Exoplanet Exploration Program Update

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Jet Propulsion Laboratory
California Institute of Technology
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Program Overview
Program Updates
Science Highlights
What’s Coming Up
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
ExEP is a Program Office within the NASA Astrophysics Division
Exoplanet Missions

Missions:
- Spitzer
- Kepler
- JWST
- TESS
- Gaia
- PLATO
- CHEOPS

NASA Missions
- Hubble

ESA/European Missions
- CoRoT
- New Worlds Telescope
- Habitable Exoplanet Imager (LUVOIR)

W. M. Keck Observatory

Ground Telescopes with NASA participation

1 NASA/ESA Partnership
2 NASA/ESA/CSA Partnership
3 CNES/ESA
NASA Exoplanet Exploration Program

Space Missions and Mission Studies
- Kepler, K2
- WFIRST
- Decadal Studies
  - Starshade
  - Coronagraph

Supporting Research & Technology
- Key Sustaining Research
  - Large Binocular Telescope Interferometer
  - Keck Single Aperture Imaging and RV
- Technology Development
  - Coronagraph Masks
  - High-Contrast Imaging
  - Deployable Starshades

Communications
- NASA Exoplanet Science Institute
  - Archives, Tools, Sagan Fellowships, Professional Engagement

https://exoplanets.nasa.gov
Exoplanet Exploration Program
Astrophysics Division, Science Mission Directorate

Program Office (JPL)
PM - Dr. G. Blackwood
DPM - K. Short
Chief Scientist - Dr. K. Stapelfeldt
Chief Technologist - Dr. N. Siegler

Program Science Office
PCS - Dr. K. Stapelfeldt
DPCS - Dr. E. Mamajek

Program Business Admin Office
Mgr - R. Lemus

Business Operations
Resources - B. Nomoto
Schedule - G. Luzwick

Program Engineering Office
Chief Engineer
K. Warfield

Kepler Mission Management
Manager - K. Short (acting)

WFIRST Mission Management
Manager - A. Comberiate
Business Mgr. - S Keasler

Program Science Office

Program Engineering Office

Kepler Mission Management

WFIRST Mission Management

WFIRST Project (GSFC)
PM - K. Grady
DPM - C. Peddie
PS - Dr. J. Kruk

LBTI Project
PM - Dr. P. Willems, JPL
PI - Dr. P. Hinz, UA
PS - Dr. C. Gelino, Caltech

Program Analysis Group (ExoPAG)
Dr. A. Boss, EC chair

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

Universe of Learning (JPL)
Mgr - A. Biferno Co-I

Kepler Project (ARC)
PM - C. Sobeck
PS - Dr. N. Batalha
PS (K2) - Dr. J. Dotson

Program Technology (JPL)
Mgr - Dr. N. Siegler
Deputy - Dr. Brendan Crill

NN-EXPLORE Project
PM - Dr. J. Callas, AD, JPL
PI - Dr. S. Mahadevan, PSU
PS - Dr. R. Capps, JPL

NExScI (Caltech)
Ex Dir - Dr. C. Beichman
DD - Dr. D. Gelino
Chief Scientist - Dr. D. Ciardi
Mgr - Dr. R. Akeson (acting)

Coronagraph Instrument (JPL)
PM - Dr. M. Frerking
DPM - Dr. F. Zhao
PS - Dr. J. Rhodes
DPS - Dr. L. Moustakas
# Exoplanet Exploration Program

Enables Science Today and Tomorrow

## Scope: Projects and Tasks

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| **Discover** | Kepler  
K2 | Occurrence rates for science and design of future missions  
Discoveries via photometry and microlensing, potential JWST Targets | WFIRST Microlensing Survey | Census for long period planets |
| **Characterize** | NASA Keck time  
NNEXPLORE GO, including NESSI  
NASA Exoplanet Archive | SMD Science, Exoplanet follow up and precursor science  
Transit prediction and observability for space missions  
Table of transmission spectroscopy data including from HST and Spitzer. | NEID GO  
WFIRST Coronagraph  
Original Probe Studies (Coronagraph, Starshade)  
OST | Exoplanet Mass  
Reflected Light Spectroscopy of Atmospheres |
| **Space Missions Not in the ExEP** | HST  
Spitzer | Atmospheres, microlensing discoveries  
TESS  
JWST | | Photometry, atmospheres via transmission spectroscopy |
| **Identify Worlds that Could Harbor Life** | Large Binocular Telescope Interferometer  
Technology - Competed  
Starshade Technology Development  
Starshade Readiness Working Group  
Segmented Coronagraph Design and Analysis  
Telescope Stability Workshop | Exozodiacal Dust survey  
Increasing TRL feasibility  
Decreasing inner working angle  
Increasing outer working angle  
Increasing starshade suppression  
Minimizing segmented mirror edge diffraction  
Increasing coronagraph contrast | Current Probe Starshade - WFIRST Rendezvous (Seager, Kasdin)  
LUVOIR  
HabEx  
OST  
Current Probe Precision RV in Space (Plavchan)  
Standard Definitions and Evaluation Team | Reflected Light Spectroscopy of Atmospheres  
Reflected Light, Transmission Spectroscopy  
Mass Measurements |
Wide Field Infrared Survey Telescope (WFIRST)

Dark Energy, Infrared Survey… and Alien Worlds

• WFIRST in 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 making WFIRST starshade-ready.

• Reviews for SRR/MDR: delayed to allow independent external review

Astrophysics Probe Mission Concepts

Announced by NASA March 20

• 10 proposals selected for mission concept studies
  – PI-led science team
  – NASA mission design labs at JPL and GSFC.
  – Results will be provided to 2020 Decadal Committee

• 2 exoplanet studies were “partially” selected:
  – Peter Plavchan: develop the science case for space PRV mission.
  – Sara Seager: update starshade rendezvous mission concept.

• The ExEP and PCOS / COR programs are facilitating all ten studies by supporting the PIs throughout the study and more specifically assisting the PIs in executing their design lab studies.
Starshade Technology Development (S5)

• 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
  – Developed sensing algorithms for formation flying using WFIRST CGI constraints
• Extreme precision radial velocity spectrometer (<0.5 m/s) for WIYN telescope
  – Laser frequency comb reference
• Development milestones:
  – Passed the Port Adapter Detailed Design review in May 2017
  – Instrument commissioning by August 2019
• Ongoing Guest Observer program using 40% NOAO share of telescope time for exoplanet research with existing instruments. Proposals due in late September.
• See John Callas’ talk in Wed. splinter session

NOAO 3.5-m WIYN Telescope, Kitt Peak National Observatory, Arizona
NESSI on WIYN 3.5m Observatory, Kitt Peak
The NASA Exoplanet Star (and) Speckle Imager

- Speckle images in two simultaneous colors
- Resolution at or near diffraction limit
- Companion detection and characterization to delta magnitudes of ~5
- PI: Steve Howell, NASA ARC

http://www.wiyn.org/Instruments/
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
Exoplanet Communications
Interstellar Visual Display Exhibit
Exoplanet Communications

Interstellar Visual Display Exhibit

Kepler Mission Field of View Median (171 million AU)
90% are at distances of 53–345 million AU
Program Overview

Program Updates

Science Highlights

What’s Coming Up
Exoplanet Exploration Program Science Plan

- Covers roles and processes for the ExEP Science Office.
- The Plan also contains the scientific and programmatic context for the Program Science Gap list.
- Aligned with strategy & goals of the 2014 NASA Science Plan and community reports.
- The Science Gap List would be included as an appendix to the Science Plan, similar to the ExEP Technology Plan, and provide an opportunity to align work across the agency with Program goals.
- Jointly authored by Stapelfeldt & Mamajek. First draft to be completed later this month.
Some Exoplanet Science gaps within current community priorities:

- Achieving RV sensitivity to Earth-like planets: mitigating RV jitter
- Exozodi as a noise source for flagship imaging
- Community RV facilities for Kepler, K2, TESS followup
- Dedicated WFIRST/CGI RV precursor program
- Final Kepler occurrence rates for small planets
- Quantified science yield comparison between Flagships, probes, and WFIRST
- Combining exoplanet demographics from multiple methods
- Generation of Lightcurves for TESS Full Frame Images* (external to ExEP)
NASA Exoplanet Science Institute

- Sagan Summer Schools
- Sagan Fellowship Program (new role working with STScI)
- NASA/Keck time (90 nights/yr) supports Exoplanets, Cosmic Origins, Physics of the Cosmos and Solar System Science
- Exoplanet Archive tracks exoplanet population and Kepler pipeline products
- Exoplanet Follow-up Observing Program supports Kepler & K2 sources follow-up

Confirmed in the HZ

Candidates

Irradiation – Period Distribution

19
Large Binocular Telescope Interferometer
Measuring HZ Exozodiacal Dust to Inform Designs of Future Missions

- 35-star survey, September 2018
- Progress: 26 stars observed
- Measurement Precision: ~12 zodi, one star one sigma
- See Steve Ertel’s talk at 2pm today

Phil Hinz, PI

Credit: NASA/GSFC

Credit: ESO/Y. Beletsky

Credit: ESO/Y. Beletsky

Credit: ESO/Y. Beletsky
Ground-Based Support for Space Missions
Partnering to Enable Key Projects for Strategic Reasons

Keck Observatory: (1/6 partner)
Key SMD Project and GO Investigations

Large Binocular Telescope Interferometer:
Exozodiacal Dust Survey
University of Arizona

NN-EXPLORE deploying WIYN Telescope
NEID Precision Radial Velocity Instrument
NASA Keck Time Administration

2018A Observing Opportunities

- NExScI solicits science and mission support proposals for NASA’s portion of the time on the two 10m WM Keck telescopes
- All proposals for the 2018A Semester are due September 14, 2017
  - Key Strategic Mission (KSMS) Support Proposals will be solicited in this semester to support missions in astrophysics and planetary science. 10-60 nights spread over up to 3 years
    - Precursor science or early follow-up for TESS and JWST will only be able to propose to KSMS in 2019B or for general Mission Support in 2018A
    - Non-binding letter of intent due August 16 for KSMS proposals

- PIs must be based at a U.S. institution
- Contingent upon funding, accepted proposals may receive limited funding
Kepler Close-Out
Delivering Kepler’s Legacy

• 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
**Kepler / K2**

Extending the Power of Kepler to the Ecliptic

Recently completed Campaign 13 (Taurus); now in Campaign 14 (Leo)

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

[https://exoplanets.nasa.gov/k2](https://exoplanets.nasa.gov/k2)
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.
Trappist-1 Discovery
The Richest Set of Earth-sized Planets Ever Found

ExEP’s role: Supported PI, Spitzer, & 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, travel poster.
The press release & media advisory had more web views than all NASA press releases issued in the last four months of 2016 combined.

Within a few days, the potential reach of all social media posts talking about the announcement was over 3.2 billion non-unique users (includes duplicates who may see multiple posts from different sources).

Within a few days, 99.97% of all 514,752 social media mentions of the announcement came from non-NASA sources.

#askNASA Q's on social media yielded over 10,000 questions & the scientists answering Q's on Reddit was the top item on Reddit.com on 2/22 afternoon.

On streaming TV, website pageviews and reach of NASA's own social media posts, this was a top 10 NASA story on digital of all time. (7th largest traffic day on NASA.gov since 2013; Top day for reach of NASA's own social media posts since 2015)

This story has had interest at a level seen only every 18 months-2 years.
Possible New Worlds Exoplanet Telescopes
(mid 2030s; work outside ExEP)

• Origins Space Telescope\(^1\): mid/far-infrared flagship mission
  – Primary exoplanet science case is transit spectroscopy
  – New exoplanet working group co-Chaired by Lisa Kaltenegger (Cornell) & Kevin Stevenson (STScI)

• Large Ultra-Violet Optical InfraRed Telescope (LUVOIR)\(^2\)
  – Coronagraphic imaging with deployed/segmented primary mirror
  – Large apertures & exoplanet survey samples
  – 5 instruments, equal weighting to exoplanets & general astrophysics

• Habitable Exoplanet Mission (HabEx)\(^2\)
  – Coronagraph & starshade imaging with monolithic, off-axis telescope
  – Smaller apertures & exoplanet survey samples
  – 3 instruments, including UV spectrometer & general astrophysics camera

\(^1\)Eric Mamajek, \(^2\)Karl Stapelfeldt track for ExEP
Progress in HabEx and LUVOIR designs
(work outside of ExEP)

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

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

ExEP supports technology needs
Upcoming Program-related Events

• Kepler/K2 SciCon here this week:
  – DPCS Eric Mamajek, invited conference talk: “Kepler/K2 in the Context of Future Exoplanet Missions” Fri 6/23 1:30-2pm

• Astronomy in the 2020s: Synergies with WFIRST
  – STScI Baltimore MD, June 26-28, 2017

• Sagan Summer Workshop

• 3rd Workshop on Extreme Precision Radial Velocities
  – State College PA, August 14-17 2017

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

• NExSS Workshop “Habitable Worlds 2017”
  – Laramie WY, November 13-17
The Exoplanet Exploration Program

Delivering upon these Purposes:
- Discover planets around other stars
- Characterize their properties
- Identify candidates that could harbor life

Stay connected with us through newsletter and website: exoplanets.nasa.gov/exep

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