The First European Conference on Astronomy
reported by

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I. INTRODUCTION

The first in what it is hoped will be an annual series of European Conferences on Astronomy was held at the University of Leicester on 1975 August 12–15 under the sponsorship of the Royal Society, the Royal Astronomical Society, and the European Physical Society. The structure of the conference was designed to resemble that of American Astronomical Society meetings, with invited review talks in the mornings and simultaneous sessions of contributed papers in the afternoon (with the papers one most wanted to hear inevitably scheduled in parallel). In addition, there were two evening talks, rendered somewhat informal by the excellent Leicester beer—personal views of extragalactic astronomy and close binary systems by G.R. Burbidge (University of California, San Diego) and B. Paczyński (Institute of Astronomy, Warsaw) respectively.

The X-ray astronomers were undoubtedly the stars of the show. Not only was there an abundance of data from three satellites of the post-Copernicus generation (UK’s Ariel 5; USA’s SAS 3; and The Netherlands’ ANS), but the transient source A 0620-00 (Mon X-1) provided real-time excitement by rising to become the brightest source in the sky during the course of the conference. In addition, however, the meeting proved to be an excellent forum for presenting and discussing new and controversial results in a variety of fields. The author does not claim completeness in covering the conference or agreement with all the points of view mentioned here.


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2. COSMOLOGY AND THE UNIVERSE

Perhaps the most puzzling asymmetry in all of physics and astronomy is the excess of matter (protons, electrons, neutrons, etc., and atoms made out of them) over anti-matter (anti-protons, positrons, anti-neutrons, etc., and atoms made out of them) in the part of the Universe that we can observe. Because matter and anti-matter, when they meet, annihilate with copious production of gamma rays, we know that our entire Galaxy (and cluster of galaxies, the Local Group, if there is an intergalactic gas) must be made of matter. It has, however, repeatedly been suggested (Alfvén 1965; Alfvén & Klein 1962; Klein 1966) that the asymmetry is an illusion, and that there are an equal number of galaxies (or clusters) made of anti-matter. The greatest difficulty with this idea is to get the galaxies and anti-galaxies out of the hot dense phase of the early Universe (sometimes called the Big Bang) without everything annihilating. A scenario for overcoming this difficulty has been suggested by R. Omnès (1971, 1972) and his colleagues (Aly et al. 1974). It involves the early formation of an emulsion with matter and anti-matter fluid elements (which repel each other by the pressure of the photons generated at the boundaries) followed by a phase of coalescence in which the fluid elements build up to galactic masses. The scenario has been vigorously attacked by G. Steigman (1972, 1973, 1974) on the grounds that the required effects simply do not occur and that annihilation before and during galaxy formation would result in a much higher ratio of photons to baryons than we, in fact, observe and a highly-distorted photon spectrum. The talk ‘On the annihilation of the baryon-symmetric cosmology’ by A. Ramani (Orsay, France) and J. L. Puget (Meudon, France) essentially concurred with Steigman’s attack. This is particularly significant because the authors are among Omnès’ colleagues in previous work. They point out that the mechanism normally suggested for coalescence (something like surface tension due to annihilation-generated X-rays (Aldrovandi et al. 1973) does not work because dissipation is not negligible, and second that, even if partial coalescence can be achieved while the Universe is radiation dominated further annihilation during the matter-dominated phase will produce additional photons that cannot be thermalized and that will, therefore, distort the 2.7 K blackbody radiation spectrum more than the observations allow.

Another very curious asymmetry has only recently been suggested. Standard cosmological models generally assume that the Universe is homogeneous and isotropic, and it has frequently been stated that the Hubble flow (relation of redshift to distance for distant galaxies, i.e. the expansion of the Universe) is isotropic around us to within the errors of the measurement. The very great isotropy of the 2.7 K radiation would seem to confirm this (Sciama 1971). Rubin & Ford (1975;
Rubin, Ford & Rubin 1973; Rubin et al., to be published) have, however, pointed out that, when a Hubble diagram is plotted for 96 ScI galaxies (bright, open spirals) with apparent magnitudes in the range $m_v = 13.0-15.0$ and redshifts in the range $V_r = 3500-6500 \text{ km s}^{-1}$, a strong asymmetry emerges in the sense that Hubble’s constant turns out to be $50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ in the part of the sky with small right ascension and positive declination, and $60 \text{ km s}^{-1} \text{ Mpc}^{-1}$ in the opposite direction; 21-cm neutral hydrogen velocities for the galaxies (Rubin et al., to be published) give the same asymmetry, as do studies of supernovae (Rust 1975) and various other kinds of objects (Jaakola et al. 1975). Critics of the effect (which amounts to about $1000 \text{ km s}^{-1}$ or $0.2 \text{ mag}$, depending on how you look at it, for the ScI’s used) think that there is likely to be a systematic discrepancy in magnitude estimates over the sky large enough to account for the entire effect. A. Sandage (Hale Observatories) has been among those making this suggestion (Sandage 1974, 1975). B.N.G. Guthrie (Royal Observatory, Edinburgh) has taken the next step* and reported on it at Leicester. An independent set of magnitudes and redshifts for brightest cluster galaxies, covering much of the sky, is available from the work of Sandage (1973). The magnitudes are corrected for galactic absorption, redshift ($K$-correction), and cluster richness. From these data for 42 galaxies with $V_r = 4000-25000 \text{ km s}^{-1}$, Guthrie finds a mean Hubble relation $m_v = 5 \log V_r - 6.83$. But the deviations from it are not random, being mainly positive in one region of the sky, and negative in another. The difference between the regions is $0.37^m \pm 0.12^m$ or $2200 \pm 700 \text{ km s}^{-1}$, in the same sense and for the same regions as found by Rubin et al. (to be published). The possibilities seem to be (a) that there are variations in absolute magnitudes of galaxies over large regions in space, (b) that the Hubble expansion is anisotropic for $V_r$ up to $25000 \text{ km s}^{-1}$, (c) that the Local Group or supercluster is moving at about $2200 \text{ km s}^{-1}$ relative to more distant clusters (but this would appear to violate the isotropy of the 2.7 K radiation), and (d) that the Sandage data sample also has some systematic differences in magnitude scale with position in the sky.

Standard, general relativistic cosmological models involve a so-called deceleration parameter, $q_0$ (measuring the rate at which the expansion of the Universe is slowing down due to gravity), which is directly related to the average density of mass-energy in the Universe, $\rho$, in the sense that $q_0 = 1/2 \rho / \rho_c$ where $\rho_c$ is the density that will just barely make the Universe turn around and recontract. Efforts to measure one or the other of these continue, but the situation is not presently very encouraging. Kronberg (Bonn) and Normandin (Toronto) have

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*This was previously done by F.D.A. Hartwick (1974) who also found an asymmetry, but concluded it was probably due to variable interstellar absorption.
failed in yet another attempt to detect an intergalactic medium which might contribute appreciably to $\rho$ by looking for an extragalactic component to the rotation measures of radio sources. Kiang (Dublin) claims to have discovered a mistake in all the standard determinations of the density of luminosity in the Universe (from which the mass density due to galaxies is estimated). Correcting the mistake, he finds $\rho/\rho_c = 0.02 - 1.23$, which is still not very informative. Finally, J.Gunn (Caltech) and B.Tinsley (Yale) have re-examined one of the standard methods of determining $q_0$, namely the appearance of the Hubble diagram for galaxies of large redshift, and they conclude that either (a) the expansion of the Universe is accelerating, or (b) it is not possible to measure $q_0$ in this way because the intrinsic brightnesses of galaxies change too much with time, or (c) possibly, both of these (Gunn & Tinsley 1975).

3. GALAXIES AND QUASI- STELLAR OBJECTS

One of the many distressing problems that continue to be associated with quasi-stellar objects is the location of the material producing the absorption lines seen most often in QSOs with large emission redshifts. W.L.W.Sargent (Caltech) points out that there are difficulties with either interpretation. On the one hand, if the absorbing material has been expelled from the QSO and remains near it, the combined constraints of density, mass, and distance from the quasar (obtained from the types and strengths of lines seen) lead to an absorbing cloud with a ratio of thickness to breadth of $10^{-6}$ which requires some $10^{60}$ erg to get it to where it is at the speed at which it is seen to be going. On the other hand, if the absorbing material is in intervening clouds at the distances given by the absorption redshifts, then the clouds must be comparable in size to galaxies, but commoner (about $0.4$ Mpc$^{-3}$) implying appreciable intergalactic material with non-zero heavy-element abundance. Sargent and Gunn plan an attempt to discriminate between the two unsatisfactory situations by measuring the $\text{Mg I}/\text{Mg II}$ ratio in the $z = 0.61$ absorption system of the QSO PHL 938 ($z_{em} = 1.9$), which should depend strongly on whether or not the QSO is nearby.

The radio astronomers continue to supply copious data for an increasing number of sources at ever-increasing spatial, temporal, and frequency resolution. No single, coherent picture of source structure, formation, and energetics has yet emerged, however, and perhaps none should be expected, given the wide range of phenomena exhibited. Among head–tail sources (which are strung out to one side of the optical galaxy) the magnetic field appears to run roughly parallel to the source axis. This is also the case for the longest (800 kpc) such source yet found, IC 711, as studied by Vallée and A.S.Wilson (Leiden). In the large double-radio sources, on the other hand, the magnetic field, at
least in the bright tips of the components, runs perpendicular to the source axis (work on the Westerbork Synthesis Radio Telescope, reported by Willis (Leiden)). Meanwhile, according to J.R.Shakeshaft (Cambridge) the double components themselves tend to be aligned along the major axis of the associated optical galaxy, as if they had been thrown out along the equatorial plane, but such a sling-shot model does not seem to be consistent with the constant alignment of components in sources showing several pairs. On the statistical side, a Dutch–Italian collaboration (Ekers, Jaffe, Perola, Fanti, and Lari) finds that the luminosity function of faint radio sources is the same for elliptical galaxies in and out of rich Abell clusters, presenting difficulties for any model where interaction with a surrounding medium is important. Finally, a co-operative effort between Willis, Oosterbaan, and Ruiter (Leiden) and Arp (Hale Observatories) confirms that the fraction of optical identifications which are galaxies increases dramatically from bright optical objects (about one-third in the 3C catalogue, for instance) to faint ones (84 per cent in the sample fainter than $m \sim +22$).

Extragalactic X-ray astronomy is presently discovering the various kinds of variability that radio and optical astronomers have had to live with for years. The Ariel 5 high-latitude survey failed to find several moderately bright Uhuru sources, meanwhile discovering a couple of new and apparently transient ones (Cooke, Elvis and Pounds, Leicester). These sources have no optical identifications and could in principle be galactic, but there is no doubt that Cen X-1 is extragalactic, and it has, on average, been getting brighter since 1970. A comparison of Uhuru, Copernicus, OSO 7, and new Ariel 5 data by Stark, Davison and Culhane (London) indicates that the source has brightened by a factor of at least two over the past year. There has been no noticeable change in the amount of obscuring material required to produce the low-energy turnover in the spectrum, which remains large ($1.32 \times 10^{22}$ H atoms cm$^{-2}$).

4. THE MILKY WAY, INTERSTELLAR MATTER AND COSMIC RAYS

The arm structure of our own and other galaxies is now generally attributed to spiral density waves, as discussed, for instance, by Lin, Yuan & Shu (1969). One problem with the original analysis was that the dispersion relation for the waves gave a term in the growth rate for the arm instability which was independent of the number of arms in the spiral, despite the fact that nearly all observed spiral galaxies have two arms. A.H.Nelson (Cardiff) has now plugged part of this loophole by including the next higher-order term in the Vlasov–Poisson equations. The result is decreasing instability with increasing number of arms, $m$, at least in the limit of large $m$. Another destabilizing mechanism which makes $m = 2$ dominate $m = 0$ or 1 is evidently required. Additional
insight is contributed by a computer simulation of a 25000-star galaxy by D.R.K. Brownrigg (Reading). In addition to verifying the conclusion of Ostriker & Peebles (1973) that putting at least one-third to one-half of the mass in a halo prevents the occurrence of instabilities in the disk of the galaxy, the study shows that (for a halo:disk ratio of 3:1) spiral structure develops quickly and that a two-arm mode gradually grows to dominance.

When it comes to the central regions of our Galaxy, even the structure, let alone the mechanism responsible for it, remains in dispute. Despite yet another round of 21-cm data collecting (Cohen 1975) and interpreting, R.J. Cohen (Jodrell Bank) concludes that it is not possible to distinguish the results of a series of explosions in the galactic nucleus from the appearance of non-circular motions associated with a central bar.

On a smaller scale, a phenomenon well known to all connoisseurs of colour pictures for elementary astronomy classes is the stripy appearance of the nebulosity associated with the Pleides (especially Merope and Maja). V. Icke (Cambridge) suggests that this is due to large-amplitude waves of the soliton type. Such waves are able to pass through other wave trains of similar type without disruption, and may be among the strong, non-linear, constant amplitude solutions which are found for the wave propagation equation when dynamical terms are included in the diffusion coefficient.

Like the Pleides, most young star clusters are seen to have ionized hydrogen associated with them. Some also have cooler, denser gas present in molecular form. A.I. Sargent (Caltech) has detected both $^{13}$C$^{16}$O and $^{18}$C$^{16}$O in the vicinity of the associations Cepheus OB3 and Perseus OB2. The observations imply the presence of rather large (10–50 pc) and massive ($1 - 4 \times 10^4 M_\odot$) molecular clouds having densities near $10^4$ atom cm$^{-3}$. The CO hot spots, infrared sources and compact H II regions within the Cepheus cluster are all in the same general area, but do not coincide. They would seem to represent stars or protostars in different stages of formation.

Cosmic rays in both the intermediate (few GeV) and very high ($\gtrsim 10^{19}$ eV) energy ranges are generally included among the components of the interstellar medium of our own Galaxy, the former because it would require a forbidding, though not absolutely impossible, amount of energy to fill all space with them, and the latter because they should not be able to travel through the 2.7 K radiation background long enough to get here from outside the Local Group. Dodds, Strong and Wolfendale (1975) have now verified the galactic nature of the GeV cosmic-ray protons. Their argument is that an isotropic cosmic-ray distribution interacting with galactic neutral hydrogen would produce
significantly more gamma rays than are seen (Fichtel et al. 1975) in the direction away from the galactic centre. The evidence for the high-energy particles is not so comforting. Another Durham group (J.L. Osborne, M.White, A.W.Wolfendale and P.Kiraly, also of Budapest) finds that the directions of arrival of cosmic-ray showers with energies above $10^{19}$ eV tend to avoid the galactic plane, as would be expected for extragalactic rather than galactic particles. They also, very tentatively, suggest an association of arrival directions with 10 quasars which Arp has pointed out as possibly being associated with the Local Group.

5. STARS AND THEIR REMNANTS

Accretion disks, consisting of matter in orbit around a central star and falling down onto it, have become so popular in connection with the X-ray binaries (Section 6) that they have slopped over into the field of star formation. T Tauri-type stars are believed to be pre-main sequence objects with active surfaces. Two of them, FU Orionis and V 1057 Cygni have undergone unusually strong (up to 6 mag) and long-lasting (years or decades) flares. B.Paczyński (Warsaw) suggests that their behaviour can best be understood in terms of an accreting disk of matter around each of them. The source of the matter is the remainder of the collapsing protostellar cloud found, for instance, in the models by Larson (1973). Instabilities in the disk then produce the outbursts, while the disk itself is responsible for a significant fraction of the luminosity of the system as well as for the anomalous spectra and rather large rotation velocities of these two objects.

However it is that stars form, one thing that virtually all astronomers have agreed upon (at least since the time of Eggen, Lynden-Bell & Sandage 1962) is that the stars in globular clusters all formed at the same time to within a few hundred million years. V.Castellani (Frascati) has recently completed a new analysis of the morphology of globular-cluster HR diagrams and the period–colour–luminosity relation for cluster RR Lyrae variables. He concludes that more than a single parameter (metal abundance) must vary among the clusters in order to account for the observations. Other workers (Butler 1974; Demarque 1974) have reached similar conclusions, and suggested varying amounts of differential rotation and varying amounts of mass loss during the red-giant phase as likely parameters. Castellani, on the other hand, has focused on age and helium abundance. He concludes that the helium abundances must range from $Y = 0.25$ (in M3) to $Y = 0.34$ (in ω Cen) and the ages differ by $4-5 \times 10^8$ years in order to match the data. Both these conclusions, but particularly the age one, are in strong contradiction to the conventional wisdom about the early evolution of our Galaxy (reviewed, e.g. Trimble 1975), which requires all the globular clusters to form within the free-fall time of gas from the halo to the disk (about $2 \times 10^8$ years).
Pulsars continue to provide various surprises. R.T. Ritchings and A.G. Lyne (Jodrell Bank) have studied single pulses from 34 objects and conclude that old pulsars do not just fade away, but rather flicker out, missing a larger and larger fraction of their expected pulses as time goes on. In addition, Ritchings & Lyne (1975) find that drifting subpulses drift in opposite directions for old and young object. But it is no longer quite as clear as it used to be what we mean by a young or old pulsar. The lack of correlation between their periods ($P$) and rates of period change ($\dot{P}$) as well as the lack of correlation between slowing-down ages ($\propto P/\dot{P}$) and kinematic ages (distance from the galactic plane divided by proper motion in the $Z$-direction) (Lyne, Ritchings & Smith 1975) suggests that $P/\dot{P}$ may provide only an upper limit to the real age. This is reassuring, particularly for a few long-period pulsars whose $P/\dot{P}$ ages are longer than the age of the universe (reciprocal of the Hubble constant).

Despite these problems, the Crab Nebula pulsar retains its status (based on the identification with the supernova of AD 1054) as youngest pulsar of all. Its activity is consistent with its status. Within one three-month period during the past year, there was (a) an increase in the pulse width near 400 MHz corresponding to the precursor pulse being smeared into the main pulse (Lyne & Thorne 1975), (b) a general increase in the radio flux (J.M. Rankin, Iowa), (c) optical activity in the central region of the nebula (J.D. Scargle, Santa Cruz), and (d) a change in the X-ray pulse profile. The most interesting assumption is that these events are all related and reflect increased turbulence in the gas along the line of sight to the pulsar due to an outburst from the neutron star.

Meanwhile, the Crab Nebula itself is proving to be not quite so completely unlike other supernova remnants as is generally advertised. Its conspicuous central X-ray source is harder, brighter and smaller than those associated with Cas A and the Tycho remnant. But during the 1974 November lunar occultation of the Crab, F. Seward, T. Palmieri and A. Toor (Livermore) detected additional, softer emission from the region which is consistent with a thermal source having a spatial extent comparable with the optical and radio-emitting parts of the nebula, a luminosity near $10^{38}$ erg s$^{-1}$, and a temperature near 0.8 keV. This is far more compatible with the X-ray characteristics of other remnants than is the smaller source associated with the pulsar. In addition, A.S. Wilson (Leiden) and K.W. Weller (Bologna) have pointed out that the radio source 3C 58 resembles the Crab not only in spatial distribution of luminosity and spectral index, but also in polarization and magnetic-field strength and structure. The chief difference is, of course, the absence of a pulsar or any associated high-energy activity in 3C 58.
6. GALACTIC X-RAY SOURCES

An increasing number of familiar kinds of objects in the Galaxy are beginning to be known as sources of X-rays, along with the supernova remnants which were among the first sources identified. The bright stars Capella and Sirius have each now been seen by more than one group (Brinkman 1975; Catura, Acton & Johnson 1975; Mewe et al. 1975). Their X-ray luminosities are considerably less than their optical ones, and the X-rays seem to be due to thermal emission from a hot corona, whose ultraviolet emission has also been detected in the case of Capella, and gives a consistent temperature. Thermal bremsstrahlung from hot gas, in this case in an accretion disk, is also the most likely source for the X-rays seen from the U Geminorum star SS Cygni. The soft (0.1–0.3 keV) flux reported by Rappaport et al. (1975) from a rocket flight on 1973 March 30, when the star was optically bright has been confirmed by D.R. Hearn (MIT) and others using SAS-3 data for 1975 June 25.3, when the source was again optically bright. Continued monitoring by ANS has shown that the X-rays continue at about 1 per cent of the high-state level when the star is optically faint (Heise 1975). The very soft X-ray source in Coma Berenices whose apparent discovery (as MX 1313 +29) was also reported by Hearn has subsequently been identified with the very hot white dwarf HZ 43 (Clark 1975). The source shows no variability on time scales from 0.1 ms to several hundred seconds, and had the same brightness in three observations separated by many months (one a pre-discovery observation by the Berkeley group). The X-ray data in combination with UBV colours and ultraviolet data from Apollo–Soyuz suggest a thermal (blackbody) source with a temperature of about 110 000 K (Margon 1975). This conveniently fills the gap between normal white dwarfs and the hotter nuclei of planetary nebulae.

In addition to clarifying the nature of familiar objects, X-ray astronomy has drawn our attention to several new kinds of things. It is not quite clear just how many new kinds of things are involved. There is, for instance, a group of bright sources in the direction of, and presumably grouped around, the galactic centre which may or may not be examples of the class of X-ray binaries discussed below. None of them shows a single unique binary period in the range of hours to weeks, but the light curves derived from Ariel 5 surveys of the region nearly all show quasi-periodic behaviour with time scales of a few days, which persists for at least a few cycles (M.G. Watson and G.R. Eadie, Leicester). It will take much longer stretches of data to establish whether there is a single period for each source which comes and goes, or a succession of different periods, or accidental beating among several periods (due, for instance, to a group of sources in a globular cluster all being counted as a single source), or something else. The nature of these sources is of
some interest since they supply about 90 per cent of the total X-ray luminosity of our Galaxy. Studies of X-ray sources in other galaxies do not shed very much light on the problem. The brightest source in the Small Magellanic Cloud (SMC X-1) has an optical identification (Sanduleak 160), which places it firmly in the binary class, while the brightest sources in the Large Magellanic Cloud do not.

The four (± one) variable X-ray sources identified with globular clusters may constitute another distinct class of objects. Because these clusters contain only old Population II stars, it is not possible for the type of binary system associated with the galactic-plane X-ray sources (relatively massive, close, and containing a collapsed component) to have survived in them to the present time. Several authors (Bahcall & Ostriker 1975; Silk & Arons 1975, preprint) have explored the possibility of producing the X-ray by gas accretion onto a massive (∼1000 M\(_\odot\)) central black hole. J.Frank (Cambridge), on the other hand, suggests that such a central black hole might gobble up entire stars that venture too close to it (driven inward by binary encounters). This would also produce X-rays. Fabian, Pringle & Rees (1975) find, alternatively, that it is possible to bring the sources back within the binary class by means of two-body encounters and tidal captures which can produce binary systems containing collapsed stars continuously over the life of the cluster. Precise positions of the sources would help to distinguish the various models, since the binaries could occur anywhere in the core of the cluster, but a massive black hole would have to be exactly at the centre.

The majority of the remaining galactic X-ray sources are confined to the disk and are of two types—relatively constant (in the sense that they are seen by several experiments months or more apart, though not necessarily at the same brightness level) and distinctly transient (in the sense that they fall below the limits of present detectors on a time scale of weeks or months). It is at least possible that there is a continuum between the two kinds of sources. Cir X-1 and Aql X-1, both of which are now considerably fainter than they were when seen by Uhuru, but which have not disappeared completely, may be examples of intermediate objects.

Eight or more (depending how rigorous one's standards are) of the relatively constant sources have been established as binary systems either on the basis of optical identifications with reasonably normal stars or on the basis of X-ray pulsations which show the Doppler effect of orbital motion. Certain or probable binaries with massive primaries (\(\geq 10 M_\odot\)) include Cyg X-1 (HDE 226868), Cen X-3 (Krzeminski's star), 2U 0900-40 (HD 77581), 2U 1700-37 (HD 153919), SMC X-1 (Sanduleak 160), and 3U 0352+30 (X Per). Those with lower mass
primaries ($\lesssim 2.5 M_\odot$) are Her X-1 (HZ Her), Cyg X-2 (identified with a 15th magnitude G star), Cyg X-3 (infrared identification only, due to high obscuration), and Sco X-1 (0.8-day period in both brightness and radial velocity). New data on nearly all of these were presented at Leicester. We mention here only a few of the more striking results.

Cyg X-1, because of the large mass for the X-ray emitting component implied by the orbit of the visible star, remains the best case for the detection of a black hole. Most of the viable models for the system that do not require a black hole involve three stars—the massive O star we see, a neutron star to make the X-rays, and a smaller main-sequence star to supply the extra mass. The high stability of the 5.6-day orbit period (seen in both optical light and X-rays) reported by A. Peacock and his colleagues (Leicester) now makes the triple-system models seem quite implausible and the black-hole explanation more likely. On the other hand, G. Auriemma and his colleagues (Frascati) reported the detection of very strong pulsed optical emission with a period of 83.525 ms, lasting 10 min out of about 30 min of observing time. The duty cycle is about 0.25 and the amplitude up to 5 per cent. The onset of pulsation appeared to be associated with a slight general brightening of the object. Such regular pulsations (they report a deviation from the mean period of not more than 0.01 per cent) sound much more like a neutron star than a black hole. If the pulsation is to be attributed to material in orbit accreting onto a black hole, then the orbital radius must be stable to one part in $10^4$ for 10 min, corresponding to a drift velocity of less than $10^{-9}$ of the orbital velocity. Further observations of the pulsations are clearly urgently needed!

What is probably the most convincing detection of an X-ray emission line in a binary source to date was reported by K. Mason, P. Sanford and J. Ives (London). They find (Sanford, Mason & Ives 1975), using a proportional counter aboard Ariel 5, that Cyg X-3 shows a 6.5 keV emission line, narrower than the instrumental resolution of about 1 keV. The average strength of the feature is $0.027 \pm 0.004$ photons cm$^{-2}$ s$^{-1}$, but it varies with the 4.8-hr intensity cycle of the source so that the equivalent width remains roughly constant. Observations by the same group at other times have not shown the line, which is probably due to iron, at comparable intensity. Additional line-emission observations of this and other sources will be very important in clarifying the temperature and density structure of the accretion disks around the X-ray components.

Another way of learning about the accreting material is to study the effects on the X-rays as they pass out through the incoming gas. K. A. Pounds and his Leicester associates have examined the X-ray light curve of Cen X-3. They find occasional large reductions in the X-ray flux while the source is turning on after an extended low state near phase 0.5
of the two-day binary period which can be attributed to scattering in relatively cool, dense gas which is produced as a wake behind the neutron star as it moves through the stellar wind of its massive companion. Electron scattering is thought to be more likely than absorption because the obscuration is relatively uniform at all energies. There is evidence for similar variable grey obscuration in 3U 1700–37, according to G.Branduardi, P.Sanford and K.Mason (Mullard Space Science Laboratory, London), and in the Vela X-ray binary, 2U 0900–40, according to the Leicester group. It is probably significant that all three of these objects belong to the high-mass group in which the mass being accreted is lost in a stellar wind rather than from the Roche lobe. Shocks and wake formation will probably prove to be a common phenomenon in such sources.

The 4.8-s X-ray pulsation period of Cen X-3 remains the longest one to be interpreted as a neutron star rotation period by nearly everyone. That period has, however, been getting shorter ever since the source was discovered. I.R.Tuohy (MSSL, London) reported that the trend has continued at least through 1975 January with \( P/\dot{P} \) remaining steady at about \( 3 \times 10^3 \) yr.

The theorists have been telling us that such a spin-up of neutron-star rotation is to be expected as a result of the transfer of angular momentum from orbit to rotation as matter is accreted. The announcement by the MIT group, headed by H.Brandt, that SAS-3 had detected 283-s period pulsations from 0900–37 (= HD 77581 = Vel XR-1 ≠ Vela X-1 which is the supernova remnant) therefore came as a considerable surprise at least to the present author. In accordance with Redman's theorem* at least three explanations promptly appeared. These are a neutron star spin-down mechanism proposed by Fabian (1975), the suggestion by D.Q.Lamb (1975) that neutron stars might sometimes be formed spinning this slowly (due to angular momentum having been transported outward by convection and magnetic field during a red-giant phase), and the possibility that the star might really be rotating every millisecond or so and that what we are seeing is, in fact, its free precession (K.Brecher, 1975). A revival of the idea that the accreting star in some X-ray binaries is really a white dwarf can be expected momentarily, although a white dwarf that is above the Chandrasekhar mass limit because it is rapidly rotating is not a viable alternative in this case. Whatever its cause, the 283-s period does show a Doppler shift around the 8.95-day binary orbit of the system, permitting the measurement of a velocity amplitude (274 km s\(^{-1}\)) and a mass function (18.7 ± 1.6 \( M_\odot \)) (McClintock 1975) for the system. The fact that the estimates of the mass of the neutron star still range from 1.4 to 3.3 \( M_\odot \)

*According to the late Professor R.O.Redman (Cambridge) a competent theorist can explain any given set of data using any theory. A corollary by M.S.Longair (Cambridge) states that, in most cases, the theorist need not even be competent.
is due primarily to the disagreement among various groups of optical observers on whether the amplitude of the optical radial velocity curve is 18 or 40 km s\(^{-1}\) or somewhere in between.

The 283-s period also provides a link to our last class of objects, the transient X-ray sources. The discoverers of GX 1+4 (= 3U 1728-24 = GX 2+5 in the Copernicus catalogue) originally reported it (Lewin, Ricker & McClintock 1971) to have regular pulsations with a period of about 2·3 min. The report was treated with some scepticism. But two of the recent, well-studied transients have shown similar periods, 405 s for A1118-61† in 1974 December and 104 s for A0535+26‡ in 1975 April. These two sources have in common with GX 1+4 and the Vela binary unusually hard spectra. The modulation can be large, amounting to 80 per cent of the total flux in the case of 1118-61, according to the MSSL group. In addition to their generally hard spectra, the transients with definite periodic behaviour seem to have in common that as the intensity increases, so does the amount of absorbing material along the line of sight, according to G.K. Skinner and others at MSSL. This implies that the outburst is triggered by an increase in the accretion rate, rather than the clearing away of obscuring material. Possible optical identifications with emission-line B stars (Be) have been suggested for 1118-61 and 0535+26 by J. Bahcall (Princeton) and P. Murdin (RGO) respectively.

Of the transient events in general it can be said (K. Pounds, Leicester) that they have low galactic latitudes, implying distances of at least 1-2 kpc, and thus luminosities of \(10^{37-38}\) erg s\(^{-1}\). Maximum brightness is generally or always preceded by one or more precursor flares (over several days) which tend to have harder spectra than the main outburst. The amount of absorbing material between us and the source can get either larger or smaller as brightness increases. The data available from MSSL experiments in 1975 August were consistent with obscuration increasing in sources which showed periodic fluctuations and decreasing in the others. After a plateau at maximum brightness, the sources then decay away with time scales of weeks or months. Because so many of the short time-scale ones will be missed, the present rate of detection (at least seven from 1974 November to 1975 September) may imply a rate in the Galaxy of as many as 100 transients per year.

Other transients (including 1524-62 = TrA X-1 in 1974 November; 1742-28 near the galactic centre in 1975 February; and A0620-00 in 1975 August) have shown no periodic pulsation despite careful searches down to levels of 1 per cent or better. These sources have in common much steeper (softer) spectra than those with periodic pulsation. One

†The data are given by Ives et al. (1975).
‡The data are given in a series of four papers Rosenberg et al. (1975), Coe et al. (1975), Ricketts et al. (1975) and Kaluzienski et al. (1975).
of them \( (1742 - 28) \) has been associated with a transient radio source seen at about the same time and place by the radio observers at Jodrell Bank (Eyles \textit{et al.} 1975). The class includes both rapidly and slowly fading (like Cen X-4) sources.

A member of the non-periodic class, A0620–00, the brightest transient seen so far, appeared a few days before the Leicester conference and rose to maximum brightness during the meeting. The source, whose X-ray light curve is shown in Fig. 1, has displayed most of the standard features of transients including an initial slow rise, several precursor flares during which the spectrum softened from a

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{xray_light_curve.png}
\caption{The X-ray light curve of the transient X-ray source A0620–00 as seen by the University of Leicester experiment aboard the Ariel 5 satellite (courtesy K.A.Pounds, Leicester). The source showed most of the standard features of transient events, including precursor flares during which the spectrum softened and a partial recovery during the decline phase.}
\end{figure}
photon number slope of about \(-1.65\) to about \(-5.1\), a broad maximum, and gradual decline interrupted by a partial recovery on about October 1. Optical and radio emission from it have also been detected.

AO620-00 was first seen (Elvis et al. 1975) by the Leicester experiment aboard Ariel 5 on 1935 August 3 at a level of 38 Uhuru units. By August 6 it was as bright as the Crab Nebula (Elvis et al. 1975), and by August 11 the brightest source in the sky at 20 000 Uhuru units (Turner 1975). The MIT experiment aboard SAS-3 picked up the source on August 8 when it was as bright as Sco X-1 in the 1.4–5 keV band (Matilsky 1975). By August 15 it was four times as bright as Sco X-1 in the 1.5–5 keV band, but only half as bright in the 5–15 keV band, indicating its very soft spectrum. The SAS-3 experiment produced a sufficiently accurate position that an optical identification could be made by Boley & Wolfson (1975). On August 15 they found a star rather brighter than 12th magnitude at \(a = 6^h 20^m 11^s\), \(\delta = -0^\circ 19^\prime 10^\prime\) which showed no spectral features at a dispersion of 120 Å mm\(^{-1}\) and which had been fainter than 17th magnitude at the time of the Palomar Sky Atlas picture of the area. Subsequent optical studies (Warren & Robertson 1975; Dolan 1975; Peterson et al. 1975) showed the star to fluctuate in brightness and colour over the range \(B = 11.2–11.4\) \(B−V = +0.05–0.2\) on times scales of 30–60 min (in late August), to have the polarization characteristic of interstellar matter in its direction, and to show emission lines of H\(\alpha\),\(\beta\), \(\gamma\), \(\delta\) and \(\epsilon\), He II \(\lambda 4686\), O III \(\lambda 3444\) and N III \(\lambda 4634–4640\), the brightest lines having an intensity of about 10 per cent of the continuum in early September. The continuum spectrum was essentially flat over the range 3000–10 000 Å. The optical emission has gradually faded along with the X-rays, reaching apparent magnitude 12.2 by mid-October (Bortle 1975). Mauder (1975) has reported a low-amplitude, \(4 \pm 0.3\)-day photometric period, which might imply that the object is in a binary system.

Armed with the SAS-3 X-ray position, radio astronomers at Arecibo and National Radio Astronomy Observatory also detected AO620-00 on August 15 (Craft 1975; Owen et al.). The radio spectrum is also quite flat, having, for example, a spectral index of \(+0.1 \pm 0.1\) between 1400 and 2695 MHz on August 18. At peak brightness, the radio, optical and X-ray fluxes were each about one tenth of a Jansky (though only radio astronomers usually report their observations this way), and the spectra in all ranges, including infrared and ultraviolet were consistent with thermal bremsstrahlung, although the radio might also have been non-thermal. The radio emission decayed quite rapidly—about a factor of 5 in the week following detection. Perhaps most curious of all is the evidence found by Liller (1975a) that this is not the first outburst of AO620-00. A search of old Harvard plates has revealed that, in 1917, the same star reached an apparent
magnitude $B = 12$ and displayed a nova-like light curve, remaining bright for 75–150 days. It dropped to 20th magnitude or fainter in the interim, implying an amplitude of at least 8 mag. The star is quite red at minimum light (Ward et al. 1975). If the object is interpreted as a recurrent nova (the recurrence period of 57.5 years is not an unlikely one), then this amplitude implies (in accordance with a standard relation of variable star brightnesses to periods and amplitudes) that the source was intrinsically very bright. The resulting distance is about 11 kpc (Liller 1975b) and the implied X-ray luminosity some $10^{39}$ erg s$^{-1}$. One should probably not worry that this violates the Eddington limit, since the source is only too obviously not in hydrostatic and thermal equilibrium. On the other hand, the interstellar polarization and absorption seem to be more nearly consistent with a distance of 1–3 kpc, which would yield an X-ray luminosity about like those of other binary and transient sources.

The theorists have, of course, been having a marvellous time with the transient sources. The majority vote is for some sort of binary system in which the rate of mass transfer varies drastically. Stars from sub-dwarfs on up to supergiants have been suggested as the donors and collapsed objects from white dwarfs to black holes as the recipients. Suggested mechanisms for controlling the rate of transfer also provide a pleasing variety, from intrinsic pulsation of the donor star and eccentric orbits to interruption of the mass flow which prevents our seeing the X-rays most of the time by a nova-like (nuclear) outburst on the accreting star.

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