Jet Propulsion Laboratory
California Institute of Technology

NASA Exoplanet Exploration Program

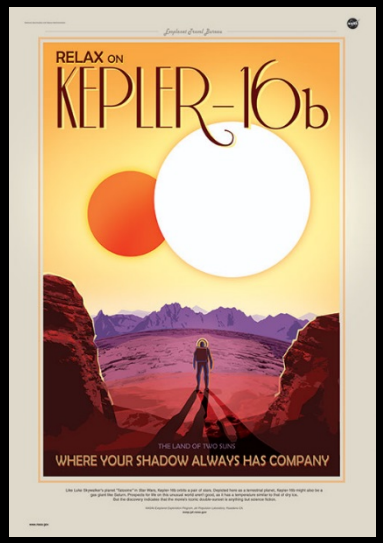
Gary Blackwood
Program Manager

Office of Safety and Mission Assurance

Leadership Meeting

February 9, 2016

Exoplanet Travel Bureau



NASA Exoplanet Exploration Program

A Program within the NASA Astrophysics Division

Purpose described in 2014 NASA Science Plan

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

The Search for Life in our Galaxy

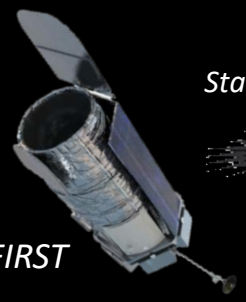
ExEP serves the science community and NASA APD by Implementing NASA's space science vision for exoplanets

http://exep.jpl.nasa.gov

NASA Exoplanet Exploration Program

Space Missions and Mission Studies

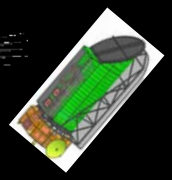
Kepler, K2



WFIRST

Decadal Studies
Probe-Scale

Starshade



Coronagraph

Public Communications

Supporting Research & Technology

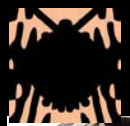
Key Sustaining Research

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

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 - Vacant
Program Chief Scientist – Dr. K. Stapelfeldt
Program Chief Technologist – Dr. N. Siegler

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

7301
Program Science Office
Dr. K. Stapelfeldt (326)
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 Probe STDT - Starshade[1]
Dr. S. Seager, MIT

7311
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Business Admin. Mgr – R. Lemus (731)
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Project Acquisition Manager – W. Kert (268)
Staff Assistant – K. Miller (731)
Staff Assistant – J. Gregory (731)

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K. Warfield (312)

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

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

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

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

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

735
NASA-NSF Exoplanet Observational Research
Manager – Dr. P. Willems, AD (383D)
Proj Scientist – R. Capps (acting)
Massachusetts Institute of Technology Team
Pennsylvania State University Team

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

706
JPL WFIRST Project Office
Project Manager, P. Barela
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)

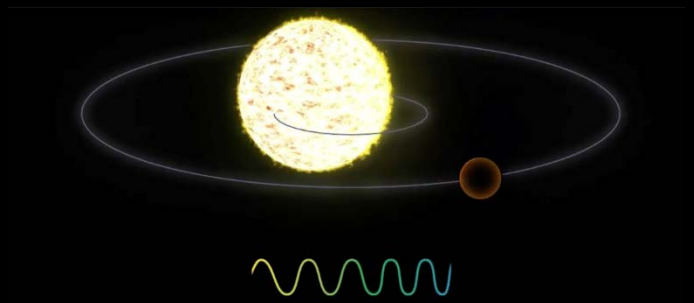
WFIRST TAC[1]
Dr. A. Boss
Carnegie Institution

[1]Reports to NASA HQs APD

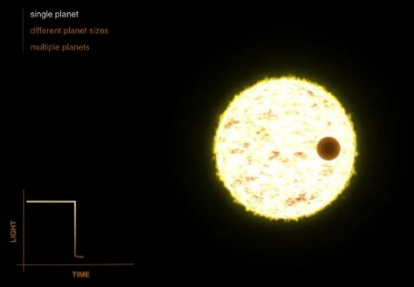
February 2, 2016
R. Lemus
Exoplanet Exploration Program

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

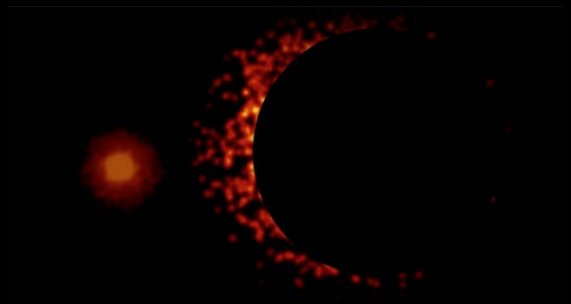
Five Ways to Find an Exoplanet



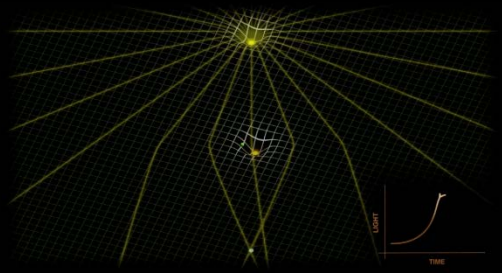
Watching for Wobble
(Radial Velocity)



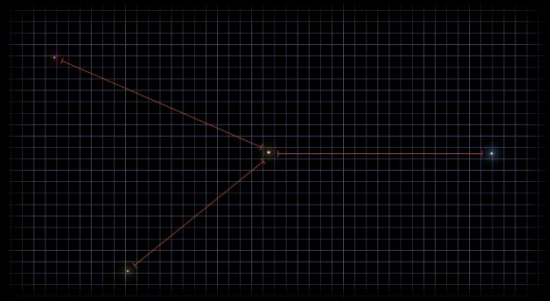
Searching for Shadows
(Transits)



Taking Pictures
(Direct Imaging)



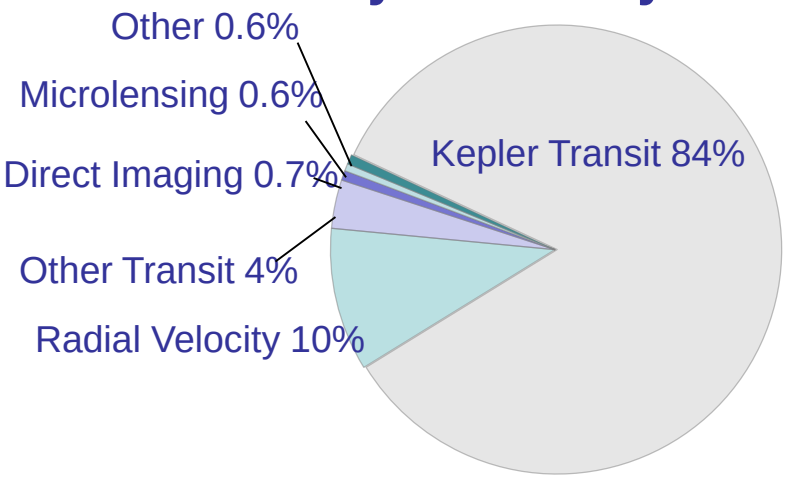
Light in a Gravity Lens
(Gravitational Microlensing)



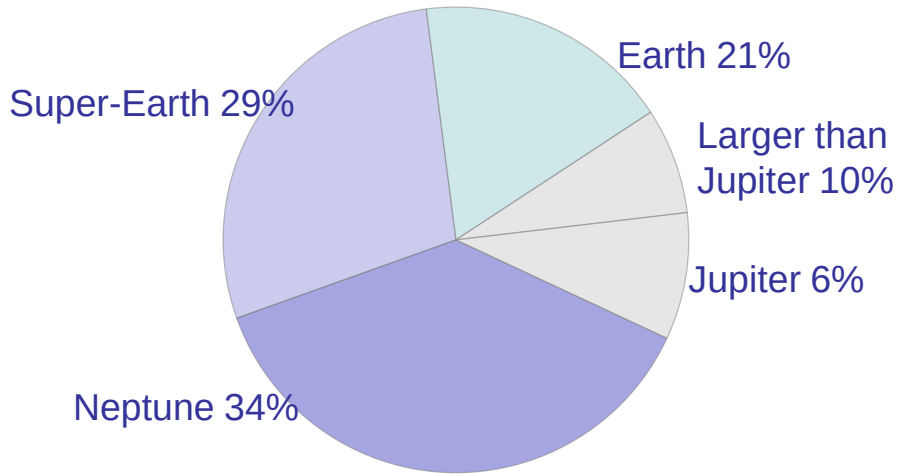
Miniscule Movements
(Astrometry)

Exoplanet Science News – Exoplanet Scorecard

All Exoplanets (Confirmed & Candidate) by Discovery Method



Kepler Exoplanets (Confirmed & Candidate) by Radius



Total Exoplanets: 5636 (1935 confirmed)

Total in the Habitable Zone (HZ): 301 (92 confirmed)

Total Super-Earths & Earths in HZ: 69 (13 confirmed)

Definitions

Larger than Jupiter: >15 Earth radii

Jupiter (Gas Giant): 6-15 Earth radii

Neptune (Ice Giant): 2-6 Earth radii

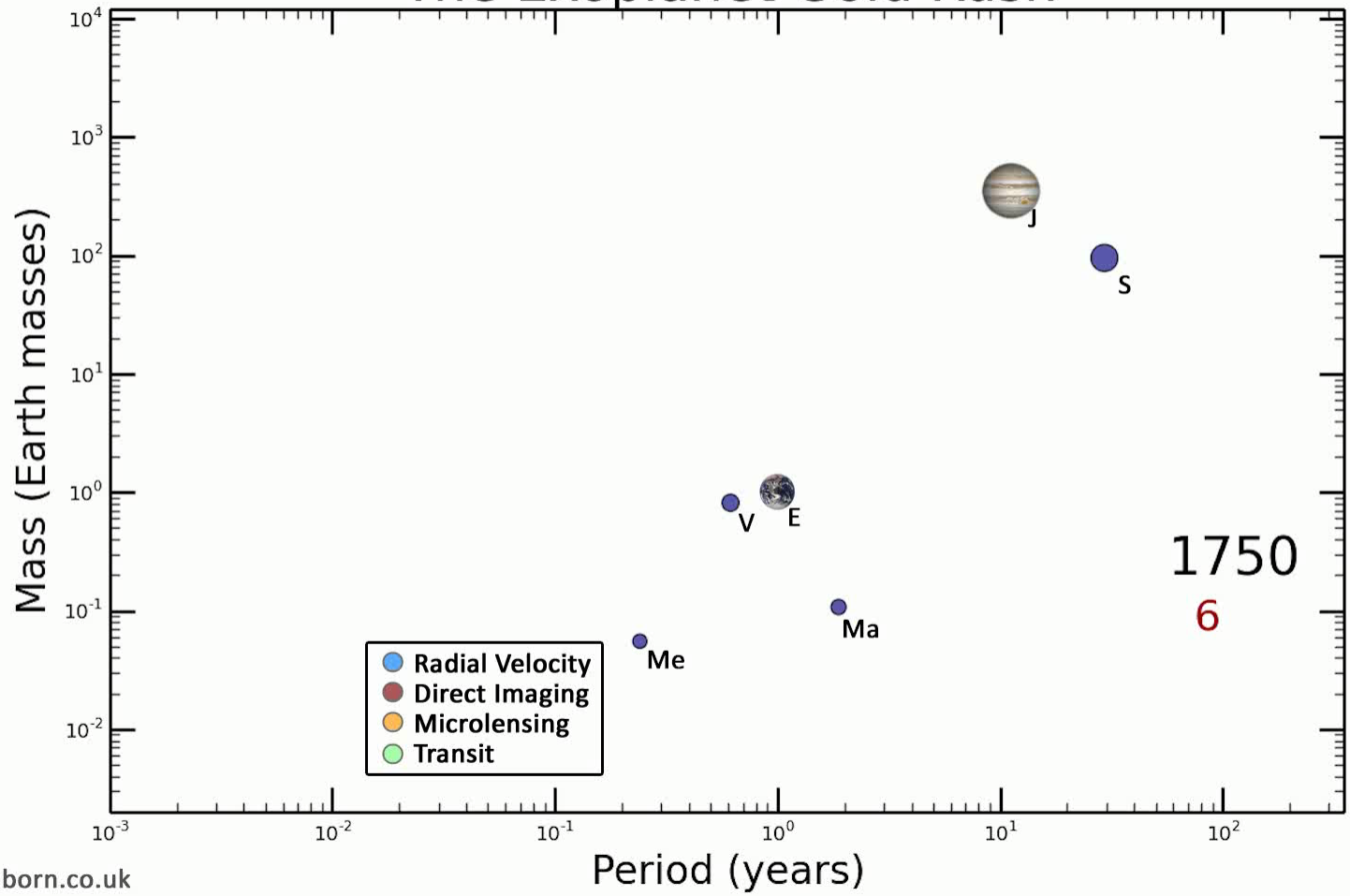
Super-Earth: 1.25-2 Earth radii

Earth: 0.5–1.25 Earth radii

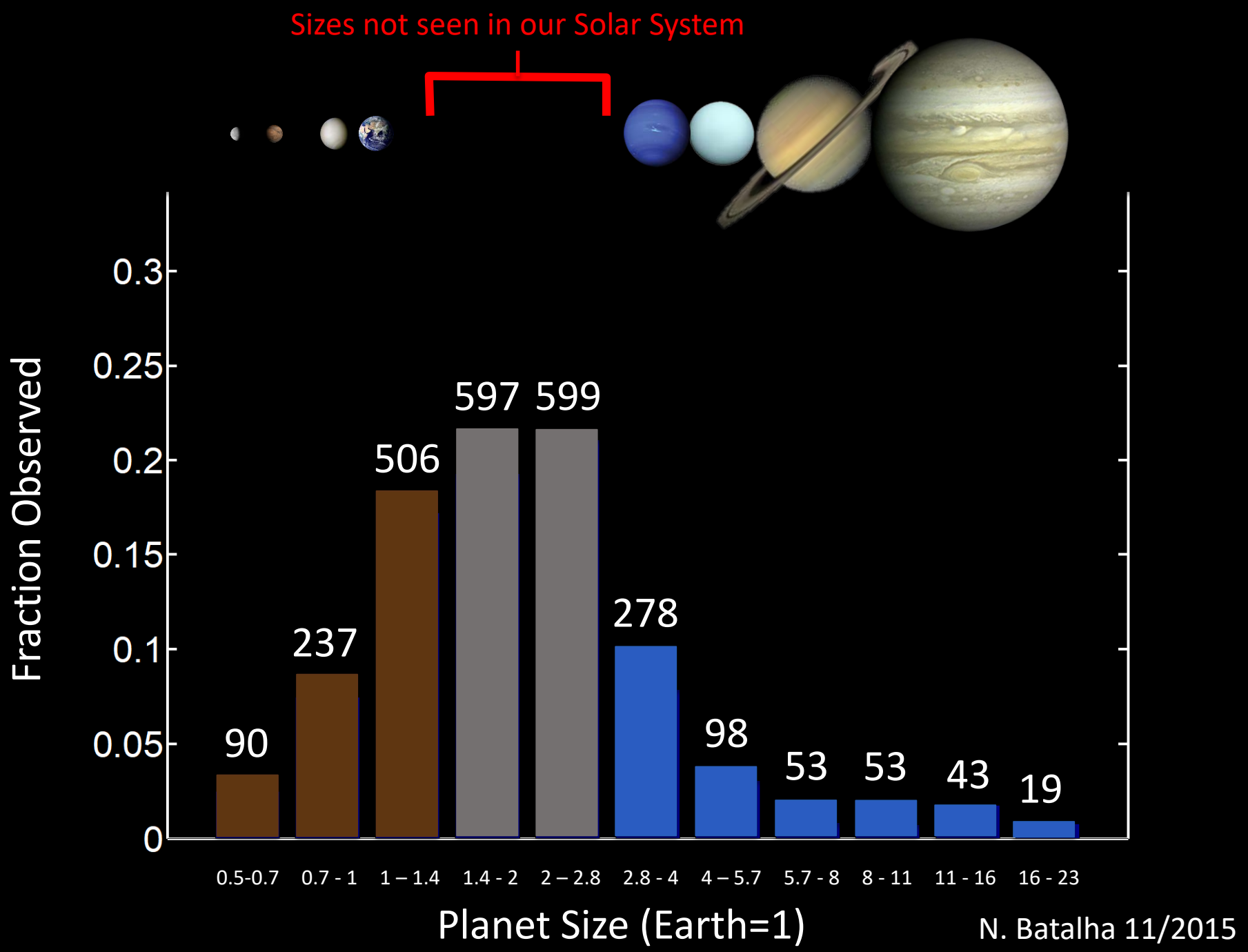
Habitable zone: 0.75-1.77 AU, scaling as $L_\star^{1/2}$

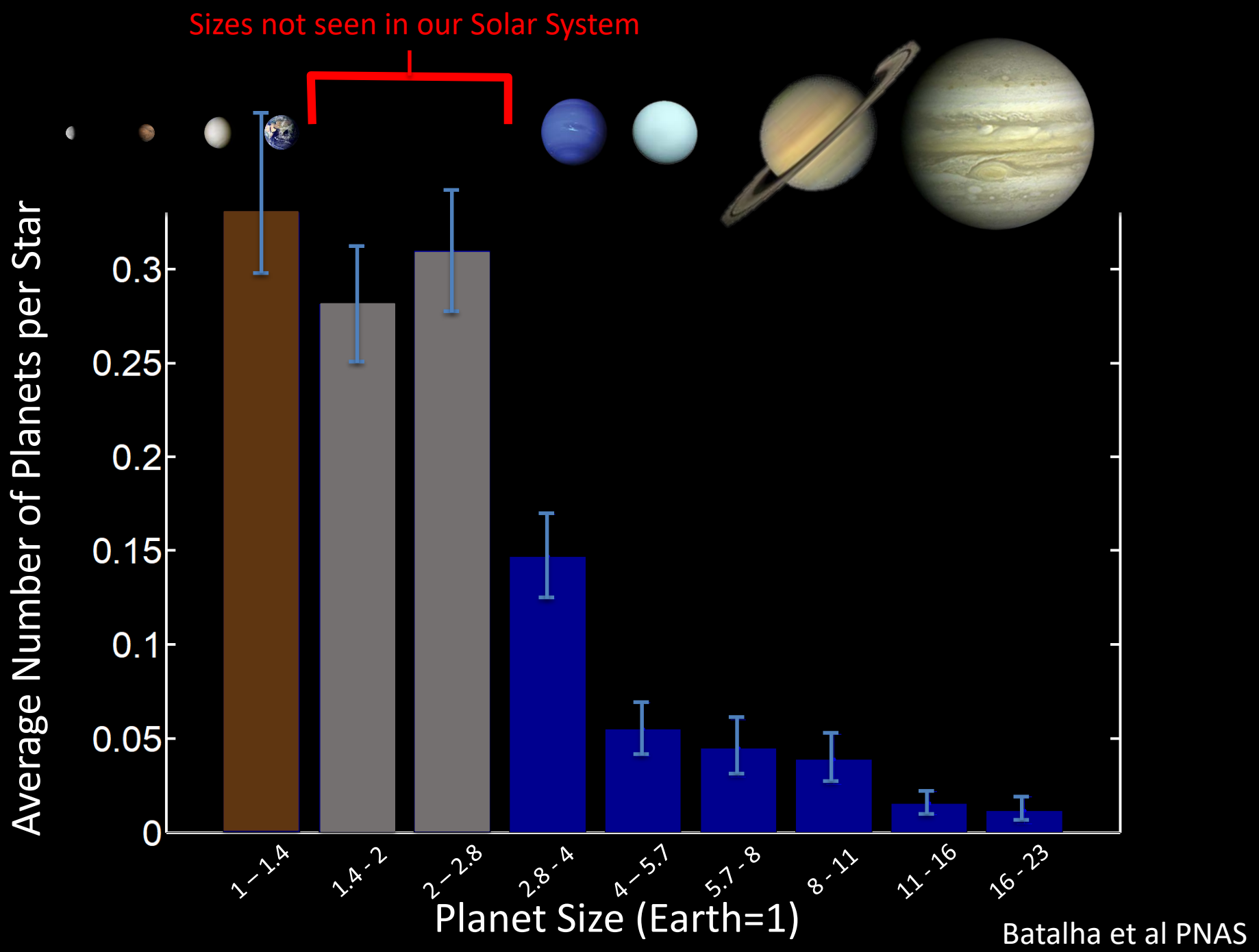
Ref.: http://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html - Updated 28 Jan 2016

The Exoplanet Gold Rush



www.hughosborn.co.uk

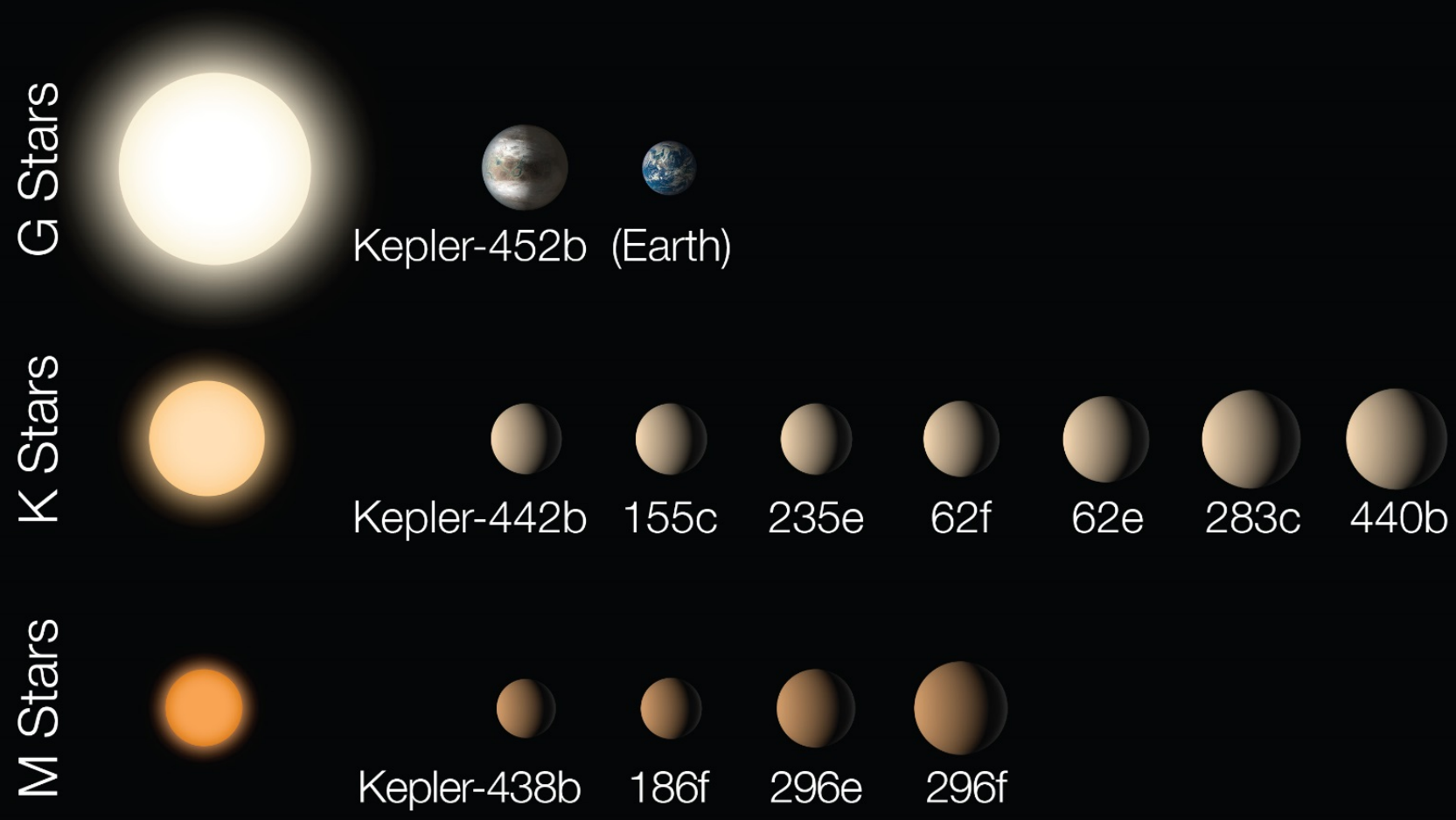

Sizes not seen in our Solar System
Fraction Observed
0.3
0.25
0.2
0.15
0.1
0.05
0
90
237
506
597
599
278
98
53
53
43
19
0.5-0.7
0.7 - 1
1 – 1.4
1.4 - 2
2 – 2.8
2.8 - 4
4 – 5.7
5.7 - 8
8 - 11
11 - 16
16 - 23
Planet Size (Earth=1)
N. Batalha 11/2015


Sizes not seen in our Solar System
Average Number of Planets per Star
0.3
0.25
0.2
0.15
0.1
0.05
0
1 – 1.4
1.4 - 2
2 – 2.8
2.8 - 4
4 – 5.7
5.7 - 8
8 - 11
11 - 16
16 - 23
Planet Size (Earth=1)
Batalha et al PNAS

Kepler's Small Habitable Zone Planets

As of July 2015

Planets enlarged 25x compared to stars



Kepler’s Amazing Results

1

Planets orbiting other stars in the Galaxy are common.

.

2

Planets with sizes between 0.5 and 2 times Earth are the most common.

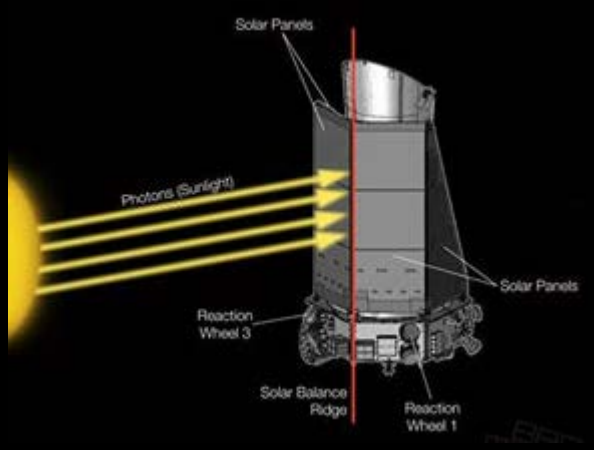
3

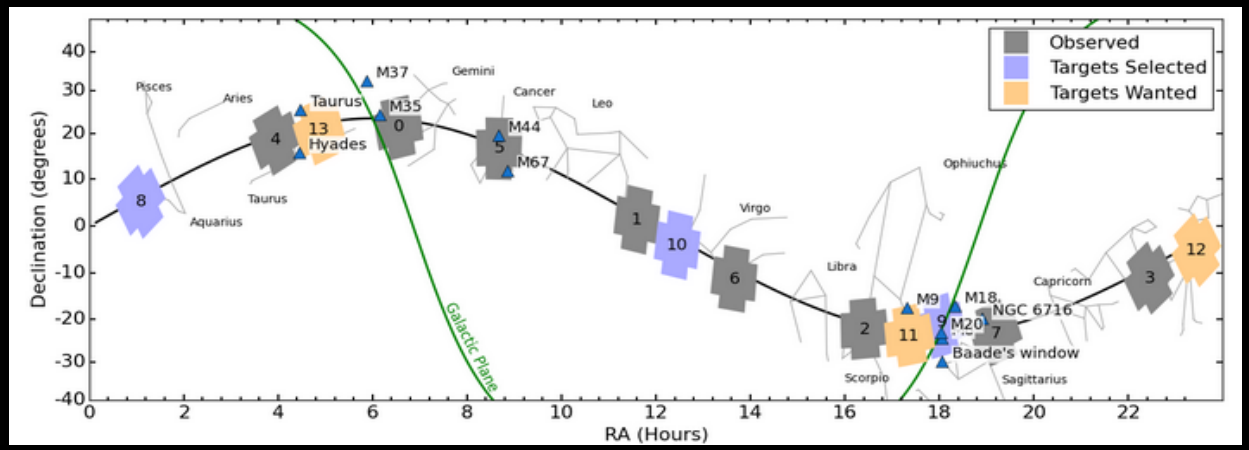
Planets with sizes between 0.5 and 2 times Earth that orbit in the Habitable Zone of their stars are common.

Kepler K2

Extending the Power of Kepler to the Ecliptic

- Spacecraft is healthy. Sufficient fuel for at least 17 campaigns
- High-value exoplanets: small, rocky, nearby, orbiting bright stars:
  - 32 confirmed exoplanets in 23 systems; >300 candidates
  - About 50 likely rocky, 6 are in the habitable zone
  - Of these 5 are suitable for atmospheric characterization (HST, JWST)
- Campaign 6 data to be released February 11
- Campaign 9 (Microlensing) starts April. Early WFIRST experiment
- K2 does much more than exoplanets!





WFIRST

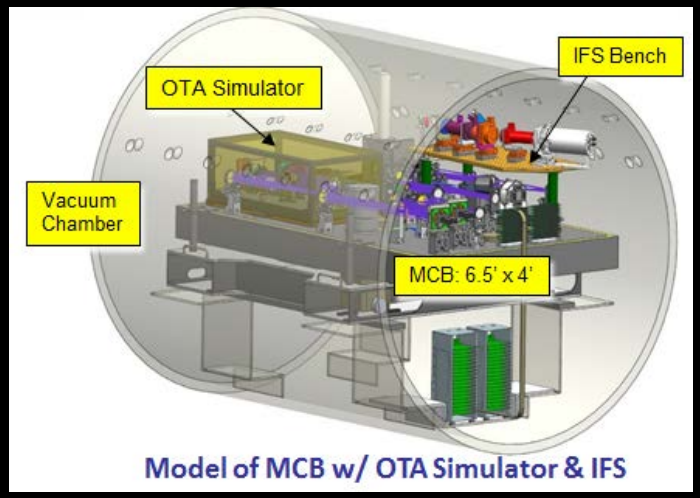
We can drop “AFTA” now

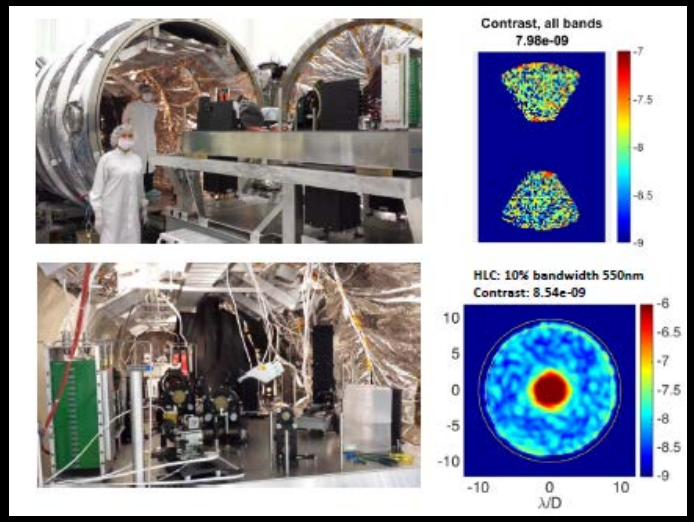
- WFIRST technology (Coronagraph and IR detectors): All milestones completed per plan
- Completed latest design cycle (L2 orbit)
- Successful Mission Concept Review (MCR) 12/8-9
- FY16 Omnibus Appropriations Bill: $90M for WFIRST
- WFIRST Formulation Science Team Announced: ten Science Investigation Teams (SITs) and two Adjutant Scientists: D. Spergel (Widefield) and J. Kasdin (Coronagraph)
- Underway: four-month Wide Field Instrument Industry Concept Study
- NASA Key Decision Point (KDP)-A, February 17

Technology - Coronagraph

All WFIRST technology milestones met on schedule

- Delivered a modelable coronagraph bench to WFIRST Coronagraph team
- Demonstrated broadband (10% at 550nm) high raw contrast (<1e-8) in a static environment for both
  - SPC (Shaped-Pupil Coronagraph) with WFIRST telescope pupil
  - HLC (Hybrid Lyot Coronagraph)
- Demonstrated low-order wavefront error sensing and close-loop tip/tilt correction (<0.4 mas rms per axis)
- Next: milestones for detector, PIAACMC, coronagraph raw contrast in dynamic environment





WFIRST Project Organization Chart

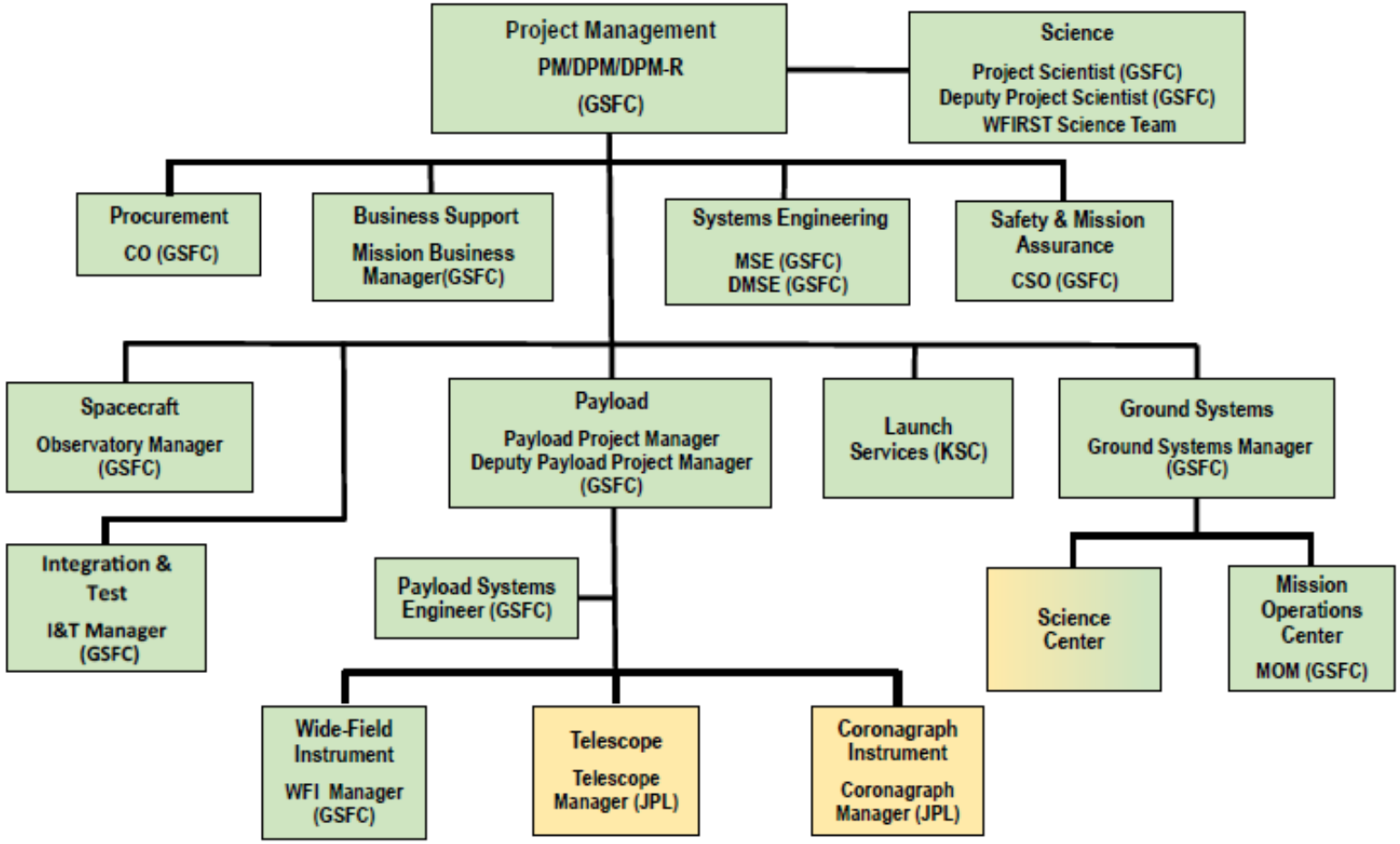
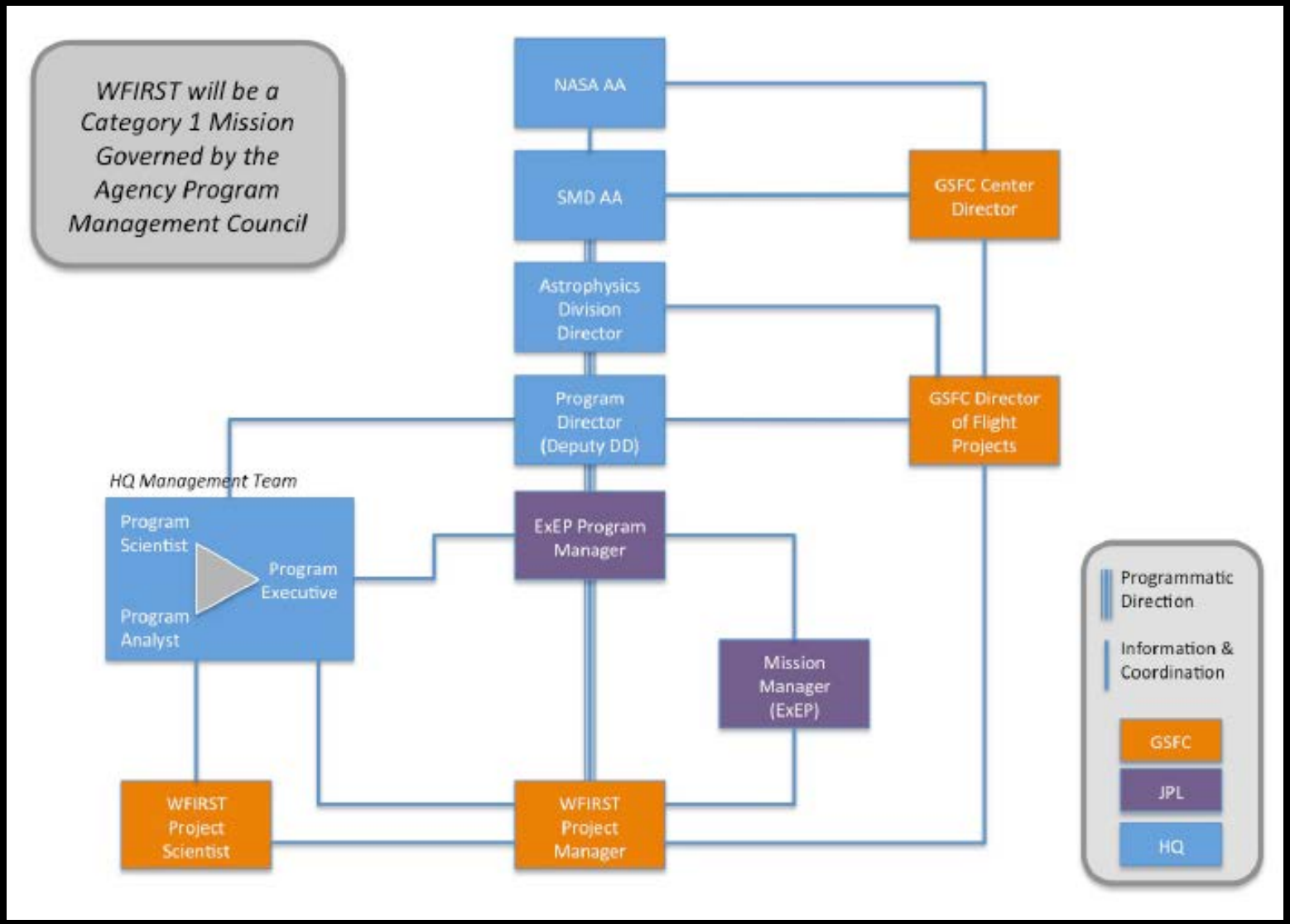


Figure 1. WFIRST Project Organization Chart

*Yellow coded boxes reflect the JPL work, which is managed through a single JPL project manager. The Science Center is only partially JPL effort.

Governance Structure – from pre-ASM and Formulation Agreement

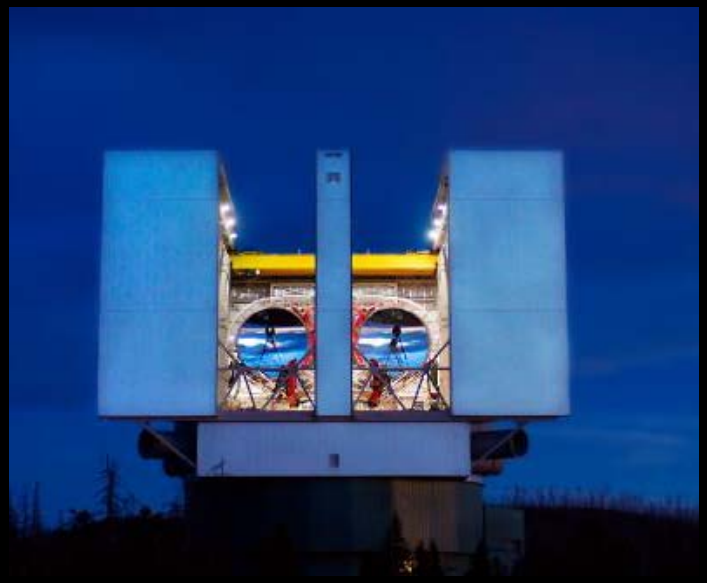


Large Binocular Telescope Interferometer

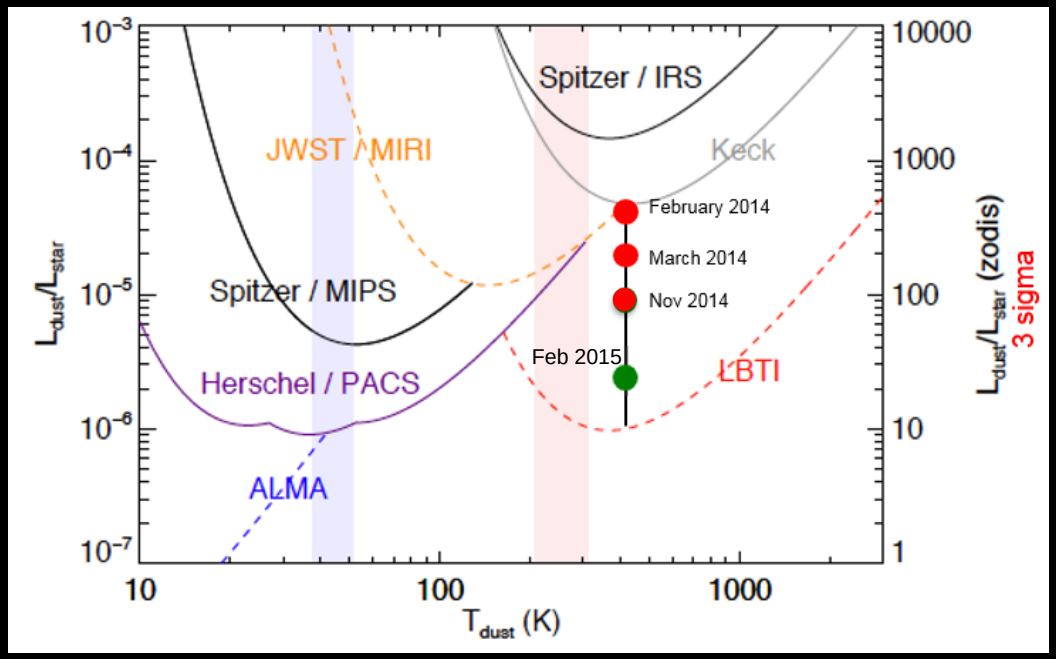
Measures exozodiacal dust in habitable zones

Phil Hinz, PI

THE UNIVERSITY OF ARIZONA



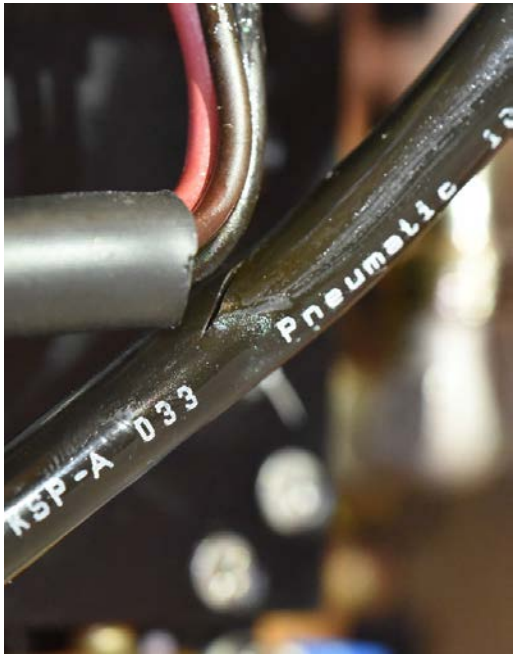
LBTI Performance



- Demonstrated 12 zodi sensitivity for a solar twin at 10 pc at May 2015, <6 zodi single star sensitivity planned for April 2016 Science Operations Review
- HOSTS survey interrupted by glycol leak in secondary mirror but repairs are nearly complete and binocular operation will restart January 2016
- Plan for 32 star survey giving <2 zodi mean uncertainty over survey population
- Results of HOSTS survey to inform next decadal survey on direct exoplanet imaging: Survey deliveries Sept 2016 and Sept 2017

Findings from LBT's Failure Review Board

- The hose on crate 5 in the DX unit most likely failed due to high temperature caused by close proximity (possibly direct contact) with Thin Shell Safety (TSS) jumper wires
  - The TSS was left energized for the duration of the summer shutdown, with no glycol circulating in the hose to cool it while in presence of the hot wire.
  - We have no evidence for a general weakening of the hoses due to age, altitude, high ambient temperature inside the unit, etc., however such degradation has not been ruled out
- The charred jumper wires of the DX crate 4 TSS are plausibly explained by a ground fault caused by the glycol from the leak shorting the TSS circuit on the TSS board and/or the actuators associated with crate 4. There appears to be **low risk that such catastrophic failure will occur without glycol (or some other shorting mechanism)**
  - Analysis of the TSS circuit [2] indicates that when the load impedance drops below 120 milliOhms, the regulating circuit of the current source become unstable.
  - A plausible explanation is that glycol shorted the TSS 4 circuit, providing the return path to reduce the load impedance below the 120 milliOhms stability point, allowing extreme current to flow through the wires
- The recurring discoloration of TSS jumper wire insulation and associated Molex connectors is probably due to overheating caused by excessive current. This excessive current is likely due to instability of the current source when load impedance is below 120 milliOhms and an imbalance between parallel jumper wires. As this is not yet fully understood, **operation of the TSS should be minimized until a permanent solution is implemented**



- Motivation
  - 2010 Decadal Survey calls for precise ground-based spectrometer for exoplanet discovery and characterization
  - Follow-up of current missions (K2, TESS, JWST, WFIRST)
  - Inform design/operation of future missions
- Scope:
  - Extreme precision radial velocity spectrometer (<0.5 m/s) for WIYN telescope is in procurement
    - Down-select of competing proposals March 8
    - Winning team invited to deliver telescope port adapter
    - Instrument to be commissioned by July 2019
  - Ongoing Guest Observer program using NOAO share of telescope time for exoplanet research

Massachusetts Institute of Technology
PI: G. Furesz

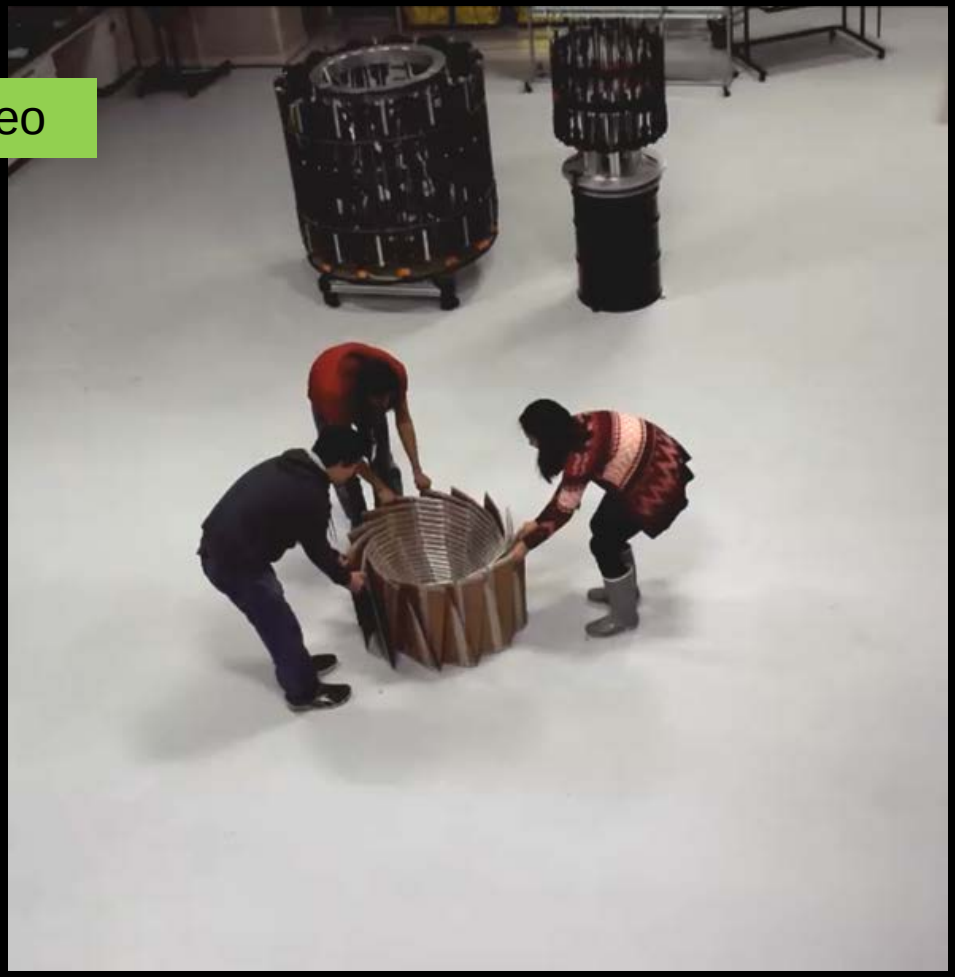
PennState
PI: S. Mahadevan

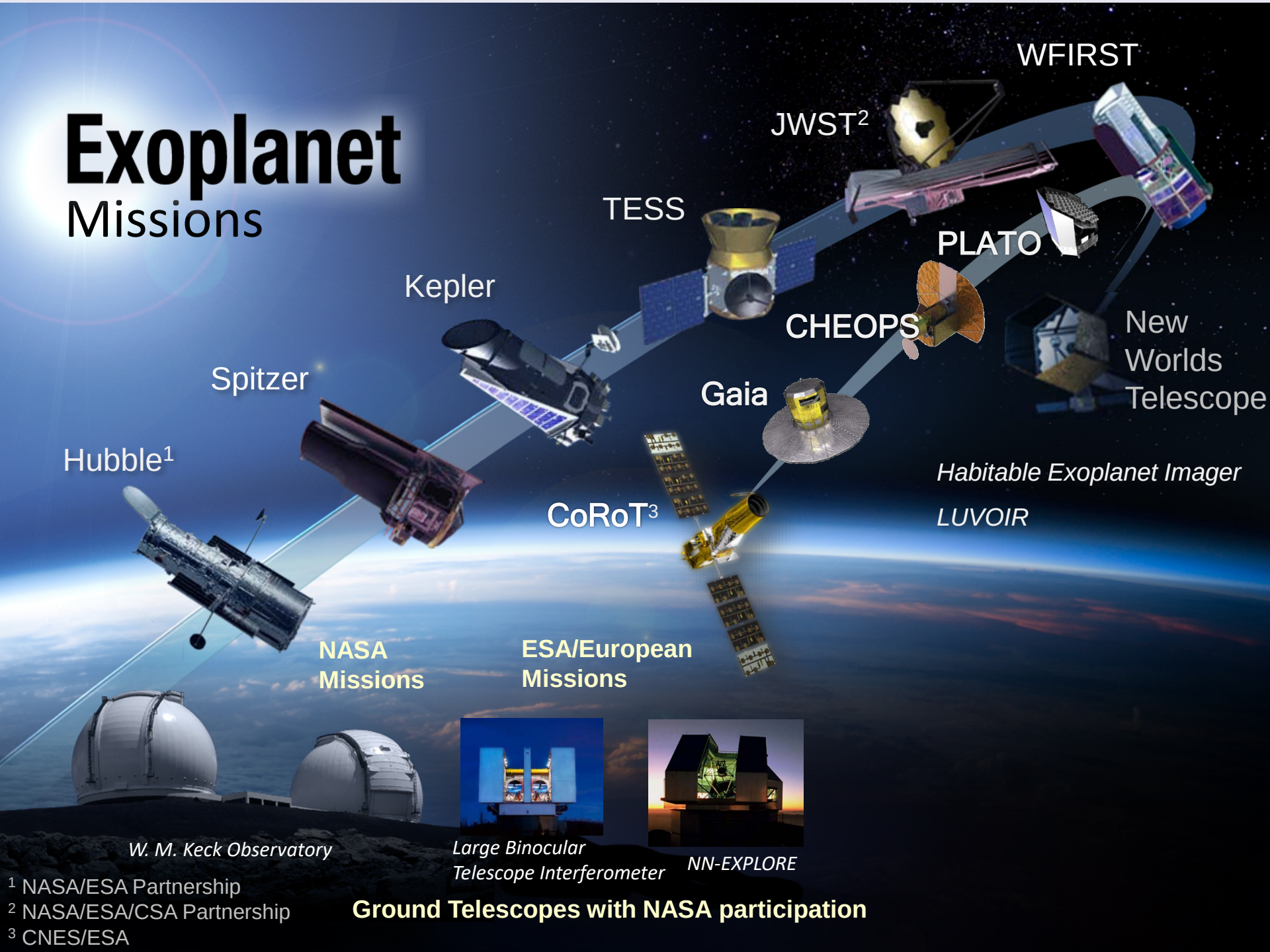
3.5m WIYN Telescope
Kitt Peak National Observatory
Arizona

Technology Accomplishments and Status

5m origami starshade optical shield

Video





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

Astro 2020 Large Mission Studies

Study	Program Office	Center Program Office	Study Center	Center Study Scientist	Study Office Manager	Center Line Management
X-Ray Surveyor	PCOS	GSFC	MSFC	Jessica A. Gaskin	Gregg K. Gelmis	Martin Weisskopf
Large UV Optical and IR Surveyor	COR	GSFC	GSFC	Aki Roberge	Julie Crooke	Mark Clampin TBD
FAR IR Surveyor	COR	GSFC	GSFC	Dave Leisawitz	Kate Hartman (Acting)	Mark Clampin TBD
Habitable ExoPlanet Imager	ExEP	JPL	JPL	Bertrand Mennesson	Keith Warfield	Moshe Pniel Jeff Booth Charles Lawrence

Jet Propulsion Laboratory
California Institute of Technology

BACKUP

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Acknowledgements

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

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- Work was also carried out at NASA's:
  - Goddard Space Flight Center
  - Ames Research Center
- Work was carried out as well under contracts with the National Aeronautics and Space Administration and:
  - Princeton University
  - University of Arizona
  - Northrop Grumman Aerospace Systems
  - National Optical Astronomy Observatory (NOAO)
  - Massachusetts Institute of Technology
  - Penn State University