

Exoplanet Exploration Program Updates

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June 18, 2020

ExoPAG 22, Virtually Everywhere

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Artist concept of Kepler-16b

NASA Exoplanet Exploration Program



Astrophysics Division, NASA Science Mission Directorate

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

Program purpose per Charter from Astrophysics Division

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

ExEP serves the science community and NASA:

- Focal point for exoplanet science and technology
- Integration of cohesive strategy for future discoveries

<https://exoplanets.nasa.gov>

Exoplanet Missions

NASA Missions

Non-NASA Missions

Hubble¹

Spitzer

Kepler

TESS

JWST²

CHEOPS⁴

Gaia

CoRoT³

Roman

ARIEL (CASE)

PLATO

LUVOIR⁵

Starshade
Rendezvous⁵

HabEx⁵

Origins⁵

W. M. Keck Observatory

Large Binocular
Telescope

WIYN

SMARTS 1.5m⁶

AAT

MINERVA-Australis

Ground Telescopes with NASA participation

⁵ 2020 Decadal Survey Studies

⁶ NSF Partnership (NN-EXPLORE)

¹ NASA/ESA Partnership

² NASA/ESA/CSA Partnership

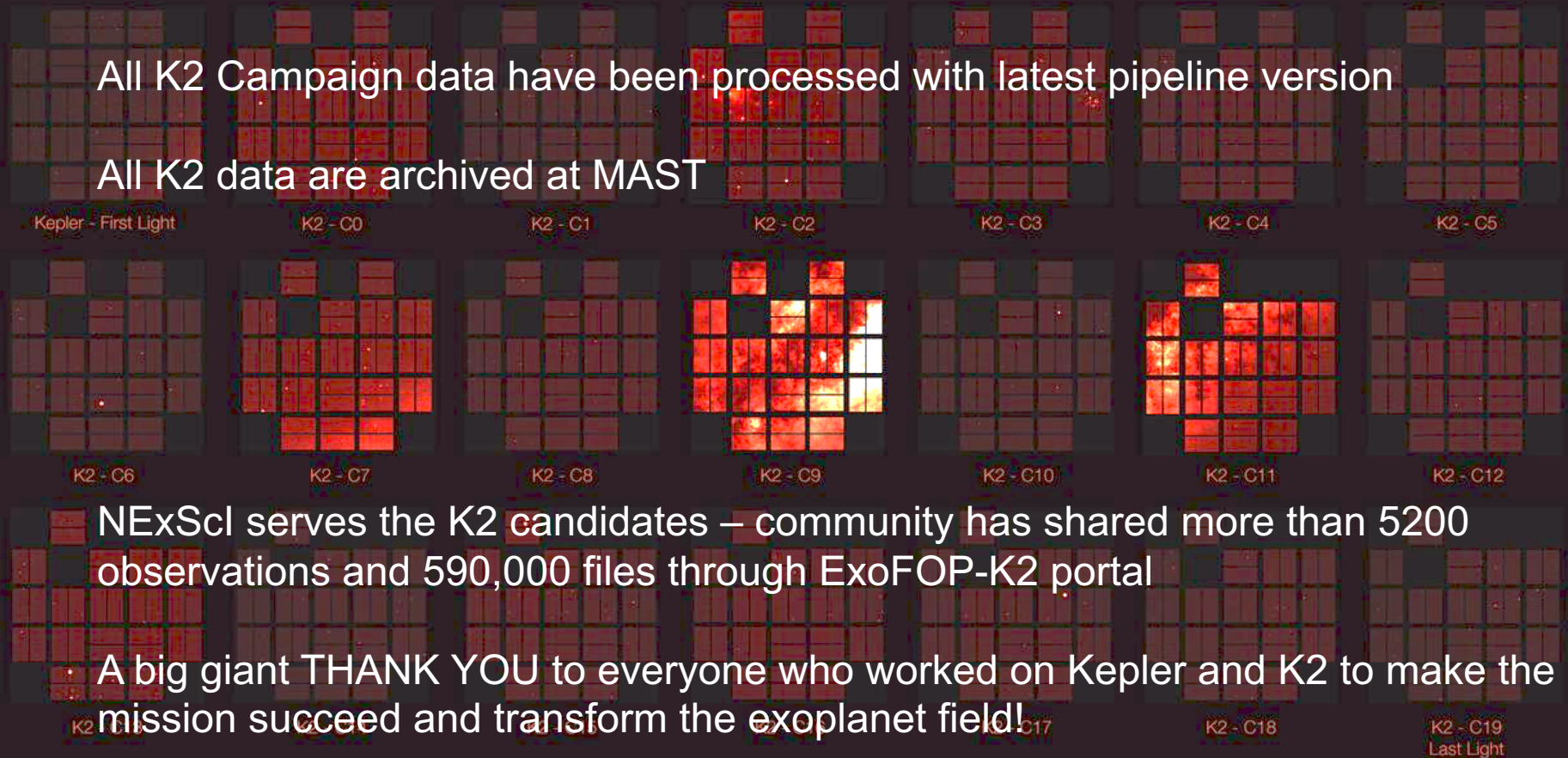
³ CNES/ESA

⁴ ESA/Swiss Space Office

Kepler's/K2

All K2 Campaign data have been processed with latest pipeline version

All K2 data are archived at MAST



NExScI serves the K2 candidates – community has shared more than 5200 observations and 590,000 files through ExoFOP-K2 portal

A big giant THANK YOU to everyone who worked on Kepler and K2 to make the mission succeed and transform the exoplanet field!

The Kepler space telescope examined twenty-one patches of the sky during its nine and a half years of operation. Within these regions, Kepler gathered high precision brightness

measurements of over half a million stars facilitating the discovery of thousands of exoplanets and yielding insight into a multitude of other astrophysical phenomena. On the back are interesting objects unique to each field of view.

NASA Exoplanet Exploration Program



Space Missions and Concept Studies

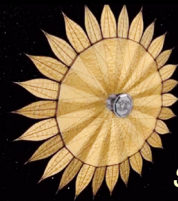
Kepler K2



Large- and Probe-Scale
Mission Concepts

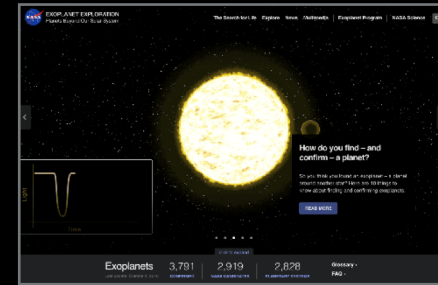


Coronagraph



Starshade

Exoplanet Communications

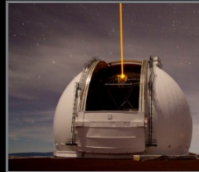


Supporting Research & Technology

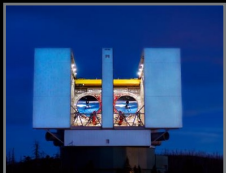
Key Sustaining Research



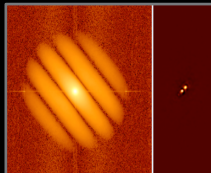
NN-EXPLORE



Keck Observatory

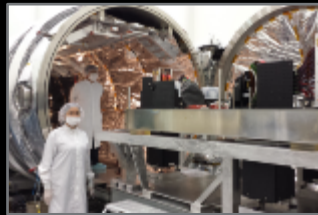
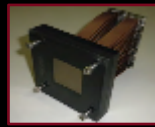


Large Binocular
Telescope
Interferometer

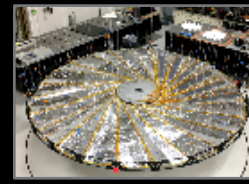
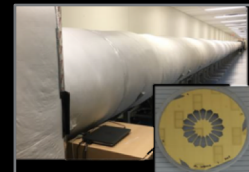


High Resolution
Imaging

Technology Development

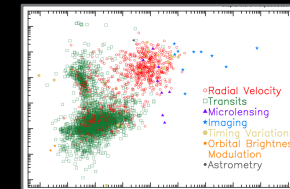


Coronagraph
Technology
Development



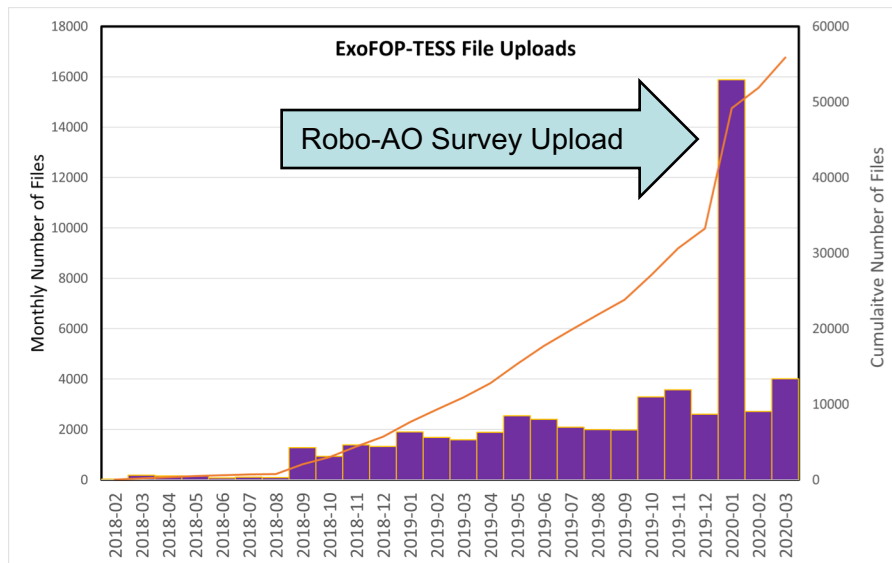
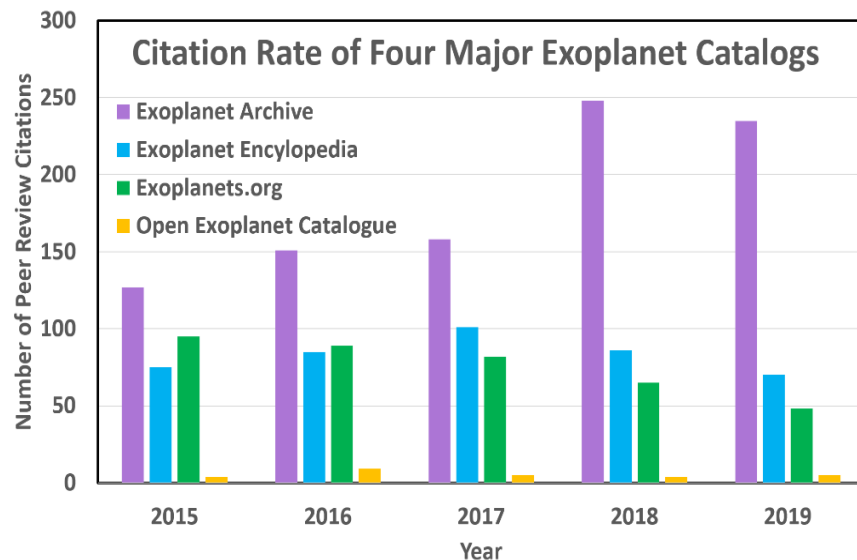
Starshade
Technology
Development (S5)

NASA Exoplanet Science Institute (NExSci)



Archives, Tools, Sagan Program,
Professional Engagement

- **Exoplanet Archive:** 4164 confirmed planets w/51 TESS planets
- **5-Year Programmatic Review of Archive/ExoFOP:** “Excellent/Very Good”
 - Panel recognized the growth of the Archive content and usage over the past 5 years.
- Beta-release of the new **Planetary Systems table**, **Composite Parameters table** (both with TAP API), and Overview Pages are on their way
- **ExoFOP** continues to support community TESS (and Kepler and K2) follow-up
 - >1900 TESS Objects of Interest (TOIs)
 - >430 community TOIs → 67 cTOIs converted to TOIs by the Project
 - >65,000 files community files (~3000/month)
 - >11,000 recorded observations
 - Consolidation of ExoFOP-Kepler, ExoFOP-K2, and ExoFOP-TESS into one portal underway



- **Community access** to observing resources for exoplanets and more
- **Keck – Strategic programs** from all areas of astrophysics and planetary science
 - 7 exoplanet GO programs approved for 2020B
 - 2 continuing exoplanet Key Strategic Mission Support programs for TESS and Kepler (20A-21A)
- **NN-EXPLORE**
 - WIYN: NEID (PRV and daily solar data); NESSI (HRI); WHIRC (NIR imaging/time series); HYDRRA (MOS)
 - Southern Hemisphere PRV
 - SMARTS-CHIRON (stellar spectra, ~ 10 m/s)
 - AAT-Veloce (PRV on 4m; $\sim 1 - 5$ m/s)
 - Minerva-Australis (4x0.7m; $\sim 2 - 10$ m/s)
 - Special 2020B Call for Minerva-Australis
 - 285 hours available
 - Due date 16 July 2020
 - <https://nexsci.caltech.edu/missions/Minerva/>

Observing Resources

NExSci provides access to a variety of observing resources in support of community research primarily in exoplanets, but also general astrophysics and planetary science.

NASA Time on the Keck Observatory

The cornerstone of the NExSci supported observing resources is the NASA Keck Time. NExSci manages NASA's partnership with the W. M. Keck Observatory. Both Keck 1 and Keck 2 telescopes and all instruments are available to the community for exoplanet, astrophysical, and planetary science observations. More information on Keck instrumentation and how to apply for NASA Keck time can be found [here](#), in Waimea, Hawaii. The Keck telescopes are two 10-meter aperture telescopes whose primary mirrors are each composed of thirty-six 2 meter mirror segments.



NN-Explore Program

NASA and the National Science Foundation have established the NASA-NSF Exoplanet Observational Research (NN-Explore) partnership to support community exoplanet research. The NN-Explore program was created in response to the community need for observational resources for exoplanet discovery and characterization. There are multiple resources available to the community through this partnership; more information on how to apply for time through the NN-Explore Program can be found at the [NOIRLab Call for Proposals](#)



WIYN

The cornerstone of the NN-Explore Program is the NASA partnership on the WIYN telescope located at Kitt Peak Observatory. The premiere instrument on the telescope is the high precision radial velocity machine NEID which is a high resolution spectrometer capable of radial velocity precisions of 30 cm/s. Also available on WIYN is the high spatial resolution optical speckle imager NN-Explore Exoplanet Stellar Speckle Imager (NESSI). Other instruments available to the community include WHIRC, Hydra, and ODI.



SMARTS-CHIRON

CHIRON on the SMARTS 1.5m telescope located at the Cerro-Tololo Observatory is a fiber-fed high resolution spectrometer capable of radial velocity precisions of a few meters per second. Through the NOIRLab partnership in the SMARTS consortium, NASA has made available time for exoplanet confirmation and characterization - especially for TESS planetary candidates.



AAT-Veloce

Veloce is a stabilized high resolution echelle optical spectrograph on the Anglo-Australian Telescope (AAT). Veloce uses a fiber bundle to reach radial velocity precisions of a few meters per second or better. Through the NN-Explore partnership, NASA has made available time for exoplanet confirmation and characterization - especially for TESS planetary candidates.



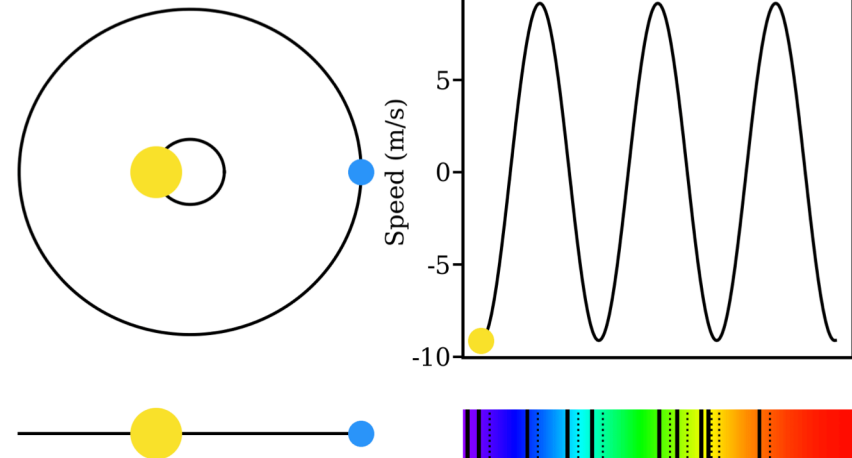
Minerva-Australis

Minerva-Australis is an array of 0.7m telescopes all feeding a single precision spectrograph. The facility is located at Mt. Kent Mt. Kent and is able reach radial velocity precisions of a few meters per second. Through the NN-Explore partnership, NASA has made available time for exoplanet confirmation and characterization - especially for TESS planetary candidates.

(last updated May 21st, 2020 21:50:35)

- **Sagan Summer Workshop on EPRV**
 - Our 20th Workshop in the series!
 - 20 – 24 Jul 2020
 - Fully virtual; building off of NASA-NSF EPRV working group
 - <https://nexsci.caltech.edu/workshop/2020>
- **Calendar of Virtual Exoplanet Talks**
 - Submit your online talk for viewing
 - https://nexsci.caltech.edu/missions/remote_exoplanets.shtml
- **Exoplanet Demographics**
 - 9 – 12 Nov 2020
 - Contributed talks deadline 09 July
 - For more info: Jessie Christiansen
 - <https://nexsci.caltech.edu/conferences/exodem/>

Alysa Obertas (@AstroAlysa)



Calendar of Virtual Exoplanet Talks

During these times of COVID, exciting exoplanet science is still taking place from home offices across the country and around the globe. People are sharing their work online giving wider access to talks.

To have your exoplanet talk listed here, please fill in this [Google Form](#)

Events will be listed on this page by month, and also on this [Google calendar](#)

All times are local to the host institution.

June 2020

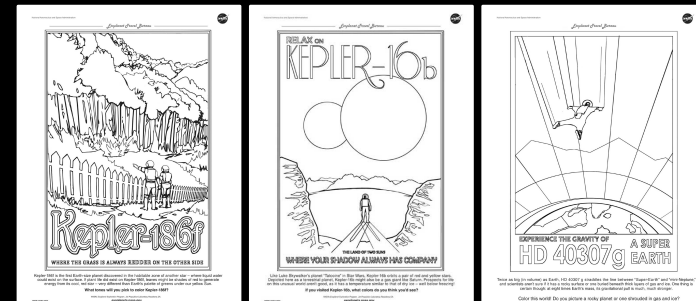
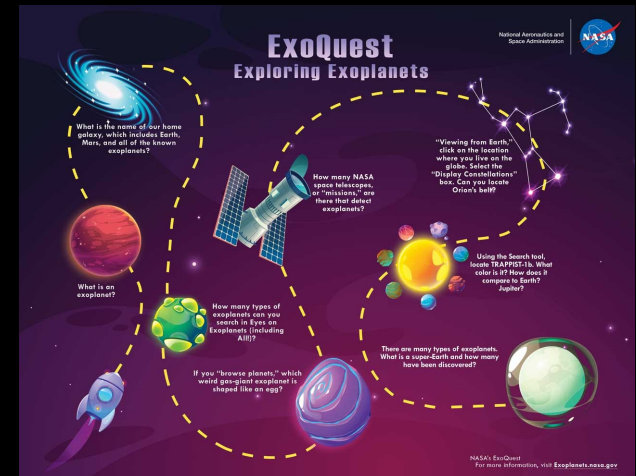
Date/Time	Host Institution	Speaker	Viewing Link	Contact
June 29 11 am (MST)	Univ. of Arizona	Regis Ferriere (University of Arizona/ Ecology & Evolutionary Biology and iGLOBES International Research Laboratory)	Modeling life-planetary Feedbacks in Anoxic Worlds: Implications for Habitability and Biosignatures	Serena Kim
June 22 11 am (MST)	Univ. of Arizona	Stefano Facchini (European Southern Observatory)	TBA	Serena Kim
June 15 11 am (MST)	Univ. of Arizona	Dániel Apai (Univ. of Arizona)	Nautilus: A Giant Space Telescope with a New Optical Technology for Large-Scale Biosignature Surveys	Serena Kim
June 8 11 am (MST)	Univ. of Arizona	Alex Bixel (Univ. of Arizona)	Testing Earth-like Atmospheric Evolution on Exo-Earths	Serena Kim

May 2020



Date/Time	Host Institution	Speaker	Viewing Link	Contact
May 19	Univ. of Washington	Zoe Todd (Harvard Univ.)	What Can the Planetary Environment Tell Us About Origins of Life?	Daniel Larsen

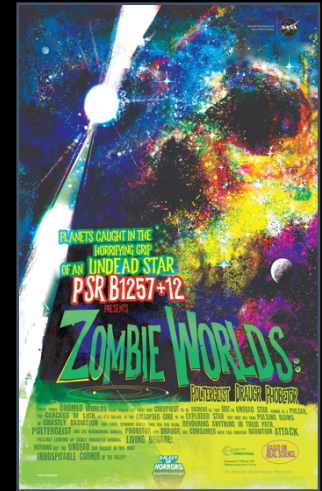
Exoplanet Resources: NASA at Home

- Collection of Exoplanet Resources:
<https://exoplanets.nasa.gov/news/1643/explore-exoplanets-at-home-with-nasa/>
- Exoplanet Travel Bureau Coloring Pages:
<https://exoplanets.nasa.gov/news/1634/download-our-exoplanet-coloring-pages-and-colorwithnasa/>
- Eyes on Exoplanets Scavenger Hunt:
<https://exoplanets.nasa.gov/quizzes/exoplanets-savenger-hunt/>
- NASA at Home Resource collections:
 - NASA STEM at Home: <https://www.nasa.gov/stem>
 - Learning Space with NASA at Home:
<https://www.jpl.nasa.gov/edu/learning-space/>
 - NASA at Home:
<https://www.nasa.gov/specials/nasaathome/index.html>



ExoComm Cheat Sheet

- Website: <https://exoplanets.nasa.gov/>
 - Planet Counter
 - Eyes on Exoplanets
 - Multimedia Gallery
 - 5 Ways to Find a Planet (downloadable animations):
<https://exoplanets.nasa.gov/5-ways-to-find-a-planet/>
 - Exoplanet Travel Bureau (VR and Posters!):
<https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/>
 - Galaxy of Horrors (3d planets and Posters!):
<https://exoplanets.nasa.gov/alien-worlds/galaxy-of-horrors/>
-  NASAExoplanets
-  @NASAExoplanets
- Universe of Learning (PI STScI, Co-Is: IPAC, JPL, Sonoma State, Harvard SAO): <https://www.universe-of-learning.org/>



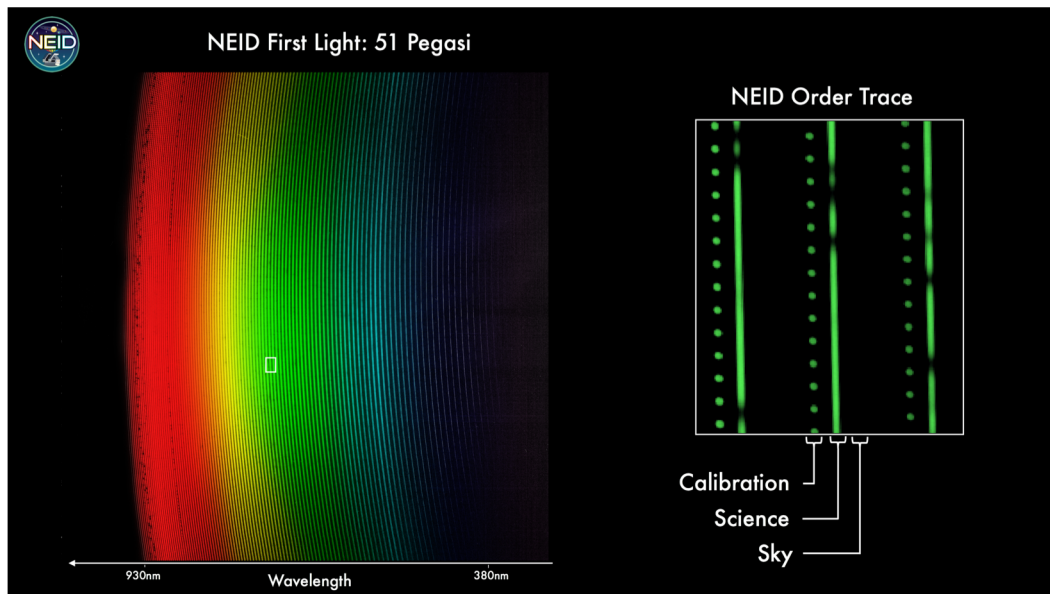


NN-EXPLORE Update

John Callas, Manager
Jet Propulsion Laboratory

NEID Status

- NEID Instrument and Port Adapter delivered to WIYN.
 - Commissioning underway when pandemic interrupted.
 - KPNO currently closed; NEID warmed up.
- Hopeful for shared-risk GO in late 2020B and commissioning completion by January/February 2021.
- Full GO and GTO expected for 2021A.
 - with NEID standard stars and solar data released immediately.



More information: <https://exoplanets.nasa.gov/exep/NNExplore/>

TESS Follow-Up Support

Southern Radial Velocity



SMARTS/Chiron



AAT/Veloce

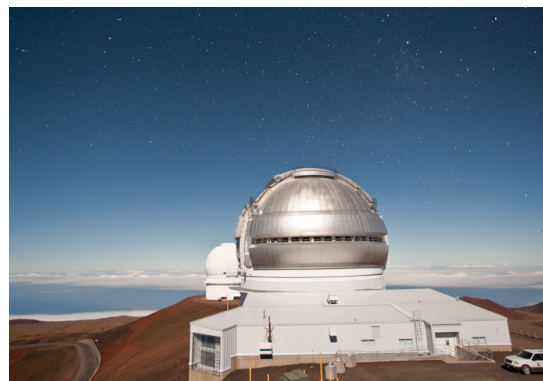


MINERVA-Australis

High-Resolution (Speckle) Imaging



WIYN/NESSI



Gemini-North/Alopeke



Gemini-South/Zorro

More information: <https://exoplanets.nasa.gov/exep/NNExplore/>

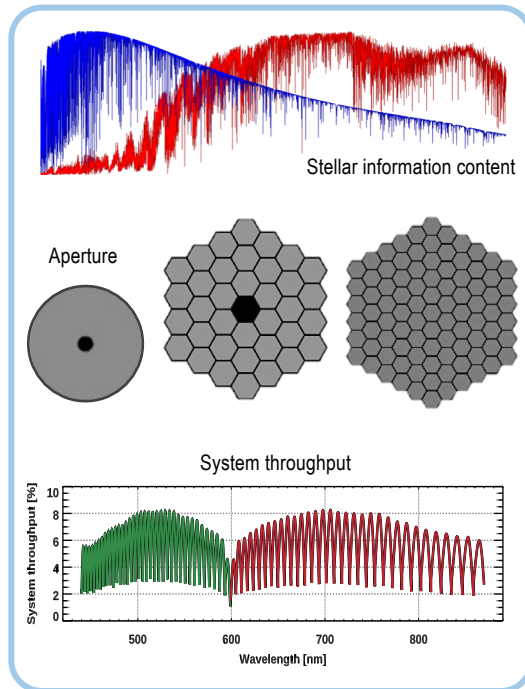
"Mass is the most fundamental property of a planet, and knowledge of a planet's mass (along with a knowledge of its radius) is essential to understand its bulk composition and to interpret spectroscopic features in its atmosphere."

"NASA and NSF should establish a strategic initiative in **extremely precise radial velocities** (EPRVs) to develop methods and facilities for measuring the masses of temperate terrestrial planets orbiting Sun-like stars."

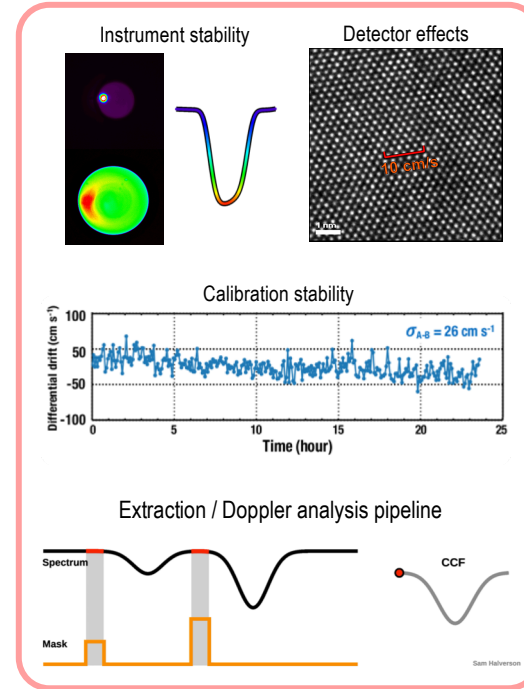
- Formed an EPRV working group (~36)
- Established eight sub-groups
- Held 3 face-to-face, multi-day workshops
(St. Louis, New York, Washington)



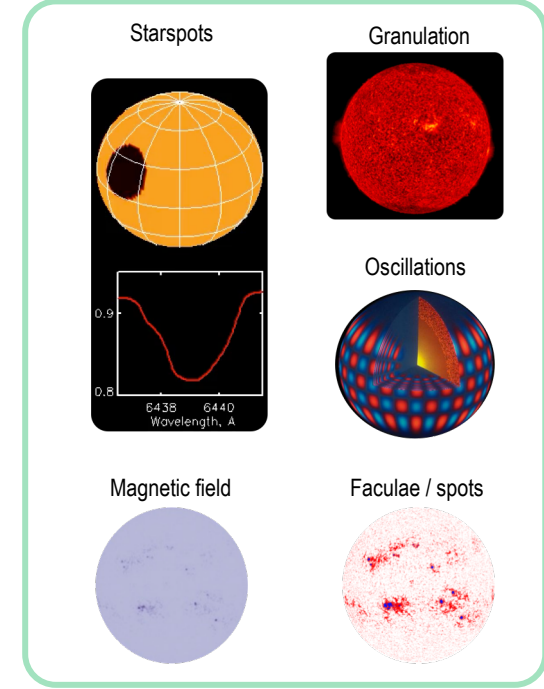
Radial Velocity Precision

 σ_{RV}
 σ_{photon}
 σ_{facility}
 σ_{star}


Telescope Aperture
and Cadence



Technology/Instrumentation and
Tellurics Research



Stellar Variability and
Data Analytics Research

Proposed Architectures

Proposed Research

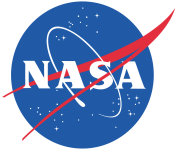


Jet Propulsion Laboratory
California Institute of Technology

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. © 2020 All rights reserved.



Program Science Update

Eric Mamajek

Deputy Program Chief Scientist

NASA Exoplanet Exploration Program Office

Jet Propulsion Laboratory, California Institute of Technology

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Government sponsorship acknowledged

CL#20-2491

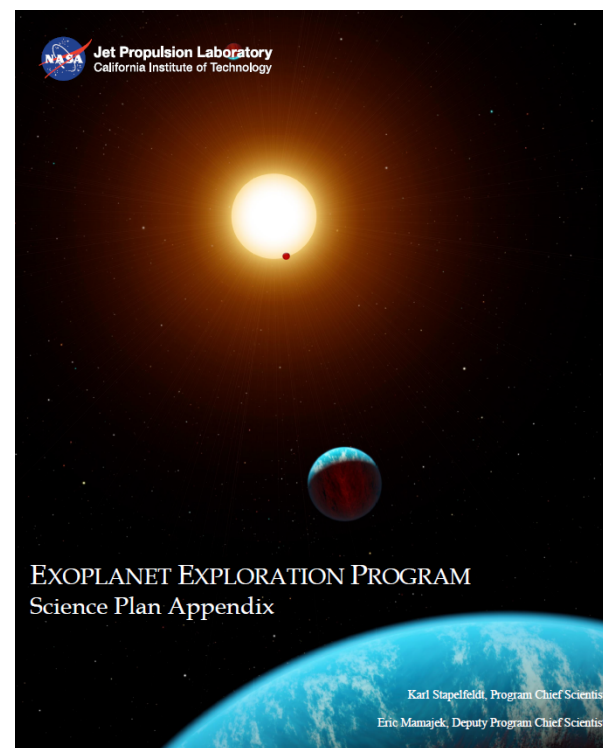
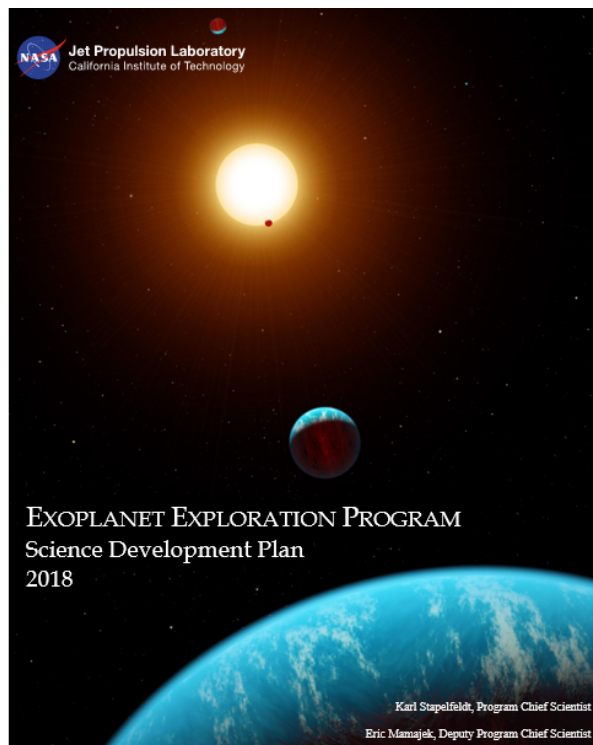
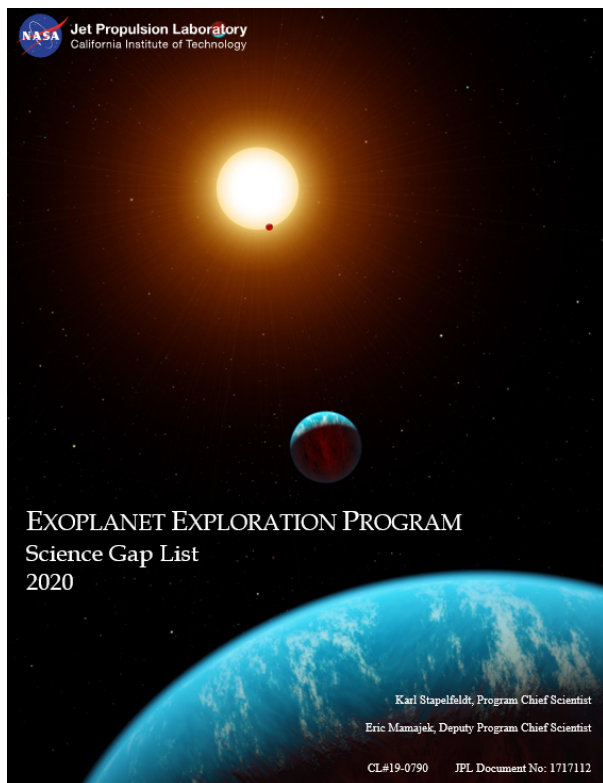
Exoplanet Science Plan and Science Gap List



- The ExEP Science Plan has tactical scope for the implementation of science goals assigned to ExEP by NASA HQ and flowing from community policy documents. It now consists of
 - The **Science Gap List** (SGL) specifies areas where additional science work would advance Program goals
 - The **Science Development Plan** defines roles and relationships between exoplanet scientists at HQ, Program Office, ExEP Projects, NExSci, and ExoPAG. It also lays out the process for SGL updates.
 - The **Science Plan Appendix** provides background information on state of the field, upcoming missions and facilities, and knowledge needed to inform ExEP objectives in five subdisciplines of exoplanet research (context for the SGL).
- Documents at <https://exoplanets.nasa.gov/exep/science-overview/>
- The Science Plan documents are intended for use in proposal solicitation, writing, and evaluation; mentioned in [2020 XRP](#) call ([ROSES E.3 Exoplanets Research](#))

Three Exoplanet Program Science Plan documents

Authored by ExEP Program Chief Scientists
Stapelfeldt & Mamajek
Reviewed by ExoPAG EC and NASA HQ



ExEP Science Gap List topics

(grouped by topic, no implied priority in ordering)



- Spectral characterization of small exoplanets
- Modeling exoplanet atmospheres
- Spectral signature retrieval
- Planetary system architectures
- Occurrence rates for HZ exoplanets (e.g. η_{\oplus})
- Yield estimates for exoplanet direct imaging missions
- Properties of exoplanet host stars
- 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 distribution of exozodiacal dust
- Measurement of accurate transiting planet radii

Revisions to the Science Gap List



- Community input on the 2018 SGL was solicited at the June 2019 ExoPAG meeting and by emails to the exopagannounce list; 3 month window for responses
- Program Chief Scientists revised gap list during fall 2019
 - Gap descriptions were updated to reflect research and programmatic progress, clarified in some cases, and revised to take into account the community inputs received
 - We felt that the community inputs could be adequately addressed by revising the gap descriptions without adding new gaps
- The revised (2020) ExEP Science Gap List was approved and posted 3/2020
- For 2020, we'll proceed with similar process & schedule, and continue annually
- In 2021 we will also update the Science Plan appendix to take into account the Decadal Survey recommendations and NASA's response (A new Astrophysics Implementation Plan)
- **Call for input on ExEP Science Gap List now open through September 30, 2020.**
- **We welcome discussion of the ExEP Science Plan content at any time, please contact Karl.R.Stapelfeldt@jpl.nasa.gov & Eric.Mamajek@jpl.nasa.gov**

Update on LBTI exozodi survey results

- $\lambda = 10\ \mu\text{m}$ nulling interferometer on the 2 x 8.4m Large Binocular Telescope
- HOSTS exozodi survey completed in May 2018 with 38 stars measured
- [Ertel et al. 2020](#) final survey paper has been published. Extended $10\ \mu\text{m}$ emission detected in 4 of 23 sun-like stars, at levels ≥ 150 zodis
- **Best-fit distribution function has a median of 3 zodis, $+1\ \sigma$ level of 9 zodis, & 27 zodi upper limit at 95% confidence level [Sun-like stars]**
- Key implications: Future imaging missions can achieve their science goals against the nominal 3 zodi background. But uncertainty in the median affects the S/N and integration times for exoEarth spectroscopy, especially for smaller apertures such as WFIRST starshade rendezvous.
- HOSTS team continues to work on papers treating individual stars. Summer team meeting plans in flux due to COVID-19.



Should NASA invest in further work to reduce exozodi uncertainties ?

- In early March Univ. of Arizona delivered a 28 page report on potential upgrades to LBTI. The ``sensitivity study'' found:
 - For bright stars, telescope vibrations dominate the null uncertainty; for fainter stars, it's excess detector noise.
 - A factor of 2-3 improvement in system sensitivity may be achievable with vibration mitigations and a new detector
 - Lab tests with new detector candidate will complete by this fall
- Little further work would be needed if Decadal selects an imaging mission
- Should the HOSTS survey be repeated with an upgraded LBTI, or NASA pursue
 - Ground-based near-IR interferometers for hot zodi studies ? (CHARA, VLTI)
 - Thermal-IR coronagraphy with ELTs ? JWST spectroscopy ?
 - Roman CGI Project Scientists & Science Teams are considering CGI's potential capabilities for an exozodi survey. A possible science program for after the tech demo?
 - Capability depends strongly on whether the CGI performance exceeds the current requirements. If yes, a CGI 2-hemisphere survey could surpass LBTI's sensitivity. But might not know until on-orbit. Teams are preparing a paper with the details.

ExoPAG Suggestions Status



- Findings from ExoPAG 21:
 - On the need to invest in databases to support programs related to achieving NASA's strategic goals → **New SAG forming for this issue**
 - On the topic of ExoPAG providing input to other Divisions and programs on topics related to Exoplanets → **PSD and ESD liasons to ExoPAG have been named**
 - On the topic of evolution in the Exoplanet Research Program (XRP) outcomes and funding lines → **Being discussed internally at NASA HQ**
- Science Analyses:
 - coordinate/monitor research on exoplanet demographics (Christiansen/ Meyer) → **SIG2 very active; NexSci-sponsored ExoDem conference 11/2020**
 - coronagraph metrics & data challenges (Jensen-Clem) → **SAG 19 (data challenge closed at the end of Jan, need new update)**
 - strategies for mitigating JWST delays (Teske / Deming) → **SAG 20 (Closed: final report posted to ExoPAG website)**

Additional suggestions and status in backup slides; they'll be discussed further in business meeting Friday. New suggestions can be added through "Ideas" in Slido.

Follow NASA Exoplanet Exploration Activities



- Exoplanet Exploration Program public website:
<https://exoplanets.nasa.gov>
- ExEP website for the scientific community:
<https://exoplanets.nasa.gov/exep>
Includes dedicated areas for ExoPAG, ongoing technology work, science planning, and a document archive of prior studies & reports
- NASA Exoplanet Science Institute with the NASA Exoplanet Archive: <https://nexsci.caltech.edu>
- Sign up for the ExoPAG mailing list (~700 subscribers):
<https://exoplanets.nasa.gov/exep/exopag/announcementList/>

Backup slides

ExoPAG Suggestions Status



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ExoPAG Suggestions Status



- Connections to policies in development:
 - Define RV strategy to reach precision of 1 cm/sec, per recommendation of NAS ESS report → **EPRV WG presentation is completed and posted, NASA HQ factoring into FY21 budgeting decisions, EC can choose to monitor implementation. Full EPRV WG report is being written.**
 - Should ExoPAG respond in any way to NAS ESS & Astrobiology reports, and if so how ? (EC & all) → **There has been no clamor to do this, seems like the time has passed for any action**
 - Ongoing discussions of issues affecting future exoplanet exoplanet flagships. One clear issue is the likelihood that PRV will not be able to provide masses/orbits for a large fraction of HabEx/LUVOIR targets. Should flagships skip those targets? Take data and develop a strategy for interpreting spectra with no mass info? Or push for astrometry capability that could take up the slack? What technologies needed for astrometry? → **ExEPO holding internal discussions, welcomes EC input on ways to go forward**

ExoPAG Suggestions Status



- Connections to policies in development (continued):
 - Coordination of exoplanet inputs to decadal surveys (Meadows, outside of ExoPAG) → **Done for Astro2020, ongoing for Planetary Decadal (advertised multiple times since 5/17/20). So far 7 white papers listed.**

ExoPAG Suggestions Status



- Interaction with other NASA Programs:
 - Invite Lori Glaze to visit ExEP JPL staff and facilities (Stapelfeldt)
→ (on hold for now due to COVID-19)
 - Great observatories joint PAG with PCOS & COR (Meyer)
→ **Done, report posted** <https://cor.gsfc.nasa.gov/sags/sag10-draft.php>
 - Invite OPAG and VEXAG present to ExoPAG
→ **Done at ExoPAG 20. What is next step in terms of external PAG participation in ExoPAG? SIG3 to consider?**
 - Make ExoPAG members aware of next VEXPAG and OPAG meetings so they may possibly attend (Meadows/Kataria) → **Pending; tied into the possibility of appointing potential cross-PAG observers**
 - ExoPAG presentations at VEXPAG and OPAG (Meadows/Kataria)
→ **Pending; tied into the possibility of appointing potential cross-PAG observers**
 - Joint ExoPAG / planetary PAGs meetings (Meadows) → **Exoplanets in our Backyard Meeting took place at LPI in Feb 2020. Possible sequel?**

ExoPAG Suggestions Status



- Supporting resources for the community:
 - Expand access to ground telescopes for K2 & TESS followup (Blackwood/Hudgins) → **TESS GI program has been augmented to support this. Southern PRV: Chiron & MINERVA Australis.**
 - Assess demand for funding support for ground telescope followup (Hudgins / Barclay)
 - **HQ internal assessment of XRP proposal pressure in this area**
 - Assure that NASA exoplanet archive can handle upcoming vast increase in planet counts (Hudgins / Blackwood)
 - **Done, addressed in 2019 budget cycle**
 - How2 guides for new actors getting involved in TESS followup, tailored to different audiences of amateurs, small colleges, and professionals (Christiansen / Barclay). → **No actions taken: suggest ExoPAG get an update from astronomers involved w/TESS followup, then decide how to proceed.**

ExoPAG Suggestions Status



- Supporting resources for the community (continued):
 - Is further coordination needed of TESS community followup, especially spectra ? (Barclay / Christiansen) → **Seems like this would be covered by the T-FOP. What else might be needed?**
 - Opacity webserver for atmosphere modelers (Kempton)
→ **Get an update from Batalha & Lewis**
 - Mission stars target list for Exoplanet Archive
→ **ExEPO scientists refining lists from mission studies, need to vet for missing stars, will post at NExSci later in 2020. Proto-SAG to recommend scope of Archive holdings needed.**

ExoPAG Suggestions Status



- Topics to cover at future EC telecons or ExoPAG f2f meetings:
 - Citizen science → **Schedule presentation from Marc Kuchner (GSFC)**
 - Small sats → **Done - 3 presentations at ExoPAG 21**
 - Create new exoplanet animations
 - **Need detailed inputs to the ExEP Comms team, none received since the summer 2018 suggestion**
 - Synergy of ground & space observations
 - **Some discussions of this topic between ExEPO and CfAO community in the context of high contrast imaging**
 - Microlensing progress review talk
 - **Invite speaker for a talk at ExoPAG 23**

LBTI Sensitivity Study

LBTI conducted a study of its as-built sensitivity following the HOSTS survey and found two main limiters to performance with paths to future improvement:

- Vibrations in telescope secondary swingarm limit exozodi sensitivity for bright stars (future survey can damp them or observe during quiet periods)
- Excess low frequency noise in IR sensor limit sensitivity for all stars (future survey can replace Aquarius sensor with H1RG sensor)

