GRAVITY'S INFLUENCE ON THE DEVELOPMENT OF THE SOLAR SYSTEM

RONALD E. MICKLE
Denver, Colorado 80211

ABSTRACT

Gravity attracts. That attraction is the essence of a power that governs and affects all matter. And, more interestingly, gravity sets up a tension of mutual attraction resulting in an order that extends to all matter. For five billion years, gravity has exerted its influence on our solar system. Not until the mid-17th century was Isaac Newton able to validate the heliocentric system by mathematically proving gravity's existence through use of his universal laws of gravity. These laws explained why and how the planets orbit the sun and discounted the age-old theory of an earth-centered system [Kaufman & Freedman, Universe, Fifth Edition]. Even though the universal laws of gravity assist in explaining the interactions within the solar nebula, they don't encompass the variables involved in the evolution of the solar system.

Gravity's role in the development of the solar system, from the interstellar medium (ISM), to the solar nebula and finally to the current system, can help us understand our universe. There are two slightly opposing theories for the solar system's development: A terrestrial planet formed in the inner region and the Jovian-size planet in the outer, versus the Jovian-size planet formed in the inner region. The discussion here will focus on a two-planet model of evolution: one terrestrial and one Jovian.

1. EARLY FORMATION

It is widely accepted that the solar system formed out of the solar nebula, through the coalescing of grains of dust and gas by gravity and chemical bonding. According to Jayawardhana, scientists are taking a closer look at the protoplanetary disks (proplyds) evolving in star forming regions such as the Orion Nebula, viewing them as a snapshot of our early Solar System (See Figure 1). But these proplyds are relatively young and have not formed planets. What will these proplyds look like billions of years from now? We can only theorize.

Figure 1
One-million-year-old disks, such as this one in the Orion Nebula, contain mostly gas and show no evidence for planet formation.
STScI/HST

We first start with the formation of the solar nebula out of the gas and dust in the ISM, with gravity exerting its presence. Newton's universal law

inversely proportional to the square of the distance between them [Kaufman & Freedman]. So, as the dust and atoms of the ISM came closer to each other, gravity exerted an even greater influence. The atoms and grains of dust began to attract each other, drawing the ISM into an ever-smaller area. This cold area of gas and dust exerted very little pressure on the surrounding medium. The cold, low pressure allowed for further contractions. If the temperature had increased early on, then the pressure would also have increased, thereby halting the formation of the solar nebula. The gravitational forces continued the contraction of the ISM until a slight rotation of the solar nebula began. If the rotation hadn't begun, the material of the ISM would have contracted into the protosun leaving nothing from which the planets could form [Kaufman & Freedman]. As the solar nebula continued to contract, it rotated faster.

The greatest concentration of matter was at the center of the nebula, forming the protosun. At this point the protosun was a collection of dust and gases and not yet a true star. As gravity drew matter from the nebula into the protosun at faster speeds, the matter began colliding with itself resulting in the release of thermal energy known as the Kelvin-Helmholtz contraction.

During the rotation of the proplyd, gravity continued to cause grains of dust and gases to coalesce into millions of small objects. The low condensation temperature of gases such as ammonia and methane allowed them to remain solid and combine with the dust to form rocky materials. These materials were evenly distributed throughout the proplyd, so material used to form a planet in the inner region of the nebula also existed in the outer region.

2. INNER REGION

The inner region of the proplyd went through several temperature variations during the sun's development. The early protosun, which was more luminous than it is today, produced temperatures of approximately 2,000 K in the inner region, which was greater than the condensation temperature of substances such as aluminum, iron, nickel and silicates. Water, methane and ammonia had long since vaporized leaving mainly the rocky substances to which they had been attached.

As the protosun settled to a steady-state thermonuclear reaction, it cooled, as did the inner region. This resulted in temperatures below the condensation point for the heavier elements; these elements condensed back into solids, coalescing into ever-larger pieces, held together through chemical bonds and gravitational forces. Further accretion of substances formed asteroid-like objects called planetesimals, which were roughly 10 kilometers in diameter [Kaufman & Freedman, Universe, Fifth Edition]. Accretion continued until an object reached the approximate size and mass of the moon. This protoplanet was composed primarily of substances with high condensation temperatures such as iron, silicon, magnesium, sulphur, nickel, aluminum and calcium, which condensed out when the inner region of the solar nebula cooled. For the next 100 million years, the protoplanet continued to sweep up material from the inner solar system until all the inner solar nebula material was used up, forming a terrestrial planet [Kaufman & Freedman].

3. OUTER REGION

While the inner region went through variations in temperature during the sun's evolution and remained hot, the temperatures in the outer region remained low, less than 50 K. Ice particles and ice-coated dust grains, which were unable to remain solid in the inner region due to high temperatures, survived in the cold outer region. Where the terrestrial planet relied on rocky planetesimals formed from substances with high condensation temperatures, the outer region had an abundance of solids from ice-forming substances such as ammonia, methane and water. Hydrogen and helium being the most abundant gases in the solar nebula, remained gases. Eventually, enough material came together to form a planetesimal of rock and ice. This process of accretion continued until a protoplanet reached a mass between five and ten times that of the terrestrial planet. This formed the core of what would become the Jovian planet. Due to the low temperature, hydrogen and helium gases moved relatively slowly and were easily captured by the gravitational force of the newly formed core of rock and ice. As the Jovian core accreted more and more hydrogen, it became more massive.

Helium atoms were also present, but in far fewer numbers[1]. The Jovian planet's gravitational attraction became so great that it drew in the remaining hydrogen gas from the solar nebula's outer region. This runaway growth continued until there was nothing left in the outer region, as illustrated in Figure 2.

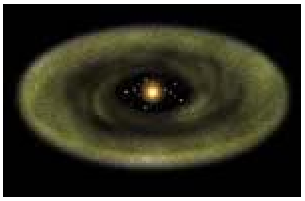

Figure 2
By 10 million years, most of the gas is gone, and either planets or planetesimals have already formed.
Astronomy: Elisabeth Rowan

4. OPPOSING THEORIES

Twenty-four computer simulations were conducted by scientists at Queens University in Ontario and the Southwest Research Institute in Colorado with varying parameters, including the assumption that four or five ice- rock cores formed between 5 and 10 astronomical units (a.u.) from the sun[2]. Over a period of 100,000 years from the time the solar nebula started its contraction, a Jupiter-size planet formed which destabilized the system. Its gravity sent the other rock and ice core planets to larger orbits between 20-30 a.u. [Astronomy 2000] In addition to the larger planets, smaller rocky planetesimals would probably have been dislodged and moved to the outer regions where they were gravitationally captured by these larger members. This could account for the terrestrial-like satellites orbiting several Jovian planets.

Nine of the most recent extrasolar planets discovered orbit their parent star between 0.13 and 3.2 a.u. [Sky & Telescope 2000], which compares to orbits in our own system from inside Mercury to an orbit approximating the asteroid belt. The orbits of six of those extrasolar planets would lie inside that of the Earth's. Thus far, this follows the formation mentioned

---

[1] There are 10^{12} H atoms to $7x10^{10}$ He atoms.

[2] Computer simulations performed by Carnegie Institution of Washington (U.S.) indicated that the gravity between small pebbles was too weak to allow accretion into planetesimal size objects.

earlier for the terrestrial planet. Observations show the majority of the discoveries are Jupiter-size planets located in the inner region of the proplyds.

Although researchers using computer simulations have found that planetesimals forming from the accretion of small pebbles is not likely[2], larger planetesimals do form and increased gravitational attraction allows them to build to Earth-size planets. Then comes the question, how do the gas giants form? Scientists agree that there is more than enough rock and ice in the outer region of a solar nebula to form cores of 10-Earth-masses, but is there sufficient time for the planetesimal to accrete enough gas before the stars wind evicts the remaining gases [Jayawardhana 2000].

5. CONCLUSION

Although the universal laws of gravity are used to explain the formation of the terrestrial and Jovian planets, questions remain unanswered. The use of Newtonian mechanics explains how gravity's influence brings bodies together to form protoplanets and planets, but does not explain how planetesimals coalesce from pebble size objects, yet it does occur. As discussed in the previous paragraphs, the terrestrial planet may form in the inner region of the solar nebula and the Jovian-size planet in the outer region. Here again, research and computer simulations have shown that the Jovian-size planet could form in either the inner or outer region.

Gravity is the major player in planetary formation, from bringing the interstellar medium into a proplyd, to the formation of the solar nebula, and on to the solar system. But there are many variables which must be taken into account before we can begin to formulate a comprehensive picture of how planets form. With over 50 extrasolar planets discovered to date, the astronomical community has started building a database from which conclusions can be made.

The suggestion that [Sky & Telescope 2000] "stars with several giant planets may be common" sounds fairly reasonable. If we consider this, then we might also consider our solar system to be a fair representation of the formation of a star system with planets.

6. REFERENCES

Astronomy Magazine, Nov 2000, pages 26 & 28.
Jayawardhana, R., September 28, 2000, www.Astronomy.com, *Spying on Planetary Nurseries*.
Kaufman & Freedman, *Universe,* Fifth Edition, pages 75-76, 88-91, 173-177, 498, 754.
Sky & Telescope Magazine, Nov 2000, pages 24-25.

ACKNOWLEDGEMENTS

This paper was prepared by the author as part of the curriculum requirement of ©Swinburne Astronomy Online course. Thanks to Dr. Sarah Maddison (SAO) and Joanie Mickle for editorial comments.