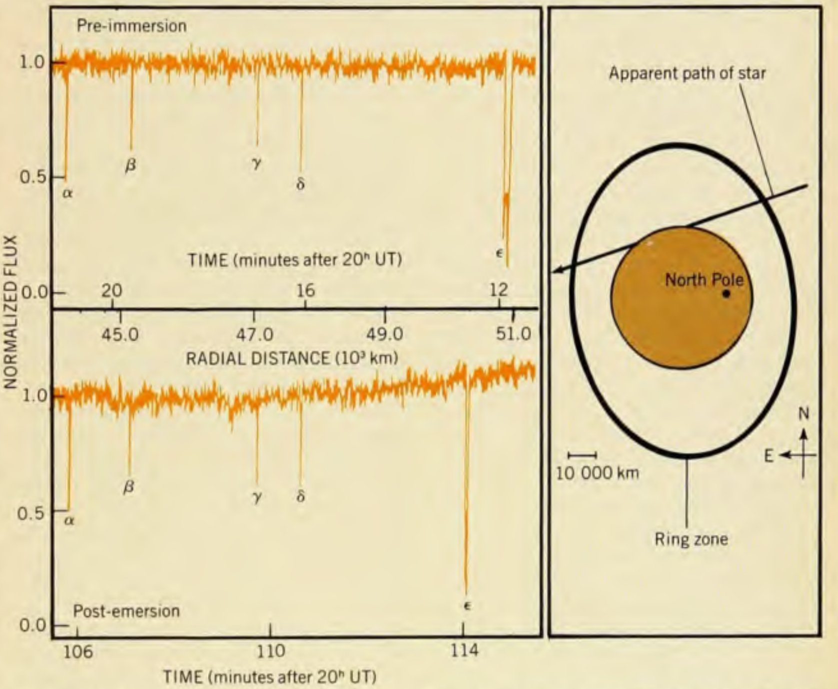
search & discovery

Occultation observations reveal ring system around Uranus

Much precise calculating and thorough planning went into preparations earlier this year for the first observed occultation of a star by the planet Uranus, but it was chance—and cautious allowance for chance—that led to the serendipitous discovery of five or more rings about the planet. Large uncertainties in the time at which the occultation would commence and in estimates of how far north it would be visible caused several observers to turn on their photometric equipment well in advance of the predicted moment—and only thus did they detect the unforeseen dips in the occulted star's light intensity that revealed Uranus as the second ringed planet in the solar system. Three groups promptly reported the unexpected dips, which they originally thought were caused by small Uranian satellites. James L. Elliot, Edward Dunham and Douglas Mink (Cornell University), aboard the flying Kuiper Airborne Observatory, saw brief occultations both before and after the star passed behind Uranus.[1] Robert L. Millis and Lawrence H. Wasserman (Lowell Observatory) and Peter V. Birch (Perth Observatory, Western Australia) have reported similar pre-immersion observations by Millis, Birch and Daniel Trout (Perth),[2] and J. C. Bhattacharyya and K. Kuppuswamy (Indian Institute of Astrophysics) at Kavalur, Madras, also reported a single event. The Cornell group was the first to suggest that the brief occultations were due to thin rings—not small satellites—because the time intervals between their pre-immersion and post-emersion events were nearly equal.



Detecting the rings. At left are the photometric tracings obtained by James Elliot's group at Cornell University during the pre-immersion and post-emersion periods; the existence of thin rings is implied by the symmetry of the events and by their narrowness. The star's light flux (normalized to 1.0 for full visibility) is plotted against time—the brightening of the morning sky caused the upward slope in the lower record. (Adapted from reference 1.) The figure at right shows the aspect of the ring zone as seen from Earth (North at top; East toward the left).

Confirmation of the rings. The existence of five rings—designated by Elliot, from the innermost out, as alpha, beta, gamma, delta and epsilon—is well established. Millis's data indicate the presence of two additional objects (possibly rings or satellites) inside the orbit of alpha, and a possible eighth ring ("zeta") beyond epsilon has been reported by Joseph Churms, who observed post-emersion occultations by alpha, beta and so on through zeta from Cape Town, South Africa. Confirmation also comes from Benjamin Zellner III (University of Arizona), whose data—obtained at Perth—show two occultations by alpha and one

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Will supergravity unify quantum theory with general relativity?

Recently some theorists have been trying to unify general relativity and quantum theory into a framework called "supergravity." The hope is that supergravity theory will provide a link between gravitation and particle physics. So far the work can be characterized as highly mathematical and limited to a relatively small group of practitioners. But enthusiasm among its proponents runs high.

Supersymmetry. Supergravity is an example of supersymmetry, which extends the Poincaré group as a symmetry of space-time by adding four new generators that behave as spinors; these generators vary as the square root of the translations, just as Dirac's equation is the square root of the Klein-Gordon equation. Supersymmetry is a global symmetry and is the first symmetry in particle physics that permits one to unify particles of different spin and statistics in the same multiplet. It was known previously that this unification could not be achieved within the usual mathematical framework for symmetries, namely Lie algebras. In supersymmetry, this problem is solved because the underlying framework is that of graded Lie algebras, in which both commutators and anticommutators occur.

The idea of supersymmetry was first introduced in 1971 by Yu. A. Golfand and

E. P. Likhtman (then at the Lebedev Institute) and was followed by some papers by D. V. Volkov and V. P. Akhulov (Kharkov) and other collaborators. At the time, this work went almost unnoticed. Two years later it was rediscovered by Julius Wess (Karlsruhe) and Bruno Zumino (CERN), who independently found the algebra of supersymmetry (starting from the dual-resonance model). Further, they constructed a number of examples of renormalizable supersymmetric models, establishing in this way the possible connection with particle physics; the possibility of an extension to local supersymmetry was also raised by Wess and Zumino and by Abdus Salam and John Strathdee (International Centre for Theoretical Physics). This idea was eventually embodied in supergravity.

Supersymmetry might be compared to the discovery in 1925 that electrons require a spinor representation of the Lorentz group, in the sense that a new kind of representation for symmetries is involved. In supersymmetry, the theorists found that within the framework of quantum field theory, one could have symmetries for which the conserved generators transformed as spinors. Once supersymmetry was introduced a rapid and systematic development ensued, especially in Western Europe.

One interesting idea to describe global supersymmetry was proposed by Salam and Strathdee, who introduced the notion of a superfield that depends on the four space coordinates plus four new parameters, the components of an anticommuting Majorana spinor.

From the beginning of work in supersymmetry, theorists considered the possible connection with gravity. (Because Einstein's theory of gravity can be considered the gauge theory of the Lorentz group, as U.T. Yamma had pointed out, it is only natural to ask what additional forces would result from gauging the new spinor symmetry.) Early work was done by Volkov and V. A. Soroka (Kharkov), and by Wess and Zumino.

The goal of many in the field was to formulate an explicit field theory in which supersymmetry would appear as a local or gauge invariance and which would incorporate gravitation. The 1975 approach of Richard Arnowitt and Pran Nath (Northeastern University) followed the superfield idea of Salam and Strathdee in enlarging the Riemannian geometry to include new degrees of freedom. Their superfield has components corresponding to both the gravitational and the electromagnetic field. Using their gauge supersymmetry theory, Arnowitt and Nath were able to show that the supergravity equations arose as a limit to a singular geometry of the gauge supersymmetry equations.

Supergravity. Daniel Freedman and Peter van Nieuwenhuizen (State University of New York at Stony Brook) and Sergio Ferrara (Frascati) were working together on this problem. Generally the representations of supersymmetry go into equal numbers of Bose and Fermi states differing by one-half a unit of spin. The graviton with spin 2 has as its companion spin $\frac{3}{2}$. They therefore knew that the particles described by the desired theory should transform in an irreducible representation of the supersymmetry algebra and that the natural representation contained the spin-2 graviton and a spin-$\frac{3}{2}$ particle. They constructed[1] a supergravity theory that was formulated in terms of physical fields for these particles.

At CERN Zumino and Stanley Deser, who was visiting from Brandeis University, were trying to construct a consistent theory of the spin-2 Einstein field and the spin-$\frac{3}{2}$ field. For many years attempts to couple higher-spin fields had led to grave difficulties. As Deser told us, the consistency is closely related to local supersymmetry. The formulation that Deser and Zumino produced[2] was simpler but equivalent to that of the Stony Brook group, being based on an appropriate minimal coupling between the fields.

All this was "pure" supergravity. However, to make supergravity more realistic, it appeared that one must bring in lower-spin particles as "matter" supermultiplets interacting with the gravitational and supergravitational potentials. If gauge supersymmetry or local supersymmetry is a true gauge principle, Freedman said, one should be able to take every supermultiplet with global supersymmetry and extend it to local invariance by coupling it to the spin-2 and spin-$\frac{3}{2}$ particles, just as C. N. Yang (Stony Brook) and Robert L. Mills (Ohio State University) did in 1954 with isospin. A number of groups were able to accomplish this for both spin $(1, \frac{1}{2})$ and $(\frac{1}{2}, 0)$ matter multiplets. For example, if one couples supergravity to the dual-resonance model (which was one of the starting points of supersymmetry), one obtains a much clearer form of its dynamics; this work was done by Deser and Zumino.

Another approach is to construct field theories that are unified, because particles of spin 1, spin $\frac{1}{2}$ or spin 0 appear with spin $\frac{3}{2}$ and spin 2 in a single irreducible representation of an extended supersymmetry algebra. Such algebras involve spinor charges with an internal symmetry quantum number; these were studied by Rudolf Haag (Hamburg), Jan Lopusanski (Wroclaw University in Poland) and Martin Sohnius (Munich).

Murray Gell-Mann (Caltech) and Yuval Ne'eman (Tel Aviv University) studied the representations of extended supersymmetry, and determined the composition of the new supermultiplet containing gravity and supergravity. The internal symmetry, they found, could be an SO(N) for any N up to 8.

The corresponding extended supergravity field theories have been constructed for the case of SU(2) internal symmetry by Ferrara and van Nieuwenhuizen (and also investigated by Deser, Wess and Zumino) and for SU(3) by Freedman and by Ferrara, Joel Scherk (École Normale Superieure in Paris) and Zumino. Some results on the SU(4) theory have been given by Ashok Das (Stony Brook). At the moment there are no explicit models for $N > 4$. In the present framework, Freedman and van Nieuwenhuizen feel it appears possible to construct these unified field theories only for internal symmetry groups SU(N) with $N \leq 8$, so that the formalism is very restrictive. Freedman and Das have shown that a Yang–Mills SO(N) gauge invariance can be incorporated. They hope that the resulting formalism can encompass unified theories of the weak and electromagnetic interaction, which rely on Yang–Mills symmetry.

Traditionally, gravitational theories are not renormalizable. The renormalization procedure usually applied to quantum electrodynamics does not work, and quantities that are in principle observable turn out to be infinite. Recently Mark Grisaru (Brandeis), van Nieuwenhuizen and Jos Vermaseren (Stony Brook) discovered various explicit examples that the lowest-order quantum corrections are finite in supergravity, and they gave a theoretical explanation of this result. This was the first time, van Nieuwenhuizen told us, that quantum gravity yielded finite results. Grisaru and Terry Tomboulis (Princeton University) then showed that also various second-order quantum corrections are finite, while Deser, John Kay and Kellogg Stelle (Brandeis), using supersymmetry invariance requirements, have shown that for ordinary supergravity the lowest-order and second-order quantum corrections are all good. However, at third order they found that renormalizability could fail. Deser said that extended supergravity might avoid these third-order difficulties and be good all the way.

The unification of quantum theory and general relativity has long been one of the fundamental problems of theoretical physics, and supergravity might be the scheme that yields a completely finite theory of quantum gravity, van Nieuwenhuizen and Deser feel.

Can a geometrical formulation of supergravity be found? The Riemannian approach used by Arnowitt and Nath in eight-dimensional superspace can do it at a singular limit and for SO(2) supergravity. An alternative formulation first suggested by the Volkov group has been worked out recently by Wess and Zumino. This approach, based on a non-Riemannian description of superspace with torsion, reproduces pure supergravity.

Very recently Samuel W. MacDowell and Freydon Mansouri (Yale University) have reformulated Einstein's gravitational theory with a cosmological term 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.

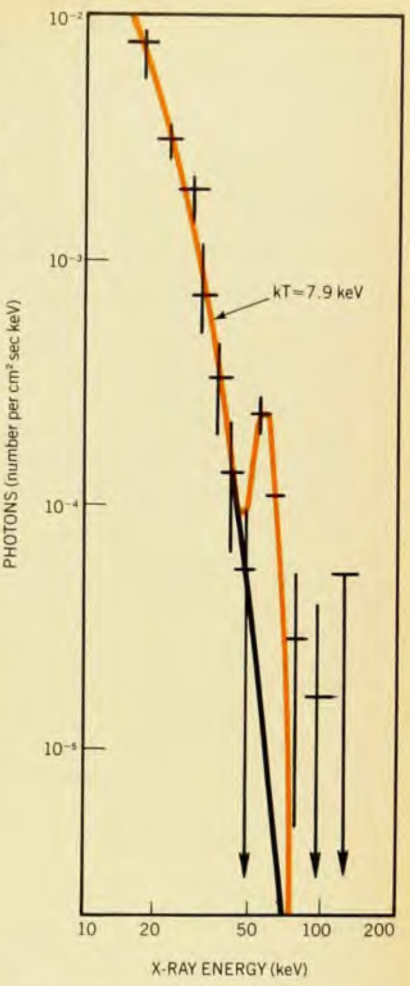
The energy spectrum of Hercules X-1 was measured by a collaboration consisting of Joachim Trümper, Wolfgang Pietsch, Claus Reppin and Bruno Sacco of the Max Planck Institute in Garching and Eckhard Kendziorra and Rüdiger Staubert of the Astronomy Institute of the University of Tübingen.[1] Trümper reported 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

References

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