Combined URSI/G-AP Session, Paper 3, 9:00 A.M., Wednesday, Schoenberg Hall

THE WHOLE-EARTH ARRAY — DEVELOPMENTS IN VERY-LONG-BASELINE INTERFEROMETRY

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Radio astronomers, in common with many others who work with radio antennas, have always felt rather handicapped by the basic physical relationship between the size of an antenna (measured in wavelengths) and its resolving power (or beamwidth): $\Delta\theta \sim \lambda/D$, where $\Delta\theta$ is the beamwidth in radians, λ the wavelength and D the diameter of the aperture. The largest fully-steerable antennas used as radio telescopes have dimensions of at most a few thousand times their minimum useable wavelength; as a result the beamwidth of such instruments, and hence the angular resolving power, is at best a few minutes of arc.

Radio astronomers have for some time evaded this limit by use of interferometers (1). Small antennas at distances of many thousands of wavelengths have been connected by coaxial cable or microwave link to obtain information about the angular distribution of radio sources on smaller angular scales. When many such observations are made with different spacings and orientations of the small antennas, two-dimensional radio maps may be obtained with resolution of the order of the wavelength divided by the largest spacing between the antennas. This process is known as aperture synthesis (2). By means of this technique many radio sources have been mapped with resolutions of ~ 10 seconds of arc. Microwave-linked interferometers have been extended to baselines of several hundred kilometers, giving resolving powers of ~ 0.1 second of arc (3).

About eight years ago it became clear that wide-band tape recordings might permit us to dispense with the real-time link between the elements of an interferometer. If so, then the elements might be arbitrarily far apart, subject only to the restriction that the radio source to be studied must be simultaneously visible at both observing sites. The tape recordings are later played back in synchronism, and the two recorded signals are cross-correlated as are the signals which come directly from the antennas in a real-time interferometer. This technique has come to be known as very-long-baseline interferometry (VLBI).

For the VLBI technique to succeed, it is necessary that each recording station be equipped with an atomic frequency standard with sufficient stability that the two receiving local oscil-

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lators do not slip in phase by more than about a radian in the duration of a recording. Rubidium and hydrogen standards have been used for this purpose. Furthermore it is necessary that the recording medium preserve time with an error of less than the reciprocal of the recording bandwidth. Time is kept with the necessary accuracy by a clock driven from the atomic frequency standard. Both digital and analog recording schemes have been successfully used, with bandwidths of ~ 1 MHz. The technique was first applied to study of distant radio sources by independent groups in Canada and in the USA in 1967 (4, 5). Baselines have been extended to nearly the earth's diameter at wavelengths as short as 3 or 4 cm, giving angular resolutions finer than 10^{-3} seconds of arc.

Results from the first several years' work with this technique have been reviewed by Burke (6) and Cohen (7). It has been found that many distant radio sources, especially those which show variations of the intensity of their radio emission, have components with angular sizes of ≤ 0.001 seconds of arc. Since these sources are thought to be 10^8 to 10^9 light years distant from us, the linear diameters of these components are less than a light year. In one relatively nearby radio galaxy (only 3×10^7 light years away!) a component with a diameter of perhaps a light month has been detected (8).

When tuned to the wavelength of a radio spectral line, the radio interferometer can give information about the size and shape of the regions emitting the line radiation. Of particular interest have been VLBI studies of interstellar masers. These are regions which emit intense radiation in the 18 cm lines of the OH molecule or in the 1.3 cm line of H_2O. Because of their extremely high surface brightness, maser amplification in the interstellar medium seems to be the only plausible explanation for these objects. Angular diameters of 0.005 and 0.05 seconds of arc have been observed for the OH sources and < 0.001 seconds of arc for the H_2O sources. At distances of a few thousand light years, this would correspond to dimensions of the order of the radius of the earth's orbit. In the case of the OH sources, the more <u>distant</u> ones seem to have the greater diameter. This leads us to suspect that the measured diameter is really the result of scattering in the interstellar medium. At the shorter wavelength of the H_2O line, the scattering is expected to be much smaller, and the observed angular diameters are also smaller (9, 10). These masers are usually located near strong sources of infra-red emission, and it is thought that they are pumped by energy at infra-red wavelengths.

Diameter changes are seen in many of the sources with variable-intensity radio emission (11, 12). In the best-established case, the quasi-stellar source 3C 279, a very clear change in the interferometric visibility function was seen over an interval of four months, corresponding to a change in diameter of

9 percent in that time. (The change in angular diameter was 0.14 x 10^{-3} seconds of arc.) This object has a redshift of 0.538 implying a distance of about 6 x 10^9 light years. At this distance the apparent transverse velocity implied by the observed diameter change is about ten times the speed of light (12). Although it is quite possible for an object which is expanding at a velocity close to that of light to appear to expand at superlight velocities (13), there are several difficulties in applying this explanation to 3C 279. The observations are still too incomplete to define the exact shape of the expanding source, and these difficulties may go away when the true source shape is known. If the source were very much closer than the distance implied by its redshift, the problem posed by its rapid expansion would disappear; however we would then have to find a cause for its redshift other than the general expansion of the universe.

VLB observations are now proceeding from simple diameter measurements to rough two-dimensional mapping of the small components of radio sources on the scale of 10^{-3} seconds of arc. For this purpose observations are made with pairs of antennas at locations all around the world. Stations used have included many different radio observatories and antennas of the NASA Deep Space Network. In a very real sense we are making of the whole earth a gigantic antenna array.

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