Exoplanets—habitable or not?

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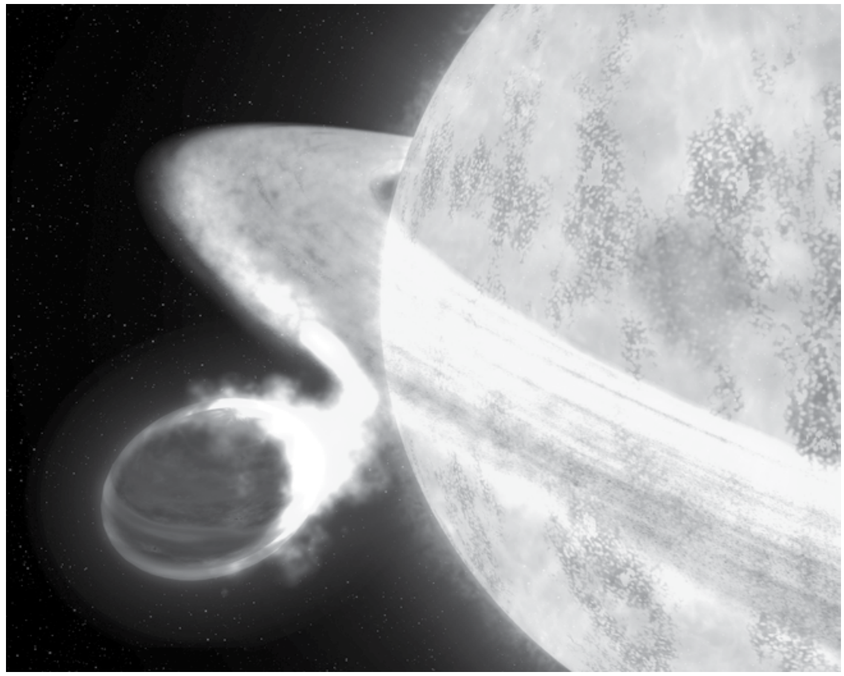


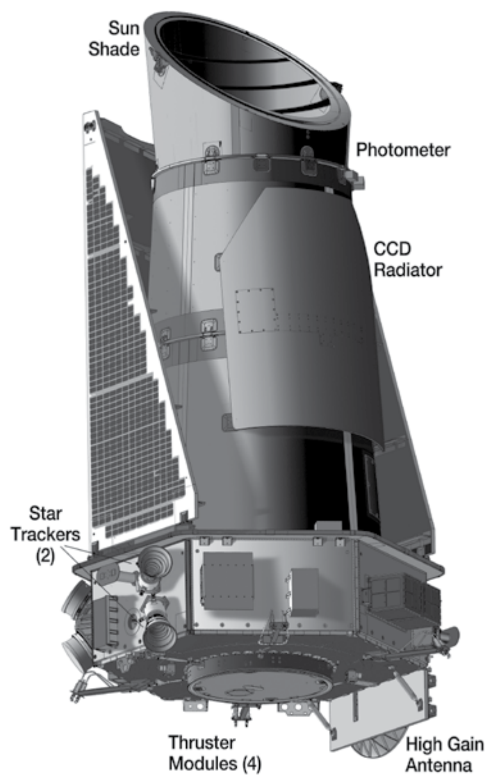
Figure 1. Artist's rendering of exoplanet WASP-12b. Gases and even metals are escaping the planet and falling into the star. Graphic from NASA and Wikipedia.

Research on extrasolar planets gives much attention to finding Earth-like planets in what is referred to as the 'habitable zone' (HZ) of their stars. On one hand, modern techniques have had much success in finding exoplanets, yet a new challenge to habitability has presented itself. Often scientists search for dwarf stars to be candidates for habitable exoplanets. This is because a larger star would have its HZ farther from the star and the planets would be harder to find and detect, being farther from the star. Thus, exoplanets closer to their stars are easier to detect. There are now nearly 300 exoplanets that are considered in the HZ of their stars, as listed in the NASA Exoplanet Archive.[1] This generally implies the planet has a temperature range that is conducive to the presence of liquid water and possibly carbon dioxide in the planet's atmosphere. Yet, it has been reported recently in a paper by Luger and Barnes that from models of the formation of these stars and their exoplanets, water could have been eliminated from these exoplanets early in their history.[2]

The Kepler space telescope provided many new exoplanet candidate objects through its precise transit measurements. As of 9 May 2015, NASA's Exoplanet Archive[1] lists 8,662 exoplanet candidates from the Kepler space telescope detections. These possible exoplanets are known as Kepler Objects of Interest (KOI). Though the pointing mechanisms of Kepler partially failed in 2013, the Kepler spacecraft has been put back into service though in a somewhat less precise mode. Much extrasolar planet research has been turned towards confirming the detections and analyzing the results. Confirmed exoplanets from all detection methods are now 1,832 from the NASA Exoplanet Archive.[1] Of the KOI objects, the NASA archive lists 297 that are considered to be in the habitable zone. In the NASA Exoplanet Archive this is based solely on the radiation equilibrium temperature being between 180 Kelvin and 310 Kelvin. This is the temperature that an object would be at the given distance from the star based on the amount of energy it receives and reradiates.

The habitable zone

The term 'habitable zone' has at least two definitions. The first is based on the equilibrium temperature of the planet primarily and has been called the 'optimistic habitable zone'. In our solar system this would encompass the region from just inside the orbit of Venus to just outside the orbit of Mars. Another concept for the HZ has been termed the 'conservative habitable zone' or CHZ. The CHZ is defined based on climate models and the greenhouse effect in a planet's atmosphere. Thus the inner edge of the HZ would be where there is sufficient carbon dioxide, water, or other greenhouse gases in the atmosphere that there would be a runaway greenhouse effect. This would lead to the planet being too hot for life, similar to Venus. Then the outer boundary of the HZ would be at a distance where carbon dioxide in the planet's atmosphere would freeze and fall onto the surface.[3] A recent source from 2013 put forward a modification of this 'conservative habitable zone' that specifically applies to cool dwarf stars such as class M dwarfs.[4] M dwarf stars are very common and are one of the most common types where exoplanets are detected. The number of M dwarf stars has generated a lot of optimism that there could be many possibly habitable Earth-like planets in our galaxy. It is indeed likely that there could be many exoplanets in our galaxy within the habitable zone based on the conservative definition above.



Graphical layout from NASA

Figure 2. Cross-sectional design of the Kepler Space Telescope photometer instrument. Kepler is equipped with a 0.95 m (37 in) aperture Schmidt-type telescope and a 1.4 m (55 in) primary mirror. Kepler does not take photos but looks for dips in the light curve of a star that indicates a planet could be passing in front of it (called a transit).

But this in itself is no guarantee that life would be possible on such planets.

In 2014 Luger and Barnes brought attention to a new issue that makes habitability less likely assuming naturalistic formation models for stars and planets.[2] For dwarf stars, exoplanets tend to be very close to the star. According to stellar models, young stars are brighter and this can lead to processes that either drive water off the planet or cause photolysis of water vapour. M dwarf stars in particular tend to have very intense emission in the X-ray and extreme ultraviolet portions of the electromagnetic spectrum. The ultraviolet part can cause dissociation of water vapour. Secondly, if an exoplanet formed a significant atmosphere it is likely that the greenhouse effect would be intense due to the intensity of the radiation from the star. The runaway greenhouse effect for planets very close to the star could be extremely intense and could also cause the dissociation of water vapour. Intense flare events could also have devastating effects for living things on exoplanets so near their stars.

The effect of the dissociation of water could be the build-up of oxygen in the exoplanet atmosphere (or external to the planet). The detection of oxygen around exoplanets could be mistaken by scientists as evidence of life, such as from the photosynthesis of plants. Thus, the combination of high temperatures near the star and destruction of water could make an exoplanet utterly barren of life, even though it is observed in the habitable zone. The authors make this statement about the problem, “In general, we find that the initial phase of high luminosity may compromise the habitability of many terrestrial planets orbiting low-mass stars.”[2]

The migration of a planet from a distance inward towards the star would not change the basic problem because of the timeframes involved. Exoplanets near their stars would usually be assumed to have migrated inward because of the presence of a disk near the star as the system was forming, or from the influence of other planets that may no longer be present. During the inward migration the planet may not be hot enough to lose water. But as a planet migrates inward tidal forces tend to round its orbit. Then a debris disk could dissipate away or fall into the star and this would stop the migration. Thus the planet could come to a stable orbit near the star where it may be very hot. The migration would typically be thought of as lasting several million years at most and there would still be long periods of time near the star that could ‘burn off’ the water.

Conclusion

The study of extrasolar planetary systems is very relevant when one considers how these systems are different from our own. Our solar system is designed to be a safe and stable ‘neighbourhood’ for Earth, and Earth is designed for our benefit. In a young-age creation view, the exoplanets may have been created essentially as they are with little loss of water since creation. On the other hand, it is also possible that there could be significant loss of water and atmospheric gases from an exoplanet, even in several thousand years. Water vapour, oxygen, and other substances have been detected escaping from some exoplanet atmospheres into space. Naturalistic origins theories tend to come with their own liabilities. The changes in exoplanet atmospheres over time is an issue worth watching to see what develops from further research.

References

1. NASA Exoplanet Archive, exoplanetarchive.ipac.caltech.edu. This research has made use of the NASA Exoplanet Archive, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program.
2. Lugar, R. and Barnes, R., Extreme water loss and abiotic O_2 buildup on planets throughout the habitable zones of M Dwarfs, *Astrobiology* **15**(2):119–143, 2014; arxiv.org/abs/1411.7412.
3. Batalha, N.M., Exploring exoplanet populations with NASA’s Kepler Mission, *PNAS* **11**(35):12647–12654, 2 September 2014, doi: 10.1073/pnas.1304196111 .
4. Kopparapu, R.K., A revised estimate of the occurrence rate of terrestrial planets in the habitable zones around Kepler M-dwarfs, *The Astrophysical J. Letters* **767**(1):1–5, 10 April 2013, doi: 10.1088/2041-8205/767/1/L8 .