vard), principal investigator of the HEAO-2 project, pointed out to us that these Doppler shifts also make it clear for the first time that the x-ray source material is co-moving with the supernova shock wave. One could have imagined that the thermal x rays came primarily from static interstellar gas heated by the passing supernova shock wave.

Clusters of galaxies. M87 is a giant elliptical galaxy sitting near the center of the Virgo cluster, 15 or 20 megaparsecs distant from us. M87 is surrounded by an enormous cloud of hot gas, rich in heavy elements. Throughout most of its volume, this cloud appears to be isothermal at a temperature of about 3×10^7 K. But the MIT group has concluded from measuring the intensities of several oxygen and iron x-ray lines that the central region of the cloud, close to M87, must be significantly cooler. In particular, they find that the Lyman α line of hydrogenlike oxygen is 7 times brighter than one would expect for a uniform cloud temperature of 3×10^7 K. The spatial resolution of the Bragg spectrometer is insufficient to provide a detailed profile of the thermal gradient in the central region, but the group calculates that they are seeing a continuum of decreasing temperatures as one approaches the center of M87, with the mass of radiating gas per unit temperature interval roughly constant over the entire temperature range of the cloud.

The MIT group believes that their M87 spectra are well described by a "radiatively regulated accretion model" put forward by William Mathews (Lick Observatory) and Joel Bregman (now at NYU) in 1978. In this model, intergalactic gas is continually flowing into the vicinity of M87, driven in by the thermal pressure gradient of the hotter outer reaches of the cloud. The rate of inflow is regulated by the rate at which the inner gas is radiatively cooled, mostly by x-ray emission. This cooling takes place in the central region because the radiation rate increases as the square of the gas density. Calculating from a such a model, the MIT group concludes that M87 is continually accreting to itself extragalactic material from the cluster gas cloud at a rate of 2 to 4 solar masses per year. They reach similar conclusions from a less detailed study of the galaxy NGC1275 in the center of the Perseus cluster.

Paul Gorenstein, Michael Lecar and Daniel Fabricant of Harvard have looked at the outer reaches of the 300-kiloparsec-wide M87 gas cloud with the Einstein Observatory's imaging proportional counter. From surface-brightness and spectral measurements in this hot outer region, where the x-ray emission is too faint for the Bragg spectrometer, they conclude that the total mass of the cloud is too great to be gravitationally bound by the visible mass of the M87 galaxy. They are led to conclude that, in addition to its observable mass, M87 must therefore have a "dark halo" (perhaps neutrinos, perhaps underluminous stars) surrounding the optical galaxy and bringing it up to more than 10^{13} solar masses—ten times its visible mass.

The Einstein Observatory is not likely to survive the summer of 1981, Giacconi told us sadly. It is running out of the gas that is necessary to orient it and stabilize it against the constant torque of gravitational gradients and atmospheric friction. A lot of this gas was expended last fall because of a gyroscope failure. But HEAO-2 has already more than fulfilled its original 1-year mission. —BMS

References

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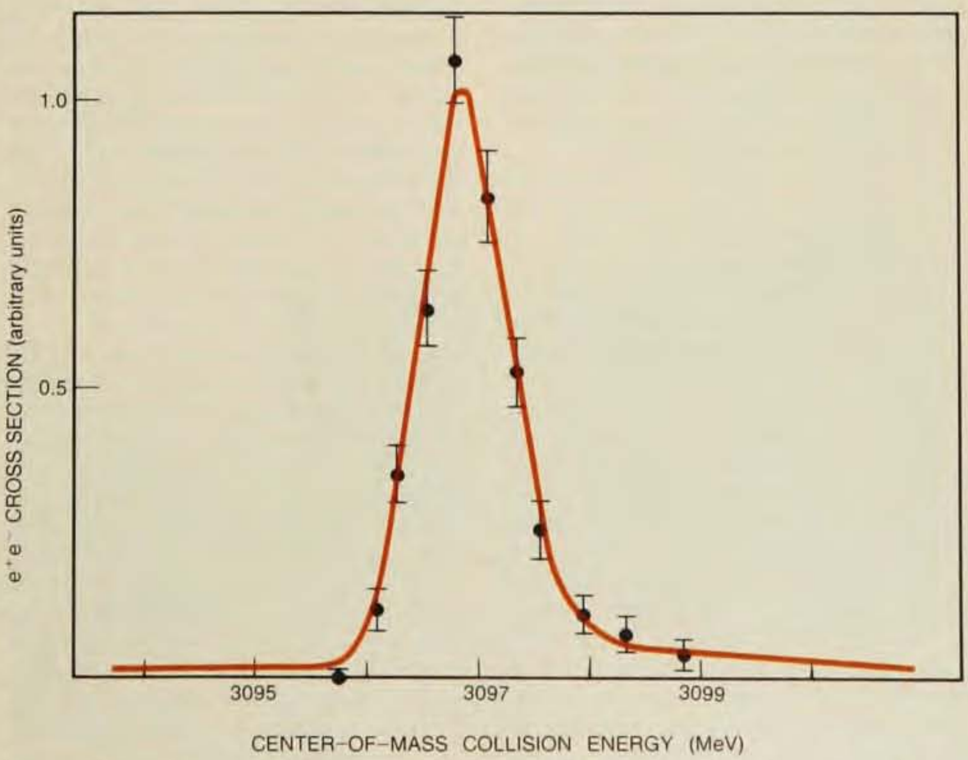
Physics at VEPP-4 e^+e^- collider

A new electron–positron storage ring, at Novosibirsk in central Siberia, has recently begun doing physics. The VEPP-4 colliding-beam accelerator is designed to collide electrons with positrons at center-of-mass energies up to 14 GeV. When it achieves its design energy and luminosity, VEPP-4 will be one of only two e^+e^- storage rings in the world capable of producing at high rates the "bottom-flavored" mesons that carry the recently discovered bottom (b) quark (PHYSICS TODAY, October 1980, page 19).

For the moment, Cornell's CESR storage ring has a virtual monopoly on the production of these B mesons. The effective threshold for the creation of bottom-flavored mesons in e^+e^- collisions is a resonance at 10.55 GeV, discovered last year at CESR—implying a lowest B-meson mass near 5.2 GeV. 10.55 GeV is above the maximum collision energy available to the older e^+e^- machines, SPEAR (at SLAC, Stanford) and DORIS (at DESY, Hamburg). Ironically, the more energetic new generation of storage rings at SLAC and DESY (PEP and PETRA), designed to go up to center-of-mass energies of 38 GeV, offer comparatively meager e^+e^- collision rates at energies as low as 10 to 12 GeV, the region of greatest interest for the study of the B mesons and the unflavored $\bar{b}b$ "bottomonium" states.

VEPP-4 is the latest in a series of e^-e^- and e^+e^- storage rings designed at



Mass of the J/ψ meson was measured at the new Novosibirsk e^+e^- storage ring, VEPP-4, with an uncertainty of $\pm$ 0.09 MeV. This order-of-magnitude increase in precision was accomplished by exploiting resonant depolarization of the electron and positron beams to calibrate beam energies. The mass of the ψ' was also measured, with similar precision.

Novosibirsk under the leadership of Gersh Budker, who died in 1977 (see PHYSICS TODAY, September 1977, page 78). Budker also originated the idea of electron cooling for proton–antiproton storage rings (PHYSICS TODAY, August 1980, page 44). VEPP-2 and its higher-luminosity successor VEPP-2M have been doing e^+e^- physics with colliding beams in the (center-of-mass) energy region from 400 MeV to 1.4 GeV since 1966.

The VEPP-4 storage ring will accelerate bunches of electrons and positrons circulating in opposite directions around its 380-meter circumference to beam energies as high as 7 GeV. As of October, the electron and positron beams had only been pushed up to about 3 GeV per beam, and physics results have only been reported at center-of-mass energies up to 3.7 GeV.

The highest luminosity (collision rate per unit scattering cross section) achieved thus far by VEPP-4 is 3×10^{28} $cm^{-2} sec^{-1}$, at an energy of 1.85 GeV per beam. It is generally agreed that to do useful physics in the 10-GeV region (5 GeV per beam), an e^+e^- colliding-beam machine must achieve luminosities on the order of 10^{30} $cm^{-2} sec^{-1}$, corresponding to about 100 events/nanobarn per day. Burton Richter of SLAC told us that when an e^+e^- machine has achieved sufficient positron injection intensity, so that its luminosity is limited primarily by beam–beam perturbing interactions, the luminosity should grow as the fourth power of the energy. But at present, VEPP-4's luminosity appears still to be limited by the injected positron current. Richter expressed confidence that the Novosibirsk machine would eventually achieve adequate luminosity to do good physics at center-of-mass energies above 10 GeV.

J/ψ mass determination. Even at its present low luminosity and energy, the Novosibirsk machine has already produced an interesting piece of physics. At the 20th International Conference on High-Energy Physics, held last summer at Madison, Wisconsin, Alexander Skrinksky, Budker's successor as director of the Novosibirsk laboratory, reported new determinations of the masses of the J/ψ and ψ' mesons with absolute accuracies of about 0.1 MeV. This represents an order of magnitude reduction of the uncertainties on the masses of these famous bound states of the charmed quark and its antiquark.

These extraordinarily accurate mass determinations were obtained by a technique originally employed to improve the mass determinations of lighter vector mesons at VEPP-2M. The accuracy of the absolute determination of the mass of a narrow e^+e^- resonance is limited by the precision with which one knows the beam energy at which the resonance is observed. Because of the uncertainties on the magnetic fields and particle trajectories in the ring, traditional methods of beam calibration cannot determine the energy to better than about 0.1%. The Novosibirsk technique takes advantage of the tendency of electron beams in a storage ring to become polarized, with their spins antiparallel to the magnetic field of the ring. (Positron beams acquire the opposite polarization.) If one then applies a high-frequency perturbation, one can depolarize the circulating beams abruptly, at a perturbing frequency that depends sensitively on the beam energy.

The depolarization is accomplished by a solenoid that can be driven at a variable high frequency, wound around a nonmetallic segment of one of the VEPP-4 straight sections. When the frequency of the perturbing magnetic field inside the solenoid equals the $g-2$ precessional frequency of the electron and positron spins (due to the departure of their gyromagnetic ratios from 2), the beams suddenly lose their polarization, permitting one to deduce the beam energy very accurately from the observed depolarizing frequency.

The masses determined by this technique were 3096.93 ± 0.09 MeV for the J/ψ, and 3686.00 ± 0.10 MeV for ψ'. It will probably be some time before theorists know what to make of these extra significant figures. A similar technique was recently used at SLAC to check the calibration of the SPEAR beam energies. Instead of a high-frequency solenoid, which would have required inserting a nonmetallic segment in the SPEAR vacuum pipe, the SLAC group used the machine's betatron frequency as the depolarizing perturbation, varying it by changing the quadrupole focusing fields of the ring. This method achieves a precision of only 0.5 MeV (at 3 GeV per beam), but the SLAC group did not think that the additional accuracy obtainable with a solenoid justified the expensive machine modifications it would have required.

Another unique feature of the VEPP-4 design is the fact that the magnetic field of its main magnetic detector is an integral component of the bending field of the ring. Magnetic detectors permit one to measure the momentum of scattered particles by their curvatures. Most magnetic detectors installed in colliding-beam storage rings have solenoidal coils, so that the axial field of the detector leaves unscattered beam particles unperturbed. The magnetic field of the VEPP-4 detector, by contrast, is transverse to the ring plane. The consequent bending of the colliding beams as they pass through the detector requires a kink in the 55-meter-long straight section that houses the ring's three interaction regions.

There are detectors with transverse magnetic fields at other storage rings—for example the split-field magnet at the CERN Intersecting Storage Rings. But they use reversed compensating fields to cancel any net bending of the beam. Whatever advantages the pure dipole field of the VEPP-4 detector may offer as a spectrometer, it poses two potential problems. The bending of the intense beam will generate considerable synchrotron radiation in the middle of the detector. Secondly, given the fixed geometry of the kink in the straight section, it will not be possible to vary the magnetic field strength in the detector at will.

The VEPP-4 ring consists of two semicircles of 45-meter radius, connected by two straight sections. One straight section houses the interaction regions and their detectors, while the other receives the e^+ and e^- beams, already partially polarized, from the smaller VEPP-3 booster inside the VEPP-4 ring. The accelerating system in VEPP-4 uses a special high-power "gyrocon" radio-frequency tube developed at Novosibirsk. Delays in bringing the gyrocon into operation have kept the accelerator below its design energy until now. It is expected that VEPP-4 will soon be brought up to 5.5 GeV per beam, making it possible to do experiments in the region of the four upsilon resonances (vector-meson bound states of $b\bar{b}$) that have been discovered between 9.4 and 10.55 GeV.

—BMS

High priority for comet and asteroid exploration

Exploration of asteroids and comets should have a high priority on the list of possible US space activities for the 1980's, with the primary goal of determining their composition, structure and history. So concluded the most recent study of the Space Science Board's Committee on Planetary and Lunar Exploration, headed by Eugene Levy (University of Arizona). Its report, *Strategy for Exploration of Primitive Solar-System Asteroids, Comets and Meteoroids: 1980–1990*, completes a three-part series of science strategies for exploration of the solar system.

The Space Science Board works under the aegis of the National Research Council, not NASA, and as such is the only independent body formally charged with advising NASA on scientific objectives and strategy. The Committee recommends that NASA conduct reconnaissance and initial spacecraft exploration of comets and asteroids by 1990 and 1995, respectively. Copies of the Committee's report are available from the Space Science Board, 2101 Constitution Avenue, Washington, D.C. 20418.