Computer simulation of a ring-shaped telescope aperture (a), the speckle pattern caused by random atmospheric phase distortion (b) and the restored image after one iteration with 25 phase-shifter segments (c). The sharpness criterion was maximization of light through a small hole. These results from LBL resemble other work being done at Hughes Research Laboratory. (From reference 1.)

atmospherically introduced phase errors. Instead their feedback system continuously adjusts the positions of an array of separately movable mirrors in order to maximize a quantity that they call the "sharpness" of the image. They have proved analytically that maximization of the image sharpness will necessarily lead to a completely restored image. Muller and Buffington have investigated the effects of several different definitions of sharpness by computer simulations. A good definition would be the integral of the square of the intensity across the image, but a definition that is easier to implement would be simply maximizing the light through a small hole in a mask.

Freeman Dyson of the Institute for Advanced Studies collaborated with Muller and Buffington by laying the theoretical ground rules for general schemes of optical image improvement, establishing that diffraction-limited resolution in a large, ground-based telescope is in principle possible, and setting forth various expectations and limitations.

At Hughes Research Laboratory, Thomas O'Meara, Wilbur Brown and Larry Miller are applying some of the experience gained in work with transmitter control systems to the problem of optical image improvement, with modifications appropriate to the difference between coherent light and white light from astronomical objects. Like Muller and Buffington, they use image quality as a measure of atmospheric distortions, but differ in some of the definitions of image quality. O'Meara feels that they consider a different variety of maximization systems by using different control algorithms.

The Hughes team is working with analog as well as digital interface systems. For this purpose they are modifying a process of dithering, which is used in transmitter control to maximize the power arriving at a point target. So far they have found no intrinsic advantage favoring either analog or digital processors.

What is the reason for the sudden surge of progress in this field? A general scheme was proposed by Babcock as early as 1953[4] but was presumably never implemented because the technology was not then available. According to Hardy the Itek group first pointed out several years ago that the technology was ready and encouraged development of such systems. O'Meara felt that in addition to the great recent improvement in technology, a motivating factor has been the demonstration that similar systems work for transmitter control. —BG

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Quick-change negative-ion source for accelerators

A negative ion source that can provide high yields of nearly all known stable negative ions and enables the user to vary the ion species within minutes has been developed[1] by Roy Middleton and Charles T. Adams of the University of Pennsylvania, Philadelphia. The negative ions are formed directly from a solid surface by the sputter action of 30-keV positive cesium ions resulting in a negative ion current of the order of 10 microamps. A unique feature here is that a simple, long-lived surface ionization source (similar to a type used in thrusters for space satellites[2]) produces the cesium ion beam, rather than the duoplasmatron conventionally used in negative-ion sources, eliminating the problems caused by the presence of plasmas and gases. This new source, developed at the Penn Tandem Accelerator Laboratory, is particularly applicable to Tandem Van de Graaff accelerators, which must use negative ions and have, until now, been unable to live up to their full potential as universal accelerators of all varieties of ions. High-energy linear accelerators, as well as atomic-beam experiments, could also incorporate these sources.

There is now a great deal of interest in interactions between fast-moving heavy ions and matter, in nuclear as well as atomic physics, and the Tandem Van de Graaff appears very well suited to this kind of experiment. It was designed as a way of reaching higher energies with Van de Graaff accelerators of limited voltage. In the Tandem a negative ion at ground potential is accelerated through the maximum voltage, converted to a positive ion and then accelerated back to ground potential. If the accelerating voltage is, say, six million volts, then stripping off only the extra electron plus one other results in a 12-MeV positive ion. With a heavier ion, such as sulfur, not just two but seven electrons might be stripped and, at ground potential, the S^{6+} would have an energy of 42 MeV.

The catch, however, has been to form the negative ions. Two usual methods have been charge transfer to a positive ion in a donor gas, and direct extraction, from a plasma. Neither method is very efficient, and the gases present tend to clog and poison the ion sources, especially for many heavy ions. To eliminate the difficulties caused by gases, Middleton and Adams tried to form negative ions directly by sputtering a solid target surface with heavy atoms. M. Müller and Günter Hortig (Heidelberg) had shown that coating the sputter surface with a monolayer of alkali metal ions (preferably cesium) greatly increased the yield of negative ions produced by sputtering with heavy ions, typically krypton. Although the mechanism is not understood, cesium does have the lowest ionization potential (2.8 eV) of any alkali metal.

In the present design, the function of the sputtering beam and the cesium coating are performed by cesium alone. Here cesium serves as sputterer as well as activator or electron donor. It is vaporized in a boiler at about 300 deg C, then passed through a hot (1100 deg C) tungsten sponge that ionizes about 99% of the atoms to Ce^+ ions. After being accelerated to 30 keV the atoms are aimed at the target, which is a hollow cone mounted on a rotatable copper wheel. The sputtered negative ions are extracted and accelerated to ground potential, then injected into the accelerator. (After their work, Middleton told us, they learned of the work of Victor Krohn,[2] who in 1962 had shown that sputtering with cesium ions is a highly efficient way to produce negative ions.)

The copper target wheel, which may be compared with a revolver chamber, can be rotated within minutes to change the conical target and resulting negative-ion beam. With other negative-ion sources, this process can take several hours. Inclusion of a gas inlet close to the sputter target allows an experimenter to generate ions that are not conveniently available from solids. Ammonia (NH_3) gas, for example, with a titanium cone results in the formation of NH^- and NH_2^- ions, which, for the purpose of forming a high-energy beam of nitrogen ions for nuclear physics studies, are as good as N^-.

Middleton tells us that the group at Penn is trying to develop a tritium ion source and is testing the idea with deuterium. He notes that normally tritium sources consume about 10–20 cm^3 of the gas per hour, whereas he hopes to get 500 hours of use from 100 cm^3 of tritium absorbed in a thin titanium target and avoid the hazards of handling tritium gas. —MSR

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Binary pulsar

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system where M_1 and M_2 are the masses of the pulsar and its companion and i is the orbital inclination) to be 0.13 solar masses. By restricting M_1 to those values reasonable for a neutron star, they found that the ratio M_1/M_2 must be close to unit. For a very different ratio, the orbital inclination would have to be small, which is unlikely, given the large observed radial velocity, roughly 10^{-3} c (where c is the velocity of light). And, if the inclination is large, say 90 deg, a large companion would eclipse the pulsar at some point in the orbit. No eclipse is observed, so the companion must be both massive and small.

Should the second star turn out to be an observable pulsar or have measurable spectral lines of any sort, the binary masses could be found rather easily. But this situation is unlikely, even if the star is a pulsar: It may be a pulsar but not be beamed in our direction. Or, the radiation may be too weak to be observable from this distance, roughly five kiloparsecs. (If it were as strong as the known pulsar, it would have been detected during the original search.) But even if the companion is not directly observable, absolute timing of the pulses, probably possible to within 10^{-4} sec, is expected to reveal details not available from pulsars alone in space.

Tests of general relativity. As the pulsar orbits its companion, we can watch as the degree of penetration of the gravitational fields varies. Taylor and Hulse point out that changes of both v^2/c^2 and GM/c^2r (where v is the velocity of the pulsar, G the gravitational constant, and r the orbital radius) during the orbit are great enough to cause changes of several parts in 10^6 in the period. The time dilatation effect here would be observable as an apparent change in pulse rate. This experiment is the analog of the radar ranging studies done by Irwin Shapiro and his colleagues (Massachusetts Institute of Technology), without the interference of the solar corona. Accurate observation of the dilatation effect could distinguish between general relativity and scalar–tensor theories.

If the perihelion shift of the neutron-star orbit were observed it might also distinguish between general relativity and the other theories. Astronomers have noted a large perihelion shift of Mercury, but tests in the solar system are confused by the unknown effects of the Sun's oblateness. The highly elliptical form of the orbit also increases the perihelion effect.

A spin precession may also be observable. This effect would be the analog of an experiment planned by Francis Everitt, William Fairbank and their colleagues at Stanford University (based on the ideas of Leonard Schiff), in which a spinning quartz ball is placed in an orbiting satellite. General relativity predicts a gravitational coupling of the orbital and spin motion that would lead to a spin precession of a few arcsec per year. According to Remo Ruffini (Institute for Advanced Study, Princeton), a similar effect should be observable in the binary pulsar of the order of 0.6 deg per year; the result would be that within one year or so, the orientation of the pulsar beam will have changed.

Nature of pulsars. Spin precession is also one of the effects that would increase our understanding of the physics of neutron stars. Once the effect for the pulsar has been compared with that for the quartz gyroscope, we will have a test not only of general relativity but also of the geometry of the emission region of the pulsar. The satellite test would give quantitative results about gravitational effects so that changes in pulsar radiation intensity could be interpreted in terms of neutron-star structure. At present, the emission is believed to come from conical regions off the rotation axis.

The predictions of what we will learn about neutron stars from this binary are, of course, more speculative than the plans to test gravitational theories with more accurate versions of solar-system studies. As of now, all we know about collapsed objects has been learned from single pulsars themselves and from binary x-ray sources, or x-ray sources in combination with normal stars. The latter allow us to estimate the mass of collapsed objects.

Several years ago, the Soviet astrophysicist V. F. Schwartzman of the Shternberg Astronomical Institute, Moscow had argued that a pulsar could not exist in a binary with a normal star. But no one had yet observed pulsars in combination with any other star, although the existence of binary pulsars was not unexpected. Tom Gold (Cornell) suggests that the probability of forming such objects in pairs or discs may be higher than the probability of forming them singly. He postulates that a large proportion of supernova explosions may be "fizzlers": The supernova may be spinning too fast to collapse all the way and so the event "fizzles," and multiple semi-collapsed stars result, with less energy emission.

In a less speculative vein, Gold is looking forward to learning about the precessional periods of the pulsar—periods other than the main revolution period. For an object spinning at a given rate (known from the pulses) the precession is affected by the degree of flattening, and the degree of flattening is determined by the density. The question of magnetosphere interaction is also intriguing: If pulsar radiation comes from the magnetosphere of the star, one star rushing through the magnetosphere of another should cause magnetic-field disturbances observable as changes in pulse shape and in radiation polarization. —MSR □