ExEP Science Update

ExoPAG 27

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Program Chief Scientists

NASA Exoplanet Exploration Program Office

Jet Propulsion Laboratory, California Institute of Technology

Government sponsorship acknowledged

CL#23-0045

New ExEP Science Postdocs

Dr. Emily Gilbert @JPL

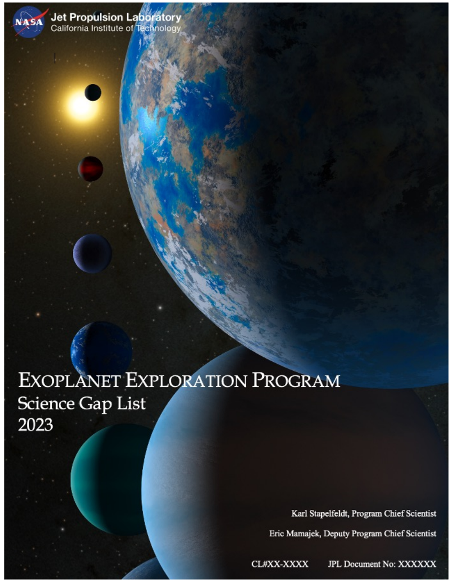
TESS results for active stars
Smallsats (incl. Pandora)
TOI-700 system of HZ super-Earths

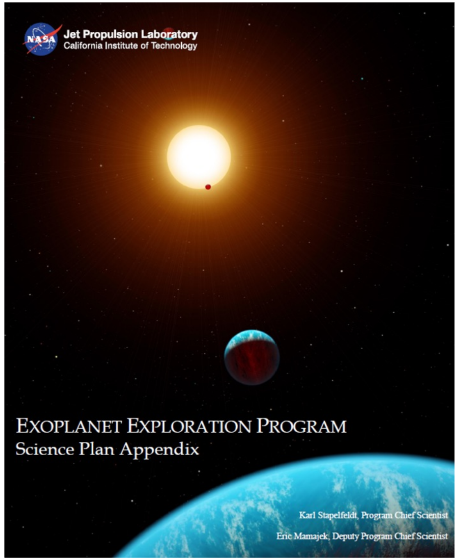
Dr. Catherine Clark @NExScI

Speckle surveys of red dwarfs
ExEP/Ames high resolution imaging program
Astronomical instrumentation

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 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 2023.
  - 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 (not updated since 2018).
- 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 2020/21/22 XRP calls (NASA ROSES Exoplanets Research Program)

What does a science gap look like ?

- **Definition of "science gap"**: *"the difference between knowledge needed to define requirements for specified future NASA exoplanet missions and the current state of the art, or knowledge which is needed to enhance the science return of current and future NASA exoplanet missions."*

- A **science gap** is concise enough to be described in roughly 1 page of text and consists of 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 do **not** 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**. Individual projects are left to track their own internal science gaps.

SCI-	Gap Title
1	Spectroscopic observations of the atmospheres of small exoplanets
2	Modeling exoplanet atmospheres
3	Spectral signature retrieval
4	Planetary system architectures: occurrence rates for exoplanets of all sizes
5	Occurrence rates and uncertainties for temperate rocky planets (eta-Earth)
6	Yield estimation for exoplanet direct imaging missions
7	Intrinsic properties of known exoplanet host stars
8	Mitigating stellar jitter as a limitation to sensitivity of dynamical methods to detect small temperate exoplanets and measure their masses and orbits
9	Dynamical confirmation of exoplanet candidates and determination of their masses and orbits
10	Precursor observations of direct imaging targets
11	Understanding the abundance and distribution of exozodiacal dust
12	Measurements of accurate transiting planet radii
13	Properties of atoms, molecules and aerosols in exoplanet atmospheres
14	Exoplanet interior structure and material properties

2023 Science Gap List Revision Process

- Community input on the 2022 Science Gap List was solicited at the June 2022 ExoPAG 26 meeting and by emails to the exopagannounce list.
- The 3 month input window for responses closed at the end of September.
- We received 16 unique gap list suggestions from the ExoPAG EC and the broader community. **Thank You!**
- Program Chief Scientists reviewed all these inputs and made their own changes as well, revising the gap list during Oct-Dec 2022. Draft gap list table will be delivered for HQ review shortly.
- Developed two new gaps:
  - **Gap #15: Quantify the impacts of stellar contamination on transmission spectroscopy for measuring composition of exoplanet atmospheres and develop mitigation methods**
  - **Gap #16: Advance biosignature research to improve interpretation of spectra of potentially habitable worlds**
- Working towards posting 2023 ExEP Science Gap List by the end of January, in time for the release of the 2023 NASA ROSES proposal call on 2/14/23.

2023 Gap List revisions (1)

Gap #01: Spectroscopic observations of the atmospheres of small exoplanets	Acknowledged launch of JWST and early observations relevant to atmospheres of small exoplanet.
Gap #02: Modeling exoplanet atmospheres	Spun off new gap on biosignatures (#16)
Gap #03: Spectral Signature Retrieval	Spun off new gap on impacts of stellar contamination on transmission spectroscopy (#15)
Gap #04: Planetary system architectures: occurrence rates for exoplanets of all sizes	Updated language on ExoPAG SIG 2 Demographics. Updated references. Updated language on exoplanet formation/evolution models for summary and 'capability needed' sections.

2023 Gap List revisions (2)

Gap #05: Occurrence rates and uncertainties for temperate rocky planets (eta-Earth)	Explicitly encourage detection of rocky temperate exoplanets upon which eta-Earth estimates depend. Updated recent results and references.
Gap #06: Yield estimation for exoplanet direct imaging missions	Updated several recent results and references for 'capability today.'
Gap #07: Intrinsic Properties of known exoplanet host stars	Acknowledged Gaia DR3 contributions to improved stellar data.
Gap #08: Mitigating stellar jitter as a limitation to the sensitivity of exoplanet dynamical measurements	Updated language on importance of EPRV for Habitable Worlds Observatory (summary, capability needed). Updated language on state-of-the-art radial velocity spectrographs. Added mention of 2nd EPRV ROSES call, EPRV Research Coordination Network (RCN)

2023 Gap List revisions (3)

Gap #09: Dynamical confirmation of exoplanet candidates, determination of their masses & orbits	Minor updates on language for TESS and NEID.
Gap #10: Precursor Observations of Direct Imaging Targets	Minor updates regarding relevance to Habitable Worlds Observatory, KPF commissioning/availability, Gaia DR3 and prospects for DR4.
Gap #11: Understanding the abundance and distribution of exozodiacal dust	Minor updates mentioning Roman/CGI paper and warm zodi results.
Gap #12: Measurement of Accurate Transiting Planet Radii	Minor updates to language on facilities contributing to TESS Follow-up program, single transit exoplanets.
Gap #13: Properties of Atoms, Molecules and Aerosols in Exoplanet Atmospheres	No updates. Recent gap added in 2021.
Gap #14: Exoplanet Interior Structure and Material Properties	No updates. Recent gap added in 2021.

2023 Gap List revisions (4) - new gaps

ExEP NASA EXOPLANET EXPLORATION PROGRAM

NEW Gap #15: Quantify the impacts of stellar contamination on transmission spectroscopy for measuring composition of exoplanet atmospheres and develop mitigation methods	***Spun off from Gap #3: "Spectral Signature Retrieval" :*** *Informed by ExoPAG SAG 21 Report (Rackham, Espinoza, et al. 2022). Transit spectroscopy is an important method for probing the composition and structure of the atmospheres of exoplanets, and for the next two decades will be the primary means of studying the atmospheres of small rocky exoplanets. The method relies on time-series stellar spectroscopy, monitoring wavelength- dependent brightness variations. However, the stellar disk that the planet crosses is heterogeneous, with spatial and temporal variations in emission from the photosphere, chromosphere, spots, faculae, and plages - whose effects can conspire to mimic some molecular band features expected for exoplanets. To exploit observations with current (e.g., HST, JWST) and future (e.g., IROUV) space observatories, we need to be able to quantify the degree of stellar contamination, and develop mitigation strategies.*
NEW Gap #16: Advance biosignature research to improve interpretation of spectra of potentially habitable worlds	***Spun off from Gap #2 "Modeling Exoplanet Atmospheres":*** *Based on Astro2020 Decadal Survey recommendation to NASA to build a mission "to search for biosignatures from a robust number of about ~25 habitable zone planets.", NASA will work towards designing a "Habitable Worlds Observatory."* *JWST capable of searching for some biosignatures for some transiting small exoplanets.* *Several frontier topics for biosignatures pointed out in An Astrobiology Strategy for the Search for Life in the Universe (2018) NAS report and Astro2020.* *Spectral signs of Technosignatures included in this gap.*

ExEP Target List for Precursor & Preparatory Science

- As Astro 2020 has settled on a future IR/O/UV direct imaging mission and its approximate scope ("***Habitable Worlds Observatory***"), the community can start work towards improving our knowledge of the stars that will likely be the targets for fulfilling the Decadal goal to search for biosignatures from a robust # of ~25 potentially habitable planets (~100 cumulative habitable zones [HZs] surveyed)
- ***Challenge: Can we generate a provisional list to get to ~100 cumulative HZs in an architecture-agnostic way?***
- **A refined list of high priority stars needs to be constructed and made publicly available to motivate**:
  - ***precursor science*** (short-term to inform mission design to fulfill Decadal goals) and eventually
  - ***preparatory science*** (long-term to inform mission target sample and provide data to interpret observations)
- **There is very little flexibility in the choice of targets!**

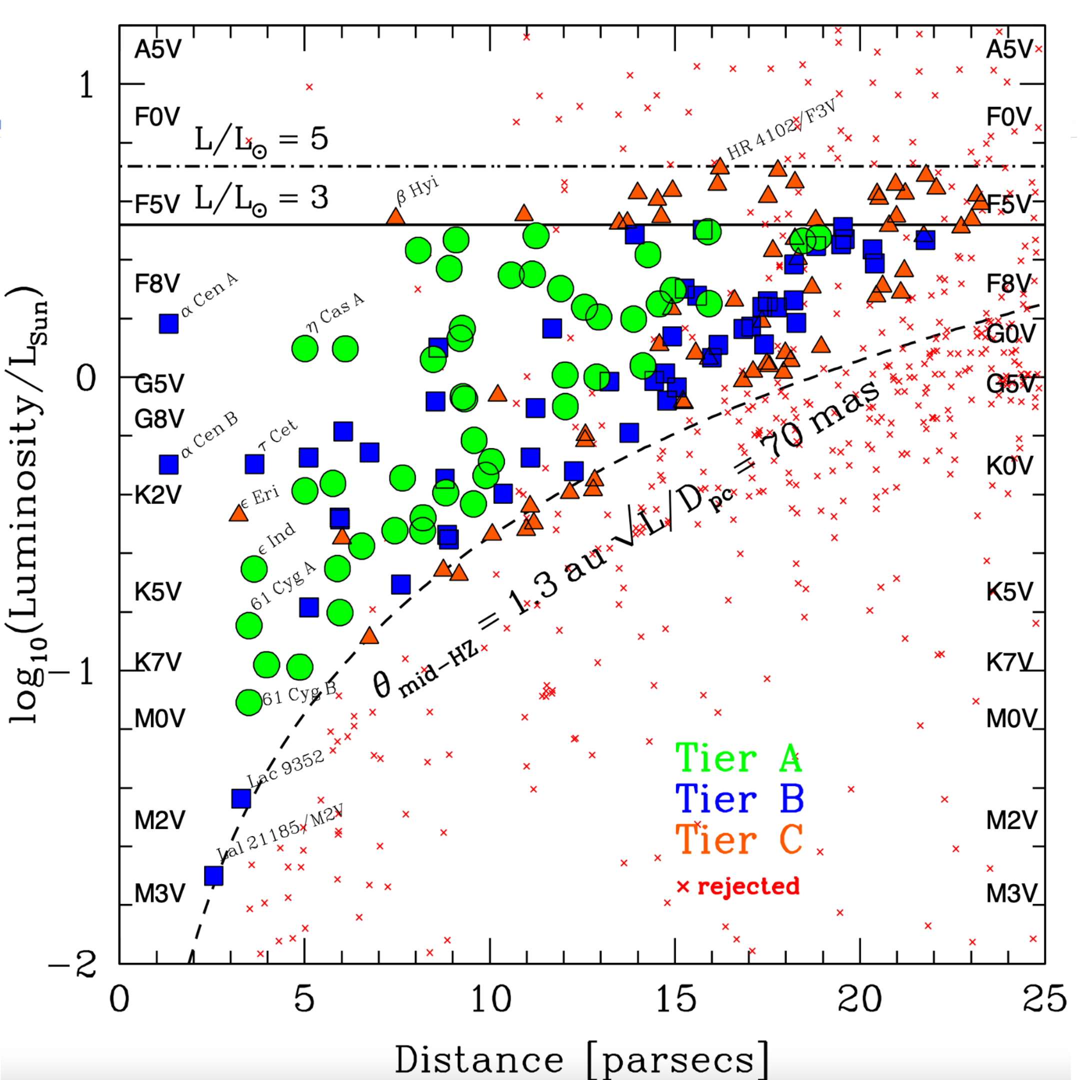
  We have limited numbers of stars with the brightness and proximity required to have exo-Earths with accessible
  - brightnesses,
  - planet-star brightness ratios, and
  - angular separations
- **We need carefully vetted stellar samples and parameters** (esp. luminosities!), photometry, binarity (resolved & spectroscopic)
- We can check against previous efforts (target lists from LUVOIR & HabEx studies, EPRV Working Group report). Approximately ~10% stars missing from previous lists, and many study targets were unrecognized close binaries

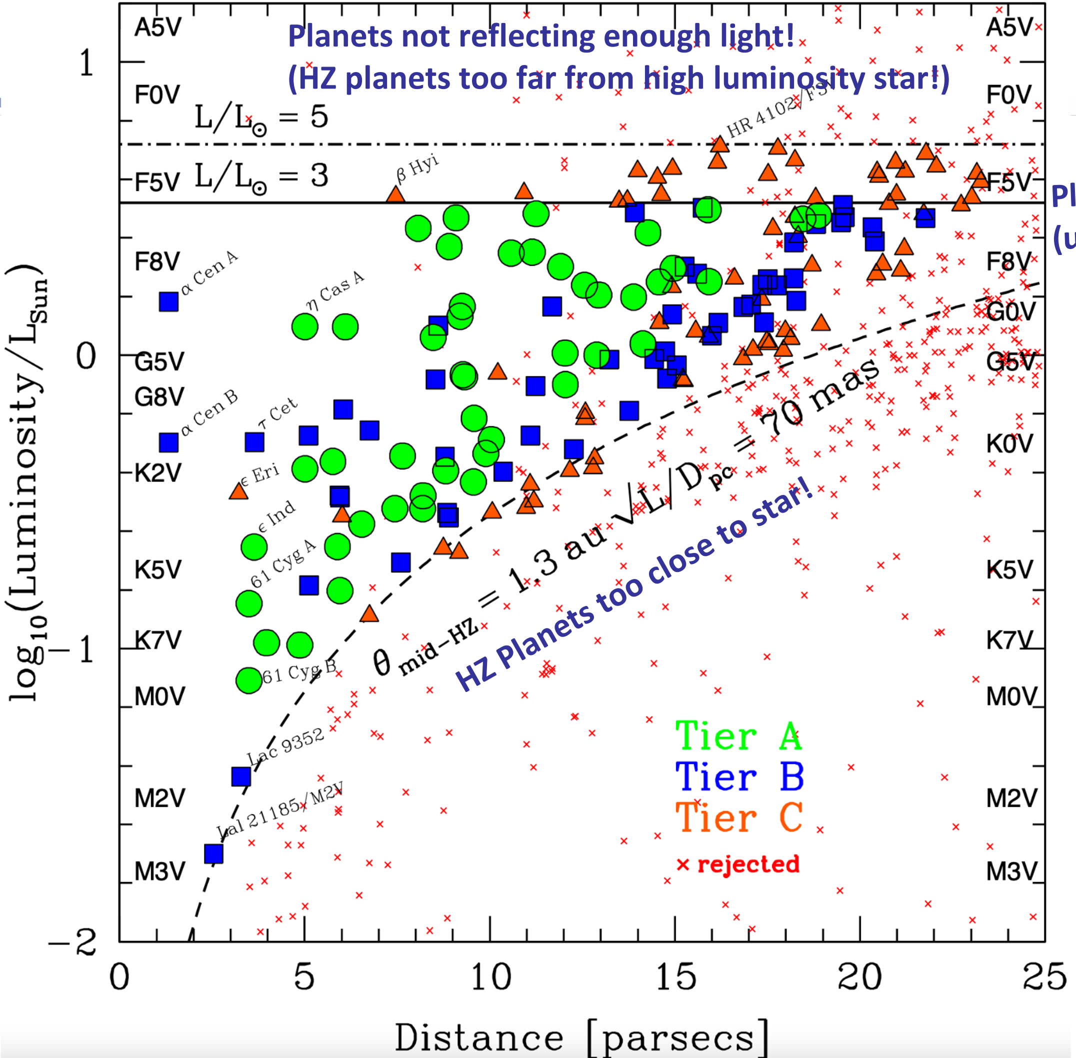
ExEP Target List for Precursor & Preparatory Science

- Selection: *What are the best systems to search for exo-Earths given angular separations of habitable zones and expected brightnesses of HZ rocky exoplanets?* *Iterative process* -> select into **3 tiers**
- Assumptions:
  - Factored in hab zone adopted by Decadal (0.95-1.67 au*)
  - HZ angular size will scale as ~ $\sqrt{L/L_{Sun}}$ / D_{pc}
  - Geometric albedo = 0.2 (following HabEx/LUVOIR)
  - Raw contrast 1e-10
    - post-processing 4e-11 (Δmag=26) for Tier A & B
    - post-processing 2.5e-11 (Δmag=26.5) for Tier C
  - Adopted planet mag limits Rc=30.5 (Tier A), 31 (Tier B&C)
  - Included criteria for known multiplicity & disk properties
- Made 12 representative test exoplanet cases: HZ planets of
  - Planet radii of 1.0 Re "Earth" & 1.4 Re "Super-Earth",
  - Planets observed at phase angles 90° and 63° "gibbous",
  - Separations at Earth-equivalent installation distance (1au*), middle of hab zone (1.3au*), usable outer HZ limit (1.55au*)
- **Target stars retained if >=half of test exo-Earth cases detectable!**

Parameter	Tier A	Tier B	Tier C
IWA constraint	83 mas	72 mas	65 mas
Exoplanet brightness limit (Rc)	30.5 mag	31.0 mag	31.0 mag
Exoplanet-star Brightness ratio limit	4e-11	4e-11	2.5e-11
Disk criterion	No known dust disks of any kind	No disk, or KB disks OK if Ldisk/L* <= 10^{-4}	All disks OK, even if Ldisk/L* >=10^{-4} or detected HZ warm dust disk
Treatment of binaries	Single or binary companion > 10" sep	Single or binary companion > 5" sep	Single or binary companion > 3" sep
Number of Stars	**47**	**51**	**66**

** = scaled as $\sqrt{Luminosity/L_{Sun}}$*


A5V
F0V
F5V
F8V
G0V
G5V
G8V
K0V
K2V
K5V
K7V
M0V
M2V
M3V
$L/L_\odot = 5$
$L/L_\odot = 3$
HR 4102/F3V
β Hyi
α Cen A
η Cas A
α Cen B
τ Cet
ε Eri
ε Ind
61 Cyg A
61 Cyg B
Lac 9352
Lal 21185/M2V
$\theta_{mid-HZ} = 1.3\ au\sqrt{L}/D_{pc} = 70$ mas
Tier A
Tier B
Tier C
× rejected
$\log_{10}(\mathrm{Luminosity}/L_{Sun})$
Distance [parsecs]



Planets too faint!
(usually multiple effects out here)

Other issues:
Stellar multiplicity
Disks / zodi background
Large exoplanets in HZ

Parameter	Tier A	Tier B	Tier C
IWA constraint	83 mas	72 mas	65 mas
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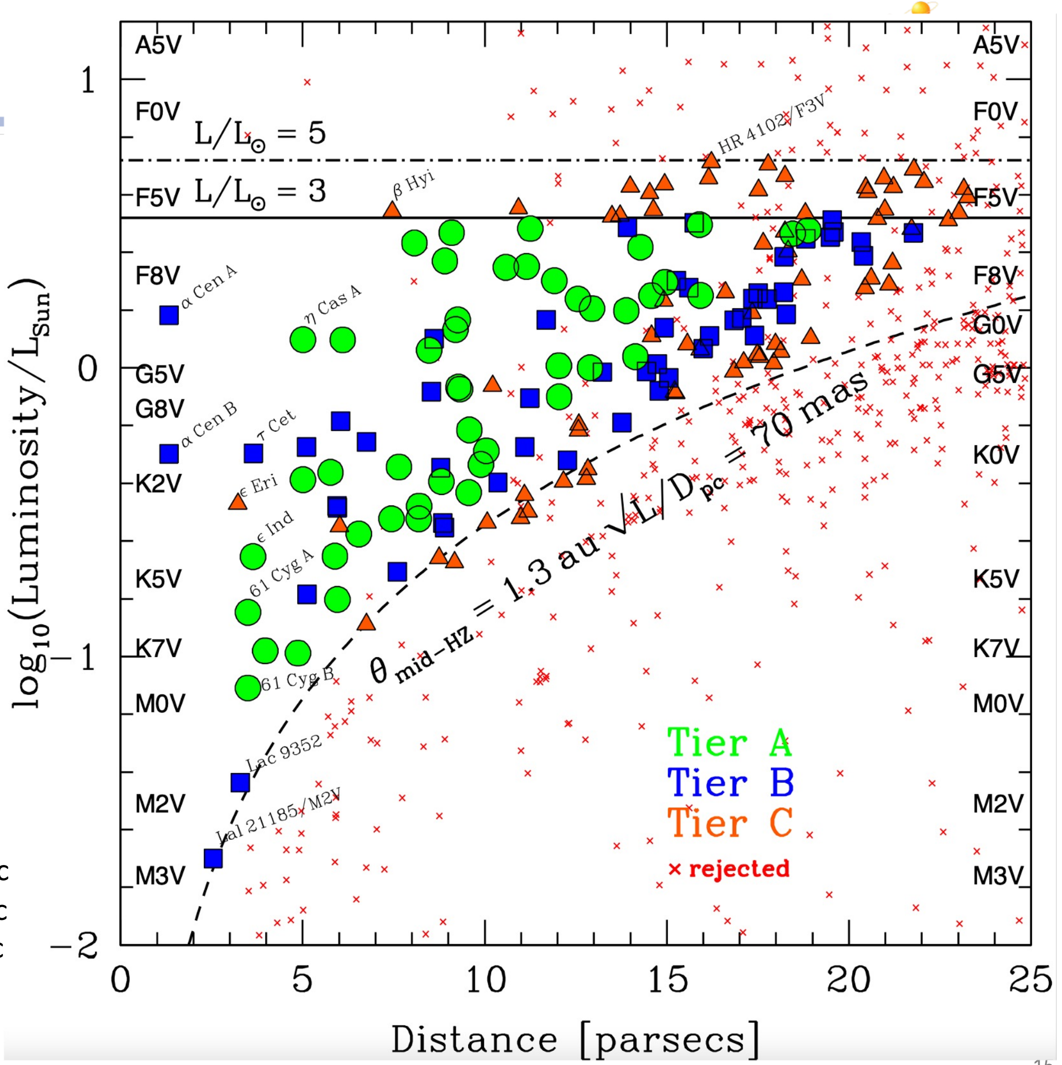
Sample	F	G	K	M
Tier A	14	15	17	1
Tier B	15	23	11	2
Tier C	37	17	12	0
Total (A+B+C)	66	55	40	3

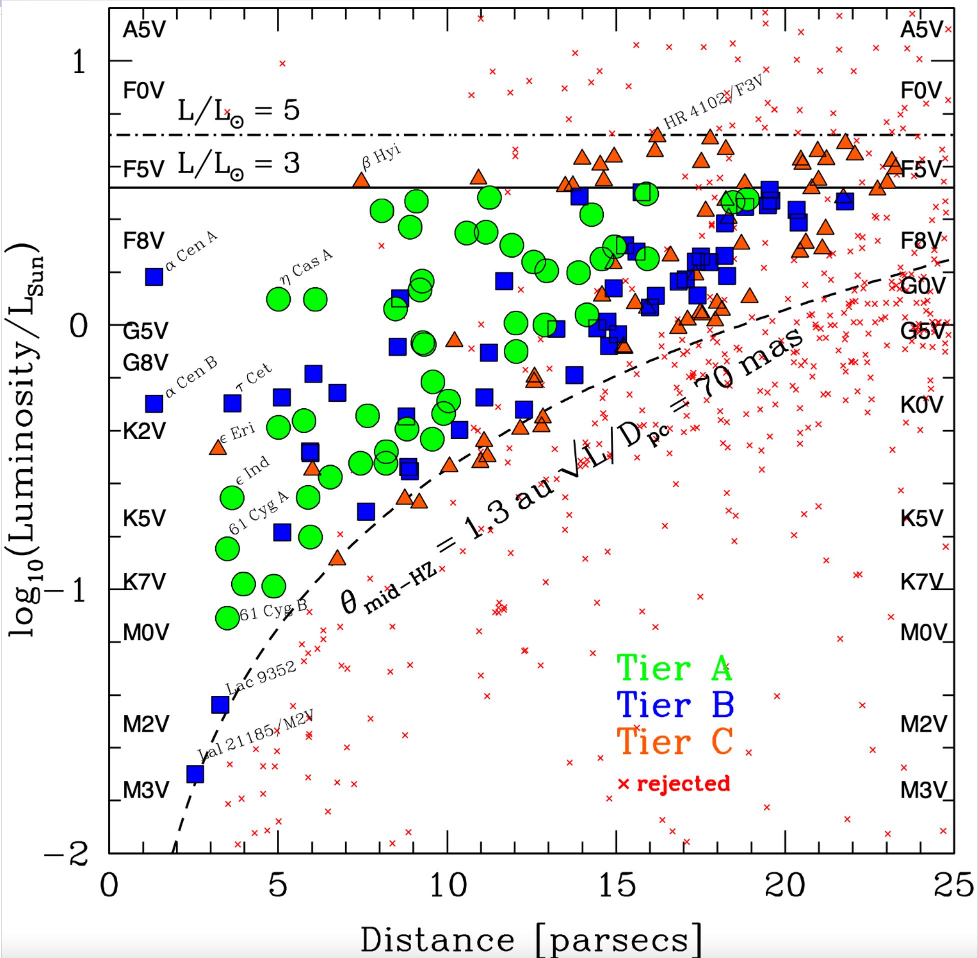
Approx. magnitude & distance limits:

F*s: V < 6.0, d < 23.3 pc
G*s: V < 6.4, d < 20.5 pc
K*s: V < 7.0, d < 12.8 pc
M*s: V < 7.5, d < 4.0 pc



ExEP Target List for Precursor & Preparatory Science

- Table of stars and related data and calculated quantities underwent peer review in Dec by subject matter experts.
- Data table and documentation will be posted soon
- **Initial (2023) version of star list table and documentation is available upon request** (email mamajek@jpl.nasa.gov, karl.r.stapelfeldt@jpl.nasa.gov)
- **Long term home for table & documentation will be on NExScI web page (by end of January). Release and website will be advertised via ExoPAG email list**
- Plan to update the table and documentation periodically as knowledge of stars improves or survey parameters/strategy evolves.
- Target stars being added to "Eyes on Exoplanets" as part of "Where We Explore" theme
- See talk Monday 11:00am AAS241 session 116.07 Extrasolar Planets: Direct Imaging I



HWO Exoplanet Science Metrics

- Metrics provide a way of quantifying the science accomplished by different mission architecture options. Community discussion & general agreement on metrics is a needed input to GOMAP
- The yield of HZ rocky planets was the primary metric employed by the HabEx & LUVOIR studies, but a common definition of spectral characterization was lacking. Reconciling this, and developing additional metrics, is a way to move GOMAP forward in 2023
- In spring 2023 ExEP will convene a Science Metrics Working Group (SMWG) to provide a forum for advancing the metrics for HWO exoplanet science. Upcoming steps:
  - Assemble a steering committee
  - Begin public virtual discussions, as well as plan for an in-person session at the 2023 summer AAS
  - Provide findings to the GOMAP core committee by fall 2023
  - See upcoming exopagannounce emails for further details

Acknowledgement

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