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

Illustration Credit: NASA Ames/JPL-Caltech

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

(Current) HabEx Study Team

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

EX-OFFICIO STUDY TEAM MEMBERS	
Hudgins, Doug (NASA HQ)	HabEx Deputy Program Scientist
Still, Martin (NASA HQ)	HabEx Program Scientist
Warfield, Keith (NASA JPL)	HabEx Study Manager
Marois, Christian (NRC Canada)	CSA Observer
Mouillet, David (IPAG Grenoble)	CNES Observer
Prusti, Timo (ESA)	ESA Observer
Quirrenbach, Andreas (Heidelberg Univ)	DLR Observer
Tamura, Motohide (Univ. of Tokyo)	JAXA Observer

(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

ExEP
ExoPlanet Exploration Program

Study Deliverables

All products delivered to APD Deputy Division Director

PCOS
Physics of the Cosmos Program
COR
Cosmic Origins Program

M1	**Comments on Study Requirements and Deliverables** – Accept the study requirements/deliverables and submit plan--- or – Provide rationale for modifying requirements/deliverables	**April 29 2016[1]**
O1	***Optional: Initial Technology Gap Assessment*** – *To impact PCOS/COR/ExEP 2016 technology cycle*	**June 30 2016**
M2	**Detailed Study Plan** – Document starting point CML – Deliver detailed study plan for achieving Decadal CML – Deliver resource required to meet the deliverables for the study duration – Deliver schedule to deliver milestones	**August 26 2016**
M3	**Complete Concept Maturity Level 2 Audit** – Identify, quantify and prioritize technology gaps for 2017 technology cycle	**February 2017[2]**
O2	***Optional: Update Technology Gap Assessments***	**June 2017**
M4	**Interim Report** – Substantiate achieving Concept Maturity Level 3 – Deliver initial technology roadmaps; estimate technology development cost/schedule	Early **Dec 2017[2]**
M5	**Update Technology Gap Assessments** – In support of 2018 technology cycle	**June 2018**
M6	**Complete Decadal Concept Maturity Level 4 Audit and Freeze Point Design** – Support independent cost estimation/validation process	**August 2018**
M7	**Final Report** – Finalize technology roadmaps, tech plan and cost estimates for technology maturity	**January 2019**
M8	**Submit to Decadal**	**March 2019**

[1]APD will provide final study requirements by May 2016 (see "Near Term Activities")
[2]Timed to influence following NASA budget cycle

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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*

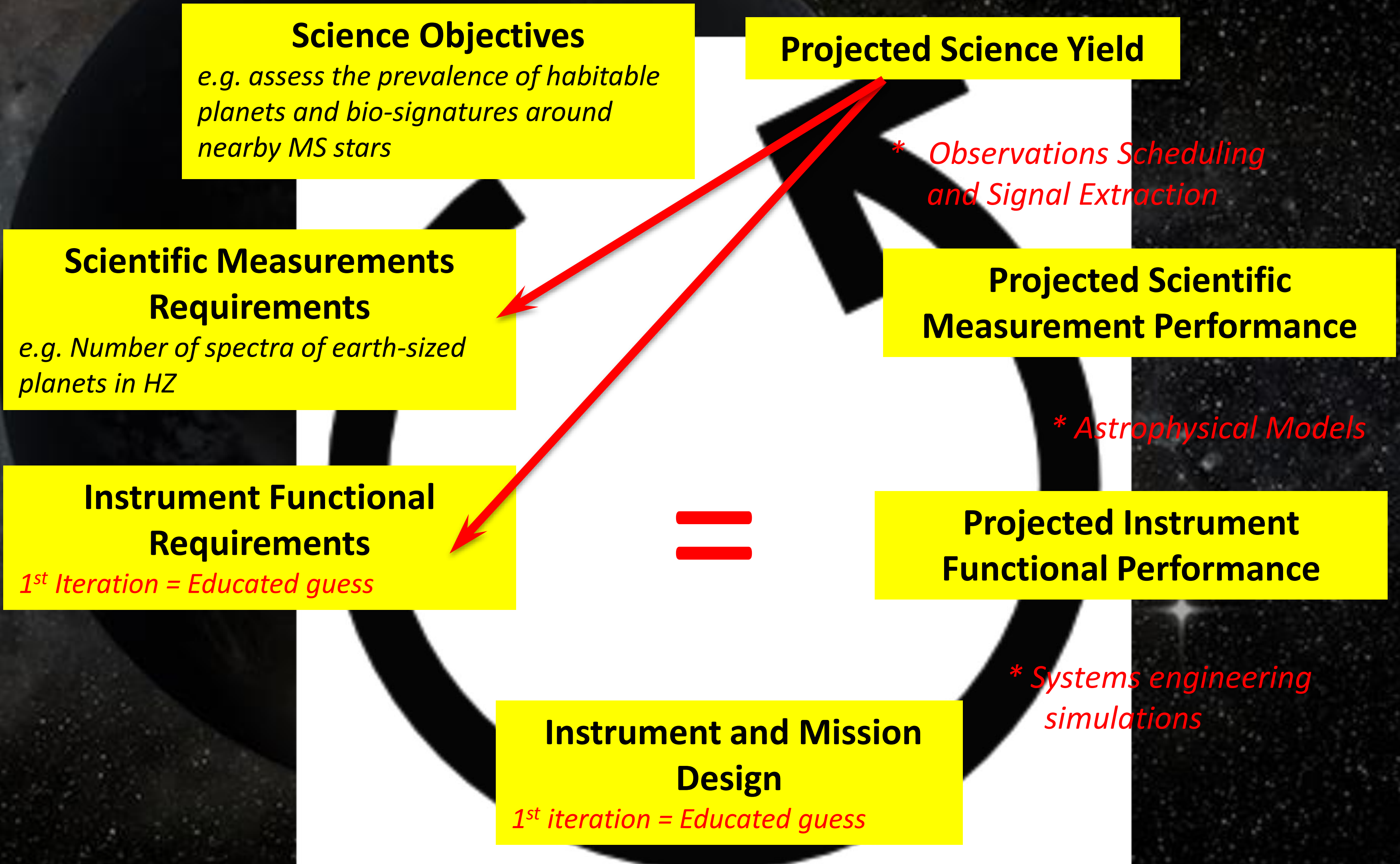
Instrument Functional Requirements
e.g. Contrast, Spectral resolution, band-pass and physical IWA

Projected Instrument Functional Performance

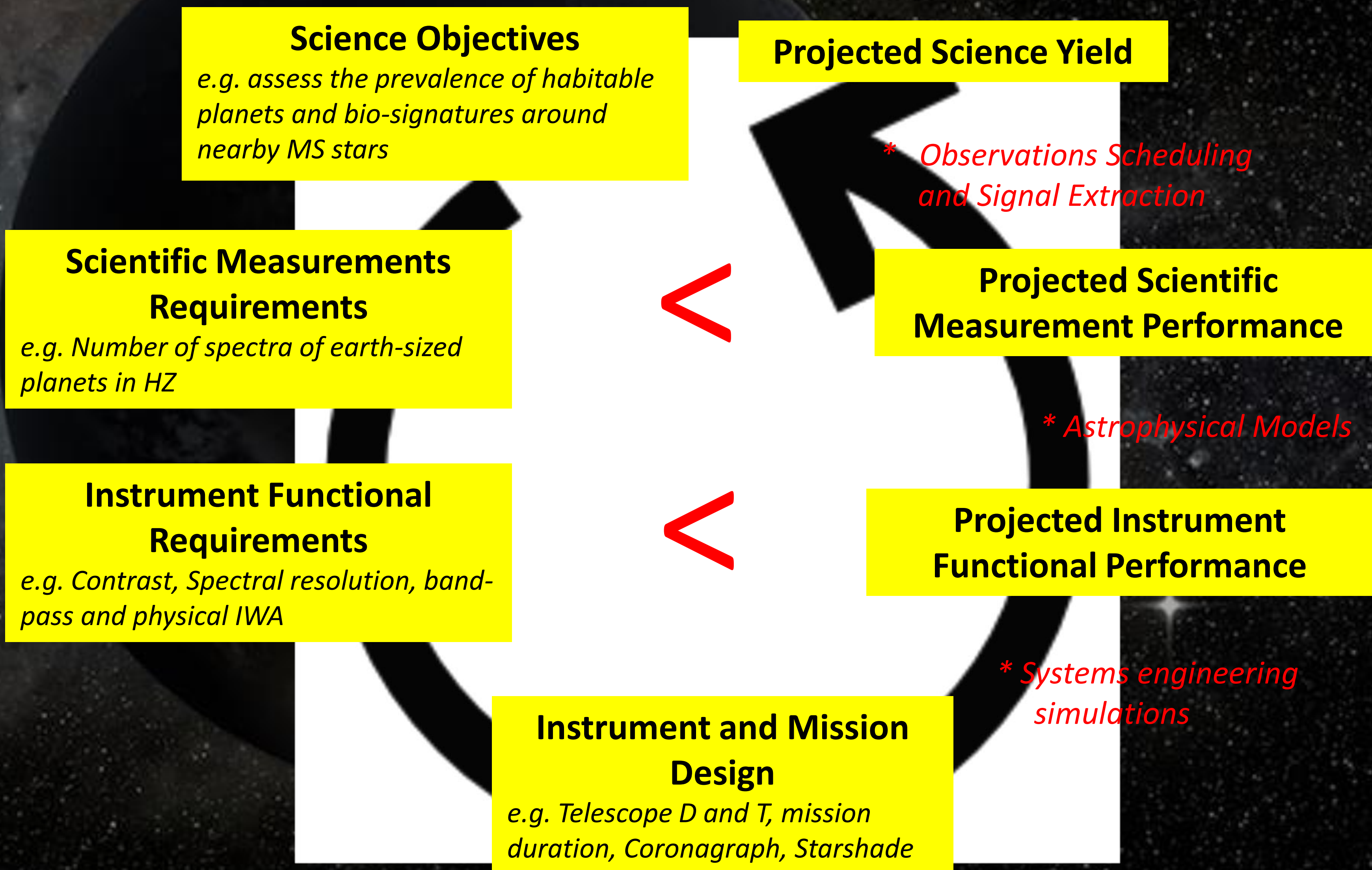
** Systems engineering simulations*

Instrument and Mission Design
e.g. Telescope D and T, mission duration, Coronagraph, Starshade

Iterating from Science Objectives to Mission Requirements and Design



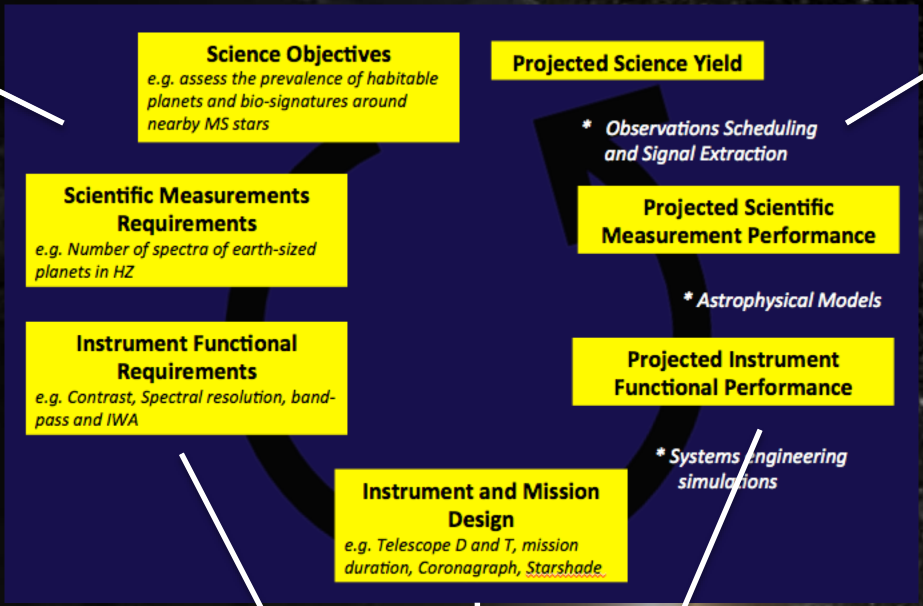
Iterating from Science Objectives to Mission Requirements and Design



Main Concept Study Products

Mission Goals & Science Parameters

Expected Scientific Outcome



DRM

Technical gaps

Cost estimate, Top level Development Schedule

Practical Approach for 1st Iteration

- Define first cut Exo-Earth Science MUSTs *(λ-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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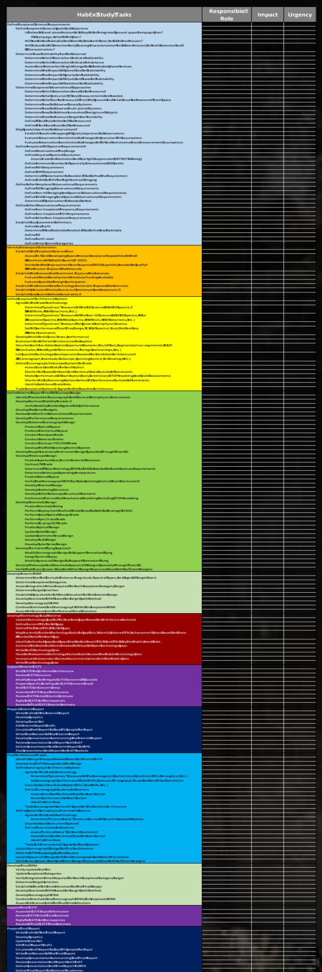
Part of a much larger list of Key Science Questions

- Identified at 1st face-to-face meeting



- *Can planet masses be determined in advance, concurrently or after HabEx for science enhancement? (Gaudi)*
- *Should HabEx include an RV precursor obs program as an integral part of the mission? (Gaudi)*
- *How to establish that a planet is rocky? (Rogers, Robinson)*
- *How well can/ shall orbital parameters be constrained from direct imaging measurements? (Cahoy)*
- *What defines habitability and what are the corresponding observational requirements? (Robinson, Turnbull)*
- *What are the MUSTs and WANTs to be able to look for bio-signatures (λ-range, R, S/N ; Domagal-Goldman)*
- *Exoplanet discovery and characterization: what are the expected synergies between ground and space by 2035? (Guyon, Mawet)*
- *What are the basic definitions for Earth-like, habitable, biosignature, eta_Earth, HZ, "in" the HZ ? (Robinson, Turnbull)*
- *What is the minimum number of "bona fide" exo-Earth spectra required for success? (All)*
- *What are the non-exoplanet science killer apps of HabEx and what are the associated instrument requirements? (Somerville, Scowen & Stern)*
- *Are these compatible with the habitable exoplanet top level science goals?*
- *What drives the high contrast OWA requirement? (Stapelfeldt)*

Establishing MUSTs and WANTs for biosignatures *(led by Shawn D.-G., preliminary)*

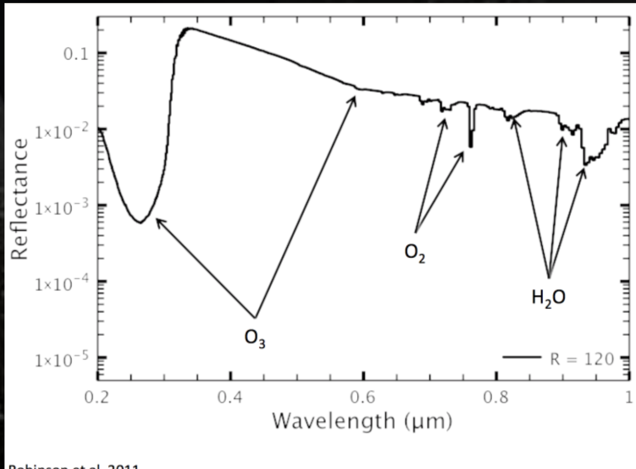
- What we could say for a mission from 0.4(*) to 1.0 μm @ R=70:
  "We found the presence of water and biosignature gases (O_2 and O_3) on that planet, but did not search for abiotic sources of those gases."
- For a mission that goes out to 1.7 μm
  "We found the presence of biosignature gases (O_2 and 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."

MUST

WANT

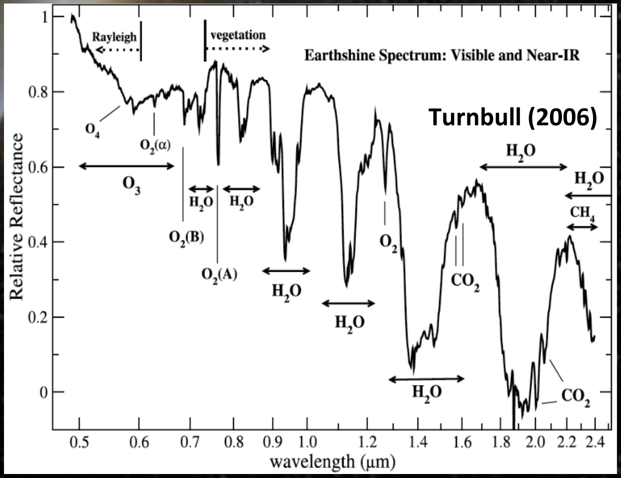
STRETCH

Source: Turnbull (2006)



Robinson et al. 2011

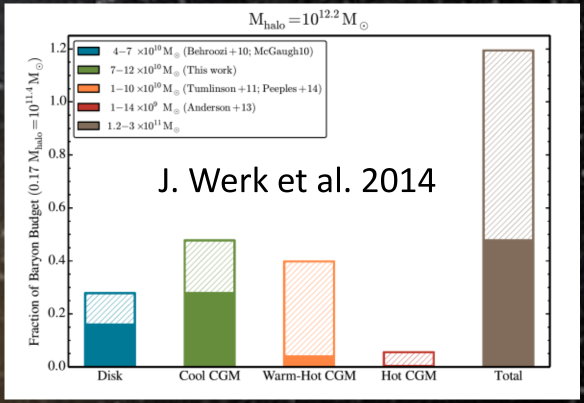
B. Mennesson, ExoPAG presentation



Establishing General Astrophysics Science goals and associated instrument requirements

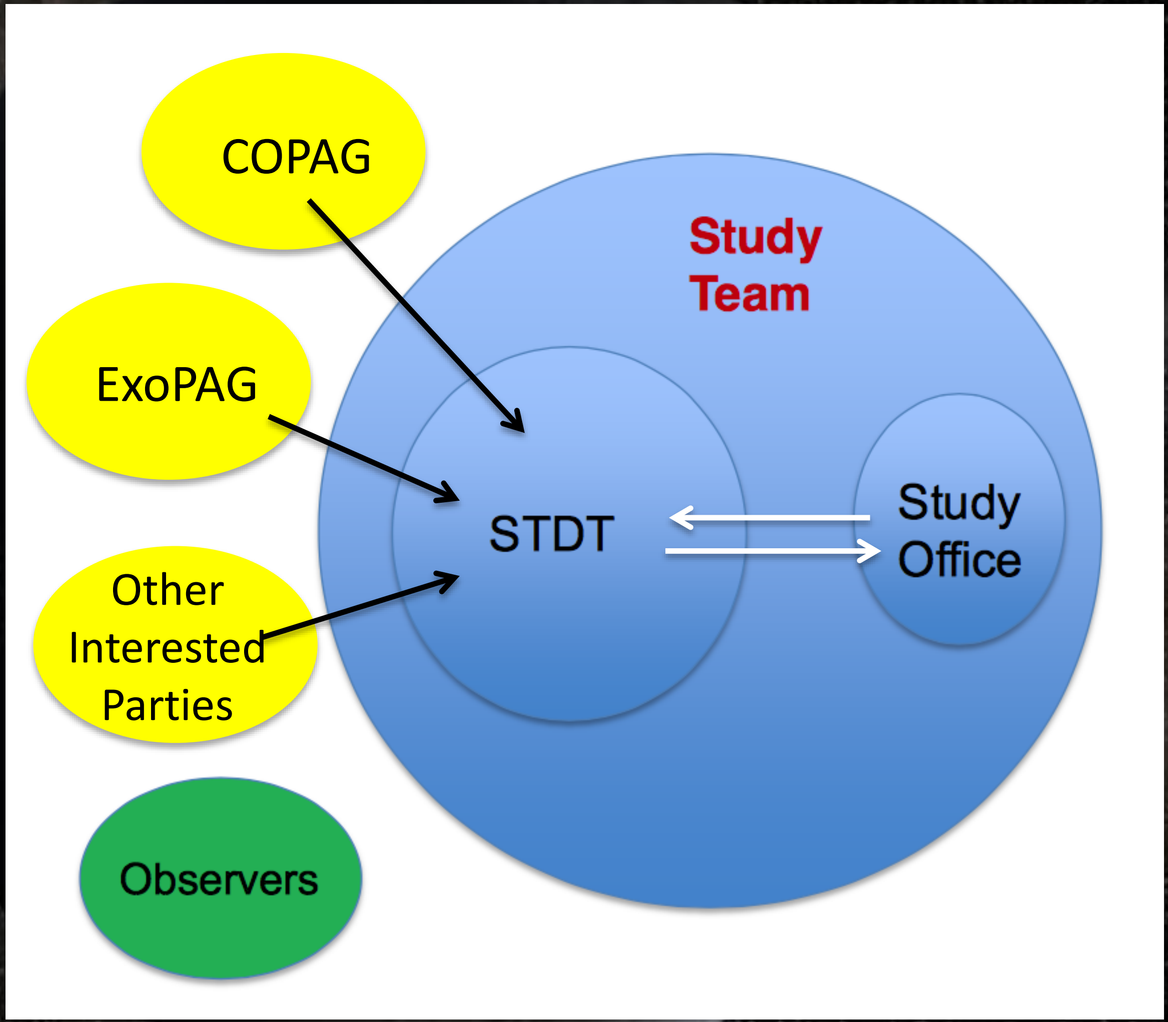
(Scowen + COPAG members inputs, Somerville & Stern; preliminary)

- 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

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 Reqts (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

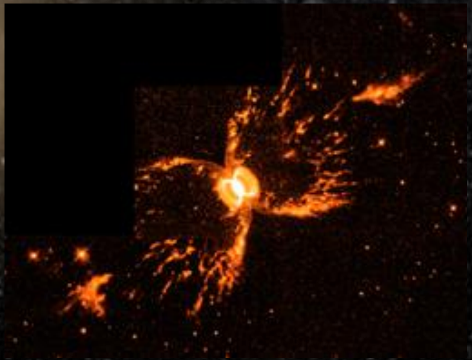
- Next face-to-face STDT meeting: August 3-4 in Pasadena
  - Contact bertrand.mennesson@jpl.nasa.gov to attend in person
  - In person attendance will be capped to 50 people
  - Remote participation at https://ac.arc.nasa.gov/HabEx

- News and relevant material at www.jpl.nasa.gov/habex

BACK-UP SLIDES

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

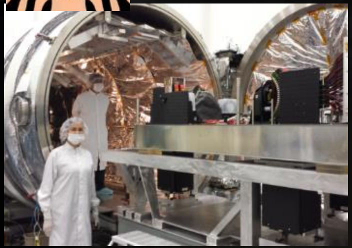


- STDT will direct design team to explore key trades (λ, D, FoV, R)
  - For the primary science goal *and* for non-exoplanet studies (secondary payload(s))

Why do we need a concept study?

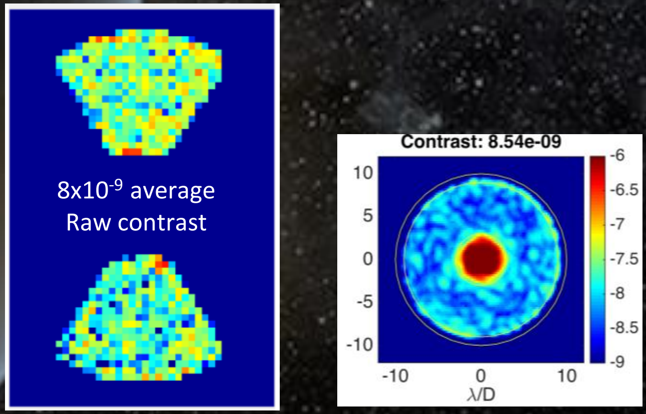
- Need to fold in recent advancements in scientific knowledge and high contrast imaging technology:
  - Only recently have the Kepler results started to constrain η_Earth
  - Final analysis of Kepler results and η_Earth value to come mid 2017
  - New powerful post-processing techniques for high contrast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

Coronagraph Masks



High-Contrast Imaging

Deployable Starshades



WFIRST-like aperture broad-band lab demos

- Exo-C and Exo-S probes were targeted at \$1B
  - HabEx Concept study will aim to understand how to scale up and build up on these studies

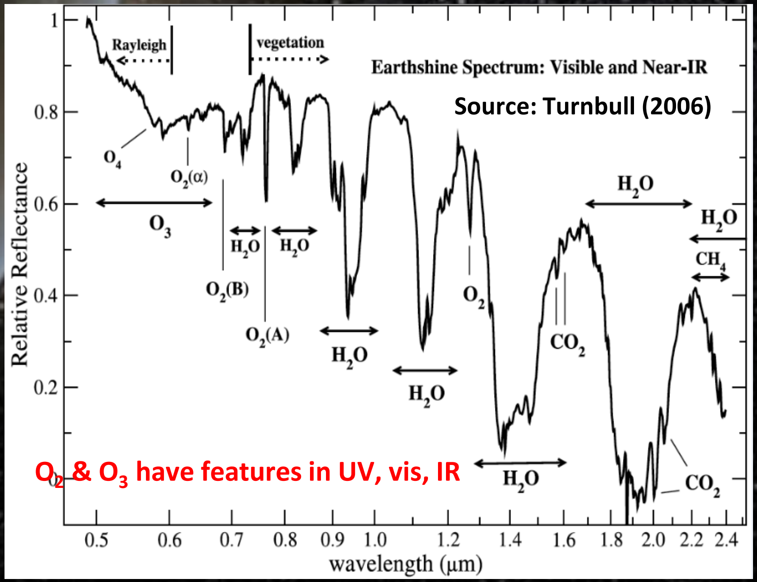
Status of Study Office Team

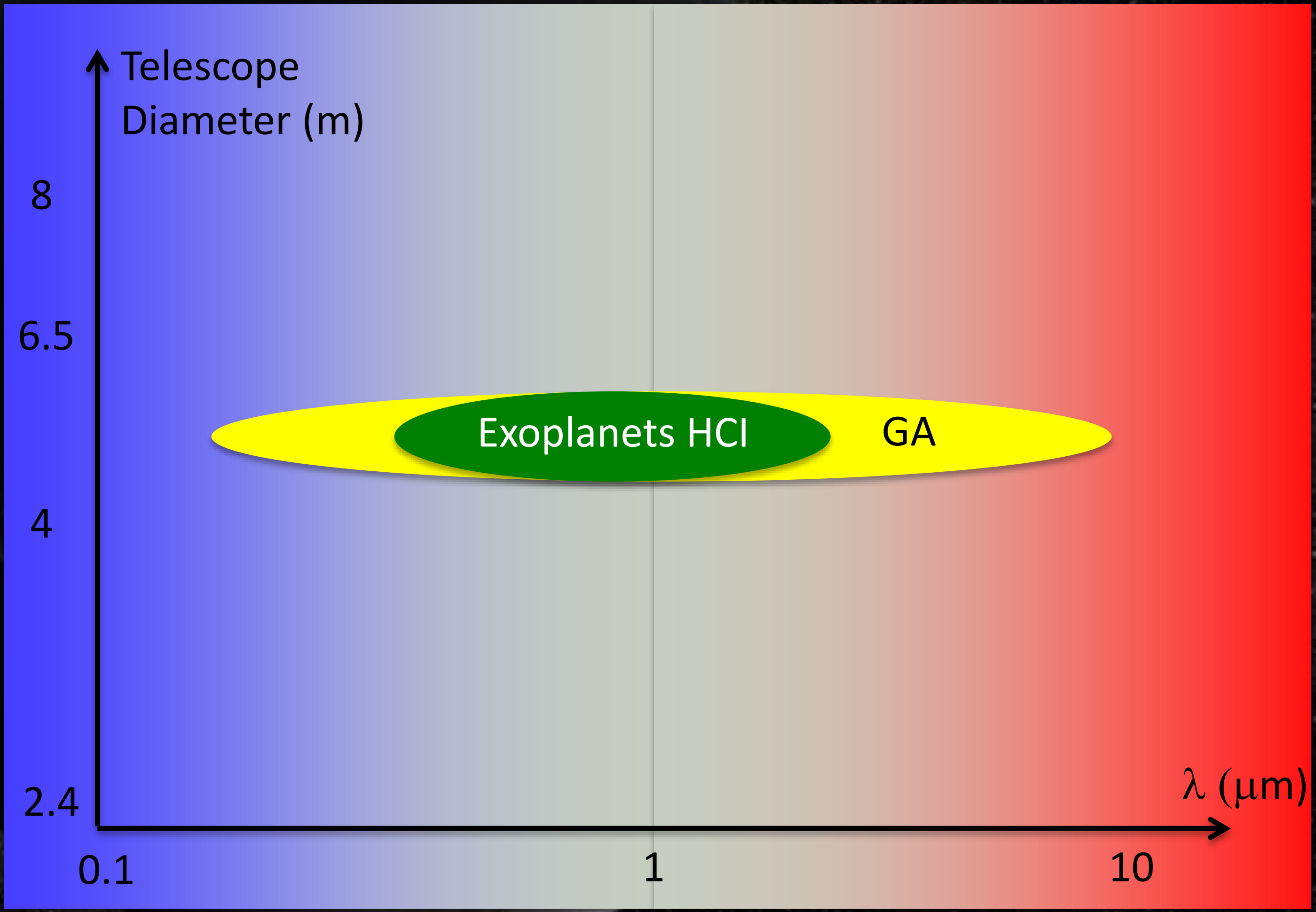
- Core Team being built as we speak, but most key roles already filled:
  - K. Warfield (Study Manager), B. Mennesson (Study Scientist),
  - G. Kuan (Lead Systems Engineer), S. Martin (Lead Instrument Engineer)
  - S. Shaklan and D. Lisman (Coronagraph and Starshade Technology),
  - P. Stahl (MSFC, Optical 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




Telescope
Diameter (m)
8
6.5
4
2.4
Exoplanets HCI
GA
λ (μm)
0.1
1
10