Jet Propulsion Laboratory
California Institute of Technology

Exoplanet Exploration Program Updates

Dr. Gary H. Blackwood, Program Manager

Dr. Karl R. Stapelfeldt, Program Chief Scientist

Jet Propulsion Laboratory

California Institute of Technology

July 29, 2018
ExoPAG 18, Cambridge MA

Artist concept of Kepler-16b

Program Updates

Program Investments

LBTI Science Results and Implications

Science Gap List

NASA Exoplanet Exploration Program

Astrophysics Division, NASA Science Mission Directorate

NASA's search for habitable planets and life beyond our solar system

Program 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

https://exoplanets.nasa.gov

Exoplanet

Hubble[1]

Spitzer

Kepler

JWST[2]

TESS

CHEOPS

Gaia

CoRoT[3]

Starshade Rendezvous[5]

WF

PLATO

OST[5]

NASA Missions

Non-NASA Missions

W. M. Keck Observatory

Large Binocular Telescope Interferometer

NN-EXPLORE

Ground Telescopes with NASA participation

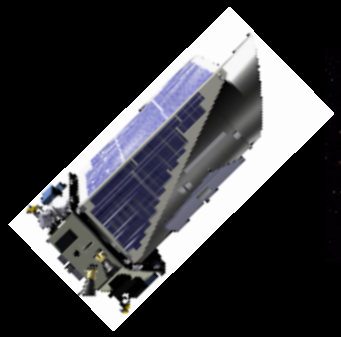
[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA
[4] ESA/Swiss Space Office

[5] 2020 Decadal Survey Studies

NASA Exoplanet Exploration Program

Space Missions and Mission Studies

K2



Probe-Scale Studies

Starshade

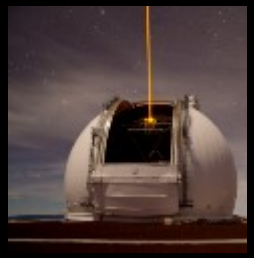
Coronagraph

Communications

Supporting Research & Technology

Key Sustaining Research

NN-EXPLORE



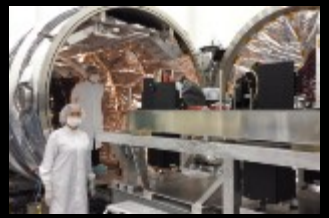
Keck Single Aperture Imaging & RV

Large Binocular Telescope Interferometer

Technology Development

Occulting Masks

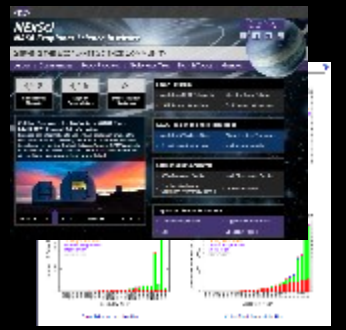
Deformable Mirrors



High-Contrast Imaging

Deployable Starshades

NASA Exoplanet Science Institute



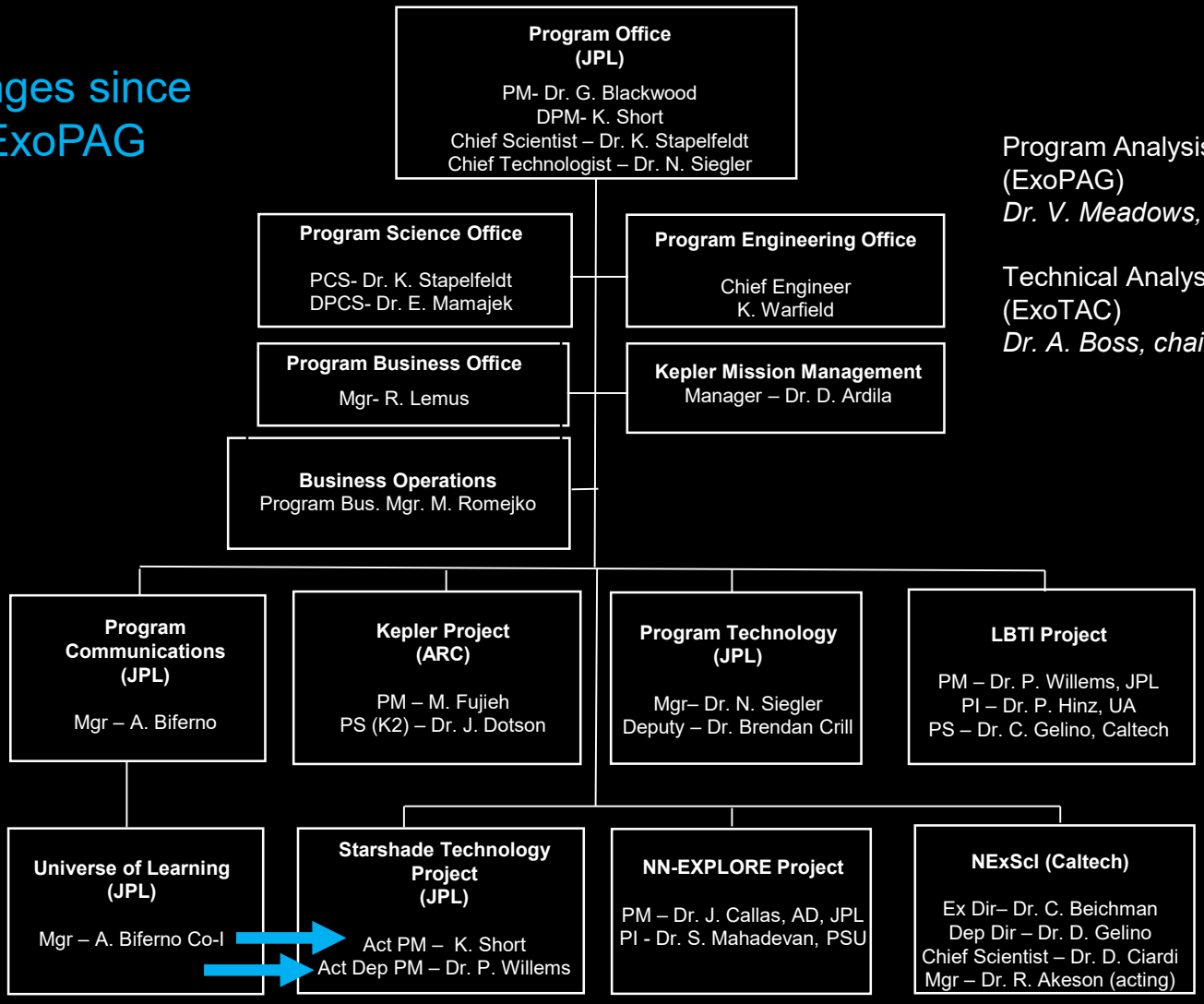
Archives, Tools, Sagan Fellowships, Professional Engagement

https://exoplanets.nasa.gov

NASA Exoplanet Exploration Program

Astrophysics Division, Science Mission Directorate

Changes since last ExoPAG



Program Analysis Group (ExoPAG)
Dr. V. Meadows, EC chair

Technical Analysis Committee (ExoTAC)
Dr. A. Boss, chair

New Leadership in ExEP Projects

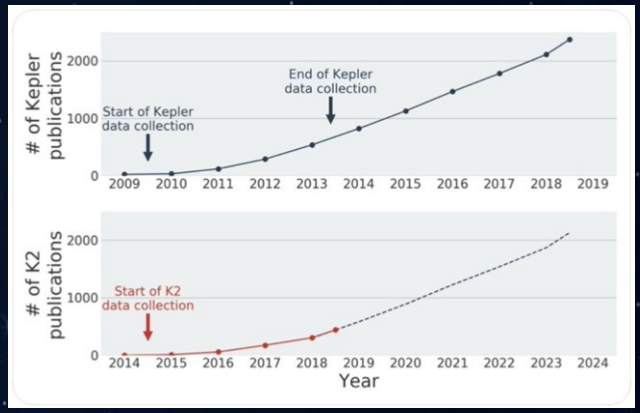
Starshade Technology Development Activity

Kendra Short
Manager, acting

Dr. Phil Willems
Deputy Manager, acting

Kepler K2

- Spacecraft in safe mode due to drop in tank pressure
- C18 interrupted after 51 days of observations
- Data to be downlinked on 08/01
- C19 will begin as planned on 08/06
- C17 being processed, to be followed by C0. C3 is being reprocessed.
- Kepler/K2 SciCon V
  March 4-8, 2019; Glendale CA



Exoplanet Communications

Exoplanets.nasa.gov - 22nd Annual Webby Winner

- Webby People's Voice Award
  … in the *Weird* Category!

Award Accepted by:
Arielle Samuelson, JPL
ExoComm Specialist

Alien Planets are Not SciFi !

Other Program Highlights

- **LBTI** completed HOSTS survey with 38 stars
- Cross program **technology coordination** with PCOS/COR
- **51 Peg Fellows**: interface with Heisig-Simons Foundation
- **Science Gap List** posted for review
- **Follow-up Observing** site provide to TESS by NExScI
- A-Team study (for J. Mather, E. Peretz) of **Remote Occulter:** an Earth-orbiting starshade with a ground-based telescope
- **NExScI exoplanet archive** continues to add new data sets
- **Decadal Survey Testbed**: first light in HCIT
- **Support to WFIRST**: MEMs DMS, coronagraph testing, starshade ICD
- Support to **Large Mission Studies** and **Probe Studies** (interim reports go public on 8/15)

ExoPAG Student Session

Your Suggestion at ExoPAG 16

Trappist-1e voted best
"Study Abroad" Destination

(within 12 parsecs of Earth)

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NN-EXPLORE NEID

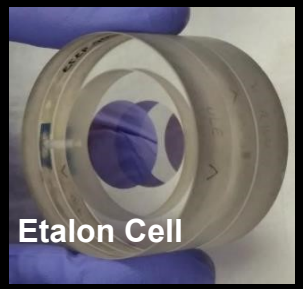
NASA-NSF Exoplanet Observational Research

PennState

PI: S. Mahadevan

- Precision radial velocity spectrograph (goal 27 cm/s) at the WIYN Telescope, Kitt Peak
- Status:
  - Facility construction nearly complete
  - Next Steps: Coating of off-axis paraboloid, delivery of blue arm of laser frequency comb, delivery of port adapter
- Plan for commissioning August 2019
- NOAO Provides:
  - GO 90 nights per year, start 2019B
  - GTO 30 nights per year for 5 years
  - NExScI will provide the automated RV pipeline and archive database

NEOS Camera



NN-EXPLORE NEID

NASA-NSF Partnership for Explanet Discovery and Characterization

The **NEID** spectrograph goal is **27 cm/s** radial velocity precision with a **380 nm - 930 nm** bandwidth (RV coverage for F-M stars and stellar activity indicators) and R = 100,000 spectral resolution of bright (V<12) stars. NEID will employ a **Laser Frequency Comb** and white-light etalon calibration systems.

NN-EXPLORE provides a 2 semester/year Guest Observer (GO) program, administered by NOAO. There is limited funding support, sufficient to cover travel, modest research expenses, and publications costs, provided by NASA to observers under the NN-EXPLORE Program through NExScI.

Semester A proposals due September 30 (awards announced mid-Dec).

Semester B proposals due March 31 (awards announced mid-June).

Stage 1 (now) - With current WIYN instruments, targeted to general exoplanet-related research, with particular emphases on follow-up observations of Kepler/K2 targets and observations in preparation for TESS. 50 to 60 nights/semester awarded.

Stage 2 - WIYN observations with NEID **beginning with 2019B** (September 1, 2019).

NEID instrument commissioning by July 2019.

Approximately 90 nights per year of GO awarded observing.

The guaranteed time observations (GTO) is ≥30 nights per year for 5 years.

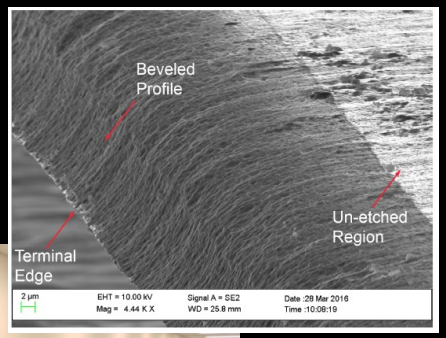
NExScI will provide the automated RV pipeline and archive database.

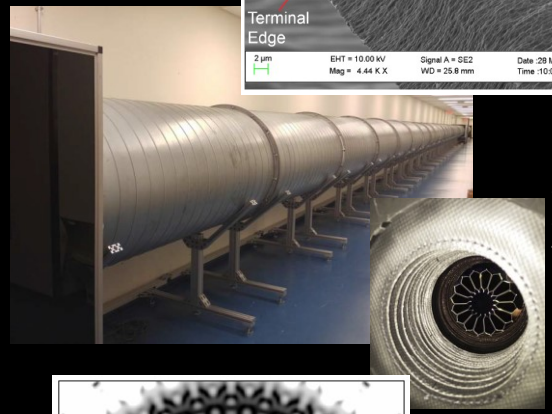
Starshade Technology Development (S5)

Reach Technology Readiness Level 5

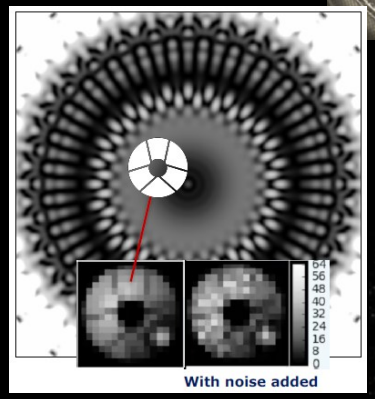
- Technologies of optical suppression, formation flying, and mechanical deployment
- Completed mechanical architecture trade – selected *wrapped petal* architecture
- Technology plan and implementation plan to be delivered for approval to HQ Sept 2018
- RFI released July 27 (FBO): seek new capabilities and interest in an industry forum for S5 goals

Etched amorphous metal edge segment





Princeton starlight suppression testbed



Lateral position sensing

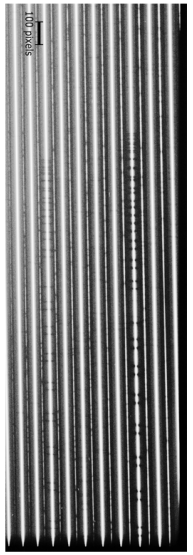
Wrapped Petal architecture

Program Investments

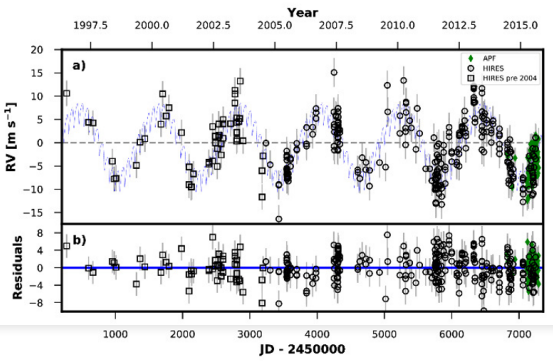
Ground Science that Furthers NASA Level 1 Requirements

- NExScI is providing access to **HIRES PRV data reduction pipeline** (contact: David Ciardi)
  - Initial release Sept 28 2018, for use with data 2019A forward
  - Subsequent release provides analysis of earlier data
- NASA and NSF providing support to **US Access to Southern RV** – starting 2019A (contact: David Ciardi)
  - CHIRON on the SMARTS 1.5m telescope – 40 nights/semester
  - Complements Keck/HIRES and WIYN/NEID
  - Augmentation of existing NN-EXPLORE program
- Continue community access to **speckle high resolution imaging** (contact: Steve Howell, ARC; David Ciardi, NExScI)
  - Stellar characterization of TESS candidates Three speckle instruments available to the community through NOAO
  - WIYN/NESSI (39 mas), Gemini-N/'Alopeke (17 mas), Gemini-S/DSSI

Access to Keck HIRES PRV Data Reduction Pipeline

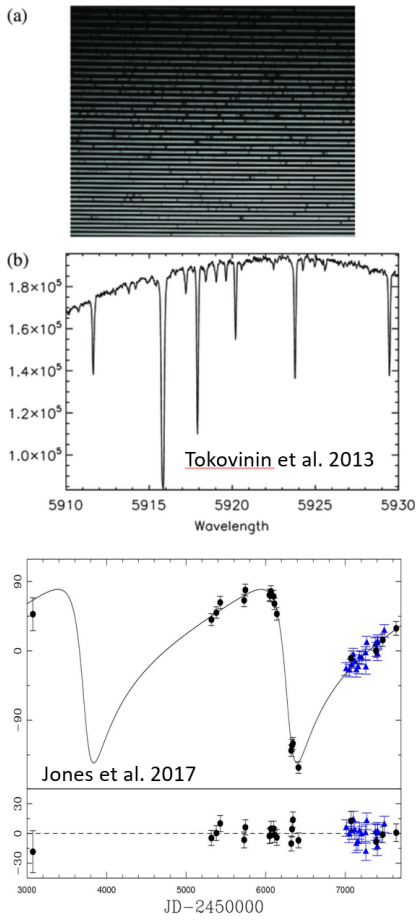


- NASA access to Keck/HIRES currently offers the only precision radial velocity (PRV) capability openly available to the US community
  - NEID becomes operational 2019B
  - NEID complements HIRES: Different Latitudinal Sky Coverage (50% of TESS southern ecliptic sky), Longitudinal Coverage of Orbits, Brightness of targets, Surveys vs Targeted Observations
- NExScI is developing a processing environment for Keck HIRES data in collaboration with the Keck HIRES PRV team at Caltech and WM Keck Observatory (WMKO)
  - Provides a publicly available capability to produce radial velocities at the few m/s level from HIRES data
  - Requires observers follow a specific observing sequence which will be documented at WMKO
  - Builds on the existing IDL software package developed by the California Planet Search team
  - Software will be accessed on a server at NExScI and invoked through a Python interface
  - Uses Python interface to Keck Observatory Archive for data retrieval
- Status
  - CPS software package code delivered and fully operational on NExScI servers
  - Python interface to KOA for data extraction developed
  - Documentation for telescope/instrument set-up and pipeline operations delivered
  - Initial release by Sept 28, 2018 with test data set
- Available for community use in 2019A (see August 15 Call for Proposals)
  - Initial release will work only on data obtained in 2019A and going forward
  - Subsequent release will all allow analysis of earlier data obtained in specified configuration



NASA & NSF Support for US Access to Southern PRV

- TESS is performing a (nearly) all-sky search for transiting planets around bright stars
  - Survey starting in the southern ecliptic sky
  - Bright stars enables detailed follow-up and characterization
- PRVs are needed for
  - Planetary masses (and densities): planet demographics, atmosphere characterization
  - Orbital solutions: system demographics, transit and eclipse predictions
  - Binary identification and characterization
  - Spectra for stellar classification
- US community has limited public access to precision radial velocity (PRV) facilities – especially with regards to the southern hemisphere targets.
  - Keck/HIRES and WIYN/NEID have limited access to southern hemisphere
- NASA and the NSF/NOAO have agreed to an augmentation of the existing NN-Explore Program
  - CHIRON on the SMARTS 1.5 telescope
  - ≈>10 m/s precision enables mass determinations of super-earth mass and larger planets (depends on stellar host)
  - 40 nights per semester – augmentation to current NOAO-SMARTS time
  - Queue-mode observations
  - Raw data available through NOAO Science Archive
  - Some data processing through Georgia State University available (1-d wavelength calibrated spectra)
  - Call for proposals will be through NOAO via the NN-Explore Program
  - Starts in 2019A – likely available through 2021A



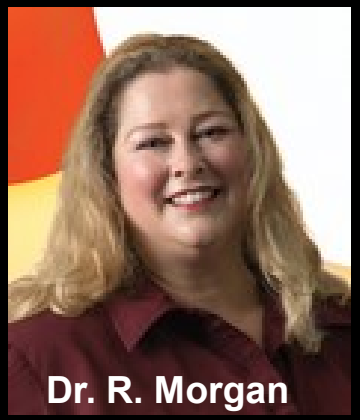
Standard Definitions and Evaluation Team

Supporting the Large Mission Studies for Exoplanet Direct Imaging

- Chartered to provide a consistent, transparent yield analysis using common input parameters
  - https://exoplanets.nasa.gov/exep/resources/documents/
- Next deliverable (Aug) following the interim reports
- Yield analysis: EXOSIMS and Starks' AYO
  - https://github.com/dsavransky/EXOSIMS
  - https://asd.gsfc.nasa.gov/luvoirdev/tools/
- Input parameters adopted for occurrence rates, HZ, planet radius, albedo, etc.
- Improvements for final reports evaluations: update occurrence of cold giants with RV occurences and dynamical stability constraint (Plavchan & Dulz)
- Contact Rhonda Morgan

Rhonda Morgan
Bruce Macintosh
Dmitry Savransky
Chris Stark
Avi Mandell
Ruslan Belikov
John Krist
Eric Nielson

STDT Liaisons:
Courtney Dressing
Karl Stapelfeldt
Klaus Pontoppidan



Dr. R. Morgan

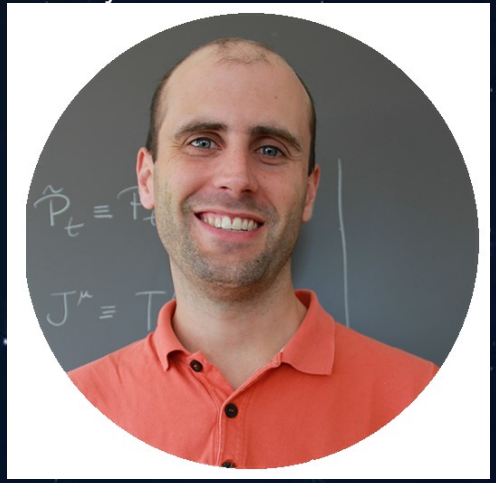
NHFP 2018 Sagan Fellows

Ian Czekala
University of California, Ber

Johan Mazoyer
Jet Propulsion Laboratory

Erik Petigura
California Institute of Technology

Kamber Schwarz
University of Arizona



Daniel Tamayo
Princeton University

NASA Hubble Fellowship Program

- Beginning with the 2018 Call for Proposals, the Sagan, Hubble, and Einstein Fellowship Programs were combined into one program funded by STScI

Sagan Fellows

- Ian Czekala, University of California-Berkeley, *A Uniform Measurement of Pre-Main Sequence Stellar Masses and System Architectures Using Protoplanetary Disks*
- Johan Mazoyer, Jet Propulsion Laboratory, *Can We Detect Exo-Earths with Future Large Space-Based Coronagraphic Instruments?*
- Erik Petigura, California Institute of Technology, *The Origin of Small Planets*
- Kamber Schwarz, University of Arizona, *The Evolution of Volatile Molecules from Protoplanetary Disks to Exoplanet Atmospheres*
- Daniel Tamayo, Princeton University, *A Million-Fold Speedup in the Dynamical Characterization of Exoplanet Systems*

2018 Sagan Summer Workshop

July 23-27, 2018

- 2018 Sagan Summer Workshop: “OMG! Did I Really Just Find an Exoplanet?”
- 165 people registered, 125 attending hands-on sessions
- 27 invited speakers
  - Transit Photometry
  - Follow-up Observations of Transit Candidates
  - Radial Velocity Surveys
  - Planetary Characterization Observations
  - Microlensing
  - Finding Planets with Direct Imaging
  - Astrometry

Presentations and videos:
http://nexsci.caltech.edu/workshop/2018/

Livestream: >20 attended actively online

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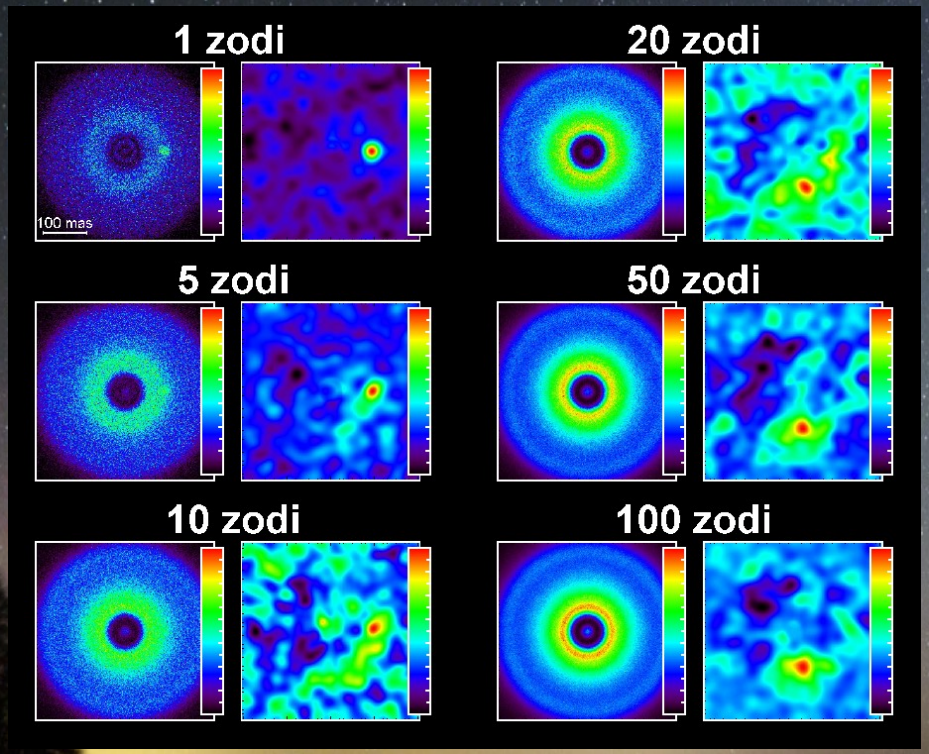
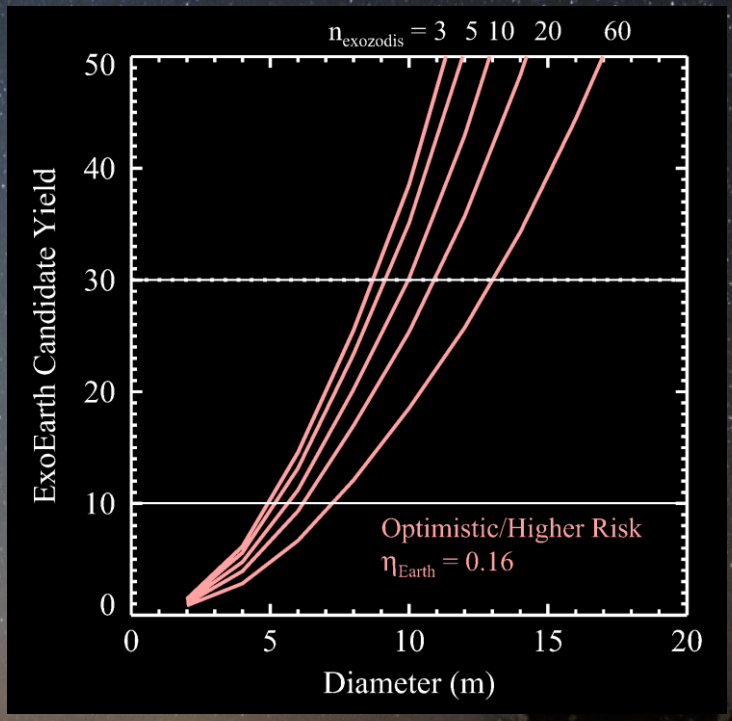
7/29/2018

Image by Rudi Dobesberger

Levels of warm exozodi affect the yields for future direct imaging of habitable exoplanets (Roberge et al. 2012)



Simulations for 4m telescope, Defrère et al. (2012)

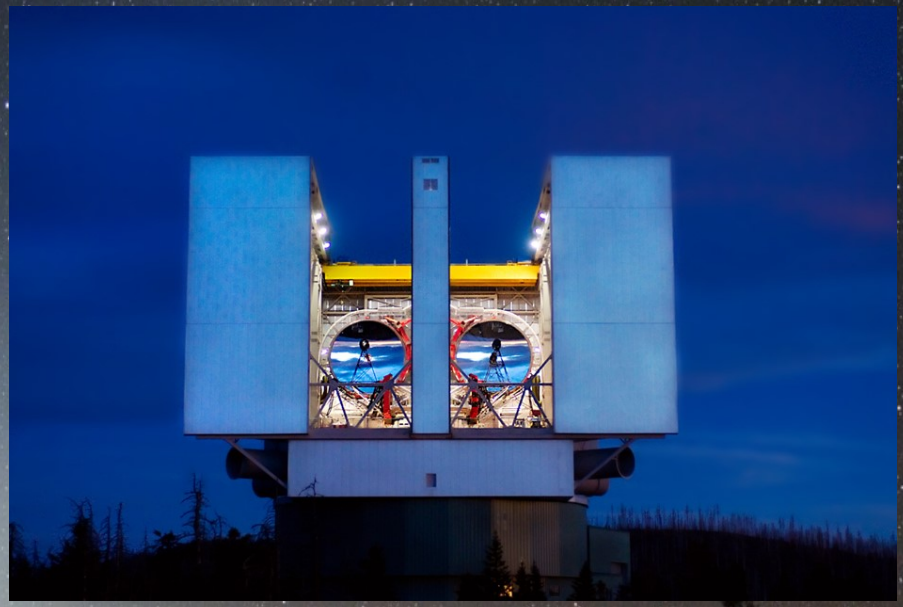


C. Stark et al. (2015, 2016)

Confusion from dust clumps remains an issue but may be solved through synoptic imaging

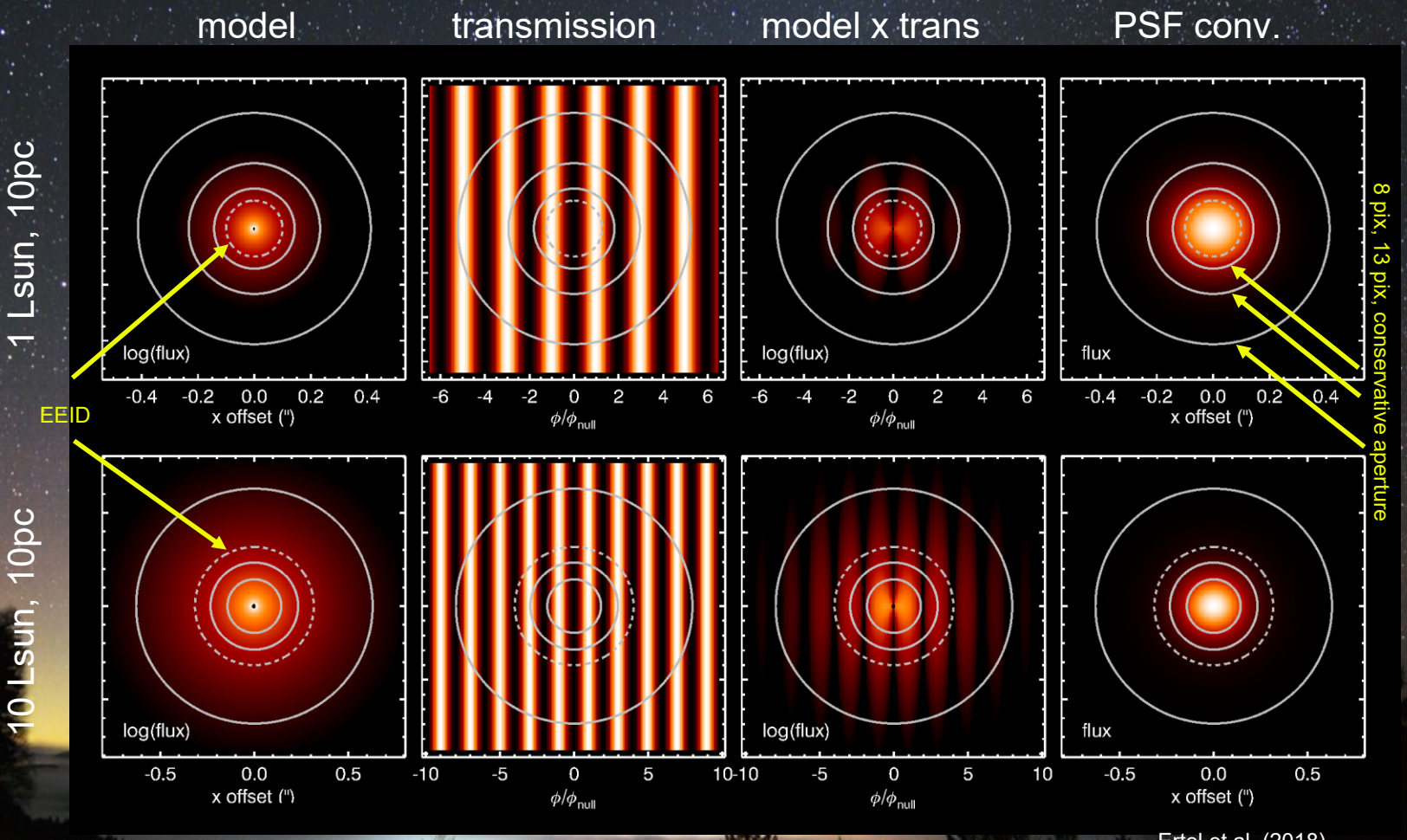
LBT Interferometer at Mt. Graham, Arizona

- Two 8m telescope on common mount, LBTI instrument integral to telescope design, few warm reflections, more optimal 22 m baseline
- NASA-funded key science project “Hunt for Observable Signatures of Terrestrial Systems”, or “HOSTS”, 2012-2018.
- Unbiased survey of 39 stars just completed. 10 detections, 6 new, and first detections around sun-like stars.



Interim survey results for 30 stars appear in Ertel et al. 2018 A.J. 155 194

How LBTI measures exozodi



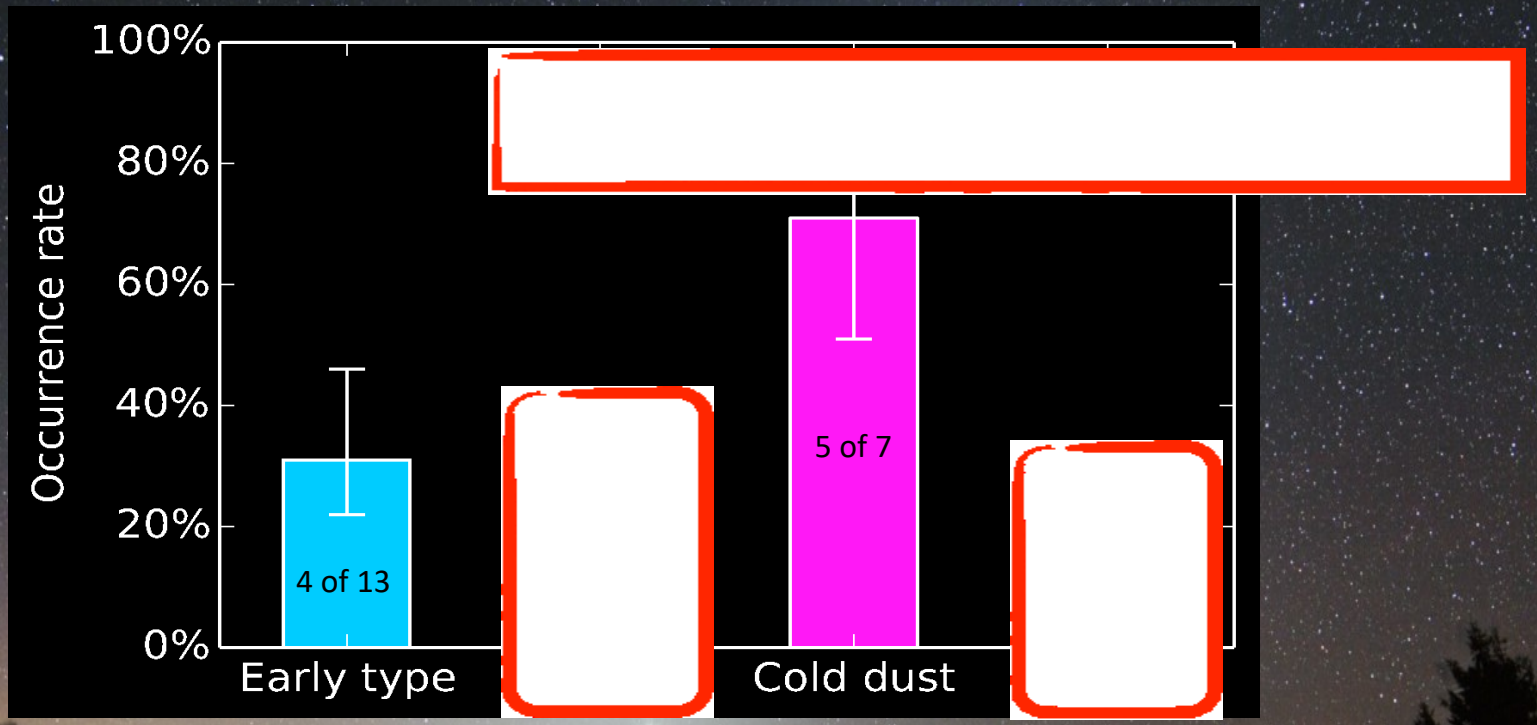
Ertel et al. (2018)

Specific stars with LBTI detections

Strong detections	η Crv, β Leo, β UMa, ζ Lep, **13 UMa***
Sun-like stars	ε Eri, **13 UMa***, **θ Boo**, 110 Her
Early type stars	Vega, β UMa, **δ UMa**, β Leo, η Crv, ζ Lep
No cold dust	**δ UMa, 13 UMa***, **θ Boo**
Also interesting	Vega (little warm dust), τ Cet (no detection)

* Suspicion that excess may arise from previously unknown stellar companion, TBC

HOSTS results



- Probability that stars **with and without cold dust** have the **same occurrence rate: p = 0.003**
- Similar incidence rate for **Sun-like and early type stars** comes at **~4x lower sensitivity around Sun-like stars**

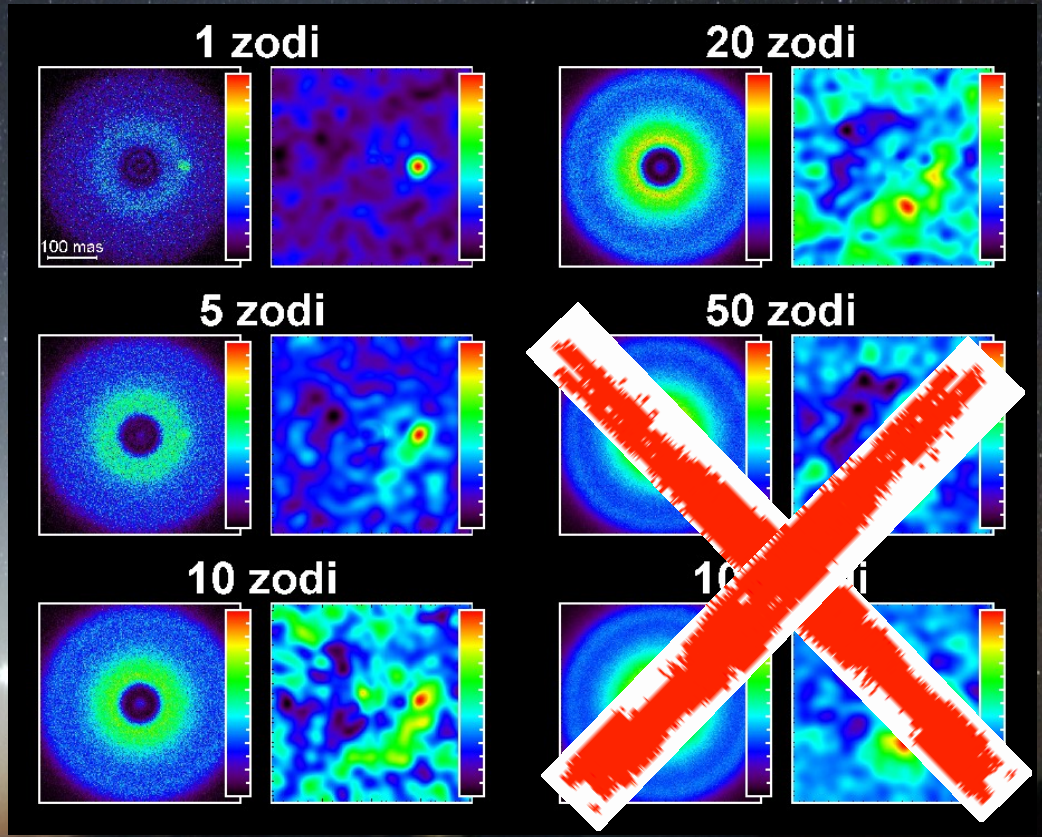
Overall limits to median exozodi level

Interim upper limits on median zodi level for stars without cold dust (95% confidence, assuming lognormal distribution):

- 13 zodis for all stars,
- 26 zodis for FGK stars

The latter value is most relevant to future direct imaging missions

These limits are expected to drop when results for the final 9 stars observed in 2017-2018 are included



Simulations for 4m telescope, Defrère et al. (2012)

Implications of HOSTS results (1)

- ~ 80% of the stars surveyed lack detectable extended emission at 10 μm, and thus are not very dusty.
- The 26 zodi interim upper limit on the median exozodi level is a factor of 5 improvement vs. Keck interferometer results. The median exozodi level could still be lower than this.
- The correlation found between HZ dust and cold Kuiper Belt dust means that Spitzer & Herschel dust detections can be used to (de)select targets for studies of HZ exoplanets.
- Further LBTI observations, or WFIRST coronagraph imaging later on, could be used to screen more targets and provide more sensitive limits.
- Solar system levels of warm dust remain undetectable at nearby stars

Implications of HOSTS results (2)

- Larger space telescopes can cope better with higher levels of exozodi. At the interim HOSTS exozodi upper limit, R= 70 spectroscopy of a fiducial Earth analog around a solar analog at 10 pc is
  - Robustly possible with the LUVOIR 8 & 15 m architectures
  - Viable for the HabEx 4m architecture
  - Very diffiicult for the WFIRST 2.4m architecture. Success would require final HOSTS survey to determine a lower median, observe closer and less dusty targets, observe at lower spectral resolution.
- Remaining uncertainty in exozodi level implies that integration times for detection & spectroscopy will remain uncertain by a factor of several
- For New Worlds mission architectures that are observing time limited, tighter exozodi limits could enable the use of a smaller space telescope.

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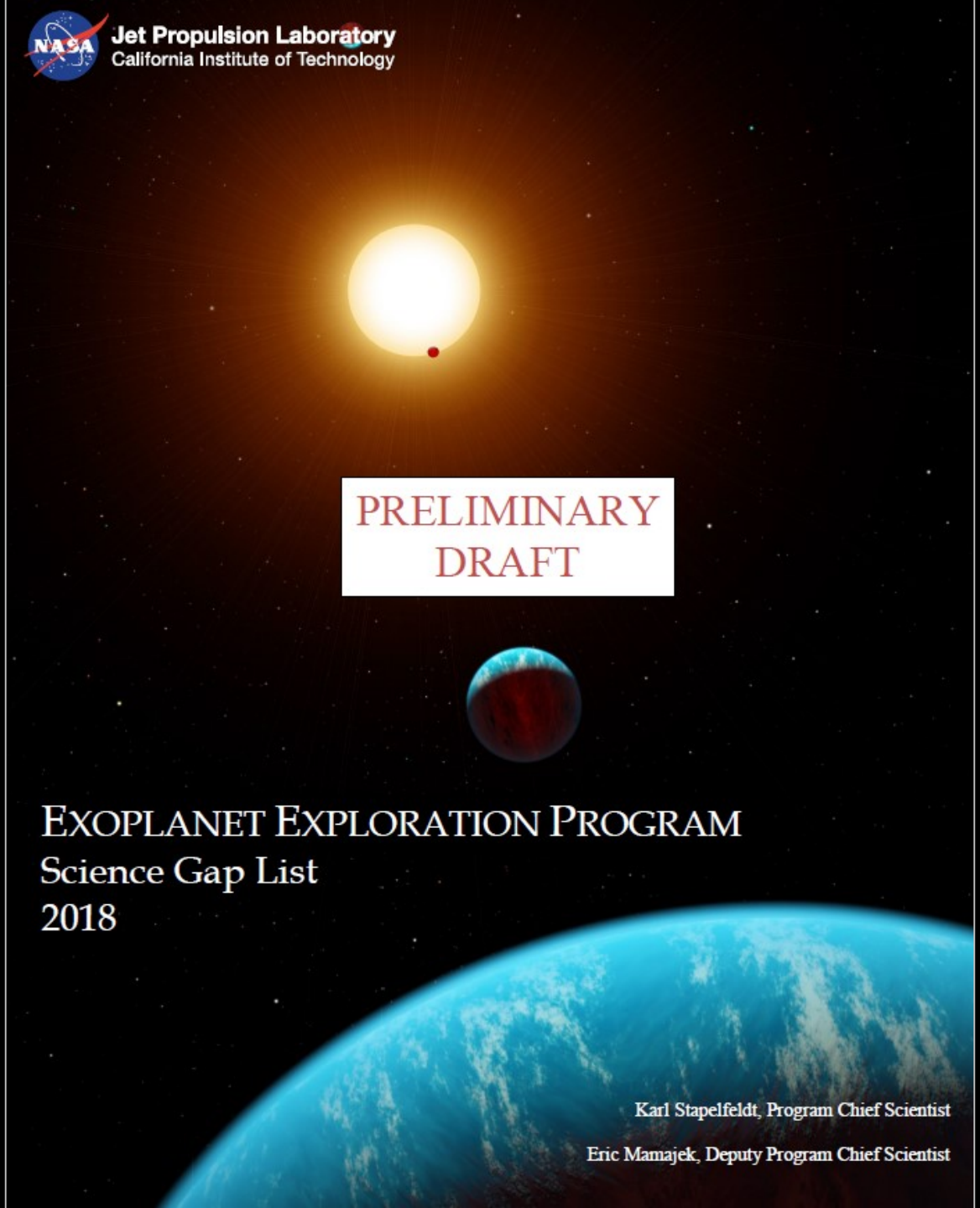
Jet Propulsion Laboratory
California Institute of Technology
PRELIMINARY
DRAFT
EXOPLANET EXPLORATION PROGRAM
Science Gap List
2018
Karl Stapelfeldt, Program Chief Scientist
Eric Mamajek, Deputy Program Chief Scientist

What is the ExEP Science Gap List ?

- A *science gap* is defined as the difference between what is needed to define requirements for specified future NASA exoplanet missions and the current state of the art, or which is needed to enhance the science return of current and future NASA exoplanet missions.
- NASA exoplanet missions, and thus the gaps, flow from community priorities stated in the Astro2010 Decadal Survey as interpreted in the NASA Science Plan and NASA Astrophysics Implementation Plan.
- Currently the gap list is used as a measuring stick when evaluating possible new activities: if a proposed activity could close a gap, it would be considered for greater priority for Program resources
- Since the January ExoPAG, the gap list has been updated and consolidated in response to inputs from HQ and the ExoPAG EC

ExEP Science Gap List as of July 2018
(grouped by topic, no implied priority in ordering)

Spectra characterization of small exoplanets
Modeling exoplanet atmospheres
Spectral signature retrieval
Planetary system architectures
Occurrence rates for HZ exoplanets (e.g. $\eta_{\oplus}$)
Yield estimates for exoplanet direct imaging missions
Improve target lists and stellar parameters for exoplanet missions
Mitigate stellar jitter as a limitation to exoplanet dynamical measurements
Dynamical confirmation of exoplanet candidates, determination of their masses & orbits
Precursor surveys of direct imaging targets
Understand the abundance and substructure of exozodiacal dust
Measurement of accurate radii for transiting exoplanets

Path forward on ExEP science gap list

- Now linked on public ExoPAG website, will soon be moved to new family of pages on https://exoplanets.nasa.gov/exep/science
- Larger Science Plan document, which provides context for the gap list, will be posted in mid-August.
- Comments welcome on both documents through September.
  - What is missing, needs different emphasis, or better clarity ?
- Release of NAS Science Strategy reports will motivate updating of both documents
- We would welcome 1-2 ExoPAG members to work with us more closely on finalizing these documents

Jet Propulsion Laboratory
California Institute of Technology

exoplanets.nasa.gov

Acknowledgements

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

- Work was carried out as well under contracts with the National Aeronautics and Space Administration and
  - University of Arizona
  - National Optical Astronomy Observatory (NOAO)
  - Pennsylvania State University

- Contributions from ExEP program leadership and staff gratefully acknowledged

BACKUP

Ongoing ExEP Support to WFIRST

- Provide the High Contrast Imaging Testbed for WFIRST Coronagraph (CGI) testing
- Backup deformable mirror technology
- Starshade accommodation support
- Polarization studies: confirmed software accuracy
- NExScI archive for UKIRT microlensing survey of galactic bulge
- The ExoPAG is one of the forums that the community can become engaged with WFIRST development