Science Yield Modeling with EXOSIMS

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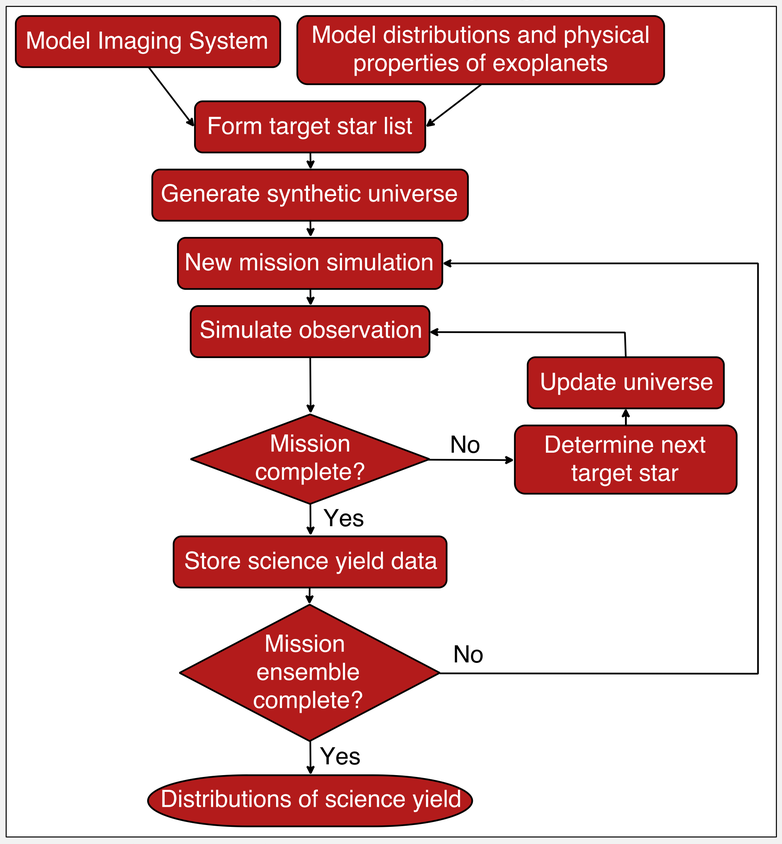
EXOSIMS

- Exoplanet Open-Source Imaging Mission Simulator
- Performs ensembles of mission simulations to determine distributions of science yield
- Developed as part of WFIRST Preparatory Science investigation
- Initial code released
- Alpha release: February 2016
- Continued updates through 2017
- Community driven project
- Visit: https://github.com/dsavransky/EXOSIMS
- Interface Control Document and other documentation included

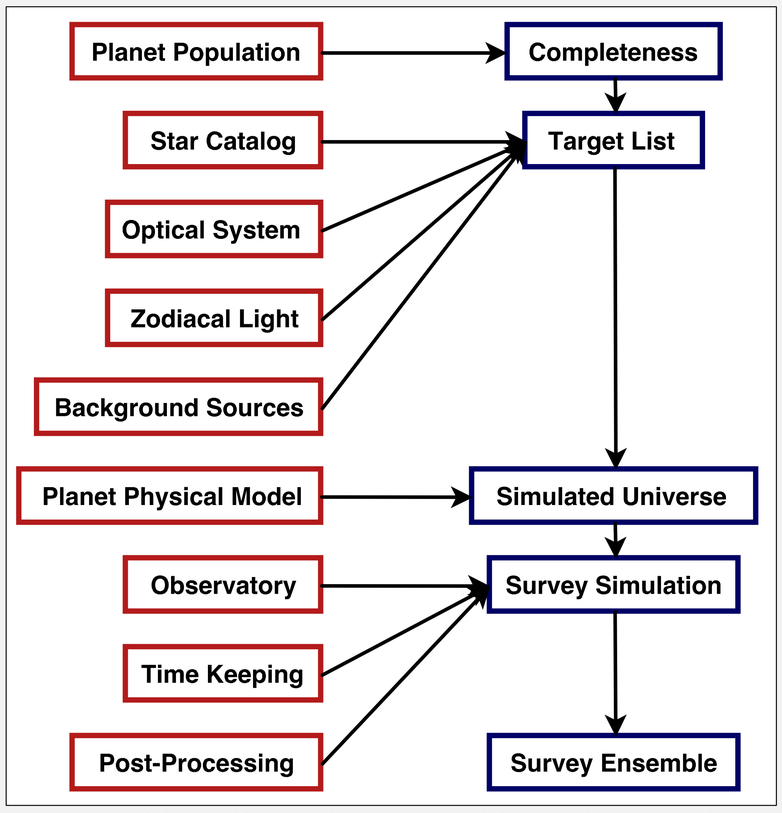
Simulating Direct Imaging Missions



Flowchart of simulation of exoplanet direct imaging mission ensembles yielding distributions of science yields

EXOSIMS Framework

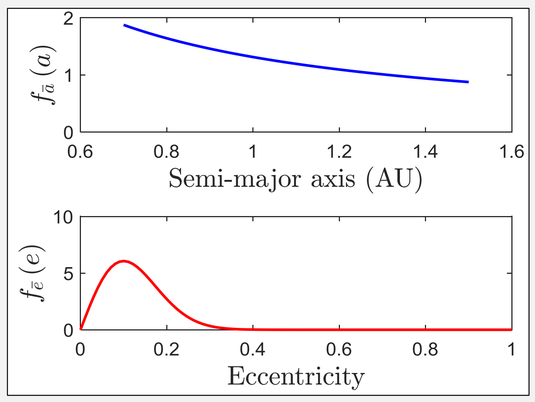
- Integrates independent modules written in Python performing well-defined tasks into unified mission simulation
- Allows user to investigate multiple mission or system designs by only modifying modules with design changes
- Interface control document defines input/output specification for each module



EXOSIMS modules. Red boxes indicate input modules and blue boxes indicate simulation modules

Planet Population Module

- Probability density functions
  - Semi-major axis
  - Eccentricity
  - Orbital orientation
  - Geometric albedo
  - Planetary radius
  - Planetary mass
- Minimum and maximum values of these quantities



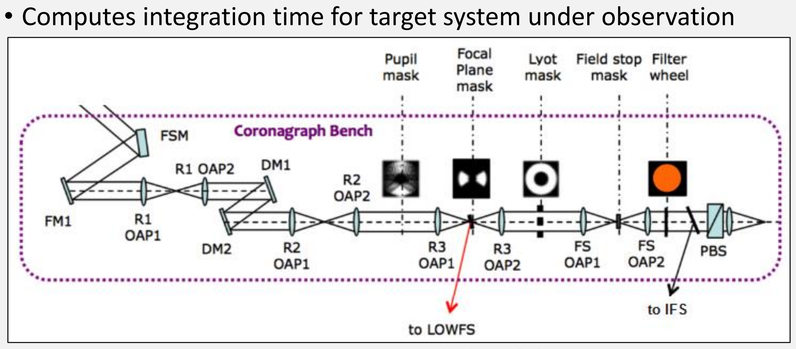
Log-uniform probability density function for semi-major axis and Rayleigh distribution for eccentricity

Star Catalog Module

- Lists of stellar properties (e.g., position, proper motion, mass)
- Wrapper for existing star catalogs

Optical System Module

- Models optics and starlight suppression systems (e.g., inner and outer working angle, contrast, and throughput)
- Describes science instruments (e.g., detector details)
- Computes integration time for target system under observation



WFIRST coronagraph chain [1]

Zodiacal Light Module

- Computes local and exozodiacal light levels for each target system

Background Sources Module

- Provides density of background for target stars
- Used in post processing to determine false alarms

Planet Physical Model Module

- Models light emitted or reflected in wavelengths of interest
- Generates synthetic spectra or band photometry

Observatory Module

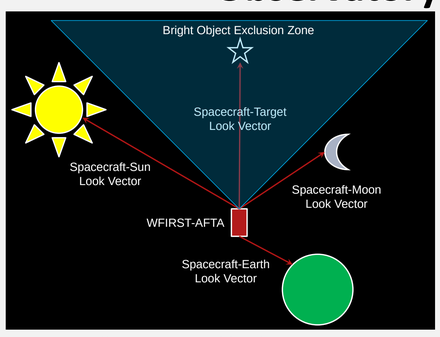


Illustration of look vectors

- Computes orbital position vector
- Computes look vectors to bright objects to determine observable stars at given epoch
- Can be adapted to track fuel consumption or cryogen depletion

Time Keeping Module

- Encodes mission start time and duration
- Updates current mission time within simulation

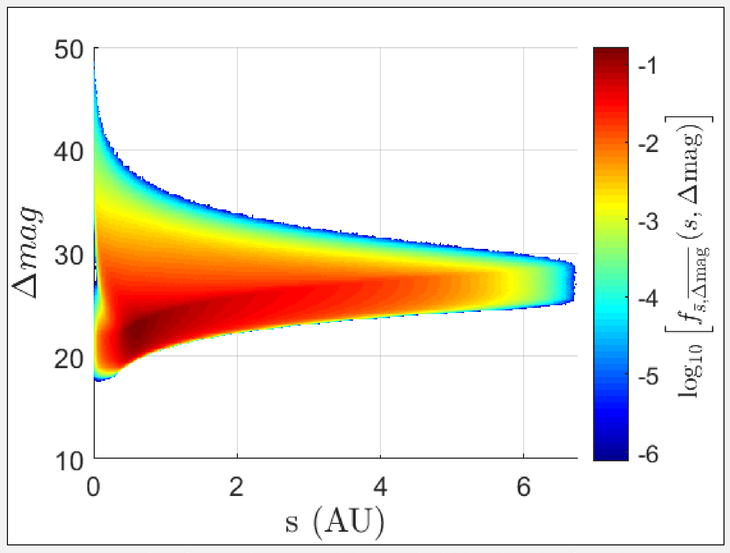
Post-Processing Module

- Effects of post-processing on simulated observation
- Determines detection state
  - True positive (real detection)
  - False positive (false alarm)
  - True negative (no detection when no planet present)
  - False negative (missed detection)

Simulation \ Reality	Planet	No Planet
Planet	Real Detection	False Alarm
No Planet	Missed Detection	No Detection

Completeness Module

- Probability of planet detection based on planet's apparent separation from star and difference in brightness (magnitude) [2]
- Computed by integrating joint probability density function generated from probability density functions in Planet Population
- Updates completeness values for systems previously observed



Example of completeness joint probability density function

Target List Module

- Generates list of target stars (based on input modules)
- Or list of pre-determined targets (e.g., stars with planets determined via radial velocity measurement)

Simulated Universe Module

- Creates synthetic universe of systems in target list
- Propagates planet position and velocity vectors in time

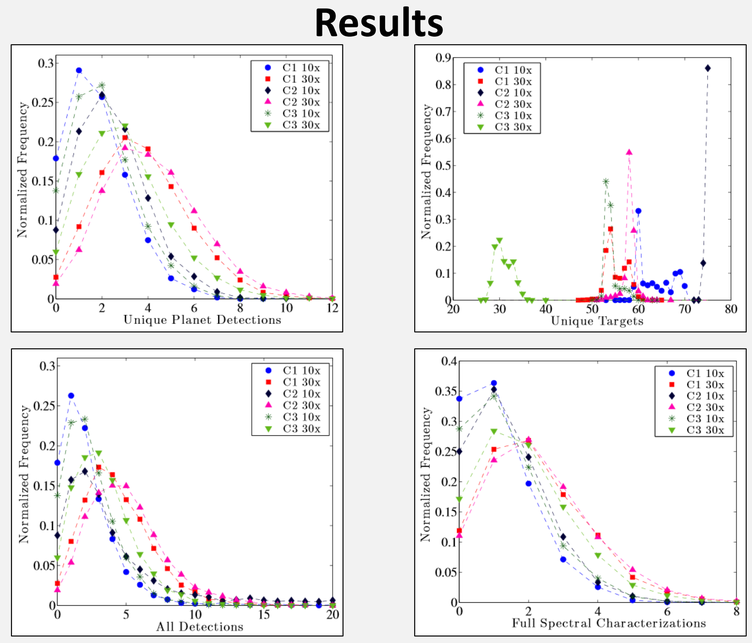
Survey Simulation Module

- Performs specific simulation
- Returns mission timeline – list of observations and outcomes
- Encodes final state of simulated universe and observatory

Survey Ensemble Module

- Runs multiple survey simulations

Results



Examples of results obtained from mission simulation ensemble with EXOSIMS [3]

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Acknowledgements

This work is supported by NASA Grant No. NNX14AD99G issued through the Goddard Space Flight Center and by NASA Grant No. NNX15AJ67G.

References

[1] Spergel, D., et al., (2015). Wide-Field InfraRed Survey Telescope-Astrophysics Focused Telescope Assets WFIRST-AFTA 2015 Report. *arXiv: 1503.03757*.
[2] Brown, R. A., (2005). Single-Visit Photometric and Obscurational Completeness. *ApJ*, 624:1010-1024.
[3] Savransky, D. and Garrett, D., (2016). WFIRST-AFTA Coronagraph Science Yield Modeling with EXOSIMS. *J. Astron. Telesc. Instrum. Syst,* 2(1):011006.