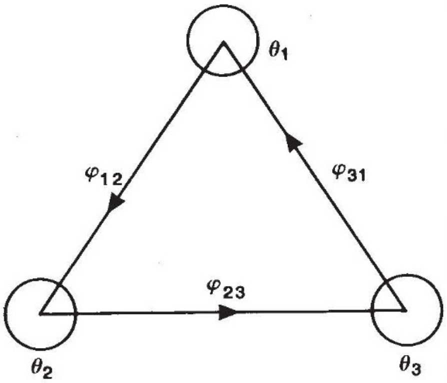

FIG. 2 Closure phase with a three-element interferometer. The interferometric phases are denoted by ϕ_{12}, ϕ_{23} and ϕ_{31}. Each element suffers from local atmospheric corruption (giving phases marked θ_1, θ_2, and θ_3). Because the difference of the atmospheric phases enters the interferometric phase, the closure phase — which is the sum of the three interferometric phases, taken in the order shown by the arrows — is independent of the atmospheric phases.

must and even with the VLA for making the highest-quality images by eliminating local errors.

Closure-phase imaging requires a minimum of three elements and benefits rapidly with increasing number of elements. The technique has been successfully demonstrated at optical wavelengths by using say, five to seven small portions (just a few inches across) of a large optical telescope to mimic the different interferometric elements. Application of radio VLBI software to such data has resulted in images at the limit of the resolution of the telescope (about 40 milliarcseconds) and with quality comparable to routine radio VLBI images. Several separated-element optical/infrared interferometers with three to six elements and resolutions approaching a few milliarcseconds are now in various stages of planning and construction.

The recent advent of adaptive optics as well as declassification of adaptive-optics technology by the US Department of Defense has made interferometry in general, and infrared interferometry in particular, more attractive than ever. Adaptive optics is similar to closure-phase imaging in that the signal from the source is used to correct for atmospheric errors, but it is done at the time of observing. Adaptive optics allows the use of apertures larger than set by the atmosphere. In particular, at a good site like Mauna Kea, the use of adaptive optics enables the use of the entire 10-m area of the Keck Telescope for 10-μm interferometry.

The construction of a second 10-m telescope only 80-m away from the first Keck telescope offers possibility of a very sensitive infrared interferometer with resolutions of 25 milliarcseconds at 10 μm and 5 milliarcseconds at 2 μm. The interferometer offers the possibility of directly detecting warm Jupiter-sized planets in orbit around nearby stars. (Sadly, the wobble of the pulsar PSR1829-10, caused by the orbit of its newly discovered planet (M. Bailes *et al. Nature* **352**, 311–313; 1991), is too small for any interferometry.) Young stars and their protoplanetary disks will be favourite targets as well. It should also be possible to place constraints on the size of the infrared-emitting regions of active galactic nuclei.

Although the addition of the second 10-m telescope will allow progress on these fronts, true imaging would require the addition of at least one more telescope and preferrably more. As in radio VLBI, it is not necessary for all the telescopes to have the same size. Indeed, at the longer wavelengths, the sensitivity of a fully phased array is determined by the total collecting area.

The European Southern Observatory has ambitious plans for interferometry as well. The Very Large Telescope (VLT) project, which is fully funded, consists of four 8-m telescopes to be located in Paranal, Chile. Interferometry between the four telescopes as well as two to four additional 1.8-m telescopes is an explicit part of the VLT project. Thus by the end of this decade we may well have two rather powerful infrared interferometers in operation.

And the future? The recently released Bahcall report has recommended the construction of a large, VLA-style, optical/infrared array. Adaptive optics in conjunction with creation of 'artificial stars' by laser illumination of the upper atmosphere may allow the use of large elements and effectively overcome the sensitivity limit of closure phase techniques. The ultimate interferometer would be put in space. The absence of an atmosphere allows large apertures, long integration time, access to the ultraviolet region, freedom from thermal background (important at long infrared wavelengths) and, most importantly, precision astrometry. The Bahcall report recommends an interferometer with sensitivity to 20th magnitude objects and with astrometric accuracy between 10–30 microarcseconds. Such an instrument would give three orders of magnitude of improvement in accuracy and three to four orders of magnitude increase in sensitivity over the Hipparcos astrometric satellite. The scientific gains of such an interferometer will be truly enormous: distance scale, mass distribution, planet detection. While the astrometric gains are obvious, the gains in imaging, judging from the historical experience of high-resolution imaging, can be expected to be revolutionary as well. □

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DAEDALUS

Deep cold

To a swimmer, the surface of the sea may not seem very warm; but the depths are colder still. At a depth of 800 m it is only 6 °C and dropping steadily. The deeps reach 2 °C. In theory, energy could be extracted from this thermal gradient. A floating thermal power station, with conventional turbines but a low-boiling working fluid, has been proposed. Daedalus now plans to use the oceanic temperature difference to power a novel submarine. It is simply an underwater glider, a sealed plastic envelope inflated into a wing-like hydrofoil. Cunningly, it is inflated with heavy water.

The 'heavy-waterglider' is ballasted to be slightly denser than surface seawater. It is towed out to sea by a tug, and simply released. It tilts nose-down and glides at a shallow angle into the depths. Now heavy water has an unusual property: below 11 °C it expands on cooling. At 3.8 °C it freezes, with even greater expansion. So as the heavy-waterglider sinks into the ocean and begins to cool down through this range, it slowly expands. Even if it doesn't freeze, it ultimately becomes less dense than the water around it. Its nose comes up, and it starts a buoyant glide upwards again. The steady climb towards the hotter surface soon warms it up: it begins to contract. At the surface it is warming and contracting so fast that it soon loses the last of its buoyancy. It then heads down into the frigid depths on a second 'vertical tack'. It will travel endlessly.

This wonderful thermal oscillator will need careful design. It must glide efficiently enough to travel a useful distance on each tack; its thermal inertia and rate of heat flow must be chosen to switch it rapidly between strong positive and strong negative buoyancy at the top and bottom limits of its trajectory. The heavy water may need modifying, by mixing in other solvents.

Automatic navigation is another problem. An electronic steering package, powered by a small propeller projecting into the craft's slipstream, will maintain a compass course, updated by a satellite 'fix' at each rise to the surface. As the craft approaches its destination, it will be guided to rendezvous with the receiving tug by sonar steering commands.

Oceanographers will love the heavy-waterglider. Fleets of these cheap, simple vehicles will carry instruments and take samples over huge tracts of deep ocean and long periods of time, and return them safely to port. Their brief enigmatic appearances on the surface, and occasional encounters with fishing nets, will fuel new nautical tall stories about sea-monsters. Trials are being conducted in Loch Ness.

DAVID JONES