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Konstantin Gringauz 1918–1993: Approach to Scientific Biography

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Abstract. The paper briefly presents scientific accomplishments of Professor K.I. Gringauz, who was a pioneer of in-situ space plasma studies and discovered the Earth's plasmasphere and the solar wind.

1 Toward space studies

Konstantin Iosifovich Gringauz (Fig. 1) was born on July 5, 1918, in Tula city, about 150 km south of Moscow. At the age of three he moved with his family (father – pharmacist, mother - housekeeper) to the Samara/Kuibyshev city on the banks of the Volga River where he attended school. As a boy he became an enthusiastic radio amateur and on finishing school in 1935 he enrolled in the Electrophysical Faculty of the Popov Electrotechnical Institute in Leningrad. In the spring of 1941 Gringauz received his Diploma specializing in frequency modulation, then a brand new topic, and continued his work in the Radiotechnical Laboratory, which he had joined in 1940.

In the first winter of the great siege of Leningrad (1942) Gringauz was evacuated to Moscow. After recovering from the effects of the siege in the summer of 1942 he received an assignment and moved via Kuibyshev (the site of Soviet government during WW II) to a former gramophone factory in Belowo city, Siberia. Within a few months a couple of engineers educated the personnel of this factory and organized production of small, rugged, and sensitive radio transmitters and receivers for tanks.

Closer to the end of war, in the winter of 1944 Gringauz was appointed member of government Commission for studying of the effectiveness of tank radio communications under battlefield conditions. Using a short visit to Moscow on the way from Poland in 1945 he passed the entry examinations required for post-graduate studies, and, after V-J day, obtained a position in a then classified institute NII 885 (now Institute of Space Instrumentation) where he became involved in studies of radio-wave propagation in the ionosphere. In 1947 Gringauz began to collaborate with Sergei Korolev, father of the Soviet space rocket program, and in 1948 for the first time he participated in the launching of a modified German V2 rocket (at Kapustin Yar launch site) which carried a radio sounder experiment to study the ionosphere.

Fig. 1 Professor of Space Recearch Institute of Russian Academy of Sciences Konstantin Iosifovich Gringauz in the age of his seventies.

After receiving his Ph.D. degree in 1949 Gringauz was put in charge of a laboratory for radio technology (1950). This led to a series of experiments in which phase-locked transmissions at 24 or 48 MHz and 144 MHz were used to measure the electron density $n_e(h)$ profile in the Earth's ionosphere. The first published measurements on 26 June, 1954 (V-1D geophysical rocket reached an altitude of only 106 km) showed clearly the presence of a sporadic E-layer at 102 km. A series of three measurements up to altitude of ~ 200 km (V-2A rocket) were made on 16 May, 25 August and 9 September, 1957, again showing sporadic E-layers in two last cases and also a general increase of $n_e(h)$ toward apogee. Finally, with rockets V-5A capable of reaching 480 km altitude, the F-layer of the ionosphere was probed on three occasions in 1958 (21 February, 27 August, and 31 October), and it was demonstrated that, in contrast to then

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current ideas, the electron density did not decrease rapidly above the F-layer maximum.

2 Pioneering experiments

In the mid 1950's Gringauz's laboratory was selected for the preparation of a plasma payload for the massive orbiter (later Sputnik 3) that would be launched by a yet not-existent rocket designed by Korolev. At the start of International Geophysical Year in 1957 the rocket was built and tested. The US was hoping to launch the world's first satellite, but progress on orbiter observatory was slow. Consequently Korolev proposed a less ambitious project; Gringauz's laboratory was selected for the construction and production of transmitter and antennae for the first Earth orbiter – 'Sputnik' in Russian. Following the launch of Sputnik 1 (Fig. 2) on October 4, 1957, the 'beep..beep' of this transmitter was heard by politicians as well as radio scientists and hams around the world. Gringauz was very proud to have provided such a prominent contribution to Sputnik 1. In particular he liked to tell that he was the last to touch the Sputnik 1: "I had to do the final check to make sure the transmitter was going to work ... there was a special cover in the nose cone, so I reached inside, checked the 'beep..beep..beep' signal and knew everything was alright... Then the cone was sealed for the last time."

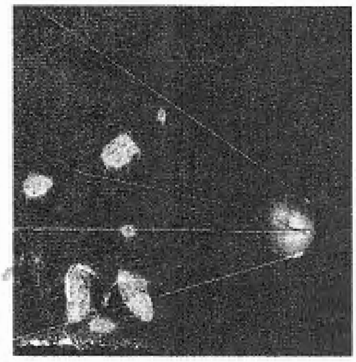

Fig. 2 Sputnik 1 with two shorter antennae for 40.002 MHz and two longer antennae for 20.005 MHz frequencies, campaigned vigorously by K.I. Gringauz.

There had been some debate as to whether or not the decameter ($f \approx 20$ MHz, $\lambda \approx 15$ m) transmissions would be easily detectable through the ionosphere. The upper panel of Fig. 3 illustrates generally correct idea that radio waves with frequencies less than the ionosphere critical frequency $f\ cos^2\varphi < f_{cr}$ will be reflected off the ionosphere. But on the basis of his radio phase experiments with geophysical rockets Gringauz was confident that inhomogeneity of the ionosphere would enable the radio signal to penetrate to the ground (lower panel of Fig. 3), and his judgment was confirmed as correct, with the receiving distance being as much as 10,000 km. The transmissions continued for three weeks and were used to monitor the pressure and temperature within the orbiter.

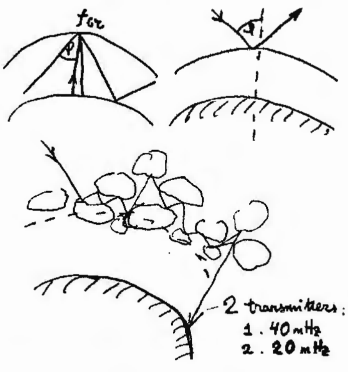

Fig. 3 Sketch prepared by K.I. Gringauz to illustrate different arguments in favor of reflection/ transmission of decameter radio waves through the ionosphere.

Sputnik 3, which weighed 1327 kg, was launched on 15 May, 1958, with 12 scientific instruments aboard. A quite different type of experiment was prepared by Gringauz and his group on this occasion, namely a spherical ion trap to make in situ ion density measurements in the upper ionosphere. In all, some 10,000 retardation spectra were measured, thus supporting their previous rocket measurements of relatively high (~ 10^5 cm^{-3}) charged particle density well above the maximum of the F-layer.

The ion trap technique was further developed for the first interplanetary spacecraft Luna 1 (launched on 2 January, 1959), using for the first time, a suppressing grid (Fig.. 4, $\varphi_{g1} \approx -200$ V) to suppress photoelectrons. Similar grids were used afterwards in a large number of space plasma measurements being the key element of various Faraday cups and providing about two orders of magnitude reduction of the parasitic current due to photoelectrons. Additional modifications were made for Lunas 2 and 3 and Venera 1 (launched on 12 September 1959, 14 October 1959, and 1 February 1961, respectively). The outer grid voltages of four ion traps on Lunas 1 and 2 were fixed as φ_{g2} = +15, 0, - 5, and -10 V, ranged between +25 and -19 V on Luna 3, and fixed as +50 and 0 V on Venera 1 (two traps). The ion traps of Luna 2 (Fig. 5) looked in tetrahedral directions thus all four sensors could not be illuminated in the same time aboard the spacecraft rotating with uncontrolled attitude. By present-day standards these were very simple instruments indeed but they nevertheless lead to some remarkable discoveries, notably the solar wind, the plasmasphere and plasmapause, and the inner plasma sheet and magnetosheath plasmas.

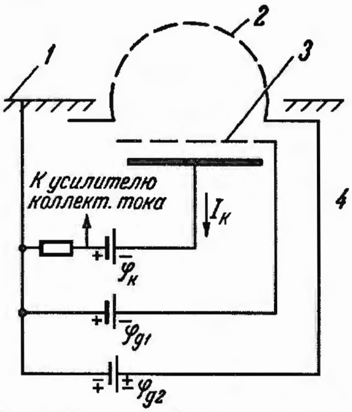

Fig. 4 Schematics of ion traps with three electrodes: 1 – spacecraft surface, 2 – external grid, 3 – suppressor grid, 4 – collector. Russian 'К усилителю коллект. тока' in original publication corresponds to 'to the amplifier of the collector current' I_K.

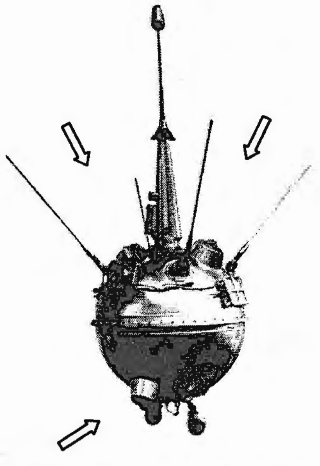

Fig. 5 Luna 2 spacecraft was the first to reach another body in the solar system. K.I Gringauz's ion traps are marked by arrows.

The solar wind, then termed the "solar corpuscular radiation", was directly observed in interplanetary space for the first time by Lunas 2 and 3 in 1959 and by

Venera 1 in 1960. Approximately equal positive collector currents in all of four ion traps of Luna 2 (Fig. 6b) permitted to evaluate total solar wind ion flux as $2 \cdot 10^8$ cm^{-2}s^{-1}. The voltages chosen were such that it was not possible to measure the energy of the particles concerned. The sunward-directed ion traps of Venera 1 proved that ions were coming from the solar direction and in one case increased solar wind flux was followed by a geomagnetic storm. Measured solar wind fluxes were 2-3 orders of magnitude lower than had been considered likely on the basis of models of the behavior of comet tails and of the interplanetary medium under discussion at that time. These results were first published in 1960 and were presented at COSPAR meetings in Florence (1961) and Washington (1962). Table 1 summarizes the results of initial solar wind measurements, confirming correctness of Gringauz's first observations.

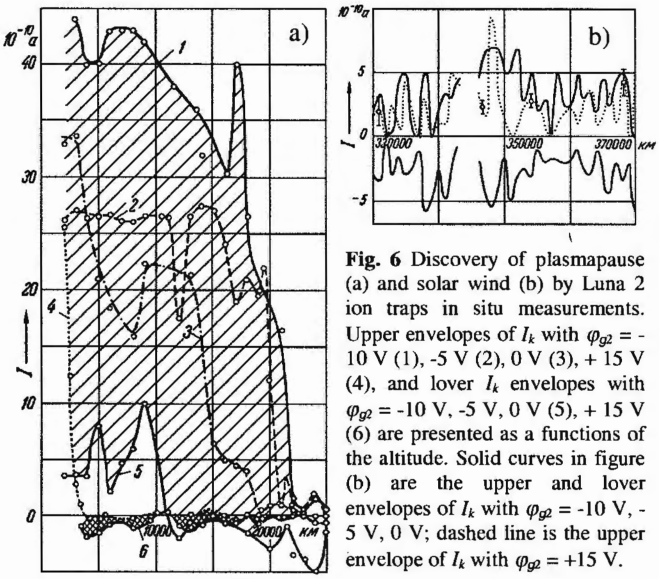

Fig. 6 Discovery of plasmapause (a) and solar wind (b) by Luna 2 ion traps in situ measurements. Upper envelopes of I_k with φ_{g2} = -10 V (1), -5 V (2), 0 V (3), + 15 V (4), and lover I_k envelopes with φ_{g2} = -10 V, -5 V, 0 V (5), + 15 V (6) are presented as a functions of the altitude. Solid curves in figure (b) are the upper and lover envelopes of I_k with φ_{g2} = -10 V, -5 V, 0 V; dashed line is the upper envelope of I_k with φ_{g2} = +15 V.

Table 1.

Spacecraft	Country	Data	Ion flux, cm^{-2}s^{-1}
Luna 2	USSR	1959	2×10^8
Luna 3	USSR	1959	4×10^8
Venera 1	USSR	1961	1×10^9
Explorer 10	USA	1961	3×10^8
Mariner 2	USA	1962	2×10^8
Mars 1	USSR	1962-63	1×10^9
Explorer 18 (IMP 1)	USA	1963-64	1×10^9
Zond 2	USSR	1964	3×10^7-5×10^8
Mariner 4	USA	1964-65	3×10^7-2.5×10^9
Venera 3	USSR	1965-66	1.5×10^8-2×10^9
Pioneer 6	USA	1965-66	2×10^8-1×10^9

The extended plasma envelope of the Earth was detected originally by Storey by means of whistler observations. The first *in situ* measurements in this region were made by the ion traps of Gringauz and his group in 1959 which showed the existence of a plasma with temperatures not greater than some tens of thousands of degrees at altitudes up to ~20,000 km. What was discovered was a sharp negative gradient of collector currents I_k (Fig. 6a) and the (inferred) ion density at about 4 Earth radii, the existence of which Gringauz, in his paper given at the 1961 COSPAR meeting, emphasized as being "beyond doubt." The existence of this boundary, now referred as the plasmapause, that bounds the cold Earth's plasma region – the plasmasphere, was soon confirmed by Carpenter, again using whistler techniques. In fact Gringauz had difficulty in convincing some of his Soviet colleagues in the validity of the observations, especially later when the U.S. satellite Explorer 12 showed no such effect; however, it was clear that the instrument concerned in this case was not functioning properly (due to its sensitivity to solar UV) although this was not known in the Soviet Union at the time. More details of the history of plasmapause discovery were presented by both Gringauz and Carpenter in the monograph by J. Lemaire et al. "The Earth's Plasmasphere" (Cambridge University Press, 1998).

Early counter measurements in radiation belts, which had been discovered by Van Allen and by Vernov, suggested that the flux of energetic electrons in the outer radiation belt might be as high as 10^{10} - 10^{11} cm^{-2}s^{-1}. But negative collector currents with φ_{g2} = +15 measured by Luna 2 ion traps (Fig. 6a) were less than ~ 10^{-10} A at altitudes less than 22,000 km. Since the traps responded to particles of any energy above that defined by the retarding potential, the electron fluxes were certainly less than $2 \cdot 10^7$ cm^{-2}s^{-1}, a result which was first published in 1960 and presented at the COSPAR meeting in Washington in 1962. The controversy was resolved later by Brian O'Brien and was connected with the fact that radiation belt electrons have relativistic energies rather than ~ 20 keV originally assumed (corresponding to expected auroral particles) and produced multiple counts in energetic particle counters.

The ion trap experiment of the Luna 2 spacecraft made also the first observations of the plasma sheet, at the time called the "third radiation belt." In the region 10 - 14 Earth radii in the anti-solar direction, negative currents were measured in all four traps indicating the presence of electron fluxes of the order of $(2 - 4) \cdot 10^8$ cm^{-2} s^{-1}. Since there was no corresponding response in the energetic particle detectors it was deduced that the electrons were relatively soft (< 20 keV). This result was reported at the COSPAR meeting in Florence in 1961. Similar results were reported from the Venera 1 spacecraft, which, in contrast to Luna 2, exited the magnetosphere on the sunward side. In a paper published in 1961 with I.S. Shklovskii as co-author it was noted that a bow shock in the supersonic solar wind might be the cause but that the particles seemed to be the same as those observed on the night side so that the term "third radiation belt" was appropriate. In fact we now know that two independent phenomena are involved, namely the plasma sheet on the night side of the Earth and the magnetosheath on the dayside, both being rather similar in terms of soft electron fluxes.

In recognition of his pioneering works in space plasma studies Gringauz was awarded in 1960 the Lenin Prize, then the highest in the USSR. In 1959 he moved with his group to the Radiotechnical Institute of the USSR Academy of Sciences and took a position as a head of the space research department. This was transformed in 1971 into the laboratory for interplanetary and near-planetary plasma studies of the newly organized Space Research Institute of the Russian Academy of Sciences. He received a professorship in radiophysics in 1970.

In the decade 1961 to 1971 Gringauz was involved in experiments on a number of spacecraft, including the Venus missions Veneras 4 and 6, and on the first lunar orbiter Luna 4. Experiments of his group aboard Cosmos 2 (1962) orbiter provided evidence of the lack of charged particle thermodynamic equilibrium in the Earth's ionosphere while Luna 4 (1964) experiments proved the existence of the geomagnetic tail downstream to lunar orbit. The bow shock associated with Venus was discovered by Venera 4 on October 18, 1967, just one day before it was detected by Mariner 5 and confirmed in 1969 by Venera 6.

10

Many different ionospheric experiments were completed by Gringauz's group in the next decade aboard Cosmos 378, Intercosmos 2, 8, 10, 12, 14, 18, 19, and Cosmos 900 Earth's orbiters. Though providing global coverage, plasma measurements aboard orbiters can hardly be interpreted in terms of local ionosphere vertical profiles, especially useful for theoretical analysis. These vertical profiles of different physical properties of ionospheric plasma were measured by Gringauz's group during series of Vertical 1 – 5, 7, 10 geophysical rocket launches up to 1500 km altitudes. The first Venus orbiters, Veneras 9 and 10 (1975), provided a further opportunity to examine the plasma environment of the planet. The plasma and magnetic field experiments aboard Venera 9, 10 discovered the magnetotail of Venus while multiple crossings of the planetary bow shock permitted the position of this boundary to be determined in the period of solar activity minimum.

Especially interesting results were deduced from the measurements of electron plasma component by Gringauz's PL 42 retarding potential analyzers in the shadow of Venus. The nighttime ionosphere of this planet was found in 1967 by Mariner 5 radio-occultation, but its source was not understood for a long time. Direct measurements of electron spectra at altitudes of 1500-2000 km revealed the existence of intense ~ 10^8 cm^{-2} s^{-1} electron fluxes with energies exceeding several tens of eV (Fig. 7a). Taking into account that these electrons can ionize neutral atoms of the nighttime atmosphere, Gringauz et al. evaluated the resultant equilibrium electron density profile $n_e(h)$. Correlation of the calculated $n_e(h)$ profiles with results of almost simultaneous radio-occultations (Fig. 7c) led them to the discovery of the ionization source of the Venusian nighttime ionosphere and pushed them to correct available models of its nighttime atmosphere (curves 1,2 in Fig.7b) by about two orders of magnitude (line 3 in Fig.7b). Subsequent in situ PVO measurements confirmed both that magnetotail electrons really reach ionospheric heights, and that the planetary nighttime atmosphere is much less dense (curve 4 in Fig.7b) than was assumed before.

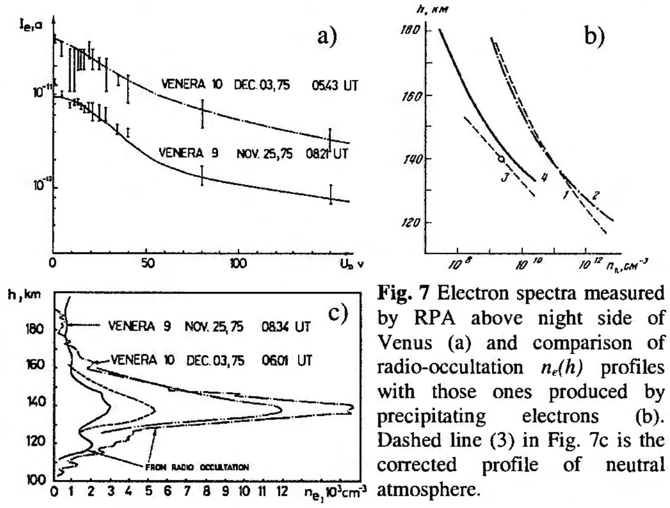

Fig. 7 Electron spectra measured by RPA above night side of Venus (a) and comparison of radio-occultation $n_e(h)$ profiles with those ones produced by precipitating electrons (b). Dashed line (3) in Fig. 7c is the corrected profile of neutral atmosphere.

Also in the seventies Gringauz used his chance to participate in the discovery of the Martian magnetosphere from the first Martian orbiters. The bow shock crossing was clearly seen in the data of his modulational Faraday cups (for ions) and retarding potential analyzers (for electrons). The position of this boundary as measured by Mars 2,3 (1971) and Mars 5 (1974) is presented in Fig. 8. Before these measurements Martian bow shock was touched only ones by Mariner 4 (1965). Different structures in the near-Martian plasma – magnetosheath, magnetopause, magnetotail, boundary layer, were generally described after Mars 2, 3, 5 measurements. All these structures were found later in Phobos 2 (1989) plasma and magnetic field measurements, though a proper understanding of physical processes prevai-ling in the formation of the Martian magnetosphere (and, hence, terminology used for its description) is not well established.

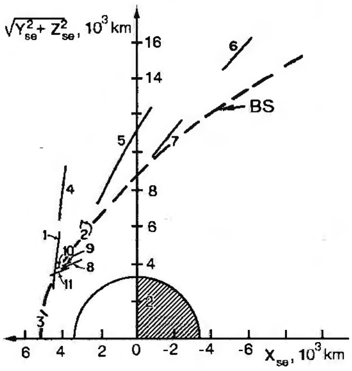

Fig. 8 Martian bow shock (BS) crossings by Mars 2: 1 - 17.02.71, 2 - 08.01.72, 3 - 12.05.72; Mars3: 4 - 15.12.71, 5 - 09.01.72, 6 - 21.01.72, 7 - 21.01.72; and Mars 5: 8 13.02.74, 9 - 20.02.74, 10 - 22.02.74, 11 - 24.02.74.

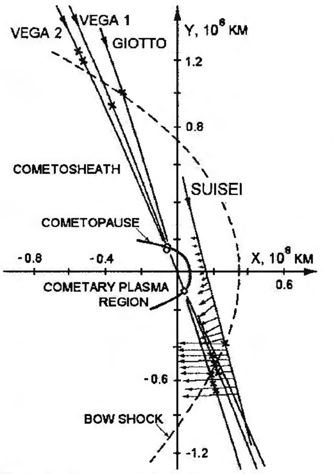

Fig. 9 Spacecraft trajectories near Halley's comet and locations of the *mass-loading bow shock* (crosses), *cometopause* (circles), *cometosheath*, and *cometary plasma region* as identified from plasma in-situ observations.

Perhaps the crowning achievement of Gringauz's career was the design and implementation of the robust and self-confident Plasmag experimental package on the two Soviet probes to Halley's comet, Vega 1, 2 (1986, Fig. 9). The ram-direction Faraday cup of this package was used to determine the neutral gas density profile

$n_n(r)$ of cometary coma. Those first in situ measurements in Fig. 10 were presented to the scientific community meeting in IKI on the day after the Vega 1 flyby and are the most distant neutral gas measurements in all cometary missions. These observations, together with revealed solar wind deceleration due to pick-up of ions of cometary origin, were shown to be consistent with a total outflow of ≈ $1.3 \cdot 10^{30}$ molecules/s ≈ 40 tons/s. Though the existence of the unique cometary mass-loading bow shock (Fig. 9) was predicted by the theory, it was observed for the first time by the Plasmag instrument. Closer to the cometary nucleus, in the cometosheath, an unpredicted distinct transition to a slow-moving dense plasma was observed (the cometopause), within which in the cometary plasma region it was possible to obtain a mass spectrum on the assumption that the ions were singly charged (Fig. 11). The ions detected by the ram direction electrostatic analyzer of Plasmag package were atomic and molecular hydrogen, carbon, the water, carbon monoxide and carbon dioxide groups and heavier species with masses around 60, 70 and 85. By exploiting the solar and ram direction Faraday cups, evidence for magnetic reconnection and plasma acceleration was found in the vicinity of a field reversal.

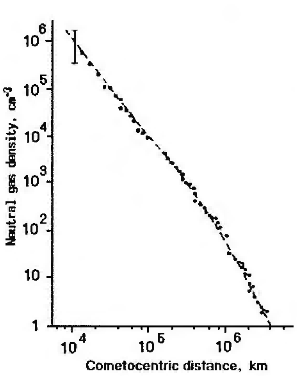

Fig. 10 Neutral gas density profile determined from Vega 1 Plasmag measurements on March 6, 1986. Dashed line – theoretical model.

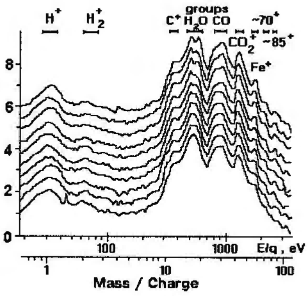

Fig. 11 *First in situ measurements of cometary ion* energy/charge (mass/ charge) *spectra* at cometocentric distance of (1.4 - 1.7)·10^4 km.

In 1986, following the success of the Vega missions, Gringauz was awarded the State Prize of the USSR in recognition of his scientific achievements. In 1988 he received the COSPAR Award for outstanding contributions to space research made during his 40 years involvement in the field.

The last space experiments TAUS, HARP, and SLED in which Gringauz actively participated (during the Phobos 2 mission) led also to a number of new findings. In addition to the plasma structures revealed by Mars 2,3,5 orbiters the plasma sheet in the Martian magnetotail was discovered by the TAUS team (Fig. 12). The observations demonstrated that the plasma sheet in the Martian magnetotail surrounded the magnetic neutral sheet, similar to the plasma sheet in the geomagnetic tail. However in contrast to the case of the Earth the Martian plasma sheet mainly consisted of planetary heavy ions (m/q >3). 2-D ion spectra measured by TAUS demonstrated a supersonic, highly anisotropic ion distribution function in this region. Detailed statistical considerations permitted an evaluation of the loss rate of planetary oxygen through the plasmasheet as ~ 150 g s^{-1}. TAUS measurements also revealed the deceleration of the solar wind upstream of the Martian bow shock. An analysis of this deceleration permitted a determination of the height profile of the planetary neutral gas corona and of the upper limit of the Martian atmosphere loss rate as < 2.5 kg s^{-1}. If this rate were permanent, the present planetary atmosphere would be dissipated in ~ $3 \cdot 10^8$ years and, therefore, loss of the neutral gas through the corona is important in the evolution of the Martian atmosphere. An analysis of electron spectra measured by HARP in the plasmasheet and magnetotail lobes led to the conclusion that these electrons can be considered as the source of the ionization in Martian nighttime atmosphere.

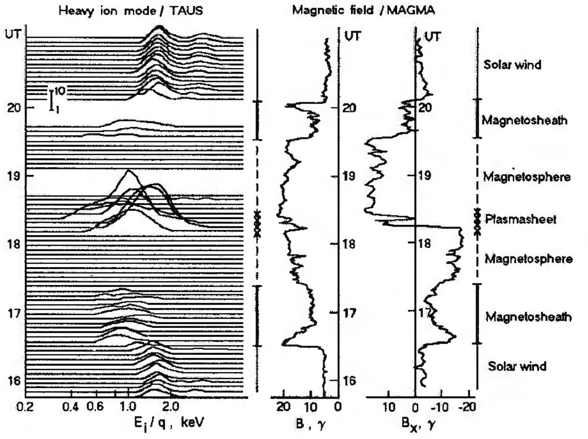

Fig. 12 Spectra of ions as measured by TAUS on March 16, 1989 and magnetic field value B and B_x component by MAGMA measurements.

4 Concluding remarks

Konstantin Gringauz collaborated widely in his scientific activity. Most of the sensors for the experiments of his group were developed, produced, and tested together with the Moscow Institute for Vacuum Technology. Electronics for space experiments were built originally in-house and than for the Prognoz, Mars 2, -3, -5, Venera 9, -10 missions together with the Odessa Politechnical Institute. International collaboration began with the Intercosmos 2 orbiter with scientists from East Germany, Bulgaria, and Csehoslovakia participating originally on the data analysis stage. These countries together with Poland and Hungary were involved afterward in the space hardware development for other Intercosmos and Vertical missions. In the course of preparations for the Vega mission Gringauz developed a close relationship with members of the Max-Planck Institut für Aeronomie in Lindau and later, in connection with the Phobos missions, also with scientists from Ireland, Austria, Belgium and USA.

Konstantin Gringauz was active in COSPAR from 1961 onwards and was most recently co-Chairman of Interdisciplinary Space Plasma Scientific Commission. For a long time he was a Chairman of the Solar Wind and

Interplanetary Magnetic Field section of IAGA. He was an initiator and a Chairman of the Solar Wind and Interplanetary Magnetic Field Section of the Russian Geophysical Committee, and a member of the Editorial Board of the international scientific magazine Il Nuovo Cimento. He was elected as a Member of the International Academy of Astronautics and participated in the activity of the Russian Association of the Members of this Academy. His outlook was always positive and friendly, even during the more difficult periods of the cold war.

Konstantin Gringauz was an intense, enthusiastic and well-read person, with interests in music, art, literature, history and especially politics. It is characteristic of him that in 1988, during the gradual reforms that were taking place in the Soviet Union, he published a telling criticism of the Soviet space program in a leading newspaper 'Pravda', the first occasion on which this had happened. He maintained his scientific activities to the very end of his life as co-principal investigator of an experiment being prepared for the scheduled Mars-96 mission. His death occurred on 10 June, 1993, as a result of a heart attack, shortly before his 75th birthday.

Table 2 briefly summarizes the milestones of the carrier of Professor Konstantin Iosifovich Gringauz. He married Irina Nikolaevna Danilova in 1954 and she survives him, together with their daughter Tatiana and granddaughter Masha.

Table 2.

1918, July 5	Born in Tula, Russia
1921	Moved to Samara on the Volga river where attended school, became radio amateur
1935	Enrolled educational Electrotechnical Institute, St.-Petersburg
1941	Diploma in frequency modulation, then a brand new topic; continued to work in Radiotechnical Laboratory (since 1940)
1942	Winter – evacuated to Moscow from city blockaded by Germans Summer – work in Belovo city, Siberia, on production of tank radio transmitters and receivers
1944	Studies of effectiveness of tank radio communications in battlefield conditions, Poland Passed entry exams for postgraduate studies
1945	Position in classified institute Postgraduate studies of radio wave propagation in the ionosphere
1947	Beginning of collaboration with Sergei Korolev
1948	Participating in launching V2 rocket with radio sounder
1949	Gained his Ph.D., in charge of laboratory for radio technology
1952-1958	Ionospheric measurements by UHF waves transmitted from Geophysical rockets First information on the slow decrease of electron density above F_2 layer
1957	Participation in the launching of the first Sputnic (in charge of 'beep-beep' transmitter)
1958	First in-situ studies of the upper ionosphere and its irregularities from Sputnic 3 geophysical observatory
1959-1960	Participation in research aboard the Luna 1-3 spacecraft Discovery of the Earth's plasmasphere Correction of estimations of particle flux in the Van Allen belts First observations of the Solar Wind
1960	Awarded Lenin Prize (highest in USSR).
1962 1966	Plasma experiments aboard Cosmos 2; evidence of the lack of charged particles thermodynamic equilibrium in the ionosphere.
~~1964~~	Experiments aboard the first Moon orbiter Luna 4; evidence of geomagnetic tail existence downstream at lunar orbit
1967-1976	Plasma experiments aboard Venera 4,6 landers and the first Venusian Venera 9,10 orbiters Discovery of origin of the nighttime ionosphere of Venus
1970-1979	Ionospheric experiments aboard Cosmos 378, Intercosmos 2, 8, 10, 12, 14, 18, 19 and Cosmos 900
1970-1981	Series of in-situ plasma experiments aboard Vertical 1-5, 7, 10 rockets
1971-1973	Participation in the discovery of the Martian magnetosphere from the first Martian orbiters Mars 2, 3, 5
1972-1984	Solar wind and magnetosphere plasma experiments aboard high apogee Prognoz 1-7, 9 orbiters
1982-1986	Design and implementation of plasma experiments aboard the Halley's comet probes Vega 1, 2 Discovery of previously unknown cometary plasma structures - the "cometosheath" and "cometopause"
1986	Award of State Prize of USSR for scientific achievements
1988	Experiments aboard Phobos 2 mission Authorship of paper with first public criticism of the Soviet space program COSPAR award for outstanding contribution to space research
1989-1993, June 10	Continuation of the analysis of Vega and Phobos mission results Preparation of experiments for the Mars 96 mission.