photons of the magnetic field, whose wavelength is relativistically contracted, serve as the high-energy "pump" mode in this three-mode process; the plasma wave is the "idler" mode that absorbs the energy remaining from the inelastic Raman scattering, and the scattered light, whose frequency is less than that of the pump, is the "signal" mode. The laser is thus analogous to the well-known parametric amplifier.

The Columbia–NRL group has been working to upgrade their apparatus. They have also been investigating ways to reduce the effect of second-order Stokes (two inelastic scattering events) and of anti-Stokes (inelastic scattering to higher frequency) processes, Marshall told us. Such processes detract from the growth of the laser intensity, and are therefore undesirable.

Both the Stanford and NRL lasers are tunable by adjusting the electron-beam energy. One can also vary the period of the rippled magnetic field and thereby change the frequency of the output, but that is a more complicated procedure. Most lasers are restricted to fairly narrow ranges, whose wavelengths are determined by atomic or molecular energy levels. Even dye lasers are limited by the absorption bands of available dyes. The energies of free electrons are not so constrained. In fact, Madey told us, it should be possible to reach the ultraviolet with storage-ring devices. The Stanford group is investigating a number of possibilities for improving the performance of the lasers; Madey and David Deacon, a former graduate student of his, have, for example, suggested using isochronous electron optics to keep the electrons bunched, which should permit much higher power levels. The absence of a medium (fluid or glass, say) in which the laser action takes place provides a further advantage for high power levels: Conventional lasers are often limited in power or spatial resolution by nonlinear optical effects in the lasing medium; again, free-electron lasers are not subject to these problems.

The field is an actively developing one, and some of its earlier history is obscured by security classifications. Our earlier report, a recent report in *Nature*[3] and the latest volume (5) of *Physics of Quantum Electronics* all contain accounts of the development of the idea. In 1951 Henry Motz[4] built the "undulator" to produce spontaneous radiation from an electron beam in a periodic transverse field, and the ubitron was invented in 1960 by R. M. Phillips.[5] In 1968 Richard Pantell and his collaborators[6] in the Electrical Engineering department at Stanford and, Madey,[7] independently in 1971 suggested using relativistic beams to produce the scattering. Elias has proposed[8] using a high-intensity pump wave at far-infrared frequencies together with a recirculating beam, accelerated electrostatically, to obtain continuous radiation, tunable from infrared to ultraviolet frequency. His proposal will be funded by the Office of Naval Research, Elias told us, and he expects the machine to be ready in the early 1980's.

Potential applications. Now that the feasibility of at least two varieties of free-electron laser has been demonstrated, their potential applications are being investigated. Charles Brau, who is heading a group working on the subject at Los Alamos, told us that he foresees high-efficiency, high-power, low-cost lasers that would be useful for large-scale industrial processes. This would happen, Brau said, when the device produces photons at about one cent per mole of photons, or a capital cost of a few dollars per watt. He expects that the overall efficiency of the free-electron lasers will approach about 40% (total ac input to light output) with the electron-beam-energy recovery techniques being developed at Los Alamos. Although not everyone we talked to shares Brau's optimism, they do agree the laser will be a very good capital investment for producing photons even if it does wind up being somewhat more expensive than traditional lasers. And Granatstein told us that recent theoretical calculations at NRL also gave efficiencies in the 40% range. (For comparison, the CO_2 laser, which is one of the most efficient currently available, has a demonstrated overall efficiency of 15–20%.)

One obvious use of such a high-power source of relatively narrow-band radiation is in industrial chemistry, to supply energy to specific reactions. For example, Brau told us, one could use such a source to clean the exhaust gases from combustion by selectively decomposing noxious substances. Similarly, one could purify the feedstocks for chemical processes by selective destruction of contaminants. That process has already been investigated, using an argon-fluoride laser, for silane gas. Coal gasification is another potential application.

Kumar Patel of Bell Labs told us that the high intensity, short pulses of radiation enable one to do time-resolved studies of transient phenomena, as well as more usual sorts of spectroscopy. Bell Labs is building a free-electron laser tunable over a broad range of frequencies, which they intend to use for analytic studies, at least initially.

A further type of application, particularly of the sub-millimeter radiation produced by the Columbia–NRL laser, is for radar, an application that clearly interests the Air Force and Navy, which are supporting much of the Columbia–NRL work. Marshall told us that the coherence and high peak power of the radiation make it very attractive for this use.

The line width ($\Delta\lambda/\lambda$) of the lasers is about 2% for the Columbia–NRL experiments and somewhat less than 0.2% in the Stanford experiments. The latter approaches the width of pulsed dye lasers. For most of the applications that are foreseen, including the industrial photochemistry applications, one does not need particularly narrow emission lines, Madey told us. The high power, coherence, and tunability are already very attractive properties. The Trento and Frascati groups have organized a conference that was to be held near Trento in June, to explore the potential for applying free-electron lasers to chemistry. —TVF

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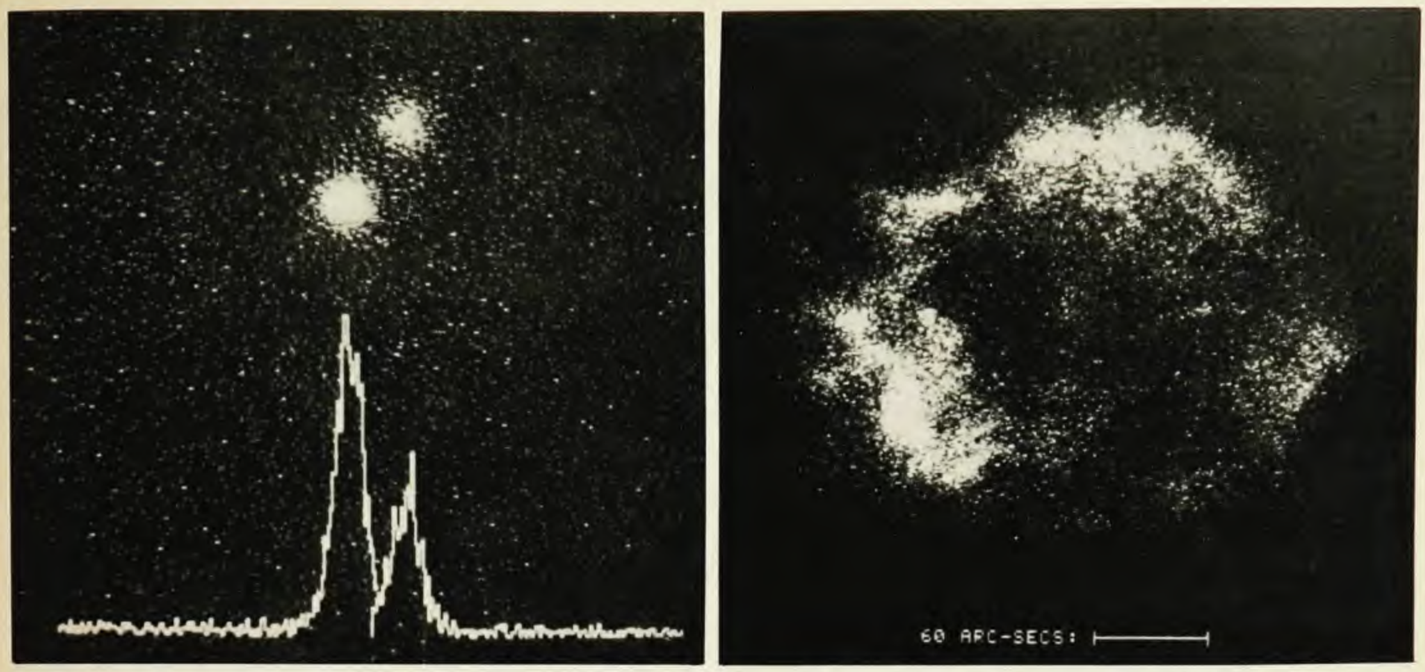
High-energy astronomers take a look at x-ray sky

The second orbiting High Energy Astronomy Observatory started its normal operations on 7 January. It has already produced more than a thousand x-ray images, many of them spectacular pictures of supernova remnants, quasars, galaxies, clusters of galaxies, stars and clusters of stars. It has also produced a number of puzzles, most notably for theories of pulsar formation.

The pictures are produced with a high-resolution grazing-incidence reflecting telescope that can be focused on one of four interchangeable instruments, including a television-like multichannel system with a roughly 5-arc-sec resolving power and an imaging proportional counter with a one arc-min resolving power and very high sensitivity. These instruments provide an increase in sensitivity of a factor of 1000 and an increase in spatial resolution (in one measure) of a factor of 40 000 over earlier instruments. As Riccardo Giacconi, principal scientific investigator of the project, put it, in the twenty-odd years since its beginning, x-ray astronomy has evolved as much as optical astronomy did in the years from Galileo to Palomar.

The rate at which data are being received has so far permitted only preliminary investigations; more than a thousand new x-ray sources have already been found in the pictures, for example, and other data are coming in at a comparable



X-ray pictures of supernova remnants. On the left is a pair of remnants seen in the Large Magellanic Cloud; the curves show the intensity profile across the central part of the picture. On the right is Cassiopeia A, the remnant of a supernova that occurred around 1657, but was not seen by contemporary astronomers. The structure of the expanding gas cloud shown differs slightly from that seen in radio and optical frequencies.

rate. There are several technical papers on some of the new findings in the works, but a detailed examination will take some time. The preliminary results can tentatively be divided into two groups—those concerning sources within our galaxy and those concerning more distant, cosmological sources.

Galactic sources. HEAO-2 has observed x rays from stars of all ages, from protostars beginning their formation to the remnants left after their death. Supernova remnants, in particular, have provided interesting new results.

Perhaps the most startling aspect of all the pictures of supernova remnants taken so far is that only the Crab Nebula and the Vela Nebula show x-ray emissions from a central star. Besides the Crab, there are at least four other known supernovas that were sufficiently recent that any remnant neutron star at the core should still be hot enough to emit thermal x rays. Even in the case of the Crab pulsar, the steady emission is so much fainter than the pulsed component that it has not yet been detected. The absence of a hot remnant has serious implications, Robert Novick of Columbia, one of the investigators in the project, told us. Either compact stars are not generally left behind after supernova explosions, or the compact objects cool off much faster than theorists had expected. If compact objects, such as neutron stars, are not formed by most supernova explosions, current theories of pulsar formation will have to be revised. There are now so many known pulsars that, given the average rate of supernova explosions, nearly every one would have to have produced a pulsar. If the compact objects are formed but have cooled enough so they no longer emit detectable amounts of x rays, the equations of state for neutron stars will have to be revised. Don Lamb, a theorist from the University of Illinois (on leave at MIT), told us that one possible explanation would lie in the process of "pion condensation," in which protons and neutrons form states containing virtual pions. (An analogous process is the formation of electron-hole excitons in a semiconductor. In neutron stars, protons and neutron-hole states combine to form virtual pions.) The greatly enhanced neutrino production associated with the pion condensation could, perhaps, cool a neutron star rapidly enough to produce the observed temperature limits.

The high-resolution pictures of super-

The Einstein Satellite

The second orbiting High Energy Astronomy Observatory was launched on 13 November 1978 and started normal operations on 7 January this year. Shortly after it was launched, the observatory was nicknamed "Einstein" to honor the centennial of his birth. It carries a 60-cm, high-resolution grazing-incidence reflecting x-ray telescope whose images can be examined with any one of four interchangeable instruments:

- a high-resolution television-like system that has an effective resolving power of about 5 seconds of arc
- an imaging proportional counter with a resolving power of about one arc-minute
- a cooled solid-state silicon spectrometer
- a focal-plane crystal spectrometer

The scientific program of HEAO-2 is operated by a consortium consisting of the Harvard–Smithsonian Center for Astrophysics, MIT's Center for Space Research, Columbia University and the Goddard Space Flight Center. Riccardo Giacconi of Harvard–Smithsonian is the Principal Investigator with overall scientific responsibility for the program. In addition to groups at each of the four participating institutions, by now about 150 scientists from other institutions have participated in the program. The observatory is thus a truly national facility, Giacconi said, like Kitt Peak and other national observatories. Giacconi expects that about 300 investigators a year will use the satellite.

The instruments have been working as well as anyone could have hoped, Giacconi said. There have been a few minor faults—one of the three star-tracking devices has failed and the imaging proportional counter's gain has been drifting, for example—but these have not materially affected the observation program.

The useful life of the satellite is now expected to be about two years; it is limited by the availability of gas to stabilize and point the telescope. Giacconi said that conservation measures may extend the life somewhat, but not appreciably. Unfortunately NASA decided early in the planning for this satellite to use gas instead of magnetic torques, which would not have limited the useful life of the satellite.

The next x-ray satellite is currently in the planning stages. It probably cannot be launched before 1988, even if the design and construction proceed smoothly. Thus it appears that there will be a minimum gap of five years during which the only data—both for new explorations and for confirming or elaborating earlier observations—will come from rocket flights. NASA has, however, indicated a willingness to fund analysis and interpretation of the HEAO-2 data for three years after the satellite dies.

nova remnants, such as Cassiopeia A, the Crab Nebula, Tycho's supernova, and others can be compared with the radio and optical pictures to obtain better information about the dynamics of the expanding gas and the mixing of heavy elements into the interstellar medium. Steven Holt, one of the HEAO-2 investigators at Goddard, and his colleagues, using the cooled silicon spectrometer on the satellite, have seen emission lines from many heavy elements in addition to those of iron and silicon that had been seen before.

A large number of supernova remnants seen in the Magellanic Clouds will provide a very useful "laboratory" for testing models of stellar and galactic evolution. Because they are at a known distance from the Earth their absolute luminosities and other data can be computed. David Helfand of Columbia, another of the investigators, told us that these remnants are anomalously bright, perhaps because the interstellar medium in the Magellanic clouds contains less material of heavy elements than our own galaxy. One puzzling phenomenon is an intense gamma-ray burst on 5 March (reported in an IAU telegram, number 3356) from a known supernova remnant in the Magellanic cloud. The burst put out a vast amount of energy in an extremely short time—at power levels up to 10^{37} watt, in the range of quasar emissions—however, x-ray observations made soon after the burst show no change from before, Novick told us.

There are also x-ray emissions from globular clusters and from stars of nearly every spectral class, from young stars not yet on the main sequence that had previously only been seen in the infrared, to main-sequence and old stars. Some of these sources are surprisingly bright. Leon Van Speybroeck (of the Harvard–Smithsonian Center for Astrophysics), who designed the telescope optics, has been able to resolve a number of x-ray sources in the Andromeda galaxy, which will, again, provide an interesting comparison with objects found in our own. Previously x rays had been expected only from stars with well-developed coronas; the observation of x rays from stars not expected to have coronas will challenge theorists to come up with models of stellar evolution that produce coronas or other mechanisms for generating x rays in more types of stars, Helfand said.

The observation of x rays from globular clusters produced further evidence that Jonathan Grindlay, a young astrophysicist at Harvard, has a charmed life for seeing x-ray bursts. In November, 1975, Grindlay was the first to find an x-ray burst (PHYSICS TODAY, April 1976, page 17), and he was at the telescope in Cerro Tololo when an optical burst occurred that correlated with an x-ray burst. Grindlay has suggested that some x-ray burst sources may be associated with collapsed remnants or centers of globular clusters (PHYSICS TODAY, January 1979, page 17). While he was on duty at the receiving station at the Goddard Space Flight Center, the Einstein satellite observed an x-ray burst from a globular cluster.

Extragalactic sources. Earlier x-ray observations with rockets and satellites such as Uhuru and HEAO-1 suggested that there is a diffuse background of x rays of cosmological origin. Some astrophysicists have interpreted these results to mean that there is a hot intergalactic gas, which could support the hope that there is enough mass in the universe to close it under gravitation. The earlier results were far from conclusive, and the observed radiation could as well have been due to many faint and unresolved point sources. The deep-sky survey by HEAO-2 appears to strongly favor the latter interpretation. Looking at regions of the sky with no known sources and outside the galactic plane, the telescope found large numbers of faint point-like sources, many of them quasars. Harvey Tananbaum of Harvard–Smithsonian, who is one of the investigators in the project, told us that the current data indicate that at least a third of the "background" actually comes from discrete sources and that the minimum figure is probably more like two-thirds. At this point, he said, one could almost ask if there is any appreciable diffuse background at all.

The deep-sky survey has also identified a number of quasars, a few of them previously unknown. The observatory has seen known quasars with red shifts up to about 3.1, among the largest known. Tananbaum said that the sensitivity of the detectors is sufficiently great that one should be able to see quasars with red shifts up to about 4, if there are any. The x-ray emission from quasars has a continuous spectrum, however, so that measurement of red shifts must await identification of optical counterparts to the x-ray sources.

The telescope also looked at emissions from clusters of galaxies. The analysis of these observations is a long-term project, but some interesting trends are already beginning to emerge. In addition to a diffuse emission, some clusters have concentrated sources, mostly associated with a few larger galaxies; other clusters exhibit a concentrated x-ray core, often associated with a large elliptical galaxy. Tananbaum said that it appears as if the former are clusters in the process of formation while the latter are more developed clusters in which much of the intergalactic gas has concentrated around a heavy central galaxy.

With the Einstein satellite, Giacconi said, x-ray astronomy has joined the mainstream. The sources being investigated are no longer those that are "special" or "intrinsic" x-ray sources, but the general objects of astronomy and cosmology, from stars to clusters of galaxies. One perhaps surprising aspect of this latest jump in resolution and sensitivity is that no inexplicable class of new cosmological objects has appeared, Lamb said; each previous new class of instruments seems to have found, very quickly, a new class of objects. But, he added, the observatory is still young and many of its data are still unanalyzed. It is unlikely that the Universe has come to the bottom of its bag of tricks for this—or any other—field. —TVF□

Oak Ridge Heavy Ions

The column structure shown in the photograph was tested during the week of 7 May, prior to installation of the acceleration tubes in the 25-MV Pelletron tandem accelerator. On 10 May, physicists from the National Electrostatics Corp produced a maximum potential of 32 MV, suggesting that the basic column structure will operate well at its design potential of 25 MV. Oak Ridge spokesmen believe this 32 MV is a record for a laboratory-produced potential difference.

The heavy-ion facility consists of the Oak Ridge Isochronous Cyclotron and the Pelletron; the combination will allow acceleration of heavy ions with masses as high as 150 with sufficient energy to overcome the Coulomb barrier. The facility is scheduled to be completed in the latter part of this year and to be ready for users early next year.

in brief

Brookhaven National Laboratory has awarded a $39-million contract to Ammann & Whitney Safeguard Construction Management Corp for managing the construction of tunnels, experimental halls and support buildings for Isabelle. □