SALTUS Probe Class Space Mission: Enabled by 20-m Inflatable Mirror

Daewook Kim[1,2], Jonathan W. Arenberg[3], Yuzuru Takashima[1], Art Palisoc[4], Christopher Walker[2,*]
[1]*Wyant College of Optical Sciences, University of Arizona, 1630 E. University Blvd., Tucson, AZ 85721, USA*
[2]*Department of Astronomy and Steward Observatory, University of Arizona, 933 N. Cherry Ave., Tucson, AZ 85721, USA*
[3]*Northrop Grumman Systems Corporation—Space Sector, 1 Space Park Drive, Redondo Beach, CA 90278, USA*
[4]*L'Garde, Inc., 15181 Woodlawn Avenue, Tustin, CA 92780, USA*
**cwalker@arizona.edu*

Abstract: SALTUS (Single Aperture Large Telescope for Universe Studies) is a mid/far-infrared telescope concept utilizing a 20-m scale inflatable mirror antenna. The light-weight mirror utilizes a membrane architecture that has been developed and characterized specifically for space-based applications. The telescope's end-to-end optical design and optimization process unleashes the unprecedented photon collecting power of a large space aperture. A series of inflatable mirror prototypes have been designed, manufactured, and tested. These tests confirmed the optical performance of the apertures under space-like conditions. This paradigm changing approach will allow the realization of a new generation of space telescopes far larger than can be achieved utilizing conventional technologies.

1. Science

Single Aperture Large Telescope for Universe Studies (SALTUS) is a probe-class NASA mission concept, advancing OASIS architecture [1], for a space-based observatory that will utilize an inflatable 20-m scale reflector. SALTUS is based on a high accuracy inflatable antenna technology advanced from the Inflatable Antenna Experiment (IAE) project (Figure 1) along with a heterodyne receiver system to observe at THz frequencies with unprecedented sensitivity and angular resolution. Chemistry along the star- and planet-formation sequence regulates how prebiotic building blocks—carriers of the elements CHNOPS—are incorporated into nascent planetesimals and planets. Spectral line observations across the electromagnetic spectrum are needed to fully characterize interstellar CHNOPS chemistry, yet to date there are only limited astrochemical constraints at THz frequencies. [2] As part of a survey of H_2O and HD toward ∼100 protostellar and protoplanetary disk systems, SALTUS will also obtain statistical constraints on the emission of complex organics from protostellar hot corinos and envelopes as well as light hydrides including NH_3 and H_2S toward protoplanetary disks. Line surveys of high-mass hot cores, protostellar outflow shocks, and prestellar cores will also leverage the unique capabilities of SALTUS to probe high-excitation organics and small hydrides, as is needed to fully understand the chemistry of these objects.

Fig. 1. **Left:** 14-m diameter IAE (Inflatable Antenna Experiment) system during the test operations in space with the Space Shuttle *Endeavour*. [3] This inflatable antenna designed and manufactured at L'Garde in 1997 is the predecessor of SALTUS, which is a mid/far-infrared telescope concept utilizing an advanced 20-m scale inflatable mirror antenna. **Middle:** 5-m diameter off-axis subsector of the IAE undergoing photogrammetry testing at the L'Garde facility. The "dots" are retro-reflective targets for photogrammetry. The measured surface accuracy of this predecessor antenna was already achieving ~0.32 mm RMS relative to the best-fit parabolic surface. **Right:** SALTUS/OASIS deployable architecture enabling stowed configuration for launch and deployed-and-inflated telescope in space. [1]

2. SALTUS architecture based on advanced inflatable mirror technology

SALTUS consists of the inflatable primary mirror antenna, referred to as A1, connected to the spacecraft by 3 (or less) deployable booms as shown in Figure 1 (right). The science object light from the A1 is reflected in to the corrector module inside the spacecraft payload, which has aberration compensation optics for wavefront correction similar to OASIS. [4] The inflatable antenna itself is constructed from membrane materials (e.g., about 6.7 µm thick polyimide film). The front side of the inflatable (i.e., canopy side) is transparent in the science wavelength while the rear side membrane is reflective. This thin film allows SALTUS to reach the critical film strain to achieve designed and optimized target surface profile with low pressures. [5] The highly accurate and scalable inflatable mirror antenna technology has been realized, advanced, and matured through a shaped parabolic reflector modeling, manufacturing, and testing processes. [1, 5, 6]

The performance of 1-m inflatable reflector was thoroughly characterized by measuring shape response to dynamic perturbations in a thermal vacuum (TVAC) chamber as shown in Figure 2. [6] Phase-measuring deflectometry mounted at the viewing window of the TVAC chamber was used to track shape change in response to pressure change, thermal gradient, and controlled puncture simulating the space like environments and small particles, which may create punctures. The optical test demonstrated the high-fidelity performance of A1 in such space like environment. [6]

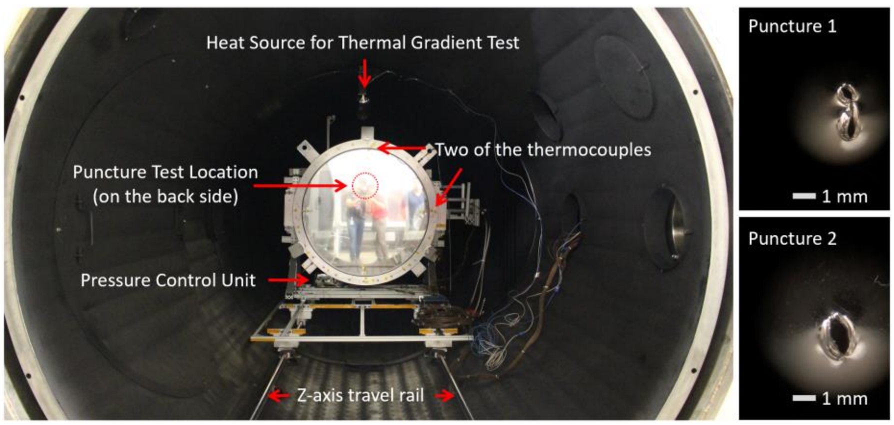

Fig. 2. **Left:** TVAC test set up for the 1-m inflatable mirror antenna prototype including heat source for the thermal gradient experiments. The A1 internal pressure was controlled using a pressure control unit. **Right:** The controlled puncture images on the reflective rear side membrane of the 1-m inflatable prototype.

3. Conclusion

TVAC testing results successfully demonstrated the stable optical performance of the 1m inflatable membrane reflector assembled at the University of Arizona. Surface changes in response to perturbations in low-temperature, near-vacuum conditions, were monitored by the differential deflectometry through a week-long campaign. The data results produced 500 × 500 pixel resolution A1 rear surface maps (i.e., reflective surface) with a repeatability of ~150 nm RMS within the cryogenic vacuum environment (T = 140K, P = 0.11 Pa). As a scaling-up performance demonstration, a larger scale inflated A1 is modeled and optimized at the L'Garde using Finite-element Analyzer for Inflatable Membranes (FAIM) [5] for 3 m class prototype demonstration.

4. References

[1] Jonathan W. Arenberg et al., “OASIS architecture: key features,” Proc. SPIE 11820, Astronomical Optics: Design, Manufacture, and Test of Space and Ground Systems III, 118200S (24 August 2021).

[2] Bergner JB et al., “Astrochemistry With the Orbiting Astronomical Satellite for Investigating Stellar Systems,” Front. Astron. Space Sci. 8:793922 (2022).

[3] “Spartan 207/Inflatable Antenna Experiment Flown on STS-77,” L’Garde Inc. Corporate Presentation Report (14 February 1997).

[4] Yuzuru Takashima et al., “All reflective THz telescope design with an inflatable primary antenna for Orbiting Astronomical Satellite for Investigating Stellar Systems (OASIS) mission,” Proc. SPIE 11820, Astronomical Optics: Design, Manufacture, and Test of Space and Ground Systems III, 118200P (24 August 2021).

[5] Arthur L. Palisoc et al., “Analytical and finite element analysis tool for nonlinear membrane antenna modeling for astronomical applications,” Proc. SPIE 11820, Astronomical Optics: Design, Manufacture, and Test of Space and Ground Systems III, 118200U (24 August 2021).

[6] Quach, Henry et al., “Surface Measurement of a Large Inflatable Reflector in Cryogenic Vacuum” Photonics 9, no. 1: 1. (2022).