Next Generation Visible Nulling Coronagraph

Mission yield optimization studies show that characterizing dozens of Earth-like planets requires an aperture in excess of 8 meters in diameter [1]. In their Beyond JWST report [2], the Association of Universities for Research in Astronomy (AURA) committee has also recommended a 10-12 meter space telescope to enable a broad array of general astrophysical observations, including resolving structure everywhere in the universe to 100 parsecs. A large-aperture space telescope capable of combined exoplanet and cosmic origins science presents a compelling science case with broad community support, and is one of four candidate flagship missions to be studied for the 2020 Decadal Survey [3].

Such large apertures must use a deployable segmented architecture to maintain compatibility with existing and planned launch vehicles. However, segmented apertures increase the amount of diffracted starlight as compared to unobscured monoliths, presenting a challenge to many coronagraphs. Developing starlight suppression techniques that can accommodate the diffraction from segmented apertures is of high priority. We propose to build and demonstrate the Next Generation Visible Nulling Coronagraph (NG-VNC) as a starlight suppression system that is compatible with a segmented aperture typical of a 10-meter-class deployable space telescope.

The existing Visible Nulling Coronagraph (VNC) at Goddard Space Flight Center (GSFC) is a lateral-shearing interferometer that is compatible with segmented apertures. The VNC has demonstrated a stable contrast ratio of $5.7\times10{-9}$ at an inner working angle (IWA) of $2\lambda/D$ (where l is the wavelength, D is the aperture diameter; see Figure 1) over a narrow bandwidth (<1% at 632.8 nm) using a segmented deformable mirror [4]. This is the deepest nulling achieved with any visible interferometer [5].

Our team has begun designing, modeling, and evaluating the NG-VNC, an evolution of the VNC concept that uses new phase occulting (PO) optics (see Sections 2.3 and 2.4). The NG-VNC with PO optics is a single nulling interferometer (nuller) that delivers: (1) full-field observing, (2) high throughput, and (3) high-order stellar disk suppression, all while maintaining high-contrast performance with a segmented aperture, at small IWA, over broad bandwidths. By realizing high order stellar disk suppression with a single nuller, the number of optics is reduced, which increases overall throughput, reduces mass, volume, and complexity, and thereby reduces cost and risk.

In addition to the new PO architecture, the NG-VNC will include additional upgrades to the existing VNC design: (1) the use of two deformable mirrors (DMs) enabling simultaneous control of misalignment aberrations and polishing defects that give rise to phase and amplitude errors over the entire field-of-view; (2) additive manufacturing techniques that will simplify the alignment effort of the nuller cavity while enhancing stability and robustness through the elimination of mechanical joints; and (3) partnering with Ball Aerospace Technology Center (BATC) to construct a Star-Planet Source (SPS) emulator, consisting of a calibrated pair of sources of known contrast ratio and adjustable separation. Furthermore, as part of this proposed effort, we will partner with the University of Rochester to leverage their expertise in wavefront sensing to develop enhanced broadband sensing and control algorithms for the NG-VNC. Section 2.4 provides a detailed description of the key technology components.

The proposed effort will advance the PO optics from TRL 3 to TRL 4 by demonstrating the NG-VNC in a lab environment, and comparing performance to predictions made by analytical models. The demonstration milestone is to use the NG-VNC with a segmented aperture telescope to achieve and hold a true contrast of 1×10^{-8} at an inner working angle of $3\lambda/D$ within a spectral bandpass of $\Delta\lambda = 40$ nm at a central wavelength of 632.8 nm for 1,000 seconds on three separate occasions separated by at least 24 hours.