# Keck Synergies with NASA's Roman Coronagraph and Future Coronagraphic Space Missions

Vanessa P. Bailey & Bertrand Mennesson
Jet Propulsion Laboratory, California Institute of Technology

In this whitepaper, we are responding to a direct request to provide a near-term perspective on how Keck might contribute to or complement the Nancy Grace Roman Space Telescope (Roman) Coronagraph Instrument; we are also providing a perspective on potential synergies with a future exo-Earth direct imaging mission. Keck could assist the Roman Coronagraph and future missions with target discovery and vetting. Keck could additionally serve as a useful proving ground for new technologies and techniques for future missions. This whitepaper is not intended to be an official endorsement or recommendation from Roman or NASA; rather is the opinion of the authors, based on their personal experience on the Roman team and on the HabEx concept study team.

The Roman Space Telescope is set to launch in ~2026, and its payload will include the Coronagraph Instrument: a high-contrast imager, polarimeter, and spectrograph that will operate at ~500-900nm. It could take the first reflected-light images of a mature gas giant planet around a nearby solar analog. It is predicted to be able to detect planets with planet-to-star flux ratios of $10^{-8}$ to $10^{-9}$, at working angles as small as 0.15". The nominal observation period of the Coronagraph Instrument is launch + 21 months, or ~2026-2028.

Additionally, the Astro2020 Decadal Survey recommended that NASA develop a technology and mission maturation program in preparation for a ~6m near-IR/optical/UV large strategic coronagraphic mission optimized for the spectral characterization of Earth-sized rocky planets (flux ratios of ~1E-10 at ~0.1"), with a goal to enter phase A mission development by the end of this decade.

Target vetting consists of deep adaptive optics imaging of fields surrounding potential direct imaging planet targets that have thus far only been detected with indirect methods (eg: radial velocity (RV) or astrometry). The purpose is to search for faint, nearby background stars that could contaminate the Roman or future mission observations. Space observatories have little to no flexibility to adapt observing plans in the event a contaminant is discovered; a quarter or half a night of Keck precursor observations on a target can prevent tens of hours of wasted Roman time. Despite the substantial difference in raw contrast achieved by NIRC2 vs. Roman, NIRC2 has still placed meaningful limits for several Roman targets. This is because extinction drops as wavelength increases, and because many Roman targets have high proper motions, placing the future Roman field of regard several arcseconds from the stars' current positions. Keck could similarly be used to vet potential targets for a future direct imaging mission well before launch. The earlier the Keck observations are taken, the farther the future mission fields of regard are from the stars' current positions; hence, less-advanced AO performance can be accepted

for observations taken sufficiently far in advance. For late-breaking targets or for targets with low proper motion, Keck near-IR AO instrumentation upgrades to achieve higher contrast would help keep pace with the deeper detection limits needs of a future mission.

Keck could also potentially discover new targets for the Roman Coronagraph or for future missions. Continued high-precision or extreme-precision RV monitoring of bright stars, especially those with long-term RV trends, might discover new ice or gas giants that Roman or a future mission could detect in reflected light (EPRV is discussed in detail in other whitepapers). Continued near-IR AO imaging surveys of bright stars[1], especially with upgraded instrumentation with smaller inner working angles and higher contrast, would also be very beneficial. Such surveys could discover new circumstellar disks or self-luminous young gas giants that could be further characterized by Roman or a future mission at <1um, fleshing out their spectral energy distributions. The 2023 Gaia release should provide a large pool of young target stars with Gaia vs Hipparcos accelerations to choose from, so that an efficient, targeted coronagraphic survey can be conducted at Keck with tens of favorable targets.

Additionally, we believe that Keck is very well-positioned to study on-sky some of the key technical trades to come for the design of future missions, including trades between spectral resolution, wavefront control performance and coronagraphic inner working angle. In particular, the recent development at Keck of high contrast capabilities at ~ lambda/D separations using high dispersion coronagraphy (NIRSPEC at R ~ 37,000) provides an excellent platform to test innovative coronagraphic approaches that could be considered in design trades. A great example is the Keck Planet Imager and Characterization instrument (KPIC) installed at Keck in 2019 in conjunction with a dedicated low-order wavefront correction system, and its planned 2022 extension to very small inner working angles using Vortex Fiber Nulling (VFN).

Lastly, given the expected ~10 year development timescale of high-contrast coronagraphs for the US and European ELTs, we note that there is a unique science window of opportunity for Keck. With upgraded high-contrast capabilities, Keck could dramatically improve our understanding of planet formation processes via atmospheric characterization of a much larger sample of young exoplanets than currently accessible.

**In summary:** Keck investment in high-contrast instrumentation for exoplanet detection and spectral characterization at working angles commensurate with the diffraction limit would benefit both Roman and future missions. It could provide invaluable technical lessons about coronagraphic wavefront sensing, post-processing and overall architectures. Keck could additionally support target identification and vetting for Roman and future missions. Keck can capitalize on the KPIC “head-start” and on previous major Observatory investments in wavefront sensing and AO correction capabilities by accelerating the currently planned KPIC/VFN developments and/or by testing potential variants of nulling coronagraphs and high-contrast aperture masking instruments.

[1] Roman is currently planning targets Vmag <~ 7, but may be able to go fainter, pending future tests.