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coronagraph: Telescope Noise Modeling for Exoplanets in Python

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Software

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Summary

coronagraph is an open-source Python package for generalized telescope noise modeling for extrasolar planet (exoplanet) science. This package is based on Interactive Data Language (IDL) code originally developed by T. Robinson (Robinson, 2018), and described in detail with science applications in (Robinson, Stapelfeldt, & Marley, 2016).

Briefly, coronagraph uses analytic relations to calculate the photon count rates for a variety of astrophysical, telescope, and instrumental noise sources. These include photons from coronagraph speckles, zodiacal and exozodiacal dust, telescope thermal emission, dark current, read noise, and clock-induced charge. The model also includes Earth's atmospheric transmission and emission spectrum from the UV through the near IR for ground-based telescope modeling (Meadows et al., 2018). Photons from a user-provided exoplanet source spectrum are compared against sources of noise to provide wavelength-dependent signal-to-noise (S/N) ratios and synthetic observations. The model also features "reverse" S/N calculations, which provide the requisite exposure times per wavelength interval such that a user-specified S/N is achieved on the exoplanet spectrum.

The coronagraph model was designed to assess exoplanet science capabilities for near- and far-term future telescopes. Since the computations are all relatively simple and analytic, coronagraph is ideal for fast sweeps across a range of possible telescope, instrumental, astrophysical, and planetary parameters to investigate primary noise sources and the feasibility of different science case. However, coronagraph may be impractical for existing telescopes or telescope concepts that have mature designs due to the "first order" nature of the model. Additionally, systematic errors (e.g. from speckle subtraction), stray light from companion stars and/or background objects, and time-dependent (red) noise terms are not considered. More specific or detailed use cases than those outlined above may be appropriate for the Exoplanet Open-Source Imaging Mission Simulator (EXOSIMS) (Savransky, Delacroix, & Garrett, 2017).

coronagraph has already been used in numerous practical science applications. This includes peer-reviewed work on the potential for direct-imaging Proxima Centauri b with ground- and space-based telescopes (Meadows et al., 2018), and the detectability of exoplanet aurorae on Proxima Centauri b (Luger et al., 2017). The coronagraph model is used within NASA Goddard's interactive tool **Coronagraphic Spectra of Exoplanets** (Tumlinson & Arney, 2018), and is actively being used to motivate science cases for next-generation, space-based, direct-imaging mission concepts (Bolcar et al., 2016; Mennesson et al., 2016).

The coronagraph package may also be used to simulate signal-to-noise ratios and synthetic spectra for transiting exoplanets in transmission and emission. The transiting exoplanet modules extend the potential science applications of coronagraph to non-coronagraph-equipped telescopes, enabling studies relevant to a far-infrared surveyor mission concept (Cooray & Origins Space Telescope Study Team, 2017).

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