National Aeronautics and Space Administration

FY24 Strategic University Research Partnership (SURP)

Next Generation Exoplanet Mission Simulations: Atmospheric Constraints

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Objectives: Add atmosphere spectral retrieval capabilities to the EXOSIMS exoplanet direct imaging mission simulation software. The current software output declares success of a spectral observation when the photometry meets SNR for a specific spectral resolution and wavelength, which were determined by external studies using advanced, high fidelity spectral retrieval codes. By adding a moderate-fidelity, fast retrieval code to EXOSIMS, the software output will be the successfully retrieved molecular species. This shifts the performance metric of the end-to-end yield simulation closer to the science performance goal of the mission, which is to search for biosignatures in Earth-size planets in the habitable zone of nearby stars. Adding spectral retrieval capability to EXOSIMS requires adding atmospheres to its synthesized exoplanets.

Background: The National Academies' "Decadal Survey on Astronomy and Astrophysics 2020" set forth a vision for the coming decade that would take key steps towards a long-awaited goal of astronomy and astrophysics: the direct imaging of Earth-sized planets in the habitable zones of nearby, Sun-like stars. The NASA Habitable Worlds Observatory (HWO) will provide breakthroughs in exoplanet science, especially in regard to characterization and the search for habitability and life. We aim to quantify search and characterization metrics using EXOSIMS, an exoplanet yield modeling tool used for direct imaging missions. HWO is driven by atmospheric characterization, so we need to push EXOSIMS into a regime where we can ask statistical questions about the gasses that a given mission architecture detects for different types of exoplanets. For the first time, EXOSIMS will provide statistical constraints on broad atmospheric characterization metrics and give more information about atmospheric archetypes. Through development and use of this modeling tool, we will better constrain the field of astrobiology and combine the use of predictions from statistical models with using these missions to quantify and constrain the likelihood of habitable worlds in actual practice. Our approaches emphasize characterization of exoplanet atmospheres to understand their evolution.

Significance/Benefits to JPL and NASA: The Astro2020 Decadal recommendation for an exoplanet direct imaging mission is an exciting opportunity for JPL to participate significantly in the next astrophysics flagship mission. Given NASA's investments in JPL's capabilities for the Roman Space Telescope Coronagraph Instrument (CGI), JPL would like to build the starlight suppression system(s) for HWO. The science performance understanding needs to advance in sophistication from instrument parameters (e.g., wavelength, bandwidth, spectral resolution, and signal-to-noise) to the level of molecular species that can be detected in the habitable zones around which stars. This will refine our expectation of the true science goal — biosignatures — and provide the tool needed to scrutinize the architectures for parameters that drive molecular species count, not merely the exoplanet count.

This work forges a new collaboration with U Arizona in atmospheric modeling. Co-I Robinson and JPL Co-I Hu are leaders in the field of direct imaging spectral simulation and retrieval, and their collaboration will be a powerful force in the shaping of HWO and exoplanet science for terrestrial planets.

Approach and Results:

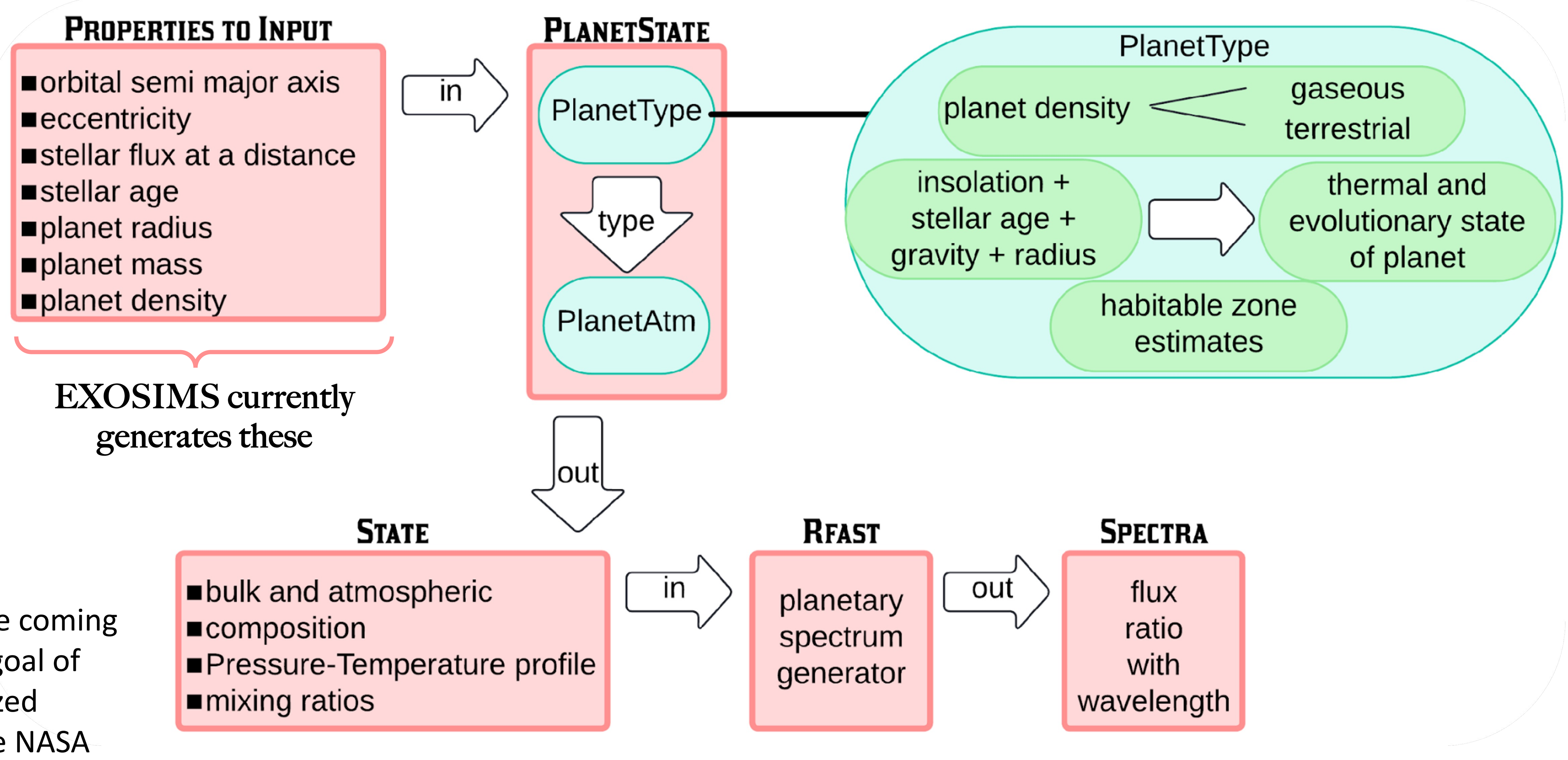

Figure 1. Planned new workflow to be added to EXOSIMS

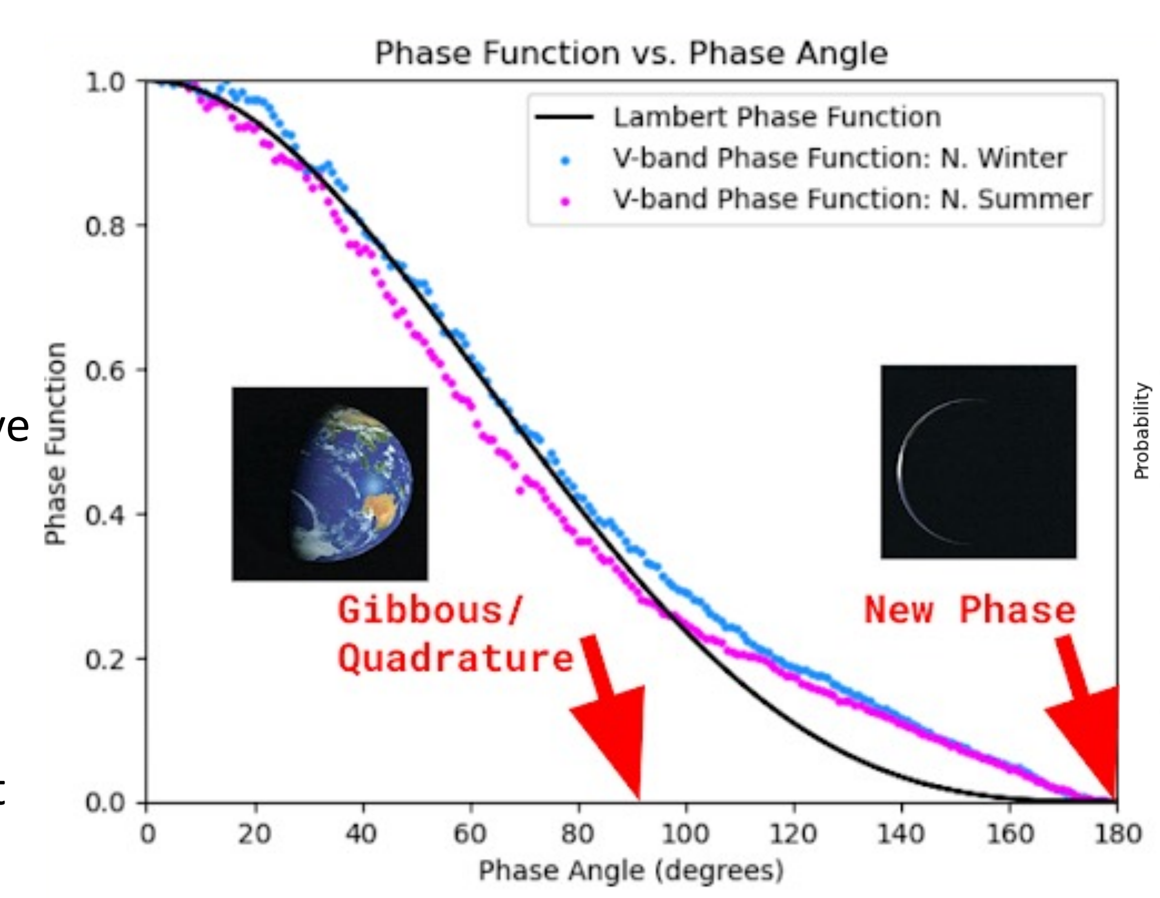

Figure 2. Comparison of currently used Lambert phase function and a realistic Earth phase function for northern winter and northern summer. The realistic phase function has higher reflectivity in from 90 degrees (or maximum elongation, or quadrature) to almost 180 degrees, which is a slim sliver of reflectivity.

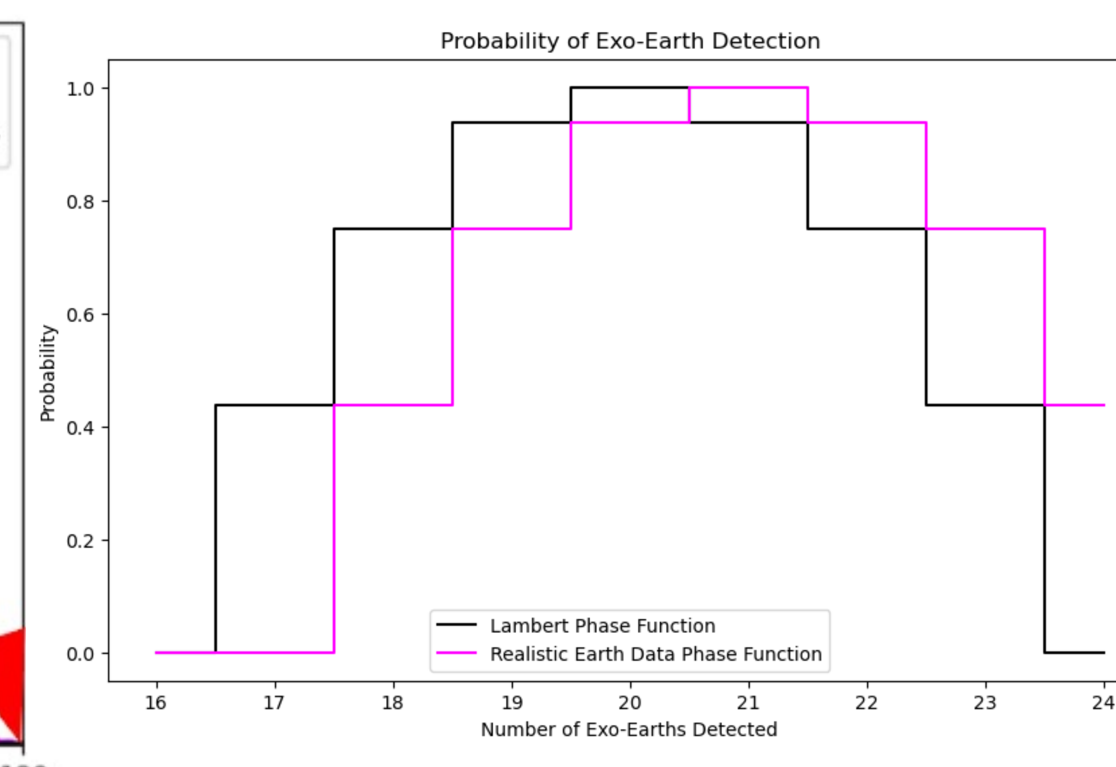

Figure 3. The probability of photometric detection of an exo-Earth improved slightly when using the realistic Earth phase function in comparison to the Lambert phase function. This is due to the increased reflected of the realistic phase function for phases between 90 and 180 degrees.

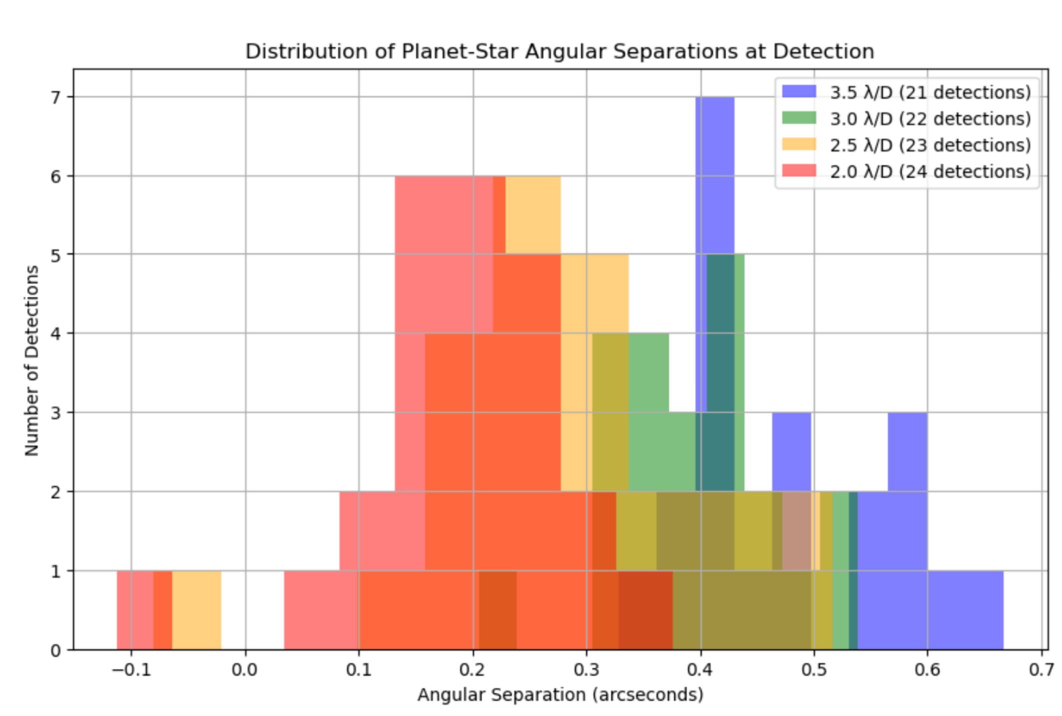

Figure 4. The histogram of number of exo-Earths photometrically detected as a function of angular separation of the exo-Earth at the time of the observation. The several values for inner working angle (IWA) cutoff of the coronagraph show the improved yield that a smaller IWA can bring.

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Publications:

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