and logging wastes to oil. The expanded animal waste plant should be in operation by June of 1973, according to G. Alex Mills, chief of BuMines' division of coal, and the wood waste plant could be built within 2 years. A full-scale commercial plant incorporating the BuMines process for either animal or wood wastes could be in operation by 1980, he estimates.

Many developmental problems remain to be investigated in the pilot plant operations. Foremost among them is evaluation of economic feasibility. BuMines has been extremely reluctant to calculate operating costs of a commercial plant by extrapolation from laboratory work, and has generally justified its work primarily on the value of the product oil ($4 to $5 per barrel) and the cost of conventional methods of waste disposal (as much as $10 per ton). Because of the need for pressurized reaction vessels, however, hydrogenation is clearly the most costly of the conversion technologies.

The principal technical problem to be resolved in the pilot plants is the refinement of methods for handling the solids and introducing them to the reactor under pressure. Other problems include refinement of the process for maximum oil yields, separation of oil from the solids, and minimization of pollution, including control of sulfur emissions and purification of process water. But balanced against any pollution from the conversion facility, of course, must be the tremendous decrease in other types of pollution arising from safe disposal of the wastes.

The second major route for production of synthetic fuels is pyrolysis or destructive distillation. A major disadvantage of pyrolysis is that the process generally produces at least three different fuels—gas, oil, and char, for instance—thus multiplying collection

Speaking of Science

The Decline of the Hubble Constant:

It is my enormous pleasure to ask Allan Sandage to take us on a trip through that enormous dimension of time and space in which he feels at home—Martin Schwarzschild, introducing the Henry Norris Russell lecturer, 138th meeting of the American Astronomical Society, Michigan State University, 15–18 August 1972.

The universe may have started with a big bang, or it may have always been in a steady state. There are few measurements of the nature of the universe, and the most important has been found greatly in error. Allan Sandage presented evidence for the big bang, and announced that new data on the time lapse since the initial explosion give an age for the universe that is consistent with the ages of life, the earth, and the stars. The well-known astronomer from the Mt. Wilson and Palomar Observatories further predicted that within the next 10 years it may be possible to tell whether the universe will keep expanding forever or eventually slow down and contract.

Following the tradition of eminent astronomers such as Russell himself, who laid the groundwork for the understanding of stellar evolution, Sandage spoke eloquently and authoritatively. His presentation touched almost every point in modern cosmology; indeed, it seemed to signal that the study of the evolution of the universe had progressed a step closer toward becoming a full-fledged empirical science. However, some of the arguments made at the end of the talk were clearly speculative, arguments thought by some of the younger astronomers in the hall to be reminiscent of a grand but perhaps less rigorous age of astronomy.

Since Edwin Hubble established, in 1921, that the universe is expanding, it has been known that more distant galaxies recede faster. The constant of proportionality in the relation between the velocity and the distance of a galaxy (the Hubble constant) indicates an age for the universe under certain assumptions about the expansion. With the best techniques of his day, Hubble determined a constant which indicated an age of only 1.8 billion years. But even in the late 1930's this was known to be less than the age of the earth's crust. Either the simple "big bang" model was incorrect, or the Hubble constant was wrong. This famous discrepancy was a prime motivation for the "steady state" model developed by Hermann Bondi, Thomas Gold, and Fred Hoyle, which describes a universe that has no beginning or end, but continuously remakes itself according to a fixed and immutable pattern.

The original measurement of the Hubble constant was in error. In fact, the Hubble constant has changed so often that it is a notable example of a mutable constant. According to Sandage, "It has gone down linearly with time," and has now reached a value that makes the age of the universe consistent with the age of its constituents. The most important announcement at the Russell lecture was that the new age of the universe, estimated from the remeasured Hubble constant, is 17.7 billion years, an age remarkably close to the best estimated age of the galaxies (12 to 15 billion years).

The Hubble constant is difficult to measure because there are random velocities of galaxies in addition to the velocities of expansion. Galaxies receding at such great speeds that these perturbations are insignificant are so far away that their distances are extremely difficult to measure. According to Sandage, "You have to look so far in order to see cosmological velocities that individual stars cannot be seen. So you have to devise a technique to bridge the gap between the place where precision indicators [of distance] exist and where the universe is really expanding without any perturbing effects."

Measurement of distance must be done in many successive steps, beginning with the calibration of Cepheid stars in our galaxy (a peculiar class of variable stars whose brightness can be determined by the cycle of variation in their intensities), next measuring the angular sizes of certain hydrogen regions in galaxies near ours, then using distances of further hydrogen regions to calibrate the absolute luminosities of galaxies having a cosmological velocity. Distance can be determined from absolute luminosities by the inverse square law.

In 1932, Hubble established a value of 530 kilometers per second per megaparsec as his constant (a megaparsec is about 3.3 million light years), but the scales of optical magnitude were not accurate for faint objects because and marketing problems. Because pyrolysis is performed at atmospheric pressure, however, construction and operating costs should be lower than for hydrogenation. Several groups have investigated pyrolysis, including BuMines, but the most advanced process was developed by Garrett Research and Development Company, La Verne, California, the research arm of Occidental Petroleum Corporation.

The Garrett pyrolysis process is part of a complete system designed for disposal of urban refuse. Waste is first shredded and dried, and inorganic materials are removed for recycling or disposal. The organic waste is then reshredded and heated by a proprietary heat-exchanger, developed by Garrett, to about 500°C in an oxygen-free atmosphere. Each ton of refuse produces almost 1 barrel of oil, 140 pounds of ferrous metals, 120 pounds of glass, 160 pounds of char, and varying amounts of low energy gas (400 to 500 Btu per scf). The gas is recycled to provide the oxygen-free atmosphere for pyrolysis and, with part of the char, is burned to supply heat for the process.

The oil thus produced contains about 33 percent oxygen, less than 1 percent nitrogen, and less than 0.3 percent sulfur. Because of the high oxygen content, the energy value of the oil is only about 10,500 Btu/lb. The specific gravity of the oil is about 1.3, however, compared to 0.98 for No. 6 fuel oil, so the energy content is actually about 75 percent that of fuel oil by volume.

Garrett claims to have invested more than $3 million in development of the pollution-free process and has tested it for more than a year in a 4-ton-per-day pilot plant at La Verne. The company recently received a contract to build a $4 million, 200-ton-per-day demonstration plant that will handle all the solid wastes produced by the com-

A New Age for the Universe

certain nonlinearities in photographic plates were not understood. Furthermore, the absolute scale of Cepheid brightness was in error, as discovered by W. Baade in 1952. Correcting these two errors reduced the Hubble constant to about 265. In 1956, it was stated to be 180, then after corrections of Hubble's data for other errors, Sandage estimated in 1958 that the best value was 75. The value Sandage announced at the Russell lecture, based on the first complete remeasurement, was 55 ± 7. Sandage commented quite candidly on the contrast between his estimated error and the enormity of mismeasurement over the years.

> Now that's an incredibly small error, 15 percent of the value. Hubble said his value was good to 15 percent also. HMS [Humason, Mayall, Sandage] said their value was good to 15 percent, and the value of 75 is good to 15 percent. Almost everybody, when quoting distances . . . quotes 15 percent. So that's kind of unrealistic, but Martin Schwarzschild said today that one should always underquote the errors so as to give himself some enthusiasm to continue on with the problem.

The problem of the next 10 years, as Sandage sees it, is to look out to greater distances to see whether the linear relationship between the distance and velocity changes. The largest red shift used by Hubble or Sandage was 0.46, but Sandage thinks it will be possible to find the distances of certain galaxies with red shifts of 0.8. [The red shifts of some quasi-stellar objects (QSO's) are almost as great as 3.] The point of measuring objects with larger red shifts is that they may be far enough away so that the time for light to travel to us is a significant fraction of the age of the universe. If the universe is slowing down because of the braking action of its own gravitational forces, then the speeds of very distant galaxies will be observed as larger than one would expect because they would be observed at the expansion rate of an earlier age; in other words, the Hubble relationship would not be exactly linear. Thus, better data at large red shifts will allow astronomers to determine a second constant, called the deceleration parameter. In Friedmann's equation that describes many cosmological models, a deceleration parameter of −1 indicates a steady state universe, a value of + ½ indicates a flat Euclidean universe, and a value greater than + ½ indicates a universe that is decelerating and will eventually contract. The best value available from the present data (1 ± 1) is not definitive, but slightly favors a "big bang" history for the universe.

After stating so succinctly the outstanding problem that must be solved to ascertain what the future of the universe will be, Sandage ventured the suggestion that there is already enough evidence to determine the past. Though many scientists have questioned whether the very large red shifts of QSO's are really indicative of velocities near the speed of light, Sandage presented some arguments in favor of the traditional interpretation. He then estimated that the light from QSO's with the largest red shifts was emitted before 89 percent of the history of the universe had elapsed. Furthermore, data that Sandage presented in his talk suggested that the 200-inch Mount Palomar telescope should be able to detect QSO's with red shifts larger than 3, but searches for objects listed in the 4th and 5th Cambridge catalogs of radio sources have not revealed any. Looking further out in space is equivalent to looking further back in time, and Sandage suggests that suddenly the objects run out.

> If one could substantiate that a red shift limit of 3 is real, have we actually observed the edge of the universe or the horizon of the universe in time? If so, this would be a fairly decent proof that the universe has not always been the way it is now, that it has evolved. This plus the agreement of time scales [the age of galaxies and the age of the universe] would surely be an indication of an evolution: the world did begin.

While astronomers reared in the oriental cultures express very little interest in cosmology, scientists educated within the western Judeo-Christian tradition continue to be fascinated with questions about the orgin of the world. The Russell lecture ended with a powerful allusion to the religious overtones of that fascination.

> The best text that could be indicated here would be that in the beginning there was darkness upon the deep. There was light, and out of that light came everything that we now observe.

Astronomers, of course, will continue making observations.—William D. Metz