Lessons for the Future: HabEx

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# HabEx Mission Concept Study vs HWO START-TAG Phase

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*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
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