Progress toward optical design and fabrication of ultralight, large aperture transmissive lenses for space telescopes

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Abstract: A new type of telescope primary called a MODE lens is described that is being developed for large-diameter space telescopes. Optical design, fabrication, and testing are described with current progress and plans.

OCIS codes: 110.6770, 090.1970, 220.1920, 220.4610, 220.3620, 220.4840

Large-aperture space telescopes have traditionally been based on reflective optical primaries, due to practical difficulties fabricating in traditional refractive systems and their associated mass. Reflective systems also have an intrinsic advantage with respect to optical bandwidth, in that mirror system are achromatic. However, there are critical disadvantages to mirror systems in terms of the precision required for fabrication of the surfaces, alignment tolerances required for mirror components and obstruction of the aperture by that secondary mirror and mounting structures. A thin, ultralight and large aperture refractive lens would have advantages in these aspects. In this presentation, we discuss progress toward the optical design, analysis, and fabrication of a new type of lens that we call a multi-order diffraction engineered surface (MODE) lens. It can be made very thin and with large aperture. Its chromatic performance is reasonable for exoplanet transit studies, and it can be made nearly diffraction-limited.

Extrasolar planets are among the most challenging objects to study and, of these, planets that may be like Earth are at the forefront of current and future astrophysics. The most detectable signatures of distant life are thought to be gases present in the atmosphere with abundances that are inconsistent with abiotic production *and* have large absorption cross sections in the visible/near-infrared. Absorption spectroscopy with high signal to noise ratio is possible only if a vast number of photons can be collected. Our team has proposed a space telescope architecture [1] that could search for atmospheric biosignatures in ~1,000 potentially Earth-like exoplanets using MODE-lens telescopes.

The 24 cm diameter MODE lens prototype consists of a multi order diffraction (MOD) front surface and a diffraction Fresnel lens (DFL) back surface that is designed to operate over the astronomical R-band (589 nm to 727 nm). The MOD surface is divided into five zones, and each zone has 2196 orders of diffraction, as shown in Figure 1(a). The MOD front surface provides most of focusing power and each zone is aspheric to reduce monochromatic aberrations. Because the power of MOD is refractive, it suffers refractive dispersion like a traditional refractive lens. The DFL back surface provides a low cost and low mass solution to make the MOD achromatic, because of the extreme dispersive property of diffractive Fresnel lens. To correct the off-axis aberrations, a special type of zonal lens structure is adopted, and MODE lens curves toward the focus.

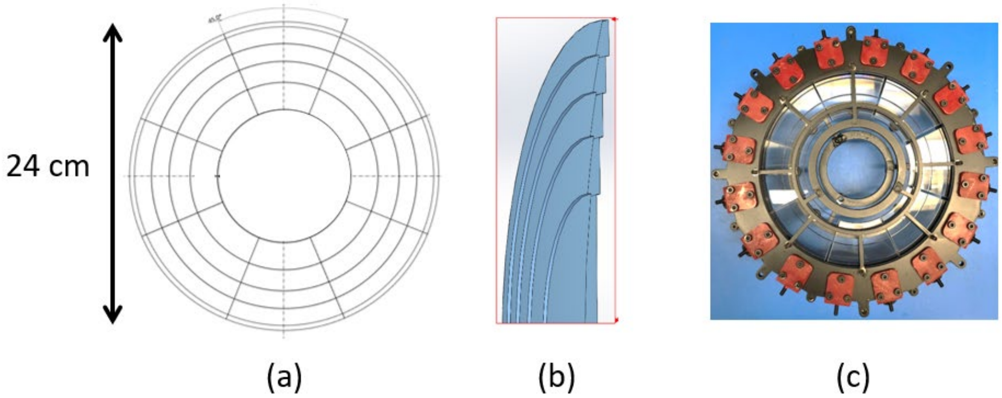

Figure 1. a) Design of the MODE-lens 24 cm diameter prototype; b) cross-section view of the primary; and c) Kinematically Engaged Yoke System (KEYS) to align and assemble the MODE lens segments.

The 24 cm prototype will be molded from L-BSL7 low-temperature glass with precision glass molding (PGM) [2, 3]. The 24 cm diameter lens is composed of nine segments. The ~10 cm diameter segment size is limited due to the chamber size of our glass molding machine. Acquiring high quality diffractive structures in molded glass is challenging, but we have developed a comprehensive technical scheme including single point diamond turning NiP plated on top of a CuNi substrate. Initial results indicate a 2 nm rms surface roughness and about 50 nm peak-to-valley surface variation is obtained.

A unique KEYS (Kinematically Engaged Yoke System), as shown in Fig. 1(c), is used to align the MODE lens segments, where ball bearings on the end of ultra-fine alignment screws kinematically engage with the step-like features of the MODE lens surface. The KEYS system constrains 5 degrees of freedom of each lens segment. Rotation of the segment about the optical axis is left unconstrained. The alignment of the segments is guided and verified using vertical scanning white light interferometry and deflectometry. The wide dynamic range of the metrology approach ensures high-fidelity measurement of the MODE segments and the entire assembly's optical performance when it is far away from or near its final specification performance. Also, real-time deflectometry using a multiplexed sinusoidal fringe pattern guides the segment alignment and assembly process with respect to gravity and thermal gradient changes. [4]

Our on-sky tests will use Steward Observatory's 61" Kuiper telescope to provide a guiding/tracking platform. First, an Imaging performance demonstration will target individual bright stars to measure the on-sky point spread function of the telescope, followed by observations of globular clusters and extended objects (e.g., Moon, Saturn) to verify image quality and quantify field distortion, any residual optical aberrations and/or internal reflection and scattered light. Second, a photometric stability demonstration will obtain hundreds of images of bright variable stars (W UMa contact binaries) to verify photometric stability. Finally, in our most challenging test, we will observe hot Jupiter exoplanets that transit nearby bright stars. The signal introduced during these transits is at the 1% level and will last approximately 1.25 hours. A successful detection of these challenging transits will unequivocally establish MODE-lens based telescopes among state-of-the-art astronomical telescope architectures.

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