kick, but if the pulses are too short each one contains too little energy. The group has varied the time between pulses from 1.5 microseconds up to tens of microseconds.

With this system they have observed the momentum distributions after various evolution times and they have seen the transition from classical diffusion in momentum space (at extremely short times) to the localization that occurs after the quantum break time.[5] "Theorists have made some very specific predictions," Raizen told us, "relating the diffusion rate during the initial diffusive phase, the break time and the localization length—the spread in momentum space that occurs. By observing the time evolution of this process we've verified some of those predictions for the first time."

They have also seen quantum resonances in the pulsed system. In between kicks the phase of an atom's quantum state evolves like that of a free particle: $e^{-(it/\hbar)(p^2/2m)}$. Quantum resonances were predicted to occur when the period of the kicks matches the period of this phase, and Raizen's group has observed this. One signal is a dramatic change in line shape at the resonant pulse periods.[5]

Numerous other experiments are possible using either the modulated or the pulsed system. The effective Planck's constant $\hbar'$ of the quantum kicked rotor is an adjustable parameter in the experiment. This should enable the study of questions related to the correspondence principle in the limit of small $\hbar'$. (The Rydberg-atom experiments have also studied this.) It is also possible to study the effects of noise and dissipation on dynamical localization.

Another phenomenon of particular interest, Raizen told us, is the Anderson problem. In condensed matter physics this is the transition from an insulator to a conductor in three dimensions. Casati, Italo Guarneri (University of Milan) and Dima Shepelyansky (Budker Institute, Novosibirsk) have shown that one can obtain a system equivalent to the Anderson problem in three dimensions by taking a one-dimensional kicked rotor and modulating the amplitude of the kicks with two frequencies that are incommensurate with the kicking frequency. Localization in momentum space in the rotor system is the analog of an electron being pinned in an insulator. "We're setting up to study this next," Raizen told us.

Graham P. Collins

References

1. F. Haake, *Quantum Signatures of Chaos*, Springer, New York (1991).
2. F. L. Moore, J. C. Robinson, C. Bharucha, P. E. Williams, M. G. Raizen, Phys. Rev. Lett. **73**, 2974 (1994).
3. J. C. Robinson, C. Bharucha, F. L. Moore, R. Jahnke, G. A. Georgakis, Q. Niu, M. G. Raizen, B. Sundaram, Phys. Rev. Lett. **74**, 3963 (1995).
4. E. J. Galvez, B. E. Sauer, L. Moorman, P. M. Koch, D. Richards, Phys. Rev. Lett. **61**, 2011 (1988). J. E. Bayfield, G. Casati, I. Guarneri, D. W. Sokol, Phys. Rev. Lett. **63**, 364 (1989).
5. F. L. Moore, J. C. Robinson, C. F. Bharucha, B. Sundaram, M. G. Raizen, "An Experimental Realization of the Quantum Kicked Rotor," U. of Texas preprint, in preparation.
6. G. Casati, I. Guarneri, D. L. Shepelyansky, IEEE J. Quantum Electron. **24**, 1420 (1988).
7. P. M. Koch, K. A. H. van Leeuwen, Phys. Rep. **255**, 289 (1995).
8. R. Graham, M. Schlautmann, P. Zoller, Phys. Rev. A **45**, R19 (1992).
9. P. J. Bardroff, I. Bialynicki-Birula, D. S. Krähmer, G. Kurizki, E. Mayr, P. Stifter, W. P. Schleich, Phys. Rev. Lett. **74**, 3959 (1995).

Astronomical Image Processing May Improve Breast Cancer Diagnostics

Medical and astronomical researchers have collaborated to apply sophisticated image processing techniques to detect microcalcifications in mammograms.

Over the last few decades, astronomical image processing has become extremely sophisticated, encompassing image reconstruction and restoration, image filtering, object detection and classification. A collaboration from the Space Telescope Science Institute, in Baltimore; Johns Hopkins University; and the Lombardi Cancer Research Center at the Georgetown University Medical Center, in Washington, DC, is hoping to apply some of these methods to detect telltale signs of breast cancer in a digitized mammogram. The project was catalyzed over a year ago by Benjamin Snavely, program director for advanced technologies and instrumentation in the NSF division of astronomical sciences, which recently awarded the collaboration a $50 000 grant from the Small Grants for Exploratory Research Program.

Finding a faint star in a blurry image amid other emission sources turns out to be similar to finding a microcalcification amid the complex background structures in a mammogram. Clusters of microcalcifications are one of several types of objects whose presence in mammograms is indicative of breast cancer; they appear as faint, pointlike spots. According to Matthew Freedman (Georgetown), a member of the collaboration, roughly one-third of breast cancer cases have microcalcifications no larger than 50–100 microns in size. Currently mammography shows microcalcifications of about 250 microns or larger; one can't usually see the smaller ones without image processing.

Workers at Space Telescope Science Institute developed a large collection of image processing software after the spherical aberration in the Hubble Space Telescope's primary mirror became apparent soon after launch in April 1990. The software was intended to compensate for the telescope's loss of dynamic range and spatial resolution, Robert Hanisch of STScI told us.

At Georgetown radiologists are conducting a clinical trial of whole-breast digital mammography based on storage phosphor imaging technology. The system's detection capability is limited by noise from the random flux of x-ray photons, by structural feature noise (due to normal anatomical structures that resemble microcalcifications) and by the presence of breast ligaments.

In preliminary studies Freedman gave Hanisch and Richard White (STScI) four digital mammogram images; on two of them Freedman showed them where the microcalcification clusters were and with the other two he told them nothing. Hanisch and White first tried Fourier domain filtering on the images, but the approach failed to spot only the microcalcifications—the fibrous nature of the breast tissue, the edge of the breast and the edge of the exposure frame all contribute to the highest spatial frequencies in the Fourier transform.

The procedure that did work was a three-stage process. First Hanisch and White used the well-known image processing technique called unsharp masking, in which one smooths the image heavily and then subtracts the smoothed image from the original image. The result was that features in the brightest regions of the image were overemphasized. So the second step was to improve the filtering by normalizing the image variances. The third step was to apply an adaptive filter to smooth regions where there are no statistically significant data values above a given threshold, but to apply no smoothing in regions where significant values are found. When all three steps have been followed, one is left with an image showing small-scale structures that exceed a given threshold compared with the local mean. (See the cover of this issue.)

The STScI group was able to see the microcalcifications previously seen by Freedman and, in the two blind analyses, to identify microcalcifications that were hard to find in the unprocessed data.

This year the team members want to determine the limiting size of detectable microcalcifications and the limiting signal-to-noise ratios that lead to reliable identifications.

Steven Salzberg (Hopkins), the principal investigator on the NSF grant, has been working on automatic detection schemes using neural networks. The collaboration hopes later to be able to automate the classification of suspicious microcalcifications.

Still later on, Freedman told us, the collaboration may also try image restoration (deconvolution) to increase the dynamic range and to improve the resolution of the shape of the microcalcifications. Freedman believes that the results of the collaboration with the astronomical imaging experts will be applicable to digital mammography in general.

Another technique being used to improve digital mammography also grew out of work on the Hubble Space Telescope. Last year NASA announced that an extrasensitive charge-coupled device developed for Hubble is being used in a digital camera system for spot mammograms. The CCD camera system enables doctors to replace surgical biopsy in some cases with stereotactic large-core needle biopsy.

Susan Blumenthal, deputy assistant secretary for health in the US Department of Health and Human Services, has been trying to help the medical community take advantage of the imaging technologies developed by the defense, space and computer graphics industries to improve breast cancer detection. She is setting up a panel on dual-use technologies. For example, John Wood, lead optics engineer for the Hubble, told us that CIA-developed neural network software that searches for groups of tanks in a forest is being adapted for use in mammography. The software looks for changes in a complex scene.

At a recent press conference Senators Arlen Spector and Bob Kerrey, who head the Senate Intelligence Committee, urged the CIA and other intelligence agencies to release their advanced imaging techniques for medical applications. Georgetown's Freedman believes that mammography may very well benefit from some of these techniques.

GLORIA B. LUBKIN

X Rays Illuminate Dynamics On Near-Atomic Length Scales

Eighty years after x rays were first used to determine the structures of well-ordered crystals, coherent x-ray beams are beginning to probe the atomic-scale dynamics of random distributions of matter.

When a beam from a laser or some other coherent light source scatters off a random distribution of matter, it produces an interference pattern of light and dark "speckles" that is uniquely determined by the instantaneous matter distribution at the scale of the light's wavelength. And if changes occur in the sample as a function of time, the speckle pattern evolves to reflect those changes. Physicists exploit this phenomenon when they investigate the diffusion of micron-sized particles in liquids, for example, with techniques like photon-correlation spectroscopy and dynamical light scattering.

In principle, it should be straightforward to extend such techniques to shorter and shorter wavelengths until one can measure the dynamic fluctuations of matter at the atomic scale. However, it is less than five years since researchers demonstrated that synchrotron storage rings could produce coherent x-ray beams of sufficient intensity to generate a speckle pattern,[1] let alone reveal the dynamics of the system off which the beam scattered. Even with the most intense beams now available, one must take care in selecting the system to be investigated and designing the experiment so that x-ray photon counting statistics are high enough to provide an adequate signal-to-noise ratio. Physicists working at the European Synchrotron Radiation Facility[2] in Grenoble and at Brookhaven National Laboratory's National Synchrotron Light Source[3] have apparently found two winning combinations for using coherent-x-ray speckle to elucidate the short-length-scale dynamics of relatively slow processes in disordered materials.

Because no sufficiently intense x-ray laser has yet been developed (see PHYSICS TODAY, October 1994, page 19), researchers prepare coherent x-ray beams by first filtering out all but the desired wavelength with a monochromator—a crystal of material oriented so that it diffracts only x rays of that wavelength—and then collimating the beam by passing it through a pinhole in a metal foil. The resulting coherent beam then scatters off the sample. Researchers measure the speckle pattern by scanning it with a single-point detector or by imaging the complete pattern with an area detector.

The group working at ESRF, which consisted of Stephan Brauer and Brian Stephenson of IBM; Mark Sutton, Ralf Brüning and Eric Dufresne of McGill University; Simon Mochrie of MIT and Gerhard Grübel, Jens Als-Nielsen and Douglas Abernathy of ESRF, examined the speckle pattern of x rays diffracted from the binary alloy Fe_3Al near the critical temperature T_c for an order–disorder transition. In this system the order and disorder express themselves only at the atomic level. Below T_c the alloy's ordered phase, in which Fe and Al atoms occupy alternating lattice positions in the crystal, is favored because of its lower energy. This leads to a fairly static long-range order with a periodicity of 2 atomic spacings, or about 3 Å, in the crystal's structure and a correspondingly static speckle pattern. Above T_c the long-range ordering of Fe and Al atoms is lost, and time-dependent critical fluctuations of short-range order appear, causing the speckle pattern to fluctuate as well. Despite less-than-optimum detector resolution and limited signal, the researchers did observe an abrupt transition between the characteristic static and fluctuating speckle patterns as they raised the temperature through T_c in small increments.

The group working at NSLS, Steven Dierker of the University of Michigan, Ronald Pindak and Robert Fleming of AT&T Bell Labs, Ian Robinson of the University of Illinois and Lonny Berman of Brookhaven, looked at the x rays scattered at small angles to the incident beam by an opaque colloid of gold nanoparticles with an average diameter of about 300 Å suspended in glycerol. Coherent interference of scattered x rays from individual gold nanoparticles produced a speckle pattern that fluctuated as the particles underwent Brownian motion. By recording a movie of the fluctuating speckle