APERTURE: A Precise, Extremely-large Reflective Telescope Using Re-configurable Elements

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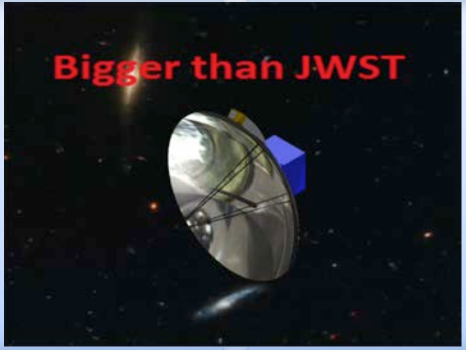
Concept

- Large mirrors with post deployment correction
- Used for both GEO Earth observing and the next generation space telescope, ATLAST, a 16 m diameter telescope
- Allow NASA to carry out missions that requires large and precise membrane
- Phase I will show the feasibility of the concept with a study of key components and a demonstration of 2-D figure modification on the $\lambda/20$ scale

Study Approach

- Determine base materials to be deployed
- Determine magnetic smart materials to use
- Determine a design for the flying write head
- Determine method to generate magnetic field
- Determine how to coat extremely large surface
- Determine how to characterize the mirror figure
- Determine how to keep the shape much longer than the time required for modification



Benefits

- The proposers' teams and the greater scientific community could then become involved in new exciting studies of the universe and space exploration
- Earth applications such as active optics control under wind loading for ground base observatory
- The project will keep a critical mass of technical expertise together and be a terrific platform for educating students
- This project will build a collaboration between Illinois Space Grant Members

Evaluation Notes

(Proposers Leave Blank)

Introduction to Concept

The proposed concept uses Magnetic Smart Material (MSM) to apply figure corrections to extremely large (≥16 m diameter) deployable reflective optics. The first step of the deployment will utilize an umbrella-like structure and MSM to achieve a roughly parabolic shape for the optics. The inside of the "umbrella" will be the reflective surface, while the outside will be coated in MSM. A magnetic write head will move to different locations on the MSM coated side to manipulate the MSM, changing the shape of the optics and eliminating any deviation from the desired final shape.

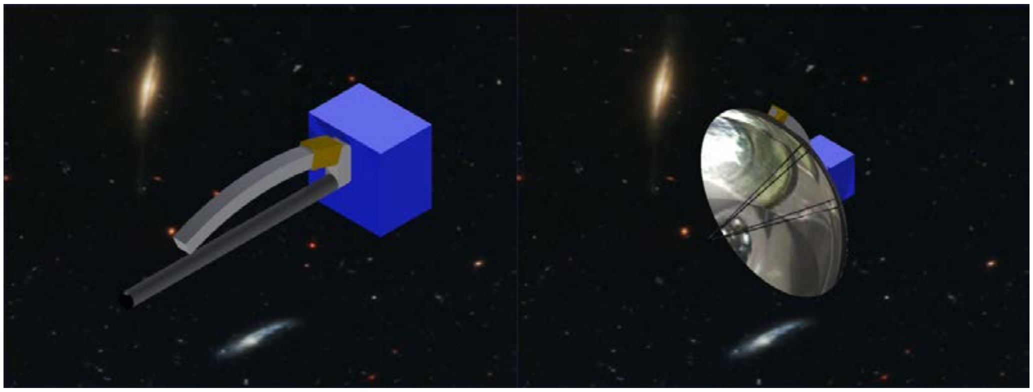


Figure 1. Before and After Deployment (Write Head in Gold Color Moves along the Curved Arm, while the Curved Arm Rotates about the Center Axis)

Enabling High Quality Observation

The size of space telescope and Earth imaging satellite has always been limited by the fairing size of launch systems. Specifically, shrouds are limited to 4 to 5 meter diameter by currently launch systems [1][2][3]. The concept of membrane mirrors has been around for many years [5] and references there in, and recent excitement has been generated by a concept funded by DARPA [6]. The DARPA approach uses diffraction from the mirror surface, whereas our concept uses the more classic and better concept of reflection from the mirror surface. Using the proposed method, high quality images could be made from the extremely large optics, opening up a wide variety of opportunities for new discoveries.

This will be a game changing technology for astronomy as astronomy is always light limited (see also [4]). In addition, Earth observing science would greatly benefit from our technology as it is highly desirable to be in GEO orbit with enough angular resolution to make up for the increased distance from LEO.

Innovation

As noted above, the general concept of membrane and deployable mirrors is not new. Some form of electrostatic or piezoelectric control with wires has been studied in the past e.g. [6], [7]. A big disadvantage is that wires must be attached to every point on the mirror for which actuator control is needed. What is new and exciting about our approach that has never been tried before is to use a "flying'' magnetic write-head that can modify the mirror figure without attachment to the mirror surface. In contrast, 20 years ago [8] an approach with magnetic coils attached to the mirror was tried. See also [9] which describes a more recent design that did not contact the mirror, but the electromagnet was fixed relative to the mirror. However, so far the ability to provide post deployment figure corrections to the level of $\lambda/20$ has eluded the space community. If any of these prior approaches had revolutionized the way to produce large deployable mirrors, the JWST might not have been built as it was, and DARPA would not be considering other approaches as well. A holy grail for these mirrors is 1 kg/m^2, which translates into 1 mm thickness of water. As this is so difficult, we will target instead 10-20 kg/m^2, still 2.5 to 5 times lower than JWST such that the potential launch costs saving just to LEO would be nearly $100M if a 10 kg/m^2 versus if a 50 kg/m^2 JWST-like mirror were used.

Technical Approach

To develop this technology, several aspects will be explored: (a) Determine just the right material that is both flexible enough to be folded up yet rigid enough to maintain figure with fine adjustments post deployment; (b) Determine the best magnetic material to coat the mirror that is also flexible and does not distort the figure beyond possible correction; (c) Determine a design for a flying write head that has a strong enough magnetic field to affect the desired changes on the required length scales across the mirror; (d) Determine an approach to vary the magnetic-field strength and direction (two permanent pole magnets whose orientation and distance from the mirror changes the magnet field versus an electromagnet with changing current); (e) Determine how to coat large monolithic membranes with the requisite material or how to stitch together segments that are small enough to coat easily; (f) Determine how to characterize the mirror figure in orbit (can use lessons learned from JWST); (g) Determine how to ensure the figure can hold its shape for times longer than (at least 10x) the time required to bring the figure into shape.

The group at Northwestern University has been working to adapt magnetic smart materials (MSM) to modify the shapes of relatively rigid pieces of glass or electroformed nickel for X-ray mirrors. Shape changes of a micron have been produced and shapes have been demonstrated to hold over months. Deployable antennae have been flow for years, e.g. ATS-6 from Lockheed Martin [11]. However, many details need to be filled in before our proposed approach can be shown to work. Thus, we place the approach at TRL 1, and plan to demonstrate that with a Phase II award we will be able to carry through to TRL 3. During Phase I the following tasks will be completed: (a) design and develop a test on 5 cm x 5cm pieces to show $\lambda/20$ is plausible; (b) design and develop a procedure for testing the flying write head concept.

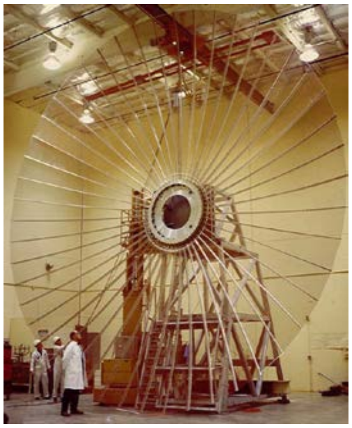


Figure 2. ATS-6, Ref [11]

Investigators

Professor Melville P. Ulmer (PI) is a NIAC Fellow and has worked on various aspects of both deformable X-ray and deployable visible band optics. Besides his own experience in optics design, his group includes coating experts and coating facilities, material scientists, mechanical engineering modelers, and profilers to measure shape changes. Professor Victoria Coverstone (Co-I) is the director of the center for Advanced Research for the Exploration of Space at UIUC. Within the center, students perform research in mission design using both NASA and custom built software and participate in multi-disciplinary aerospace systems engineering. Within the center, two CubeSat spacecrafts are being developed and are among the small satellites that NASA has selected to fly as auxiliary payloads in the ELaNa program. One craft is a solar sail demonstration called "CubeSail," and the other is a remote sensing satellite called "LAICE."

Potential Mission

ATLAST, the next generation UV-Vis space telescope that will replace the Hubble Space Telescope, is based on a 16 m diameter mirror. [10] At this time, daunting as it is from a technological point of view, ATLAST has the full backing of the Space Telescope Science Institute because the science is so compelling. Below from the ATLAST webpage are two versions of a possible design for ATLAST. The proposed concept will enable ATLAST to achieve desired performance without imposing strenuous budget or launch vehicle requirements.

Figure 3. Possible ATLAST Design 1

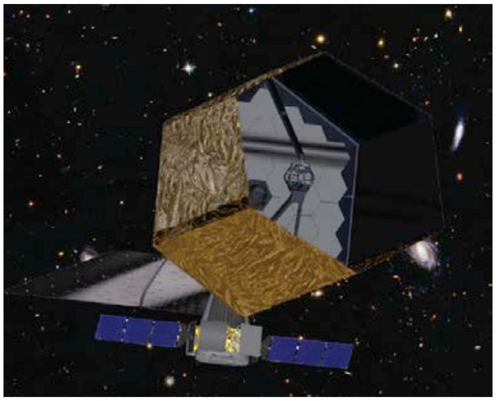


Figure 4. Possible ATLAST Design 2

Other Benefits

As noted above, Earth observing would greatly benefit from being in GEO so the satellites can monitor a fixed location on the Earth. A modified design on Earth would enable active optics control on the primary mirror of a telescope which would allow compensation for wind loading as well as atmospheric turbulence. For example, [12] has shown that compensation for wind loading for The European Extremely Large Telescope can be ten times more than the compensation needed to correct for atmospheric turbulence. Thus correction for wind loading is important and the corrections are most easily coordinated with corrections for the atmosphere with the same set of actuators. Besides the technical benefits, the proposers' teams and the greater scientific community will then become involved in new exciting studies of the universe and space exploration; the project will keep a critical mass of technical expertise together and will be a terrific platform for educating students; and, this project will build a collaboration between Illinois Space Grant Members.

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