Cosmic Chemistry: Planetary Diversity

So Mr. Holmes, What is the Problem?

STUDENT TEXT

INTRODUCTION TO PLANETARY DIVERSITY

The problem is the origin and nature of the planets, a topic of great fascination to humankind. After reading a description of the physical properties of the planets, it is easy to be impressed with the diversity found in our solar system. Just how and when were the planets formed in the first place and what processes led to their individual and amazingly diverse characteristics? The answer is a resounding, "We do not know!" Over the years various ideas relating to planetary formation have been advanced, but to this point these ideas remain as highly-debated theories.

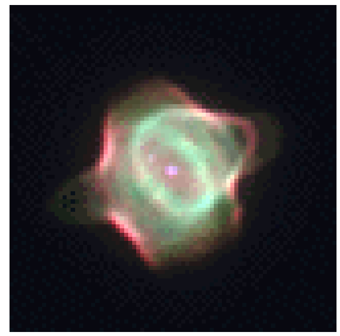
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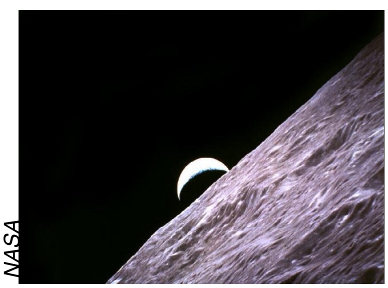
Image of the youngest known planetary nebula, the Stingray nebula (Hen-1357).

A fundamental difficulty with developing a successful theory of planetary origin stems from the fact that we begin from an unknown initial state, such as the state of affairs 4.5 billion years ago. It becomes necessary to *assume* an initial state having certain properties and then demonstrate that this initial state can lead to a final state consistent with our contemporary knowledge of the solar system. Unfortunately, there are several different paths leading from the initial to the final state, and the problem becomes even more complicated because of the difficulty of deciding which one is correct. Developments of successful theories in this area are also hampered by the fact that we possess information about only *one* planetary system.

The Genesis mission clearly will provide valuable information about the initial state, since pristine material issuing forth from the sun will be collected and analyzed. Other space probes have immensely expanded our knowledge of the composition of the planets, and at some point in the future, enough data will have been gathered from planetary scientists to propose a detailed and defensible history of how each planet was formed and how it has evolved.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Much effort has been directed toward the development of a grand unified theory of solar system formation. In this effort, workers traditionally have treated the solar system as a puzzle in which they considered a small number of boundary conditions and then attempted to find a complete unified solution.

It is customary to list questions that need to be answered by the proposed theory if it is to be considered acceptable. Some of the major features of the solar system that a successful model of planetary evolution might address are as follows:

1. Why are there nine planets?
2. Why do all of the nearly circular planetary orbits lie in essentially the same plane, and why do all the planets rotate counterclockwise around the sun?
3. Why is there a central unit (the sun) that is so much more massive than the sum of the remaining parts of the system?
4. Why are the planets located in orbits at such great distances from the sun?
5. Why do the planets have such different chemical make-ups and how is this related to their positions relative to the sun and to their masses?
6. Why do *most* planets rotate about their own axes in the counterclockwise direction with orbital "tilts" of less than 29°?
7. Why does the sun rotate on its own axis in almost the same plane as the planets and in the same direction as *most* of the planets?

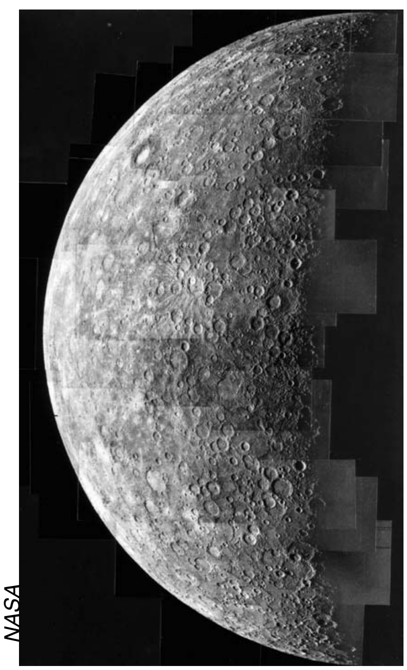
8. Why does the sun rotate so much more slowly than do the planets? More precisely, why does the sun possess less than 2% of the angular momentum but nearly all of the mass of the solar system? (Note that this question is closely related to question 4 above.)
9. Why are the small, dense, slowly rotating, rocky planets closer to the sun and why do they have few satellites? And why are the large, less dense quickly rotating, gaseous planets farther from the sun and why do they tend to have many satellites and rings?
10. Why do meteorites have different chemical and geological properties from those of terrestrial and lunar rocks, and why do some of them contain unique isotopic abundances?

Providing answers to all of these questions clearly is a tall order for any theory of solar system evolution and over the years many theories have been offered as solutions to the problem. More recent views, which some claim to be more realistic and pragmatic, suggest that we are dealing with "a system in which many stochastic events occur, with the end result that all planets and satellites are different." This is to say that the solar system simply is the result of chance events that are governed by the basic laws of chemistry and physics. (For a more complete treatment of this view, see chapter 7 of "Solar System Evolution: A New Perspective" by Stuart Ross Taylor.)

Tracing the history of the various grand unification theories that have been put forth is beyond the scope of this introduction. There is an extensive list of resources and references in this module for your further study.

It is possible, however, to classify these theories into one of several very broad categories, as follows:

- Formation of the planets is unrelated to the formation of the sun.
  - Scenario #1: Planets were formed after the sun became a normal star, *either* from matter derived from the sun itself or from matter stolen from a passing star. These theories are often referred to as "tidal theories."
  - Scenario #2: Planets were formed after the sun became a normal star from matter captured from interstellar space.
- Formation of the planets is intimately related to the formation of the sun, with the understanding that the two processes might have occurred simultaneously or consecutively.



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This mosaic of Mercury was taken by the Mariner 10 spacecraft during its approach on 29 March 1974. The mosaic consists of 18 images taken at 42 s intervals during a 13 minute period when the spacecraft was 200,000 km (about 6 hours prior to closest approach) from the planet.

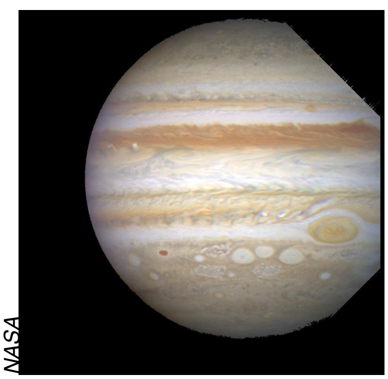

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Image of Jupiter taken by Hubble Space Telescope.

The concepts of planetary formation most often discussed in recent times usually are derived from the idea that the sun and the planets were formed in concert with one another. Readers should keep in mind that this is a complicated and often controversial subject and that the topics covered in the module are only the tip of the iceberg. (And you know what happened to the Titanic when it encountered an iceberg!)