Double-barreled astronomy

The Large Binocular

TWO NEW "EYES" take in the sky at the Large Binocular Telescope (LBT) Observatory on Mount Graham in Arizona. This fall, astronomers made their initial observations using both telescopes, achieving "first binocular light." LARGE BINOCULAR TELESCOPE CORPORATION (LBTC)/JOHN HILL

A unique observatory now taking shape atop Arizona's Mount Graham will one day best the Hubble Space Telescope. /// **BY BRUCE DORMINEY**

LBT'S LARGE BINOCULAR CAMERA reveals the richness of open cluster M67. Astronomers took the tri-color mosaic earlier this year as part of the camera's commissioning. LBTC/EMANUELE GIALLONGO, VINCENZO TESTA, STEFANO GALLOZZI (ROME OBSERVATORY)

Telescope opens *both* eyes

The world's largest telescope is finally turning its twin "eyes" to the sky. In September, from its perch atop southeastern Arizona's 10,500-foot (3,200 meters) Mount Graham, the Large Binocular Telescope (LBT) made its first observations using both of its twin main mirrors.

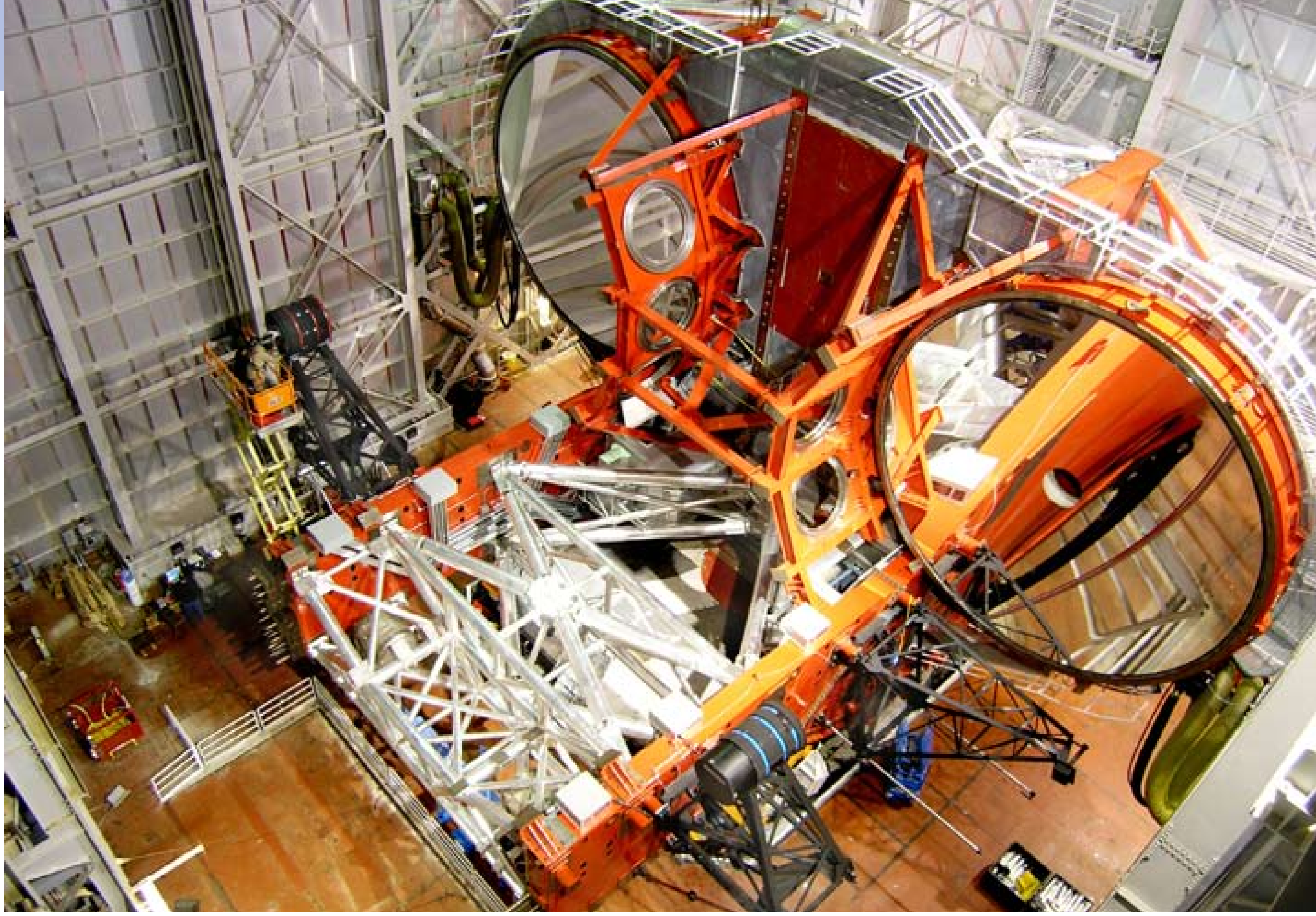
After 20 years of design and construction, the LBT has finally started doing astronomy. But the $130 million instrument won't reach its full observing potential until 2010. When it does, though, no optical scope in existence will match its resolution. The LBT will produce images nearly 10 times sharper than the Hubble Space Telescope, currently astronomy's gold standard.

Giant binoculars

LBT Technical Director John Hill explains that, whatever their specific cosmic interest, astronomers want two things in a telescope: large light-collecting area and high resolution. The LBT provides both — in spades.

Its two 8.4-meter primary mirrors sit on the same steerable mount. Their centers are 14.4 meters apart, providing a collecting area equivalent to a single 11.8-meter telescope. But, because of its binocular arrangement, the telescope will have the resolution of a 22.8-meter telescope. When both sides are fully operational, astronomers will be able to operate them separately or together.

The LBT's wide field of view, spatial resolution, and sensitivity promise image quality equal to a space-based scope. They should help scientists untangle conundrums about how our universe unfurled



LBT'S TWIN 8.4-meter primary mirrors are spaced 19.7 feet (6 meters) apart in an altitude-azimuth mount. With its binocular design, the LBT can match the resolution of a 22.8-meter telescope. LBTC/RAY BERTRAM

from the Big Bang into its current structure, with galaxies of all shapes and sizes congregating in massive galaxy clusters separated by vast voids.

By the end of 2009, when all planned mirrors and instruments are installed, the LBT will be capable of seeing wavelengths from the near-ultraviolet down to the submillimeter range, which abuts the radio spectrum. Its *forte* will be wide-field surveys of faint objects — from the faintest galaxies ever observed to planets circling Sun-like stars. The LBT will offer new details about how dusty interstellar clouds "spin down" to form nascent stars and planetary systems. And it may even determine how often solar systems like ours blossom in the Milky Way Galaxy.

Rocky road

The LBT achieved first light with a single primary mirror in October 2005. Science observations began only in January 2007 — a year and a half behind schedule. Then came the worst southern Arizona weather LBT Director Richard Green can remember.

"Commissioning took longer than normal because below-freezing temperatures caused technical issues with the primary mirror," Green says. "We made a dozen small changes to its support system and it worked flawlessly, but it took about a year to accomplish that. What's amazing about this project is that almost everything is

HOW DOES LBT'S ADAPTIVE OPTICS WORK?

Ground-based interferometry would never be possible if not for the correcting power of adaptive optics, a method of canceling out distortion caused by atmospheric turbulence. But for adaptive optics to do its job, observatories first need to measure the shape of such turbulence several hundred meters above the telescope.

Laser and natural guide stars probe turbulence 1,000 times per second. Information from these atmospheric snapshots determine how deformable mirrors in the telescope's optics must warp to compensate for the atmosphere.

On the LBT, the scope's 35.8-inch (91 centimeters) secondary mirrors will perform these corrections. Once they're installed in 2009, the secondaries' 672 magnetic actuators will adjust the mirrors and remove distortions. — *B. D.*

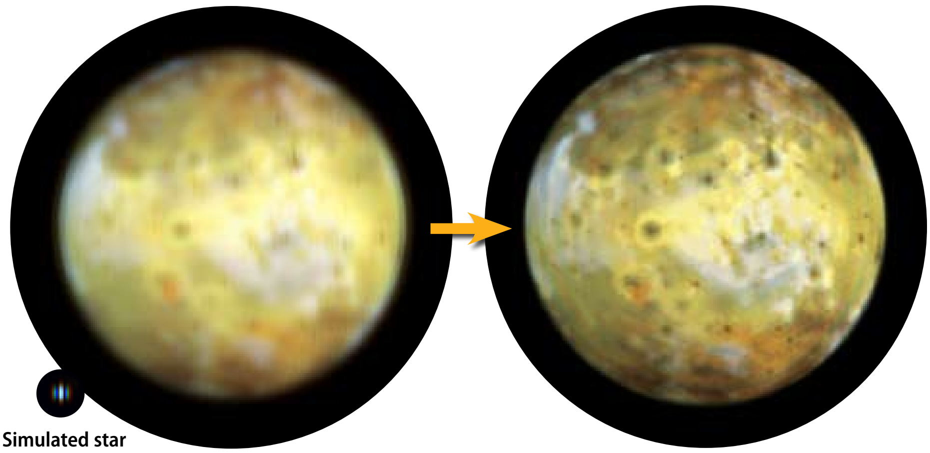
Bruce Dorminey *is the author of* Distant Wanderers: The Search for Planets Beyond the Solar System *(Copernicus Books, 2001). His most recent* Astronomy *article was "What lurks between galaxies?" in September 2007.*

being done for the first time in some way. It just takes time."

Astronomers expect to see scientific papers from the LBT's first observations at January's American Astronomical Society meeting. However, routine science using all of the telescope's planned instruments isn't expected until 2010.

When research does begin, the principal U.S. investors — the University of Arizona, the Ohio State University, and the Tucson-based Research Corporation — will respectively get a quarter, about one-sixth, and one-eighth of the observing time. Nearly half of the LBT's observing time will go to partner institutions in Italy and Germany.

ASTRONOMERS IMAGED the edge-on spiral galaxy NGC 891 in Andromeda October 12, 2005, as a "first light" milestone for the LBT's first mirror. The image required ten 30-second exposures using the Large Binocular Camera, placed at the first mirror's prime focus. LBTC



A SINGLE LBT IMAGE is sharpest in one direction and fuzziest perpendicular to it. These simulated views of Jupiter's moon Io and a single star show this effect of the scope's binocular aperture. The sharpest image occurs in the direction containing both mirrors (horizontally, in this case). The perpendicular direction (vertically, here) shows the lowest resolution.

BY TAKING SEVERAL IMAGES a night, LBT astronomers can achieve the resolution of a 22.8m, circular-aperture scope. As the night progresses, targets rotate relative to the line between the two mirrors. This means the region of best resolution also changes across the target. Combining the images raises LBT's resolution. STAR AND IO IMAGES: LBTC/E. K. HEGE AND J. R. P. ANGEL

Fast, deep cameras

Science observations actually began with the first of two Italian-built Large Binocular Cameras (LBCs) installed on the telescope. Emanuele Giallongo, Rome Observatory's director and the LBC principal investigator, says he and colleagues will carry out wide-field surveys of distant galaxies to better understand how galaxies began clustering and clumping as early as 1 billion years after the Big Bang. "The LBC is very efficient: In a few hours you can reach 26.5 magnitude," he notes. That's 10 times faster than other cameras.

Astronomers already have used the first Large Binocular Camera to survey Kuiper Belt objects at the outer edge of our solar system and to follow up on gamma-ray bursts (GRBs) halfway across the universe. David Trilling, an astronomer at the University of Arizona in Tucson and the principal investigator on the LBT's Kuiper Belt Survey, says his team completed 8 hours of observations in the visible spectrum. They were searching for ancient so-called classical Kuiper Belt objects (KBOs) 12 to 19 miles (20 to 30 kilometers) across. Such objects lie well beyond Pluto's orbit, on circular orbits in the ecliptic's plane.

When both cameras are working on each side of the telescope, Trilling says he will benefit from observations in two separate wavelengths. The first camera is sensitive to light in the blue portion of the spectrum, while the second will be more attuned to red light. "Comparing the flux from two different wavelengths will roughly tell us if the surface [of a KBO] is rock or ice — and even what type of ice it might be," he explains.

Further afield, Notre Dame astronomer Peter Garnavich led an optical survey of gamma-ray bursts. His team has already published eight circulars on LBT observations of six GRBs at distances from 6 to 12 billion light-years. Eventually, Garnavich's team will use the LBT to follow up on GRBs located by NASA's Swift satellite.

"Most of the Swift-discovered bursts have very faint afterglows, making them harder to follow for long periods with small telescopes," Garnavich says. "Since GRB afterglows can be followed with smaller telescopes in minutes to hours after the burst, we try to pick a time when the burst is too faint for other telescopes." The LBT is well suited for catching fading GRB afterglows.

The birth of galaxies

Unlike any current ground- or space-based telescope, the LBT's unique power presents an opportunity to probe the universe's first brush with galaxy formation some 500

THE FAMOUS CRAB NEBULA (M1) supernova remnant was an LBT target during tests in spring 2007. The 36-megapixel Large Binocular Camera produced this true-color image using one of the telescope's primary mirrors. LBTC/VINCENZO TESTA ET AL. (ROME OBSERVATORY)

THE LBC IMAGED imaged NGC 6946, a face-on spiral in Cepheus September 18, 2006. Astronomers created this composite of images through ultraviolet, blue, and green filters using the blue-optimized Large Binocular Camera and a single primary mirror. The image proved the telescope's tracking and camera were nearing the reliability astronomers expected. LBTC/VINCENZO TESTA AND CHRISTIAN DESANTIS (ROME OBSERVATORY)

million years after the Big Bang. The LBT's sensitivity will allow astronomers to take spectra — light broken into its constituent colors — in a way that neither the Hubble nor the Spitzer space telescopes can.

LUCIFER, the LBT near-IR Spectroscopic Utility with Camera and Integral Field Unit for Extragalactic Research, is due for installation in early 2008. This German-built imager and spectrograph specifically targets objects observable in the near-infrared.

The Ohio State University is building MODS, the Multi-Object Double Spectrograph. Optimized for observations from the optical to the ultraviolet, MOD is scheduled to begin routine science observations by late 2009.

LUCIFER will take images and spectra of objects ranging from nearby low-mass stars to the most distant quasars. MODS will take spectra of the faintest objects possible, from stars to galaxies, while measuring their compositions and distances.

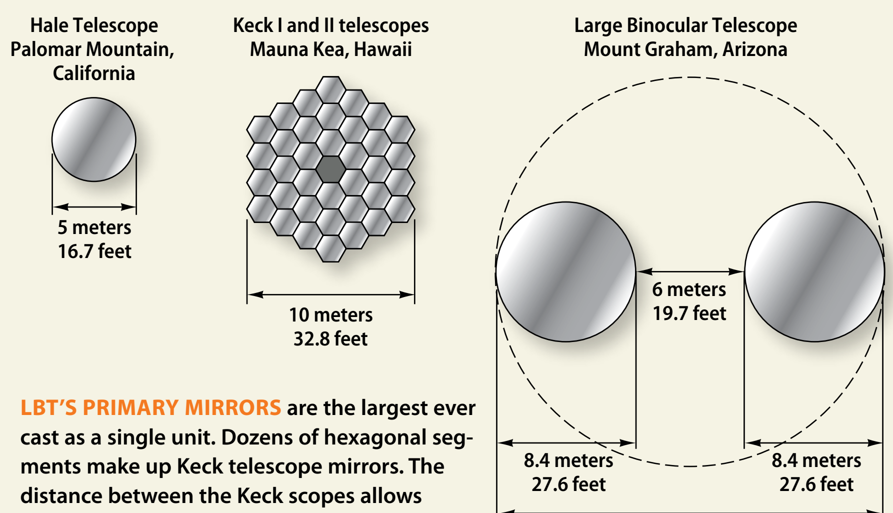
"The LBT will be essential in following up what Hubble sees in the infrared," says Richard Ellis, a Caltech astronomer who has been studying galaxy formation for more than 30 years. That's in part because the LBT will enable astronomers to use new ground-based technology that far exceeds Hubble's current instrument package.

Ellis believes the LBT will explore the cosmos as it was some 500 million years after the Big Bang. That's at the end of the so-called Dark Ages, roughly when the first stars formed. No telescope will take us farther back until the 2013 launch of Hubble's successor, the James Webb Space Telescope.

"Hubble images have shown us what we're missing," Ellis explains, "so we need spectra of these faint galaxies to place them in time. We have huge surveys of the morphologies and masses and star-formation rates of thousands of galaxies at different points in cosmic history. But it's the understanding that always lags behind."

In fact, he says, the LBT would be "astonishingly effective" if a single instrument could merge its light-combining interferometry with its spectra-capturing

How the Large Binocular Telescope compares to other big scopes



LBT'S PRIMARY MIRRORS are the largest ever cast as a single unit. Dozens of hexagonal segments make up Keck telescope mirrors. The distance between the Keck scopes allows them to be used as an interferometer. The Keck interferometer bests LBT's resolution, but LBT has a field of view about 10 times wider.

LBT's twin mirrors provide the resolution of a single 74.8-foot (22.8m) mirror.

ASTRONOMY: THEO COBB

ability. Using interferometry in a spectroscopic mode, the LBT would be able to look at distant galaxies in the process of merging and see how each subcomponent is moving within the merger. This, in turn, would give cosmologists new insight into how the earliest galaxies evolved into life-bearing, carbon-rich, grand spirals like our own Milky Way. A German-initiated study for such a camera is already under consideration, and a working device may be installed on the telescope by 2012.

Seeing exoplanets

Theorists believe the universe's carbon — the stuff that forms the basis of life as we know it — reached its production peak some 7 billion years ago. Thus, the seeds of life were planted when the universe was only half its current age. How did we get from there to here? Do solar systems like ours lurk around other nearby stars? This lonely mountaintop structure should provide some tangible answers.

Astronomers have found more than 200 planets circling Sun-like stars. Many are gaseous Jupiter-like objects in short, often highly elliptical, orbits. Thus, the question remains: Does nature make solar systems like ours — with giant planets in distant, circular orbits — in abundance?

NASA is partially funding a 4-year LBT survey that will use an instrument known as the LBT Interferometer (LBTI) to learn more about the technology necessary for the space agency's own future planet-hunting missions. The LBT's sensitivity at mid-infrared wavelengths is perfectly suited to look for Jupiter-mass planets less than a billion years old.

Phil Hinz, an astronomer at the University of Arizona and principal investigator on the LBTI, says the telescope will scour the area around 80 young, nearby, Sun-like stars. It will search for dust left over from planetary formation in systems that may be similar to our own. Hinz says the LBT will also use an optical coronagraph, which blocks out a star's overwhelming light, as part of the same survey to take snapshots of young Jupiters.

The best hope for such LBTI science is the beginning of 2010. That's when astronomers anticipate both images and low-resolution spectra of such planets. By then, construction may have begun on an ambitious LBT follow-on project.

FOR THE LBT, INTERFERENCE IS A GREAT THING

In 2009, with the LBT's secondary mirrors installed, the telescope will use technical wizardry to produce high-resolution images of almost anything on the sky. The process, called optical interferometry, uses light's wavelike nature to combine the incoming photons. This includes the ability to combine multiple images to gain the resolution of a larger scope.

But there's more. The LBT takes advantage of constructive and destructive interference. When the peaks and troughs of incoming light waves from both mirrors coincide almost exactly, they add together for a brighter image. When the light peaks from one mirror align with the troughs from another, the waves cancel out.

But because these matchups are never perfect, the resulting images always contain bright and dark fringes where, respectively, the light waves add together or subtract. "Instead of seeing round dots for all the stars, you would see these round dots crossed by fringes," says Tom Herbst, chair of the LBT scientific advisory committee at Germany's Max Planck Institute in Heidelberg.

LINC-NIRVANA, a German-built interferometric instrument, is due for installation on the LBT by the end of 2009. It will use constructive interference in the near-infrared to enhance LBT's view of faint objects over a wide field. Herbst is the instrument's principal investigator.

The LBT Interferometer will use destructive interference for its "nulling mode." Astronomers will delay the beam from one of the telescope's apertures to produce a 180° phase shift, causing the light waves' peaks and troughs to cancel out one another. Dark fringes will appear across the combined image, and this, in turn, will block out part of the sky like Venetian blinds across an open window. — *B. D.*

LIGHT AND DARK fringes cross an LBT image displayed on a monitor in the telescope's office-like control room. LBTC

The next superscope

An international consortium with key participation by the University of Arizona and Carnegie Observatories already is planning the Giant Magellan Telescope (GMT). The estimated $500 million GMT would consist of seven LBT-sized, 8.4m mirrors mounted on a single steerable mount. This leviathan may see first light at Las Campanas Observatory in Chile by 2017.

Once GMT wraps up, astronomers may push for a more difficult follow-on project. In cold, dry, infrared-friendly Antarctica, a telescope like GMT would be an unparalleled planet-finder. "In Antarctica, with something like the GMT," Hinz says, "you would be on the edge of being able to detect an extrasolar Earth."

It's hard to imagine such a billion-dollar project getting off the ground today. But if a GMT clone ever does sprout to scan Antarctic skies, it will be the culmination of a technological and scientific journey that began with giant binoculars on an Arizona mountaintop.

WEB EXTRA Learn more about LBT's difficult origins at www.Astronomy.com/toc.