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THE CONTRIBUTION OF K. I. GRINGAUZ TO SPACE RESEARCH†

M. I. VERIGIN and G. A. KOTOVA
Space Research Institute, Moscow, Russia

and

W. I. AXFORD
Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany

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Abstract—The pioneering work of K.I. Gringauz in connection with the early Soviet interplanetary missions is recalled. This outstanding scientist received the Lenin Prize in 1960, the State Prize of the USSR in 1986 and the COSPAR Award in 1988. Copyright © 1997 Elsevier Science Ltd

Konstantin Iosifovich Gringauz was born on 5 July 1918. As a boy he was an enthusiastic radio amateur and on finishing school, enrolled in the Electrotechnical Institute in Leningrad (St. Petersburg) from which he received his Diploma, specializing in frequency modulation, in 1941. He continued his work in the Radiotechnical Laboratory but in the first winter of the great siege of Leningrad was evacuated to Moscow. In the following summer he was moved to Belovo, Siberia, where he worked on the production of transmitters and receivers for tanks. In 1944 he was in Poland carrying out studies of the effectiveness of radio communications under battlefield conditions.

In 1944 Gringauz became involved in studies of radio-wave propagation in the ionosphere. In 1947 he moved to a laboratory for radio-wave propagation in the newly established rocket development organization of Korolev and in the following year participated in an experiment using a radio sounder on a V2 rocket. Gringauz was put in charge of a laboratory for radio technology. This led to a series of experiments, first using modified V2 rockets and later using Soviet rockets, in which phase-locked transmissions at 24 or 48 MHz and 144 MHz were used to measure the electron density profile in the Earth's ionosphere. The first measurements on 26 June 1954, reached an altitude of only 108 km but showed clearly the presence of a sporadic E layer at 102 km. A series of three measurements to altitudes of $\sim$200 km was made on 16 May, 25 August and 9 September 1957, again showing sporadic E layers in two cases and in these cases also a general increase of the electron density to apogee. Finally, with rockets 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 the current ideas, the electron density did not decrease rapidly above the F layer maximum.

During this period Gringauz and his group were engaged in the preparation of experiments for the first Soviet spacecraft then being developed in Korolev's Institute. He was very proud to have provided the famous transmitters on Sputnik 1 which made a triumphant announcement to the world following the successful launch of 4 October 1957. In particular he liked to tell that he was the last to touch the Sputnik: "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 all right... then the cone was sealed for the last time." There had been some debate as to whether or not the 20 and 40 MHz transmissions would be easily detectable through the ionosphere but Gringauz was confident that this would be the case, 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 conditions within the spacecraft.

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 ion density measurements in the upper atmosphere. In all some 10,000 retardation spectra were measured, and it was shown that there were relatively high ($\sim 10^5$ cm^{-3}) densities well above the maximum of the F-layer.

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The ion trap technique was further developed for the first interplanetary spacecraft Luna 1, using for the first time a grid (at ~ + 200 volts) to suppress photo-electrons. Additional modifications were made for Lunas 2 and 3 and Venera 1. The outer grid voltages were + 15, 0, -5 and -10 V on Lunas 1 and 2, ranged between + 25 and -19 V on Luna 3 and + 50 and 0 V on Venera 1. Multiple traps were used: four, each with different look directions, in the case of the three Lunas and two, looking in the solar direction, in the case of Venera 1. 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.

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. The voltages chosen were such that it was not possible to measure the energy of the particles concerned, only the ion flux above 15, 25, 50 eV respectively. It was found that the ion flux was of the order of 2×10^8–1×10^9 cm^{-2}s^{-1}, that the particles were coming from the solar direction and that in one case high solar wind flux was followed by a geomagnetic storm. The fluxes measured were substantially 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).

The extended plasma envelope of the Earth was discovered originally by Storey by means of whistler observations. The first *in situ* measurements were made by the ion traps of Gringauz and his group on Luna 2 in 1959 which showed the existence of a plasma with temperatures not greater than some tens of thousands of degrees at distances of up to four Earth radii. What was significant was a sharp negative gradient of detector current and inferred ion density observed at about 4 Earth radii, the existence of which Gringauz, in his paper given at the 1961 COSPAR meeting, emphasized as being "beyond doubt". This result referred to the plasmapause which was almost contemporaneously and independently discovered by Carpenter, again using whistler techniques. In fact Gringauz had difficulty in convincing some of his Soviet colleagues of 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.

Since the ion traps were current-measuring devices, they responded to particles of any energy above that defined by the retarding potential. Thus it was possible to check inferences based on early counter measurements which suggested that the flux of energetic electrons in the outer radiation belt might be as high as 10^{11} cm^{-2}s^{-1}. The traps showed that the electron fluxes were certainly less than 2×10^7 cm^{-2}s^{-1}, a result which was first published in 1960 and presented at the COSPAR meeting in Washington in 1962. It is possible to infer on this basis that the electrons concerned had relativistic energies rather than the ~ 20 keV originally assumed (corresponding to expected auroral particles).

The ion trap experiment on the Luna 2 spacecraft was particularly successful in that it also made 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 $\times 10^8$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 first Venus mission in 1961 which, in contrast to Luna 2, exited the magnetosphere on the sunward side. In a paper published in 1961 with Shklovskii as co-author it was noted that a bow shock in the supersonic solar wind might be the cause but 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 rather similar in terms of soft electron fluxes.

In the decade 1961 to 1971 Gringauz was involved in experiments on a number of interplanetary spacecraft, including the Venus missions Veneras 4 and 6, and on the first lunar orbiter. The bow shock associated with Venus was discovered from Venera 4 on October 18 1967, just one day before it was detected by Mariner 5 and confirmed in 1969 by Venera 6. The first Venus orbiters, Veneras 9 and 10, provided a further opportunity to examine the plasma environment of the planet and it was shown that there is a night-time source of ionospheric plasma.

In 1971–1974, with Faraday cups (for ions) and retarding potential analyses (for electrons) on the spacecraft Mars 2, 3 and 5 Gringauz participated in the discovery of the Martian bow shock and a possible magnetosphere. The bow shock was clearly seen in the electron data and also in the field strength determined by the magnetometer. This was confirmed by means of the plasma spectrometer TAUS carried on Phobos mission in 1989 which also showed the existence of moderately energetic (– 1 keV) heavy ions in the plasma sheet around the magnetic field reversal in the magnetotail of the planet.

Perhaps the crowning achievement of Gringauz's career was the design and implementation of the complex Plasmag experimental packages on the two Soviet probes to Halley's comet, Vegas 1 and 2. These showed the presence of the bow shock followed by the expected slow decrease in the solar wind speed associated with ion pick-up. The ram-direction Faraday cup was used to determine the neutral gas density profile and this together with solar wind speed variation, was shown to be consistent with a total outflow of 1.3×10^{30} molecules/s. Closer to the cometary nucleus, a distinct transition to a slow moving dense plasma was observed (the "cometopause") within which it was possible to obtain a mass spectrum on the assumption that the ions were singly charged. The ions detected 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. Soft electron fluxes were found close to the comet suggesting the existence of a heating process perhaps associated with the pick-up effect.

As a result of his pioneering work in connection with the early Soviet interplanetary missions, Gringauz was awarded the Lenin Prize in 1960. In 1986, following the success of the Vega missions, he was awarded the State Prize of the U.S.S.R. in recognition of his scientific achievements. In 1988 he received the COSPAR Award for outstanding contributions to space research made for his 40 years' involvement in the field.

Konstantin Gringauz was active in COSPAR from 1961 onwards and was most recently co-Chairman of Commission D. He collaborated widely, beginning with scientists from Bulgaria, Poland and Hungary. In the course of preparation for the Vega mission he 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 Michigan. He maintained his scientific activities to the very end of his life as co-principal investigator of an experiment being prepared for the future Mars-96 mission.