INTERVIEW

WITH DR. MAIKEL RHEINSTADTER

THE ORIGINS OF LIFE LAB AT MCMASTER UNIVERSITY

Interviewers: Ishita Paliwal[1] and Caitlin Reintjes[2]

1. McMaster University, Honours Integrated Sciences, Class of 2021
2. McMaster University, Honours Integrated Sciences, Class of 2021

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ABSTRACT

One of the many novel scientific studies being conducted at McMaster University focuses on uncovering the origins of life, specifically, how the first cells were formed. Dr. Maikel Rheinstadter, from the Department of Physics and Astronomy, has developed a planetary simulator that effectively replicates environmental conditions both on Earth and other potentially habitable planets in the solar system. His team works to discern how the first cells may have developed on these planets by investigating the idea that water-based life was formed in warm, volcanic ponds. The following interview provides further insight into Dr. Rheinstadter's research project.

Dr. Maikel Rheinstadter, Ph.D.

Dr. Maikel Rheinstadter is a professor and researcher in the Department of Physics and Astronomy at McMaster University, where he carries out groundbreaking research in the field of membrane biophysics.

► Please briefly describe your research. How is your planetary simulator able to effectively replicate Earth's conditions?

We are trying to understand how the first basic cells may have formed on Earth and other potentially habitable planets. To do so, we must understand how life came to be on Earth. Although there are different theories for the origins of life, we follow the idea that life was formed in warm little volcanic ponds, in rough and extreme conditions of various temperatures, acidity, and salinity. In these volcanic fields, there are biological molecules. Seasons, changes of temperature, and humidity played a significant role in the polymerization of RNA, DNA, proteins, and peptides. That is why we built this lab which has a planet simulator (simulation chamber) that can mimic early Earth conditions at different ages of the planet. For instance, the machine simulates how conditions on the Earth's surface changed from a lack of atmosphere to the development of oxygen.

► Is the planet simulator specific to Earth?

No, the simulator was built to investigate water-based life: it controls temperature (-20 to 120˚C), humidity (0 to 100% RH), radiation (145 to 1000 nm), pressure and atmosphere. The simulator can, for instance, create a desert which is hot and dry, a rainforest that is hot and humid, make it freeze to create arctic conditions, or create various forms of precipitation, such as rain, snow, and ice.

► Why focus on water-based life?

Life on Earth has developed in water, so water-based life simulations are essential to understanding where more complex organisms, such as humans, come from. There are also other proposals of life-based on different atomic elements. However, hydrogen, carbon, and oxygen are the most abundant elements, both on Earth and everywhere in the universe.

► What do you attribute to your laboratory's success in researching the origins of life?

For a long time, scientists favoured the proposal that life was formed inside the oceans, and that the earliest forms of life came out of the ocean, upon formation. Laboratory experiments tried to recreate life in water, however, never succeeded. When we tried this, it was hard to make chemical reactions occur underwater, especially, in salt water. For biological systems, salt molecules are disruptive to biological structures such as membranes. A few years ago, we started to work with Dr. David Deamer from the University of Santa Cruz, who brought forward the idea that life was formed in warm little ponds. He could show that when cycles in temperature and humidity are added to warm ponds, RNA was polymerized from single nucleotides. We started to collaborate and developed techniques to see them and visualize how they organize and react. These first results and publications formed the basis of the origins of Life Lab. Essentially, we did these preliminary experiments without a planet simulator and could present evidence that these conditions can polymerize the basic building blocks of life.

► In previous interviews, you stated that basic cells were found to form in the simulator after just a few days, which is much faster than you had expected. How long did you originally think it would take for these cells to form? Why do you think they appeared faster than hypothesized, and what does this tell us about the origins of life?

The simulator can mimic a day in a few minutes. When I designed the simulator, I felt this was important because as we know, it took a long time for life to form on Earth. The first occurrence of biological molecules to the creation of first cellular life took half a billion years, so we expected the process to be very slow. However, when we performed the first experiments on the planet simulator, we observed evidence of basic cells and traces of RNA surprisingly quickly. The overall process of forming these elements turned out to be much faster than expected, which was surprising and totally unexpected for everybody. The sequence from using nucleotides to form RNA and making simple cells happened at the same time.

► Do you think such rapid cell development occurred because you had provided the necessary conditions in the simulator? Whereas on early Earth it would have taken time for the conditions to come together?

One potential explanation is that we probably found a 'sweet spot' in the conditions, which makes cell development more likely to occur. The problem is that while basic cells form relatively easily, not all cellular materials may be biologically relevant and functional. A lot of cells may not be biological cells; they may look like cells but may, for instance, not be able to reproduce. In each pond, one may find a particular genetic code which may or may not be functional. In order to produce functional cells, I think that we would have to combine the content of different ponds. As a result, the genetic material would also be combined because each pond may have produced different codes. This process likely took a lot longer.

> "We observed evidence of basic cells and traces of RNA surprisingly quickly"

► Recently your lab has succeeded in creating protocells, which are cells that are not yet considered to be alive as they are not fully biochemically functional. What are the specific differences between protocells and real cells that permit the latter to retain the capacities of metabolism and replication?

Three basic components are required for metabolism and replication; a cell membrane and cell wall, enzymes, and genetic material to allow functioning as a biological system. Some molecules we produce in the simulator must function as enzymes and must promote the appropriate biological reactions in order to support life. Then, the RNA we synthesize must carry information such as a protein sequence, otherwise, the RNA cannot function. The cell membrane must retain some functionality to maintain the circulation of nutrients and waste into and out of the cell. Each component of a cell needs functionality. The prediction of functionality depends on the chemical and physical composition.

► **What proof would you be looking for in order to change the classification of protocells into fully fledged cells?**

That is something we are currently working on. Our first big accomplishment was to show that these cells form relatively easily and we must assume that this process is happening in the universe every second, millions of times. The number of potentially habitable planets that have conditions similar to Earth is in the millions, if not billions. So, every second these protocells form somewhere in the universe, which I find totally mind-blowing. However, not every planet may progress as Earth did and is capable of combining different protocells in a way that results in a living system. Now that we have these first protocells, the next step is to prove or disprove that these cells are capable of replication, demonstrating selectivity, and initiating some sort of metabolism.

► **How could your lab's current findings be used to understand how life has formed in the rest of the solar system?**

The fundamental question for us is, "Where did life come from on Earth?". However, many people are more interested in the question: "Are we alone in the universe?". The simulator is made to mimic different planets with varying compositions. We are able to simulate planets that orbit different stars with varying degrees of light intensity, frequency, and amounts of ultraviolet (UV)/infrared (IR) light in order to mimic any potentially habitable planets that astronomers find. The simulator is computer controlled, so we can add planetary rotation, the path of the planet around its star, temperatures, lengths of seasons and days, and the intensity of daylight to the simulation.

► **More laboratories are now planning the construction of other planet simulators to further study the origins of life. Are there any improvements you would make to the current planet simulator in order to test future hypotheses?**

Right now, we are still learning how to use the planet simulator. It is the first of its kind and not only a huge science project, but also a huge engineering accomplishment. It is very difficult to build such a machine and ensure that it is functional. Right now, the simulator does exactly what we want it to do. In the next generation of simulators, one might want to include analytical tools, for instance, to see how cells grow in situ. We could also attach a spectrometer within and search for biological signatures as a function of biogeochemical cycles.

► **What is the biggest challenge that your team has faced so far in your research?**

Every step of the way was challenging, otherwise, someone else would have done this already. At every step, we had to overcome obstacles and limitations by improving techniques and tools.

► **What tools do you use other than the planet simulator?**

We developed and improved tools to detect cells and determine if RNA was formed. These tools and techniques had to be developed along the way, otherwise we could not prove or disprove anything that has happened within the simulator.

► **Did you have to develop the tools from scratch or improve existing tools?**

We had to develop these tools from scratch and are still improving these tools. For example, humans are composed of DNA, so there are many tools that exist that allow us to work with DNA. However, there are very few tools to work with RNA and particularly short strands of RNA that are only a few nucleotides (20-30) long.

► **Finding the origins of life is a very complex process. How has forming an interdisciplinary research team aided in this process?**

Having an interdisciplinary team did not help– it was essential. An interdisciplinary research question requires an interdisciplinary research team. For example, in the latest paper on antibiotic resistance, our team worked with colleagues and utilized techniques and materials from their disciplines, such as biochemistry and medicine.

► **What tools do you use other than the planet simulator?**

Next, we want to work towards fully functional protocells and prove they work as biological cells. We also want to identify a transcription mechanism for RNA through a non-enzyme-driven process, since they would not be available under prebiotic conditions. These are all fundamental and big questions ahead of us.

CONCLUSION

The research carried out by Dr. Rheinstadter and his team is interdisciplinary and revolutionary. They are seeking to answer what is potentially one of the largest questions in science to date, by working to uncover the origins of life. This research will not only satisfy scientific curiosity but could also have promising applications to the fields of medicine and neuroscience, making it a ground-breaking field with almost limitless potential.