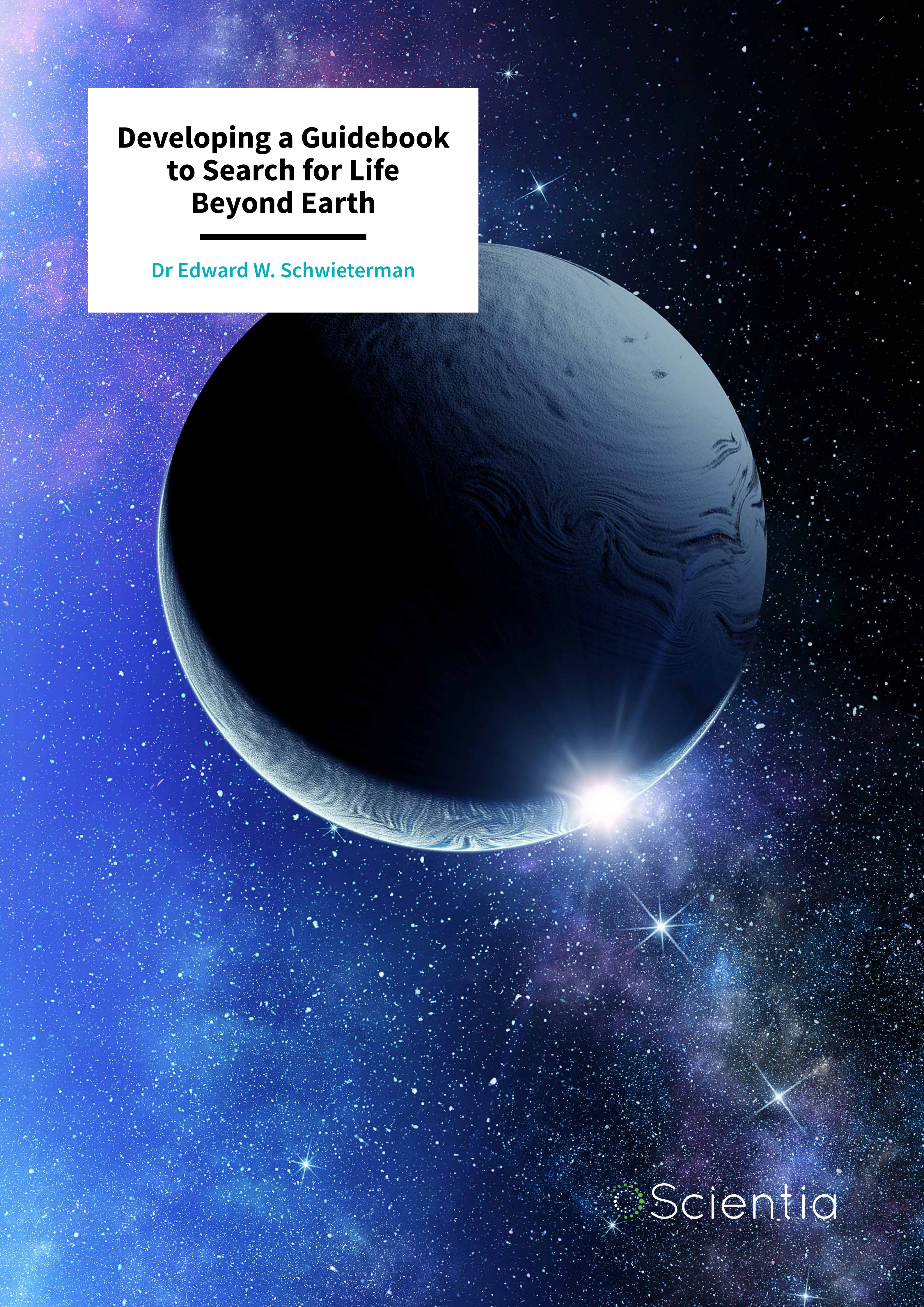
# Developing a Guidebook to Search for Life Beyond Earth

Dr Edward W. Schwieterman



Scientia

# DEVELOPING A GUIDEBOOK TO SEARCH FOR LIFE BEYOND EARTH

Are we alone in the universe? Searching for life beyond our Solar System is one of the most ambitious efforts humans have ever undertaken. Because we do not have the ability to travel to distant exoplanets, scientists must rely on indirect clues that could help us find extraterrestrial life. **Dr Edward Schwieterman** and his colleagues at the University of California, Riverside, have been developing advanced methods to determine the habitability of planets and detect the elusive signs of life from afar.

**Where is Everyone?**

Beyond our protective atmospheric blanket, space is a vast and harsh frontier. Is our world – with its mild temperatures, breathable air, and abundant life – unique in the universe? Searching for other habitable environments and extraterrestrial life is a deeply compelling scientific objective. Answering this question with certainty would fundamentally reshape our understanding of our place in the cosmos.

Humanity has made significant strides towards finding an answer during the last four decades. We have progressed from not knowing whether planets existed outside our own planetary system, to identifying over 4300 planets orbiting other stars – so-called 'exoplanets'. This number is increasing almost daily, with new discoveries facilitated by observatories such as NASA's space telescope TESS. TESS and the Kepler mission before it identify exoplanets by the characteristic dimming effect they have on a host star's light as they cross in front of it. Some of these exoplanets are small, rocky planets like Earth, and may possess conditions conducive to the presence of life.

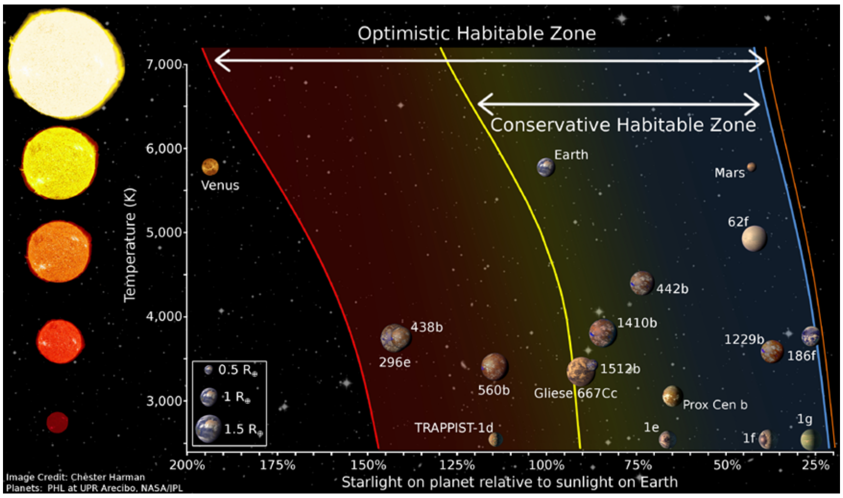
These discoveries offer unprecedented opportunities to search for extraterrestrial life. However, we are exceedingly unlikely to be able to reach these distant planets in the foreseeable future. As such, it is imperative to develop technologies that can identify life unambiguously across the immense gulf of interstellar space.

We are currently transitioning from simply detecting exoplanets towards detailed investigations of their atmospheres and surfaces. Writing the guide to finding life among our Sun's neighbouring stars is Dr Edward Schwieterman and his colleagues in the Department of Earth and Planetary Sciences at the University of California, Riverside. Dr Schwieterman's research group uses a range of experimental and modelling techniques to determine the potential habitability of planets and plausible signatures of life.

**Seeking a Habitable Zone**

Having discovered thousands of exoplanets, the next stage in the search for extraterrestrial life is to identify those with potentially habitable environments. Above all else, this means liquid water – believed to be a key requirement for life. The conventional 'habitable zone' is the range of distances around a star in which liquid water can exist. If an exoplanet is too close to a star, surface water will evaporate, and if it is too far from the star, surface water will freeze.

Atmospheric greenhouse gases, such as carbon dioxide, play a role in stabilising planetary surface temperatures from the hotter inner edge (where the star's light is brightest and warmest) to the cooler outer edge (where less star light reaches). However, advanced Earth-like life, such as animal life, is unlikely to be able to survive throughout the whole range of the habitable zone. 'To sustain liquid water at the outer edge of the conventional habitable zone, a planet would need more than ten thousand times the carbon dioxide in Earth's atmosphere today,' explains Dr




Schwieterman. 'That's far beyond the levels known to be toxic to human and animal life on Earth.'

Additionally, most of the exoplanets discovered so far orbit around stars that are quite different from our own Sun. Smaller, cooler, red stars constitute over 70% of the stars in our Milky Way galaxy. These red dwarf stars are believed to promote the accumulation of toxic gases, such as carbon monoxide, in planets' atmospheres. Dr Schwieterman and his research team developed an advanced model that incorporated these factors, to produce an illustrative 'Habitable Zone for Complex Life', with a far more restricted range than the conventional habitable zone. Outside of this range, within the limits of the conventional habitable zone, the only life that could exist is likely to be microbial.

However, the template of life on Earth is not necessarily inclusive of all evolutionary pathways that could exist throughout the universe. As-yet unknown compensatory mechanisms may allow advanced life to exist in the extreme conditions found on other planets. Although our definition of life is limited by our understanding, our search efforts are aided by the laws of physics and chemistry, which are the same throughout the universe. Finding even microbial life on an exoplanet would be an extraordinary discovery.

### Seeking a Habitable Planet

Being within the Habitable Zone does not necessarily guarantee that an individual planet is habitable. The next problem is how we would affirmatively detect habitability and life on a distant exoplanet. Clues about the conditions on planetary surfaces can be gained through imaging techniques. However, even the best images of distant exoplanets have all the information collapsed into a single point of light.

Images of Earth taken by the space probe Voyager 1 provide a representative example. Taken from approximately 6 billion kilometres away, the Earth appeared – as described by popular science communicator Carl Sagan – as a 'mote of dust suspended in a sunbeam.' By comparison, the nearest exoplanets are over 40 trillion kilometres from us. But these tiny 'motes of dust' can still provide useful clues into the exoplanet's conditions. For example, this light can be split into its component wavelengths, revealing the fingerprints of individual molecules that constitute the atmosphere, such as oxygen and carbon dioxide. In addition, a characteristic 'glint' can signal the presence of liquid such as water on the planet's surface.

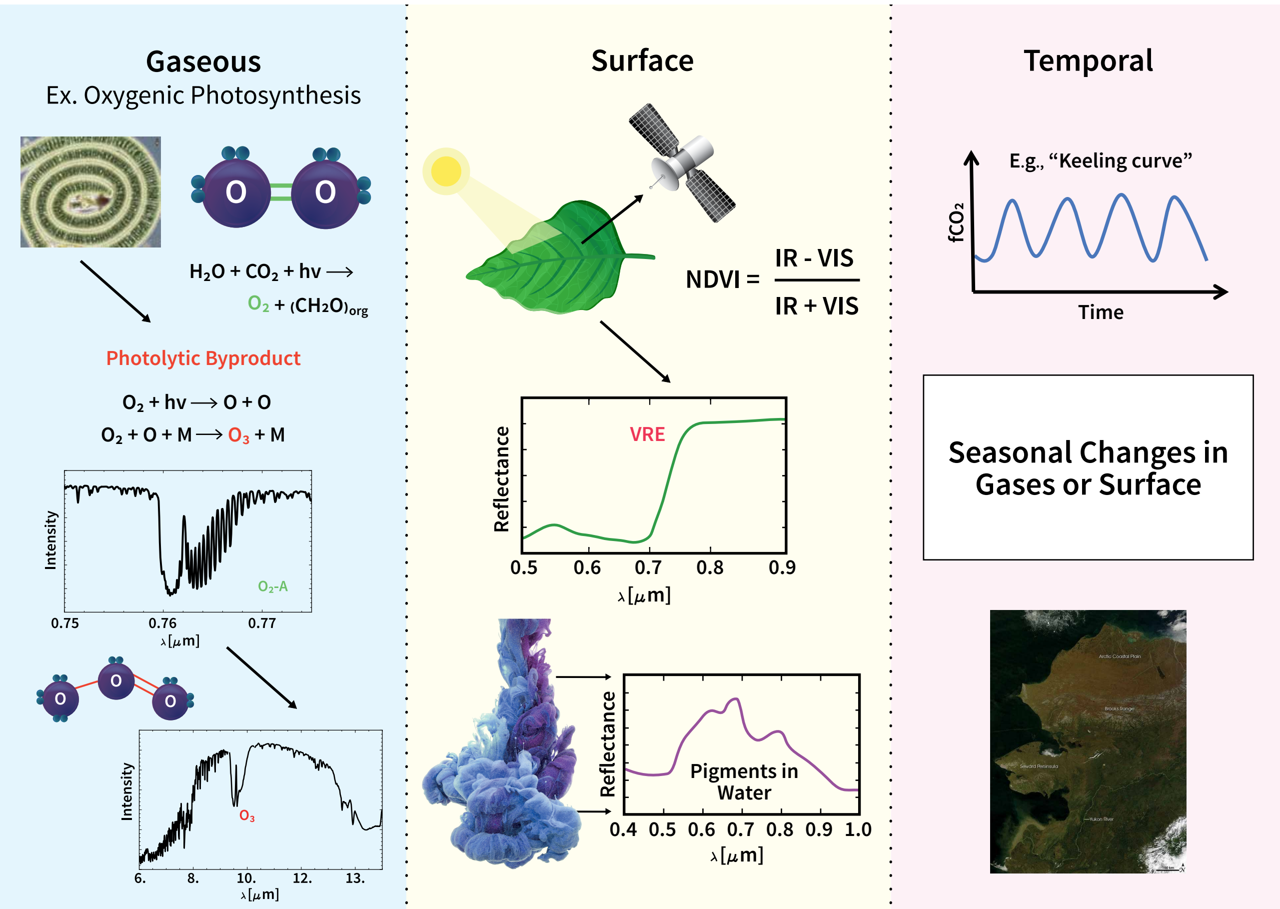
The intensity and colour of the light reflected by the planet can also help scientists determine the surface composition of the world. Finding signatures suggesting both surface water and atmospheric carbon dioxide could suggest that the planet's surface maintains hospitable conditions.

### Seeking a Sign of Life

The next step in the search is to find positive indicators of life – called 'biosignatures'. Biosignatures are substances, objects or patterns that are produced by life and can be separated from potential non-living sources. They can be separated into surface, atmospheric or gaseous, and temporal signatures.

Oxygen is often considered a gaseous biosignature because plants, algae and other microbes produce enormous amounts of it, replenishing the oxygen lost to geological processes. However, non-living processes can also be a primary source of oxygen for planets orbiting other stars, potentially leading to 'false positives' for extraterrestrial life. Therefore, interpreting the presence of oxygen as a biosignature depends largely on the environmental context. Dr Schwieterman suggests that multiple gaseous biosignatures could provide more compelling evidence of a legitimate biosignature, particularly if these gases are in a 'chemical disequilibrium', and would otherwise react without a constant source.

Breaking the signals of light reflected by the planet's surface into component wavelengths, indicative of the absorption and reflection properties of a planetary surface, can help scientists find surface biosignatures. For example, plants on Earth absorb most red and blue light, and reflect green (hence their green appearance), along with infrared light. Absorbing red light and reflecting invisible infrared light gives rise to the 'vegetation red-edge effect' – the characteristic sudden increase in reflected light near the infrared range. This phenomenon is used to map vegetation over the Earth's surface, and could be used to detect plant-like life on exoplanets.




Temporal biosignatures are time-dependent cycles in gaseous or surface biosignatures. We observe this in the seasonal changes on Earth. For example, vegetation growth in the spring and summer causes a decrease in the concentration of atmospheric carbon dioxide in the Northern Hemisphere, which then increases again as plants die back during the autumn and winter.

The signs of life on exoplanets may not be an exact replica of what we observe on Earth, though it is the only example we have available of a habitable and inhabited world. By digging deep into our planet's history, Dr Schwieterman has gained a glimpse into multitudes of possible life-bearing conditions that could help us link our observations of exoplanets with possible biosignatures. 'Over billions of years of persistent habitability, the prevailing chemical state our planet's atmosphere and surface has undergone extraordinary shifts including from an anoxic, hazy, orange world three billion years ago to the oxygen-rich pale blue dot we take for granted today,' he explains.

Dr Schwieterman and his colleagues describe a 'Purple Earth' from billions of years ago, before the development of photosynthesis observed in modern plants. Some microbes from this period used a different compound called retinal – similar to the compound found in the retina of the human eye – which reflects red and blue light, hence its purple appearance. A 'green-edge effect' could be a possible biosignature for exoplanetary life that uses his compound to collect light energy.

**There's Still No Place Like Home**

The challenge remains to identify irrefutable biosignatures to aid our search for extraterrestrial life. 'Practically, prospective exoplanet biosignatures will be only tentative signs of life with other possible explanations,' says Dr Schwieterman. 'However, we can systematically gain confidence by obtaining more and more information about the target planet and its properties, and thereby slowly rule out all explanations other than life. Finding life elsewhere will require patience.' One possible shortcut to this process would be to find evidence of 'technosignatures' – unambiguous signals of an advanced or technological civilisation, sought by projects such as 'Search for Extraterrestrial Intelligence' (SETI).

We are perhaps far more likely to find evidence of microbial extraterrestrial life. Dr Schwieterman's research has helped to inform the development of new techniques for the search for biosignatures, and his suggestions – such as the inclusion of ultraviolet detectors on future telescopes to better detect ozone – could prove invaluable.

With much work still to do in the search, we may be waiting a while to get an answer to the age-old question. In the meantime, Dr Schwieterman leaves us with a thought: 'I think showing how rare and special our planet is only enhances the case for protecting it; as far as we know, Earth is the only planet in the universe that can sustain human life.'

# Meet the researcher

**Dr Edward W. Schwieterman**
Department of Earth and Planetary Sciences
University of California, Riverside
Riverside, CA
USA

Dr Edward W. Schwieterman currently holds the position of Assistant Professor of Astrobiology in the Department of Earth and Planetary Sciences at the University of California, Riverside. He previously earned his PhD in Astronomy and Astrobiology at the University of Washington, before continuing his postdoctoral research at UC Riverside and the Georgia Institute of Technology. Dr Schwieterman's main research interests include observing Earth as an exoplanet and modelling the chemistry and spectral appearance of terrestrial planet atmospheres. His research includes exploring the nuances of planetary habitability and identifying and assessing remotely detectable biosignatures. Dr Schwieterman's work has contributed to the study and design of next generation space-based telescopes, such as NASA's Large UV/Optical/IR Surveyor (LUVOIR) and Habitable Exoplanet Observatory (HabEx) mission concepts and improvements to computational models of atmospheric chemistry. In addition to his research, Dr Schwieterman aims to inspire and train the next generation of planetary scientists and astrobiologists through a range of courses, workshops, and presentations.

## CONTACT

**E:** eschwiet@ucr.edu
**W:** www.eddieschwieterman.com

## KEY COLLABORATORS

Michaela Leung and Daria Pidhorodetska, University of California, Riverside
Dr Tim Lyons, University of California, Riverside
Dr Giada Arney, Dr Shawn Domagal-Goldman and Dr Ravi Kopparapu, NASA Goddard
Dr Shil Dassarma, University of Maryland
Dr Sonny Harman and Dr Niki Parenteau, NASA Ames
Dr Victoria Meadows, University of Washington
Dr Stephanie Olson, Purdue University
Dr Sukrit Ranjan, Northwestern University
Dr Chris Reinhard, Georgia Institute of Technology

## FUNDING

NASA Interdisciplinary Consortia for Astrobiology Research (ICAR) Program
NASA Exobiology Program
UC-Mexus Program

## FURTHER READING

S Ranjan, EW Schwieterman, CE Harman, A Fateev, C Sousa-Silva, S Seager, R Hu, Photochemistry of Abiotic Habitable Planet Atmospheres: Impact of New H2O Cross Sections, The Astrophysical Journal, 2020, 896, 148.

EW Schwieterman, CT Reinhard, SL Olson, CE Harman, TW Lyons, A limited habitable zone for complex life, The Astrophysical Journal, 2019, 878, 19.

S DasSarma, EW Schwieterman, Early evolution of purple retinal pigments on Earth and implications for exoplanet biosignatures, International Journal of Astrobiology, 2018, 20, 241.

SL Olson, EW Schwieterman, CT Reinhard, A Ridgwell, SR Kane, VS Meadows, TW Lyons, Atmospheric seasonality as an exoplanet biosignature, Astrophysical Journal Letters, 2018, 858, L14.

EW Schwieterman, et al., Exoplanet Biosignatures: A Review of Remotely Detectable Signs of Life, Astrobiology, 2018, 18, 663.

EW Schwieterman, TW Lyons, CT Reinhard, Signs of life on a global scale: Earth as a laboratory for exoplanet biosignatures, The Biochemist, 2018, 40, 22.

UC RIVERSIDE
UNIVERSITY OF CALIFORNIA