At the symposium banquet in the Statler-Hilton Hotel, those at the head table included (left to right): Cyril Hazard, University of Sydney, Australia; Rudolph Minkowski, University of California; Thomas Matthews, California Institute of Technology; W. W. Morgan, Yerkes Observatory; P. G. Bergmann, Yeshiva University; Fred Hoyle, Cambridge University, England; Mrs. E. L. Schucking, University of Texas; and J. Robert Oppenheimer, Institute for Advanced Studies, Princeton. Unless otherwise indicated, delegate pictures with this article are by Al Mitchell, director of information, Graduate Research Center of the Southwest.

Dallas Conference on Super Radio Sources

LOUIS C. GREEN, STRAWBRIDGE OBSERVATORY, HAVERTOWN COLLEGE

In mid-December an exciting international symposium on gravitational collapse as related to the problem of ultrahigh-energy radio sources was held in Dallas, Texas. The gathering of some 400 astronomers and relativity experts was sponsored by the Southwest Center for Advanced Studies, the University of Texas, and Yeshiva University, with the support of a number of government agencies.

Many of those who attended felt that they had been at a historic occasion where new ideas of paramount importance were presented that may profoundly influence all future thinking in the field.

In what follows, we shall take some account of the theoretical aspects of the discussion, and note some observational material not already familiar to readers of this magazine.

In recent years, astronomers have felt an increasing need for new ideas concerning possible sources of the energy that maintains the intense radio radiation we receive from certain extragalactic objects. The older thought that such a source represented the collision of two galaxies has dropped out of favor, for it has become apparent that in the best-examined cases no second galaxy is involved. Indeed, among the well-known objects, only for NGC 1275 in Perseus is collision still a possibility.

Furthermore, the collision of two galaxies is none too effective in releasing energy. Even in the dense parts of a galaxy, the stars are small compared with their distances apart, and the star clouds of colliding systems should pass through each other. Energy release would be significant only when gas and dust clouds in one galaxy collide with those of another.

It has been known for some time that energies of the order of $10^{62}$ to $10^{63}$ ergs are needed to account for the radiation that we receive here on earth from many of the radio sources. The recent recog-
William A. Fowler, physicist at Kelllogg Radiation Laboratory of California Institute of Technology.

nition of several very remote, very strong, small-diameter radio sources (SKY AND TELESCOPE, June, 1961, page 311) suggests that the upper limit of 10^10 ergs may be too conservative. Jesse L. Greenstein calls these objects "quasi-stellar radio sources" in the Scientific American for December (page 54), and at the Dallas symposium this California Institute of Technology astronomer described the peculiarities of their optical spectra.

Such a source is perhaps 10 to 30 times as luminous as the brightest elliptical galaxy. For example, 3C 273 in Virgo, which is not the intrinsically most luminous of these quasi-stellar objects, has an apparent photographic magnitude of 13 and a spectral red shift corresponding to a velocity of recession of 47,400 kilometers per second. This indicates a distance of about 1/4 billion light-years and an intrinsic brightness of 3C 273 equal to a trillion (10^12) suns! Since our own sun radiates 3.8 \times 10^{33} ergs per second, this amazing object must release about 4 \times 10^{33} ergs each second.

How long has this tremendous outpouring of radiation been going on? We do not know with certainty for any of the quasi-stellar objects, but presumably the outflow has continued since some catastrophic event — some great explosion.

\*This distance was computed from the rule of thumb that, for nearer galaxies, apparent velocity of recession increases 100 kilometers per second for each million parsecs distance.

Dr. Smith and Dorrit Holleit of Yale Observatory have checked thousands of photographs from a dozen observatories ("Sky and Telescope," June, 1963, page 311). This latest plot includes plates for recent years from Sonneberg Observatory.

shall we say — until the expanding system reached its present size.

If we assume that the expansion has taken place at right angles to the line of sight and with the velocity of light, then we shall underestimate the time required. Calculations yield ages of the order of 10^10 to 10^11 years. Let us take the larger figure, which is still conservative. Since there are 3.2 \times 10^{11} seconds in a year, the quasi-stellar sources must have been shining for something like 3 \times 10^{31} seconds. In this time, then, 3C 273 would have emitted at least 10^{39} ergs.

From the relative amounts of optical and radio energy, we believe these sources are producing synchrotron radiation, which was first clearly recognized in the case of the Crab nebula and has since been suggested for a number of other cosmic radio emitters. It occurs on earth in the radiation of those large particle accelerators, the synchrotrons, which physicists use so widely. "Relativistic electrons" are required, that is, electrons with velocities close to that of light, moving through magnetic fields.

Harlan J. Smith, who presented the photographic light curve of 3C 273 seen below, at right points out this quasi-stellar source on a photograph. Its 1950 position is 12° 26' 5", +2° 21', and the area seen here is about a degree wide, with north up. 3C 273 is shown on chart 214 of Hans Vehrenberg's "Photographic Star Atlas." The bright star at the left edge of Dr. Smith's picture is 10th-magnitude BD +3° 2657, at 12° 27' 6.6, +2° 30'.

In astronomical cases, it is difficult to see how such negatively charged electrons can be separated from positively charged ions in any large numbers. The most likely ion is the proton (hydrogen nucleus). The mechanism that accelerates the electrons will accelerate an equal number of protons, and the latter, in view of their much greater masses, will take the major portion of the available energy. Furthermore, the electrons are much more subject to energy losses, so that in the end only one percent of the total energy goes to them. Thus, if we wish the electrons to be able to radiate 10^{10} ergs, we must search for some process capable of supplying 10^{11} ergs to the cosmic body as a whole.

As a start in our search, we ask what energy would result from the complete annihilation of all the matter in our own Milky Way galaxy. Very roughly, the galaxy's total mass is 2 \times 10^{11} times the sun's mass of 2 \times 10^{30} grams, or 4 \times 10^{41} grams. The Einstein equation \( E = mc^2 \) tells the energy \( E \) in ergs that can be obtained from a mass of \( m \) grams: \( c \) is the velocity of light, 3 \times 10^{16} centimeters per second. Substituting in the formula, we find that 4 \times 10^{41} ergs is roughly the energy obtainable from the total rest mass of the galaxy.

No known nuclear process or series of processes is capable of converting mass into energy in this wholesale fashion. In fact, if hydrogen is changed into iron, the most efficient possible series of reactions, we could transmute only 0.01% of the mass. In actual practice, the fraction is likely to be much smaller. Furthermore, unless the temperatures are considerably higher...
CONDENSING MASSIVE OBJECTS

<table>
<thead>
<tr>
<th>Outer region with rotation</th>
<th>Inner region without rotation</th>
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<tr>
<td>Breakup into bodies</td>
<td>Swarms of white dwarfs</td>
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<tr>
<td>with mass of 100 suns</td>
<td>Continued contraction</td>
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<td>Modified C-N cycle</td>
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<td>Emission of radiation</td>
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<td>the Seyfert galaxies</td>
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were recognized as far more satisfactory. What then is new about gravitational contraction to make us reconsider it now?

Helmholtz pictured the sun as contracting from a uniform rareded medium of very large, virtually infinite radius to its present size. Instead, let us consider as one possibility a dispersed body of perhaps 100 million times the sun's mass, which might evolve to reach a very small radius.

Fred Hoyle of Cambridge University and William Fowler of Caltech discussed these possibilities on our first meeting at Dallas, December 16th. Primarily, they were reviewing their recent work done with Geoffrey and Margaret Burbidge, and the investigations of Hoyle and J. V. Narlikar. Much of the discussion can be summed up in a slightly modified form of a chart Hoyle used. In it, contraction increases from top to bottom, while rotation decreases from left to right.

As the original giant body begins to contract, with an accompanying increase in its rate of rotation, the crucial question is whether or not the magnetic lines of force are "frozen" into the material. If, as seems likely, magnetic field and material move together, an early breakup into many fragments is impossible. The interlocking of inner and outer regions means that in the inner part rotation is unimportant (at least for a time), but the outer part rotates more rapidly than it otherwise would.

In the next stage, further contraction and hastening rotation of the outer region lead to an ever more flattened system.

The flattening continues until spherical volumes, centered on the equatorial plane and equal in diameter to the thickness of the rotating disk, contain some 100 solar masses. At that point, there ensues a breakup into bodies of about that size.

Arguments can then be raised that high temperatures will develop in these large masses (or be already present as a result of earlier contraction), temperatures high enough to modify substantially the ordinary carbon-nitrogen energy generation cycle. This is a relatively leisurely process in the solar interior, maintaining solar radiation for billions of years. But here, after going slowly at first, it explodes in a "whooosh." The time scale for hydrogen burning becomes of the order of only a week, and one after another the sub-condensations of 100 solar masses go through the whoosh. Hoyle suggests that the tremendous energy released in this rather catastrophic process would be observable as a quasi-stellar radio galaxy. There might be 10,000 of these subcondensations in one system.

Irregularity in the occurrence of the whooshes may be related to the brightness fluctuations of some of these objects, which were so effectively demonstrated at the meeting by Harlan J. Smith, University of Texas. At this stage, great outbursts of gas (moving at perhaps several thousand kilometers per second) can be imagined, perhaps significantly related to those strange objects, the Seyfert galaxies.

Turning now to the right-hand side of Hoyle's chart, we follow the development of the inner region as contraction continues. High densities are reached and, if enough rotation has been retained in this inner part, multiple breakup into small bodies will occur. The bodies could be white dwarfs or possibly neutron stars. (To explain the difference, we can quote two phrases used later in the meeting by John Wheeler of Princeton. If the gravitational attraction inside a star is so great that it "crushes out the chemical forces," the electrons are not bound to nuclei but are shared by them, and we have the degenerate matter of white dwarfs. If the gravitational effect is even stronger and "crushes the electrons onto the protons," then neutron stars would result.)

However, if not enough rotation has been retained, the contraction would continue. A dramatic possibility is that the object goes on contracting until it develops an "event horizon," becoming unobservable to the outer world except by the static gravitational field it leaves behind. We remember that light reaching us from a strong gravitational field should be reddened, indicating some loss of energy. If the gravitational field is that of a star, the degree of reddening depends

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E. Margaret Burbidge, who with her husband does astrophysical research at the University of California at La Jolla, discussed peculiar galaxies.

At left, R. A. Lyttleton, Cambridge University, talks with another English theoretician, W. H. McCrea of Royal Holloway College, Surrey.

Maarten Schmidt of Mount Wilson and Palomar Observatories, who made the optical identification of the components of the 3C-273 radio source.
on the mass of the star divided by its radius. As the radius shrinks, the reddening increases and so does the energy lost by the light. Eventually, the radius could become so small that the light could escape only at the cost of losing all its energy. If there were no energy left, there would be no light either. At such a time, the body is said to have withdrawn inside an event horizon.

If rotation does not become fast enough to stop contraction before the event horizon is reached, indefinite further contraction takes place, with "crushing of the rotation." In the usual cosmological theories, this course of events leads to the final contraction of the body into a point - a singularity - but Hoyle emphasized that in his steady-state cosmology the singularity is not reached.

With somewhat greater rotation, gravitational waves would be more important, and might promote fusion of the immensely massive and dense primary body. Hoyle suggested that the separating fragments might be somehow analogous to the multiple structure of certain radio sources. Finally, with still greater rotation, oscillations of the primary body become a dominating phenomenon.

Later in the sessions, Hoyle noted a suggestion by the Russian astronomer V. L. Ginzburg. In some quasi-stellar radio sources there must be a high density of photons as well as of electrons. By collisions with electrons, the photons could gain substantial energies - the inverse Compton effect - so that these sources should emit intense gamma rays as well as visible light.

The chief argument that the quasi-stellar sources are very remote is based on the large red shifts of their spectral lines, comparable to the displacements for the remotest observed galaxies. In his lecture, Greenstein discussed the possibility that the red shifts of these sources were gravitational effects such as described above, rather than due to recession. This alternative would make the sources small, comparatively nearby, but massive objects. On this view it is difficult, though not impossible, to reconcile the known information about their luminosities, spectra, masses, and radii.

Why, too, have we failed to observe effects on the motions of ordinary stars in the direction of these sources? A body of $10^6$ to $10^8$ solar masses, if placed inside our galaxy, would change markedly the motions of its stellar neighbors. If the quasi-stellar sources are near to but outside our galaxy, questions arise as to their total number and observability. Although everyone agreed that the possibility of gravitational red shifts should be examined, it seemed the general opinion, shared by Greenstein, that recession was a more probable explanation of the spectrum line displacements.

Margaret Burbidge, astronomer at the University of California at La Jolla, considered a series of alternative explanations. The interaction of matter and antimatter could annihilate mass, converting it to energy. But how are matter and antimatter to be kept apart until the right moment of interaction? Again, we can conceive of very large galaxies gaining energy by accretion of matter from space, but even the largest of them cannot collect enough energy this way. Third, a great deal of energy could be gained from turbulent motions in the early evolution of a galaxy. Unfortunately for this hypothesis, ellipsoidal galaxies, which are much stronger radio emitters than the spirals, are far too smoothly structured for turbulence to be important.

She spoke of a fourth hypothesis that involved the magnetic fields of galaxies. Winding up a magnetic field in which gas is intermeshed, causing the lines of force to break and produce a flare, does not fit well with the slow rotations and lack of gas in elliptical galaxies. As for supernova explosions, since $10^8$ of them would be needed, how could they all reach the same evolutionary stage simultaneously? To have supernovae trigger one another would require a million or more stars per cubic parsec. Such a density might exist undetected in the centers of galaxies, but even then it is difficult to explain how the trigger mechanism would work. Lastly, the lack of gas in ellipticals makes it difficult to adopt A. G. W. Cameron's suggestion of the simultaneous formation of a large number of stars.

From Cornell University, E. E. Salpeter reviewed the physics of neutron stars.
Between the short lines is the 18th-magnitude object that corresponds to the compact radio source MSH 14-121, on a Palomar Schmidt red plate. The overexposed image of 15 Librae, magnitude 5.6, is at lower left. North is up in this picture, of which the vertical extent is about 0.7 degree.

which we have mentioned above, Wheeler took the discussion a step farther. General relativity implies at the end of collapse a new kind of physics, where matter itself is crushed out of existence. He pointed out that there is no equilibrium configuration for aggregates of more than \(10^{37}\) nucleons (protons and neutrons). If the difference between numbers of massive particles of matter and antimatter is conserved during the crushing process, then this difference must be in the form of an as yet unknown variety of radiation—distinct from gravitational waves, electromagnetic waves, and neutrinos.

To five previously known quasi-stellar sources, Caltech astronomer Thomas Mathews adds four more and one probable. Optical spectra confirm identification for seven: 3C-47, 48, 147, 196, 245, 273, and 286; color is relied on for 3C-9 and 3C-43. For MSH 14-121, pictured above, the spectrum does not show the usual characteristics of these sources.

Another Cornell theoretician, Thomas Gold, explored an alternative to one part of Hoyle’s evolutionary scheme. After Hoyle’s cloud has broken up into individual units (stars), can such a star system, as distinct from a mass of gas, undergo collapse? Classical analysis has indicated that after most of the stars have escaped, the remainder will slowly collapse to form a single very large body. For ellipsoidal galaxies this would take of the order of \(10^{20}\) years, such a prodigious length of time that the collapse “simply doesn’t happen,” Gold said.

The classical analysis assumes that the structure of the system remains fine-grained, that is, condensations of intermediate size or large subgroups of stars will not form. When this assumption is dropped, Gold finds that the evolution becomes much more rapid, even if the subgroups are not permanent. Under the greater interaction we understand why the elliptiodal galaxies have so smooth a variation in brightness from center to edge. Otherwise they would have to be regarded as fossil structures that came into being in much their present form.

There is an important difference between the evolution of a star system and a gas system. The former can shed both energy and angular momentum (rotation), by shedding stars. In contrast, a mass of gas sheds energy through the loss of its fastest molecules but not much angular momentum. The almost spherical shape of globular clusters suggests that they have indeed lost most of their angular momentum.

When 99 percent of the stars have escaped from a system (a reduction from \(10^{11}\) to \(10^7\) for an elliptical galaxy), then multiple collisions among the remaining stars will become increasingly frequent, especially in very dense systems. These collisions would release large amounts of energy. Are the small areas in galaxies where radio emission is strong the regions in which multiple collisions are happening often?

Of course, it is the gas-poor elliptical systems that are the strong radio sources, not the gas-rich spirals. On the other hand, none of the globular clusters, which are practically devoid of gas, are known as radio sources. In Gold’s picture, the present dispersed state of certain radio sources would be regarded as the aftereffects of happenings in galactic nuclei.

On the final afternoon of the conference, E. J. Dyson pointed out that the basic difficulty with collapse as a source of the energy for radio galaxies is that its time scale is much too short. Little energy is released until the density becomes very high, and then a great deal is produced in a very short time, of the order of a day. F. L. Schuckling of the University of Texas emphasized that cosmic rays, X-rays, gamma rays, and the contents of intergalactic space had been largely omitted from the symposium discussions. P. G. Bergmann, of Yeshiva University, warned nonrelativists that all the models discussed were special cases of very high symmetry, because of the mathematical difficulties of more general treatments. He pointed out that at some future date theories that are both relativistic and quantized will give us new ways of looking at the universe in the small; whether they will be important in the large no one knows. With this session a most interesting conference came to an end.

One of three very small radio sources observed by Cyril Hazard at Jodrell Bank about a year ago is MSH 14-121 (pictured above), which is probably quasi-stellar. This record at 75-cm. wavelength during a lunar occultation immersion on December 22, 1962, shows that MSH 14-121 has two components, first one and then the other disappearing (right to left). They are about 40 seconds of arc apart and each less than one second in diameter. The vertical lines at top indicate minutes of time.

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Radio Spectrum Allocations to Astronomy

Astronomers have been haunted by the possibility that radio exploration of the universe will become practically impossible in a few years. Already, radio astronomy has given exciting insights into solar system objects, our Milky Way, other galaxies, and previously unimagined sources. But cosmic radio noise is weak, whether we are measuring 21-centimeter radiation of hydrogen from the Association of Giant Galaxies, background noise from the Crab nebula, or microwave thermal emission by the planet Mars. Each year such observations are increasingly impeded by a mounting flood of man-made signals, as the commercial and military needs grow for new communications frequencies. This is a worldwide problem and it must be solved by international agreements to preserve certain frequency bands for astronomical use.

The world agency that deals with frequency allocations is the International Telecommunications Union, which held a five-week Space Radio Communications Conference in Geneva, Switzerland, in October and November. At that time, allocations were made that afford radio astronomers limited relief, as indicated by the following excerpts from a report to SKY and TELESCOPE by Geneva correspondent Elliott P. Fagerberg:

Delegates of 57 nations approved a revision of ITU radio regulations that gave radio astronomers exclusive use of the vital frequency band 1400 to 1427 megacycles, which contains the 21-cm neutral hydrogen line. After long hours of negotiation, representatives of Soviet bloc countries agreed to withdraw fixed and mobile radio services from this band, thereby clearing it for the reception of cosmic signals at radio observatories anywhere in the world.

As the chart shows, a dozen other bands have been earmarked for radio astronomy (in some cases to be shared with meteorological satellites and services and radio navigation). But these bands have not been completely cleared of other uses. For example, harmful interference may be encountered in the 1664.4-1668.4-mc. band, which contains the recently discovered hydroxyl (OH) interstellar lines (see page 71). Some 26 nations* that include the United Kingdom and the U.S.S.R. use this region for fixed and mobile transmitters.

Another example is 4990-5000 mc., which is exclusive for astronomy only in the Western Hemisphere (except Cuba), for it is shared with fixed and mobile services in Europe, Asia, and Africa. Soviet bloc countries and several others have not cleared such bands as 10,680-10,700, 15,350-15,400, and 19,300-19,400. The situation is even worse for 2690-2790, where 17 nations (including the Philippines) use the band for other purposes.

At the highest frequencies, 31,300-31,500 mc. is exclusive for astronomy except in Cuba, the United Arab Republic, and most Iron Curtain countries. 58,000-58,400 mc. is exclusive only in Europe and India, yet even there it is shared with radio navigation services.

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<th>WAVELENGTH (Centimeters)</th>
<th>FREQUENCY (Megacycles/Second)</th>
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<tr>
<td>1</td>
<td>33,000-34,400</td>
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<td>31,300-31,500</td>
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<td>73.00-74.60</td>
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<td>1,000</td>
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On the other hand, progress has been made in the vital region of the radio spectrum that falls in the ultrahigh frequencies (UHF) of television. Many readers will recall controversy concerning the assignment of channel 37 to a station in Paterson, New Jersey (SKY AND TELESCOPE, June, 1963, page 307). In the Western Hemisphere 608 to 614 megacycles is reserved for radio astronomy "until the future administrative radio conference after 1974." Cuba, however, has not agreed to this (nor to seven other allocations). As reported in SCIENCE for November 15, 1963, the Federal Communications Commission will assign the Paterson station some other frequency. By a 5-2 decision, the FCC voted to reserve channel 37 for astronomical use for 10 years, recognizing "the vast potential offered by radio astronomy for adding significantly to our knowledge of the universe."

In the African broadcasting area, the 606-614-mc. band is allocated to radio astronomy, and it will also eventually become available in Europe. The 610-614 mc. (as other frequencies are found for broadcasting services now operating in it. Most of the requests for the Inter-Union Committee on Frequency Allocations for Radio Astronomy and Space Research Services (IUCAF) were accorded by the conference. However, the 79.75-80.25 and 150-153 mc. bands were not granted. Perhaps most serious of all, the 326.4-328.4 mc. band that contains an anticipated deuterium line was not reserved for astronomy.

At the conference, it was recognized that radio astronomy has made many contributions to the technology of radio communications, and that further action is needed in its interests. Hakon Sterky, director-general of the Swedish Board of Telecommunications, sponsored a resolution to this effect, which was unanimously adopted by the conference. It recommended that "the next ordinary administrative radio conference should give further consideration to the provision of improved frequency allocations for radio astronomy; and in the meantime, administrations should afford all practicable protection to the frequencies now allocated to radio astronomy on a shared basis with other radio services."

TEMPERATURE STUDY OF JUPITER

The news note bearing this title on page 17 of last month's issue contains preliminary values of brightness temperature, according to Bruce C. Murray, California Institute of Technology. He points out that somewhat revised numbers are scheduled for publication in the April 1st Astrophysical Journal.

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