possible for the Chinese to refer to "several hundred thousand design personnel" [*Ching-chi Yen-chiu* **1965**, No. 11 (1965); translated in *U.S. Joint Pub. Res. Serv. Pub. No. 33,768* (1966).
23. *Ching-chi Yen-chiu* **1965**, No. 11 (1965).
24. *Ibid.* **1965**, No. 9 (1965); translated in *U.S. Joint Pub. Res. Serv. Pub. No. 32,793* (1965).
25. After graduation of the 1963 class it was reported (New China News Agency, 14 Aug. 1963) that China had graduated "well over 1.1 million" persons from colleges and universities since 1949. "Post-liberation college graduates include 370,000 engineers, 325,000 teachers, over 110,000 physicians and pharmacologists, over 100,000 agronomists and foresters, and more than 70,000 natural scientists." To arrive at the 1965 estimate an attrition rate was applied to the 1963 data, and adjustments were made, to include persons who graduated prior to 1949 and after 1964.
26. Much of the basic information for these estimates is contained in the study by Cheng (*11*) and by L. A. Orleans, *Professional Manpower and Education in Communist China* (National Science Foundation, Washington, D.C., 1961).
27. There are thousands of experienced workers in China who have worked their way up through the ranks and attained the title of engineer with little formal education. Although excluded from consideration here, some of them may be engaged in R & D.
28. For a more detailed methodology see the original paper from which this article is adapted, in *An Economic Profile of Mainland China* (Joint Economic Committee, Washington, D.C., 1967), pp. 549–578.
29. Although, at the official exchange rate, $1 equals 2.355 yuan, such conversions are rather meaningless and I have avoided them. However, one might say, just for the record, that this figure is roughly equivalent to $110 million.
30. This statement is based on a conversation between Charles Taylor of the Toronto *Globe and Mail* and an official of a Tsinan factory, as reported in the New York *Times*, 8 Aug. 1965. It is precisely this system of incentives that is referred to as "economism" and is being attacked by the leaders of the Great Cultural Revolution. Presumably all incentives have been abolished at least for the present.
31. There are a number of series of estimates of Communist China's gross national product. This estimate is based on data shown in Y. L. Wu *et al., Economic Potential of Communist China* (Stanford Research Institute, Menlo Park, Calif. 1964), vol. 3.
32. China's military budget is a puzzle in and of itself and is certainly outside the bounds of this inquiry. What proportion of the expenditures are in the area of R & D is a question difficult to approach from either the military or the R & D side. The cost of China's nuclear program, for example, is variously estimated at between 1 and 2 billion yuan—a reasonably broad range, considering the nature of the available information. The R & D share of this program should not constitute more than a fraction of the total.
33. Figure 1 is adapted from a chart prepared by Mr. Wang-chi, Science and Technology Division, Library of Congress.

Quasars: Rapid Light Fluctuations

Observed light fluctuations may provide evidence for a recently discussed mechanism for quasars.

W. H. McCrea

Surprising new discoveries about light fluctuations in a particular quasi-stellar object (quasar) may be interpreted as occultation effects, as Cannon and Penston (*1*) were the first to point out. With this clue, I use here the published observations to infer as much as possible about the structure of the quasar. The resulting model is remarkably like one I proposed for quite other reasons. If it is valid, it shows that a quasar may be regarded as an early stage in the formation of a system like the nucleus of a galaxy; at any instant, the optical radiation would come from one or a few temporary stars situated among a very large number of protostars, the occultations being caused by some of these. In the first place, the possible significance of the work is to show that features of these observations may soon lead to much detailed information about the constitution of quasars. Moreover, insofar as the present interpretation is correct, it strongly indicates that the quasar manifestation must be sought in an early stage in the evolution of the type of system considered here and not at a very late stage as suggested from time to time.

The author is research professor of theoretical astronomy in the University of Sussex, England, and, at present, foreign visiting professor of the American Astronomical Society in the Berkeley astronomy department.

Observational Data

Observations by Sandage (*2*) and by Kinman, Lamla, and Wirtanen (*3*) show that the optical brightness of the quasar 3C 446 was apparently steady during most of 1964 and 1965, that it began to increase in late 1965, and that by mid-1966 it was about 20 times brighter than in previous years. Since then, observations, including those of Wesselink and Hunter (*4*) and of Cannon and Penston (*1*), show rapid fluctuations of brightness. The agreement between the various sets of observations is good, but the picture obtained by combining them is more complex than that obtained from any one set.

The significant features of the rapid fluctuations appear to be the following; the first six were obtained by combining all the available luminosity measurements into a single "light curve." (i) The maximum brightness in every oscillation appears to be the same (about $m_{pg} = 16$) within the uncertainties of the measurements. Without more closely spaced observations, this is perhaps a safer statement than that of Cannon and Penston about the "flat top," although its significance may be similar. (ii) The minima attained seem to have significantly different values. In fact, the oscillations may be described as dips below 16^m with depths ranging from about 10 to 70 percent in brightness. (iii) In general, in any fluctuation, both the main fall and main rise in brightness are abrupt (lasting less than a day), and there is no evidence of asymmetry. (iv) During the almost 200 days of the observations, there were some ten clearly discernible dips. (v) A rough estimate of the fraction of the total time spent at or near maximum brightness is 50 percent. Again, a better estimate seems impossible without more closely spaced observations. (vi) Features (iv) and (v) imply that the average duration of a dip is about 10 days. (vii) The radiation in the optical continuum shows a high degree of polarization which does not seem to vary much throughout the observations, although the position angle of this polarization appears to fluctuate somewhat. (viii) Comparison with other quasars, and possibly with 3C 446 itself when it was first observed, shows that 3C 446 has been seen under circumstances exceptionally liable to manifest such fluctuations.

Interpretation

Feature (iii) excludes any known cause of fluctuation in the production of radiation. Therefore, we consider a *geometrical* effect, the possibilities being the switching-on of radiation at the observer by a "searchlight" effect or the switching-off by a "shutter" effect, that is, occulation. Features (i) and (ii) definitely point to the latter. Indeed, Cannon and Penston first suggested to me the possibility of an occultation effect several months ago; in their paper (*1*), they discuss one form it might take. There are two main possible forms, and we consider these in turn.

Case 1. Suppose that in a quasar most of the optical emission at any instant comes from a few discrete sources. Suppose these sources to be situated among a large number of opaque bodies in random motion, the bodies being large in size compared with the sources. Viewed from outside the system, one or the other of the sources will, from time to time, be occulted by one of the moving opaque bodies. Then that source will be totally eclipsed for a time interval that is large compared with that of the partial phases. The reduction of apparent luminosity will be an appreciable percentage of the total luminosity from the postulated small number of active sources. Such fluctuations in luminosity will be distributed irregularly in time and will vary in depth according to the particular source that happens to be temporarily cut off. Also, there could be occasional multiple effects. All these inferences are in qualitative agreement with the observed features. We seek to make the agreement quantitative.

If the optical luminosity is produced mainly by n comparable sources, the eclipse of any one source would reduce the total luminosity by about $100/n$ percent. Hence, feature (ii) indicates that n is between about 2 and about 10; as a compromise, we adopt

$$n = 5 \tag{1}$$

Incidentally, the amount of the reduction and the number of different amounts (signifying the occultation of different component sources) appear to be compatible.

According to any known interpretation of the red shift $z \equiv \Delta\lambda/\lambda$, a process that we observe as having duration t would have duration $t/(1 + z)$ at the source. In the case of 3C 446 with $z = 1.4$, feature (vi) implies a mean proper duration of an occultation of about 4 days, or 5 for a central occultation. Using observed speeds in other quasars, Cannon and Penston adopt for the typical relative transverse speed of source and occulting body

$$V = 3000 \text{ km/sec} \tag{2}$$

If we assume the body to be spherical of radius r, the distance traveled in 5 days at speed V is $2r$; this gives

$$r = 6.5 \times 10^{13} \text{ cm} \tag{3}$$

or approximately 4.3 astronomical units.

Let N be the total number of opaque bodies in the system, so that, disregarding overlapping, their total projected area is $\pi N r^2$. Let R be the effective radius of the whole system, so that its projected area is πR^2. If we suppose the n discrete sources and the N opaque bodies to be distributed at random through the system, then the chance of one of the sources being occulted at any instant is roughly $n(\pi N r^2)/\pi R^2$. This disregards the overlapping of the opaque bodies and the fact that some would be behind the sources, both of which would decrease the chance; on the other hand, it ignores the fact that we look through a greater depth near the center of the system, and it neglects any concentration toward the center, circumstances tending to improve the chance. So we can work with the rough estimate and set it equal to the 50 percent estimate in (v), obtaining

$$nN(r/R)^2 = \tfrac{1}{2} \tag{4}$$

Later on, we give reasons for taking the mass of an opaque body to be approximately the solar mass $M_\odot$. So, apart from the effect of other contributions to the total mass, a mean speed V^* for random motions in the system according to the virial theorem is given approximately by

$$V^{*2} = GNM_\odot/R \tag{5}$$

where G represents the gravitation constant. Finally, we may estimate roughly

$$V = 2V^* \tag{6}$$

on the ground that occultations are most likely to occur between objects moving transversely in opposite directions so that the significant relative speed is about double the mean speed. With Eqs. 1–3 and 6, we can now solve Eqs. 4 and 5 for R and N, and we find

$$R = 7.2 \times 10^{18} \text{ cm} \tag{7}$$

(approximately 2.3 parsec), and

$$N = 1.2 \times 10^9 \tag{8}$$

Apart from the value of the mass of a typical opaque object, we have appealed only to observed properties of quasars. If our approach is correct, we have inferred that in 3C 446 the radiation comes from about five discrete sources and that these are situated among some 10^9 opaque bodies each of radius a few astronomical units, the whole system being some 5 parsec in diameter.

We have to note that an estimate of the mean free path l between collisions of opaque bodies under the conditions envisaged is given by

$$4\pi r^2 l = 4/3(\pi R^3/N) \tag{9}$$

With the values in Eqs. 3, 7, and 8, this gives, approximately,

$$l = 2.4 \times 10^{19} \text{ cm} \tag{10}$$

and the time t^* taken to travel this distance at speed $V^* = 1500$ km per second is about

$$t^* = 5.1 \times 10^3 \text{ years} \tag{11}$$

We later discuss the significance of the values in Eqs. 10 and 11.

Case 2. Suppose that in a quasar most of the optical emission at any instant comes from a single source. Suppose that this source is situated among a large number of opaque bodies in random motion, and suppose that the source and the bodies are all of comparable size. Viewed from outside the system, the source will from time to time be partially occulted by one of the moving opaque bodies. The resulting fluctuations in luminosity will be distributed irregularly in time. They will be of various depths depending upon the fraction of the source that becomes obscured; total eclipse will be improbable. So far as they go, these inferences are again in qualitative agreement with the observations, and again we seek to make the agreement quantitative. We shall later compare the cases.

In accordance with Cannon and Penston (*1*), we shall again use Eq. 2 and illustrate the case by taking the source and the opaque bodies to have the same radius r for which we adopt the value from their paper; this radius is

$$r = 7.5 \times 10^{13} \text{ cm} \tag{12}$$

Let N and R have the same meaning as in case 1. A partial occultation will occur if the center of the source in projection is within distance $2r$ of the center of one of the opaque bodies and behind it. Hence, the chance of some portion of the source being occulted at any instant is roughly $\pi N(2r)^2/\pi R^2$. The reasons for using this rough estimate are the same as before; now in place of Eq. 4 we have

$$N(2r/R)^2 = 1/2 \qquad (13)$$

Also we have Eqs. 5 and 6; so we now use Eqs. 2, 6, and 12 to solve Eqs. 5 and 13, and we now find

$$R = 7.6 \times 10^{18} \text{ cm} \qquad (14)$$

(approximately 2.5 parsec), and

$$N = 1.3 \times 10^9 \qquad (15)$$

The difference between Eqs. 7 and 8 and Eqs. 14 and 15 is not significant. The reason for the similar results is that the chance of a partial occultation of the one somewhat extended source in case 2 is about the same as the chance of a complete occultation of one of the small number of discrete sources in case 1.

In view of the fact that these results are so similar, then also the results corresponding to Eqs. 10 and 11 must be about the same in case 2. If the approach in case 2, rather than in case 1, is correct, we should have inferred that in 3C 446 the radiation comes essentially from one particular source that is situated among some 10^9 opaque bodies, both the source and each of the opaque bodies being a few astronomical units in radius, the system as a whole being some 5 parsec across.

While Cannon and Penston discuss a similar mechanism, they relate it in a general way to a somewhat different model proposed by the authors whom they quote (*5*, *6*); we cannot here enter upon a detailed comparison.

Theory

I recently proposed a mechanism that might produce the quasar phenomenon in just such a system as that which emerges in both cases 1 and 2. The proposal may be regarded as the outline of a theory of the formation of the nucleus of a galaxy. In the numerical illustration (*7*), I contemplated a concentration of interstellar material of mass equal to some 10^8 $M_\odot$ situated near the center of a galaxy, and I supposed its destiny to be the formation of some 10^8 stars in a region having the dimensions of a galactic nucleus. I contemplated two possibilities for the first-stage fragmentation of this material. If nearly all the initial fragments are of appropriate masses for forming normal stars, then presumably such stars will develop in the ways usually studied. On the other hand, if the initial fragments mostly exceed the critical mass (about 50 $M_\odot$) for forming a normal star, I conjectured they would evolve rapidly to a state in which they would liberate nuclear energy explosively. In the example, I inferred that there could be some 10^6 explosions of such temporary stars within a characteristic time of about 10^5 years. The suggestion is that the whole occurrence is of the character of the recognized violent events in galaxies and that, during the interval while the explosions are proceeding, the system constitutes a quasi-stellar object. At any instant in this stage, the optical emission would be contributed predominantly by just one or a small number of the exploding temporary stars. The random sequence of explosions would produce a resultant brightness varying in times of the order of a month or longer. It would not, of course, produce the much more rapid light fluctuations discussed in this article.

If temporary stars are formed in this way from the first-generation fragments, then the ultimate normal stars which are to be the end product must be formed out of second-generation (or later) fragments. Any such fragment will collapse under free fall, as modified by whatever rotation it may possess, until it becomes sufficiently opaque to form a protostar. Hoyle (*8*) estimated that this stage occurs at radius about 5×10^{13} cm. Mestel (*9*) estimated that it occurs when the density reaches about 10^{-8} g cm^{-3}; for solar mass, this implies radius about 3.6×10^{13} cm.

If the model in case 1 or 2 is identified with a model of the sort proposed here, the radiation source or sources are the temporary stars that happen to be active; the opaque bodies are the protostars, and the system is at a stage when a large proportion of these have been formed. The account obtained in this way seems to be self-consistent. In particular, the fact that r given by Eqs. 3 and 12 is about the estimated radius of a protostar seems particularly significant. Also, it is remarkable that the value of N in Eqs. 8 and 15, which at first sight is startlingly large, is of about the expected number of protostars that inevitably existed during the formation of the nucleus of a large galaxy.

For the purpose of the preceding section, the average mass of a protostar is taken to be about a solar mass. The result (Eq. 11) implies that any one of the protostars would collide with another once in a time of the order 10^4 years, and we might expect that it would not survive more than a few such collisions. As it stands, this is not unduly restrictive, for it is of the essence of the theory that it is a transient state of the system with which we are confronted. However, the protostars would, of course, be in orbits in the gravitational field of the system and, if such orbits were predominantly in one direction, the probability of collision would be reduced.

Discussion

If the optical radiation of a quasar comes from the explosion of temporary stars, each such star would form a compact source. But we do not know at present whether this should be interpreted as being of approximately starlike size or somewhat larger; that is to say, we do not know whether case 1 or case 2 provides the more significant picture. The evidence of the observations is rather ambiguous. Some features of the light fluctuations seem to favor case 1; on the other hand, as some of the observers have emphasized, the existence and variation of optical polarization seem to support case 2. Fortunately for the theory, so far as it goes at present, its acceptability does not seem to depend crucially on the ability to discriminate between the cases.

If this account of the rapid fluctuation of a quasar is valid, the essential feature is the presence of a large number of relatively extended opaque bodies. This strongly suggests that we are dealing with a system that is young. It is difficult to see how such objects could occur in the late stages of evolution of a large stellar cluster or of a galactic nucleus, which have been considered on other grounds.

References and Notes

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10. For discussions, I thank many astronomers, particularly R. D. Cannon, M. V. Penston, and Drs. G. Field, T. D. Kinman, R. Minkowski, J. G. Phillips, and A. J. Wesselink.