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MORPHOLOGICAL ASTRONOMY.

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I. Historical Sidelights.

A review of the development of astronomy reveals a series of most entertaining adventures, errors and omissions in addition to great discoveries and achievements. A spirit of individualistic enterprise is apparent at all times, which often borders on the revolutionary. This spirit could not fail to produce results which are important for progress in all manifestations of life, both scientific-technological and philosophical-sociological.

The subject matter of astronomy nonetheless is so vast that even the most prodigious individual efforts must fail to cover the whole accessible territory. Many fruitful regions have necessarily been left unexplored. The fascinating problem thus presents itself to develop methods which will allow us to gain an overall perspective of what still can be done, of what is possible with available means and manpower and of what might come if these means were radically expanded beyond those presently realized. The solution of this problem may be sought through the application of what can be called the *morphological method.*

The morphological method essentially is nothing more than an orderly way of looking at things. The only innovation which we propose is to carry morphological thinking to a degree of generality not commonly realized. Our aim is to achieve a schematic perspective over all of the possible solutions of a given large-scale problem. Naturally not all of the solutions which we are thus led to visualize can be carried out individually in all detail. Because of unavoidable limitations on time and means a choice must obviously be made, and preference must be given to some specific solutions. With the general perspective achieved, this choice will however be more rational and organic than it would be if one engaged haphazardly in work on this or that solution of a given problem.

Morphological thinking, without having been strictly formalized, has actually been applied by many scientists in the past, particularly by mathematicians. For instance, the introduction of generalized coordinates and the formulation of general laws of classical mechanics by Lagrange is

a case in point. Another example is the analysis and synthesis of the possible geometrical spaces. In physics, biology, botany, geology, and other disciplines the morphological method also has played an important role. In sociology and statecraft, where prejudices, conventions and narrow ideologies interfere, the method is more difficult of application although it is precisely in these fields where it could be most beneficial.

A brilliant example of the power of the morphological procedure may be found in the scientific achievements of Faraday, from whose work its essential features become clearly apparent. Instead of exploring the world of the physical phenomena in the light of causal chains, that is, time sequences of cause and effect, it is rather *the interrelation between coexisting aspects of nature* which is stressed. Thus Faraday, instead of investigating this or that physical effect, was interested primarily in correlations among all phenomena. In visualising the various fields of physics, that is, geometry, kinematics and dynamics, heat, electricity, magnetism, optics, and gravitation, he asked for bonds between them and set out to explore them systematically. Faraday's successes along this line of thought and experimentation are well known. For instance, his law of induction established the triple relation among electricity, magnetism and mechanical motion. He also attempted to find the connection among electricity, magnetism and gravitation, but did not succeed. This feat has not even been achieved to-day. Although Einstein demonstrated the fundamental interplay between geometry and gravitation, we are still trying to establish a general field theory which will result in a unified concept of the gravitational and electromagnetic fields. Astronomical observations of events in distant space may well be destined to furnish us with the first significant clues on this old problem.

As a peculiar sidelight, it is of interest to recall that the morphological method in its full extent was perhaps for the first time consciously applied to problems which presented themselves in connection with the scientific efforts during the recent world war. In this emergency it became apparent that not even the richest nation can afford to experiment helter-skelter along all the lines of technical development which present themselves. For instance, the choice of weapons, devices or methods of warfare without the guidance of a general perspective outlook may prove inadequate and even fatal.

The morphological method, in all of its implications, was during the past decade applied systematically and successfully in the field of propulsive power plants. Because of the forceful incentives provided by the emergency, not only was the morphological analysis of jet engines carried out theoretically but also all of the means were made available to carry out the results of this analysis in practice. This lucky circumstance, which often is absent in peace-time life, contributed largely to the successes achieved. These successes are embodied in the construction and operation of a whole series of remarkable jet engines as well as in the integrated and extended knowledge which was acquired on the whole problem of propulsive power.

II. Description of the Morphological Method.

As we have already stated, the essence of the morphological method is direct thinking and direct action. This combination would appear to be

the major asset of free men and of the democratic way of life. If this way of life is to survive, this asset must be developed and its results must be developed with all of the means at our disposal.

Morphological thinking will not be popular among dictators. It can only succeed if we let no doctrines or prejudices stand in our way. Its application will have to overcome severe obstacles even in the field of general science where objectivity and tolerance are often not as widespread as they are supposed to be. Indeed, the morphologist is not just a scientist who busies himself with problems in a specific field, thus establishing himself as a respectable astronomer, physicist, biologist and so on. The morphologist for the solution of his problems will trespass into many fields. He will thus arouse the anger of those professionals who may have great special knowledge but who fail to see beyond the boundaries of their domain.

On the other hand the morphologist will also find friends and he will have no difficulty in convincing many people who recognize that fundamentally they have been working with his method, even though they may never have formulated it explicitly. For the benefit of those men we here state some of the essential features of morphological thinking and we shall attempt to describe the resulting outlook on coming problems in astronomy.

We should perhaps state first that morphology originally was concerned with the geometrical shapes of things and with the change of these shapes with time. In this sense Goethe occupied himself with the morphology of plants, that is, their patterns and the change of these patterns during growth.

We have taken the liberty to generalize the scope of morphology so that it embraces the investigation not merely of geometrical patterns but of all characteristics of things, whether they be material or spiritual.

Morphology thus concerns itself with the qualitative patterns of all things. Quantitative aspects enter on the secondary plane when the decision has to be made which of the possibilities brought to light by the basic morphological analysis best serves a desired purpose.

The morphological method proceeds as follows:

1. A specific problem is formulated. This problem, to start with, may be of a sufficiently general nature to satisfy a morphologist and to provide ample opportunity for him to apply his method. On the other hand, the original problem may be so restricted as not to leave room for the application of the method. In this case the morphologist will generalize the original problem and seek to achieve its solution within the extended inquiry.

For instance, the specific problem may be to invent, design and construct a telescope which will make possible certain observations. Now, those charged with this task may succeed or they may not. If head-on attacks on the problem end in failure we suggest that the morphological method be tried. That is, instead of asking for a special telescope, one first attempts to achieve a perspective over all possible telescopes and their performance characteristics. This calls for the second step of our method.

2. A schematic representation is attempted of the totality of the possible things (telescopes) falling within the category under discussion.

This representation is advantageously arranged in terms of significant

qualitative and quantitative parameters which are relevant to the problem. For instance, in our example of telescopes one significant parameter, not usually considered in the past, is the ratio r of the energy entering the aperture to the energy absorbed in the recording instrument. This ratio may be

$$A_1\colon\ r>1 \qquad A_2\colon\ r\cong 1 \qquad A_3\colon\ r<1 \tag{1}$$

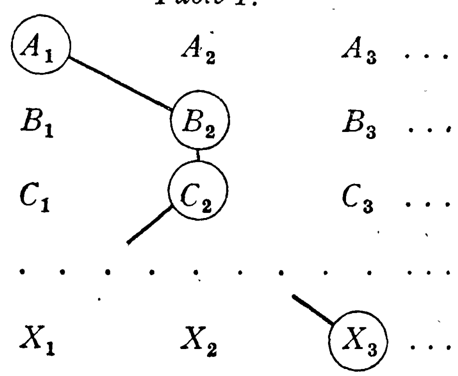
This first parameter $A(A_1, A_2, A_3)$ is thus a matrix of three elements.

The second parameter, or the matrix $B(B_1, B_2, B_3, B_4,$ etc.) may qualify all of the recording instruments, such as photographic plates, ionization chambers, photocells and so on, which are at our disposal.

The third parameter C might describe the type of interaction of the light with the optical parts of the telescope, that is, if reflection, refraction, diffraction, etc., is made use of.

Continuing in this fashion we arrive at the following array of parameters represented by their matrices.

Table I.



The number of elements contained in the matrices A, B, etc., are n_A, n_B, etc., respectively. If we circle one element in each matrix and connect these circles we shall have arrived at a schematic representation of a special type telescope. There are

$$n = n_A n_B n_C \ldots n_X \tag{2}$$

types of imaginary telescopes.

It is a fundamental principle of the morphological analysis that all of the potential telescopes are capable of realization except for those which are cancelled out by internal contradictions in our scheme and those which are not possible because some fundamental principle of science, such as the second law of thermodynamics, stands in the way. Some of the chains of circles may not uniquely define one telescope but may embrace several solutions. We must then expand our array of matrices (or as we call it, the morphological box) by adding more parameters. By doing this we finally arrive at a box in which each chain of circles represents either one and only one telescope or must be ruled out. If we think of the morphological box as having X dimensions and n cells or compartments our analysis of the totality of telescopes is complete if each compartment contains either one possible realizable element or none.

3. The third step of the analysis consists of a performance analysis of all of the possible telescopes arrived at in the preceding reasoning. Here the morphological method strives towards an evaluation of all

telescopes on the basis of very general theorems, rather than individual evaluation. For jet engines activated by chemical energy, such a general theorem has been found in the form of a *universal thrust formula* which permits calculation of the performance characteristics of all engines. For our example of telescopes an analogous theorem remains a problem for the future.

4. The final step of the morphological analysis is related to the request for *direct action*. This means that the results of the preceding analysis are taken seriously and steps are taken to construct and operate all of the solutions contained in the morphological box. Here, obviously, limitations of time, means and manpower demand some choice. This choice, however, now can be made wisely, taking into account the specific problems whose solutions appear most desirable.

III. The General Problem of Astronomy.

This problem is of course greater than that of establishing a perspective on all telescopes. Indeed it is so great that it would be difficult to define. A morphological analysis of astronomy as a whole is an overwhelmingly immense undertaking and therefore beyond the scope of this lecture. We shall nevertheless try to discuss some of the basic elements of such an analysis. From this discussion it will become clear that in order to carry out a really satisfactory morphology we must first clear up a number of problems about which our knowledge is presently at best of a speculative nature. We shall treat some of these problems in more detail and finally relate what has been done specifically by the author and some of his colleagues in Pasadena to lay the ground-work for their solution.

Some of the basic elements entering the problem of astronomy are as follows:—

(*a*) Observation of celestial phenomena.
(*b*) Experimentation with celestial phenomena.
(*c*) Theoretical integration.
(*d*) Use of the knowledge gained in construction.
(*e*) Dissemination of the knowledge and its bearing on all activities of Man.

(*a*) While observations have been going on for a long time, very much more remains to be done and we shall see how the morphological analysis opens up new possibilities.

(*b*) Experimentation with celestial phenomena was probably not even dreamed of until very recently. During the past years radar contact with the Moon has been achieved and many other ways to experiment directly with the Sun and the other members of the planetary system are within our reach.

(*c*) The theoretical integration of the data collected by observation and experimentation naturally lends itself best to the total application of the morphological method since no obstacle such as lack of means, apparatus and so on can seriously hinder this activity. It is therefore somewhat surprising that theoreticians have not availed themselves effectively of the method.

(*d*) The knowledge gained from astronomical observations has been used, well or badly, at almost all times in the conduct of our earthly

affairs. However, the application of this knowledge to active interference in material celestial affairs and the reconstruction of sections of the universe other than the surface of the Earth has not yet been realized. It remains a distinct possibility for the future, which we shall touch upon later.

(*e*) Finally, the dissemination of the knowledge gained to all human activities has also taken place but, in our estimate, has been lagging far behind the results achieved in the accumulation of knowledge as such.

We now proceed to give a few highlights on the five basic elements mentioned, as we have visualized them in our efforts on problems in astronomy.

(*a*) *Observation of Celestial Phenomena.*

We choose for discussion four fundamental aspects of this problem which we have constantly kept in mind. The limited scope of this lecture prevents us from discussing aspects of equal importance, upon which others have been engaged.

The four basic aspects which we have in mind are:

(α) The instruments to be used for observation.
(β) The location of these instruments.
(γ) The alternative of manned and unmanned instruments.
(δ) The objects of observation. The physical contents of the universe and the laws governing them.

(α) *The Instruments.*

Here the following possibilities immediately suggest themselves. Since all sorts of messengers are travelling through the celestial spaces, various instruments may be visualized to intercept these messengers and to gain knowledge from them. This means that one must think of devices sensitive to all sorts of electromagnetic radiations, from the longest wavelengths to the shortest, and apparatus responding to all kinds of corpuscular radiations consisting of molecules, atoms, ions, protons, electrons and other elementary particles. Much has been done in recent years to develop instruments along the lines which we have schematically represented in Table I. It seems to us, however, that one important possibility embodied in the third inequality of equation (1) has not received the attention which it deserves. One way to realize greater integrated flow of energy at the focal surface of an instrument than through the entrance aperture is the construction of a *photo-electronic telescope*. This type of device has been advocated by V. K. Zworykin and the author since before the war. Some component parts were built at the Radio Corporation of America Laboratories under Zworykin's direction in 1941, but developments were stopped because of the emergency.

The photo-electronic telescope essentially works on the principle shown in Figure 1, which is self-explanatory. Instead of directly and finally recording the incoming light on the image surface, a layer of some material such as cadmium is interposed for emission of photo-electrons. Rays of light are thus replaced by beams of electrons which are more flexible inasmuch as they can be deflected and enhanced in many more ways then light.

The photo-electronic telescope introduces the following new features:

(1) Electrons can be accelerated from the image surface to the recording surface and terrestrial power can thus be usefully fed into the telescope to increase the original intensity of the light signals. Only the background fluctuations limit this multiplication of energy. The photo-electronic telescope is thus a device for which $r < 1$.

(2) Uniform background of light manifests itself as a direct electric current and may be eliminated by electric compensation, a possibility which does not exist in an optical telescope. The sky background or even the uniform disk of the Sun may thus be scanned away. Again fluctuations determine the limit of amplification.

(3) Although the original image may move, dance or scintillate as a result of motions in the telescope or because of the unsteadiness of the atmosphere, the refocused image on the recording surface can essentially be steadied. This may be achieved by means of Zworykin's image stabilizer. This is a device consisting of a deflecting or electron-emissive pyramid with electron multipliers attached to its four faces. As the image

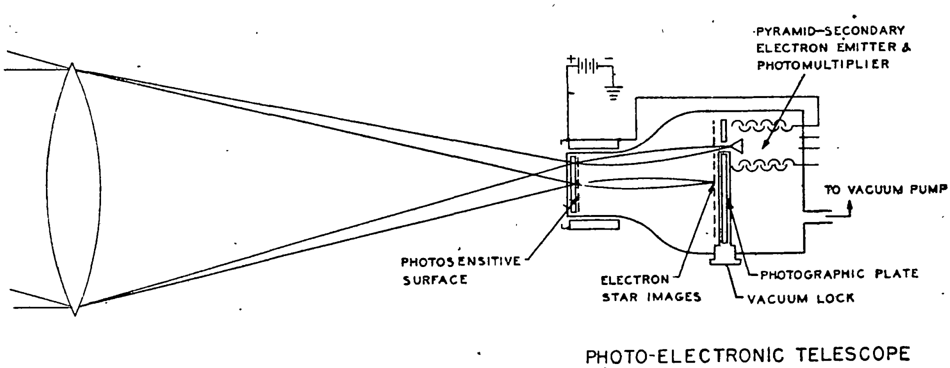


Figure 1.

moves away from the apex of the pyramid the multipliers activate currents in four magnetic coils surrounding the image tube. The correcting magnetic field drives the final image back to the apex of the pyramid. Zworykin has actually built such an image stabilizer and with it the first step is made toward partial "elimination" of atmospheric disturbances which until now seemed to be incapable of compensation.

Even an extended field may be steadied in principle if more than one stabilizer is introduced; that is, if one uses differential stabilization.

(4) Automatic guiding of a telescope may be accomplished through the operation of devices similar to that described in the preceding section.

(5) Images from photo-electronic telescopes can be televised and the search for novæ, supernovæ, variable stars, comets, meteors, etc., can be put on a "mass production" scale, even if the telescopes are of relatively limited definition and light power.

Further developments upon which our group in Pasadena has been working are the Schmidt telescopes and auxiliary devices used with them. We were lucky enough during the years just before the war to demonstrate the power of the new telescopes in the search for supernovæ, white dwarfs, and other special stars, as well as in the investigation of extended objects such as the clusters of nebulæ and the search for special-type nebulæ.

Among the auxiliary instruments, the successes achieved with mosaic

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transmission gratings are perhaps the most noteworthy. Through the persistent co-operation and the ingenious efforts of Professor R. W. Wood three full-size mosaic gratings are now available for the 18-inch Schmidt telescope on Palomar Mountain. The most perfect has 800 lines to the inch, while the two others have 1440 lines/inch. They are all of the sawtooth type with one very strong first order. The simultaneous photography of the direct images and the first-order spectra of all stars in a large field of 10° to the 12th apparent magnitude has proved of great advantage. Already during the first trials Nova Cygni of 1942 was discovered.

The mosaic gratings promise to be of great importance for wide-angle telescopes of large aperture. For instance, it is difficult to construct an objective prism covering the full aperture of the 48-inch $f/2{\cdot}5$ Schmidt telescope which has now been completed for the Palomar Mountain Observatory. Experimentation with mosaic gratings for this telescope is therefore contemplated. In order to facilitate the task of mounting the mosaic of thin replica gratings consisting of films of Egyptian lacquer or the like, individual gratings of about 20 inches in size will be necessary since too many of the largest replicas now available (5 in. × 7 in. surface) would be needed.

(β) *The Location of the Astronomical Instruments.*

The fact that astronomical instruments until recently were bound to the surface of the Earth obviously is a great disadvantage. The two principal difficulties have their origin in the interference of the atmosphere. Many, indeed most, of the celestial messengers which impinge from interplanetary space on the Earth's atmosphere are completely absorbed before penetrating very far. Ultraviolet rays, soft and medium X-rays, atomic rays and rays of elementary particles of little penetration do not get through the atmosphere. On the other hand, those rays, like visible light, which traverse the atmosphere are weakened and distorted.

It is therefore important to develop means to observe events in the universe from vantage points above the Earth's atmosphere. This is now made possible through the use of rockets as carriers of scientific instrumentation. Cameras, cosmic ray apparatus, etc., have already been carried aloft to heights of about 200 km. by V2 rockets and valuable preliminary results have been obtained. However, to eliminate the greatest part of the atmospheric absorption, it is estimated that heights of perhaps 1000 km. must be reached. This is possible with long-range rockets driven by more powerful propellants than have hitherto been used. Also, a study is being made of ejecting small secondary rockets from larger carrier rockets. In this way conventional propellants will suffice to achieve the altitudes required for getting an unimpaired view of the universe. The morphology of astronomy thus includes the morphology of rockets, which has been discussed in other places.

(γ) *The Alternatives of Manned and Unmanned Instruments.*

When unmanned rockets are carrying scientific instruments, either the records taken must be telemetered back to the observers on Earth or the records must be recovered. Both methods involve great work and skill, and many of the efforts are wasted. All rocket men are therefore dreaming

of vehicles which will carry observers to great heights. Even high-flying conventional aircraft offer possibilities not yet exploited. Rocket planes will serve even better, and manned rocket vehicles flying to great heights are clearly within the realm of present-day engineering possibilities.

(δ) *The Objects of Observation.*

The discussion of these objects from the viewpoint of morphology will occupy the greatest part of this lecture. This is natural, since in this field we possess the greatest back-log of experience and it is relatively easy to project our plans for the immediate future. Again, I hope to be excused for emphasis on the efforts which my colleagues and I have made.

With regard to the objects of observation, two problems immediately come to mind. These refer to

(δ_1) The contents of the universe and its nature, both qualitatively and quantitatively.

(δ_2) The physical laws governing the interactions of the celestial bodies and the general fields.

(δ_1) *The Contents of the Universe.*

In the past, various objects in the universe were selected for observation, somewhat at random. This procedure has many shortcomings, which may be summed up by the general verdict of "selectivity". A few words may not be amiss concerning the effects of this selectivity. We may say that because of selectivity we are still lacking a complete view and balanced perspective on astronomical events.

Selectivity has been introduced in the following ways. First, it was natural to investigate the brightest visible objects. Faint objects, and those entirely invisible because of intrinsic faintness or because of interference of the atmosphere, have been neglected. Second, we are located in a very special spot of our own galaxy and our immediate and easily accessible surroundings may not contain a representative sample of the universe. Also, absorbing interstellar clouds are troublesome. Third, the galaxy itself in which we are located is a very special one. Its contents may not embrace all of the objects to be found elsewhere. A fourth severe difficulty has its origin in the length of the periods of observation necessary, especially when faint objects are involved. Because of the fact that we are not able to make continuous recordings over long periods of time, we most certainly picture the material members of the universe as much steadier objects than they actually are. Some inkling that this is so was obtained during our search for both supernovæ and dwarf stars. In the fifth place, human deficiencies and prejudices certainly play an important role; and sixth, the interpretation of data recorded is subject to variations of viewpoint.

It is thus clearly a major task of modern astronomy to achieve greater objectivity. Some steps which we can make will be discussed. For instance, the attempt may be made to discover and order objects according to some intrinsic characteristics such as mass, size, and luminosity. This task embraces objects from the smallest to the largest; that is, from elementary particles to clusters of nebulæ and to the accessible universe as a whole. If many objects of the same class are found, the population of each class is to be determined in quantitative terms. This problem in the

past has been approached in partial terms. Classes of stars and of nebulæ, etc., were established and so-called luminosity functions were determined. In every case it is improbable that a final solution has been found.

Selectivity can often be unmasked by two criteria. Firstly, one must be suspicious of maxima in the distribution curves of any class of objects. Such maxima may of course be real, and may be determined by the intrinsic physical nature of the objects in question; or they may be of a statistical nature, such as the maximum in the Gaussian error curve. In cases, however, where one cannot prove clearly that one of these two reasons is operative, one should be cautious and extend the analysis. In the second place, it is often wise not to take the presented astronomical data at face value, but to do a little theoretical thinking on the basis of elementary principles.

We have applied the two principles just mentioned to the investigation of the large-scale distribution of matter in the universe. As a result of this procedure, we feel that we have achieved new insight into the distribution functions of nebulæ and of stars of various kinds. The results described in the following discussion will perhaps stimulate further researches in the line of eliminating selectivities. We think it good advice to consider most progress in human activities as resulting from the remorseless elimination of obstacles to both thought and action. Construction of new things then always seems to follow automatically.

Our main aim, then, is to arrive at a true picture of the physical contents of the universe. Starting from very large objects, we first discuss some investigations on the clusters of nebulæ. Multiple nebulæ and large clusters were found immediately, as soon as telescopes of large depth-penetration or of large field had been constructed. It is noteworthy that clusters of nebulæ, in contradistinction to most other known celestial objects, are not discernible to the unaided eye. But even telescopic operations over long periods of time did not reveal the true nature and the correct distribution of clusters of nebulæ. A good preliminary view, however, has been achieved in the past decade through the use of Schmidt telescopes and particularly the 18-inch instrument on Palomar Mountain. I say preliminary, because even this telescope is not capable of photographing a complete cluster of nebulæ on one plate in its full geometrical extent and at the same time to reach all the member nebulæ. The 48-inch Schmidt telescope now completed will come much nearer to accomplishing this task.

With the 18-inch Schmidt the following important insight was gained.

Clusters of Nebulæ.

Large clusters of nebulæ are of the order of ten million light years in diameter, and in the five brightest magnitudes they contain thousands of nebulæ. These clusters may be regular in all statistical aspects, or they may be irregular. Examples of the regular type are the clusters in Coma, Perseus, Hydra, and Cancer. Examples of the irregular type are the Ursa Major Cloud and the clusters in Virgo, Pisces, Fornax, Centaurus, and so on.

The regular clusters offer a fascinating field of investigation. Their observation results in good tests of the laws of statistical mechanics applied to assemblies of objects interacting according to the law of gravitation.

As a secondary result, the average masses of nebulæ may be determined and our knowledge of the action of Newton's law can at once be extended from distances characteristic of the dimensions of the planetary system, or the separation of double stars, to distances of the order of millions of light years.

The following results have been achieved. Some large clusters such as the one in Coma exhibit spherical symmetry, with the fluctuations in spatial distribution arranging themselves within the limits theoretically expected for stationary gravitational assemblies.

The radial distributions of nebulæ in these clusters very closely approximate those originally predicted by Emden for bounded isothermal gravitational gas spheres. This is an indirect proof that Newton's law of gravitational interaction is operative at distances of the order of one million light years.

These conclusions are reinforced by the outcome of recent tests on the expected relation between the density of matter in these clusters and the random peculiar motions of its members. Quantitatively this relation is as follows:

$$\alpha = (\overline{w^2}/12\pi\Gamma\rho_0)^{\frac{1}{2}} \quad (3)$$

$\overline{w^2}$ is the mean square of the velocities of the members of a cluster whose central mass density is ρ_0. Γ is the universal gravitational constant. The so-called "structure index" α has the dimension of a length. At the distance α from the centre of the cluster, the density is reduced by a fixed fraction from ρ_0. For instance, at the distance $r = 40\alpha$ the density is $\rho(r) = 0{\cdot}001\rho_0$, a figure which it is useful to remember since in practice the range from ρ_0 to $\rho_0/1000$ is the one actually accessible to observational counts both in regular globular clusters of nebulæ as well as in globular nebulæ. The formula was originally derived by Emden for stellar models. It is, however, not applicable to actual stars, in which, as Eddington has shown, the presence of the radiation density is a decisive factor modifying the density distribution. The formula, on the other hand, is valid in good approximation both for stationary globular nebulæ and for clusters of nebulæ, a fact which was not anticipated by Emden. Nevertheless, as a second approximation, the fact must be taken into account that the member nebulæ of a cluster and the stars in a nebula are not all of the same mass, which results in segregation effects well known in Boltzmann distributions.

For nebulæ we have in order of magnitude

$$\alpha_N \cong 5 \times 10^{19} \text{ cm.} \quad (4)$$

while for large clusters of nebulæ

$$\alpha_{cl} = 2 \times 10^{22} \text{ cm.} \quad (5)$$

The structural index is thus of the order of the radius of the nucleus of these objects.

A further check of the stationary character of regular clusters of nebulæ can be given through an analysis of the segregation of various types of nebulæ. Objects of large mass should be expected to be concentrated towards the centre, while the radial distribution curve should be flatter for the less massive objects. Preliminary investigations have borne out this expectation, but the 48-inch Schmidt telescope will be needed for completion of the analysis.

The study of irregular clusters also bears out the concept of segregation of different objects. By a method of artificial regularization of irregular clouds of nebulæ, it was shown, for instance in the Virgo cluster, that spatial concentrations are more pronounced for bright nebulæ than faint ones, and also that the tendency to clustering is greater for elliptical nebulæ than for spirals and irregular nebulæ. This indicates that bright elliptical nebulæ are presumably the most massive among stellar systems, with masses of the order of 10^{11} times the mass of the Sun.

The dispersion in velocities in various clusters lies in the range from 100 km./sec. to 1500 km./sec., while the field nebulæ are characterized by perhaps half these dispersions in velocity.

While Emden isothermal gravitational gas spheres should be infinite in extent, actual clusters of nebulæ and the nebulæ themselves are finite in size. The problem of what bounds these objects is a most interesting one. We have arrived at the preliminary conclusion that the boundaries are delineated by a transition from an assembly obeying Boltzmann's statistics to one in which Smoluchowski statistics prevails. That is, at the boundary of one of these assemblies, the population becomes so tenuous that the gravitational interactions among its members become too infrequent and too inefficient to transfer momentum and energy sufficiently fast to establish a Boltzmann statistical distribution, and more or less free trajectories in a central field of force must be analyzed in order to determine the spatial distribution of matter.

Through investigation with Schmidt telescopes, estimates of the sizes of clusters of nebulæ have grown considerably. In fact these clusters seem to be almost space fillers, and relatively little room is left for the so-called detached field nebulæ. Much insight should be gained through the photometry of all nearby nebulæ. A complete survey of all nebulæ to apparent magnitude 15·5 is under way with the 18-inch Schmidt.

NEBULÆ.

A new and very detailed investigation of the morphological types of nebulæ is being undertaken by Hubble. On the luminosity function much work remains to be done. Some years ago this function was considered well established and was thought to be of the type of a Gaussian error function expressing the number of nebulæ $n(M)dM$ in the interval dM of absolute magnitude as

$$n(M) = (2\pi\sigma^2)^{-\frac{1}{2}} \exp\left[-(M-M_0)^2/2\sigma^2\right] = 0{\cdot}47 \exp\left[-(M+14{\cdot}2)^2/1{\cdot}45\right] \quad (6)$$

the most probable magnitude being $M_0 = -14{\cdot}2$ and the dispersion $\sigma = 0{\cdot}85$.

However, the observations with the 18-inch Schmidt have already invalidated this formula. A series of significant preliminary results has been achieved which points the way and which is in better accord with simple theory. According to this theory, a maximum in the luminosity function is very unlikely. From considerations of statistical mechanics, intrinsically faint nebulæ should exist in great numbers since no dynamical obstacle prevents their formation, which, in any event, must be the result of close encounters of large nebulæ. These have enough kinetic energy to disrupt each other severely during such encounters.

There is a great question of course what constitutes either a cluster of nebulæ or a nebula, and what their respective boundaries are. The statis-

tical mechanics of gravitational assembly has not been worked out and a definitive answer is not possible. For instance, there remains the fundamental problem in how far component condensations in large systems should be considered as separate entities in the luminosity function. For instance, one might as a first step look upon systems whose density falls from a central value ρ_0 to a fraction say $\rho_0/1000$ as a separate system. This type of analysis will require much future work which has only been started.

Some of the results so far achieved are as follows. First, it could be shown that the luminosity function (6) has its origin in the selective observation of the central parts of clusters of nebulæ where the massive objects are concentrated. For the outskirts of the clusters, similar luminosity functions can be established, but with their maxima shifted

Table II.

Range in Absolute Magnitude	*Nearby stellar systems for most of which presumably* $\mu \leq 23$
− 8·25 to − 9·10	Leo system, NGC 2419.
− 9·10 to − 9·95	None.
− 9·95 to − 10·80	NGC 147, NGC 185, Sculptor and Sextans systems, Wolf-Lundmark nebula.
− 10·80 to − 11·65	NGC 205, NGC 6822, IC 1613.
− 11·65 to − 12.50	Fornax system.
− 12·50 to − 13·35	Messier 32.
− 13·35 to − 14·20	None.
− 14·20 to − 15.05	Messier 33, Small Magellanic Cloud.
− 15·05 to − 15·90	None.
− 15·90 to − 16·75	Large Magellanic Cloud.
− 16·75 to − 17·60	Galaxy.
− 17·60 to − 18·45	Messier 31.

toward smaller absolute magnitudes. The summation of all of these curves would result in a more representative distribution of luminosities, which tends more and more toward a function monotonically decreasing with increasing brightness of the nebulæ.

Secondly, to check the expectation of a luminosity function which increases monotonically with decreasing brightness of the nebulæ, a search was undertaken for intrinsically faint stellar systems in our neighbourhood. For the local group of nebulæ, which is arbitrarily defined as comprising all objects within a distance given by the distance modulus $\mu = 23$, the picture presents itself to-day as follows.

No more bright systems are likely to be found than were known a decade ago, unless, through infra-red analysis, nebulæ can be discovered which are now heavily obscured by the interstellar matter of the Milky Way. Restricting ourselves to the unobscured regions, more and more intrinsically faint nebulæ have been found during the past decade. The Sculptor and Fornax systems were discovered at Harvard. They are interesting also for another reason, inasmuch as their stellar content was proved to be different from the spirals and more similar to that of star clusters.

c

A search for faint nebulæ was also made with the 18-inch Schmidt telescope, using some interesting new criteria to distinguish nearby intrinsically faint systems from far-away brighter ones. Two very faint nebulæ were found in Sextans and in Leo. Unfortunately these criteria are of little help in the case of concentrated systems, such as small globular and elliptical nebulæ. NGC 147 and NGC 185, which are of this type, have recently been resolved by Baade and have been proved to be members of the local group of nebulæ. Including these the nearby stellar systems fall into the ranges of absolute magnitudes shown in Table II.

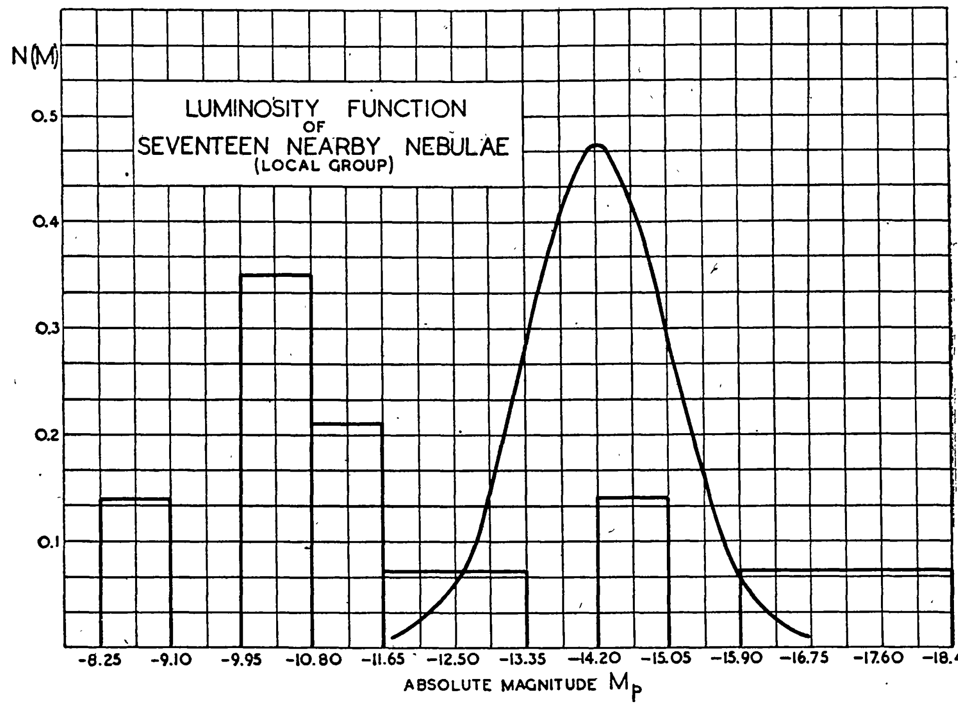

Figure 2.

As in a table published in 1941, we have included the Wolf-Lundmark nebula and the systems in Sextans and Leo. Actually, for our purposes it is not important whether or not these systems are strictly within the local group or whether their distance modulus is somewhat greater than $\mu = 23$. The essential point is that no absolutely bright systems are going to be added to our table, even if the distance modulus is somewhat larger than $\mu = 23$. On the other hand, the range of the faint nebulæ almost certainly will receive many new recruits as soon as a sufficient number of photographs taken with the 48-inch Schmidt become available.

The luminosity function of the nearby nebulæ presents itself to-day as shown in Figure 2.

The distribution thus obtained, in addition to the segregation effects observed in the clusters, indicates that the original luminosity function must be abandoned. Similar expanded views will no doubt result in connection with other characteristics of nebulæ about which relatively dogmatic ideas are circulating to-day. These other characteristics concern

the relation of mass to luminosity, the internal motions, the morphological types of nebulae, and perhaps most interesting of all, the stellar or generally speaking the material content. As usual, progress has been in steps. First, all nebulæ seemed to be alike, while later the picture was expanded to two types of stellar populations I and II. However, it appears obvious that such over-simplifications can only maintain themselves as long as the observational data are of poor quality. In spite of this there are many indications that nebulæ are very diversified. Among the properties which might be significant is the relative content of dispersed matter to condensed matter (stars). There seem to be nebulæ in which the contribution made by stars to the visual radiation is negligible, while fluorescent light from vast gaseous nebulæ is preponderant. The stellar population of these nebulæ is certainly different from the types I and II. Very striking differences attending the frequency of appearance of novæ and of supernovæ in apparently similar stellar systems also indicate that not all is well with an over-simplified schema. In view of the fact that diagrams relating spectral types of stars with their magnitudes, frequencies of pulsation, etc., have in the past been taken so seriously as a base for extended theoretical speculation on the generation of energy in stars and their evolution, I feel that in the near future a very much greater effort must be made to arrive at a representative record of the possible types of stars and other large condensations of matter.

THE STARS.

Although many may feel now, or may have felt until recently, that the glorious eras of great astronomical discoveries were things of the past, any modern experienced observer with a background of theory is probably convinced of the exact contrary. At Palomar in the period 1936 until 1942, we have concentrated our efforts mainly on expanding our knowledge of stellar types. Gratifying success was had in the discovery of supernovæ, variable stars, white dwarfs, emission-line stars and the like. Unfortunately, the war severely interrupted a very promising development and we are still trying to re-establish full-scale efforts. At the present time, a broad foundation is being laid for the discovery of common novæ, both in the Milky Way system and in some nearby galaxies. Although common novæ have been known for centuries, no really representative collection of these exploding stars is available to-day. For instance, the data on light curves, spectra and especially on the frequency of occurrence are perhaps poorer than in the case of supernovæ.

SUPERNOVÆ.

Eighteen of these giant explosions were discovered with the 18-inch Schmidt telescope at Palomar. In particular, 837 nebulæ brighter than the thirteenth apparent magnitude, which are listed in the Shapley-Ames catalogue, were systematically searched. Five supernovæ were found, and from the periods of observation it was deduced that the average frequency of appearance of supernovæ in these nebulæ is

$$n_s = \text{one supernova per nebula per 359 years} \qquad (7)$$

A similar analysis applied to all of the fifty supernovæ now on record in all sorts of nebulæ leads to a result of similar order of magnitude. Some

peculiarities of the frequency distribution are still puzzling. Although spirals, elliptical and irregular nebulæ seem to be characterized by similar frequencies n_s on the average, some individual nebulæ seem to be favoured beyond anything which might be ascribed to statistical fluctuations. For instance, within forty years three supernovæ appeared in NGC 3184 and two each in NGC 4321 and NGC 6946 respectively. The goal therefore is to achieve the discovery of, say, one hundred supernovæ in a well-controlled search with the 48-inch Schmidt telescope.

The classification of supernovæ according to types and luminosity certainly needs more work. At present, the distribution curves of the different types appear to possess maxima dependent upon the luminosity. The danger exists, however, that these are due to the selectivity of our efforts. Also, it is unlikely that our short search could have produced representatives of all types actually occurring. There are definitely two types.

Supernovæ of Type I.

The object found in IC 4182 in August 1937 is the prototype of this class. With the discovery of this supernova the observation of giant stellar explosions could, for the first time, be put on a really satisfactory basis. Because of its great intrinsic and apparent brightness and the lucky circumstance of early discovery, the light curve and the spectral development could be observed in great detail for several years. With the distance quite accurately known a very reliable estimate could be made of an absolute lower limit of the energy liberated. From these data the first proof was derived, several years before the advent of nuclear fission and of the atom bomb, of *the existence of nuclear chain reactions.*

Many more supernovæ of type I were discovered in the years following 1937, and a surprisingly similar sequence of changes in brightness and character of the spectra could be established. The spectra, however, are of such an odd character that a rational explanation still remains to be given. The mean absolute photographic magnitude of supernovæ of the type I is of the order $M = -14$ and therefore equals that of bright nebulæ.

Supernovæ of Type II.

The objects in NGC 5907 and NGC 4725 discovered at Palomar furnished the first reliable prototypes of this class. The mean absolute brightness of supernovæ of type II is smaller than that of type I and corresponds to an absolute photographic magnitude $M = -11$. Type II seems to be more frequent than type I. The spectra resemble more those of common novæ with a very high velocity of the expanding gas shells (order of 5000 km./sec.). The light curves of type II are also distinctly different from those of type I, as is schematically indicated in Figure 3.

Supernovæ of Other Types.

It would be presumptuous to think that the short survey conducted at Palomar could have resulted in the discovery of all possible types of supernovæ. Actually, objects like the supernovæ in NGC 4559 discovered at Harvard in 1941 do not fit exactly into the classes I and II. Also the ancient supernova observed by the Chinese in 1054 A.D., which gave rise to the Crab Nebula, seems to be of another type. The low velocity of

expansion of the Crab Nebula is difficult to associate with the characteristics of type I. Indeed, if supernovæ of the type I expelled the gases at such low velocities, their spectra almost certainly should be easily interpretable. As a working hypothesis I have adopted the idea that the velocities of expansion of supernovæ of type I surpass the 10,000 km./sec. mark. This hypothesis is strengthened by the simple analysis resulting in the luminosity-expansion relation which is to be discussed later on. In this connection, the striking difference between the remnant of Tycho's star of 1572 (no remnant star or nebulosity has yet been found) and the Crab Nebula with its hot central star is significant. It is difficult to admit that, in spite of similar absolute luminosities and light curves, these two supernovæ could belong to the same class. Until it is proved otherwise, we thus propose to consider the supernova of 1054 A.D. in Taurus a representative of a type III.

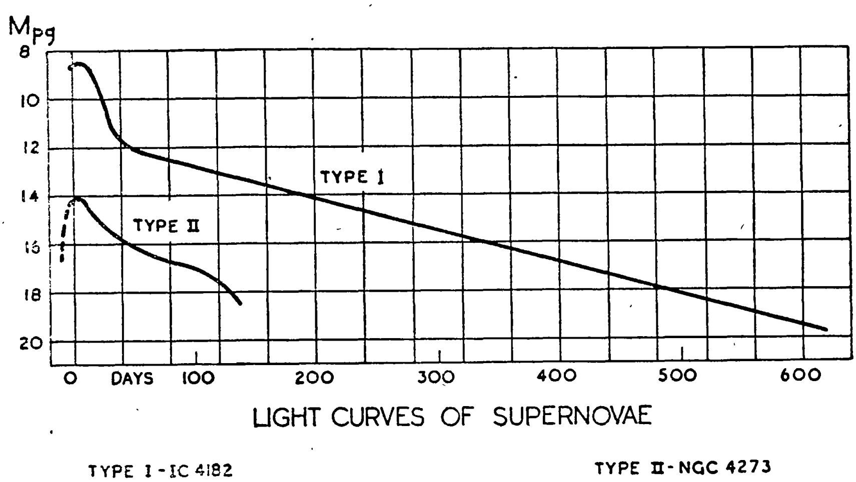

Figure 3.

Because of the tremendous effort involved in the discovery of supernovæ with the 18-inch Schmidt telescope, it is intended to use if possible the 48-inch Schmidt telescope to further our knowledge of supernovæ.

COMMON NOVÆ.

In order to establish the various classes of common novæ and to cover the transition regions, upwards to supernovæ and downwards to regular and irregular variables of all types, a systematic search for variable emission-line objects is now under way at Palomar. It appears possible, at least in selected regions of the Milky Way, to cover all objects to about the fourteenth apparent magnitude, since one faint nova of this brightness has already been found.

VERY BLUE FAINT STARS.

It is perhaps now generally admitted that the original Hertzsprung-Russell diagram is the result of selective observation. To establish a more representative diagram, we have therefore embarked on searches for stars in various ranges of physical characteristics.

As a first class of stars, we have chosen those of negative colour index and apparent magnitude in the range $10 < m_{pg} < 15 \cdot 5$. This search has already proved fruitful, inasmuch as 46 stars were found which are either definitely white dwarfs or must be subdwarfs or normal main-sequence stars at distances so great that they constitute the first proof of the existence of an intergalactic stellar population. This latter conclusion also finds some partial support in the discovery of supernovæ far on the outskirts of extragalactic nebulæ.

(δ_2) *The Physical Laws.*

It seems to us that often very detailed theories have been made in astrophysics, and much useless effort has been spent, on the basis of insufficient observational records. These efforts include theories on cosmology, the apparently expanding universe, the evolution of stars and nebulæ, and so on.

We reiterate that what is perhaps most needed is a more determined effort towards vast expansion of the range of interests in observation, and towards establishment of simple theoretical principles and relations. In this line we offer a few conclusions which we have reached, as well as some preliminary suggestions treating briefly a variety of subjects.

The observational analysis of the *law of force* acting among various bodies may make use of

Geometry, that is, counts of these bodies in cells of a sub-divided space;

Kinematics, that is, the combination of distribution in space and in velocities;

Dynamics, that is, the observation of accelerations.

While the last method provides for a check of the gravitational law for nearby bodies, only the first two are available for very distant objects. As already discussed, it has been possible through use of the Emden-Boltzmann statistics and the virial theorem to check the validity of Newton's law for the interaction of nebulæ separated by millions of light years, and also to derive values for the masses of nebulæ and the average density of matter in space. In extension of this analysis some most interesting generalizations of the principles of statistical mechanics remain as problems for the future. These are: the distribution laws in assemblies characterized by diverging or conditionally converging integrals; the distribution in assemblies which do not obey the Boltzmann statistics but which are so tenuous that the methods first introduced by Smoluchowski and Knudsen for the investigation of rarefied gases must be applied; and the distribution in stationary assemblies in which one or more dynamic parameter such as the flux of radiation or the "hydrodynamic" flow is held constant. In all of these cases no equation of state in the ordinary sense exists and the commonly used thermodynamic functions such as the entropy, free energy and so on, lose their meaning and must be replaced by new ones.

The General Theory of Relativity and the Theory of the Expanding Universe.

It is a peculiar circumstance that so little effort has been made to check a theory so widely accepted as the general theory of relativity. In addi-

tion to the original tests proposed by Einstein, literally nothing has been done. We have, therefore, embarked on the following ventures.

As a start we have attempted to test for the law of force at great distances, and confirmation of Newton's law was obtained for bodies separated by millions of light years.

A check for the deflection of light was proposed through the idea of compact nebulæ acting as gravitational lenses. In this same line the idea of *nuclear matter* of a density of the order 10^{14} grams/cc. was proposed. Such matter should exist in neutron stars, perhaps ancient remnants of supernovæ which will act as gravitational lenses *par excellence*. Such stars, although of negligible intrinsic luminosity, should through lens action appear as stars showing a composite spectrum of all of the surrounding stars. Neutron stars also make possible, in principle, a reversal of time. Judging from the frequency of supernovæ, neutron stars should exist nearby and should be observable with the 48-inch Schmidt. A determined search for neutron stars, and for nebulæ acting as gravitational lenses, is intended with this instrument.

The theory of the expanding universe has presented many difficulties. We have proceeded along several lines to deduce new evidence pro or contra. The existence of large stationary clusters of nebulæ seems to testify against a real expansion of the universe. So do Hubble's counts of nebulæ at great distances. In addition, tests have been undertaken of the behaviour of fundamental physical constants as a function of time. Some preliminary observations have been made on the properties of light such as the velocity c, Planck's constant h, the charge e of the electrons, and so on, when quanta and particles have travelled a long time. Much work remains to be done along these lines.

A most interesting conclusion concerning the existence of nuclear chain reactions could be drawn from the occurrence of bright supernovæ. The argument runs as follows. A bright supernova emits in the form of visible light the energy

$$\epsilon_{\text{vis}} \cong 5 \times 10^{48} \text{ ergs.} \tag{8}$$

in the period of the first 200 days. From various considerations, including the properties of the remnant star of the supernova of 1054, we must assume that the supernova explosions are processes in single stars. A large heavy star of mass 100 times that of the Sun amounts to 2×10^{35} grams, containing $2 \times 10^{35}/1{\cdot}66 \times 10^{-24} \sim 10^{59}$ protons. Even for such a star the energy liberated per proton is of the order

$$\Delta\epsilon >> 5 \times 10^{-11} \text{ ergs} \cong 30 \text{ eV} \tag{9}$$

since in addition to the visual energy a supernova certainly generates large amounts of other types of energy. The value of $\Delta\epsilon$ is much larger than the greatest energy liberated per proton in the most energetic chemical reaction. The conclusion therefore is justified that in a supernova outburst we deal with a nuclear chain reaction coupled perhaps with a gravitational collapse to nuclear matter. In any case, a nuclear chain reaction is the initiating phenomenon, and we deal with a fusion process on a large scale. The extent to which nuclear fission may be involved in addition to fusion remains to be investigated.

Fortunately some supernovæ, notably the object in NGC 4636, were caught on the rise, the speed of which is also in accord with the assumption

of nuclear chain reactions. We here therefore have one more example how apparently academic astronomical observations led the way to the discovery of phenomena of the greatest import.

In this connection, attention is called to the possibility that cosmic rays are generated in supernovæ. At least two processes exist which, through generation and subsequent collapse of extended electric fields, convey large kinetic energies to charged elementary particles.

The first process is as follows. If a large mass consisting of N positive and N equal negative charges e is forcibly split at random in two parts, the most probable net charge on each part is

$$E = 2e\,[Np_1\,(1 - p_1)]^{\frac{1}{2}} \qquad (10)$$

If, therefore, the stellar remnant (of radius R) of a supernova contains the fraction p_1N of the protons of the original star, and the expelled gas shells carry with them $(1 - p_1)N$ protons, the electric potential built up between the two becomes

$$\Phi = 2e\,[Np_1\,(1 - p_1)]^{\frac{1}{2}}/R \qquad (11)$$

Inserting for R the Sun's radius and for the charge of a proton $e = 4{\cdot}8 \times 10^{-10}$ e.s.u., we get

$$\Phi \geq 10^{10}\ \text{volts} \qquad (12)$$

a value which satisfactorily accounts for some of the major characteristics of the bulk of the cosmic rays.

The second process is almost certainly also operative. It involves the systematic separation of charges of both signs under the action of the enormous radiation driving the gaseous shells outwards. The electric potential thus built up between the stellar remnant of a supernova and the expanding shells is of the order

$$\Phi = (8\pi\gamma Mc^2/L^3)^{\frac{1}{2}} \qquad (13)$$

where M is the mass of the original star, c the velocity of light, L the distance which the gaseous shell has travelled to the point where the radiation pressure ceases to exert a segregating effect on the ions, and γ the fraction of the energy Mc^2 which has been converted into the energy of the built-up electric fields. Φ in this case may attain values of the order of

$$\Phi \simeq 10^{19}\ \text{volts.} \qquad (14)$$

It thus appears most probable that at least a part of the cosmic rays is generated during the restoration of the electrical equilibrium among the various parts of a star separated during a supernova explosion. It will be a fascinating task to check these conclusions through direct observations on nearby supernovæ or through some ingenious indirect observations.

In the line of establishing simple astrophysical theory, we refer to the relations which should exist between certain integral parameters of novæ and of supernovæ. If the energy in one of these stellar cataclysms is assumed to be liberated practically instantaneously, the following simple relation between the luminosity at maximum, L_{max}, and the velocity of expansion, v, can be established:

$$L_{max} = 3\pi R_0 c\mu v^2/2 \qquad (15)$$

where R_0 is the radius of the original star, c the velocity of light and μ the material thickness of the shell, for instance in grams/cm.^{2}, at which the shell ceases to be opaque for the radiation centripetally impinging on it. In terms of absolute magnitudes our formula reads

$$M_{max} = -5 \log_{10} v + M_1 \qquad (16)$$

where

$$M_1 = 88{\cdot}8 - 2{\cdot}5 \log_{10} 3\pi R_0 c\mu/2. \qquad (17)$$

Inserting observational values for M and v, we obtain for $R_0\mu$ a range

$$2{\cdot}7 \times 10^{10} \text{ gm./cm.} < R_0\mu < 2{\cdot}7 \times 10^{12} \text{ gm./cm.} \qquad (18)$$

which is reasonable. In Figure 4 we present some theoretical curves in relation to values for M_{max} and v actually observed for novæ and supernovæ.

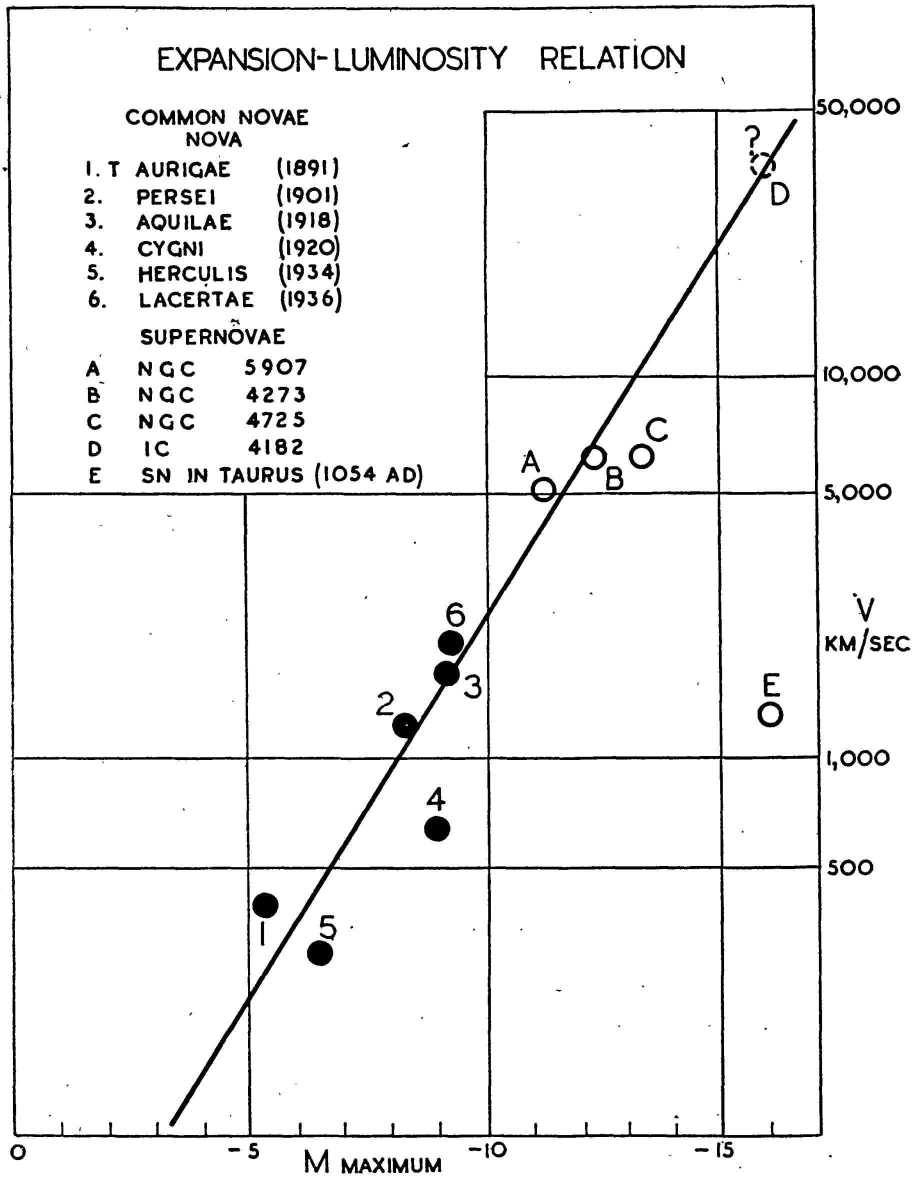

Figure 4.

We feel that supernovæ of type I are located high up on the central straight line. If this assumption is correct, the supernova of 1054 A.D. in Taurus in this case can hardly be considered as belonging to type I, but must be a representative of a third type.

(*b*) *Experimentation with Celestial Phenomena.*

The possibility of some rudimentary form of experimentation with the members of the planetary system has existed for some time by using radio waves and radar. The general possibilities have been greatly enhanced through the availability, brought about as a result of the war, of rockets as carriers of scientific instrumentation. Much has already been done with V2 rockets to observe conditions in the upper atmosphere and to get data on cosmic rays and the spectrum of the Sun. In many ways the atmosphere remaining above the maximum height (200 km.) of the V2 is still very troublesome. For ultraviolet light, soft X-rays, atomic rays, and other messengers of space are still absorbed far too efficiently to be observable.

The author, therefore, is working on rockets to reach 1000 km. height. By means of secondary rockets to be launched from primary carrier rockets, this goal should not involve too many difficulties.

In the second place, work is in progress to eject small test particles from the carrier rockets with velocities surpassing the velocity of escape from the Earth. Designs are being made, and have partly been realized, to confer such velocities upon test bodies whose masses lie in the range from milligrams to one kilogram. With these bodies the outskirts of the Earth's atmosphere can be explored, hypersonic aerodynamics may be studied both in the Boltzmann and Smoluchowski regions of the atmosphere, and a direct exploration of the electromagnetic field around the Earth appears possible. It is also hoped that the collisions of the test bodies with the Moon and other planetary bodies can be observed and a new method of direct experimentation with these bodies can be established.

(*c*) *Theoretical Integration.*

In the past, scientists were very busy with the exploration of specific problems. A theoretical integration of all of the important individual results therefore seems in order. Such an integration should ease further progress and should also help to bring within reach the faster and more efficient dissemination of astronomical knowledge.

(*d*) *Use of the Knowledge Gained.*
Reconstruction of the Universe.

As already mentioned, the knowledge gained in astronomy has had wide applications in the conduct of human affairs at almost all times. A fascinating book might be written on these applications. An extrapolation of these applications which lies in the line of morphological thinking, and which we might just as well visualize cold-bloodedly, since it appears inevitable, is the *reconstruction of the universe.* The reconstruction of the Earth naturally comes first. One of the biggest problems which comes to mind is the nuclear stabilization of the Earth. Since no fundamental principle seems to stand in the way of realizing nuclear fusion on a large scale, the danger exists that the whole Earth might be exploded by experiments not carefully handled. Thinking of how to stabilize the Earth against this eventuality, therefore, is a part of morphological astronomy. In the wake of the realization of large-scale nuclear fusion there will, no doubt, follow plans for making the planetary bodies habitable by changing them intrinsically and by changing their positions relative to the Sun. These

thoughts are to-day perhaps nearer to scientific analysis and mastery than were Jules Verne's dreams in his time.

(*e*) *Dissemination of Knowledge.*

The communication of knowledge among men may be taken as synonymous with the problem of education. It would perhaps appear wise to leave this controversial subject untouched. We should, however, fail the morphological way of thinking if we did not investigate the relation of astronomy or of any other special scientific discipline to all aspects of life. At the outset two things must be established, namely, a purpose of education and a way to achieve this purpose. Those who are familiar with the morphological method and have applied it successfully themselves will not be surprised when I state that the final result of the application of this method to educational problems departs considerably from conventional views and methods.

In the past, the purpose of scientific education was essentially restricted to the teaching of special disciplines. The aim of the universities has been and still is to produce astronomers, physicists, chemists, physicians and so on. This approach in many ways has utterly failed us. This is especially true if we admit as the purpose of education the *creation of realities that are in agreement with the avowed purposes of Man*. Although these purposes have been stated often and well, the actualities present a disastrous state of affairs in which the avowed purposes often can hardly be recognized.

To eliminate the discrepancy between men's plans and the results achieved, a new approach is necessary. Morphological thinking suggests that this new approach cannot be realized through increased teaching of specialized knowledge. This morphological analysis suggests that the essential fact has been overlooked that *every human is potentially a genius*. Education and dissemination of knowledge must assume a form which allows each student to absorb whatever develops his own genius, lest he become frustrated. The same outlook applies to the genius of the peoples as a whole.

We can only suggest here that astronomy and astronomers may be destined to play an important role in the morphological reconstruction of both the human society and the material universe. This inherent potentiality has its origin in the vast perspective which the study of astronomy naturally entails, as well as in the fact that any attempt to arrive at an organic understanding of celestial happenings ultimately involves the necessity of comprehensive knowledge of all other scientific disciplines and human activities.