THE ORIGIN OF COSMIC RAYS (INTRODUCTORY REMARKS)

V.L. Ginzburg,
P.N. Lebedev Physical Institute,
Academy of Science of the USSR, Moscow.

The field of study, which by tradition is still called 'the problem of cosmic ray origin', is now at a watershed, at a turning point. For this reason the time chosen for the present Symposium is especially suited.

The above thesis needs to be confirmed and elaborated. To this end it will not be out of place first to dwell briefly upon the history of cosmic ray studies.[x)]

1912: the discovery of cosmic rays. As a matter of fact, the "dark" current in ionization chambers was studied even earlier but it seems correct to associate the actual discovery of cosmic rays with the flights of V. Hess. If a precise date of the discovery of cosmic rays is needed, August 7th, 1912, when Hess undertook his most successful flight, is suited best of all.
1927 (approximately): the extraterrestrial origin of cosmic rays became accepted (it was supposed earlier that the observed ionization might result from the presence of radioactive elements in higher atmospheric layers). First indications of the fact that cosmic rays are not a hard γ-radiation appeared. Specifically, the geomagnetic effect and the existence of high-energy charged particles in the atmosphere were revealed which indicated the corpuscular nature of cosmic rays.
1936 (approximately): the existence of the geomagnetic effect and, therefore, the fact that primary cosmic rays are high-energy charged particles was no longer in doubt.
1939-41: primary cosmic rays were proved to be for the most part protons. Such a conclusion was drawn from the results of measurement of the East-West asymmetry and from the study of primary particles using balloons.
1948: nuclei of some elements were discovered amongst the primary cosmic rays. By 1950 these data obtained with balloons (mainly with the aid of emulsions) had been confirmed and enlarged.

So, it was only in 1950 that the composition of primary cosmic

G. Setti, G. Spada, and A. W. Wolfendale (eds.), Origin of Cosmic Rays, 1–6.

https://doi.org/10.1017/S0074180900074301 Published online by Cambridge University Press

rays became clear in the first approximation (for the electron flux only an upper limit was determined, which was of the order of one per cent of the total flux). A number of papers also appeared anticipating the further development of cosmic ray astrophysics (1934 Baade and Zwicky - a hypothesis on cosmic ray acceleration in supernova flares; 1949, Fermi - a statistical acceleration, the role of the interstellar magnetic field). Nevertheless, cosmic rays remained an object of secondary importance in astrophysics and for astrophysics. This is quite clear since there existed data on cosmic rays near the Earth only, and a high degree of cosmic ray isotropy did not permit the acquisition of observational data on their sources.

1950-53: emergence of 'cosmic ray astrophysics'. The scope of cosmic ray astrophysics I understand to be just the range of questions to which the present symposium is devoted. True, a more general name, "high-energy astrophysics" is used when one has in mind also gamma-astronomy and cosmic high-energy neutrino astronomy. It would be reasonable to understand the problem of cosmic ray origin only as the one concerning the origin of cosmic rays observed near the Earth.

What happened in 1950-53 consisted, in fact, in the establishment of the role of the synchrotron mechanism of electromagnetic wave radiation in space and, therefore, in establishing a connection between cosmic rays (or, more precisely, their electron component) and a certain considerable part of cosmic radioemission, and in some cases also, optical radiation. As a result the study of cosmic rays embraced the whole of our Galaxy and the Metagalaxy. Cosmic rays proved to be a Universal phenomenon and an exclusively important source of astronomical information. At the same time an energetic and a dynamical role of cosmic rays in supernova remnants, in the interstellar space and in radiogalaxies is very significant.[y)]

By the fifties the model of the cosmic ray origin which seemed then most probable, namely, the galactic halo model had already been discussed in detail (3-5). However, to prove this model it was necessary to make sure, firstly, that the cosmic ray energy density outside the Galaxy $W(CR,Mg)$ was much less than $W(CR,G)$ where $W(R,G) \simeq 10^{12}$ erg/cm^3 is the energy density of cosmic rays in the Galaxy (by 'Galaxy' we mean the volume $V \simeq 10^{68}$ cm^3, which corresponds to a quasi-spherical or to a somewhat flattened "cosmic ray halo" with characteristic dimension $R \simeq 3.10^{22}$ cm). The condition $W(CR,Mg) \ll W(CR,G)$ implies, evidently, that not a single metagalactic model of the origin of the major part of cosmic rays observed near the Earth is valid. Secondly- the existence of the cosmic ray halo would follow from the proof of the existence of a radio halo (when moving away from the galactic plane, the relativistic electrons responsible for the radiohalo lose their energy and the magnetic field strength may also decrease considerably; from this it is clear that the dimensions of the halo of cosmic rays, for the most part protons, may substantially exceed the dimensions of a somewhat bright radio halo).

To disprove convincingly the metagalactic model and to prove the existence of the halo turned out, unfortunately, to be a very difficult task and took almost a quarter of a century. But I am sure that now the work is done mainly owing to gamma-astronomical observations in the direction of the galactic anti-centre (which supports Galactic but not Metagalactic models) (ref. 6) and to astronomical studies of edge-on galaxies NGC 4631, NGC 891 and others, which have halos, and also to the observation of a radio halo in the Galaxy itself. One may hope that all the corresponding data obtained during the last few years will be presented at this Symposium. In any case, I cannot dwell upon this material now (see refs. 7-10 and the literature cited there).

I cannot guarantee, however, that everybody will agree with the statement on the existence of a convincing proof of the validity of the halo model (in the above-mentioned sense); to discuss this problem is one of our goals. But if one agrees with what has been said, an important phase in the study of the cosmic ray origin is already concluded. The opinion expressed in the beginning as to what concerns the turning point in the development of cosmic ray astrophysics should be understood in just this sense.

As has been said, this branch of astronomy is about 30 years old (one can say differently, subject to one's attitude: 'only 30 years' or 'already 30 years'). Everybody, evidently, realizes how much restricted we are in our possibility to glance into the future. However, it is natural and even necessary to think of what will become of high-energy astrophysics, say, by the beginning of the XXI'st century, or even by 2012 - a centenary of cosmic rays.

It is, of course, hardly possible to make a reliable prognosis and I for one do not claim this. Therefore, I shall restrict myself to enumeration, in the order of discussion, of some key problems and branches of further investigations.

1. Equipment on satellites and high-altitude balloons will make it possible to specify considerably the data on the chemical and isotopic composition of cosmic rays at different energies. In the first place one may hope for the determination of the chemical composition at energies up to 10^{12}-10^{13}eV/nucleon and the amount of radioactive nuclei, ^{10}Be, at $\frac{E}{mc^2}$ up to 10, i.e. already in the relativistic region. We are going to determine the electron, positron and antiproton spectra with high accuracy and over a wide energy range.

2. In order that one might obtain information on cosmic rays in the sources and on cosmic ray propagation (including generation, various secondary processes, etc.) from the data on primary cosmic rays near the Earth, it is necessary to perform calculations on the basis of diffusion models (8,11,12). The role of the galactic wind (convection) should be clarified, various plasma effects should be taken into account, etc.

https://doi.org/10.1017/S0074180900074301 Published online by Cambridge University Press

3. The analysis of acceleration mechanisms is connected with what has been said above. Namely, we mean an analysis of acceleration in the explosion of a supernova itself, acceleration near pulsars and in turbulent supernova remnants, acceleration by shock waves (with account taken of diffusion) within young remnants and outside them. One of the main goals of investigations is now to clarify the role of acceleration by shock waves in young supernova remnants themselves (including their boundaries) and in interstellar space at distances up to 100 pc from the supernovae. By the way, I am inclined to think that acceleration proceeds mainly within young supernova remnants and acceleration by shock waves from supernova in interstellar space, and that acceleration connected with novae and other stars does not play an essential role (at $E \gtrsim 10^{10}$eV). However, these questions are open and it is not easy to give reliable answers to them. A possible method is the registration of radio and gamma-rays from supernovae and the surrounding regions.

4. Radioastronomical observations of edge-on galaxies will help to specify the character of electron motion in the halo. There are also certain possibilities here for the Galaxy as a result of detailed radio mapping of the sky at different frequency bands. The study of synchrotron radiation for radio galaxies, active galactic nuclei and quasars is a separate question.

5. It is possible and even very likely that in the eighties gamma astronomy will undergo the same development as did X-ray astronomy in the seventies. In any case the perspectives of galactic and extragalactic gamma astronomy are most promising.

6. As to the cosmic rays of superhigh energy, $E \gtrsim 10^{17}$eV, there exists a great vagueness. One of the possibilities is that particles with $E < 10^{19}$eV are produced mainly in the Galaxy while particles with $E > 10^{19}$eV come mostly from the Local Supercluster. To discover the origin of particles with $E>10^{17}$eV in different energy ranges one will have to undertake labour-consuming measurements of mean anisotropy and the directions of the paths of individual particles (anisotropy measurements are interesting and important also at lower energies). The problem of establishing the chemical composition of particles with $E \gtrsim 10^{7}$ is, of course, also urgent.

Besides, we should note that in the eighties, and probably even later, the maximum attainable energy with accelerators will correspond, in the laboratory system, to $E = \frac{2E_c^2}{Mc^2} \simeq 2.10^{15}$eV (colliding beams of protons with an energy $E_c = 10^{12}$eV in each beam). Therefore, at $E > 2.10^{15}$eV cosmic rays will evidently long remain the only source of particles. It is, of course, difficult to work in this region (suffice it to mention that the intensity of particles with $E > 10^{16}$eV makes up no more than 10^2 particle/km^2 ster. h.), but there still exist certain possibilities such as by studying extensive air showers at mountain altitudes.

7. Realization of the DUMAND project will permit registration of neutrinos with energy $E_o \gtrsim 10^{12}$ eV with a rather high angular resolution of about 1^o. This technique offers some exclusive opportunities, among which there is a detection of neutrinos from quasars and active galactic nuclei (10,13). Since it is only neutrinos (besides gravitational waves) that are able to penetrate deep into matter, it is high-energy neutrino astronomy that seems to offer a solution of the fundamental question of the origin of cores of quasars and active galactic nuclei (the dilemma is if the core is a black hole or a magnetoid-spinar (13)). Neutrinos from a supernova flare in the Galaxy could also be registered in the more modest under-ground installations which exist already.

Neutrino astronomy (and, in particular, high-energy neutrino astronomy), along with gravitational wave astronomy, is the last known reserve (in the sense of using essentially new channels of astronomical information). There can be no doubts as to the necessity and inevitability of the development of neutrino astronomy.

The above enumeration is, of course, rather conditional and incomplete (suffice it to mention also X-ray astronomy, the study of high-energy particles and photons from the Sun and from the magnetospheres of the Earth, Jupiter and other planets, etc.). What has been said is already enough, however, to realize the scale of work to be done. When in all the branches mentioned sufficient data are accumulated (aperiod of 20-30 years is probably enough and at the same time not too much) high-energy astrophysics will play a still more outstanding role in astronomy than it does today. Besides there is no doubt that some unexpected things are to be encountered, and this is one of the attractive features of Science. One can only envy those men who will see the astronomy of the XXIst century in all its richness.

NOTES

x) See, for example, the monograph (1) which includes as appendices a number of original papers, and also the collection of original papers (2).

y) The state of cosmic ray astrophysics as well as the history of the problem by 1958 are clear, for example, from ref. 3 and the Proceedings of the Paris Symposium (4). The situation in 1964 may become clear, I hope, from the book (5), which also contains a rather large bibliography.

REFERENCES

1. Hillas, A.M., 1972, 'Cosmic Rays', Pergamon Press.
2. Selected papers on cosmic ray origin theories. Ed. Rosen, S., Dover Publications, New York, 1969.
3. Ginzburg, V.L., 1956, Nuovo Cim. Suppl. 3, 38,; 1958, 'Progress in Elem. Particle and Cosmic Ray Physics', Amsterdam, 4, 339.
4. 'Paris Symposium on Radio Astronomy', Stanford Univ. Press, Stanford, 1959.
5. Ginzburg, V.L., and Syrovatskii, S.I., 'The Origin of Cosmic rays', Pergamon Press, 1964.
6. Dodds, D., Strong, A.W., and Wolfendale, A.W., 1975, 'Galactic γ-Rays and Cosmic Ray Origin', Mon. Not. R. astr. Soc. 171, 569-577.
7. Phil. Trans. Roy. Soc. London A277, 317, 1975.
8. Ginzburg, V.L., and Ptuskin, V.S., 1976; Rev. Mod. Phys. 48, 161, 675; 1976 Sov. Phys. Uspekhi, 18, 931.
9. Ginzburg, V.L., 1978, Sov. Phys. Uspekhi, 21, 155.
10. 16th International Cosmic Ray Conference. Conference Papers v. 1-14, Kyoto, Japan, 1979.
11. Ginzburg, V.L., Khazan, Ya. M. and Ptuskin, V.S., 1980, Astrophys. and Space Sci. 68, 295.
12. Carvalho, J.C., and Haar, D. ter., 1979, Astrophys. and Space Sci., 61, 3., Wallace, J.M., 1980, Astrophys. and Space Sci. 68, 27, Owens, A.J., and Jokipii, J.R., 1977, Astrophys. Journ. 215, 677.
13. Berezinsky, V.S., and Ginzburg, V.L., Mon. Not. R.A.S., 1980 (in the press).

The list of references is not representative and to a considerable extent must in more detail, than was possible in the text, present the speaker's opinion. I give it because I suppose a much more extensive literature will be cited in other reports.

https://doi.org/10.1017/S0074180900074301 Published online by Cambridge University Press