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Relativistic Astrophysics

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From 23 to 27 January, the 1967 Texas Symposium on Relativistic Astrophysics was held in New York City, as a successor to symposia held in 1963 and 1964, at Dallas and Austin, respectively. In this article we attempt a general review of the subject matter of relativistic astrophysics and summarize recent developments reported at the 1967 symposium (*1*).

The 1963 symposium was organized shortly after the discovery of quasars, when it became evident that fantastically large quantities of energy were being stored in very small volumes, and that the gravitational collapse of large masses might provide suitable sources of such energy. The purpose of the 1963 symposium was to bring together astronomers, physicists, and workers in general relativity for interdisciplinary discussions of the problem. The intent of subsequent symposia has also been to provide a common forum for these three classes of scientists, and *relativistic astrophysics* has become an umbrella term encompassing problems of interest to all three groups.

These problems involve observational aspects of cosmology, including the nature of quasars and the isotropic background radiation; tests of general relativity; cosmic rays; and x-ray and gamma-ray astronomy. They were discussed at length at the 1967 symposium.

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Isotropic Background Radiation

At one time the speculations of Gamow and some of his collaborators on the early history of the universe and on the cosmological synthesis of the elements attracted much attention (*2*). Gamow and his colleagues discussed the universe in terms of its contents of radiation and of matter. At the present epoch, the rest-energy density of all matter in the universe exceeds the energy density of the radiation, and this disparity will increase as the universe expands. However, in the past, when the universe was denser, the energy density of the radiation was dominant, and the expansion was controlled by the properties of the radiation.

At a very remote time, when the universe had an expansion age of less than 1 second, the temperature exceeded 10^9 degrees Kelvin. At that epoch there was a general equilibrium among the various forms of matter. Much of the radiative energy was converted into electron-positron pairs. These particles underwent fairly rapid weak interactions with neutrons and protons, with resultant emission of neutrinos and antineutrinos and establishment of an equilibrium ratio of neutrons to protons which favored the latter. The neutrinos and antineutrinos acquired an energy density comparable to that of the radiation; they also participated in the weak interactions that established the proton-neutron ratio (*3*).

As the temperature fell with the expansion of the universe, the neutrinos ceased to interact rapidly with nucleons, the electron pairs underwent annihilation, their energy being added to the radiation field, and hence the proton-neutron ratio was "frozen." If the density of matter at this time had been very low, then the neutrons would have decayed, and all matter would have become hydrogen. However, it appears unlikely that the density of matter could have been so small. At higher densities a variety of nuclear reactions will take place that will produce He^4 from the neutrons and protons. Recent calculations (*4, 5*) show that 25 to 30 percent, by mass, of the matter present will form helium under a wide range of initial conditions.

Gamow had argued that processes of neutron capture on helium would occur, heavier elements thus being synthesized. As the universal expansion continued, the energy density of the matter surpassed that of the radiation, and the matter presumably became free to clump together to form galaxies. As the radiation continued to expand with expansion of the universe, the photons were continually red-shifted, so the blackbody temperature of the radiation is now very low. Gamow estimated (*6*) that it would be 6°K.

This picture encounters grave difficulties concerning the formation of the heavy elements. There are no particle-stable nuclei at mass number 5, and at mass number 8 the beryllium nucleus is extremely short-lived. It was expected that the abundances of the elements in stars would be everywhere the same, but it was soon observed that this was not the case, and that very old stars were often highly deficient in heavy elements as compared with the sun. Hence there was a tendency to reject the above model, and to make the half-joking remark that "Gamow's theory is a wonderful way to build the elements all the way up to helium." Recent developments have indicated that this statement should be taken seriously.

At the Bell Telephone Laboratories, A. A. Penzias and R. W. Wilson were trying to track down the sources of background noise in a horn antenna operating at 7.5-centimeter wavelength, in order to facilitate an investigation

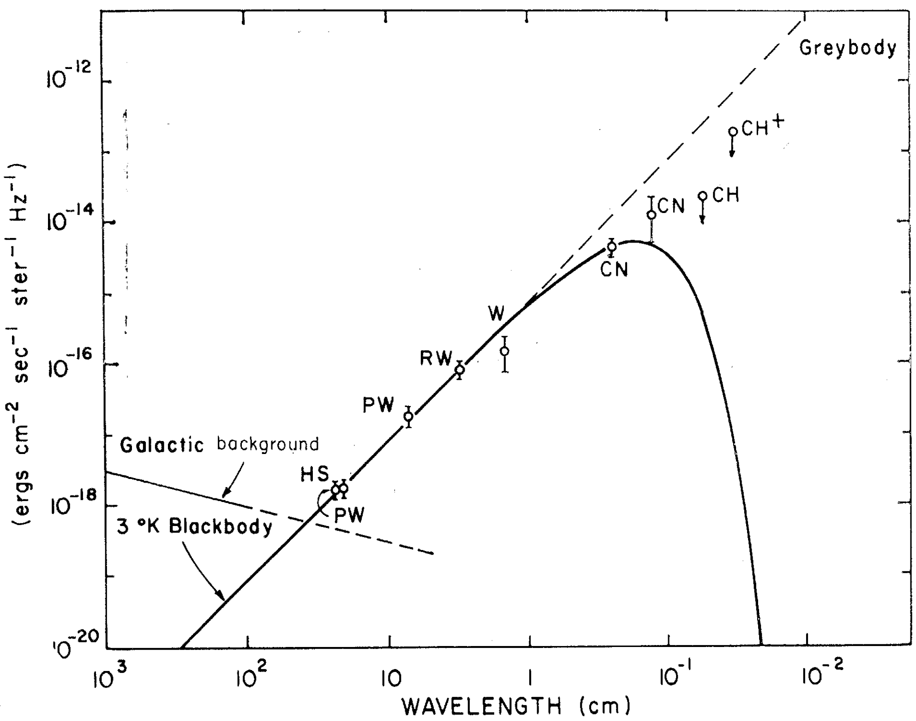

Fig. 1. Intensity of the isotropic background radiation as determined from microwave measurements and inferred from interstellar molecular lines. *HS*, Howell and Shakeshaft; *PW*, Penzias and Wilson; *RW*, Roll and Wilkinson; *W*, Welch, Keachie, Thornton, and Wrixton. [Prepared by P. Thaddeus]

of the spectrum of galactic continuum radiation at high latitudes. In this process they found that there was present in the sky an isotropic emission which, if it were blackbody radiation, would have a temperature of about 3.5°K (*7*). Independently, at Princeton, R. H. Dicke wondered whether background radiation of cosmological origin (he called it the "primordial fireball radiation") might be detectable. He suggested to P. J. E. Peebles that it would be desirable to calculate the temperature to be expected for this radiation at the present epoch. Peebles, unaware of the earlier work, found that the present-day temperature of the radiation would be about 10°K. This higher value for the temperature resulted from the assumption that the matter density, when the temperature was 10^9 degrees Kelvin, was high enough to produce a closed universe. Two Princeton experimenters, P. G. Roll and D. T. Wilkinson, began assembling the apparatus necessary for observing the expected radiation at a wavelength of 3 centimeters (*8*).

In time the Princeton and Bell Laboratories groups learned of each other's work, and it appeared that there was positive evidence for the existence of the primordial radiation (*9*). Other groups subsequently undertook measurements at additional wavelengths. At the symposium, Penzias reported on the progress to date. The accumulated measurements in the microwave region (*7, 8, 10*) are shown in Fig. 1. Also shown is the curve to be expected for blackbody radiation having a temperature of 3°K. It may be seen that the points fit this curve very well. It was also reported by R. B. Partridge that further observations by the Princeton group show that deviations of the background radiation from isotropy are much less than 1 percent along a great circle of the sky.

It may be seen in Fig. 1 that all of the microwave measurements lie on the low-energy side of the blackbody peak, where the curve is linear. If the spectrum were to continue rising in this linear fashion, it would correspond to graybody radiation at some higher temperature, rather than to 3°K blackbody radiation. Hence it is important to establish experimentally whether or not the spectrum corresponds to a curve for 3°K blackbody radiation. Some indirect evidence for such a correspondence has been found by P. Thaddeus and J. F. Clauser (*11*) of the Institute for Space Studies, and, independently, by G. B. Field and J. L. Hitchcock (*12*) at Berkeley. The moment of inertia of the CN molecule is large enough so that the rotational levels in the ground state are closely spaced together. In the case of interstellar CN molecules, the populations of the two lowest such levels should be given by a Boltzmann distribution in equilibrium with any blackbody radiation present in space. Certain electronic transitions upward from these levels correspond to absorption lines in the visible region of the spectrum. Thus, these lines can be used as an interstellar "thermometer." Thaddeus reported on measurements of such interstellar CN absorption; they are consistent with a temperature of 3°K. The wavelength in the spectrum of the background radiation corresponding to this transition is 0.26 centimeter. The measured point is shown in Fig. 1; it indicates that the radiation probably follows the blackbody curve rather than the graybody curve. Other interstellar molecules, such as CH, have smaller moments of inertia, hence their spectra provide poorer thermometers. Nevertheless, some upper limits have been obtained from CH lines; they indicate that the radiation intensity falls below the graybody curve at still shorter wavelengths. In all these cases it is necessary to make the assumption that collisions do not perturb the Boltzmann distributions of the molecules, and there is some uncertainty in this assumption.

If the cosmological interpretation of the background radiation is correct, does it follow that helium also has a cosmological origin and that the helium-hydrogen ratio should everywhere be the same? This matter was discussed by J. L. Greenstein of the California Institute of Technology. There appears to be evidence on both sides of the question. On the one hand, roughly the same helium-hydrogen ratio characterizes the ionized gas regions of many external galaxies and also the planetary nebulae of our own galaxy; this ratio is about the 25- to 30-percent required by the hypothesis of cosmological synthesis. On the other hand, certain old hot stars belonging to the galactic halo population (horizontal-branch-B stars) are found to have very little helium in their surface layers (*13*). Greenstein also finds some indication of low initial helium content in white dwarf stars.

It was then remarked by G. S. Greenstein, reporting on work by J. W. Truran, A. G. W. Cameron, and himself (*14*), that his father's observations of low helium contents in the surface layers of horizontal-branch-B stars should not be taken as evidence that the stellar *interiors* are similarly depleted in helium. In stars with high surface temperatures and slow rates of rotation, the surface layers should be sufficiently stable for helium and heavier ions to undergo gravitational settling below the photosphere.

R. V. Wagoner of the California Institute of Technology reported on calculations of the cosmological synthesis of light elements that were carried out in collaboration with W. A. Fowler and F. Hoyle (*5*). It is possible to find a unique set of conditions, corresponding to an open universe with the mass density about equal to the observed value in galaxies, which gives a synthesis of D^2, He^3, and He^4 relative to hydrogen in the proportions that apparently existed in the primitive solar system. On the other hand, if one wishes *not* to make primordial helium, then fairly extreme assumptions are required.

K. Greisen (Cornell) examined possible interactions between cosmic rays and the background radiation (*15*). The radiation would cause attenuation of very energetic particles: electrons would lose energy through Compton collisions with the photons, the energies of the photons thus being raised to the x-ray and gamma-ray regions; very-high-energy photons would be eliminated by photon-photon collisions, and fast protons would lose energy through photoproduction of mesons. There is, so far, very little evidence for or against the presence of the background radiation in terms of such effects. However, the fact that the very highest energy events detected by large shower arrays have been observed at all is a little disturbing, since the primary protons responsible for these events should be seriously attenuated by radiation interaction processes.

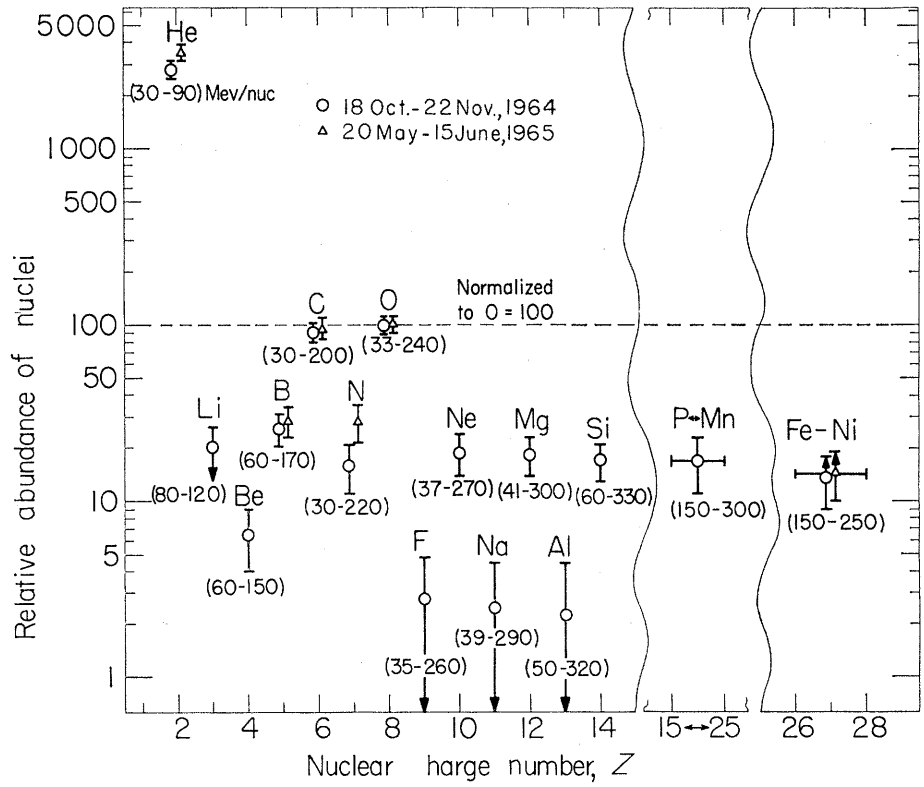

Fig. 2. Early results on abundances of lower-energy cosmic rays obtained with the OGO-I satellite (*17*).

Cosmic Rays

Two decades ago the flux of primary cosmic radiation was of great importance to physicists as the only available source of high-energy particles. Nowadays accelerators provide much more dependable particle beams in the energy ranges of interest, and cosmic rays are studied primarily for the *astrophysical* information they provide.

One important source of astrophysical data is the charge spectrum of the primary cosmic rays. This spectrum depends in principle on the composition of the source, the charge dependence of the accelerating mechanism, and spallation in both the source and the interstellar medium. It has been known for many years that the elements carbon through iron are substantially overabundant in the primary cosmic rays, with respect to their abundance in the sun, but it has not been possible to say whether this circumstance should be attributed to the source or to the acceleration mechanism. In any case, it has been concluded from the abundances of lithium, beryllium, and boron, as well as from the He^3/He^4 ratio, that the primary cosmic rays have traversed about 3 grams per square centimeter column. If their path lies in the interstellar material in our galactic disk, then, at the earth, the cosmic rays have an effective lifetime, before diffusing out of the disk, of only a few million years (*16*).

At the symposium, new information on relatively-low-energy cosmic rays (about 100 Mev per nucleon) was provided by J. H. Simpson (University of Chicago). The data were obtained from cosmic-ray experiments carried aboard spacecraft, primarily Mariner IV and IMP III. The Mariner experiments showed that the intensity of cosmic rays increased toward the orbit of Mars even at the time of minimum solar activity, thus indicating that the interstellar fluxes outside the solar-wind cavity are higher than the observed fluxes near the earth. The IMP experiments gave important new data on composition.

Among the medium-weight elements in the earth and the sun there is a considerably greater abundance of even-charge-number elements than of odd-charge-number elements. This phenomenon is also observed in the lower-energy cosmic-ray primaries. Some preliminary results (*17*) on the relative abundances obtained by Simpson are shown in Fig. 2. At the symposium he reported that the upper limit on the cosmic-ray abundance of fluorine is now less by an order of magnitude than that shown in Fig. 2, being less by at least three orders of magnitude than the abundance of oxygen; in fact, no fluorine nuclei at all were detected in the spacecraft experiments.

The low abundance is not inconsistent with the composition of the sun, but it does indicate that the lower-energy primaries cannot have traversed much interstellar matter. Therefore, their average age must be much less than that of the more energetic primaries. Perhaps a particular astrophysical event of the recent past was responsible for accelerating most of these nuclei. At any rate, the result is a very surprising one and indicates the importance of carrying out additional cosmic-ray experiments aboard spacecraft.

Further abundance results have been obtained with a very different technique by R. M. Walker (Washington University) and his colleagues at the General Electric Research Laboratory (*18*). They studied radiation-damage tracks left by heavy charged particles passing through certain minerals in meteorites. Only iron and heavier elements can be detected by this technique. In the sun, the elements with charge greater than 30 are less abundant than iron by several orders of magnitude, so we would expect cosmic-ray experiments with short exposure times to record a vanishingly small flux of such elements. The advantage of meteorites is thus clear: they have long exposure times in space.

The meteorite work showed that these "very very heavy" primaries with charge greater than 30 are in fact overabundant relative to their abundances in the sun. Thus the overabundance of the medium and heavy elements does not stop at iron; it is a phenomenon that may enable us to discriminate between various sources and acceleration mechanisms.

It has become clear in recent years that processes responsible for the acceleration of cosmic rays can be both more complex and more efficient than the moving magnetic mirrors originally postulated by Fermi. P. A. Sturrock (Stanford) pointed out that certain particle-plasma wave interactions can result in rather efficient energy exchanges. This is but one aspect of the interactions of waves with other waves and with general plasma turbulence. Sturrock refers to such acceleration processes as stochastic acceleration (*19*). He considers that some such mechanisms may be operative in plasmas associated with the quasars.

There is still considerable disagreement about the place, or places, where acceleration of the cosmic rays occurs. Two points of view were presented at the symposium. V. L. Ginzburg (Lebedev Physical Institute) reviewed the rival hypotheses of galactic and extragalactic origin of cosmic rays and concluded that the most efficient source of cosmic-ray injection into our galaxy has been the supernova explosions that occur in the galaxy itself. G. R. Burbidge (University of California, San Diego), on the other hand, defended the theory of extragalactic origin in the strong radio galaxies and quasars. A critical uncertainty in these arguments is the question of whether or not our galaxy has a halo; radio astronomers are no longer certain on this point. Hence it is not clear whether the cosmic rays that escape from the galactic disk are being stored in a galactic halo.

Quasars

The term *quasar*, proposed by H.-Y. Chiu (*20*), has been adopted by nearly everyone but the astronomers, who call these phenomena "quasi-stellar objects." Quasars were discovered as intense optical emitters associated with strong radio sources; next it was found that many similar optical radiators are *not* detectable radio sources. The angular diameters of the radio sources were shown to be very small (often $\leqslant 0.1$ second of arc) by means of lunar occultation observations and also from the relatively high frequencies where self-absorption is observed in the radio spectra. The small angular diameters led W. A. Dent (*21*) to suspect that the linear sizes might correspond to light-travel times (through the sources) that are sufficiently small to permit detection of variations in their radio fluxes over periods that are short compared to a human lifetime. He monitored the strongest radio source among the quasars, 3C 273, and established the existence of such variations. Optical intensity fluctuations were also known for this source, and we now know that such phenomena are characteristic of quasars.

By the standards of optical astronomers, quasar continua are very blue; superimposed on them are broad emission lines (20 to 100 angstroms wide) due to both forbidden and permitted atomic transitions. The relative strengths of the lines show that the gas density is large ($\sim 10^7$ atoms per cubic centimeter) as compared to that of the nebulae in our own galaxy. Fairly narrow absorption lines (~ 10 angstroms) are also found.

One can measure the red shifts $Z = (\Delta\lambda/\lambda)$ corresponding to the positions of lines in quasar spectra. They are very large, ranging from $Z = 0.158$ for 3C 273 to $Z = 2.2$ for PKS 0237-23. On the basis of the cosmological theory, these red shifts are attributed to the general expansion of the universe. On that hypothesis, PKS 0237-23 is the farthest known object and lies at a distance of 2500 megaparsecs, for a simple world model. (The radius of the observable universe is ~3000 megaparsecs.)

The great distances (according to the cosmological model) of quasars imply great absolute luminosities: $\sim 10^{47}$ ergs per second for 3C 273, as against $\sim 10^{44}$ ergs per second for a normal galaxy. Straightforward interpretation in terms of the synchrotron mechanism leads to a value of $\sim 10^{61}$ ergs for the energy content of a typical quasar. This corresponds to the rest energy of $\sim 10^7$ suns. A normal galaxy contains $\sim 10^{11}$ stars and has a diameter of ~ 20 kiloparsecs. But most astronomers agree that a substantial fraction of the quasar radiation must originate in a volume that is extremely small relative to that of a galaxy, because the time scales of intensity fluctuations may be as short as a few days (*22*). Thus, several workers have expressed serious doubts as to the validity of the cosmological distance hypothesis, and this question now constitutes the focal point of a major controversy: Where are the quasars?

An alternative hypothesis is the "local Doppler theory." According to this theory the quasars were produced by a gigantic explosion that occurred in our own or some neighboring galaxy. On this model, the luminosities are modest, for the distances are much reduced—for example, 180 kiloparsecs for 3C 273 (*23*).

The red shifts have also been interpreted in terms of a *gravitational* origin. The forbidden emission lines place some observational constraints on a model of this sort. Their presence alone sets an upper bound to the density of their region of origin, and their widths set limits on the gradient of gravitational potential in that region. Greenstein and Schmidt (*24*) considered and rejected the most obvious case—namely, one in which these lines are formed in a tenuous gas that surrounds a condensed massive object. A more complex gravitational red-shift model is attributable to F. Hoyle and W. A. Fowler. They suggest that the gas that produces the lines is at the *center* of the quasar, which consists of a cluster of neutron stars or collapsed objects. The gas is thus in a potential well, the forbidden lines provide no useful constraints, and the quasars may lie at "middle" distances of ~ 100 megaparsecs.

G. R. Burbidge discussed a possible upper limit to observed red shifts of absorption lines. He found that, for each of the ten quasars with $Z_{\rm abs} >$ 1.9, the value for $Z_{\rm abs}$ was in fact close to 1.95. This result seems to support a gravitational model, but the data on which it is based are rather meager; for example, a number of the red shifts are based on only one observed spectral line.

Although many new quasar observations were obtained during the year preceding the latest Texas Symposium, these have not always clarified the problems involved. For example, the infrared observations discussed by F. Low (University of Arizona) reveal that every simple alternative possibility for the appearance of the infrared spectrum of a quasar can be found in nature. Some quasars have infrared emission that is very strong compared to that expected from interpolation between the optical and the radio-frequency measurements. Others have just that infrared flux predicted by interpolation. Finally, there appear to be some quasars that are *too weak* in the infrared.

The accuracy of the positional data provided by radio observations is now good enough so that optical identifications of the sources can easily be made in unobscured regions of the sky. From 100 to 200 quasars have so far been identified, on the basis of the criterion that the optical object must be blue and must lie within the limits of error of the position indicated by the radio observations. Recently, A. Braccesi (California Institute of Technology) noted that the identification process is greatly facilitated if photographs are taken at wavelength of 8000 angstroms as well as in the ordinary optical regions, since quasars are much stronger at that wavelength than other "blue" objects are. Confirmation of identifications is provided by the measurement of red shifts; these measurements are now available for about half of the quasars.

Radio emitters that lie in unobscured regions but for which no corresponding optical object can be found are called "unidentified sources." The nature of such sources was a controversial subject at the symposium: P. A. G. Scheuer (Cambridge University) considers that they are mostly quasars; J. G. Bolton (Commonwealth Scientific and Industrial Research Organization) finds that they are mostly *not* quasars but, rather, are radio galaxies; and C. Hazard (Cornell-Sydney University Astronomy Center) concludes that the unidentified sources include both quasars and galaxies in comparable numbers. The arguments are based on two methods of classifying radio sources: (i) classification in terms of the extent to which the sources scintillate (that is, undergo rapid apparent intensity fluctuations) due to diffraction effects in the interplanetary gas; (ii) classification in terms of the spectral index, α, defined by $S_\nu \sim \nu^\alpha$ where S_ν is the flux density and ν is the frequency.

Scintillations increase rapidly with decreasing angular size, and they are regularly studied in programs for obtaining source diameters. All workers agree that quasars are stronger scintillators than the radio galaxies are, but some astronomers find that the scintillation properties of the unidentified sources resemble those of quasars, whereas other workers report that they are closer to those of the galaxies. There is some agreement in the area of spectral characteristics, however. In particular, Bolton found, from data obtained at wavelengths of 21 and 11 centimeters, that the ratio

$$\frac{S_\nu \text{ (21 cm)}}{S_\nu \text{ (11 cm)}}$$

is < 1.6 for quasars and > 1.6 for most radio galaxies and unidentified sources; a similar result was obtained in the wavelength range 6 to 20 centimeters by K. I. Kellermann at the National Radio Astronomy Observatory. Bolton concludes that the unidentified sources are radio galaxies so distant that they are too faint to appear on the Palomar Schmidt plates that are used for optical identifications. This conclusion is supported by several other arguments and findings, including the fact that the "luminosity functions" (plots of log N against log S, where N is the number of objects and S is the flux density) for radio galaxies, quasars, and unidentified sources are all different. However, the luminosity function for galaxies and unidentified sources *taken together* resembles that found for quasars. We may infer from this that if the radio galaxies and the unidentified sources are similar, then their distribution in the universe resembles that of the quasars, but if they are dissimilar, then no two of the three classes of objects have similar distributions.

A. T. Moffet (California Institute of Technology) summarized the present information on *intrinsic* flux-density variations in extragalactic radio sources. The amount of variation is a function of wavelength; the largest variations tend to occur in the spectral regions where $\alpha \gtrsim 0$. According to one simple model (*25*), a cloud of relativistic electrons is injected into the magnetic field surrounding the quasar. The cloud is at first opaque to its own synchrotron radiation, but as it expands it becomes transparent at longer wavelengths. At any epoch, if the source is opaque at a given wavelength, its intensity there should be on the rise, whereas at higher frequencies, where the source is already transparent, the intensity decreases. Thus a local maximum in the radio spectrum of the quasar will move down the spectrum toward longer wavelengths (this is called the "whipping rope effect"). The interpretation is complicated by the fact that there may be several electron clouds, with different birth dates, but the behavior of at least some of the radio quasars can be explained.

In the area of optical intensity variations, the most spectacular development has been a three-magnitude increase (an increase by a factor of 16) in the continuum emission of 3C 446; this increase was discovered by A. R. Sandage (Mount Wilson and Palomar Observatories) (*26*). An equally remarkable phenomenon is the presence of variations in the *polarization* of this radiation. T. D. Kinman (Lick Observatory) reported on measurements made by E. Lamla, C. A. Wirtanen, and himself. Their data for the blue region of the spectrum show that, during the 3C 446 outburst, the position angle of the electric vector changed by 90 degrees in a period of 1 month and then returned to its original value in another month.

The first detection of variations in the *radio* polarization of cosmic sources has evoked considerable interest. Using the 85-foot reflector at the University of Michigan Radio Astronomy Observatory, H. D. Aller and F. T. Haddock observed quasars 3C 273, 279, and 345 and showed that both the position angle and the amplitude of the polarized-flux component change with time, at least at the frequency of obervation, 8000 megacycles per second. Unfortunately, the results of polarization variability have not been shown to be of aid in testing models of quasars.

Are the quasars distributed uniformly about the celestial sphere? If they are not, then a powerful argument for a noncosmological interpretation of these objects would exist, unless we are willing to admit that the universe is anisotropic in some respects or that it is inhomogeneous on the length scale corresponding to $Z \sim 1$ (*27*). P. Strittmatter (University of California, San Diego) reported on an investigation of this question by J. Faulkner, M. Walmsley, and himself. They sorted quasars according to red shifts and found that 10 of the 11 quasars in the group with largest red shifts ($Z > 1.5$) were concentrated in two areas that are nearly opposite each other in the sky. Penston and Rowan-Robinson (*28*) claim that this result is an effect of observational selection. In any case, Sandage announced at the symposium that two more quasars with red shifts above 1.5 have been found to lie outside the "preferred" regions of Strittmatter *et al.*, and P. A. G. Scheuer discussed the work of D. J. Holden, who finds that the luminosity function of radio sources in the 4C (Fourth Cambridge) catalogue is not a functon of direction. Neither the 4C nor any other catalogue of radio sources is limited to quasars, let alone those with $Z > 1.5$, but a fair appraisal of the present situation seems to be that anisotropy in the distribution of extragalactic sources, or any subset thereof, has not been confirmed.

The *origin* of the energy contents of quasars continues to be a fertile ground for the imagination of theoreticians. Energy released as part of the evolution of a dense, massive star cluster was discussed by T. Gold (Cornell), and a "supernova interpretation" of quasars was championed by S. A. Colgate (New Mexico Institute of Mining and Technology). Development of a cluster depends upon the occurrence of collisions and the loss of stars through "evaporation." Further, there may be faster collective mechanisms at work. The energy released by collisions should be related to the variations in the luminosity of the quasar; thus, if these fluctuations show periodicity, the collision theory would be ruled out. In fact, periodicity has been reported for the optical radiation of 3C 273, but the data are rather crude, and Gold believes that random collisions at the rate of some 20 to 30 per year can account for the observations.

Colgate's calculations of the development of a self-gravitating star cluster suggest that stars may coalesce to form objects of approximately 30 to 50 solar masses. These then evolve very rapidly to the supernova state. The supernovae contribute to the energy content of the system through the kinetic energy residing in the matter ejected in their explosions.

Are there any real grounds at present for preferring one of the several interpretations of the quasar red shifts to any of the others? Sandage, himself an observationalist and staunch supporter of the cosmological model, stated that "no crucial experiment has yet been performed, or if it's been performed, we don't know about it, or if some people know about it, not everyone agrees." Not all physicists are so charitable. According to V. L. Ginzburg, "To consider that the local theory of quasars is comparable to the cosmological one is to say that a model which ignores theoretical physics is comparable to one that takes it into account."

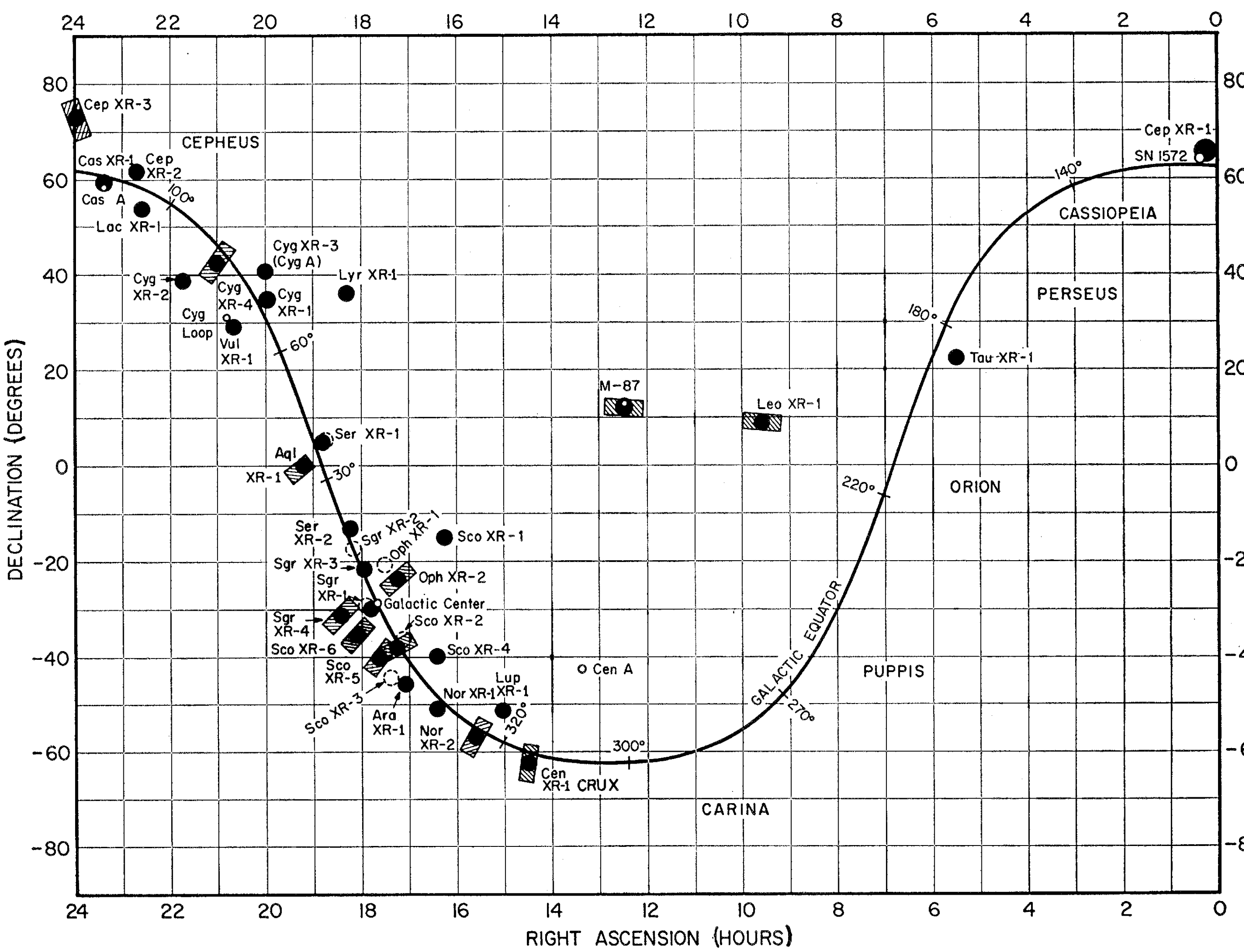

Fig. 3. Distribution of x-ray sources in galactic coordinates as determined by Friedman, Byram, and Chubb (*54*).

Discrete X-Ray Sources

Observation of the cosmos at wavelengths below 100 angstroms (photon energies above 0.12 kev) is still in its infancy. Apart from solar programs, the total duration to date of the rocket observations, which are responsible for the bulk of our knowledge on discrete x-ray sources, is about 1 hour. The groups active in this field are summarized in Table 1 (omissions are inevitable and inadvertent).

These astronomers are largely addressing themselves to the basic questions, Where and what are the x-ray sources? The Naval Research Laboratory (NRL) and American Science and Engineering Corporation (ASE) groups have contributed greatly to the solution of this problem. H. Friedman reported on an NRL survey at 1.2 to 12 kev, in which 29 sources were found (Fig. 3). Their distribution over the sky shows a striking association with the disk of our galaxy, and there is further clustering in two directions: toward the galactic center and in Cygnus. By making some educated guesses—namely, that the Cygnus sources lie in the Orion-Cygnus spiral arm, that the other clumping corresponds to objects in the Sagittarius arm, and that the proportional distribution of these sources with Z-distance from the galactic plane resembles that of most stars—the NRL workers estimated mean values of 1250 and 2500 parsecs for the distance from the sun to the Cygnus and Sagittarius groups, respectively. Attempts to detect radio-frequency radiation from objects discovered by x-ray techniques have thus far yielded negative results (*29*).

The situation with respect to the optical identification of x-ray sources is reminiscent of the status of radio astronomy in the late 1950's: the accuracy of the source positions is very poor, by the standards of the optical workers, and the results of different groups are not always in accord. As was also true in radio astronomy, there is no general nomenclature scheme, so the various observers in x-ray astronomy use different names for the same object (the NRL system is used here). This is probably just as well, however, because the "same" sources may not in fact be identical. Variability in the x-ray fluxes of some sources has also been reported, but this variability is uncertain, due to the limited data available.

Table 1. Experimental programs in x-ray and gamma-ray astronomy (solar astronomy is excluded).

Organization	Vehicles*	Energy range	Typical reference
American Science and Engineering	R	1–25 kev	(*36*)
Bologna University	B	20–200 kev	(*37*)
Cornell University	B	> 1 Gev	(*38*)
Case Institute of Technology	B	> 30 Mev	(*39*)
Goddard Space Flight Center	B	10–100 kev 30–500 Mev	(*40*)
Kamerlingh Onnes Laboratorium	B	20–130 kev	(*41*)
Lawrence Radiation Laboratory	R	< 1–100 kev	(*42*)
Lockheed Missiles and Space Company	R	2.5–16 kev	(*43*)
Massachusetts Institute of Technology	B	15–100 kev	(*44*)
	S	> 100 Mev	(*45*)
Nagoya University	R	2–20 kev	(*46*)
Naval Research Laboratory	R	0.2–12 kev	(*47*)
Rice University	B	23–455 kev	(*48*)
Smithsonian Astrophysical Observatory	B	> 50 Mev	(*49*)
Southwest Center for Advanced Studies	B	2–60 kev	(*50*)
University of California, San Diego	B	16–120 kev	(*51*)
University of Leicester	R	0.8–8 kev	(*52*)
University of Rochester	B	> 50 Mev	(*53*)

* B, balloons; R, rockets; S, satellites.

As of January 1967, only two x-ray sources had been identified with certainty—the well-known Crab nebula and Scorpius XR-1 (Sco XR-1). The latter source is discussed in detail below. In addition, tentative identifications with several other objects had been suggested; these objects included other supernova remnants and two radio galaxies. At the symposium, Sandage announced the identification of a Cygnus source, Cyg XR-2, with an object of stellar appearance, like Sco XR-1.

The identification of Sco XR-1 was discussed by R. Giacconi (ASE), Sandage, and M. Oda (University of Tokyo). A joint ASE–Massachusetts Institute of Technology team (*30*) made proportional counter observations of the source on 8 March 1966, using wire-grid modulation collimators to obtain increased spatial resolution. They found the angular diameter to be $\lesssim$ 20 seconds of arc, and they also obtained two probable positions of the source, each with a precision of about 1 minute of arc. Theoretical considerations suggested that the optical appearance of Sco XR-1 should be that of a blue, starlike object of 13th magnitude or brighter. Such a star was in fact then detected at one of the two possible source positions, by workers using the 74-inch Tokyo reflector, and the observation was confirmed at Palomar (*31*). The optical spectra and the photoelectrically obtained colors (which give a crude energy distribution) of Sco XR-1 resemble those of stars of the class called "old novae." By analogy to data for such stars, a distance of roughly 250 parsecs can be derived. Considerations of the absorption due to interstellar matter, however, lead to an apparent contradiction in the distances derived for this object by two other methods. The strength of the interstellar H and K lines of ionized calcium, as measured on the optical spectra, implies a distance of at least 200 parsecs, whereas the intensity of the source in the energy range just below 0.28 kev, where the opacity of interstellar matter is great, suggests a distance of no more than 100 parsecs.

The photoelectric observations of Sco XR-1 have revealed a "fast flicker" with an amplitude approaching 1 percent over a time scale of 1 minute; there are also slower changes that can amount to a factor of 2 or more in one day.

I. S. Shklovskii (Sternberg Astronomical Institute) suggested, also by analogy to the properties of old novae, that Sco XR-1 may be a binary star. According to his "layered model," the more massive component of the binary is a neutron star in the accretion stage. There is a gradation in temperature from a hot central region at $T = 5 \times 10^7$ degrees Kelvin through the surrounding, extended atmosphere. The energy source required to maintain the x-ray emission is provided by the infall of gaseous matter flowing from the other component of the binary, a dwarf star that provides the optical continuum. The emission lines observed in the optical spectrum are thought to arise in gas flowing between the two stars. Other theoretical models for Sco XR-1 have been discussed by Cameron (*32*), Johnson (*33*), Manley (*34*), and Matsuoka *et al.* (*35*).

On the basis of the rather crude x-ray positional data that were available in the fall of 1966, Sandage made a photographic survey of a 4- by 4-degree region surrounding Cyg XR-2. Subsequently, more accurate information was provided by the ASE–MIT group, which led to an identification of Cyg XR-2 with a 16th-magnitude blue star noted on the Palomar plates. If the identification is confirmed, Cyg XR-2 and Sco XR-1 will be "charter members" of a newly recognized class of stars, located in our own galaxy, whose x-ray luminosities considerably exceed their optical outputs.

References and Notes

1. The 1967 Texas Symposium had a registration of approximately 650 persons. The organizing committee and sponsoring organizations consisted of A. G. W. Cameron, Belfer Graduate School of Science, Yeshiva University, and NASA Goddard Institute for Space Studies; Ivor Robinson, Southwest Center for Advanced Studies; and E. L. Schucking and Alfred Schild, University of Texas. The symposium was cosponsored by the American Physical Society and the American Astronomical Society and was supported by the Office of Naval Research, the National Science Foundation, the U.S. Atomic Energy Commission, the National Aeronautics and Space Administration, the Carnegie Institution of Washington, and the General Electric Space Sciences Laboratory.
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Hydroxylation-Induced Migration: The NIH Shift

Recent experiments reveal an unexpected and general result of enzymatic hydroxylation of aromatic compounds.

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In 1955, Mason and his collaborators discovered that the enzymatic oxidation of 3,4-dimethylphenol to 4,5-dimethylcatechol led to the incorporation of oxygen from molecular oxygen but not from water (*1*). This observation was in sharp contrast to the concept of biological oxidation held at that time, and it paved the way for the investigation of an important class of enzymes now known to introduce atmospheric oxygen into a large and diverse group of substrates. These oxygenase enzymes, the subject of several recent review volumes (*2*), function in a bewildering variety of metabolic processes and differ substantially in many aspects of their action. The use of O^{18}, a heavy isotope of oxygen, has greatly increased current knowledge of the mechanism of action of oxygenases, including the large and important subgroup known as hydroxylases or "mixed function oxygenases."

Recent studies in our laboratories with aromatic substrates labeled in specific positions with deuterium or tritium have uncovered what appears to be a fundamental property of aromatic hydroxylation reactions. These experiments indicate that a frequent conse-