and supergravity with a cosmological term in a unified way. MacDowell told us their approach is purely geometric and makes clear the underlying group structure of the theory. They showed that both theories can be formulated in terms of the curvature components of a space built upon a four-dimensional space-time phase manifold with a local gauge group (or supergroup) structure. All the fields are gauge fields belonging to the adjoint representation of this group. For pure gravity this group is a de Sitter group, Sp(4); for supergravity it is a supergroup obtained from the former by adding the 4-spinor generator. Paul K. Townsend (Stony Brook) and van Nieuwenhuizen have shown that this geometrical description also applies to SO(2) supergravity.

Ultimately a realistic model of supergravity will have to take into account symmetry breaking, which will produce a Goldstone fermion. The corresponding Higgs effect has been studied by Deser and Zumino, as has the problem of the size of the induced cosmological term.

—GBL

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Evidence for 10^{12}-gauss field on neutron star

A sharp spike in the x-ray energy spectrum from Hercules X-1 may have provided the first direct measurement of the magnetic flux on the surface of a neutron star. The German discoverers of this peak have interpreted it as cyclotron emission from electrons circulating around magnetic field lines in the polar region of the star. The associated magnetic field strength would be about 5×10^{12} gauss, in good agreement with theoretical predictions that the field on the surface of neutron stars should range from 10^{10} to 10^{13} gauss.

The measurement of such a strong magnetic field in this particular neutron star is of special interest because it may be one of the oldest pulsating stars. One observer believes that, according to the usual scenario for the birth of a neutron star in a supernova remnant, the age of Hercules X-1 may exceed a billion years: Hercules X-1 forms a binary system with a normal star whose mass is about 2.5 solar masses. A normal star of this size would remain on the normal sequence approximately a billion years before it would begin to enlarge and spill its mass onto the companion neutron star. Only when the neutron star begins to accrete this mass does it become an x-ray emitter. If Hercules X-1 is indeed this old, the existence of a 10^{12}-gauss field would indicate that the magnetic field does not decay significantly as time increases.

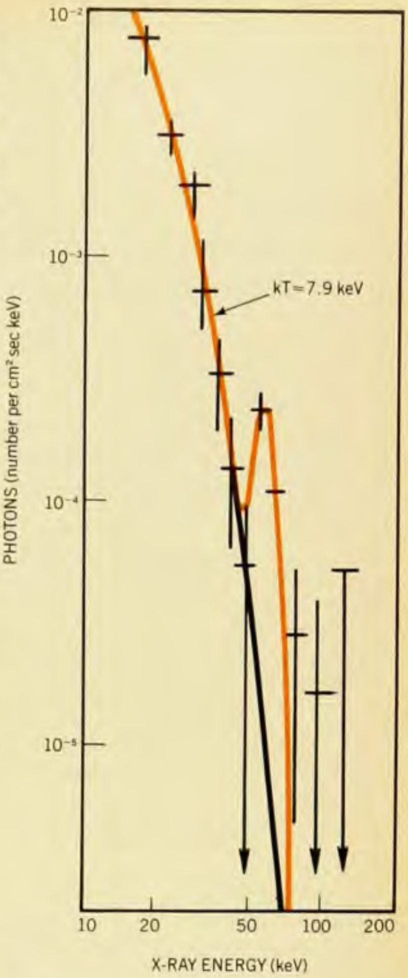
The energy spectrum of Hercules X-1 was measured by a collaboration consisting of Joachim Trümper, Wolfgang Pietsch, Claus Reppin and Bruno Sacco of the Max Planck Institute in Garching and Eckhard Kendziorra and Rüdiger Staubert of the Astronomy Institute of the University of Tübingen.[1] Trümper reported the results at the Eighth Texas Symposium on Relativistic Astrophysics in Boston last December.

The team detected the x-ray emission from Hercules X-1 in the energy range from 15 to 125 keV during a four-hour balloon observation on 3 May 1976 from Palestine, Texas. The object was at phase 0.72 to 0.82 of its 1.7-day orbit. The measurements were made with two scintillation-counter telescopes, oriented parallel to one another, that could follow the source.

In all the data up to at least 70 keV, the 1.24-second pulsations associated with Hercules X-1 are clearly present. These pulsations constitute firm evidence that the energy spectrum is truly associated with the rotating neutron star. The measured spectrum between 15 and 50 keV can be represented by an exponential of the form $\exp(-\hbar\omega/kT)$, with kT equal to 7.9 keV. A strong and rather narrow line appears around 53 keV, as seen in the figure.

The peak in the energy spectrum might have three possible origins, the first two of which are dismissed by the experimenters as being inconsistent with the observed intensity: If the x rays are of atomic origin, they argue, the radiation must be a line such as the Lyman-alpha from platinum-77. The abundance of such an element is, however, insufficient to account for the observed intensity. Similarly, if the energy peak results from a nuclear gamma ray, it would have to come from a nucleus such as americium-241. The production rate for this nucleus is not great enough to produce the intensity of the measured line. The only remaining possibility is the x-ray emission from electrons circulating around magnetic field lines. This mechanism for emission, which is known as cyclotron radiation, had been predicted to occur in the hot, highly magnetized plasma at the polar caps of accreting neutron stars. The predictions were made in papers by Yu. N. Gnedin, R. A. Sunyaev and M. M. Basko in 1974 and 1975.[2]

Information is contained not just in the existence of the x-ray peak itself but in the narrowness of its width. In particular, the narrow line can only come from a region within which the magnetic field variations are small. This fact gives a means of estimating the area of the x-ray emitting region. The investigators cite a conservative upper limit for the ratio of the energy width (full width at half maximum) to the peak energy of 0.35. This ratio would be a limit to the fractional change in magnetic field strength within the emitting region. If the magnetic field is dipolar, the emitting polar-cap region can then be estimated at about 1% of the total surface area of the star.



This unexpected narrow peak appeared in the x-ray spectrum of a binary pulsar, Her X-1. If this spike results from electron cyclotron emission, it implies that the magnetic field on the surface of this neutron star is about 10^{12} gauss. (From ref. 1)

Malvin Ruderman of Columbia comments that this estimated area is roughly the size that one would expect for the accretion cap of a neutron star. In other words, one would anticipate that the accreting matter would fall upon and heat strongly an area that is about 1% of the surface of the x-ray star.

No one knows whether similar emissions originate in other binary x-ray pulsars, but most might be surprised if they did not. No doubt the recent experiment might stimulate a search for such lines.

—BGL

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Uranus rings

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by beta, and from S. K. Gupta and H. S. Mahra at the Uttar Pradesh Observatory (Naini Tal). All the rings but epsilon might better be called ribbons, for the ring system of Uranus appears to consist mainly of gaps. Calculations by Brian G. Marsden (Smithsonian Astrophysical Observatory) yield radii of approximately 45 000 km for alpha and 52 000 km for epsilon, measured from the center of Uranus;[3] yet in this nearly 7000-km-wide belt, epsilon—the broadest of all detected rings—is estimated to have a width of only 50–100 km, and the others are much narrower.

In 1973 Gordon Taylor (Royal Greenwich Observatory) first predicted the occultation of SAO 158687, a ninth-magnitude red giant, by Uranus on 10 March 1977. It was hoped that light curves obtained as Uranus moved between the star and Earth would reveal information concerning the temperature, pressure and composition of the planet's atmosphere and provide a means to determine the diameter and oblateness precisely. The Cornell and Lowell groups, which had earlier cooperated on the observation of an occultation of the star Epsilon Geminorum by Mars,[4] began coordinating their efforts in 1976 to observe the Uranus event.

A flight into dawn. On the night of the occultation Elliot and his associates flew above 75% of Earth's atmosphere, on a course that would take them far south over the Indian Ocean, in a modified C-141 aircraft—the Kuiper Airborne Observatory—made available by NASA's Ames Research Center. With them the Cornell team carried a three-channel occultation photometer attached to the 91-cm KAO telescope. Three observation wavelengths—6190 Å, 7280 Å and 8520 Å—were selected to maximize the brightness of the star with respect to Uranus. About 40 minutes before the occultation by Uranus was expected, a sharp decrease in light intensity was observed for seven seconds, followed by four lesser ($\approx$1 sec) dips. After the 25-minute occultation by the planet, the pattern was repeated in reverse. The morning sky's brightness ended observations.

Meanwhile, at Perth, Millis and his collaborators, due to their geographic position, actually detected the first unexpected drop in signal level—lasting about eight seconds—some 70 seconds ahead of the Cornell team. Using a single-channel photometer in conjunction with Perth's 61-cm telescope, Millis had begun observing in the 8500-Å region almost an hour before the anticipated time for the occultation. The failure of a beamsplitter in Millis's photometer caused the team to miss both the delta and alpha rings, but they still recorded five events, counting the two between alpha and Uranus, before dawn; the shadow of Uranus itself passed south of Perth. Millis's record shows considerable detailed structure in his first-detected event (later to be known as the epsilon ring).

At Kavalur, despite predictions that the shadow of Uranus would miss India (it did), Bhattacharyya observed and recorded the Uranian events for 90 minutes using the observatory's 102-cm telescope. About 40 minutes before the occultation by Uranus he noted a dip of 53% in the star's brightness for about nine seconds; several more sharp spikes were recorded before the Indians lost sight of the planet. Bhattacharyya told us the major event seen at Kavalur was the epsilon occultation; it has since been reported that the weaker fluctuations he detected match with the alpha, beta, gamma and delta events recorded elsewhere.

When the first anomalous occultation was observed aboard the Kuiper aircraft, Elliot, still on the plane, contacted Marsden, who heads an international information clearinghouse for discoveries of transient astronomical phenomena. (Marsden put out a statement that same day that a previously unknown satellite of Uranus had been detected.) When the Kuiper plane landed in Australia around 9:30 in the morning Millis was there to meet it; Elliot's first words to his fellow observer as he stepped off the plane were "How many satellites did you see?". It was not until he was back at Cornell that Elliot unrolled his chart record and found the correlations between pre-immersion and post-emersion occultations that spelled rings.

The rings take shape. The very brief duration of occultations by the ribbons indicates that they have widths of only a few kilometers; Uranus's shadow crossed Earth's surface at about 12 km sec^{-1}, so Elliot estimates the narrow rings are only 12 km wide. On the same basis, he has determined a width of approximately 85 km for the immersion section of epsilon and 35 km for its emersion section. Epsilon must therefore either be elliptical or inclined to the plane of the other rings and satellites; it is also possible that portions of two incomplete rings were observed, rather than different chords of a single object. Marsden cites the Sun, Neptune and Uranus's satellites as possible sources of perturbations that would result in "imperfect" rings.

None of the rings were seen to obscure the star completely; Elliot saw an occultation of about 90% in the case of epsilon, while the light intensity was cut off by approximately 50% for alpha, beta, gamma and delta and by only 20% in the case of two events that correspond to Millis's inner objects. The implication is that the rings are composed of many small objects with diameters of less than four-to-six km, the projected diameter of SAO 158687 at Uranus. The maximum obscuration observed by Millis, in the epsilon ring, corresponds to an optical thickness of 2.3, about twice that of Saturn's B ring.

Many questions remain. The old science-fiction art that showed multitudes of ringed planets floating in space no longer looks quite so unrealistic in the light of the Uranus discovery. But if ringed systems are common in the universe, it is at least clear that they are not all alike. We asked Marsden why the rings of Uranus, in contrast with Saturn's, are so very narrow, with such wide gaps between them. He told us that resonances account for the gaps in the Saturnian rings; the famous Cassini's division, for instance, occurs because particles orbiting at that distance from Saturn would have exactly half the period of Mimas, the innermost confirmed moon—every two revolutions such particles would find themselves in the same orientation with respect to Mimas and would tend to be pulled out of place. Such resonances can sometimes produce *enhancements* of particle density as well—thus, perhaps, are thin rings formed.

Uranus's ring system, according to Marsden, may be a relatively new object in comparison to the age of the solar system, and it may—especially in the case of epsilon—be unstable in the long term. However, "things happen slowly out there," in Marsden's words, and the rings should certainly last long enough to check on them another time. A search has already begun with the object of locating other, fainter stars whose paths may be crossed in the future by Uranus, its ring system . . . or Neptune. An observed occultation by Neptune nine years ago revealed no rings. —FCB

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in brief

The Massachusetts Institute of Technology is building the Alcator C tokamak at a total cost of $6.4 million. The device will have a capability of reaching 140-kG magnetic fields.