Relativistic Astrophysics

A report on the Second Texas Symposium

By I. Robinson, A. Schild, and E. L. Schucking

Scientists of 1965 see the universe with diverse eyes. They look with the two-hundred-inch pyrex mirror on top of Mount Palomar, with a hundred thousand gallons of cleaning fluid buried more than a mile underground, with scintillation counters flying in rockets and satellites, with a retina covering several square miles of the New Mexico desert at Volcano Ranch, with a steel bowl two hundred and ten feet across at Parkes in Australia, and with a gently swinging aluminum bar in Maryland, waiting patiently for the tremor of a gravitational wave.

Some of these eyes perceive only darkness, some have blurred and distorted vision, others detect a profusion of fine detail. Scientists have mapped the sky with meticulous care as they see it by radio waves, light, x rays, γ rays and cosmic radiation. There are some striking differences among these charts.

The finest picture is that available in the optical region. By comparison, the universe as seen in the radio spectrum is rather bare. A radio astronomer confined to strictly professional sources of information would not think of distinguishing between night and day. He discovered the sun by chance as late as 1943. He would have no reason to regard the quiet sun as an energy source of importance on the local scene; it is very faint besides Cygnus A which is 10^{13} times farther away. In a region where Palomar plates show millions of stars and thousands of galaxies, only one subject, insignificant on the photograph, may appear on the corresponding radio, x-ray, or γ-ray map.

It is only within recent years that the optical and radio maps of the skies have begun to merge. This "two-color" picture of radio and light reveals a new universe. It is not the smooth, quiet, placid world which the "black and white" map of conventional optical astronomy had shown. As staining revealed the mysteries of cell division and genes under the microscope and showed the dynamic nature of life, so the two-color maps of the sky, pinpointing hot spots of great energy events, are initiating a revolution in our view of the cosmos. Majestic galaxies, giving the impression of dull harmony, are now believed to evolve in a cataract of explosions that involve millions of solar masses.

Supernovae were the first indication that violent events play an important role in the life and death of a star. Now we see that such cataclysms occur on a galactic scale, beside which supernovae look like innocent firecrackers. High-energy particles, so difficult to obtain in laboratories on earth, are commonplace in the skies, and illuminate it with synchrotron light. Relativity theory, until recently believed to be unimportant for astronomy, provides the basic laws that govern these great events.

The new observations may give more than a new picture of galactic and cosmological evolution. The merging of the radio and light maps of the sky led to the discovery of the quasi-stellar and strong radio sources, whose tremendous energy output may well present a problem in basic physics.

At present, the other maps seem to be painfully unrelated to the optical picture. When they become sharper and more precise, when they begin to show common features, we can expect the new "many-color" view of our universe to lead to new revolutions in astronomy and in physics.

This will only be achieved by the concerted effort of scientists from many different fields. Optical astronomers will have to join forces with elementary-particle physicists, radio astronomers will have to talk to cosmic-ray experts. The Texas Symposia on Relativistic Astrophysics were con-

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ceived with the deliberate purpose of overcoming the traditional segregation of specialists in their narrow cubbyholes.

The first symposium was held in Dallas in December 1963.* It dealt mainly with optical and radio observations of quasi-stellar sources and with theories which offered promise of explaining the enormous energy releases.

The second symposium was held at the University of Texas in Austin, from December 15 to 19, 1964.** It continued the discussion of quasi-stellar sources and reported on the progress made in the preceding year. Half of the symposium was devoted to the new maps of the sky, to x-ray, γ-ray, and cosmic-ray astronomy, to the search for cosmic neutrinos and to the possible large-scale implications of the breakdown of CP-invariance.

The opening session was chaired by P.A.M. Dirac of Yeshiva and Cambridge Universities. Participants were welcomed by C. H. Green of the Graduate Research Center of the Southwest, W. W. Heath of The University of Texas, John Connally, governor of the State of Texas, and E. L. Schucking, on behalf of the organizing committee.

Geoffrey Burbidge from the University of California, San Diego, was the first speaker. He reported that the strongest radio objects may be the result of events involving energies of 10^{64} erg. Such an energy, equivalent to the mass of five billion suns, is about a thousand times larger than the energy proposed a year earlier at the Dallas Symposium. Astrophysicists had then assumed that the fast-moving atomic particles in these sources were accelerated by a mechanism of almost 100 percent efficiency. Burbidge, assuming that the Lord was no better an electrical engineer than the terrestrial builders of the biggest nuclear accelerators at Brookhaven, CERN, and Berkeley, came up with an efficiency factor of only 0.03 percent for the cosmic machines.

Not everybody in the audience agreed. It was held against the argument that electrical engineers on earth are limited by the conductivity of copper, whereas the Lord, in the vast vacuum of space, might have other means at His command. Burbidge thought that the only way of reducing the energy estimates was to bring these radio sources implausibly near to us. In conclusion, he recalled the difficulties that had beset astronomy more than thirty years ago when nuclear energy, the energy source of the stars, had yet to be discovered. He suggested that our difficulty in understanding strong radio sources might point to a gap in our knowledge of basic physics.

John Bolton of CSIRO, Sydney, one of the founders of modern radio astronomy, an art that was developed largely at the antipodes, also discussed in detail the properties of the strong radio sources. With his beautiful new instrument, the 210-foot dish at Parkes near Sydney, he found evidence that not all of the volume of the huge clouds is evenly filled with high-energy particles. He said that his observations were more indicative of shell-like structures with bright spots. This would indicate that the energy, calculated by assuming a uniform distribution of particles over the emitting volume, had been overestimated. At this stage, the chairman of the meeting, Murray Gell-Mann of the California Institute of Technology, took the microphone and asked: "Would Dr. Burbidge please defend his volume?"

He did.

Among the beautiful new results presented by Bolton were measurements of the direction of polarization of the radiation from strong sources. Many of them look like dumbbells or hourglasses hundreds of thousands of light years long, leaky magnetic bottles containing high-energy cosmic rays. Bolton's observations show that in many cases the direction of the magnetic field is perpendicular to the long axis of the dumbbell with an accuracy of one percent.

Thomas Matthews, of Caltech's Owens Valley Radio Astronomy Observatory, had shown earlier in the day that these dumbbells exhibit bright edges at both ends. In these regions, it is believed, the gas smashes its way into the ambient medium.

Since astronomers have available for interpretation only static pictures of these cosmic explosions, it is often difficult to say how evolution is occurring, and at what stage it is being observed. Frequently they can only guess. Radio astronomers had believed that the biggest objects were the older generation in the radio community, while the

* The proceedings of the first Texas symposium have been published under the titles *Quasi-Stellar Sources and Gravitational Collapse*, \$10.00, and *Gravitation Theory and Gravitational Collapse*, \$6.50, both by the University of Chicago Press, Chicago and London.

** Over four hundred scientists from all over the world attended the Austin symposium. It was sponsored jointly by the University of Texas and the Southwest Center for Advanced Studies, with support of the Aerospace Research Laboratories (Wright Patterson Air Force Base), Air Force Office of Scientific Research, Atomic Energy Commission, National Aeronautics and Space Administration, National Science Foundation, Office of Naval Research, American Astronomical Society, and the American Physical Society.

quasi-stellar radio sources, smaller in size, were the new born. Bolton told the audience that he thought evolution might go the other way: the strongly energetic radio sources were not on the verge of radio death, but in fact were infants which later collapsed into the less energetic smaller objects, including quasistellars. "I am very happy that somebody is following this line of approach," commented Fred Hoyle amiably, "because I think it is wrong."

Although they are not the most spectacular radio transmitters, the quasi-stellar sources are objects of enormous and bewildering brilliance, brighter than a million million suns. Maarten Schmidt of the Mount Wilson and Palomar Observatories, who had identified the first of them in 1962, reviewed carefully the evidence that these were indeed the most distant objects in the universe, and were not being confused with nearby large celestial bodies. Disposing first of the possibility that the red shift is gravitational and that these objects are as heavy as the sun, smaller than Austin, and at a distance of fourteen kilometers, Dr. Schmidt led his audience step by step to the conclusion that they are at least several million light years distant, and probably much further away. His model of a quasi-stellar source is a shell-like structure, with an outer cloud, huge but very thin, filled with atomic particles of high energy which emit radio synchrotron radiation. It may be several thousand light years across, much smaller than an ordinary galaxy. Within this radio cloud lies a thin shell of glowing rarefied gas with a diameter of some ten light years. This region emits light predominantly at a few fixed frequencies. The extreme brilliance of the quasi-stellar comes from an inner, much smaller core, a hot superstar of perhaps a hundred million solar masses with a temperature in excess of 10 000°C. Its diameter may be as small as one light year.

Allan Sandage of Mt. Wilson and Palomar reported that, in the few weeks preceding the Austin Conference, he and his colleague, P. Veron, had found fifteen new quasi-stellar sources in a systematic search with the 48-inch Palomar Schmidt telescope. This brought the total count to 34, leaving some others whose identification is not yet certain. Sandage described how he found these objects by taking survey photographs of the sky, first with a violet, and then with an ultraviolet filter. After the first filter has been removed, the photographic plates are shifted so that the stellar image seen through the second filter is slightly displaced. This makes it possible to spot these objects which are more brilliant in ultraviolet light than in violet. There may be more than 80 000 of these "interlopers," as Sandage called them, which are possible candidates for identification with quasi-stellar radio sources. One of them has the same position as the second entry in the third Cambridge catalogue of radio sources, known for short as 3C2. This "star" of 20th magnitude is very probably located in the depths of space-time, much further out than anything seen before.* Its light, which reaches us now, may have been emitted before the solar system was formed (5×10^9 B.C.). It is running away from us at something very close to the speed of light, but the precise velocity

* Maarten Schmidt has just measured the red shift of 3C9. It corresponds to a special relativistic recession velocity of four-fifths that of light (May 1965). See Table 1.

Table 1.* Properties of quasi-stellar sources with known redshift. The fluxes are computed under the assumption that the cosmos is a Friedman universe. The cosmological constant is assumed to be zero, the space curvature positive, the present value of the Sandage parameter $q_o = -\ddot{R}R/\dot{R}^2 = 1$, and the Hubble constant 100 km/sec/Mpc.

Source	*Red shift* $z = \frac{\lambda' - \lambda}{\lambda}$	*log of intrinsic radio flux emitted at 10^9 Hz in $W(Hz)^{-1}$*	*log of intrinsic optical flux emitted at 10^{15} Hz in $W(Hz)^{-1}$*
3C 273	0.158	26.8	23.8
3C 48	0.367	27.5	23.0
3C 47	0.425	27.0	22.5
3C 147	0.545	27.9	23.1
3C 254	0.734	27.4	22.9
3C 245	1.029	27.5	23.5
CTA 102	1.037	27.6	23.5
3C 287	1.055	27.8	23.4
3C 9	2.012	28.1	23.6

* M. Schmidt, Astrophys. Journ. 141, 1299 (1965).

The transportable 25-ft dish in Yorkshire. With Mark I at Jodrell Bank, it forms an interferometer of maximum baseline 180 000λ. (H. P. Palmer)

has not yet been measured. Sandage reported a four-fold change in brightness for 3C2 over the last two years. This is many times more than the fluctuations previously observed in quasi-stellar radio sources.

Henry Palmer of the Jodrell Bank Radio Observatory near Manchester started the hunt for quasi-stellar sources nearly a decade ago. At the symposium in Austin he reported on the observations he had made with the world's largest scientific instrument, a radio interferometer a hundred and thirty-two kilometers long. Palmer revealed that some of the quasi-stellar sources have an apparent radio diameter of only a fraction of a second of arc. He predicted that the quasi-stellar source CTA 102 may have a radio diameter as small as one hundredth of a second of arc. This source was recently reported by Russian radio astronomers to have variable radio brightness, which led some of them to suggest that it was a broadcasting station operated by extraterrestrial intelligence.

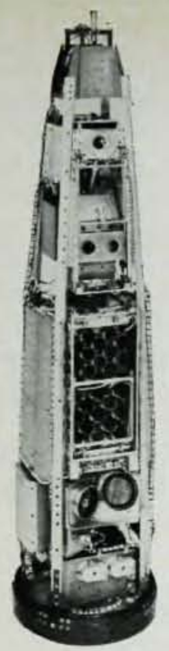
J. E. Baldwin of Cambridge University showed that the quasi-stellars are distinguished from other radio sources by their radio spectrum. W. W. Morgan, of the Yerkes Observatory, reviewed the properties of D-galaxies, supergiant systems which are predominant among the radio sources identified with optical objects.

The next sessions of the symposium were devoted to what may be called exotic astrophysics, the exploration of the skies through the observation of relativistic particles and high-energy radiation. The speakers were mostly physicists. This accounted for a quantum jump in terminology: the act of detecting the sun's visible radiation is an observation; that of observing its neutrino flux is an experiment. The first of these sessions was chaired by A. E. Chudakov of the Soviet Academy of Sciences. He presented some recent work by V. L. Ginzburg, who again was unable to attend the conference.

Bruno Rossi of the Massachusetts Institute of Technology reported on cosmic rays of the highest energy. At Volcano Ranch in New Mexico, the MIT group recorded about a dozen large air showers, each caused by a primary proton with energy larger than 10^{19} electron volts. Data from Mount Chacaltaya in Bolivia indicate that the cosmic-ray spectrum has a kink at about 10^{17} electron volts. Particles below this energy, Rossi suggested, come from our own galaxy, those above from outside. Fred Hoyle, on the other hand, believes that all the high-energy cosmic rays are emitted by strong radio sources.

Ken McCracken, of the Southwest Center for Advanced Studies, discussed the local cosmic-ray background. He said: "In the same way that an astronomer may be hindered in his work by peculiarities of his local environment, in that atmospheric dust, and man-made lights may limit the scope of his work, so is the cosmic-ray physicist limited in his ability to measure the properties

Central region of galaxy cluster Abell 2199. Supergiant is NGC 6166 = 3C 338. Insert is Andromeda Nebula M 31 reduced to linear scale of cluster. NGC 6166 is a prototype supergiant. Main body of M 31 as shown is about 24 000 pc. Cluster photo from National Geographic Society—Palomar Observatory Sky Survey; M 31 photo from 6-inch refractor plate by E. E. Barnard. (W. W. Morgan)



Cosmic x-ray experiment payload flown in October 1964 on an Aerobee rocket. (Giacconi, Gursky, Waters, Rossi, Clark, Garmire, Oda, and Wada)

of the cosmic radiation in the galaxy by 'bad seeing'—in this case, the reason for the bad seeing being the magnetic fields which pervade the solar system." He reviewed in detail the solar cosmic-ray component.

Peter Meyer of Chicago University, one of the discoverers of primary cosmic-ray electrons, discussed their origin. These electrons, together with protons, could be injected into the galaxy by supernova remnants. They may also arise, together with a larger number of positrons, from the collision of cosmic-ray protons with interstellar hydrogen. Meyer's observations on the electron-positron ratio in primary cosmic rays point to a supernoval origin.

George Clark of MIT reported on recent observations of cosmic γ rays, photons ranging in energy from 10^4 to more than 10^{15} electron volts. In a balloon experiment of July 1964, he observed a peak in the counting rates when the Crab Nebula was within the field of view of his scintillation detector, which was sensitive in the range 15 to 62 keV. He stated that the Crab Nebula, the only known source of x rays in this region of the sky, was also likely to be the source of the higher-energy radiation. This seems to be the first observation of a cosmic γ-ray source.

Philip Morrison of MIT gave a masterly review of the whole field of cosmic γ rays. He stressed the need for further observations in order to distinguish the relative importance among different production mechanisms. He pointed out that the isotropic component of the γ rays may originate from the collision of starlight with relativistic electrons. Through this inverse Compton effect, soft photons are converted into hard γ rays.

R. Giacconi, of American Science and Engineering, reported on x-ray observations with detectors flown in a rocket in October 1964. The x rays were in the range 0.5 to 15 Å. He and his coworkers resolved two new sources near the galactic equator. Each of these point sources has intensity less than 1/10 Scorpio (one Scorpio being the new intensity unit of the x-ray astronomer). It is the flux of the brightest x-ray source, 10^{-7} erg cm^{-2} sec^{-1} between 2 and 8 Å. This flux, in the visible range, would be that of a sixth magnitude star.

Herbert Friedman of the Naval Research Laboratory, with the energetic assistance of his chairman Hayakawa, wrote on the blackboard the locations of ten discrete x-ray sources in the sky, giving the latest results from observations made with Geiger counters aboard unstabilized Aerobee rockets. Astronomers in the audience took down the coordinates, and prepared to search for peculiar objects on their photographic plates. Friedman's observations showed conclusively that the x rays from the Crab Nebula in the constellation Taurus (Tau XR-1) did not have a point source. This disposed of the theory that they came from a neutron star. The x rays could be the high-energy tail of the synchrotron-radiation spectrum arising from the inner parts of the Crab cloud. The Scorpio source (Sco XR-1) has not been definitely identified with a known optical object. I. S. Shklovsky, who also was again unable to attend the conference, had suggested that it might be the remnant of a supernova which exploded about 50 000 years ago in our vicinity, some 150 light years away. Prehistoric astrologers must have greeted the sudden appearance of this object, as bright as the full moon, with something of the respect and bewilderment which the quasi-stellar objects have evoked in our own generation. Friedman concluded: "All of the x-ray sources observed lie rather close to the galactic plane and within plus and minus 90° of the galactic center. This distribution resembles that of galactic novae and suggests that all of the x-ray sources thus far observed may be associated with supernova remnants in our galaxy."

G. Wataghin of Turin University gave the results of new calculations on URCA processes and on equilibrium problems which include neutrinos at high temperatures and densities.

The neutrino session continued with a report by R. D. Davis of Brookhaven National Laboratory. He discussed the chances of catching neutrinos from the sun. The main part of his equipment will be a tank 20 ft in diameter and 48 ft long, filled

The Davis neutrino observatory in the Barberton (Ohio) mine, 2300 ft underground. The two 500-gallon tanks are filled with perchloroethylene (C_2Cl_4). Neutrino radiation transforms ^{37}Cl into radioactive ^{37}Ar.

with cleaning fluid (C_2Cl_4). This will be buried in a deep mine, under more than 4400 ft of rock. It is hoped that a few of the chlorine atoms in the fluid will undergo the reaction $\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^-$. Positive results would give the first direct proof that the sun is in fact a nuclear fusion device. If Davis' \$600 000 neutrino eye does see solar neutrinos, it will actually be looking right into the sun's central region, which is inaccessible to all other scientific instruments.

In 1953, Frederick Reines from the Case Institute of Technology and his coworker C. L. Cowan were the first to detect neutrinos produced by a nuclear reactor. Reines described two neutrino telescopes. The first is to be buried this year 2000 feet deep in a salt mine near Cleveland. It is made of lithium and is designed to detect solar electron-neutrinos by the reaction $\nu_e + {}^7Li = {}^7Be + e^-$. The second telescope, located two miles underground in the East Rand Proprietary Gold Mines near Johannesburg, South Africa, is constructed to detect energetic muons produced by high-energy neutrinos (ν_μ) in the surrounding rock. If such neutrinos are seen, there won't be many of them. A friend told Dr. Reines: "You may possibly have a long-distance record for commuting to an experimental site, but you are one of the few under these conditions who can commute between counts." Dr. Reines remarked: "It is interesting that despite the size of this detector, it has too little sensitivity, by perhaps a factor of 10^3 or more, to detect an expected flux of true cosmic (that is, extraterrestrial) neutrinos of high energy. But we must take one step at a time and see whether, as we increase our sensitivity, nature is as we think it is or whether some surprises might not be in store for us."

John Bahcall from Caltech reviewed different possibilities for neutrino detection. He stressed that a neutrino-spectroscopic study of the solar interior should be included in the long-range program as a means of determining quantitatively conditions in the interior of the sun—in much the same way as astronomers have already studied its surface by photon spectroscopy. He discussed possible observations of neutrinos from strong radio sources and their connection with mass estimates of the hypothetical W^- boson. Bahcall also proposed that the military be persuaded to surrender their supplies of tritium to the neutrino enthusiasts to build detectors. Luis Alvarez from Berkeley, chairman of the session, expressed his doubts about the technical feasibility of this approach to nuclear disarmament. In the discussions, G. G. Zatsepin, delegate to the symposium from the Soviet Academy of Sciences, was in favor of building neutrino observatories on the moon. Hong-Yee Chiu of the Goddard Space Flight Center preferred a detector, consisting of 1000 tons of completely ionized ^{37}Cl, located at the outer limits of the solar system on the planet Pluto. He envisaged counting time of a few hundred years, and conceded that his Pluto experiment required a civilization more affluent than our own.

The next session was chaired with commendable firmness by Leopold Infeld of the Polish Academy of Sciences. R. K. Sachs of The University of Texas proposed tests which would enable astronomers to deduce the structure of the universe from their observations without begging the question by presupposing a particular cosmological model, such as a homogeneous isotropic Friedman universe. He pointed out that spherical galaxies or clusters at a great distance might all appear elliptical in shape because they are seen through ripples of gravitational waves which pervade the space-time ocean.

This gathering of physicists and astronomers was a natural environment for the discussion of the possible new long-range force proposed by J. Bernstein, T. D. Lee, N. Cabibbo, J. Bell, and J. K. Perring. A hard apple had struck the heads of these physicists a few months earlier: the CP-invariance experiment of Christenson, Cronin, Fitch, and Turlay. J. H. Christenson of Columbia University described the experiment. Gerald Feinberg, also from Columbia, reported cautiously on the hypothetical new long-range force. This fifth force, much weaker than the gravitational interaction, was invented in order to preserve time-reversal symmetry in elementary-particle processes. It would affect matter and antimatter differently

CHARGED PARTICLES

Extending the capabilities of research equipment

Results from Tandem Research Program

The Tandem Research Group has made notable progress in the past year. Significant experimental results from the program are:

1. 250 mA high-brightness positive ion beam from an expanded-plasma source operating at 38 kv.

2. 270 μA analyzed beam of H_1^+ ions out of the Research Tandem with 320 μA H^- injection and water-vapor stripping.

3. 2.0 μA analyzed dc beam of He^- ions. The previous maximum current routinely available has been 0.1 μA with the EN source.

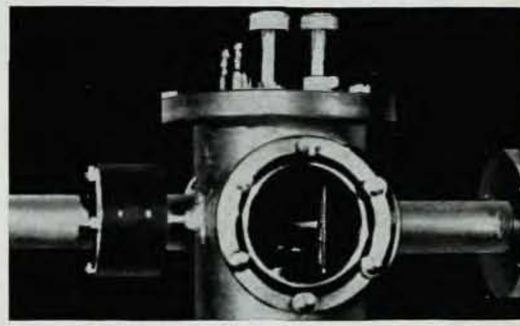
Doubly Charged Helium Ions

Components are now available for converting 3, 4 and 5 MeV machines to produce He^{++} ions at higher energies. Specifications: 30 μA at 5.0 MeV; 10 μA at 7.0 MeV; 5 μA at 10.3 MeV. More than double this current performance has been demonstrated but with some loss in stability and reliability. Multiple-charge states (2, 3 and 4) of neon, oxygen and nitrogen have also been produced with the new kit installed in a 3 MeV Van de Graaff. Beam energies from 5.04 MeV to 9.8 MeV and beam currents from 0.1 to 10 μA were observed. For details on the new HE^{++} kit and experimental results, write for Technical Note #13.

Optical Spectroscopy of Excited Atomic States

When an energetic beam of ions is passed through a thin foil, the charge state of the ion may change, either up or down. The emitted particles may be left in states of electronic excitation from which visible light is subsequently emitted during de-excitation. The emitted light spectrum is characteristic of the excited ion. When particle beams of approximately 0.4 μA or more are used, the light is sufficiently intense for spectroscopic analysis.

The refinement and application of this technique promises to be of major importance in the theory of atomic structure, in measuring hot plasma temperatures, and in acting for the means of energy loss in fast fission fragments in an absorber. Perhaps most importantly, it will help determine the relative abundance of the elements in the sun and other stars, which is the basis for theory of stellar evolution, the origin of the chemical elements, the age of astronomical objects and the nature of the stellar energy. For further details, ask for Technical Note #10.

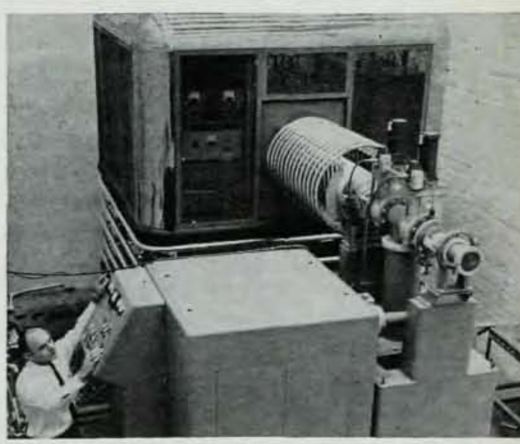


A nitrogen beam, 0.8 μA at 2 MeV, passes from right to left through a carbon foil approximately 9 $\mu g/cm^2$ thick.

Intense Ion Beams at 500 kv

The ICT-500 keV positive ion accelerator now being built by High Voltage Engineering operates at energies from 100 to 500 keV dc and pulsed. In performance tests, the machine has produced analyzed ion beam currents from 4 mA at 100 keV to 10 mA from 300 to 500 keV. 10 mA dc positive ion beam currents of H^1, H^2, and D^1 have been produced at a target located 6 feet from the end of the acceleration tube. Beam diameter is 15 millimeters maximum for all particles over the entire energy range. Previous experience with a similar machine of 300 keV maximum energy showed 15 mA of d_2^+ and a 3 centimeter beam diameter. The ICT-500 positive ion accelerator is designed for dc and pulsed operation in the nanosecond and microsecond range with a minimum pulse length of 2 nsec. at a repetition rate of 2.5 Mc/s. Pulse content is 1 mA protons and 0.7 mA deutrons.

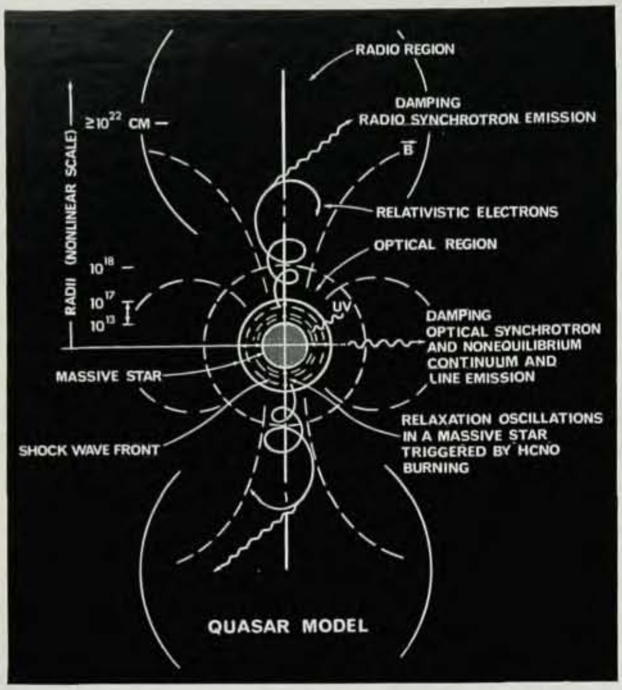
The particle source utilized with the ICT-500 positive ion accelerator is an expanded plasma type which has produced 70 mA total beam at 500 kv.



The high-brightness, intense ion beam produced by the ICT-500 accelerator is eminently suited for laboratory production of 14 MeV neutrons for cross-section measurements, dosimetry studies, weapons-effect simulation and special low-density target experiments.

For detailed information, write to Technical Sales, High Voltage Engineering Corp., Burlington, Mass. or HVE (Europa) N. V. Amersfoort, The Netherlands. Subsidiaries: Electronized Chemicals Corporation, Ion Physics Corporation. ARCO Division, Walnut Creek, California.

HIGH VOLTAGE ENGINEERING



W. A. Fowler's quasar model. Relaxation oscillations between radii of 10^{13} and 10^{17} cm are energized in a massive star by HCNO burning at about 2×10^{8} °K. Shock waves transmit energy to tenuous outer envelope from which relativistic particles are ejected into surrounding region. An associated dipole magnetic field channels particles into two regions ($\geqq 10^{22}$ cm) where radio synchrotron emission occurs. Optical synchrotron radiation comes from region immediately surrounding star ($\sim 10^{15}$ cm). Nonequilibrium continuum and line emission are also stimulated in this region by ultraviolet radiation from star. It is this region which is visible and not star itself.

[*Physics Today,* April 1965, p. 88]. Limitations on the range and strength of the force are provided by measurements which verify Einstein's principle of equivalence. R. H. Dicke of Princeton University reviewed the Dicke-Eötvös experiments which show that the acceleration toward the sun of gold and aluminum are equal to within the impressive accuracy of one part in 10^{11}. He said: "Some idea of the required sensitivity can be obtained by noting that this requires the detecting of a relative acceleration as small as 6×10^{-12}cm/sec^2. Starting from rest a body would reach the enormous velocity of 1.2×10^{-4}cm/sec after being accelerated a whole year at this rate."

Freeman Dyson chaired the next session, devoted to general discussion and summaries. Thomas Gold of Cornell University discussed his model of a quasi-stellar source: an extremely dense cluster of stars where frequent collisions give rise to fluctuating emission of light. Harlan Smith of the University of Texas summed up the observational results on quasi-stellar sources. He proposed "stark", the astronomer's quark, as a new name for these intriguing objects. His motion was not seconded. "Quasar" received the most enthusiastic support. The vote was twenty ayes to some four hundred abstentions. Other summaries were given by S. Hayakawa of Nagoya University on x-ray and γ-ray astronomy, G. Cocconi of CERN on cosmic rays, W. A. Fowler of Caltech on neutrinos, R. Hanbury Brown of Sydney University on radio astronomy, G. Gamow of Colorado University on cosmology, J. Bjorken of Stanford University on CP-violation, and T. Page of Wesleyan University on optical astronomy.

The symposium concluded with a seminar on gravitational collapse, chaired by L. Gratton of the University of Rome and J. A. Wheeler of Princeton University. Short theoretical papers were presented by J. Bardeen and W. A. Fowler (Caltech), S. A. Colgate, M. May, and R. H. White (Livermore), C. W. Misner (Maryland), R. W. Lindquist (Texas), R. A. Schwartz (NASA and Columbia), D. H. Sharp, L. Shepley, and K. S. Thorne (Princeton), J. N. Snyder (Illinois), A. H. Taub (Berkeley), and L. Gratton (Rome). They dealt mainly with the collapse of large masses under their own gravitational weight and with the resulting release of energy which may be the origin of the strong radio sources. These papers revealed the impressive progress achieved during the preceding year in relativistic hydrodynamics applied to astronomical situations with strong gravitational fields. Fowler suggested that quasi-stellar sources consist of pulsating and rotating supermassive stars, energized by nuclear reactions, with radio and optical emissions from extended surrounding regions which the star excites with ultraviolet radiation and relativistic particles. Only after the exhaustion of nuclear energy would gravitational energy from collapse become available and the evolution of a quasi-stellar into an extended radio source become possible.

Astrophysics today draws on a wide range of talents from many countries. Scientists came to the symposium from Argentina, Australia, Brazil, Canada, England, Denmark, France, Germany, Holland, Hungary, India, Ireland, Israel, Italy, Japan, Mexico, Pakistan, Poland, Sweden, the USA, and the USSR. There was widespread regret at the absence of several distinguished Soviet scientists who are not permitted to attend meetings outside the Soviet Union, and of one well-known West-European physicist who was refused a US visa.

A third Texas Symposium on Relativistic Astrophysics is planned for December 1966.