# 15. PHYSICAL STUDY OF COMETS
# (L'ÉTUDE PHYSIQUE DES COMÈTES)

PRESIDENT: V. Vanysek.
VICE-PRESIDENT: A. H. Delsemme.
SECRETARY: J. Rahe.
ORGANIZING COMMITTEE: L. Biermann, G. Herzberg, B. Levin, N. Richter, E. Roemer, F. Whipple, K. Wurm.

## INTRODUCTION

The following triennial report on the progress in the physics of comets is written in a slightly different form from that in the previous volume of *Reports on Astronomy*, 1970. All sections were written by the undersigned on the basis of contributions submitted by L. Biermann, A. H. Delsemme, O. V. Dobrovolskii, B. Donn, G. Herzberg, V. P. Konopleva, Rhea Lüst, J. Rahe, V. Riives, E. Roemer, S. K. Vsekhsvyatskii, F. Whipple and K. Wurm. The aim of this Report is not to present a review of all papers published and results obtained in recent three years, and many publications are not mentioned explicitly. The published papers which are reviewed in *Astronomy & Astrophysics Abstracts* are quoted here by eight digits which mean the A & A volume (first two digits) and the reference number.

A generally accepted assumption that the asteroids and comets are keys to the history of the solar system is obviously the reason why the interest in the physical study of comets has been increasing in recent years. Arguments for the icy-conglomerate cometary nucleus (although of not definitely specified kind) are put forward, particularly by the successful extraterrestrial measurements of $L\alpha$ resonance lines of hydrogen and OH of two bright comets in 1970.

The large production rate of gases (about $10^{30}$ molecules $s^{-1}$ for moderate bright comets) has been confirmed.

The interaction of comets with interplanetary medium is still one of very interesting astrophysical problems of solar physics.

More frequently discussed problems of the exploration of comets by spacecrafts have been studied by an increasing number of specialists who find such missions very valuable for different scientific objectives.

Current information about comets' appearance is given by Roemer in the Comet Notes in the Publications of the Astronomical Society of the Pacific through 1971, and from January 1972 in the new Journal of that Society, *Mercury*.

The Kiev University Observatory continues publishing the Cometary Circular.

There were the following international meetings directly or indirectly devoted to the study of comets:

1970 Leningrad, *IAU Symposium* No. 45, 'The Motion, Evolution of Orbits, and Origin of Comets' (ed. by G. S. Chebotarev, E. I. Kazimirchak-Polonskaya, B. G. Marsden, 1972);

1971 Tucson, *IAU Colloquium* No. 12, 'Physical Studies of Minor Planets' (ed. by T. Gehrels in 1972, NASA SP-267 (07·012·027);

1971 Albany, *IAU Colloquium* No. 13, 'Evolutionary and Physical Problems of Meteoroids';

1971 Saltsjöbaden, *Nobel Symposium* No. 21, 'From Plasma to Planet' (ed. by A. Elvius in 1972 (07·012·028)).

Proceedings of the NASA-sponsored Tucson Comet Conference held early in April 1970 were published by the Lunar and Planetary Laboratory (G. P. Kuiper and E. Roemer, eds., 1972) under the title 'Comets – Scientific Data and Missions'.



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IAU Colloquium No. 22, 'Asteroids, Comets, Meteoric Matter' was held in Nice, April 1972. At the COSPAR XVth Plenary Meeting in Madrid (May 1972) several contributions were devoted to the study of comets, too.

The VIth Conference on Cometary Problems was held in Kiev in autumn 1971.

Cometary Science Working Group appointed in 1971 by NASA proposed a report concerning the comet missions (the report was issued by the IIT Research Institute, December 1971 (NASA Contract NASW-2144)).

Next special symposium on cometary physics is proposed tentatively for 1974.

Proceedings of the above mentioned meetings are valuable sources of references to important recent contributions to cometary physics.

The contemporary state of cometary physics was reviewed by Biermann (05.102.017, 06.102.012), Vanýsek (07.102.017) and Delsemme (1972).

The second part of the *Atlas of Cometary Forms (Cometary Tails)* by Rahe, Donn and Wurm (03.003.099) is reported to be in fair progress. Richter and Högner began to prepare the IInd part of their *Isophotometric Atlas of Comets* (*Part I* – (01.003.065)) including all comets since 1957 up to now. The second edition of Part I will be published in 1973.

## OBSERVATIONS

The use of the OAO-2 and OGO-5 satellites for comet investigation in 1970 means an important milestone in cometary physics. Nevertheless, significant improvements have been achieved in the ground-based observations, too. Narrow-band photometry, polarimetry, high resolution spectroscopy, infrared (up to several microns) observations are used more frequently. Beside them, non-professional astronomers Beyer (07.102.012), Waterfield, Seki and several others have provided valuable observations of the physical appearance of faint comets.

Nevertheless, there is still an unfavourable situation in acquiring sufficient observational data. Some estimations show that the number of astronomers who specialize in observing the comets has decreased to 25% of those working seventy years ago!

There exists a large amount of observations of different kinds for brighter comets, particularly for the two bright objects in 1970 (Tago-Sato-Kosaka = 1969g = 1969 IX and Bennett = 1969i = 1970 II), chiefly because more observers do participate, using smaller instruments. Even here, however, the observations made by proper methods remain few, and faint comets are still almost 'unknown' objects for cometary physics.

The observing time used for observation with large instruments (i.e. above 100 cm in dia) is extremely small. The best situation seems to be at the University of Arizona where the observational programme of comets continues fairly steadily with the two large reflectors, the 154 cm telescope of the Lunar and Planetary Laboratory and the 229 cm reflector of the Steward Observatory. Some 200 plates of comets per year have been obtained by Roemer over the triennium, many of 19th magnitude or fainter. However, the main task of these observations are the astrometric results which are properly of interest of Commission 20.

Very encouraging is the successful attempt made by Roemer to detect P/Encke at magnitude 20·5 near the aphelion point of its orbit.

Observatories in the U.S.S.R. (Kiev, Crimea, Dushanbe and Byurakan) provided photographic and photoelectric observations of the two above mentioned bright comets. In Kiev a Photographic Atlas of Comet 1965f was prepared.

Narrow pass bands are widely used in *photometry* and *polarimetry*. Bugaenko *et al.* (07.103.100) used ten interference filters ($\lambda\lambda$3600–7500) with a half-width $\lambda = 0{\cdot}02\lambda_{\rm eff}$ for photoelectric polarization measurements of the continuum in the head of Comet Bennett in the Nasmyth focus of the 122 cm reflector of the Crimean Astrophysical Observatory.

Konopleva and Garazdo-Lesnykh (05.102.008) made monochromatic surface photometry of the same comet with the interference filter ($\lambda\lambda$3880 and 4730) in the Cassegrain focus of the 70 cm reflector at Kiev.

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The Tautenburg Observatory (G.D.R.) in cooperation with the Astronomy Department of the Charles University, Prague, investigated high resolution plates of 1970 XV and 1970 II obtained with the big Tautenburg telescope, comparing them with narrow-band photoelectric photometry made at the Ondrejov Observatory.

Högner and Richter worked on the large scale Tautenburg plates of Comet 1970 II by means of the new contrast filtering method. By this method all parts of the comet, the structure of tail, head, envelopes and the nucleus itself can be studied on the basis of only one long exposed plate.

In the Goddard Space Flight Center (U.S.A.) Rahe has reduced photometric plates of 1969 IX and 1970 II taken by McCracken with the Goddard Ritchey-Crétien telescope. Plate scale was about 16″ per mm and narrow-band filters for $C_2$, $C_3$, CN, $CO^+$, Na and continuum were used. Some of these plates were taken over the image intensifier. These data provided isophotes with best spatial resolution.

*Photographic* and *visual photometry* methods were newly discussed by Demenko (05.041.003; 06.102.019), Konopleva and Garazdo-Lesnykh (05.102.008) and Tarashchuk (05.102.010).

Theoretical formulae for the calibration of negatives were proposed by Riives (05.102.001) expressing the relationship between the photographic density and surface brightness. Absolute magnitudes and photometric parameters of 48 comets observed in 1965–69 have been determined by Vsekhsvyatskii and Il'ichishina (05.102.019).

Vsekhsvyatskii (1972) analyzed secular changes of the intrinsic brightness of P/Holmes, P/De Vico-Swift and P/Tempel-Tuttle and found a secular decrease of 0·01 of the brightness estimated for these objects in the last century.

Polarimetric measurements of bright comets have been discussed by Clarke (06.103.101), Osherov (06.103.134). A large amount of polarization data not yet published are reported by the Tokyo University, the Haleakala Observatories, Hawaii, and the Astronomy Department of the Charles University, Prague. (At the very recent colloquium on polarimetry held in Tucson in November 1972 one session was devoted to cometary results; however, no further details were available before finishing this Report.)

Molecular bands polarization was studied by Golovin and Romashin (05.103.109). They found it to be about 10% for Comet 1969 IX while continuum polarization was 20–40% and increased with wavelength (Babaev *et al.*, 03.103.101; Grigorian and Abramian, 04.103.101).

The improvement in photometric methods of bright comets is, unfortunately, not extended to faint comets. The system H$\beta$ and the *uvby* photometric system recommended in the last Commission Report (i.e. *Reports on Astronomy*, 1970, p. 143) for the photometry of faint comets have not been widely applied (it must be noted that this recommendation is sometimes misinterpreted as a recommendation of the UBV system, which is not suitable for such a purpose ).

The progress in *cometary spectroscopy* has recently been reviewed by Arpigny (1972) who presented also references concerning the high dispersion spectroscopy results.

The spectroscopic observations in the visual range are still limited to bright and moderate bright comets. Nevertheless, the first spectrograms with the image tube camera were obtained of the faint P/d'Arrest comet by R. E. White using the Cassegrain spectrograph of the Steward 229 cm telescope. It is clear that the instrumental capability exists for far more work of this kind, if sufficient importance could be documented to justify the large telescope time involved.

The study of the $C^{12}/C^{13}$ ratio from high-dispersion spectra of Comets 1969 IX and 1970 II made by Owen (1970) leads to the conclusions that within observational errors the ratio is identical with terrestrial carbon.

The spectrophotometric gradients of 1970 II determined by Babu and Saxena (1972) indicate a reddening of continuum relative to the Sun, similarly as the measurements of Bugaenko *et al.* (07.103.100) mentioned above.

The spectrograms of comets obtained in the coudé focus of the 193 cm telescope of the Haute Provence Observatory are significant source of spectroscopic data for cometary physics. The reduction of the plates obtained is being carried out at the Observatory of Marseille and at the Institute of Astrophysics of Liège.

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Woszczyk (04·102·028) did a very detailed investigation of cometary spectra of high resolution in the region $\lambda 3883$–$3914$ and $\lambda 4180$–$4752$ on the plates of Comets Encke 1960 I, Burnham 1959 VII, Candy 1961 II, Seki-Lines 1962 III, Honda 1962 IV and Ikeya 1963 I. The dispersion of these spectra which cover the region of 3000 to 8900 Å is from 10 Å $mm^{-1}$ to 78 Å $mm^{-1}$.

Sivaraman reported that the slit spectra of Comet 1970 II obtained at the Kodaikanal Observatory were used for the study of the Na emission and its dependence on solar activity. The significance of the Na emission in comets for similar studies was discussed by Bappu and Sivaraman earlier (02.102.034).

A new *Atlas of Cometary Spectra* which will contain reproductions of all available medium- and high-dispersion spectra is still in preparation.

*Infrared observations* of bright comets (particularly of Comet 1970 II) were published by Myer (07.103.100), Lee (1972), Westphal (1972), Johnson *et al.* (05.103.111), Maas *et al.* (03.103.102). The wavelengths ranging from 2·2 to 22 $\mu$ and usually the spatial scans of the cometary head and tail were made. 70 $\mu$ flux measures of the nucleus of 1970 II were made from an aircraft operating in the stratosphere (Kleinmann *et al.*, 05.103.109). In both comets the infrared flux appears to be of thermal origin. Meisel (1972) has recently reported that infrared measurements obtained with image one micron tube slit spectra with the dispersion of about 40 Å $mm^{-1}$ are significant for the study of the CN red system and vibrational overtones of polyatomic species contouring CH or OH bands.

*Radioastronomical observations* of comets have been unsuccessful so far.

## NUCLEUS

*The structure* of the cometary nucleus has recently been discussed by Lyttleton (07.102.006) who reviewed some arguments against the solid nucleus and in favour of the idea that the cometary nucleus is a cloud of fine separated particles. One of his major arguments is the shrinking of the observed comas with decreasing heliocentric distance. However, this is an effect caused by the shrinking of the gaseous coma following approximately the $r^{7/4}$ law ($r$ = heliocentric distance) for the linear size of the visible coma. Moreover, the very realistic assumption of a large gas production in comets and consequently the effect of gas-dust interaction on the cloud stability were not taken into consideration. Particularly the high rate of the gas production is a crucial argument for the icy-conglomerate nucleus. Although a definite description of the entire structure of the cometary nucleus still remains in the frame of hypothetical models, some kind of the icy-conglomerate nucleus seems to be the best approach to the reality at present.

*The origin of comets* (or their nuclei) in general is usually studied by analysing their orbits, which is the domain of Commission 20. Physical problems related to the comet formation are discussed in connection with condensation processes of volatile elements in the primordial solar nebula (Fullerton and Huebner, 1972; Shimizu, 1972). Whipple (1972) studied the formation of cometary nuclei as accretion process in a Laplacean-type nebula. Alfvén (03.107.001) proposed the jet streams as one possible mechanism for creation of comets. This process seems to be not quite compatible with the icy-conglomerate model.

*The lifetime* of a cometary nucleus need not be necessarily considered as the lifetime of its entire existence but as the time in which such a body produces observable cometary phenomena in the solar radiation field, which distinguish the cometary appearance from the asteroidal one. The asteroidal appearance might be one possible final stage of some comets and the existence of asteroids like Icarus, Geographos, Apollo, Adonis and Hermes, or the Hilda group supports this idea.

It is quite possible (Vanýsek, 07.102.025) that very old and still active icy-conglomerate cometary nuclei may exist at the outer boundary of the asteroidal belt. The search for these comets among very faint asteroids with the mean motion $\leqslant 600''$ could be very important to the better understanding of the comet-asteroid relation.

In principle two ways of the evolution are shown to be possible (Shulman, 1972): The evolution without the dust-shield formation, and with the crust developing. The brightness of the nucleus is decreasing without considerable shrinking and the nucleus becomes an asteroid-like body. This idea was used also for estimation of the age of short-periodic comets (Konopleva and Shulman, 04.103.120).

The structure of the nucleus was again estimated from cometary brightness outbursts.

The collisions of comets with hypothetical interplanetary boulders can be followed by the splitting or minor destruction of the surface of a cometary nucleus (Marsden and Sekanina, 06.102.014).

The interaction of the nucleus with interplanetary shock waves was also discussed as another possible mechanism which can lead to comets' outbursts (Eviatar *et al.*, 04.102.011, 04.102.015).

Shulman (1972) considered combined effects of galatic and solar cosmic rays on comets. Galactic cosmic rays can induce a chemical process as the synthesis of complicated hydrocarbons in the surface layer. Cosmic rays of solar origin can cause accumulation of these hydrocarbons and eventually initiate surface destruction.

It is shown by Sekanina (03.102.015) that the point of maximum surface temperature of the rotating nucleus of a comet deficient in volatile substances lags behind the subsolar point, and that there is no radial component of the resultant repulsive force of the escaping gas acting on the nucleus. The vapourization law for water snow is compatible with the character of the nongravitational acceleration found in the motions of a number of short-periodic comets (see also Report of Commission 20).

*Shape and spin* orientation of the cometary nucleus is very difficult to establish. The method of light curve successfully used for asteroids is not easily applicable to comets. The brightness variation of the photometric nucleus of comets may be due to various processes. The only one direct evidence of nuclear rotation has been the spiral structure (apparently of dust) in some comets (Rahe *et al.*, 03.003.099). Such a feature was precisely observed in Comet Bennett (Larson and Minton, 1972) which implies a rotation period of about 35 hr when the velocity of dust streams is about 0.6 km $s^{-1}$.

Visual and photographic observations are used by Mrkos (07.103.129) for the estimation of the head diameter and the size of the nucleus of P/Mrkos-Pajdušáková. The resulting radius varies between 0·4 to $2{\cdot}9 \times 10^4$ cm.

## COMETARY NEUTRAL ATMOSPHERE

The major event of the last three years has been the discovery of the huge *hydrogen halo* and of the brightness of the hydroxyl coma from space observations with OAO-2 and OGO-5 (see Code and Savage, 1972; and Bertaux and Blamont, 03.103.102, or Code, 1972).

The most discussed observational results are the photometry in the L$\alpha$ resonance line of the H. cometary atmosphere.

Important studies were published by Keller (05.102.033, 07.102.020) who computed a theoretical model for the L$\alpha$ emission of comets on the basis of single and multiple scattering. The results for the production rates ($\sim 10^{30}$ atoms per s), velocities of outflow ($\sim 8$ km $s^{-1}$) and lifetimes ($\sim 1$–$2 \times \times 10^6$ s) of the H-atoms are in good accordance with measurements of Comet Bennett carried out by Code and Bertaux and Blamont and confirm Biermann's predictions. The brightness distribution and distortion of the L$\alpha$ isophotes can be explained by a radial outflow velocity of 8 km $s^{-1}$ of hydrogen atoms from the coma centre. This large velocity probably comes from the energy difference between the dissociation energy of the parent molecule involved, and the photon it has absorbed. If $H_2O$ is the parent molecule, half of the possible hydrogen atoms should have a velocity larger than 10 km $s^{-1}$, but as the other half may come from the further dissociation of OH, no sharp velocity discrepancy has emerged so far.

In 1970 II, because of optical depth effects, a 3000K temperature limits the observed central brightness of the coma in L$\alpha$ (Mendis *et al.*, 07.102.007). In 1969 IX, the L$\alpha$ halo centre was fainter, and the extent of its optical depth much smaller (Jenkins and Wingert, 07.103.106). An observed brightness law $r^{-6}$ ($r$ = heliocentric distance) for the central part of each H and OH comas of 1969 IX was explained by Delsemme (05.102.025) as a three-step process, namely the vapourization of water snow, the photodissociation of the water vapour, and the photoexcitation

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of the water vapour, and the photoexcitation of the resonance-fluorescence of H and of OH. This model has been criticized by Wallis (1972).

Huebner (04.102.006) investigated the expected intensities of some *microwave* transitions of simple molecules containing cosmically abundant elements. Emission from 'young' comets should be on the border of being observable (e.g. HCN). The search for formaldehyde (Huebner and Snyder 04.103.101) in Comet Bennett during its perihelion passage carried out with the NRAO 140 ft telescope failed, similarly as the search for $H_2O$ (Clark *et al.*, 06.103.101), presumably because of excessive beam dilution.

From microwae emission thresholds as well as from secular decay rates of comets the high densities proposed by Malaise (03.102.011) to explain the collisional effects observed in the rotational structure of CN (0-0) bands must be upper limits. However, high densities are by and large confirmed: Production rates of $10^{30}$ molecules of water per second are likely for moderate bright comets. This gas production rate implies a large directional factor to explain the nongravitational forces. However, their dependence on distance suggests vapourization controlled by water ice only.

*Physical properties of the dust* in cometary atmospheres are estimated from colorimetric, polarimetric and infrared data, usually using theoretical models of optically thin polydisperse media as reference models.

Some spectrophotometric results led to the conclusion that the spectral distribution in the cometary continuum resembles the spectral distribution of G8V stars and this is due to the selective scattering on small particles. The positive colour excess was again confirmed recently in Comet 1970 II.

However, spectrophotometric results for Comets 1968 I, 1968 V and 1968 VI show that the reflected or scattered light is 'grey' and the continuum energy distributions for these comets follow closely the spectrum of the Sun (Gebel, 04.103.105). It seems to be impossible to obtain any reasonable conclusions for the dust particles size and physical properties from the colorimetric observation in the visual spectral range.

Polarimetric measurements seem to be more efficient tools for the study of the actual physical properties of the dust component in comets. It is shown that the high 'positive' polarization (i.e. the electric vector perpendicular to the polarization plane is greater than the parallel one) is to be found for absorbing clouds (even with moderate absorbers) with the maximum between phase angles 60°–90°, while the opposite case, the 'negative' polarization near angles 150°–170° is very typical of clouds with dielectric particles. The change of polarization with phase angle may help to distinguish the type of particles (Vanýsek, 05.106.029).

Serious problems arise when elongated particles are dominant in the cometary dust. Clarke (06.103.101) shows that the plane of vibration (or the plane of polarization) for Comet 1970 II sometimes deviates significantly from one of the two possible orthogonal positions to the scattering plane. Such a deviation can be explained by scattering on the aligned elongated particles. It was shown by Harwit and Vanýsek (1971) that an efficient alignment mechanism might be caused by the bombardment by solar wind protons. The rate at which the alignment occurs depends also on the gas flow from the nucleus. The polarization plane near the nucleus would be more arbitrarily oriented than in the tail, where the solar wind effect dominates.

The most decisive method for determining the physical characteristics of cometary grains are the measurements in the infrared. By comparing the continuum flux of the comet in the visual and infrared regions the optical albedo may be estimated assuming that the infrared emission is determined mainly by the absorbed visible solar radiation.

In such a manner the particles diameters were estimated in Comets 1969 IX and 1970 II (O'Dell, 05.102.023) to be about $0{\cdot}1\ \mu$ and the albedo value was found to be $0{\cdot}3 \pm 0{\cdot}15$.

However, these methods are not quite unbiased because the assumed scattering efficiency of the particles consequently involves – even if only approximately – the optical properties of the dust.

The infrared measurements lead to a colour temperature 1·4 times higher than of a black body. Therefore, the infrared absorbitivity is obviously lower than the visual one, which is generally valid for many various kinds of material. The emission peak near $10\mu$ in continuum of 1970 II was tentatively identified as due to silicate grains (Maas *et al.*, 03.103.102).

Sharp dust gradients also seem the correct explanation of infrared observations (Myer, 07.103.100) as a cone of dust was observed visually and on photographs of 1970 II.

The vapourization rate of dust has been studied by Huebner (03.102.012). The vapourization of a halo of icy grains seems to explain rather well the brightness distributions of the continuum and links it to the brightness profile of the molecular emissions in Comet 1960 II (Delsemme and Miller, 06.102.006; 06.102.007); this casts some doubt on the existence of some *parent molecules* which are no more needed for explaining brightness profiles. The distribution of polarization in the head of 1970 II can indeed be explained by vapourizing icy grains, but alternately by the alignment of elongated particles, according to Harwit-Vanýsek's mechanism.

Nevertheless, even if the *solid hydrates of gases* (*clathrates*) in icy grains are the source of the observed radicals in comets, the relative abundance of other prospective parent molecules may remain substantial, and there is no reason for excluding them as possible sources of observed radicals. One of the strong arguments for the 'clathrate' model rises from short lifetimes of parent particles exposed to the solar radiation field. The lifetimes of hypothetical precursors have been derived from the photometric profiles of cometary heads as products of expansion velocity and lifetimes. However, the interpretation of the photometric profiles is difficult from the experimental as well as theoretical point of view. The proposed direct method (Vanýsek, 02.102.047) for determining the precursors' lifetimes from the emission light curve during a brightness outburst has, unfortunately, not yet been applied.

It must be noted that a recent study of dust tails made by Wurm and Mammano (1972a) shows no relation between dust features and the neutral gaseous coma.

The problems of the *dynamic of neutral gas* in cometary atmospheres were discussed in an important monograph by Shulman (1972). The behaviour of the gas flow in the collisional region near the nucleus is studied as well as its interaction with dust particles. A theory is developed for the case of the gas flow in transient regions between collisional and collisional-free atmosphere.

The *brightness distribution* and distortion of the comas of 5 comets have been used by Dolginov and Gnedin (05.102.016) in connection with a model assuming an initial Maxwellian velocity distribution of the vapourizing gas, to derive terminal velocities (some 0.8 km $s^{-1}$ at 1 AU), temperatures (more than 1000K at 1 AU) and scale lengths for the $C_2$ and CN decays ($1$–$2 \times 10^5$ km for each, at 1 AU). The dust production rate must reach $10^7$–$10^8$ g $s^{-1}$ to explain that optical depth which enlarges the scale lengths behind the coma.

Isophotes of the first comprehensive set of narrow-band filter photographs with high spatial resolution obtained at Goddard, reported by Rahe for Comets 1970 II and 1969 IX, in $C_2$. $C_3$, CN, $CO^+$ sequences, Na emission and in continuum demonstrate the different behaviour of different kinds of particles and provide fine data for a quantitative analysis. The preliminary results have shown that the conclusions about the production of radicals from the icy particles based on low resolution isphotes must be revised. This follows also from the analysis of isophotes obtained by Vanýsek (07.102.026) from filter band photographs of Comet 1970 XV taken in the Schmidt focus of the convertible 200 cm Tautenburg telescope.

The *decay scale lengths* of CN and $C_2$ are also obtained by Ishida and Kosai (04.103.103; 05.103.111) for 1969 IX and 1970 II and the ratio for the radical versus precursor lifetimes was found a low 5 for CN and a lower 3 for $C_2$. Although the wide band filters and low space resolution may have downgraded these results, it may be suggested that this ratio is either variable (icy grains?) or still very uncertain.

### IONIC TAILS (TYPE I)

The ionic tails were studied on an enormous amount of material obtained chiefly for the bright comets of 1970.

Jockers and Rhea Lüst (07.103.106) investigated the *kinematics of the tail* material of Comet 1969 IX and obtained the velocity field of the ionized material for 4 nights. The velocities are in the range

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of 50 to 300 km $s^{-1}$. For the same comet Ishida and Kosai (04.103.103) obtained velocities of 120 to 600 km $s^{-1}$ in the long rays. Some short side rays indicated velocities larger than 1500 km $s^{-1}$ and lower than 100 km $s^{-1}$.

Further detailed analysis of ionic tails of 1969 IX made by Jockers *et al.* (1972) shows that the measured aberration angles between the tail axis and the radius vector are compatible with a tangential component of the solar wind velocity up to 20 km $s^{-1}$, while the assumption of a purely radial solar flow leads on some days to solar wind velocities incompatible with the geophysical and satellite data. The lifetime of the ion structures was in the range of several hours to 0.5 day.

A set of photographs obtained in Dushanbe and Kiev have been used by Dobrovolskii *et al.* (1971) for the determination of the *repulsive force* parameter $1 + \mu$ which was found in the range from 290 up to several thousands (see also Vsekhsvyatskii and Demenko, 07.103.100).

The ionic tails have been studied for many years as qualitative indicators for *solar wind data*. New determination of the bulk velocity from the orientation of the ionic tails (Brandt *et al.*, 1972) is in agreement with the model whose components are: radial 415 km $s^{-1}$, azimuthal 6 km $s^{-1}$. Some relation between the solar activity and rapid changes in the appearance of 1968 I was found. Bakharev (05.103.104) confirmed that fast changes in the observed size of the cometary head are in close connection to the changes in the solar wind behaviour. The statistical study published by Andrienko *et al.* (06.102.002) shows that there is a strong correlation between the geomagnetic activity and brightness of comets situated at the heliocentric distances $r < 1.5$ AU and close to the equatorial plane of the Sun.

The 'waviness' in the tail of Comet 1908 III has been studied again by Brandt and Hardorp (03.102.013) in view of satellite measurements of the solar wind components. However, no definite conclusions have been reached.

In contrast to the above mentioned positive results in the comets-solar wind (or solar activity) relations it seems that negative results follow from a careful study of the behaviour of some well-known objects.

Bouška (05.102.029) studied fluctuations in the brightness of some comets and showed that many cometary flares deduced from visual observations whose accuracy is very problematic, can be explained by observational errors only. In view of these conclusions the correlation between the brightness fluctuations of comets and the solar activity seems to be suspicious.

The irregular 'oscillations' in the ionic tail axis in comets have been sometimes brought into connection with changes in the flow conditions in the solar wind. However, in their recent study (based on the analysis of well-known observations), Wurm and Mammano (1972b) defend the assumption that these oscillations are due to minor variations in the emission conditions and sources of $CO^+$ ions which Wurm supposes to be close to the nucleus.

Monitoring done by Roemer of such an object of unusual physical activity as is P/Schwassmann-Wachmann 1 has shown that this comet remained fairly quiet during the mid-August-to-September 1972 interval in spite of unusual solar activity early in August.

Photographs of Comet 1970 II made by Miller with the Michigan Curtis Schmidt on March 7, 8, 1970, and subsequent nights show no difference in normal comet development on March 7 through 12, even if a strong solar wind shock was reported. Satellite measurements of solar wind speed and magnetic field indicated passage of an unusually strong interplanetary shock with velocity of about 1150 km $s^{-1}$. This shock should have reached the heliocentric distance of the comet about March 8.0.

Similar results are reported by Burlaga *et al.* (1972) in a very detailed study made at Goddard. In view of these results, one must seriously consider the possibility that a large abrupt change in momentum flux of the solar wind is neither necessary nor sufficient to cause a large disturbance in a comet tail.

New theoretical work on the *plasma flow* around a comet (Brosowski and Wegman, 1972) led to a new estimate of the distance of the bow shock from the cometary nucleus of only $\geqslant 1 \times 10^6$ km for a typical case, as had also been proposed by Wallis (06.074.023). The shock should be considerably weaker than suggested before. The flow pattern found for the rear parts leads to displacements of filamentary structures which are consistent with those observed in many comets (Biermann and Rhea Lüst, 1972).

The Kelvin-Helmholtz instability was used by Ershkovich and Chernikov (07.102.008) in a theoretical interpretation of the kinematics and oscillation of ionic tails.

The controversy on the place and mechanism of *generation of the* $CO^+$ ion has not yet been settled either. More morphological arguments are given by Wurm and Mammano (1972b) for an ion source in the nuclear region, while laboratory rates of dissociative recombination exclude it (see Biermann, 1970).

### NEUTRAL TAILS (TYPE II AND III)

The Finson-Probstein model of dust comets has successfully been applied by Sekanina (1972) to preperihelion photographs of Comet 1970 II taken at Cerro Tololo by F. D. Miller. A significant proportion of fine dust has been found for which the radiation pressure exceeds the solar gravity. The average size of particles was probably smaller than that of particles of Comet Arend-Roland.

The parameter of the repulsive force $1 + \mu = 0{\cdot}8$–$1{\cdot}4$ slightly increasing with heliocentric distance was determined for 1970 II by Dobrovolskii and Ibadinov (06.103.101).

Wurm and Mammano (1972a) studied the formation of dust tail of Comet 1970 II. The dust particles leave the vicinity of the nucleus only within a certain cone directed to the Sun. Parabolic envelopes enhancing the nucleus are formed by dust reaching distances $3 \times 10^4$, $6 \times 10^4$ and $10^5$ km. There exists no relation between the production and motion of dust features and neutral coma gases. Wurm and Mammano ascribe a significant role in the kinematics of dust tails to the electrical charge of dust particles.

### LABORATORY RESULTS

In recent years some very interesting laboratory results (other than spectroscopic) on cometary-like material in the form of ices as molecules have been reported. Delsemme and his associates have published results on the behaviour of *ice* and *water clathrates*. Delsemme and Wenger (03.022.009) reported a high density amorphous ice ($2{\cdot}3$ g cm$^{-3}$) formed by slow condensation in experiments between 93 K and 100 K. This high density was not found by Siever *et al.* (1970) and it may not be consistent with other earlier experiments on condensation of water at low temperatures. Delsemme and Wenger (03.102.007) have studied the characteristics and vapourization behaviour of the methane clathrate.

Considerable information on the properties of ice appear in the proceedings of the 1968 Munich Symposium on the Physics of Ice (Riehl *et al.*, 1969). It must be noted, however, that an earlier symposium report (Kingery, 1963) contains considerable data on both snow and ice applicable to cometary problems. In the Ioffe Physical Institute, Leningrad, Ibadinov and Kaimanov (04.102.005) continue in laboratory experiments concerning the sublimation of icy-conglomerate mixtures.

In a continuation of astrophysical related *photochemistry*, Stief and his collaborators (Stief *et al.*, 1971; Stief, 07.102.018) have photolyzed methylacetylene, an interstellar molecule. $C_3$ appears to be primary fragment (Stief and Payne, 1972) and methylacetylene (propyne) is suggested as a potential source of cometary $C_3$. Jackson and Faris (1972) have studied the collisional quenching of the $B^2\Sigma^+$ state of CN by several molecules. A review of cometary photochemistry was prepared by Jackson (1972).

*Laboratory simulation of ionic tails* continues with a paper by Kubo *et al.* (03.102.004). A critical compilation of ultraviolet photoabsorption cross-sections for 24 atoms between 3000 and 10 Å has been prepared by Hudson and Kieffer (1971). Hudson (05.022.065) has also prepared a critical review of ultraviolet cross-sections for 19 molecules of astrophysical and aeronomic interest. An extensive bibliography of photoabsorption cross-section data has been published by Hudson and Kieffer (1970).

*Fluorescent excitation* of CN in the static system was newly discussed by Myer and Nicholls (03.102.001). Several laboratories in the U.S.S.R. (Physico-Chemical Institute of the State University Kharkov; State University, Uzhorod, and the Ioffe Physical Institute, Leningrad) have achieved considerable progress in the study of the electron impacts excitation mechanism of the cometary radicals.

Cherednichenko (04.102.003; 05.102.004) published theoretical results for the photodissociation of ammonia, water and hydrogen peroxide.

During the last three years a number of investigations have been carried out in various *diatomic molecules* and ions which are of potential interest for the study of cometary phenomena. A good deal of work has been done by Herzberg (1970) on the $H_2$ molecule, including precise values for the dissociation energy and the ionization potential (Herzberg and Jungen, 1972), as well as a study of an emission continuum in the near vacuum ultraviolet (Dalgarno *et al.*, 04.022.050) A new spectrum of ArH has been found by Johns (1970) and the absorption spectrum of HF in the vacuum ultraviolet has been investigated (Di Lonardo and Douglas, 1972). Forbidden transitions in CO and SO have been studied by Herzberg *et al.* (1970) and the absorption spectra of CN and $N_2$ in the vacuum ultraviolet have received further attention (Lutz, 04.022.062; Ledbetter, 1969).

Among the molecular ions studied should be mentioned $C_2^-$ (Lagerqvist *et al.*, 1969), $C_2^+$ (Meinel, 1972), $SiH^+$ (Douglas and Lutz, 04.022.060) and $CN^+$ (Lutz, 05.022.002). (For a review see Herzberg, 1971.) Several of these spectra are in the accessible region and might be found in strong cometary spectra. Quite recently a spectrum of $H_2O^+$ has been obtained.

## SPACE MISSIONS TO COMETS

Small bodies like asteroids and comets have recently become an interesting target for future space missions. Two main groups of scientific objectives which justify such projects can be noted: (a) Comets may still contain the primordial material as their structure probably represents the structure of small bodies in the early history of the solar system; (b) The composition of the gaseous cometary atmospheres – both neutral and ionized – studied in situ will permit more detailed study of solar wind interaction with comets, which, consequently, can lead to conclusions concerning the utility of ionized comet tails for large-scale solar wind behaviour.

The well-known periodic comet *Halley* should be the object of a space mission at its return in 1986. However, a retrograde orbit makes this comet a difficult target for a space mission. Newell *et al.* (07.051.031) presented a list of perihelion passages of several periodic comets selected for missions in the years 1980–98. There are 16 cases classified as 'good', 12 'fair' and 10 'poor' for a flyby rendezvous approach of a spacecraft.

Friedlander *et al.* (07.051.028) discussed in detail opportunities of using different flight modes (Jupiter perturbation, solar or nuclear power low-thrust transfers) to make a flyby or rendezvous approach to P/Encke (1980), P/d'Arrest (1982) and P/Kopff (1983).

For the *early mission* (i.e. before 1980) P/d'Arrest and P/Grigg-Skjellerup have been discussed. Very economic seems to be the very early mission to Comet Grigg-Skjellerup in 1977 (Ness *et al.*, 1972; Farquhar and Ness, 1972) using the IMP spin stabilized spacecraft and/or solar probe HELIOS.

Serious difficulty in the planning of a future comet mission rises from the nongravitational effect on the cometary orbits (for details see Report of Commission 20). From this point of view for instance P/d'Arrest seems to be an unfavourable object. Also the serious problem of an early recovery necessary for the correction of the ephemeris (which may still remain inaccurate for the rendezvous mission manoeuvre) must be taken into consideration.

## PRIORITIES IN THE FURTHER WORK

Physical structure of comets together with other small bodies contains a great amount of not yet deciphered information about the early history of the solar system. Moreover, the resulting effects of the complicated mechanism of plasma interaction in space are demonstrated in their ionic atmospheres. Therefore the study of cometary physics provides substantial contribution to the development of the Earth and environmental sciences. For the future work the following priorities for the next decade should be mentioned.

(a) *Ground-based observations*: Using of large telescopes for the high-dispersion spectroscopy with image intensifiers, narrow-band photometry and polarimetry with high space resolution, systematical medium- and low-dispersion spectroscopic and photometric monitoring of faint comets. Relative infrared spectroscopy and polarimetry (including airborne and balloon observations). Further attempt of microwave detection of molecular emission in bright comets. Using of high power laser techniques for the study of the cometary dust.

(b) *Extraterrestrial observations*: Measuring in L$\alpha$ and OH emission, absolute UV and infrared spectroscopy.

(c) *Relation to other studies*: Extensive cooperation with specialists interested in the interplanetary and interstellar dust and molecules. Special attention should be paid to laboratory experiments concerning the molecules of astrophysical interest and to the study of behaviour of comet-like solid state particles in the solar radiation field, and to plasma physics experiments simulating the interplanetary space conditions.

(d) *Space missions*: Realization of an early comet mission (not later than 1980) by some economic equipments which have successfully been used in the contemporary space programme.

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V. VANYSEK

*President of the Commision*