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Using CubeSat/micro-satellite technology to demonstrate the Autonomous Assembly of a Reconfigurable Space Telescope (AAReST) ☆

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ABSTRACT

Future space telescopes with diameter over 20 m will require new approaches: either high-precision formation flying or in-orbit assembly. We believe the latter holds promise at a potentially lower cost and more practical solution in the near term, provided much of the assembly can be carried out autonomously. To gain experience, and to provide risk reduction, we propose a combined micro/nano-satellite demonstration mission that will focus on the required optical technology (adaptive mirrors, phase-sensitive detectors) and autonomous rendezvous and docking technology (inter-satellite links, relative position sensing, automated docking mechanisms). The mission will involve two "3U" CubeSat-like nanosatellites ("MirrorSats") each carrying an electrically actuated adaptive mirror, and each capable of autonomous un-docking and re-docking with a small central "15U" class micro/nano-satellite core, which houses two fixed mirrors and a boom-deployed focal plane assembly. All three spacecrafts will be launched as a single ~40 kg micro-satellite package. The spacecraft busses are based on heritage from Surrey's SNAP-1 and STRaND-1 missions (launched in 2000 and 2013 respectively), whilst the optics, imaging sensors and shape adjusting adaptive mirrors (with their associated adjustment mechanisms) are provided by CalTech/JPL. The spacecraft busses provide precise orbit and attitude control, with inter-satellite links and optical navigation to mediate the docking process. The docking system itself is based on the electromagnetic docking system being developed at the Surrey Space Centre (SSC), together with rendezvous sensing technology developed for STRaND-2. On orbit, the mission profile will firstly establish the imaging capability of the compound spacecraft before undocking, and then autonomously re-docking a single MirrorSat. This will test the docking system, autonomous navigation and system identification technology. If successful, the next stage will see the two MirrorSat spacecraft undock and re-dock to the core spacecraft in a linear formation to represent a large (but sparse) aperture for high resolution imaging. The imaging of stars is the primary objective, but other celestial and terrestrial targets are being considered. Teams at CalTech and SSC are currently working on the mission planning and development of space hardware. The autonomous rendezvous and docking system is currently under test on a 2D air-bearing table at SSC, and the propulsion and precision attitude control system is

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currently in development. Launch is planned for 2016. This paper details the mission concept; technology involved and progress to date, focussing on the spacecraft buses.

1. Introduction

In recent years, there has been a desire to develop space-based optical telescopes with large primary apertures. The current state-of-the-art in terms of development is the James Webb Space Telescope (JWST), which has a primary aperture diameter of 6.6 m [1]. JWST represents a major advance in space telescope design due to its use of mechanically deployable (hinged) elements for its primary mirror. However, there is a limit to how large an aperture can be constructed in this way, given the limitations imposed by the diameter of the launch vehicle. One method to overcome this limitation is to autonomously assemble, in orbit, mirror elements fixed to small independent spacecraft (Fig. 1). In doing so, a telescope with a large, segmented primary mirror can be constructed. Furthermore, if each of these mirrors is manufactured to have an identical initial shape (and then adjusted upon assembly), a substantial reduction in manufacturing costs can be realized. We believe that autonomous assembly of such elements is a key enabler for a lower cost approach to the orbital deployment of large telescopes with aperture diameters of 10 m or more.

In order to prove the feasibility of such a concept, a collaborative effort has been set up between the California Institute of Technology (CalTech) and the University of Surrey–Surrey Space Centre (SSC), with the top-level objectives of developing a low-cost, small satellite mission to demonstrate all key technological aspects of *autonomous assembly* and *reconfiguration* of a space telescope based on an optical focal plane assembly (*camera*) and *multiple* mirror elements synthesising a single coherent aperture, and to demonstrate the capability of providing *high-quality* images using a such a telescope. The project, which has been running since 2009, is known as “AAReST” – for the “Autonomous Assembly of a Reconfigurable Space Telescope”. The aim is to be ready for launch in 2016.

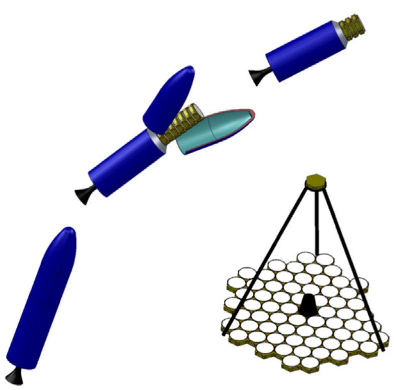

Fig. 1. On orbit assembly of a large space telescope from small autonomous “MirrorSat” elements.

2. Mission concept

From the top level mission objectives, a series of more detailed system design requirements follow:

The mission must involve *multiple* spacecraft elements.
All spacecraft elements must be *self-supporting* and “*intelligent*” and must cooperate to provide *systems autonomy* – this implies that they must be each capable of independent free-flight and have an Inter-Satellite Link (ISL) capability.
Spacecraft elements must be *agile* and *manoeuvrable* and be able to *separate* and *re-connec*t in different configurations – this implies an effective Attitude and Orbit Control System (AOCS), and Rendezvous & Docking (RDV&D) capability (sensors and actuators).
All Spacecraft elements must lock together *rigidly* and *precisely* and provide a *stable* platform for imaging – this implies a precision docking adaptor and precision Attitude Determination and Control System (ADCS).
The mirror elements must be capable of independent motion and/or shape adjustment and wavefront sensing in order to synthesise a single coherent aperture.

These requirements have resulted in the composite spacecraft concept shown in Fig. 2.

The spacecraft bus, ISL, AOCS, precision ADCS, propulsion and RDV&D systems are largely the responsibility of the Surrey team, with support from the University of Stellenbosch. The optical systems (mirrors, cameras, wavefront sensors, and mirror selection system), aperture synthesis, and deployable boom are largely the responsibility of CalTech, with support from the Air Force Research Laboratory (AFRL) and NASA Jet Propulsion Laboratory (JPL).

The AAReST mission will involve two “nanosatellite” class vehicles based on 3U CubeSat-type structures (“MirrorSats”), which each carry a Deformable Mirror Payload (DMP) and a central “15U” microsatellite (“CoreSat”), which houses two rigid Reference Mirror Payloads (RMPs) and a “Camera Package” mounted on a deployable carbon-fiber composite boom.

All the three spacecrafts will be launched as a single ~40 kg microsatellite package with a stowed volume of 0.4 m by 0.4 m by 0.6 m (Fig. 3).

During launch, the MirrorSats, Camera Package and Boom are held rigidly onto the CoreSat via Frangibolts and burn-wires. However, once in orbit, the boom will be released to deploy the Camera Package to form a prime focus telescope of 1.2 m focal length, and 0.3° field-of-view, where the primary mirror is divided into a sparse