Jet Propulsion Laboratory
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Flowing Science Goals to Mission Concept and the Importance of Metrics

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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

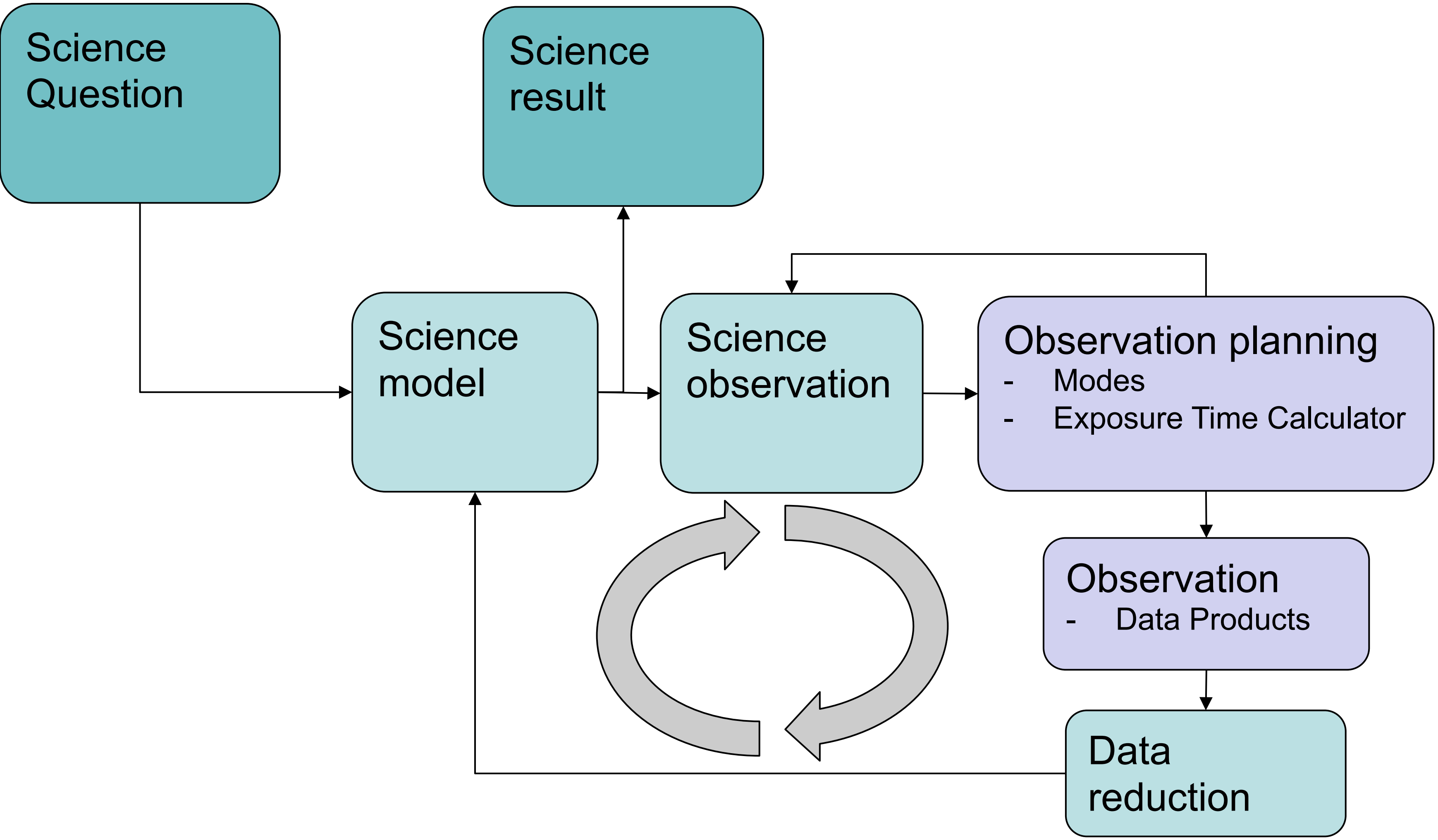
- Mission Architecture with supporting technologies, science objectives, flagship capabilities that fit into decadal science per cost box
- Trades strategy to drive technology development to support Decadal constraints boxes
- Transition processes
- Technology roadmaps, timelines and mature technologies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

Fig 7.3
Astro2020

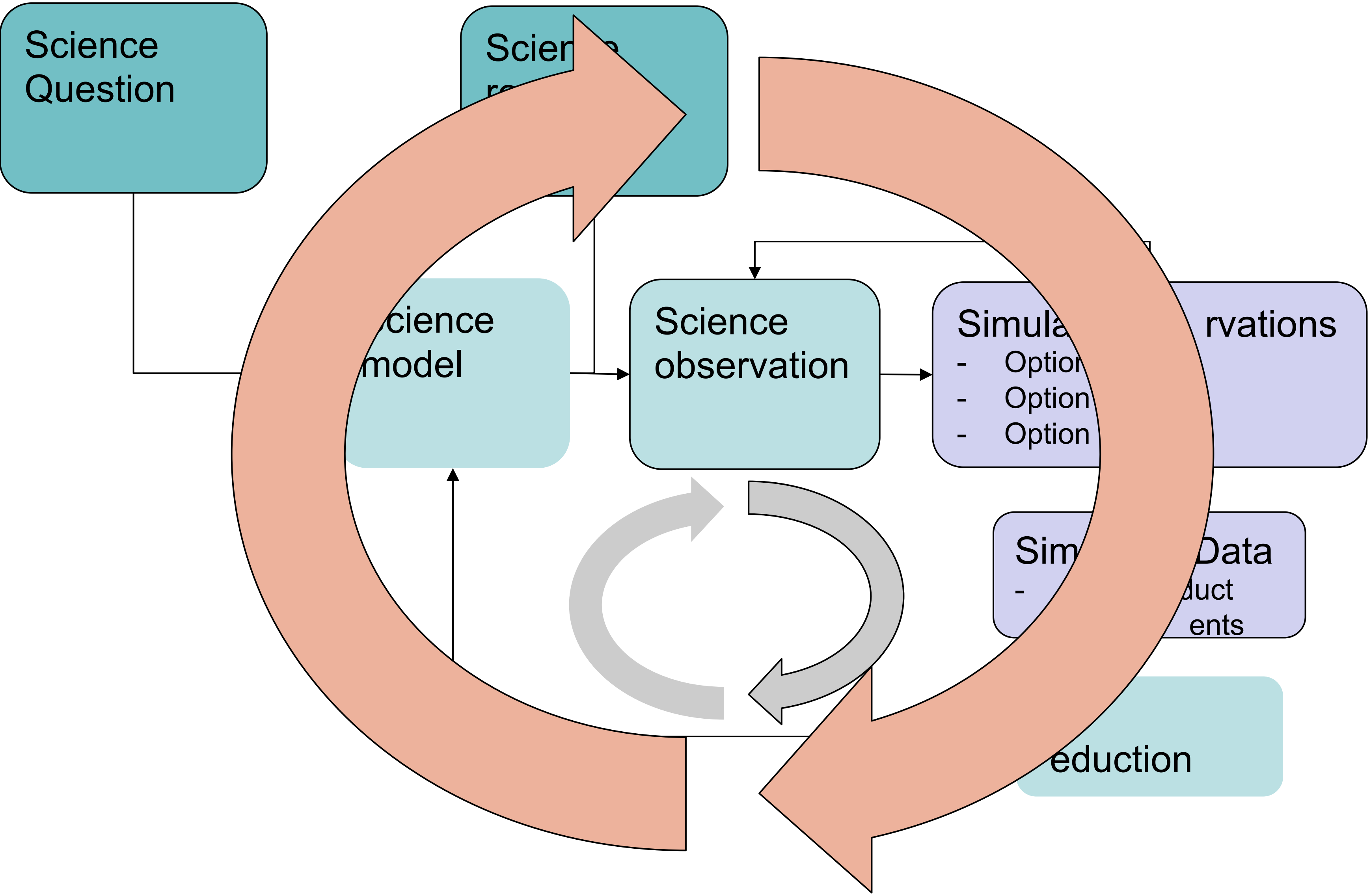
HOW ARE YOU GOING TO DO YOUR SCIENCE?

WHAT DO YOU NEED TO DO YOUR SCIENCE?

Planning an observation on an existing instrument



Planning an observation on a NEW instrument



Science Traceability Matrix (STM)

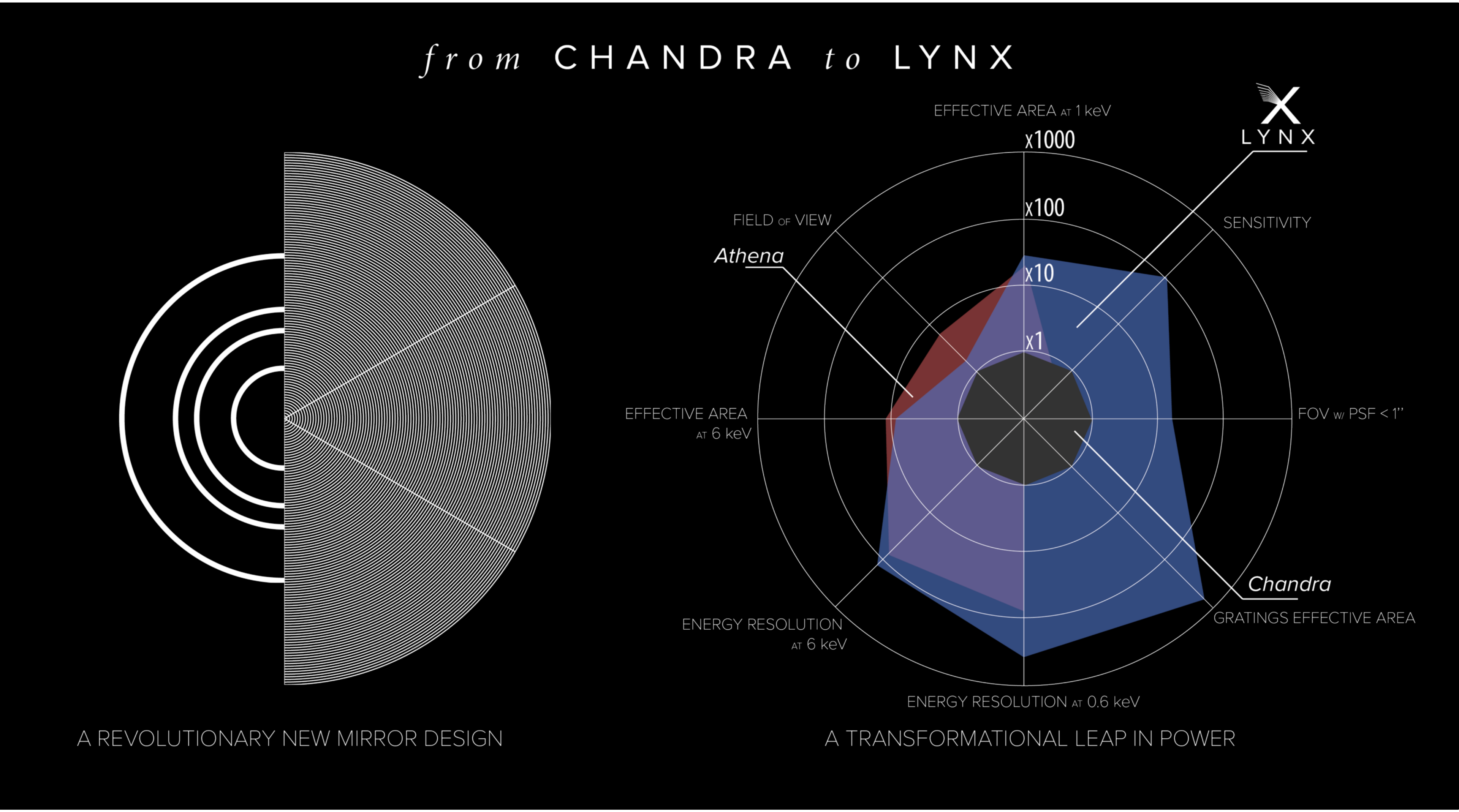
- **A tool to communicate how the science shapes the mission**
- **Flows the science goals and objectives to instrument and mission requirements**
- **Science objectives should be quantified**
- **Shows a well-understood concept**

Science model | Measurement model | Instrument performance model | Mission model

Table 2: *Origins* Science Traceability Matrix

NASA Science Goals	*Origins* Science Goal/ Question	Science Objectives	Science Requirements: Science Observable	Science Requirements: Measurement Requirement	Instrument Requirements: Parameter	Instrument Requirements: Technical Requirement	Instrument Requirements: Instr	Instrument Requirements: CBE Performance	Mission Requirements: Driver	Mission Requirements: Parameter
How does the Universe work?	[illegible] supermassive black holes from reionization to today?	[illegible] cosmic noon and 10 $M_\odot$/yr at z~5, performing the first unbiased survey of the co-evolution of stars and supermassive black holes over cosmic time. Measure the metal and dust content of at least 10^5 galaxies out to z=6 as a function of cosmic time, morphology, and environment, tracing the rise of heavy elements, dust, and [illegible]	[illegible]	[illegible]	Spectral line sensitivity	[illegible] at 250 µm (1 hr; 5σ)	[illegible]	[illegible] at 250 µm (1 hr; 5σ)	stability and systematic error con[illegible]	[illegible] cold aperture with a temperature <6K. • Down to a line flux sensitivity of 10^{-19} W m^{-2} ability to map better than 0.15 deg^2/hr and efficient scan mapping at a rate as high as 60 arcsec/sec. • To enable access to all targets of interest, the field of regard shall be 4π sr over the course of the mission.
			Multi-tiered survey leveraging a deep 1 deg^2 2 µm imaging from JWST NIRCAM, a ~500 deg^2 medium depth survey for large- scale structure overlapping with WFIRST-HLS, and map the full [illegible]	Extragalactic: In a deep integration the ability to resolve the CIB at 50 µm and de-blend the 250 µm map. Galactic: Ability to map star-forming regions, including point sources with flux densities ≤ 0.5 [illegible]	Wavelengths	50 and 250 µm	FIP- continuum mapping	50 and 250 µm		
					Angular resolution	≤3" at 50 µm to resolve > 99% CIB		2.1"		
					Flux Density sensitivity	1.75 µJy (5σ) at 50 µm over 1 deg^2 in 400 hours. 3.8 µJy (5σ) at 250 µm over 1 deg^2 in 25 hours.		0.2 µJy (5σ) at 50 µm over 1 deg^2 in 400 hours. 0.6 µJy (5σ) at 250 µm over 1 deg^2 in 25 hours.		
					Polarization sensitivity	1% (3σ) in linear and circular polarization		0.1% (3σ), 1 degree in pol angle		

Instrument Models inform potential capability



From LYNX Final report

Exoplanet science yield model

ExEP NASA EXOPLANET EXPLORATION PROGRAM

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

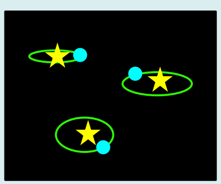
Measurement model

Instrument performance model

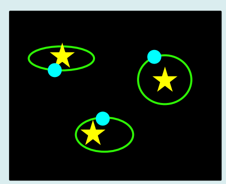
Mission model

⟨n⟩ planets characterized

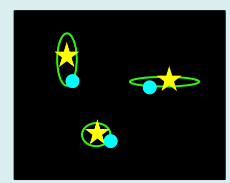
Universe n



Universe n+1



Universe n+2



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

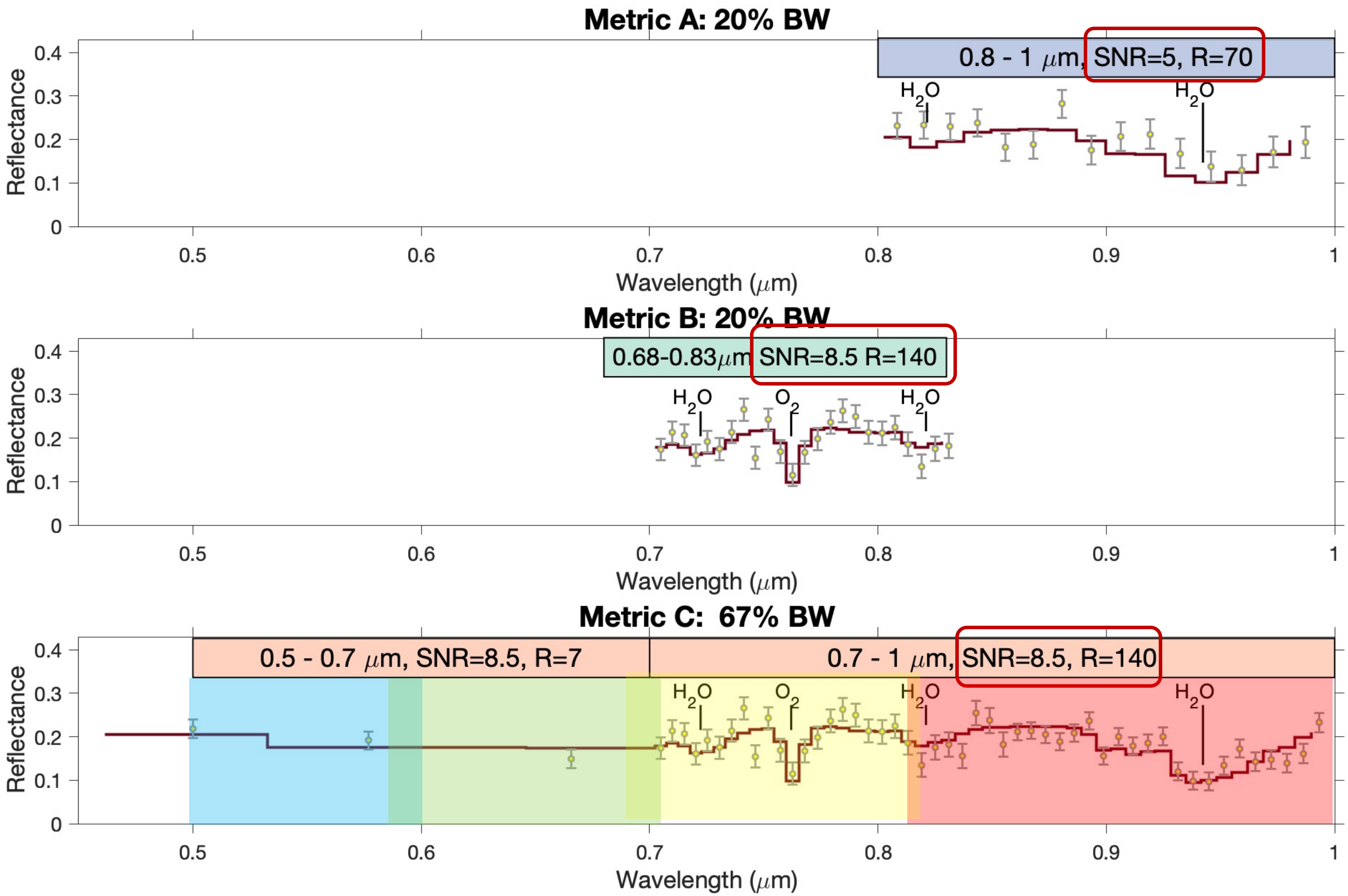
– Creates Monte Carlo ensembles of missions.

https://github/dsavransky/EXOSIMS

THE IMPORTANCE OF METRICS

Exoplanet metric: number of habitable zone exoplanets spectrally characterized to a specific SNR, R, BW

Metrics may represent different tiers of science goals



H_2O line reconnaissance

O_2 line reconnaissance

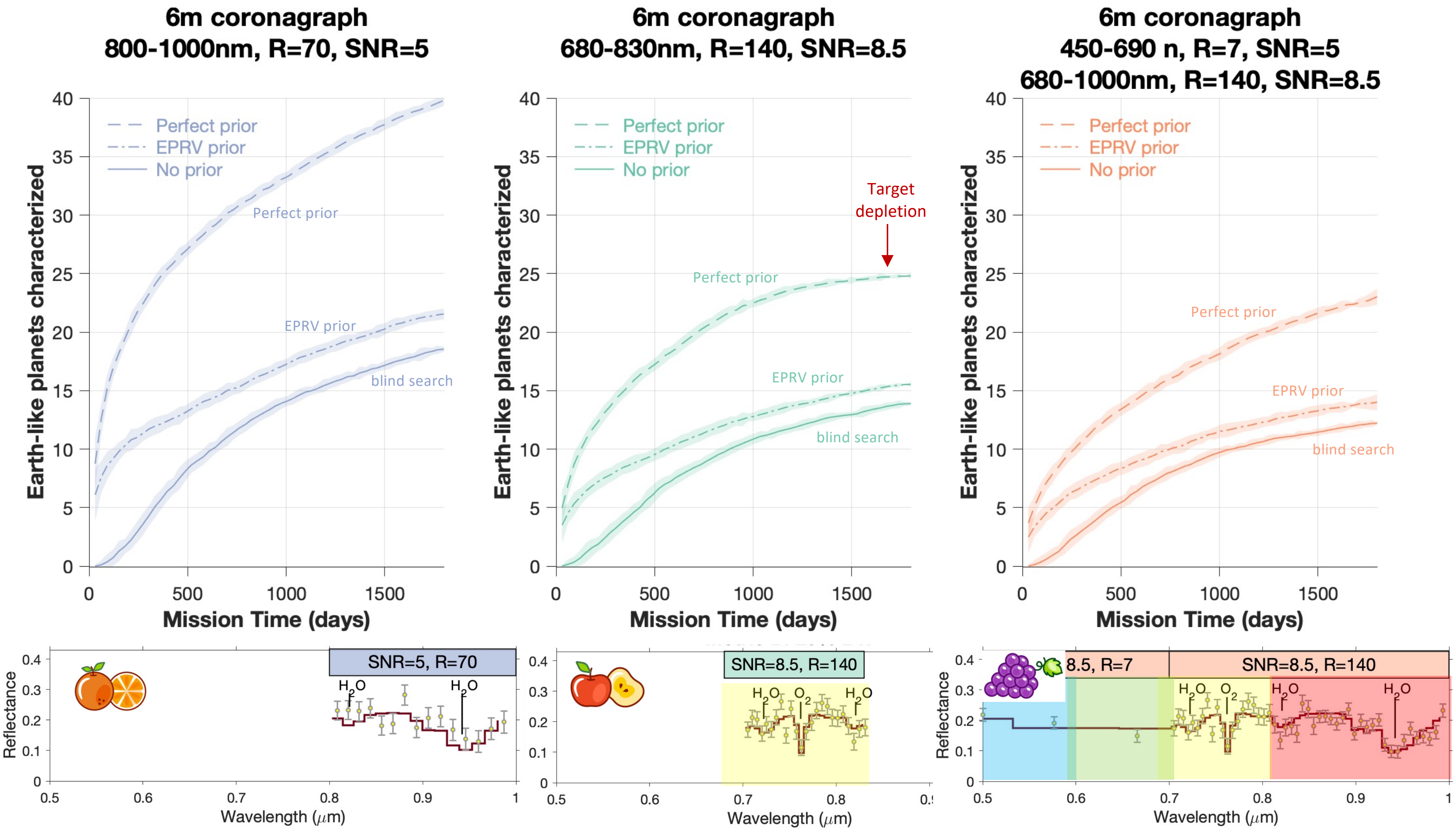
Broad Spectra Coronagraph

Ty Robinson simulated earth spectra at 7.5 pc

Different yield metrics reveal different sensitivities

EXEP NASA EXOPLANET EXPLORATION PROGRAM

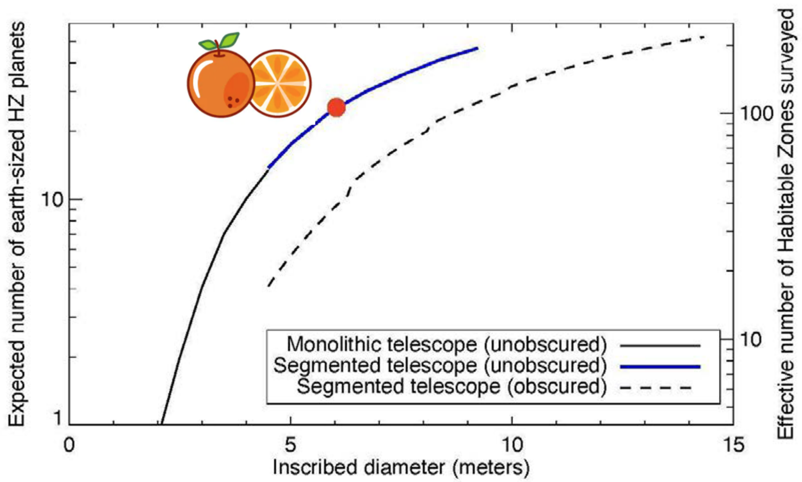
Observing scenario, SNR, spectral resolution, number of sub-spectra, and precursor knowledge effect yield.



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

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

?

?

?

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

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 this workshop to identify the work that needs to be done to design good metrics

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.

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Fig 7.3

BACKUP

Common Comparison

https://exoplanets.nasa.gov/exep/studies/sdet

Standard Definition and Evaluation Team

Overview

Two of the four large mission concept studies for the Astrophysics Decadal Survey were designed to directly image and spectrally characterize earth-like exoplanets. In 2016, the Astrophysics Division chartered an Exoplanet Standard Definition and Evaluation Team (ExSDET) for the purpose of providing an unbiased science yield analysis of the multiple large mission concepts using a transparent and documented set of common inputs, assumptions and methodologies.

Over the course of the past three years, the ExSDET has responded to the direction provided in the charter and the required deliverables by performing the following tasks:

- Develop analysis tools that will allow quantification of the science metrics of the mission studies
- Incorporate physics-based instrument models to evaluate both internal and external occulter designs
- Establish the science metrics that define the yield criteria
- Cross validate the various analytical methodologies and tools
- Provide complete evaluations using common assumptions and inputs of the exoplanet yields for each mission concept.

The primary goal of the SDET Final Report is to present the best understanding of the exoplanet imaging and characterization capabilities of the current STDT observatory and instrument designs, along with their nominal operating plans, using common input assumptions and analysis methodologies. This report is explicitly *not* intended to present an exploration of the capabilities of the full design spaces available to the various mission concepts. Due to large uncertainties in the astrophysics inputs, particularly exo-earth occurrence rate, the yield values should be considered relative rather than absolute.

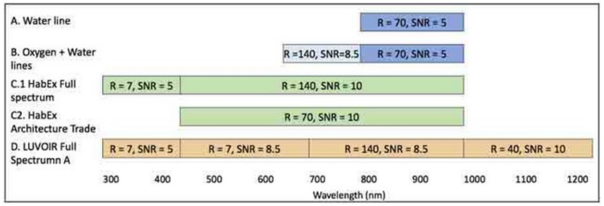


Figure 1. Characterization metric A facilitates a quick search for the water line at 940 nm with a

Documents

- SDET Charter
- SDET Final Report

Cases

- Case 1: HabEx 4H hybrid, metric C1
- Case 2: LUVOIR B, metric A
- Case 3: HabEx 4C, metric C2
- Case 4: HabEx 4S, metric C2

Links

- EXOSIMS on Github
- AYO for LUVOIR
- Habitable Exoplanet Observatory (HabEx)
- Large UV-Optical-Infrared Surveyor LUVOIR

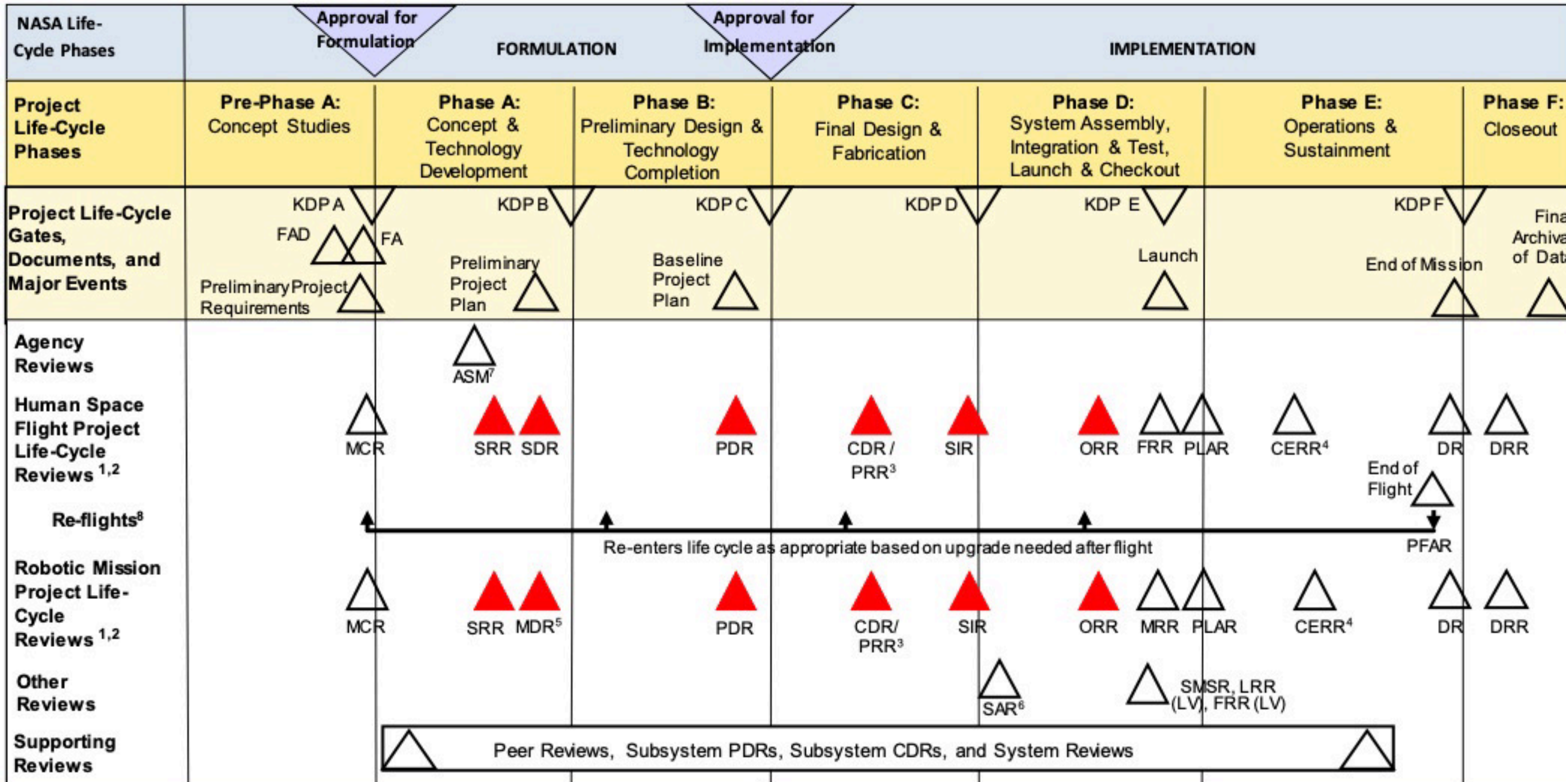
Papers

- EXOSIMS Overview in JATIS
- EXOSIMS Overview
- EXOSIMS Validation

- AYO 2014
- AYO 2015
- AYO 2016 Starshades

You can find more details in the Final Report

NPR 7120.5F



FOOTNOTES

1. Flexibility is allowed as to the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.
2. Life-cycle review objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-5.
3. PRR is needed only when there are multiple copies of systems. It does not require an SRB. Timing is notional.
4. CERRs are established at the discretion of Program Offices.
5. For robotic missions, the SRR and the MDR may be combined.
6. SAR generally applies to human space flight.
7. Timing of the ASM is determined by the MDAA or AA, as compliant with NPD 1000.5 and may take place at any time during Phase A.
8. Placement of arrows is notional. See Section 2.2.4.3 for more guidance on reflights.

ACRONYMS

ASM - Acquisition Strategy Meeting
CDR - Critical Design Review
CERR - Critical Events Readiness Review
DR - Decommissioning Review
DRR - Disposal Readiness Review
FA - Formulation Agreement
FAD - Formulation Authorization Document
FRR - Flight Readiness Review
KDP - Key Decision Point
LRR - Launch Readiness Review
LV - Launch Vehicle
MCR – Mission Concept Review
MDR - Mission Definition Review
MRR - Mission Readiness Review
ORR - Operational Readiness Review
PDR - Preliminary Design Review
PFAR - Post-Flight Assessment Review
PLAR - Post-Launch Assessment Review
PRR - Production Readiness Review
SAR - System Acceptance Review
SDR - System Definition Review
SIR - System Integration Review
SMSR - Safety and Mission Success Review
SRB - Standing Review Board
SRR - System Requirements Review

Red triangles represent life-cycle reviews that require SRBs. The Decision Authority, Administrator, MDAA, or Center Director may request the SRB to conduct other reviews.