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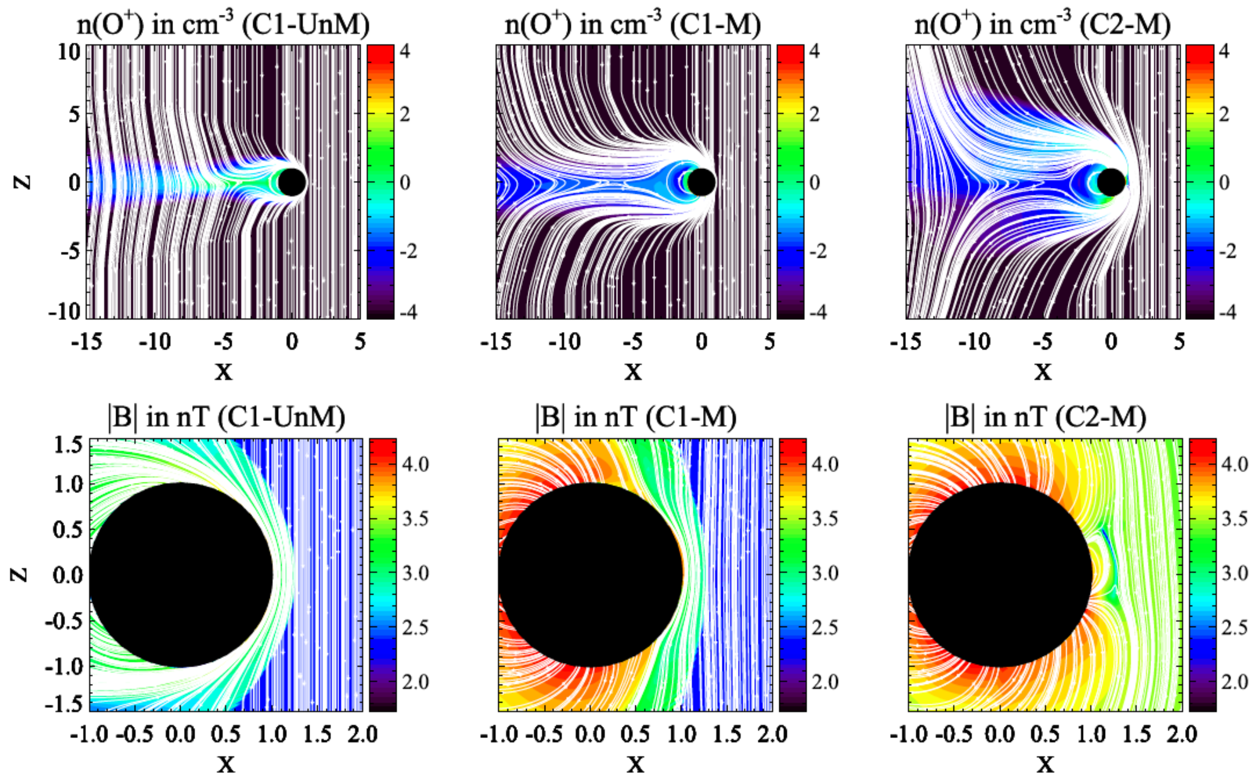
Are “Habitable” Exoplanets Really Habitable?

New findings show that the stellar wind from red dwarfs may induce such catastrophic atmospheric loss from otherwise habitable exoplanets that life could not evolve.

ExoPlanet and Red Dwarf Solar Flare, by Chuck Carter.



The upper panel of the image shows how planetary oxygen ions escaping from the planet during planet-stellar wind interaction for both unmagnetized and magnetized cases. The bottom panel shows how the plasma boundaries compressed by the strong stellar wind pressure. The planetary magnetic field has a shielding effect to some extent. If the plasma boundaries become too close to the planet body, then the stellar wind can directly strip the atmosphere away, like currently unmagnetized Mars.

The Science

It is mostly assumed that life might be found on "exoplanets," planets orbiting stars other than our sun, if there is liquid water on them. The classical definition of the habitable zone is the region around a star where a planetary surface can support liquid water, being neither too hot nor too cold. Temperature and pressure are related, and so an atmospheric pressure comparable to that of Earth's is also required.

But this definition of "habitability" largely ignores the impact of the stellar wind, the stream of charged particles released from the star, and the explosive release of plasma and magnetic fields on the erosion of an exoplanet's atmosphere.

In the last decades, the study of exoplanets has witnessed a tremendous creative surge. Research now encompasses a wide range of fields, ranging from astrophysics (the study of plasmas in the universe), to heliophysics (the study of our sun and solar system), and atmospheric science (how the particles and energy that are routinely emitted from the sun interact in the thermosphere, the highest layer of the atmosphere, and the ionosphere within the layer).

We study the exoplanet called Proxima Centauri b (PCb). This is the closest planet to the red dwarf Proxima Centauri, the closest star to the sun (4.2 light years away) in the constellation Centaurus, with a mass about 1/8th that of the sun. PCb has a mass slightly larger than that of the Earth, and it rotates around the star every 11 days.

For our study, a multi-species, magnetohydrodynamic model was developed that solves the individual continuity equation for H^+, O^+, O_2^+ and CO_2^+ ,, together with one momentum and one energy equation for the group of ions, and includes charge exchange and photoionization. In contrast to previous models, we include a self-consistent calculation of the ionosphere, with the lower boundary of the simulation extending down to 100km above the planetary surface, which is close enough to accurately capture the effects of the stellar wind and activity on the planet's atmosphere. A non-uniform, spherical grid is used to accurately capture the multi-scale physics.

The Impact

This work studied the impact of exoplanetary space weather on the climate and habitability, and offers fresh insights into the habitability of exoplanets, especially those orbiting so-called M-dwarfs (stars much smaller and cooler than the sun), such as Proxima Centauri b (PCb) and the TRAPPIST-1 system in the constellation Aquarius.

The evolution of life takes billions of years. Our results indicate that PCb and similar exoplanets are generally *not* capable of supporting an atmosphere over sufficiently long timescales when the total stellar-wind pressure is high. It is only if the pressure is sufficiently low, and if the exoplanet has a sufficiently strong magnetic "shield" like that of the Earth's magnetosphere, can the exoplanet support an atmosphere suitable for supporting life. To further complicate matters, the habitability zone of M-dwarfs evolves over time. If the stellar wind pressure was higher at earlier epochs, this would have led to increased escape rates. Hence, even with a shielding magnetic field, the atmosphere may have eroded too soon (e.g., after "only" millions of years).

Summary

This work sheds light on atmospheric losses from M-dwarf exoplanets in the habitability zone, and clearly delineates the role of the planetary magnetic field that protects a planet, and the strength and other characteristics of the stellar wind. We have shown that Venus-like exoplanets are characterized by high atmospheric escape rates when the magnetic field is weak, but these values are reduced to an extent when a dipole magnetic field exists. Hence, Proxima Centauri b may undergo significant atmospheric erosion over billions of years, in both the magnetized and unmagnetized cases.

Predicting the habitability of far distant planets must be taken with due caution since there are many inherent uncertainties. Future missions, such as the James Webb Space Telescope (JWST), will be essential for getting more information on stellar winds and exoplanet atmospheres, thereby paving the way for more accurate estimations of stellar-wind induced atmospheric losses.

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Publications

C. F. Dong, M. Lingam, Y. J. Ma, and O. Cohen, “Is Proxima Centauri B habitable? -- A study of atmospheric loss”, *The Astrophysical Journal Letters*, **837**, L26 (2017). arXiv:1702.04089

Related Links

For the TRAPPIST-1 exoplanets,

C. F. Dong, M. Jin, M. Lingam, V. S. Airapetian, Y. J. Ma, B. van der Holst, “Atmospheric escape from the TRAPPIST-1 planets and implications for habitability”, submitted, arXiv:1705.05535

For ocean planets:

C. F. Dong, Z. G. Huang, M. Lingam, G. Toth, T. I. Gombosi, A. Bhattacharjee, “The dehydration of water worlds via atmospheric losses”, *The Astrophysical Journal Letters*, **847**, L4 (2017). arXiv:1709.01219