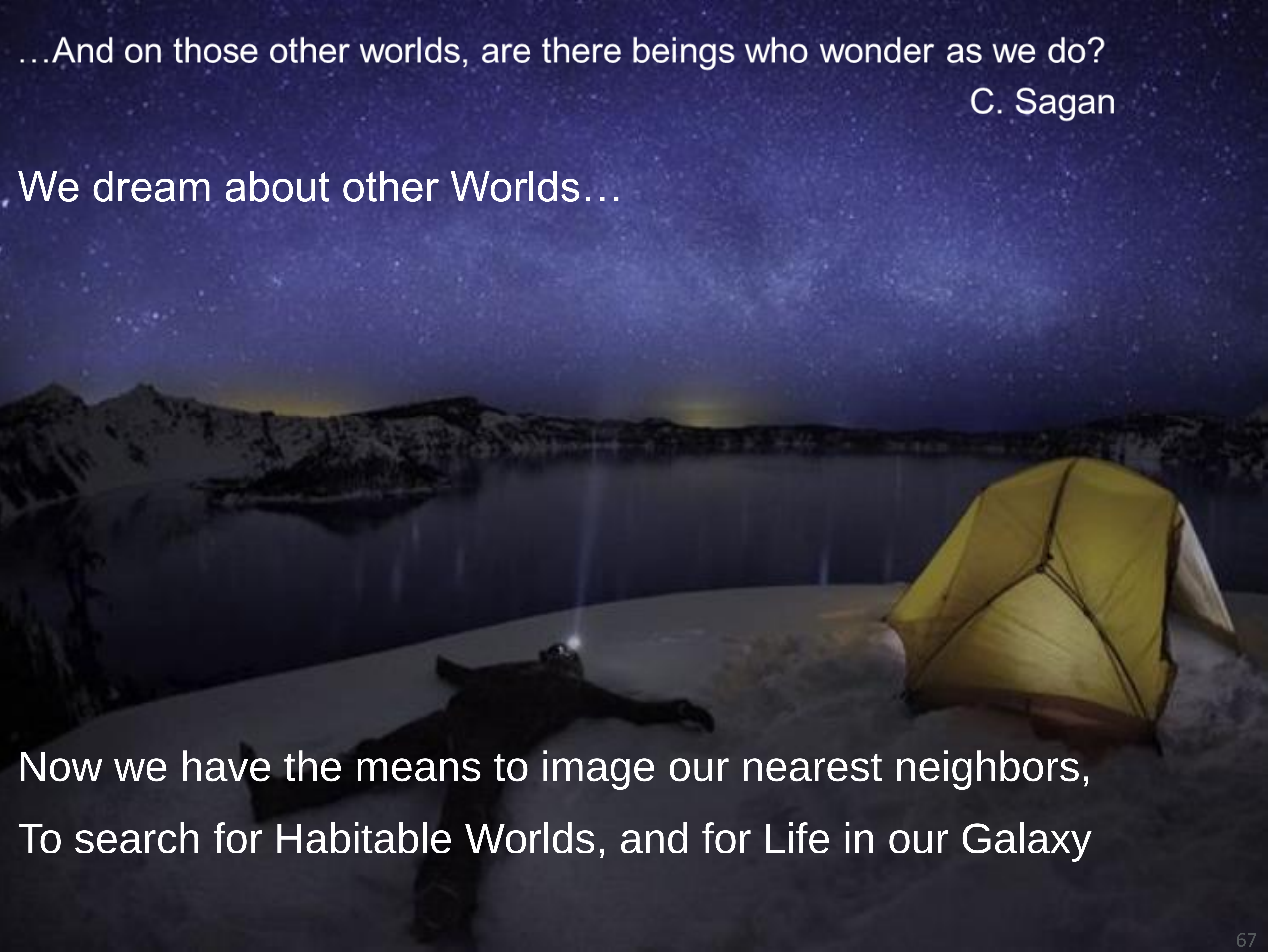
- **FAR IR Surveyor** – The Astrophysics Visionary Roadmap identifies a Far IR Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.
- **Habitable-Exoplanet Imaging Mission** – The 2010 Decadal Survey recommends that a habitable-exoplanet imaging mission be studied in time for consideration by the 2020 decadal survey.
- **UV/Optical/IR Surveyor** –The Astrophysics Visionary Roadmap identifies a UV/Optical/IR Surveyor as contributing through improvements in sensitivity, spectroscopy, high contrast imaging, astrometry, angular resolution and/or wavelength coverage. The 2010 Decadal Survey recommends that NASA prepare for a UV mission to be considered by the 2020 Decadal Survey.
- **X-ray Surveyor** – The Astrophysics Visionary Roadmap identifies an X-ray Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.

Enabling Decadal Mission Readiness

Program Office Leadership for Exoplanet Science

- What can we do now for a solid story in 2020 to assure TRL5 readiness by 2024?
- Approach:
  - Engineer a technical and programmatic solution
  - Start by assessing technology success criteria and capability today => technology gaps leads to technology plan
- ExEP will facilitate, plan, advocate for technology readiness to maximize likelihood that exoplanet missions are ranked highly by the next Decadal Committee

In Closing…



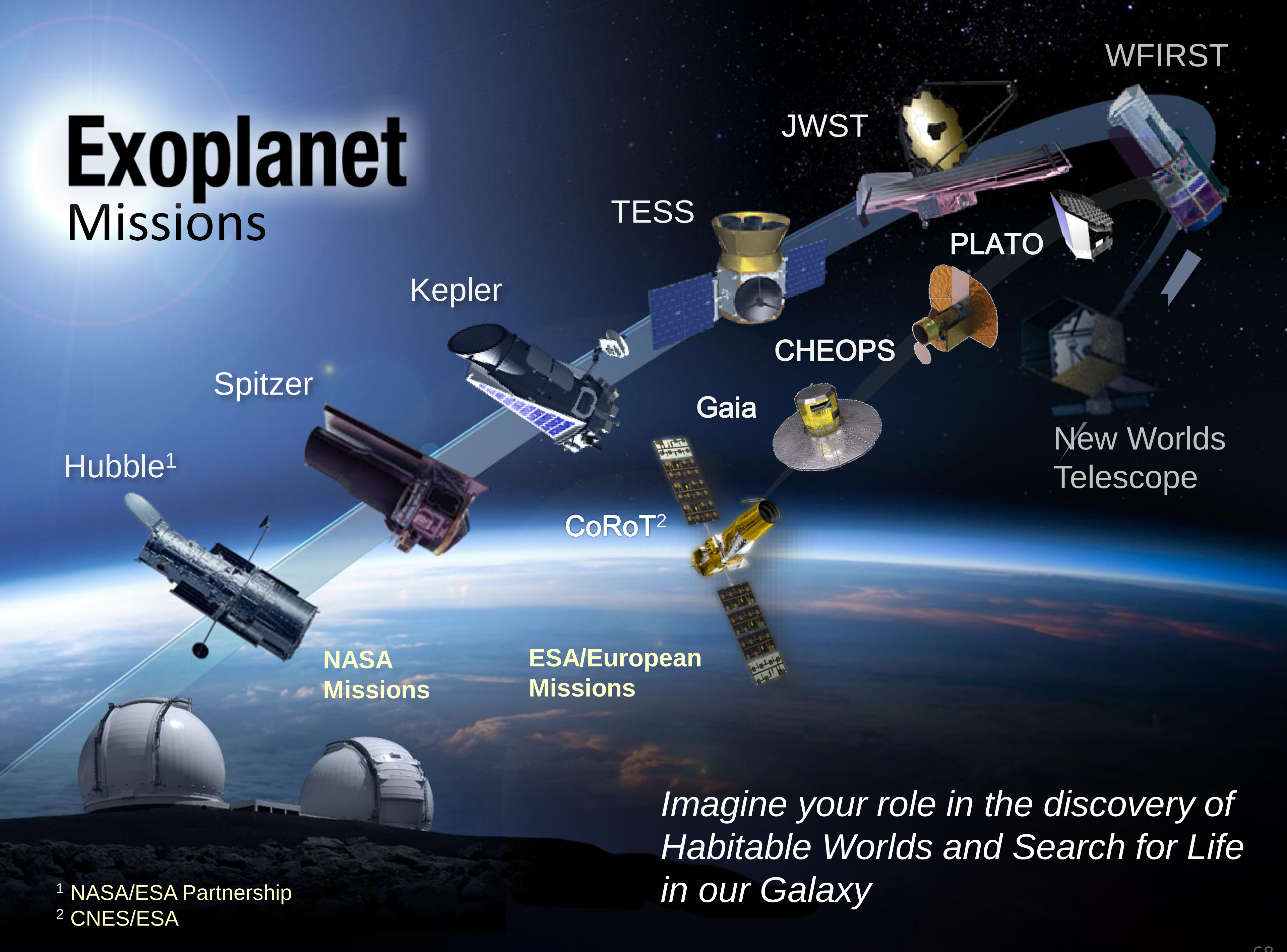
…And on those other worlds, are there beings who wonder as we do?

C. Sagan

We dream about other Worlds…

Now we have the means to image our nearest neighbors,

To search for Habitable Worlds, and for Life in our Galaxy


Exoplanet
Missions
WFIRST
JWST
TESS
PLATO
Kepler
CHEOPS
Spitzer
Gaia
New Worlds
Telescope
Hubble1
CoRoT2
NASA
Missions
ESA/European
Missions
Imagine your role in the discovery of Habitable Worlds and Search for Life in our Galaxy
1 NASA/ESA Partnership
2 CNES/ESA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

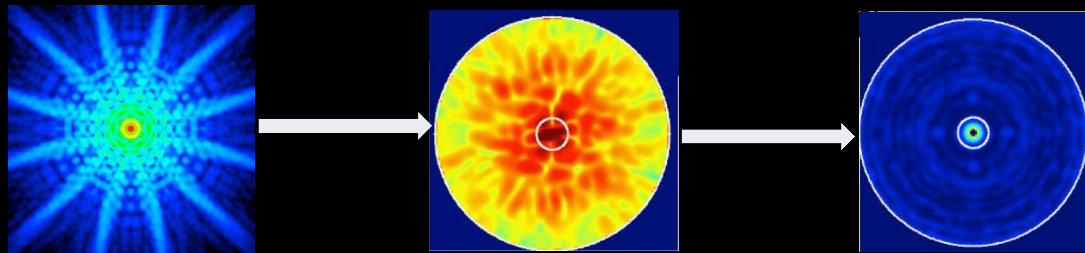
Acknowledgements

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

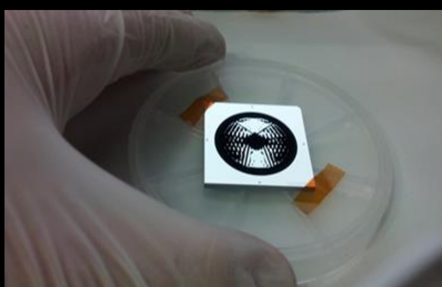
Jet Propulsion Laboratory
California Institute of Technology

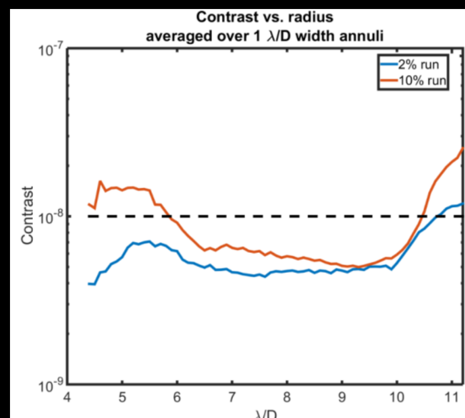
Backup

Coronagraph Masks for WFIRST/AFTA

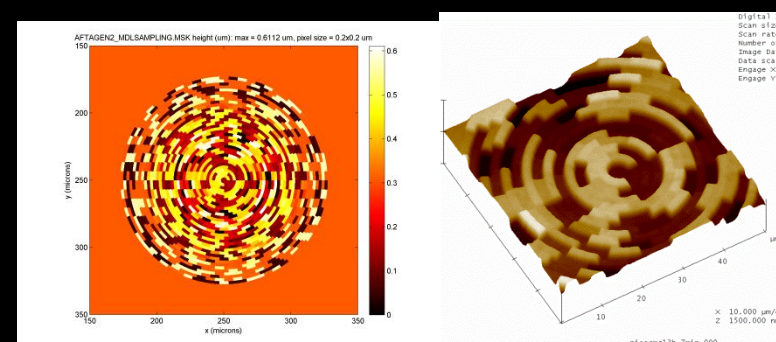


Reflective shaped pupil mask
Jeremy Kasdin, Princeton

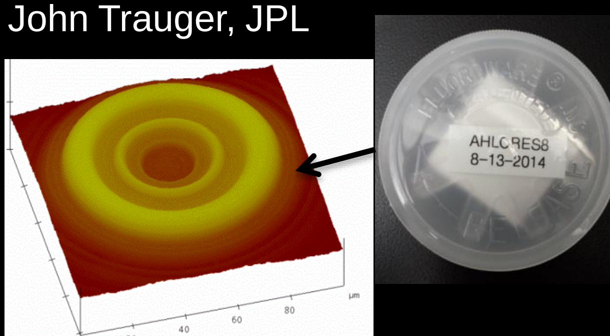




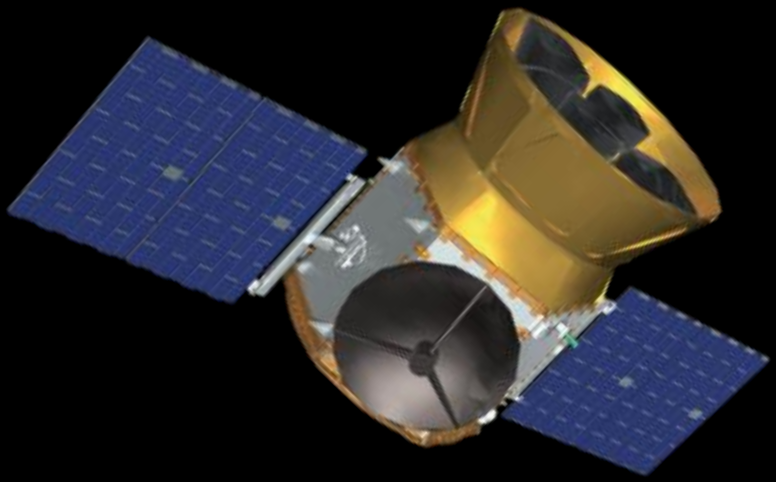
PIAA-CMC focal plane mask (backup)
Olivier Guyon, U. of Arizona



Transmissive hybrid Lyot mask
John Trauger, JPL



TESS
Transiting Exoplanet Survey Satellite



Standard Explorer (EX) Mission

PI: G. Ricker (MIT)

Mission: All-Sky photometric exoplanet mapping mission.

Science goal: Search for transiting exoplanets around the closest and brightest stars in the sky.

Instruments: Four wide field of view (24x24 degrees) CCD cameras with overlapping field of view–operating in the Visible-IR spectrum (0.6-1 micron).

Operations: 2017 launch with a 2-year prime mission

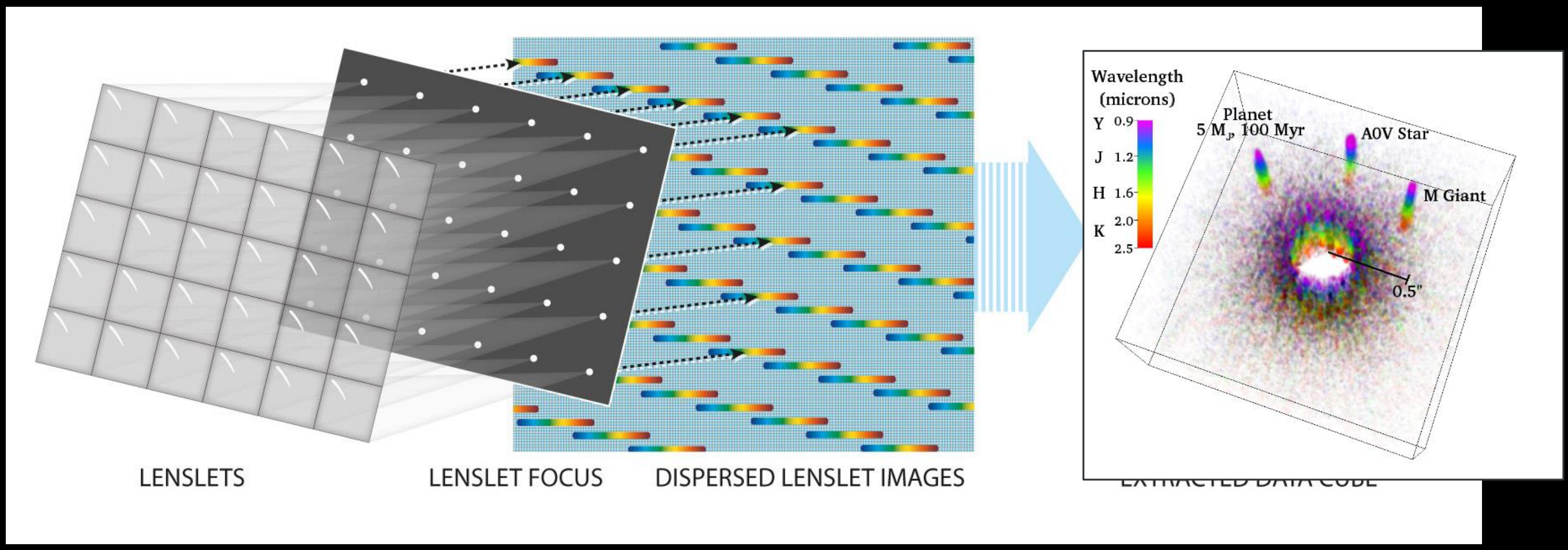
CURRENT STATUS:

- Major partners:
  - PI and science lead: MIT
  - Project management: NASA GSFC
  - Instrument: Lincoln Laboratory
  - Spacecraft: Orbital Science Corp
- Development progressing on plan.
  - Preliminary Design Review (PDR) successfully completed Sept 9-12, 2014.
  - Confirmation Review, for approval to enter implementation phase, successfully completed October 31, 2014.

Characterizing the Spectrum of Exoplanets

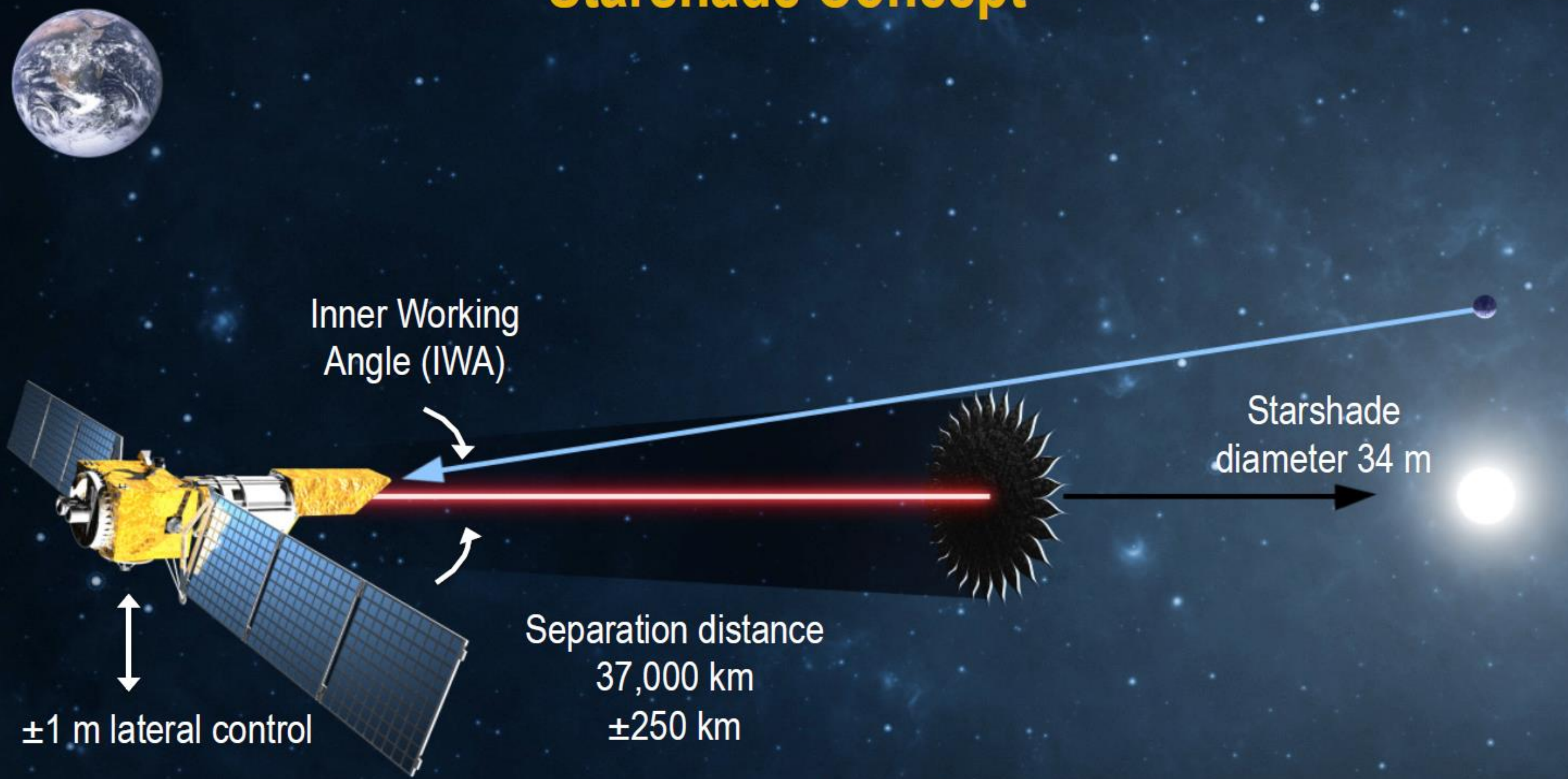
Integral Field Spectrometer

- Low spectral crosstalk needed for spectral science data
- Extracts data cube
- Used in post-processing for speckle suppression



M. McElwain, Roman Fellow, GSFC

Starshade Concept



Telescope diameter 1.1 m

- Contrast and inner working angle are decoupled from the telescope aperture size
  - A simple space telescope can be used
  - No wavefront correction is needed
- No outer working angle

Read more about technologies, studies, and the Exoplanet Exploration Program at

http://exep.jpl.nasa.gov

Ways to Become Involved

- ExoPAG: SAGs, and SIG
- EPDS initiative
- Program and decadal studies
- Competitive Funding:
  - Exoplanet Research Program (XRP)
  - Astrophysics Data Analysis Program (ADAP, supports archival Kepler/K2 research)
  - K2 Guest observer program
  - Astrophysics Theory Program (ATP)
  - Hubble Guest Observer program (supports exoplanet research).
  - SAT / ROSES / TDEM for exoplanet technology development

Read more at: http://exep.jpl.nasa.gov