A water detection technique to shortlist potentially-habitable exoplanets

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So far, NASA's Kepler has led to the discovery of 2 325 exoplanets. But clearly not all of them are habitable. To help detect suitable candidates, identify the range of atmospheric conditions on planets with water and shed light on how planetary magnetic fields originate and evolve, the HOTMOL project is devising new tools relying on spectro-polarimetry.

How do planetary magnetic fields originate and evolve and how efficiently do they shield the atmospheres from dehydration by the stellar wind? Detecting magnetic fields in planetesimals and exoplanets will provide a new dimension in our understanding of habitability.

To qualify as an exoplanet, a planetary object needs to meet four criteria: a mass or minimum mass equal to or lighter than 30 Jupiter masses; the presence of a host star; sufficient follow-up observations and validation to rule out the possibility of facing a false positive; and the availability of such information along with other orbital and physical properties in peer-reviewed publications.

Identifying an Earth-like planet that can sustain life is, however, a whole other story. Life as we know it notably requires liquid water, an element that current technologies are not capable of detecting.

To overcome this problem, the EU-funded HOTMOL (Hot Molecules in Exoplanets and Inner Disks) project uses spectro-polarimetry in the hope of detecting hot molecules—water vapour and other volatiles—on exoplanets and in the inner part of protoplanetary disks.

The HOTMOL project is led by Prof. Dr Svetlana Berdyugina from Albert Ludwigs University of Freiburg in Germany. She outlines how the project will lead to sensitive methods for detecting hot molecules on exoplanets, and how such results are fundamental for advancing current understanding of the star+planet system.

How can the presence of hot molecules inform us about the presence of water on specific exoplanets?

We find hot water molecules in stars and hot Jupiters, at temperatures of thousands of degrees, and cold water molecules and ice in interstellar clouds and the outskirts of the Solar system, at only a few degrees Kelvin.

To create life as we know it, liquid water on the planetary surface is a prerequisite. But detecting liquid water on exoplanet surfaces, and especially on a potentially-habitable Earth-size planet, is not yet possible. However, what we do know is that, if water exists on the surface, it must also be present in the planetary atmosphere in the form of water vapour, evaporating under stellar irradiation together with other related molecules. These hot molecules are key to defining the habitability of planets, and devising sensitive methods to detect them on exoplanets is the first step towards detecting extraterrestrial life.

What kind of methods did you come up with to detect these hot molecules?

The major problem in studying exoplanetary systems is to separate the planetary light from the outshining stellar light. To achieve this, the HOTMOL team employs a smart double-differential technique called spectro-polarimetry.

Firstly, the planet signal is distinguished in spectral lines, because particular molecules may not be present in stellar spectra or can be shifted in velocity with respect to stellar lines. Secondly, planetary spectral lines become conspicuous in polarised light near certain orbital phases. Thus, the lines would appear and disappear in polarised light periodically as the planet orbits the star. This approach increases detection sensitivity by at least an order of magnitude, and it is also a sanity check for the detection of molecules using only spectroscopy.

The spectral and polarisation signals combined provide unique information on physical conditions in both exoplanets and near-stellar planetesimals. An unexpected spin-off of this project was employing the same technique for detecting photosynthetic organisms on distant planets. We have measured polarised spectra of terrestrial plants and bacteria and computed spectra of Earth-like planets with photosynthetic biosignatures. We showed that our technique is much more sensitive than others to such biosignatures. It is possible that such signals can be searched for with current large telescopes in a few nearby planetary systems, especially around Alpha Centauri A and B stars, if planets were to be found there one day.

How do these techniques compare to current ones?

Current observations employ only unpolarised flux and spectra to detect exoplanets. The HOTMOL team leads the effort to power these studies with polarised light. As explained earlier, the sensitivity is already an order of magnitude better in polarised light, but it is still being improved by implementing new optics and electronics technologies.

Moreover, polarised flux variations are observable independently of whether the planet transits the star or not, which provides this technique with a potential for application to a much larger sample of exoplanets. A spectral cross-correlation technique employed by others has proven its potential to detect exoplanets. Enhancing it with polarisation measurements will deliver a wealth of information on the physics of their atmospheres.

What would be the technical prerequisites to using these tools in exoplanet research?

While developing novel techniques is our first challenge, implementing them for a broad usage is our final goal. In particular, having a dedicated observing facility such as a network of telescopes equipped with high-sensitivity polarimeters is an important prerequisite.

Together with our collaborators at the University of Turku (Finland) and the University of Hawaii (USA) we have constructed several copies of our high-sensitivity polarimeters which are employed in telescopes around the world: in La Palma and Tenerife (Canarias), Mauna Kea and Haleakala (Hawaii), and at the end of this year also in Tasmania. We are also members of the PLANETS telescope consortium (Polarized Light from Atmospheres of Nearby Extra-Terrestrial Systems) together with the Hawaii (USA) and Tohoku (Japan) Universities. This telescope to be constructed at Haleakala will be one of the dedicated facilities in our network.

Unambiguous detection of life on exoplanets requires a much larger facility. The first steps will be perhaps made with the 30m-class telescopes, such as the ESO E-ELT to be built in Chile, but systematic studies of life distribution in the solar neighbourhood will require a 100m-class facility such as the Colossus and Exo-Life Finder (ELF) telescopes to which we contribute science cases.

What do you still need to achieve by the end of the project?

During the four years of the project we have developed many theoretical tools and obtained and analysed a lot of observational data. The last year of the project is dedicated to finalising many publications which are now being prepared by team members. Towards the end of the fifth year we will organise an international conference and school on hot molecules and biosignatures in exoplanets, where we will present our results and provide the community with tutorials on how to use our tools and data.

When and how will these tools be made available to the community?

Making our theoretical tools available for use by a broader community is one of HOTMOL's major goals. We have developed a dedicated website where our tools can be run online, even using a mobile phone. They now include computations of molecular magnetic properties, molecular polarised spectra, exoplanetary transits and eclipses, polarised reflected light from exoplanets, and stellar scattered polarisation. We continue adding more tools for exoplanetary studies and will maintain this website beyond the project end. Our resources also include data obtained with our instruments. The use of the tools is free for everybody via online registration.

More information: Project website: www.hotmol.eu/

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