Jet Propulsion Laboratory
California Institute of Technology

Introduction to the ExoSET

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PROCESS: Great Observatories Mission & Technology Maturation

INPUT

Flagship Proposals

- LCIT: Cost and schedule risk
- Concepts: Design options, capabilities
- Technology requirements & plans
- Targeted science

Decadal Survey

- Science prioritization
- Programmatic cost & timing box
- Execution risk box

Wavelength Coverage

- Capabilities: existing, planned, sun-setting

PROCESS

Burndown GO Program Risk:

- Iterate Science Goals using teams to trade science and performance.
- Perform scientific simulations to define key objectives
- Develop converging, mission-specific technical capabilities using development roadmaps, subsystem-level demonstrations, and demonstration of production processes of sufficient scale, with multi-functional teams of scientists, technologists & industrial partners
- Define Mission Architecture. Trade achievable capabilities
- Transition to design by supporting the Flagship Program Office

Leverage Technology & Build Foundations

- Enable smaller projects (Explorers to Probes) to address wavelength gaps, vet new technologies, mature Technology Readiness Level or Manufacturing Readiness Level
- Manage GO Grants Program to build science base for long-cycle capabilities

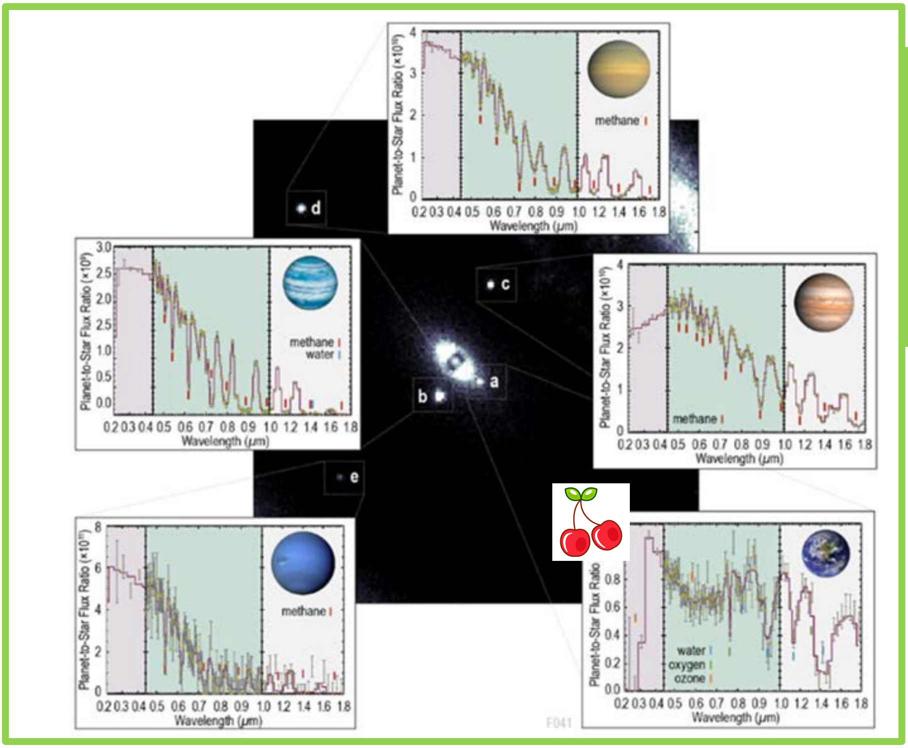
OUTPUT

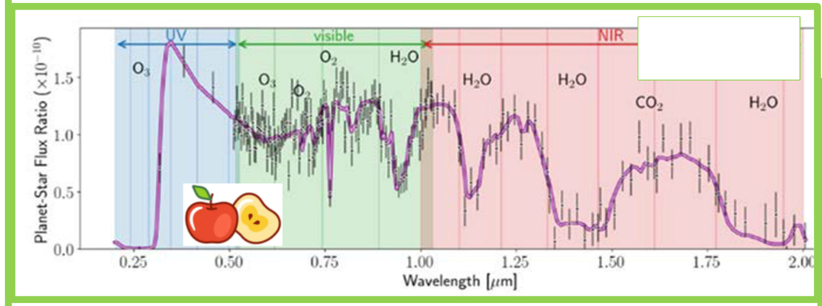
- Mission Architecture with supporting technologies, science objectives, flagship capabilities that fit into decadal science per cost box
- Trades strategy to drive technology development to support Decadal constraints boxes
- Transition processes
- Technology roadmaps, timelines and mature technologies
- Wavelength gap forecasts & coverage strategy, incl. program size

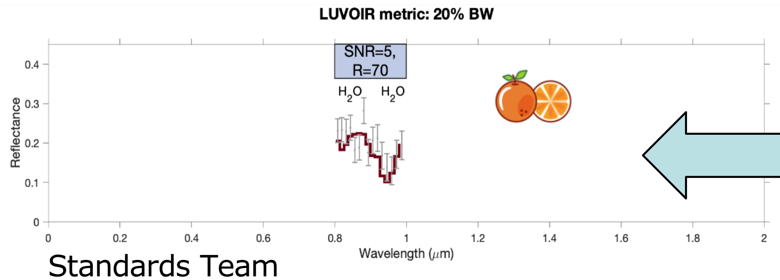
Fig 7.3 Astro2020

Astro2020 recommendation for exoplanets

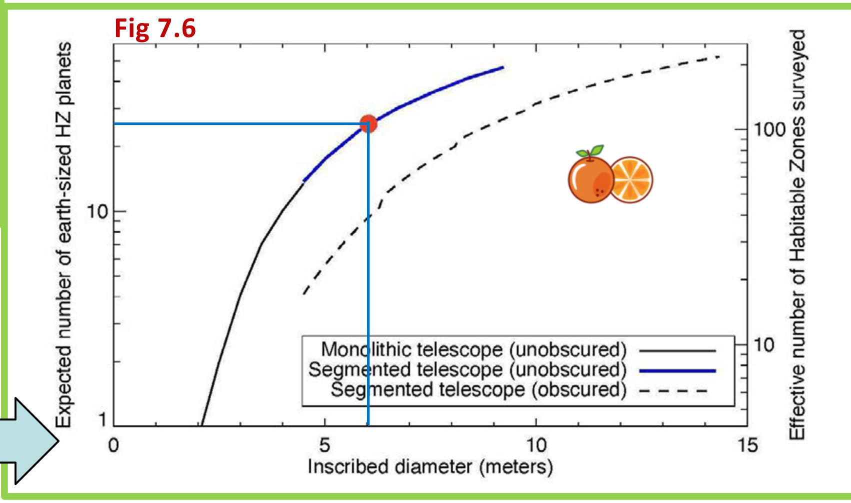
- Astro2020 recommended a “future large IR/O/UV telescope optimized for observing habitable exoplanets and general astrophysics” to be **ready by end of the decade**
- Astro2020 recommended “to search for **biosignatures** from a **robust number** of about ~25 habitable zone [exo]planets”







Standards Team

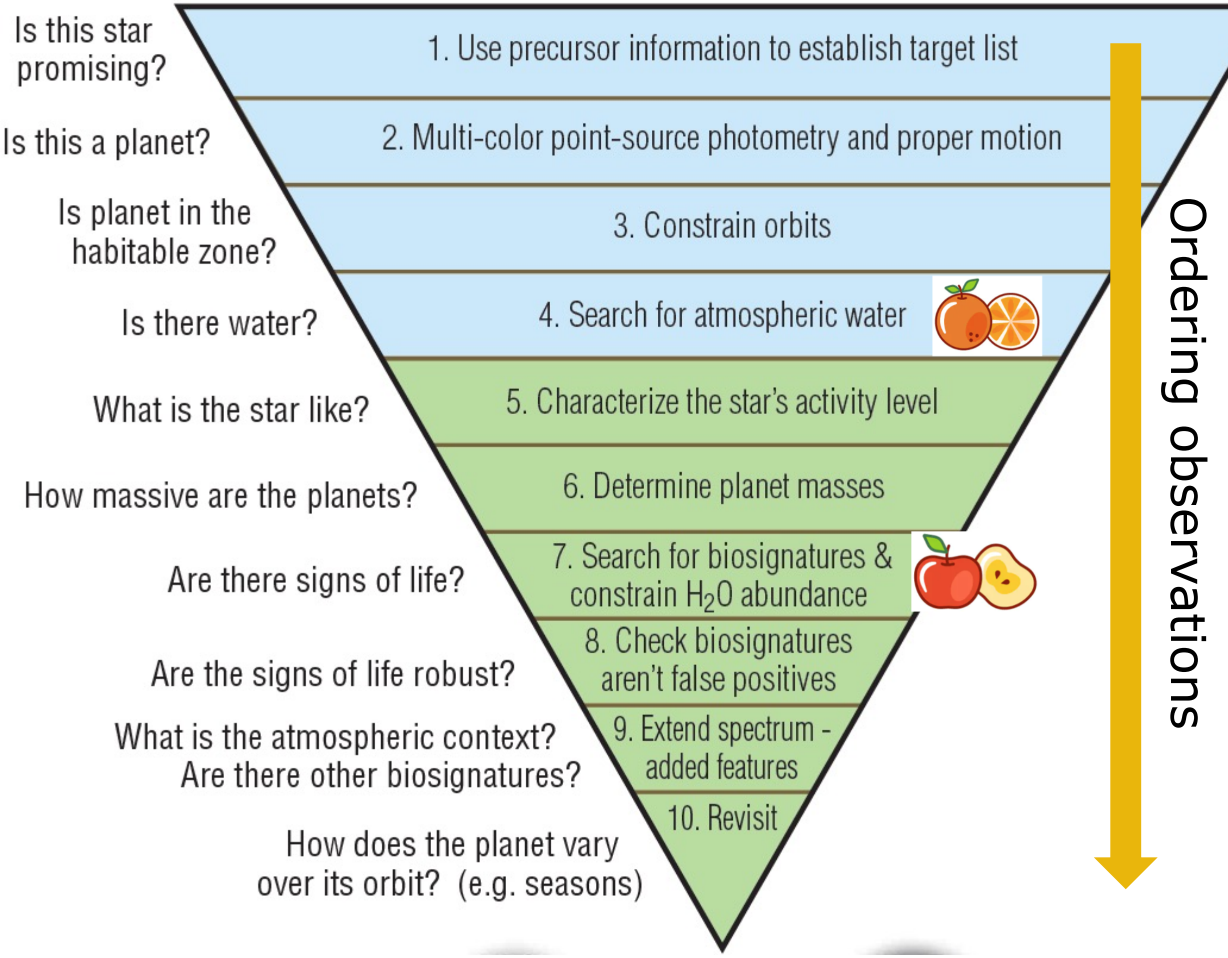


- Building on the work done by large concept studies and the Standards Evaluation Team, we can iterate, address nuances, and incorporate progress to map exoplanet science goals to planet characterization to metrics

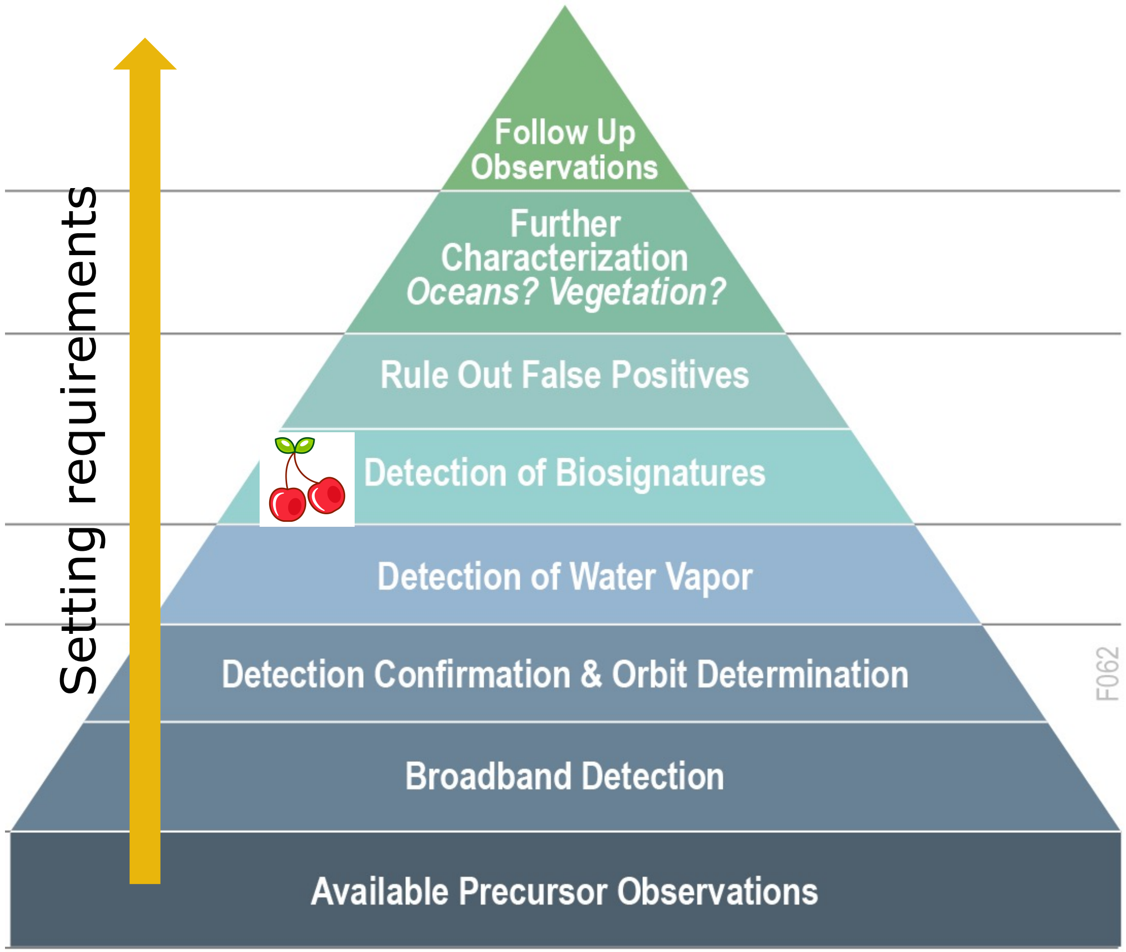
This will not be easy!

- Characterization is complicated, and will likely involve multiple measurements. … This means we’ll have more than one metric

Observing Strategy impact on metrics



LUVOIR Final Report Fig. 3-11

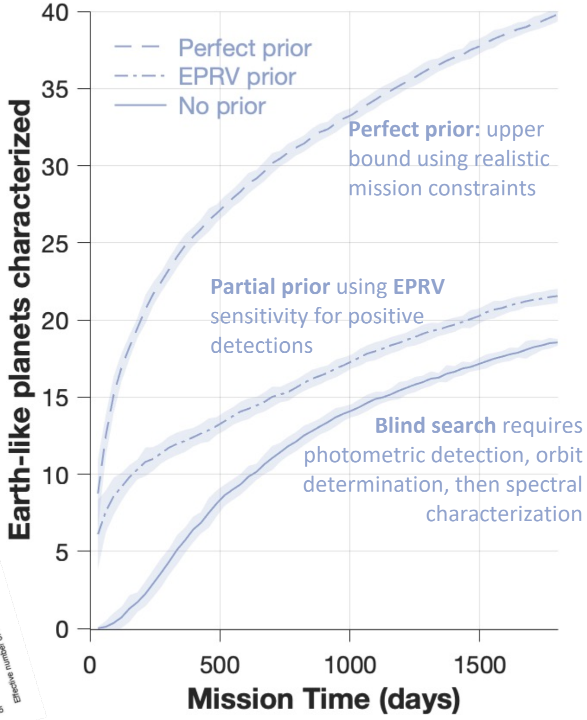


HabEx Final Report Fig. 3.1-1

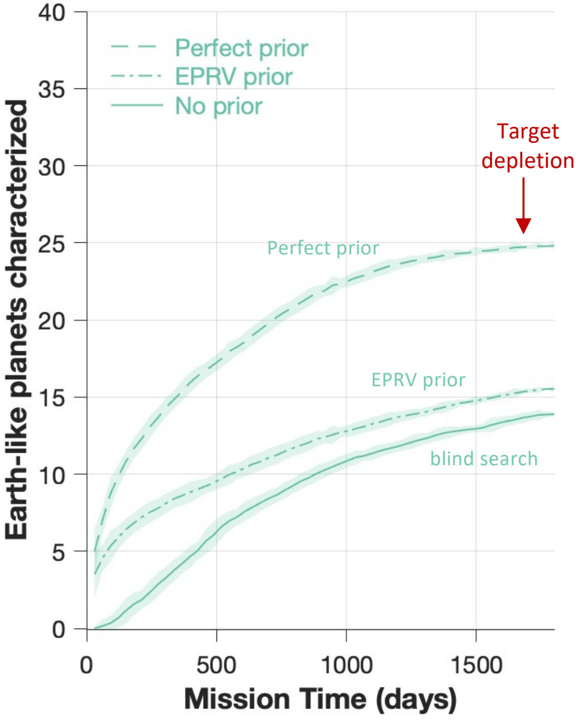
Different yield metrics reveal different sensitivities

Observing scenario, SNR, spectral resolution, number of sub-spectra, and precursor knowledge effect yield.

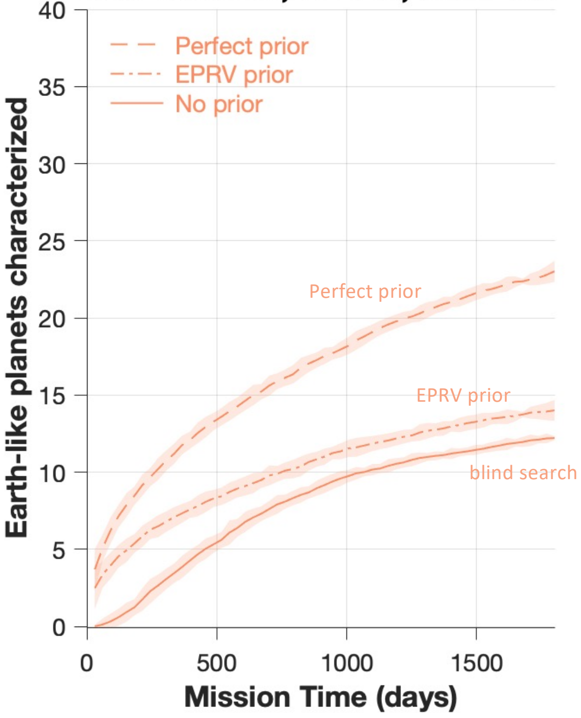
6m coronagraph
800-1000nm, R=70, SNR=5

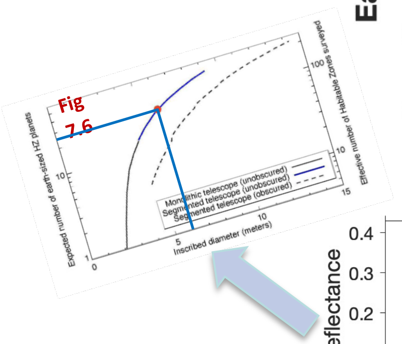


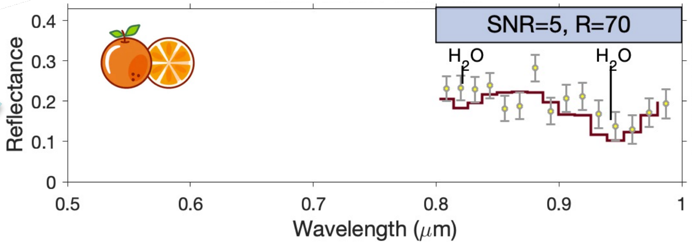
6m coronagraph
680-830nm, R=140, SNR=8.5

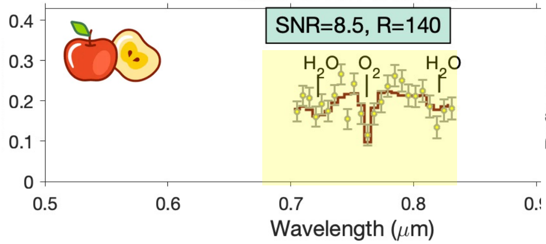


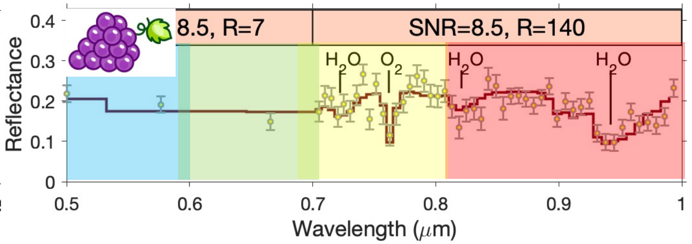
6m coronagraph
450-690 n, R=7, SNR=5
680-1000nm, R=140, SNR=8.5











More comparisons of metric impact on architectures in Morgan et al. 2021
https://doi.org/10.1117/1.JATIS.7.2.021220

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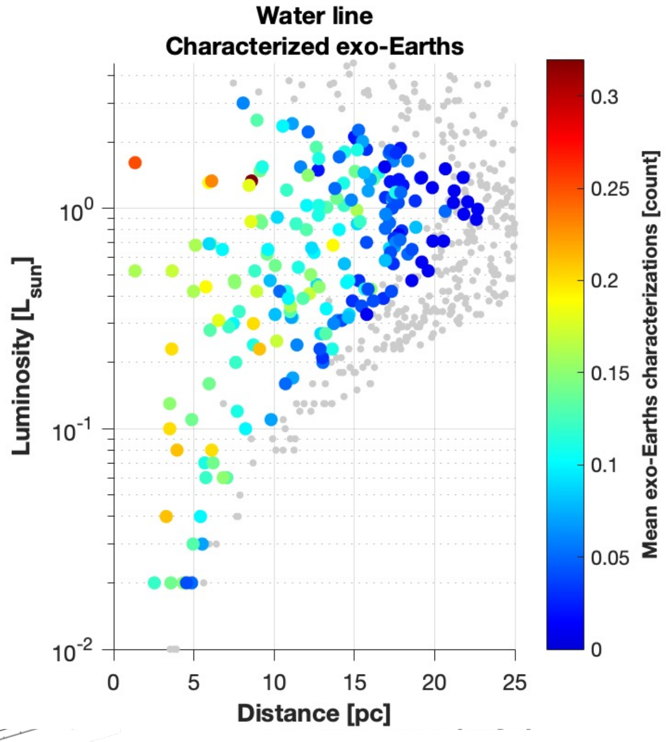

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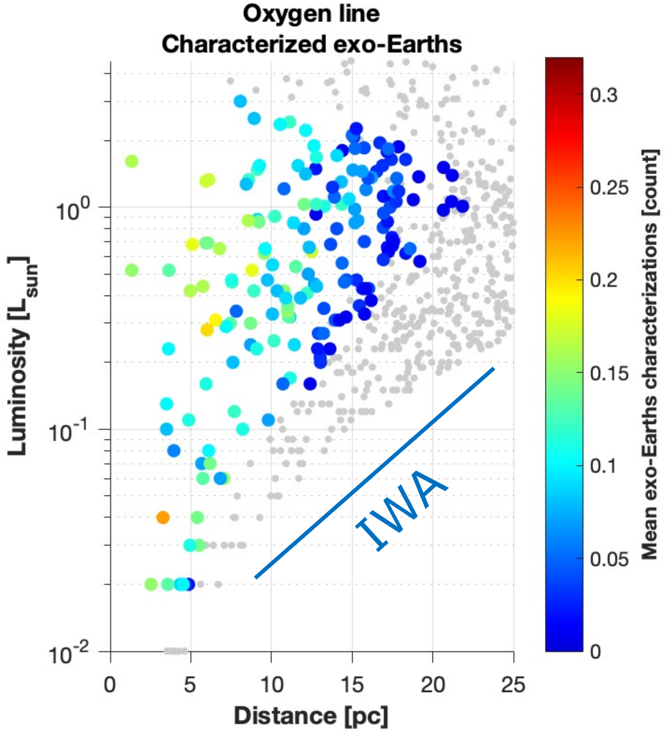

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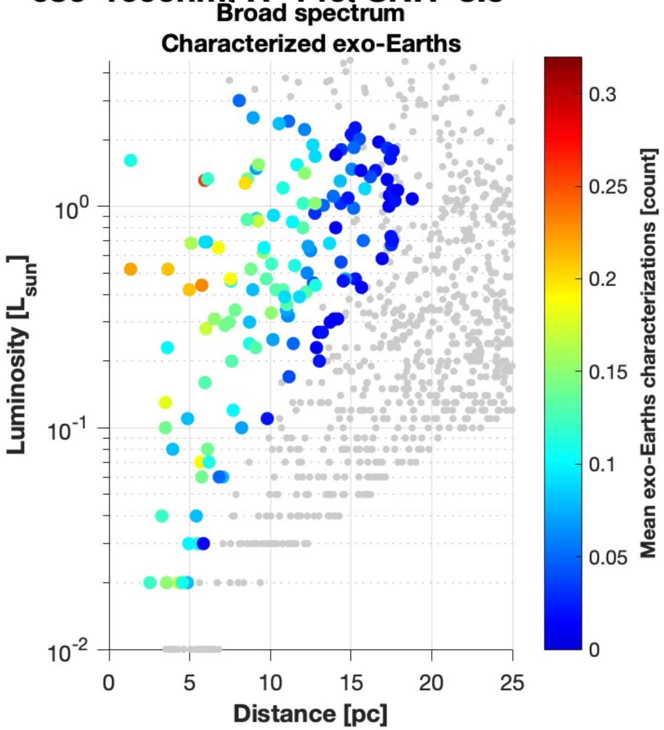

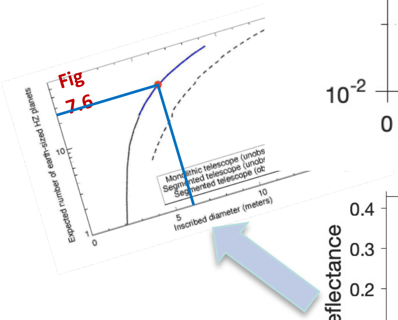

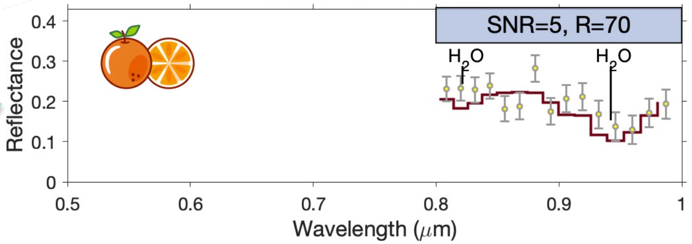

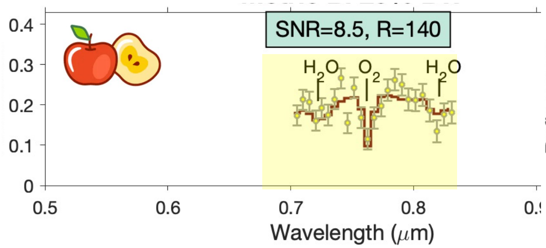

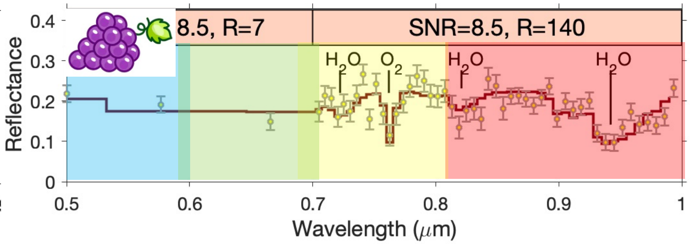

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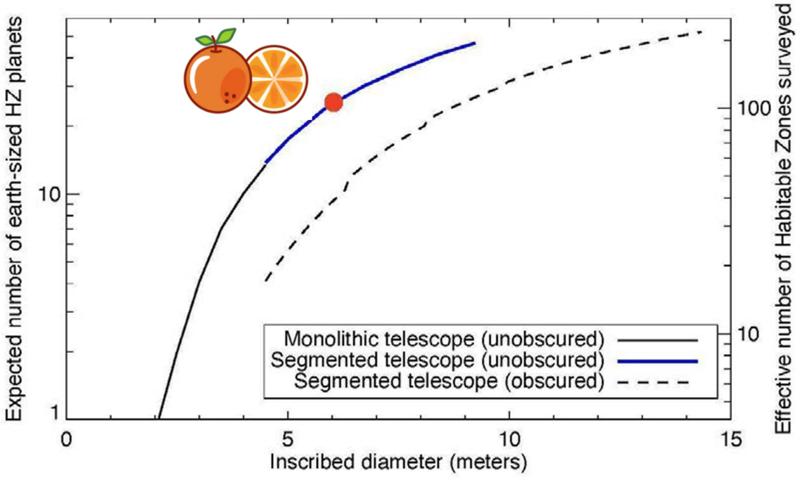
Metrics quantify performance sensitivity to key parameters

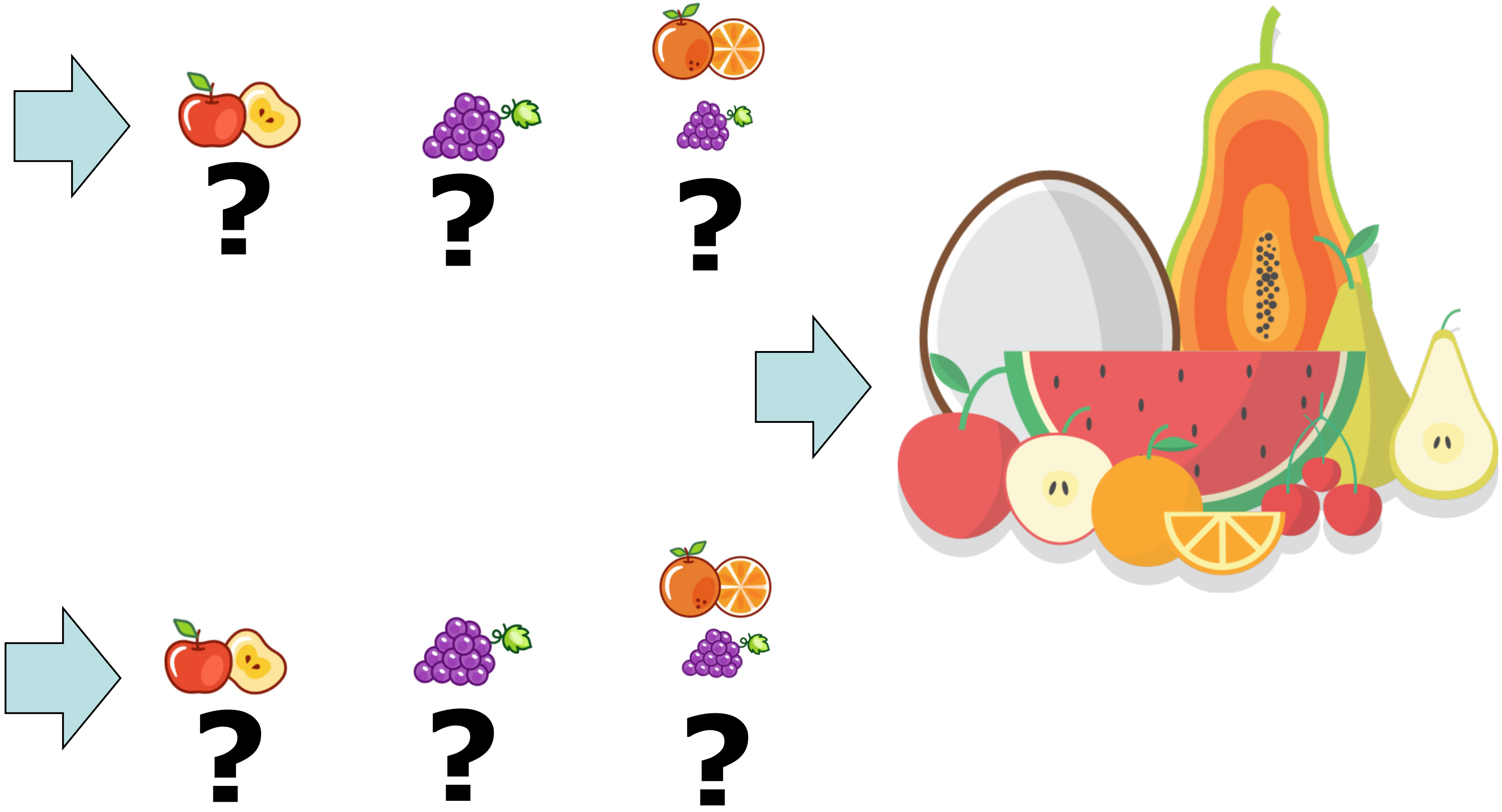
What is the shape of the curve for other metrics?
For tiered observing scenarios that combine metrics?



Stark, MacIntosh, Mawet 2017

$$\text{Yield} = 6 \times (D/5\text{m})^{1.97} (T_{int}/\text{yr})^{0.32} (41\text{mas}/IWA_d)^{0.98} \times (\eta_E/0.1)^{0.96} (A/0.2)^{0.65} (3/Zodi_{median})^{0.17}$$

Stark et al. 2014



What are good metrics going forward?

- **Represent the desired science measurable at a quality required to accomplish the science goal**
  - Clearly communicate apples from oranges
  - Computationally tenable for many iterations and trades
- **Defining the science metrics is work**
  - That will require iterating on the science performance models
  - That will likely require iterating on the measurement models
  - There are nuances that are worth understanding EARLY
  - There is an opportunity with the precursor science workshop (August 2-4) to identify the work that needs to be done to design good metrics
- **NASA-led Science Evaluation Teams (SETs) can help the community understand the relationship of science metrics observing strategies and to technology use cases**

We as a community need to be clear on which metric we are using so that there are not apples to oranges comparisons muddying the trades.

Science Evaluation Team (SET) Purpose

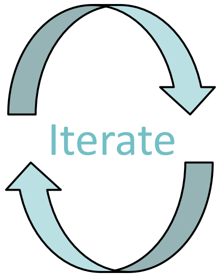
- **The work of the ExoSET and larger great Observatory SET will help the community and the NASA-led strategy teams to understand science yield and inform early strategic technology investments and put us in a better position to have a compelling mission by the end of the decade**

- **The SET evaluates**
  - It does not make decisions
  - It does not set science goals

Exoplanet Science Evaluation
as trailblazer for other Stage 1 SETs

- **Provide an objective, transparent yield evaluation in service to APD for the community to unpack the Decadal recommendation for exoplanet direct imaging and general exploration of the sensitivity of the 6-m aperture space**
  - Combined community effort with experienced experts
  - Two yield codes provide cross-validation and increased confidence
    - Provide training or support for new community users to the open-source yield code
  - Configuration management of astrophysical inputs and modeling assumptions
    - Work with the community to build consensus on astrophysical inputs and when to update them
- **The first critical activity is to examine metrics for yield with the community**
- **Reports to APD**
  - Interfaces to the community via the ExoPAG and potential future SAGs/SIGs
  - Coordinates closely with the Science and Technology Strategy Teams via liaisons to the SST and TST and via the GOMaP Leadership team meetings
  - Membership is currently in the APD approval process

Stage 1 main tasks



- **Figures of Merit**
- **Sensitivity study of key parameters**
- **Prepare modeling codes for Stage 2 AoA and trades**

Let's make the next Great Observatories successful

1. **Stage 3 success: A Successful External Review**
   a. Mature, compelling concept by end of the decade
2. **Stage 2 success**
   a. Evaluate science performance to provide quantitative feedback on Stage 2 activities such as analysis of alternatives and trades
3. **Stage 1 success**
   a. Iterate with and support the community in identifying and understanding the metrics
   b. Quantitatively use the science metrics to support the SST and TST in understanding and prioritizing the science and technology
      a. Inform early science and technology investments
      b. Sensitivity study of key parameters
   c. Update modeling codes for anticipated Stage 2 activities (AoA, trades)

Upcoming

- **Precursor Science workshop 2 Aug 2-4**
- **SETs community workshop(s) in CY23**

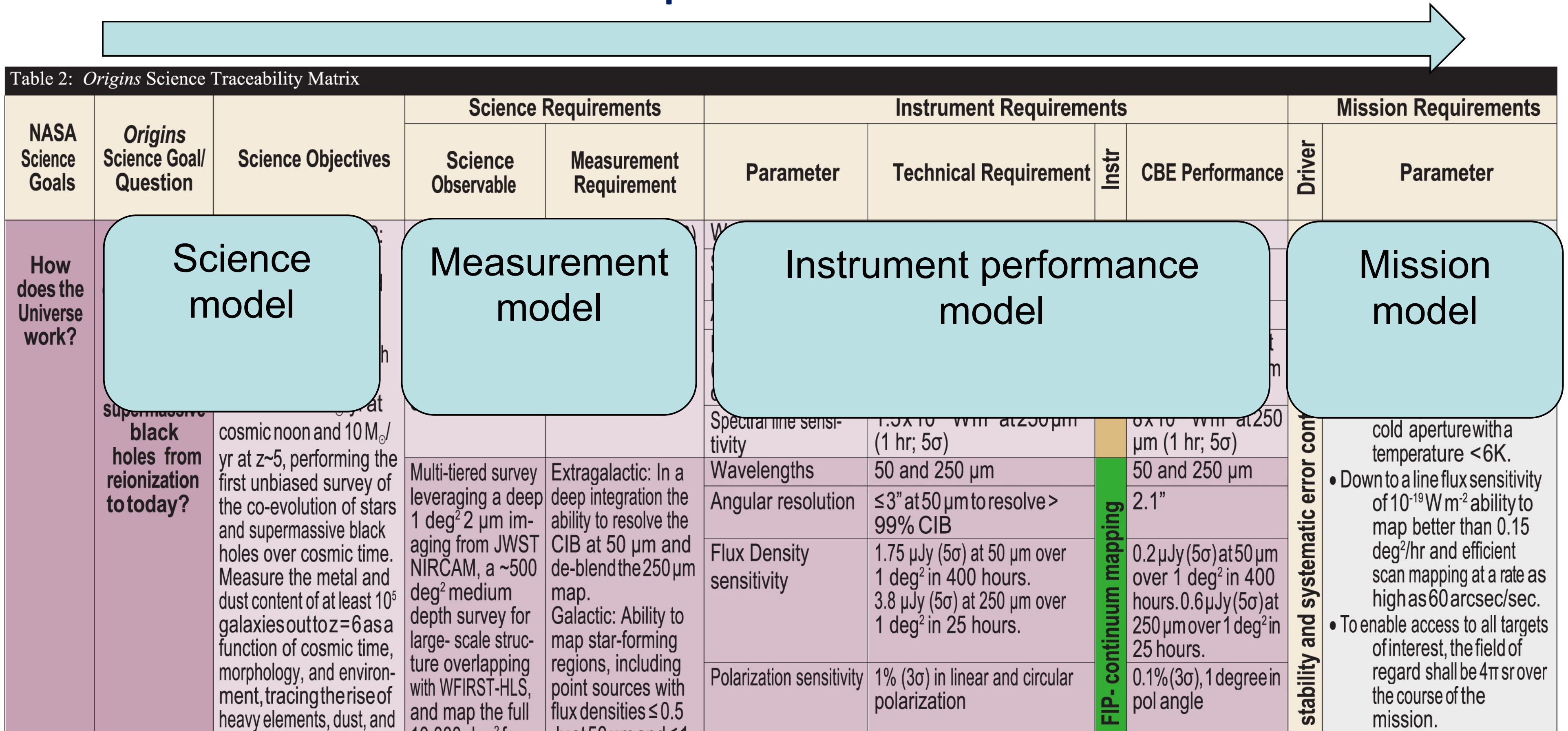
- **Relevant talks at AAS**
  - Thursday 2:50 pm, Ballroom C, R. Morgan et al., **Sensitivity of exo-Earth yield of a 6 m IR/O/UV telescope to bandwidth, SNR, and spectral resolution**
  - Thursday 2:20, Ballroom C, S. Hasler et al, **The Role of Exoplanet Photometry in Orbit-Fitting of Directly Imaged Multi-Planet Systems**
  - Thursday 9 am, iPoster 408.05, L. Pogorelyuk et al., **Fast Multi-planet Orbit Fitting for Exoplanet Direct Imaging**

- **Resources:**
  - **Standards Team Final Report detailing common yield inputs and assumptions**
    - https://exoplanets.nasa.gov/exep/studies/sdet/
  - **EXOSIMS open source mission simulation tool:** https://github.com/dsavransky/EXOSIMS

BACKUP

Science Traceability Matrix (STM)

- A tool to communicate how the science shapes the mission
- Flows the science goals and objectives to instrument and mission requirements
- Science objectives should be quantified
- Shows a well-understood concept



Exoplanet science yield model

Astrophysical Inputs
Star list
exozodi
Occurrence rate
Planet radii
albedo

Instrument Parms
Aperture
Throughput, QE
Contrast, IWA, OWA
Spectral Resolution
Bandwidth, SNR

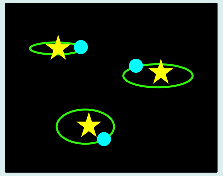
Mission Constraints
Lifetime
Observing allocation
Observatory orbit
Solar keepout
Observing scenario

Measurement model

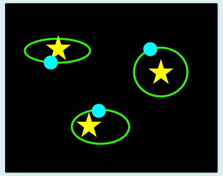
Instrument performance model

Mission model

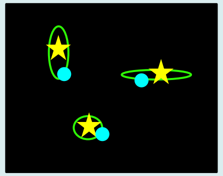
Universe n



Universe n+1



Universe n+2



⟨n⟩ planets characterized

EXOSIMS: Open source. Python. Parametric. Probabilistic. Modular.

– Creates Monte Carlo ensembles of missions.

https://github/dsavransky/EXOSIMS