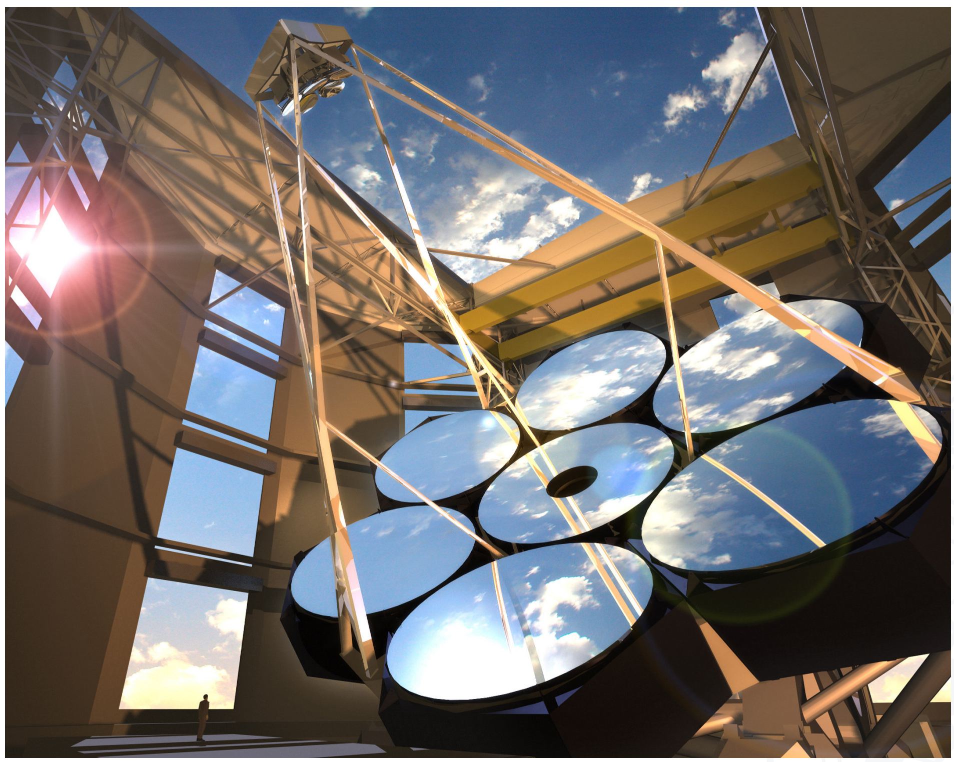
THE KAVLI PRIZE

ASTROPHYSICS PRIZE EXPLANATORY NOTES

Ever since Galileo turned his first telescope towards the heavens 400 years ago and found evidence that planets orbited the sun and not the earth, advances in telescope technology have allowed us to expand our horizons and learn our place in the universe. Using telescopes, astronomers have discovered new planets and moons in our solar system, revealed that our planetary neighbourhood is just a small part of a vast galaxy, that our galaxy is just one of many billions across the universe, and that most objects in the universe are flying away from us at high speed because of its overall expansion.



The Giant Magellan Telescope (GMT) will open a new window on the universe for the 21st century. Scheduled for completion around 2018, the GMT will have the resolving power of a 24.5-meter (80 foot) primary mirror - far larger than any other telescope ever built. It will answer many of the questions at the forefront of astrophysics today and will pose new and unanticipated riddles for future generations of astronomers. (Credit: Giant Magellan Telescope - Carnegie Observatories)

New ways of polishing lenses, or of casting and coating mirrors, have allowed astronomers to see further and further into space, and further back in time. Telescope makers soon realised that for astronomy, bigger telescopes are better. A larger light-collecting area lets you see fainter and hence more distant objects. A wide aperture also lets you discern smaller features. As a result, telescopes grew steadily over the centuries until, that is, gravity kicked in. Because lenses can only be supported around the edge, when they get too big they start to sag under the effect of gravity. The lens in the Yerkes Observatory's 40-inch (102 cm) refracting telescope, completed in 1897, was the largest used for research.

By the middle of the 20th century, reflecting telescopes ran up against the same problem. Mirrors were made of large slabs of glass with one face ground into a curved shape and coated with a thin layer of aluminium. But as the mirror was moved to point at different parts of the sky, gravity would distort its shape, ruining the optics. The 5-metre wide Hale Reflector, built in 1948, and Russia's 6-metre BTA-6, finished in 1965, were the last of their kind – the supporting structures needed to keep the mirrors rigid were too expensive to build and too massive to turn smoothly to follow the motion of the stars. Telescope technology progressed little for decades.

Jerry Nelson, Ray Wilson and Roger Angel were all grappling with the same problem: how do you ensure that a mirror keeps a perfect reflecting surface while it is assaulted by gravity, wind and changes in temperature? Each came up with a very different approach, but Angel's was perhaps the most traditional. He strove to make mirrors much lighter, while maintaining rigidity, so that gravity could not get such a hold.

Angel started out by melting Pyrex dishes in a small potter's kiln and testing its

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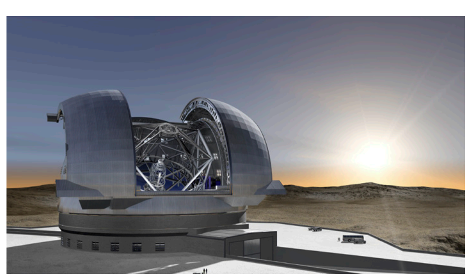
properties. This convinced him that cheap borosilicate glass was light, strong and rigid enough for his purposes. He started making mirrors by casting them in a mold containing an array of hexagonal pillars to give the finished mirror a honecomb pattern of holes. This reduces the mirror's weight to one-fifth that of an equivalent traditional mirror while maintaining rigidity. But that was not all. While the glass was cooling and solidifying, he would spin the mold so that centrifugal force gave it a ready-made curved surface.

To get to the final desired curvature Angel developed a computer controlled polishing device whose tool could change shape while moving over the mirror to achieve complex aspherical surfaces. His work led to a renaissance in large-mirror telescopes. He cast 6.5-metre mirrors for the MMT telescope and the twin Magellan telescopes, plus two 8.4-metre ones for the Large Binocular Telescope. In 2008, for the Large Synoptic Survey Telescope, he cast a doughnut-shaped 8.4-metre mirror with a 5-metre mirror in the central hole.

Ray Wilson had a different solution to the problem. Instead of striving to make a mirror rigid against the effects of gravity, he decided to make mirrors that were thin, flexible and lightweight, and then actively managing their shape with computer-controlled actuators attached to the back and supported by a rigid frame. A key innovation was the computer control system which, as the telescope moved, could sense errors in the wavefront moving through it and correct the mirror shape for the effects of gravity, wind and temperature minute-by-minute - a technique known as active optics.

Wilson's system was first tested in the European Southern Observatory's New Technology Telescope, completed in 1989. That gave ESO the confidence to build its Very Large Telescope, made up of four 8.2 metre telescopes that could work together or independently. The twin Gemini 8.1-meter telescopes as well as the 8.3-metre Subaru Telescope all use so-called thin meniscus mirrors following Wilson's scheme.

Jerry Nelson's solution was more radical still. He abandoned the idea of a single large mirror altogether and instead cast a large number of small hexagonal mirror tiles that could be put together to form a single reflecting surface. The approach was tricky because it meant that all the off-centre tiles needed complex aspherical shapes. Nelson achieved this by bending the mirror blank with carefully positioned weights, grinding its surface into a spherical curve, and then letting it relax back into its natural shape producing the required aspherical curve on the polished surface. Once these roughly 1.5-metre tiles are put together to form a large mirror, their positions are actively controlled by computerised actuators to constantly maintain a perfect reflecting surface.



The artist's impression shows the future European Extremely Large Telescope (E-ELT), which is currently being planned by the European Southern Observatory (ESO). This revolutionary new ground-based telescope will be the largest optical/near-infrared telescope ever conceived, and will serve as "the world's biggest eye on the sky". Credit: ESO/H. Zodet

The twin 10-metre Keck telescopes were the first test of Nelson's segmented mirror design—each with 36 tiles—followed by the 9.2-metre mirrors of the Hobby-Eberly Telescope and the South African Large Telescope, and the 10.4-metre Grand Canaries Telescope.

In awarding the 2010 Kavli Prize for Astrophysics to Nelson, Wilson and Angel, the judges said they used "truly innovative solutions" to overcome the hurdles they faced, adding: "All three telescope concepts have had outstanding successes, leading to a wide range of fundamental discoveries."

Their impact does not stop there, but will soon allow telescopes to make a leap to truly enormous sizes. Angel is already casting the seven 8.4-metre mirrors for the Giant Magellan Telescope which together will act as a single 24.5-metre mirror. Nelson is involved in the planned Thirty Meter Telescope, whose mirror will be made up of 492 segments. ESO's planned European Extremely Large Telescope will also have a mirror of 984 segments, making it 42 metres across. And their influence even extends into space: the James Webb Space Telescope, the successor to Hubble, will have an 18-segment 6.5-metre mirror.

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