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Mirror, Mirror

Astronomers in Arizona are racing to build the biggest telescope ever.

By DENNIS OVERBYE

TUCSON — In the cavernous bowels of the University of Arizona's football stadium, Roger Angel's mirror furnace was spinning like a captured flying saucer at a stately five revolutions per minute.

It was a contrivance that Monty Python or Doc Ock might have designed – 30 feet across and 10 feet high, carapaced with red boxes, steel beams, black cables, flashing lights and metal air ducts snaking from its body like octopus arms.

An orange glow, from 18 tons of molten glass heated to 2,100 degrees Fahrenheit, was peeking through openings around the ducts as they flashed by.

That glass was on its way to being part of the heart of what could be the largest telescope in the world 10 years from now. And so, nearby, several dozen sweltering astronomers and other dignitaries were roaming catwalks, wandering among giant mirrors and mirror polishing machines and swigging bottled water while they kept a weather eye on monitors showing what was going on inside the furnace.

One camera was focused on a set of marks on the furnace wall – not unlike the ones on a child's closet door – used to gauge the level of the molten glass inside. The level had been falling in the last day as the temperature ramped up and chunks of glass the size of cobblestones softened and began to flow down into narrow channels forming a honeycomb pattern.

The glass would stop falling when it had completely filled the honeycomb structure. Meanwhile, centrifugal force would have whipped the overflow into a perfect parabola 28 feet across – the desired shape for sweeping up starlight dispersed into foggy invisibility over billions of light-years and compressing it into crisp bright dots astronomers could read like a newspaper to learn what was happening around a distant sun or when the universe was born.

That was the moment the real work could begin.

"This project is very gutsy," said Dr. Angel, a slender, gray-haired astronomer who runs the Steward Observatory Mirror Laboratory. He has been building mirrors and populating mountaintops with telescopes this way for 20 years, but nobody has ever built something like this.

If everything works out, the mirror now forming in Dr. Angel's saucerlike furnace will be only the first of seven making up a giant telescope with the light-gathering power of a mirror 70 feet across. The Giant Magellan, as it is called, would be twice the size of anything now operating on Earth or in space, and four times as powerful. But there are many challenges. To blend their light at a common focus, Dr. Angel explained, all seven mirrors will have to be part of the same giant parabola. That means that all of them except the central mirror must have an unusual "wickedly curved" asymmetrical shape.

And there is the cost. The Giant Magellan will cost half a billion dollars – money that its collaborators, a consortium of eight institutions, does not yet have.

To show that they can make such a mirror, and perhaps shake loose some of that half billion, the collaborators – which include the Carnegie Institution of Washington; Harvard; the Massachusetts Institute of Technology; the Smithsonian Astrophysical Observatory; the Universities of Arizona, Michigan and Texas; and Texas A&M – announced this year that they would go ahead and make one, at a cost of some $17 million, and they invited everyone to watch.

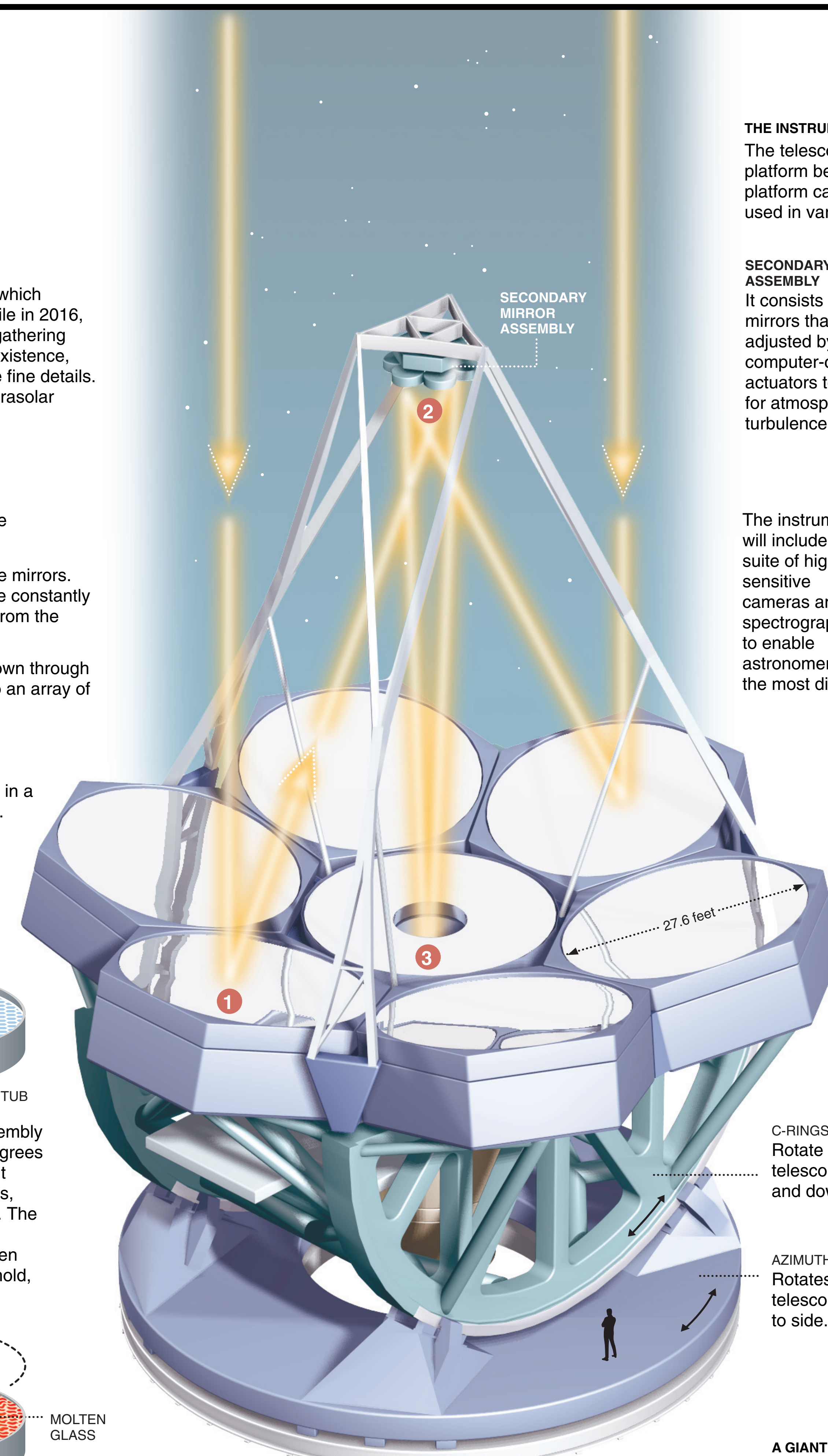
"Everybody in collaboration believes we need to test this technology," said Wendy Freedman, director of the Carnegie Observatories and chairwoman of

AIMING FOR THE STARS

The Giant Magellan Telescope, which astronomers hope to build in Chile in 2016, would have four times the light-gathering power of any telescope now in existence, and remarkable ability to resolve fine details. That should enable it to view extrasolar planets directly.

HOW IT WORKS

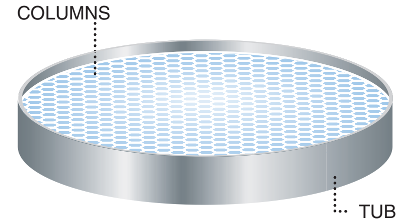
1. Collected light reflects off the primary mirrors ...
2. ... to a second set of concave mirrors. These secondary mirrors are constantly adjusted to reduce blurring from the atmosphere.
3. The light is then reflected down through a hole in the center mirror to an array of instruments.



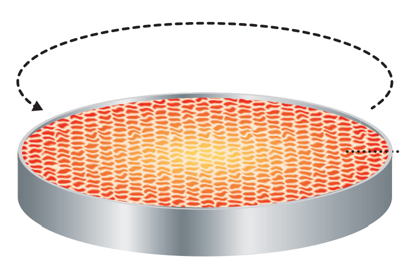
MAKING A MIRROR

The spin-casting method results in a lightweight honeycombed mirror.

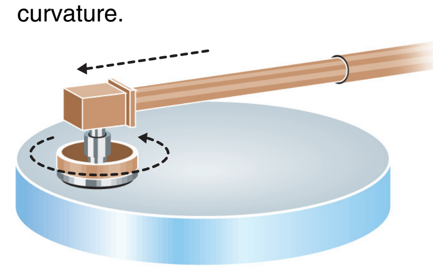
1 A tub is filled with hundreds of ceramic fiber columns. Twenty tons of glass are then arranged on top.



2 In a spinning furnace, the assembly is heated to more than 2,100 degrees Fahrenheit. As the glass melts, it flows down between the columns, creating a honeycomb structure. The centrifugal force of the spinning furnace moves more of the molten glass to the outer edge of the mold, creating a concave surface.



3 After cooling, the columns are removed, and a polishing machine is used to grind the surface to its final curvature.

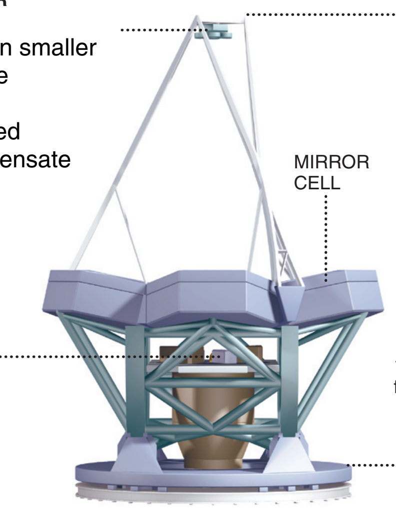


THE INSTRUMENTS

The telescope's instruments are located on a platform below the central mirror. A portion of the platform can rotate so different instruments can be used in various combinations.

SECONDARY MIRROR ASSEMBLY

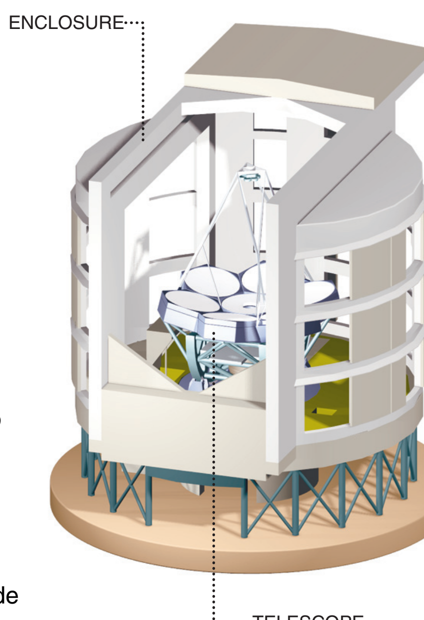
It consists of seven smaller mirrors that can be adjusted by computer-controlled actuators to compensate for atmospheric turbulence.



The instruments will include a suite of highly sensitive cameras and spectrographs to enable astronomers to study extrasolar planets, black holes and the most distant objects in the universe.

THE ENCLOSURE

To shield it from wind and stray light, the telescope will be housed in a 213-foot-tall rotating enclosure.

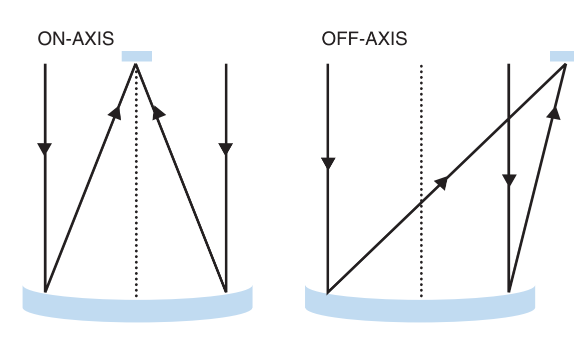


C-RINGS
Rotate the telescope up and down.

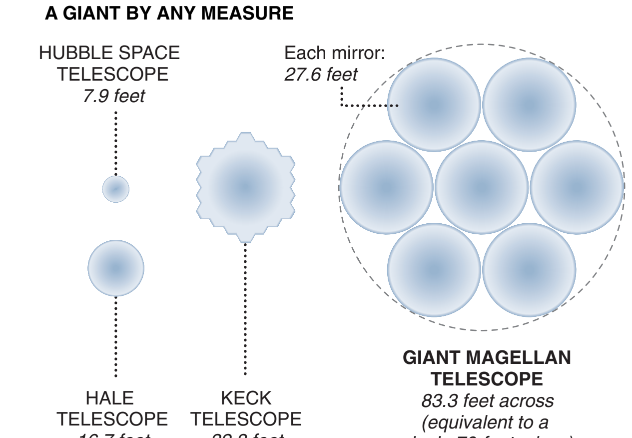
AZIMUTH DISK
Rotates the telescope side to side.

THE CURVE

Most telescope mirrors are "on-axis," focusing light directly above the center of the mirror. With this telescope, the six outer mirrors send their light "off-axis," reflecting it to a region off to the side of the mirror's center.



A GIANT BY ANY MEASURE



Sources: Carnegie Observatories; Steward Observatory Mirror Lab; Paragon Engineering

Frank O'Connell/The New York Times

the Giant Magellan board, adding that if the test fails the project will not proceed.

Robert Kirshner of Harvard said, “It’s kind of brave to get started before you know you're going to finish.”

Dr. Freedman added that they had to start making mirrors now, money or not, to meet their goal of beginning limited operations in Chile in 2013 and finish in 2016.

Making that date will allow them to overlap with the National Aeronautics and Space Administration's James Webb Space Telescope, scheduled for a 2011 launching and keep pace with their rivals, a consortium including the California Institute of Technology, the University of California and the Canadian Astronomical Association that wants to build a telescope 100 feet in diameter, using a radically different technology.

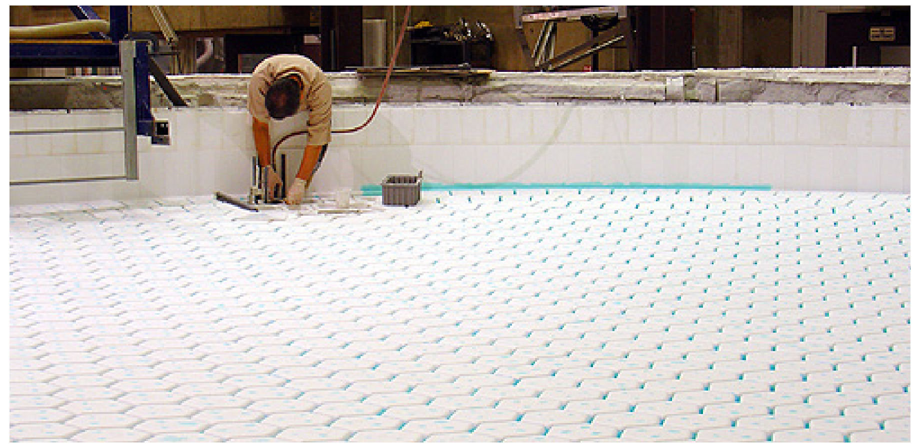
The result in late July was a weekend rendezvous in the desert, part fund-raising party, part seminar on telescope making and part family reunion. Many participants had worked together on other projects, like Magellan, the new telescope's namesake, which consists of twin 21-foot-diameter telescopes at Las Campanas, a Carnegie observatory in Chile, and the Large Binocular Telescope being built on Mount Graham in Arizona.

“Carnegie is returning to its roots,” said Richard Meserve, the Carnegie Institution’s president in a talk, recalling that it was Carnegie telescopes that Edwin Hubble used to discover the expansion of the universe.

Dr. Angel said part of the pleasure of the Giant Magellan project was working with old friends who could talk in shorthand.

In the mirror lab’s air-conditioned conference room, Stephen Shectman from Carnegie said: “I’ve been coming here for 26 years. I thought I was done. But now we’re just starting again.”

Ever since Galileo’s time astronomers have made telescope mirrors and lenses by grinding flat disks of glass together. But such rubbing produces a spherically shaped mirror that must then be reshaped into a shallower curve known as a parabola – a delicate and error-prone process that has been the bane of many amateur and even professional astronomers. It was in the testing part of this part of the process, for example, that the builders of the Hubble Space Telescope stumbled, necessitating a dramatic series of



Lori Stiles/University of Arizona, above and left.

spacewalks in 1993 to fit the orbiting telescope with corrective lenses.

Moreover, as mirrors have gotten bigger, the traditional method wastes a lot of glass and time. Dr. Angel estimated that about 20 tons of glass would have to be scooped out to make the new mirror. “That’s a lot of glass at $40 a kilogram,” he said.

Astronomers and physicists have long known, however, that the surface of a spinning liquid will form a parabola. Indeed, telescopes have been built using spinning pools of mercury as a mirror.

Dr. Angel, who was born in Lancashire, England, and earned a doctorate in physics at Oxford, said he was interested in astronomy as a child and once starting grinding a mirror for a telescope but never finished it. After completing his degree, in the late 1960’s Dr. Angel went to work at Columbia, which was a center for the growing new field of X-ray astronomy, and he went along.

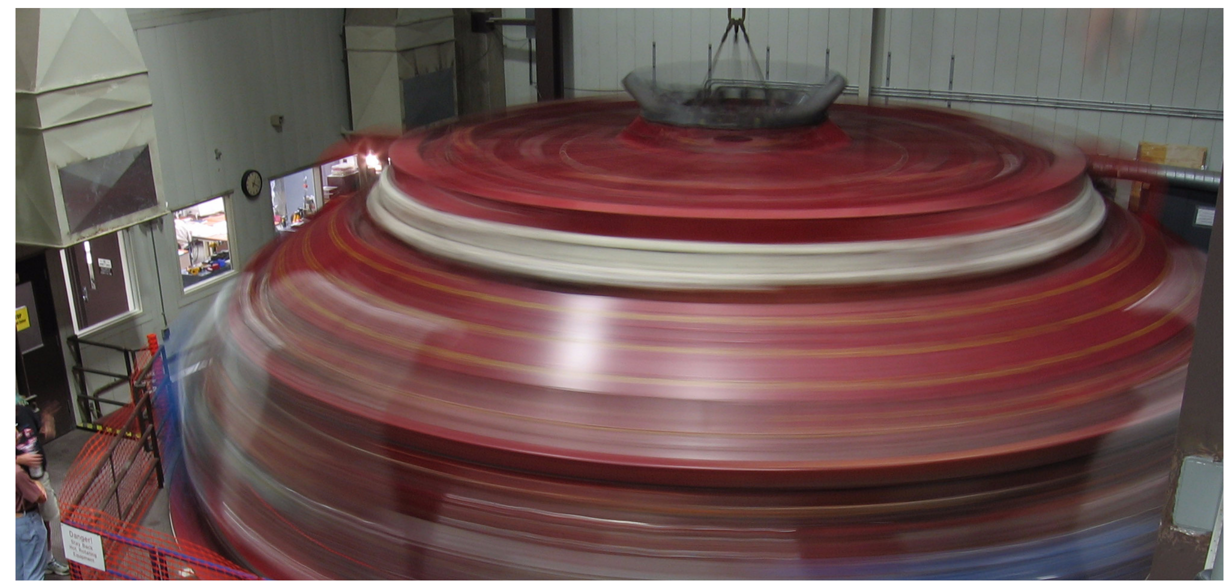
“I came into astronomy as an instrument builder,” he said.

At the University of Arizona, where he moved in 1975, Dr. Angel started experimenting with casting mirrors in a kiln in his backyard in Tucson.

He found that by pouring the molten glass into a honeycomb structure he could make a mostly hollow mirror that was light, stiff and adjusted quickly to changes in the air temperature that would distort and disable fatter mirrors. Dr. Angel's friend and colleague Nick Woolf had emphasized these features as the key to building large telescopes in the future.

In 1985, a rotating furnace was installed under the football stadium, continuing a tradition in this country of important science projects under football stadiums. (The first controlled nuclear reaction occurred beneath the University of Chicago’s old football stadium in 1942.) In 1990, it was enlarged to accommodate mirrors as large as 28 feet.

The present project grew out of the success of the Magellans, built by Carnegie,



Dr. Patrick McCarthy/Carnegie Observatories

A spin-casting furnace casts the mold to build the mirror for the Giant Magellan Telescope, above. Top left, ceramic fiber cores are installed to complete the mold for the mirror. Top right, a layer of glass is stretched into the mold for casting.

Harvard, Arizona, M.I.T. and Michigan, and completed in 2002. The Magellan astronomers like to brag about the quality of the images from these telescopes, which they attribute to the smoothness of the mirrors and the stability of the atmosphere at Las Campanas, where the Giant Magellan would be built.

“These mirrors work,” Dr. Freedman said.

Astronomers say the Giant Magellan, augmented with so-called adaptive optics that reduce the blurring from the atmosphere, would be an invaluable tool, among other things, for hunting and studying planets around other stars.

“Bigger is better in a big way to see faint objects around bright ones,” Dr. Angel said.

It could be years before the Giant Magellan group will know if their gamble has paid off. The mirror is scheduled to cool until late October, when technicians will pop the lid off the flying saucer oven and lift the new mirror out.

Only then will begin the arduous task of polishing and testing it. The testing is the big problem, Carnegie’s Dr. Shectman said, “There’s a schedule – two years, but....,” he said, his voice trailing off.

And if after all this they don't get the money for the rest of the telescope?

“We didn’t spend time on Plan B,” Dr. Angel said.

As the Giant Magellan mirror was baking Dr. Angel and his colleagues led tours through what looked like a giant geek's playground. Towering into the shadows of one corner was a 400-ton tower for testing mirrors. Nearby, trailing a tangle of wires like a Medusa’s head, hovered a thick aluminum disk the size of a small dinner table with padded feet.

That is the polisher, which can be bent under computer control as it strokes and shapes the mirror. To succeed, the mirror must be polished to within a millionth of an inch of the desired curve, Dr. Angel said.

A freshly polished 21-foot mirror built for Lockheed was sitting on its stand like a frozen whirlpool, honeycombs visible in its depths. Against the wall, hanging in a red steel frame, was a 28-foot mirror, the second of two that have been built for the Large Binocular Telescope on Mount Graham (the first is already in the telescope).

In still another corner was a polishing tool – a lump of curved granite a couple feet across covered with half-inch squares of black pitch – the same thing amateurs have been using forever.

“That’s the great thing about this business," Dr. Angel said. “On the top it’s high-tech, but at the bottom it’s centuries old, two bodies rubbing against each other.”

Dr. Angel’s mirrors start off as white sand on the Florida Gulf Coast. It is cooked into borosilicate glass in one-ton batches in barrels at the Ohara glassworks in Japan and then smashed into smaller chunks.

Dr. Angel said the most important property of the borosilicate, besides low thermal expansion, was its uniformity, which allowed it to cool and harden without any built-in stresses that could later warp the mirror.

That and the fact that it melts at a finite temperature.

Dr. Angel’s furnace generates two million watts. While they were casting their first 28-foot mirror, Dr. Angel explained, the furnace sprang a leak. The level of molten glass fell and kept falling. Some of it wound up on the floor, leaving part of the mirror's surface denuded.

The astronomers had to resort to what Dr. Angel calls a “crème brûlée process,” adding more glass to the top of the mirror and firing the furnace up to remelt the top.

It worked, but the astronomers were still relieved on Giant Magellan casting day when the glass level held at the two-and-a-half-inch mark.

“It’s good to check that off,” Dr. Freedman said.

That night, the astronomers and their supporters gathered for a banquet and mused about the future.

Besides looking for alien planets, the Giant Magellan astronomers would like to investigate the so-called dark energy that seems to be splitting the universe apart.

But, as Dr. Kirshner noted, dark energy and extrasolar planets – the two big selling points for telescopes today – didn’t exist 10 years ago and wouldn't have been on anybody's list of things to do. “You can’t honestly predict what you're going to do,” he said.

Patrick McCarthy of the Carnegie Observatories told the group, “The most important tool we take to the observatory is an open mind.”