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SHAPE CONTROL OF OPTICAL REFLECTORS FOR SPACE AND EARTH APPLICATIONS

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Summary: Large telescopes are complex mechatronics systems involving several layers of control and a large number (up to several thousands) of actuators and sensors. This paper reviews some of the technical challenges which are driving the design of the next generation of earth-based and space telescopes.

Space telescopes: Space astronomy made a giant step in the 1990's with NASA's Hubble Space Telescope based on a monolithic mirror of 2.4m-diameter, with an areal density of 180 kg/m^2. More recently, the Herschel telescope was launched by ESA in 2009, with a primary mirror of 3.5m-diameter and an areal density of 22 kg/m^2. Herschel is the largest existing space telescope; larger telescopes need to be folded in order to be stowed in the fairing during launch. The James Webb Space Telescope is currently in its final stage of manufacturing; its 6.5m-diameter primary mirror consists of 18 hexagonal segments, folded during launch, with an areal density of 20 kg/m^2. Being deployed in orbit, the final shape of the primary mirror may only be achieved by active control.

Large aperture space reflectors are necessary to collect more light and to achieve higher resolution. Applications include astronomy, earth observation, lidar, laser communication and spectroscopy. There is a need for future reflectors with diameters of 10 m and more. The tight weight and volume constraints of current launchers call for a change of paradigm in terms of stowability and areal density; diameters up to 20 m will only be possible if an areal density of 3 kg/m^2 or less may be achieved.

This change of paradigm is offered by the so-called gossamer spacecrafts and membrane optics. The use of adaptive doubly curved elastic shells is one option; the reflector is molded in its final shape and rolled for stowage. Once released in orbit, the reflector will unfold on its own strain energy. The sources of surface figure error are: manufacturing, creep in rolled configuration, thermal gradients and gravity gradients.

Imaging applications are the most demanding in terms of the surface figure accuracy; the final wavefront error of a fraction of the wavelength will be achieved with a secondary wavefront corrector acting in a way very similar to the Adaptive Optics for earth based telescopes, with a large number of independent degrees of freedom. In this way, the surface figure accuracy requirements on the primary reflector are lowered to the capability of the secondary wavefront corrector.

Earth-based telescopes: A diameter of 8 m (VLT) is considered as the maximum for a monolithic primary mirror, for manufacturing as well as logistic reasons (the mirror must be transported to the top of a mountain). The Keck telescope is currently the largest existing telescope; it consists of 36 segments leading to a primary mirror of 10 m. Several Extremely Large Telescopes projects have been initiated in recent years; the E-ELT telescope of ESO is currently under procurement; it will consist of about 800 segments for an external diameter of 39 m. No need to say that such a disruptive jump with respect to previous projects is a venture into unknown territory. The paper examines some of the challenges associated with scaling the telescope structure and especially the control-structure interaction resulting from increasing the control bandwidth (to maintain accuracy with increasing size) and the lower structural natural frequency typical of large structures.

Adaptive Optics: The remaining part of the paper summarizes the effort that is being conducted at the Active Structures Laboratory of ULB in the development of deformable mirrors for wavefront correction with a large number of degrees of freedom, for application in both space and earth-based telescopes. A concept of segmented deformable mirror is discussed, where the segments consists of a thin deformable substrate actuated by a unimorph piezoelectric PZT layer acting in d31 mode. This concept allows to combine a large number of degrees of freedom with a lightweight design and a large natural frequency of the mirror (equal to that of a segment). The paper discusses the morphing capability of the concept as well as various manufacturing techniques for producing the deformable mirrors: gluing under electrical voltage to handle the bias voltage of the PZT actuator, laser cutting to achieve sharp edges, laser design of electrode patterns.