Complex Life, By Jove!

By: Leslie Mullen

The gas giants in our solar system. From left: Neptune, Uranus, Saturn, and Jupiter. *Credit: NASA*

One of the tenets of astrology is that the positions of the planets affect us. For instance, the position of the planet Jupiter in your chart is supposed to indicate good luck for a certain aspect of your life.

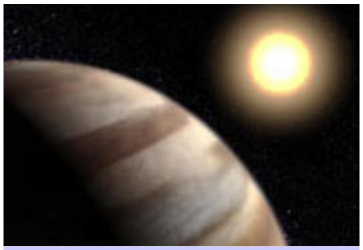
In an eerie echo of astrology, some scientists are now saying that the position of Jupiter in our solar system was very good luck for life on Earth.

Jupiter is about 5 astronomical units (AU) away from the Sun − far enough away from Earth to not have interfered with the development of our planet, and yet close enough to gravitationally deflect asteroids and comets, limiting the number of dangerous impacts.

Impacts by asteroids and comets can create cataclysmic events that destroy life − witness the demise of the dinosaurs 65 million years ago, widely believed to have been brought about by a "killer" asteroid impact. Without Jupiter, instead of being hit with a killer asteroid every hundred million years or so, we´d get one every 10,000 years. This reduction in impacts enabled the Earth to develop both simple and complex forms of life.

But gas giant planets like Jupiter don´t always help in the development of complex life. Consider, for instance, that while Jupiter deflects many asteroids away from Earth, it also is responsible for most of the asteroids in the first place. When planetesimals were clumping together to form the terrestrial planets, the gravitational influence of Jupiter prevented a fifth planet from forming. Instead, today there is the asteroid belt that lies between Mars and Jupiter − a sad echo of the planet−that−never−was.

"Only a small fraction of the original material was left behind to become the asteroid belt," says Alan Boss of the Carnegie Institution of Washington. He says that Jupiter excited this material to high orbital eccentricities, causing much of it to collide with the Sun and the growing terrestrial planets.



"Jupiter does not prevent asteroid impacts on the Earth − it causes them," says Alan Boss of the Carnegie Institution of Washington.
Credit: US DOE

"Jupiter does not prevent asteroid impacts on the Earth − it causes them," says Boss. "Asteroids can still be kicked out of their orbits and sent on paths that intersect the terrestrial planets."

Mars also was affected by Jupiter´s gravity during the early formative years. Mars is only half the size and one−tenth the mass of Earth, prevented by Jupiter from accumulating enough mass to become an Earth−like world capable of sustaining complex life. The lower mass of Mars, in combination with its low magnetism, prevented the planet from retaining an atmosphere − a vital necessity for life to exist and thrive.

If Jupiter were a little more massive, or if it was closer to the Sun, the Earth might have suffered the same fate as Mars. If Jupiter were close enough to the Sun to reside in the habitable zone − 0.8 AU to 1.7 AU for our solar system, or roughly from the orbit of Venus to the orbit of Mars − then the Earth and the other terrestrial planets would never have formed at all. Jupiter´s gravitational influence would have prevented rocky debris from coalescing into planets. The inner solar system instead would have become a barren asteroid belt.

"Habitable zones tend to be only a few AU in width, so if there is a Jupiter−mass planet inside the habitable zone, it is highly unlikely that another planet of any mass could form or exist so close by," says Boss. "Instead, the only hope for habitability in such systems would be on moons orbiting the Jupiter−mass planet."

Could it be that a solar system devoid of gas giants might have the best chance for developing life? If gas giants like Jupiter and Saturn had never formed in our solar system, three Earth−like planets might have developed instead of just one. Lacking the gas giants, Uranus and Neptune−like icy planets likely would have formed in the Jupiter−Saturn region. This system would have been relatively asteroid−free, since most of the rocky debris in the early solar system would´ve coalesced into planets.

George Wetherill of the Carnegie Institution of Washington has suggested that without Jupiter and Saturn, there would be many more comets in the Kuiper Belt (shown above).
Credit: www.ifa.hawaii.edu

But a Jupiter−free solar system would still have to contend with comets − small bodies of water ice that, in our solar system, come from places like the Kuiper Belt and the Oort cloud. Comet impacts can be as disastrous to life as asteroid impacts.

"In systems without asteroid belts, impactors come from the comet belts," says Donald Brownlee, an astronomer at the University of Washington in Seattle. "There is evidence that most stars form distant comet belts around them."

George Wetherill of the Carnegie Institution of Washington has suggested that without Jupiter and Saturn, there would be many more comets in the Kuiper Belt. These comets would wander into the inner solar system so frequently that the Earth would be struck by a major comet impact every 100,000 years.

Despite the devastation caused by asteroid and comet impacts, a solar system free of these bodies may not be the best thing for the evolution of life.

For one thing, comets may be necessary for life to emerge on terrestrial planets. It is thought that comets act as delivery systems for organic material and water, elements that were necessary for the origin and development of life on Earth. According to Brownlee, Jupiter´s scattering of cometary debris probably delivered most of our oceans.

Although asteroid and comet impacts can destroy life, they also set the stage for new evolutionary life forms to emerge. By clearing a planet of the more dominant organisms, other life forms can move to fill in the recently vacated ecological niches.

"If Jupiter was not there, or if it was smaller or further away, then there might not be an asteroid belt and thus no asteroid impacts," says Brownlee, "This can be good or bad depending on the situation. The dinosaurs were certainly not fans of the asteroids, but then they might not ever have evolved without the asteroids."

The evolution of complex life on Earth owes a lot to happenstance situations like asteroid or comet impacts. Not only did dinosaurs probably owe their very existence to such impacts, but so too do humans. If the asteroid impact that killed the dinosaurs had never occurred, perhaps our ancestors would not have been able to evolve beyond the small rodents that constituted the Mammalian branch 65 million years ago.

Jupiter planets − rare or commonplace?

How often do gas giants appear in other solar systems? In our search for planets outside our solar system, all the planets discovered to date are gas giants like Jupiter and Saturn. This does not mean that all the planets to be found are gas giants, however. An inherent bias in the search method is that it can only detect very massive planets.

Almost all the extrasolar planets found so far were detected with the radial velocity, or "Doppler" technique. This technique looks at how stars are affected by the gravity of an orbiting planet. Over the course of an orbit, the planet will pull at the star from different sides. Scientists measure the Doppler shift of the starlight to tell when the star is moving slightly away from us or toward us, and from this they can roughly determine the mass and orbit of the planet that causes the shift.

Over 100 Jupiter−mass planets have been found to date, from a survey of over 1,000 stars − nearly all the solar−type stars within 30 parsecs. However, Jupiters that are further away from their stars take longer to complete an orbit, and therefore require longer periods of astronomical observation. These stars might harbor many more Jupiters that have not yet been detected.

Several extrasolar giants are extremely close to their stars, and many scientists believe, due to the conditions necessary for gaseous planet formation, that they must have formed further away from their stars and then migrated inward. Such behavior would be a death warrant for life on inner terrestrial planets like Earth, causing the planets to be flung outside of the solar system, away from the heat and light of their star. The highly elliptical orbits of many extrasolar Jupiters are thought to be caused by such orbital turf battles.

Estimating the number of Jupiter−mass planets in the galaxy greatly relies on our understanding of planet formation. For a long time, it was thought that gas giants formed the same way terrestrial planets did − by the slow accretion of matter over many millions of years. However, the accretion model has a fundamental problem − how do gas giants accumulate enough gas before the gaseous disk around a young star dissipates?

"(Jupiter−mass planets) are made of gas, and gas is lost very early in some solar systems due to intense ultraviolet irradiation from nearby stars," says Brownlee. "The success of Jupiter formation may vary with location and time due to the build up of heavy elements in the galaxy."

Boss´s disk instability model suggests a different manner of gas giant formation. In his model, the disk of gas and dust that swirl around a young star develop points of instability. These disturbed areas become gravitational wells, accumulating more and more matter until they form the gas giant planets.

A recent computer model by Lucio Mayer and Thomas Quinn of the University of Washington, which was based on Boss´s disk instability model, found that gas giants like Jupiter can form in only 1,000 years. Their computer simulation produced planets 2 to 12 Jupiter masses, with elongated orbits rather than the more circular orbits of the planets in our own solar system.

"If the disk instability mechanism can work, then most planetary systems should have gas giant planets," says Boss. "However, if core accretion is the mechanism that forms gas giants, then most planetary systems may only have failed cores that grew too slowly to accrete enough gas to become gas giants. In other words, they would be full of ice giants like Neptune instead. Only observations will prove which is right."

What´s Next

Understanding the role that Jupiter plays in our own solar system can help astronomers narrow their search for habitable planets around other stars. While current planet search techniques are limited to the detection of very massive planets, finding a planet similar to Jupiter in mass and orbital distance might indicate places where Earth−like planets could be found.

After 15 years of observations, an extrasolar planet with an orbital distance similar to Jupiter´s was detected in 2002. This planet, orbiting the star 55 Cancri in the constellation Cancer, orbits at approximately 5 AU. However, the planet has a mass about 4 times that of Jupiter, and this larger mass may affect the inner solar system in ways our own Jupiter does not.

In addition, this solar system contains two other Jupiter−mass planets in tight orbits around their star: one at .115 AU, the other at .241 AU. These inner gas giants suggest there probably aren´t any terrestrial planets within the star´s habitable zone.

Still, scientists are optimistic about finding other Jupiter−mass planets at similar orbital distances in the near feature. Such solar systems will be prime candidates for NASA´s Terrestrial Planet Finder, a space−born telescope designed to take visual images of Earth−mass planets. The Terrestrial Planet Finder is due to be launched sometime between 2012 and 2015.

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