Imaging Polarimetry for ExoPlanet science & astrophysics

James B. Breckinridge
jbreckin@caltech.edu

1. Key science questions

Polarization measurements of astronomical sources in the UVOIR contain substantial astrophysical information on star formation & evolution, interstellar medium, and gas cloud dynamics. The asymmetry of aligned dipoles in interstellar matter selectively absorb the thermal emission from background stars to reveal the presence of magnetic fields and their anomalies in the galaxy and in the neighborhood of stars[1]. Unpolarized radiation that scatters from planetary atmospheres and circumstellar disks becomes partially polarized to reveal structural dynamics, chemistry, aerosols, and surface features. The value of precision imaging polarization measurements to general astrophysics is well known across the UVOIR region[2],[3].

Data from the imaging photopolarimeters on Pioneers 10 and 11 and the Voyagers showed that Jupiter-like exoplanets will exhibit a degree of polarization (*DoP*) as high as 50% at a planetary phase angle near 90°. Polarization measurements of the planet's radiation in the presence of light scattered from the star reveals the presence of exoplanetary objects and provides important information on their nature. de Kok, Stam & Karalidi (2012) showed that the *DoP* changes with wavelength across the UV, visible and near IR band-passes to reveal the structure of the exoplanet's atmosphere.

Several theoretical models[4],[5] show that the *degree of polarization* changes with wavelength across the UV, visible and near IR band-passes to reveal the structure of the exoplanet's atmosphere, its climate and even details of the orbital elements of the exoplanet system[6].

Polarimetric imaging of exoplanets has the potential to reveal important details of atmospheric composition, radiative transfer, aerosol & chemical composition, cloud-cover, and surface composition. Polarimetric imaging reveals important information about grain sizes in protoplanetary dust clouds, and their role in planet formation. Contrast sufficient for terrestrial exoplanet imaging requires polarization control[7],[8].

Much work has been done to calibrate telescopes for the radiometric measurement: photo-polarimetry, by treating the telescope and imaging system as neutral density filter whose transmittance depends on the sky position. The role of polarization in the image formation process and the control of unwanted radiation is new[7].

Polarimetric imaging of astronomical sources provide critical astrophysical and exoplanet information. All polarization measurements are made with telescopes and instruments that contribute their own polarization signature, which is, in some cases larger than the polarizance of the astronomical source. Internal polarization changes the shape of the image. Light spills out around the focal plane mask to flood the coronagraph with unwanted radiation.

2. Technical capabilities

To observe physical phenomena across the bandwidth 100 to 5,000 nm several new technical capabilities are needed. These are: 1. Control of scattered light to 1:1E10 contrast; 2. Coronagraph/telescope internal polarizance < 0.01%; 3. Integration times of 10 hours with 0.001 arc second stability. 4. Photon counting high dynamic range detector; 5. Low spatial resolution (~256x256), R~70 spectrometer; 5, greater than thirty-meter squared collecting area; 6. Twelve-meter baseline aperture; 7. A UVOIR optical system with end-to-end transmittance of >10%; 8. Cost effective technical system architecture.

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[3] Perrin, M. D., et al. 2009a, ApJ, 707, L132
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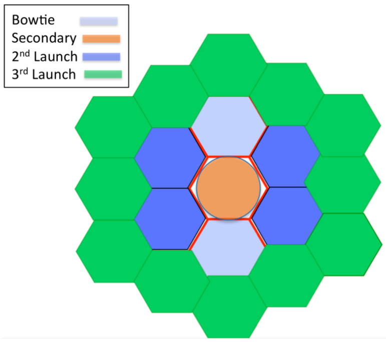
3. Relevance of the four mission concepts

Precision high angular resolution imaging and coronagraphy is of most interest to the ultraviolet, optical and infrared (UVOIR) communities and the Habitable-Exoplanet Imaging Mission. The angular resolution of the Far-IR surveyor will be insufficient. To be cost effective the UVOIR and the Habitable-Exoplanet Imaging system need to use the evolvable space telescope (EST) concept, which requires several new technologies discussed below.

4. New Technologies

A minimum number of new technologies are needed to implement the EST for the UVOIR and the Habitable-Exoplanet Imaging Mission. Table 1 describes the engineering concept and the technical capabilities of each of the three stages of a space telescope that would be developed, launched, assembled and operated in the 2030's and beyond. The first Stage telescope would consist of two ~4-m hexagonal mirror segments, a prime focus instrument module and a support structure to separate the instruments from the primary mirror. A sunshield would provide thermal protection for the telescope, and a spacecraft bus would provide the necessary power, communications and attitude control. Stage 2 and Stage 3 components are robotically docked, in cis-lunar space or at L2, in a fashion similar to that commonly used by the space station. At each stage the optical structure is then autonomously aligned to form a working optical telescope.



Parameter	**Requirement**	**Goal**	**Notes**
Telescope Aperture	≥ 10 meters	≥ 16 meters	≥ ATLAST
Stage 1	Bow-tie	4 x 12 m	Two hexagonal segments
Stage 2	Filled Aperture	12 m	Twelve hexagonal segments
Stage 3	Filled Aperture	20 m	Eighteen hexagonal segments
Wavelength	100-2400 nm	0.09-670 µ	UVOIR, Far-IR under evaluation
Field of View	5 to 8 arcmin	30 arc-min	Wide Field VNIR Imaging
Diffraction Limit	500 nm	200 nm	Enhanced UV/Optical resolution
Primary Segment Size	1.97 m	3.93 m	3.93m flat-flat
Primary Mirror Temp	≤ 200K	100K	Minimize heater powe, MIR obs.
Design Lifetime	15 years	> 30 years	On-orbit assembly and servicing

Stage 1 of the EST has a 4 x 12 meter sparse aperture primary mirror and a prime focus instrument module with room for instruments: a wide field camera for the UVOIR, an exoplanet coronagraph, and a UV spectrometer. Prime focus instruments have the very high transmittance and very low residual polarization characteristic of optical systems with few fold mirrors and near-normal incidence optics that reduce the presence of the unwanted ghost images. The instrument complement for each stage would depend on the science drivers that could be best addressed with 12 x 4-m sparse aperture, a 12-m filled aperture, and a 20-m filled aperture. Note, the Stage 1 telescope can be rotated around its line of sight, and images acquired at roll angles of 0, 60 and 120 degrees can be combined to achieve the spatial resolution of a 12-m filled aperture.

The spatial resolution of the Stage-1 and Stage-2 telescopes will thus range from 20 to 100 mill-arc-seconds for the near IR (0.9 to 5 µ), 6 to 20 mas for the Visible (0.3 to 0.9 µ) and 1.9 to 6.3 mas for the UV instruments (0.09 - 0.35µ). The resolution of the Stage 3, 20-m EST will be 40% better than Stage 2. We currently envision the installing a larger sunshield for the Stage 3 20-m telescope. Specifically, new technologies in these areas will be required: Low intrinsic polarization and tilt compensated telescope and instrument designs, High dynamic range photon counting detectors, Image plane masks and Lyot stops optimized for full vector complex amplitude and phase wavefronts, Low polarization coatings, Vibration and thermal control optimized for coronagraphy, Innovative coronagraph concepts, design, breadboard test and development, Self-assembly of telescopes in space and autonomous alignment and control, A cost-effective large space telescope followed by an instrument with minimum number of reflections each with the smallest possible angle of reflection is needed.

5. Large mission needed

A large mission is needed to obtain the needed high angular resolution and large collecting area to obtain the needed SNR, particularly for exoplanets at $m_V<32$.