ExEP Science & Gap List Update
for ExoPAG 25

Karl Stapelfeldt & Eric Mamajek

Program Chief Scientists

NASA Exoplanet Exploration Program Office

Jet Propulsion Laboratory, California Institute of Technology

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Astro2020 saw it our way

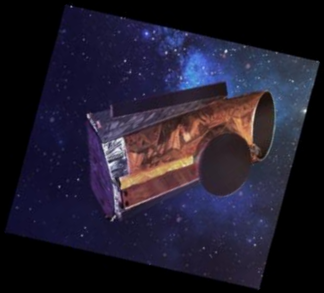
Worlds and Suns in Context

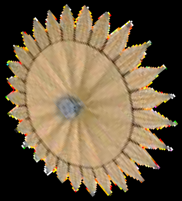
Pathways to Habitable Worlds

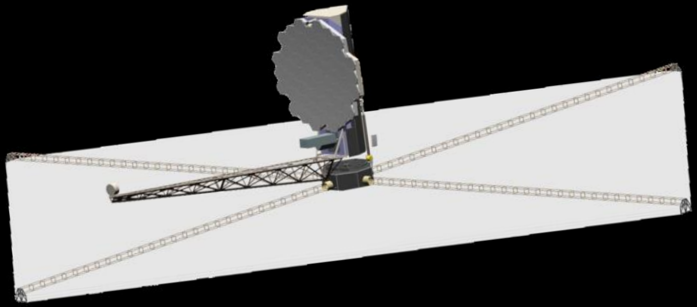
Are there habitable planets harboring life elsewhere in the universe ?

Is the Earth unique ?

Are humans alone?

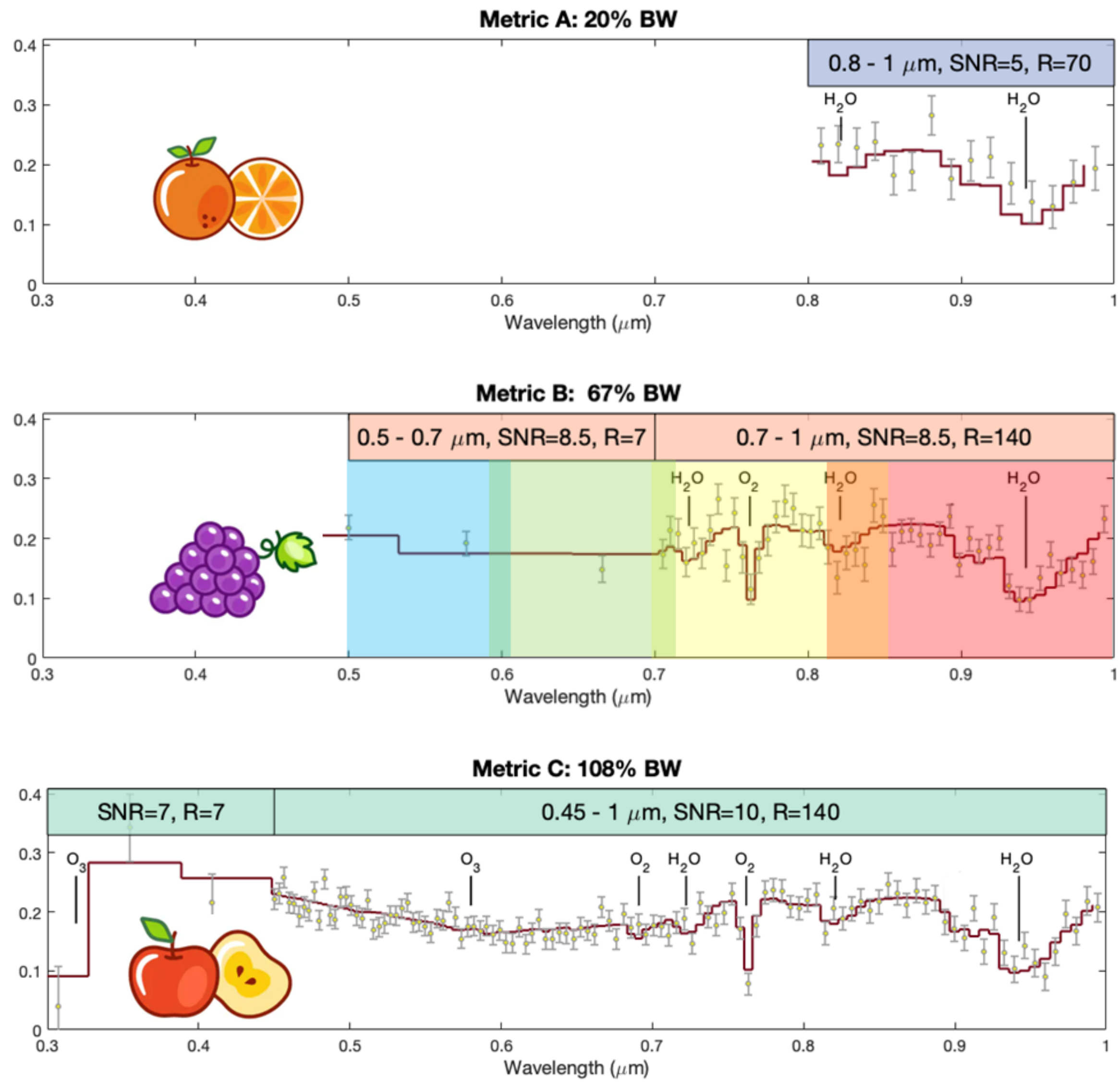






IROUV Open Question 1:
Which Spectral Characterization Yield Metric ?

- The HabEx & LUVOIR study reports used different metrics for reporting their yields of spectrally characterized exoplanets
- The choice of metric can strongly affect the mission yield numbers
- Near-IR wavelength coverage will be very limited, and different for every target
- A community consensus on the metric(s) to be used in architecture trades will be needed



Figures adapted from Morgan+ 2021, JATIS 7 021220

IROUV Open Question 2:
What is the strategy for planet mass determinations ?

NASA EXOPLANET EXPLORATION PROGRAM

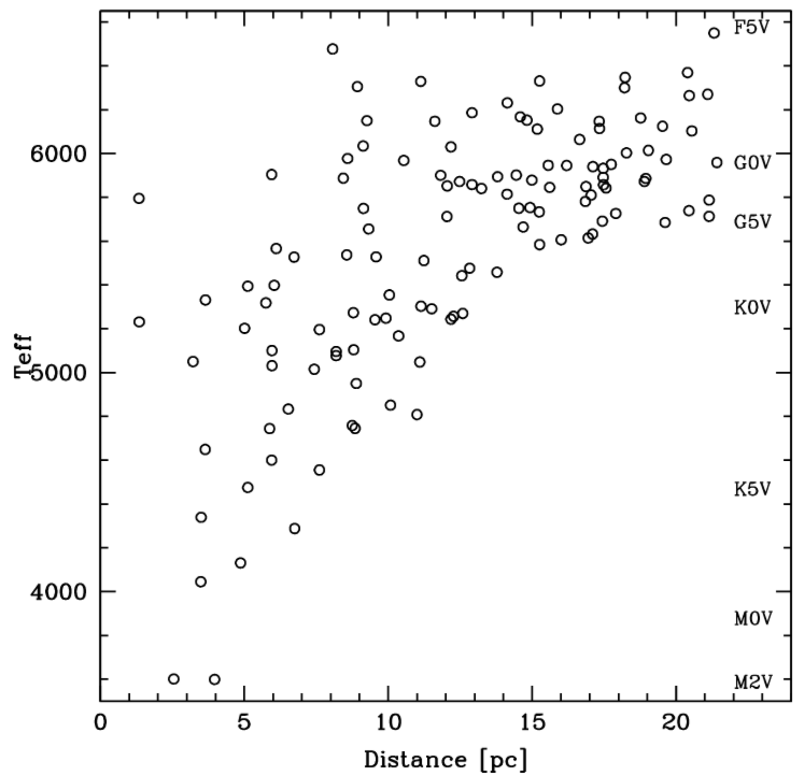
- Planet masses are hugely valuable for interpreting atmospheric spectra, the planet type, and the system architecture
- The Exoplanet Science Strategy's EPRV initiative is a program designed to get these masses, its implementation is pending
- BUT: Roughly 30% of the LUVOIR/HabEx target stars are too hot, or too fast-rotating, for the needed high-precision EPRV measurements (see EPRV WG final report)
- Need to evaluate the programmatic options to address this:
    1. Live with the lack of mass info for these targets, interpret these spectra as best we can. Assess the science impact of this choice.
    2. Study how to incorporate a precision astrometry capability in the IROUV mission itself, if feasible. But a 6m telescope is on the small side for this.
    3. Study a separate flight mission dedicated to follow-up precision astrometry on the exoplanets detected in this target set. $$$ option

IROUV Open Question 3:
How to make progress on uncertainties in $\eta_\oplus$ and exozodi ?

- Thanks to Kepler and LBTI, the estimates of $\eta_\oplus$ and exozodi provided to Astro2020 were encouraging enough to prioritize an exoplanet direct imaging mission !
- Post-Astro2020, the IROUV mission maturation program is likely to focus on how to balance risks across mission yields, costs, and technologies.
- Precursor science work that reduced the $\eta_\oplus$ and exozodi uncertainties would inform the eventual architecture trades
- Smart people have been working both issues for a long time … what new approaches could be taken ?
- An ongoing ExoPAG SIG 2, and the proposed new SAG on exozodiacal dust, could be the needed focal points for progress in these two areas.

IROUV Open Question 4:
Target List for Precursor & Preparatory Science

- The ExoPAG SAG 22 report lists the information we'd like to have on exoplanet host stars.
- Now that the scope of the future direct imaging mission is settled, the community can start work to build up this data for the ~200 IROUV targets
- The nearby stars with accessible HZs are defined by the inner working angle of the starlight suppression system, the limiting magnitudes and contrasts for making spectra with sufficient S/N, and by binarity issues. There is little flexibility to choose different targets.
- The LUVOIR-B or HabEx lists are not exactly the right ones for the future 6 m mission, **a refined list needs to be built & made available to the community**

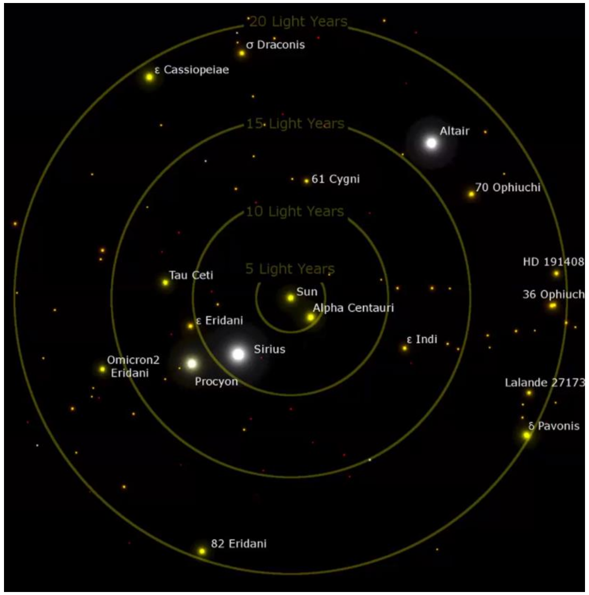


- ExEP Program Office Scientists are converging on a star list where the IROUV mission could access HZ rocky planets. We'll circulate it soon for SME review, and post it at NExScI in the next month or so.

Where We Explore

Community engagement on the prime targets for Exoplanet Exploration

Upcoming telescopes cannot reveal potentially habitable exoplanets around every star. Only a select group of stars are near enough & bright enough to see into their HZs, or have a small HZ planet that is aligned for transits. These are the stars where we have the best chance to discover another Earth – The stars **“Where We Explore”**.

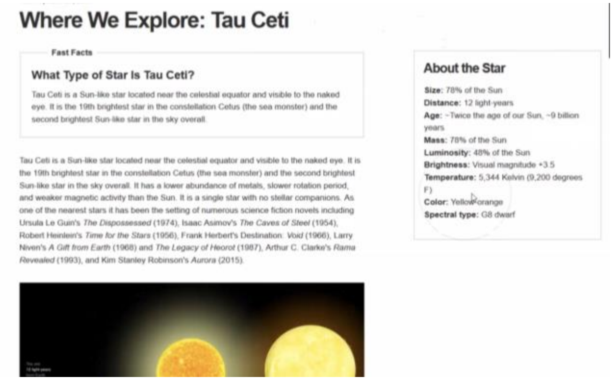


Goals:

- Raise awareness of the limited family of stars where planets with Earth-like conditions could be found in the next few decades
- Focus the public’s imagination on these stars and engage them in the evolving story and process of Exoplanet Exploration
- Build excitement for future discoveries and the telescopes that will make those observations

Products in Development:

- Descriptive content on the most promising targets, initially for about ~50, to be shared in tranches
- Will include timelines chronicling exploration milestones for each system



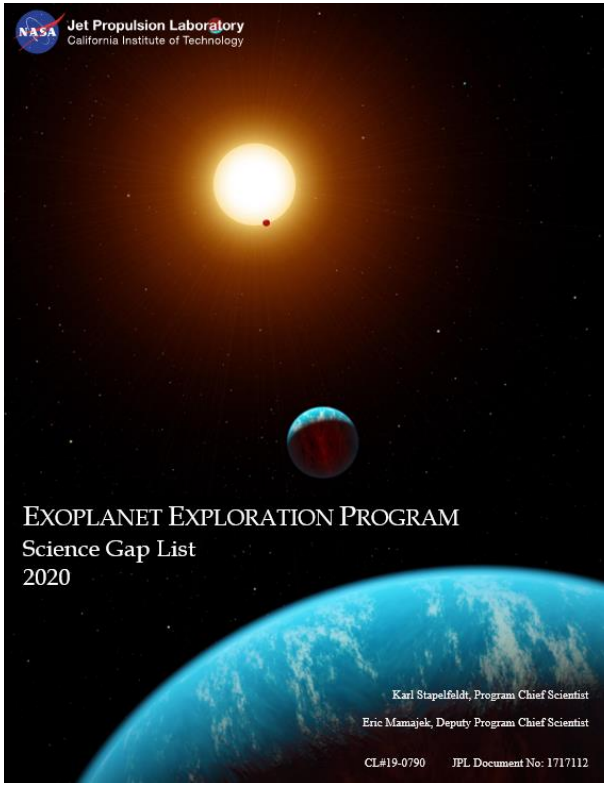
Prototype content by Anjali Tripathi

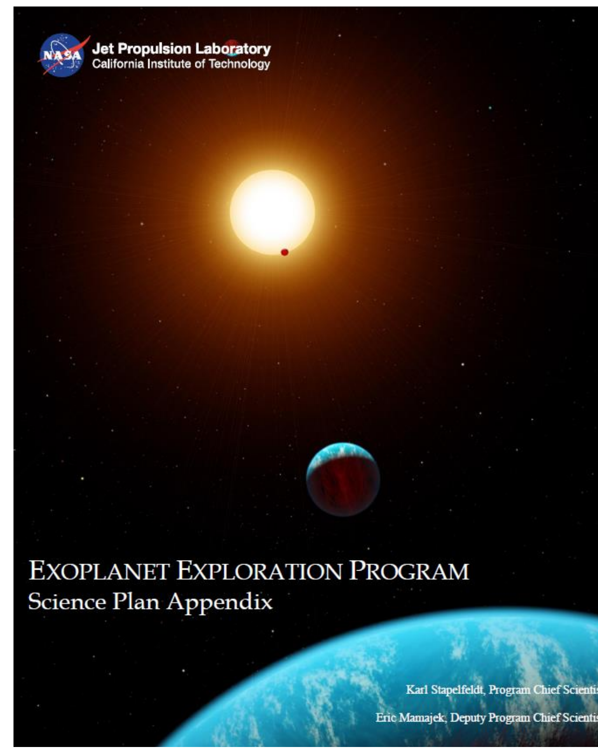
Science Gap List

Three Exoplanet Program Science Plan documents

"All ExEP approaches, activities, and decisions shall be guided by science priorities"

-- NASA Exoplanet Exploration Program Charter





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

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 consists of
  - The **Science Gap List** (SGL) specifies 14 research areas where additional work would enhance the science return of current and upcoming NASA missions, or provide info needed for the design of future missions. Updated annually.
  - 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. Relatively static.
  - The **Science Plan Appendix** puts the SGL in context with the state of the field, upcoming missions and facilities, and knowledge needed to inform ExEP objectives in five subdisciplines of exoplanet research. To be updated in 2022.
- Documents at https://exoplanets.nasa.gov/exep/science-overview/
- The Science Plan documents are intended for use in proposal solicitation, writing, and evaluation; they were referenced in the 2020 & 2021 XRP calls (NASA ROSES Exoplanets Research Program)

What does a science gap look like ?

- A science gap is concise enough to be described in roughly 1 page of text and consists of these 5 elements :
  - A gap Title
  - Summary description
  - "Capability Needed", i.e. the data sets, modeling, or analysis products that would significantly benefit NASA exoplanet missions
  - "Capability Today", which in comparison to the Capability Needed defines the existing science gap
  - "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, it needs to be cross-cutting. We leave it to individual projects to track their internal science gaps.

2021 Science Gap List Revision Process

- Community input on the 2021 SGL was solicited at the June 2021 ExoPAG meeting and by emails to the exopagannounce list. The 3 month window for responses closed at the end of September.
- We received 37 unique gap list suggestions from the ExoPAG EC and the broader community, a very healthy set of inputs. **Thank You !**
- Program Chief Scientists reviewed all these inputs and made their own changes as well, revising the gap list during 2021 October & November, delivering a draft gap list table to our HQ Program Scientists just before the holidays
- We have added easy references to the Astro2020 recommendations
- The number of ExEP science gaps is unchanged at 14
- Yesterday the final version of the document was cleared by JPL for public release, it will go out for signatures this week
- The 2022 ExEP Science Gap List will be posted later this month, in time for the release of the 2022 NASA ROSES proposal call on 2/14/22.

2022 Gap List revisions (1)

Gap #01: Spectroscopic observations of the atmospheres of small exoplanets	Modified gap title to better distinguish from Gap #03, updated the count of TESS small planets, referred to small planets in JWST Cycle 1 programs, referred to new Astro2020 priority for this area, updated references.
Gap #02: Modeling exoplanet atmospheres	Added text on greenhouse gases, need to reconcile discrepancies between current models, and explicit mention of using solar system planets for model validation.
Gap #03: Spectral Signature Retrieval	Updated status of community data challenges, referenced the ExoPAG SAG 19 final report, described 2021 efforts of ExoPAG SAG 21, Roman CGI SITs, and JWST ERS teams.
Gap #04: Planetary system architectures: occurrence rates for exoplanets of all sizes	Referenced the need to include emerging astrometric constraints from Gaia datasets, some small changes in wording and updating of references.

2022 Gap List revisions (2)

Gap #05: Occurrence rates and uncertainties for temperate rocky exoplanets (e.g. $\eta_{\oplus}$)	Expanded & re-wrote the summary, underscored the relevance to the Astro2020 target mission yield, updated references. Left out mention of any possible TESS contribution to knowledge of $\eta_{\oplus}$
Gap #06: Yield estimation for exoplanet direct imaging missions	Cited the new impetus from Astro2020 for a specific mission yield of HZ rocky planets, and the importance of yield estimates to 2020s mission maturation architecture trades, updated references
Gap #07: Intrinsic Properties of known exoplanet host stars	Added a statement on the importance of timeseries measurements of stellar activity, updated status of CUTE & SPARCS missions and ESCAPE SMEX proposal, referenced stellar properties list in SAG 22 report.
Gap #08: Mitigating stellar jitter as a limitation to the sensitivity of exoplanet dynamical measurements	Expanded summary to provide more clarity, added mention of the EPRV WG final report and the selected ERPV Foundation Science ROSES proposals, updated references.

2022 Gap List revisions (3)

Gap #09: Dynamical confirmation of exoplanet candidates, determination of their masses & orbits	Revised the summary, clarified separate requirements of PRV for mass and continued transit observations for ephemerides, need for continued TESS mission extensions to accomplish the latter, updated references.
Gap #10: Precursor Observations of Direct Imaging Targets	Expanded text throughout, put the focus on the target list for Astro2020's direct imaging mission, referenced datasets recommended by SAG 22 report, rejected precursor imaging of target backgrounds, added references.
Gap #11: Understanding the abundance and distribution of exozodiacal dust	Noted Astro2020's silence on the need for future exozodi work. Referenced new XRP-funded LBTI work, upcoming new VLTI instrument, and added need for theoretical modeling of dust sources & dust transport
Gap #12: Measurement of Accurate Transiting Planet Radii	Expanded summary on what limits the accuracy of transiting planet radii, compared TESS follow-up needs to the scope of Kepler follow-up, added mention of the role of asteroseismology

2022 Gap List revisions (4)

Gap #13: Properties of Atoms, Molecules and Aerosols in Exoplanet Atmospheres	Added Astro2020's reflected light direct imaging mission to the list of "customers" for work in this area.
Gap #14: Exoplanet Interior Structure and Material Properties	Improved the summary, now pointing out the cross-Divisional connection to Earth interior geophysics and results from the Juno and InSight missions.

2022 Process for Science Gap List Revisions

- Will follow similar process & schedule as last year: After the XRP proposal deadline, there will be a call for community inputs to update the SGL.
- Open comment period through September 2022, internal NASA work on revisions during the Fall, leading to a new SGL by January 2023.
- In 2022 we are updating the 60-page Science Plan appendix to reflect progress in the field, connect the science gaps to the new Decadal Survey recommendations, and align with NASA HQ's developing plans for implementing them.

<u>We are eager to see the community shrink these science gaps through innovative research !</u>