Part V

Towards New Concepts of Nature

Stellar Evolution and Galactic Evolution*)

—From THO theory to star-like problem—

Mituo TAKETANI

(October 1964)

The central problems of the ancient natural philosophy are still remaining the fundamental problems of the contemporary physics and they never go out of mind of the physicists. These are, for example, problems on the ultimate structure of matter asking with what those atoms and elementary particles are ultimately composed, problems on how the endless universe and those heavenly bodies were constructed and are going to evolve, and problems on the origin of life. In ancient days, the philosophers did not always neglect the reality, but they put basis of their speculation on their daily experiences and attempted to solve such fundamental problems in a single step with help of the logic and the reasoning. Such an approach towards the natural phenom ena became sciences. Really, it committed mistakes and spread contaminations in cases when their logic and reasoning was fallen into a religious dogmatism. But, on the other hand, it established a brilliant tradition such as an introduction of concept of "atom" in the Greek philosophy. What led them to a dogmatism was not their ambition to tackle with those great fundamental problems but their imagination to be able to solve the problems in a single step.

Now, in the modern physics, great successes were obtained not by a method of aiming at the immediate solution in a single step, but by the accumulated efforts of step by step approach towards the object. But, on the contrary, *too much emphasis is now placed* on technical and detailed scrutinization. As a result, there appears at present a trend to regard that the scrutinization is the essence of the natural science and a challenge to the great fundamental problems is a business for dilettantes but not for the scientific experts. Particularly after World War II, we notice a strong inclination towards the technicality. But, of course, we physicists must always investigate the problems in their most fundamental basis.

---

*) Contributed as the first paper in the special issue of the journal *Kagaku* (Science), Oct., 1964, on "Evolution of Galaxies and Origin of Cosmic Rays", and is compiled in the author's book "*Gendai-no Riron-teki Sho-mondai*" (Theoretical Problems at the Present Age) (Iwanami Co. Ltd., Tokyo, 1968).

Problems of the space-time and the matter have been investigated in the special and general relativity theory, but we are at present only at the entrance of their clarification. The gravity is the central problem of the general relativity, but almost nothing is known on relation between the gravity and the elementary particles. Recently, remarkable progress was made in the investigation of the structure of the elementary particles, but I think that it is only pointing out an entrance into a new field.

It is possible to have a view that most of the fundamental problems, such as those on the universe or on life, remain still unsolved and we are not yet clear on direction of the research. But, in another aspect, one can say that the progress in these twenty years have gradually made the problems clearer. In other words, before the war these fundamental problems were dominated by mysticisms and irrationalisms, while at the present those ideologies have been almost removed and there is a general atmosphere of expecting that the scientific efforts will ultimately be able to resolve all of the problems.

This paper concerns the collaborative study of the Japanese group, reviewing how they have been exploring one of the fundamental problems of the universe.

THO theory—1955

For reconstructing Japanese physics after World War II, I felt confident over the two, our theory of elementary particles and our study on the cosmic radiation, as its basis.

Problems of the universe have continuously been our concern since the old days. In those days, we had the following two clues to the problem, one being the analysis of cosmic-ray phenomena from a point of view of the theory of elementary particles and the other being the continuous observation of time variation of the cosmic-ray intensity, in particular the study on the effect from the solar activity, which was carried out as a routine work by Nishina's laboratory of the Institute of Physico-Chemical Research.

On the problems of origin of the elements, and how the existing elements in the universe were being created, there was a proposal called the α-β-γ theory[1] from a foreign country. According to their idea, the primordial matter was concentrated to super high density at the very beginning stage of the universe, and then it happened an explosive scattering of the matter. A main part of the present elements were considered to have been synthesized at this initial stage of the universe. Along this idea, C. Hayashi of Kyoto University, under the guidance of H. Yukawa, investigated details of their theory from a point of view of the theory of elementary particles and constructed the so-called α-β-γ-Hayashi theory.[2] Yukawa thus had a strong interest in the universe problem since those days.

In 1954, I consulted with Yukawa and made the following proposal. "In recent years we had remarkable progress in the fields of nuclear physics and theory of elementary particles. While, we should always keep in mind whether various astrophysical phenomena in the universe can be clarified by our newly obtained knowledge in physics or not. I ask now the question as to what extent will this be possible with the present progress." I proposed to the Research Institute for Fundamental Physics to organize a symposium on the above question, and it was held in February, 1955.[3] The symposium was remarkable in establishing collaboration between astronomers and physicists for the first time in Japan. At that time, S. Hayakawa was on the staff of the Institute and took care of the organization. At the symposium, J. Hitotsuyanagi of Tohoku University gave a series of elaborate lectures and the physicists put various questions to the lectures. In this way, we carried out step by step construction of our own views on how to understand various astrophysical phenomena. In addition, we were able to receive the latest information from a review on the Proceeding of the International Conference of Astronomy at Liege in 1954, by the colleagues of astronomy. Through the symposium, we were able to establish a new point of view or a new way of approach which is referred to as the THO theory.[4] Outline of the theory is described as follows. At that time, the analysis on chemical elements in stars made it possible to investigate the relative abundance in stars of hydrogen and elements heavier than carbon—the astronomers often call them metallic elements —and it was found that some stars are relatively rich in the metallic elements while others are very poor. The former group of stars was known as the population (I) and the latter as the population (II). Of course, hydrogen occupies a major part of the composition of all the stars, but the observation[5] showed the existence of the two different groups of stars with a different relative abundance of the metallic elements. We took notice of the existence of these two groups of stars and asked what is its significance in evolution of the universe.

Although it was not known to us, in 1953 before the THO theory there was the work of Schwarzshild and Spitzer,[6] in which they discussed the origin of elements in the universe with particular attention to the two populations of stars. They assumed that stars of the population II were constructed at the very initial stage of the universe and those stars synthesized heavier elements in themselves and made catastrophic explosions, spreading the synthesized matter into space, from which stars of the population I were constructed. They believed that all such processes were carried out at the initial stage of the universe. It is true, that their theory is more advanced than the α-β-γ-Hayashi theory in a certain respect.

Through our discussions at the symposium, we found that a consistent picture could not be obtained under such assumption that all the main processes occurred only in the very beginning stage of the universe. It was our point of view that such processes of element synthesis, redistribution of matter and star formation should be occurring continuously in every stage of evolution of the universe. In fact at that time there were already some proposals on the theory of the stellar evolution, but none of them were systematic. For example, there were attempts to explain the evolutionary passage of the population II stars, but no theory was comprehensive enough to include the problems concerning the population I stars. In addition, it was known that the population II stars are moving with high velocity in the so-called Galactic halo, without being confined in the Galactic disc where the population I stars are concentrated. The THO theory was proposed to cover comprehensively and consistently over all such observational data of astrophysics. Here we assume that the universe in its early stage was filled with the population II-like primordial gas of a small abundance of the metallic elements. Then, there were formed a number of gas clouds from which the stars were formed through gravitational contraction. The stars with larger mass ended their life-span in a short period, turning after the explosion back into

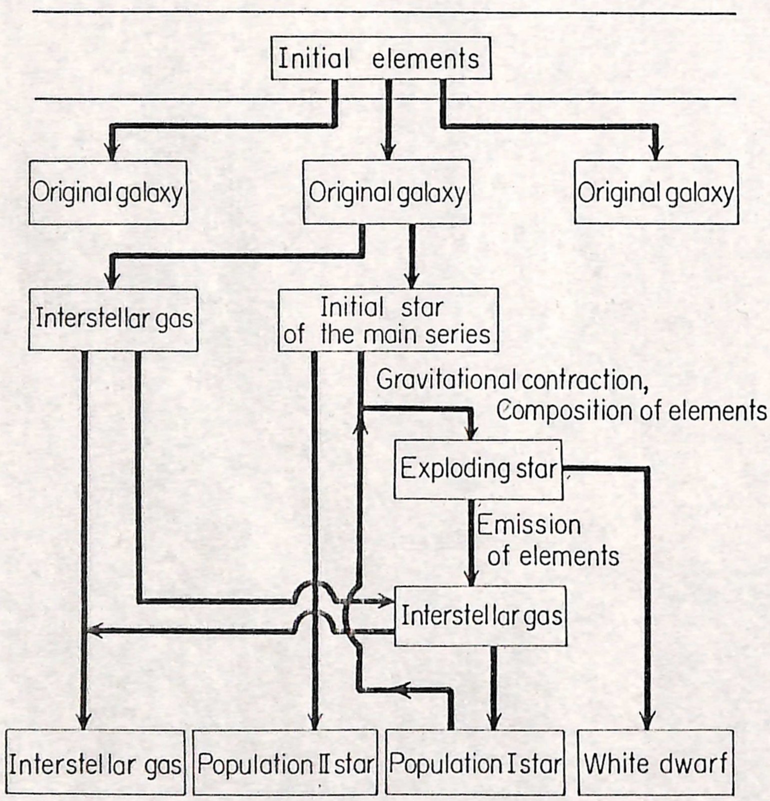

Fig. 1. Stellar evolutionary scheme in THO theory.

interstellar gas with abundant metallic elements.. New stars were formed again from the gas, and a cycle of the processes was repeated. The gas went gradually condensing towards the Galactic plane, and the present population I stars were created. The present population II stars of globular clusters are understood now as remains of the Galaxy of its early stage, so that they are occupying the Galactic halo without being confined to the Galactic disc. Figure 1 is an illustration of those processes in the THO theory.

After establishing a line of approach at the symposium, the two groups of physicists, S. Nakamura and his colleagues in Tokyo, and S. Hayakawa, C. Hayashi and their colleagues in Kyoto, started systematic computations on the processes of stellar evolution and element synthesis. Then, after seeing the success, C. Hayashi and his colleagues developed the theory into a more complete and comprehensive form and performed a large amount of numerical calculations with use of an American electronic computer. The results were compiled in a special issue of *Supplement of the Progress of Theoretical Physics* in 1963.

Later development

In summer of 1955, a half year after the symposium, the International Conference on Peaceful Use of Atomic Energy was held in Geneve, and Bhabha from India pointed out the importance of the fusion reaction as a future atomic energy source. We were already discussing the fusion problem at the aforementioned symposium. In fact, our proposal in 1954 to hold the astrophysics symposium was motivated in part by our criticism against the current view in Japan on the atomic energy development, which focused attention only on the uranium reactor and accelerated a short-sighted method to introduce immediately foreign uranium reactors, making the parliament to approve the first budget for the atomic energy in the spring of 1954. On the contrary, we thought that the fusion reactor would be the prospective winner for future atomic energy, and an ideal to mankind will be to realize on the earth some of the exothermic nuclear reactions occurring inside a heavenly body, which is believed to be a kind of fusion reactors. At the discussion meeting[7] held by the publishing office of "*Kagaku-Asahi*" (a science journal) after the symposium with the proposal of the THO theory, we made particular emphasis on a point that a star is an ideal nuclear reactor. Our proposal happened in coincidence with Bhabha's statement both in the idea as well as the date.

In April of 1956, we had another symposium at the Research Institute for Fundamental Physics in Kyoto, on problems of how to approach the realization of artificial fusion reaction. Here, the discussion was made between our colleagues specializing in astrophysics, nuclear physics and solid state physics. The conclusion was that it would be fruitless to put forth an effort blindly for attaining high temperature plasma in a single step by the electric discharge technics or else. Our opinion was that the shortest way would be first to establish the plasma physics through systematic studies on the plasma itself. Here we recognized the importance of research on stellar plasma, seeing that Alfven and other astrophysicists had already established a basic theory of plamsa. I think those ideas, combined with our study on acceleration mechanism of the cosmic rays, made an important contribution to Japanese physics in this field. Incidentally, just at the end of the symposium, we received news on Khruchatov's success of accessing high temperature plasma. Then afterwards, the fusion research in Japan did not always follow our advice and it was dominated by a number of the "pachin-ist"—those who blindly researched into the high voltage electric discharge technics after Khruchatov. It was only after their vain efforts of a few years, that progress of the Japanese research came back to the original direction of our proposal.

Japanese cosmic ray research had already attained the international level at the time of the proposal of the THO theory. Following a line of the THO theory, S. Hayakawa made a theoretical study on the heavy nucleus component of cosmic rays and presented a hypothesis of the supernovae origin as its basis. Previously, there was Fermi's theory of acceleration mechanism with magnetic clouds in the Galaxy and also a theory of the solar origin of cosmic rays. While, Hayakawa's theory assumed that the cosmic rays are produced at the moment of supernova explosion where heavy elements are synthesized and their parts are accelerated to cosmic-ray energies at the same instance.

In foreign countries, origin of the cosmic rays was discussed mostly in relation with radio astronomy, and there was a proposal of the supernova origin hypothesis from this side, too. Hayakawa's theory was derived, on the contrary, from his analysis of chemical composition of the cosmic rays. In Japan, the study was started with cosmic ray analysis and then went to problems of the universe, following the process of steps along our knowledges on the theory of elementary particles and atomic nuclei.

Evolution of the galaxies—1960

In November 1960, we made a step forward by having a symposium at the Research Institute Fundamental Physics together with our colleagues in cosmic ray research, raido-astronomy, astrophysics, theory of elementary particles and nuclear physics, and we established a line of the collaborative study on the galaxies. Originally, the THO theory was not confined only to problems of the stellar evolution, but it also provided a comprehensive picture covering formation of the Galaxy and element synthesis as a history of the universe since the initial stage. Thus, the symposium on galaxies was a natural extension, or a further development of the THO theory. There, the discussions were started with morphological problems of galaxies. I prepared a number of questions on galaxies, and through discussions on those questions we constructed a new picture and established the direction of our future study.

Untill that time, Hayashi and his collaborators were successful in clarifying more or less a general outline of the stellar evolution, and their results were often useful for the discussion. One of the main problems at the symposium was on the effects of the magnetic field in the universe. We obtained a general idea on the magnitude and form of interstellar magnetic field in the universe through studies on the cosmic rays. The Japanese group took an approach to the cosmic magnetic field through the cosmic rays, while in other countries the radio-astronomy made remarkable progress and together with the powerful resolution of the 200″ telescope of the Mt. Palomer Observatory, it provided us interesting examples on the relation between the shape of the galaxies and their radio-emissions.

Thus, the discussion was focused on the role of the magnetic field on various cosmic phenomena, such as how the magnetic field acts in constructing the shape of a galaxy or where is a source of acceleration of the cosmic rays.

The next problem was on the formation process of a star from the interstellar gas. Hayakawa emphasized an effect of the cosmic rays as an energy source in the process. Then, there came a problem of the interstellar gas in a galaxy being controlled by the magnetic field.

Another important problem was on the existence of the central nuclaus of a galaxy. It was suggested that something important may not yet be disclosed in this nuclear part like a mystery, and its revelation could be one of the central problems in the future. In addition, some people pointed out the existence of galaxies of various strange shapes, such as one with a jet-like object extending from the center, and stressed that all of them are strong sources of radio-emission. Other raised a question on the high energy limits of the existing cosmic-ray particles and of the acceleration mechanisms. One possibility in our consideration was to assume that the cosmic-ray acceleration mechanism is not confined within our Galaxy, but some of the distant galaxies with intense radio-emission are generating cosmic-rays of super high energies. The other possibility was to assume the existence of a strong magnetic field in the Galactic halo which is effective for the acceleration. Indeed, it was natural to speculate that the radio-galaxies would be one of important sources of the cosmic rays, because they were supposed to be associated with strong magnetic field. For such discusssions, the cosmic ray colleagues participated with strong enthusiasm.

It must be mentioned that, at that time, the only proposed theory for the radio-galaxy was to assume a collision of two galaxies as mechanism of the strong radio-emission. It was because the telescopic observation showed examples of interacting galaxies. But, it was not completely clear how a collision of two galaxies would cause release of huge amounts of energies. Investigation on this question lead us to a further development, as will be seen later.

Since then, our collaboration group had a series of meetings for discussions about twice a year, and exchanged information and accumulated the results. But, I may say that the main line of our study was laid at the symposium in 1960.[8]

Nebula M82 and star-like

In 1962, I met Fujimoto and Yokoi in São Paulo, Brazil. At that time, K. Suga and his collaborators were carrying out an extensive air shower experiment at Chacaltaya Cosmic Ray Observatory (altitude 5200 m) in Bolivia, and Fujimoto and Yokoi were exposing emulsion chambers there in collaboration with the Brazilian group. Fujimoto met Suga in Bolivia and came back to São Paulo with the experimental information of Suga on the directional non-isotropy of super high energy cosmic rays. We discussed the information and advanced step further. It was on the problem of how the cosmic rays were generated in galaxies other than our Galaxy. The fundamental points of our argument were, firstly, to assume that the upper limit of energy of cosmic rays is determined by a scale of the concerned magnetic field, and, secondly, to introduce a parallel relation such that a radio-galaxy with strong radio-emission will proportionally generate cosmic rays of strong intensity. On the basis of the above two assumptions, we constructed the composite energy spectrum of cosmic rays from those of the Galactic origin and of the extra-Galactic origins. This theory was reported at the La Paz Conference in July, 1962.[9] Until then, people believed that the extra-Galactic cosmic rays would be of so small an intensity that they would not be observed. But our theory suggested that the air shower data, particularly the Japanese data, were showing the existence of the extra-Galactic component of super high energy.

In 1963, we had two meetings, in May and September. The meeting in September was held at the Institute of Plasma Physics, for detailed discussions on the interstellar magnetic field and the plasma. Besides, the Tohoku group made a report on their detailed calculation on shape of galaxies with the dynamics and the magnetic-hydrodynamics, and their results draw attention of the attendants.

Soon after, there were reports of two spectacular discoveries. One was observation on Nebula M82 by Americans, which showed a large explosion of the central nucleus of M82 and an associated violent outer flow of the gas.[10] Hatanaka, introduced their report for us on Nov. 1st, at the Institute for Nuclear Studies, and we enjoyed the discussion together. A week later, we had the sudden death of Hatanaka. It was our great grief to lose this most able and invaluable collaborator, who was together with us from the beginning of the THO theory, at this important moment of our study. As this example of an explosion of the central nucleus of a galaxy, shows, it became clear about radio-galaxies for which the hypothesis of colliding galaxies had been the only proposed model though not quite acceptable, that the central nucleus, of which we have stated in the preceding section that a mystery might be concealed there and where both stars and interstellar gases are distributed very densely, can be a center of the galactic explosion with intense radio-emission. In addition, not before long, there came news of discovery of a new heavenly object named a star-like.[11]

American physicists and others immediately tried for a theoretical explanation of the star-like, and they proposed a model of gravitational collapse assuming that the explosion is caused by falling of matter into a very strong and singular gravitational field of a star or a galaxy. Though the gravitational collapse is an attractive hypothesis, we felt very skeptical of their concentration only on this possibility.

The present point of arrival

With those serious problems in hand, we again had a symposium in February of this year (1964) at the Research Institute for Fundamental Physics. After thorough discussions, we arrived at a conclusion that the star-like is to be regarded as an explosion of the central nucleus of a galaxy, as we anticipated. A basis of our conclusion was a statistical consideration of galaxies. We compared relative number of galaxies in general, radio-galaxies and newly found star-likes. Assuming that all of them are existences of one and the same kind, we were able to estimate a life-span of the active period of a galaxy to be observed as a star-like. A consistent result was obtained, if a galaxy makes one to ten big explosions of the star-like type on an average in its whole life. We already know from the visual example of M82 that an ordinary galaxy would turn into a radio-galaxy through the explosion. A consideration on the energy balance gave results supporting the above view.

Mechanism of explosion of the galactic nucleus had been discussed since the discovery of M82, and several proposals had been made so far. Among them, Fowler and Hoyle[12] assumed a chain reaction of stellar explosions. But there was no evidences to believe that one stellar explosion induces another explosion of neighboring stars.[13] Another possibility of them was to assume an explosion of a super massive star, but here, too, remained unsolved the problems on formation mechanism of such super massive stars and on its relation to an ordinary galaxy. In addition, those phenomena, which were considered as important bases for their proposal, turned out after thorough examination not to require uniquely their way of explanation. Those include the bar-like structure stretching out from a star-like and also time fluctuation of light intensity of a star-like. Thus, we concentrated our efforts in clarifying the relation between the radio-galaxy and the star-like.

On the basis of those studies, we are keeping at present a view that the star-like is an explosion of the galactic nucleus. For mechanism of the explosion, we are thinking over the effect of interaction between interstellar gas and stars in the galactic nucleus, which has not been considered by foreign physicists. We postulated that the coexistence of dense gas and crowded stars is an essence of the collective stellar explosion, and named the idea the "pile" theory. The name was chosen to express a kind of analogy to mechanism of the nuclear pile, in which coexistence of uranium fuels and moderators is essential as would be for stars and interstellar gas in the star-like.

Thus, it seems to me that an explosion of the galactic nucleus opened a new insight into various problems which had remained so far hard to be understood.

Of course, I am not denying the attractive idea of Fowler and Hoyle and only future development will be able to give the answer. But, my speculation is that a singular situation of the gravity may not appear in such a direct way as in the star-like phenomena and it would be better to look for the singular gravitational phenomena in somewhat different directions. As we are able to obtain a consistent picture over galaxies in general, radio galaxies and star-likes, as we have seen, I think that we should at this moment pursue our present direction of the study. Of course, we should be prepared, and we are really expecting, to encounter some new phenomena of the universe which are contradicting the known principles of the present physics, because the universe is endless.

Thus, I may say that we now have several important bases for the study in our hands through our collaborative study, since the THO theory, carried out by our colleagues in the theory of elementary particles, astrophysics, nuclear physics, cosmic ray research and others. We are able, at present, to attempt to construct a general perspective on the universe problem. Of course, we are far from the completion of the understanding, and only at the entrance to the exploration into problems of the universe.

The light was the only means of observation in astronomy before the war. After the war, the radio came in as a new means of observation. We are now putting the cosmic rays as the third. The cosmic rays play not only a role as a means of observation, but a role as one of the important media of energy in the cosmic phenomena. Finally, I want to stress that a particular nature of our collaborative study lies in establishing new teamwork between the astronomers and the physicists, in making full use of the theory of elementary particles and cosmic ray research, which have a tradition in Japan, and also of conscientious application of the philosophical methodology.

References

1) R. A. Alpher, H. Bethe and G. Gamov, Phys. Rev. **73** (1948), 803.
2) C. Hayashi, Prog. Theor. Phys. **5** (1950), 255.
T. Hatanaka, C. Hayashi S. Hayakawa, S. Nakamura, S. Obi, M. Taketani and H. Yukawa, "Discussion on Nuclear Reactions in the Universe" in Kagaku-Asahi **15** (1955), No. 4, 41.
3) M. Taketani and S. Nakamura, "Nuclear Physics and Stellar Objects" in Kagaku **25** (1955), 305.
T. Hatanaka and S. Obi, "Stellar Populations and Their Evolution" in Kagaku **25** (1955), 436.
4) M. Taketani, T. Hatanaka and S. Obi, Prog. Theor. Phys. **15** (1956), 89.
5) W. Baade, Appl. J. **100** (1944), 137.
6) M. Schwartzschild and L. Spitzer, Observatory **73** (1953), 77.
This paper was not known to any one of us at the time of the symposium in 1955. After our paper of the THO theory was submitted for publication, Prof. Hitotsuyanagi as a referee of our paper noticed us about their paper to cite it in our paper.
7) Kagaku-Asahi, April (1955) cited in Ref. 2).
M. Taketani and T. Toyoda, *Nuclear Reactor*, Lecture series on physics (Iwanami Co. Ltd., 1955), begins with an emphasis on the thermonuclear reactor.
8) From Symposium on Galaxies', Kagaku-Asahi, January, (1961); Soryushiron Kenkyu (Mimeographed Circular in Japanese) **23** (1961), No. 1; **24** (1961), No. 1; Prog. Theor. Phys. Suppl. No.30 (1964); No.31 (1964).
9) Proceedings of La Paz Conference, (1962).
The content was published again in the Prog. Theor. Phys. Suppl. No. 30 (1964).
10) C. R. Lyndo and A. R. Sandage, Appl. J. **137** (1963), 1005.
11) M. Schmidt, Nature **197** (1963), 1040.
12) W. A. Fowler and F. Hoyle, Rev. Mod. Phys. **36** (1964), 545.
F. Hoyle and W. A. Fowler, Month. Notices Roy. Astron. Soc. **125** (1963a), 169.
13) K. Aizu, unpublished.