several months of observation.

Exactly what general relativity predicts for the orbital-period decrease is not completely clear. Taylor's group used a result from the standard, but approximate, calculation given (as an exercise) in the text by Landau and Lifshitz. The approximations, such as assuming the masses are moving slowly (compared to c) and are points, ought not to affect the validity of the result. Douglas Eardley, a theoretist at Yale, believes that the exact calculation has not yet been done, and some recent work using approximation schemes gives different results. It is clearly a challenge to the theorists to clarify the situation, Taylor said, so that when further data give more precise results, they will serve to test the theory.

The data from PSR 1913 + 16 will have an impact on other theories of gravitation as well. In fact, most other theories, but not general relativity, predict dipole radiation. Eardley and Clifford Will at Stanford have shown that, in general, the dipole radiation is larger than the quadrupole radiation predicted by general relativity. Because of symmetry, the dipole term vanishes when the orbiting objects are identical. However, the inferred near-equality of the masses is based on general relativity, Taylor told us; if other theories of gravitation are used in analyzing the data, the inferred masses may not be equal, so that dipole radiation would be expected. The pulsar observations may thus provide a crucial test for these theories. New data to refine the current results from PSR 1913 + 16 are eagerly awaited. —TVF

Scanning acoustic microscopy

The resolving power of the scanning acoustic microscope now rivals that of the optical microscope. Since Calvin Quate and Ross Lemons reported building the first scanning acoustic microscope in 1974, Quate's group at Stanford has been able to improve the resolution of this instrument every year by about a factor of two; they now report they have achieved resolutions of about half a micron.[1] Quate recently described his progress in an invited paper at the March meeting of The American Physical Society in Chicago. Quate's group has also recently reported the results of the first experiment with a photoacoustic microscope,[2] a new instrument that generates sound waves by heating a sample with a pulsed laser.

Ultrasonic imaging has in recent years become a common tool of medical diagnosis. Such devices generate sound waves in the region of a few megahertz, corresponding to wavelengths of the order of a millimeter in water. By contrast, acoustic microscopy in Quate's lab is done at frequencies up to 3 GHz, producing wavelengths down to 0.5 microns in water at a temperature of 60°C. The resolution of such devices is determined by the velocity of sound in water (1.5 km/sec), because water is the medium generally used to couple the sample to the detector (and the source). Wavelength is proportional to propagation velocity. Joseph Heiserman of Quate's lab has developed an acoustic microscope designed to operate at temperatures as low as 2 K. With the reduced speed of sound in cryogenic liquids, the Stanford group looks forward to resolutions three times as good as those of optical microscopes by the end of this year.

Beyond the question of resolution, light and sound probe materials differently, yielding different kinds of information about the object under scrutiny. Sound waves can penetrate obscuring layers opaque to light. While light microscopy senses variations in the (complex) refractive index, acoustic microscopes are sensitive to small changes in mechanical parameters such as elasticity. In cases of interest such acoustic parameters often exhibit significantly greater microscopic variation than do the optical parameters. The new photoacoustic microscope, which is something of a hybrid between these two classes of microscopy, is a sensitive probe of the variation of light-absorption characteristics in a structure.

The central component of Quate's acoustic microscope is a small sapphire crystal that can serve as both source and detector of the sound signal. One surface of the sapphire is flat, making contact with a piezoelectric transducer, while a hemispheric concavity in the opposite surface serves as an acoustic lens. In the reflection mode of operation, one such sapphire crystal serves as both source and detector; a transmission microscope will have two such sapphire devices—the source on one side of the sample and the detector on the other.

The piezoelectric transducer is a thin coating of zinc oxide that converts electrical rf signals to sound waves and vice versa, up to 3 GHz. The concave spherical lens has a radius of the order of a hundred microns (smaller at higher frequencies). It is covered by a very thin layer of glass that serves as an impedance match between the sapphire and the water that links the acoustic source (or detector) to the sample being observed. Water transmits sound much more efficiently than does air, but the attentuation rate increases as the square of the frequency. To achieve microscopy at 3 GHz, Quate and coworkers had to use a sapphire lens of focal length only 45 microns, and even over such a tiny interval they had to heat the water to 60°C to reduce attenuation.

Scanning acoustic microscope. The system operates as a scanning microscope, with the sample moving under the source in a raster pattern. The detected signal is displayed on a cathode-ray screen, with a frame consisting of several hundred lines. The scan rate produces several frames per second. The scanning acoustic microscope has been used to date primarily for non-invasive examination of biological systems and microelectronic circuits. Quate told us that the reflection mode of acoustic microscopy has proven more useful than the transmission mode. In the reflection mode, the acoustic signal is emitted in 20-nanosecond pulses, so that the Stanford group can isolate the reflected signal from the emitted signal at the source/detector by a time-gating circuit. For the study of highly polished non-biological systems, the reflection mode has presented no particular difficulties. But the Stanford group has only recently learned how to do reflection microscopy with biological systems mounted on ordinary slides.

With the rapid evolution of microelectronic technology, it has become important to investigate flaws in microcircuit elements manufactured by new techniques. These circuits contain structures of micron dimensions etched from semiconductor or metallic layers that are often only a few thousand angstroms thick. Quate believes that acoustic microscopy is well suited to look for flaws in such microstructures. The semiconductor patterns are frequently covered by metallic gates and other electrodes, which visible light cannot penetrate. Defects in construction and bonding can often be easily detected by the consequent spatial variations of the acoustic parameters of the structure. The non-destructive character of acoustic microscopy allows one to examine microcircuits under actual operating conditions.

In the years since Quate and Lemons built the first scanning acoustic microscope, several laboratories in this country and Europe have built similar instruments, but none of these have gone to the 3 GHz frequency where the Stanford group has achieved a resolution of 0.5 microns. Such high resolution is not essential for microcircuit examination. Rolf Weglein and Robert G. Wilson at Hughes Research Labs have examined integrated circuits in the reflection mode with a 375-MHz scanning acoustic microscope whose resolution was measured to be 1.7 microns.[3] They were able to examine successive subsurface layers for voids, cracks and other defects by varying the object distance from the acoustic lens. The groups at Stanford and Hughes had shown that by moving the sample normal to the focal plane one can also identify and monitor the thickness of layers deposited on various materials such as sapphire, garnet and quartz by characteristic acoustic signals.

At still lower frequencies, Chen Tsai

and his group at Carnegie-Mellon University have also been able to focus on successive layers and interfaces of thick production-line microelectronic components with a 150-MHz scanning acoustic microscope in the transmission mode. They report[4] that they can easily detect and characterize microscopic alloy spikes, inclusions, voids, and bonding defects too small to be spotted by arduous x-radiography. Microelectronic manufacturers have shown considerable interest in the potential for non-destructive quality control promised by such results coming out of the few labs with scanning acoustic microscopes. Though there exists a commercially available variant of the acoustic microscope, a non-focusing device known as a scanning-laser acoustic microscope (manufactured by Sonoscan Inc. of Bensonville, Ill.), which operates at 100–500 MHz, and employs a laser beam as the acoustic detector, microscopes of the kind developed by Quate are not yet available on the market.

For biological applications, the non-invasive nature of acoustic microscopy ought to make possible studies *in vivo*. At this early stage, Quate told us, when his group is still surveying the opportunities opened up by the newly achieved resolution, their cellular studies have been done mostly with "fixed" (non-living) cells. But with their present scanning rate, they may soon be able to study life processes at the cellular level. Quate points out that elasticity may be a useful indicator in living tissue. There is evidence that the velocity of sound is increased in malignant tissues. The time dependence of the elasticity of red blood cells may be useful for studying various types of anemia by acoustic microscopy. Kumar Wickramasinghe of the Stanford group has been able to detect the doubling of the DNA content of ovarian cells prior to cell division.

Photoacoustic microscopy. Quate's group recently published the results of their first experiment with a new kind of hybrid acoustic microscope developed by them.[2] In this photoacoustic microscope, the acoustic detector is the same sapphire lens plus transducer described above, but the acoustic source is replaced by a mode-locked laser, heating the sample with a 210-MHz train of 0.2-nanosecond light pulses. The sample surface is heated by absorbing light from the laser pulses, and the resulting periodic thermal expansion generates sound waves at 210 MHz and higher harmonics in the sample. By tuning the detecting transducer to 840 MHz, the Stanford group was doing its microscopy at the third harmonic of the laser pulse frequency. The size of the laser spot is comparable to the sound wavelength in water; so it does not seriously degrade the resolution of the microscope.

In photoacoustic microscopy, the sound wave serves primarily to detect the physical phenomenon of primary interest, namely light absorption at a given optical (as distinguished from modulation) frequency. The strength of the acoustical signal is a measure of the amount of light absorbed at a particular microscopic spot in the sample. Light absorption properties can serve as characteristic signatures of different materials. Therefore, by comparing the results of scans with different optical frequencies, one can detect the location of microscopic concentrations of particular substances.

Quate told us that he hopes to be able to locate DNA in cell nuclei by this technique, taking advantage of the 260-nanometer absorption band characteristic of the DNA molecule. One could also stain living cell structures at a level low enough to do no harm, but sufficient to cause observable absorption at the color of the stain. Quate believes that the laser power levels needed to generate detectable acoustic waves in these biological applications would not damage the living cells. For microelectronic applications, one could probe substrates of microcircuits by choosing optical frequencies to which the obscuring layer is more or less transparent. This would be useful for example in the microscopy of silicon structures epitaxially grown on sapphire crystals. —BMS

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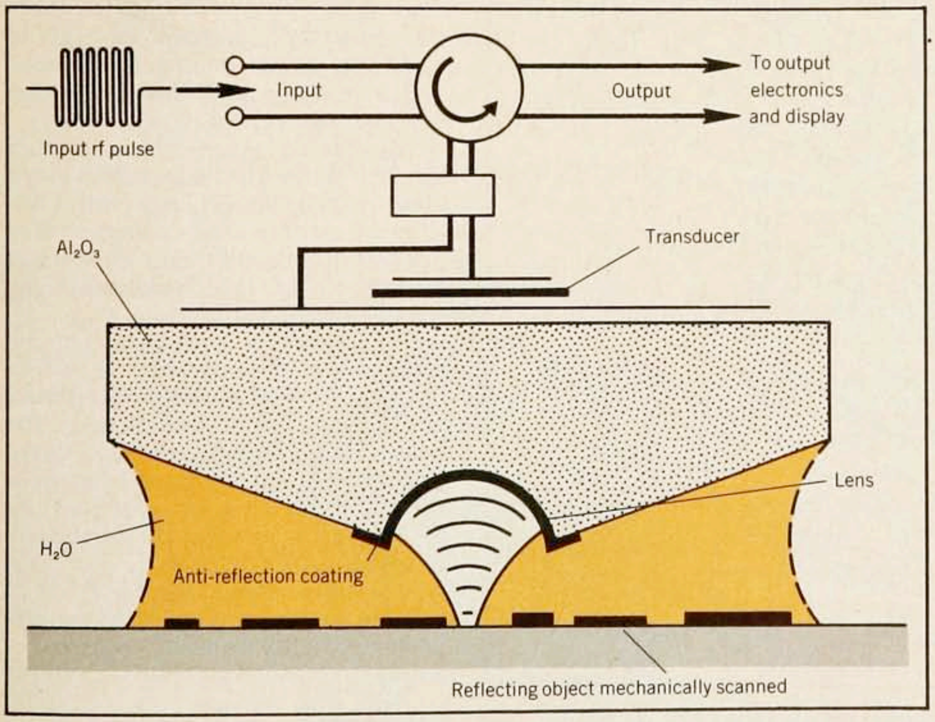

Scanning acoustic microscope used at Stanford in the reflection mode. The transducer imparts to the sapphire lens a 3-GHz acoustic input signal in 20-nanosec pulses and picks up the reflected signal from the scanned object. The lens has a focal length of 45 microns and is covered by a thin layer of glass. The resolution of the microscope is half a micron, the wavelength of 3-GHz sound in water. The object is moved in a raster pattern of several hundred lines per frame, and the output is displayed on a cathode-ray screen at several frames per second.

Limit on space isotropy improves thousandfold

One of the fundamental postulates of the special theory of relativity is that the speed of light is uniform in all directions, and is independent of the motion of the emitter or the observer. A recent report[1] from the Joint Institute for Laboratory Astrophysics (National Bureau of Standards and the University of Colorado) in Boulder has greatly increased the precision with which we know that the postulate agrees with experiment.

The fundamental experiment to confirm the postulate is, of course, the Michelson–Morley experiment. The new experiment, which was performed by A. Brillet of the Laboratoire de l'Horloge Atomique (Orsay) and John L. Hall of JILA, in principle measures the same effect, but it differs somewhat in details. In particular, the experiment's extremely high sensitivity depends on high-precision stabilized-laser techniques pioneered by Charles H. Townes and Ali Javan at MIT and developed, among others, by Hall.[2] The new work extends the null result by a factor of 4000 below that found earlier by T. S. Jaseja, Javan, J. Murray and Townes[3] in an experiment done with two lasers mounted at a right angle to each