

## Actuated Carbon Fiber Reinforced Polymer Mirror Development

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The AURA Study of Future Space-Based Telescopes presented at the 225th meeting of the American Astronomical Society (AAS 225) details the compelling science case for launching a large-aperture, high resolution space telescope in the 2020s and points to the need to initiate technical development work now to inform the 2020 Astrophysics Decadal Survey. Whether we are seeking to observe the faintest objects in the universe or discern Earth-like planets hidden in the glare of their parent star, larger collecting areas in space are needed.

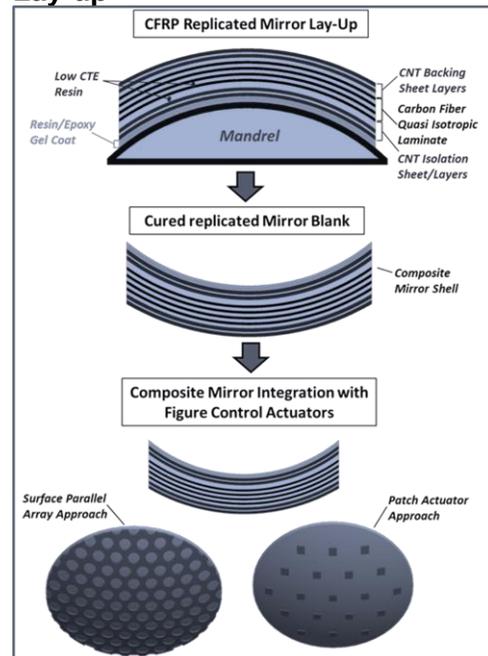
Astronomical flagship missions after James Webb Space Telescope (JWST) will require affordable larger aperture space telescopes and the science requirements may drive optical figure stability to as tight as 10's of picometers over 10's of minutes. Advances in lightweight mirror and metering structure materials such as Carbon Fiber Reinforced Polymer (CFRP) that have excellent mechanical and thermal properties, e.g. high stiffness, high modulus, high thermal conductivity, and ultra-low thermal expansion make these materials excellent candidates for a low cost, high performance Optical Telescope Assembly (OTA). It has been demonstrated that mirrors built from these materials can be rapidly replicated in a highly cost effective manner.

Telescopes of appropriate size, 10 to 20 meters, built via conventional substrate materials such as glass and Beryllium, will be prohibitively expensive and will take many years to fabricate. Active (actuated), replicated CFRP optics offer very low-cost scalable manufacturing, production times on the order of weeks vs years, minimal system level (expensive) ground testing, and low-mass. Removing the optics from the cost and schedule critical paths coupled with cost and schedule reductions will allow for production of larger apertures at lower areal densities thus making a 20 m segmented primary mirror possible from a cost/schedule perspective.

An Evolvable Space Telescope (EST) that is assembled in orbit can substantially reduce the cost of a large aperture optical system, establish science operations early, and spread funding requirements over several years. Actuated CFRP mirrors support the ability to expand/evolve the size over time via on-orbit assembly and alignment. We can leverage the early CFRP mirror development work at NGAS and establish the materials, designs, and processes necessary for large-format precision optics using state-of-the-art composite technologies.

Northrop Grumman Aerospace Systems with our subsidiary Adaptive Optics Associate Xinetics (AOX) have developed a novel approach to active carbon

**Figure 1. CFRP Replicated Mirror Lay-up**



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composite optics (Figure 1). Our approach replicates a high-optical quality finish by laying-up the composite directly on a super-polished mandrel and using special materials and processes to mitigate fiber print-through resulting in an optical quality surface finish. We correct any residual wavefront errors due to spring-back, resin shrinkage or any other error sources with a low number of our actuators, a technique previously demonstrated at TRL 6 on SiC mirrors. These actuators not only correct manufacturing errors but combined with our demonstrated wavefront control approach also provide on-orbit fine alignment correction capability during in-space assembly or due to structural changes from outgassing, and the actuators use the same electroceramic material used to actuate the Articulating Fold Mirrors within Hubble's Wide Field Planetary Camera 2.

A recent independent R&D program yielded a promising surface roughness of 2nm and correctable low-order wavefront errors of 5-10 microns. We have successfully actuated 4 inch and 6 inch diameter samples, producing results which agree with our Finite Element Analysis (FEA) models. We are currently actuating a 12 inch sample (Figure 2). Our efforts in the near term will focus on improving surface finish to a few Angstroms, demonstrate the process on concave mirrors, then scale to the 1.5 to 2.5 m aperture sizes making them ideally suited to be integrated into an Evolvable Space Telescope (EST) architecture approaching the 10 to 20 m size. The emergence of commercially available Carbon Nanotube (CNT) and carbon nanofiber mat materials, and low CTE adhesives has allowed us to make substantial, rapid improvements in CFRP surface finish and figure.

Key advantages of CFRP optics over traditional optics substrates:

- Replicated optical surface (i.e. no polishing required)
- Low mass and low CTE
- Rapid production schedule compared to other substrates

Designing a large telescope to survive these first few minutes of its life during launch results in an over-designed structure compared to the on-orbit structural loads it will experience, thus driving up cost and expanding schedule.

Using our approach to CFRP optics, when combined with robotic assembly of an EST on orbit, minimizes launch-imposed design and cost constraints. Instead of a complex, fully assembled space telescope, we can launch bundled components on smaller rockets. We can optimally package our CFRP mirror segments within launch containers which would carry the launch loads. Once on orbit, the robotic assembly spacecraft would then connect each mirror segment to a mirror backplane and spacecraft launched previously. This approach will substantially reduce system costs, flatten funding requirements, and maximize the science product.

**Figure 2. 30 cm CFRP Flat Segment**

