Flights from Chaos

By Harlow Shapley

FLIGHTS FROM CHAOS

A SURVEY OF MATERIAL SYSTEMS
FROM ATOMS TO GALAXIES

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The thesis of this book was presented in a series of five lectures given in New York City in November and December 1929. Since then, the Supergalaxy Hypothesis has been further developed. Minor alterations have been made in classification and sub-classification throughout the series of material systems. There has evolved a clearer concept of the Cosmoplasma; interstellar and intergalactic space, which is traversed at all points with the radiation of all stars, is found to be of increasing significance because such regions are the graves of expiring stars and may contain the cosmic soil from which new suns and galaxies arise.

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Flights from Chaos

Chapter I

CONFUSION

IT IS fortunate that we are customarily unaware of our twisting, slipping, whirling, flying motion through space; we might otherwise lack the courage to explore and analyze the surrounding world. The planet on which we are established, where we record and contemplate celestial phenomena, is remarkably flighty and unstable. Its crust apparently slips relative to the terrestrial core, and perhaps it also pulses irregularly, to the confusion of accurate time keeping. The axis of the planet does not hold fast, and its unsteadiness produces complicated latitude variations that become involved in our attempts to determine the accurate positions of stars. The rotation of the Earth slows down and the day lengthens unevenly because of the Moon's attraction and the changing form of the Earth itself. Intricate motions arise from lunar and solar drags on the bulged equator of the planet.

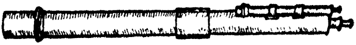
Many of these minor motions, sometimes irregular and obscure, contribute to the observer's dismay when he seeks most accurate knowledge of the stars. In general surveys, however, as in ordinary terrestrial life, the small irregularities are pretty well ignored and we concern ourselves mainly with the major motions of the planet. Of these principal movements we certainly should not remain unaware, nor can we, in our studies of planets and stars, ignore them, even though they, too, are unrecognized or of little concern to any but the astronomical technician.

Among the planet's most conspicuous drifts and gyrations, which contribute confusion to the picture, we may list:

1. Daily rotation—a thousand miles an hour at the equator, and three fourths as fast in the latitude of New York City and Rome.
2. Monthly revolution about the Earth-Moon center—thirty miles an hour.
3. Annual revolution around the Sun—twenty miles a second.
4. Solar system's motion with respect to neighboring stars—thirteen miles a second.
5. Motion of local star system with respect to other star clouds and the globular star clusters—approximately two hundred miles a second.
6. Drift of Milky Way system with respect to remote external galaxies—perhaps a hundred miles a second.

In living terrestrially, in developing biologically, and even in studying earthly things, we need know nothing of our planet's cosmic behavior; but all of these principal motions must be remembered and allowed for in studies of the various parts of the sidereal universe. In practice, we regard the motions as non-terrestrial. We speak of moon-rise and sun-set. We carry on the counting, measuring, and statistical analysis of stars, and the contemplation of sidereal phenomena, as though we ourselves were fixed and centrally placed as the procession goes by.

A more general complexity, however, presents itself when broad spaces of the sky are considered, or large numbers of bodies. It arises from the variety of sidereal types, the confusion in stellar motions, and the difficulties of finding the dimension of depth as readily as we find place on the surface of the sky. Obvious physical perspective is lacking. We can easily get the direction of a star or nebula, but where is it along the direction line? And with regard to time—we record phenomena as they appear now, but how about the past and the future?



Our immediate goal is an escape, or a partial escape, from the chaos of mixed motions, mixed types, mixed positions; from the complex of radiation, the irregularities of organization, and the confusion of developmental tendencies. If we examine some sample regions, we shall learn what sorts of materials and material systems must be surveyed, analyzed, and untangled.

The familiar constellation of the Big Dipper (Ursa Major) affords a convenient region for sampling. The quadrilateral of bright stars, marking the bowl of the dipper, encloses only a thousandth of the whole sky, but a profusion and confusion of objects emerges at once when a census is made of this relatively barren and inconspicuous bit of the material universe. At first glance the casual observer sees practically nothing at all except the four boundary stars—α, β, γ, and δ Ursae Majoris—anciently named Dubhe, Merak, Phekda, and Megrez. They look much alike, stars of the second and third magnitudes, but differences appear on close examination. Star α is orange-tinted and its spectrum shows the presence in the star's atmosphere of the vapors of many chemical elements; the stars β, γ, and δ are much alike in color and temperature, but differ from α in their apparently simple spectral composition, dominated by hydrogen. The three stars are alike also in amount and direction of motion, from which α deviates.

Looking into the dipper's bowl more closely we find with the unaided eye nearly a dozen faint stars—the number visible depending on acuteness of vision and transparency of the atmosphere. These ten or twelve stars are not unlike to the unaided eye; but the spectroscopically and telescopically reinforced eye sees a very different picture. The colors of the rainbow appear; the stars are of varied hues; some are hot, with spectra of simple appearance, and others are cool and complicated. A reference to suitable star catalogues reveals surprising diversity also in the quantity and direction of their motions.

In this quiet-appearing region we come upon heterogeneity in structure, motion, distance, and age—a confusion that becomes enhanced when we penetrate below the limit of brightness perceptible to the unaided eye. The fainter our telescopes reach, the more frequent the stars. By the time we have reached one fifteenth the brightness of the naked-eye limit, about a hundred stars can be counted in the dipper's bowl; at a thousandth there are three thousand; at a millionth of this brightness, which is near the limit attained by the greatest modern photographic telescopes, the stars enumerable in the bowl of the Big Dipper are approximately one hundred and fifty thousand!

In looking out through the scattered stars in the direction of Ursa Major we find some objects less than a hundred light years distant. But generally the distance must be expressed in thousands of light years, and many of the stars are beyond the range of astronomical measurement. Among the fainter objects we observe about a hundred hazy luminous patches that lie at distances of millions of light years—quite beyond the stellar system we call our Galaxy. These inconspicuous but tremendous objects are members of the family of spiral nebulae—themselves galaxies, each composed of its millions or billions of stars, but so deeply sunk in the depths of space that only faint glimmers of light come to us. The light from many of these spirals is so enfeebled by diffusion in space that the keenest eye aided by the most potent telescope fails to see them; but the photographic plate, with persistent exposure, makes a clear and lasting record.

In this external world of spiral nebulae the photographic telescope discovers, not far from the center of the dipper's bowl, a most astonishing congregation. It is a strongly concentrated cloud of sixty nebulae—a galaxy of galaxies—with the distance from the Earth, according to Baade's estimate, a hundred and fifty million light years.

Not all the hazy non-stellar objects in our sample region are external galaxies. The largest nebulosity, on the border of the dipper's bowl, is the Owl Nebula—a relatively nearby organization of quite a different sort. It is not a star, nor a wisp of cosmic dust, nor is it composed of stars, like the remote spirals; but rather it is star plus gas plus dust. Its angular diameter is a tenth that of the full Moon. Small telescopes show its owl-faced disc, with a star of the twelfth magnitude in the center.

Small optical power will also show that many of the stars in the Big Dipper are not single and isolated bodies like our Sun, but doubles or even triples. A careful study further informs us that some of the stars are inconstant in light, either varying in a manner that astronomers can explain as due to eclipses in a binary system, or more frequently varying in a manner that so far has defied satisfactory explanation.

In résumé—the appearance of simplicity and uniformity disappears when the population in a sample region of the sky is examined. Among these hundred and fifty thousand stars we find giants and dwarfs, doubles and variables, nebulosity and remote galaxies, and a confusion of ages, motions, distances, and dimensions.

There are hundreds of thousands of original photographs of stars in the plate collection at Harvard. We shall choose one of these photographs for a second sampling of the material universe, and survey its impersonal catch of starlight. Once more we find an appalling richness in number and a profusion of types. The chosen photograph is A 3228, a plate fourteen by seventeen inches, exposed for two hours in the Bruce photographic telescope at the Harvard station near Arequipa, Peru. The photograph was made on August 13, 1898. A full description of the phenomena it records would fill a volume.

We shall merely make a list of its interesting objects that can most easily be identified:

1. The planet Saturn, first of all, making a tremendous impression on the plate, even though it is but a planet shining weakly by reflected light; its nearness to the Earth, 1.3 light hours, gives it an enormous advantage over the thousands of giant stars which are at distances measured in light centuries.
2. Saturnian satellites, several of which are sufficiently clear of the glare of the planet to be independently photographed.
3. Phoebe, the very faint ninth satellite of Saturn, especially to be remarked, for it was originally discovered on this plate.
4. The asteroid Iris, one of the brightest of the swarm of minor planets that circulate in the solar system outside the orbit of Mars. Iris was the seventh asteroid known, discovered about a century ago, and it is peculiarly variable in light. Nearer to us than Saturn and his satellites, Iris also makes a strong impression on the photographic plate—a heavier mark indeed than the combined images of a hundred of the faintest stars, though the asteroid with a diameter of a few hundred miles is but a ten billionth the volume of an average star.
5. The globular star cluster Messier 80, which lies at a distance of fifty seven thousand light years. Among its thousands of giant stars are representatives of many types—variable stars,

probably binaries, cool red stars, hotter yellow ones, and bluish stars, hottest of all. The crowding of these objects results in star images that on our photograph appear hopelessly fused.

6. A stream of dark nebulosity, vaguely associated with the stars of moderate distance and so opaque in places that remoter systems are hidden from view.

7. Uncounted thousands of stars—variables, doubles, and multiple groups—in the same profusion of types, distances, dimensions, and motions that we find in the bowl of the Big Dipper.

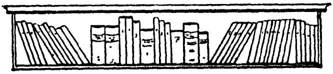
The photographic plate is fogged; we have photographed, in addition to stars, the general illumination in our own atmosphere, the light of the night sky. This faint diffused light, affecting evenly the whole plate, has probably come from many sources—remote unresolved stars, meteoric particles in the solar system, auroral light in the upper air, and reflections from dust grains in the lower atmosphere.

We might proceed with other sample regions of the universe, but everywhere we should find evidences of apparent chaos. If the chosen region were not an area on the surface of the sky, as in the two samples described above, but were a definite large volume of space, the results would be much the same. Within one hundred light years of the Sun we find:

Double stars like Sirius and Procyon;
Variables like one component of Castor;
High speed dwarfs such as Barnard's "runaway star";
High luminosity stars like Vega;
Peculiar white dwarfs;
A section of interstellar space travelled by cosmic meteors, by the molecular ejecta of comets, by ionized gases, and by spent radiation in an astonishing range of wave lengths;
A solar system composed of the dwarf central Sun, planets, comets, asteroids, moons, and meteor streams;
A terrestrial crust populated with a bewildering variety of organic systems.

So much for the mixture in the Sun's neighborhood.

If we take a sample page from any general star catalogue we see the same heterogeneity recorded; if we take any single volume of a general astronomical journal we again find many kinds of bodies and systems under study and discussion, from the minutest of atomic structures to the largest of stellar groups.



Chemical elements have long since been classified, and out of a welter of material substances a high degree of order has been revealed in the atomic world. In the animal and vegetable kingdoms the biologist has made progress towards order, and his numerous classifications have provided some of the materials needed for contemplation of the origin, growth, and destiny of organic forms. The astronomer, also, has made some advance toward untangling the thread of sidereal structure.

In my own studies I have had recent need to classify the types of galaxies, to look over the various kinds of star clusters, and to set up provisional categories among binary stars and star clouds. With the hope of contributing somewhat to the clarification of our view of organizations throughout the cosmos, I propose in the following pages to extend my classifications, and work through the general taxonomic problems in the field of cosmogony. We may fail to attain the desired clarity of view, but at least we shall realize useful by-products—the appraisal, for example, of current researches, the deduction of working hypotheses, exploratory glimpses into fields bordering on various branches of science, and a listing of the unknowns near the inner and outer boundaries of the material world.

Chapter II

THE PLEIADES AND THEIR KIND

Most famous of all star clusters, the Pleiades provide a starting point for our discussion of the kinds of material systems. This group of high temperature stars has appealed to men in various ways—an incitation for the researches of scientists and an inspiration for the songs of poets. As the dancing daughters of Atlas the Pleiades appear in "Endymion," they are sung by Hesiod, Milton, Meredith; they were thought of by Maedler as possibly marking the center of the universe. Their motions and magnitudes and spectra have been examined by scores of modern astronomers; they appear in the folk lore of all countries. Compact, bright, accessible to northern observers, they have been studied more than any other stellar group.

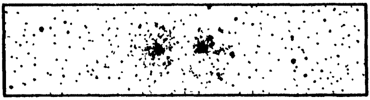
It is just this characteristic of forming a physical group that attracts us now to the Pleiades. The brighter members are much alike in magnitude and have nearly identical motions and spectra. It is not a trick of perspective that brings them together in the sky—they undoubtedly form a physical system, a gravitational unit. We see in them a celestial organization, and are confident that these bright stars, and the scores of fainter ones that travel with them, have had a common origin and move toward a common destiny.

The Pleiades, however, are not a model of all star clusters. A thin veil surrounds them—a veil revealed by photography, but invisible to the naked eye. In this respect the Pleiades differ from the neighboring star cluster of the Hyades, around which no such veil is apparent. In the Pleiades the light of the brighter stars is of such high intensity that the surrounding clouds of dust and gas are in part made luminous; the lower temperatures of the stars in the Hyades could not appreciably incite the radiation in a similar nebulosity.

In other characteristics as well, the Hyades, thirteen degrees distant and situated in the head of the Bull, are different from the Pleiades. They are more scattered in the sky, for one thing; for another, they belong to different stellar types as shown by spectrum analysis. Among the brighter Hyades some are yellow, though most of them are white. In the Pleiades it is not until faint stars, comparable with our Sun, are reached that moderate temperatures and yellow colors are found.

There are literally hundreds of clusters scattered along the Milky Way, differing from one another in size, form, brilliancy, spectral make-up, motion, and distance from the Earth. The Big

Dipper, or Ursa Major group, is a familiar constellation and also a real physical system. Except for the two stars at the extreme ends of the dipper, the configuration moves as a unit through space. Other naked-eye stars, far from the region of Ursa Major, are also a part of the cluster. Their membership is recognized through their spectra, their speed, and the direction of their motion in space. Two Class A stars of the second magnitude, β Aurigae and α Coronae Borealis, belong to the Ursa Major system. But the most striking member of the group is the most conspicuous of all stars, Sirius, the Dog Star, which will always be more talked about than any body because of the company it keeps. It is one of the Sun's nearest neighbors; it is paired up with one of the queerest companions in the known sidereal universe; and it flocks with the Ursa Major stars.



The average star cluster is of course more obviously organized than the Ursa Major group. If we go searching along the Milky Way with a small telescope we have no difficulty in picking up a score of systems of varied appearances. If we attempt a general interpretation of their part in the universal scheme, we must first attempt to get some order out of the apparent chaos by arranging them in classes. The simplest device, perhaps, is to group them as follows:

GALACTIC CLUSTERS
Pleiades type
Hyades type

As far as we can now tell, more than ninety per cent of the clusters along the Milky Way fall naturally into these two groups. The chief distinction between them lies in the fact that one has for its brightest members blue and white stars of spectral classes B and A, whereas the other has among its giants a sprinkling of yellowish and orange stars as well. The spectra of the ten brightest stars in the Pleiades and in the Hyades show this contrast:

THE PLEIADES		THE HYADES	
Star	Spectral Class	Star	Spectral Class
Alcyone	B5e	θ_1 Tauri	A5
Atlas	B8	ϵ Tauri	K0
Electra	B5	γ Tauri	G0
Maia	B5	δ Tauri	K0
Merope	B5e	θ_2 Tauri	K0
Taygeta	B5	Br 601	A0
Boss 879	B8e	Br 639	A5
Boss 851	B5	κ Tauri	A3
Boss 872	B8	υ Tauri	A5
Boss 861	B8	Br 605	A0

For practical purposes, however, the spectral classification of galactic clusters is too coarse; moreover, it employs difficult criteria, since the study of spectra in crowded regions and for faint stars is uncertain. With more knowledge and greater telescopic power we may be able in time to subdivide effectively on spectral grounds. It appears better for our current studies of these celestial objects, which we call open clusters, or galactic clusters (because of their preference for the Milky Way), to subdivide the class into several groups on the basis of appearance in the sky. Recently a scheme has been worked out at the Harvard Observatory as follows:

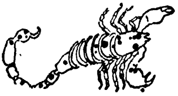
GALACTIC CLUSTERS

a. Field irregularities
b. Star associations
c. Very loose groups
d. Loose groups
e. Restricted groups
f. Compact groups
g. Dense groups

In the process of classifying the clusters we first clearly noticed that the thousands of recognizable irregularities in the thickly strewn star fields of our Milky Way system should be considered fragmentary groups and therefore classed along with the conspicuous open star clusters. It is easy to show by the laws of chance that a random distribution of stars in space should give us some irregularity in distribution throughout any small section of the sky. But the irregularities we actually observe in many regions far exceed those permitted by the laws of probability.

Some may be due to the hiding of stars by dark nebulae; but most of them must be attributed to faint groupings which are hints of weak organizations—hints, perhaps, of vestigial or incipient systems, the remnants or the promise of more obvious clusters.

Next in order after the almost innumerable and altogether uncatalogued field irregularities are the star associations. The Ursa Major group is the best example, but there are several others, many of which have only partially emerged from the profusion of data on the motions and positions of stars. With the increase of information we shall certainly add to the class of recognized star associations and no doubt find that some of them are interpenetrating. Thus greater knowledge may indicate anew the chaotic conglomerate that constitutes the stellar universe.



Our casual telescopic explorations along the Milky Way leave us satisfied that the preceding classification, or one like it; will include all the clusterings and organizations we meet—providing we do not go too far. But suppose we come to the Trapezium in Orion. This compact group of exceedingly hot stars, involved in the Orion Nebula, is composed of four bright and two faint members. Can we appropriately call this a star cluster and place it in the same general category with Praesepe and the Pleiades? Or is it more felicitously considered an exaggerated case of double or multiple stars, such as astronomers recognize by the thousands?

Again, in the Southern Milky Way, we may come upon Messier 22, a globular system richer than the richest of the galactic clusters. Outside of the Milky Way we find a similar organization, the great cluster in Hercules. Like the Orion Trapezium, these objects do not fall within the foregoing classification. It seems that when we seek to classify the Pleiades and their kind we have chosen only a convenient and fairly distinct interval in a series of stellar systems. We have been working with conspicuous and easy objects. Before we settle down to business systematically, it may be well to look at larger organizations in a little detail, and also at those that are poorer and smaller than the clusters of the Milky Way.

Chapter III

DEEPER INTO STELLAR ORGANIZATION

IN THE little constellation Scutum Sobieski is situated one of the most distinct star clouds of the Milky Way, visible and much observed from both northern and southern hemispheres. The Scutum Cloud is approximately ten degrees in diameter, and not far from its center is the well known galactic cluster Messier 11. Frequently it has been suggested that Messier 11 may be the nucleus of the much greater system; we find it difficult to determine just where the cluster melts into the Scutum Cloud. The boundaries of the cloud, however, seem to be fairly definite. It gives every evidence of being a discrete stellar organization, but unlike the galactic clusters with their few hundred members, or the globular clusters with their thousands of members, its population must be counted by the millions. Irregularity in structure and outline and diversity in size and spectral make-up are general characteristics of star clouds; but all those now recognized, within the Milky Way and without, are giants in mass compared with clusters.

It may be difficult to decide which of the star clouds along the Milky Way are distinct organizations. We experience no such uncertainty when examining the two Clouds of Magellan. At distances of the order of ninety thousand light years these two irregular star clouds are distinctly separated from the Milky Way stream —they are in high galactic latitude and apparently clear of all other systems of stars. The Large Cloud, according to recent measurements, is eleven thousand light years in diameter; the Small Cloud, six thousand light years. They will be discussed in some detail in later pages, because the Clouds of Magellan have contributed significantly to the understanding of our own stellar system. We suspect that if they were in low galactic latitudes, among the Milky Way star clouds, we should not recognize them as of unusual import. But finding them outside the Milky Way and replete with information and suggestion, we are tempted still farther into space where there are other isolated star clouds, comparable to the Clouds of Magellan and therefore, perhaps, like those of the Milky Way.

Examining objects that are more remote than the Magellanic Clouds, we come upon Messier 33, one of the best known of the spiral nebulae. Its nebulous appearance, however, is an illusion, arising from optical limitations. The Milky Way is a milky haze to the unaided eye. Through a small telescope, which resolves the Milky Way, the Clouds of Magellan appear nebulous, but an instrument of moderate size reveals their millions of individual stars. Through both small and moderate sized telescopes Messier 33 appears to be a structure of nebulous spiral arms; but the largest reflectors have photographically resolved it also into a great star cloud.

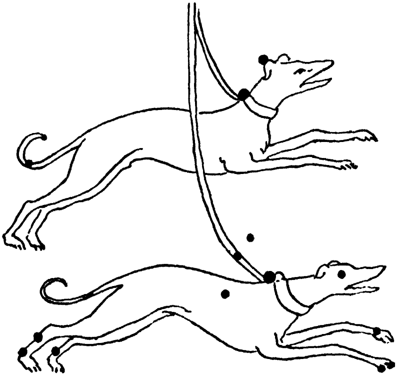
Objects like Messier 33 are numbered by the thousands. They are scattered throughout space for millions of light years. Their forms are various; their role in the structure of the universe is important. It is obvious that star systems larger than galactic clusters must be sorted out and classified in any objective consideration of the universe. The classification of globular clusters, star clouds, or spiral nebulae would not be so necessary if our studies were confined wholly to minute analyses of individual objects. But once the general organization is conceived, or an endeavor is made to treat a large group of objects, steps must be taken towards establishing order. Hence we shall find that astronomers have proposed various classifications of the greater systems, though without much attempt to achieve general harmony or to tie up one group with another.

Turning to organizations simpler than the galactic clusters we find among nebulae and multiple stars as much diversity and need for systematization as among star clouds. The Trapezium in the Orion Nebula has been mentioned; a similar group is Messier 8. Both are nebulous groups—stars and nebulosity commingled. These two nebulosities are much the same, but we need not look far before we find other kinds of objects classed as nebulae or nebulous systems. Some are symmetrical; others irregular. Some show gaseous spectra; others have spectra similar to those of the involved stars. Some are bright; some are dark. Clearly, a sorting over of the various objects of this kind will help much in clarifying the complex of minor systems.

The Trapezium in Orion has been considered also as a multiple star. The North Pole star is triple. There are scores of multiples which are generally classed and catalogued with the thousands of known double stars. The double stars, moreover, are of many sorts. Among the bright stars we recognize: Sirius and its odd companion; Algol and its relatively dark associate which is really not at all dark, being many times brighter than our Sun; two or three hundred other eclipsing stars like Algol, and two or three thousand "spectroscopic" binaries like Spica and Capella.

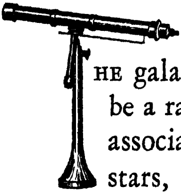
Smaller still in the series of material systems are the planetary organizations such as ours, the families of satellites, and the swarms of meteoric stones and irons that go to make up the comets. In a very casual survey we recognize sidereal systems of many orders, running from minor affairs like the Earth-Moon system up through planetary systems, double stars, galactic clusters, globular clusters, star clouds, to the galactic system itself. There are systems less than the least mentioned and greater than the greatest.

To make the survey of material systems useful and comprehensive it will be well to stop here with the superficial view and start at once at the bottom of the series, going upward class by class. Perhaps the series of principal divisions, from the minutest to the greatest, will form the most attractive phase of the panorama. The most useful part of the survey may be the provisional subclassifications that can be proposed and discussed; their practical value lies chiefly in the new interpretations they suggest, the affiliations they bring forth, and the guidance they give to further research.



Chapter IV

CORPUSCLES—THE MINUTEST OF MATERIAL SYSTEMS



THE galaxy-hunting astronomer may appear to be a rare spirit, blessed with the privilege of associating always with grand affairs—big stars, long times, great spaces. But he does not greatly delude himself. His is also a world of littleness. His first sidereal measurement takes him out of touch with dimensions galactic to the minutest of things. To measure he must see. To see he must have light. To have light he must be in contact with the infinitesimals of the submicroscopic world.

There is no avoiding electrons, whose diameters are a millionth of a millionth of a millionth of a mile, when we measure the galactic system, whose diameter is a million, million, million miles. We need to consider the behavior of the individual radiating mechanism, consisting of one atom, when we analyze the behavior of an individual radiating star composed of more than 1,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000 atoms. Stars and atoms must be taken together, light waves and light years, electron motions and the drifts of galaxies.

A survey of material systems will therefore remain rightly in the astronomer's field when it includes clusters in which the units are stars, and atoms in which the units are corpuscular electrons and protons. The astronomer continually goes to the physical laboratory for guidance in theory and for experimental facts; the physicist frequently goes to the stars for inspiration and for data.

It is our ambition now to start at the bottom and work our way up in the world. We shall therefore begin with electrons.

Two questions assail us immediately: (1) Are electrons and protons systems, or are they indivisible electromagnetic material units? And (2) if we should grant them the standing of material systems, what right have we to claim for electrons and protons the distinction of being the smallest?

To consider the second question first: we have no right whatever to maintain doggedly that we have reached the ultimate in infinitesimal material systems when we deal with these familiar material units. Experience should quickly teach us how unsafe such an assumption would be. A few decades ago not even the atom would have been admitted to the society of systems. Atoms were the little, hard, ultimate chunks of matter, indivisible by grace of name and experiment and scientific dogma. But atoms are no longer listed as ultimates, they are now among the best known of material systems; and even their unit components cannot maintain the former atomic role of being the indivisible stones of which the material universe is built. Experience certainly recommends caution in asserting any lower limit in the organization of the microcosmos.

On the other hand, since we can know of electrons and protons and the units of radiation only by using electrons and protons and units of radiation in our technique of measuring and comprehending, it may be that we have already got near the bottom of *measurable* units and systems of units. Light waves and electrons can be rather handily used to measure those bodies and systems of bodies in the material world that are larger than electrons and light waves. In the relatively coarse-grained world in which we are to work, they are efficient tools. But in a hypothetical sub-electronic world, where there may be systems within systems indefinitely, our coarse-grained tools no longer bring information to our coarse-grained minds. It may be that we are stopped in our explorations downward, not because the limit is reached, but because of our inherent awkwardness.

To register our conviction that the series of systems extends downward, and that for us its limit is indeterminate, we shall start our list of the series of material systems with an empty dotted line, and give it the class number −5. The first recognizable systems, therefore, have the number −4. These small entities may be appropriately given the generic name Corpuscles, and we start out thus:

−5 . . . . . .
−4 CORPUSCLES
  α. . . . . .
  β. Light quanta
  γ. Electrons
  δ. Protons

Before we comment on the various kinds of corpuscles as systems, before we wonder at the dotted line that appears among them, let us indulge one idle fancy. Is our inability to get deeper into the minutiae of the microcosmos or, in the other direction, farther into trans-galactic space tied up somehow with our own dimensions? It is a singular fact that electrons, in diameter, are just as much smaller than a man as he is smaller than a supergiant red star, the biggest body he measures. The observer is thus geometrically near the middle of the range. Also, in material content he is in a middle position. The biggest definitely organized and closely coherent bodies we measure are these giant stars that contain about 10^{58} corpuscles (electrons and protons). An average man's body contains 10^{29} corpuscles—halfway down towards the unit electron.

If the observer and interpreter were as large as Betelgeuse might he fail in his survey to reach objects smaller than the meteors and moons, but perhaps go far beyond our metagalactic system in the direction of things extensive? Or if he were of the dimensions of a bacterium, might not the sub-electronic world open up easily, though he fail to comprehend or measure the stars and larger parts of the sidereal universe?

If, however, the technique of measurement and understanding always involves light of the wave lengths and properties we know about, a displacement of the observer from the middle of the scale does not help in penetrating the cosmos. Bacterium or Betelgeusian—he finds that the tools, not the vision, set the limits, or at least constitute the handicap. New tools are needed, not a dimensional displacement of the observer.

Our pivotal position in the scale of dimensions is probably just another of the grim illusions that make man appear to be importantly in the midst of the measurable world. As with his once flourishing geocentricism, further research may again easily decentralize him. We can attach no cosmic significance to his position in the universe. We are, as remarked above, indulging a vain fancy.

* * *

There is a large element of danger in writing about corpuscles. The knowledge concerning them has grown so rapidly in recent years that now we know practically nothing about them. Are light quanta waves or particles? Nobody quite knows. Eddington seeks to escape the question by calling light quanta wavicles. Are electrons and protons particles or waves? They have long been considered particles—practically ever since their recognition at the beginning of the present century; but experiments of most recent times, by Davisson, Thomson, Dempster, and others, show these fundamental units of matter behaving as though composed of waves. Structure begins to emerge. There is organization within electrons. Apparently we should answer affirmatively our earlier question: Are electrons and protons systems? And although we can give no convincing picture, nor quote a satisfying definition of these fundamental entities themselves, the fact that structural details and possible subdivisions are coming to light justifies our tentative listing of corpuscles as material systems and not as single units.

Sooner or later we may be forced to define the word "system" as used in these chapters; but that unhappy time will be postponed, in the hope that a definition may be inferred rather than explicitly stated. An electron in the nucleus of an atom, according to the momentary concept, may be quite a different thing from an electron at large. If it is a system when free, it may be otherwise when bound.

In the attempt to understand the nature of these fundamental entities—the quanta of radiation, and the negative and positive electromagnetic units of mass—experiment and theory go forward in a most confusing and encouraging way. Year by year the atomic models and formulations are built up and pulled down; but all this destruction of models and abandonment of interpretation represents progress. A theory is correct so long as it is useful in guiding further investigation, especially if the investigation tends to overthrow the theory that inspires it.

Returning to the suggested working classification of corpuscles:

α. . . . .
β. Light quanta
γ. Electrons
δ. Protons

we should make two admissions. First, there are those who, though accepting the equivalence of matter and radiation, still prefer that light quanta be excluded from a listing of material systems. They consider that matter when transformed into radiation is immaterial. This merely indicates that in a close analysis we have the problem of indicating what we accept as constituting matter. The precise definition of this word, as well as of the word "system" will be avoided.

Second, we admit helplessness with regard to the subclass α. Undoubtedly it is a highly important class in the universe. Seeing the dotted line, some would be tempted to write the word Ether, or something more vague. Quanta of Action, Units of Space-time, Etherons, Phytons, Psychons —merely words on the tongue are most of these— products of the continual groping for fundamentals. But it is not very daring to predict that when we have, in a few years, more stable knowledge concerning light quanta and electrons we shall be able to fill in subclass α without much hesitation. I feel that when such a step is taken it will be wise to put in another empty subclass under Corpuscles, always leaving one unfilled, as an intimation of hope and an indication of temporary ignorance.

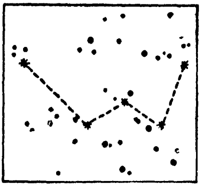
There may be vagueness and rather evident futility in all attempts to suggest useful classifications of the minutest of material systems. Protons differ fundamentally in mass and properties from electrons and light quanta. Should they be in the same general group? In any event it is profitable to list these physical entities together, to admit the instability of scientific knowledge concerning them, and to hope that in a general panorama of material systems the inclusion of these tools of physicist and astronomer will help to fill in the picture.

Contemplation of the corpuscular nature of the material universe is most certainly relevant in our studies of stars, galaxies, and intergalactic space—for supposedly empty space is full of dispersing light quanta, and it is continually travelled by wandering electrons and protons; possibly space itself is constructed out of subclass α of the class of corpuscles! The behavior of electrons in the interiors of stars is also a problem important to the understanding of higher systems. Corpuscles are indeed at the heart of modern astrophysics.

Although we recognize the special significance of light quanta and of the possible unknown kinds of corpuscles in the structure and operation of the material universe, we shall proceed to deal with material systems of higher orders that are built up of two types of corpuscles—the electrons and protons. From this point we accept them as defining material, and proceed to treat of the higher systems with which we can deal more definitely and authoritatively than with corpuscles. This definiteness arises, no doubt, from our building henceforth only with electronic and protonic bricks. Possibly also our self-assurance depends somewhat on not knowing how little we know.

Chapter V

UP FROM THE MICROCOSMOS



WE WERE just remarking that our ignorance of the ultimate nature of the entities in the material underworld is matched only by our temerity. We bravely discuss corpuscles, realizing that the vast body of knowledge concerning them leaves us ignorant of what they really are. We shall proceed with equal confidence to consider atomic systems and molecular structures—using them as stepping-stones to higher things.

It is customary to make pictures or models of the atoms of matter to help in thinking about their structure and behavior. A familiar model is the "planetary" atom in which the nucleus, mainly protonic, represents the Sun, and circulating electrons play the role of planets; but certainly this image is a working convenience only. It has become more familiar as time passes, but less convincing. Improved models are continually put on the market. The physicist and the astronomer use them eagerly for a month or a year, use them effectively, and drop them as soon as something better appears. And although his research prospers and his knowledge of atomic performance grows, the investigator remains disconcerted by the innocently asked question: What are the realities underlying all these atomic phenomena, the arrangements of electrons, the machinery of the absorption and emission of radiation? The reality may well be so fundamental, Sir James Jeans suggests, as to be beyond the grasp of the human mind. To quote Jeans further,

> It is just for this reason that modern theoretical physics is so difficult to explain, and so difficult to understand. It is easy to explain the motion of the earth round the sun in the solar system. We see the sun in the sky; we feel the earth under our feet, and the concept of motion is familiar to us from everyday experience. How different when we try to explain the analogous motion of the electron round the proton in the hydrogen atom! Neither you nor I have any direct experience of either electrons or protons, and no one has so far any inkling of what they are really like. So we agree to make a sort of model in which the electron and proton are represented by the simplest things known to us, tiny hard spheres. This model works well for a time and then suddenly breaks in our hands. In the new light of the wave-mechanics, the hard sphere is seen to be hopelessly inadequate to represent the electron. The hard sphere has always a definite position in space; the electron apparently has not. A hard sphere takes up a very definite amount of room, an electron—well, it is probably as meaningless to discuss how much room an electron takes up as it is to discuss how much room a fear, an anxiety or an uncertainty takes up.

Too many books, both simple and technical, brief and prolonged, have been written on the subject of atoms to justify another detailed story.

For our purpose we need only remember that electrons and protons and some included energy are the corpuscular constituents of atomic systems. We shall also recall, with the assistance of the following tabulations, that chemical analyses of the crust of this planet have already revealed the presence of all but one or two of the ninety two probable kinds of atoms.

We need not take long for the survey of atoms, for the chemical elements have long afforded the best example in the inanimate world of the fruitfulness of a systematic detailed classification. We observe that the elements can be placed in "groups" and in "periods." The eight groups divide the elements chiefly on the basis of structure, since similarities in chemical behavior in each group arise from similarities in atomic structure. One of the many different ways of presenting the "periodic system" so as to illustrate the structural groups is given below. In this double-entry table the seven different periods assemble the elements chiefly on the basis of complexity and mass. The periods are therefore assigned Arabic numbers, and the structural groups, Roman numbers, in accordance with the convention adopted in this volume and described in some detail in Chapter X.

The most obvious and indisputable classification of the kinds of atoms is the simple listing in order of "atomic number," as shown in the census of elements on page 39. Arabic numbers are appro-

The Periodic System of the Elements

Period	Group I		Group II		Group III		Group IV		Group V		Group VI		Group VII		Group VIII	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
1	1 H															2 He
2	3 Li		4 Be			5 B		6 C		7 N		8 O		9 F		10 Ne
3	11 Na		12 Mg			13 Al		14 Si		15 P		16 S		17 Cl		18A
4	19 K	29 Cu	20 Ca	30 Zn	21 Sc	31 Ga	22 Ti	32 Ge	23 V	33 As	24 Cr	34 Se	25 Mn	35 Br	26 Fe 27 Co 28 Ni	36 Kr
5	37 Rb	47 Ag	38 Sr	48 Cd	39 Y	49 In	40 Zr	50 Sn	41 Nb	51 Sb	42 Mo	52 Te	43 Ma	53 I	44 Ru 45 Rh 46 Pd	54 Xe
6	55 Cs	79 Au	56 Ba	80 Hg	57–71 (rare earths)	81 Tl	72 Hf	82 Pb	73 Ta	83 Bi	74 W	84 Po	75 Re	85. .	76 Os 77 Ir 78 Pt	86 Rn
7	87. .		88 Ra		89 Ac		90 Th		91 Pa		92 U					

Census of the Chemical Elements

Atomic Number	Name	Atomic Number	Name	Atomic Number	Name
1	Hydrogen	32	Germanium	63	Europium
2	Helium	33	Arsenic	64	Gadolinium
3	Lithium	34	Selenium	65	Terbium
4	Beryllium	35	Bromine	66	Dysprosium
5	Boron	36	Krypton	67	Holmium
6	Carbon	37	Rubidium	68	Erbium
7	Nitrogen	38	Strontium	69	Thulium
8	Oxygen	39	Yttrium	70	Ytterbium
9	Fluorine	40	Zirconium	71	Lutecium
10	Neon	41	Niobium	72	Hafnium
11	Sodium	42	Molybdenum	73	Tantalum
12	Magnesium	43	Masurium	74	Tungsten
13	Aluminium	44	Ruthenium	75	Rhenium
14	Silicon	45	Rhodium	76	Osmium
15	Phosphorus	46	Palladium	77	Iridium
16	Sulphur	47	Silver	78	Platinum
17	Chlorine	48	Cadmium	79	Gold
18	Argon	49	Indium	80	Mercury
19	Potassium	50	Tin	81	Thallium
20	Calcium	51	Antimony	82	Lead
21	Scandium	52	Tellurium	83	Bismuth
22	Titanium	53	Iodine	84	Polonium
23	Vanadium	54	Xenon	85	....
24	Chromium	55	Cesium	86	Radon
25	Manganese	56	Barium	87	....
26	Iron	57	Lanthanum	88	Radium
27	Cobalt	58	Cerium	89	Actinium
28	Nickel	59	Praseodymium	90	Thorium
29	Copper	60	Neodymium	91	Protoactinium
30	Zinc	61	Illinium	92	Uranium
31	Gallium	62	Samarium		

priate here, for with minor exceptions each succeeding atom is more massive and more complex than those that go before. Two corpuscles suffice to build a hydrogen atom. Four hundred and seventy six are necessary in the structure of one unit of uranium.

* * *

Before we leave the subject of atoms, where we find the classification essentially complete, we shall mention briefly half a dozen miscellaneous facts concerning these fundamental material systems.

1. The arranging of the elements into groups and periods was undertaken long before a complete array was possible. The periodic table of twenty years ago had many blank spaces. Now only two vacancies remain, numbers 85 and 87, and number 87 has apparently been discovered very recently and merely awaits isolation, naming, and further analysis. The chief properties of elements can be predicted, in advance of discovery, from their places and their group relationships in this scheme of classification. In fact, it is the blank spaces in the table that incite such searches and discoveries.

2. Recent discoveries of chemical elements are as follows:

Atomic Number	Element	Discoverer	Date
72	Hafnium	Coster, Hevesy	1922
43	Masurium	Tacke	1925
75	Rhenium	Doljsek, Druce, Heyrowsky	1925
61	Illinium	Hopkins, Cocke, James, and Fogg	1926

3. In the Earth's crust, and in the atmospheres of the Sun and stars, the atoms of even atomic number are about ten times as abundant as those of odd number. The even numbered elements are also more likely to be complex, showing isotopic forms—that is, atoms of slightly different weight and nuclear make-up, but of the same chemical behavior and external structure, appear as a single element. Thus there are two kinds of iron atoms, one of them fifty four times as heavy as a hydrogen atom and the other fifty six times as heavy. There are three isotopes of sulphur and eleven of tin. Practically all of the important additions to our knowledge of the species of atoms are due to Aston's investigations in the Cavendish Laboratory.

4. There is little or no direct evidence of any atom heavier than uranium, notwithstanding our extensive searches of the crust of the Earth and the atmosphere of the Sun. We cannot sample the interior of the Earth, nor have we got below the surfaces of stars. Our whole knowledge of the constitution of the universe has come through spectroscopic analysis of the light of stars and nebulae, chemical analysis of meteorites, and our variously acquired information concerning the chemistry of the Earth's crust. Undiscovered elements of unguessed properties are not impossible. Thousands of the absorption lines in the Sun's atmosphere still remain unassigned to known chemical elements. The

spectroscopist believes, however, that these chemical indicators will ultimately be traced to some of the well known atoms, and that they do not indicate unknowns in the list of elements.

But what are the possibilities that the heavy elements have sunk below the surfaces of the stars and are beyond our range of spectroscopic analysis? Jeans argues strongly for the existence deep in Sun and stars of such ultra-uranium atoms. He surmises that they may be highly radioactive, like the known heavy atoms from radium to uranium, and that the ultimate source of stellar energy can be sought successfully in the spontaneous decay of heavy unstable elements in stellar interiors. The familiar elements of the Earth's crust are essentially permanent atoms which do not dissolve into radiation.

If the Earth contained any appreciable portion of the ultra-uranium atoms, according to Jeans, "it would be too hot for us to live on. The same circumstance endows the earth with a kind of melancholy immortality; it is exempt from the general destiny of matter to turn into radiation, and will continue to exist long after the stars have turned into darkness and all light and life have vanished from its surface."

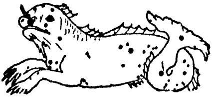
There is at present, I should say, just enough evidence for the existence of atoms heavier than uranium to justify our leaving the list of elements open at the heavier end.

5. The most abundant elements in the Earth's crust are oxygen, silicon, aluminium, sodium, calcium, iron, potassium, and magnesium. Russell has deduced from a study of the spectrum of the Sun the relative amounts of various elements in the solar atmosphere. The atoms occurring most frequently are as follows:

Atom	Relative Number	Atom	Relative Number	Atom	Relative Number
Hydrogen	300,000	Potassium	6	Titanium	0.15
Oxygen	1,000	Calcium	5	Vanadium	0.10
Magnesium	65	Aluminium	2.5	Copper	0.10
Nitrogen	40	Nickel	1.0	Zinc	0.08
Carbon	25	Manganese	0.8	Scandium	0.004
Silicon	20	Sulphur	0.5	Strontium	0.002
Sodium	15	Chromium	0.5	Barium	0.002
Iron	15	Cobalt	0.4	Germanium	0.001

6. We must consider the crust of the Earth chemically as a sample of the rest of the universe, especially if we accept any of those hypotheses of planetary origin that derive the Earth from the body of the Sun. But as representative star stuff, our planet may be misleading. If it originated from the Sun, it probably typifies only surface material. The terrestrial tests, moreover, leave the Earth's whole interior unknown. We have direct knowledge of only the surface of a planet derived from the surface of a star; the

heavier elements may have sunk. So far as our analyses go, they reveal marked similarity in the chemical constitution of the crust of the Earth and of the atmosphere of the Sun, the only great deviation being the superabundance of hydrogen at the Sun's surface. The discrepancy may be accounted for by the early escape of this lightest of elements from the Earth's weak gravitational control.

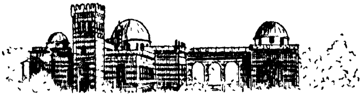


Atoms are ubiquitous. Their significance in the gamut of material systems comes from their widespread occurrence. On the other hand, molecules, the combinations of atoms, are specialized and localized systems. We find molecules, to be sure, on the surface of the Earth in amazing variety; the kinds of compounds are almost numberless in the organic and inorganic kingdoms. But throughout the visible universe, molecules are uncommon forms of matter, for planets appear to be rare phenomena, and in stars matter is mainly atomic and corpuscular.

Molecules exist, of course, in the wandering interstellar meteors and in some of the materials thrown out of the planetary system from the heads and tails of comets by explosion and radiation pressure. Also at the surfaces of the stars, especially those of low temperature, a few kinds of molecules are identified through absorption bands in the stellar spectra. But there are only a few, and below the surfaces, where most of the known material of the universe lies, there is no possibility of molecules. Atoms, although more stable, can exist inside the stars only in battered condition, for they are much ionized at the high interior temperatures. Even on the surfaces of stars like the Sun, where nearly all terrestrial molecules would be dissociated, the susceptible atoms are thoroughly stripped of their outer electrons.

* * *

It is worth noting that the normal condition of matter throughout the known universe is the highly ionized gaseous state, since nearly all recognized matter is in the form of stars. The usual state of the atoms of any chemical element is therefore not the customary neutrality we know on the Earth's crust and in our laboratories, but an ionized state, involving positively charged nuclei moving in a medium of radiation and free electrons negatively charged. Atoms are customarily struggling to capture loose electrons and become neutral, seeking to fill their retinues depleted by radiation and collisions and to satisfy the excess positive charges on their nuclei. The satisfied neutral atoms of the planetary crust and of the meteorites represent an exceptional cooled-off condition in the material universe. Very uncommonly, it appears, do the gases have the opportunity of liquefying and freezing into the waters, rocks, and organic phenomena of a planetary surface. Organisms, congealed out of normally gaseous substances, exist exotically in a world that is chiefly composed of hot and hungry atomic nuclei, of the electrons which they forever capture and lose again, and the radiant energy that arises from these violent activities below the surfaces of stars.



To this point an abbreviated classification of material systems would read as follows:

−5 . . . .
−4 Corpuscles
    α. . . .
    β. Light quanta
    γ. Electrons
    δ. Protons
−3 Atoms
    1 to 92 . . . (Hydrogen to Uranium . . .)
−2 Molecules
    1 to n (*e.g.*, H_2O, CH_2OH, N_2O)

with water, alcohol, and laughing gas suggested as typical molecular systems.

The molecules already recognized in Sun and stars through the intermediary of their spectra are the following:

- Titanium oxide
- Water
- Scandium oxide
- Hydrocarbon
- Cyanogen
- Zirconium oxide
- Magnesium hydride
- Calcium hydride
- Aluminium oxide
- Carbon
- Hydrogen
- Oxide of Boron

A number of these molecules appear in the hot stellar atmospheres in quite unusual form—the water vapor on the Sun being HO instead of the familiar H_2O, the hydrocarbon appearing as CH instead of the familiar methane gas, CH_4. It is probable that in the upper atmosphere of the Sun molecular forms exist other than those here listed, but their discovery is for the present beyond our analytical technique.

Under the peculiarly favorable conditions of low temperature, the aggregation of atoms and molecules into systems higher than molecules occurs readily in meteoritic and planetary bodies. Molecules grade imperceptibly into the crystals and colloids; and these two forms of molecular structures appear more or less definitely as units in higher aggregates. Realizing fully that there is no sharp demarcation from the simplest molecule of hydrogen to the largest terrestrial organism, we may propose the following tentative working classification as we come up through the microcosmos from the sub-microscopic world:

−2 MOLECULES
−1 MOLECULAR SYSTEMS
  I. Crystals
  II. Colloids
0 COLLOIDAL AND CRYSTALLIC AGGREGATES
  α. Inorganic substances (*e.g.*, minerals, meteorites, clouds)
  β. Organic substances (*e.g.*, organisms, colonies)

Molecular systems and colloidal and crystallic aggregates are narrowly localized, for there is, of course, even less chance for loose molecular associations at the surface of a star than for simple molecules. Organic colloids decompose so easily that they have a still more restricted cosmic distribution, unless we postulate, without just reason, the existence of numerous happily situated planets. Earth-like planets are about the only suitable domiciles, in a hard material world, for delicacies like plants and animals. Stars are too vigorously hot; nebulae are too thin and cold. Meteorites, comets, moons, and minor planets are all naturally hostile to organisms.

The reason has now appeared for assigning in the preceding chapter the number −4 to the class of corpuscles. It permits the assignment of Class 0 to colloidal aggregates. Thus it follows that practically all of the microcosmos is within the negative part of our series of classes. The macrocosmic systems—planets, clusters, galaxies, and the like—appear on the positive side.

Class 0 is a transition group. It marks the point where the organizing forces cease to be electrical and molecular and become gravitational. Some colloidal aggregates are microscopic, or even ultramicroscopic—many protophyta and protozoa, for instance; and some systems that normally fall in Class −1 are easily visible. In general, however, Class 0 is a transition point for dimensions as well as for controlling force; it marks a crossing from the microscopic to the macroscopic, from the essentially physico-chemical field to the realm that is predominantly astronomical; and at the crossing mineralogy, geology, and biology appear. It is here that the organic colloidal aggregates enter the cosmic picture.

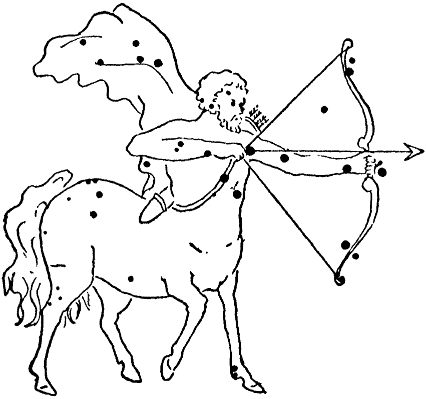
Chapter VI

NOTE ON ORGANIC COLLOIDAL AGGREGATES

OUR adopted working classification of material systems has thus far built itself into the following scheme:

- −5 . . . . .
- −4 CORPUSCLES
  - α. . . . . .
  - β. Light quanta
  - δ. Electrons
  - γ. Protons
- −3 ATOMS
  - 1 to 92 . . (Hydrogen to Uranium .
- −2 MOLECULES
  - 1, 2, 3, . . n
- −1 MOLECULAR SYSTEMS
  - I. Crystals
  - II. Colloids
- 0 COLLOIDAL AND CRYSTALLIC AGGREGATES
  - α. Inorganic (*e.g.*, minerals, meteorites)
  - β. Organic (*e.g.*, organisms, colonies)

It is to be observed that man and his societies, along with the other animals and the plants and their societies, appear parenthetically in Class 0, subclass β. Although the material of this subclass has been the subject of ninety nine per cent of all books and articles written since books and writing were devised, its place in our present scheme is quite incidental; its discussion should be correspondingly brief, because detailed analyses of the subclasses are not within the scope of this survey. It may, indeed, be appropriate, since organic colloidal aggregates have been so compendiously treated in many ways, to attempt here no ordering of the class, but to turn at once to more widespread cosmic phenomena.



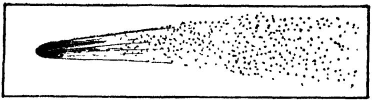
Chapter VII

SYSTEMS OF IRON AND STONE

HUNDREDS of millions of shooting stars daily burn their way into the Earth's atmosphere. Many millions of them are bright enough to be seen with the unaided eye. All of them might be catalogued; that is, their brightness, speed, color, length of train, and direction of motion could be recorded if the Earth's surface were sufficiently covered throughout the hours of darkness with competent observers. But the serious students are few, and we should consider ourselves fortunate if records of one millionth of the daily catch of bright meteors found their way into our permanent stock of knowledge.

The protective terrestrial atmosphere wards off the myriads of high-speed particles coming from interplanetary space. For the continuance of life on the planet it is well that they are stopped. Few of them get within twenty miles of the Earth's surface before their flight is ended and their materials are spread into the atmosphere as gas and ashes. For them it is a sudden termination of a long meteoric career—a few seconds of burning contact with a planet's atmosphere after billions of years of cold travel in space.

The meteor observer finds little rhyme or reason in the numbers, directions, and speeds of most of the shooting stars. On occasion, however, clear evidence appears of group motions and systematic tendencies, of the existence of meteoritic associations. He observes, for instance, meteors streaming from a particular section of the sky on a particular date each year. Let us consider briefly a few of these examples of material systems, and then look beyond the Earth's atmosphere for other types of meteoritic organization. Having got clear of the microcosmos and of the terrestrial surface, we shall find that gravitation is the system-maintaining agent.



On the ninth of February in 1913 a celestial phenomenon was widely observed that has since been designated as a "meteoric procession." A stream of fireballs (large meteors), first seen in western Canada, proceeded southeastward, nearly parallel to the Earth's surface, for more than five thousand miles, disappearing finally in the mid-equatorial Atlantic Ocean between Brazil and Africa. The procession was recorded by many on land and sea, and several astronomers have investigated the nature of the phenomenon on the basis of the submitted reports. It appears that four or five groups of meteors followed one another over this long path, each group composed of some exceedingly bright fireballs as well as numerous smaller meteors. The slowing down of the motion by the friction of the atmosphere and the interruption by the equatorial bulge of the Earth were the two chief factors in the capture of a remarkable stream of cosmic bodies. Perhaps only the lower members of the stream were trapped, the higher members passing the equator and ultimately escaping from the Earth's atmosphere.

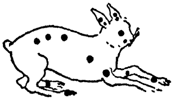
The significance of the procession of 1913 is the indication that these groups of meteoric irons or stones, which moved with a speed of a little less than ten miles a second across Canada and the northern United States, constituted a material organization, feebly held together, when out in space remote from stars and planets, by the mutual gravitational attraction of the individual bodies. The stream was three thousand miles or more in length. Of its thickness we have little evidence, because meteors higher than fifty miles would not become luminous in the exceedingly rarified atmosphere at their slow speed of ten miles a second.

On August 10, 1927, many residents of New England reported a very bright meteor. Systematic inquiry showed that the phenomenon had been observed from widely separated localities. It showed moreover that the times of apparition were not the same, and therefore that not one but many bright objects of meteoric nature had been observed by hundreds of people. The meteors, at least some of them, appeared to be travelling in parallel paths. The stream was so thin that no individual saw more than one or two of the bodies, but at least twenty eight different fireballs were traced in Dr. Fisher's study of the display. The streaming was in progress for more than an hour; the leaders must have been thirty thousand miles or more ahead of the end of the procession.

The foregoing accounts are descriptions of typical minor streams of shooting stars, which differ from the great meteor showers chiefly in dimensions. But there are still smaller and exceedingly compact systems. In 1863 Schmidt, observing in Athens, saw through a small telescope a swarm of bright meteors so close together that when seen without the telescope they appeared as a single object. Frequently on the plates of the Harvard collection of meteor photographs the meteoric trains are found to be double or multiple—an indication that two or more bodies may have been moving closely together in nearly parallel paths until deflected and extinguished in the Earth's atmosphere.

The term "minor comet" has been suggested for these meteoric groups. The name is appropriate. The more we study the comets and the annual showers of meteors, the more we appreciate the close connection between the two. The Perseid meteor shower in August and the Leonid meteor shower in November move in the paths once followed by Tuttle's and Tempel's comets. Halley's comet follows the path pursued by the Eta Aquarids, a stream of meteors that the Earth meets in early May.

The processions of fireballs and meteors that we designate as minor comets exhaust themselves in the Earth's atmosphere in a few seconds, minutes, or hours; but the great meteor streams, such as the Perseids, which move in long orbits around the Sun, are commonly strewn along the whole path and some of them appear in the Earth's atmosphere each year as the planet crosses their orbit in its annual trip around the Sun.



Not many catastrophes happen to the Earth, except those of its own making, like floods, earthquakes, and sudden continental shifts. The tidal disturbances by Moon and Sun are not catastrophic; they are steady and predictable. The inflowing radiation from the Sun and stars is not disturbing—it has no large surprises. The rain of meteoric ash adds little to the heat or mass of the planet. We roll along, in fact, so smoothly and quietly in the vacuum that is interplanetary space, keeping so well isolated from major bodies like the Moon, the planets, and the stars, and so well insulated from the speeding gases, irons, and stones, that nothing much happens cosmically.

In view of this quiet and predictable behavior, the meteoric procession of 1913 could with reason be called the most spectacular astronomical event in which the Earth has played a part since the great Leonid shower of nearly one hundred years ago. But this superlative claim is valid only with regard to well-observed phenomena. The Earth has had at least one other unpredicted adventure that has made a deeper impression. In 1908 it collided with what was probably the head of a small comet.

The Podkamennaya Tunguska Meteorite is the formidable name given to this fall of meteoric matter which struck the Earth with more effect than anything in recorded history. The place of the fall is in central Siberia—an uninhabited region between the rivers Podkamennaya Tunguska and Chuna. At about seven o'clock in the morning of June 30 the meteor proceeded from south southwest to north northeast, falling with such violence that the accompanying hot air wave was felt at remote distances; it scorched and destroyed the forest for many square miles, annihilated fifteen hundred reindeer, and dammed the river Ognia, throwing into it the cliffs from the banks. The numerous funnels in the ground at the place of fall indicate that this assailant was not a single body but a meteoritic association.

There is an indication that the Tunguska mass belongs to the meteor system associated with the Pons-Winnecke comet. It fell at the time of the closest approach of the Earth to the comet's orbit and the predicted source of the Pons-Winnecke meteors was, for the region of the Podkamennaya Tunguska, in the direction from which the meteorites came. The comet itself, however, at the time of the fall, was on the opposite side of its orbit.

Many comets have been known to divide, and some have had companion comets follow the primary at intervals of many years. If the Tunguska mass had been seen outside the Earth's atmosphere, it probably would have been considered a very small comet, and a mathematical discussion of its motion would have yielded an orbit similar to that of the Pons-Winnecke comet.

Here and there over the surface of the Earth are indications of other encounters of our planet with drifting stones and irons. A fifty-ton meteorite lies at the surface of the ground near Grootfontein, Southwest Africa. The great Greenland irons, which fell in prehistoric times, have been laboriously transferred to the American Museum in New York where many other huge meteorites are collected. The greatest impression on the Earth's surface definitely recognized as meteoric is Meteor Crater in the Arizona Desert.

The total number of recorded finds and falls of meteorites is still less than one thousand. Most frequently a meteoric fall involves more than one fragment, sometimes hundreds or thousands. The Pultusk fall in Poland in 1868, for example, resulted in the distribution over many square miles of more than a hundred thousand pieces. Such fragmentation of a meteor frequently occurs explosively in the Earth's atmosphere.

We have evidences of the organization of meteoric particles in meteor showers such as the Perseids, in "minor comets" composed of unrecovered fireballs, and in the showers of stones that are partially recovered. We have, therefore, no hesitation in treating meteor streams and ordinary comets as objects of the same kind in slightly different forms. The dark and bright diffuse nebulosities of interstellar space also have some of the properties of meteoric swarms, and consequently we propose the following subclassification:

+1 METEORITIC ASSOCIATIONS
    1. Meteor streams
    2. Comets
    3. Centralized diffuse nebulae

With increasing knowledge, and a richer body of good observations, we shall eventually have the means of classifying meteor streams. Perhaps we shall divide them into:

I. Annual showers, such as the Andromedes, Perseids, and Quadrantids
II. The sporadic meteoric processions (minor comets)
III. Double and multiple meteors, such as those recorded on the Harvard plates

There is need, however, for systematic meteoric observation of a precise and persistent sort before such differentiation will be useful in guiding theoretical and observational studies. And special equipment must be provided and trained personnel developed before the necessary precise observations can be persistently accumulated.

The meteoric streams might also be classified, on the basis of speed, as "hyperbolic" streams and "elliptic" streams. The division would, except in rare instances, segregate the cosmic meteors from those that are members of the solar system. If the speed exceeds forty three kilometers a second, after allowance for the orbital and rotational motions of the Earth and for the Earth's attraction, the orbit with respect to the Sun is hyperbolic. Bodies travelling with such velocities have come into the solar system from interstellar space, and are of the utmost importance in studying the chemistry of the universe. Meteors with velocities less than forty three kilometers a second are practically always members of the solar system; some of them are associated with existing or extinct comets, and others may always have been independent meteors. But again we must emphasize that knowledge of meteoric speeds is too fragmentary to make such a classification useful or even possible.

A working classification of comets that will be valuable in studies of their life histories can be based on the nature of the orbits:

(a) Elliptic; short periods, less than ten years
(b) Elliptic; long periods, between ten years and ten thousand years
(c) Parabolic (open orbits, eccentricity is unity)
(d) Hyperbolic (orbits more open, eccentricity greater than unity)
} non-periodic

(a) Forty five comets with periods less than ten years are now known; most of them have periods close to six years, or about half that of the planet Jupiter. In general they are small, faint, and worn out. Jupiter has had much effect on their orbits in the past and so clearly continues to influence their motions at present that they are rightly considered members of the Jupiter family almost as definitely as are his outer satellites. Of course the Sun is master of the short period comets and Jupiter is only the highly perturbing body, whereas the reverse is true of the Jovian satellites—Jupiter rules and the Sun disturbs.

The meteoric nature of comets subjects them to rapid attrition. Through the agencies of the Sun's heat and radiation pressure and the differential perturbations by the planets they tend to dissolve. For at least one comet, that bearing the name of Encke, there is an additional agency of decay—a resisting medium which is steadily shrinking the orbit and shortening the period. This comet now holds the cometary record of 3.3 years for the fastest complete turn around the Sun.

The ability to form tails upon approach to the Sun has practically been lost by the short period comet; its tail-forming potentialities have become exhausted through too frequent performance. The material remaining in the comet's head and envelope is not so susceptible to radiation pressure as formerly and therefore the dust and gases are not driven out in the form of an appendage to be ultimately ejected from the solar system. Cometary tails, we may note in passing, may be well classified on the basis of curvature, with its implication of the speed with which material particles are driven from the head by light pressure from the Sun; but most of the observed comets are only telescopic objects, and have brief tails, if any at all.

The group of short period comets appears to be doomed to dissipation into thin meteor streams. Already a few have persistently failed to return as comets to the neighborhood of Sun and Earth; within our brief interval of astronomical studies they have been transformed.

(b) More than sixty comets are known to have periods between ten and ten thousand years. Some of them are very celebrated objects. Halley's comet, for instance, has more than twenty appearances on record, and has in times past played a significant and sinister role in human superstition and behavior. Its mean period is seventy seven years, but it is buffeted about by planetary perturbations, coming sometimes a year or so sooner than average time, and sometimes a year or so later. The orbits of many long period comets are very elliptic and their inclinations to the plane in which the planets move are high. For protracted intervals they are free from planetary disturbance and from the devastating radiations of the Sun. Circumstance therefore favors longer life for them than for the comets of short period.

(c) The "parabolic" class of comets is populous, containing three fourths of all those in our records. It includes not only periodic comets whose orbits are so long that an open parabola fits the observed positions when near the Sun as closely as a closed ellipse, but also those for which the observations are so rough or so few that only approximate orbital elements can be obtained. Actually, of course, no orbit is strictly parabolic, with eccentricity exactly unity. The parabola is used merely as the simplest curve for representing the motion. It is almost certain that the majority of the orbits are elliptic, with periods in excess of ten thousand years. Strömgren and others have shown that probably all observed comets are really members of the solar system, which would imply, of course, that parabolic and hyperbolic orbits do not exist.

(d) The "hyperbolic" comet is, however, not completely unknown. Planetary perturbations may either reduce or enlarge the orbit—may retard or accelerate the motion. If the net increase in velocity is sufficient, a comet moving in an elliptic orbit is thrown out of the solar system. The eccentricity becomes greater than unity, the motion changes to a hyperbolic course, the comet drifts clear of the planetary system and thenceforth travels alone through interstellar space. Among the five hundred or so that have been computed not more than ten orbits are known to be hyperbolic; probably all of these orbits were elliptic until Saturn or Jupiter interfered.

If an external observer could look at the cometary family of the Sun, seeing all members, probably four features would be particularly striking.

1. The total population of objects that a terrestrial observer would recognize as comets (if he had a chance to see them at fairly close range in the solar neighborhood) is of the order of hundreds of thousands. Only about half a dozen of them, mostly telescopic, are seen from the Earth each year, although probably twenty five come annually to perihelion (the point of the orbit that is nearest the Sun) at distances less than that of Jupiter.[1]

2. All but a few thousand of the comets spend most of their time outside the orbit of Neptune. They move in all directions, forming around the solar system a tenuous shell faintly reminiscent of a planetary nebula.

3. The short period comets, almost without exception, move in orbits not highly inclined to those of the planets—an indication that they once moved in much greater orbits but, having low inclinations and coming near the major planets, have become trapped and reduced. Comets with highly inclined orbits have escaped the planetary capture mechanism.

4. The gradation is continuous from a body easily recognizable as a comet to the myriads of minor meteor groups. In the last analysis a single meteoric dust grain, as long as it is large enough to be controlled by gravitation and not dominated by light pressure, has the characteristics and privileges of the greatest comet.

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[1] Estimates by Russell, Dugan, and Stewart.

The rapid deterioration of comets under the gravitational and radiational stresses of the solar system is a matter of deep interest. Many cosmogonists would prefer to consider planets and comets of the same age and of the same origin. Planets, however, cannot well be younger than two thousand million years; and Bobrovnikoff has brought forward evidence that our horde of comets must have come into existence in the past million years or so. The rate of decay, which can be estimated from observed changes in the brightness of periodic comets, appears to be so rapid that the whole cometary family is doomed to early extinction. With the tentative suggestion that the Sun may have picked up the contemporary comets and perhaps much meteoric material during a relatively recent passage through a nebulous region of space, we must leave this mystery of the origin and former home of the comets to future investigators.

The diffuse nebulae, dark and bright, will appear in two widely different places in the general classification of material systems. Nebulosities with sharp boundaries, or with obvious centralization, rightly belong in the class of meteoritic associations. A centralization or a sharp boundary indicates gravitational organization, and it is now commonly admitted that the obscuring cosmic clouds are chiefly composed of fine dust—that is, of meteoric matter. Frequently associated with the dust and larger particles in such diffuse nebulae are quantities of gas, which under proper irradiation from neighboring hot stars appears bright and shows a gaseous spectrum.

Evidence for the theory that the dark nebulosities are exceedingly large and sparse "dust and gravel banks," irregularly strewn through interstellar space, is found in the study of star motions. Fine dust is a most effective light screen —much more effective than gas. For example, a very small puff of smoke will cut down the light of a star more than the Earth's gaseous atmosphere, hundreds of miles in thickness. The dark nebulosities are detected by the blocking of the light of distant stars. It can be shown that if gases instead of dust were involved in these extensive obscurations, the total mass of material necessary would be so great that it would dominate gravitationally the motions of all stars in the neighborhood; but no abnormalities of star motions are noted in the nebulous regions of the Milky Way. On the other hand, fine meteoric dust is so efficient as an obscuring agent that it would require no more material than that of one average-sized star to form an opaque dark nebula covering an area two parsecs[1] in diameter. Such a nebula, of course, would not measurably affect stellar motions.

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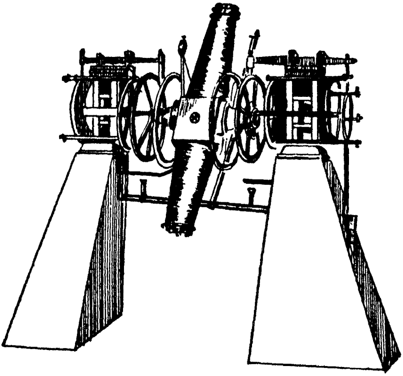
[1] A parsec is equivalent to 3.26 light years, or approximately twenty million million miles.

The great Orion Nebula is both bright and dark. It is undoubtedly composed to a large extent of meteoric matter. Is it not a great nest of comets and meteor streams? If the solar system should pass through such a region (and some seven or eight million years ago it was not far from the Orion Nebula) it would probably come away generously outfitted with clouds of meteoric matter and for a few thousand years would present a brilliant show. Gradually the comets would fade, a few would be ejected from the system, and the many others would slowly degenerate into a more dispersed form of meteoritic association.



Chapter VIII

MOONS

IN THE seventh day of January in the present year [Galileo wrote during those first glorious weeks of the astronomical telescope in 1610] when I was viewing the constellations of the heavens through a telescope, the planet Jupiter presented itself to my view, and as I had prepared for myself a very excellent instrument, I noticed a circumstance which I had never been able to notice before, owing to want of power in my other telescope, namely, that three little stars, small but very bright, were near the planet; and although I believed them to belong to the number of the fixed stars, yet they made me somewhat wonder, because they seemed to be arranged exactly in a straight line, parallel to the ecliptic, and to be brighter than the rest of the stars, equal to them in magnitude . . . I scarcely troubled at all about the distance between them and Jupiter, for, as I have already said, at first I believed them to be fixed stars; but when on January 8th, led by some fatality, I turned again to look at the same part of the heavens, I found a very different state of things, for there were three little stars all west of Jupiter and nearer together than on the previous night.

A few further nights of excited observing and checking of positions, and Galileo had found a system within a system, found four small bodies swinging around Jupiter as Venus and Mercury and the other planets are moving around the Sun.

The new system of moons resembles the Earth-Moon system, Galileo noted, but also differs from it:

> . . . for now we have not one planet only revolving about another, while both traverse a vast orbit about the Sun, but our sense of sight presents to us four satellites circling about Jupiter, like the Moon about the Earth, while the whole system travels over a mighty orbit about the Sun in the space of twelve years.

It was nearly three hundred years after the discovery of the Galilean satellites of Jupiter before the modern telescopes began to sketch in the full picture of the Jovian system. Barnard at the Lick Observatory found the fifth satellite, a faint and difficult object, nearest of all to the planet and probably not more than a hundred miles in diameter. Photography entered the field of satellitic research early in the present century, and four more small satellites were found in the

JOVIAN SATELLITES

Name	Year and Discoverer	Mean Distance	Period of Revolution	Diameter
		kilometers	*d h m s*	*kilometers*
5th	1892, Barnard	181,200	0 11 57 22.70	160?
Io	1610, Galileo	421,300	1 18 27 33.51	3,730
Europa	1610, Galileo	670,500	3 13 13 42.05	3,150
Ganymede	1610, Galileo	1,069,300	7 3 42 33.35	5,150
Callisto	1610, Galileo	1,881,000	16 16 32 11.21	5,180
6th	1904, Perrine	11,450,000	$250^d.68$	130?
7th	1905, Perrine	11,730,000	260.06	40?
8th	1908, Melotte	23,500,000	738.9	25?
9th	1914, Nicholson	24,100,000	745.0	25?

Jupiter family. The sixth, seventh, and ninth were shown on plates made at the Lick Observatory, the eighth at Greenwich. With its secondary bodies of various sizes, distances, and periods, Jupiter, on a smaller scale, strikingly mimics the solar system.

The system of satellites, the accompanying table shows, differs in arrangement from the Sun's family of planets in one conspicuous feature—that of pairing. In Jupiter's system the sixth and seventh, and the eighth and ninth satellites form two pairs. A comparable situation in the solar system would be found if the Earth and Venus had orbits of essentially equal size, or if Uranus and Neptune were at the same distance from the Sun. Another difference is of interest: Jupiter cannot have moons much more distant than the eighth and ninth without the Sun's stealing them away and adding them to the swarms of asteroids or comets; but the Sun is so completely isolated from other stars that numerous planets more remote than Neptune and Pluto could exist, and carry on normal and orderly planetary lives, without danger of gravitational temptation and capture by neighboring stars.

In many respects the contrast is sharp between the satellite system of the Earth and that of Jupiter. The Earth-Moon system is unique among the planets in the relative sizes of the two bodies. Our system approximates a double planet, for the Moon's diameter is one fourth that of the Earth, and its mass is so appreciable—more than one per cent of the total mass—that the Earth, through the Moon's persistent attraction, must circulate monthly around a common center of gravity some three thousand miles from the center of the Earth. There are, to be sure, combinations of nearly equal bodies among the stars, especially among those recognized as eclipsing binaries. The stars, however, are in another class—they are objects of a higher order, more active, more energetic—radiating gaseous bodies rather than parasitic cold and crusted planets.

Jupiter, unlike the Earth, is twelve thousand times as massive as its largest moon and probably fifty thousand million times as massive as the outermost. It is effectively the master of its flock, while the Earth plays more the role of a domineering companion. The contrast in numbers and relative sizes of moons suggests that the systems have arisen in different manners—the Earth-Moon system by fission in the early days of the Earth, and the Jovian family partly through disruption by a passing body (was the Sun the disrupter in the days when Jupiter's orbit was long?) and partly, perhaps, by the capture of the outermost moons from the contiguous zone of roving asteroids. The eighth and ninth satellites of Jupiter move in retrograde orbits, violating the custom in the solar system that rotations and revolutions are in the counterclockwise direction as seen from the north.

There is little likelihood of new examples of the Earth-Moon type of satellitic system among our planets. Among them there is no suggestion of planetary instability verging on fission, no prospective tidal disturbance of sufficient magnitude to disrupt well-seasoned planets.

The Jovian type of satellitic system is, however, common. For example, the moons of Mars are relatively minute compared with their primary. Discovered visually with the large telescope of the Naval Observatory in Washington, they are difficult to see and photograph because of their intrinsic faintness and their proximity to the bright surface of Mars. The high speed of the inner moon, Phobos, which circles around the planet more than three times while the planet is rotating once, provides a very puzzling problem for those who would account for details of the origin of the planetary systems on the basis of current cosmogonic theory. Have these tiny bodies been pulled or ejected from the primordial

Martian Satellites

Name	Year and Discoverer	Mean Distance	Period	Diameter
		kilometers	*d h m s*	*kilometers*
Phobos	1877, Hall	9,380	0 7 39 13.851	15?
Deimos	1877, Hall	23,460	1 6 17 54.9	8?

Martian surface, or have they been enticed gravitationally out of the adjacent asteroid belt? Their diameters of five or ten miles, as indicated in the tabulation, are like those of the minutest known asteroids, and they may be no larger than some of the particles that make up the head of a great comet.

The four moderate-sized Uranian moons, some of whose properties are here tabulated, appear in a system of the Jovian type. Their motions, all in one plane athwart the orbital plane of the Earth, which is near the principal plane of the whole solar system, mark these Uranian satellites as a peculiar lot. But the equator of the planet itself is similarly inclined to the principal plane—the whole system is tipped at a high angle. Proper respect is paid Uranus by its satellites, but no regard is shown by planet or satellites for the rotational customs of the inner solar system, where the orbits are all near the principal plane and the directions of rotation and revolution are nearly all alike.

Uranian Satellites

Name	Year and Discoverer	Mean Distance	Period	Diameter
		kilometers	*d h m s*	*kilometers*
Ariel	1851, Lassell	191,700	2 12 29 20.8	900?
Umbriel	1851, Lassell	267,000	4 3 27 36.7	700?
Titania	1787, W. Herschel	438,000	8 16 56 26.7	1,700?
Oberon	1787, W. Herschel	586,000	13 11 7 3.5	1,500?

Neptune with its single unnamed satellite is of the Jovian rather than the terrestrial type, though it approaches the latter more nearly than any of the other planets. The satellite appears to be not more than one thousandth as massive as its primary.

A third and most astonishing type of satellitic system is presented by Saturn. Here we have first a Jovian type, with satellites as shown in the accompanying table; but along with these very ordinary satellites is the extraordinary ring system composed of innumerable millions of moonlets or meteoric particles.

Saturnian Satellites

Name	Year and Discoverer	Mean Distance	Period	Diameter
		kilometers	*d h m s*	*kilometers*
Mimas	1789, W. Herschel	185,700	0 22 37 5.25	650?
Enceladus	1789, W. Herschel	237,900	1 8 53 6.82	800?
Tethys	1684, J. D. Cassini	294,500	1 21 18 26.14	1,300?
Dione	1684, J. D. Cassini	377,200	2 17 41 9.53	1,200?
Rhea	1672, J. D. Cassini	526,700	4 12 25 12.23	1,750?
Titan	1655, Huygens	1,220,000	15 22 41 26.82	4,200
Hyperion	1848, G. P. Bond	1,480,000	21 6 38 24.0	500?
Iapetus	1671, J. D. Cassini	3,558,000	79 7 56 24.4	1,800?
Phoebe	1898, W. Pickering	12,930,000	$550^{d}.44$	250?

Despite a keen eye and a keener imagination Galileo was as much baffled by the Saturnian system as he was satisfied with his account of Jupiter and the four moons. Christiaan Huygens, the real discoverer of the rings as rings, has eloquently explained how Galileo's telescope failed in power and definition to unravel the mystery of Saturn and how he himself partially solved its problems:

> When Galileo made use of the telescope, noblest invention of our Belgic nation, for observation of the heavenly bodies, and before all other men, disclosed to mortals those very celebrated phenomena of the planets, the most wonderful of his discoveries, it would seem, were those relating to the star of Saturn. For all the other phenomena, though justly calling for our wonder and admiration, were still not of a kind to make it necessary to question strongly the causes of their existence. But Saturn's changing forms showed a new and strange device of nature, the principle of which neither Galileo himself nor, in all the time since, any of the astronomers (with their permission be it said) has succeeded in divining. Galileo had first seen this star shining, not as a single orb, but in what seemed to be a triple form, as two smaller stars in close proximity to, and on opposite sides of, a larger star, in line with its center. And seeing this form continue for nearly three years with no change, he had become firmly convinced that, just as Jupiter was provided with four satellites, so Saturn was provided with two, which, however, had no motion, and so would always cling to the sides of Saturn in the same position. But when Saturn came forth alone, quite destitute of his former retinue of satellites, Galileo was obliged to change his opinion. Astonished by what he saw, he tried to reach by conjecture the cause of the appearance, and made a few predictions as to the time when the former phase was due to recur. But, it was shown by the event, these predictions were not then fulfilled according to his expectations, nor, it appeared, was Saturn satisfied with having only two aspects. For a succession of other strange and marvelous forms was revealed, which I find first

described by Josephus Blancanus and Franciscus Fontana—forms of such unusual appearance that they were considered by many as a mockery of the eyes, shapes adhering to the lenses rather than existing in the heavens; but after the same forms had been seen by more, it became clear that it was no false evidence that revealed them.

And so I was also drawn by an urgent longing to behold these wonders of the heaven. But I had only the ordinary form of telescope, which measured five or six feet in length. I, therefore, set myself to work with all the earnestness and seriousness I could command to learn the art by which glasses are fashioned for these uses, and I did not regret having put my own hand to the task. After overcoming great difficulties (for this art has in reserve more difficulties than it seems to bear on its face), I at last succeeded in making the lenses which have provided me with the material for writing this account. For upon immediately directing my telescope at Saturn, I found that things there had quite a different appearance from that which they had previously been thought by most men to have. For it appeared that the two neighboring appendages clinging to Saturn were by no means two planets, but rather something different, while, distinct from these, there was a single planet [the satellite Titan], at a greater distance from Saturn and revolving around him in sixteen days; and the existence of this planet had been unknown through all the centuries up to that time.

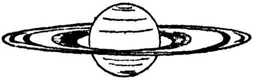
After Huygens' discovery of the great satellite Titan, the true form of the appendages of the planet, the inclination of the system of rings to the ecliptic, and the reason for the various disappearances that Galileo observed, it took the genius of Maxwell and Keeler to prove that the rings are composed of myriads of moons; and it required the discoveries of five other astronomers to complete the list of satellites.

The classification of satellitic systems is simple and needs no further subdivision:

+2 Satellitic Systems
  I. Earth-Moon type
  II. Jovian type
  III. Saturnian type

The classification is clearly on the basis of structure.

Except for calling attention to the diversity in the number and arrangement of these tertiary bodies in the solar system, the classifying of satellites can serve little purpose in the study of the universe at large. Unfortunately we shall probably never have occasion to study the moons of the planetary dependents of other stars.



Contemplating the types of satellitic systems, we are led to ask ourselves some satellitic questions, a few of which have been foreshadowed in the preceding pages:

What contribution have the comets, and especially the asteroids, made to the membership of the families of moons? The tiniest satellitic bodies known are those in the Martian and Jovian groups, on either side of the zone of asteroids. We have, therefore, grounds for suspecting that there have been planetary raids into asteroidal territory.

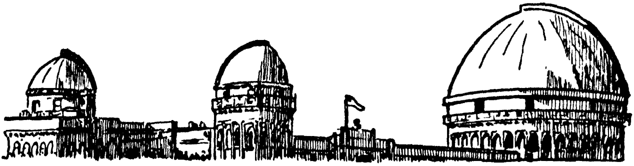
Have we found all the satellites of the planets? The existence of tenth members in the systems of Saturn and Jupiter has been strongly suspected. but observations of the suspected bodies are insufficient to provide orbits that would insure rediscovery. Satellites one or two hundred miles in diameter would be exceedingly faint and difficult to find for any planet beyond Saturn.

Are there meteor-sized bodies circulating around some of the planets—around the Earth, for instance? Temporarily, perhaps, but lunar perturbations would not permit stable orbits.

Are there vestigial or perhaps temporary rings around any planet other than Saturn? In the particles involved in producing the zodiacal light we have perhaps the Sun's dim analogue to Saturn's rings.

Were the materials that now compose the rings of Saturn at some past time the substance of one or more satellites that have suffered disruption gravitationally? The Darwin-Jeffreys theories of the Earth-Moon system intimate some such fate in the remote future for our own satellite, if tidal effects of Earth, Moon, and Sun remain essentially as potent as now.

The deepest question incited by considerations of the various types of satellitic system is of course the inquiry into the origin of the solar system itself. An ambitious task is this answering of questions on the genesis of a planetary system composed of such remarkably dissimilar objects—gaseous star, high density Earth, luminous comets, meteoritic rings, asteroidal belt, nickel-iron meteorites, coronal streamers, and interplanetary electronic flows. The origin of various moons is but a by-problem in this more serious intricacy.



Chapter IX

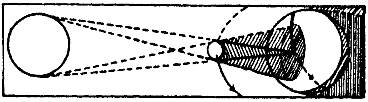
STARS, WITH PLANETS AND WITHOUT

A PLANETARY structure, as I choose to define it, is a system composed of a star with a permanent entourage of gravitationally controlled particles. A moment's thought suffices to show that most of the visible universe comes within this category. The planetary structure that has the Sun for its dominating central mass has an envelope of planets, asteroids, and comets—a very numerous family, for the asteroids of all sizes must be numbered by thousands, and comets by hundreds of thousands. There may be very few planet-endowed systems throughout the galaxies; certainly most of the double stars are free of permanent planetary or cometary families because of devastating perturbations. But even if there are only a few stars in the universe in the condition of our Sun, yet we shall see that all stars must be regarded as planetary structures.

It is difficult to conceive of a star without a corona, and coronal streamers are to some extent gravitationally controlled. We look to the cosmic meteor, however, for definite assurance that all stars are family stars. There is growing evidence that a large proportion of the meteors encountered by the Earth's atmosphere travel with more than parabolic velocity—that is, they strike the Earth's atmosphere with speeds greater than those possessed by freely falling bodies in the solar system. Such particles have come from interstellar space, and their original speeds compound with those generated by the Sun and planets.

Millions of cosmic meteors, we believe, daily strike the Earth—an extremely minute target in the void of interplanetary space; billions must be rushing past the Sun and other stars. Some are trapped in stellar atmospheres, slowed down, and permanently captured from the roving interstellar hordes. Some of the small dust particles ejected from comets' tails go into space at increasing speeds, never to return to the solar system. They become members of the world of interstellar meteors—material for the building up of stellar envelopes. The zodiacal light, which at certain times of the year appears clearly as a faint glow extending upward from the western horizon, is doubtless one indication of the Sun's innumerable family of meteorites, gas, and meteoric dust.

I have perhaps taken too many words to emphasize a rather obvious point—that presumably all stars are planetary structures, as here defined. Some may have planets and, at least for a time, their own systems of comets. But most stars probably have no secondary bodies larger than meteors in their gravitational organizations. A few have such dense accumulations of surrounding gases and meteoric particles that the envelopes themselves are luminous.



A general one-dimensional working classification thus develops:

+3 PLANETARY STRUCTURES
- I. Stars, with meteors
- II. Stars, with planets, comets, and meteors
- III. Stars, with nebulous rings or envelopes
  - (I) Planetary nebulae
  - (II) Ring nebulae

Probably most of the stars must be placed in the first subclass. Our solar system appears in the second division. A hundred or so nebulous objects, marked in general with symmetry of form and peculiarity of spectrum, appear in the third. The only difference between ordinary planetary nebulae and ring nebulae is that in the latter the central star appears detached from the surrounding envelope or ring. The two types are doubtless of similar origin and differ only in structural details. Novae, the explosive "new stars," might be assigned to this third subclass, at least those for which the spectrum changes from a stellar to a nebular type. Stars of the peculiar Wolf-Rayet type also are allied with the bodies in this same division.

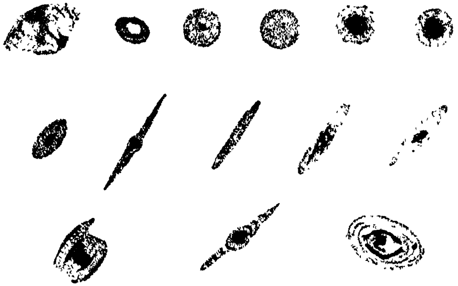
In going from the class of satellitic systems to the class of planetary structures, a definite advance has been made in average dimensions and average mass. There may be some planetless subdwarf stars no larger than Jupiter, but, so far as our records go, these lilliputians are uncommon. The average planetary structure is many times greater in size and mass than the satellite systems we know.

* * *

Other classifications of stars come to mind. There is the rough division into dwarfs and giants, with the supplementary categories of subdwarfs and supergiants. The best known and most used classification of stars is, of course, the one that arranges them according to spectral type. The forty or fifty individual spectral classes are based on observable differences in temperature and conditions of ionization in the stellar atmospheres. But these classifications of spectra refer essentially to the stars themselves and not to the stars plus their dependents—to bodies and not to systems.

The bringing together of planetary nebulae and systems of planets on the basis of gravitational operation has a history. In the early days of nebular discovery and discussion some objects were classed as green nebulae, some as white, in indication of the predominant radiation. Among the green nebulae were many of symmetrical form, their images disc-like rather than stellar points. In appearance the nearest analogy to these sidereal objects was afforded by the surfaces of the planets of the solar system; hence the nebulae were conveniently called "planetary," and the name has remained. The objects were of course always recognized as not planetary in dimensions; they are of enormous size—billions of times the volume of the Earth. Formerly they were grouped with irregular and diffuse nebulae. The present classification brings the planetary nebulae and their near allies, the ring nebulae, into the same general sidereal class with our planetary system. The convenient name has become appropriate.

By listing one kind of true nebular organization in the class of planetary systems and allying other nebulosities with the meteoritic associations, the usefulness of a general classification in clarifying details is illustrated. There has been a tendency heretofore to lump together all diffuse and gaseous nebulae, whether of the planetary type or irregular, whether luminous or dark. There are overlapping examples, of course, and the assignment of an object to a class will therefore not always be clear or unambiguous; but assuredly there is justification for recognizing the heterogeneous nature of the gaseous nebulae and for assigning them to various places. Moreover, we have not finished with the consideration of such nebulae; they will appear later in still another class, cosmically in a more significant role.



Chapter X

DOUBLE AND MULTIPLE STARS

LOOKING over our survey of gravitational systems we find, to this point, in order of increasing mass and dimensions,

+1 Meteoritic Associations
+2 Satellitic Systems
+3 Planetary Structures

that is, meteors, moons, and family stars. The next step leads to the prevalent stellar duplicity.

The most logical classification of double and multiple stars appears to be one based on structure, with subdivisions as follows:

+4 Double and Multiple Stars
- I. Close systems
  - (a) Eclipsing
  - (b) Spectroscopic
- II. Visual systems
  - (α) Gravitational
  - (β) Optical
- III. Moving pairs and Multiples

The class of double and multiple stars clearly illustrates the use of the notation I have chosen for various subdivisions of the major classes of material systems. The Arabic numerals designate the division and subdivision of systems according to mass and dimensions. They have been used, therefore, for the major classes. They appear within Class −3, Atoms, to indicate the various atomic structures in order of increasing mass and complexity. The three subclasses of Meteoritic Associations—meteor streams, comets, and centralized diffuse nebulae—also bear this Arabic notation, because meteor streams differ from comets chiefly in being smaller, and diffuse nebulae are obviously greater in size and mass than either, but perhaps do not differ from them fundamentally in other respects.

The Roman numerals are used to indicate structural differences such, for instance, as those between the Earth-Moon type and the Saturnian type of satellitic system, and between the main subdivisions of double stars.

The letters in Roman type distinguish the classes that seem to differ chiefly or entirely because of the relative position of the observer. The close double stars that show periodic eclipses differ from other close double stars only because we are for the former near the orbital planes in which the components revolve around their common center of gravity. From a suitable position in space every spectroscopically discovered double star could be observed as an eclipsing binary. This classification on the basis of appearance is wholly geocentric, and is of empirical interest only; it may be useful as a step in research, but is not especially significant in the understanding of systems.

The Greek letters are used to designate the differentiations based on the nature of the systems. The division is more fundamental than that based on structure, or at least it appears to be. Thus, quanta and electrons are quite different kinds of corpuscles; gravitational and optical double stars are, in like manner, fundamentally different sorts of visual systems.

Distinctions between the various types of subclassification are not always clean cut, and occasionally the choice of notation has been arbitrary. For instance, the galactic clusters, described in Chapter II, are classified with Roman letters because apparent form and apparent concentration are the most important factors in separating the various types; but true structural differences from one type to another are also present. The globular clusters are classified in Chapter XI on the basis of structural differences; but appearance—that is, position with respect to the observer—as well as structure and massiveness, is a factor in separating the classes. Notwithstanding these occasional ambiguities, the general use of a varied notation for the varied kinds of subdivision of the major classes seems worth maintaining. The ambiguities will not delude us much of the time. A strictly uniform procedure, such as a classification altogether in terms of increasing mass or dimensions within each major class, is certainly inadvisable and, in fact, impossible. For a working classification measurable properties other than dimensions or mass frequently prove to be more useful.

Double stars are actually known by the tens of thousands. We estimate that there are undiscovered millions among the stars that have been photographed. Probably one star out of every three or four in our Galaxy is double or multiple. This twinning and tripling and multiplying of stars immediately strikes the student of cosmic affairs as the stellar response to internal strain. The partition of a star may arise in various ways; but current studies of stellar forms and motions suggest that close binaries have come about almost exclusively through the fission that becomes necessary to a stellar mass when its speed of rotation becomes too great.

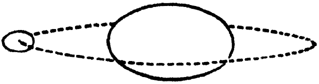
Rotational fission can account in a straightforward way for the birth of close double stars; but it is not necessarily the mode of genesis for visual doubles, in which the components, though connected by gravitational ties, are separated by hundreds of millions of miles. Such binaries may have developed from close pairs, driven apart by long continued tidal action and perturbations of passing stars; but it is more probable, I believe, that the components originated as widely separated stars in some primal cluster or nebula. But whatever their origin, they and the close binaries are gravitational systems—larger in mass, on the average, than a single star with its envelope of meteors, comets, or nebulosity, and smaller than those stellar groups recognized as galactic clusters.

Visual double stars are so called because the individual components can be separately seen. In contrast, the spectroscopic and eclipsing binaries remain unresolved even with the greatest telescopic power. Zeta Ursae Majoris, the star of second magnitude at the bend of the handle of the Big Dipper, was the first recognized visual binary, discovered nearly three hundred years ago. The significance of double stars in astronomy was not generally recognized, however, until near the end of the eighteenth century, when Sir William Herschel began his systematic surveys and found, through repeated measures extending over many years, that these pairs of stars are more than mere optical doubles arranged by chance along the line of sight.

Knowledge of double stars grew rapidly. A hundred years ago Struve already had catalogued more than three thousand double systems (a few of them multiple), and a century's observation has since provided material for the study of motions and the calculation of orbits, masses, luminosities, and distances. Celestial mechanics spread from the planets to stellar systems. Stars began to be weighed in terms of the Sun. The same law of gravitation was shown to control the motions of remote double stars and the planetary activities in the solar system.

As the double star observer reaches to increasingly fainter stars, he must diminish the adopted upper limit of angular separation of the components or he will include in his working list too many false pairs. In searching for doubles among first magnitude stars, he might well adopt a separation of a minute of arc as a practical working limit; for twelfth magnitude stars, a second of arc would be appropriate. If wider limits are taken, the resulting "discoveries" will be much more numerous, but his catalogue will be more frequently marred by the inclusion of the essentially worthless optical doubles.

The periods of revolution in the visual binary systems vary from a few years to a hundred thousand years or more. For many of the shorter period binaries the relative motions of the components can be detected through micrometric measurements extending over a few years. Many doubles have made several complete revolutions since their discovery. When the periods are in excess of a hundred years we have in general only partially observed orbits. And when a period exceeds a thousand years the relative motion of the components is immeasurably small, and chiefly a matter of inference; that such a pair is certainly a physically connected double can usually be learned only through the circumstance of a common motion of the components with respect to neighboring stars.



Many of the best known bright stars are visual doubles. The most famous of long period variables, Mira Ceti, has a faint and rather mysterious blue companion of relatively recent discovery. The star of greatest apparent brightness, Sirius, has a faint companion of extraordinarily high density that is not much larger than the Earth in diameter but nearly equals the Sun in mass; its discovery is described below. Procyon has a similar faint companion; Capella and the nearest of all stars, α Centauri, are both doubles in which the components are of somewhat similar brightness. In the system of α Centauri there is also a third member—a pronounced dwarf—which at the present time appears to be slightly nearer the Sun than the two bright components and is appropriately named Proxima.

Triple systems such as α Centauri are not uncommon, and occasionally the multiplicity is of higher order. Castor, for instance, is composed of two second magnitude stars of the whitish spectral class A0. They revolve around their common center of gravity in a period of several centuries. Each of these bright stars is itself a close double—a spectroscopic binary of short period. A little more than a minute of arc away from the pair of pairs is a third member, of spectral class M0, a red dwarf star that is also a spectroscopic binary. Moreover, the components of the dwarf pair move about their center of mass in an orbit so oriented in space that for terrestrial observers periodic eclipses occur. We can, thanks to these eclipses, compute that the two dwarfs are each 2.6 times as dense as the Sun and one half as massive, with six tenths of the solar radius. The system of Castor is therefore not the single star that the casual observer might suppose, but a multiple system of six components.

The true visual binaries may be classified:[1]

I. α Centauri class, with components of similar brightness and period of revolution less than a century
II. Sirius class, with one component much fainter than the other, period less than a century
III. 61 Cygni class, with magnitudes similar, components widely separated, and the period in excess of a century
IV. Most common class, with components widely separated, magnitudes the same or different, no orbital motion as yet shown
V. Capella class, binaries discovered spectroscopically and not resolved visually except through the intermediary of the interferometer

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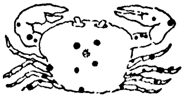
[1] See Henroteau, "Handbuch der Astrophysik," vol. 6, p. 340, 1928.

Binary stars have been and will continue to be highly important in problems of stellar evolution. Our knowledge of stellar masses, for instance, comes largely from binaries; the derived relation of mass to intrinsic luminosity also depends primarily on these systems. The work of discovering, measuring, and computing has been heavy, but thoroughly justified by results. Incidentally, the observation of visual double stars is one of the few astronomical fields left to visual methods. Nearly all astronomical observations once dependent on the visual telescope and the human eye have been taken over by the photographic telescope and the sensitive though impersonal photographic plate.



The discovery of the duplicity of Sirius was not the ordinary routine finding of a double star—a simple telescopic observation of two stars unusually close together. The new companion was discovered gravitationally long before it registered itself optically. It was a creation of the mind, we might say, before it materialized. The unusual nature of the discovery and the importance of the companion in physics, geometry, and astronomy possibly justify a brief reference to astronomical history.

To the German astronomer Bessel, at Königsberg, goes the credit for a new method of sidereal exploration and for the inferential discovery of the faint companions of Sirius and Procyon. That Sirius has a relatively large motion across the sky with respect to remote telescopic stars had long been known. It moves toward the southwest 1″.3 in a year—an amount equal in fourteen hundred years to the angular diameter of the Moon. The conspicuous annual motion did not lessen its usefulness in Bessel's astronomical work on the accurate determination of time. With its motion precisely known, the star is just as valuable for correcting the errors of our observatory clocks as if it were stationary.

A century ago, however, the regularity of the motion of Sirius became doubtful. Bessel was a persistent and penetrating student of time determinations and stellar motions. His first suspicion of inconstancy in the motion of Sirius dated from about 1835. Irregularities greater than the observational errors appeared in the corrections to the clock time, which were registered daily at the Königsberg Observatory with every observed passage of Sirius across the meridian. Bessel traced out the course of the irregularities and in 1844 remarked that "if we were to regard Sirius and Procyon as double stars, the change in their motions would not surprise us." The motion of Sirius around the center of gravity of itself and a companion star, he reasoned, should give rise to the observed irregularities. Gravitational law had revealed what the telescope could not show. A few years later Peters analyzed the observations of Sirius further and determined that the deviations from uniform motion in a straight line could be accounted for by assuming an orbital revolution in fifty years.

In 1862 Alvan Clark, the famous American telescope maker, tested out a new 18-inch refractor on Sirius. He had not thought to discover a double star, but the excellence of the telescope, the keenness of his eye, and the position of the companion with respect to its powerfully radiating primary were all propitious. Since that night Sirius has been known as a double star—perhaps the most significant in the sky.

Later it was found that the Sirian companion is white, not red like most dwarf stars; it is the first and most certain of the white dwarfs—a lilliputian star which shines with high efficiency from a planet-sized surface. The dimensions of the companion being small and the total weight nevertheless sufficiently great to disturb the motion of Sirius, we conclude that under its small surface the matter must be highly compressed. The mass is, in fact, about equal to that of the Sun; the average density throughout the star is accordingly fifty or sixty thousand times that of water—a ton to the cubic inch! In the interior, the atoms of matter are in an extreme condition of ionization and packing.

A test of the theory of relativity can be based on the measured shift toward the red of the spectral lines of the Sirian white dwarf. The star is also a boon to theories of stellar evolution, or more often a confusion to them.

Sirius itself appears to be a normal star and was probably born (if stars are born) at the same time as its white dwarfish companion. Why has Nature handled one differently from the other? Why have the atoms of the companion collapsed while those in Sirius remain at such normal expansion that the average density is much like that of the Sun and of water? Which *is* the abnormal star? Is it necessarily the companion?

Extreme dwarf stars are difficult to find and identify certainly, except those in double systems, and even then they are discoverable only when the systems are near the Earth. We cannot be sure that the white and yellowish dwarf stars are not the most numerous type of stellar body in the universe. There may be a million within a thousand light years of the Sun, for all we know. What phase of stellar development do they depict? How do they bear on the decline of stars, the decay of matter, the death of the universe?

In the face of such perplexity we are tempted to take theories of stellar evolution calmly and devote our energies for the present to the collection of further information on the kinds and numbers of stars—their extremes in brightness, speed, distance, mass, and density.

Little need be said of the close double stars—systems in which the components are separated generally by only a few million miles and which appear therefore through the telescope and on the photographic plate as single points of light. They are discovered either through light variations revealing them as eclipsing binaries, or frequently, when their orbits are so inclined that the eclipses are shallow or non-existent, by means of the spectroscope. Zeta Ursae Majoris was the first spectroscopic binary known, as it was the first visual double. Pickering and his colleagues at the Harvard Observatory noted the periodic doubling of some of the absorption lines in the spectrum of one of the components. On the Doppler principle, according to which the light of a receding body reddens and that of an approaching body shifts toward the blue, the periodic doubling and shifting of lines in the spectrum of Zeta Ursae Majoris was immediately attributed to its binary character. The frequency of such systems has already been intimated. There are more than a thousand spectroscopic binaries catalogued, and nearly four hundred eclipsing binaries. Hundreds remain to be discovered during the next few years.

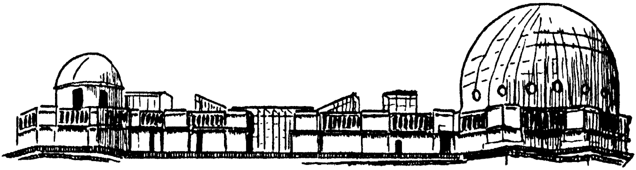
The eclipsing binaries might be divided into those that eclipse partially in each revolution and those that undergo total eclipse. Or they might be classified on the basis of length of period, or, for those with orbits computed, in terms of mean density or shape of the component stars. But all the criteria are at present impractical for classificatory purposes. Every system is different. Until we have more material, or some definite need arises in statistical discussions, there appears to be little basis for classifying the hundred eclipsing binaries for which orbital elements have been derived, or the whole four hundred according to superficial criteria.

A classification of spectroscopic binaries has been proposed by Henroteau, but it also is indistinct. The periods of these close double stars range from a few hours to many years. Some are giants, but most are of moderate or low luminosity. They are remarkably useful in our general study of stellar systems, revealing mass and sometimes star diameters. We feel that we really know much about them. The light curve and the dynamics of the eclipsing binary star, for example, are satisfactorily interpreted in practically all details. It is the only kind of variable star that we can now explain completely and confidently; for the other kinds we must use temporary and only partially satisfying hypotheses.

The third general subdivision of double and multiple stars—the moving pair—is a natural step between the loose star clusters and the wide visual doubles that show little or no orbital motion in the course of observations extending over a few score years. The wide double is detected, as noted above, not only by juxtaposition of the components but by their common motion, which differentiates them from neighboring stars. The moving pairs, on the other hand, are detected by motion alone. Occasionally, but not often, radial velocities are available, confirming the evidence of parallel motions on the surface of the sky.

One of the most interesting moving pairs is described by Adams. It is in the southern sky ($15^h 6^m$, $-16°$) and consists of two ninth magnitude stars separated by five minutes of arc, which is about a hundred times the maximum separation of ordinary ninth magnitude visual double stars. Both components are of a spectral type just slightly redder than that of our Sun; their radial velocity is 300 kilometers a second away from the Sun and their annual proper motion is $3''.76$. From these two components of the motion, one along the line of sight and the other athwart it, we compute that the velocity in space is 580 kilometers a second, a computation made possible by knowledge of the distance of the stars. The peculiarity of the two stars lies in their high and identical speed and their parallel paths, separated from each other by nearly a trillion miles. The mutual gravitational influence must be exceedingly minute.

It is hard to imagine what may have been the origin of such wide systems, unless they are the survivors of a cluster of stars. If, for example, all but two of the Ursa Major group were diverted from the system, those remaining two, separated perhaps by many light years, would continue the journey through space as a moving pair, similar in spectra and in speed, driven by unknown forces in a common direction.



Chapter XI

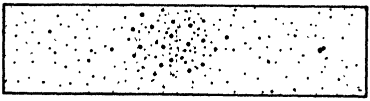
CLUSTERS

Six stars in the heart of the Orion Nebula, as we have already pointed out, form one of the links between double stars, which circulate about their centers of gravity in a few hundred or a few thousand years, and the clusters of stars in which the revolution periods must be measured in millions of years. The Orion Trapezium group may be considered either a rich multiple or a sparse cluster. There are other intermediates, but if the stars number more than ten we generally assign the group to the cluster category.

The great variety in galactic clusters, not only in number of stars but also in structure, is indicated above in Chapter II. The proposed classification—field irregularities to dense groups—is one-dimensional. If we knew enough about the spectra we could identify the members of each subclass as being also of the Pleiades or the Hyades type. Again, we might subdivide the various subclasses of galactic clusters on the basis of number of stars involved, or range in brightness of the members. Trumpler has proposed and used a spectral classification, and also a two- or three-dimensional classification based on concentration, range of brightness, and population. It is difficult, however, to determine the total population of a galactic cluster because our telescopes show for the faint groups only the most luminous members. Because of this selectiveness the range in brightness is a poor criterion of class. Moreover, the forms, dimensions, and membership of nearly all galactic clusters are difficult to ascertain because of the richness of the star fields in which they lie. Where cluster ends and galactic star field begins is a matter more of guesswork than of judgment; and the number of the stars, within the limits of the cluster, that actually belong to the system is not always decipherable from star counts or spectrum analysis. In view of the difficulties, I propose to adopt only the simple empirical scheme of Chapter II, in the attempt to bring some measure of order out of confused variety.

The plan of the classification is obvious; we are dealing chiefly with compactness and central concentration. The further we are removed from a galactic cluster, the greater its apparent compactness. There are, to be sure, real differences in density, that is, in the linear separation of individual stars; but the scheme I use does not attempt to recognize them directly, and is based on the apparent distribution of cluster members. If the Pleiades, which are of Class c, were ten times as remote they would probably be classed as f or g. If they were in one of the distant external galaxies we should probably see them as a single nebulous star, and not recognize the group as a cluster at all. On the other hand, if we were within the Pleiades, with its members in all directions, no clustering whatever would be apparent, although eventually the study of the motions of the stars would reveal their gravitational association and perhaps lead us to classify the system as Class b.

The classification of galactic clusters not only introduces an element of order but also leads to interesting contemplation of the development of sidereal systems. A study of distances and dimensions emphasizes the facts that the division into classes has involved more than appearance and that real differences in central concentration exist among galactic clusters. With further work on distances a revision of the classification in terms of structure will become possible.



Richer than the richest of the galactic clusters are the globular systems, which, in general, are not found near the galactic circle. Not only in this matter of position in the sky but in other characteristics they show qualities so distinct from those of galactic clusters that they clearly belong in a different group. There are some details, however, in which the two types are alike.

The similarities tempt us to look for genetic relationships; the differences lead us towards a new theory of the galactic system.

Galactic clusters, such as the Pleiades and the Hyades, and globular clusters have the following points of resemblance:

(a) They are composed of stars of various spectral classes.

(b) They are gravitational systems, as obvious and definite as binary stars, though the periods of revolution or oscillation of the stars with respect to the gravitational centers of the clusters are immeasurably long.

(c) Their distribution in the sky indicates membership in the galactic system.

(d) The brighter stars in almost every galactic and globular cluster are objects of high luminosity—giants compared with the Sun, and frequently supergiants.

The differences are more significant than the similarities:

(a) The galactic clusters are closely confined to the Milky Way, all but two or three being within three thousand light years of the galactic plane; the known globular clusters are found in all galactic latitudes, most numerous near the boundaries of the Milky Way, but none within two thousand light years of the galactic plane.

(b) The galactic clusters are distributed around the whole circuit of the Milky Way; the globular clusters are almost entirely absent from the northern half of the sky.

(c) Galactic clusters are composed of tens or hundreds of stars, rarely of thousands; the globular systems contain tens or hundreds of thousands.

(d) The average radial velocity of the galactic clusters, so far as known, is moderate—rarely over forty kilometers a second; the globular clusters move with an average radial velocity of more than a hundred kilometers a second.

(e) The galactic clusters, at least the two or three hundred in our catalogues, are almost wholly within four thousand light years of the Sun; all the globular clusters are more than ten thousand light years away and at least a third of them more than a hundred thousand light years distant.

(f) Galactic clusters are of irregular form and of various sizes and degrees of richness; the globular clusters, with a few exceptions, appear to have comparable dimensions and comparable total luminosities, suggesting similar numbers of stars.

In view of these many important differences between the two classes of clusters, it is rather surprising that astronomers have thought to link them together in a single scheme. There is not much reason for this attempt, except the somewhat vain desire of finding a clue to the development of the galactic system. If a globular cluster, which normally appears to oscillate back and forth across the galactic plane, were captured and its motion directed to and fro through the dense star regions along the galactic plane, it appears probable that such a rich system would in time degenerate into a sparse galactic group—the Hercules cluster might become a Hyades, given time enough and sufficient knocking about in heavily disturbing star fields. But the capture and appropriate diversion of a globular cluster, with consequent transformation from globular to galactic type, seems to be dynamically unlikely.

At first the absence of globular clusters from the lowest galactic regions, where galactic clusters are numerous, appeared to indicate that the former are unstable in such a region and become transformed rapidly into the poorer galactic type. But very few intermediate forms are found—hardly a single genuine one. Studies of the distribution of obscuring material in the Sagittarius region indicate, however, that there may be many globular clusters near the galactic circle, hidden behind dark nebulae.

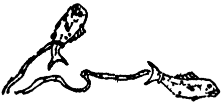
In a later chapter, when supergalaxies are discussed, I shall again refer to the anomalous situation of the globular star clusters. For the moment we shall accept the evidence that the two general classes of clusters are fundamentally different, and in classifying them we shall not try to carry through for the globular clusters the same plan that is found most efficacious for the open systems.

A hundred globular clusters are known; all but half a dozen of them lie beyond the reach of the unaided human eye, and the few that are visible appear only as insignificant hazy patches. When the eye is reinforced with good telescopic power, these brighter clusters are resolved into swarms of stars. Increase of telescopic power, especially when used photographically, shows the individual stars in the remotest and faintest clusters. In practically all of them the stars are conspicuously concentrated to the center—so crowded, in fact, that rarely is a photograph made in which the star images are not confluent.

The dense central crowding is one of the chief hindrances to research on the numbers of stars in globular clusters, and on their magnitudes and distribution. Unfortunately none is near the solar system. At a distance of nearly twenty thousand light years, the nearest are yet so far that as soon as we try to study the central stars of the Sun's luminosity and fainter, we encounter impenetrable confusion. For giants and supergiants in some of the loosest globular clusters, however, the magnitudes and distribution can be found, providing we use short exposure photographs.

The similarity of the globular clusters makes the classification of the hundred known systems difficult. They differ from one another chiefly in apparent brightness and size, as the natural consequence of varying distances from the observer. But some are richer than others in supergiant stars, some are not circular in projection but plainly elliptical, and with close attention intrinsic differences in central concentration can be discerned. It is on the basis of intrinsic concentration that a working classification has been devised. On the Harvard system the globular clusters are placed in twelve groups in order of decreasing concentration. Perhaps we have used too many subdivisions; between Classes II and III there is little difference, and little between X and XI. But between III and X, or even III and VI, the difference is conspicuous.

When we study the distribution, average color, or other properties of globular clusters, we find little correlation with class. The classes undoubtedly indicate structural variety, at least among the giant and supergiant stars, but we have not yet ascertained the meaning of the differences from one class to another. Probably they are associated with age and with stage of development or decay, or are indicators of past dynamical encounters with other stellar systems, or reflect some differences in place of origin or primordial state. Future studies will show, or future speculations will intimate more happily than we can now suggest, why some globular clusters are poor in giant stars, some are exceedingly rich in variable stars, some are tightly compressed at the center while others are as loose in organization, as far as their bright stars are concerned, as the most compact classes of galactic clusters.



Keeping in mind the possibility of classifications in more than one dimension, not only for clusters but for many other groups considered in our general survey, we can well adopt for the current presentation a one-dimensional scheme and add to our progressive series the following:

+5 Galactic Clusters
  a. Field irregularities
  b. Star associations
  c. Very loose groups
  d. Loose groups
  e. Restricted groups
  f. Compact groups
  g. Dense groups
+6 Globular Clusters
  I. Most concentrated systems
  II. . . . .
  . . .
  . . .
  XII. Least concentrated systems

A current catalogue of galactic clusters containing 249 entries has been prepared at the Harvard Observatory. No attempt is made to include objects of classes a and b. The list is necessarily incomplete for groups c and d, because they are frequently indefinite or inseparable from small star clouds or field irregularities. The following tabulation shows the number of clusters in each class:

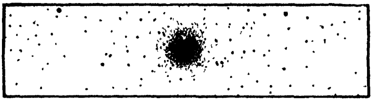
Class	Number
c	20
d	85
e	67
f	47
g	30
Total	249

The numbers of globular clusters falling in each of the twelve subclasses are as follows:

Class	Number	Class	Number
I	4	VII	8
II	7	VIII	10
III	7	IX	10
IV	12	X	9
V	12	XI	9
VI	11	XII	4

A further and very important difference between the globular and the galactic clusters should be emphasized at this point. None of the galactic groups is known to contain Cepheid variable stars, whereas nearly every globular cluster that has been thoroughly examined possesses these distance-revealing variables. In consequence, the globular clusters have been important in giving us the dimensions of the galactic system and our situation within it. The galactic clusters, on the other hand, are difficult to place in distance with any assurance of accuracy; we can only tell, from the apparent magnitudes of their bluish stars, or by some similar device, whether or not they are relatively near the Sun.

The globular clusters constitute a superstructure whose size and form are determined through the Cepheid variables. Because of its symmetrical arrangement with respect to the galactic plane, this higher organization may be considered as part of the galactic system. It has a diameter in excess of two hundred thousand light years—a length immensely greater than any our survey has hitherto recognized, and of considerable significance when galaxies are measured and intercompared.



Chapter XII

STAR CLOUDS AND GALAXIES

Good stellar photographs show near the borders of the Large Magellanic Cloud, among the sharp images of individual stars, a half dozen hazy images. Large reflectors are not yet available for decisive examination of these objects, but a comparison with clusters along the borders of the Milky Way indicates that they are typical globular clusters; further investigation shows them to be members of this neighboring galaxy.

A better opportunity for the comparison of the dimensions of globular cluster and galaxy could not be found. From the Cepheid variables we know that the distance to the Large Cloud is between eighty and ninety thousand light years. Its total linear diameter, computed on the basis of this distance and the measured angular diameter of seven degrees, is approximately eleven thousand light years, whereas the linear diameters of its globular clusters are scarcely more than a hundred light years. Despite the disparity in size there are no obvious intermediate forms between cluster and star cloud; and in the scale of gravitationally organized material systems, the Clouds of Magellan may be taken as the next step beyond globular star clusters.

In size and in population the Large Magellanic Cloud is the equivalent of hundreds, perhaps thousands, of clusters. It includes them as subordinate parts. There are in the Cloud only a few clusters of the globular class, but scores of open groups, some rich in nebulosity like the Pleiades, some containing exceedingly luminous supergiant stars. But all these clusters, open or globular, are secondary and small in terms of galactic dimensions.

Our reasons for considering the two Magellanic Clouds as individual galaxies are easily presented. The most conspicuous objects of the southern sky, they look like detached parts of the Milky Way, quite clear of the clouds and strata of stars that make up our galactic system. Their speeds of recession with respect to the Sun are 170 miles a second for the Large Cloud and 105 miles a second for the Small Cloud; their distances from the galactic plane are 47,000 and 63,000 light years, respectively. They contain many sorts of highly luminous stars, various kinds of clusters and nebulae, and, as we go toward fainter magnitudes, an increasing profusion of objects, which is characteristic of our own Galaxy. But most significant of all is the similarity of the Clouds of Magellan to numerous other external systems. They seem to be the nearest of a fairly common type of irregular star cloud.

The link connecting these two nearby "island universes" with external galaxies of the spiral nebula type is a vague object discovered some forty years ago in the constellation of Sagittarius. Barnard, the original observer, working with a small visual telescope, saw the object as a hazy elongated patch—a bit of faint nebulosity. For many years it remained unstudied, and was entered merely as Number 6822 in the New General Catalogue (N.G.C.) with the description "vF,L,E, dif." Interpreting these symbols we see that Barnard described the object as "very faint, large, extended, diffuse." He saw no indication of stellar structure; he did not suspect that here was another stellar universe.

A few years ago at the Cordoba Observatory in the Argentine, at the Mount Wilson Observatory in California, and at the Harvard Observatory in Peru, N.G.C. 6822 was further studied with greater telescopic power. It was then found to be composed of many stars and some bright gaseous nebulae. On the basis of the brightness of its giant stars I made a preliminary estimate of the distance as about 800,000 light years. A subsequent detailed study by Hubble at Mount Wilson revealed the presence of Cepheid variable stars, and led to the conclusion that N.G.C. 6822 is 700,000 light years away, and that its diameter is 3,500 light years. It is obviously similar to the Clouds of Magellan.

Once we have become aware that the Magellanic Clouds represent a definite type of external system, we may assign to the class other irregular nebulous objects. Lundmark has tabulated among the isolated extra-galactic nebulae over twenty objects of this Magellanic sort. At Mount Wilson and at Harvard it has been found that among the various clouds of extra-galactic nebulae three or four per cent are of the irregular type. If that percentage holds throughout all explorable space, there must be within the reach of existing telescopes some thirty or forty thousand "Magellanic Clouds"—all the more reason to study attentively the nearest representatives of the class.

Some astronomers see in the structure of the Clouds of Magellan traces of spiral arrangement. The comparability of these objects with true spirals is shown most definitely, however, not by their structure, but by the association of similar star clouds with typical spiral nebulae in groups of external systems. In the great Coma-Virgo cloud, for instance, the irregular forms have the same total brightness and approximately the same angular diameters as the other types of extra-galactic objects, such as true spirals, barred spirals, and spindle nebulae. Nearly all of the irregular star clouds are so remote that they cannot be resolved into individual stars, but there is little doubt of their stellar composition.

For purposes of convenient nomenclature, we shall call the various types of spiral nebulae and the associated forms "Galaxies," including the Magellanic Clouds and their kind in this comprehensive class along with the Great Andromeda Nebula and the members of the remotest clusters of extra-galactic nebulae. We shall generally reserve the word "nebula" for the objects, either luminous or dark, composed of dust and gas—subordinate nebulous members of our own and other galaxies. The interiors of some of the spheroidal systems may not be stellar; distance and telescopic weakness conceal information about their composition. But until we have good reason to believe otherwise, we shall consider that all the systems in the category of external galaxies are composed chiefly of stars.

* * *

Before we proceed to sketch a classification of the many forms of galaxies, it will be valuable to note how much these nearby Clouds of Magellan resemble some of the star clouds of the Milky Way. If, for instance, the Large Cloud were in low galactic latitude, in or near the Milky Way girdle, could we distinguish it clearly from the many other star clouds that contribute to the general appearance of the Milky Way? I suspect that we could not. Should we, therefore, consider that perhaps the Clouds of Magellan are great fragments detached from our own galactic system? And might we not also consider some of the faintly delineated Milky Way clouds as discrete systems, comparable in dimensions with the isolated Magellanic Clouds? In asking these questions we are entering new ground, we are inquiring into the fundamental structure of our galactic system.

In view of our new knowledge concerning external galaxies, how can we fit our Milky Way system into the cosmic scheme? When from globular clusters we received our first intimation of the dimensions of the Galaxy, I was led to propose the working hypothesis that ours is a gigantic discoidal system, some two or three hundred thousand light years in diameter, ten thousand or so light years in thickness, and quite unlike the Clouds of Magellan or other external systems. It appeared not to be a spiral nebula, mainly because of its great dimensions. It might have grown from the combination and smoothing out of various star clouds and star clusters, rotating, perhaps, around the center in Sagittarius, some fifty thousand light years from the Sun.

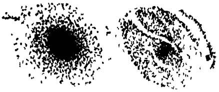
This working hypothesis of a dozen years ago was beset by certain difficulties, which will be considered in a later chapter. The objections were recognized at the time, and new material has since emphasized the need for revision. For instance, resolution of the nearer spirals into stars and our present comparison of individual regions of the Milky Way with outside galaxies indicate the necessity of modifying or extending the earlier hypothesis of the origin and the structure of the macroscopic features of the galactic system.

In order to test hypotheses of galactic structure, and to check the dimensions directly, special efforts are being made at the Harvard Observatory and elsewhere to find the distances of the star clouds along the Milky Way. They lie mainly beyond the range of spectroscopic investigation, and wholly beyond the power of trigonometric methods of measurement. The best approach seems to be through the laborious study of variable stars, which serve as indicators of distance, and the general investigation of stars of high luminosity. The inquiry into the space distribution of galactic clusters, novae, and planetary nebulae also becomes a feature of the star-by-star measurement of the size and structure of our galactic system. The fainter the stars we reach, the deeper we penetrate into the Milky Way structure.

Within the last few years many thousand photographic plates have been accumulated at both the northern and southern stations of the Harvard Observatory, in pursuance of the program of measuring galactic star clouds by means of the variable stars. The Milky Way has been laid off into 204 fields, overlapping in such manner that all of the sky along the galactic circle is covered. The observatory's collection of plates made during the past forty five years supplements the large number of photographs especially taken for the research. At least a hundred thousand will be useful in the general assault on stellar variation. Two or three thousand new variables have already been found, and before the work is completed, some ten or twenty years hence, probably ten or twenty thousand more will have been added to the list which in 1925 numbered only about twenty eight hundred.

Further attention need not be given here to the methods and details of this variable star survey, which should ultimately tell us more than can otherwise be discovered concerning the structure of remote parts of our galactic system. It suffices now to point out that the variables are beginning to give us an idea of the dimensions of the individual star clouds of the Milky Way. The diameter of the cloud in Scutum is estimated as fifteen hundred light years; but this value depends more on studies of spectra and star counts than on investigations of variable stars. The remote star clouds in Sagittarius are being outlined by the variables alone. We find that the dense fields of faint stars in that region are probably all comprised in a single system, cut up badly by the intervening dark nebulosity. The diameter of this star cloud must be some thirty or forty thousand light years; it is much larger than the Clouds of Magellan or the average external galaxy, but no larger than the great Andromeda spiral or the giant members of some of the remote clusters of galaxies.

The measurement of the dimensions of Milky Way star clouds is as yet in a preliminary state. Probably we are not premature, however, in saying that several seem to have dimensions and stellar content comparable with those of external galaxies. It becomes clearer, as we consider these galactic structural details, that our classification should bring into one general category the distinct parts of our own Milky Way, the Magellanic Clouds, and the remoter galaxies of both the irregular and the symmetrical types.



In recent years observers with suitable equipment have gone enthusiastically into the game of galaxy hunting. The further from home, the richer the field. We now talk of distances of hundreds of millions of light years. But galaxy hunting could well begin at home. If we treat some of the Milky Way clouds as comparable to the Magellanic Clouds, and therefore, effectively, as galaxies, should we not also consider as a galaxy the system of stars that closely surrounds the Sun?

In studying the distribution of globular star clusters, I was led some years ago to consider the circumstance that stars near the Sun fail to show the same galactic circle as that outlined by Milky Way star clouds. Further, when the globular star clusters appeared to show that the galactic center is at a great distance from the Sun in the direction of Sagittarius, and yet the evidence from star counts seemed to indicate that the Sun is near the center of the stellar system, the question arose as to whether the star distribution in the solar vicinity might not be only a local phenomenon; our Sun—might it not be near the center of a subsystem, but remote from the real galactic center?

The hypothesis of a system within a system found favor both with the facts of observation and with most of the students of the subject. I proposed that we call the great star cloud surrounding the Sun the "local system." A hint of its existence is seen in the work of Sir John Herschel and B. A. Gould on the distribution of the naked-eye stars. The brightest stars form a belt—Gould's belt—which is inclined some twenty degrees to the plane of the Milky Way. Newcomb concluded that this distribution of bright stars could easily be accounted for on the principles of chance. An investigation by Charlier in 1916 showed, however, that the naked-eye

B stars are arranged symmetrically with respect to a plane that is not coincident with the commonly accepted plane of the Galaxy.

It was just at this time that my difficulties arose with the prevailing assumption of a heliocentric galaxy. The working hypothesis suggested above became immediately obvious. Let us postulate a local star cloud, its central plane inclined to the Milky Way, the Sun not far from the center (which is perhaps in the direction of Carina in the southernmost Milky Way), and this whole local system displaced about fifty or sixty thousand light years from the center of the supersystem outlined by globular clusters.

When the study of the distribution of Class B stars, initiated by Charlier, was extended to fainter magnitudes, it appeared at once that we were dealing with two different systems: the general galaxy and the local cloud. Faint B stars were narrowly confined to the conventional galactic plane; the bright B stars to the plane of a secondary galaxy, inclined some twelve or fifteen degrees to the galactic circle. From the study of these Class B stars it is easy to deduce that the diameter of the local system in its plane is of the order of six or seven thousand light years—a pretty rough estimate, but one that seems to be supported by other researches. No doubt straggling members of the local system may be found at a distance of ten thousand light years, and it has been suggested that its dimensions are considerably larger than at first supposed. There is also a rather faint possibility that it may be not a dynamical unit but merely the chance arrangement of several small and independent stellar groups or streams of stars.

We should be able to have better ideas of the existence, structure, and dimensions of the local system if we could be transferred to a point far outside—removed, for example, to a planet a hundred thousand light years distant. It is confusing to be inside a stellar cloud and unable to disentangle surely the members of the local system from members of the general galactic field. We cannot easily tell whether other clouds of stars are separate and distinct, or in contact with or penetrating our own.

The search for galaxies seems to justify the belief that we are inside one of them, although as yet unable to determine its form. It may be like a typical spiral or spheroidal galaxy, or irregular and broken like a Magellanic Cloud. Its dimensions are surprisingly reminiscent of those derived for external galaxies and surmised for other star clouds of the Milky Way.

Recognition of the local system leads also to a new view of the two Clouds of Magellan. From their velocities in the line of sight it can be shown that, with respect to the supersystem of globular clusters, the Magellanic Clouds are not receding with the high velocities mentioned in a foregoing paragraph. For it is found, from the rather meager measurements available, that the globular clusters as a group also appear to be receding toward a point in the southern sky. Their high recessional speeds, however, are relative only to the Sun, not to the galactic system as a whole. Indeed, the fact that the clusters remain distributed more or less symmetrically with respect to the galactic plane must indicate that the recession is apparent only. They cannot be truly receding and still maintain their structural relation with the galactic system. It is much simpler to interpret this apparent movement of the Magellanic Clouds and all globular clusters toward a southern point as merely a reflection of the motion of our local system toward a point in the northern sky.

If our local star cloud is indeed a distinct system, is it not reasonable to expect motion relative to the general galaxy, or at least relative to the great galactic nucleus? Fortunately there is good additional evidence for high speed motion of our local system—a motion that simulates a rotation about the same galactic center as that indicated by the distribution of globular clusters. A study of the relative motions of stars near the Sun gives some support—not yet unquestioned—for this "galactic rotation," or, perhaps we should say, for this motion of the local system with respect to the galactic mass as a whole. More conclusive evidence comes from a study of the systematic motions of the external galaxies, and from the preponderant direction of the motions of high speed stars near the Sun—stars that may be members of the general galactic field through which our system moves, or members of some other star cloud through whose borders we are penetrating.

* * *

To return to the Clouds of Magellan: let us accept the view that their observed recessions are but a reflection of our local system's speed of about two hundred miles a second toward Cygnus. Recalculating their velocities on this basis, we obtain much smaller values, comparable with the average values for globular star clusters when they too have been corrected for the local system's motion. These are the true motions of the Magellanic Clouds, the velocities impressed on them by the total of neighboring gravitational masses.

We conclude, therefore, that the Large and Small Clouds of Magellan are not escaping at high speed from our galactic system. We shall consider them isolated components of the same higher organization that includes our local system; they are not external, but internal galaxies, nearer to us than are many of the globular star clusters. They lie in high galactic latitudes and thus give to our whole galactic conglomerate a less discoidal form than we had previously assumed. The globular star clusters also outline a much less flattened system than that indicated by star counts or by the narrowness of the Milky Way girdle.

It begins to appear that the conception of our Galaxy as a great discoidal system is but another of those illusions that arise from the rather helpless position of the observer. For a long time he was deluded by his observations into believing that the Earth was the center of the universe. Later he visualized the Sun as the center, or near the center, fortifying his belief with the discovery that the numbers of stars in all directions fall off with distance from the Sun. Having learned that this last phenomenon arises from our situation in a local star system, he may again have been led through the chance arrangement of a few star clouds spread out approximately in the plane of our own local galaxy to a misconception of the form and unity of the galactic system. A revised hypothesis is emerging from current studies—a supergalactic system is displacing the unified discoid of stars and stellar clouds.

It has taken many preliminary words to sketch in a few necessary details of the picture of star clouds and galaxies, preparatory to a working classification; but in getting these materials together we have covered, openly or tacitly, some of the most interesting developments of recent sidereal astronomy—the measurement of the Milky Way; the resolution of spiral nebulae into stellar systems; the survey of the Magellanic Clouds and their identification with a numerous class of external systems; the elucidation of star distribution in the solar neighborhood as evidence of a local system with dimensions comparable to those of external galaxies; the intimation of galactic rotation or, at least, of the motion of the local system with respect to the general galactic system; and the hypothesis that the Magellanic Clouds, the local system, the hundred globular clusters, and the distinct star clouds of the Milky Way all together form a complex of higher order. This supersystem must again be taken into consideration after we have developed the classification of individual galaxies.

As a matter of convenience we shall divide the star clouds and galaxies into two main groups, internal and external systems. The internal systems differ from the external mainly in position relative to the observer, and in the same way the various kinds of internal systems also differ from one another. If the observer were located in the Scutum cloud his researches would ultimately convince him that he is in a "local system." To the Scutum observer our system would be a Milky Way star cloud. To an observer in the

Magellanic Clouds our system would be one of several star clouds of the Scutum type, and his cloud would be the "local system."

For the internal galaxies and star clouds the following classification is devised, more as a convenience in forming a picture than as a useful analysis:

+7 STAR CLOUDS AND GALAXIES
- a. Internal systems
  - (a) Local Cloud
  - (b) Scutum type
    - (α) Real
    - (β) Apparent
  - (c) Magellanic Clouds
- b. External systems

In advance of the detailed studies of variable stars and similar objects, it is impossible to say whether there are many separate star clouds along the Milky Way, or whether most of the apparently distinct clouds result merely from the limitations set by obscuring matter. Certainly the long rift in the Milky Way, from Cygnus south to Centaurus, is an effect of obscuration. This rift divides the great central star clouds of the Sagittarius region, and it serves to delimit several bright star clouds both north and south of the celestial equator.

The obscuring nebulae are relatively near the Sun—not out in the neighborhood of the star clouds they occult. Other obscuring matter may be there, as yet undetected; but nearly all of the recognized dark clouds are within one or two thousand light years of the Sun. They are, it seems, a part of the local system. To a considerable extent they follow the course of the secondary galaxy rather than the conventional galactic circle. Perhaps they are for our local system the counterpart of the obscuring bands that appear in so many edgewise spirals. In fact, I take their nearness to the Sun as evidence that our local system is a fairly typical galaxy, and accept their absence at great distances to be an indication that many star clouds in our galactic supersystem are fortunately either free of conspicuous obscuration or so inclined to the galactic plane that their obscuring nebulosities do not interfere with our investigations.

External galaxies (extra-galactic nebulae) have been arranged in groups according to various schemes. Four of the plans should be mentioned to indicate both the variety in types and our failure to set up wholly satisfactory classes.

At Heidelberg, where for years the external systems have been extensively studied photographically and visually, Professor Max Wolf has devised and used a noncommittal pictorial system. The twenty three different types, shown in the drawings on pages 86 and 147, are assigned letters. They are sufficiently diverse in form to include some of the planetary nebulae as well as all external systems. Intermediate grades between the various types can be set up, and the classification thus has the advantage of providing many categories without suggesting any hypothesis, evolutionary or otherwise. The classification, however, is not very convenient for statistical investigations of external systems. On the Heidelberg plates the individual stars in the galaxies are not separately seen; the classification is based altogether on the appearance of integrated images.

Working mainly with large-scale photographs at Mount Wilson, Hubble has proposed a useful classification, especially applicable to those systems that are near and bright enough for detailed inspection. There are several hundred objects that can be unambiguously classified on Hubble's scheme; but tens of thousands on existing photographic plates are too faint and too indistinctly shown to warrant useful assignment to his classes. The same is true of Lundmark's classification mentioned below; while, on the other hand, the Harvard classification, also described below, sorts out the faint thousands of galaxies in a manner useful for preliminary statistical studies, but is not descriptive or discriminating enough to classify the brighter objects satisfactorily.

Hubble's classification is as follows:

Type	Symbol
A. Regular Nebulae	
1. Elliptical	En
(n = 1, 2, ... 7, indicates the ellipticity of the image without the decimal point)	
2. Spirals	
(a) Normal spirals	S
(1) Early	Sa
(2) Intermediate	Sb
(3) Late	Sc
(b) Barred spirals	SB
(1) Early	SBa
(2) Intermediate	SBb
(3) Late	SBc
B. Irregular Nebulae	Irr

Extra-galactic nebulae too faint to classify are designated by the symbol "Q."

The classification proposed by Lundmark for external systems (he calls them Anagalactic Nebulae) is as follows:

Type	Symbol
1. Anomalous nebulae	Aa
2. Globular, elliptical, elongated, ovate, or lenticular nebulae	Ae
a. Very little compressed towards center	Ae0
b. Slightly compressed towards center	Ae1
c. Somewhat compressed towards center	Ae2
d. Rather compressed towards center	Ae3
e. Much compressed towards center	Ae4
f. Very much compressed towards center	Ae5
The letter "a" is added if absorption is present, *e.g.*,:	Ae3a

Type	Symbol
3. Magellanic nebulae	Am
a. Very little if at all compressed towards the center	Am0
b. Different degrees of compressibility	Am1-Am5
4. Spiral nebulae	As
a. Spiral structure barely seen	As0
b. Different degrees of compressibility towards center	As1-As5
Spiral arms continuous	As1c-As5c
Spiral arms broken up into patches or separate points	As1b-As5b
c. One-branched spirals	Aso
d. Spiral arms form a bright ring	Asr
e. Doubtful connection of ring with the center (Saturn-shaped)	Ass
f. Rings or arms connected with center through a bar (pinwheels or Curtis ϕ-type)	Asp
g. Spiral arms have an appendix nebula	Asa

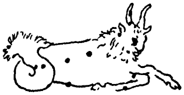
When large-scale photographs are available, such as those provided by large reflecting telescopes, so much variety is found in the individual nebulae that Reynolds has suggested the general inadequacy of all the foregoing classifications. It would indeed be more instructive to publish a homogeneous series of photographs of all the brighter galaxies rather than depend on classificatory descriptions alone. But Hubble has made good use of his various classes in deriving important statistical conclusions on relative dimensions, distances, and luminosities; and the Harvard classes have been useful in correlations of form, magnitude, and angular diameters for the thousands of unresolved faint and distant galaxies.

The investigations of external systems at the Harvard Observatory have been devoted mainly to the recording throughout large sections of the sky of the positions, numbers, total magnitudes, and other properties of the faint objects shown on photographs made with the Bruce 24-inch telescope. Angular diameters and apparent brightness can be measured directly on the plates, but since these properties depend on the distance of the object we can well leave them out of the classification and keep it definitely on a structural basis. The ellipticity of the image depends on the actual shape of the object as well as on the position of the observer; we shall take it as one of the factors in a two-dimensional classification. The other factor is the apparent degree of central concentration of light, which appears on the photographic negative as concentration of blackness of image. The ellipticities range from 1 to 10 in order of decreasing elongation; the concentrations range from a to f in order of increasing central blackness. Hence the plan that has been used at Harvard for some years in the classification of external systems may be presented as follows:

External systems
a1 a2 a3 a4 a5 a6 a7 a8 a9 a10
b1 b2 b3 b4 b5 b6 b7 b8 b9 b10
c1 c2 c3 c4 c5 c6 c7 c8 c9 c10
d1 d2 d3 d4 d5 d6 d7 d8 d9 d10
e1 e2 e3 e4 e5 e6 e7 e8 e9 e10
f1 f2 f3 f4 f5 f6 f7 f8 f9 f10

The obviously irregular or spiral forms are indicated by an i or s preceding the class symbol.

In this array of sixty types, which was devised before the present survey of material systems was undertaken, the Roman letters and the Arabic numerals do not conform strictly to the conventions described in Chapter X. The classification might be revised to fit the meanings adopted for the various symbols; but it has already been extensively used at Harvard and elsewhere, and a revision of terminology is hardly justified.

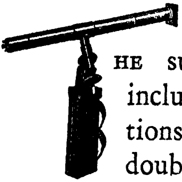


It appears that for external galaxies there are several classifications, none wholly satisfactory or comprehensive, each with advantages and in its own field useful for analysis of the increasingly larger numbers of objects. Hubble's system does not include degrees of central concentration; Lundmark's classification does not explicitly involve the forms of the images, though it could readily be extended to include them. The Harvard plan includes both form and concentration, but does not discriminate, for instance, between the various types of spirals; as a working classification, however, it does not need this refinement, since the photographs for which it is peculiarly adapted frequently show little of structural details.

The most important result of this survey of galaxies is not the working classification of external systems, but the bringing of spirals, spindles, star clouds, and the local galaxy into one category, with the intimation that immediately surrounding us is a system of higher order.

Chapter XIII

SUPERGALACTIC SYSTEMS



The survey of gravitational systems has included to this point meteoritic associations, satellitic systems, planetary structures, double and multiple stars, galactic clusters, globular clusters, and galaxies. As we proceed along the list we methodically go towards larger masses and greater dimensions; and because of the greater dimensions we also progress in the direction of weaker and less effective gravitational attraction. As a consequence, the average periods of rotation, revolution, or oscillation in the various systems increase in length. The average rotational period of a planet is a few hours; its average revolution time is a moderate number of years. But the long period double star revolves in terms of hundreds of years, and the oscillation period of a star in a star cluster or in a galaxy must be counted in thousands or millions of centuries.

Though the larger systems have periodic times so long as to be humanly immeasurable, we can with confidence speak of them as gravitational organizations. Gravitation is inevitable. If two organizations are in the same part of the sky and have comparable dimensions or brightness, or show parallel motion, we can assume with some safety and without direct knowledge of their distance that they are associated; if they are at all near each other gravitation ties them up. We are not likely to be misled frequently by the chance apparent juxtaposition of objects widely separated along the line of sight.

Until recently little has been known or thought concerning multiple galaxies, gravitationally linked, and the higher combinations of sidereal systems. But the discoveries of recent years concerning supergalactic organization attract increasing attention. They have further impressed upon us the immensity of the measurable universe, the generality of its laws, and the cosmic minuteness of the Local System with its open clusters, double stars, and planetary structures, its drifting comets and meteors. The universe lies chiefly outside our own galactic system. As the solar system is to our Galaxy with its millions of stars, so is our Galaxy to the higher system of systems.

The well known spheroidal galaxy, Messier 60 (N.G.C. 4649), and a nucleated spiral, N.G.C. 4647, are nearly in contact. They do not differ greatly in brightness or size. Their integrated photographic magnitudes are 10.5 and 12.8, respectively; their angular diameters are 236″ and 150″. The chance is small that two such objects would only accidentally appear to be in contact. Among the brighter external galaxies dozens of doubles and multiples are known, and among the very faint and remote objects there are hundreds. For these fainter galaxies, of course, chance alignment may be more frequent; there are undoubtedly a few recorded pairs that are optically rather than gravitationally double. But true doubling is common and is of deep significance in the world scheme. It reflects the universality of gravitational law; it hints at incomprehensible intervals of time.

The best known multiple galaxy is the group in Andromeda. The Andromeda Nebula itself, Messier 31, is a giant among external systems, its longest diameter being forty thousand light years or a little more. Less remote from its center than its own tips are two other elliptical galaxies. The smaller and fainter systems are not merely optical companions. The spectroscope shows that the velocities of all three are of the same sign and of approximately the same amount. There is not the slightest doubt that the Andromeda trio forms a supersystem, small in number but great in total dimensions. The two companions are small in comparison with Messier 31, but even so they are average-sized galaxies.

Frequently when two or more galaxies are in actual contact some of the members appear to be considerably disintegrated and occasionally there is evidence of a scattered field of faint stars near or surrounding the colliding systems. The quintet in Pegasus, sketched on page 143 is such a collisional group. One of its largest members seems to be binuclear; a detached filament, like an arm broken off, is shown clearly on the original photograph, and throughout a considerable area north of the group there appears a hazy background that may well be a scattered field of stars, arising perhaps from the numerous interpenetrations and disrupting perturbations of these four or five galaxies which for innumerable millenia have moved to and fro with respect to their common gravitational center.

The general tendency of galaxies to assemble gravitationally results in a variety of organizations. A classification of these higher systems can well parallel that of the stars. Corresponding to individual stars, multiples, and star clusters we have galaxies, multiple galaxies, and clusters of galaxies. And to designate the system including all of these I propose to use Lundmark's term, the Metagalactic System—or, more briefly, the Metagalaxy. Hence we have the following classes:

+7 STAR CLOUDS AND GALAXIES
  a. Internal systems
  b. External systems
+8 MULTIPLE GALAXIES
  1. Double systems
  2. Small groups
+9 SUPERGALAXIES
  I. Coma-Virgo type
  II. The Galactic System
+10 THE METAGALAXY

For many years astronomers have been aware that the northern galactic hemisphere is much richer than the southern in relatively bright spiral nebulae. An uncommon richness in all types has been noted throughout the constellations Coma and Virgo and somewhat less conspicuously in neighboring constellations. A few years ago Miss Ames and I undertook a detailed study of the Coma-Virgo region. We found a concentrated group of bright objects, all so nearly alike in angular dimensions and luminosity that the conclusion could not be avoided that we are here dealing with a supersystem. Later studies showed its probable extension many degrees towards the southeastward. It is an enormous organization—several million light years in extent, with a total population of the order of five hundred galaxies. The approximate distance to the center of the group is eleven million light years; diameters of the individuals range from one or two thousand light years to more than twenty thousand, with the diameters of a large majority falling between five and seven thousand light years.

Space need not be taken here to describe our researches on the Coma-Virgo supergalactic system, except to note that in pushing the analysis in this region far beyond the cloud of bright galaxies we have found three or four other distinct and very remote groups, lying at distances in excess of a hundred million light years but probably differing very little from the bright Coma-Virgo cloud in structural detail and in content.

Further investigations of the arrangement of faint galaxies, as shown on plates made at many observatories, have revealed the existence of at least fifty distinct groups of external systems. Wolf, Hubble, Lundmark, Curtis, Baade, and others have made investigations of some of these faint groups. Many are less rich than the Coma-Virgo cloud; but a few are far more populous. Probably the majority of the members in most clouds are fainter than the limit of the photographic plate—we can deal only with the giant and supergiant galaxies, because, as with star clusters, we are telescopically limited to studies of only the most luminous members.

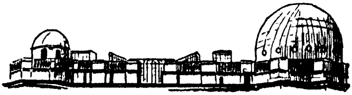
Nearly all of the groups of galaxies that have so far come into our knowledge can be assigned roughly either to the subclass "Small groups" under Multiple Galaxies or to the "Coma-Virgo type" of Supergalaxy. But what of our own system? In the preceding chapter we suggested that our galactic system cannot be satisfactorily compared with a single spiral nebula. It is too large, for one thing; for another, many of its units are of the same size as typical spirals.

As a working hypothesis, it seems advisable to consider the galactic system as coordinate with the Coma-Virgo group and with similar supergalaxies. Probably it differs from such systems mainly in appearance, but again we are handicapped by being inside and deprived of a clear objective view. If we reject the Clouds of Magellan and the globular clusters as bona fide members of our supersystem, we note how much more flattened it appears to be than the average cloud of the Coma-Virgo type.

The quintet in Pegasus has the appearance of a flattened group of galaxies, since three or four of the members seem to have nearly parallel galactic planes. I propose that this small group may give us a picture of our own galactic system —star clouds in contact and scattered fields of stars. Undoubtedly for an observer in one of the individual galaxies of the Pegasus quintet the motions of the surrounding stars would imitate our star streaming and galactic rotation.

In ten or fifteen years the study of the magnitudes and motions of galactic stars and of the distances and distribution of faint variables may give us the equivalent of an external view of our own galactic system. It may show us that we are fairly well separated from star clouds such as those near the galactic center in Sagittarius, and possibly that our system is in contact with the Cygnus star cloud. It may show us whether our supergalaxy comprises only a few abnormally large galaxies, in addition to the globular star clusters and the Magellanic Clouds, or is composed of dozens of systems of average dimensions.

It is well to point out that at least three other interpretations of our Milky Way can be advanced: the original discoidal theory, the view that our galactic system is a single great spiral nebula (an ancient hypothesis), and the hypothesis that it is composed of a pair of spiral nebulae—the local system and the Sagittarius cloud. None of these is a satisfying hypothesis. The supergalaxy hypothesis interpretation that is developing out of our present attempt to classify material systems is much more adequate in that it clears up several difficulties of the other hypotheses and makes our own place in the sidereal universe appear normal rather than special and unique.



Among the advantages of the hypothesis of the supergalaxy in the interpretation of important data of observation, the following should be mentioned:

1. The possibility of the transformation of globular clusters into galactic clusters need no longer be considered—the two types, according

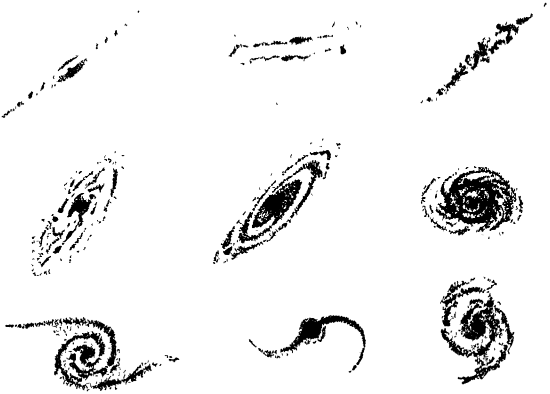
to the new view, are probably of different origin. The globular clusters may be born as we find them or may be the residual nuclei of spiral and spheroidal galaxies that have squandered the main parts of their population in disruptive evolution or in encounters with other galaxies; and the galactic clusters may be dissolving nuclei in the spiral arms of the local galaxy and of similar neighboring star clouds.

2. The localization of the obscuring nebulosities in and near the local system is most easily explained on the supergalaxy hypothesis, as noted in the preceding chapter.

3. The apparent abnormality of our position in the universe—in an unparalleled discoidal system, or in a spiral with a diameter forty or fifty times that of the average galaxy—is removed, for now our local system emerges as an ordinary star cloud or galaxy and the Galactic System as a supergalaxy with dimensions falling well within the range of other recognized supersystems.

In summary, the multiple galaxies can be conveniently divided into double systems and small groups; the supergalaxies can be satisfactorily assigned for the present to two structural types—the roughly spherical cluster typified by faint groups in Coma-Virgo, and the considerably flattened stellar organization with some of its individual galaxies in contact, our own galactic system being representative of this class.

Finally, we propose as Class 10 the all-inclusive Metagalactic System. What is its population in galaxies? Millions at least. What is its diameter? Certainly thousands of millions of light years. There is evidence that a rough uniformity in the frequency of galaxies is maintained throughout all space now within our reach, but our telescopes have not yet struck bottom. They do not indicate that we are even approaching the borders of the system. The Metagalaxy must remain for the present as the vague supersystem—all-comprehensive but incomprehensible.



Chapter XIV

THE COSMOPLASMA

The Metagalactic System is not the material universe. Of galaxies and supergalaxies it is all-comprehensive, as I define it; but it does not include the random stars or the lost planets that have become detached from galaxies and rove through intergalactic space. It does not include those comets or meteors that have been ejected from our planetary system, unless their speeds are sufficiently low to keep them members of the local galaxy. To complete the survey there must be established a higher class that includes both galactic and intergalactic materials.

In retrospect let us assemble the classification of material systems of the macrocosmos, first recalling that in exploring the microscosmic world we dealt in turn with corpuscles, atoms, molecules, molecular systems, and colloidal and crystallic aggregates:

+1 Meteoritic Associations, 1 to 3
+2 Satellitic Systems, I to III
+3 Planetary Structures, I to III
+4 Double and Multiple Stars, I to III
+5 Galactic Clusters, a to g
+6 Globular Clusters, I to XII
+7 Galaxies, a, b

+8 MULTIPLE GALAXIES, 1, 2
+9 SUPERGALAXIES, I, II
+10 THE METAGALAXY

Throughout this long series of systems the presence of organization is obvious. Motions are orderly, associations are close, and physical similarities prevail. Not only the existence of gravitational groups but their physical limits have been rather clearly indicated. We can speak therefore, with confidence, of material *systems* throughout the whole survey from corpuscles to the Metagalaxy.

But what of the constituents of the material universe that do not present recognizable organization? What of the cosmic meteors and the particles driven off with increasing speed from the heads of comets? What of radiation itself?

If these important entities cannot be appropriately listed in a survey of material systems, at least they must be included in a general survey of the material universe. The greatest unsolved mysteries of the physical world probably lie in this realm of unorganized or dimly organized particles and corpuscles that move speedily and perhaps endlessly through intergalactic space.

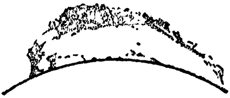
For this vague substratum of the material universe I suggest the name Cosmoplasma. It is the matrix in which planets, stars, and galaxies rotate; it constitutes the sidereal medium in which material systems undergo organized motion and development. We know so little as yet of the Cosmoplasma that a description of its materials should be brief. Let us first suggest a tentative classification:

+11 THE COSMOPLASMA
- α. Interstellar particles
  - (1) Cosmic meteors
  - (2) Diffused nebulosity
- β. Interstellar gas
  - (1) Electrons and protons
  - (2) Atoms
  - (3) Molecules
- γ. Radiation
- δ. . . . .

Stars die off. From this conclusion there seems at present to be little escape. We no longer hesitate to accept the equivalence of matter and radiation, considering them merely as different forms of energy. Radiation depletes the masses of stars. In consequence of the high temperatures resulting from the activity of their atoms and corpuscles, the Sun and the other stars radiate away enormous quantities of energy, which can be measured in grams, pounds, or tons.

An ordinary 40-watt electric light radiates in two million years, if it can tap sufficient stores and persist, one ounce of energy. In a second the Sun radiates from its surface four million tons. The contrast in candle power between lamp and star is startling, but the important consideration is the great loss each second to the mass of the Sun. In a year's time the Sun radiates one hundred and thirty million million tons into space, and as yet we see no adequate source for replenishing this loss. Through its active radiation, therefore, the Sun is evolving—that is, it is dying off as a luminous body. Fortunately for those interested in the persistence of terrestrial protoplasm, the mass of the Sun is sufficiently large to suffer such an enormous annual diminution for more than a million million years before it loses as much as a tenth of its total material.

Although the progress of the energy degradation of the stars, measured in our units of time, is exceedingly slow, we must admit that time is long in the sidereal universe, and these stars that now shine upon us must eventually become obscure. Until we visualize a mechanism by which stars are replenished, we must accept the probability that throughout the millions of galaxies they are changing irreversibly into radiation. Are there perhaps galaxies so old that the stars have burned away to faint or cold cinders, their available energy melted into space? A million years ago the Sun was larger—presumably all stars, or nearly all stars, were then more massive. Our planets have existed for about two billion years, and since their birth the Sun has forty times poured out into space the equivalent of the Earth's weight in the form of light.



We might dwell on this picture of the degradation of the universe, but it is more important for our inquiry into the Cosmoplasma to note that the material universe is after all not mainly in the stars and nebulae; it is dispersed throughout intergalactic space. All of the Sun's radiant energy emitted before the Pyramids were built is well outside the local system, except for less than a millionth of one per cent, intercepted by the planets. All radiation emitted before the Pleistocene age is outside the galactic system, still receding, so far as we can tell or surmise, at the rate of 186,000 miles a second. The light emitted in pre-Cambrian times is now far beyond the remotest galaxy that telescopes have shown us. In other words, it is quite probable that the major part of the original solar system is not in our Sun and planets but is spread weakly throughout immeasurable regions of space. The other stars have also spent their substance. The recognizable universe appears to be a composite of dying embers, each flame surrounded by the hungry cold of space that not only absorbs the heat and light but eventually exhausts the fuel supplies on which the doomed flames feed.

Shall we escape the "heat death" of the universe through some existing or forthcoming reversal of cosmic processes—some building up of stellar masses? Has space itself potentialities of maintaining the energy supply of stars? Cannot the expended radiation reform into corpuscles, atoms, molecules, and eventually nebulae and stars, replacing fading stars with fresher universes? It is safer to ask such questions than to attempt their answers. A few years more and some of them will be clarified through special observations. Others will yield, as time goes on and the picture becomes more clear, to speculations that momentarily may be satisfying. But most questions of this sort will long remain unanswered, growing more complex as our knowledge advances. Therein, of course, lies the fascination of our attempt to comprehend.

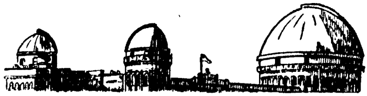
When we begin to explore the Cosmoplasma we find, as intimated above, that this substratum of the universe contains not only the major mysteries but perhaps also the major portion of the materials themselves. Even if we were to regard radiation as immaterial in the strict sense, we must recognize the probability of vast amounts of matter in finely divided form spread throughout space, driven here and there by radiation and thus unable to take part in ordinary gravitational organizations. Let us look further into these other constituents of the Cosmoplasma.

Through spectroscopic studies of certain classes of stars we know of interstellar atoms and molecules. Some of the important absorption lines in stellar spectra arise neither in the atmospheres of the stars themselves where the light originates nor in the Earth's atmosphere where the light reaches the spectroscope; they can best be accounted for by a substratum of ionized gases lying between star and observer.

So far as the substratum of ionized calcium is concerned, our present indications favor the view that the atoms move with the local system—they show evidence of galactic rotation. They are therefore a part of the local system, though not associated with the individual stars. There can be little doubt, however, that other electrons, protons, atoms, and molecules have been thrown quite outside the galactic system and are now constitutents of the general Cosmoplasma.

Many of the diffused nebulosities show no special central organization. If they are composed of gases and dust, a general diffusion into space must result, since the gravitational attractions are insufficient to hold the small particles in distinct nebulous clouds. In other words, diffused nebulosities of small mass can have no definite boundaries and the escaping particles must scatter into the cosmic substratum.

Meteors, as we have noted in Chapter VII, are of two types—those belonging to the solar system and moving in closed orbits about the Sun, and the cosmic meteors, moving at high speed in open orbits, being principally the stones and irons of interstellar space. We do not yet know what speed a passing meteor must have to be independent of the local system and of the larger Galaxy—probably a hundred kilometers a second would suffice. At the Earth's distance from the Sun a speed greater than forty-three kilometers a second would result in escape from the solar system. Interstellar meteors undoubtedly exist in great abundance, and presumably intergalactic meteors also exist in large but unknown numbers with considerable but unpredictable total mass.



The density of interstellar gas in the solar neighborhood is estimated by Eddington to be 10^{-24} grams per cubic centimeter. This value is equivalent to a single atom for each cubic inch. This density is of course inconceivably low; a cubic foot of air at the Earth's surface contains five trillion trillion atoms. Interstellar space is indeed an exceedingly high vacuum. Light traverses such a medium for thousands of years with scarcely any diminution of intensity or speed, and without suffering appreciable change of color, except when passing through heavily nebulous regions.

Whether the space between galaxies is less heavily populated with electrons, atoms, molecules, and meteorites than the interstellar space within the local galaxy, we cannot say; but an examination of the colors of remote external systems shows that the scattering and blocking of light by intergalactic media is also extremely small, even when a distance of ten million light years is involved and an interval of ten million years.

I suspect that the most important division of the Cosmoplasma is that designated by δ . . . Our inability to fill in the blank is an acknowledgment of temporary ignorance but not of despair. Again we might be tempted with the word Ether, as for Class -4, α. But if the blank is filled in, even tentatively, with some vague and speculative entity, I should like to create the further Class ϵ . . . We need thus to symbolize the belief and hope that something very fundamental and probably entirely new awaits our discovery or formulation in the domain of the Cosmoplasma.

Chapter XV

PROGRESS TOWARDS ORDER

Comprehensive and final, the word Universe seems most obvious for the name of our ultimate class. Astronomers have frequently abused the term, to be sure, by speaking of "island universes" or by applying it to special sections of the Galaxy or to special concepts of world structure. In our present usage, the Universe includes every material thing we know, not only all of the material systems, from corpuscles to the Metagalaxy, but also the constituents of the Cosmoplasma. Is it not natural and appropriate therefore to terminate the survey at this point, with the classes running from −4, Corpuscles, to +12, The Universe?

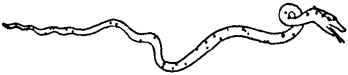
If a hundred years ago we had surveyed the systems within the universe as then comprehended, it is certain that at both ends the list of recognized material systems would have been more limited. Atoms were not treated as systems, but as units. Electrons were unknown. In the macrocosmos there were vaguely understood galaxies, but nothing higher was definitely visualized. Very little was accurately known, of course, concerning sidereal distances or stellar population. The warning of scientific history is certainly that our ever growing knowledge of The

Universe may soon cross present boundaries, and that we should allow for systems beyond those now conceived. Scientific pronouncements concerning unsurpassable limits in dimensions and masses or ultimates in organization are likely to be mere dogma.

I suggest, therefore, that Class +13 . . . be set up, partly as a matter of safety, partly as a challenge.

As soon as we see the unfilled line beyond +12, The Universe, a number of possible fillers come naturally to mind. We want to write in at once something that transcends the material universe. Some would offer "The Absolute" as an appropriate class name, though they might find it indefensible in a list of material systems. Others would suggest "Mind" for Class +13; but probably they could not meet the argument that Mind falls outside this essentially one-dimensional material classification. If Mind appears at all, might it not possibly enter every class and subclass? Or be the predominant element in a second dimension of the classification?

In the event that +13 . . . is filled in, I would propose the class +14 . . . , believing it best, as a precaution, to leave the door open when there is so much fire among the colloidal aggregates. It is because of this activity in subclass β of Class 0 that the series should also be left open at the other end, −5 . . . ; it may not be long before the hypothetical constituents of corpuscles are themselves resolved into material systems.



The total classification of material systems can now be assembled. It must be considered tentative in parts, and as flexible rather than static. It represents progress towards order, but not a complete escape from chaos. New researches should soon suggest modifications and further progress. In some respects the general picture is not wholly satisfying. For one thing, it makes us conscious of the varieties of our ignorance. For another, it is necessarily non-homogeneous in the subclasses. At best it is a *working* classification, designed to give perspective and to guide further inquiry into the relationships of types of organization.

The complete listing, which has grown out of the preceding chapters, is shown on the following pages.

A CLASSIFICATION OF MATERIAL SYSTEMS

−5 . . . . . .

−4 CORPUSCLES
  α. . . . .
  β. Light quanta
  γ. Electrons
  δ. Protons

−3 ATOMS
  1 to 92 . . .

−2 MOLECULES
  1 to n

−1 MOLECULAR SYSTEMS
  I. Crystals
  II. Colloids

0 COLLOIDAL AND CRYSTALLIC AGGREGATES
  α. Inorganic (minerals, meteorites, etc.)
  β. Organic (organisms, colonies, etc.)

+1 METEORITIC ASSOCIATIONS
  1. Meteor streams
  2. Comets
  3. Centralized diffuse nebulae

+2 SATELLITIC SYSTEMS
  I. Earth-moon type
  II. Jovian type
  III. Saturnian type

+3 PLANETARY STRUCTURES
  I. Stars, with coronae and meteors
  II. Stars, with planets, comets, etc.
  III. Stars, with nebulous envelopes
    (I) Planetary nebulae
    (II) Ring nebulae

+4 DOUBLE AND MULTIPLE STARS
  I. Close systems
    (a) Eclipsing
    (b) Spectroscopic
  II. Visual systems
    (α) Gravitational
    (β) Optical
  III. Moving pairs and multiples

+5 GALACTIC CLUSTERS
- a. Field irregularities
- b. Star associations
- c. Very loose groups
- d. Loose groups
- e. Restricted groups
- f. Compact groups
- g. Dense groups

+6 GLOBULAR CLUSTERS
- I. Most concentrated systems
- II. . . . .
- . . . .
- XII. Least concentrated systems

+7 GALAXIES
- a. Internal
  - (a) Local system
  - (b) Scutum type
    - (α) Real
    - (β) Apparent
  - (c) Magellanic Clouds
- b. External
  - a1 a2 a3 a4 . . . . . a10
  - b1 b2 b3 b4 . . . . . b10
  - . . . .
  - f1 f2 f3 f4 . . . . . f10

+8 MULTIPLE GALAXIES
- 1. Double systems
- 2. Small groups

+9 SUPERGALAXIES
- I. Coma-Virgo type
- II. The Galactic System

+10 THE METAGALAXY

+11 THE COSMOPLASMA
- α. Interstellar particles
  - (1) Cosmic meteors
  - (2) Diffused nebulosity
- β. Interstellar gas
  - (1) Corpuscles
  - (2) Atoms
  - (3) Molecules
- γ. Radiation
- δ. . . . .

+12 THE UNIVERSE (SPACE-TIME COMPLEX)

+13 . . . .

The possibility of more elaborate subdivision for many of the classes has been mentioned several times in preceding chapters. Fairly good alternative classifications are available here and there. It should be remembered, however, that *systems* rather than *bodies* have been under discussion. A list of the kinds of material bodies would be simpler and shorter; the main items, perhaps, would be quanta, electrons, atoms, molecules, meteorites, (satellites), (planets), stars, (nebulosity), the classes in parentheses being of doubtful necessity if meteorites are broadly conceived. If we were developing this classification of bodies, we should also enter into the field of variable star classification, and considerations of the spectra of stars. Both of these are important in astronomical research, but they are omitted from our survey since they are clearly outside its scope.

It is obvious that very extensive subdivisions can be and have been made of Class 0, β, Organic Colloidal Aggregates—classifications into kingdoms, phyla, classes, orders, families, genera, species, varieties, races, and so on—but to go into that matter here would be clearly a demonstration of prejudice, vanity, and over-emphasis. We hear enough of organisms. We might more justly proceed to class comets according to length of tail or double stars in terms of color.

Aside from the general panorama, the most satisfactory outcome of the present study is the light it has thrown on the place of the local system in the Metagalaxy. It is a relief to find that we need not assume our galactic system to be an organization of unique type and of abnormal consequence. The supergalaxy hypothesis, which brings this relief, may be an incomplete interpretation of Milky Way structure; but it suggests numerous researches, and, as it stands, appears to be more tenable than the previous conception of the galactic system.

In any one class the dimensions and masses may vary enormously, especially for colloidal aggregates and meteoritic associations. But in general the main classification has been developed in order of increasing size. The trend is shown in the following tabulation, where approximate diameters are expressed in centimeters. If we choose to substitute miles for centimeters, we can do so with sufficient approximation by diminishing each exponent by 5. Thus, the average diameter of a molecule is 10^{-7} centimeters, or 10^{-12} miles; and that of an average satellitic system is 10^{11} centimeters, or 10^{6} miles.

The estimate of the diameter of the somewhat hypothetical "closed universe" is based on very provisional data interpreted with the general theory of relativity. The diameter of the metagalactic system is merely an indication of the distances of the remotest galaxies now photographed with the large telescopes. Although accuracy cannot be claimed for the estimates of diameter, they are certainly of the right order of magnitude.

DIAMETERS OF MATERIAL SYSTEMS

	cm
Proton	10^{-13}
Atom	10^{-8}
Molecule	10^{-7}
Colloid	10^{-6}
Comet and Meteor Stream	10^{7}
Earth-moon System	10^{11}
Solar System	10^{15}
Galactic Cluster	10^{19}
Globular Cluster	10^{20}
Star cloud and Galaxy	10^{22}
The Galactic System	10^{23}
The Metagalaxy	10^{27}
The Universe (radius)	10^{29}(?)

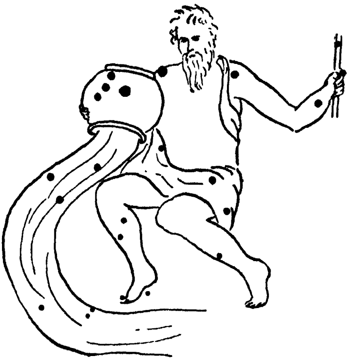
In mass, as well as in linear dimensions, the systems classified have progressed from less to greater. They therefore show increasing numbers of corpuscles (electrons and protons). In the final tabulation we list some main structures and indicate approximately the number of corpuscles constituting an average system. To express the weights in tons the exponents should be diminished by 30 (*e.g.*, the Sun contains 10^{27} tons of matter).

Numbers of Particles

Hydrogen atom	2
Mercury atom	400
One gram	10^{24}
Comet	10^{44}
Earth	10^{52}
Sun	10^{57}
Globular Cluster	10^{63}
Galaxy	10^{67}
Supergalaxy	10^{68}
The Universe	$>10^{73}$(?)

Once more we end the list with a question mark; for even when we leave radiation out of the count, it is still difficult to estimate the amount of material in the Cosmoplasma. If the total were more than a hundred times the amount concentrated into recognized or surmised stars and nebulae, probably the speeds of individual stars would be much higher than those observed. But certainly in the form of dim or dead stars, and of interstellar gas and meteors, there might be, suitably distributed in space, several times as much material as is concentrated in the luminous stars and recognized nebulae.

With these tabulations of dimensions and masses we bring to a conclusion the discussion of the kinds of material systems. Orientation in the physical world has been the general guiding ambition—orientation and stimulus. The survey has been developed in order to show to what extent a unified classification of all known material systems can be devised; to provide practical subdivisions for several classes; to find the relation of our galactic system to external galaxies; to emphasize the importance of the substratum of particles, gas, and radiation that constitute the Cosmoplasma; to sort out into appropriate categories such undifferentiated objects as gaseous nebulae; and to mark the place of organisms in the cosmic scheme. I feel that the survey has been justified if it gives the thinker material for thought and the experimenter some intimations of fertile fields.



Concerning Illustrations

The sketches have been made by Miss Muriel Mussells. Several of them represent particular astronomical phenomena.