Leaflet No. 273—January, 1952

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ASTROPHYSICS: 1951

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In recent years, and especially in 1951, new branches of physics that were not usually thought of as likely to affect the progress of astronomy, have begun to play outstanding roles in the observations as well as in theory

Radio and radar astronomy have assumed tremendous importance. They have already contributed much to our knowledge of the sun, the moon, the meteors, the earth's atmosphere, the stars, and the galaxies; yet they are now only in the pioneering stages. Many astronomical papers have considered the effects of shock waves, explosions, etc.; fields which were previously reserved for aerodynamists or experts on explosives. Nuclear physics has invaded astronomy for good. Electronic techniques, developments on infrared receivers, new optical devices are constantly being introduced.

Important new astrophysical equipment has been installed, partly in the Southern Hemisphere—especially in Australia and South Africa. A gratifying spirit of team work has inspired several cooperative installations in South Africa and Australia. Theoretical work has kept pace with the observations, providing the desired balance between theory and observation. On the whole, 1951 has been a year of real progress. Astrophysics appears to be in a stage of rejuvenation brought about by the impact of numerous new physical techniques and theories.

With the passing of Eddington, Jeans, and Milne, it might have been expected that the British school of theoretical astrophysics which has contributed so much to the progress of our science would decline. Recent issues of the *Monthly Notices of the Royal Astronomical Society* and of the *Observatory* dispell such a fear. The latest papers by well established scholars (such as Cowling or Jeffreys), by members of the Cambridge group, (such as Hoyle, Lyttleton, Bondi, or Gold), or by new men (such as W. H. Ramsey or P. A. Sweet) prove that the torch will be carried on and that we may still depend on the British theoretical astrophysicists. Since our British colleagues will soon have excellent new observational facilities in Hermonceux, we may expect a great deal of interest in observational problems as well. Other theoretical centers have sprung up recently on the continent (Paris, Liège, . . .), adding their efforts to those of the already renowned schools in the Netherlands, Scandinavia, and Germany. Of course, the active American schools of theoretical astrophysics at Princeton, Harvard, and especially at Yerkes are persevering in their endeavors. A wide range of problems has been undertaken. New blood has been transfused by Chandrasekhar and his collaborators into such seemingly stabilized questions as star counts and stellar statistics. Many important theoretical papers have come from Russia, Japan, and Australia.

Some observers doubtless think that, in certain fields, there are as many theories as there are workers! Indeed, the situation is sometimes confusing. Yet progress requires theory as well as observation. If the theoretical assumptions lead to an agreement with good observational results the theory is strengthened. If not, let the theorist revise his assumptions. In either case we have learned something. On the other hand the theorist is sometimes hampered by lack of precision of observational results. He finds the reading of certain observational papers difficult and unprofitable, because they fail to point out clearly the physically significant features. Good observations indeed remain the basis for astronomical progress; their careful presentation is also essential.

To be sure, there have been many theoretical papers on radiative equilibrium, on line profiles, on models of stellar atmospheres, and other classical topics, in which many obscure points require attention. In many cases new directions have been followed on the basis of hydro- or electrodynamics. Turbulence and allied phenomena in stellar atmospheres and in interstellar clouds have been studied extensively under the impetus of Chandrasekhar's Henry Norris Russell Lecture, of Heisenberg's investigations, and of the Paris Symposium on Cosmic Aerodynamics. For supergiant atmospheres, Struve has shown that the classical aerodynamical theory of turbulence is not satisfactory; a supergiant must probably be thought of as a net-work of prominences activated by forces which have nothing to do with turbulence. Studies on the internal structure of various types of stars have included considerations on expanding shock waves, thus applying to astronomy the investigations carried out during the war, especially in England, on the formation, propagation, and decay of blast waves. Similar considerations have been introduced in the physical theory of meteors, where the question of drag—dear to the aerodynamists—is important, as well as the "reverse-rocket" action.

The most recent data on the light elements obtained by the nuclear physicists have been used in astrophysics. The proton-proton cycle which may be an important source of nuclear energy in the sun and almost certainly is in the late type dwarf stars has led to the search for the isotopes of helium in the sun. The deficiency of lithium in the sun has been tentatively ascribed by Greenstein and Richardson to very slow circulation with a period of the order of 700 million years, down to at least half the solar radius.

The electromagnetic theories developed by Cowling, M. Schwarzschild, and Miss Gjellestad have found an important application in the remarkable magnetically variable stars discovered by Horace W. Babcock. The results on one such star, HD 125248, have been published in detail. In this star, the magnetic field intensity at the pole varies roughly from + 7600 to — 7600 gauss; the field reverses in a rapid progressive manner over the surface. Certain elements seem to be concentrated in separate atmospheric zones, the rare earths near the pole, the chromium atoms in an equatorial belt, while others (iron and titanium) seem to be rather uniformly distributed. It appears that the star is a magnetic oscillator in which the dipole axis is essentially coincident with the axis of rotation and with the line of sight. While many observational features remain puzzling, we have gained some tentative understanding of these magnetic stars which certainly play an important role in astrophysics. Horace Babcock has under investigation other magnetically variable stars of various types, some showing large variations of intensity in the spectral lines, others not.

Actually, electromagnetic effects must be considered in many celestial objects, even in comets' tails. It has usually been assumed that the motions in comet tails are due to pressure exerted by solar radiation on the cometary molecules. However, there remain considerable difficulties when radiation pressure alone is taken into account. Biermann has shown that electromagnetic effects due to particles expelled from the sun play a dominant role in forming the long comet tails. Variations in the brightness of comets also appear to be due to solar influences. Eventually the comets will enable us to study the field of action of the sun at large distances from it.

Theoretical investigations have also been based on the properties of solids. Ramsey has developed Russell's idea of a relationship between the planets and the white dwarf stars on the basis of the atomic theory of metals. Whipple has continued his discussion on the implications of his "dirty iceberg" model of comet nuclei. Various astronomers had considered several years ago that the gases in comets at large heliocentric distances were frozen. The nature of these solidified gases has not been made too clear yet; recent work by Belgian astronomers stresses the importance of the solid hydrates of methane and other gases in this connection.

Such considerations may eventually find another application in the study of stellar dust. The idea that interstellar space may contain tiny solids made up of hydrogen, carbon, nitrogen, and oxygen at low temperature has been receiving more and more attention. It has been suggested that certain unidentified interstellar absorption bands discovered by Merrill are actually due to these tiny solids. Recently, Spitzer and Bates have envisaged an evaporation process of the solids in the neighborhood of stars. A detailed discussion of the physical structure of interstellar smoke is thus as desirable as additional laboratory work on the absorption spectra of solids made up of H, C, N, and O at low temperature. The latest observational work on interstellar polarization by Hiltner and Hall demonstrates the need for further investigations, theoretical and experimental, on the interstellar grains which are responsible for the polarization. The matter of the interstellar magnetic field acting upon these grains is still under discussion.

Better and better observations and theories have been devoted to the problem of the abundance of elements in the stars and interstellar space. The experimental and theoretical work on the intensities of spectral lines has also made some progress, however at too slow a pace. Although a few spectroscopists cooperate wholeheartedly with astronomers, their number has become too small in recent years. Among many observational results, those of Merrill and Buscombe on the relative intensities of lines of various metals in the spectra of classes Me and Se is especially noteworthy since they may provide the missing clue for an understanding of the subdivision among the coolest stars.

Spectroscopic observations have furnished valuable data on all types of astronomical objects. The new diffraction gratings ruled at various institutions, especially at Mount Wilson by H. D. and H. W. Babcock, have been put into operation. The new Cassegrain spectrograph of the 74-inch Radcliffe reflector in Pretoria, used by Thackeray, has already brought long awaited data. During recent years every effort has been made to extend the astronomical spectral range in the ultraviolet as well as in the infrared and beyond (radio-waves). In 1951 notable advances have been made in the infrared and, in particular, in the region of radio waves. The infrared spectrum of the earth's atmosphere has been investigated at the Ohio State University, the University of Michigan (in cooperation with Mount Wilson), and at the Jungfraujoch scientific station in Switzerland. Atmospheric constituents which were unknown a few years ago, such as CH_4, CO, and N_2O, have been studied extensively. At the Jungfraujoch, Migeotte and Neven, using the Liège spectrograph, have obtained with very high resolution, the solar (rather the telluric) spectrum from 16 to 24 microns, a region hitherto covered only with low resolution. They have now covered the solar spectrum from 1 to 24 microns with high resolution. The astronomical spectra in the photographic infrared have brought many unexpected results. Even the problems of the night airglow and of the polar aurora have been completely revived, essentially as a result of Meinel's excellent infrared spectrograms.

Radar and radio astronomy have given spectacular results. Radar echoes from meteors (due to ionized gas columns left by them) have been extensively investigated in daytime as well as at night. From these it appears that the existence of any appreciable number of interstellar meteors as bright as the eighth visual magnitude is doubtful. The radar reflection from the moon has been used for ionospheric research. More and more radio observations are being installed or extended. Sydney, Australia, has now one of the best equipped radio observatories in the world. Other efficient installations are found in England (especially in Manchester, the unastronomical atmosphere of which is no obstacle to radio astronomers with their giant radio mirror of 65 meters diameter!), in Canada, U.S.A., France, Holland, Norway, Belgian Congo, India, and Japan. The Finnish astronomers plan to install a radio telescope within the arctic circle, where the sun can be continuously observed in summer time. After some fruitful work with their old German radar mirror of 25 fee, diameter, the Dutch astronomers, under the leadership of J. H. Oort and H. Minnaert, are now erecting a 25 meter mirror with equatorial mounting. A wide new spectral range extending roughly from one centimeter to ten meters is now open. The various celestial objects will reveal new properties. The radiation from the moon observed by Piddington and Minnett at wavelength 1.25 cm provided information which at first sight seemed to conflict with Pettit and Nicholson's old temperature determinations based on infrared radiation. However, everything worked properly when it was realized that the emissions at 1.25 cm come from a depth of about 16 inches within the surface of the moon, and that some lag due to heat conduction had to be considered.

Better information on the outer layers of the sun, including the corona is being obtained. Eclipses can be observed by radio even in rain or hail (except at the shortest wavelengths). More point sources which may be radio-stars are being discovered, none of them clearly identified as yet except the Crab Nebula. The radio energy from several galaxies has been observed at Manchester and Cambridge, especially the Andromeda Nebula, M 33 (in Triangulum), M 51 (in Canes Venatici) and M 101 (in Ursa Major). Important advances have been made in the knowledge of our galaxy: radio waves penetrate dark clouds much better than visible radiation, and thus are adapted to studies of the central parts of the galaxy. The most important advance is the discovery of discrete radiation emitted at the approximate wavelength 21 centimeters (frequency 1430 megacycles) by the cool interstellar clouds, i.e. by 90 percent of the clouds. This emission was predicted seven years ago by H. C. van de Hulst. It was found recently by Ewen and Purcell at Harvard and a few weeks later by C. A. Muller in Holland. The Dutch Radio Astronomy Research Group had started organizing observations toward the detection of the 21 cm emission over two years ago. Limited space does not permit us to go into the details of this remarkable observation, nor to consider its consequences. Certainly the experience gained during the war with radar has had a tremendous impact on astrophysics.

Molecular spectra have still been somewhat neglected in comparison with the study of atoms. Yet there is definite progress in this field also. Merrill has pursued his spectroscopic investigations of peculiar stars, following the only good method in this complex problem: to secure the best possible observational information. Struve's concentrated attack on the Beta Cephei variable stars is proceeding successfully; there is real hope that his detailed and accurate observations, helped by theoretical discussions such as those by Ledoux, will clear up this puzzle. Struve has suggested the intriguing working hypothesis of a satellite travelling very rapidly around the Beta Cephei star; this hypothesis bears some relation to the occasionally revived double-star theory of Cepheid variables (Hoyle, Lyttleton). The studies of planetary nebulae by O. C. Wilson (internal velocities) and by Minkowski (structure in monochromatic light), using the Hale reflector, bring us one big step closer to an understanding of the planetary nebulae. The work on comet spectra has received a new impetus from the theoretical investigations by Oort and Schmidt on the origin and development of comets. The strong cometary emission near $\lambda 4050$, which had thus far resisted all attempts at identification, appears to be on the point of losing its status as the strongest unassigned cometary band: it seems to be due to the triatomic molecule of carbon, C_3.

Photoelectric photometry has become more and more widespread. In addition to the well-known installations at Washburn, Lick, Mount Wilson, Yerkes, McDonald, Indiana, U. S. Naval, etc. . . ., photoelectric equipment has been set up at many other observatories, including those in America (Arizona, Vanderbilt, Oklahoma, . . .), in Europe (Leiden, St. Michel, Cracow, Russia, . . .), in Australia, in South Africa, and in Japan. Electronic receivers of very high quality have been developed in France by Lallemand. There is indeed work for many more photometers! A photoelectric observer at the 100-inch reflector can obtain good measures to the 19th magnitude, but there is also a great need for many observations on the fairly bright stars accessible to small telescopes. Most types of celestial objects have been studied to some extent: asteroids, stars of constant and variable brightness, galactic nebulae, clusters, galaxies. The comets have thus far been neglected, although their monochromatic photometry would provide badly needed data. Of course the visual and photographic techniques of photometry have not been abandoned: new flare-stars have thus been discovered.

The writer has deliberately refrained from making reference to the recent work with the Hale reflector and with the big Schmidt telescope at Palomar. This work in itself would have required a special *Leaflet* which the writer would have been unable to prepare from his location in Europe. It is fully realized that many investigations have been neglected in this review, especially those on stellar populations, collisions of galaxies, origin and evolution of the solar system, etc. . . , on which the writer felt especially incompetent to comment.

For instructive views on the predicted future developments in astronomy, the reader is referred to the article by O. Struve in the commemorative issue (Vol.251, No. 1, January, 1951) of the *Journal of the Franklin Institute.*