search & discovery

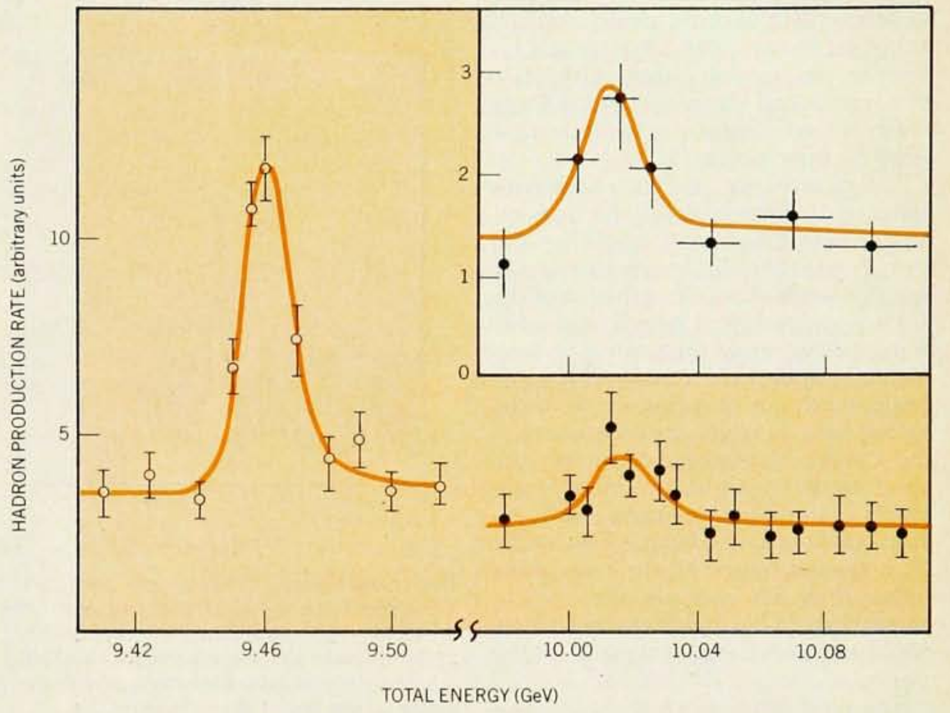
DESY verifies two upsilon states; evidence for fifth quark

By stretching the energy limits of the DORIS storage ring to its fullest, experimenters at DESY in Hamburg have observed the upsilon and upsilon prime at roughly the masses reported in 1977 by Leon Lederman and his collaborators (PHYSICS TODAY, October 1977, page 17)—9.46 and 10.02 GeV/c^2. But the new experiments have 20 times better energy resolution, primarily because they are done in an e^+e^- storage ring.

The new observations are generally taken as further evidence for the existence of a fifth quark, known as "bottom" whose charge is $-\frac{1}{3}e$. Knowing the exact mass difference between the Υ and Υ' gives further clues as to the nature of the force between quarks. The popular theory, quantum chromodynamics, assumes that the underlying force is the same for all quarks, regardless of their flavor (up, down, strange, charm, bottom, the predicted top, . . .).

The DORIS experiments provide an added fillip: Observations with PLUTO, DASP-2 and the NaI Lead-Glass Detector all show that outside the narrow energy region of the upsilon resonances, jets are

continued on page 19



Hadron production rate at DORIS versus total energy as observed by the NaI Lead-Glass Detector (bottom curves) and DASP-2 Detector (inset). The Υ yield measured by the NaI Lead-Glass Detector is included with the same scale and acceptance. Note the Υ' at 10.02 GeV from both experiments.

Satellite and Chilean telescopes correlate x-ray burst

Beginning in late 1975, astronomers have detected intense, brief, and often repetitive bursts of x rays from an ever-increasing number of pointlike sources. Recently a Harvard–MIT group reported observing an optical burst correlated with such an x-ray burst. Meanwhile, analysis of ten of the 30-odd known x-ray bursters has revealed a surprising degree of uniformity among them. Work on theoretical models is also proceeding, and at least one model has recently given good agreement with the observed properties of the bursters.

X-ray bursters were first observed with the Astronomical Netherlands satellite, which has since been turned off, and confirmation quickly came from the SAS-3 orbiting observatory, which still provides much of the data on the bursters. Other discoveries followed soon after (PHYSICS TODAY, April 1976, page 17), with most of the sources lying roughly in the direction of the galactic center. A few of the sources appear to be associated with globular clusters, and five have been identified with faint blue star-like objects. Typically, the bursts rise in about a second to a peak intensity about 10 to 50 times the steady emission and die down over several seconds or even minutes. All the bursters repeat, some of them with fairly regular periods of hours or days; others burst erratically, and many of the sources turn off for periods of days, months or perhaps years.[1]

The first optical burst. A group composed of Jonathan Grindlay (at the Harvard–Smithsonian Center for Astrophysics) and Jeffrey McClintock, Claude Canizares, Jan van Paradijs, L. Cominski, Fuk Kwok Li, and Walter H. G. Lewin (all at the Center for Space Research at MIT) observed[2] a simultaneous optical and x-ray burst from one of the known sources; the event was also reported at a meeting of the High Energy Astronomy Division of the American Astronomical Society in La Jolla in September. The x-ray burster MXB 1735 − 44 is associated with a steady source, 4U 1735 − 44, as well as a faint blue star-like object. The identification of the burster with the "star" was made possible by a very precise determination of the burster's position by another group at MIT.[3] In early June, Grindlay, McClintock, and Canizares used the 1.5-m telescope at Cerro Tololo Inter-American Observatory to monitor the stellar object; simultaneously, van Paradijs, Cominsky, Li and Lewin were working in Cambridge on the x-ray data transmitted from SAS-3. The group in Chile saw two optical bursts, but the first occurred while SAS-3 was dumping data to a ground station, so that only the sec-

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onto a black hole of about 10 solar masses such as could remain after the collapse of a globular cluster. This model can reproduce many of the observed properties of the bursts. Accretion instabilities can also arise for smaller objects, but do not produce the kinds of bursts usually observed. However, one burster, the "rapid burster" MXB 1730-335, produces brief, rapidly repetitive and relatively weak bursts, as well as occasional intense bursts that have the commonly observed properties. Lewin suggests[1] that the rapid bursts may be due to accretion instabilities while rarer, larger bursts are due to fusion flashes.

Although the data from the optical burst are being analyzed extremely thoroughly, everyone involved is hoping for more correlated bursts. Routine monitoring of the bursters is, however, difficult. There are many other experiments with valid claims on satellite and telescope time, and the bursters are not predictable enough for scheduling observations at useful times. Lewin's group has scheduled a total of eight weeks of observing time on SAS-3 to examine burst sources during April–July 1979. Optical observers who wish to cooperate with these observations are invited to contact Lewin or other members of the group at the Center for Astrophysics of the Massachusetts Institute of Technology.

—TVF

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Two upsilon states

continued from page 17

visible. That is, the decay products tend to be emitted in two oppositely directed jets, a behavior expected from quarks. Although jetlike behavior had been observed earlier at SPEAR, the DORIS experiments show that, as expected for higher energy, the cones of the two jets become even narrower. At still higher energies, which will become available when CESR at Cornell, PETRA at DESY and PEP at SLAC start doing experiments, the study of jets is expected to provide a much better test of quantum chromodynamics. QCD assumes that each photon makes a quark and an antiquark, each of which ends up as a jet. At higher e^+e^- energies, the quark or antiquark should sometimes emit a gluon, giving rise to a three-jet event.

In the first observation of the upsilon resonances, done at Fermilab by a group from Columbia University, Fermilab and the State University of New York at Stony Brook, two or three bumps had been found[1] in the cross section for production of muon pairs in 400-GeV proton–nucleus interactions. The most recent analysis of the data, Lederman told us, gives a mass difference between the Υ and Υ' of (590 ± 35) MeV. He noted that the splitting between the J/ψ and the ψ' is 589 MeV, suggesting that the splitting for such resonances was independent of the mass of the constituent quarks.

This is contrary to various theoretical expectations based on fitting a potential model to charmonium data; these predicted $\Upsilon\Upsilon'$ splitting of about 400 MeV. The ψ resonances are assumed to be a bound state of a charmed quark, c, and its antiquark and the mass of the charmed quark to be roughly half the mass of the ψ. Similarly, the Υ resonances are assumed to be the bound state of a bottom quark, b, and its antiquark and the mass of the b quark to be roughly half the mass of the Υ.

As theorist Kurt Gottfried of Cornell recently told us, "in electrodynamics, we know the interaction of photons and electrons, and how this leads to Coulomb's law. On the other hand, in QCD we know the basic interaction between gluons and quarks. But the resulting interaction between quarks and antiquarks is not yet understood. All these potentials one uses are guesses, not theories."

DORIS results. Electron–positron storage rings are capable of giving cleaner and better resolved data on resonances like the ψ and Υ. So, accelerator specialists at DESY decided to push the total energy of the DORIS storage ring beyond its original total operating energy (8.6 GeV). By operating DORIS as a single-ring, single-bunch machine, the machine experts reached energies as high as 9.6 GeV total energy and finally more than 10 GeV. At 9.6 GeV, the PLUTO[2] and DASP-2[3] groups confirmed the existence of the Υ at (9.46 ± 0.01) GeV; they obtained a partial width for decay into e^+e^- pairs of (1.2 ± 0.2) keV, ¼ the J/ψ partial width for decay to e^+e^- pairs.

Last July DESY machine experts added additional cavities to DORIS so that the total energy was raised to more than 10 GeV, allowing the search for the Υ', but the machine did not reach an energy high enough to see the possible third bump reported by Lederman and his collaborators, at 10.4 GeV, which would correspond to Υ''.

A few days before the Tokyo conference on high-energy physics in August, the upsilon prime was detected by two groups simultaneously. A collaboration among DESY, the Universities of Hamburg and Heidelberg, and the Max Planck Institute of Physics in Munich, using the NaI Lead-Glass Detector, found[4] the Υ' to have a mass of (10.02 ± 0.02) GeV and that the mass splitting was (0.56 ± 0.01) GeV. When this precise value is imposed on the Fermilab data, Lederman told us, their Υ'' peak becomes a ten-standard deviation effect (previously a three-standard deviation effect).

The detector used by the NaI Lead-Glass Detector group has a central nonmagnetic instrument to observe the direction of charged particles; it is surrounded by sodium iodide and lead-glass detectors to measure the total energy of electrons, positrons and gamma rays. Each detector has a large angle of acceptance, covering 86% of 4π.

A collaboration of DESY with the Universities of Dortmund, Heidelberg and Lund, using the DASP-2 detector, which has an inner nonmagnetic detector covering 70% of 4π, can see both gammas and charged particles. DASP-2 has a double-arm spectrometer, too, but this device is not crucial to the Υ' experiment. The group reported[5] the same value for the Υ' mass as found in the NaI Lead-Glass Detector experiment. The DASP-2 result for the mass splitting was (555 ± 11) MeV.

The observed widths, σ, in both new DORIS experiments are roughly 9 to 12 MeV, consistent with the energy resolution of the storage ring. When the two groups reported their results at the Tokyo conference, some participants questioned how well the absolute energy could be determined when the DORIS magnets were being operated near saturation. DESY experimenters replied that they felt the absolute energy they reported was reliably determined.

By measuring the partial width for Υ and Υ' decaying into e^+ and e^- and the absolute cross section, the DORIS experimenters were also able to settle the question of the b quark's charge; it is ⅓ for the b, not ⅔. This second possibility had not been eliminated by the earlier Fermilab experiment because its interpretation had some model dependence, according to Lederman.

Interest in the spectroscopy of the upsilon, whose excited states are sometimes called "bottomonium," is high. A number of groups are preparing to look for these states, just as was done for charmonium, after the J/ψ and ψ' were found. As Sheldon Glashow of Harvard, who pioneered the concept of charm, recently explained to us, the behavior of the charmonium system is a very limited tool for studying the nature of the quark-quark interaction. "How fortunate we are that Nature has provided us with a fifth quark with a much larger mass as a further probe. The number of $b\bar{b}$ states that will be accessible experimentally should be considerably larger than we have already found in the charmonium system [about seven states]."

Of particular interest will be the observation of a particle with the unfortunate attribute known as "naked bottom." This would be a particle resembling the charmed D meson and would contain only a single b quark together with an antiquark of a different flavor. Because these quarks must be produced in pairs, the particle should appear at a total energy of about 11 GeV, Glashow explained, after a characteristic rise in cross section associated with a number of small but broad bumps. It may take many, many months to find such a resonance, he noted. For the D meson, found at SLAC, it took 18 months.

Also of interest, of course, will be the "top" quark, whose mass is presumably greater than that of the b quark, because it has not been found yet. It is expected that in weak decays the b quark will couple mostly to the t. It must also couple slightly to the up or charmed quark, Glashow said, because naked bottom was not detected in beam-dump experiments at Fermilab.

Now that it appears we need at least six quarks, Glashow said, we also need three angles to describe them, rather than just the Cabibbo angle required with four quarks. In fact, he went on, the present format of particle physics requires 17 parameters, each as fundamental as the fine-structure constant. These are the masses of the six quarks, the masses of the three charged leptons (electron, muon and tau), three angles (known as θ_1, θ_2 and θ_3), one *CP*-violating phase, the mass of the Higgs boson, the strong coupling and fine-structure constants, $\sin^2\theta$ (the Weinberg angle) and G_F (the Fermi coupling constant). One of these parameters is dropped to set a mass scale, and you are left with 17, he said. But Glashow believes the number of parameters will go still higher—that more and more quarks will be found, and that "things will get much more complicated before they get simpler."

Ground-breaking ceremony for Isabelle on 27 October. From left are Congressman Jerome Ambro, Undersecretary of Energy Dale Myers and Gerald Tape, president of Associated Universities, setting the first concrete survey monument. The $275-million storage ring will produce two 400-GeV proton beams. At present Isabelle is scheduled for completion in 1986; $23 million have been appropriated by Congress for construction in FY 1979.

Planned experiments. For the time being, DORIS is out of action because it is being used as an injector for PETRA, which will soon be ready for experiments with 5–19 GeV electrons and 5–19 GeV positrons. The old PLUTO detector is already in place there, and two major detectors are being installed—the Mark J (a collaboration among the University of Aachen, DESY, MIT, NIKHEF in Amsterdam and the Institute for High-Energy Physics in Peking) and TASSO (a collaboration among Aachen, Bonn, DESY, Hamburg, Imperial College, London, Oxford, Rutherford, Weizmann Institute and Wisconsin). For a while the machine experts were having difficulty getting enough current in PETRA at the injection energy. PEP, the new storage ring at SLAC, is scheduled to operate this October in the same energy range as PETRA.

Late this spring or summer, DORIS will start looking for the Υ family, but by that time PETRA may be able to look for the Υ''. However, for low-lying states of the Υ, lower-energy storage rings are preferable because the luminosity is higher (expected to be three or four times higher) at the needed energies. Thus CESR at Cornell, which will have up to 8 GeV in each beam, will be almost ideal. It is scheduled to be ready for experiments some time in late spring; CESR will have one multi-purpose detector, CLEO (patra), which will be operated by a collaboration among Cornell, Harvard, Rochester, Syracuse, Rutgers and Vanderbilt. It is capable of studying detailed decay modes—into pions, kaons and so on. Lederman (recently named director of Fermilab) and his collaborators from Columbia and Stony Brook are setting up at CESR a second nonmagnetic detector, optimized to look specifically at photons and electrons; it uses a sodium iodide and lead-glass hodoscope arrangement.

And in Novosibirsk, VEPP-4 is scheduled to be running this summer with 8-GeV electrons and 8-GeV positrons. It, too, will be capable of observing the Υ states. —GBL

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