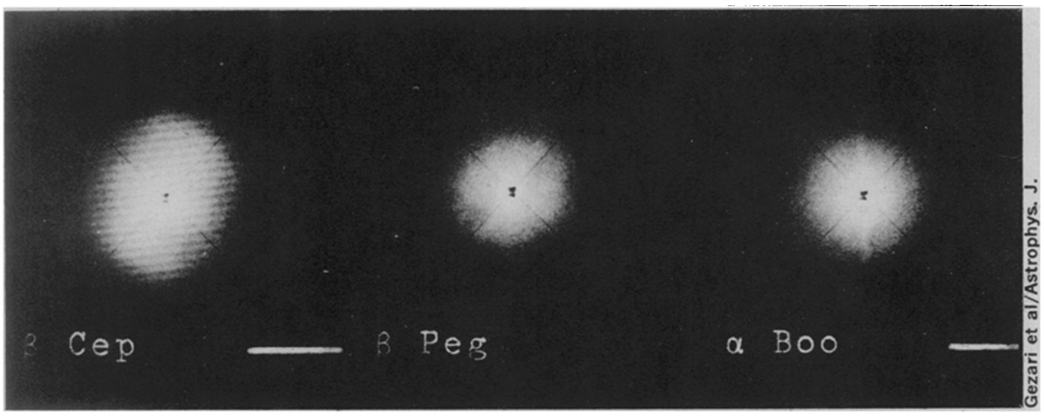
A SHARPER VIEW OF THE STARS

New techniques promise ways around the damage air turbulence does to images of astronomical objects

by Dietrick E. Thomsen



Resolution of two stellar disks and of one binary (Beta Cephei) with speckle interferometry.

The twinkling of stars has inspired a certain amount of poetry ranging from good to dismal including a famous nursery rhyme for which either Mozart or Haydn wrote the music. (There are themes in both their works that sound like it.) Many people find stellar twinkling esthetic or romantic. Astronomers wish it would go away.

As long as the earth has an atmosphere, stellar twinkling is not going to go away. Until they get a telescope on the moon, astronomers will (except for orbiting space telescopes) have to live with atmospheric distortion or find ways around it. The interesting thing is that in recent years, after millenia of cursing the atmosphere, astronomers are beginning to develop ways of repairing some of the damage it does to stellar images. There are two general methods: speckle interferometry and real-time correction using devices in or on the telescope—the so-called "rubber telescope."

What atmospheric turbulence actually does can be described as corrugation of a wavefront. When a plane wavefront from a star gets into the air, atmospheric turbulence tilts it. The turbulence varies from point to point, and so does the tilting. A plane wave comes out randomly corrugated.

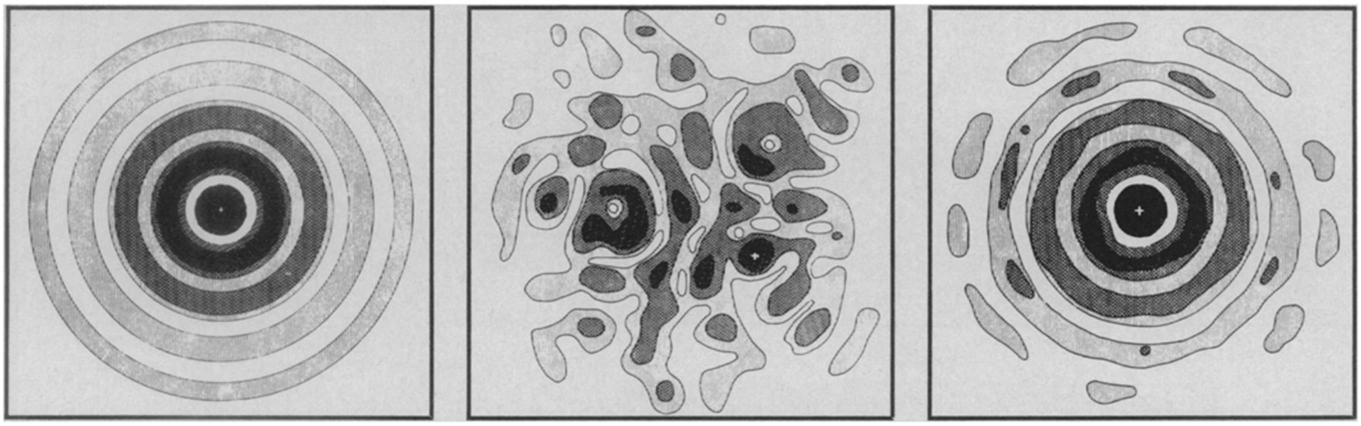
A telescope mirror is an instrument for converting angles to positions: All the light that strikes it at a given angle is sent to a single point. If a plane wave front is received, a point-for-point image of the source is produced. All the rays from one point are sent to one point, and they arrive in phase with each other. If the mirror gets a corrugated wavefront, it sends the light from one point every which way; the rays arriving at a point on the image may or may not be in phase.

The result is what is called a speckle pattern. Instead of a sharp image of a stellar disk, there is a blob in the middle where the star should be, surrounded by a bunch of dots, the speckles. The eye does not see the speckle pattern because it changes too fast. Atmospheric turbulence changes on the average about 50 times a second, and the speckle pattern changes with each change. All the eye sees is the average blur, "the big, fat, fuzzy image," as William L. Burke of the Lick Observatory describes it.

Photography is quick enough to catch the speckle patterns, and when such pictures have been obtained, they can be used to obtain information that poor seeing would normally render it impossible to get. In a 1970 paper, Antoine Labeyrie of the Paris-Meudon Observatory showed how, and since then he and Daniel Bonneau of Paris-Meudon and D. Y. Gezari and Robert Stachnik of the State University of New York at Stony Brook have done observations with the technique. Interest has spread, and a number of astronomers, have come into the business, each of them trying to improve the technology in one way or another. They include Keith Knox and Brian Thompson at the University of Rochester, Roger Lynds at Kitt Peak National Observatory, Arthur Schneidermann and collaborators at AVCO Corp., and groups at the University of Maryland and the University of Toronto.

One way the technique works is illustrated by the case of a binary that the eye can't resolve through the telescope. There will be two stars quite near each other on the image, and the light from both stars will have come through virtually the same part of the atmosphere and be identically distorted. Stachnik mentions Capella as an example. This is a binary system with components separated by about 1/20 arcsecond. From it one gets two identical, overlapping speckle patterns. The separation of identical speckles in the two patterns is related to the separation of the binary stars, and by auto-correlation techniques, finding and measuring identical speckles from the two stars, the separation of the binary can be found.

It doesn't necessarily have to be a binary. The technique works with extended objects as well. By similar means one can calculate stellar diameters. If a lot of speckle patterns are optically processed by shining coherent light through them, a kind of diffraction-limited image of the star can be built



Computer simulations of a test image with no atmospheric distortion, with atmospheric distortion and restored.

up, the sharpness of which is governed by the size of the telescope.

Observations at various observatories, especially with the 200-inch telescope at Mt. Palomar, show that the process works. Now the push is to find easier ways than film to record and process the data and to increase the data-collecting efficiency for work on fainter objects. In France Labeyrie and Bonneau are working on a television system. Stachnik and others in a collaboration between Stony Brook and the Itek Corp. are working on a system that uses the so-called Pockels effect, an electro-optical phenomenon, to record erasable images in a special crystal and process them.

This new system is expected to increase both the speed and the sensitivity of speckle interferometry. So far the technique has been limited to brighter objects, fifth magnitude and brighter.

There are many questions scientists would like to attack with the new technique. One has to do with the cosmic distance scale. The distance to the extragalactic star clusters, clusters that are in a way satellites of our galaxy, is a crucial step in the scale since all the farther steps depend on it. The accuracy of the distance measurement can be improved by precise knowledge of the orbits of binary star systems in it.

Of course the system will be used to look for previously undiscovered binaries and check the separations of those poorly documented. One important example is the subdwarf binary system Mu Cassiopeiae. If the separation of the two stars can be determined, it can be used to figure their helium content. Since these two are among the galaxy's oldest stars, such a datum would lead presumably to an estimate of the initial helium abundance of the universe.

The observers want to continue their program of measuring stellar diameters and especially to further investigate the curious fact, discovered by Labeyrie and Bonneau, that the diameter of Betelegeuse varies according to the color of the light one views it in.

And finally they want to take speckle interferometry to extragalactic sources, to study the nuclei of Seyfert galaxies and some of the quasars in the hope of collaborating with radio astronomical interferometry to investigate the structure of those bodies.

Amidst all the ferment, however, there are negative views. Burke, for example, an interested observer of the goings on, says that because speckle interferometry is restricted to bright objects, "it will never solve our seeing problems."

Now suppose that instead of correcting the distortion of the images after recording them, one were able to do it in real time. This is the "rubber telescope" concept. It means compensating for the phase distortions while the light is still in the telescope, corrugating the mirror or some other correcting element so that it just compensates for the atmospheric distortion at any point on the image. Two examples of this kind of work are the project of Richard A. Muller and Andrew Buffington of the Lawrence Berkeley Laboratory and the Real Time Atmospheric Corrector being worked on by John Hardy and others at Itek.

In principle the mirror can be divided into movable sections that can each be moved to compensate for turbulence in its sector.

Muller's work began mathematically. The importance of the mathematics is that once one has an acceptable mathematical definition of image sharpness, the expression can be used to construct a feedback system. A sensor senses the sharpness of the image that a telescope gives. From this determination and the mathematics it decides how to move one after another of the small segments of an adjusting plate placed in the path of the light between the mirror and the image plane. The feedback system adjusts the correcting elements till it gets an optimum image.

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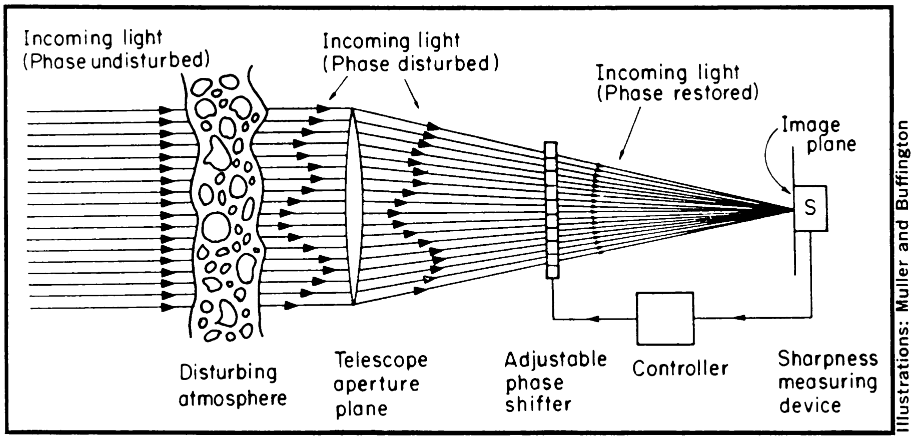

Proposed "rubber telescope" compensates for atmospheric distortions of light.

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find a way to get some useful scientific observations out of the tests."

The enormous weight of the antennas (214 tons each) and their diesel-electric transporters (70 tons) will be distributed across two sets of standard railroad tracks, separated by an 18-foot distance between their centerlines. If it is an irony that the antennas of the most sophisticated radio astronomy observatory in the world will be moved about on railroad tracks, it is further irony that the tracks, and the ties on which they will rest, will be not new, but used. The prices of new timber ties and railway-track steel have skyrocketed in the past year or two. So VLA officials have been scrambling to obtain what they need from no-longer-used railroads on military bases and other government facilities.

The sprawling array will cross ranch property boundaries, one county line and U.S. Highway 60. A standard railroad crossing will be built where the northern arm goes across the highway. When the antennas are moved into various configurations along the array, they'll occasionally have to cross the highway, creeping along at rates of 5 miles per hour. "There's a clear view for 10 miles in either direction so there shouldn't be any problem," says Wells. "But," adds Egler, "I sure bet we see some surprised motorists."

The antennas will make their observations not from the main tracks, but from permanent observing stations, 100 feet off to the side, connected by spurs perpendicular to the main railway. This will leave the main tracks free to carry personnel and maintenance equipment and alleviate the need for access roads. There will be 72 of these observing stations, giving astronomers great flexibility in positioning the 27 antennas. Each station will have three foundations, one for each leg of the antenna. The foundations are meant to prevent overturning of the antennas and to support them in a precisely fixed position.

Every antenna could be moved to a new position within 48 hours, according to Wells. Since only one antenna will be moved at a time, observations can proceed without interruption.

But it will be seven more years before all the construction and testing is completed and astronomers are making full operational use of all antennas at once. The construction is not all that difficult, but the funding is being spread out over a number of years so that the chunks of money required from any given budget year are smaller. Loyal engineers, Wells and Egler fully understand the budgetary realities, but they can't disguise a certain wistfulness about the length of time required. Says Egler: "If we had all the money at once, we could finish this up in two years." □

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If there are 25 elements in the corrector, there is less than a millisecond to adjust each one since the turbulence changes about every 20 milliseconds. Yet Muller and Buffington think it can be done.

Itek's RTAC is in essence a rubber mirror. The basic element is a piezoelectric crystal. When a voltage is applied to a piezoelectric crystal, it can be made to expand or contract. The crystal has independent electrical connections for each two seconds of arc across its surface. Thus each element of that diameter can be individually squeezed or expanded. The surface of the piezoelectric crystal is covered with a thin layer of aluminized glass to do the actual reflecting.

The deformable RTAC mirror deforms according to instructions given by a shearing interferometer that makes an instantaneous map of the wavefront as it enters the telescope. RTAC is a reimaging device that can be mounted on an existing telescope and will work on the light reflected by it.

A laboratory model of RTAC now exists and has done well in tests on artificially degraded images. Within the year Hardy and collaborators hope to try it out on actual stars. It is expected to be useful for objects as faint as 10th to 12th magnitude.

These are only a few of the projects intended to help astronomers with their seeing difficulties. Success would remove a serious age-old frustration. Astronomers' feeling about it is exemplified in the tone of Stachnik's voice when he says of RTAC: "They show an image of a star distorted. They flip a switch, and the image shrinks to a little dot." □

. . . Infrared *(from p. 135)*

advantage is that radio receivers are more sensitive to amplitude and frequency differences than infrared ones at present. Heterodyne techniques have also been tried in infrared interferometers. Testing with artificial light sources indicates that one can get interference fringes this way. The actual spacing between the two telescopes that would be set up in a working model is still a matter of controversy.

Given the techniques now available, what do you see? Starting near home, infrared can be used to study the atmospheres of the planets. Take Mars for example. Infrared confirms that carbon dioxide is there. Infrared can be used to study the temperature of the Martian atmosphere as a function of height above the surface and pressure. This is one way to measure variations in the height of the surface.

The same can be done for other planets. Work on the pressure and temperature of gases on Jupiter has only recently been done. Among other things it found a lot of ammonia there.

By knowing the detailed structure and activity of other atmospheres planetary scientists can come to understand the earth's better. The atmosphere of Venus is 100 times as heavy as the earth's; that of Mars one hundredth as heavy. Scientists cannot experiment on the earth's atmosphere by, say, heating it up 50 degrees and seeing what happens, but by observing the atmospheres of other planets they can see some of what the possible effects of changes in our own might be.

Further out in the galaxy the beginning and the end of a star's life provide circumstances where infrared observation is especially valuable. Dust clouds appear to be the places where stars are born. "One can see through them in the infrared," says Rank. "It's impossible to see through them in the visible." The temperature of the dust is characteristically anything from 150 to 300 or 400 degrees K.

In the clouds one sees relatively warm objects that are totally invisible optically. These are presumably the spots where dust and gas are condensing into stars. The infrared observers want to study the time scale of star formation and the mechanisms by which it occurs.

Toward the end of its life a star may puff off a cloud of gas which forms a dusty, gassy halo around the star. How the dust gets formed presents astronomers with a chicken-or-egg problem, says Rank. Dust particles don't like to form unless there are other dust particles around, but somehow the process has to get started.

Once the dust forms, infrared astronomy can study its chemical composition. One finds calcium carbonate, silicates (sand), ordinary minerals. The dust is similar to rocks on earth. "It's interesting to know that that's the way it is," says Rank.

To further universalize chemistry—to prove that the far reaches of the universe are made of stuff much like that in our corner of it—one can study the chemistry of distant galaxies. Infrared will prove a useful medium in this endeavor.

Finally there are the now famous—and strange—infrared sources in the centers of galaxies. One question to settle, says Rank, is whether the sources are really in the centers or whether it just looks that way. Of course the big question is: What are they?

And who knows what new species of infrared-emitting object may be discovered next week. The universe, seen and unseen, is full of many more kinds of things than Horatio's philosophy ever dreamed of, and one has to watch closely to keep up with the astronomers as they discover them. □