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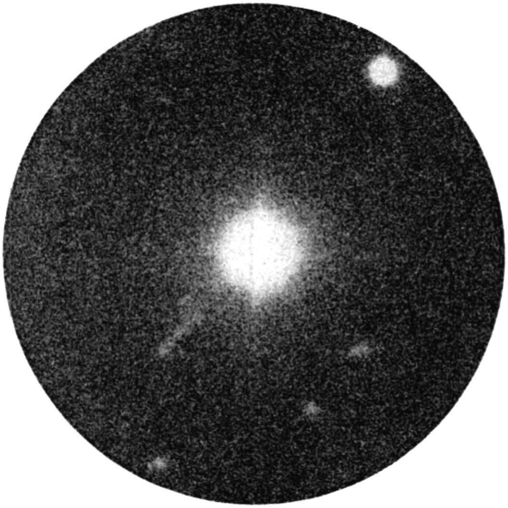

Through 200-inch telescope, mysterious 3C 273, in Constellation Virgo, clearly shows its huge tail.

What are quasi-stellars?

Heavens' New Enigma

by ALBERT ROSENFELD

Scientists have suddenly become aware of some things out there in the skies which they had never noticed before, and they could hardly be more excited if they had just zeroed in on a formation of flying saucers. The excitement is clearly justified: the newly discovered things-out-there are fantastic fiery objects as massive as a million suns. They burn with a brightness that would eclipse a hundredfold our entire galaxy with its 100 billion stars. They appear faint, but only because they are billions of light years away from us. Among them are the most distant celestial bodies yet detected—one six billion light years from earth, one perhaps 10 billion—as well as the most dazzlingly luminous object ever before seen in the universe.

Everything about these newly recognized phenomena is on such a stupendous scale—especially the unheard-of energies they produce—that even the astronomers, accustomed to dealing on a cosmic scale, are caught in open-mouthed astonishment. Like Hollywood producers suddenly in possession of a movie that is *really* colossal, scientists find themselves at a loss for adequate superlatives. In place of precise terminology, they resort to poetic description. Physicist J. Robert Oppenheimer describes them as "incredibly beautiful," as "spectacular events of unprecedented grandeur." Caltech Astronomer Jesse L. Greenstein has called them "perhaps the most bizarre and puzzling objects ever observed through a telescope."

For the moment, because these bizarre and puzzling objects are something like stars (though far too big to be stars) and because they spew out radio waves in reckless profusion, they have been given an unwieldy name: "Quasi-stellar radio sources."

No theory in all astrophysics fully accounts for these quasi-stellar radio sources. Their very existence is an affront and an outrage to all scientific sense and reason. Yet they undeniably exist. To explain them and their behavior, some of the most respected scientists of the Western world recently gathered at the Southwest Center for Advanced Studies in Dallas. There an all-out intellectual effort was made to solve this new mystery of the universe.

Ever since the techniques of radioastronomy were first developed 20 years ago, scientists have been aware that certain regions of the sky emit radio waves. Some of these sources of radio emission turned out to be galaxies. Others *appeared* to be ordinary galaxies—but they emitted extraordinarily large quantities of radio waves, millions of times what might be expected, with no way to explain the production of such energies. The mystery was deepened by the belated realization that some of the most intense radio sources were not galaxies at all.

But through the years no one could figure out any process by which any star, or even any galaxy with billions of stars, might possibly produce the energy for these gigantic radio emissions. After a number of preliminary theories were examined and rejected, everyone finally agreed that such extraordinary energies could only be generated by events of catastrophic violence.

But what sort of events? A collision of galaxies was one of the first suggestions. But computations soon made it clear that even colliding galaxies would produce only a piddling fraction of the energy emitted by these radio sources. Astrophysicist Geoffrey Burbidge of the University of California at La Jolla proposed an even bolder idea. He knew that some of the normal radio sources in our own galaxy had been identified as exploding stars, called supernovae. Might, then, such an explosion be the answer? Certainly a single supernova could not do the trick. But what about a chain of explosions? An A-bomb explosion is caused by a chain reaction of fissioning atoms when the uranium reaches a certain critical mass. Burbidge theorized that a chain reaction of supernovae might also occur—each one setting off the others around it in turn—when a galaxy reached a certain critical stage in its evolution.

The trouble with this idea was that it called for a highly improbable kind of galaxy with a core of stars ready to explode into supernovae and so densely packed that they could be detonated at the rate of 10 to 1,000 per year. (In our own galaxy a supernova occurs less than once in a century.)

Among those reluctant to accept Burbidge's idea was the celebrated cosmologist, Fred Hoyle of Cambridge University. In collaboration with Physicist William A. Fowler of Caltech, he proposed an even more daring theory: gravitational collapse. The greater an object's mass, the greater its gravitational force. If a star could attain a certain mass—say a million to 100 million times the mass of our own sun—then its gravity would become 100 times as powerful as the forces generated by the strongest known nuclear reactions. Such a super superstar, in the normal course of its evolution, would contract. When it contracted to a certain critical volume, the gravitational field would cause the star to collapse in upon itself.

The process would be something like the detonation of a nuclear weapon by *implosion*—that is, by a number of inward-directed explosions which close in on the fissionable material. As Hoyle theorizes, gravitational collapse would be "catastrophic implosion" on a cosmic scale. In place of Burbidge's chain explosion of supernovae, Hoyle was proposing a single super superstar exploding inward on itself. Such an implosion could conceivably provide the prodigious quantities of energy which intense radio sources need to keep going.

But the Hoyle-Fowler thesis had holes, too. The main criticism is that the most massive stars are no more than 65 times as massive as the sun. But a star would have to be several million times more massive than the sun to achieve gravitational collapse. Moreover, all calculations, including Hoyle's own, indicate that as stars get much bigger than any now known, they become unstable and break apart. Theoretically, if a star could somehow reach the size of Hoyle's hypothetical super superstar, it might achieve stability. But no one could explain how a star might get through all the intermediate, unstable sizes until it attained the requisite proportions.

Another important objection to Hoyle's idea was built into Einstein's general theory of relativity. Gravity, as every earthling knows, is what keeps us all from floating off into space. To escape gravity a certain speed is required—the so-called "escape velocity." To escape earth gravity, the 25,000 mph achieved by large rockets is enough. To escape from a larger planet like Jupiter, with a stronger gravitational field, would require a greater escape velocity. Now Einstein's theory predicts that if the gravitational collapse of a star did occur, the collapse would go on and the gravitational field would become stronger and stronger until it grew so powerful that it would close in upon itself; ultimately, the escape velocity would equal the speed of light, which is the speed limit of the universe. In that case nothing could get out of the star, not even light waves. Thus, instead of an intensely radiating object, sending out lavish quantities of light and radio energy, gravitational collapse would result in an invisible "black hole" in the universe. (To attain this "black hole" status, the matter comprising the earth would have to be compressed to a

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sphere slightly less than one inch in diameter.)

Hoyle's answer to this is that Einstein's theory applies only in ideal cases where the object is a perfectly symmetrical sphere. In the real world the object would not be exactly symmetrical, hence it would collapse unevenly and energy could escape. The energy from the implosion, according to Hoyle, could keep escaping for millions of years.

In 1963, ingenious new techniques for pinpointing radio sources in the sky with unprecedented precision prompted astronomers in the U.S., Great Britain and Australia to start intensive efforts to locate them with optical telescopes. This search, which Hoyle followed with great interest to see if any of his theoretical super superstars might turn up, resulted instead in the discovery of the quasi-stellar radio sources.

The tale of just one of them, 3C 273, will suffice to illustrate how revolutionary the discoveries were. (3C stands for Third Cambridge Catalogue of Radio Sources, and 273 merely means the 273rd source listed in the catalogue. Although thousands of radio sources are known, only nine of them are so far believed to be quasi-stellar.) After an Australian team of radio astronomers pinpointed the exact location of 3C 273, Astronomer Maarten Schmidt of Caltech, using the 200-inch Hale telescope at Mount Palomar, was able to locate it optically and identify it as a long-known star of the 13th magnitude in the Constellation Virgo. This star is easily visible with any good amateur telescope. Astronomers had always assumed it to be part of our own Milky Way galaxy.

Like millions of other ordinary-looking stars in the skies, this one had never been closely inspected. But now, on analyzing the spectrum of its light, scientists were astounded to find a sizable "red shift"—that is, a shifting of the spectral lines toward the red side rather than the blue side of the spectrum. This red shift has been used by astronomers for the last 35 years as a standard measure of how far away from us a distant galaxy is and how fast it is moving away from us. The measurements revealed that 3C 273 was two billion light years away and therefore outside—a long way outside—our galaxy.

Normally a star at that distance cannot be seen at all, and even a galaxy can be detected only by a Palomar-sized telescope. The fact that 3C 273 looked like a star of the 13th magnitude despite its vast distance made it easily the brightest thing yet discovered in the heavens. Could it be a galaxy? Photographs showed it was not a collection of billions of separate stars, but rather two distinct shapes—a central core accompanied by an elongated jet that appeared to have been shot out of it. Together they resembled a gigantic exclamation point in the sky. The main body of 3C 273 was much too small to be a galaxy, yet unbelievably outsized for a normal star. Nor did its spectroscopic characteristics resemble those of a star—not even a hypothetical super superstar. How could 3C 273, less than 1/1,000th of the diameter of our galaxy, be brighter than the entire Milky Way and still have enough energy left for such extravagant outpourings of radio waves? Instead of solving the old problem of how such energy is generated, the discovery of 3C 273 seemed to raise new ones.

As if this were not enough of a headache, 3C 273 turned out to have a disturbing habit: it pulsates. This discovery was made by Astronomer Harlan Smith of the University of Texas. Realizing that 3C 273 was located in a part of the sky that had been regularly photographed by Harvard since 1886, Smith went back over 2,000 photographs and noticed that 3C 273 had changed in brightness —first dimming, then flaring up— in nearly regular cycles, each complete pulsation taking 13 years. If 3C 273 had been an ordinary star, this would present no great theoretical problem. But 3C 273 is now estimated to be less than ten light years across—that is, it would take a light wave 10 years to get from one end of it to the other. How, then, can it possibly pulsate like an organized body—like, say, a light bulb? No one has a clue.

Of the quasi-stellar radio sources so far studied, 3C 273 is the closest to us. Another of them, 3C 286, is calculated by the Russian Astrophysicist Iosif S. Shklovsky to be 10 billion light years away, which would make it easily the most distant object yet detected in the universe. It is moving away from us at some 370 million mph, or 55% the speed of light. Shklovsky's distance estimate has been disputed, but U.S. astronomers have calculated that at least one other quasi-stellar radio source—3C 47—is some six billion light years away, which would still make it farther away from earth than anything previously seen in the universe.

At the end of the three-day meeting in Dallas, the scientists, having stretched their imaginations to a point that once would have embarrassed science fiction writers, were hardly less mystified than they were before they began their talks. No one at the conference could really disprove Burbidge's theory of a chain reaction of exploding supernovae, yet hardly anyone found it acceptable. Though nearly everyone was attracted by the Hoyle-Fowler theory of gravitational collapse, no one could figure out how it could actually occur. But so fantastic is the nature of the radio sources that no bets were ruled out.

Meanwhile scientists all over the world are renewing their attack on the mystery with such vigor that Hoyle believes many of the perplexing questions raised in 1963 may very well be answered in the next few years—or even sooner. No one can predict what the answers will be except that almost certainly their startling nature will make it appropriate to follow them with the shape of 3C 273: a king-sized exclamation point.