NASA SBIR 2021 Phase I Solicitation

Z8.08 Technologies to Enable Cost and Schedule Reductions for Optical System for CubeSats

Lead Center: ARC

Participating Center(s): GSFC, JPL

Scope Title:

Technologies to Enable Cost and Schedule Reductions for Optical System for CubeSats

Scope Description:

Concepts for optical systems are sought that will enable larger apertures or longer focal lengths than currently available systems, to be deployed from within small spacecraft. Relatively inexpensive small spacecraft offer several advantages over larger, more expensive spacecraft: small spacecraft can perform inspection and repair of larger spacecraft, several can be deployed for more frequent revisit rates over Earth's surface or planetary objects, and multiple craft can achieve affordable mission reliability through redundancy. To date, the utility of small spacecraft in missions involving remote sensing (in any spectral band) has been constrained by their low budget and compact size; optical sensitivity is limited in proportion to the diameter of a telescope’s aperture, and magnification is limited by the effective focal length. The cost to produce one-of-a-kind optical assemblies is disproportionate and the production times too long to incorporate into the tight budgets and schedules typical of small-spacecraft missions.

The objective of this subtopic is to receive proposals that articulate a demonstrable ability to manufacture, test, and control ultra-low-cost observing systems that can meet the reference mission performance requirements (including infrastructure issues) within a time frame and budget compatible with a small-spacecraft development cycle. For the purposes of this subtopic, small spacecraft are defined as CubeSats of 12U volume. Proposals are sought that will

- Specify observing systems figures of merit for a potential small-spacecraft mission, for example:
  - Earth resource management (commercial).
  - Maritime traffic monitoring.
  - Observations for agricultural industry.
  - Fire, flood, or other emergency monitoring.
  - Lunar exploration precursors or observation of human activity at the Moon.
  - Remote spacecraft health inspection.
Near-Earth object detection.
In-space or lunar-to-Earth optical communications.
Other reference mission to be specified by proposer.
• Include discussion of current state of the art for telescope optical parameters (sensitivity, resolution, and magnification within a spectral band).
• Include production cost and schedule significantly improved by the proposed system design.

Significant areas for proposals are:

• Concept systems that are modular in nature that can be produced in quantities larger than the single-unit production typical of spaceflight hardware builds (for instance, batch or lot production yielding flight units in the quantity range of 30 to 50).
• Concepts that will enable large deployable apertures (optical and related, such as sun shades enabling larger apertures) and/or longer focal lengths than currently available systems that can be implemented from within a 12U small spacecraft. The concepts of large deployable optical apertures and focal lengths for small spacecraft address the fact that small spacecraft are inherently size constrained.

Requirements to be addressed in the project should include specific needs for each wavelength application region, for example:

• For UV/Optical:
  • Wavefront Figure <5 nm rms
  • Wavefront Stability <1 nm/10 min
  • First Mode Frequency >500 Hz
  • Actuator Resolution <1 nm rms
• For EUV:
  • Slope <0.1 microrad

Also needed is ability to fully characterize surface errors and predict optical performance.

Expected TRL or TRL Range at completion of the Project: 3 to 6
Primary Technology Taxonomy:
Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
Level 2: TX 12.4 Manufacturing
Desired Deliverables of Phase I and Phase II:

• Prototype

Desired Deliverables Description:
Prototype optical system appropriate for inclusion in a 12U CubeSat with up to 8U
available for optics. A CubeSat-class precision optical system with an undeployed aperture constrained by a 0.2-m diameter (fits within a 12U volume). For Phase I, deliverables should include a design reference mission relevant to the optical system design, with key performance parameters identified. Identification of key relevant subcomponents of a telescope system that require a prototype demonstration for fabrication, test, or control technology required for a successful Phase II delivery of a prototype.

Ideally, Phase I includes a reviewed preliminary design and manufacturing plan that demonstrates production feasibility, appropriate material behavior, process controls, and optical performance. Mounting/deploying issues, especially with consideration to small spacecraft, should be resolved and demonstrated. While final manufacturing and assembly will be conducted in Phase II, the preliminary design should address how optical, mechanical (static and dynamic), and thermal designs and performance analysis will be done to show compliance with proposed performance measures, survival of the launch environment, and performance in the space environment (Earth orbiting or deep space).

In Phase II, the project could build a prototype and complete environmental qualification testing of the optical system (or a single node in the case of a multi-element system), including measuring optical figure before and after vibration testing, acoustic testing, and thermal cycling. It would also demonstrate that the telescope maintains optical figure in a reference thermal environment including thermal gradients.

A successful mission-oriented Phase II would yield a credible plan to deliver (in Phase III) flight hardware within the allocated budget for a fully assembled and tested telescope assembly that can be integrated into the potential mission. This plan would demonstrate an understanding of how the engineering specifications of their system meet the performance requirements and operational constraints of the mission (including mechanical and thermal stability analysis). Cost and schedule goals and optical performance goals are listed under State of the Art and Critical Gaps.

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State of the Art and Critical Gaps:

Technical Challenges
Ultrastable, normal incidence mirrors with low mass-to-collecting area ratios, affordably produced and delivered, modular and readily integrated into CubeSat-class form-factor, are desired.

Affordably Manufactured, Easily Integrated, Readily Available

After performance, affordability is the most important metric for an advanced optical system, and long telescope fabrication times add significant program cost. Current normal incidence space telescopes in the 0.2- to 0.5-m aperture class have lead times of 12 to 18 months and cost $1 million to $5 million. This research effort seeks a 10x reduction in schedule and cost for precision optical components: a lead time of 4 to 6 months and a cost of $100K to $500K for a 0.2- to 0.5-m aperture-class telescope. Options should be offered for modular and easy installation into a CubeSat-style payload enclosure, with considerations for maximizing aperture sizes, reliable deployment (if required), and reliable optical alignment.

Large Deployable Apertures for Small Spacecraft

Small spacecraft are inherently size constrained. Given the tight volume constraints of CubeSats and other small spacecraft, deployable systems for these platforms need to be highly volumetrically efficient and may employ novel configurations or deployment mechanisms relative to their larger brethren. Systems that can deploy a larger aperture then nominally available in a fixed system can address this constraint.

Affordably Manufactured, Easily Integrated, Readily Available

To accomplish NASA CubeSat-class missions, the mirrors and even entire optical assemblies must be delivered on CubeSat-class schedules after they have been specified. Earth-observing missions and astronomical applications often involve assembling and testing one or many spacecraft within a matter of months from concept to delivery. Optics that can be quickly procured as "catalog items" upon specification must be fabricated and ready for installation—preferably as an assembled module including optics bench and mounting hardware "plug and play" ready—or risk not being available on time for the tight mission schedules.

Relevance / Science Traceability:

A new class of low-cost, optically stable, wide-spectral-range telescopes designed specifically for small spacecraft have application in a variety of exploration, commercial, and science missions. Existing missions can be accomplished in novel and more affordable ways with small spacecraft, and new missions will be enabled by high-performance telescopes in small spacecraft. A few examples include:

- Earth resource management.
- Maritime traffic monitoring.
- Observations for agricultural industry from low Earth orbit.
- Satellite optical crosslinks or lunar satellite-to-Earth optical communications.
- Lunar exploration in situ resource utilization (ISRU) or landing site surveyors or manned surface mission operations observation.
- Remote spacecraft health inspection/monitoring.
- Near-Earth object detection or exoplanet transit detection in deep space.

References:

Types of large sparse systems are described in this SPIE paper: Large sparse aperture space optical systems, Aden B. Meinel, Marjorie P. Meinel, 1 August 2002, Optical Engineering, 41(8), (2002). [https://doi.org/10.1117/1.1490557](https://doi.org/10.1117/1.1490557)

Nautilus Observatory: a space telescope array based on very large aperture ultralight diffractive optical elements, Dániel Apai, Tom D. Milster, Dae Wook Kim, Alex Bixel, Glenn Schneider, Benjamin V. Rackham, Rongguang Liang, Jonathan Arenberg, Proceedings Volume 11116, Astronomical Optics: Design, Manufacture, and Test of Space and Ground Systems II; 1111608 (2019). [https://doi.org/10.1117/12.2529428](https://doi.org/10.1117/12.2529428)