Habitable Exoplanet (HabEx) Imaging Mission Concept Study Update

Bertrand Mennesson, JPL-Caltech on behalf of the HabEx Study Team

ExoPAG Meeting # 14, San Diego, June 12 2016

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Summary

• STDT Selections
• Concept Study goals and deliverables
• Overall approach
• Key Study Questions and on-going work
• Community Input
HabEx STDT Selection (03/11/16)

• “An embarrassment of riches”: 88 very high profile scientists and technologists applied to the HabEx STDT

• Very competitive selection process led by HQ, in consultation with ExEP, JPL study team and study chairs

• Ensure a community led study by maximizing community membership

• Ensure some continuity with exo-C and exo-S studies

• Ensure a good balance in terms of expertise between:
  – The various fields of (exo)-planets + disks science and related technology
  – General astrophysics themes enabled by the largest diffraction limited optical telescope in space in the 2030’s
# HabEx Study Team

## Appointed STDT Members

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cahoy, Kerri (MIT)</td>
<td></td>
<td>Space Systems technology and Xpl spectra</td>
</tr>
<tr>
<td>Domagal-Goldman, Shawn (GSFC)</td>
<td></td>
<td>Bio-signatures and Xpl spectra</td>
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<tr>
<td>Feinberg, Lee (GSFC)</td>
<td></td>
<td>Picometer wavefront control</td>
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<tr>
<td>Gaudi, Scott (Ohio State)</td>
<td></td>
<td>Xpl Demographics / WFIRST</td>
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<tr>
<td>Guyon, Olivier (Arizona)</td>
<td></td>
<td>Coronagraph design / Wavefront control</td>
</tr>
<tr>
<td>Kasdin, Jeremy (Princeton)</td>
<td></td>
<td>Starshade and Coronagraph designs</td>
</tr>
<tr>
<td>Mawet, Dimitri (Caltech)</td>
<td></td>
<td>Coronagraph design / Disks/ Post processing</td>
</tr>
<tr>
<td>Mennesson, Bertrand (JPL)</td>
<td></td>
<td>Debris disks / High Contrast Imaging</td>
</tr>
<tr>
<td>Robinson, Tyler (UC Santa Cruz)</td>
<td></td>
<td>Atmospheric spectral retrieval</td>
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<tr>
<td>Rogers, Leslie (Chicago)</td>
<td></td>
<td>Low mass Xpl Interior structure &amp; evolution</td>
</tr>
<tr>
<td>Scowen, Paul (Arizona State)</td>
<td></td>
<td>General astro/ UV/ ISM COPAG Chair</td>
</tr>
<tr>
<td>Seager, Sara (MIT)</td>
<td></td>
<td>Starshade / Bio-signatures</td>
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<tr>
<td>Somerville, Rachel (Rutgers)</td>
<td></td>
<td>Star and galaxy formation / theory vs observations</td>
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<tr>
<td>Stapelfeldt, Karl (NASA JPL)</td>
<td></td>
<td>Disks/ ExEP CS</td>
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<tr>
<td>Stern, Daniel (JPL)</td>
<td></td>
<td>General astrophysics/ AGNs/ NIR</td>
</tr>
<tr>
<td>Turnbull, Margaret (SETI)</td>
<td></td>
<td>Mission design / target selection</td>
</tr>
</tbody>
</table>

## Ex-Officio Study Team Members

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Role</th>
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</thead>
<tbody>
<tr>
<td>Hudgins, Doug (NASA HQ)</td>
<td></td>
<td>HabEx Deputy Program Scientist</td>
</tr>
<tr>
<td>Still, Martin (NASA HQ)</td>
<td></td>
<td>HabEx Program Scientist</td>
</tr>
<tr>
<td>Warfield, Keith (NASA JPL)</td>
<td></td>
<td>HabEx Study Manager</td>
</tr>
<tr>
<td>Marois, Christian (NRC Canada)</td>
<td></td>
<td>CSA Observer</td>
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<tr>
<td>Mouillet, David (IPAG Grenoble)</td>
<td></td>
<td>CNES Observer</td>
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<tr>
<td>Prusti, Timo (ESA)</td>
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<td>ESA Observer</td>
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<tr>
<td>Quirrenbach, Andreas (Heidelberg Univ)</td>
<td></td>
<td>DLR Observer</td>
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<tr>
<td>Tamura, Motohide (Univ. of Tokyo)</td>
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<td>JAXA Observer</td>
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</table>

6/12/16
(Current) HabEx Study Team
Concept Study Goals and Deliverables to NASA APD

• “Provide a compelling science case identifying critical science questions [] to be addressed in the following decades and the technical parameters necessary to achieve these goals”

• Provide mission and observatory performance parameters that deliver these science capabilities with:
  – a DRM including straw-man payload trade studies conducted to arrive at that mission concept
  – Technology assessments
  – Cost assessment, major technical issues and risk reduction plans as a function of science capability
  – Top level schedule (and schedule risks) for development phases from phase A (> FY22) to notional launch date
# Concept Study Goals and Deliverables to NASA APD

## Study Deliverables

All products delivered to APD Deputy Division Director

<table>
<thead>
<tr>
<th>Study Deliverables</th>
<th>Due Date</th>
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<tbody>
<tr>
<td><strong>M1</strong> Comments on Study Requirements and Deliverables</td>
<td>April 29 2016¹</td>
</tr>
<tr>
<td>- Accept the study requirements/deliverables and submit plan--- or</td>
<td></td>
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<tr>
<td>- Provide rationale for modifying requirements/deliverables</td>
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<tr>
<td><strong>O1</strong> Optional: Initial Technology Gap Assessment</td>
<td>June 30 2016</td>
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<tr>
<td>- To impact PCOS/COR/ExEP 2016 technology cycle</td>
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<tr>
<td><strong>M2</strong> Detailed Study Plan</td>
<td>August 26 2016</td>
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<tr>
<td>- Document starting point CML</td>
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<tr>
<td>- Deliver detailed study plan for achieving Decadal CML</td>
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<tr>
<td>- Deliver resource required to meet the deliverables for the study duration</td>
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<td>- Deliver schedule to deliver milestones</td>
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<tr>
<td><strong>M3</strong> Complete Concept Maturity Level 2 Audit</td>
<td>February 2017²</td>
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<tr>
<td>- Identify, quantify and prioritize technology gaps for 2017 technology cycle</td>
<td></td>
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<tr>
<td><strong>O2</strong> Optional: Update Technology Gap Assessments</td>
<td>June 2017</td>
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<tr>
<td><strong>M4</strong> Interim Report</td>
<td>Early Dec 2017²</td>
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<tr>
<td>- Substantiate achieving Concept Maturity Level 3</td>
<td></td>
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<tr>
<td>- Deliver initial technology roadmaps; estimate technology development cost/schedule</td>
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<tr>
<td><strong>M5</strong> Update Technology Gap Assessments</td>
<td>June 2018</td>
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<tr>
<td>- In support of 2018 technology cycle</td>
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<tr>
<td><strong>M6</strong> Complete Decadal Concept Maturity Level 4 Audit and Freeze Point Design</td>
<td>August 2018</td>
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<tr>
<td>- Support independent cost estimation/validation process</td>
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<tr>
<td><strong>M7</strong> Final Report</td>
<td>January 2019</td>
</tr>
<tr>
<td>- Finalize technology roadmaps, tech plan and cost estimates for technology maturity</td>
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<tr>
<td><strong>M8</strong> Submit to Decadal</td>
<td>March 2019</td>
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</tbody>
</table>

¹APD will provide final study requirements by May 2016 (see “Near Term Activities”)
²Timed to influence following NASA budget cycle
Iterating from Science Objectives to Mission Requirements and Design

Science Objectives
- e.g. assess the prevalence of habitable planets and bio-signatures around nearby MS stars

Projected Science Yield
- * Observations Scheduling and Signal Extraction

Scientific Measurements Requirements
- e.g. Number of spectra of earth-sized planets in HZ

Projected Scientific Measurement Performance
- * Astrophysical Models

Instrument Functional Requirements
- e.g. Contrast, Spectral resolution, band-pass and physical IWA

Projected Instrument Functional Performance
- * Systems engineering simulations

Instrument and Mission Design
- e.g. Telescope D and T, mission duration, Coronagraph, Starshade
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**Projected Instrument Functional Performance**

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Practical Approach for 1st Iteration

- Define first cut Exo-Earth Science MUSTs ($\lambda$-range, $R$, $S/N$, min number of spectra)
- Identify ~3 or 4 potential killer apps for general astrophysics (non-exoplanet) observations with HabEx
- Using science yield estimation tools (e.g. ExoSIM), identify basic architectures (S, C, S+C) and top level requirements (IWA, contrast, aperture size) compatible with defined MUSTs (local minimum OK)
- Identify proof of concept design compatible with top level requirements
- Assess technical feasibility
- Study design compatibility with non-exoplanet science killer apps
- Iterate

Source: Turnbull (2006)
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Source: Turnbull (2006)
Part of a much larger list of Key Science Questions

- Identified at 1st face-to-face meeting

<table>
<thead>
<tr>
<th>Responsible</th>
<th>Role</th>
<th>Impact</th>
<th>Urgency</th>
<th>Define</th>
<th>Exoplanet Science Requirements</th>
<th>HabEx for science enhancement? (Gaudi)</th>
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<tbody>
<tr>
<td></td>
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<td>Should HabEx include an RV precursor obs program as an integral part of the mission? (Gaudi)</td>
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<td>How to establish that a planet is rocky? (Rogers, Robinson)</td>
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<td>How well can/ shall orbital parameters be constrained from direct imaging measurements? (Cahoy)</td>
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<td>What defines habitability and what are the corresponding observational requirements? (Robinson, Turnbull)</td>
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<td>What are the MUSTs and WANTS to be able to look for bio-signatures (λ-range, R, S/N ; Domagal-Goldman)</td>
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<td>Exoplanet discovery and characterization: what are the expected synergies between ground and space by 2035? (Guyon, Mawet)</td>
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<td>What are the basic definitions for Earth-like, habitable, biosignature, eta_Earth, HZ, “in” the HZ ? (Robinson, Turnbull)</td>
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<td>What is the minimum number of “bona fide” exo-Earth spectra required for success? (All)</td>
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<td>What are the non-exoplanet science killer apps of HabEx and what are the associated instrument requirements? (Somerville, Scowen &amp; Stern)</td>
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<td>Are these compatible with the habitable exoplanet top level science goals?</td>
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<td></td>
<td>What drives the high contrast OWA requirement? (Stapelfeldt)</td>
</tr>
</tbody>
</table>
Establishing MUSTs and WANTs for biosignatures (led by Shawn D.-G., preliminary)

- What we could say for a mission from 0.4(*) to 1.0 μm @ R=70:
  “We found the presence of water and biosignature gases (O_2 and O_3) on that planet, but did not search for abiotic sources of those gases.”

- For a mission that goes out to 1.7 μm
  “We found the presence of biosignature gases (O_2 and O_3) on that planet, found additional H_2O features, and searched for signs (CO_2, CO, O_4, pressure) that these gases were created by abiotic processes.”

- For a mission that goes out to ≥ 2.5 μm
  “We found the presence of biosignature gases (O_2 and O_3) on that planet, and secondary features (CH_4(*)) inconsistent with abiotic processes.”

Source: Turnbull (2006)
Establishing General Astrophysics Science goals and associated instrument requirements
(Scowen + COPAG members inputs, Somerville & Stern; preliminary)

• Engage the community to help identify 3-4 killer apps for a 2035 mission, e.g.:
  – Improve our understanding of galaxy leakiness and reionization
    – How much H-ionizing LyC radiation escapes from SF galaxies as a function of redshift (z< 3.5) and mass? →
      UV MOS 1000 - 4000 Å
    – Likely to remain an open Question by the end of HST’s lifetime
    – Requires high spatial R to mitigate foreground contamination
    – Would exploit HabEx potential for much higher UV throughput and detector QE than HST, and for parallel deep field observations

• Probe the CGM and the baryons life cycle using high R far UV spectroscopy of low z galaxies
  – How do gas and metals cycle in and out of galaxies?

• Galaxy evolution, including stellar and AGN feedback:
  – HabEx optical/ NIR observations will allow unique morphology studies, resolved spectroscopy and high dynamic range studies
  – Help understand how “small scale” physics and global galaxy properties are connected

• GA may level requirements on the architecture
  – If justified by killer app and compatible with top exoplanet science goals and preferred architecture

J. Werk et al. 2014
Science Community Contributions

- High interest in organizing/ funneling contributions beyond STDT per se
- Please contact chairs Sara Seager & Scott Gaudi, or individual STDT members
Leveraging past & current SAGs work and other key community studies

- Knowledge of exozodi (Mennesson, Stapelfeldt)
  - SAG 1: Debris Disks and Exozodiacal Dust (Roberge et al.)
  - Observational Data (Spitzer, KI, LBTI, VLTI, CHARA)

- Exo-Earth direct imaging and spectroscopy Reqs (Domagal Goldman, Seager, Robinson)
  - SAG 5: Exoplanet flagship requirements and characteristics (Noecker, Greene et al.)
  - SAG 16: Exoplanet Biosignatures (Domagal-Goldman et al.)
  - Check SAG 2 results on possible impact of solar system measurements

- Impact of RV observations (precursor or post-mission, Gaudi)
  - SAG 8: requirements and limits of future precision RV measurements (Latham, Plavchan et al.)
  - Fischer et al 2015 PASP report

- Impact of astrometric observations (precursor or post-mission, Guyon, Kasdin)
  - SAG 12: Scientific potential and feasibility of high-precision astrometry for exoplanet detection and characterization (Bendek et al.)

- Exoplanet occurrence rates (Rogers, Mawet, Gaudi)
  - SAG 13: Exoplanet Occurrence Rates and Distributions (Belikov et al.)
  - Final Kepler team estimates to come in 2017
Leveraging past & current SAGs/SIGs work and other key community studies

• Characterization of target sample/multiplicity (Turnbull, Stapelfeldt)
  • SAG 14: Characterization of stars targeted for NASA exoplanet missions (Keivan Stassun et al.)

• Science Drivers for non Exo-Earth planets (Robinson, Rogers)
  • SAG 15: Exploring other worlds: observational constraints and science requirements for direct imaging exoplanet missions (Daniel Apai et al.)

• Optimization of High Contrast Direct Imaging Architectures
  • TPF-C, exo-S, exo-C reports (and ES), Theia proposal, etc
  • Proposed SAG 18: Metrics for direct imaging with Starshades (T. Glassman)
  • Proposed SAG 19: Metrics for direct imaging with Coronagraphs (D. Mawet)

• General astrophysics science drivers in the UV-Visible (Scowen, Somerville, Stern)
  • COPAG SIG2: UV Visible astronomy from space
STDT Telecons and Meetings

• Weekly STDT Telecons: Mondays 1pm PT/ 4pm ET
  • https://ac.arc.nasa.gov/HabEx
  • Non STDT members welcome to listen in. Email questions and comments relevant to telecon discussions to seager@mit.edu or gaudi.1@osu.edu

• Next face-to-face STDT meeting: August 3-4 in Pasadena
  • Contact bertrand.mennesson@jpl.nasa.gov to attend in person
  • In person attendance will be capped to 50 people
  • Remote participation at https://ac.arc.nasa.gov/HabEx

• News and relevant material at www.jpl.nasa.gov/habex
HabEx Science Goals and Concept

- **Primary Goal** Requires a large ultra-stable space telescope with a unique combination of
  - Very high spatial resolution (< 30 mas) and dynamic range (~$10^{10}$)
  - High sensitivity / exquisite detectors in the optical (possibly UV and NIR)

- **Such a facility will necessarily also provide exceptional capabilities for**
  - Characterizing full planetary systems, including rocky planets, “water worlds”, gas giants, ice giants, inner and outer dust belts
  - Conducting planet formation and evolution studies
  - Star formation and evolution studies
  - Studying the formation and evolution of galaxies
  - Other general Astrophysics applications

- **STDT will direct design team to explore key trades ($\lambda$, D, FoV, R)**
  - For the primary science goal *and* for non-exoplanet studies (secondary payload(s))
Why do we need a concept study?

• Need to fold in recent advancements in scientific knowledge and high contrast imaging technology:
  – Only recently have the Kepler results started to constrain $\eta_{\text{Earth}}$
  – Final analysis of Kepler results and $\eta_{\text{Earth}}$ value to come mid 2017
  – New powerful post-processing techniques for high contrast imaging (HST/ Ground)
  – More advanced laboratory /field demonstrations of internal coronagraphs and starshade technology over the last 5 years

• Exo-C and Exo-S probes were targeted at $1\text{B}$
  – HabEx Concept study will aim to understand how to scale up and build up on these studies
Status of Study Office Team

• Core Team being built as we speak, but most key roles already filled:
  – K. Warfield (Study Manager), B. Mennesson (Study Scientist),
  – G. Kuan (Lead Systems Engineer), S. Martin (Lead Instrument Engineer)
  – S. Shaklan and D. Lisman (Coronagraph and Starshade Technology),
  – P. Stahl (MSFC, Optical Design and Development)
  – R. Morgan (Science Yield Estimation)
  – Possible additional contracts to support science yield calculations and assess impact of prior high precision RV measurements

• Developing plan to maximize the efficiency of engaging with
  – LUVOIR Team (monthly telecons/share and exchange engineering resources)
  – Existing Projects/Missions (WFIRST-CGI tech developments, Kepler & LBTI findings)
  – ExEP appointed Exoplanet Standard Definition and Evaluation Team, StarShade Readiness Working Group (SSWG), Segmented Aperture Design and Analysis Group (APD funded in FY16)
  – Industry partners: host HabEx “Industry Day” early in the study

• Preparing for delivery of concept study deliverables to HQ
  – Comments on study requirements and deliverables, due April 29, 2016
  – Deliver initial technology gaps for inclusion in ExEP, SAT/TDEM, and APRA Proposal Cycles, due June 30, 2016
  – Detailed 3 year study plan and schedule of MS delivery, August 26, 2016
HabEx Science Goals and Concept

• Overall Concept is open and to be defined by STDT with support from the study office
  – Many design options a priori possible (on/off axis telescope, segmented or not, internal coronagraph and/or external starshade)

• Primary science goal: search for and characterize potentially habitable worlds
  – Characterize Earth-sized planets in the HZ of nearby stars via direct detection and spectroscopic analysis of their reflected starlight
  – Understand the atmospheric and surface conditions of those exoplanets
  – Specifically, search for water and bio-signature gases on those exoplanets
  – Search for signs of habitability and bio activity in non-Earth-like exoplanets

Source: Turnbull (2006)