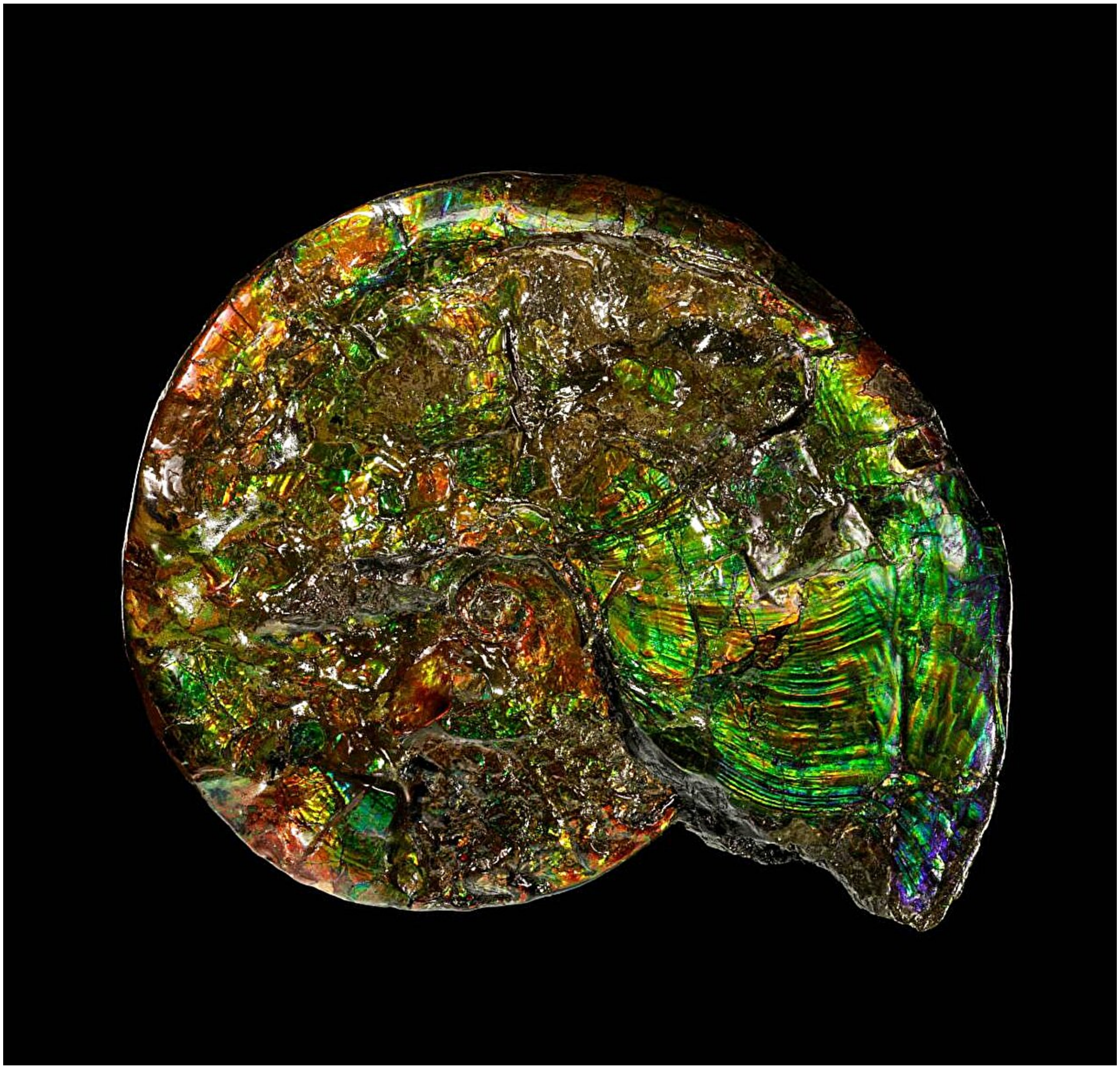
Scientists and philosophers identify nature's missing evolutionary law

October 16 2023



As Earth formed, new geologic processes, especially those related to the interaction of hot fluids with rock during igneous activity and plate tectonics, gave birth to over 1500 new mineral species (4.55 to 2.5 billion years ago). At 2.5 billion years ago, emerging biological life introduced oxygen into the atmosphere. This was a time of pivotal change, when photosynthesis began and the interaction of iron with oxygen-based minerals changed ancient life, providing the blueprint for our future evolution, together with minerals. Credit: Dr. Robert Lavinsky

A paper published in the *Proceedings of the National Academy of Sciences* describes "a missing law of nature," recognizing for the first time an important norm within the natural world's workings.

In essence, the new law states that complex natural systems evolve to states of greater patterning, diversity, and complexity. In other words, evolution is not limited to life on Earth, it also occurs in other massively complex systems, from planets and stars to atoms, minerals, and more.

It was authored by a nine-member team— scientists from the Carnegie Institution for Science, the California Institute of Technology (Caltech) and Cornell University, and philosophers from the University of Colorado.

"Macroscopic" laws of nature describe and explain phenomena experienced daily in the natural world. Natural laws related to forces and motion, gravity, electromagnetism, and energy, for example, were described more than 150 years ago.

The new work presents a modern addition—a macroscopic law recognizing evolution as a common feature of the natural world's complex systems, which are characterized as follows:

- They are formed from many different components, such as

atoms, molecules, or cells, that can be arranged and rearranged repeatedly
- Are subject to natural processes that cause countless different arrangements to be formed
- Only a small fraction of all these configurations survive in a process called "selection for function."

Regardless of whether the system is living or nonliving, when a novel configuration works well and function improves, evolution occurs.

The authors' "Law of Increasing Functional Information" states that the system will evolve "if many different configurations of the system undergo selection for one or more functions."

"An important component of this proposed natural law is the idea of 'selection for function,'" says Carnegie astrobiologist Dr. Michael L. Wong, first author of the study.

In the case of biology, Darwin equated function primarily with survival—the ability to live long enough to produce fertile offspring.

The new study expands that perspective, noting that at least three kinds of function occur in nature.

The most basic function is stability—stable arrangements of atoms or molecules are selected to continue. Also chosen to persist are dynamic systems with ongoing supplies of energy.

The third and most interesting function is "novelty"—the tendency of evolving systems to explore new configurations that sometimes lead to startling new behaviors or characteristics.

Life's evolutionary history is rich with novelties—photosynthesis evolved when single cells learned to harness light energy, multicellular life evolved when cells learned to cooperate, and species evolved thanks to advantageous new behaviors such as swimming, walking, flying, and thinking.

The same sort of evolution happens in the mineral kingdom. The earliest minerals represent particularly stable arrangements of atoms. Those primordial minerals provided foundations for the next generations of minerals, which participated in life's origins. The evolution of life and minerals are intertwined, as life uses minerals for shells, teeth, and bones.

Indeed, Earth's minerals, which began with about 20 at the dawn of our solar system, now number almost 6,000 known today thanks to ever more complex physical, chemical, and ultimately biological processes over 4.5 billion years.

In the case of stars, the paper notes that just two major elements—hydrogen and helium—formed the first stars shortly after the big bang. Those earliest stars used hydrogen and helium to make about 20 heavier chemical elements. And the next generation of stars built on that diversity to produce almost 100 more elements.

"Charles Darwin eloquently articulated the way plants and animals evolve by natural selection, with many variations and traits of individuals and many different configurations," says co-author Robert M. Hazen of Carnegie Science, a leader of the research.

"We contend that Darwinian theory is just a very special, very important case within a far larger natural phenomenon. The notion that selection for function drives evolution applies equally to stars, atoms, minerals, and many other conceptually equivalent situations where many configurations are subjected to selective pressure."

The co-authors themselves represent a unique multi-disciplinary configuration: three philosophers of science, two astrobiologists, a data scientist, a mineralogist, and a theoretical physicist.

Dr. Wong said, "In this new paper, we consider evolution in the broadest sense—change over time—which subsumes Darwinian evolution based upon the particulars of 'descent with modification.'"

"The universe generates novel combinations of atoms, molecules, cells, etc. Those combinations that are stable and can go on to engender even more novelty will continue to evolve. This is what makes life the most striking example of evolution, but evolution is everywhere."

Among many implications, the paper offers:

1. Understanding into how differing systems possess varying degrees to which they can continue to evolve. "Potential complexity" or "future complexity" have been proposed as metrics of how much more complex an evolving system might become
2. Insights into how the rate of evolution of some systems can be influenced artificially. The notion of functional information suggests that the rate of evolution in a system might be increased in at least three ways: (1) by increasing the number and/or diversity of interacting agents, (2) by increasing the number of different configurations of the system; and/or (3) by enhancing the selective pressure on the system (for example, in chemical systems by more frequent cycles of heating/cooling or wetting/drying).
3. A deeper understanding of generative forces behind the creation and existence of complex phenomena in the universe, and the role of information in describing them
4. An understanding of life in the context of other complex

evolving systems. Life shares certain conceptual equivalencies with other complex evolving systems, but the authors point to a future research direction, asking if there is something distinct about how life processes information on functionality (see also https://royalsocietypublishing.org/doi/10.1098/rsif.2022.0810).

5. Aiding the search for life elsewhere: if there is a demarcation between life and non-life that has to do with selection for function, can we identify the "rules of life" that allow us to discriminate that biotic dividing line in astrobiological investigations? (See also "Did Life Exist on Mars? Other Planets? With AI's Help, We May Know Soon")
6. At a time when evolving AI systems are an increasing concern, a predictive law of information that characterizes how both natural and symbolic systems evolve is especially welcome

Laws of nature—motion, gravity, electromagnetism, thermodynamics—etc. codify the general behavior of various macroscopic natural systems across space and time.

The "law of increasing functional information" complements the 2nd law of thermodynamics, which states that the entropy (disorder) of an isolated system increases over time (and heat always flows from hotter to colder objects).

More information: On the roles of function and selection in evolving systems, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2310223120. doi.org/10.1073/pnas.2310223120

Provided by Carnegie Institution for Science

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