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Orbiting Astronomical Satellite for Investigating Stellar Systems (OASIS): A Paradigm Shift in Realizing Large Space Telescopes

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ABSTRACT

OASIS (Orbiting Astronomical Satellite for Investigating Stellar Systems) is a space-based, MIDEX mission concept that employs a 14 meter inflatable aperture and cryogenic heterodyne receivers to perform high resolution ($R>10^6$) observations at terahertz frequencies. OASIS targets far-infrared transitions of H_2O and its isotopologues, as well as HD and other molecular species from 660 to 63 μm that are otherwise obscured by the Earth's atmosphere. OASIS will have >10x the collecting area and >4x the angular resolution of Herschel and complements the short wavelength capabilities of JWST. With its large collecting area and suite of terahertz heterodyne receivers, OASIS will have the sensitivity to follow the water trail from galaxies to oceans. OASIS represents a paradigm shift in the realization of large space apertures. Our paper will focus on how the development work for OASIS can be leveraged to realize a new generation of space telescopes.

Keywords: OASIS, terahertz astronomy, inflatable reflector, space telescope, metrology

1. INTRODUCTION

Orbiting Astronomical Satellite for Investigating Stellar Systems (OASIS) is a proposed space based NASA MIDEX mission[1] that employs a 14 m inflatable reflector as the primary antenna (A1). The overarching goal of OASIS is to follow the water trail from galaxies, through protostellar systems to the Earth's oceans by performing high spectral resolution observations of water and its isotopologues at terahertz frequencies[1,2]. In this paper we summarize the development work for OASIS which lays the foundation for realizing a new generation of space telescopes.

1.1 OASIS mission concept

OASIS space telescope (Figure 1) consists of an inflatable primary, A1, which is initially stowed in the spacecraft and deployed in orbit using three booms[3]. A1 is formed by constraining a metallized, and transparent polymer membrane (Mylar or Kapton) with a toroidal ring and inflating the space between the two membranes to form the required concave reflective shape[4]. The corrector module, and Field of View (FOV) scanner are housed in the spacecraft and deliver diffraction limited performance over the desired FOV[5] and wavelength range. The receiver module consists of cryogenic heterodyne receivers. The key requirements of OASIS are driven by its science goals[1,2]. The system architecture constraints[3] are listed in Table 1.

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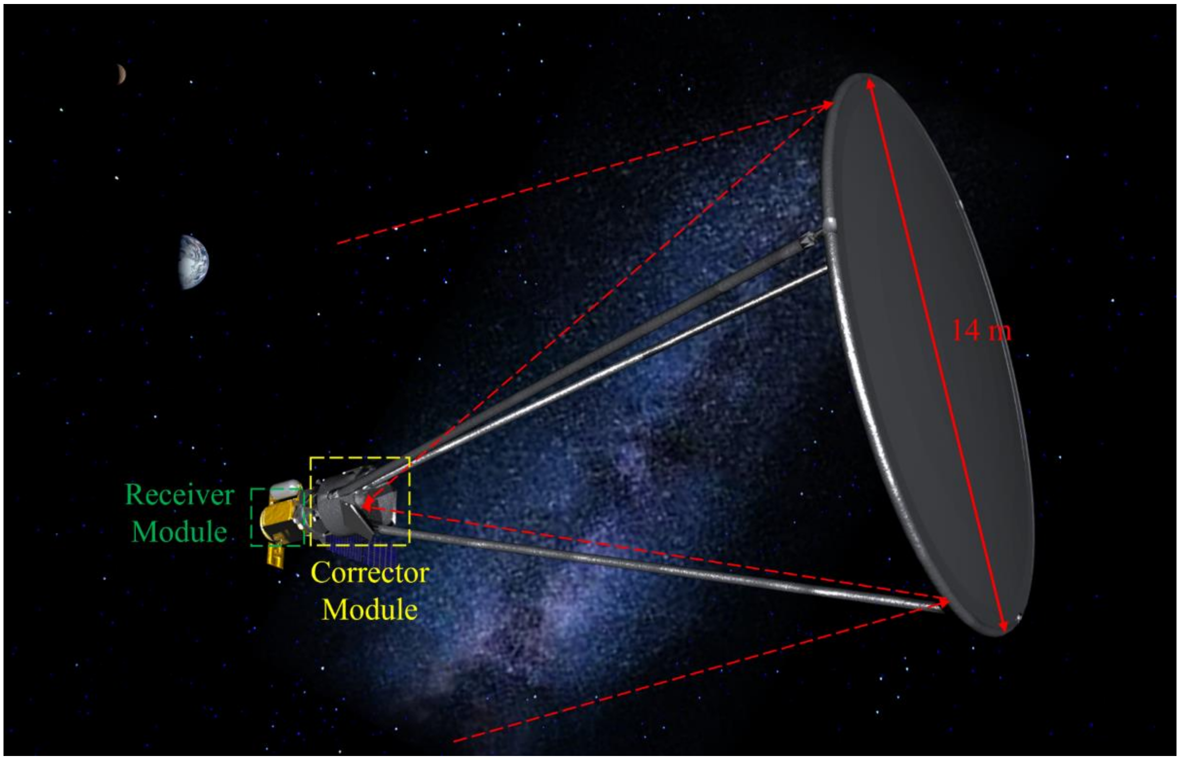

Figure 1. OASIS mission concept.

Table 1. Key OASIS requirements based on science goals and system architecture[5].

	Requirement
F/#	16
Collection area	>56 m^2
Field of view	±3 arcmin (circle)
Payload Mass/Collection area	13 kg/m^2
Wavelength	63 – 660 µm

2. MODELING AND METROLOGY

Traditional astronomical telescope design starts with a parabolic/near parabolic primary reflector. Since OASIS employs an inflatable primary, the shape of A1 is dependent on the pressure and polymer membrane material characteristics. In Sirsi, et al, 'Modeling and Characterization of OASIS Inflatable Primary Antenna by Dual Modality Metrology'[6], the Fichter solution to the Hencky curve[7] and L'Garde Inc's Finite-element Analyzer for Inflatable membranes[4] (FAIM) are used to model monolithic membrane defined by the parameters listed in Table 2. A one-meter prototype was built (Figure 2) and measured using Nikon APDIS laser radar (Figure 3). A deflectometry system was used to monitor the stability of A1 over the duration of lidar measurements. The *rms* change in sag with respect to pressure predicted by FAIM is 9.15 µm/Pa, 9.06 µm/Pa for Fichter, with a lidar measured value of 9.83 µm/Pa. The difference between predicted and measured values is much smaller than λ/20 for the shortest wavelength and will have no effect on the overall performance. The rate of change of radius of curvature with respect to pressure are matched within 6.5%[6]. This difference can be calibrated out during the testing, integration, and assembly. In conclusion, a FAIM model, along with Nikon APDIS laser radar, can be used to accurately predict and measure the surface profile of A1.

Table 2. Modeling Parameters[6].

Parameter	
Membrane Material	Mylar
Thickness	51 µm (i.e., 2 mil)
Poisson's Ratio	0.38
Elastic Modulus	0.73 x 10^6 psi
Diameter	1 m
Pressure	480 to 520 Pa

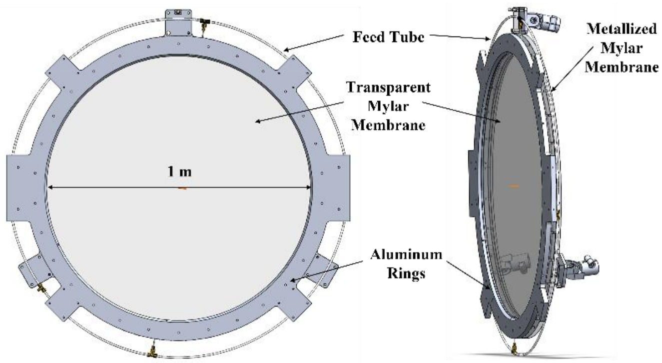

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Figure 2. 1 m A1 prototype.

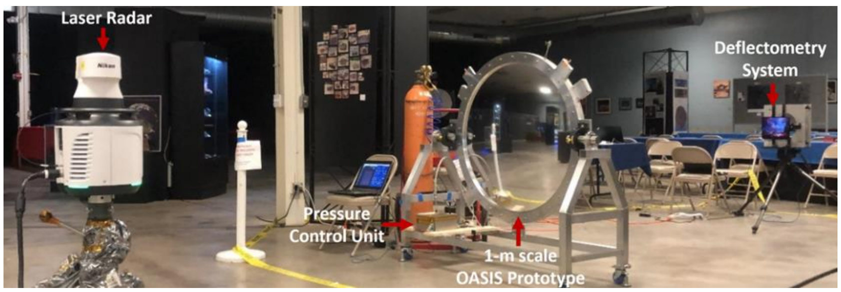

Figure 3. OASIS metrology test.

Table 3. Comparison between model and measured results[6].

Pressure Change (Pa)	**RMS Change in Sag – Fichter (µm)**	**RMS Change in Sag – FAIM (µm)**	**RMS Change in Sag – Radar (µm)**
480 →490	92.448	92.214	119.704
490→500	91.198	90.890	82.615
500→510	89.990	89.679	98.109
510→520	88.822	88.583	93.088
$\frac{d(Dev)_{rms}}{dP}$	9.06 µm/Pa	9.15 µm/Pa	9.83 µm/Pa

3. A1 PERFORMANCE IN CRYOGENIC VACUUM

The performance of the one-meter A1 prototype in cryogenic vacuum conditions was explored in Quach, et al[8]. An overhead heat source was used to introduce a thermal gradient and the temperature induced variations in the surface profile are measured using the deflectometry set-up. The predominant effect of thermal gradients on the surface is to change the optical power (Figure 4). Accurately modeling and measuring of the A1 surface profile under thermal load is part of ongoing and future efforts.

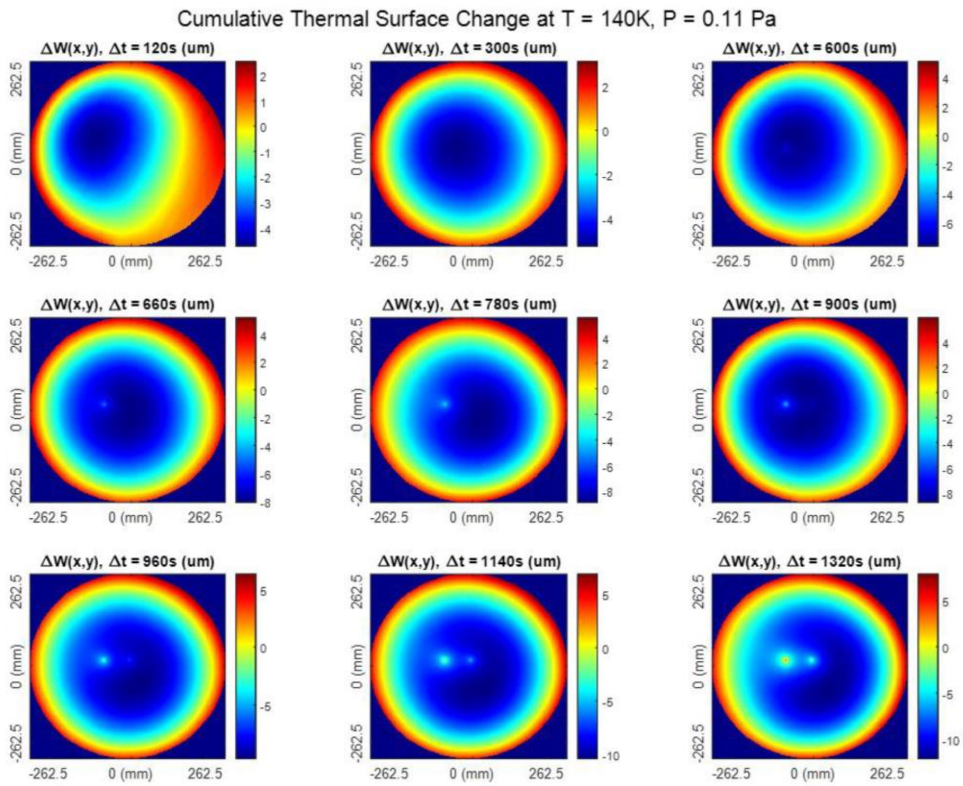

Figure 4. Deflectometry results showing thermally induced surface variations over a timescale of hundreds of seconds[8].

A puncture test to simulate micro-meteoroid impacts was also performned[8]. Figure 5 shows the effect of 0.6 mm diameter needle puncture on A1 over the duration of 230 s. Given the low pressure required to maintain the desired A1 surface in vacuum, we expect that the A1 surface remains stable after enduring micro-meteoroid impacts[3]. As expected, the A1 shape remains relatively stable over the duration of the accelerated puncture test.

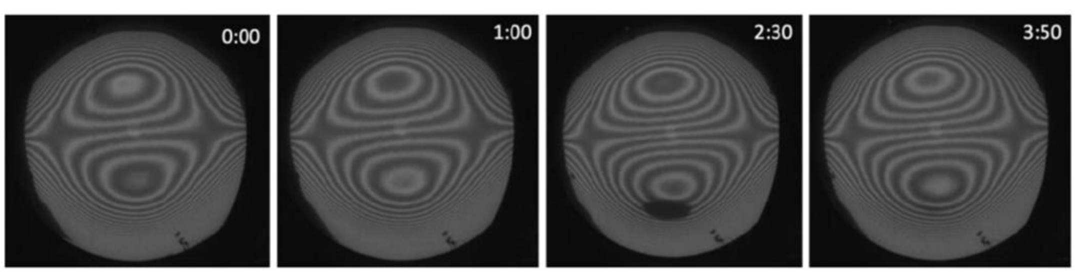

Figure 5. Accelerated TVAC puncture test showing the stability of A1 profile over the duration of 230 s.

These tests lay the groundwork for estimating the required inflatant mass, aberration correction required to compensate for the surface variation of A1 and resolution of pressure control unit.

4. SOLUTION SPACE AND OPTICAL DESIGN

The design of astronomical telescopes are driven by science goals and system architecture requirements. Since the shape of A1 is mainly dependent on pressure, it offers unique design challenges. Being a space telescope, there are additional constraints on the size of the correction optics and mass of inflatant. Since the receiver system employs cryogenic heterodyne receivers, coupling between telescope signal and receiver systems also needs to be considered. These challenges and their solutions are discussed in Sirsi et al[5], along with the detailed design of 14 m OASIS space telescope.

Solution space contour plots are developed to map the science goals to design parameters. These contour plots help in navigating the multi-variable design solution space. Figure 6 shows the solution space contour plots for Band 1 (λ~660µm) and Band 4 (λ~63µm) of OASIS. The required band dependent effective collection area is determined by the science goals (number of targets and mission duration). The solution space contour plots help in determining the optimal combination of A1 size (entrance pupil diameter) and radius of curvature which delivers the required performance while minimizing the corrector optics (M2 and M3) size.

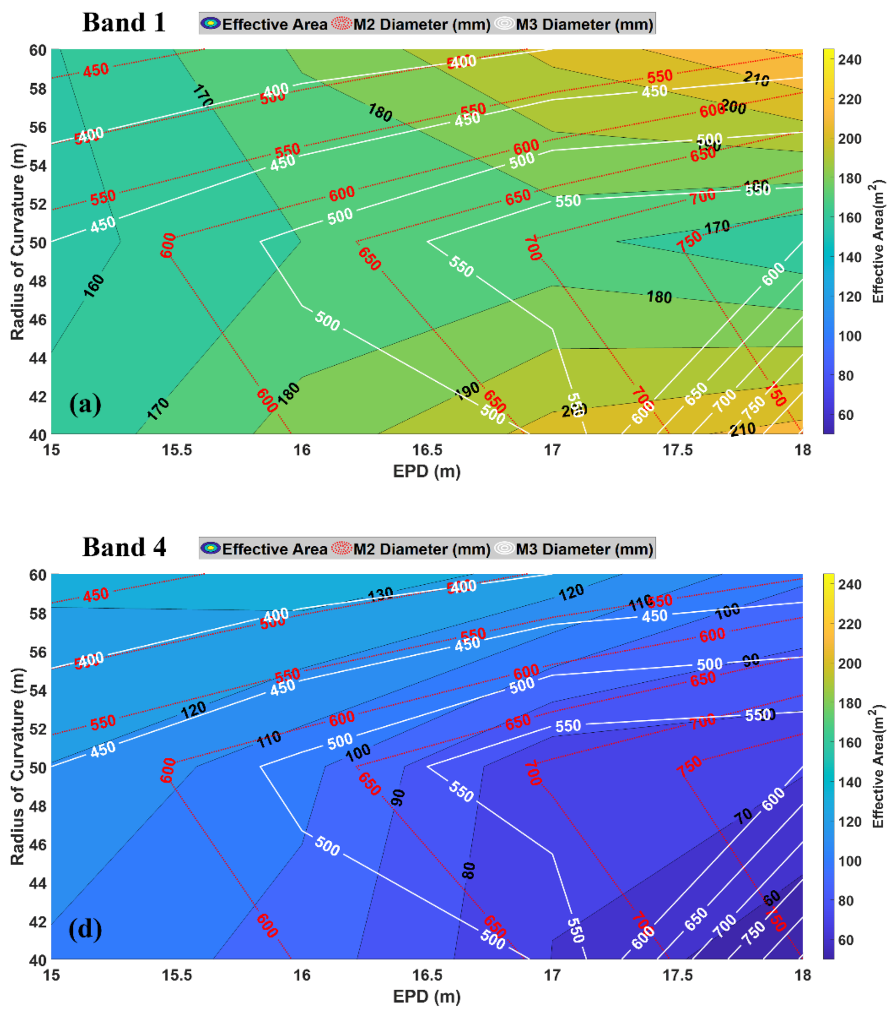

Figure 6. Inflatable optics design solution space contour plots of Band 1 (λ=660 µm) and Band 4 (λ=63 µm). Entrance pupil diameter of A1 (EPD) is plotted along x-axis, and A1 Radius of curvature along y-axis. Contour plot of effective collection area (considering the coupling between corrector and receiver systems) is overlaid with corrector optics (M2 and M3) mirror diameters[5].

The full optical design of OASIS is shown in Figure 7. The reflected ray bindle from A1 passes through the M3 hole and the M2-M3 mirror pair forms a diffraction limited image at the intermediate focal point (IF). A field lens made of high resistivity silicon placed at IF along with a steering mirror (M4) enabled FOV scanning. M5 and M6 are used to achieve an F/16 system. M7 to M9 are flat folding mirrors used to route the signal to the receiver system.

Corrector Module, FOV Scanner, and Folding Mirrors

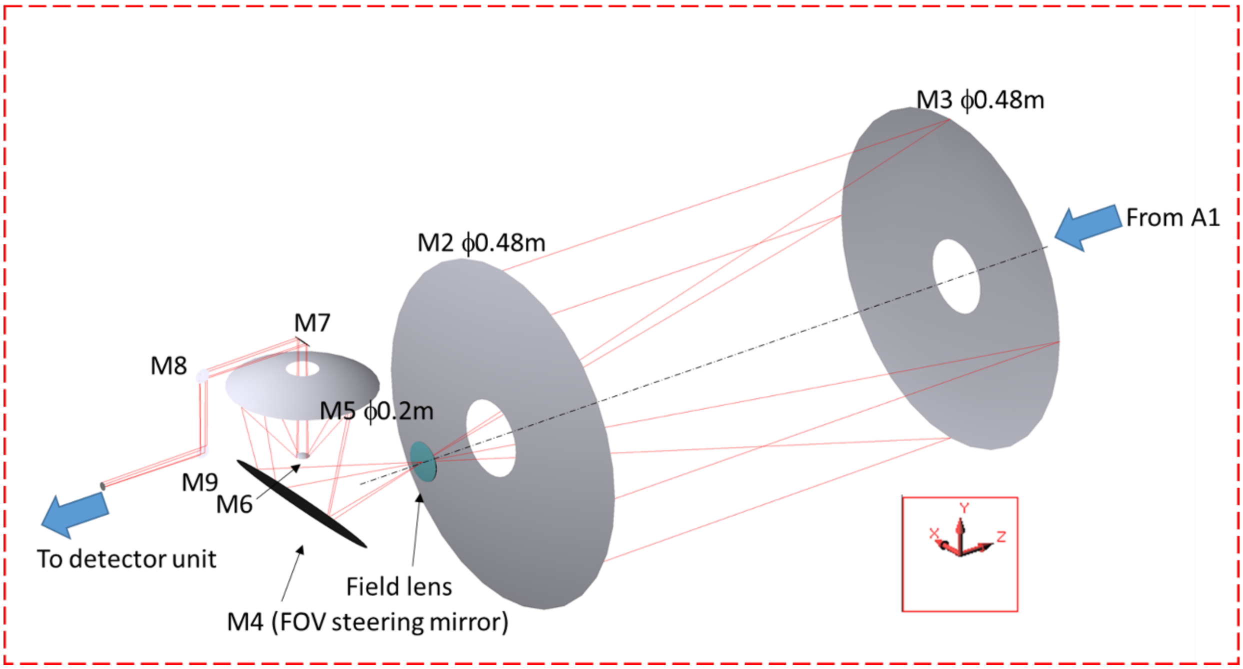

Figure 7. Ray-trace model showing the MidEx Class OASIS optical design including the corrector module, field lens, FOV scanner, and folding mirrors for 14 m diameter primary antenna A1[5].

5. CONCLUSION

The design of OASIS represents a paradigm shift in the realization of large space apertures. The first space inflatable, a 30.5 m diameter sphere (Project Echo) was successfully flown over 60 years ago. Over 25 years ago the Inflatable Aperture Experiment (IAE) demonstrated the deployment of a 14-meter parabolic antenna in space. Since then, advances in materials and optical design now enable the realization of large space apertures than can operate throughout the far-infrared. Telescopes such as OASIS will provide a new, powerful window through which we can probe our cosmic origins.

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