15. COMMISSION POUR L'ETUDE PHYSIQUE DES COMETES

Report of Meetings

PRESIDENT: K. Wurm.
ACTING SECRETARY: L. Houziaux.

First meeting, 16 August 1961

DISCUSSION OF DRAFT REPORT

The first meeting was devoted to the discussion of the *Draft Report* and of the suggestions for consideration. When closing this session, the *Draft Report* was unanimously accepted after some minor corrections in the references.

Suggestions mentioned in the *Draft Report:*

1. Monochromatic photometry. It was emphasized by several members that care should be taken to guarantee a real monochromacy and to report the properties of the filter used.

2. Spectra with higher resolution, tail spectra. Dr Swings recommends in particular the region around $\lambda 3600$ Å, which is not yet well known in its general composition. More spectra in the red are also urgently needed. Dr Herzberg points out that the region around $\lambda 3400$ Å contains bands of molecules which we may expect to appear in comets.

3. Spectra of far distant comets. It was recommended that authors who have access to large instruments may keep this problem in mind.

4. Magnitude of nuclei, colours and dimensions. The importance of monochromatic observations in the regions of continuous emission was stressed and the careful study of nearby objects with instruments of large focal lengths.

5. Monochromatic photographs, real extension of CO^+ emission in tail and head etc. Several authors recommended a more consequent change to real monochromactic observations. Dr Swings reported that a 60-cm Schmidt camera now at the Haute-Provence observatory, will be in particular devoted in the future to monochromatic observation. Dr Wurm gave some explanations with regard to the importance of such observations for the development of the physical theory.

6. Continuation of existing series of observations concerning the magnitudes and the shapes of comets. The high value of these series was generally acknowledged.

7. Laboratory investigations of observed and expected molecules. Dr Swings mentioned that Dr Philips at Berkeley is working with the analysis of molecular spectra of interest. Dr Rosen reports that he is carrying through at Ottawa an analysis of the C_3 bands.

8. Polarisation measurements. Dr Vanýsek reported that refined polarimetric observations belong to his programme of comet observations.

GENERAL COMMENTS AND REPORTS

Dr Swings reported that he has identified with certainty in the spectrum of Comet Mrkos the [O I] doublet $\lambda\lambda 6300$, 6360. Dr Roemer added that A. Deutsch has just found these lines also in a spectrum of Comet Wilson 1961 (see A. Deutsch's report below in the report of the second meeting). Dr Herzberg asked whether or not the corresponding forbidden transition of C I has also been observed; Dr Swings answered that nothing can be said about the appearance of the carbon lines since no good spectra of the region of the transition are available so far. Dr Swings and Dr Biermann suggested preparations for the launching of artificial comets and that contact should soon be made with the corresponding organisations. Dr Whipple recommended that proposals for artificial comets, as well as for space probes, be sent to NASA with a detailed explanation of the importance of such experiments.

At the end of the session Dr Wurm gave a description of a liquid-dye filter which isolates, with about 50% peak transmission, the three strong CO^+ bands in the violet region of the spectrum.

Second meeting, 22 August 1961

At the beginning of the second meeting, which was to be devoted to a colloquium on "The Structure and Development of the Gas Tails of Comets", Dr Swings requested permission to present the following recommendation.

"Commission 15 recommends the study of Encke's Comet by a space probe at its next close approach, in mid-July 1964. Observations should be made of:

(*a*) the nucleus (telescopic appearance, polarisation and color),

(*b*) the head and the near tail (in density and composition, magnetic fields, total density of the neutral particles, plasma frequency, micrometeorites, far ultra-violet emission especially that of H_2 near $\lambda 1300$).

En route to the comet the probe would collect valuable information on the interplanetary space outside of the plane of the ecliptic".

There was general agreement that this recommendation should be brought to the knowledge of members of NASA, and discussed with them.

After the discussion of this recommendation, the President asked Dr Herzberg to take the chair for the colloquium. After a brief introduction, five papers were presented, each of a duration of about twenty-five minutes. The abstracts which follow have been written by the authors themselves.

THE STRUCTURE AND DEVELOPMENT OF THE GAS TAILS OF COMETS

INTRODUCTORY REMARKS

K. Wurm

The gas tails of comets consist of singly-ionized molecules such as CO^+, N^+_2, CO^+_2 and probably some others. It was assumed originally that these ions are created through photo-ionization by solar light, and that their acceleration in a direction away from the Sun is due to light pressure. About ten years ago it became evident that neither of these assumptions is tenable. Early in the history of modern comet research we meet the suggestion of a strong influence by corpuscle streams from the Sun on cometary phenomena. However, this suggestion was not seriously discussed until after the failure of the radiation hypothesis (see L. Biermann, *Zs. f. Astrophys.* **29**, 274, 1951). Although the corpuscular hypothesis has been favorably accepted by many authors, the fact cannot be disregarded that this theory—at least in its present form—does by no means provide a satisfactory explanation of the observational facts, even of the most fundamental ones. Within the theory, only a mechanism of pure collisional interaction (ion-ion and electron-ion) has so far been worked out. It seems rather certain that this mechanism cannot be of any importance because it needs much too high ion densities in the streams, both to account for the ionization and also to explain the repulsive forces. Regarding the latter there remains the possibility of a transfer of momentum by magnetic fields. However, only very vague ideas have been so far mentioned in this respect. These can scarcely be regarded as a contribution to a theory.

In view of this situation, it was suggested that a thorough discussion be devoted to this subject at this meeting. Of the following five papers the first four are intended to state what we have to consider as observational facts with regard to the formation of the gas tails in comets. There remains for the last paper to show which of the observations the physical theory in its present state is able to explain.

2. INTENSITY- AND PARTICLE DENSITY-DISTRIBUTION IN THE HEADS OF COMETS

B. A. Vorontsov-Velyaminov

Objective prism spectra and photographs of Comet 1942*g* (1943 I) have been studied photometrically. They have shown that the brightness distribution within the approximately roundish head changes as ρ^{-1}, where ρ designates the distance from the nucleus. This law of brightness distribution remained the same over two months of observation. With the condensations of the band groups on the objective prism spectrograms the head could be traced up to $3{\cdot}7 \times 10^5$ km from the nucleus. On the other hand on the photographs in integrated light a blackening from the head emission was found up to not less than 6×10^6 km. It seems questionable whether there exists at all a limit of the head emission. Assuming a fluorescence excitation in an optically thin layer, as is established for emission in comets, from the absolute magnitudes of the monochromatic condensations the following total numbers of the most important molecules are derived: $N(CN)$ $1{\cdot}3 \times 10^{31}$, $N(C_2)$ $2{\cdot}7 \times 10^{31}$, $N(C_3)$ $7{\cdot}1 \times 10^{32}$. These are valid for a volume with a radius of $3{\cdot}7 \times 10^5$ km. The partial densities at the border of this volume are: CN—2; C_2—1 and C_3—0·04 molecules per cm^3.

Since the comet was one of small dust content, the very large radius measured on the ordinary photographs must have originated from the emission of molecules.

3. EXTENSIONS (DIAMETERS) OF THE CN AND C_2 HEADS OF COMETS

Wm. Liller

Unpredictable variations in the sizes of the coma of comets, both as a function of time and as a function of radiating molecule, are well established. Perhaps the most striking positive evidence of time-variations is illustrated by two photographs of Comet Schaumasse taken by F. D. Miller in 1952 and in 1960 (*Sky and Telescope*, **19**, 473,1960). The photographs were taken when the comet was 12 and 5 days from perihelion ($q = 1{\cdot}2$), respectively, but in the 1952 photograph the image of the coma appears almost three times larger than in the 1960 photograph.

Perhaps an even more dramatic observation of a time-change was made recently by W. Liller of Comet Burnham (1959 *k*). Using a photo-electric spectrophotometer with a wavelength passband of 99Å fixed on the C_2 emission shortward of λ5165, he obtained intensity scans across the coma of the comet a number of times at three-hour intervals centered on April 27·36. Two scans, separated in time by 65 minutes, leave little doubt that the diameter of the head, as measured at half peak intensity, changed from $5'{\cdot}5$ to $3'{\cdot}7$. Only small changes in size were noted during the remaining half-hour before dawn. D. R. Barber (*Observatory*, **80**, 198, 1960) reports that unusual brightness fluctuations took place on the same night and that the Earth was experiencing a rather intense magnetic storm at the time. The comet being only 0·21 A.U. from the Earth, may well have received a sudden increase in high-energy electromagnetic and particle radiation from the Sun.

Studies of photographic spectra of comets (*e.g.* the *Atlas of Representative Cometary Spectra*, by Swings and Haser) show clearly the relative sizes of the images of comet heads as seen in different molecular radiations. The usual order of image size (large to small) is listed here:

$$\begin{array}{c} \left.\begin{array}{c}\mathrm{CN}\\ \mathrm{C_2,\ NH}\\ \mathrm{C_3}\end{array}\right\}\ \mathrm{OH} \\ \mathrm{CH,\ NH_2}\end{array}$$

The image size in OH can differ considerably from comet to comet over the range indicated by the brackets.

Liller and N. Schultz made monochromatic isophotes of Comet 1959*k* with photo-electric spectrophotometers during its recent close approach to the Earth. Three wave-length regions were selected for study: $\lambda 5100$ (C_2), $\lambda 3900$ (CN), and $\lambda 4850$ (continuum). Isophotal contours, constructed from back-and forth-scans made at the telescope, were expressed in units of the peak intensity. When the comet was 1·02 A.U. from the Sun, the C_2 and CN contours coincided almost exactly. At a solar distance of 0·99 A.U. the comet yielded isophotes in the light of C_2 which were approximately twice the size of the contours made in continuum radiation ($\lambda 4850$). None of the isophotes showed any sign of tail; however, some raggedness in the contours suggests small minute-to-minute variations. A generally high level of solar activity continued throughout the observation.

4. TYPES OF COMET TAILS AND REPULSIVE FORCES

V. Vanýsek

Spectrographic studies of comets have shown that the straight type I tails are made up by ionized molecules (predominantly CO^+) and that the strongly curved tails of type II must consist of scattering dust particles. There exists no difficulty of principle in understanding the appearance and general shape of the type II tails. Their strong curvature leads to repulsive forces of approximately the same magnitude as that of the solar gravitation at the position of the comet. Repulsive forces of this size can be accounted for by the action of light pressure on small dust particles.

The situation is very different with regard to the scarcely curved type I tails. These are normally built up as a bundle of divergent rays and streamers issuing from the central part of the head. The absence of a perceptible curvature, as well as measurements of the acceleration of distinct condensations, have shown that repulsive forces acting on the tail ions certainly reach values of 50 to 100 times the solar gravitation. Whether the much higher values of 10^3 to 10^4 times the solar gravitation (as have been favoured by L. Biermann, P. Stumpff and some other authors) have any significance remains very questionable. Such high repulsive forces were first mentioned in the literature by A. Kopff, in connection with a study of a pair of plates of Comet Morehouse. Dr Wurm informs me that he will explain in his paper, that Kopff's extreme repulsive forces rest on a wrong indentification of two structures on the two plates in question.

We are confronted with the task of explaining repulsive forces of the order of one hundred times the solar gravitation. It has been long known that light pressure fails to be effective enough, there remaining a discrepancy of two orders of magnitude. It is an old idea that corpuscular streams from the Sun may significantly influence cometary phenomena and possibly also cause acceleration of the tail ions. Until the mechanism of the interaction between the solar corpuscles and the cometary ions has been outlined and clarified, such a suggestion is not of much value. The mechanism of a pure collisional interaction has been rather clearly described by Dr Biermann; however, it has recently become evident that this kind of accelera-tion of the tail ions demands much higher densities in the solar streams than we are allowed to accept. The next step would be to find, and to investigate critically, the mechanism of an electromagnetic interaction. Streams of solar particles may carry with them magnetic fields. Authors investigating this problem are reminded that the acceleration of the tail ions is a permanently lasting feature of cometary phenomena, and cannot be connected with occasional clouds colliding with the comet.

5. STRUCTURE AND DEVELOPMENT OF THE GAS TAILS OF COMETS

K. Wurm

The gas tails of comets are made up of ionized molecules. Since the tail as a whole must be electrically neutral, we may be certain that there exists an equivalent number of free electrons. The first question which we meet in connection with the formation of the tails concerns the production of molecular ions. It became evident many years ago that photo-ionization by the UV solar radiation cannot account for the creation of the ions. There now exists a general inclination to consider solar corpuscular streams (solar wind) as being responsible for the ionization in comets. As can be shown, however, some observational facts do not support such an assumption. The present author has earlier emphasized that the corpuscular stream hypothesis is scarcely in a position to explain why, on the one hand, the tail ions appear already close to the nucleus, whereas, on the other hand, the heads, which are built up of neutral molecules such as CN, C_2, NH and others, reach such large dimensions as observed. From the extensions of the heads, data about the average life-times τ of the neutral molecules, exposed to the "solar wind" can be derived. From the expansion of spherical halos in Halley's comet there was next derived the figure $\tau = 10^{5.5}$ seconds for the average lifetime of the molecules CN and C_2, for a heliocentric distance of one A.U. This figure rests on the assumption, indicated by the halo observations, that, up to a distance of 200 000 km from the nucleus, the molecules are not suffering an appreciable decay by ionization or dissociation. However, Dr Vorontsov-Velyaminov's results on the real extension of cometary heads, derived from photographs of Comet 1942*g* as mentioned by him above, indicate that there is no appreciable decay up to distances of some million kms from the nucleus. From this we find values of τ for CN and C_2 between 10^6 and 10^7 seconds. Such long life-times exclude proton densities of the permanent solar wind of an order larger than 10^1. To reconcile the large extension of the heads with the appearance of the tail ions close to the nucleus, there remains only the explanation that the ionization occurs by a process within the atmosphere close to the nucleus, and is limited to this region. All particles which escape this process remain neutral.

The tail ions issue from the nucleus region in sharp rays; each ray when first appearing is inclined at a large angle of 45° to 90° to the tail axis. The latter has approximately the same position as the prolonged radius vector. When growing in length the tail rays are steadily turning to the tail axis. It can be shown that the turning of the rays must be connected with a decrease of the component of the initial velocity normal to the tail axis. Despite this continuous movement of the tail rays to the radius vector, there appears no (or only a moderate) piling up of matter along the tail axis. This shows that the ion source which feeds a ray dies out when the ray reaches the tail axis.

Each ray develops independently of the others, which indicates that there exist at the same time many discrete ion sources. The mechanism of ionization remains obscure.

6. THE PHYSICAL THEORY OF COMETS

L. Biermann

It was suggested in 1951 that the acceleration of the plasma tails in comets (type I) has to be ascribed to the interaction with the solar corpuscular radiation, which itself constitutes an ionized, however macroscopically neutral, particle flux. It can be shown that the flux of momentum of the latter is sufficient, the main remaining question being how the momentum can be transferred to the cometary plasma. Two specific mechanisms were considered in 1951, namely transfer of momentum (1) by thermal electrons and (2) by magnetic fields. The observational evidence available in 1951 gave the impression that the mechanism (1) was more important, but it has since appeared that, in fact, (2) is more likely to be effective. In addition a third mechanism connected with microfluctuations in plasma has come into consideration, but estimates about its effectiveness are not yet available.

As to the mechanism of ionization, an important problem is how to account for the observed rates of cometary ion structures. A general survey of the possibilities of ionization reveals: (1) that ultra-violet solar light under normal circumstances is quite sufficient; (2) that the effectiveness of collisional ionization, assuming the electrons being sufficiently heated, is seriously reduced by a number of competing processes; (3) that the mechanism of exchange of charge proposed in 1953 has a large cross-section just for the range of proton velocities in question. The possibility (4) of binary chemical reactions have been tentatively explored, but those found so far all depend on an independent source of ions. The competition between processes (2) — (4) will require further study.

DISCUSSION

In the discussion following the presentation of the papers, A. Deutsch gave a short report on his new observations of the spectrum of Comet Wilson 1961; the following abstract was written by the speaker himself:

"A spectrum was obtained, at the coudé focus of the 100-inch telescope, of Comet Wilson at dawn on 1961 July 26. The nucleus, looking stellar, was held stationary at the center of the slit during the five-minute exposure. The slit was oriented approximately in the direction of the tail. The spectrum covers the region $\lambda\lambda$5200–6400, and the dispersion is 60 Å/mm. The nucleus produces an over-exposed, narrow streak down the center of the spectrum. A number of emission bands may be seen close to its edges. The outstanding features are the D-lines and [O I] λ6300. These lines cross the whole spectrum, but they are twice as strong on one side of the spectrum as on the other. Moreover, on the weaker (anti-tail) side, they are decidedly tilted towards longer wave-length. The velocity gradient is close to 1 km per second of arc."

The papers gave rise to extensive discussion. Since, however, this did not reveal new viewpoints beyond those already recorded above the discussion is not reported. On the other hand it may perhaps not be out of place to try to give here a brief summary of the general result of the colloquium.

As indicated in the introduction the whole discussion was intended on one hand to elaborate a clearer picture of what we are allowed at present to consider as well-recognized observational facts. From B. A. Vorontsov-Velyaminov's contribution, it has become evident that the gas heads of comets (at medium heliocentric distances around 1 A.U.) have larger dimensions than hitherto generally assumed, and consequently the probability of ionization for neutral molecules, such as CN and C_2, must be rather small, probably less than $\lambda = 10^{-6}$. The paper also gives reliable data about the abundance of molecules in the heads. W. Liller's paper seems to make it highly probable that occasionally intense corpuscular streams from the Sun can partly destroy the emitting particles in the heads. Difficult to understand are his observed minute-to-minute fluctuations in the extensions of the head; if substantiated they could only be explained by a variable contribution of a corpuscular stream to excitation. V. Vanýsek's report exhibits the state of our knowledge concerning the magnitude of the repulsive forces. Whereas those of one-hundred times the solar gravitation are certain, much higher ones can be statistically of no importance. V. Vanýsek emphasizes that these repulsive forces represent a permanent feature of comet tails, and that they cannot depend on occasional jets of corpuscular radiation from the Sun. The main points of the next paper are the different ionization probabilities observed near the nucleus and at larger distances from it. This forces us to search for the source of ionization within the atmosphere, and to abandon the direct action of an outer radiation. It is further emphasized—and this fits in with the idea just mentioned—that the surprisingly regular development of all tail rays (and the independence which each single ray shows from all others present) can hardly be reconciled with the idea of direct control by an outer influence.

As regards the confrontation of the basic physical theory with the above-mentioned observations, the situation appears rather disappointing. Evidently, we are still in the state of exploring what physical mechanisms are responsible for the creation of the tail ions and the acceleration of these ions (the two most striking processes in comets). The idea that ultra-violet solar radiation can explain the normal ionization, and the circumstances connected with the appearance of the ions, can certainly not be accepted. As explained above, the hypothesis of the corpuscular radiation in its present state also provides no solution, and somewhat larger cross-sections for the proton molecule collision cannot save the situation. Concerning the acceleration of the ions, it can only be said that the mechanism for it remains completely obscure.

It is evident that in such a situation the theory cannot be expected to shed light on the somewhat more subtle observations on the formation and movement of the tail rays, the limitation of the ionization in space, and the nature of the ion sources. Apparently, still more information from observation is needed in order to find the right basis for a physical theory.