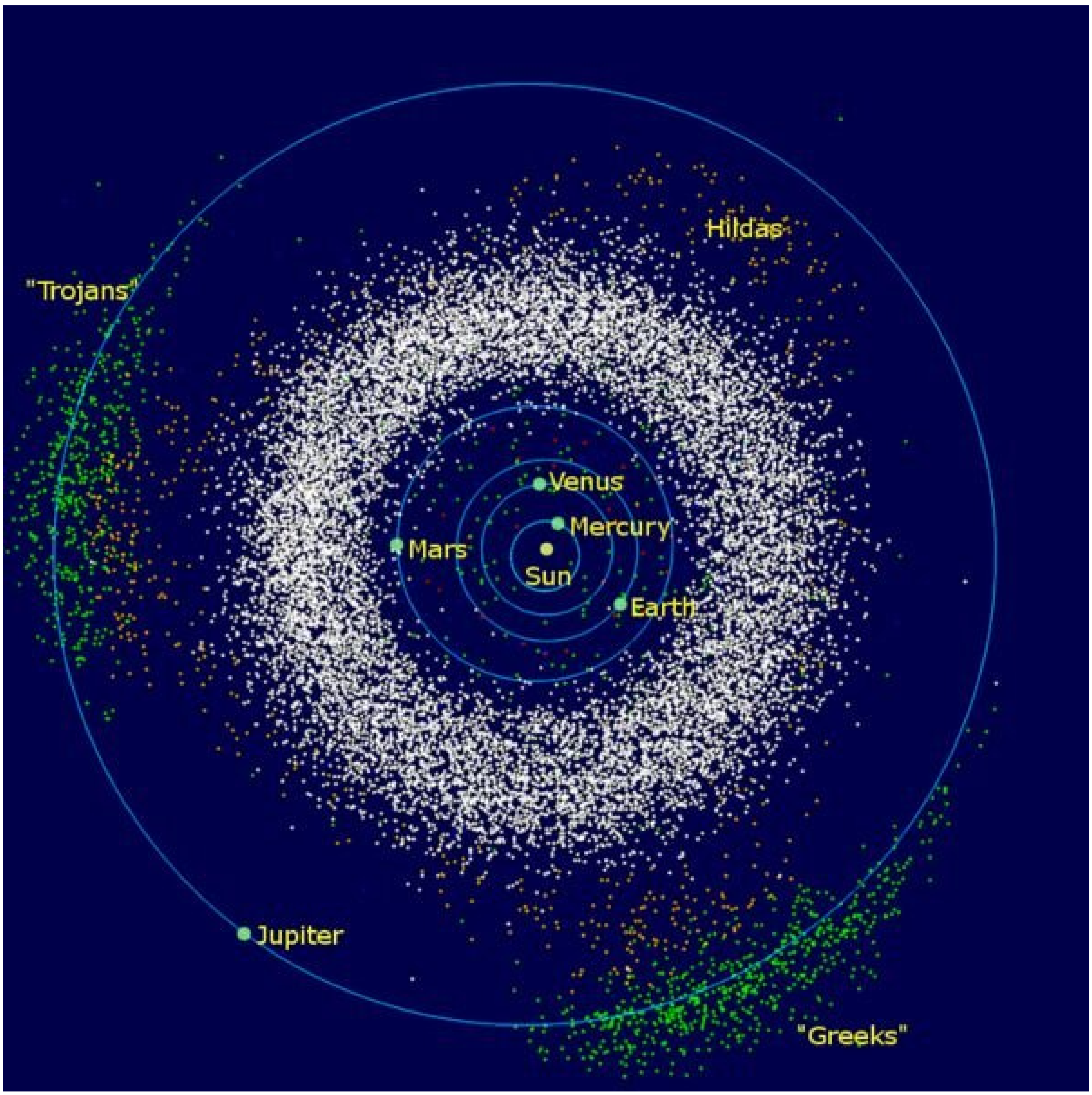
# Asteroids are dangerous, but they might also be the key to life on Earth

February 10 2022, by Evan Gough



This image shows the inner solar system, from the sun to Jupiter. It also includes the asteroid belt (the white donut-shaped cloud), the Hildas (the orange "triangle" just inside the orbit of Jupiter), the Jupiter trojans (green), and the near-Earth asteroids. The group that leads Jupiter is called the Greeks, and the trailing group is the Trojans. Credit: Mdf at English Wikipedia, Public Domain

Trying to piece together the appearance of life on Earth is a little like looking through a kaleidoscope. There are competing theories for where Earth's water came from, and there's incomplete evidence for how the moon formed and what role it played in life's emergence. There are a thousand other questions, each with competing answers. Sometimes, contradictory research is published within days of each other.

But that's nature, and that's part of the thrill of science. There's rigorous determination behind all the evidence and inquiry, and the kaleidoscope calms down over time. Order emerges, and the picture becomes clearer.

Asteroids are one of the moving pieces in the kaleidoscope. An asteroid impact caused the most dramatic extinction in Earth's history. But they may have delivered some of Earth's water and the basic chemistry for life. Their impacts may have created niches for life, too. Asteroids are dangerous but also beneficial. Like many things in nature, it's all about the amount.

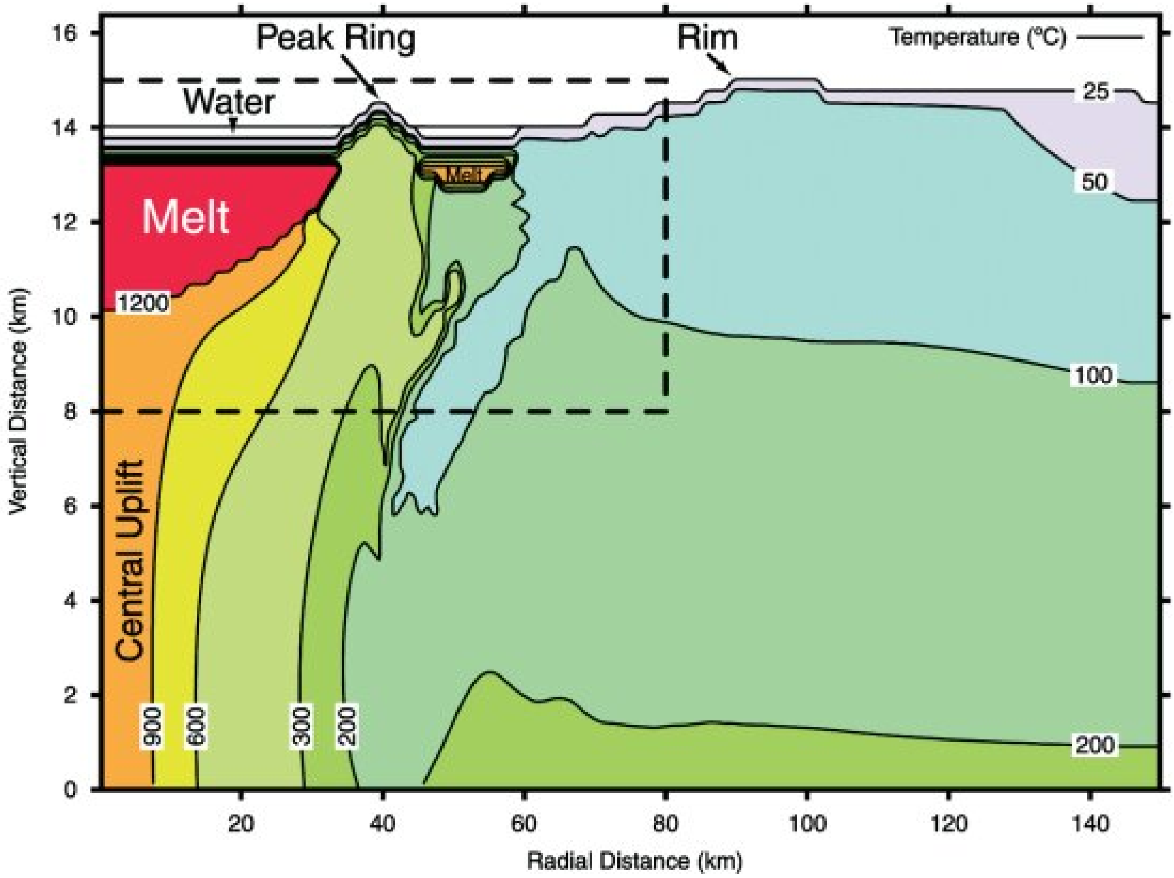
A new research paper looks at other solar systems to see if they have asteroid belts. If they do, the asteroids in those belts could contribute to habitability on planets in those systems. The paper is "Asteroids and life: How special is the solar system?" and it's available on the pre-print site arxiv.org. The lead author is Rebecca Martin, an associate professor in the Physics and Astronomy Department at the University of Nevada, Las Vegas.

It's enticing to look at our neighbors in the solar system and come to simple conclusions. The asteroid-blasted surfaces of Mercury, the moon, and Mars look like they've had the life battered right out of them (if any of them ever hosted any life.) But simple conclusions often come back to haunt us, and that's true of asteroids.

Asteroid impacts may have given life on Earth a helping hand. Their impact craters were new types of habitats, and habitat variety can be good for life. Asteroid impacts can create systems of hydrothermal vents underground that can aid life. The Chicxulub impact that ended the dinosaurs created a vast system of hydrothermal vents that lasted over one million years and chemically and mineralogically modified a giant chunk of the Earth's crust. Chemical and mineralogical variety can be good for life.

Asteroid impacts created clays that may have played a critical role in developing simple organic molecules like formaldehyde and more complex molecules like RNA. Asteroid impacts may have been essential for the transition from chemistry to biology. Their impacts could've changed Earth's atmosphere into something more conducive to life when their iron cores reacted with ocean water to release hydrogen. The resulting atmosphere may have paved the way for the emergence of organic molecules.

Nature keeps rotating the kaleidoscope, and scientists keep peering into it.




This figure is a model of the temperature at the Chicxulub impact site based on borehole samples. The impact created a system of hydrothermal vents that lasted over one million years. The impact was apocalyptic for dinosaurs, but other similar impacts further back in Earth's history may have aided life's emergence. Credit: Abramov and Kring 2007

"Given the mounting evidence for the potential role of asteroids in the emergence of life on Earth, it is not unreasonable to assume that asteroid impacts on a terrestrial planet (in the habitable zone of its host star) are a necessary condition for the emergence of life and to study the consequences of this assumption," the authors explain.

In our solar system, asteroids are concentrated in the asteroid belt. If asteroids help enable life's emergence, then asteroid belts might be necessary for life to emerge on exoplanets in other solar systems. Or, at the very least, helpful.

But the mere presence of an asteroid belt in other solar systems isn't enough. There must be a mechanism that disturbs the belt and sends the asteroids crashing into planets. In our solar system, that means the giant planets Jupiter and Saturn and the orbital resonances and relationships between them and the asteroid belt.

"Since in the solar system, the v6 secular resonance has been shown to have been important in driving these impacts, we explore how the masses and locations of two giant planets determine the location and strength of this secular resonance," the authors write.

An orbital resonance is when orbiting bodies exert regular and periodic influence on each other. There are different types of orbital resonances, and they're expressed in ratios. Astronomers call the relationship between Saturn and the asteroid belt the secular v6 resonance. Secular means long-term, and v6 denotes the sixth planet from the sun. The secular v6 resonance slows the eccentricity of asteroids until they cross Mars' orbital path. Eventually, they're ejected from the belt by a close encounter with Mars.

But for enough asteroids to collide with Earth, the only habitable planet in the inner solar system, another giant planet is needed. In their paper, the authors write, "…a second giant planet is required, and its location must fall within a relatively narrow radial region in order for sufficient asteroids to collide with the habitable planet…"

The study is based on three simulation runs of our solar system. In each run, the Earth is in its present orbital location. But each run had a different arrangement of giant planets.

The simulation outcomes shed some light on asteroid behavior in our solar system. Run 1 is our current solar system. Run two had the giant planets close to the 2:1 MMR (mean motion resonance,) and run 3 had no second planet. Earth faces the highest number of asteroid strikes in our current system. In the system with the second planet near to the 2:1 MMR, far more asteroids are ejected from the belt, but the fewest number strike Earth. With no second giant planet, the results are middling.

| Simulation | $a_J$/au | $a_S$/au | $N_{Sun}$ | $N_{Earth}$ | $N_{J,S}$ | $N_{eject}$ | $N_{outcome}$ | $N_{remain}$ | $P_{collide}$ |
|---|---|---|---|---|---|---|---|---|---|
| run1 | 5.2 | 9.58 | 288 | 126 | 9 | 1398 | 1821 | 8179 | 0.07 |
| run2 | 5.2 | 8.25 | 1033 | 30 | 10 | 6154 | 7227 | 2773 | 0.004 |
| run3 | 5.2 | - | 54 | 14 | 12 | 1050 | 1130 | 8870 | 0.01 |

This table from the study shows the details of each of the three simulation runs. Columns 2 and 3 are the orbital radii of Jupiter and Saturn, respectively. The 4th, 5th and 6th columns show the number of asteroids that hit the sun, the Earth, Jupiter and Saturn. Column 7 shows the number of asteroids that have been ejected. Column 8 shows the total number of asteroids with an outcome (either collision or ejection). The 9th column shows asteroids remaining in the simulation, and column 10 shows the probability of an Earth collision for the asteroids that have an outcome. Credit: Martin et al. 2022

## What can these outcomes tell us about other stellar systems?

"Examining observed exoplanetary systems with two giant planets, we find that a secular resonance within the asteroid belt region may not be uncommon," they write. "Hence, the solar system is somewhat special, but the degree of fine-tuning that may be necessary for the emergence of life is not excessive."

The authors examined data from NASA's Exoplanet Archive. They extracted exoplanet systems with two known giant planets greater than 0.1 Jupiter masses. The planets also had to have semimajor orbital axes greater than two au. The table below presents their sample.

The authors point out that this list of solar systems with giant planets is anything but complete. It's challenging to detect massive planets on wide orbits in distant planetary systems. But the fact that 4 out of 13 systems have orbital resonances in the right place to disturb asteroids out of their belts is still interesting. Of course, we don't know yet how common asteroid belts are or their nature and composition in other systems. Our only guide is our own solar system. If our solar system is any guide, then asteroid belts in other systems might straddle the frost line.

The authors discuss two distant solar systems targeted in the search for life around M-dwarf (red dwarf) stars.

The first is the well-known TRAPPIST-1 system. It has seven exoplanets, including three Earth-like planets in the star's potential habitable zone. There's no evidence that the TRAPPIST-1 system has an asteroid belt, but the authors point out that "…our own asteroid belt in an exoplanetary system would not be observable." The TRAPPIST-1 system could have a Kuiper Belt equivalent. Previous research shows that an external perturber could send objects from that belt crashing into the planets in the habitable zone.

The second system they mention is our neighbor Proxima Centauri. It has two detected exoplanets, and one of them is Earth-sized and in the habitable zone. Again, the presence of an asteroid belt is uncertain, though there's some evidence of a cold dust belt. There are also hints of another massive planet in the system, but that's far from certain. Previous research examined the potential for asteroid strikes on Proxima b, an exoplanet in the habitable zone of the red dwarf Proxima Centauri. In that paper, the authors examined the rate of sterilizing asteroid impacts, but that's just the other side of asteroid impacts. They can both sterilize planets and enable life.

| Host star | $M_*/M_\odot$ | $N_p$ | P1 | P2 | $a_1$/au | $a_2$/au | $m_1/M_J$ | $m_2/M_J$ | $a_{\nu_6}/a_1$ | $e_1$ | $e_2$ | $w/a_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| The Sun | 1.00 | 8 | J | S | 5.20 | 9.58 | 1.00 | 0.30 | **0.37** | 0.049 | 0.052 | 0.025 |
| HD 34445* | 1.07 | 6 | b | g | 2.07 | 6.36 | 0.82 | 0.38 | 0.10 | | | |
| HD 141399 | 1.07 | 4 | d | e | 2.09 | 5.00 | 1.18 | 0.66 | 0.20 | | | |
| 47 Uma | 1.06 | 3 | b | c | 2.10 | 3.60 | 2.53 | 0.54 | **0.53** | 0.032 | 0.098 | 0.021 |
| OGLE-2006-BLG-109L | 0.51 | 2 | b | c | 2.30 | 4.50 | 0.73 | 0.27 | **0.32** | - | 0.15 | 0.066 |
| UZ For | 0.70 | 2 | c | b | 2.80 | 5.90 | 7.70 | 6.30 | **0.33** | 0.05 | 0.04 | 0.037 |
| NN Ser* | 0.54 | 2 | d | c | 3.43 | 5.35 | 2.30 | 7.33 | 0.92 | | | |
| HD 66428* | 1.05 | 2 | b | c | 3.47 | 23.0 | 3.20 | 27.0 | 0.094 | | | |
| HU Aqr AB | 0.88 | 2 | b | c | 3.60 | 5.40 | 6.00 | 4.00 | 0.80 | | | |
| HD 30177 | 0.99 | 2 | b | c | 3.70 | 9.89 | 8.62 | 7.60 | 0.17 | | | |
| HD 50499 | 1.31 | 2 | b | c | 3.83 | 9.02 | 1.64 | 2.93 | **0.30** | 0.266 | 0.0 | 0.10 |
| OGLE-2012-BLG-0026L* | 1.06 | 2 | b | c | 4.00 | 4.80 | 0.15 | 0.86 | 0.90 | | | |
| HR 8799 | 1.61 | 4 | e | d | 16.4 | 24.0 | 10.0 | 10.0 | 0.77 | | | |
| PDS 70 | 0.76 | 2 | b | c | 20.0 | 34.0 | 3.00 | 2.00 | 0.65 | | | |

There’s a lot of data in this table, but the main takeaway is in the 10th column, bolded numbers. The bolded numbers are systems where the v6 resonance is located in the asteroid belt or where they think an asteroid belt would be. Credit: Martin et al. 2022

Astronomers are getting better and better at finding exoplanets as methods and technology improve. Soon, we may be able to detect asteroids belts, too. The James Webb Space Telescope will help with that.

It's too soon to conclude that other solar systems have asteroid belts.

There's a lot we don't know. "We caution that our conclusions are based on the classical picture of solar system formation," the authors say in their conclusion.

The giant planets may have done more than send asteroids toward Earth. They may have helped create the asteroid belt. We don't know if that's necessary for other systems.

The authors didn't touch on the migration of giant planets and how that may have affected everything. Those migrations may have depleted the asteroid belt. Would the same be true in other systems?

The JWST and other powerful observatories and telescopes will constrain some of the ideas and models we use to understand asteroid belts and their impacts on potentially habitable planets.

Once we have better constraints, the kaleidoscope will settle down, and things will become clearer.

**More information:** Rebecca G. Martin, Mario Livio, Asteroids and life: How special is the solar system? arXiv:2202.01352v1 [astro-ph.EP], arxiv.org/abs/2202.01352

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