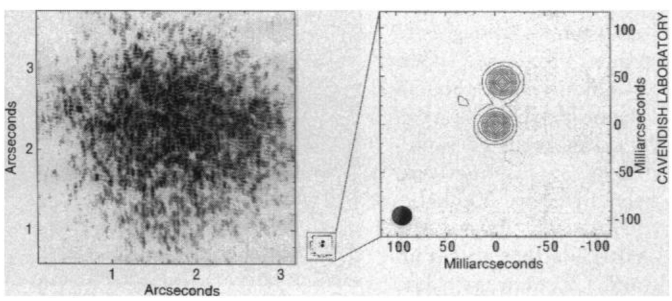
ASTRONOMY

Star-Watchers Team Up Telescopes for a Sharper View

CAMBRIDGE, U.K.—What some astronomers are hailing as a glimpse of optical astronomy's future looks decidedly unimpressive: a set of four 40-centimeter telescopes—no bigger than serious amateurs might have—mounted on steel trusses in a field near the University of Cambridge. Conduits carry light from each telescope into a steel tunnel, insulated with a thick layer of earth. But last September, this modest setup achieved a first: combining the light of separate optical telescopes to create a single image.

The initial images from this apparatus, dubbed COAST, for Cambridge Optical Aperture Synthesis Telescope, appear this month in *Astronomy and Astrophysics*. They are the first ever to distinguish the partners of the binary star system Capella, and they reveal what all the excitement is about: From a system that cost just $1.2 million, loose change compared to the $2 billion-plus price tag of the Hubble Space Telescope, the Cambridge group has achieved a resolution five times better than Hubble's.

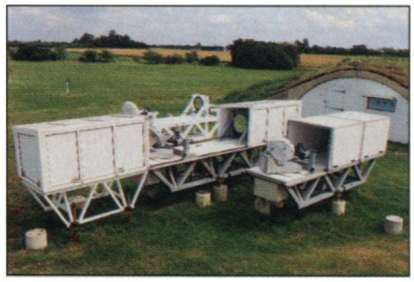
"COAST is opening a window in optical astronomy," says Ken Johnston of the U.S. Naval Observatory in Washington, D.C., which is building a similar system of its own. At the resolutions such systems could ultimately deliver, this light-combining technology should have an impact on astronomy comparable to that of the microscope in biology, he says. "All of a sudden you're seeing two or three orders of magnitude more detail than you could see before."



Dissecting a binary star. COAST's view of Capella *(right)* shows its two partners, invisible to a conventional telescope *(left)*.

The principle, known as imaging interferometry, is nothing new to radio astronomers, who have years of experience combining signals from separate telescopes. But merging optical signals is a far more demanding task. The Cambridge group's success may help overcome the lingering skepticism of astronomers who remember results from the early days of radio astronomy that "turned out not to be particularly reproducible," says Jasper Wall of Britain's Royal Greenwich Observatory. It has also encouraged the half dozen other groups trying to construct similar systems. "Whatever we can learn from them we don't have to learn the hard way ourselves," says Oskar von der Lühe of the European Southern Observatory (ESO).

Driving the rush to optical interferometry is astronomers' hunger for better resolving power. The largest telescopes, such as the recently completed Keck 10-meter telescopes on Mauna Kea, Hawaii, still show stars as little more than bright specks. Astronomers want to see details in the specks—starspots, flares, and the planets that may accompany stars. "Absolutely the only way is to have much bigger telescopes," says John Baldwin, leader of the COAST group. A telescope with a 100-meter mirror could do the job. But even if such an instrument were feasible, its performance would be limited by atmospheric distortion: "One of the problems about any kind of high-resolution imaging is that the information that's coming through the atmosphere has been very badly scrambled," says fellow COAST scientist Craig Mackay.



COAST

All together now. COAST's four mirrors send light to a buried optics laboratory, where it is merged and analyzed.

Radio astronomers, however, have developed ways to cope with these problems. The long wavelength of radio waves increases the size of the telescope needed to get a particular resolution, but also eases the path to a solution: precisely merging signals from telescopes separated by many kilometers. The resulting "interferometer" has the resolution of a single telescope with a diameter equaling the separation of the smaller linked telescopes.

The key to this strategy is aperture synthesis, invented by Cambridge radio astronomer Martin Ryle in the early 1950s. When the output of two receivers surveying a pattern of light or radio emissions is combined, it yields an interference pattern that indicates the strength of a single regular component of the pattern. Aperture synthesis builds a complete image by applying the mathematics of Fourier analysis to the output of pairs of receivers twirled through the sky into different orientations by the Earth's rotation.

Ryle's strategy worked well for radio interferometers with baselines of no more than a few kilometers. But when separations grew larger, differences in atmospheric conditions experienced by the separate radiotelescopes scrambled the relative timing of wavefronts arriving at different receivers—the so-called phase information, which is critical to forming images. In 1958, however, the British radio astronomer Roger Jennison of the Jodrell Bank Observatory discovered that some information can be recovered in the so-called closure phase—the sum of the phase differences around any closed loop of three or more detectors. By combining aperture synthesis and closure phase, radio astronomers now routinely synthesize images from telescopes thousands of kilometers apart (*Science*, 22 January 1993, p. 454).

Most optical astronomers, working at the much shorter wavelengths of visible light, have been leery of all this wizardry. As Johnston puts it, "They don't believe it will work." The tolerances needed for combining images at visible wavelengths seemed impossibly severe, and they worried that all the processing steps between raw data and final image could create unrealistic artifacts. Until now, optical interferometry has been restricted to systems that combine light from two telescopes to measure a star's diameter or relative position—applications that don't require making an image.

But after several proof-of-principle experiments, in which Mackay, Baldwin, and their colleagues masked the light of a single telescope to form separate beams and studied the resulting interference pattern, the COAST group was ready to try weaving light from separate telescopes into an image. The feat required fast, efficient detectors and high-precision laser control: "It was quite a nightmare getting it all done," says Mackay.

COAST's four telescopes, set in a 60-meter Y pattern, send their light to detectors via a system of trolley-mounted mirrors. Controlled by lasers, the trolleys move to compensate for Earth's rotation, ensuring that by the time the four beams are combined they have traveled exactly the same distance, to within a few wavelengths of light. The trolleys also oscillate at a distinctive frequency for each beam to give its light an identifying signature.

This motion has the effect of sliding each beam back and forth relative to the others, so that when the light is merged, the resulting bright and dark interference bands sweep back and forth over the intensity detectors at a different rate for each pair of telescopes. The software can then disentangle the separate interference bands from each pair, analyze them to eliminate atmospheric distortion, and merge them to generate the image.

According to Mackay, the hardest part is getting the beams to overlap exactly, then keeping them that way. On the scale of a few wavelengths of light, he says, "all the things we are using in fact are rather wobbly and jellylike." But it all worked well enough for COAST to make the first images ever of the two distinct stars in the Capella star system, which are about 100 million kilometers apart—closer than Earth to the sun.

"This demonstration is extremely important to show that this [technique] will do what it's supposed to do," says Johnston, who with his colleagues is building the Navy Prototype Optical Interferometer near Flagstaff, Arizona, where a six-beam system will generate star images by the summer of 1997. It will be joined by an array of five 1-meter telescopes slated for construction at the Mount Wilson Observatory near Pasadena, California. Still larger systems are in the offing at ESO's Very Large Telescope in Chile, whose four 8-meter telescopes will operate part-time as an interferometer, and at the Keck.

With COAST and its successors, optical astronomy will enter a new era, say proponents of the technique. "Only interferometers have the capability for imaging the surface of stars in any way comparable to what we routinely do for the sun," says Hal McAlister of Georgia State University, who heads the Mount Wilson project. The technology may also offer a view of planets around other stars (*Science*, 2 February, p. 588). "If these planets are pretty warm ... there may be a fair chance you can image them," says von der Lühe.

Some optical astronomers are more cautious. Says Charles Jenkins of the Royal Greenwich Observatory, "The question about interferometry has to be not whether it will work, but whether it can be made to work on an interesting number of objects, and that means making it work on much fainter stars." Faint objects require larger telescopes to gather more light, but atmospheric effects can scramble the crucial phase information across a single large mirror.

Antoine Labeyrie of the Observatory of Haute-Provence near Nice, a pioneer of optical interferometry who is currently constructing a prototype for an array of 27 telescopes, has no such doubts. "Large multitelescope systems," he says, "are the unavoidable evolutionary path in optical astronomy."

–Andrew Watson

Andrew Watson is a science writer in Norwich, U.K.

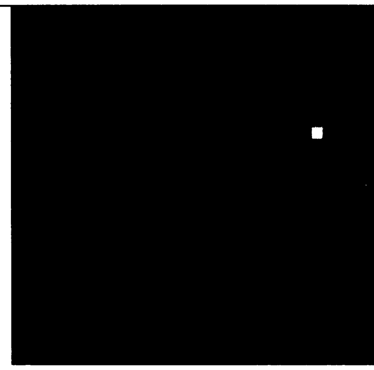
ASTRONOMY

Adding Depth to X-ray Maps

When the Bard wrote that "the floor of heaven/Is thick inlaid with patens of bright gold," he didn't know how right he was. Present-day sky-watchers, who have pushed their observations far beyond the optical wavelengths that inspired those lines, still find the display both dazzling and—yes—floorlike, because their images lack depth. The problem is acute for observers studying x-ray emissions from great bubbles of hot plasma in our part of the Milky Way, whose three-dimensional shapes should hold clues to the history of star formation. Because x-ray photos yield only a projection of these emissions, says Priscilla Frisch, a University of Chicago astronomer, "it's like looking up at the plane of the sky and saying, 'Oh, how beautiful,' but not knowing how far away anything is."

That frustrating lack of depth perception may be ending, however. At the American Astronomical Society meeting in San Antonio last month, Q. Daniel Wang of Northwestern University described a technique he calls "x-ray shadowing" for adding depth to photos like those obtained by the Roentgen x-ray satellite. Wang, who uses cool, dense clouds of neutral gas that waft through our galactic neighborhood as a kind of cosmic range finder, has begun to "put the distance scale on the x-ray emitting regions," says Frisch. His first results have also tossed fuel on a long-simmering debate about the distribution of hot plasma throughout the Milky Way.

All-sky surveys show a giant splotch of "hard" x-ray emission—the signature of a plasma, or ionized gas, at several million degrees kelvin—in the direction of the galactic center. A softer glow from slightly cooler plasma streams in from all directions. The hard emission is thought to come from a "superbubble"—a hot, tenuous region blown up like a balloon by repeated supernova explosions—centered perhaps 500 light-years away toward the constellations Scorpius and Centaurus. The dense gases that pile up around these regions are fertile ground for forming new stars.



Q. DANIEL WANG

Cool shadow. Gas cloud to the left creates dim spot by absorbing x-rays.

The soft emission is more mysterious, although astronomers are certain of one thing: Because x-rays at these wavelengths should be absorbed quickly by intervening gases in the galaxy, they must come from another plasma bubble directly surrounding the solar system. But did this "local bubble" also form from supernova explosions or, as Frisch has suggested, from a breakout, or huge leakage, from the Scorpius-Centaurus superbubble? The answer could be of more than local interest: Competing theories view the gases in the Milky Way either as a warren of hot superbubbles connected by tunnels reminiscent of the breakout scenario, or as mostly cool gas with isolated hot pockets.

The size of the bubble could be a clue: An influx of gas might heat a larger volume than a single supernova, for example. But, says Randall Smith of the Goddard Space Flight Center in Greenbelt, Maryland, "it's like being in a foggy room—we can tell that there is something [hot] right around us, but we have no idea of the distance." Enter Wang. He sought to remedy this problem by correlating patches of infrared emission—indicating the presence of cool gas clouds—with the shadows they leave on x-ray maps as they block x-ray emissions. Then Wang calculated the distance to these gas clouds by noting which stars of known distance along the clouds' sightlines are partially obscured and which aren't.

The final step is to find, say, two clouds along almost the same sightline. By comparing x-ray "colors" based on spectral features of the plasmas between Earth and each cloud, Wang infers the average plasma temperatures out to the near cloud and in the interval between the clouds. Wang's first results along one sightline show plasma at a million degrees extending some 200 light-years into space and plasma at half that temperature pushing out yet another 300 light-years. He thinks a structure of that size is more consistent with "a flood of hot gas from the Scorpius-Centaurus superbubble," possibly expanding into the remnants of a very old superbubble in our region, than with a pocket heated by a recent, local supernova.

Opponents of that view laud Wang's measurements but dispute his conclusions. Says Don Cox of the University of Wisconsin, "I think almost anything that causes heat to be deposited here—whether it's leaking in or from an explosion that happened here—would generate a structure of the kind he's seeing." But as Wang uses more sightlines to piece together a fuller picture, say Cox and others, the emerging shape should reveal golden clues to the Milky Way's structure.

–James Glanz