Multiple Order Diffractive Fresnel Lens (MOD-DFL) for Atmospheric Transit Surveying of Earthlike Exoplanets

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Abstract: A MOD-DFL is designed in the format of a large deployable space-based telescope for characterization of atmospheric content of potentially habitable exoplanets. Performance and function over a 1-2μm wavelength range is described.
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1. Introduction

Recent initiatives by NASA have highlighted the need to both locate and characterize potentially habitable exoplanets to determine the practicality of humans ultimately travelling to and inhabiting to another life-supporting planet. Of crucial important to determining whether an exoplanet supports life is evaluating the content of H_2O, O_2, and CO_2 in the atmosphere. One proposed method of exhibiting the existence of these desired molecules in an exoplanet atmosphere is to examine the spectral properties of light from the host star as the planet transits across it [1].

Accurate measurement with enough light collection for this measurement requires a space based optic with a large aperture for maximum photon collection. A solution to the issues of weight and cost of deploying a traditional telescope system of large size is to use a diffractive optical system. A diffractive optic could achieve the same optical collection and power of a traditional telescope system with a small fraction of the weight but must be carefully engineered for quality performance. Diffractive Fresnel lenses (DFLs) have been previously demonstrated in a variety of astrophysical applications [2-6]. Additionally, DFLs have been used in commercial camera lenses by Cannon [7].

Limitations to the design and fabrication of DFLs come from the relationship of decreasing feature size with decreasing F/#. In order to fabricate DFLs on the scale of 5m aperture size or more, a multiple order diffractive Fresnel lens (MOD-DFL) design is implemented. MOD-DFLs take advantage of increased maximum surface relief which, in turn, increases the feature width of the diffractive structure. Additionally, the chromatic performance of MOD-DFLs can be dramatically improved to make broadband application possible [8].

2. Optical System

The basic concept of the deployable telescope system consists of an array of space-based spherical balloons, each containing a MOD-DFL primary optic with the focal plane at the center of curvature of the balloon. This concept is outlined from launch to measurement in Figure 1.

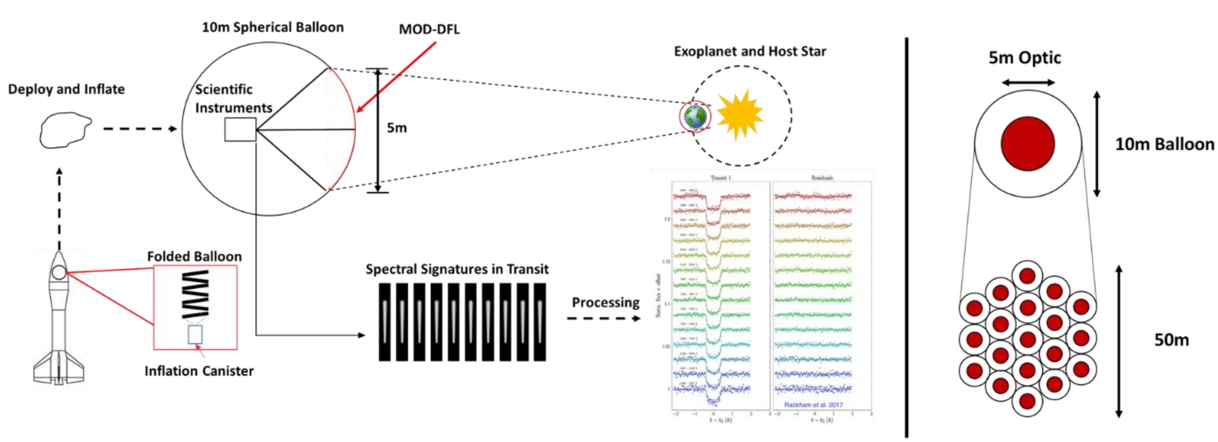

Fig. 1. The basic optical system for the MOD-DFL collection system for collection of spectral information from exoplanet atmosphere.

The system design calls for an F/1 MOD-DFL with a 5m diameter aperture and operation over a wavelength range of 1-2µm. Additionally, an optical subsystem near the center of curvature of the balloon is used to spatially disperse the spectral information for analysis.

3. MOD-DFL Design

The mod lens has diffraction efficiency and axial dispersion defined by Eqs. (1) and (2),

$$\eta = \left\| e^{jM\pi\alpha} sinc(M\alpha - m) e^{-j\pi m} \right\|^2 \quad \text{, Diffraction efficiency at order m} \qquad (1)$$

$$f(\lambda) = \frac{M}{m}\frac{\lambda_0}{\lambda} f_m \quad \text{, Focal dispersion at order m} \qquad (2)$$

and M is the order of the MOD-DFL, each m corresponds to a diffracted order, and α contains the dispersive properties of the material used. Using these concepts, a MOD-DFL with order M= 1200 is simulated. The surface relief profile mapped to a plane as well as the dispersed spots after the intentional chromatic separation of the optical subsystem are shown in Figure 2. The chosen optical material is IG4 chalcogenide with n(1.5µm) = 2.66 and an AR coating to maximize transmission in the 1-2µm wavelength range. The complete MOD-DFL is be segmented into foldable tiles fitted to the spherical balloon, allowing the primary optic to be compact for launch and deployed in space.

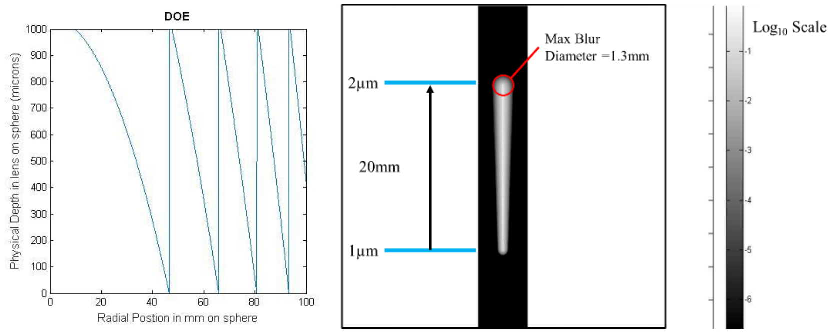

Fig. 2. (left) Partial Surface profile of a M=1200 MOD-DFL. Max surface relief is approximately 1mm. (right) The dispersed spots from 1-2µm accounting for focal dispersion and with a uniform incident power spectrum.

4. Conclusions

Exoplanet detection and characterization is an increasingly relevant field of study as the focus of human space exploration steers toward finding other potentially habitable worlds. Traditional space based telescopes face limitations due to weight and expense and, as fabrication technology improves, the viability of properly engineered diffractive optical elements as a lightweight substitute also improves. A MOD-DFL deployed into 5m or larger aperture size in space can provide the photon collection and the spectral performance needed to perform scientific measurements of the atmospheric content of exoplanets in transit.

5. References

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