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ASTROPHYSICS

Astrophysics, a branch of astronomy that deals with the physical and chemical nature of celestial objects and events, covers a vast scope since everything that lies beyond the dominant influence of the earth falls naturally into its domain. In contrast to the great variety of objects that are under the jurisdiction of its studies, the means of studying them are very limited because for obvious reasons these objects cannot be subjected to controlled experimentation. While the advant of space research has somewhat modified this situation, the basic characteristic of astrophysics, like astronomy in general, is its observational nature.

We may digress to note that astrophysics has been occasionally defined as the application of physical laws to astronomical objects. Such a definition would have included, for example, celestial mechanics which studies the motion of planets and other bodies in the solar system. While celestial mechanics treats nothing but applications of physical laws of motion and gravitation, it is ← never considered a part of astrophysics.

Actually astrophysics has its empirical origin, resulting, as we shall see, from some special means of observation. As it develops, its scope changes. This is of course true for all branches of science. For example, the domain of physics as understood by modern physicists is greatly different from what would be conceived by those who lived a century before. In fact even at a given epoch it is difficult to define the scope of a definite subject. Thus, in modern times few will venture to set the boundary line where physics ends while chemistry begins. This is because knowledge, like water in the oceans, is all-pervading and sees no boundary. Its subdivision into different subjects is made only by man for his convenience. For this reason we must resort to historical development in order to obtain a clear view of a particular subject under study. This brings us to the question of the origin of astrophysics as a branch of science and of its development as a result of advancements made in other branches of science and technology.

THREE MEANS OF ASTRONOMICAL OBSERVATION. In order to investigate the origin of astrophysics, let us first give a brief review of what can be observed of celestial bodies. Historically it was the positions of shining objects in the sky that first caught the attention of man (positional astronomy). Perhaps in the dawn of history we can not clearly distinguish astrology -- the art of predicting the events on the earth from the positions of celestial bodies in the sky -- from astronomy, the science of studying celestial bodies as an end in itself. In any case, constant observations of the night sky convinced early man that there were two kinds of celestial objects: (1) the fixed stars which revolve in their diurnal motions across the sky without changing their relative positions, and (2) the planets, i.e. wanderers according to the Greeks, that are moving on the background of the fixed stars.

The study of motion of planets in the sky led to Kepler's discovery of his three famous laws which in turn provided the clue for the formulation of Newton's law of gravitation. Thus, the observation of the positions of planets in the sky laid the foundation of classical mechanics. Then it was found (by E. Halley in 1718) that stars were not after all fixed on the celestial sphere but showed over the centuries some small displacements, called proper motions, with respect to one another. The discovery of proper motion introduced a new era of astronomical research because the interest aroused by it in measuring accurately the positions of stars (astrometry) led William Herschel in 1802 to the discovery of the existence of relative orbital motion in some visual binary stars, and F. W. Bessel in 1838 to the successful determination of the stellar distance for the first time by the trigonometric method. The existence of binaries in which two stars revolve around each other showed the universality of Newton's law of gravitation. Together with the distance determination, the orbital motion of visual binaries provides a means for measuring the masses of stars. At the same time the distance determination also paves the way to deriving the intrinsic brightnesses (i.e., luminosities) of stars.

If Newton's law of gravitation, a basic law of physics, resulted directly from positional astronomy and its universality was confirmed by astrometrical study of visual binaries, and if the measurement of positions of stars in the sky also produced two basic quantities, i.e. the mass and luminosity of stars on which astrophysical studies can be made, one would naturally guess that astrophysics begins at positional astronomy. Such a guess turns out to be wrong because by convention astrophysics excludes any study of positions of celestial objects although it does not hesitate to use its results.

Another quantity of celestial bodies that can be directly measured is their apparent brightnesses. Such a study belongs to astronomical photometry and may be traced to the Greeks who graded the stars, according to their apparent brightnesses in the sky, into six magnitudes. The stars of the sixth magnitude are the faintest visible to the naked eye while the first magnitude comprised about twenty of the brightest. The scale was arbitrary and became more so after the invention of the telescope by which fainter and fainter stars become accessible for observation. A definite magnitude scale based on exact photometric measures was set up in the first half of the nineteenth century. According to this scale one magnitude difference amounts to a light ratio of $\sqrt[5]{100}$, or approximately 2.512. In other words the brightnesses of stars of successive magnitudes bear the constant ratio of 2.512 to one another. The reason for using this rather non-linear scale was due to the fact that sensation of the eye varies as the logarithm of the light stimulus and the early works on the brightnesses of stars depended solely upon the direct visual perception. This magnitude scale is maintained even when the brightness is now measured by photographic and photoelectric methods.

Stars have different colors. It becomes obvious that when we measure the brightness of a star we must first specify the region of wave lengths (i.e. the color) in which the measurement is being made. In the early days when the human eye was used directly for determining stellar magnitudes, the measured brightness was of course always referred to the spectral region of light to which the eye is sensitive. This is the visual magnitude of stars. With the use of the photographic method for measuring stellar magnitudes, the measured brightness is in the spectral region to which the photographic plate is sensitive. This gives the photographic magnitude. By properly choosing the light filter and the detecting instrument we can nowadays measure the brightness of a star in any color. Since the color is related to the effective temperature of a star, the different brightnesses of the same star seen in different colors give a good estimate of its temperature.

Perhaps the most important brightness measurement should be such that it takes radiation of all wave lengths into consideration. In other words, it should deal with the total energy over the entire spectrum of the electromagnetic radiation, from radio waves through optical light to γ rays. Such a measure is called the bolometric magnitude. Since the earth's atmosphere absorbs radiation in wide ranges of wave lengths the bolometric magnitude of a star was not a directly measurable quantity. This is especially true for hot blue stars whose radiation lies mostly in the ultraviolet region. However, with observations carried out above the earth's atmosphere we may expect to determine the bolometric magnitude directly.

The photometric measurement of course does not limit its usefulness in the determination of effective temperature at which the star radiates. When the distance is known, the brightness measured can be immediately converted into the actual rate of energy output, i.e. the luminosity, of the star. In addition to the temperature and luminosity determinations, photometric observations of stars provide a means of examining the light variations with time (called the light curve) of celestial objects. Various interesting objects may be studied in detail, with variations ranging from as much as a million times increase in brightness, as in the case of supernovae, to the barely detectable change in brightness of one tenth of one per cent. The studies of light variation prove to be most rewarding as they reveal some physical events that are happening to the stars. Thus, supernovae, novae, and many nova-like objects clearly indicate the catastrophic explosion of stars. Among stars of less drastic variation in light some result in stellar pulsation, while others may be due to the eclipse of one component star by the other in a binary system when our line of sight lies close to its orbital plane.

That the photometric study of stars is rewarding may be seen from the discovery in 1912 by Miss H. S. Leavitt of a correlation between the periods of light variation and the apparent brightnesses for a group of pulsating variable stars in the Small Magellanic Cloud. Since the Cloud which is outside our own galaxy is fairly distant, the variables in it may be taken nearly as being at the same distance from the earth. Then the relative apparent brightnesses represent also the relative intrinsic brightnesses. It follows that a relation exists between the periods and the luminosities for these variables. This discovery not only had a far-reaching impact on the determination of distances of cosmic objects but also stimulated the study of the nature of these variables. In more than a half century since then, it has been found that variables resulting from pulsation are consisted of several physical groups each having a distinct period-luminosity relation of its own. Therefore, the pulsating variables become an outstanding problem in astrophysics at present and it all started from photometry.

These do not exhaust all that photometrical observations can do for the purpose of understanding the nature of celestial objects. We owe to photometry much of our knowledge concerning the properties of interstellar media, as interstellar space is not entirely empty but is permeated with gases and dust at low densities. The interstellar medium impresses several effects on the light that passes through it. In the first place starlight will be dimmed by the effect of scattering and absorption. Hence the stars appear fainter than they would have appeared if space were empty.

Secondly the dust particles in interstellar space scatter the blue light (of short wavelengths) more effectively than red light (of long wavelengths). The removal of blue light leaves the starlight redder as it propagates in the scattering medium. This is the so-called "interstellar reddening" and can be most efficiently studied by photometry of distant hot stars.

Another means of photometric studies that is of great importance to our understanding of interstellar media is the polarization. It was discovered in 1949 that light of distant stars becomes polarized after having passed through clouds of interstellar matter. The polarization is believed to be caused by alignment of elongated dust grains in interstellar space. There is no difficulty in having elongated particles in space, as laboratory experiments show that growth of crystals has a tendency to produce particles of just such a shape. However, why should they be aligned? The most likely explanation is that a weak magnetic field prevails in interstellar space. This created many new problems concerning the magnetic field and particles in space.

Polarization of light was discovered in another celestial source in 1954. It is the Crab Nebula which has been thought to be the remnant of a supernova explosion that took place in 1054 according to the historical record of China and Japan. The detection of polarization confirmed the suggestion that radiation from the Crab Nebula arises from relativistic electrons in magnetic field, namely the synchrotron radiation.

In addition to the amorphous interstellar medium just described, there are in the universe many extended objects that can be seen or photographed with or without a telescope. The surfaces of the moon, the sun, and the planets provide interesting objects for study either visually or by photograph. Another example is the galaxies, which can be classified simply on the basis of their morphological characteristics, such as spiral, elliptical, or irregular. All these studies may be regarded as photometric because basically they trace the light distribution in an area (i.e., the surface photometry of an extended object). They have provided a quick over-all description for extended celestial objects as revealing as a snapshot of a man on a "Wanted" poster.

Thus we have seen that photometry raises as well as helps solve many problems concerning celestial objects. Without any doubt it forms a part of astrophysics. However, it should be noted that the name "Astrophysics" was not introduced after stellar photometry had become a science of exact measurements because with photometrical results alone we could never have succeeded in comprehending the physical nature of stars, interstellar media, or other celestial bodies. The founding of astrophysics had to await the advent of the third means of observation, namely stellar spectroscopy.

SPECTROSCOPIC OBSERVATIONS AS THE EMPIRICAL FOUNDATION OF ASTROPHYSICS. While photometry (including photography) may have anticipated the coming of astrophysics, it is spectroscopy that founded this branch of modern science, because before the light could be analyzed spectroscopically, it would be meaningless to ask such questions as the chemical composition and physical state of the celestial objects. Therefore, in order to see how astrophysics became a branch of science we must go back to history of spectroscopy.

It is well known that spectral decomposition of sunlight by the prism was demonstrated by Newton as early as 1666, but the dark lines in the solar spectrum were first noticed by W. H. Wollaston only in 1802. However, the latter has made no attempt to investigate these dark lines. Therefore, it may be said that the spectroscopic study of celestial objects was started by the Bavarian optician Josef Fraunhofer who investigated systematically these dark lines and published his results of investigation in 1817. He showed by experiments that the dark lines and bands were intrinsic to the nature of sunlight and did not arise from diffraction, optical illusion, etc. He measured hundreds of what has since been called Fraunhofer lines and to the principal ones assigned letters A, B, C, D, ... some of which have maintained the usage till now.

Later, Fraunhofer found that the moon and the planets had dark-line spectra which were in general identical with that of the sun. This also held true for some of the fixed stars such as Pollux (β Gem) and Capella (α Aur). But other stars, notably Sirius (α CMa) showed quite different patterns of the line structure. In this way, stellar spectroscopy was founded and ever since the studies of the spectral lines -- whether absorption or emission -- of cosmic objects have added bountifully to man's knowledge about the universe.

Of course, Fraunhofer had no idea of the meaning of these lines. Perhaps we should attribute to Gustav Kirchhoff as the person who actually founded astrophysics because from his interpretation of the Fraunhofer lines have emerged all the possibilities for learning the physical nature of cosmic objects, as we shall see. In collaboration with the chemist R. Bunsen, Kirchhoff studied spectra of flames and metallic vapors in the electric arc and discovered the coincidence in wave length of the dark D lines in sunlight with a double bright line in the light of a sodium flame. After similar coincidence of bright lines due to other chemical elements with other Fraunhofer lines, Kirchhoff enunciated the famous laws which now bear his name and which may be stated that (1) each chemical species has its own characteristic spectra and (2) it absorbs radiation at wave lengths where it is capable to emit and vice versa.

It follows from Kirchhoff's law that the photosphere of the sun and stars emits continuous radiation while vapor in the so-called reversing layer above it selectively absorbs radiation to produce Fraunhofer lines because the reversing layer has lower temperatures than the photosphere. By identifying the absorption lines in the spectra of the sun, Kirchhoff was able to announce in 1861 the presence in its atmosphere various chemical elements such as sodium, iron, calcium, etc. that are common on the earth. The importance of this discovery is obvious, for what has been found is not only the chemical composition of the solar atmosphere but also the fact that the temperature even at the very surface of the sun must be high enough to vaporize the metals.

That the stellar matter is in the gaseous state has a far-reaching consequence, because its equation of state (which gives the density as a function of the pressure and temperature) is simple and best known. As a result of this simplicity of gaseous matter, the internal structure of the star can be studied theoretically by imposing the conditions of hydrostatic equilibrium as well as the energy transport. In this way a mathematical theory of stellar structure can be established.

Stellar spectroscopy opened up the following fields of astrophysical research:

(1) Line identification. This is a continuation of Kirchhoff's original work of identifying the spectral lines found in the

spectra of celestial objects with those produced in the laboratory. Straightforward as the identification may seem to be, this work is not completed now because there are still many lines arising from celestial sources that are not identified. For example, about 30 per cent of solar lines, most of them being faint, remain unidentified. Most of the unidentified lines in the sun and in the stars must be produced by molecules.

(2) Chemical abundance. From identification of spectral lines to the determination of the chemical abundance from the line strengths is a natural and logical step, although the actual procedure for determining the abundance is tedious and depends upon the nature of the objects (i.e., whether they are stars, nebulae or interstellar media). The result shows an approximate uniformity of chemical abundance in the universe but with some noted exceptions. By far hydrogen is most abundant. It is followed by helium with an impurity of carbon, nitrogen, and oxygen and only traces of the other elements. Here we see that even if the spectroscopic observation is not the sole reason for concluding the gaseous nature of the star, the success of theory of the stellar structure owes much to our knowledge of the chemical abundance that has been obtained from spectroscopic studies.

(3) Spectral classification. As a result of the chemical uniformity in stars, we can attribute the difference in the appearance of spectra for the majority of stars to be due to difference in temperature and pressure in their

atmospheres. This makes possible the development of empirical schemes for classifying stellar spectra in terms of two parameters: temperature and pressure in the atmospheres.

That the temperature and the pressure can affect drastically the appearance of stellar spectra is due to the excitation and ionization process of atoms and the dissociation process of molecules. Since the pressure is related to the surface gravity which in turn depends upon the radius and consequently the luminosity of the star, we can express the pressure in the atmosphere in terms of the luminosity. In this way we can tell the effective temperature as well as the luminosity of the star simply by looking at its spectrum.

In any case, the effective temperature and the luminosity are two directly observable quantities of the star. When one studies a group of stars, it is useful to plot the luminosity against the temperature of the stars in what is called the Hertzsprung-Russell, or simply H-R diagram. The resulting diagram describes the physical nature of the constituents in the group at a glance, because stars do not scatter randomly in the H-R diagram but form different sequences which are related to the age of the group. Therefore, the H-R diagram is a powerful tool for studying stellar evolution in star clusters.

(4) Emission lines. The presence of emission lines raises many interesting lines of investigation because there are

several circumstances under which they may be formed in cosmic sources. Often the appearance of some kind of emission lines presents the astrophysicist the clue as to the nature of their origin. For example, the emission lines in the spectra of gaseous nebulae led to the proposal (1927) that they are forbidden lines emitted only in a gas of very low density. Another example is the identification of the solar corona lines (1941-1942) as due to those ions in which more than ten electrons have been stripped off from the atoms. It helped establish the fact that the solar corona is at high temperatures of the order of a million degrees.

(5) Radial velocity. The small shifts in wave length of lines in the spectra of the celestial source as compared with the corresponding lines in the laboratory spectra result chiefly from the Doppler effect. This fact gives the astrophysicist an opportunity to learn the line-of-sight component of the motion of a celestial object with respect to the earth. Since the earth itself is moving around the sun, it is the usual practice to subtract the earth's motion from the measured value and to refer the line-of-sight component with respect to the sun as the radial velocity of the star. Much of our present understanding of the objects in universe come from the measurement of their radial velocities. Of the foremost significance is, of course, the establishment by

E. P. Hubble in 1929 of an empirical linear relation between the red shifts of spectral lines of extragalactic nebulae (galaxies) and their distances. Interpreted as a result of the Doppler effect, the red shifts represent recessional velocities. Thus the Hubble law indicates that the universe we live in is an expanding one, as galaxies are flying away from each other at the rate increasing with their distance. Combined with the general theory of relativity, it provides for the first time a scientific theory for the universe. To be sure, cosmology by itself is not regarded as a part of astrophysics but its empirical foundation is built on the latter.

Next we find that radial velocities of stars supply important data as regards to the motion of stars such as galactic rotation in our own galaxy (the Milky Ways system). Traditionally, the study of the galactic structure is not regarded as a part of astrophysics mainly because it concerns with the dynamical but not the physical and chemical nature, of the galactic system. But it has become increasingly difficult nowadays to separate the astrophysical problems of the relation between stellar and galactic evolution from the purely structural problem of the galaxy.

Measurements of stellar radial velocities created many new problems. It was found that many stars which appear visually as single are actually binaries with two components revolving around each other according to Newton's law. Their orbital motion makes the spectral lines oscillate back and forth with time. Such stars are called spectroscopic binaries. Sometimes we see two sets of lines corresponding to the two component stars moving in opposite directions. But in most cases only the spectrum of one component can be seen as the other component is too faint to show up even in the spectrum. The variation of radial velocity resulting from the orbital motion gives the nature of the binary orbit. Thus the spectroscopic study provides a means to understand the dynamical nature of a binary system. According to our definition, it should not be included in astrophysics, because it concerns the dynamical nature. Actually the study of spectroscopic binaries has traditionally been regarded as a part of astrophysics because it relies on stellar spectra.

Needless to say, physical problems that may be solved by the spectroscopic study do exist in connection with binary systems if the separation between the two component stars becomes so close that they physically interact. Such problems include the mass ejection, gaseous stream etc., all of which have a great astrophysical interest.

The variation of radial velocity resulting from the orbital motion of binary stars gives an important factor of measuring stellar masses. While the detailed process of mass determination cannot be described here, the reason can be simply stated because the velocity in the orbital motion reflects the force of attraction which is determined by the mass as well as the separation. This is true not only for binary systems but for all systems in the state of dynamical equilibrium. For example, the mass of our galaxy may be estimated from the velocity of galactic rotation. Also, the mass of a cluster, whether of stars or of galaxies, may be determined from radial velocities of their constituent objects.

The radial velocity measurement is of great importance in our search for the understanding of the pulsating and exploding stars. In fact, it is the radial-velocity measures that conclusively put intrinsic pulsation instead of geometrical eclipse, as the cause of light variation in some stars. In the case of novae and supernovae it is again the radial-velocity measure that actually shows the catastrophic explosion by the high velocities with which matter is ejected from the star during the sudden brightening.

(6) Line broadening. The natural width of the spectral line due to radiation damping is narrow. But in stellar atmospheres, there are many effects such as collisional damping, thermal motion, turbulence, etc., that broaden the lines. But

by far the most conspicuous mechanism of broadening of stellar lines is the axial rotation. When a star rotates, various parts of the stellar disk have different velocities. Thus, the lines produced in different surface elements are shifted by varying amounts. Taken as a whole, they show a greatly widened single line. From the width, we may estimate the speed of rotation. However, because the broadening results from the Doppler effect, there is a projection factor which we can never determine by the spectroscopic study. This can be seen by the fact that no rotational broadening will be observed if the spinning axis coincides with the line of sight. Even so, much about stellar rotation has been learned from spectroscopic studies.

(7) Zeeman effect. The atomic energy levels are splitted in the presence of a magnetic field. Hence, each spectral line in the ordinary case becomes correspondingly splitted into several components in the magnetic field. This is of course the well-known Zeeman effect. As the separation between components in the Zeeman splitting is very small, the splitting is washed out in stellar spectra by the various broadening mechanisms mentioned before. However, different components in the Zeeman splitting are polarized in different ways. Consequently, by taking the advantage of this polarization effect, one can detect the presence of the Zeeman splitting and consequently measure the magnetic field strength in the stars. <—————————— In the case of the sun, the

magnetic field at different points of the disk can be quickly obtained by what is called the solar magnetograph designed on the same principle of polarization. In any case, much has been learned about stellar magnetic field although the cause and the effect of magnetism in stars have yet to be studied.

(8) Spectroheliograph. This is an instrument designed for observing the solar surface in the light of a single spectral line. It aides the study of the solar activities.

Thus, we have seen the means of observation opened up by the spectroscopy. The name, astrophysics, was introduced in the very beginning to denote vaguely the physical problems resulting directly or indirectly from the spectroscopic observation of cosmic objects. It acquired a more definite meaning and became a term of common usage when G. E. Hale and J. E. Keeler founded in 1895 the "Astrophysical Journal" subtitled "An International Review of Spectroscopy and Astronomical Physics."

While the results of observation provide the foundation of astrophysics, we should not forget the contributions by theoreticians who, with mathematics as their instrument, help build this magnificent structure that is our understanding of the universe and its contents. Some of them, for example S. Chandrasekhar, have never observed in their whole life but their influence is felt in every corner of this branch of science.

DEVELOPMENT AND HESITATION. In order to gather more light for spectral analysis or photometric measurement or to penetrate deeper into space, we need a large telescope. Therefore, the development of astrophysics goes hand in hand with the construction of the larger and larger telescope. The situation resembles the present state of high-energy physics whose problem is to build larger and larger accelerators. The bigger their instrument, the better they can effectively do their jobs of uncovering the secret of atomic nuclei in the latter and of learning the mystery of the universe in the former case.

Thus, with the construction of big observatories, one would think that astrophysics was entering a golden age before the war. Perhaps it was thought so by astrophysicists at that time. However, with the advantage of hindsight we can see that this is not true. The construction of large observatories could not hide the fact that it was also a period of hesitation on the part of astrophysicists. They developed what they already had but failed to grasp what would turn out to be revolutionary.

In order to see this point, let us remember that astrophysics ~~studies~~ is supposed to study physical and chemical nature of all objects that lie beyond the earth's atmosphere with whatever means that is available. Since for centuries the only means that the man on the earth could make a contact with extra-terrestrial objects was through light, i.e., electromagnetic radiation in the optical region, astronomy and consequently astrophysics, had been invariably associated with the optical telescope. Such an association, resulting purely from expediency, gradually took the shape of tradition after centuries of practice. As a result, astronomy and astrophysics have become synonymous with optical observations through the telescope and the interpretation of their results. Such a synonymous notion would not encounter any difficulty if our means of contact with extra-terrestrial objects should remain througn optical radiation, as was the case in the early part of this century and before. But it is no longer true after the thirties.

The discovery of cosmic rays put astrophysicists in an acid test, although it was not even realized at that time. Here we encountered something coming from extra-terrestrial sources that could not be studied by the conventional telescope. A new contact with cosmic objects was found; some new information concerning cosmic objects might therefore be expected. Should astrophysicists undertake the study of cosmic rays? Actually such a question was not even asked at that time. Quite naturally and for good reasons, astrophysicists kept busy with their telescopes and let physicists work on cosmic rays. However, in retrospect this was the first sign that shows that centuries' tradition in astronomical science [illegible] is going to be broken by the force that has been created in the other fields of science and technology. In any case

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for a long time astrophysicists and cosmic ray physicists went their separate ways without much communication.

The other tide of revolution came about the same time when in 1932 K. Jansky discovered cosmic radio noise while he was investigating atmospheric interference in radio reception at the wavelength of 14.7 meters. Again the astrophysicists were slow in realizing the potentiality of radio emission from cosmic sources.

Thus, the two decades before the Second War may be termed as the hesitation period on the part of astrophysicists. The means for studying cosmic objects other than optical telescopes were there, but astrophysics was still imprisoned under the big dome of the optical observatories reluctant to explore the cosmos through the new techniques.

ASTROPHYSICS COMING OF AGE. The astrophysical problems are too important to let the hesitation last long. Scientists in other fields of learning soon became interested in their solutions and liberated astrophysics from the optical observatories. For example, physicists with their powerful knowledge of atomic nuclei turned their attention to energy generation in stars. When the stellar energy source is known, stellar evolution becomes understandable. This created an entirely new field of study of stellar evolution in recent years.

Then radar technique developed during the war set the stage for the rapid progress of radio astronomy. Radio waves have the advantage of not being easily attenuated in the interstellar medium. However because of long wavelengths the angular resolution of the radio telescope is poor compared with the optical telescope of the same aperture. Thus, the central point in the design of the radio telescope is to increase the effective aperture and thereby to obtain a higher resolving power, while for the optical telescope it is the collection of light that is most important.

Unlike the optical region wherein spectral lines abound, the radio region has only a few lines. By far, the most important one is, of course, the 21 cm hydrogen line arising from the transition between two hyperfine structure levels of the ground state. With this line, we can study the distribution of neutral hydrogen clouds and their motions in our own galaxy, which enable us to trace the galactic arms of our galaxy. Neutral hydrogen in other galaxies can now be studied by this same line. It provides a measure of mass of neutral hydrogen in the galaxies.

Observations of cosmic objects through radio waves have created many interesting lines of study. First, there is the general background noise both inside and outside our galaxy. The mechanism for producing the noise provides material for theoretical investigation. As a result the synchrotron-radiation process has been suggested.

The continuous radio noise coming from the extragalactic background has an important bearing on cosmology. Indeed, the radio emission observed at centimeter wave lengths appears to put the theory of an expanding universe far ahead of the competing theory of a steady state universe. But more rewarding is the study of radio emission from the discrete sources which are superimposed on the general background of noise. The discrete sources fall into three groups: sources in the solar system (such as the sun, Jupiter, etc.), sources in our own galaxy (such as the Crab Nebula) and extragalactic sources (such as the Cygnus A source). Radio emission of these objects helped us understand their physical nature. For example, radio emission of the sun has been found to be related to the solar activity. It becomes an important part of solar physics (which is a part of astrophysics). Radio observations of Jupiter and other planets have supplied results which will reveal the physical conditions of these planets (such as the magnetic field, the radiation belts resembling the van Allen belts of the earth, etc.). Similarly, studies of radio emission of the Crab Nebula have increased our knowledge about the physical conditions in supernova ejecta. This led to a possible identification of the sources in which the primary component of cosmic rays may be generated.

By far the most significant discovery in the recent years came as a result of studying extragalactic sources of radio emission. Through the combined effort of radio and optical observation a group of discrete radio sources was identified with the associated optical objects. These objects turn out to be most important in our search for the contents in the universe because they show large red shifts. While the red shift could be caused by a strong gravitational field according to general theory of relativity, it is now generally assumed that the displacement in wave lengths is due to recessional velocities associated with the expansion of the universe. If so, these objects which have been called "quasi-stellar radio source" or "quasar" (abbreviated QSRS or QSS) must be located far away in the frontier of the observable universe. It follows that the intrinsic luminosities of quasars must be enormous. Both the large distances and the enormous luminosities make quasars one of the most interesting objects in the universe. There is no doubt that studies of quasars will be one of the central problems in the years to come and will throw new light on the universe.

If we are impressed by the advance in astrophysics made after the start of radio astronomy, we must be prepared to see some equally if not more spectacular discoveries in astrophysics by observations made above the earth's atmosphere. As we know, the earth's atmosphere absorbs electromagnetic radiations in all wave lengths except two narrow bands -- one in the optical and another in the radio range. By observing above the atmospheres we are able to study a wide range of the electromagnetic spectrum. We are only in the beginning of this space age but already we have witnessed the discovery of the X ray sources in the galaxy that are of the upmost importance to astrophysics. Their discovery induced much speculations about their nature. Without doubt these sources and others yet to be discovered will provide heated discussions for the future.

However, the effect of space research on astrophysics is felt most strongly in studies of objects within our planetary system, because we are now capable to send a space vehicle to the objects of our interest. We have already witnessed the soft landing on the surface of the moon. It will be a matter of time to see a similar landing on the surface of planets and asteroids and the probing of comets. Thus, the exploration of the solar system needs the cooperation not only of physicists and chemists but also geophysicists, geologists, and even biochemists as well as biologists since the problem of extraterrestrial life is certainly one of our major interests. In short there are so many objects in the solar system and each is overwhelmingly large in terms of human experience. Now if we remember how great has been the task to study the earth, the work lying before us for a similar study of the moon, planets, satellites, asteroids, comets and the interplanetary medium will be beyond imagination. If peace reigns on the earth, it will be safe to predict that man will spend much of his energy to explore the solar system in the next few centuries. Or to put it more optimistically because man has found a way to dissipate his restless energy in space exploration, peace may prevail on the earth. If so, the study of heavenly bodies may turn out to be the salvation of the mankind. In the meantime, astrophysics will find itself entering into a new age.

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