HabEx Yield Modeling for Systems Engineering

Dr. Rhonda Morgan[1]
rhonda.morgan@jpl.nasa.gov

Michael Turmon[1], Bertrand Menesson[1], Keith Warfield[1], Dmitry Savransky[2,3], Christian Delacroix[2,3]

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]Space Imaging and Optical Systems Laboratory, Cornell University;
[3]Carl Sagan Institute, Cornell University

August 6, 2017

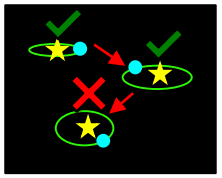
© 2017 California Institute of Technology. Government sponsorship acknowledged.

What is EXOSIMS?

https://github/dsavransky/EXOSIMS

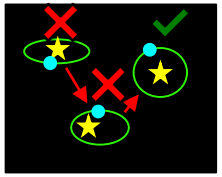
- EXOSIMS
  - Open source. Python. Parametric. Probabilistic. Modular.
  - Creates ensembles of DRMs which can be analyzed statistically.

Universe n



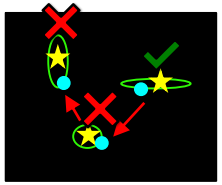
2 Detections

Universe n+1

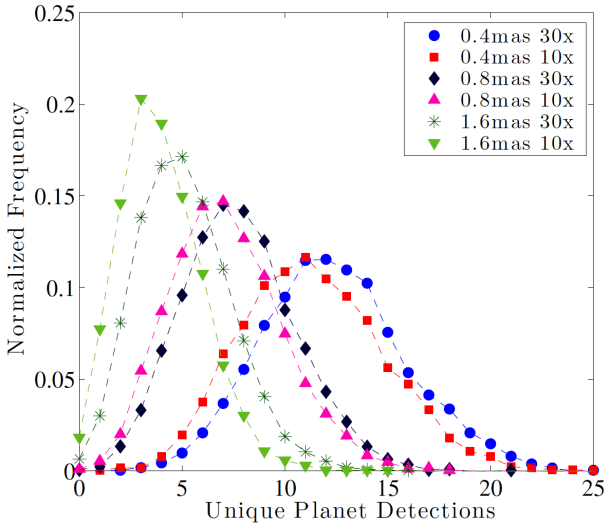


1 Detection

Universe n+2



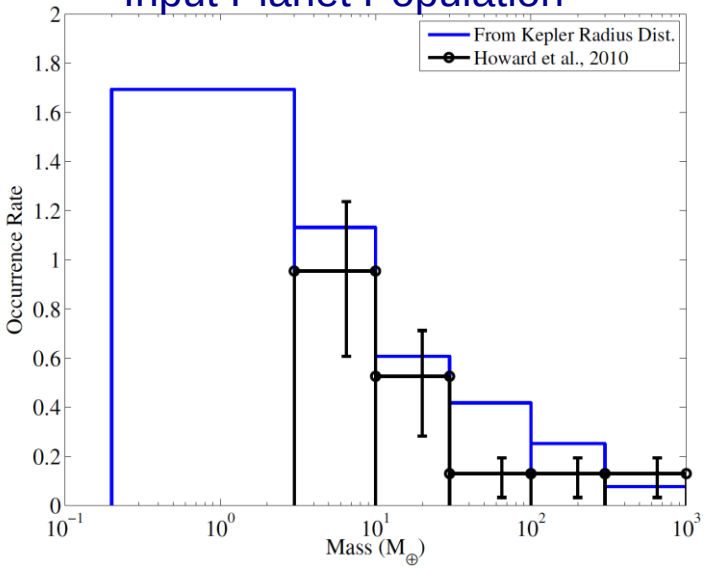
1 Detection



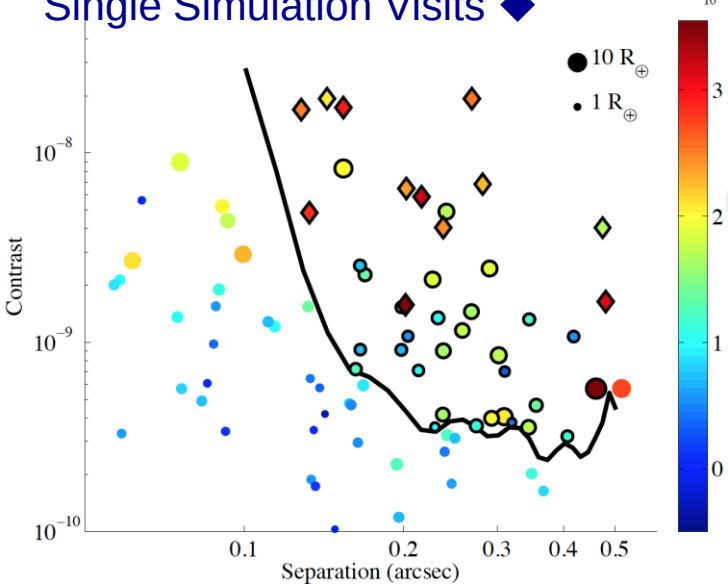
D. Savransky, et al., JATIS 2(1) 2016

WFIRST Yield Results by EXOSIMS

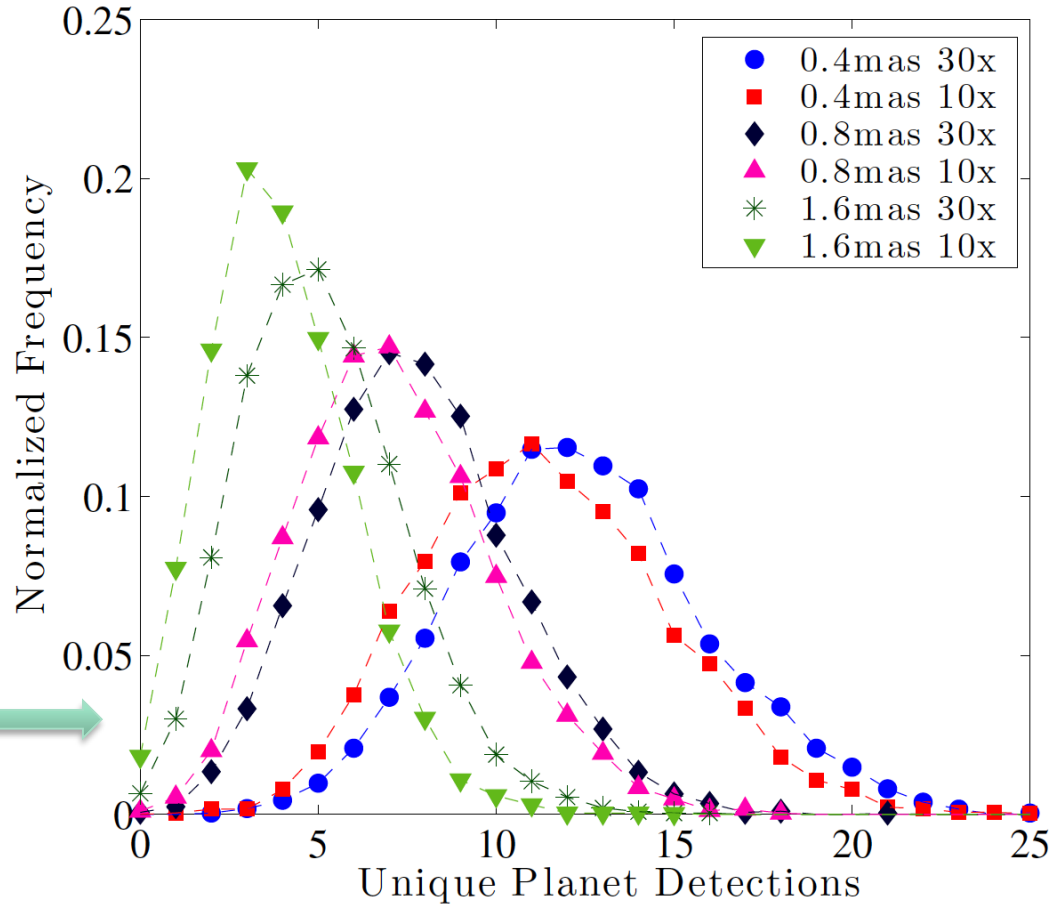
Input Planet Population



Single Simulation Visits ◆

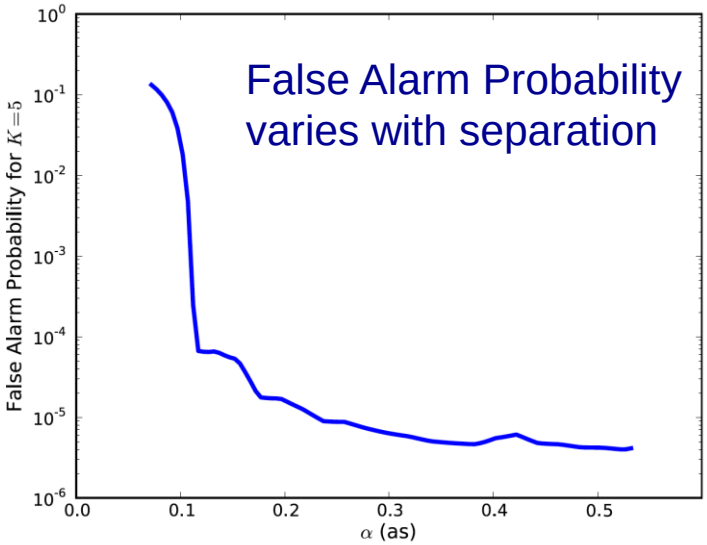


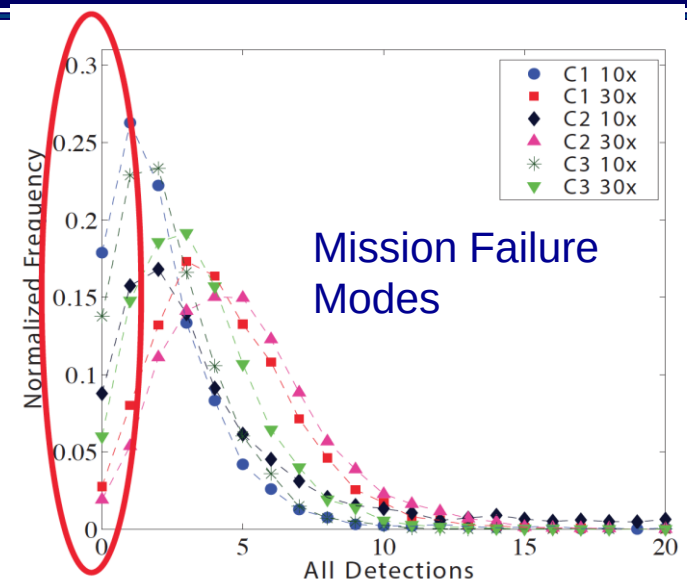
Simulation Ensemble Yield PDFs

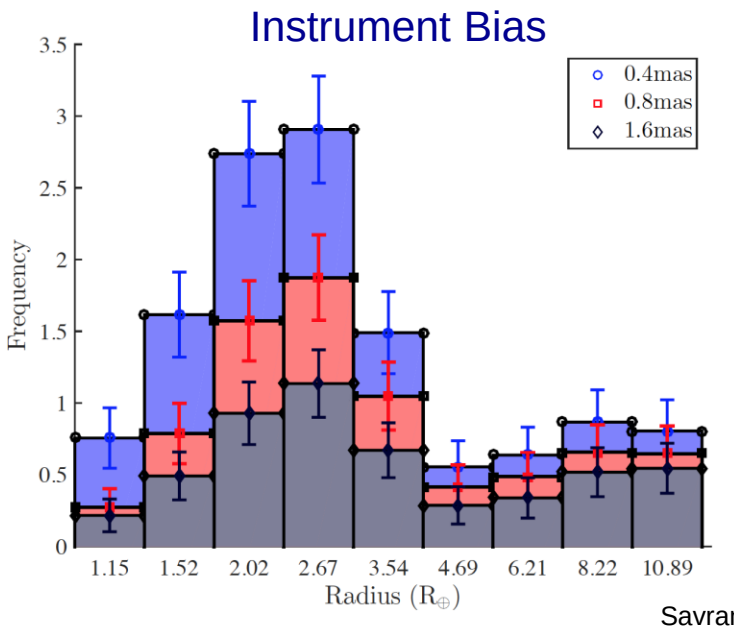


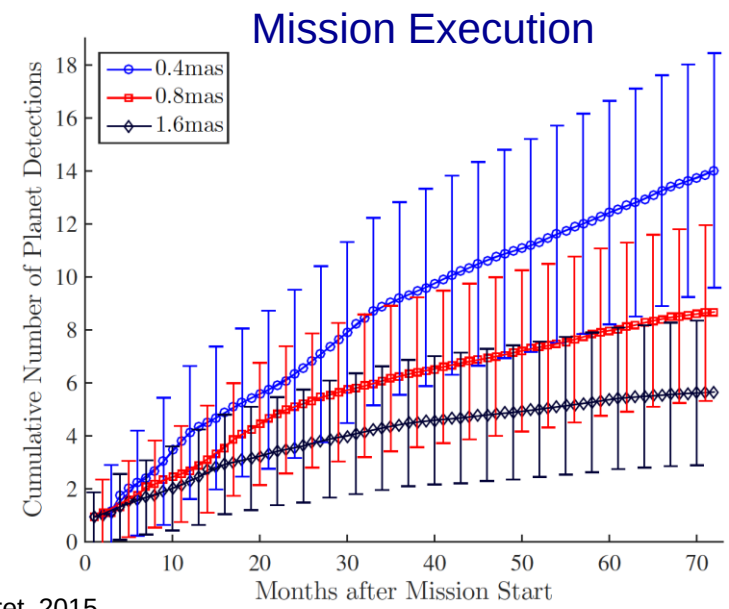
Savransky and Garret, 2015

The power of ensemble statistics



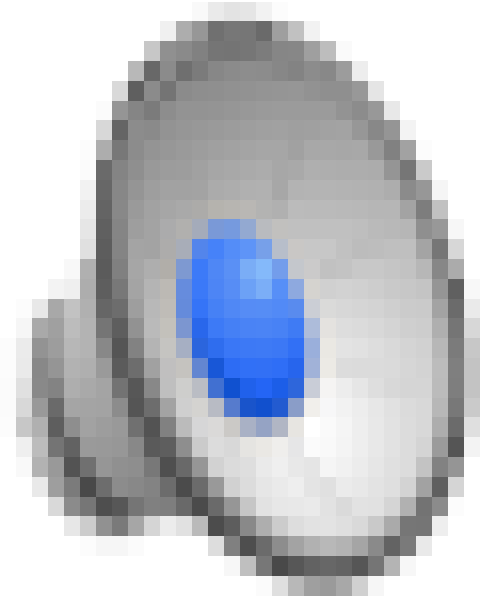




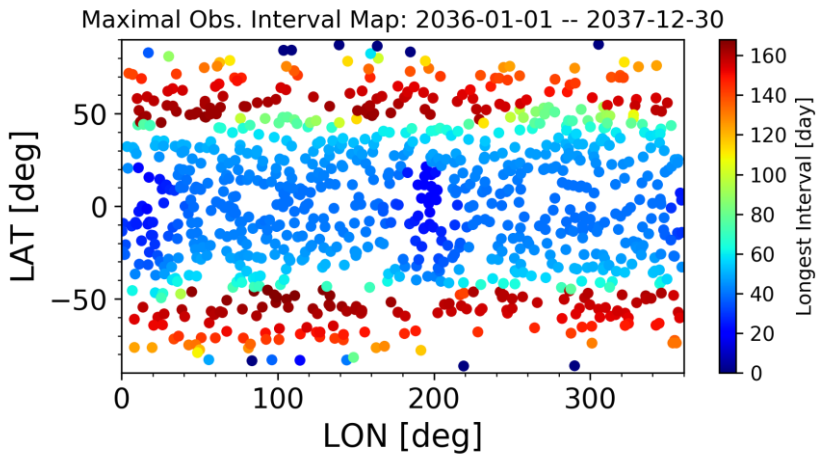


Savransky and Garret, 2015

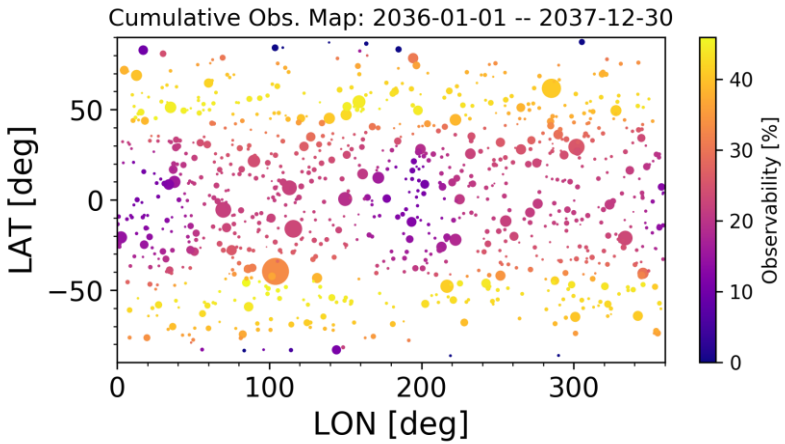
Starshade/Coronagraph DRM



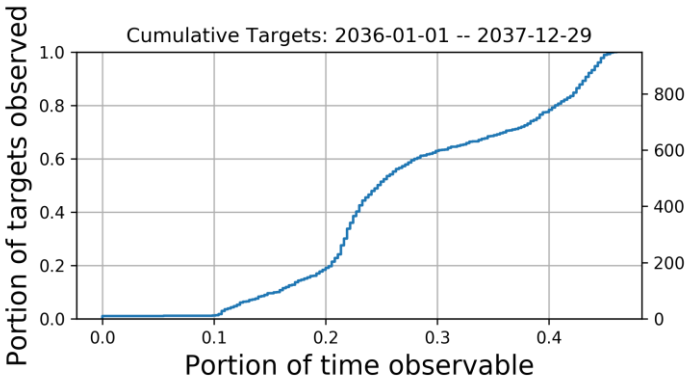
Starshade Sky Coverage Map



largest continuous interval of observability for each target (1-day granularity)



Cumulative fraction-of-time target is observable
Size of point is proportional to target Vmag.

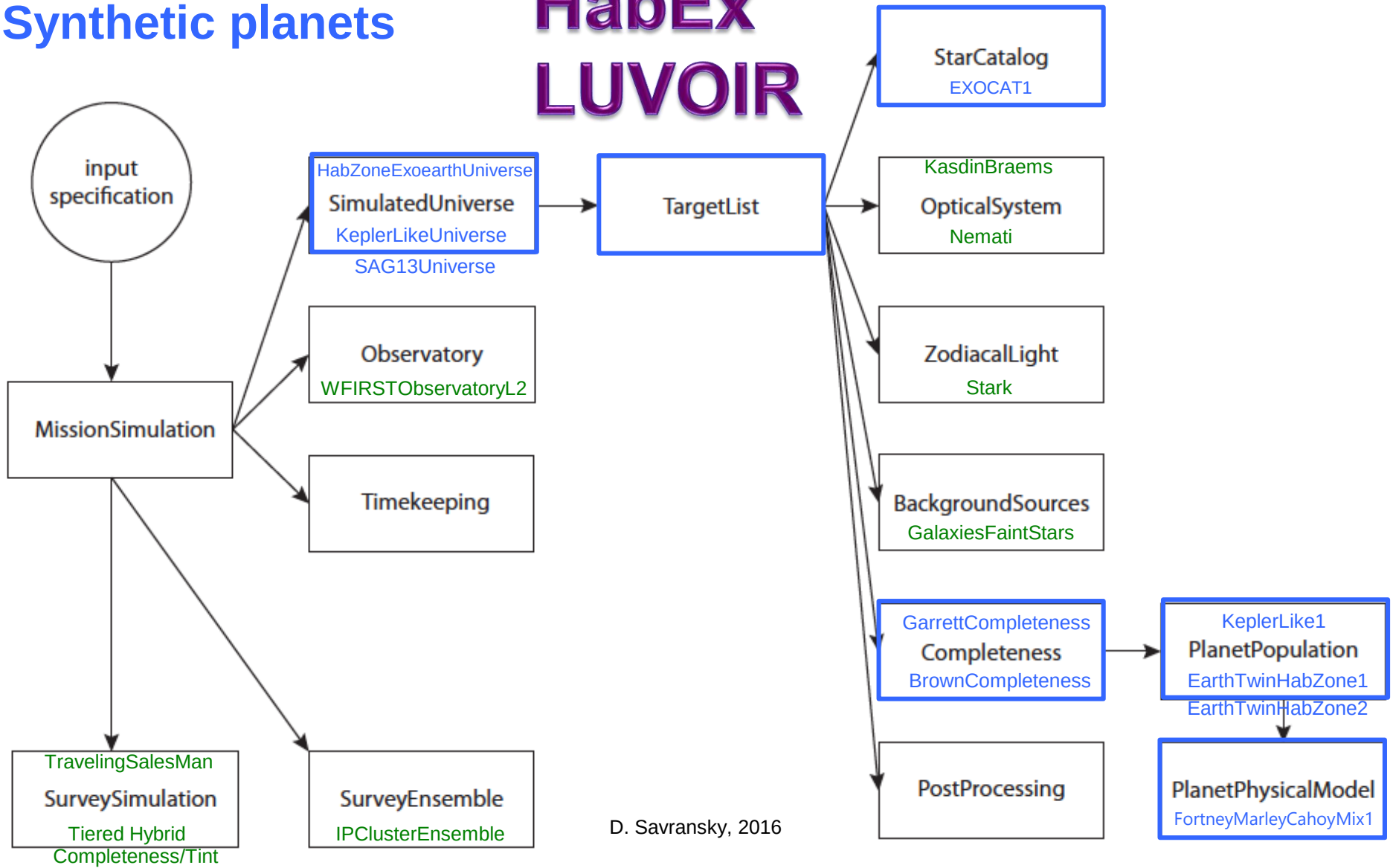


- Two year mission: 2036-2037 inclusive
- dMagLim = 26.5
- Sun keepout: > 45˚ and < 83.4˚ is OK
- Earth keepout: >35˚ is OK
- Moon keepout: >15˚ is OK
- Other bodies: > 1˚ is OK

EXOSIMS Architecture

Synthetic planets

HabEx
LUVOIR

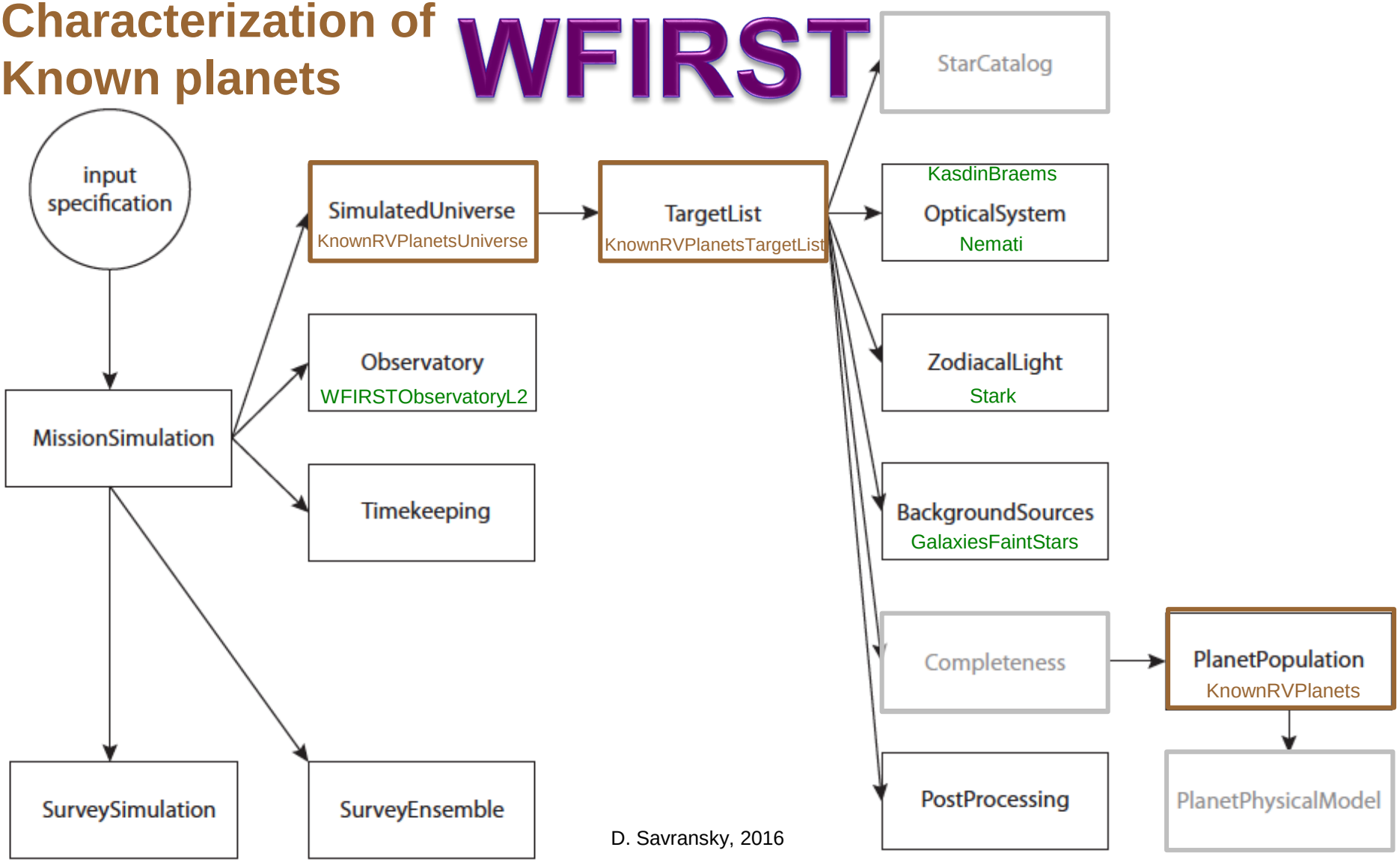


D. Savransky, 2016

EXOSIMS Architecture

Characterization of Known planets

WFIRST



D. Savransky, 2016

Inputs

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	

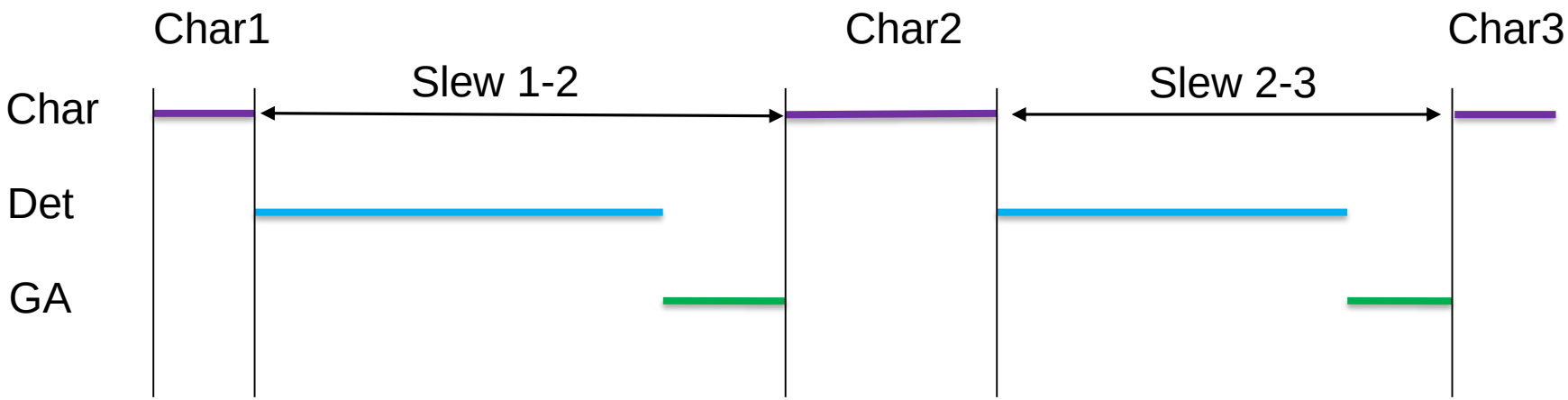
Post Processing

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	

Pictorial Schedule



- Three observing modes: Char/Det/GA.
- Multiple detection observations can occur in any blue Det window. One Char observation per Char window.
- Char vs. Det schedules link up at the hand-over points (black vertical lines), but otherwise are independent

HABEX WITH SAG-13 POWER LAW DISTRIBUTION

SAG13 Power Law parameters are Yield Simulation Inputs

Parametric fit (for G-dwarfs)

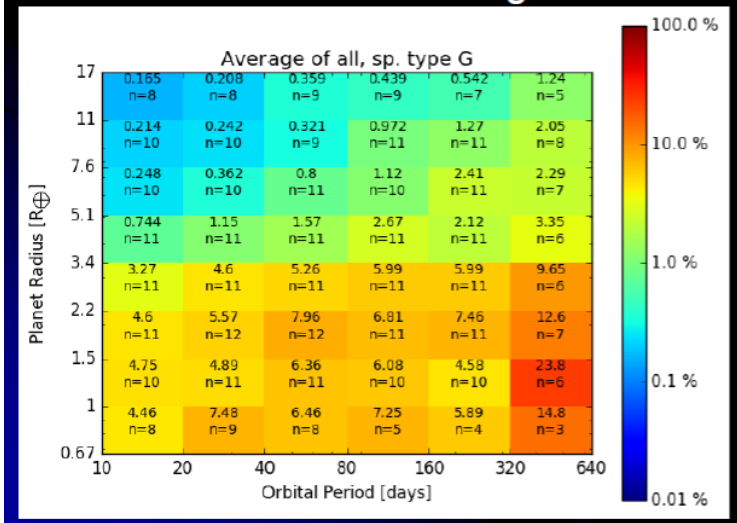
$$\frac{\partial^2 N(R,P)}{\partial \ln R\, \partial \ln P} = \Gamma_i R^{\alpha_i} P^{\beta_i} \qquad \text{in region } R_{i-1} \le R < R_i$$

(R in Earth radius, P in years)

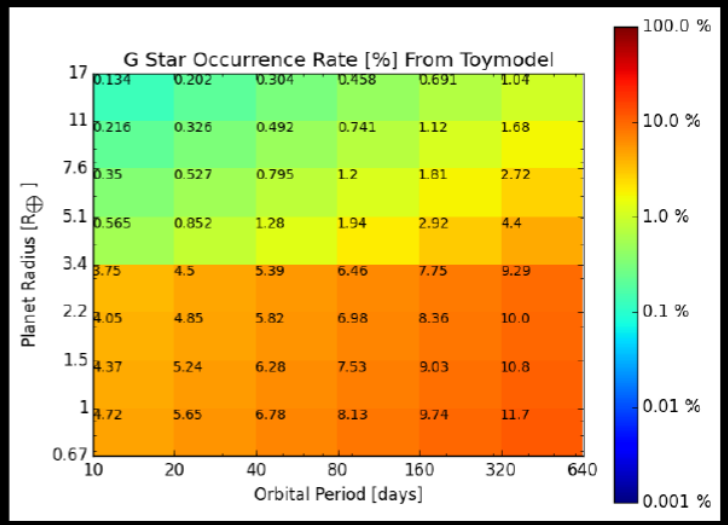
Two-piece broken power law →

i	Γ_i	α_i	β_i	R_i
1	**0.38**	**-0.19**	**0.26**	**3.4**
2	0.73	-1.18	0.59	Inf

Submission average

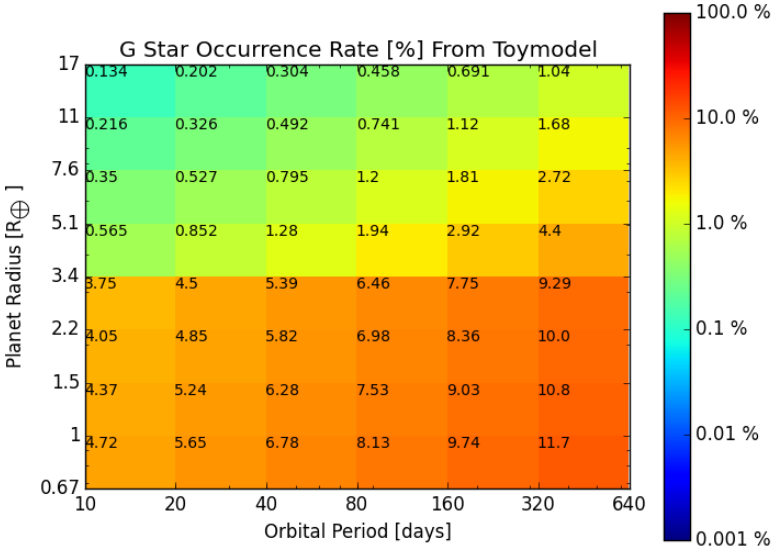


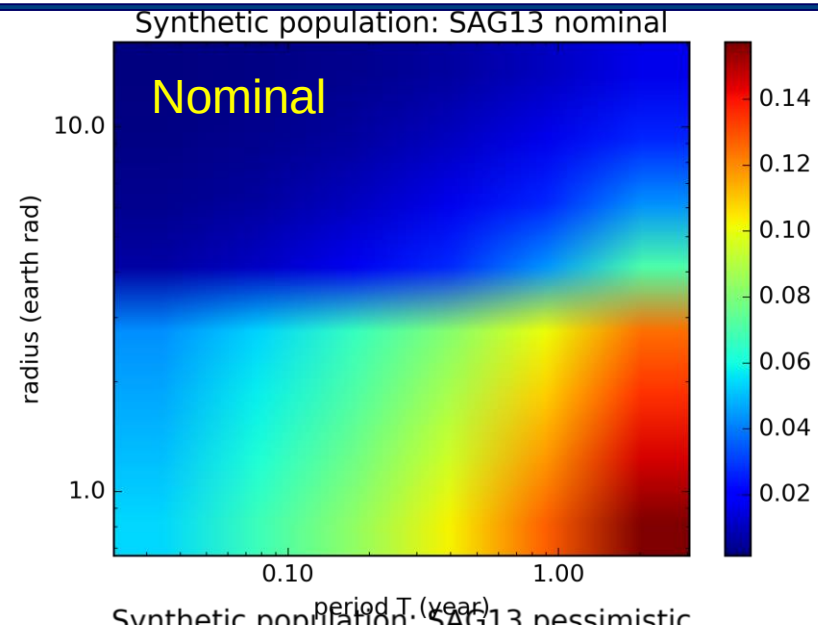
Parameteric fit (integrated across bins)

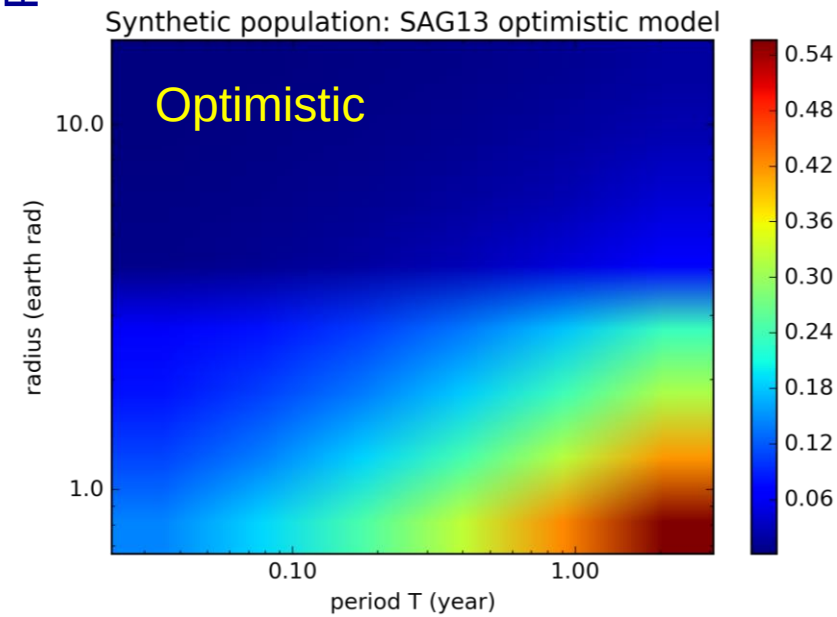


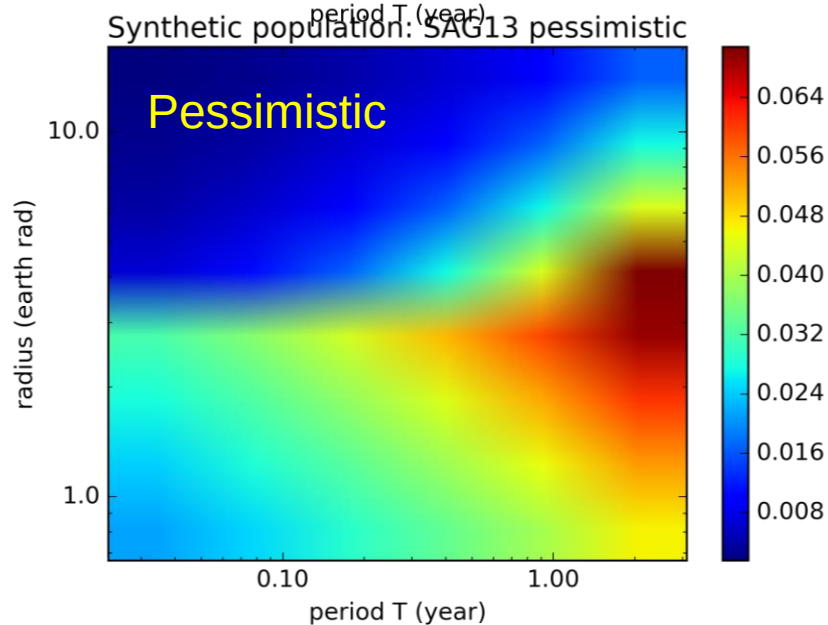
SAG13 Model as Occurrence Input

Preliminary SAG13 Models



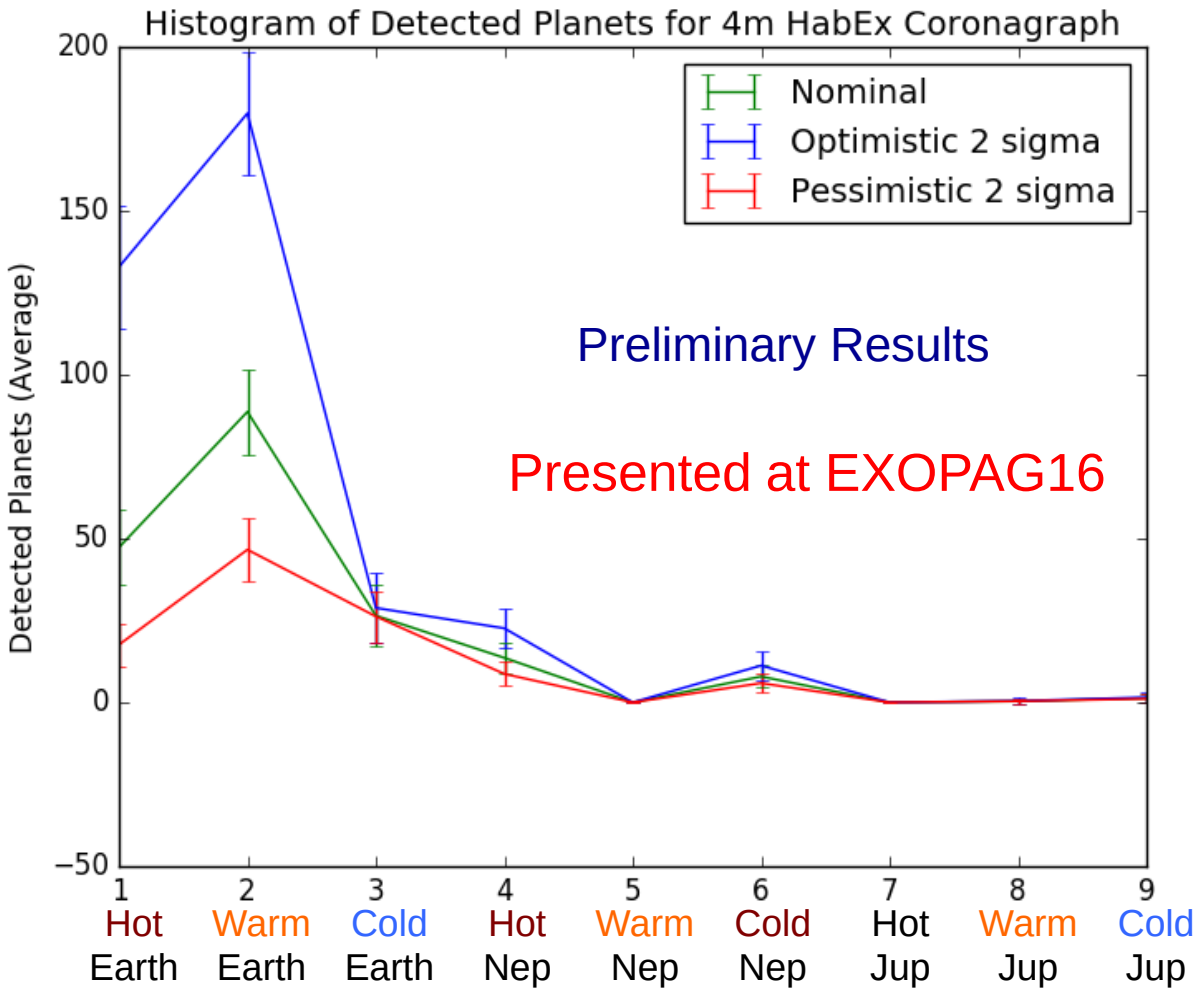






~3600 planets per Synthetic Universe

HabEx Yield Results by EXOSIMS

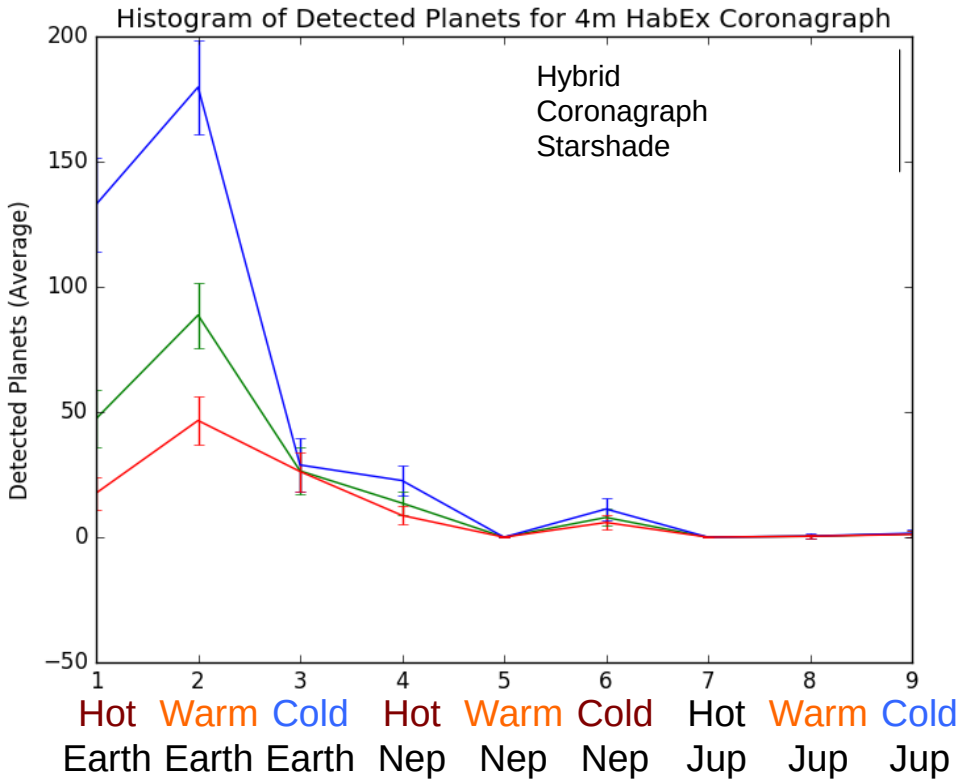


- HabEx
  - 4m unobscured, τ=0.3
  - Vector Vortex Charge 6 Coronagraph
    - 500 nm
    - BW: 0.1
    - dMagLim: 26
    - PostProc: 0.1
  - Detector
    - QE: 0.9
    - sread: 1.7e-6
    - idark: 3e-5
    - CIC: 1.3e-3
    - texp: 100
  - Geom. Albedo: 0.4
  - Mission
    - 1 year, 100%
    - sunKeepout 45 deg

Each ensemble > 500 DRMs
G-dwarf model used for all star types
Pessimistic model = broken power law fit to avg – 2sigma
Optimistic model = broken power law fit to avg + 2sigma

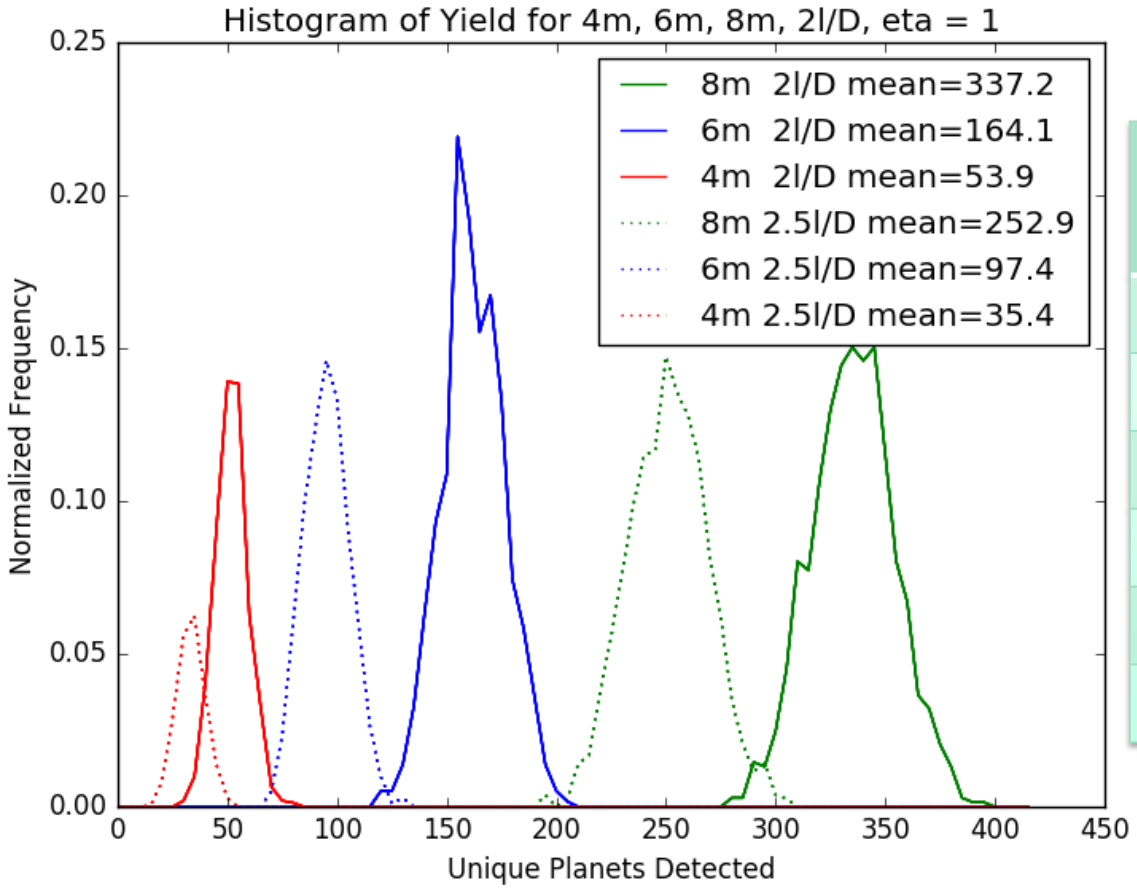
Comparison of 3 cases

- Hybrid Starshade and Coronagraph
- Coronagraph Only
- Starshade Only



TESTING

EXOSIMS and AYO, very different approaches, produce similar yields



	AYO	EXOSIMS mean	EXOSIMS std
4m, 2l/D	6.6	5.4	1.5
4m, 2.5 l/D	5.6	3.5	0.7
6m, 2 l/D	14.0	16.4	1.4
6m, 2.5 l/D	12.2	9.7	1.0
8m, 2 l/D	23.2	33.7	1.9
8m, 2.5 l/D	20.3	25.3	1.8

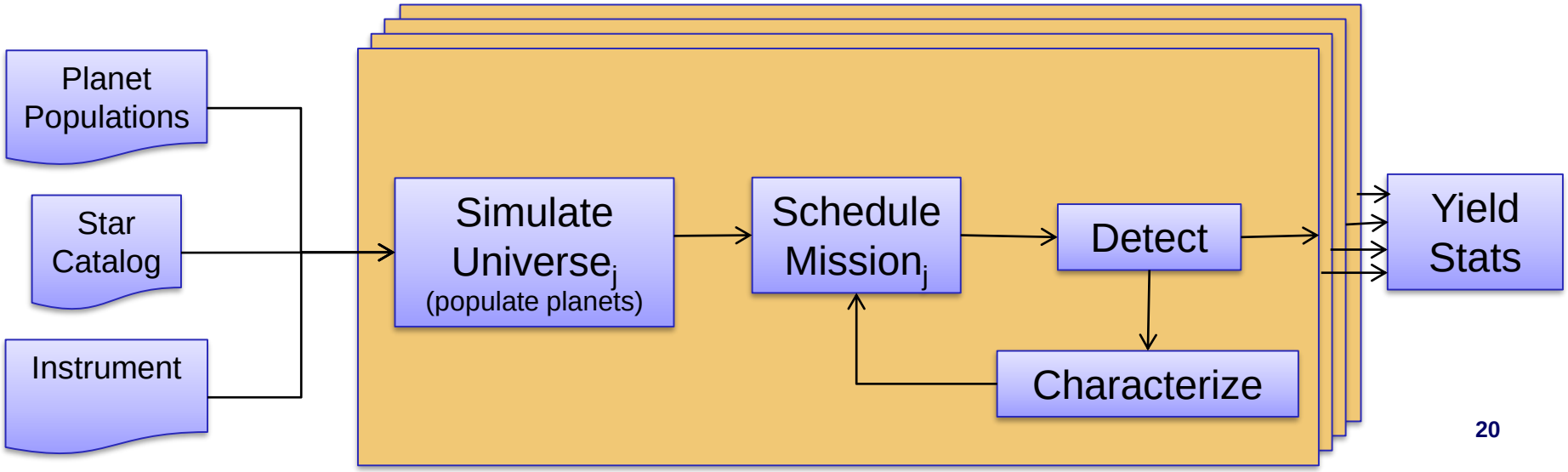
Possible sources of variance:

- Overhead accounting
- Star selection
- Exozodi throughput

BACKUP

Simulated Mission Ensemble

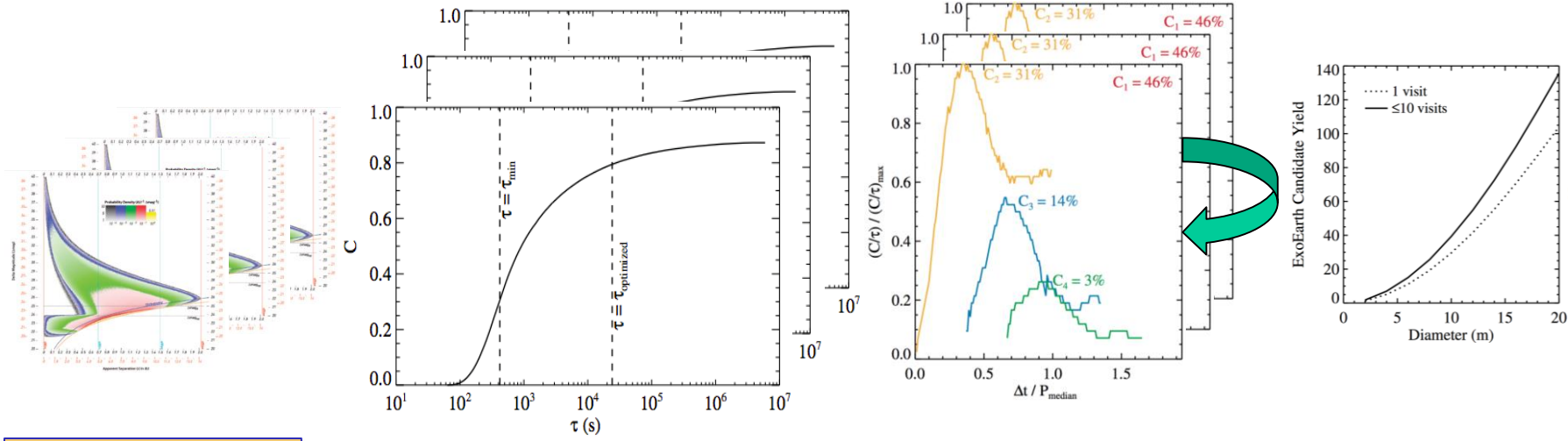
Monte Carlo DRMs (Design Reference Missions)



- 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

Chris Stark's AYO Approach

Completeness(T_{int})



Monte Carlo Planets around stars → Instrument → Optimize Int. Time Alloc. → Cumulative Completeness

Planet Classes

Star list

AYO: Altruistic Yield Optimization

Produces Static Time Budget