Standards Definition and Evaluation Team Overview

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March 21, 2017

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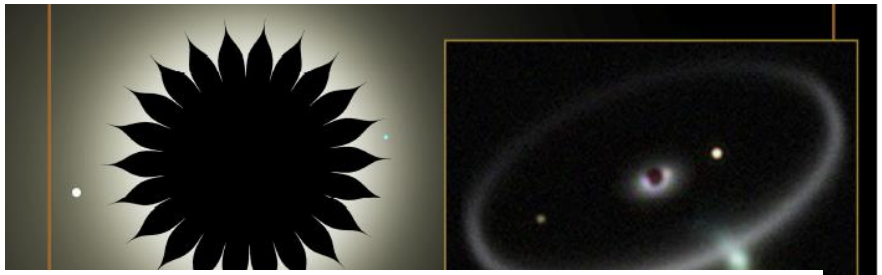
Exoplanet Probe Studies



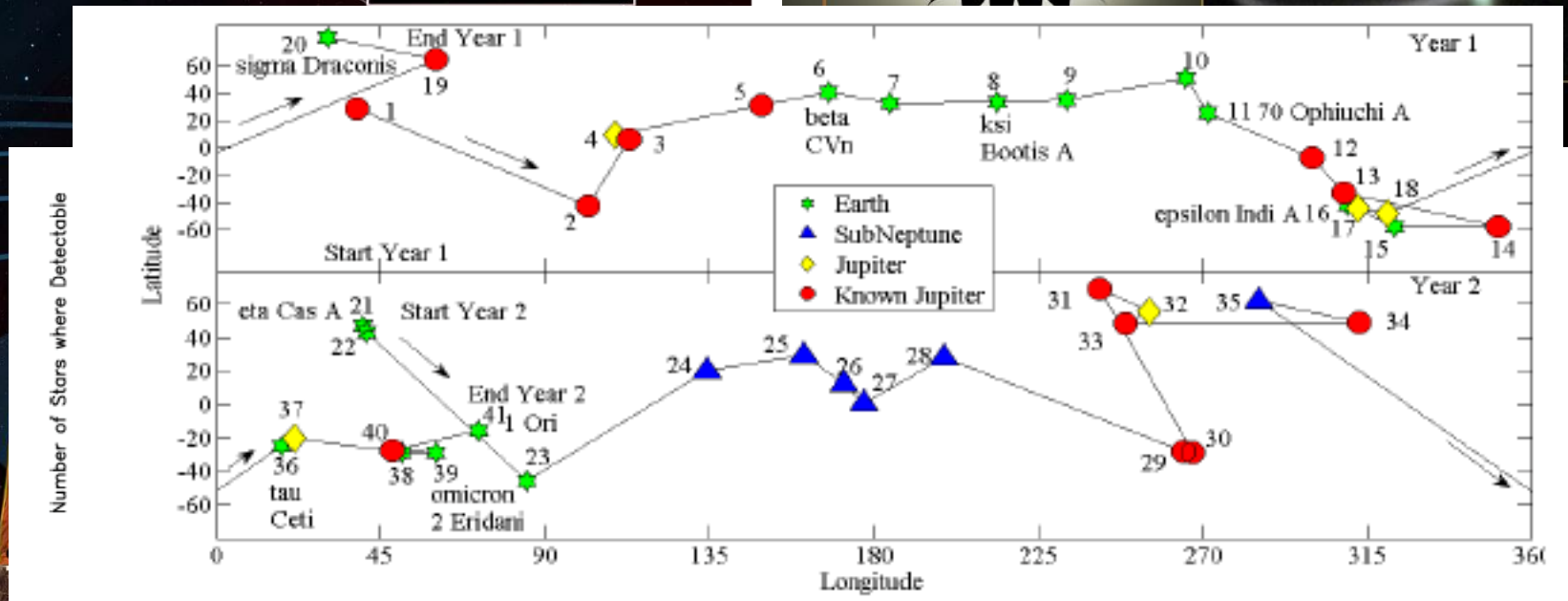


Fig Figure 5.3-1. Observing sequence for Case 1, Dedicated Mission, Earth twins in HZ. Coordinates are ecliptic longitude and latitude.

CL#15-1197

Exoplanet Direct Imaging Mission Concept

ExEP Standard Definition and Evaluation Team Charter

- APD chartered a Standards Definition and Evaluation Team to provide **transparent, common** exoplanet science yield estimates for Decadal missions and probes.
  - Standards team promotes **standard and consistent** definition of inputs and outputs for purposes of yield comparison
  - “Common yardstick, honest broker” discussed by PAGs and Senior Management, part of Management Plan
  - Draft charter: https://exep.jpl.nasa.gov/reportsAndDocuments/

Exoplanet Standard Definitions and Evaluation Team (1 of 2)

Why:

1. For APD: Science yield analyses based on transparent, unbiased, exoplanet science metrics common to direct exoplanet imaging studies
2. Document transparent, unbiased inputs, assumptions, and analysis methods common to both studies for production of these science metrics

What:

1. Deliver transparent and consistent definitions of input parameters, assumptions, and output metrics
2. Deliver transparent and unbiased analysis tools
   - Program analysis tool based on module additions to Dmitry Savransky's (Cornell) open-source tool currently funded under WFIRST Preparatory Science
   - Comparison and Cross Validation with Altruistic Yield Optimization developed by Chris Stark (STScI)
3. Utilize existing diffraction propagation instrument models to accommodate specific internal and external occulters
4. Test cases to validate the models
5. Periodic comparisons to APD for science metrics, tied to interim (M4) and final (M7) STDT deliverables defined in Management Plan

Exoplanet Standard Definitions and Evaluation Team (2 of 2)

How:

- Chartered by APD. Coordinated by ExEP for the APD/DSMT
- Small team of experts drawn from NASA Centers and from the general science community:

Dr. Rhonda Morgan	Lead, NASA Exoplanet Exploration Program, JPL	
Dr. Bruce Macintosh	Stanford University	
Dr. Dmitry Savransky	Cornell University	
Dr. Chris Stark	Space Telescope Science Institute	
Dr. Avi Mandell	NASA Goddard Space Flight Center	
Dr. Ruslan Belikov	NASA Ames Research Center	
Dr. John Krist	NASA Jet Propulsion Laboratory	
Dr. Eric Nielson	SETI, IR Direct Imaging Expert	
STDT Liaisons:		
Courtney Dressing	Caltech	(LUVOIR)
Karl Stapelfeldt	ExEP	(HabEx)
Klaus Pontoppidan	Space Telescope Science Institute (OST)	

- STDTs will plan for and produce their own science metrics
- ExSDET will work with STDTs to adopt science metrics and common definitions – chance to iterate with the teams
- ExoTAC (Alan Boss, Chair) will perform independent review of the ExSDET deliverables, as they have for prior comparison studies

ExSDET Schedule

Schedule synced to
Decadal_Studies_Management_Plan_2015_12_28_final.pdf

References

- Prior Comparative Evaluations:
  - WIRST/AFTA Coronagraph WG:
    - http://wfirst.gsfc.nasa.gov/science/AFTA_Coronagraph_Arch_Selection/Coronagraph_Downselect_Rec_Dec13_2013.pdf
  - Final reports for exoplanet probes and WFIRST coronagraph:
    - https://exep.jpl.nasa.gov/files/exep/Traub2_ExoPAG_12_2015.pdf
- SAG13 on Occurrence rates for modeling:
  - https://drive.google.com/drive/folders/0B520NCfkP4aOQUJYdmUzQTJkdkE
- The current (draft) ExSDET Charter:
    - https://exep.jpl.nasa.gov/reportsAndDocuments/
    - Comments on draft charter by STDTs invited through 5/17

Science Yield Performance Modeling

- Answer questions such as
  - How many planets of type ___ can be discovered? Characterized?
  - What instrument parameter most strongly impacts performance?
  - How can diameter be traded with coronagaph IWA?
  - What is the benefit of a priori knowledge?

- Goal:
  - Predict the number of planets of type ___ that can be discovered or characterized.
    - Estimate is limited by knowledge of planet occurrence rates
  - Show relative performance of various architectures and missions
    - Mission rules impact yield, such as detect all, then characterize all vs detect one, then characterize one.

ExEP Yield Tool

Objective:

1. A tool capable of the **consistent comparison** of the science performance of the full range of expected exoplanet mission concepts for the next Decadal Survey

   Coronagraph starshade segmented aperture filled aperture

2. Validate the tool in a transparent manner to enable confidence in the tool

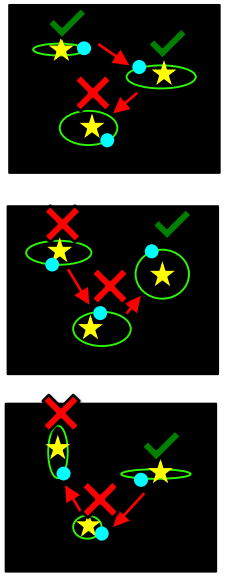
Approach: Utilize, expand, and validate the EXOSIMS framework:

- Modular
- Open Source
- Legacy

What is EXOSIMS?

https://github/dsavransky/EXOSIMS

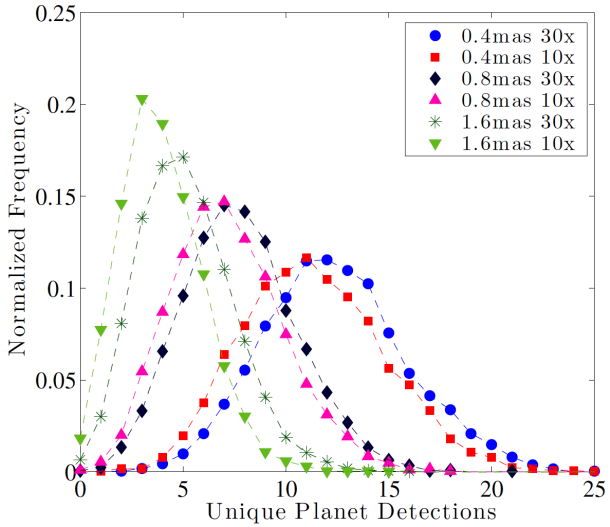
- EXOSIMS is a yield software architecture in which every model component can be independently upgraded/changed.
  - A Monte Carlo approach allows for dynamic constraints in the scheduling of the design reference mission (DRM), such as star shade fuel consumption and responses to detections.
  - Creates ensembles of DRMs which can be analyzed statistically.



2 Detections

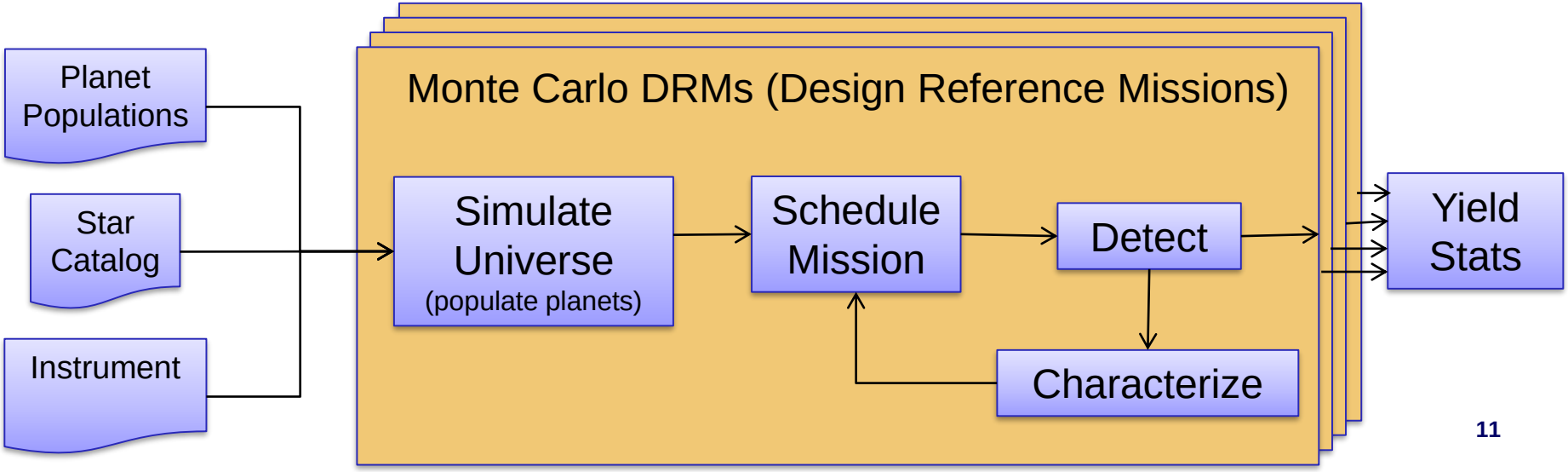
1 Detection

1 Detection



D. Savransky, et al., JATIS 2(1) 2016

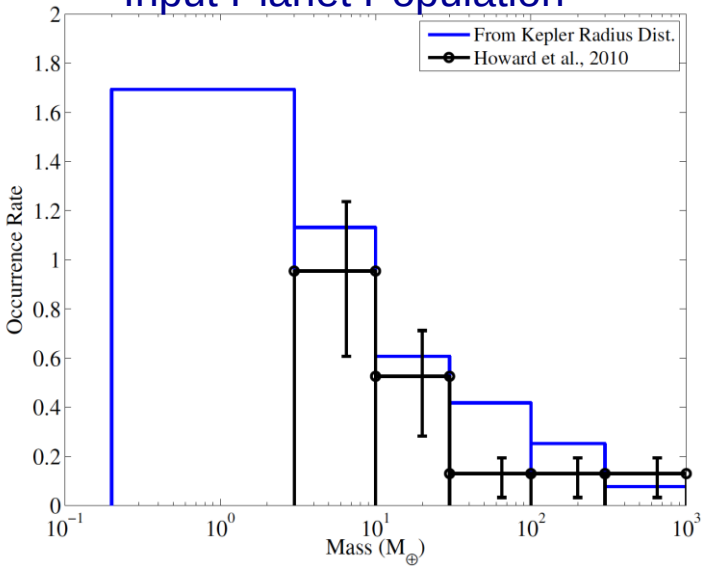
Simulated Mission Ensemble



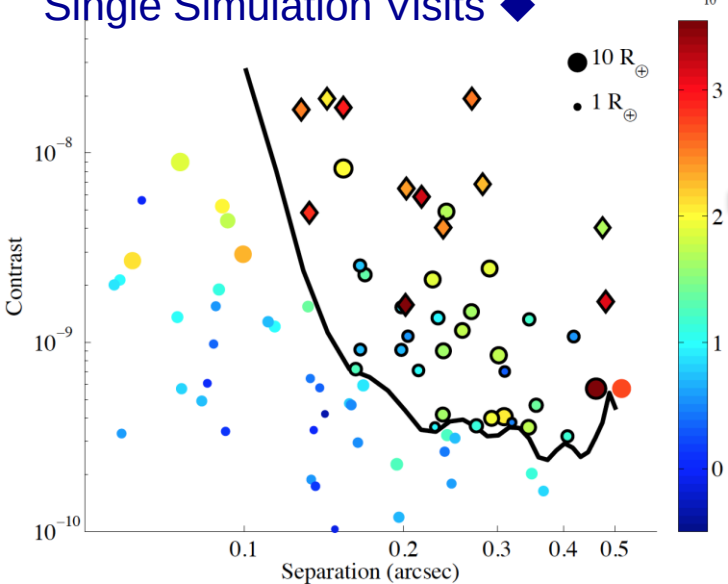
- Simulate a universe by sampling planet population distributions
- Schedule a mission using spacecraft and mission observing constraints
  - Dynamically respond to detections
- Repeat with a new universe 1,000 times

WFIRST Yield Results by EXOSIMS

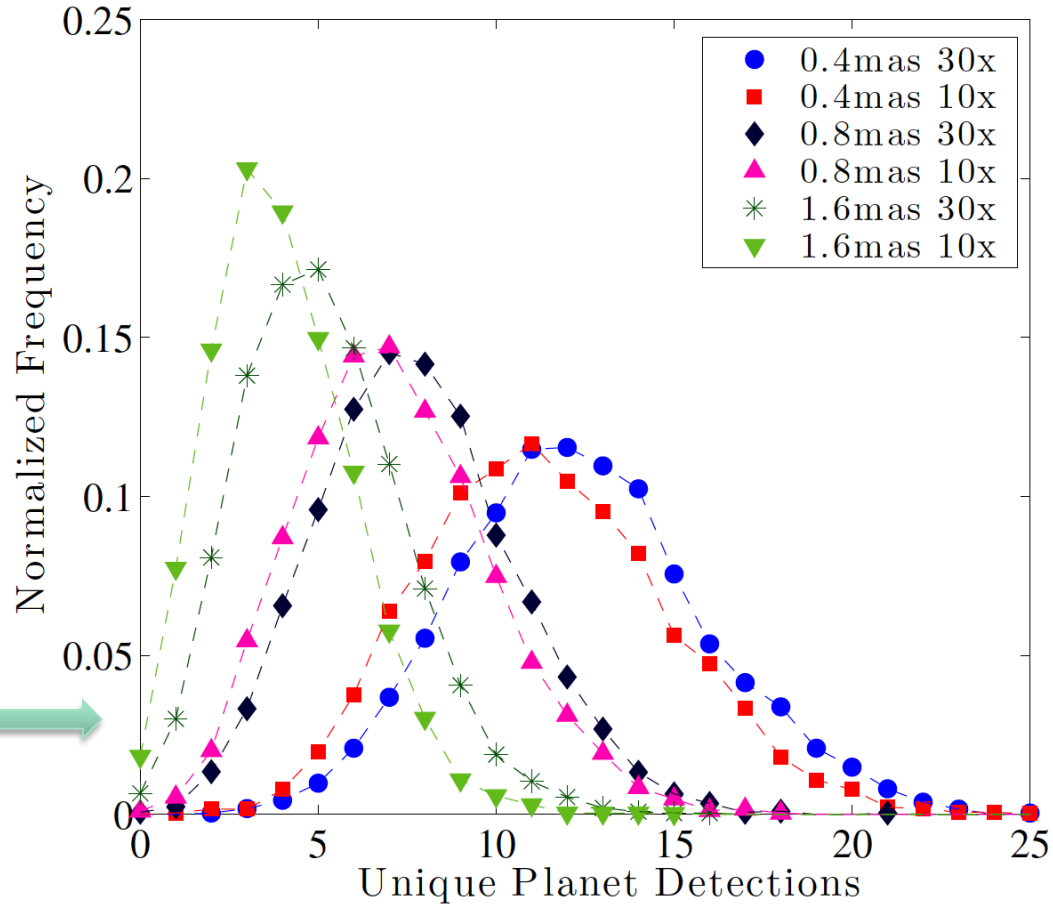
Input Planet Population



Single Simulation Visits

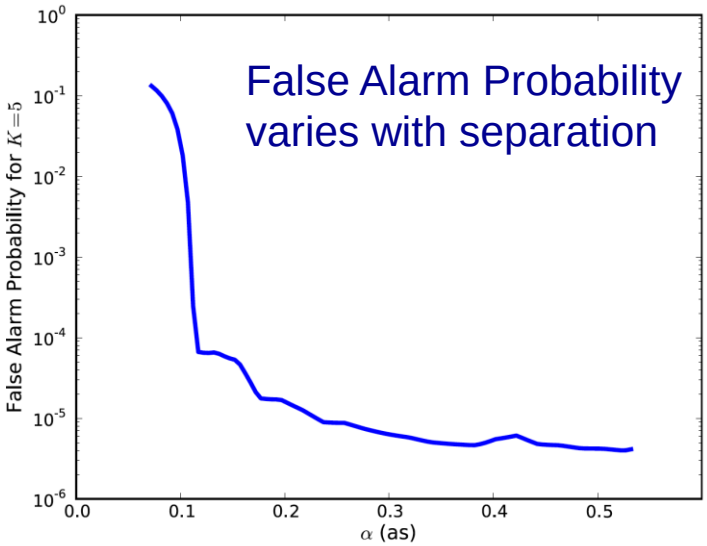


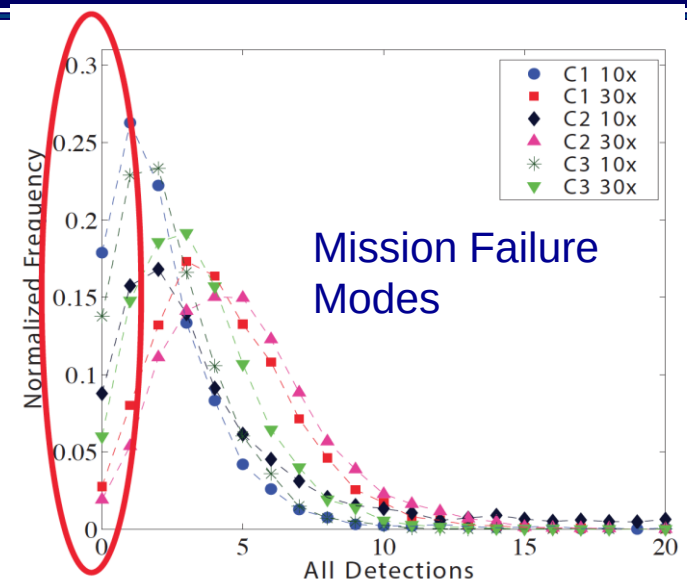
Simulation Ensemble Yield PDFs

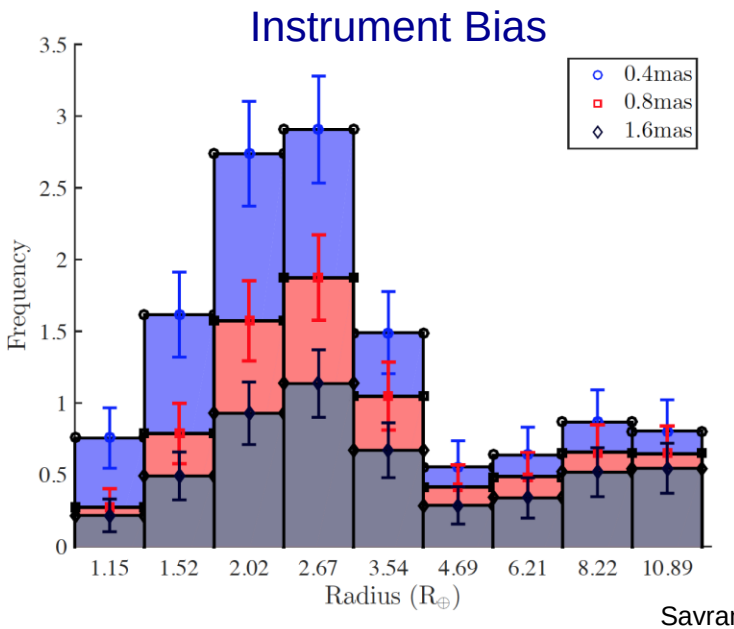


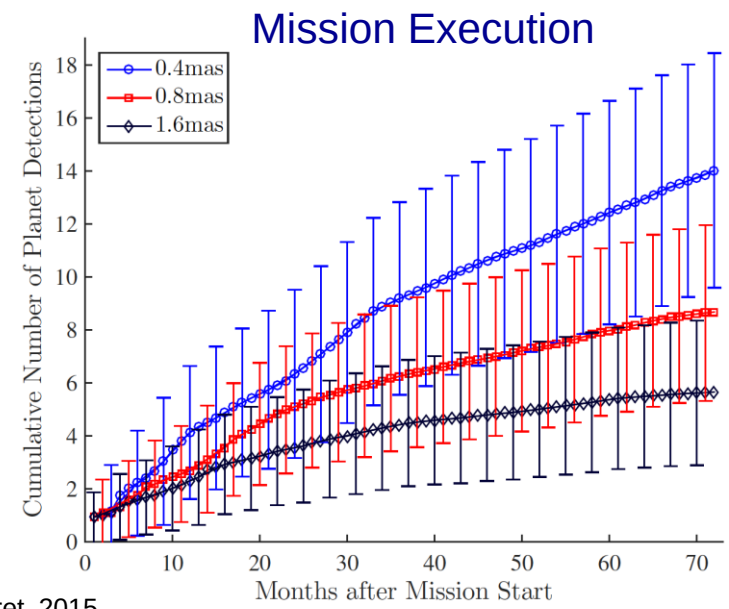
Savransky and Garret, 2015

The power of ensemble statistics





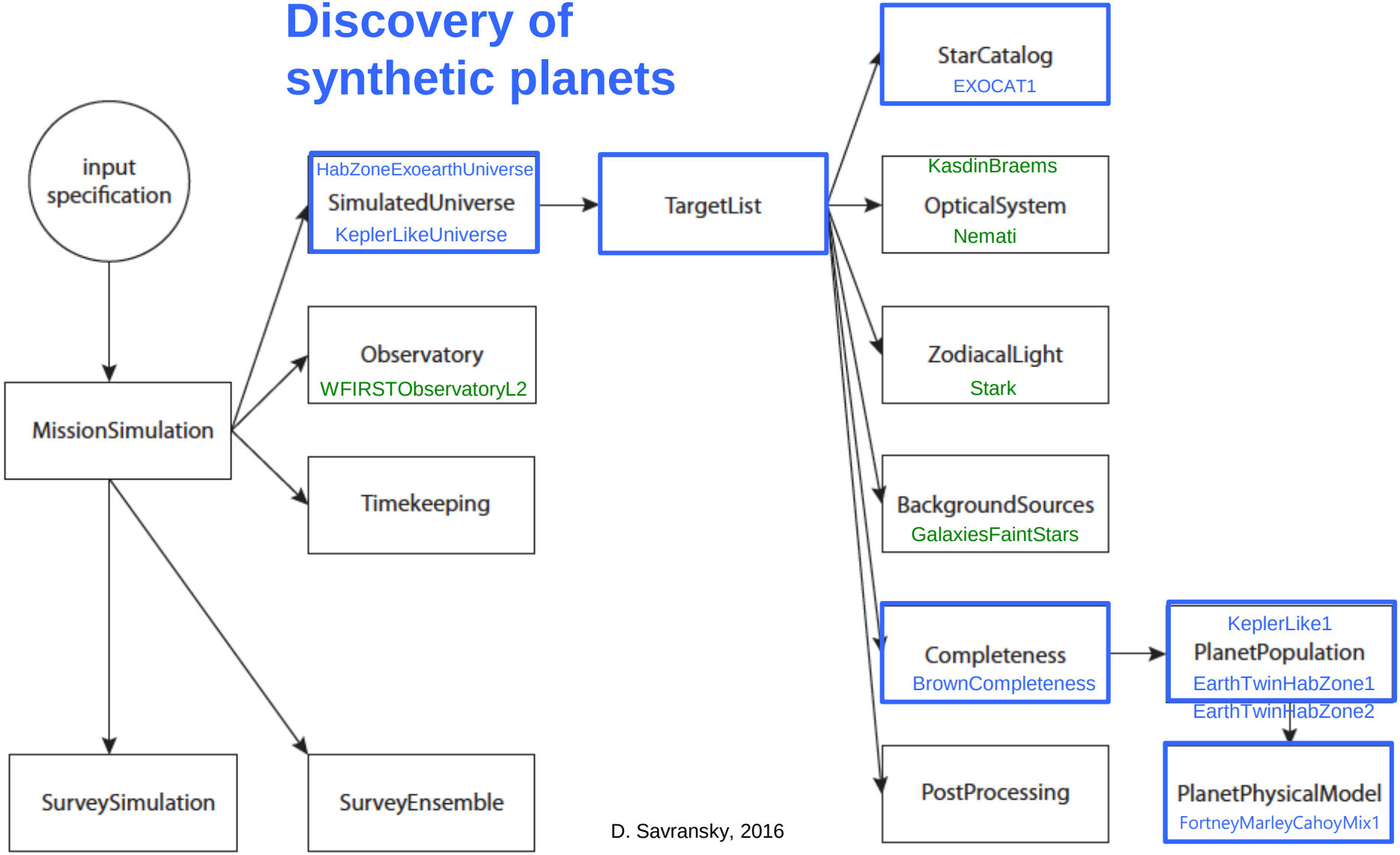




Savransky and Garret, 2015

EXOSIMS Architecture

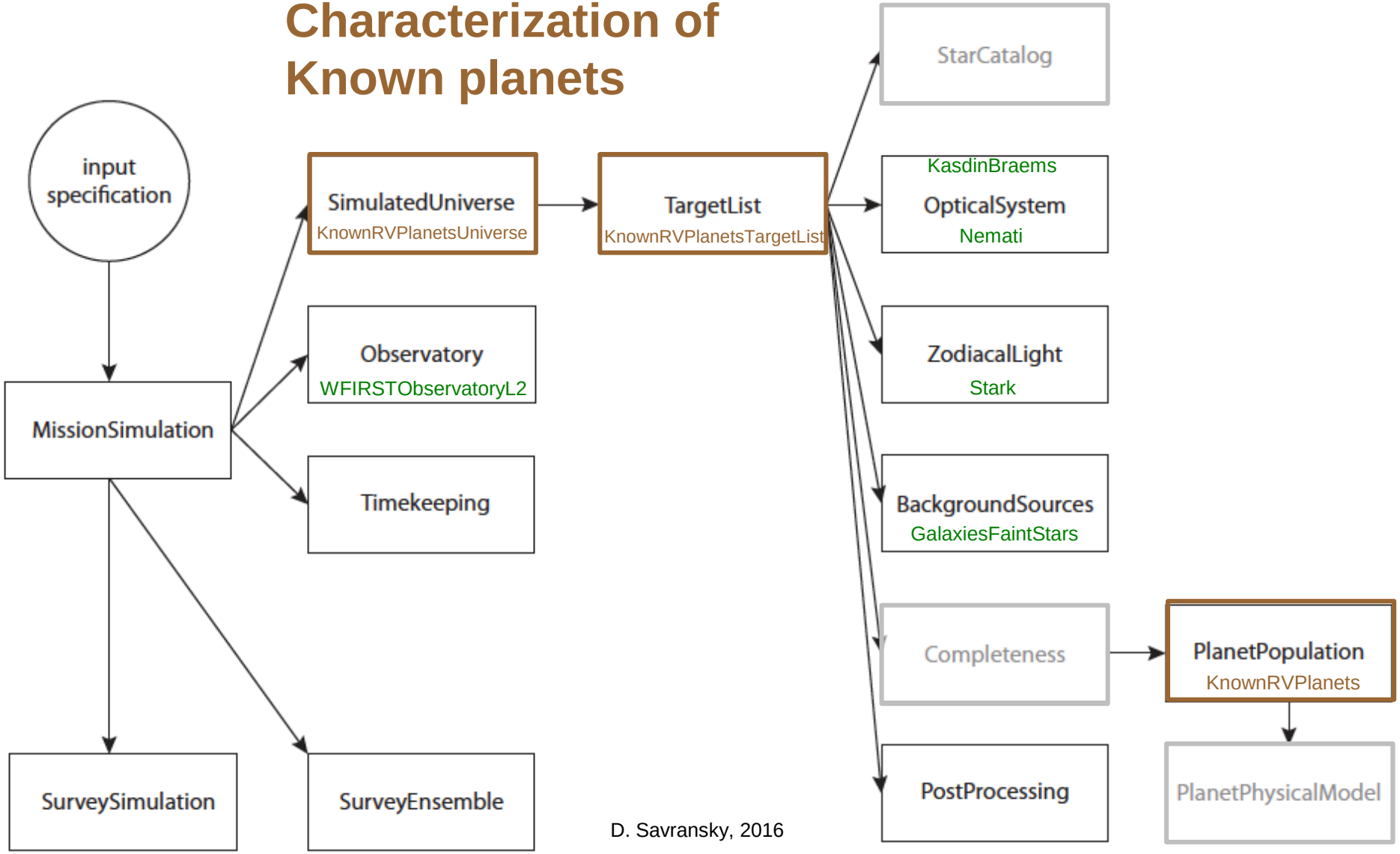
Discovery of synthetic planets



D. Savransky, 2016

EXOSIMS Architecture

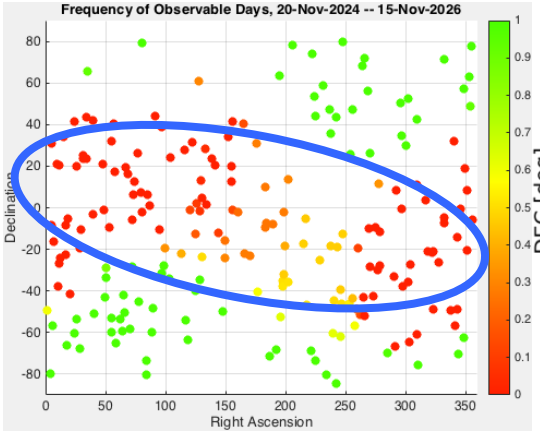
Characterization of Known planets

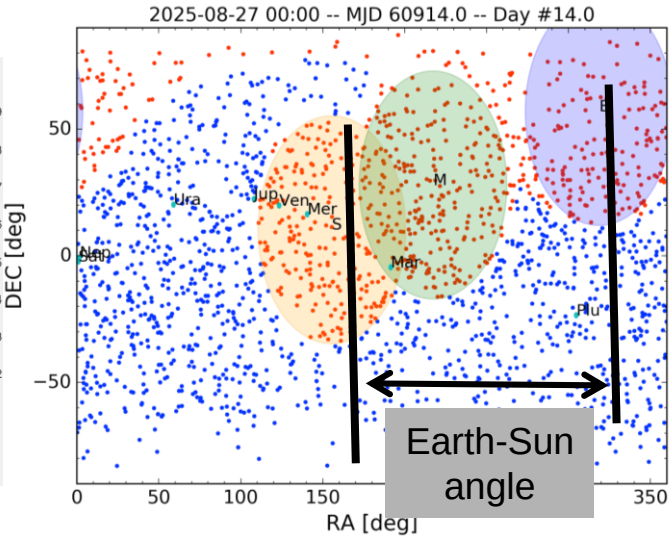


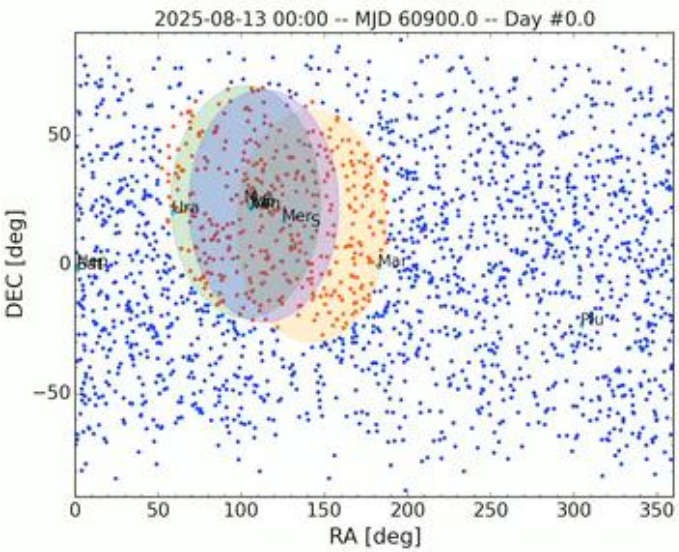
D. Savransky, 2016

Case Study: Keepout

- Keepout: function of target list and observatory
  - L2 telescope observing geometry: function of time, orbit
  - Integration testing, not unit testing: multiple interacting components
- Initial keepout (left): many targets were seldom observable
  - Cause: 45° keepout angle applied to *all* solar system planets
- Next keepout (center): large Earth-Moon and Earth-Sun angles
  - Cause: did not allow correctly for Earth's elliptical orbit
- Final keepout is corrected (right)

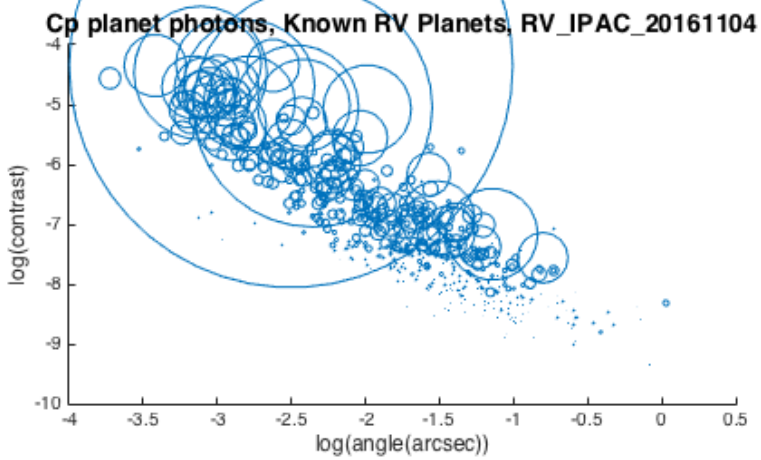


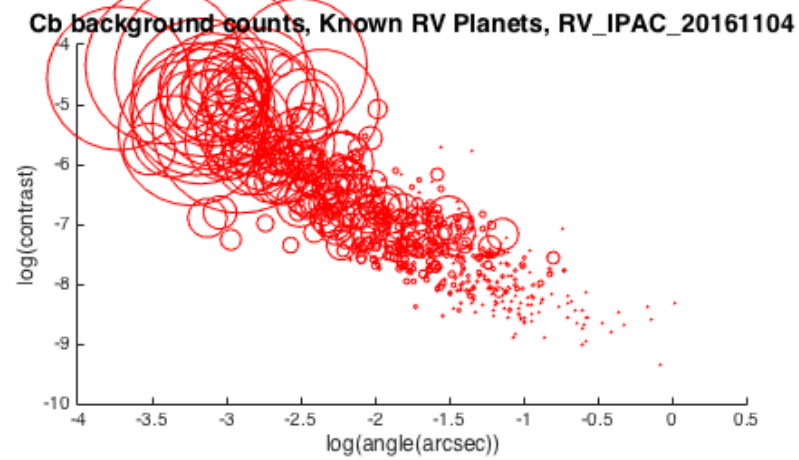


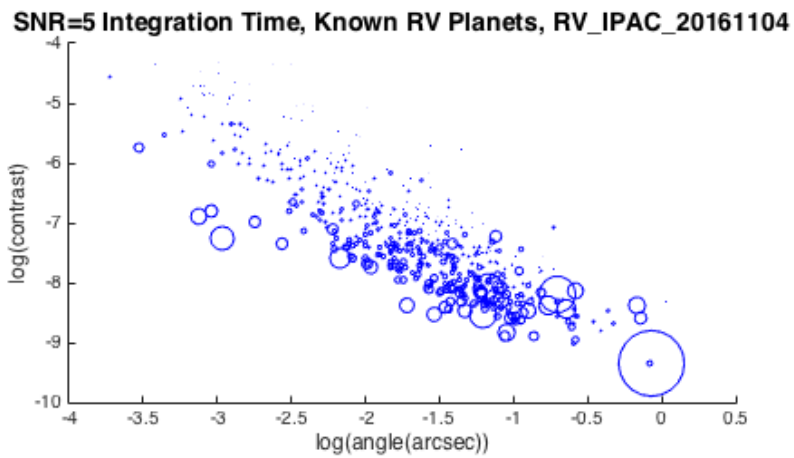


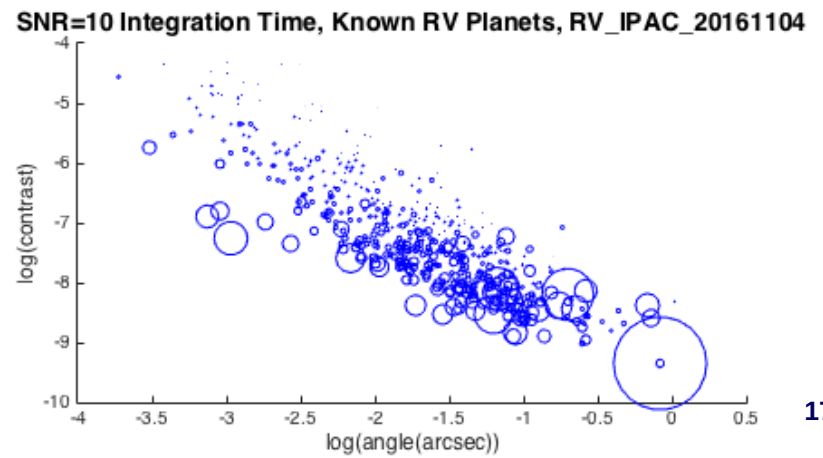
Test Case for C_p, C_b, T_{int}

- Use Known RV planets from IPAC portal
- Validated Matlab code computes photon counts from planet and background and detector noise sources and calculates integration time









Modifications for λ = 10-20 um

- Modify photon counts to include
  - Emissive planet: need emissivity and temperature
  - Emissive telescope: need emissivity and temperature
- EXOCAT1 star catalog
  - Use star temperature to calculate blackbody flux

- Standards Team needs planet physical properties

  Any of these may be a distribution
  - Radius and mass (or mass to radius relationship)
  - Emissivity (assuming albedo negligible contribution)
  - Temperature of planet
  - Occurrence rate
- Standards Team needs mission rules:
  - Portion for exoplanets, overhead time, schedule priorities

Inputs

- https://docs.google.com/spreadsheets/d/1-w1eybYV6nyX02kH7eoNWie8UinzlVnLM4F-64AagHw

ExEP Yield Input Parameters		
	Input	Notes
Astrophysics		
eta_earth	0.5	SAG-13 Integrated over box0.5< Rp 1.5 earth radius
planet radius	[0.5, 1.5] earth ra	log uniform random distribution
planet mass	1 earth mass	log uniform random distribution
geometric albedo	[0.2, 0.2]	Lambert phase function is used, uniform random distribution
semi-major axis	[0.75, 1.5] AU	log uniform random distribution
eccentricity	[0,0.35]	uniform random distribution
cos(inclination)	[-1, 1]	uniform random distribution
argument of perigree	[0, 360] degrees	uniform random distribution
ascension of the ascending node	[0, 360] degrees	uniform random distribution
exozodi mean and variance	23 mag/asec^2	constant, corrected for Mv

Telescope

Diameter of pupil	4m, 6x4m, 6m	
obscuration factor	0	off-axis primary
throughput	0.6333	Telescope only, not coronagraph
Detection lambda	550 nm	
detection bandwidth	0.2	delta_lambda/lambda
SNR detection	5	
limiting deltamagnitude	26	
minimum completeness	0.1	

Inputs cont.

Occulters

Internal Coronagraph type	HLC	
IWA (only fixed by D)	2 lambda/D	
OWA	20 lambda/D	
Contrast	1.00E-10	
core throughput	2.00E-02	
core mean intensity	4.00E-14	
Throughput for Coronagraph	0.4	occ_trans for zodi transmission

Detectors

imaging or spectrometer	imaging	
dark current	5.00E-04	defaults are for WFIRST EM-CCD
readNoise	0.007 e-	
exposure time per frame	1000 sec	
QE	0.91	
pixelpitch	5.00E-06	
focal length		FHWM sampled by 3.3 pixels
CIC	3.00E-03	
ENF	1	
EM CCd gain	1	

Post Processing

post-processing contrast factor	1/10	input can be [0,1]. 1/10 and 1/30 are common

Mission

mission lifetime	3 years	
fraction to exoplanets	1	

What SDET needs from STDTs

- Inputs
  - Occurrence from SAG13
    - Mass to radius?
  - Planet Types
    - SAG13 bins or new Ravi
  - Albedo
  - Phase function
  - Star list
- Metrics
  - Yield
    - Detection
      - Mean
      - Standard Deviation
      - Histogram
      - Wavelength, BW
    - Characterization
      - Over whole bandpass?
      - SR
    - Orbit characterization, etc

Mission Rules impact Metrics

Examples: When to revisit

100% char vs. 100% detect

BACKUP

EXOSIMS Modifications for λ = 10-20 um

- OpticalSystem. Cp_Cb_Csp
- OpticalSystem. __init__ to construct emissivity and temperature of telescope
- PlanetPopulation module for emissivity and temperature of planet
- Completeness because there's no Lambertian phase function needed for a self-emitting planet
- SimulatedUniverse for using emissivity/temperature of planet

- Not SurveySimulation
- Not PostProcessing
- Not calcIntTime