Exoplanet Yield Modeling for ExEP

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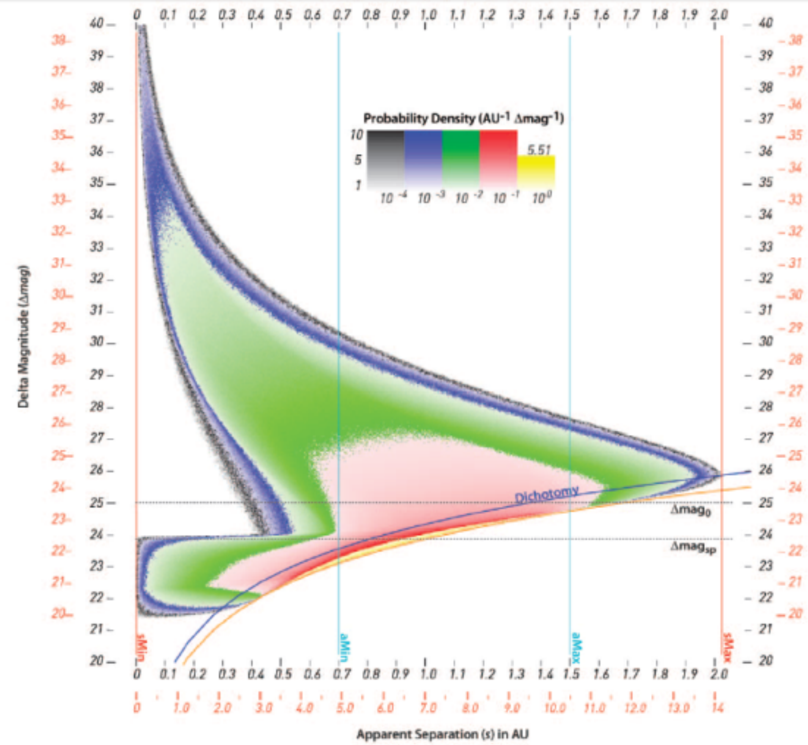
What is the Habitable Zone Discovery Space in IWA and Contrast?

Let's meet our (potential) neighbors

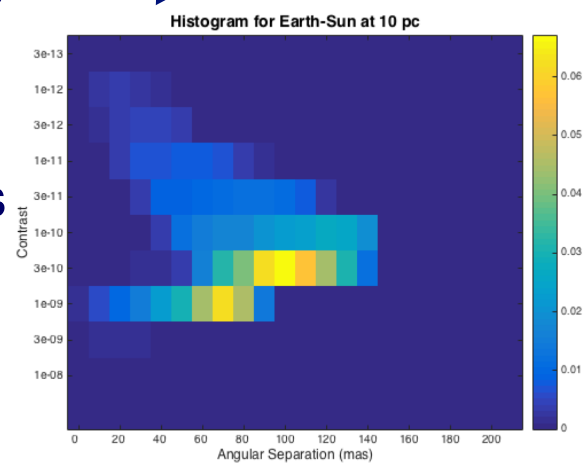
- We know the stars within 30 pc that are potential targets
  - M. Turnbull's, "ExoCat-1: The Nearby Stellar Systems Catalog for Exoplanet Imaging Missions", arXiv:1510.01731, 2015
  - Filter out binary stars (< 30 asec separation) and giants
- We can define a Habitable Zone
  - Orbital radius of 0.7 to 1.5 AU
  - Eccentricity of 0 to 0.35
- We can select a planet radius
  - Earth radius (for now)
- We can treat planet properties as probability distributions and create a Monte Carlo cloud of probable planet locations around a star
- From each MC planet location, we can calculate the reflected light relative to the star (Δmag) and the apparent separation to the observer.

Brown MC Cloud of Planet Positions

1. Simulate 10^5 planets using uniform random distributions:
   - Ecc = [0 .35]
   - HZ = [.7 1.5] AU
   - Inclination [0 180] deg.
   - R = Earth radius
2. For each star in ExoCat1
   - Scale angle
     - $s_j = s * \mathrm{sqrt}(L_j)/\mathrm{distance}_j$
   - Scale Δmag
     - $\Delta mag_j = \Delta mag + 2.5 * \log10(L_j)$
3. Histogram for each star in 2D
   1. Bin over problem space
4. Sum Histograms over all stars



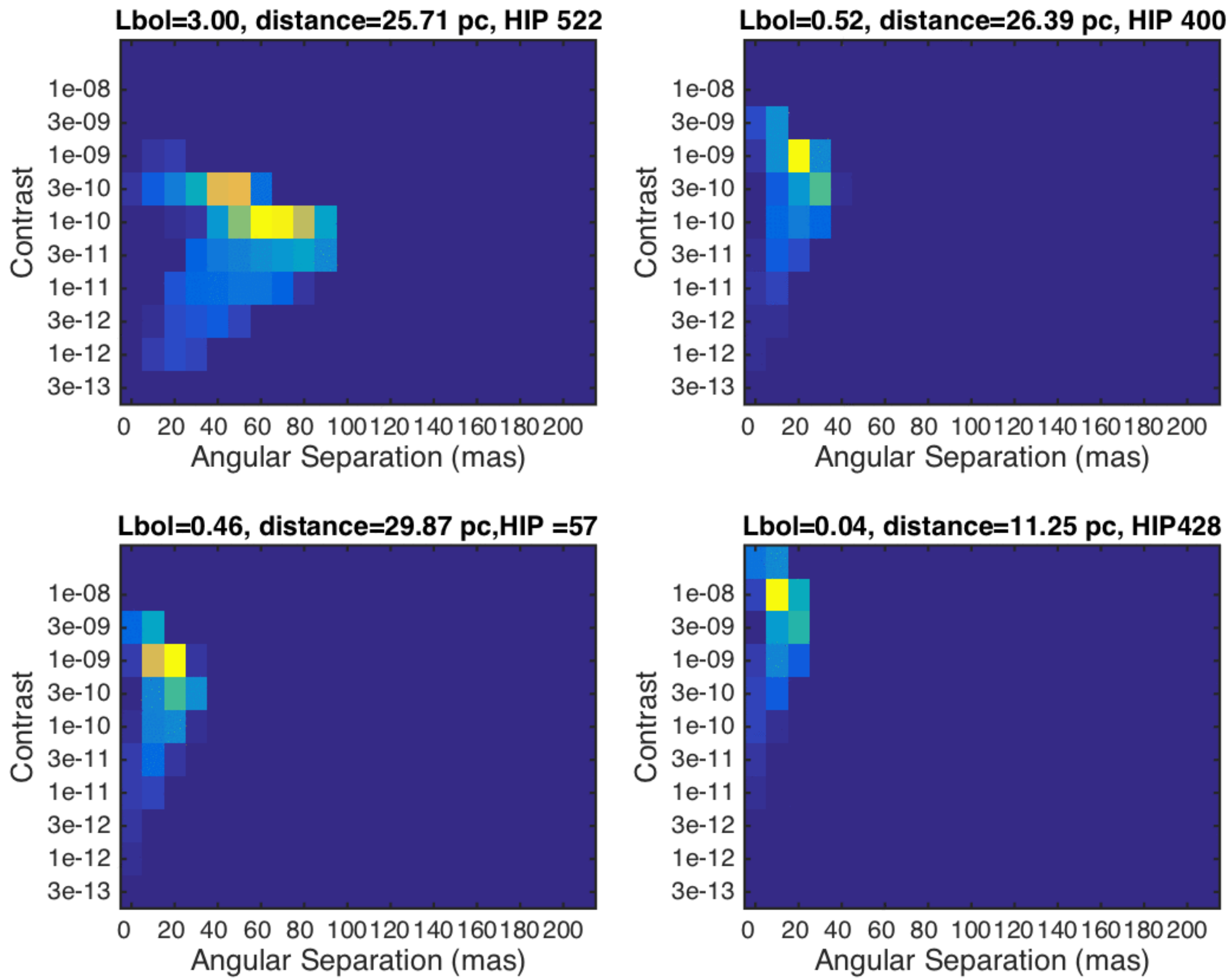
Bob Brown, 2004



HZ Earth-Twin PDF for FGKM stars

F G

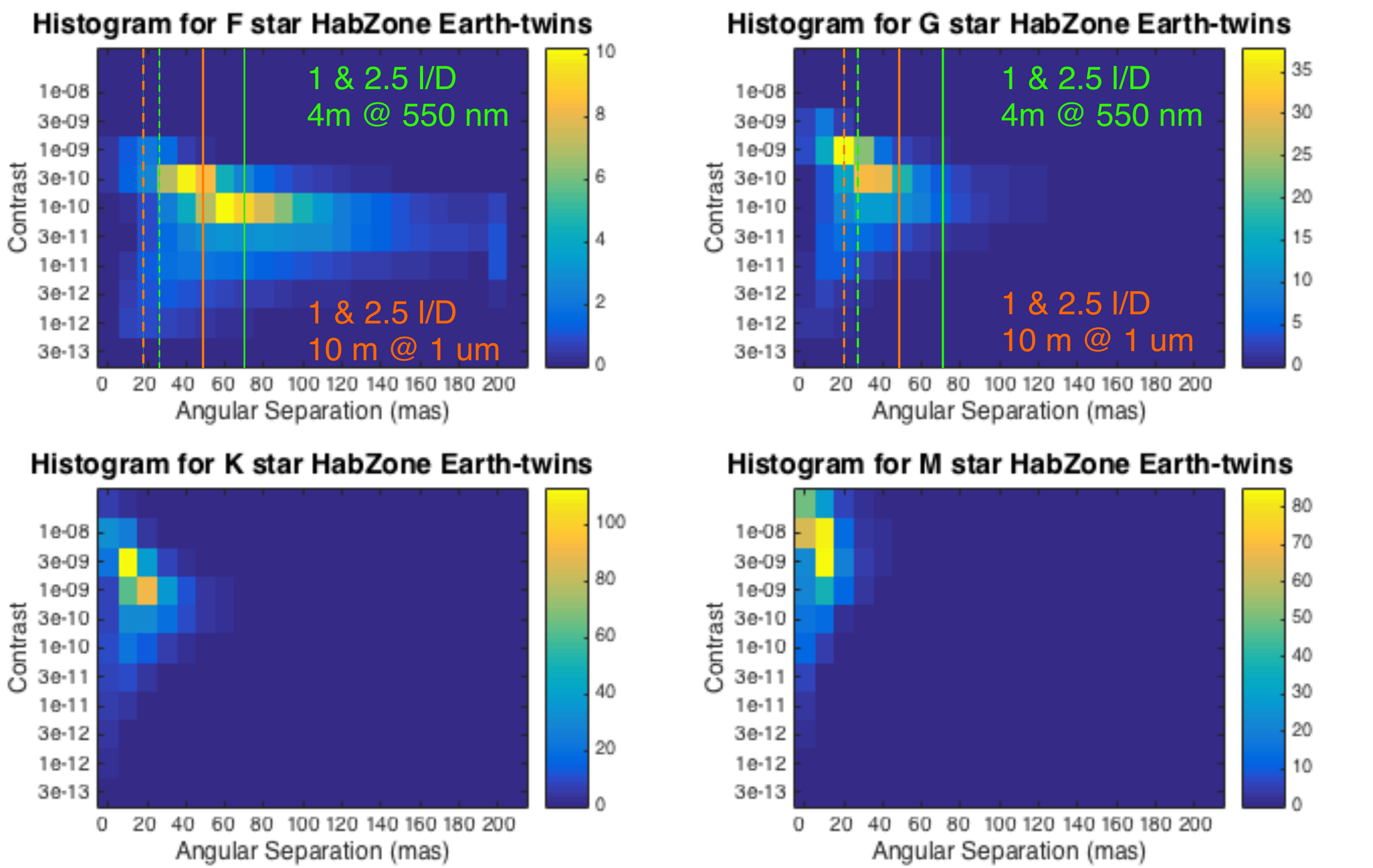
K M



2D Probability Histograms Σstars

F

G



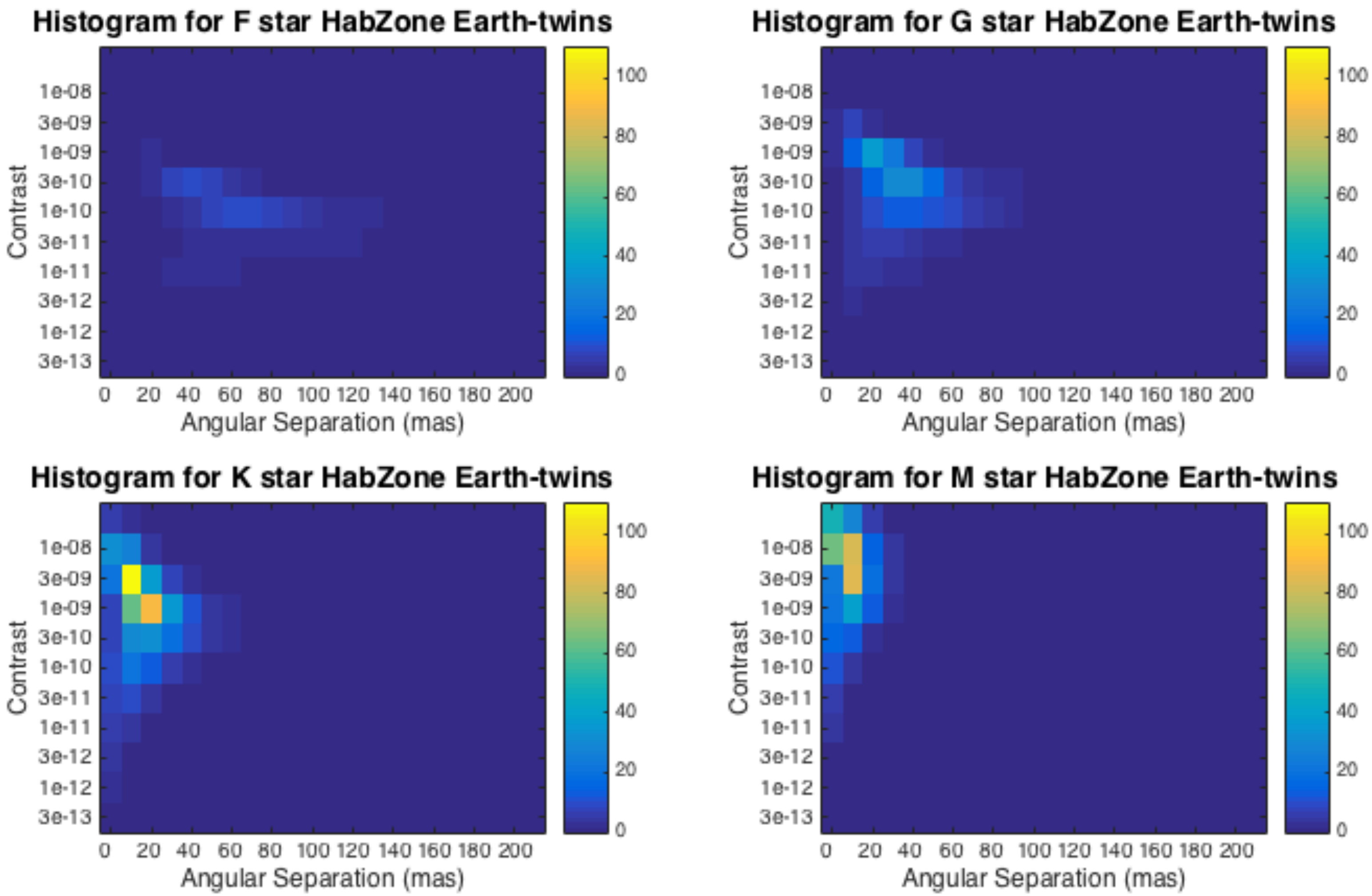
K

M

Same stretch on all star types

F G

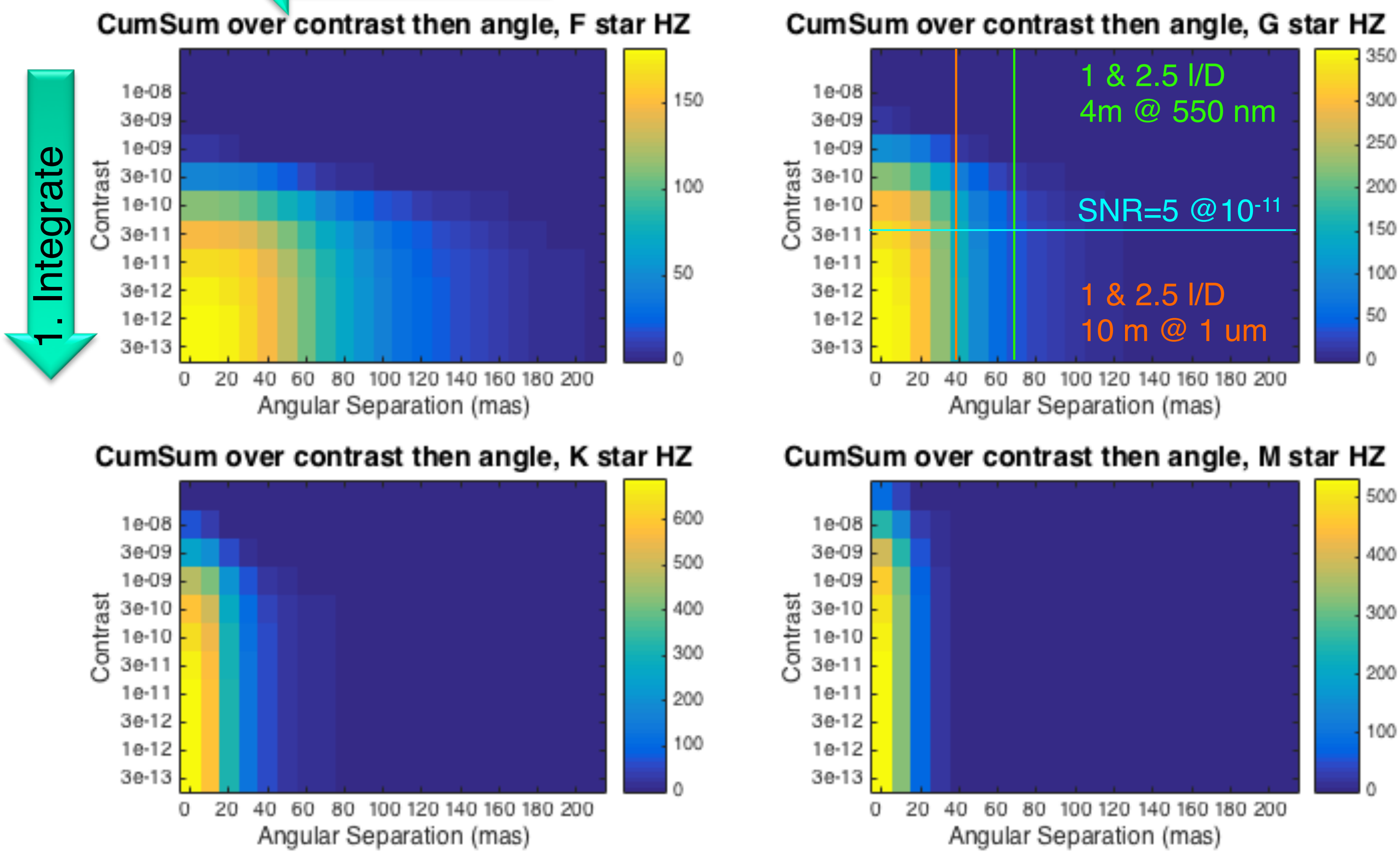
K M



Upper Bound of Completeness[1] over IWA and Contrast

[1]Completeness = η_{Earth}*plotted values

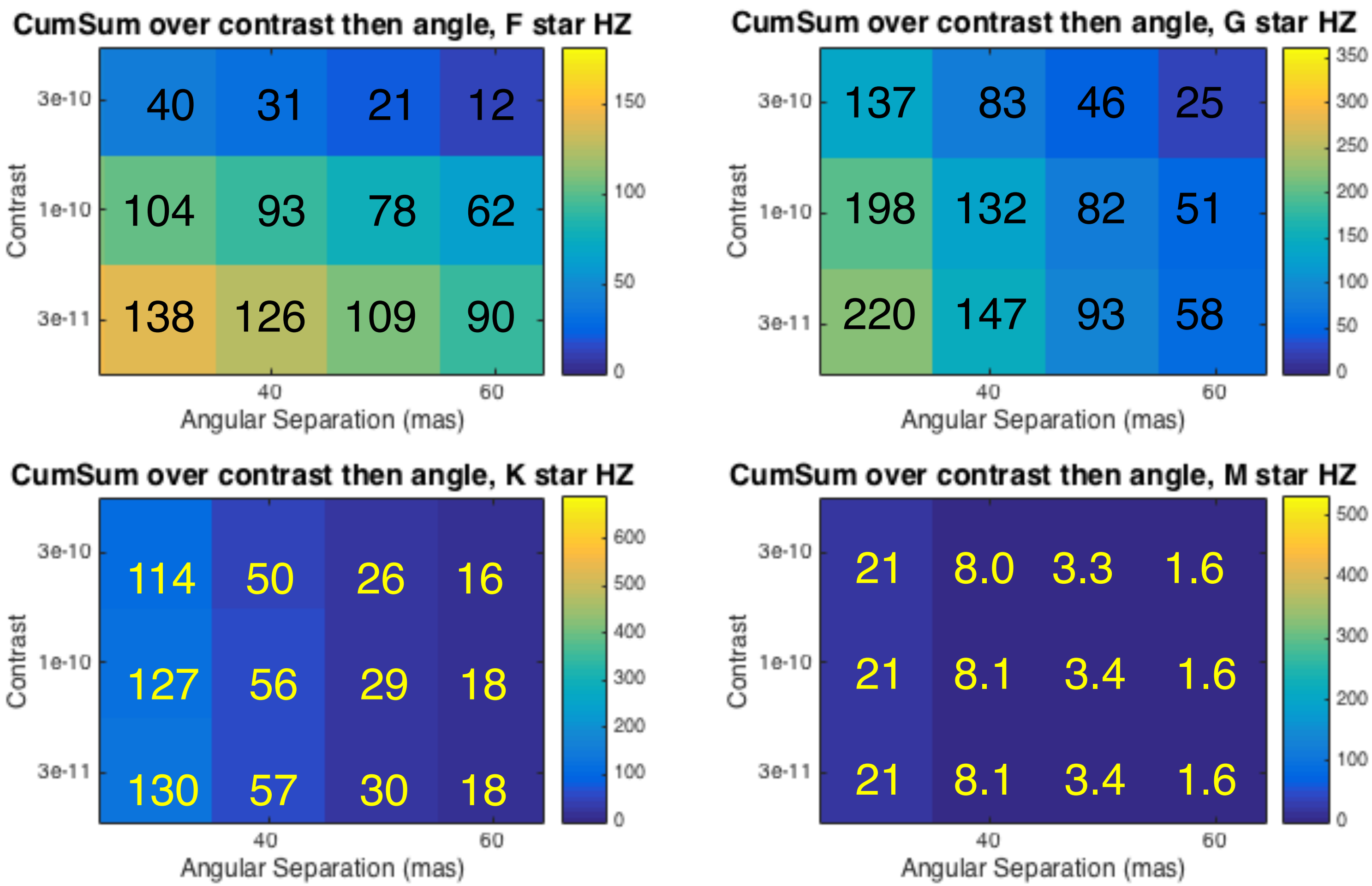
2. Integrate



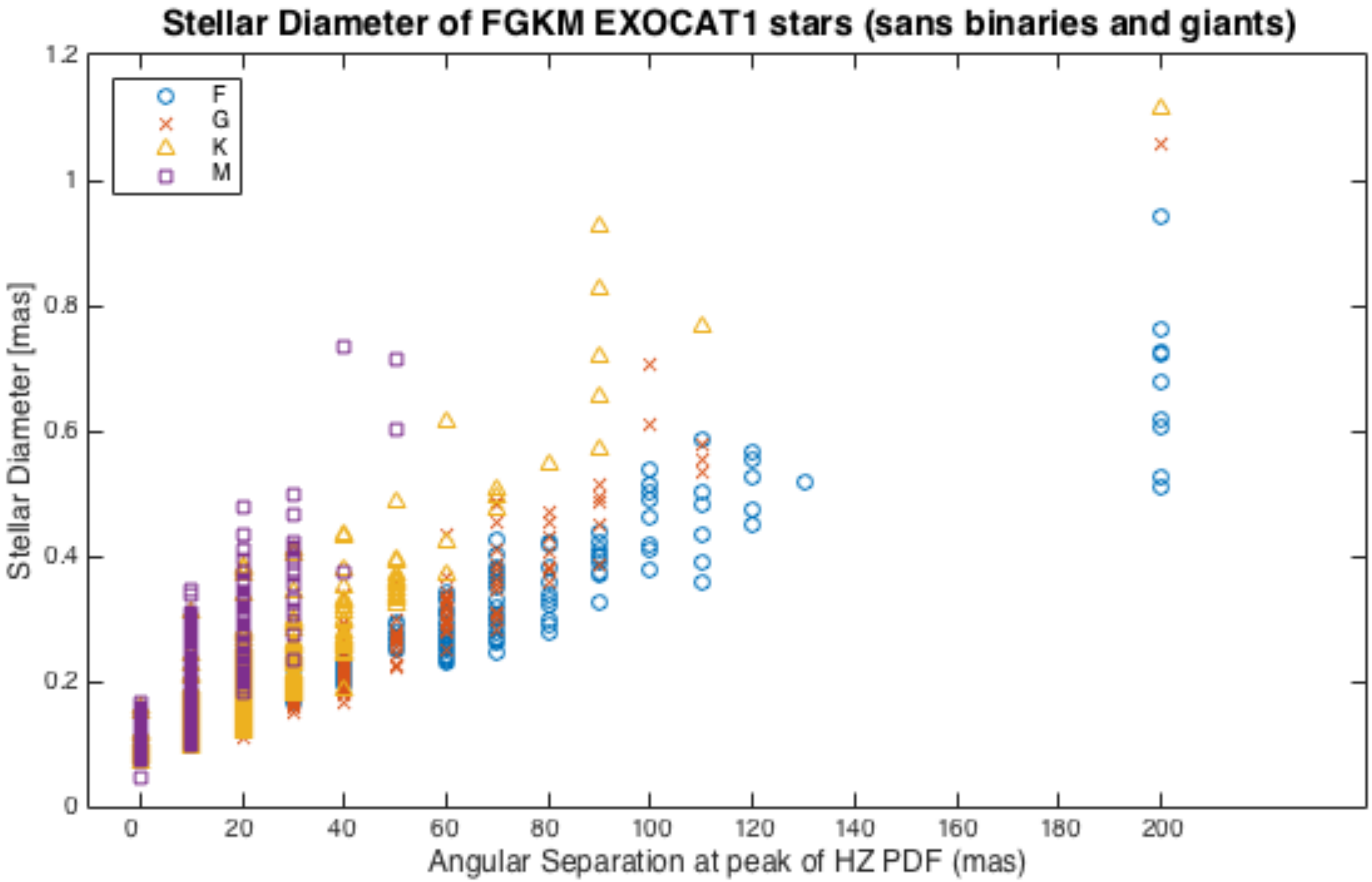
Upper Bound of Completeness[1] over IWA and Contrast

ExoPlanet Exploration Program

[1]Completeness = η_{Earth}*plotted values



Stellar Diameter



Notes

- This analysis is entirely **independent of instrument.**
- These are not yield numbers. Yield involves detection which requires an instrument.
- This is an upper bound of potential maximum yield.
- These are **single visit** (static) maximum yield upper bounds. Future work will evaluate using revisits for dynamic completeness upper bounds.

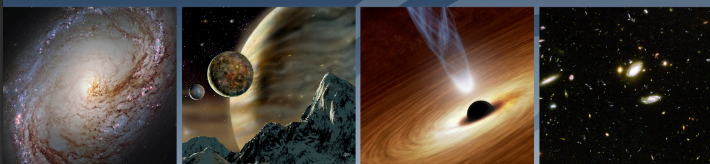
Future work

- Filter out below 30 mag (some detection threshold)
- Add revisits. Numbers will go up. Express the completeness for the observable HZ for infinite visits
- Add line for 5 SNR detection 1e-11 detection
- Dynamic Completeness

EXOSIMS

Decadal Concept Studies

Astrophysics



Large Mission Concept Studies Kick Off
AAS 227th Meeting
Kissimmee, Florida
January 6, 2016

Paul Hertz
Director, Astrophysics Division
Science Mission Directorate
@PHertzNASA

Guiding documents for the mission concept studies are posted at
http://science.nasa.gov/astrophysics/2020-decadal-survey-planning/

Large Mission Concept Studies

NASA will initiate mission concept studies of the following four large mission concepts:

- **FAR IR Surveyor** – The Astrophysics Visionary Roadmap identifies a Far IR Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.
- **Habitable-Exoplanet Imaging Mission** – The 2010 Decadal Survey recommends that a habitable-exoplanet imaging mission be studied in time for consideration by the 2020 Decadal Survey.
- **Large UV/Optical/IR Surveyor** –The Astrophysics Visionary Roadmap identifies a Large UV/Optical/IR Surveyor as contributing through improvements in sensitivity, spectroscopy, high contrast imaging, astrometry, angular resolution and/or wavelength coverage. The 2010 Decadal Survey recommends that NASA prepare for a UV mission to be considered by the 2020 Decadal Survey.
- **X-ray Surveyor** – The Astrophysics Visionary Roadmap identifies an X-ray Surveyor as contributing through improvements in sensitivity, spectroscopy, and angular resolution.

Exoplanet Probe Studies

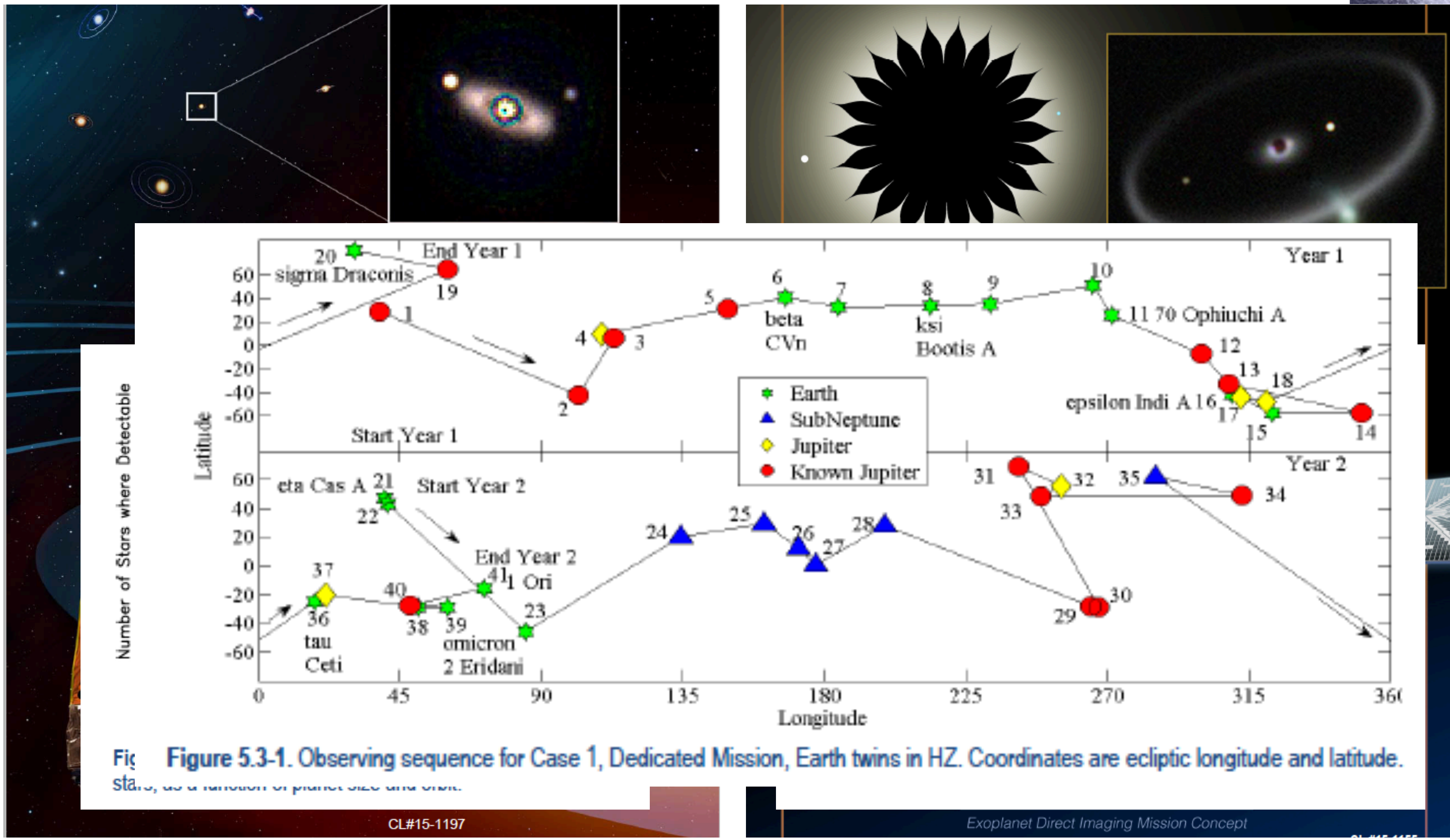


Figure 5.3-1. Observing sequence for Case 1, Dedicated Mission, Earth twins in HZ. Coordinates are ecliptic longitude and latitude.

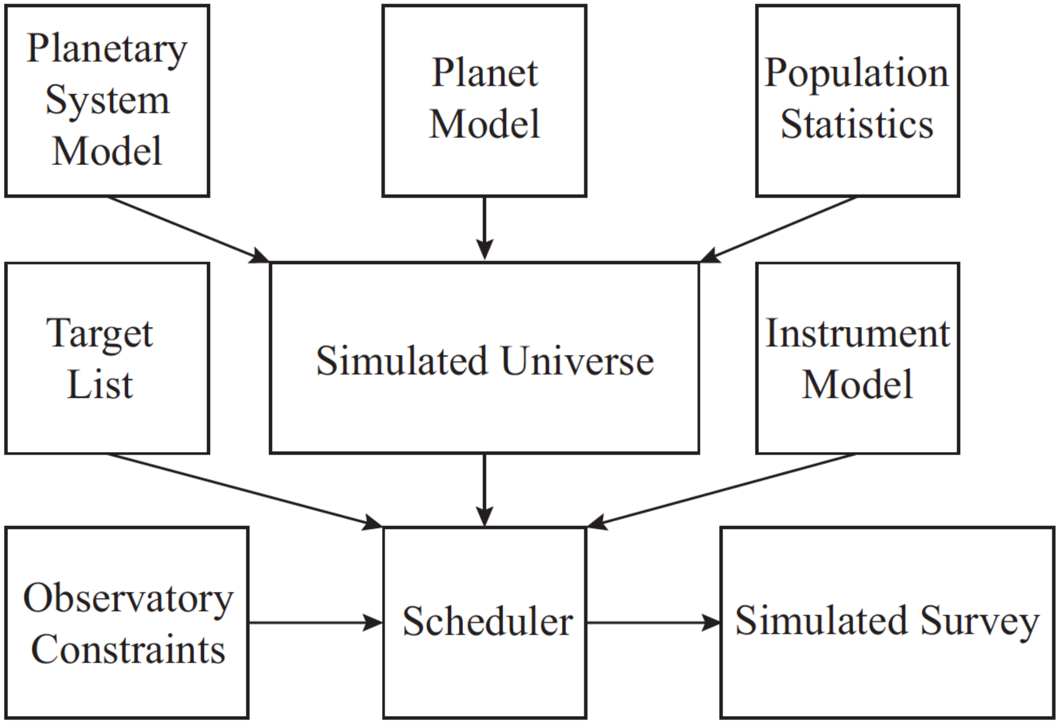
Yield Estimation for Decadal Studies

- The Decadal concept studies include two studies featuring exoplanet science. In light of this, the Exoplanet Exploration Program Office commissioned the development of a yield model to be the **standard measure** of performance for work within the Exoplanet Program
  - The yield model will be **open source and distributable** for use by the community
- ExEP is chartering 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

ExEP Yield Tool

- **Objective**: build 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

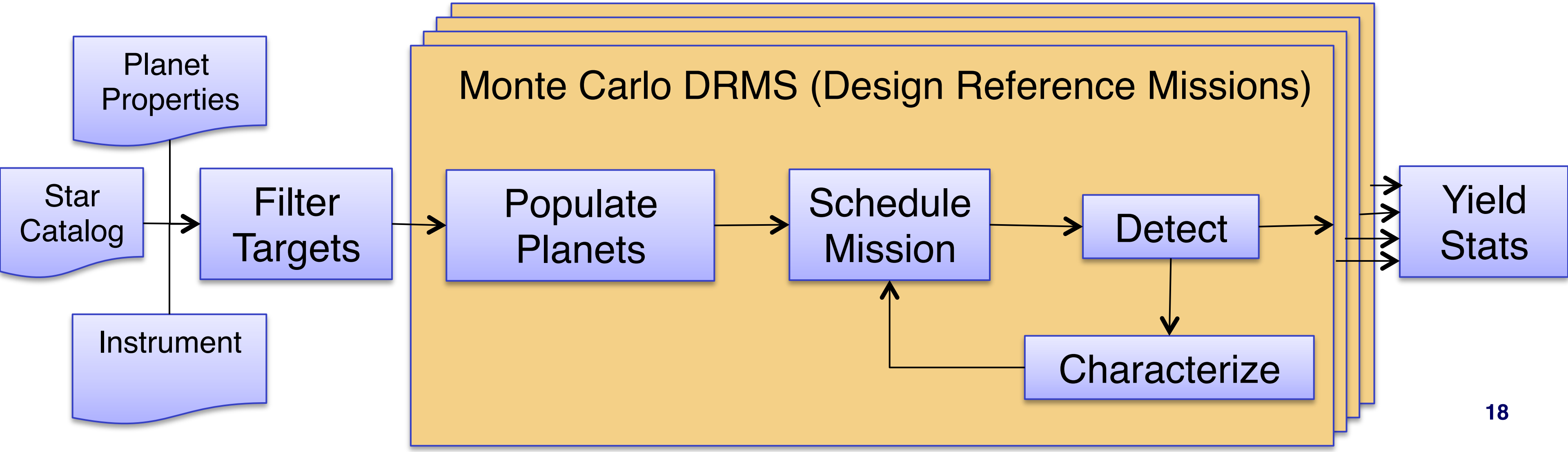
EXOSIMS Framework



D. Savransky, 2013

Science Yield Model Code Features

- Full physics-based diffraction models of coronagraph or star-shade performance
  - John Krist runs PROPER diffraction simulations for coronagraphs
  - Eric Cady runs boundary diffraction wave calculation for star shade petals
- Realistic spacecraft and mission observing constraints
- Utilizes the EXOSIMS framework by Savranksy under development for WFIRST
  - Contributions by Christian Delacroix, Daniel Garrett, Patrick Lowrance, Xiang Cate Liu, Rhonda Morgan, Michael Turmon
  - Python, open source: github.com/dsavransky/EXOSIMS
  - Object Oriented base class definitions allow for customization of modules
    - Can update model fidelity without impacting backbone
  - All parameters and modules specified via a single JSON-format text file
    - Pointers to files of star catalog and contrast data



Input Parameters

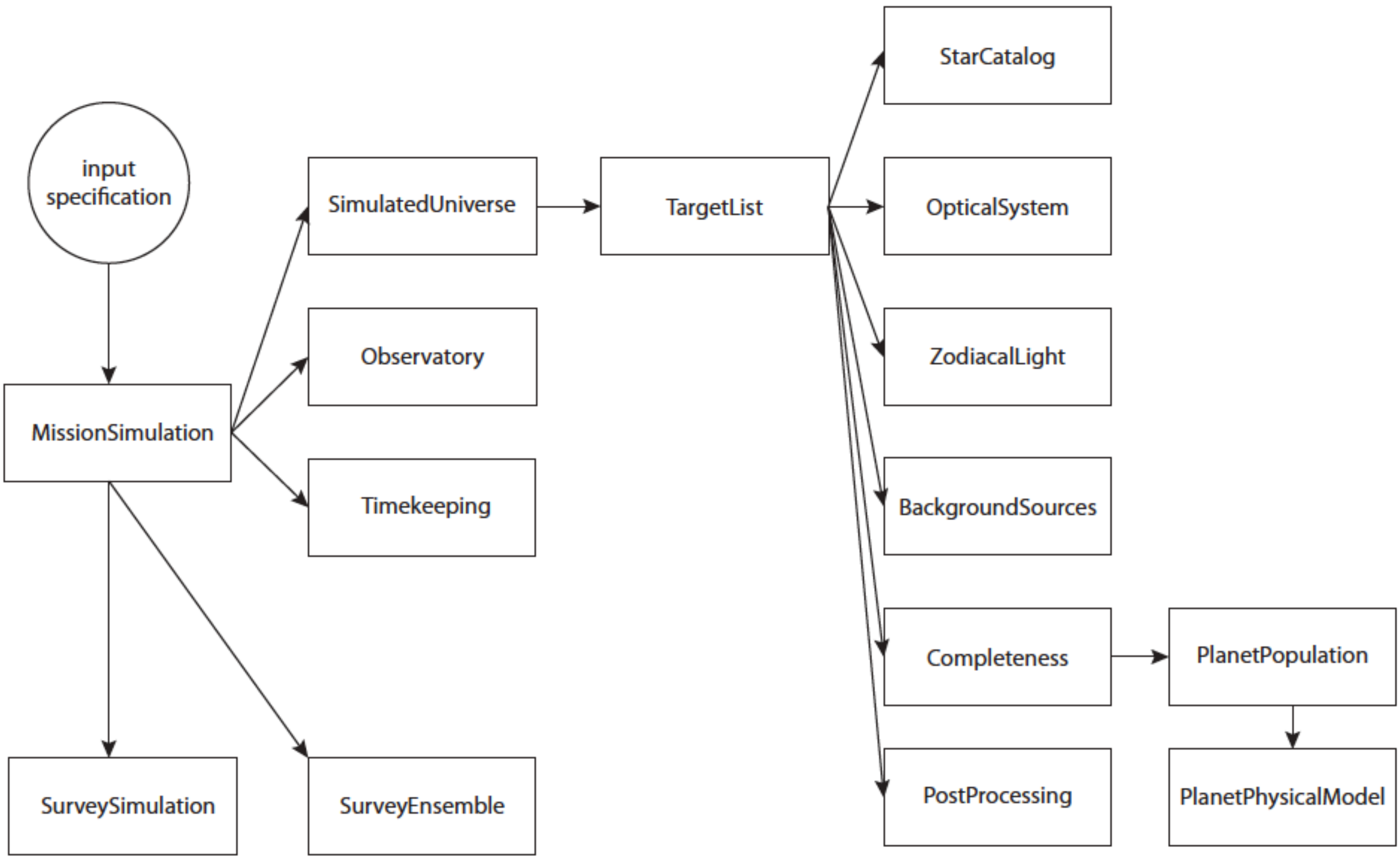
- **Astrophysics**
  - Star list: EXOCAT1 or KnownRVplanets
  - Planet Properties
  - Exozodi brightness
  - Background Sources

- **Post-processing**
  - Contrast Factor

- **Telescope**
  - D_aperture, Fill
  - Throughput(angle)
  - Contrast(λ,angle)
    - PSF
    - IWA
    - OWA
    - Jitter/WFE
  - Polarization
  - Focal Plane
    - Pixel size
    - Detector noise
    - Dark rate
  - Bandpass
  - Spectral resolution
  - IFS sampling

- **Mission Design**
  - Mission duration
  - Overhead
  - Sun angle constraint
  - Starshade propulsion
    - deltaV, fuel capacity, Isp
  - Scheduling
    - Revisit schema
    - Target priorities
    - Detection Response

EXOSIMS Architecture



Code Validation is Important

ExEP

1. Unit Tests

1. Each method (sub-function) of each module is tested
   - Often this involves instantiation of the entire simulation object
   - Point-checks against test cases verify module results
2. Xx bugs identified and fixed
3. Critical Path unit tests are 45% complete. *Complete 5/31/16*

2. **System Level** Cross Validation

1. Wes Traub's comparison of Exo-S, Exo-C, WFIRST Coronagraph, WFIRST Starshade *Complete 6/20/16*
2. Chris Stark's AYO and Other codes using standard inputs (ExoCat starlist, SAG13 occurrences) for Decadal Mission Concept Studies