34. INTERSTELLAR MATTER AND PLANETARY NEBULAE (MATIÈRE INTERSTELLAIRE ET NÉBULEUSES PLANÉTAIRES)

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PLANETARY NEBULAE

Although additional surveys with large Schmidt telescopes continue to yield small catches of additional planetaries (Kohoutek) one cannot escape the conclusion that most planetaries available to existing equipment have been detected. Much remains to be done with powerful Schmidt equipment in the southern hemisphere, especially in the Magellanic Clouds. A vast body of photometric and spectroscopic observation needs to be garnered for the numerous faint nebulae so far discovered.

Spectroscopic and spectrophotometric studies have been carried out for most bright planetaries ($\lambda < 5800$) but much remains to be done in the red and near infrared. Important advances have been made in the far infrared ($\sim 10\mu$) (Gillett, Low, Stein, Woolf) where a number of planetaries seem to show abnormally strong continua. This abnormally intense radiation has been attributed to non-thermal emission, effects of many faint lines, and to thermal emission by dust grains (Krishna Swamy, O'Dell) with perhaps the bulk of the evidence favoring the last-mentioned hypothesis. An increasing number of radio observations from 9·5 mm to 73 cm (Thompson, Colvin, Stanley, LeMarne, Kaftan-Kassim, Babieri and Ficarra, Terzian, L. Aller and Milne, Hughes) all indicate that planetaries are thermal sources.

Morphological forms and models (Khromov and Kohoutek) permit broad, general descriptions of planetaries but do not do justice to the importance of condensations and filaments evident in best photographs (Minkowski, Kron and Walker) or in spectroscopic observations (Walker, Aller, Czyzak, Kaler, *et al.*), although the reason for the formation of such condensations cannot be understood in terms of thermal instability (Field, Harrington, Mathis). Studies of line profiles in bright planetaries suggest that nebular shells may actually be rather thin, that turbulent velocities are small, that nebulae have shapes of prolate spheroids, and that there is evidence for a stellar wind (Weedman). Attempts to calculate dynamical models (Mathews, Sofia and Hunter, Tamura) show that some of the features of planetaries can be interpreted in terms of fairly simple dynamical models but fairly grave quantitative difficulties remain.

Attempts to handle stratification problems and variation of ionization, temperature and radiation field with depth in the nebula have been made (Goodson, Williams, Flower, Harrington).

Theoretical studies of the hydrogen spectra of nebulae (Cox, Mathews, Walmsley, D. George, Van Bloerkom) and of the helium spectrum (Robbins, Capriotti) have not resolved all difficulties as is evident from the mutually contradictory electron temperatures derived from features of the helium and hydrogen spectra (Lee, Kaler).

Transition probabilities for forbidden lines seem to be in a satisfactory state, while the situation for collision strengths is now much improved (Seaton *et al.*, Czyzak and Krueger, Smith). From these data additional forbidden line ratios can now be interpreted in terms of ionic densities and temperatures.

The problem of the distance scale remains a most vexing one (Gordon, Seaton, Webster). The best clues to this difficulty would appear to be offered by the Magellanic Clouds. The masses of the planetaries most likely lie between 0·09 and 0·26 solar masses (Webster). Doubts on the

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quantitative correctness of the Harman-Seaton evolutionary track have been raised by Abell and by Webster who suggest that the H-R diagrams observed for central stars represent not the evolutionary track of a nucleus of single mass and chemical composition but rather a combination of an evolutionary track and a mass-dependent sequence.

Fortunately, new observational data are being obtained for central stars of planetaries, magnitudes and colors (Liller) spectra (Lindsey-Smith, Aller, Heap) while new model atmosphere calculations incorporate increasingly sophisticated refinements (K.-H. Böhm, Hummer and Mihalas). Unfortunately the model atmospheres do not predict the observed absorption line shapes and it would appear that conditions of radiation or hydrostatic equilibrium (or both) will have to be relaxed.

The possibility of an association of X-ray sources and planetary-nebulae nuclei remains a challenge (Blanco *et al.*) but data at present are not convincing.

Arkhipova, Dockuchaeva and Kostjakova (Sternberg Astronomical Institute) have carried out absolute photometry of more than 100 planetary nebulae, and the work on the spectrophotometry of planetaries in the central region of the Galaxy is still going on. Observational study of the ultraviolet spectra of these objects in the region $\lambda < 3650$ Å has begun, and the study of their infrared spectra in the region $\lambda < 1{\cdot}1\,\mu$ is planned. Systematic *UBV* electrophotometric observations of the nuclei of planetary nebulae are in progress, particularly a search for variability. Khromov and Moros (Sternberg Astronomical Institute) have begun a study of continuous emission from planetary nebulae in the spectral region 1–$2{\cdot}5\,\mu$ to improve estimations of their electron temperatures and the temperatures of their central stars. Kazarian (Burakhan Observatory) produced a colorimetric study of central stars of 20 planetary nebulae and 10 of them were investigated spectroscopically.

Khromov in cooperation with Kohoutek (Astronomical Institute of Czechoslovakia, Prague) completed a morphological study of planetary nebulae. Khromov has begun work on the determination of their structure from intensities of forbidden lines originating in different luminosity zones. Feklistova (Institute of Physics and Astronomy, Tartu) computed the expected spectrum of a planetary nebula in the far ultraviolet region. About 100 transition probabilities were computed for different transitions in ions of C, N, O, Si and Ne.

Perinotto has started a systematic survey of high and low galactic latitude fields for the identification on objective prism plates of new planetary nebulae. He will also continue with Wurm the spectroscopic and photometric researches on the Orion Nebula. Studies in the relatively far infrared of the spectrum of gaseous and planetary nebulae have been carried out at Asiago with an RCA-Carnegie infrared image tube. Perinotto will measure the ratio Hα/[N II] in faint planetary nebulae. Wurm and Rosino will prepare a new and more extended edition of the Monochromatic Atlas of the Orion Nebula.

Y. Andrillat has made a series of researches in the near infrared ($\lambda\lambda$ 5800–8750) with the 120-cm Newtonian telescope in Haute-Provence, using a grating spectrograph with a mean dispersion of 230 Å/mm. She has determined the intensity of the hydrogen Paschen lines and the following other lines: He I 6678, 7065, 7281; [A III] 7330, 7319; [S II] 6731, 6717; [O I] 6363, 6300. Some nebulae (NGC 1976, NGC 6572, IC 418, II 4997) have been found to present a strong O I 8446 emission. The problem of the excitation of this line through a fluorescence process starting from $L\beta$ has been considered. With measures of intensity of other oxygen lines, such as [O II] 7330, 7319, [O I] 6363, 6300 it is possible to derive the density of the $L\beta$ radiation.

Future projects consider the continuation of the spectrophotometric researches on the planetary nebulae using image tubes or electronic cameras extending the infrared observations up to $1{\cdot}3\,\mu$. The Paschen decrement will be determined by infrared observations and compared with the values given by the theory of hydrogen recombination, in order to see whether there is a disagreement as is found in the highest terms of the Balmer series. The study of the line He I 10830 will bring new information to the problem of helium abundance. Finally, a further study of O I lines at 9625 and 11 830, is devised with the purpose of a better understanding of the $L\beta$ fluorescence mechanism.

Enumerated here are certain of the outstanding remaining problems in connection with planetary nebulae.

Observational

A more intensive study of planetaries in the Magellanic Clouds, which will require the very largest telescopes (apertures of about 150-inches), is urgently needed. At the same time observers will want to fill in the photometric and spectroscopic gaps for known planetaries.

High-resolution photographs such as probably can be obtained only with space telescopes are most urgently needed. A more intensive exploration of the infrared without any interference from the earth's atmosphere is needed. Certainly an exploration of the ultraviolet spectra of a number of bright planetaries is required.

Structure and kinematics

More emphasis must be placed on fine structure of nebulae, both observationally and theoretically. We do not yet understand how condensations can form. Kinematical and stratification effects need to be considered together from a unified point of view. It should be possible to solve for radiation field throughout interiors of model nebulae designed to fit real nebulae as closely as possible. A knowledge of radiation fields should make it possible to solve for chemical abundances.

Theoretical studies

Studies of the hydrogen and helium spectra do not yet explain the observational data quantitatively. There remain discordances in the relative intensities of the helium lines, the Balmer decrement, and the ratio of the Balmer lines to continua.

The problem of distances and masses

This problem still poses formidable questions, which underlie any attempt at a physical theory of stellar evolution of the central stars. The evolutionary sequences of the central stars cannot be regarded as established since we appear to have a mixture of stars of different ages, masses and luminosities.

As for many *central stars* themselves, it cannot be overemphasized that there remains a serious discordance between temperatures estimated from the appearance of the spectra and those obtained from the Zanstra method. The model atmospheres do not represent the observed spectrum lines; this may be attributed perhaps to failure of the assumption of hydrostatic equilibrium (stellar winds), non-LTE effects, etc.

H II REGIONS

Riegel has searched for 21-cm emission of H I associated with galactic H II regions, and found that in some cases no H I can be detected, while in other cases it is present, but there is no case in which the velocity dispersion is large enough to demonstrate conclusively the presence of a surrounding expanding H I region.

Observational studies by Wurm and by O'Dell and his co-workers have demonstrated the presence of dust in many H II regions. Likewise infrared observations of several H II regions by Neugebauer, Low and others have shown that the continua are much brighter than can be explained by the free-free and free-bound emission of the gas, and must be due to thermal emission by the dust.

Theoretical studies by Mathews, Code, O'Dell, and Krishna Swamy have demonstrated that radiation pressure on the dust grains can have important effects on the internal dynamics of the H II regions, and may be responsible for the central holes in some, such as NGC2244.

Radio free-free continuum and recombination-line observations of many H II regions have been carried out by Mezger, Hoglund, Schraml, Henderson, Kieter, and others. Approximate distances are derived from the observed radial velocities, and temperatures from the ratio of line to continuum strength. However theoretical work by Goldberg, Dyson, and Hjellming, and observations of several

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different lines by Zuckermann, Palmer, Penfield and Lilley show that the simple LTE assumptions are not correct, and the temperatures are therefore not well determined by this method. Observations of several lines may be used in principle to solve for both electron temperature and density, using the theory to find the dependence of b_n on these quantities. However spatial density and temperature variations complicate this method in practice. These observations show that most H II regions have turbulent (rms) velocities of order 10 to 25 km/s. In addition helium recombination lines have yielded the relative He/H abundance in nebulae.

In some H II regions several small, high-density condensations have been revealed by the radio observations. They appear to be ionized shells (cocoons) around recently formed O stars.

Dyson has computed the b_n factors for hydrogen in gaseous nebulae taking into account $n \pm 1$, 2, 3, 4 collisional transitions. The computed b_n factors have been used to compare observations of line temperatures with theoretical predictions of line enhancement. Ratios of the peak temperatures of lines of the same frequency originating from different upper quantum levels indicate line enhancement, but the interpretation depends critically on the estimate of Stark broadening.

Line profiles of the 94 α line in the Orion Nebula measured by Gordon and Meeks show good agreement with low-resolution optical measurements. Dickel, Gebel, Schmitter, Ishida and Kawajiri mapped the distribution of interstellar extinction within and in front of several H II regions by comparison of radio free-free and optical Hα or Hβ surface brightness measurements. Fluctuations of extinction of several magnitudes are found in several of these nebulae. The classical extinction law was confirmed in the region of galactic longitude 5°–130°, while possible variations were found in the region 130°–210°. Lee has studied the extinction in the Orion region by multicolor photometry of the involved stars. He confirms the abnormal extinction laws in the center of the nebula and near ζ Ori. In all cases the stars with abnormal extinction are very early-type stars closely associated with bright nebulosity but not all such stars have abnormal extinction. Similar comparisons of radio free-free and infrared P_{12} surface brightnesses in the Orion Nebula have been made by Werner, Pipher, Terzian and Houck.

In connection with the work by Courtès' group in Marseille a cooperative program of study of H II regions was begun in early 1968 by astronomers in Institut d'Astrophysique de Paris, Observatoire de Meudon, Observatoire de Lyon. The program includes identification, photoelectric and spectroscopic observations of the exciting stars ($m<12$) (Fringant, Garnier Lortet); radio observations in the continuum at 11 cm and in the H and He recombination lines (Gribenski, Lauque, Kazes). The first regions investigated were small H II regions (diameter less than 15′). Measurements of Hα, Hβ, Hγ and forbidden lines intensities are planned, in different points of some extended (bright) regions, in order to deduce detailed physical conditions in these nebulae.

Meaburn has begun a program measuring shapes, widths and intensity ratios of [S II], [N II], [O III], [O II] and H emission lines in H II regions, supernova remnants, and planetary nebulae using scanning Fabry-Perot interferometers on the telescopes at Pic-du-Midi. Similar measurements have also been made at Kitt Peak by Weedman and Smith.

Considerable theoretical work has been done by Vandervoort, Mathews, Lasker, Hjellming and others on the expansion of H II regions, driven ultimately by the ionizing radiation from the stars. A shock runs ahead of the ionization front, compressing the surrounding neutral gas, while inside the ionized region radiative cooling keeps the temperature more or less isothermal, and the expansion velocities are generally subsonic. Some of the detailed effects of density fluctuations, self-absorption of infrared cooling lines, etc. on the temperature structure of H II regions have been worked out by Rubin.

Dyson has calculated the properties of spherically symmetric self-gravitating condensations of neutral hydrogen immersed in an H II region. A condensation is represented by an isothermal gas sphere with a D-critical ionization front incident on the surface. Typical parameters of such a condensation compatible with the estimated ultraviolet radiation field in the central region of the Orion Nebula are: mass $\approx 1 M_{\odot}$; radius $\approx 10^{16}$ cm; mean density $\approx 10^{-15}$ gm cm^{-3}. The majority of condensations are stable configurations and act as sources of ionized gas which flows into the surrounding nebula.

Dyson has also studied the interaction of the supersonic gas streams from two adjacent condensations. A system of stationary shock waves is set up. Theoretical line profiles through the system give good agreement with those observed in the bright central curves of the Orion Nebula.

Goldsworthy is working on the conditions under which shocks will form within H II regions and on possible reasons for filamentary structure. His research students are working on the problem of ionization front structure – a condition has been obtained which allows ionization fronts to be treated as discontinuities and, at the same time, gives the unique solution. It is the analogue of the Chapman-Jouguet condition in conventional combustion theory. Numerical computations on finding the flow are in progress, similar to Mathews's calculations, but careful watch is being kept upon problems of stability and uniqueness. Another research student is looking at the interaction of ionization fronts with globules – in the first instance improving Dyson's treatment.

Rasiwala is studying the evolution of H II regions, with the exciting star in motion. The motion of the star produces a spherical H II region. The evolution of these regions after the birth of the star in a hydrogen cloud has been studied in two steps:

1. Finding the shape of the H II region.
2. Solving the flow problem within the region.

The hydrodynamic equations have been solved using a semi-analytical method called the "method of integral relations".

Optical spectrophotometric observations by Aller, Czyzak and Walker of NGC604, the brightest H II region in M 33 show that it has approximately the same composition (abundances of He, O, Ne and S relative to H) as the H II regions in our Galaxy.

The problem of the discrepancy between the relatively low values of the electron temperatures in H II regions indicated by low radio-frequency continuum measurements (either emission or absorption) and the higher values indicated by optical emission-line intensity ratios still remains. Temperature fluctuations along the line of sight, as suggested by Peimbert, can partly resolve the discrepancy; however they cannot explain temperatures as low as the value $T_e = 3500°$ reported for IC1805 by Rogers or 3000° reported for NGC1976 by Terzian, Mezger and Schraml. Peimbert and also Rubin have discussed how these temperature variations must be taken into account in deriving abundances from spectroscopic observations of H II regions.

On the other hand Field determined $T_e = 6100°$ for IC1805 from 38 MHz measurements, so no doubt there are still substantial observational problems connected with finite beam size, correction for foreground radiation, and absolute calibration.

Akabane, Morimoto and their colleagues are making continuum measurement of several H II regions at 4170 MHz with 30-m dish. The results obtained were compared with optical data. Yamashita and Watanabe also observed W 49 at 9·4 GHz with 10-m dish. Kawajiri and Akabane studied a statistical relation between the size of an H II region and its electron density. Sato, Akabane and Kerr estimated the distances of the W 49 components using Parkes 210-ft data.

Losinskaya and Doroshenko (Sternberg Astronomical Institute) have been investigating the velocity field in the nebulae IC443, S-22, NGC6888, and the Cygnus Loop by observations of Hα and [N II] lines using a Fabry-Pérot etalon coupled to an image-converter. The results support the idea that IC443 and S-22 are supernova remnants, and that NGC6888 originated from the ejection of the matter from the WR star HD192163 into the interstellar medium. It was shown that the filaments in Cygnus Loop nebula are one-dimensional structures. Dibay (Sternberg Astronomical Institute) has completed an observational study of some cometary nebulae, which allowed him to determine their masses, structure, dynamics and inner physical conditions. The evolution of cometary nebulae and their associated stars is being studied theoretically on the basis of the theory of the gravitational condensation and magnetohydrodynamics. Parsamjan (Burakhan Observatory) obtained observational data for a spectroscopic study of cometary nebulae.

Sorochenko and others (Lebedev Physical Institute) observed radiofrequency recombination lines of H in several bright diffuse nebulae in the millimeter and centimeter wavelength range for determining T_e distribution, inner dynamics, hydrogen level population and its deviations from thermodynamic equilibrium. Preliminary results show that the theory of the Stark-effect must be revised. It is intended to receive radiofrequency images of nebulae at $\lambda = 8$ mm with an angular resolution $2' \times 2'$; the search for new recombination radio lines will be continued.

Pikel'ner in cooperation with Sheglov has considered the influence of the stellar wind from O stars upon surrounding interstellar clouds, which possibly drives fast motions of the matter. Similar computations are in progress for the envelopes of WR stars. Dibay (Sternberg Astronomical Institute) attempted to interpret some morphological peculiarities of diffuse nebulae as "elephant trunks", globules and biconical nebulosities. All these peculiarities appear to be readily explained in the framework of the gravitational condensation of the gas possessing magnetic field during the formation of T-Tauri stars.

Courtès, Louise and Monnet have measured the widths of Hα and [N II] 6583 emission lines in several H II regions, using a photographic Fabry-Pérot interferometer. From these line widths they find effective temperatures of order 5000–11 000 K in various nebulae, and turbulent velocities of 6 to 12 km/s. They have also measured the Hα/[N II] λ 6583 intensity ratios in many of the same H II regions, and have deduced lower limits to the relative abundance N/H, which in some cases are considerably larger than the solar abundance ratio.

By means of spectrophotometry the thermal and ionization structure of H II regions has been studied theoretically by Gürtler. He finds that the "on-the-spot" approximation fails in the main parts of the region and yields electron temperatures which are too high by up to 2000 K in comparison with values computed with the exact diffuse radiation field. Density gradients and fluctuations have large effects on temperature, ionization structure and radii of H II regions.

Gerola and Panagia have indicated new possibilities of interpretation of the spectra of gaseous nebulae. They have considered the continuum emission in a gaseous nebula of pure hydrogen, in which the excitation occurs by radiative and collisional processes. In the case of collisional excitation a much greater efficiency for two-photon emission is found, which may drastically change the optical continuum.

Viotti has studied the excitation of Fe II permitted and forbidden lines in some peculiar objects and in the Orion Nebula. He found that the continuum of Eta Carinae is mainly nebular in origin, with a strong contribution of two-photon emission.

HI REGIONS

A picture of the standard interstellar cloud has been current in the astronomical literature for some time. It is taken to have a diameter of 10 pc, a density of 2 hydrogen atoms per cm^3, a mass of 20 $M_\odot$ and an internal velocity dispersion of 2 km/s. Recently Heiles has made a survey with a resolution of 10′ arc in angle and 1 km/s in velocity of a region 160 sq. deg. in area centered at $l^{II} = 120°$ $b^{II} = +15°$ which shows that the standard model is a gross oversimplification. He finds that concentrations similar to the standard cloud are rare and identifies three main groups of features. The first are sheet-like structures elongated parallel to the galactic plane with a width perpendicular to the plane of 20 pc or less and length of 100 pc or more. Their density is ~ 2 cm^{-3} and their velocity dispersion is 1·4 km/s. The second group comprises the "concentrations" which typically have a radius of 20 pc, a mass of 3×10^3 $M_\odot$ and a neutral hydrogen density of 5 cm^{-3}. Then there are the cloudlets identifiable with a surface density of 5 per sq. deg. in the region surveyed. They have a radius of 3 pc, a mass of 10 $M_\odot$, a neutral hydrogen density of 2 cm^{-3} and a velocity dispersion of 1·2 km/s which implies a gas temperature of 100 K or less. Each of these groups seems to contain about the same amount of neutral hydrogen in total.

Heiles finds no significant excess of neutral hydrogen emission in the dust clouds. This is consistent with the conclusions of some of the earlier work on this problem and suggests that the hydrogen in these regions is bound up in the form of molecules. Subsequent observations have shown 18 cm OH emission from a number of dense dust clouds. Numerous OH absorption clouds have also been found in regions along the galactic plane; however it is not possible to identify these objects with particular dust clouds because of the large optical absorption in these regions although most of these features have associated neutral hydrogen absorption indicating densities of 10–

100 atoms cm^{-3}. Formaldehyde (H_2CO) has been found in absorption both in known dense dust clouds and in the denser H and OH absorption clouds indicating clearly the presence of large concentrations of molecules in the densest clouds. Regions of even smaller diameter ($\sim 3 \times 10^{16}$ cm) have been found to emit anomalous (masered) OH radiation near many of the brighter H II regions. Densities of ~ 1 OH molecules cm^{-3} have been inferred for these regions, which may then have hydrogen densities of $10^{5\pm1}$ cm^{-3} assuming the normal abundance ratio of H/OH. Such regions may well be collapsing protostars. Anomalous H_2O emission has been found in many of these regions and shows in some cases variability time scales of the order of weeks implying size scales of 3×10^{16} cm or less in agreement with the OH results.

There has been renewed observational and theoretical interest in the temperature of the interstellar gas. A number of heating mechanisms have been investigated, including low-energy cosmic rays, supernova explosions and X-rays. These mechanisms as well as photoelectric heating tend to make the low density clouds and intercloud regions a factor of an order of magnitude or two hotter than the dense clouds with hydrogen densities of 10 cm^{-3} or more. The neutral hydrogen data now appear to be showing evidence that an appreciable number of clouds have temperatures 10^3 K or more; cloud temperatures of a few tens of K have been shown for some time. More neutral hydrogen absorption observations to give temperatures and pulsar dispersion observations to give electron densities will help decide the validity of the proposed heating mechanisms.

The heating of H I regions by low energy cosmic rays has been reconsidered by Spitzer and Tomasko and by Spitzer and Scott with detailed computations of the efficiency with which the energy of secondary electrons goes into heating the gas. The assumption that low energy particles are produced by supernovae gives an upper limit on the heating rate; the corresponding temperatures exceed 10^4 degrees if n_H is less than 0·1 cm^{-3}, and the resultant thermal instability may account for the existence of interstellar clouds.

Measurements of the equivalent widths of interstellar $L\alpha$ absorption in the rocket UV spectra of stars in Orion by Jenkins and Morton, ζ Pup by Morton, Jenkins and Brooks, and γ Cas by Morton, Jenkins and Bohlin all indicate an average line-of-sight H I density of about 0·1 atom cm^{-3}. On the other hand, observations of stars in Scorpius by Jenkins, Morton and Matilsky show a closer agreement with a value of 1 atom cm^{-3} from 21-cm emission surveys. A review of the $L\alpha$ data has been presented by Jenkins.

Nishimura calculated the structure of the radiative cooling layer behind the shock front due to a cloud collision at a velocity corresponding to Mach number 20, with and without a magnetic field. He studied the abundance of H_2, which depends greatly on the photo-destruction rate. He and K. Takayanagi discussed the destruction rate and showed that the life time of H_2 may be substantially prolonged at the center of a molecule-rich cloud.

Takayanagi and Itikawa studied the rotational excitation of CN molecules by thermal electron impact, applied the result to the interstellar CN molecules and concluded that the observed population in the rotationally excited level cannot be explained by collisional excitation unless the molecules are in a high-density H II region.

Syunjaev (Institute of Applied Mathematics, Moscow) has shown that the heating of the gas in H I regions must be caused predominantly by the metagalactic X-ray emission with energy about 270 eV.

Schmidt has emphasized that no exact value of the density ratio H/dust is available because of the lack of knowledge of the spin temperature of interstellar H and H_2. In high-latitude H I clouds the radiation pressure from stars of the disc population ejects dust. This produces a decrease of the interstellar heavy-element abundance which may be compensated by supernovae events (van den Bergh and Schmidt). Zimmermann has shown that in young H I clouds, i.e. new ones formed after cloud collisions, the heavier particles are concentrated in a thin sheet in the inner parts, while the lighter particles are distributed more or less uniformly through clouds. Schmidt has shown that reflection nebulae are probably in a cosmogonic relation with the illuminating stars, and not distributed by chance.

LARGE SCALE DISTRIBUTION, DYNAMICS AND CONDENSATIONS

Gossachinsky (Pulkovo Observatory) is studying the brightness distribution of the galactic radiation in the 21-cm line. Pariisky and others (Pulkovo Observatory) are engaged in observations of the thermal galactic radio-emission for studying the continuous radio background, the fine structure of H II regions and magnetic fields.

Ariskin (Lebedev Physical Institute) has studied the connection between spatial distribution of the neutral and ionized hydrogen between the longitudes $20^\circ\!.8 < l^{II} < 32^\circ\!.8$. Similar researches are underway at Lebedev Physical Institute for other galactic regions as well.

Herbig has analyzed in detail the rich interstellar line spectrum of ζ Oph, and found the total numbers of Na I, Ca II, K I, CH and CN absorbers/unit area, as well as upper limits to several other atoms, ions, and molecules. These data were then used together with a model of the interstellar matter distribution to find the concentrations/unit volume. There is evidence for a thin ($\approx 0{\cdot}15$ pc) dense ($n \approx 10^3$ cm^{-3}) H I layer somewhere along the line of sight to the star. Hobbs has made high-resolution ($\approx 0{\cdot}01$Å$=0{\cdot}5$ km/s) photoelectric scans of the Na I interstellar absorption lines in 77 stars using a pressure-scanned Fabry-Pérot interferometer. These observed profiles generally show multiple overlapping lines. The profiles of single components are Gaussian in some cases, but exponential in others.

Interstellar lines in coude spectra of southern early-type stars (6·8 Å/mm) taken by Thackeray are being studied by Picton (University of London Observatory) who is planning to extend the survey.

Takakubo compared the interstellar absorption lines Ca II K observed by Adams with the 21-cm H I emission line at intermediate galactic latitudes and found that the general natures of optical and radio profiles are quite similar. The correlation between the radial velocity of strongest K component and that of 21-cm is very high, while it is low for high velocity components. He also treated 21-cm G components to obtain kinematical properties of the interstellar gas.

Crampton at the DAO has obtained 60 Å mm^{-1} spectra at the 72-inch telescope and also 2·4 Å mm^{-1} and 6 Å mm^{-1} spectra at the 48-inch telescope to study interstellar K-lines in order to obtain distances of H II regions. Better results should be obtained when the re-imaging camera for the image tube, which is now being assembled, is commissioned.

Hutchings' work on Nova Del included measurement of interstellar Ca II H and K lines in more than 100 spectra. High dispersion plates showed H and K to be double and also revealed the CN lines at 3874·0, 3874·6Å.

From two-color diagrams at high galactic latitudes which are derived by using the kinematical properties of stars of different uv excesses Pfau found that in the North Galactic Polar Cap the reddening is smaller than $E_{B-V} = 0{\cdot}02$, as determined from stars 200 to 500 pc above the galactic plane. Interstellar grains which left clouds and are moving in the intercloud medium under the influence of the pressure of the interstellar radiation field and of the gravitational K_z-force must constitute a dust layer at a distance of about 150–200 pc from the galactic plane (Schmidt). The motion of dust grains during collisions of interstellar clouds, the growth and the destructive processes and the influence of the dust particles on star formation after cloud collision have been studied by Zimmermann.

Observation by means of the 21-cm line continues to provide the fullest set of data concerning the distribution of interstellar atomic hydrogen with respect to galactic longitude and latitude and line-of-sight velocity. The recently published Maryland-Green Bank Survey covers about 340 sq. deg. of sky close to the galactic plane, between $l = 11^\circ$ and 235° in the new coordinate system. The results are presented in the form of contour maps of temperature, taken at constant declination δ, plotted with respect to line-of-sight velocity $v_{\parallel}$ and right ascension α. On a typical map the contours are spaced 1 K apart; a line drawn at constant α would intersect some 60 or 80 contours, typically; a line drawn at constant $v_{\parallel}$ would intersect some 20 contours. The collection of maps therefore contains well over a million significant data points.

Kerr's review article surveys recent developments in hydrogen line studies, and also discusses their interpretation in terms of a galactic rotation curve, a map of the galactic rotation curve, a map of the galactic hydrogen arms and an estimate for the total mass of hydrogen. The 21-cm measurements only lead to a mass per unit area in a column along the line-of-sight, but for any given feature of the interstellar distribution the area within the antenna beam depends on the square of the distance assigned to that feature. In any model of the Galaxy the estimated mass therefore depends quadratically on the value adopted for R_0, the distance from the Sun to the galactic center, since this value sets the linear scale of our model. The correct measure of R_0 is still uncertain by about 20%, and its exact determination cannot be achieved by studies of interstellar matter, but only by means of astrophysical arguments.

Another simple uncertainty arises from the calibration of the antenna temperature. Thus Westerhout states that the observations of the Maryland survey have to have their temperature scales multiplied by a factor 1·18 to bring them into accord with the Australian data, in those regions where the two surveys overlap. Combining the various uncertainties it seems that there may be an error of as much as a factor 1·7 in the estimate for the mass of atomic hydrogen in the Galaxy.

The more detailed interpretations of the hydrogen distribution begin with the construction of a rotation curve and the consequent transformation of the α, δ, $v_{\parallel}$ map into a three-dimensional map in position space. As has always been done, the rotation curve and all subsequent work are based on the assumption that the systematic motion of the interstellar gas is everywhere in the azimuthal direction, and that it has axial symmetry with respect to the galactic center. This procedure eventually yields a rotation curve whose form depends on whether the observational results used come from the Northern or Southern terrestrial hemisphere. Clearly there is here an indication that some drastic oversimplification has occurred. If one cannot safely assume that the calculated rotation curve has much significance, then one cannot rely upon the location assigned to particular features of the interstellar hydrogen distribution. No doubt the map of the spiral arms is at least topologically correct, but it might be a rather distorted representation of the true structure. This must be borne in mind in discussions on the location of various features of the galactic disk, for example the twist at the galactocentric longitudes $\lambda = 90°$ and 270°.

It has of course long been realized that no model galaxy can continue to support a spiral structure if its interstellar gas is in a state of differential rotation with axial symmetry. To explain the spiral pattern one has to adopt a theory such as that of Lin and Shu who proposed that the spiral pattern is due to a density wave which moves around the Galaxy with a uniform angular velocity Ω_P (equal to 11 km s^{-1}/kpc in their model). There are two spiral arms, each wound about $1\frac{3}{4}$ times around the galactic center, with inner and outer ends at 4 and 14 kpc galactocentric distance, respectively. The arms trail, and Ω_P is everywhere less than Ω, the angular velocity of the interstellar gas in orbit about the galactic center. For example $\Omega = 25$ km s^{-1}/kpc at the Sun's position. Consequently both population I stars and the interstellar gas move so as to overtake continually the spiral pattern. The gravitational field due to the spiral arms perturbs stellar orbits by a displacement with a sin $[2\lambda - \phi(r)]$ dependence. Here λ is the galactocentric longitude, and $\phi(r)$ a phase term dependent on the distance from the galactic center. The diagram shows how this leads to a perturbed density distribution among the stars and thereby to a spiral component of the gravitational field.

But the gas is affected differently. As the diagram shows a shock is expected to form on the trailing side of each arm. Behind the shock the gas density is much enhanced, and the internal energy is large enough so that the gas motion is now subsonic relative to the spiral pattern. The gas then accelerates forward, away from the shock, passes through a sonic point and runs supersonically into the next shock (Fujimoto).

If there are such large velocity perturbations then there must also be considerable changes made in the interpretation of the 21-cm profiles. The theoretical approach to the problem of interstellar gas dynamics must also be changed. The gas flow proposed in the shock model becomes possible only if the gas which has passed through the shock can retain its internal energy long enough so as to accelerate the flow through the next sonic point downstream, and into the next shock.

The increased internal energy in the gas behind the shock might be ascribed to increased speeds

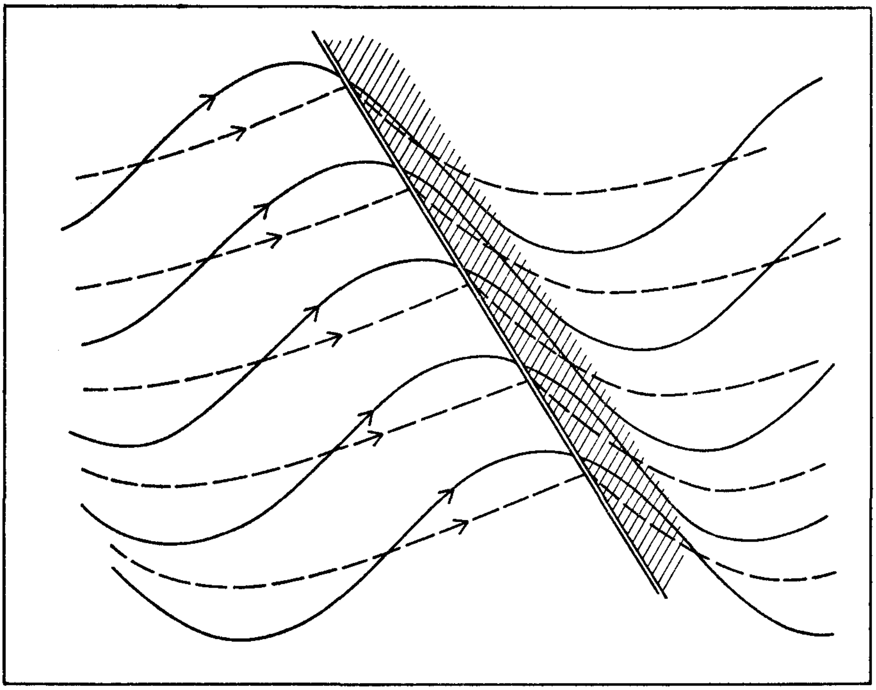

Fig. 1. To illustrate schematically how the gravitational field due to a spiral arm imposes a sinusoidal pattern on the motion of stars (continuous curves), and affects the motion of fluid elements in the interstellar gas (broken line). The shock is indicated by the double line. The crowding of the stellar orbits produces a spiral arm in the shaded region. The stars and the gas move relative to the spiral pattern in the direction as given by the arrows. The horizontal axis represents half of a circle around the Galaxy, straightened out as in Mercator's projection.

in the random motions of the gas clouds, to increased temperature or to an enhanced cosmic ray content associated with the gas. Energy of random motions would decay too fast, thermal energy would radiate too rapidly: the enhanced energy content of the cosmic ray gas thus seems the most probable. Perhaps a rather large rate of production of cosmic rays and suprathermal particles takes place behind the shock, on the side of the spiral arm where the rate of star formation is known to be above average.

Recent work by Spitzer and Tomasko and by Field, Goldsmith and Habing has shown that cosmic rays and/or suprathermal particles are most probably the main sources of heat for the H I regions in interstellar space. One might therefore expect systematic differences in the thermal state of the gas in regions behind and ahead of the spiral shocks. It would also become interesting to study, as Skilling has done, how the cosmic ray particles diffuse relative to the thermal gas. Skilling derives a maximum diffusion rate in his paper; his argument relies on the conclusion that a hydromagnetic instability occurs when the "diffusion speed" of the cosmic ray gas exceeds the local Alfvén speed. The diffusion speed is defined as the ratio of the magnitude of the net energy flux vector to the energy per unit volume for the cosmic rays, measured relative to the ambient interstellar gas. There are two further interesting consequences: following a large injection of cosmic ray energy into interstellar space, the gas and cosmic rays are effectively locked together. This might occur in regions surrounding recent supernova explosions (and probably pulsars), where the cosmic rays would tend to drive the gas. Katgert's observation of a remnant of a large scale explosive event may well be explained in some such manner.

Further, in regions where the instability occurs it will lead to fluctuations of the interstellar electron density. Rickett has found evidence for such fluctuations by his interpretation of pulsar scintillations. The typical length scale of the fluctuations is so short that they could not be produced by any hydrodynamic effect, but only by a plasma interaction.

The cosmic rays will also considerably influence the thermal state of globules and other interstellar condensations. These objects have been discussed from various points of view, either as sources of ionized gas in H II regions (Dyson) as potential sites for the formation of stars or associations of stars (McNally, Disney, Wright, Penston).

Penston has also claimed to find a good correspondence between model globules and observed features of low optical depth superposed on the Orion Nebula, but this deduction rests on a very low value for the assumed continuum opacity of a gas and dust mixture at optical wavelengths. In all these calculations some very simple law is adopted for the thermal state of the gas in the globule.

But Kahn has shown that the gas temperature is the most sensitive parameter in any calculation of the structure of a globule. The flow of heat from the exterior into the globule depends on the properties of the cosmic rays and suprathermal particles, and the rate of loss of heat by the globule should really be computed with allowance being made for the possible self-absorption of the infrared radiation which carries away the heat. This is likely to be a very delicate calculation. It seems therefore that no definite statement can yet be made about the temperature inside a globule. In particular it is not at all clear that an interstellar grain can become cool enough for solid hydrogen to condense on it. Various far-reaching hypotheses have been based on the possibility of the existence of solid hydrogen grains (Hoyle, Wickramasinghe, Reddish), but calculations by Field and by Greenberg and de Jong have shown that conditions in the Galaxy at large are never suitable for the freezing of hydrogen. It would be interesting to know how dense a globule would have to be before the grains in its deep interior become cool enough to allow the hydrogen to condense, and whether such globules are ever likely to be found in nature.

Pikel'ner (Sternberg Astronomical Institute) considered conditions of the formation of stellar groups of the condensation from massive interstellar clouds. If the number of hydrogen atoms in the column above a unit area in the cloud exceeds 10^{21}, then soft metagalactic X-rays are absorbed, the temperature in the center of the cloud decreases, and as a consequence gravitational condensation tends to begin. This process results in the formation of an association of cluster of young stars.

THE GALACTIC MAGNETIC FIELD

Significant progress has been made during the last three years in measurements of the galactic magnetic field using both optical and radio techniques. New evidence has been obtained which provides a better understanding of its strength and configuration.

A major study of the optical polarization of southern stars by Mathewson when combined with available northern data permits a realistic model to be made of the galactic magnetic field. The bulk of the stars studied lie within 500 pc of the Sun and a fraction extend out to 2 kpc so the field orientation can be mapped in depth as well as in galactic coordinates. Mathewson's field model is essentially based on the optical polarization data and at the same time makes a good fit to the distribution of polarization of the galactic non-thermal radio emission and to the Faraday rotation data of extragalactic radio sources. The model has magnetic lines of force forming tightly wound right-hand helices of pitch angle 7°. These helices which lie on the surface of tubes with elliptical cross-sections have been sheared through 40° on the galactic plane in the anticlockwise sense when viewed from the North Galactic Pole. The Sun is displaced towards the galactic center and below the magnetic axis. Such a configuration readily explains the reversal in sign of the Faraday rotation of extragalactic sources on crossing the galactic plane and gives a reasonable fit to the large amount of optical polarization data. The regions of high galactic background polarization lie along the band in the sky which is at right angles to the magnetic field – the direction in which there will be minimum galactic Faraday depolarization. This is also the band where the surveys of extragalactic radio sources show minimum Faraday rotation. Other investigations suggest that it may be possible to describe the Faraday rotation data using closed loops of field rather than tightly wound helices which pose problems for their formation.

An important characteristic of this helical or closed field is its limited extent. Neither the optical polarization nor the Faraday rotation data appear to be compatible with such a field extending right around the Galaxy; it is very local, extending perhaps ± 500 pc in the direction of galactic rotation and has a diameter of 300 pc in the galactic center direction. This magnetic field configuration would appear to be coextensive with the Local (Gould Belt) System which consists of neutral hydrogen and other population I material. However as yet it is not possible to make any detailed correlations between such parameters of the two systems as their major axis directions or precise dimensions.

In addition to the looped field both the radio galactic Faraday rotation and the optical polarization data suggest the existence of a more extended field directed approximately along the local spiral arm in the direction of galactic rotation. Mathewson claims that this field, which is probably the general galactic disc field, lies outside the looped field. The observations made so far indicate therefore that the magnetic field in the vicinity of the Sun is not typical of the spiral arms in general.

Two noteworthy observational developments have been made which allow realistic measurements to be made for the first time of the magnetic field strength in certain regions of the interstellar medium. The first is the successful detection at Green Bank and Jodrell Bank of the Zeeman splitting of the 21-cm line in interstellar neutral hydrogen clouds. A clearcut Zeeman effect is found in the Perseus arm features of the absorption spectrum of Cassiopeia A which indicate line-of-sight components of 10 to 20 μG in various absorption features. The field direction is the same as that derived from Faraday rotation measurements of extragalactic sources and pulsars in the same region of the galactic plane. The field components in the two main Orion arm absorption features are a tenth or less of the Perseus arm strengths. Magnetic fields covering a similar range of magnitudes have been detected in the neutral hydrogen absorption spectra of a number of strong radio sources. These measurements are an indication of the mean field in the denser interstellar clouds. Field strengths more typical of the general interstellar medium can now be derived from observations of the dispersion measure of the recently discovered pulsars. Values have now been obtained for the rotation measure of a few pulsars which, along with their dispersion measures, give directly the line-of-sight component of the magnetic field. Alternatively the dispersion data from all the pulsars can be used to derive a model electron density distribution which can be compared with the Faraday rotation measure distribution to provide an estimate of the magnitude of the magnetic field. A mean field strength near the Sun of 2 to 3 μG is indicated for both the looped field and the general disc field. This *mean* value appears to be a factor of 5–10 lower than the field *magnitude* necessary to account for the galactic radio synchrotron emission assuming that the cosmic ray electron density measured near the Sun applies throughout the galactic disc. Several authors have concluded that this implies that the general field is tangled and that the Faraday rotation data measure the mean component only.

NON-THERMAL EMISSION

A number of surveys of galactic radio emission have been published recently which cover large areas of the sky and have an angular resolution of 1° or better. In addition to giving the overall distribution of radio emission, they also show a great deal of structure even in regions well away from the galactic plane where the emission is synchrotron emission from relativistic electrons. Some of the most interesting structure here is in the spurs and ridges which extend from the galactic plane and in some cases show sharp edges rising to half intensity in $\leqslant 20'$ arc and extending for 10° or more. Only a few of these spurs are correlated with optical emission and their origin is still a matter of debate. A new association has been noted between the steep gradient on the outer edge of these spurs and areas of neutral hydrogen emission showing a velocity dispersion about twice that in neighboring regions. Furthermore most of the spurs are polarized and indicate magnetic fields directed along the arc of the spur. These properties are in line with expectation for an expanding front which sweeps up local magnetic field and compresses neutral hydrogen in front of the expanding shock. The event responsible is probably more energetic than a normal supernova explosion.

Observations of non-thermal emission closer to the galactic plane have now revealed about 90 objects which are believed to be supernova remnants. Nearly 20 of these have been investigated with enough angular resolution to show that they are shell sources. Polarization measurements of several show a field parallel to the edge of remnant as expected for a compression of the interstellar field. However Cassiopeia A is thought to have a radial field; perhaps this is the intrinsic field associated with the supernova explosion.

DUST

The temperature of various grain models have been computed by Krishna Swamy and Wickramasinghe using the interstellar radiation field of the solar neighborhood and the best available optical data for graphite and ice. The expected intensity of the infrared radiation from interstellar grain models of dirty ice, graphite and graphite core-dirty ice mantle has been calculated, and it has been shown that the calculated intensities from various grain models at 100μ agree quite well with the recent observations of Hoffman and Frederick. Krishna Swamy, Wickramasinghe and Hunter have calculated optical properties of interstellar silicate grains and graphite core-ice mantle particles (down to 1000Å).

The "dirty ice" model as interstellar grains has been shown to be unsatisfactory on various grounds. On the basis of the detection of complex molecules in interstellar space it is plausible to assume that these molecules are also present in the grains. The presence of these molecules gives rise to an increase in the absorption coefficient. Therefore, Krishna Swamy, Jackson and Donn have done extinction calculations for $n = 1{\cdot}3$ to $2{\cdot}0$ and for $k = 0{\cdot}0$ to $0{\cdot}5$ for the refractive index $m = n - ik$. Calculations show that $n = 1{\cdot}3$ and $k = 0{\cdot}2$, $0{\cdot}5$ gives a good fit with the observed reddening curve. The proposed absorbing icy grain model for $k = 0{\cdot}2$ also satisfies the albedo requirements. Calculations of the strength of the $3{\cdot}1\mu$ band for the model shows that the band is not detectable even for H_2O content of about 20%.

Jones and Spitzer have made a detailed analysis of magnetic dissipation in various substances, which indicates that grains containing appreciable iron impurities, either in superparamagnetic clumps, or in one or more ferromagnetic grains, can probably be oriented by interstellar magnetic fields of 10^{-6} G or less.

Low energy cosmic rays will disrupt very small grains, and if the interstellar gas is heated by such radiation the grains can probably not have formed from condensation nuclei.

Walker is continuing his analysis of the polarization of the λ 4430 interstellar line, and is studying the interstellar reddening curve between 4000Å and 5000Å, with the low-resolution 30Å mm^{-1} scanner attached to the 72-inch telescope, by comparing the energy curves of reddened and unreddened stars in Cygnus; with the help of Morris and Younger, the tracings have been digitized and processed in the available computers and seem to show very interesting discontinuities. It has not yet been possible to extend this work to other regions of the Milky Way. The variation of interstellar extinction with polarization is also being examined.

Hutching's spectrograms of stars in the cluster NGC6231 indicated a possible variation in time in the λ 4430 diffuse band in three stars. These bands were measured for depth, equivalent width, and profile on plates taken over a few years.

Maron at the Torun Observatory has studied the possibility that carbon stars, which are known to be associated with dust clouds, might have acquired the excessive carbon in their atmospheres through the process of accretion of interstellar graphite. Taking into account in his calculations the effects of radiation pressure and of mixing by convection he arrives at the conclusion that graphite grains of size about 10^{-3} cm might be accreted by cold giants and supergiants in sufficient amount to produce a carbon star spectrum.

Sharov (Sternberg Astronomical Institute) has investigated the distribution of the obscuring matter in the Andromeda galaxy and has compared the results with those for our Galaxy. Together

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with Pavlovskaya he is studying the influence of interstellar extinction upon the visible structure of the Milky Way to evaluate the possibilities of investigating the spiral structure from the surface photometry of the Milky Way.

Rozhkowsky and Kurchakov (Astrophysical Institute, Alma-Ata) have compiled a catalog of 118 reflection nebulae, which serves as the basis for the determination of their physical characteristics. Glooshkov, Kjachushev, Kurchakov and Sabitov performed spectrophotometric, colorimetric and polarizational studies of NGC7023, IC2118, the Pleiades, reflection nebula, and the Orion nebula. Some other reflection and diffuse nebulae and their illuminating stars are under investigation now. Rozhkowsky and others are studying the diffuse galactic radiation to determine the albedo of interstellar grains. According to the results already obtained, the grains in the region of the bifurcation of the Milky Way have a rather low albedo (0·3–0·4).

Minin (University of Leningrad) has computed the brightness, polarization and colors of reflection nebulae. A work on the computation of the light scattering by grains of refractive index $m = 1{\cdot}50$ with several different types of the size distribution function is being completed.

Kalandadze (Abastumani Astrophysical Observatory) has investigated interstellar extinction and the distribution of dust and stars of different spectral classes in Taurus over an area of approximately 180 sq. deg.

Working in cooperation with Kolesnik (Goloseyevskaya Astronomical Observatory), Kalandadze has studied light absorption in the direction of NGC6913. The light absorption value is 1·4–2·2 in stellar magnitudes for the first kiloparsec. The main mass of absorbing matter is situated at a distance of 400–1600 parsec.

Chuadze (Abastumani Observatory) is engaged in the study of light absorption and distribution of stars in the local system.

Schmidt has shown that most O stars have circumstellar dust envelopes. If the interstellar dust is produced in circumstellar regions with dimensions of 10^{17} cm, the interstellar Fe, Ti, Ca must condense on or in dust grains. With the assumption that the graphic particles originate in the outer layers of carbon stars several frequency distributions of the particle radii can be determined. The observed extinction curve can then be explained supposing that the graphite particles contribute only a small fraction to the interstellar dust (Friedemann, Schmidt). Apart from graphite other chemical compounds can condense in the atmospheres of cool stars – especially SiC which probably is another component of interstellar dust grains (Dorschner, Friedemann). The dust particles in the outer layers of cool stars give a possible explanation of the observed time dependent polarization of some red long period variables. The essential observational facts concerning the intrinsic polarization of these stars are explained with this hypothesis which further represents a helpful tool calculating the properties of circumstellar dust from observed variations of the intrinsic polarization (Friedemann). The silicate grains as constituent of interstellar dust are studied with regard of their origin from circumstellar phenomena, especially from planetary systems. In this connection crushing processes are treated in a quantitative way. Further the spectra of silicate grains in the middle infrared are studied (Dorschner).

Barbieri examined the problem of the illumination of reflection nebulae for several values of the electron density and dust scattering coefficient, both for optically thin and optically thick nebulae.

Sancisi with the 25-m radiotelescope of Dwingeloo has observed the region of the reflection nebulae NGC2068 finding a maximum of peak brightness temperature and a minimum of velocity width near a group of T Tauri stars. He has also reported preliminary results on the H I distribution in the Taurus region.

Future work

(1) Radiation transfer in circumstellar dust clouds and in reflection nebulae.

(2) Studies of high latitude clouds (polarization, ratio between polarization and reddening). Photoelectric *UBV* measurements in or behind high latitude clouds.

(3) Lyman α line radiation transport in H II regions with "dust globules". Explanation of the observed anomalous Balmer decrement.

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(4) Attempt to explain interstellar bands by transitions in silicate grains.

(5) Star formation in connection with cloud collisions.

(6) Molecule formation, the dust: gas ratio in H I clouds, star formation and early stages of stellar evolution.

(7) Molecules and interstellar chemical abundance (time-dependence).

Dust (continued)

This is a report of activities, many still in progress, in the subject of interstellar grains and related topics. Where conclusions are not yet substantial the various theories and observations are presented in order to serve as possible guidelines for the ongoing work.

Although no bibliography is appended at the end of this report there will be available, upon request to J. M. Greenberg, a topical list of references.

Extinction

Rocket and satellite measurements indicate a general but varying degree of continued rise in the extinction out to $\lambda^{-1} \approx 9\mu^{-1}$. The exception to this is θ Orionis which shows perhaps less extinction in the far UV than at $\lambda^{-1} = 3\mu^{-1}$. This result is a confirmation of the anomaly in the shape of the extinction curve which had been earlier recognized in the $1\mu^{-1} \leqslant \lambda^{-1} \leqslant 3\mu^{-1}$ region and which has been further confirmed for other Orion stars.

The diffuse extinction hump at $\lambda^{-1} \approx 4{\cdot}8\mu^{-1}$ has been confirmed in all the stars observed in this region of the UV.

A general value of the ratio of total to selective extinction appears to be $A/E = 3{\cdot}2$ with usually small deviations. Significant deviations with much higher values are apparently of a very local nature.

Detailed investigations of the extinction curve in the $1\,\mu^{-1} \leqslant \lambda^{-1} \leqslant 3\,\mu^{-1}$ range indicate the possible existence of a number of discontinuities in the slope which seem to be associated with diffuse absorption features.

Polarization

Considerable evidence is accumulating for sizeable variations in the wavelength dependence of interstellar polarization. Some degree of correlation with variability in the shape of the extinction curve indicates differences in grain properties. However, a substantial fraction of the stars observed exhibit a maximum of polarization in the $1{\cdot}5\mu^{-1}$ to $2\mu^{-1}$ range.

A suggestion has been made that temporal variability of polarization could be due to micro-structure in the interstellar clouds. It has been generally assumed that time variations can occur only in circumstellar regions. The idea of small scale structure in the interstellar medium is undergoing investigation also in connection with two phase theories of the H I medium.

The confirmation of circumstellar polarization has been obtained.

Scattering

Additional detailed observations of the colors and brightness of reflection nebulae have been made. A number of detailed calculations of scattering by clouds of spherical, cylindrical and spheroidal (small) particles of varying optical properties have been made. Effects of double and – by implication – multiple scattering have been calculated in some special cases. Present comparisons with observations lean toward interpretation in terms of particles of a dielectric nature and not necessarily ices.

Preliminary interpretations of the brightness of reflection nebulae in the rocket and satellite UV are in progress.

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New measurements of the diffuse galactic light have received similar interpretations by several independent workers, leading to the exclusion of simple graphite or metallic grains as the dominant interstellar scattering constituents. The tendency is a bit closer to graphite core plus ice mantle than to ices alone.

Chemical composition

The search for the contributions of a $3{\cdot}1\,\mu$ ice absorption associated with extinction has led to conflicting interpretations and the evidence for and against a significant amount of ice in or on the grains does not yet appear conclusive. The interpretation of absorption and emission features in the region between 8μ and 12μ has implied a silicate component of dust in interstellar and circumstellar regions. The diffuse absorption feature at $\lambda^{-1} \approx 4{\cdot}8\,\mu^{-1}$ has been attributed to a characteristic graphite absorption. Although interpretations of infrared spectral characteristics are not subject to detailed physical grain properties the intrinsic absorption features in the ultraviolet may be subject to strong modifications produced by grain surface properties because the wavelength is comparable to the size of the dust particles. Effects of absorption edges of ices and silicates are similarly modified. Laboratory work using the microwave analog method is to be applied to this consideration.

Grain models

High speed digital computers have been exploited to obtain exact (and in some cases approximate) calculations of extinction and polarization (also emission and absorption, and scattering) for (a) ice spheres and cylinders – varyingly oriented (b) silicate spheres and cylinders (c) spherical and spheroidal graphite (d) graphite with ice mantles (e) mixtures of graphite spheres and silicate cylinders (f) graphite cores with solid hydrogen mantles. Laboratory studies have been made of extinction by iron, carbon, silicon carbide and silica and comparison has been made with theories for "equivalent" spheres and cylinders. Agreement seems possible only for silica – which is spherical. Extinction measurements for laboratory mixtures of polycyclic aromatic molecules have given a rough approximation to the interstellar extinction in the visible. For every interstellar dust model which has been considered, counter evidence of varying degrees of strength has been adduced by different workers. On the basis of *optical* properties alone some of the arguments raised *counter* to each model – based on calculations for *smooth* particles – are respectively: (a) no positive spectroscopic evidence of ice, absorption edge of ices leads to lack of continued rise of extinction beyond $\lambda^{-1} \approx 5\,\mu^{-1}$, incorrect shape of absorption hump at $\lambda^{-1} \approx 4{\cdot}8\,\mu^{-1}$; (b) incorrect shape of absorption hump at $\lambda^{-1} \approx 4{\cdot}8\,\mu^{-1}$; (c) poor representation of reflection nebulae and diffuse galactic light, lack of continued rise in extinction etc., simultaneous reproduction of λ dependence of polarization and extinction inconsistent with maximum observed polarization; (d) lack of continued rise in extinction etc., simultaneous reproduction of wavelength dependence of polarization etc.; (e) simultaneous reproduction of λ dependence etc. It appears at present that no simple material model based on calculations for *smooth* particles can simultaneously reproduce the totality of observations of extinction and polarization and scattering. Heuristic approaches to resolving the dilemmas are not sufficiently satisfying and substantial additional theoretical and laboratory work as well as more observations appear to be required. Also other factors than purely optical ones need be considered.

Physical interactions

The formation, growth and destruction of grains have been reconsidered by many authors for a variety of conditions. The formation possibilities appear to be: (1) the "classical" theory of accretion of condensable atoms on nuclei in the interstellar medium – but in a modern context of the physical and dynamical conditions associated with spiral structure. This leads to dirty ices unless modification of chemical structure to larger molecules is achieved by way of radiation effects; (2) growth of graphite and/or silicates in cool stars. These can be either dominant components in the interstellar extinction or the nuclei for process "1"; (3) grinding down and subsequent ejection of "interplanetary material"; (4) condensation during "solar nebula" phase of star evolution. Destruction by cosmic rays and soft X-rays have been considered.

The interaction of the interstellar radiative field with dust grains in normal regions and in dense clouds have been used to calculate grain temperatures for a variety of models of grains. The most complete results appear to preclude the possibility of solid hydrogen condensing on dust. However the lack of observable neutral hydrogen in dense clouds strongly suggests the formation of molecular hydrogen on the low temperature grains. Calculations of molecular hydrogen formations have been carried out.

More elaborate calculations of grain orientation by magnetic fields and by mechanisms bringing about streaming of dust through gas have been made. Cosmic rays have been included in the orientation phenomena. Magnetic fields of the order of 2–5 μG have been shown to orient the ices and silicates significantly but not graphite. The question of achieving the maximum observed ratio of polarization to extinction by means of magnetic and streaming orientation processes has been examined quantitatively for elongated dielectric particles and for graphite cores with either ice or solid hydrogen mantles. In the light of dynamical questions for interstellar matter serious questions have been raised concerning the relaxation times for the various orientation mechanisms.

Diffuse bands

The structure of the unidentified (about 25) diffuse bands has been subjected to further detailed study. Contrary to older ideas it is now believed that the λ4430 band is highly asymmetric with an emission wing at shorter wavelength comparable with the absorption at 4430 Å. Calculations of extinction and polarization through the λ4430 band produced by impurities have been performed for grains with background absorptivities ranging from very small (dielectric) to medium and large (metallic). The asymmetry of the polarization parallels that for extinction in the band and its existence would be a relatively unambiguous means of discriminating between dielectric and metallic (or graphite) grains. It would also be used to assign relative contributions by postulated grain constituents.

Laboratory studies of absorption by Ca impurities in matrices simulating possible interstellar grain materials have indicated the possibilities of a group of bands being associated with a single type of impurity.

The distribution and correlation of λ 4430 band with extinction has been further studied.

D. E. OSTERBROCK
President of the Commission

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