Taking the Measure of the Stars

Optical interferometry, made by modern technical developments, promises a new level of detail in the knowledge of celestial objects. Astronomers hasten to include it in plans for large new telescopes.

By DIETRICK E. THOMSEN

The development of astronomical equipment has been driven by desires for greater light-gathering capacity to see fainter objects and for greater resolution to see finer detail in the structure of those objects. Recently developed techniques for making larger mirrors and for making multiple mirrors work together are responding to the first need. Even more recent developments in interferometry, which increases resolution by combining signals received at widely spaced telescopes, now cater to the second need.

Indeed, recent developments in interferometry with visible light are so promising that the designers of three large telescope projects that are intended to be large light gatherers — the U.S. National New Technology Telescope, the big binocular or Columbus project and the European Very Large Telescope — have decided to add interferometric capabilities as well.

In addition, smaller instruments designed specifically for interferometry are under construction or planned. Some of these projects were discussed during the recent meeting in Seattle of the Optical Society of America.

Interferometry began as a technique in optical laboratories, using visible light, but its most widespread use in astronomy so far has been in the radio range. Difficulties with atmospheric turbulence have hindered its application in visible-light astronomy.

In the laboratory, a light beam from a given source is split in two, sent over different paths for some distance and then recombined. If the two paths are precisely equal, the recombined waves will reinforce each other. If not, they will partially or wholly cancel each other. Imaged on a screen or in an eyepiece, the latter situation appears as a series of light and dark stripes or "fringes." A skilled interpreter can tell from the number, thickness and spacing of the fringes by what fraction of a wavelength the two paths differ. The technique can measure differences in distances and positions that are far too fine for the eye to determine with any ruler, and so it is frequently applied in research and technology.

In astronomy, radiation from a given source is received at two or more separate telescopes and then combined. From the resulting fringe pattern astronomers can deduce sizes and structural details too fine for a single telescope to show. Generally, the farther apart the receivers are, the finer is the detail that can be resolved.

However, in the real world, atmospheric turbulence continually changes the refractive properties of the air, and it changes those properties in different ways in different locations. This produces what we see as stellar twinkling, and it destroys the correlations on which interferometry depends unless the two receivers are under the same isoplanatic patch, the area in which the atmospheric refraction changes uniformly.

The size of an isoplanatic patch is difficult to determine, as research in that area tends to be classified, but it is small, too small for meaningful interferometry. In the century and a half since interferometry was developed in the laboratory, astronomers working with visible light have not been able to utilize it to any great extent. In contrast, because radio waves are not affected by atmospheric turbulence, interferometry is the most common observing technique in radioastronomy. It can even combine radiotelescopes on earth and in orbit (SN: 10/18/86, p.245).

Now it seems to be the turn of visible-light astronomy to enjoy the benefits of interferometry. The change comes largely from successes in recent years in using computer programs and active optics directed by computer-driven servomechanisms to compensate for atmospheric turbulence. The active systems differ in technical details, but the basic idea is that a sensor continually monitors the telescope's image and feeds information to the servo, which compensates by altering the shape of the mirror slightly or changing the orientation of other parts of the optics. The key is continuous feedback plus delicate mechanisms for making slight adjustments in the geometry of the optics, all of which began to be invented and developed in the early 1970s.

Usually these systems fasten onto some bright star in the field of view and make their decisions according to its image. But to avoid having to change from one reference star to another as the telescope moves, the planners of the European Very Large Telescope (VLT) plan to generate an artificial reference source, according to Fritz Merkle of the European Southern Observatory headquarters in

Garching, West Germany. There is a layer of the upper atmosphere, he told the Optical Society meeting, that scatters the yellow light of sodium — what spectroscopists call the sodium D lines. A sodium laser beam, reflected by this layer, will provide artificial sources for the VLT to monitor itself with.

In addition to the classic phase correlation interferometry, stars and other astronomical objects offer the possibility of intensity or amplitude interferometry. A star consists of millions and billions of individual light emitters, each contributing its own output. When all these signals add up to form the overall signal of the star, the sum comes out with a complicated pattern of minute fluctuations in intensity and amplitude that is related to the size of the object. When processing the received signals in an interferometer, astronomers may choose to use correlations in either of these properties to get geometric information about the source.

Antoine Labeyrie in France and astronomers in Australia have pioneered instruments dedicated to visible-light interferometry. The intensity interferometer at Narrabri, in New South Wales, Australia, has measured the diameters of a number of stars that were unobtainable otherwise. Recently, astronomers John Davis and William J. Tango from the University of Sydney have reported success with a prototype amplitude interferometer (SN: 10/4/86, p.214).

In November 1986 the Australian government granted $500,000 to the University of Sydney for construction of a stellar interferometer with a 640-meter baseline (distance between receivers). When completed, the instrument should be able to measure the diameters of about 50,000 stars (down to eighth magnitude) with an accuracy of about 2 percent. Up to now interferometry has had to concentrate on giant stars and has measured only about 30 of those.

In another year or so, a dedicated stellar interferometer will be operating on Mt. Wilson in Pasadena, Calif., according to Michael Shao and M. Mark Colavita of the Smithsonian Astrophysical Observatory in Cambridge, Mass. At the meeting, Shao described the instrument as employing a 12-meter north-south baseline to start, and later extending this to 20 meters. Ultimately it may also develop an east-west baseline of 5 or 6 meters. This Mark III interferometer, as they call it, will be used at first for astrometry, measuring star positions to an accuracy of a thousandth of a second of arc. Astrometry is important for a number of things, including the establishment of cosmic distance scales and the determination of whether stars are accompanied by dark companions that may be planets. Later, Mark III will measure stellar diameters.

Enter now the really big telescopes. Planning for the National New Technology Telescope (NNTT) began about a decade ago. As Jacques M. Beckers of the National Optical Astronomy Observatories in Tucson, Ariz., told the meeting, it was then intended to be a large light gatherer. In view of the success of the Multiple Mirror Telescope on Mt. Hopkins near Amado, Ariz., of which Beckers was director for some years, the designers of the NNTT have decided it should be a square array of four 8-meter-diameter mirrors on a common mount. The mirrors could work independently, doing as many as four different observations at the same time, or they could throw their light together in a single image, thereby equaling the light-gathering capacity of a single 16-meter mirror.

To align the mirrors properly to form a common image, the NNTT will use a system designed by Beckers that illustrates a technological application of interferometry. Optical bridges will join the mirrors in pairs. Each bridge will take a little light from the edges of the two mirrors it joins and combine that with light from a reference source. The appearance or nonappearance of interference fringes when these test signals are combined will tell the operator how to adjust the alignment of the mirrors.

Now the planners have decided to make the NNTT a research interferometer as well as a light gatherer. The mirrors will be able to operate in pairs as interferometers, and in that mode they will get the resolution characteristic of a single 21-meter telescope.

The NNTT's rather inflexible design, a close-packed, rigid square array, has disadvantages for use as an interferometer. Designing an instrument primarily as an interferometer, astronomers would want to choose a longer baseline between mirrors: The longer the baseline, the finer the resolution of detail, and they might want to make the mirrors movable. However, a long baseline can get fine resolution only along the projection of itself on the source. Astronomers want two-dimensional information, coverage of what they call the *u,v* plane. For this reason astronomical interferometers are often designed, not simply as linear arrays, but in two dimensions, as diamonds, hexagons, circles or crosses. The NNTT with its close-packed square array will give good *u,v* plane coverage, Beckers says. It will thus complement the longer-base interferometers, Beckers says.

The big binocular or Columbus project — so-called because it aims to be operational on or near the 500th anniversary of Columbus's famous voyages — is planned to consist of two 8-meter telescopes with a distance of 20 to 23 meters between their edges. This could someday be expanded to a linear array with more mirrors, according to Neville J. Woolf of the University of Arizona's Steward Observatory, who described it at the meeting. Each of these mirrors could operate independently, or they could work together as an interferometer. The project unites the University of Arizona at Tucson, Ohio State University at Columbus, the University of Chicago and a foreign institution that is not yet ready to announce itself.

The telescopes will have an unusually stubby design with a short (*f*/1) focal length to increase their stiffness, thus lessening problems due to wind and thermal stresses. The site chosen, Mt. Graham near Willcox, Ariz., has some of the darkest skies and least cloud cover in the United States, but it is also high and windy. Right now a two-year project to study design and funding is under way. Meanwhile, a somewhat lesser project, the Vatican Advanced Technology Telescope of the Vatican Observatory in Castel Gandolfo, Italy, which will use an array of similar 1.8-meter telescopes, is being watched as a kind of pilot project. If the many innovations involved succeed on a smaller scale, the prospects for the Columbus project will look favorable.

The VLT, planned by astronomers from the nations that operate the present European Southern Observatory, would be an array of four mirrors, 4 to 8 meters in diameter, along a line that could be as long as 150 meters, Merkle says, depending on the space available at the location finally chosen. These could work singly or in groups as interferometers. Ultimately, an array of smaller mirrors (1.5 to 3 meters across) parallel to the main array and one of smaller mirrors perpendicular to the main array might be added to increase the coverage in the *u,v* plane.

The precise design will depend on the space available at the site chosen. That could very likely be the European Southern Observatory's present main site at Cerro la Silla, Chile. The astronomers hope for approval by the governments concerned by the end of 1987. If that is forthcoming, they could have the first telescope operating by 1993, Merkle says.

Obtaining interferometric capability for any of these projects means overcoming a variety of complicated technical difficulties. Yet thanks to the work of such pioneers as Labeyrie and the Australians, astronomers now think it can be done.

If it is achieved, astronomy will enter a new regime of stellar studies, in addition to whatever visible-light interferometry may do for galaxies and quasars. Astronomers will be able to compare a star's size and possibly some of its surface features with its spectral class and evolutionary stage. Are giants really that big? How dwarfish is a dwarf? How does a star's size relate to its evolution? Astronomers will also gain more precise information on stellar motions, particularly those that may be induced by the presence of planets or other dark companions. □