Jet Propulsion Laboratory
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AFTA Coronagraph Science Yield Plan

(known planets, new planets, debris disks, & spectra)

DRAFT v.7

**(changes: from v.4 is chart 12 only, based on telecon ,
and from v.5 with "not export" marking
and from v.6 by removing the "not export" marking)**

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Time allocation

- Assume 1 year of total operation time for coronagraph instrument
- Assume time can be allocated throughout 6-year mission, as needed

- Assume that detailed time allocations will be decided later on the basis of mission operations, speed of each coronagraph architecture in searching and characterizing, and the pool of targets:
  - X % overhead (slew, settle, calibrate, re-calibrate, communications, etc.)
  - Y % search (locate RV planets, locate new planets, map debris disks)
  - Z % characterize (spectra of RV & new planets found in searches)

Coronagraph parameters needed from advocates

- IWA & OWA of dark hole (DH), or equivalent, per snapshot
- Angular range of DH, or equivalent, per snapshot
- Raw background contrast in DH, vs position if needed (for J. Krist)
- Optical efficiency (photons out/in) in DH (ditto)
- List of spectral bands that are feasible in the proposed configuration
- PSF of coronagraph (for J. Krist)
- Any other information deemed important by advocates

Additional hardware properties, assumed same for all

- Star tracker for fine-guidance, with accuracy a function of star magnitude
- LOWF sensor and actuator, (ditto)
- Imager, including data on QE, read noise, dark rate, cosmic-ray sensitivity, and allowable integration times
- Integral field spectrometer (IFS), (ditto)
- On-board computing power as needed

Wavefront properties (from AFTA Science Office)

- PSD of optical telescope assembly (for J. Krist)
- Body pointing RMS and drift (function of star magnitude)
- Thermal variation of wavefront, amplitude & time constant (for J. Krist)

Model planetary systems

- Use catalog of nearby stars (beta version available by ~ 3 Sept.)
- Use catalog of RV planets (by ~3 Sept.)
- Use catalog of new planets, in one or both of following forms:
  - generated at random using distribution functions in period & radius, to be estimated from existing data (~ 3 Sept.)
  - generated systematically in period & radius, so as to map out that space
- Assume exozodi brightness for two cases: 1 & 10 times local zodi
- Assume local zodi independent of direction
- Assume diffracted light background from nearby stars
- Assume model planets:
  - Lambert sphere brightness vs phase angle
  - Empirical mass-radius relation (i.e., smooth curve-fit, excluding inflated Jupiters)
  - Model-based spectra & albedo vs insolation
  - Orbit inclination 60 deg. (randomize later if needed); circular orbit
  - Random observing times, random times of periastron

Model zodi & debris disk systems

- Use zodi and Edgeworth-Kuiper Belt models in AFTA final report
- Assume models scale with distance & brightness of star
- Find optical depth factor, with respect to Solar System, needed for detection

Reference: WFIRST-AFTA Final Report, 23 May 2013, Fig. 2-24, available at:
http://wfirst.gsfc.nasa.gov/science/sdt_public/WFIRST-AFTA_SDT_Final_Report_Rev1_130523.pdf

Detection criteria

- Assume uniform background from local zodi, external zodi, diffracted light, dark rate, read noise, etc.
- Assume raw, local (position-dependent) speckle intensity in DH (informed by advocates and confirmed by J. Krist, with residual, uncorrected low-order wavefront variations from OTA, as indicated by thermal model)
- Assume systematic noise level, per FWHM of PSF, 1 sigma, to be equal to the photon-counting-limited shot noise of the raw, local speckle intensity
- Total noise is sum of 3 noise sources: background, raw speckle intensity (smoothed), and systematics
- Assume threshold factor *m* for detection, so that the planet signal S must exceed a minimum value $S_{min} = m*\text{sigma}$ within FWHM of PSF for a valid detection
- Calculate integration time for planet or disk signal to exceed minimum
- Use the full bandwidth of the most sensitive band available for each coronagraph for detection

Search method for RV planets

- Star is known, and semi-major axis (AU) & period (yr) of planet are known
- Calculate if observable during a 5-year mission; keep only observable ones
- Select maximum elongation configuration
- Calculate if planet is detectable, using S_{min} criterion
- Calculate cumulative observing time for all detectable planets, including needed multiple snapshots if DH angle is less than 360 deg.
- Calculate cumulative number of planets that are detectable vs time
- If needed for improved orbit determination, better sensitivity, or other reason, repeat at a more optimum phase angle

Search method for stars with “new” planets

- Star is known
- Planet period and radius are randomly selected from the assumed distribution functions, with random time of periapsis
- Adopt best estimate of albedo from current theory for a given type of planet, and as a function of insolation
- Assume 60 deg inclination, circular orbit, & Lambert phase curve
- Accumulate statistics on detections as a function of the population
- Use the same set of planets and observing epochs for all types of coronagraphs, but tune the integration times as needed for each coronagraph (details TBD)

Exoplanet characterization method

- Assume planet has been detected, and orbit sufficiently estimated, so little or no searching is needed
- Characterization criterion is similar to detection criterion, except here the bandwidth is smaller (e.g., 1.7% vs 20%), and the detector is different
- Use same criterion, with S_{min}(spectrum) factor instead
- Calculate the time needed to detect a spectral element at required SNR
- Calculate cumulative number of distinct spectral elements that could be recorded as a function of mission time

Science yield (exoplanets, spectra, disks) for each coronagraph

- Calculate cumulative number vs time in mission, for each category:
  - known RV planets: (1) detections, (2) colors, (3) spectra
  - new planets : (4) detections, (5) colors, (6) spectra
  - zodi disks: (7) images, (8) colors
  - Kuiper belts: (9) images, (10) colors
- Balance these modes to maximize a TBD aspect of science for the mission, using a common rule for all coronagraphs if possible, but a different rule if circumstances require