NEW WORLDS IMAGER
Astrophysics

Jet Propulsion Laboratory
California Institute of Technology

Overview:

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Key collaborators: science/engineering team with experience in mission design, including space observatory instrumentation; wavefront control hardware and control algorithms; coronagraph design, fabrication and laboratory demonstrations; high fidelity optical modeling; and science mission definition and simulations.

Goals of the proposed concept: Our science objective is the direct observation of nearby exoplanetary systems that harbor exoplanets, planetesimals, and dust/debris structures. Planet atmospheres are analyzed in reflected starlight via direct integral field imaging, spectroscopy, and polarimetry.

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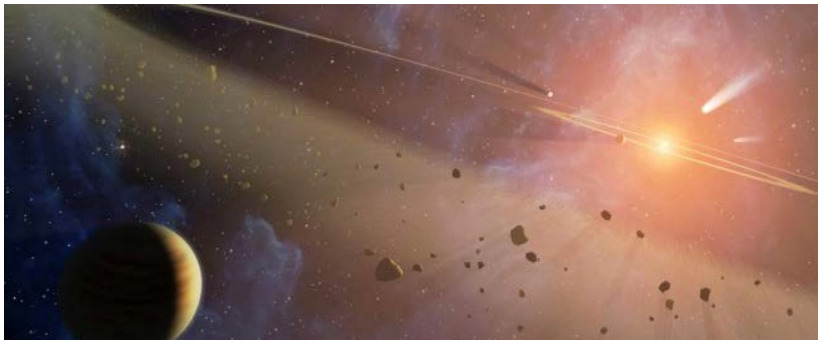

NWI / SALSO characterizes nearby exoplanet systems with direct high-contrast imaging, spectroscopy and polarimetry.

Description:

NWI is an instrument concept for high contrast exoplanet imaging, spectroscopy, and polarimetry with the SALSO telescope. Coronagraphic starlight suppression from a space platform is capable of direct imaging – for the first time– of cool, mature exoplanets at visible (400–900 nm) wavelengths in reflected starlight.

NWI combines newly developed and laboratory demonstrated coronagraph technology, protoflight qualified deformable mirrors for wavefront control, and an integral field spectrograph to create a new class of high contrast coronagraphic instrument, with circumstellar imaging sensitivities that surpass the Hubble Space Telescope by several orders of magnitude.

NWI shares the SALSO focal plane with other general astrophysics instruments.

Modular instrument concept is compatible with human and robotic servicing of the SALSO observatory.

Value to NASA:

This concept actualizes the NRC *Astro2010* decadal recommendations to advance our knowledge of exoplanetary systems. It advances New Worlds Technology Development, which was identified as the #1 priority for medium missions in the coming decade.

And it is responsive to NRC technology objectives as articulated the *NASA Space Technology Roadmaps and Priorities (2012),* which gave top ranking to *Optical Systems* and *High Contrast Imaging and Spectroscopy* among Category C Technology Objectives to expand our Understanding of the Earth and Universe).

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John Trauger, Senior Research Scientist at JPL, leads the NWI team. He was P.I. for the ASMCS/ACCESS exoplanet coronagraph mission concept study (2009), the hybrid Lyot coronagraph SAT/TDEM study and demonstration (2012), and developer of the precision deformable mirrors that are critical for coronagraph wavefront correction and have served as workhorse for JPL's High Contrast Imaging Testbed. He was P.I. for the long-lived WFPC2 instrument that provided corrected wide field imaging for HST from 1993 to 2009.

Primary Concept Goal Category:
Astrophysics

Abbreviated Concept Summary: An instrument concept for high contrast exoplanet imaging, spectroscopy, and polarimetry with the SALSO telescope. Combining newly developed and recently demonstrated coronagraph and wavefront control technologies with the 2.4 meter telescope, we launch a new class of high contrast circumstellar imaging with sensitivities that surpass the Hubble Space Telescope by several orders of magnitude.

Goal of the Proposed Application: Our science objective is the direct observation of nearby exoplanetary systems that harbor exoplanets, planetesimals, and dust/debris structures. Starlight suppression with an actively corrected coronagraph on a space platform will be capable of direct imaging – for the first time – of cool, mature exoplanets at visible (400–900 nm) wavelengths in reflected starlight. Planet atmospheres can be analyzed in reflected starlight via direct integral field spectroscopy and polarimetry. The result is a science program that begins with the characterization of the nearby radial velocity (RV) planets in orbits beyond ~1AU and continues with the detection and characterization of mature exoplanet systems beyond the RV survey limits – including giant planets and super-earths. We expect to observe and characterize a dozen earth-mass planets. There will be observations of ephemeral debris structures as the signposts of interaction between planets, asteroids, and planetesimals. Further, this concept opens yet unexplored areas of general astrophysics, including the direct imaging of faint circumstellar dust structures that track the evolution of planetary systems – from their birth as protostellar disks to their demise in post-main sequence stellar winds and protoplanetary nebulae.

Benefits of the Application: This concept actualizes the NRC *Astro2010* decadal recommendations to advance our knowledge of exoplanetary systems in the coming decade. It advances the development of *New Worlds Technology* that was identified as the #1 medium class priority for this decade. And it is responsive to the NRC technology objectives articulated in the *NASA Space Technology Roadmaps and Priorities (2012),* which gave top ranking to *Optical Systems* and *High Contrast Imaging and Spectroscopy* among Category C Technology Objectives to expand our Understanding of the Earth and Universe.

Top-level Description of the Design, Operation, and Results: We build upon our recent science/engineering studies, including ACCESS, an Astrophysics Strategic Mission Concept Study (Trauger et al. 2009) that developed the science and engineering case for a modern probe-class coronagraphic telescope. We benefit from three Strategic Astrophysics Technology / Technology for Exoplanet Mission studies that have advanced and proven our leading coronagraph technologies (Krist et al. 2012, Serabyn et al. 2012, Trauger et al. 2012). Furthermore, we are well along in the development of promising coronagraph design innovations (inspired by the recent AFTA/WFIRST opportunity) that can operate effectively even with the highly obscured SALSO primary mirror.

To detect and characterize exoplanets of sizes ranging from rocky Earth-like planets to gas giants, a space coronagraph must be capable of raw image contrasts of 10^{-9} or better in a dark field of discovery near the parent star. Post-processing of coronagraph images will provide

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detection sensitivities still fainter by an order of magnitude or more (Trauger andTraub 2007).

Observatory wavefront stability and control are key to the success of this concept. We therefore regard the telescope and coronagraph instrument as inseparable elements in an end-to-end optical system. With careful thermal and mechanical design, the space environment enables imaging capabilities well beyond that of even the largest telescopes on the ground. We will evaluate the as-is capabilities of the SALSO telescope for high contrast imaging, its thermal performance in a preferred L2 or high earth orbit, and end-to-end optical performance and tolerances using our experiment-validated modeling tools. We will further consider whether modest modifications to the thermal design or secondary mirror baffles and support structure might provide cost/performance benefits.

A stable SALSO telescope is also an outstanding platform for transit spectroscopy in the combined light of star and exoplanet (e.g., the PISA concept, Swain, POC). And a shared, exceptionally stable UV/optical space observatory is an ideal setting for advanced general astrophysics in the post-HST era (e.g., the HORUS concept, Scowen, POC).

Elements of the observatory: Our SALSO concept incorporates the following features.

- New Worlds imaging and spectroscopy as a Level 1 design priority for SALSO.
- Suppression of scattered starlight in the exoplanet discovery field of view via coronagraphic imaging, spectroscopy, and polarimetry.
- Coronagraph design based on validated high TRL methods, mature performance models, and proven technology for the control of cost, schedule, and risk.
- Shares the focal plane of an exceptionally stable UV/visible telescope (0.2-1.7 μm) in L2 or high earth orbit that supports and extends HST science.

The coronagraph instrument: Our coronagraph approach is informed by validated optical modeling and laboratory demonstrations over the past decade. We have selected three leading design options to be considered in this study.

- The off-axis subaperture coronagraph.
- The complex apodized Lyot coronagraph.
- The multi-stage vector vortex coronagraph.

In each case, a pair of deformable mirrors provides the fine wavefront control. We use protoflight qualified Xinetics deformable mirrors and wavefront sensing algorithms refined over seven years of laboratory experimentation. This approach offloads the precision wavefront control requirements from the SALSO telescope.

Performance for the subaperture case, shown in Fig. 1, is understood with reference to the ACCESS engineering study for a 1.5m off-axis coronagraphic observatory in L2 orbit. Design studies for the full 2.4m SALSO aperture have already been initiated for both the complex Lyot and multi-stage vortex coronagraphs with JPL research funding. As shown in Figs. 2 and 3, narrowband solutions exist for the Lyot and vortex coronagraphs, to be extended to spectral bandwidths of 10% and 20% in the coming year.

Expected astrophysics results: While thousands of exoplanet systems are known to exist, NWI advances our understanding of exoplanet characteristics and their diversity, probing atmosphereic compositions and cloud structures, as well as the distribution of planetesimals and debris structures. Further, NWI will observe planet formation in action in protoplanetary disks by their imprint on debris disks. The NWI shares the SALSO focal plane with other general astrophysics instruments, such as a wide field UV/visible imaging spectrometer that extends and advances HST science in the post-HST era.

Key collaborators: David Ardila, John Krist, Bertrand Mennesson, Dwight Moody, Eugene Serabyn, Mark Swain (JPL), James Breckinridge (Caltech), Gary Matthews (Excelis), Dimitri Mawet (ESO), Karl Stapelfeldt (GSFC).

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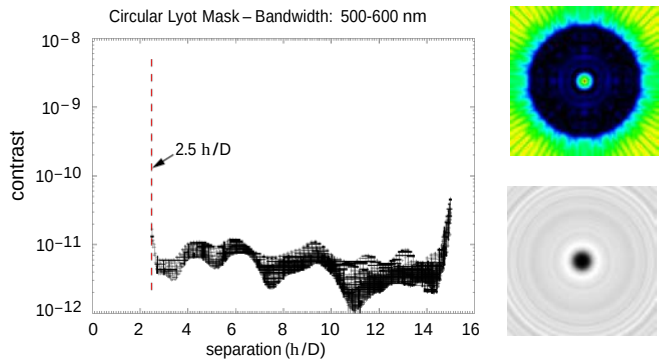

Figure 1 – Sub-aperture coronagraph. Conceptually the most mature approach, we consider the case of the unobscured off-axis subaperture with the hybrid Lyot coronagraph. Our hardware fabrication and test efforts are now focused on the circular Lyot mask shown in the figure. This extends our recent experiments with the complex Lyot coronagraph, which has routinely demonstrated raw image contrast of 5×10^{-10} at inner working angles of 3λ/D over spectral bandwidths of 10% in unpolarized light (Trauger et al. 2012). While this approach utilizes only one of the six 0.75m diameter unobscured subapertures of the SALSO telescope, it is a minimum risk path to imaging contrast levels that are unattainable from the ground, providing breakthrough characterizations for the nearest exoplanet systems.

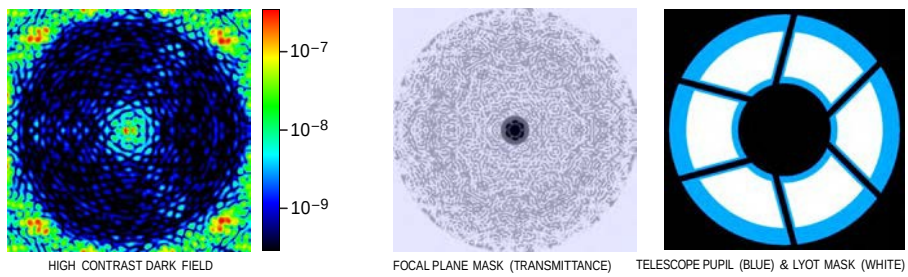

Figure 2 – The full-aperture Lyot coronagraph. Preliminary design for a complex apodized Lyot coronagraph optimized for the 2.4m SALSO telescope aperture. Shown are (left to right) the high contrast dark field with a raw contrast of 6×10^{-10} and inner working angle of 2.5 λ/D in narrowband unpolarized light; the attenuation pattern of the corresponding focal plane mask; and the Lyot stop (white) superimposed on the SALSO pupil (blue). A newly initiated study, supported by internal JPL research funding, incorporates deformable mirrors into the optimization to extend spectral bandwidths to δλ/λ = 10% and 20% as required for faint astronomical sources.

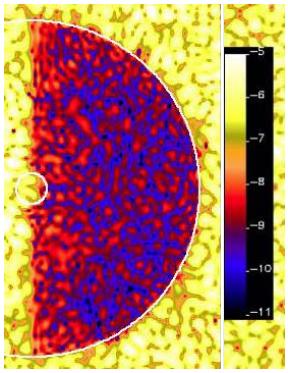

Figure 3 – The full-aperture vortex coronagraph. Predicted performance for a three stage vector vortex coronagraph with a SALSO-like telescope in narrowband polarized light. Model predictions have been performed with the PROPER package (Krist 2009). Vortex has been demonstrated and model has been validated at ground-based observatories (Palomar, VLT) and in the laboratory (Serabyn et al. 2012). This illustrates that ~10^{-9} contrast can be reached despite the central obstructions without sacrificing throughput (~75% in each of two polarizations) and an exceptionally small inner working angle (1.75 λ/D). The multi-stage vortex design will be extended to broadband light this year with JPL research funding.

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