Lessons for the Future: HabEx

Bertrand Mennesson

Jet Propulsion Laboratory, California Institute of Technology

& Scott Gaudi

Ohio State University

HabEx Mission Concept Study vs HWO START-TAG Phase

HabEx Concept Study Goals	HWO START-TAG Phase Goals

HabEx Mission Concept Study vs HWO START-TAG Phase

HabEx Concept Study Goals	HWO START-TAG Phase Goals
Identify and Quantify Science Objectives	Identify and Quantify Science Objectives

HabEx Mission Concept Study vs HWO START-TAG Phase

HabEx Concept Study Goals	HWO START-TAG Phase Goals
Identify and Quantify Science Objectives	Identify and Quantify Science Objectives
Select Baseline Architecture and Develop DRM	Understand Mission Architecture and DRM Trade Space

HabEx Mission Concept Study vs HWO START-TAG Phase

HabEx Concept Study Goals	HWO START-TAG Phase Goals
Identify and Quantify Science Objectives	Identify and Quantify Science Objectives
Select Baseline Architecture and Develop DRM	Understand Mission Architecture and DRM Trade Space
Assess Technical Performance of Baseline Architecture	Inform Future Trades: Integrated Modeling

HabEx Mission Concept Study vs HWO START-TAG Phase

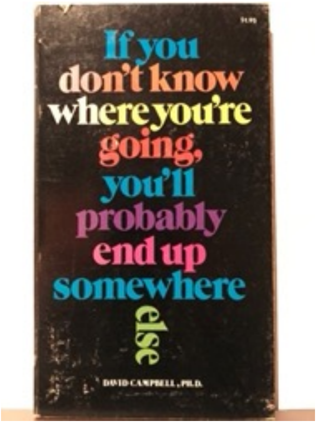
HabEx Concept Study Goals	HWO START-TAG Phase Goals
Identify and Quantify Science Objectives	Identify and Quantify Science Objectives
Select Baseline Architecture and Develop DRM	Understand Mission Architecture and DRM Trade Space
Assess Technical Performance of Baseline Architecture	Inform Future Trades: Integrated Modeling
Assess Science Yield of Baseline and Alternate Architectures	Inform Future Trades: Science Modeling

HabEx Mission Concept Study vs HWO START-TAG Phase

HabEx Concept Study Goals	HWO START-TAG Phase Goals	*Tools*
Identify and Quantify Science Objectives	Identify and Quantify Science Objectives	*STM (left part) / Physical Parameter Retrieval Simulations*
Select Baseline Architecture and Develop DRM	Understand Mission Architecture and DRM Trade Space	*STOP models & Science Yield Simulations*
Assess Technical Performance of Baseline Architecture	Inform Future Trades: Integrated Modeling	*STOP model*
Assess Science Yield of Baseline and Alternate Architectures	Inform Future Trades: Science Modeling	*Science Yield Simulations (per pointing or over ensemble)*

Different Objectives but Similar Tools Required → Lessons learned about the tools

Tool #1: Science Traceability Matrix (STM)



- Start with the science (*not the architecture*) … so you know where you are going!
- First 3 columns of STM:
  - Overarching Science Goal → Quantitative Science Goal (**testable hypothesis**) → Scientific Measurement Requirements (physical parameters and observables)
- Quantifying the science objectives drives architecture selection / trades
  - E.g. HabEx 3x3 matrix shows that exoplanet science priorities (planet type, detection vs spectroscopy) point to different starlight suppression systems (C, S, C+S) and conops
- HabEx full STM exercise took 18 months:
  - Narrow it down to the most architecture-driving science cases & rows
  - Complete the most driving STM cases, each with 2-3 levels of required science performance:
    - Easier and faster to agree upon
    - Explore science return breaking points more effectively
    - Get a feel for design drivers and revised next iteration science goals

Tool #2: Integrated (STOP) Modeling

- HabEx end-to-end STOP modeling took a long time (> 1 year)
  - Image quality in UV MOS was not acceptable at FoV edges for some of the available (lower) spectral R → late instrument redesign
  - Found that coronagraph polarization aberrations were a stronger contributor than expected, even after splitting polarizations
  - No time to revise optical telescope prescription and mitigate

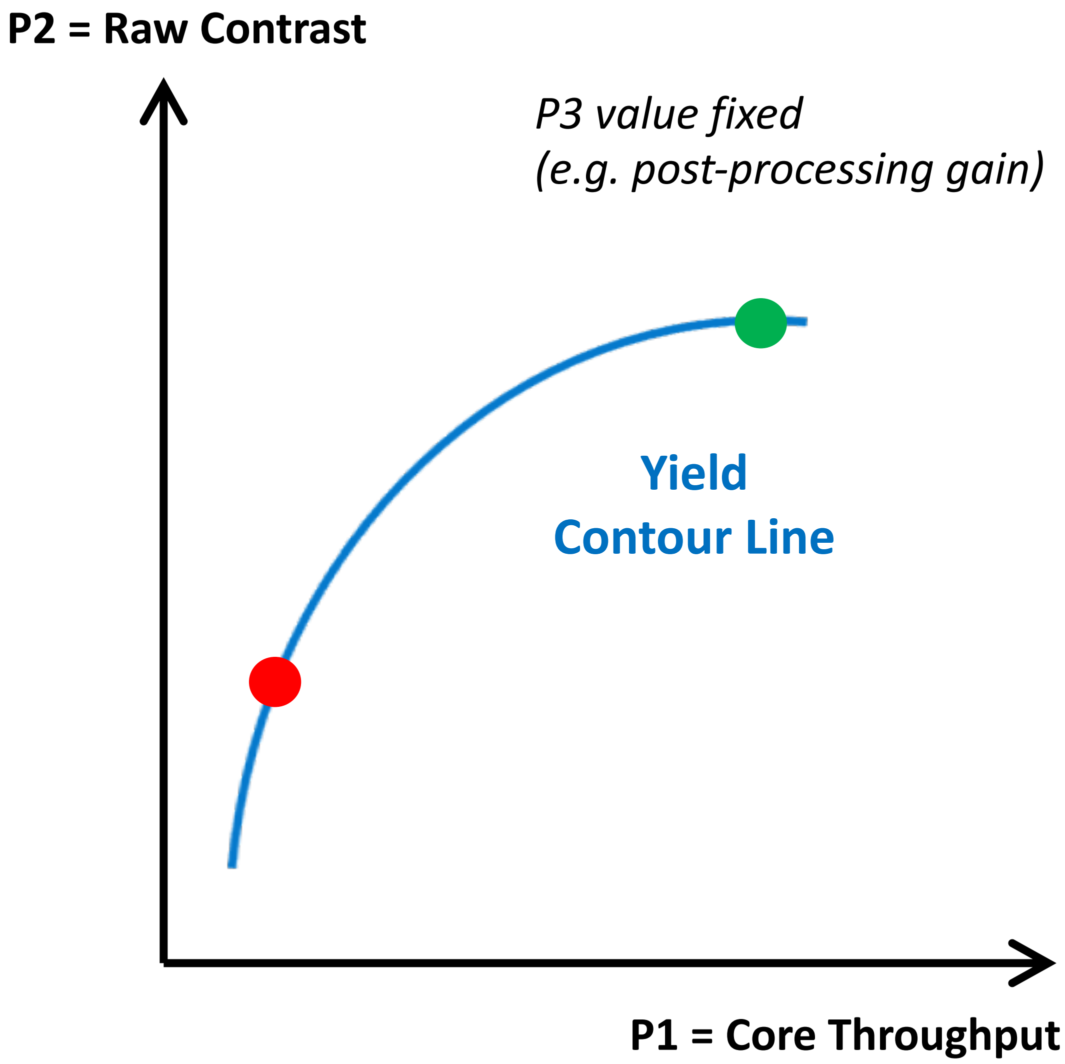
- Joint optimization of the whole (observatory + telescope + coronagraph) system is mandatory

- Key question: how detailed should integrated models be for subsequent trade decisions to be both well informed *and* timely?
  - Identify performance parameters with stronger impact on Science yield (next slide)
  - Concentrate on precisely modeling those parameters (e.g. raw contrast, post-processed contrast and off- axis throughput)

Tool #3: Science Yield Modeling (I)

- Clearly define what is meant by "yield"
  - What is the yield unit?
  - What are the main simplifying assumptions
  - What simplifying assumptions must be improved in priority to increase fidelity? (e.g. treatment of stellar companions and exozodi dust beyond pure photon noise)

- For exo-Earths direct characterization, the instrument performance parameter space is VERY degenerate
  - Some instrument and astro parameters are more critical
  - Explore param space first, based on top-level instrument characteristics to identify most critical ones and corresponding key architecture trades
  - Improve multi-D visualization to provide several "equally good" set-points to systems engineering team
    - Some combination of instrument performance may be more readily accessible



Tool #3: Science Yield Modeling (II)

- Go beyond simplifying assumptions for representative individual targets
  - E.g. Simulate actual multi-object molecular abundance retrievals from simulated observations
  - Fold results into “ensemble yield” calculations to increase their fidelity
- Maintain and update engineering parameter assumptions database
  - Version control is your friend
- Use > 1 yield estimation code
  - At least one must provide fast turnaround
  - Possibly slower & more accurate one for consistency check and validation of simplifying assumptions
- Different coronagraph modes/designs required to most efficiently characterize different planet types at various stellar distances, and for detection vs spectroscopy
  - Yield modeling tools should ideally include that extra knob for yield optimization

People and Team

- A relatively small, close-knit, highly optically-thick committee composed of scientists, engineers, technologists, community outreach members, mission development/flight project experts, policy wonks.
- Collectively, the members of this committee understand the science, technology, risk, cost, schedule, etc. issues, and can make qualitative and objective decisions and trades.
- Communications, meetings, etc., should be designed and managed such that these members have a high cross-section (optically thick).
- There should be redundancy on core competences to mitigate changes in availability and burnout.
- Members must be cognizant of and account for their personal agendas and parochial motivations.
- Social interactions are very useful for increasing cohesiveness.

Embrace Diversity

- Include people from diverse backgrounds.
- ECRs often have the most out-of-the-box ideas than are important for avoiding ‘local optima’ or ‘pre-determined outcomes’.
- Establish and enforce communication and meeting structures that allow for (and encourage!) all voices to be heard.
- Get buy-in from all members, allow for dissenting voices, and ensure that the reasons for opinions/conclusions/preferences are vocalized and documented.
- Adopt formal consensus methodologies that are designed to ensure these principles, such as the K-T Matrix method of rational decision making.
- Prioritize methods of exchanging information (in both directions) with those outside the team.

Defining and Bounding the problem

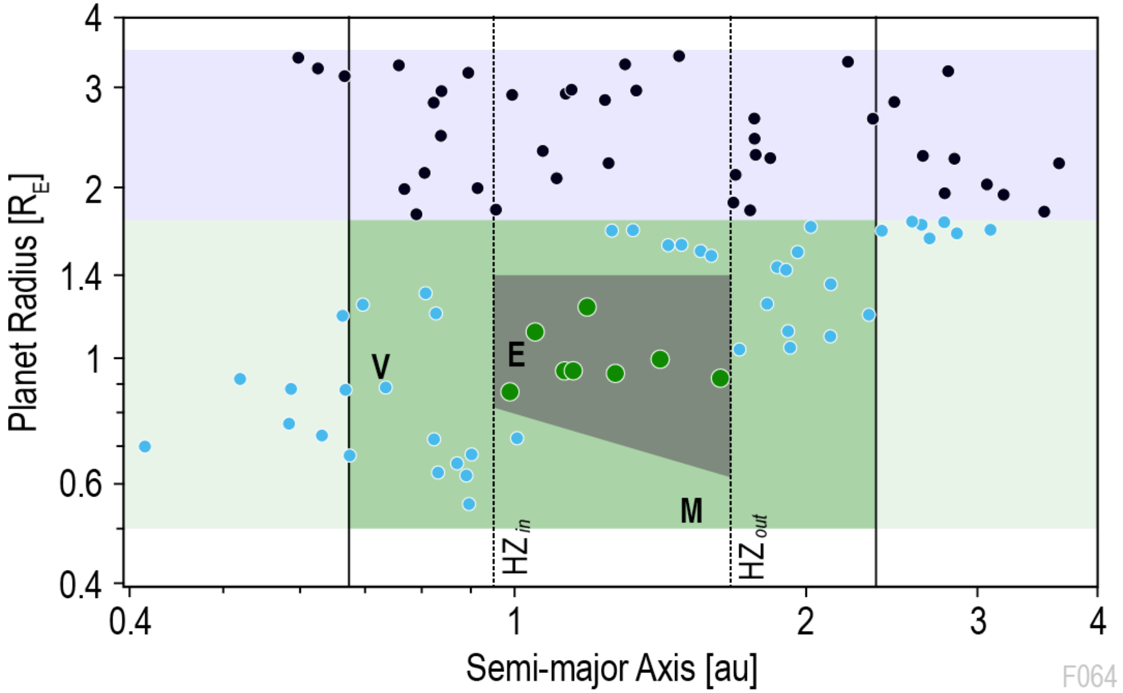
- Start with the science, but establish boundaries!
- Working within a bounded problem forces one to think hard about difficult trades, which can sometimes reveal new optima.
- Recognize that there is an inherent difference between survey and general observatory science:
  - Survey science: small number of science goals, well-defined measurement requirements, (often) require large amounts of observatory time.
  - General observatory science is typically driven by the capabilities
- HWO is unlike previous flagship missions in that it is neither a purely observatory science mission (HST, JWST), nor a primarily survey-driven mission (Roman).

Thank you

Back-up

Science Objectives and Architectures are very tightly coupled

- What does “25 exo-Earths” mean?
  - Define exo-Earth (e.g. radius and host star type)
  - Spectroscopy: define spectral band(s), R and SNR
    - Broad spectral characterization or UV access naturally favors starshades or calls for multiple parallel coronagraphs
  - Blind searches and orbital determination
    - Naturally favors coronagraphs unless starshade is refueled or multiple starshades can be used
  - Spectra + Orbits
    - A hybrid coronagraph + starshade architecture yields more exo-Earths spectral & orbital characterizations than either approach alone at a given telescope size



- What about other planet types?
  - Starshades have a higher yield of outer planets due to their larger high-contrast FoV
  - Yield per planet type depends on observing scenario
  - Keeping the trade space open before these FoMs are defined

Table 10.3-1. Rough estimates of the exoplanet science yields, cost, and technological development attached to each of the HabEx evaluated architectures. *Note that for exo-Earth yield, the number count describes exo-Earths with orbits and spectra characterized. In all cases, a 5-year mission was assumed, with a 50/50 time split between exoplanet surveys and observatory science.

	Starlight Suppression Method		
	H (Hybrid)	C (Coronagraph Only)	S (Starshade Only)
Exoplanet Yield:			
Exo-Earths:	8*	5*	5*
Rocky:	55	34	29
Mini-Neptunes:	60	39	48
Giants:	63	41	63