Building bigger telescopes from smaller segments

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New optical fabrication and control technologies may reduce the cost and delivery time of next-generation telescopes.

Astronomers have been building bigger and better telescopes for 400 years. Using these telescopes, they can already see galaxies forming in the early universe and watch giant planets round nearby stars. However, to answer the big questions of how the universe was formed and came to support intelligent life, astronomers need telescopes with still greater resolution and sensitivity. The problem is that such telescopes are estimated to cost about $1 billion each and probably will not be operational before 2020.

The biggest telescopes in operation today use either single mirrors about eight meters in diameter or an array of 36 hexagonal mirrors that are approximately 1.5 meters across. All current designs for next-generation telescopes propose simply clustering more of these mirrors to produce larger telescopes. However, such mirrors take many years to manufacture and require stable and massive support in the telescope structure. As the size of the telescope increases, the effect of gravity and wind loading becomes increasingly severe, driving up the cost and technical risk of the projects. Building the primary mirror is only part of the problem. Additional adaptive optics, using deformable surfaces, are needed to remove the effects of turbulence of the earth’s atmosphere in real time. Next-generation telescopes cannot meet their mission goals without adaptive optics, which form a big part of the overall cost of the telescope, but this technology is not yet fully integrated into their design.

My colleagues and I have a new approach: to use many thousands of low-cost, mass-produced optics controlled by a powerful computing system to form the primary mirror. This allows the position of the segments to be essentially decoupled from the structure, overcoming the effects of windshake and atmospheric turbulence on image quality. The primary mirror provides the adaptive surface. Mass production of large numbers of identical mirrors greatly lowers their cost, and the segments are light enough for their positions to be controlled directly using voice coils. These are bigger versions of the devices used in every compact disk player to control the position of the focusing lens. We expect to be able to make and mount the mirror segments for less than $4,000 per square foot and fabricate the panels at a rate of 10 square feet a day (an order of magnitude cheaper and faster than conventional technology).

We have produced a conceptual design study for a 25m-diameter telescope based on this approach. The positions of the

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Figure 2. Photograph of a prototype segment. The low-expansion substrate is supported on 9 air pistons. The position is controlled by 4 voice coils at the edges of the substrate. Inductive sensors (green) at the edges of the substrate measure its position relative to its nearest neighbors. The segment is 1 foot square.

segments are measured by using a combination of signals from inductive edge sensors and an optical wavefront sensor driven from a natural, or laser-generated, star located above the earth’s atmosphere. (The sensors are similar to those already used by astronomers to drive adaptive optics systems.) Signals are used to control the segments in order to correct any distortion of the wavefront caused by segment misalignment or atmospheric turbulence. In this design, individual segments will be about a foot square and will be assembled into panels about six square meters in area. These panels weigh about 400kg each and contain the mirror segments, support and control systems (see Figure 1). The telescope is similar in design, cost, and construction to submillimeter radio telescopes, except that the panels are built from agile segments.  

Recent work is concentrating on the development of the segment and control technology. In our most recent segment prototype (see Figure 2), the mirror substrate is a 3/8-inch thick plate of low-expansion material supported on a grid of air pistons that support the mirror. Four voice coils position the mirror over a 3mm range, and the relative position of the segment to its neighbors is measured with inductive sensors. These sensors have a noise floor of about 1nm/√Hz.

The next step is to build a single panel consisting of 64 segments and control its figure with the bandwidth, accuracy, and stability required. For this we need reliable wavefront sensing and laser-guide star technology to drive the system. In

principle, this is straightforward, but the telescope will not operate without the sensing and control system. We are therefore looking at new approaches to wavefront technology, and plans are underway to modify the sum frequency laser technology developed at the University of Chicago for use at Palomar Observatory. The biggest challenge is funding. An operational 15m telescope is estimated to cost about $70 million, a 40m telescope $400 million. We are seeking collaborators with the vision, commitment, and financial resources to proceed.

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References
