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# Scenario of Formation Processes of the Giant Planets

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## 1. Relation of formation processes of the giant planetary and solar systems

Giant planets have so large difference, in their characteristics, from that of the terrestrial type planets; that is, the giant planets have long been considered as exotic bodies which may not be directly related to the processes of the formation of the terrestrial planets. The studies on the formation process of the solar system have, however, disclosed that the solar system consists of two basic frames; *i.e.*, the sun forms central structure of the solar system, while giant planets make outer frame structures. The terrestrial type planets and the satellites of the giant planetary systems are, therefore, formed within this frame of the solar system.

The scenario of the formation processes of the solar system, that we have in the present stage of the knowledge, is:

a) Contraction of the primordial solar nebula with large mass of $10^3 M_\odot$ to $10^4 M_\odot$ (where $M_\odot$ denotes the present solar mass).

b)These large clouds are fragmented into the source nebula of the each stellar system where the central star is formed; it is well known that our sun is one of this central star.

c) After concentration of the material to the proto-star in the central portion of the nebula, there had started violent release of the energy from the central plasma region where very large convection and turbulent motions were excited due to release of the gravity energy. The violent release of the

energy had been taken place in the form of the electromagnetic wave radiations (including the wavelength range from visible to infrared wavelengths), and magnetic field formation coupled with plasma flow, and also in the form of outward transport of mass.

Before the confirmation of the existence of the bi-polar flow, it was thought that T.Tauri phase was the main period of the energy and mass release from the central body of the primordial nebula; we could then plug in the concept of Hayashi phase into this period. Recent studies of the bi-polar flow, however, show that the large amount of the mass ejection is taking place during the bi-polar flow stage that has taken place before the T.Tauri phase.

The bi-polar flow consists of two oppositely flowing out molecular flow regions (see Fig. 1 of the fourth paper in this chapter) where the out flows are taking place with speed ranging from 1km/s to 50km/s with duration of periods ranging from $10^4$ to $10^5$yrs.

## 2. Scenario of formation processes of the giant planets

The results of the study on the formation processes of giant planets presented in this Chapter 2 are obtained with the stand points to take the bi-polar flow stage as the initial period of the formation process of the giant planets, which were related to the collection of the source material for formation of the giant planets.

The scenario of the formation processes of the giant planets that have considered here are as follows:

a) The first step: This phase is characterized by accumulation of the source material in outer regions of the solar system covering the locations of the present giant planets.

b) The second step: Contraction of the accumulated source material into a large gas cloud that became eventually the giant planets is main process. We call this local concentration of the nebulae corresponding to giant planets "proto-giant planetary nebulae".

c) The third step: The processes of the angular momentum transfer with accumulation of the source material of the satellites are dominated. During concentration processes of the nebula gas into the central points corresponding to the proto-giant planets, the nebula gas is heated due to the release

of the gravity energy; the high speed release of energy might be resulted in the state of the large gas convection with turbulences that were resulted the large plasma convection flow. The inhomogeneous flow of the ionized gas may result in electric current filaments which became origin of the dynamo action. As the results of the dynamo action, then, large magnetic field were generated; the rotating magnetic field might strongly affect the formation processes of the proto giant planetary systems in the following steps.
d) The fourth step: The disc parts with the dust and gas mixed material were formed around the centers of the proto giant planetary nebulae; the formation processes are largely controlled by the rotating magnetic field.
e) The fifth step: After condensation of the material, the giant planets were formed at each center of the proto-giant planetary nebula; and also ring like distribution of the dust-gas combined material has been achieved; the material then further made accretion forming small bodies and satellites.
f) The sixth step: The source material are completely accumulated at the position of giant planets and also formed the satellites. Rings are left within the Roche's limit of each giant planet.

## 3. Confirmation of Scenario for Formation of Giant Planetary System

The investigation of scenario is required from the two sides of approaches. The first is to search for the evidences left in the solar system celestial bodies which become witness to be check points for the possible scenario; the second is to trace the basic physics for the processes that took place in the past by making computer simulations.

Observations from the ground stations, during the long history in the astronomical study fields, for these giant planetary systems have already provided the frame work data of these systems, but the new observations of the giant planet systems by the US-Voyager missions have increased revolutionary data adding following informations:
a) magnetic fields of giant planets,
b) detailed ratio of molecules and their distributions in the atmosphere of the giant planets,
c) detailed features of the satellite surfaces and,
d) features of rings, especially general informations of the existence of rings.

With developments of the super computers, the new era is approaching to pursue the complete simulation of the formation processes of the solar system and giant planets. The technique of simulations is not simple computing technique but that is intimately related to philosophy to select the scheme, *i.e.*, physics and procedures are so complicated that it is essential to select the most important key for understanding each stage of the evolution of the scenario for the formation of the solar system. General approach without special selection of scheme looks like to be possible but in the general approach it is not necessarily easy to make right trace of the track of the past evolutions that has already disappeared in the present solar system. This is partly because the computer starts to evolve within an operation program by their own hidden mechanisms due to accumulation of errors.

To solve all of these difficulties, one effective way is then to separate the evolution stages into each basic element and construct the best fitting model for the each element of the formation processes. The study results in this Chapter 2 are then given in this current of the thought. Considering all of these points, Chapter 2 consists of following five papers including this.

In the second paper, review of the resent observational results by the Voyager missions and the review of studies on interior of the giant planet have been made. From the tremendous large volume of data described in the issues of Voyager mission achievements, the limited materials are selected to have intimate relation to the scenario of the origin of the giant planets. Detailed points of the description for the observation evidences have, therefore, not been repeated, because there are many other suitable issues if we try to find the data only to know the results of the Voyager missions.

In the third paper, the quasi-linear theory of the growth of the density waves are given in the disc of the outward gas flow in the initial phase of the accumulation processes of the giant planets during the bi-polar flow. The theory is based on the Navier-Stokes equation being coupled with the self-gravity equation. As a result of the growth of the stationary components of the density waves, the seeds for the accumulation of the material as sources of the giant planets are made, during a few years, at positions corresponding to giant planets satisfying the Titius-Bode's law. It is important that Reynolds number is too large to consider the friction in the regime of pure neutral gas dynamics but the interactions of the media were provided by

the excited magnetic field in the partially ionized gas.

In the fourth paper, computer simulations for nonlinear equations of Navier-Stokes equations with the Poison's equations for the self-gravity system, under the condition for the same model treated in the third paper, have been made to confirm the growth of the density waves that have been predicted by quasi-linear theory given in the third paper. The results give confirmation that the growth of the stationary waves at locations corresponding to the positions of giant planets. The growth of the stationary waves takes place to satisfy the Titius-Bode's law in every cases of the initial conditions of the disturbances for computer running.

In the last paper, dynamics of Saturnian rings that are forming density fluctuating structure have been analyzed by computer simulation technique using many bodies model(particle model). The studies are related to the step five of the scenario for the formation processes of the small bodies that become origin of the satellites. Because the rings of the giant planets are formed in the Roche's limit, the growth is limited to the case of tenuous distribution of the elementary bodies; *i.e.*, they stay at the level of small bodies. The present analyses then can be extended in future to the general growth stage of the satellites when we apply the computer simulation technique to the regions outside of the Roche's limit.

In the present chapter, several important works that have already been carried out are not included. One of the excluded subject is studies on the effect of the electromagnetic field for the angular distribution and accumulation of material for formation of the satellites of the giant planet systems; and the other is the studies on the interior of the giant planets. The hypothesis of the electromagnetic effect from central body to the ambient disc has been checked for the case of the Uranian system (Oya, 1979), relating to the fourth step of the scenario. Though this part of works is not fully developed, there is a significant point in the result that will become important subjects of the future studies. That is, the study result suggests that the electromagnetic processes have an essential role that affects dominantly to the distribution of the source material for the formation of the satellites while proto-nebula stayed in the hot plasma stage in the proto-giant planetary system.

The studies on inside region of the giant planets are intimately related to the high pressure material physics that have been carried out from the

sides of the theory and experiments. The result of the theoretical works which has been given in the second paper, much depend on the basic studies on metallic states of the hydrogen and helium, for their analyses of real states of the internal structure of the giant planets. The detailed theoretical studies that have been made recently are given in the works by Nakamura (1987), Miyagi *et al.* (1988), Ebina and Miyagi (1989), and Nagara (1990).

## References

Ebina, K. and H. Miyagi, 1989, Anisotropic structures of metallic hydrogen, *Phys. Lett.*, **142**, 237.

Miyagi, H., T. Hatano, and H. Nagara, 1988, Structural expansion of the ground-state energy of simple metals in the local-density approximation, *J. Phys. Soc. Japan*, **57**, 2751.

Nagara, H., 1990, Structural phase transitions in dense hydrogen, in *Strongly coupled plasma physics*, (ed. S. Ichimaru), Elsevier science publishers B.V., Yamada science foundation, 663.

Nakamura, T., 1987, Quantum density of an Inhomogeneous electron gas in the local oscillator approximation, *Prog. Theo. Phys.*, **77**, 1355.

Oya, H., 1979, Electromagnetic force hypothesis for interpretation of the obliquity of the rotation axis of Uranian system, *Proc. 12th Lunar Planet. Symp., ISAS*, 151.