The Science Gap List for NASA's Exoplanet Exploration Program

Karl Stapelfeldt & Eric Mamajek

Program Chief Scientists

NASA Exoplanet Exploration Program Office

Jet Propulsion Laboratory, California Institute of Technology

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The What and Why of Science Gaps

- While knowledge gaps exist across astrophysics, our interest here is in knowledge gaps that affect the science return for missions NASA is committed to doing
- A Science Gap is a research area where additional work:
  1) Enhances the science return of a mission already flying - usually through **follow-up work**
  2) Enhances the science return & helps plan operations for an upcoming mission that is already designed – usually as **preparatory work**
  3) Provides information needed to quantify a future mission's ability to meet its science goals, and to assess mission design options – **this is precursor science**
- Before soliciting proposals or hearing entreaties for funding, it's better to set priorities in advance for the work that needs doing
- Science Gaps should be tactical, flowing down from Community priorities and NASA's established implementation plans
- A Science Gap List helps proposers sharpen their ideas and explain their proposal's relevance to NASA's goals. It is for guidance, not meant to be exclusionary.

Exoplanet Program's Science Gap List

ExEP NASA EXOPLANET EXPLORATION PROGRAM

- Development of a direct imaging mission for Earth-like exoplanets was an explicit recommendation for NASA Astrophysics in both the 2000 and 2010 Decadal Surveys – our Program has had a long time to plan for this !
- This first led to an **ExEP Technology Gap List** that has existed for more than a decade now, which has guided SAT proposals
- Kepler and TESS missions required significant preparatory & followup work to meet their science goals
- Identification of best transiting exoplanet targets for JWST and ARIEL spectroscopy requires significant preparatory work
- **ExEP's Science Gap List** is authored by Program Chief Scientists; initial internal version by Steve Unwin (2015)
- Has been made public, revised & updated annually since 2018
- Reviewed by NASA HQ, ExoPAG, and community feedback
- Now referenced in NASA ROSES proposal call for Exoplanets Research Program (XRP), used for proposal writing & evaluation
- At least half of our gaps bear directly on IROUV precursor science

2022 ExEP Science Gaps

Spectroscopic observations of the atmospheres of small exoplanets	Precur
Modeling Exoplanet Atmospheres	Yes
Spectral Signature Retrieval	Prep
Planetary system architectures: Occurrence rates for exoplanets of all sizes	Precur
Occurrence rates and uncertainties for temperate rocky exoplanets (e.g. eta Earth)	Precur
Yield estimation for exoplanet direct imaging missions	Precur
Intrinsic properties of known exoplanet host stars	Follow
Mitigating stellar jitter as a limitation to the sensitivity of exoplanet dynamical measurements	Precur
Dynamical confirmation of exoplanet candidates, determination of their masses & orbits	Follow
Precursor Observations of Direct Imaging Targets	Precur
Understanding the abundance and distribution of exozodiacal dust	Precur
Measurement of Accurate Transiting Planet Radii	Follow
Properties of Atoms, Molecules and Aerosols in Exoplanet Atmospheres	Yes
Exoplanet Interior Structure and Material Properties	Follow

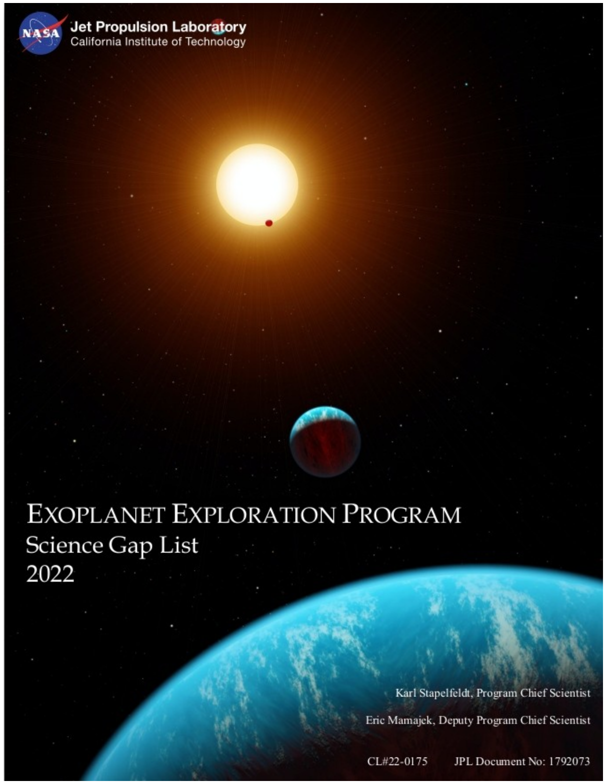
What does a science gap look like ?

- A science gap is concise enough to be described in roughly one page of text and consists of these 5 elements :
  - A Gap Title
  - A Summary description
  - The "Capability Needed", i.e. the data sets, modeling, or analysis products that would significantly benefit NASA exoplanet missions.
  - The "Capability Today", which in comparison to the "Capability Needed" defines the existing science gap
  - The "Mitigations in Progress", the efforts going on now that are likely to make progress in closing the gap
- We don't provide a "Mitigations not yet started" element – that's for individual proposers to conceive of
- To be an Exoplanet Program gap, we required it to be cross-cutting, affecting multiple program elements. Individual projects may define & track their own internal science gaps.

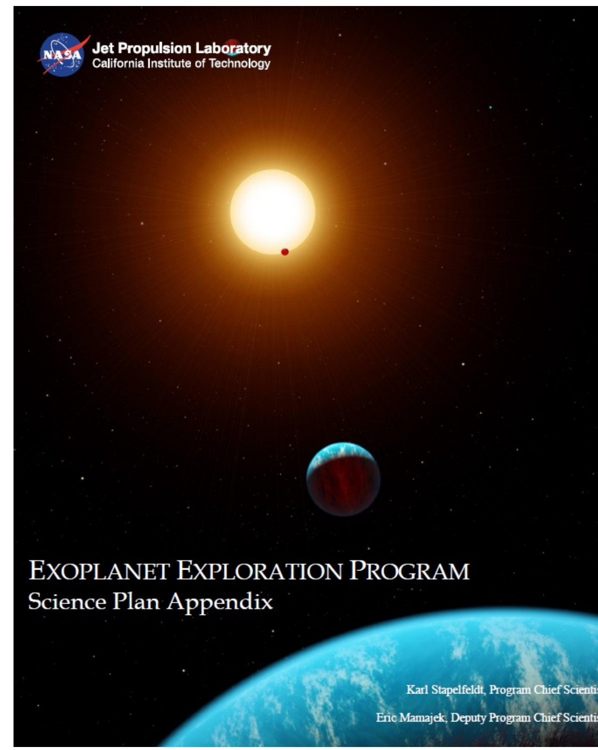
Example Science Gap Text

ID	Title	Summary	Capability Needed	Capability Today	Mitigation in Progress
SCI-10	**Precursor observations of direct imaging targets** *See SPA sections: 3 (exoplanet dynamics); 5 (properties of target stars), 6 (atmospheres & biosignatures)*	Precursor observations benefit future exoplanet missions by 1) screening for confusing background sources and close-in, low-mass stellar and substellar companions that might compromise exoplanet imaging sensitivity; 2) detecting exoplanets for future characterization, or setting observational and/or dynamical limits on their presence; 3) measuring stellar physical properties, chemical abundances and radiation environments to enable accurate planet characterization including interpretation of exoplanet spectra (see gap SCI-07); and 4) identifying systems with high exozodi levels where spectroscopy of small exoplanets may not be possible (see gap SCI-11).	Refined target lists consistent with the scope of the Astro 2020 Decadal-recommended direct imaging mission. For those targets, assess the bound companion (stellar and substellar) detection limits provided by existing data (e.g. PRV, astrometry, etc.). With the goal of detecting temperate rocky exoplanets in the target systems and other planets that may affect the dynamical stability of planet orbits in habitable zones, conduct precision RV observing programs in both N and S hemispheres (executed consistently over > 5 years), and conduct observations using other techniques which may feasibly detect small planets orbiting nearby target stars (including e.g. astrometry, and IR high-contrast imaging). Constraints on stellar multiplicity from high resolution imaging, RV and astrometry (e.g. Gaia), are needed to assess whether high contrast imaging will be feasible, as starlight suppression performance is affected by the presence of close neighboring stars. Uniform determination of stellar properties across the target sample in both hemispheres.	Howard & Fulton (2016, PASP, 128, 4401) completed a RV analysis to search for bound companions for stars in the 2014 versions of WFIRST CGI, Exo-S, and Exo-C target lists using data from California planet search. A similar study for Southern target stars has not been done. There are published (and unpublished) RV data for many potential Roman Space Telescope/CGI targets. Butler et al. (2017, AJ, 153, 208) published 61k RVs measured over 20 years for stars in Lick-Carnegie Exoplanet Survey, including many mission targets. NASA/NSF EPRV Working Group has recommended a strategy for a precursor observing program. Facilities: e.g., Keck HIRES, Lick APF, HARPS, HARPS-N, PFS-Magellan, EXPRES, MAROON-X, NEID. KPF coming online in 2022. Wagner et al. (2021, Nature Comm. 12, 922) VLT/NEAR observations of Alpha Cen A demonstrates current ground imaging IR sensitivity limits to planets around nearest targets. *Precursor catalogs*: The ERPV Working Group had sorted the pre-Astro2020 imaging mission study targets according to each star's suitability for extreme-precision Doppler measurements.	ExoPAG SAG 22 report includes recommended datasets to complete host star characterization. A catalog of the most likely target stars where small temperate planets could be imaged by Astro2020's prioritized Near-IR/Optical/UV 6-m telescope,will be posted to NExScI in early 2022, to encourage community observations and analysis of these systems. NEID GTO program on WIYN is surveying ~20% of NASA Mission Targets. EXPRES GTO program on LDT is surveying ~10-15% of NASA Mission Targets. Priority of precursor work on Roman CGI targets is unclear due to the instrument's tech demo status. Laliotis et al. are completing an archival analysis of PRV data from 5 spectrographs for ~100 S hemisphere stars likely to be targets of Astro2020 Decadal's recommended Near-IR/Opt/UV telescope. ESA Gaia mission Data Releases 3 and 4 (release date not yet announced) are expected to reveal astrometric perturbations by faint stellar companions and giant exoplanets for thousands of stars, some of which could be targets for direct imaging. Many of the target stars have been searched for close stelar companions by optical speckle imaging.

Science Gap List & Supporting Documents



“All ExEP approaches, activities, and decisions shall be guided by science priorities”
-- NASA Exoplanet Exploration Program Charter



Available for download at
https://exoplanets.nasa.gov/exep/science-overview/

Relevance to this workshop

- Astro2020's prioritization of the IROUV GOMaP effort means that the ExEP precursor science gaps should be revisited in that context, by new sets of eyes. Revisions, additions ?
- Astro2020's firm recommendation for X-ray and far-IR GOMaP development now provides the impetus for defining precursor science gaps for those missions. And non-exoplanet precursor science gaps should be defined for IROUV as well.
- Keep in mind: the gaps that most need to be identified now are the ones that affect mission architecture !
- In Thursday brainstorming, try to link ideas for precursor science work to the gap they would help to close
- Defining the performance metrics for the mission (such as spectra of 25 temperate rocky planets for IROUV) will help point you toward science gaps that need work. What do we not know, that we need to know, to calculate the values of a performance metric ? See Rhonda Morgan's talk next.
- The ROSES precursor science call for the NGOs will likely focus on the science gaps that come out of our two PS workshops