The Cosmic Succession Hypothesis

Did Life and Intelligence Rise Before Us? Alien Worlds, Lost Civilisations and the Evidence That Separates Fact from Fiction

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PROLOGUE

The Question That Changes Everything



Almost every point of light in this Hubble image is a galaxy, not a star.

NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University) and Z. Levay (STScI)

The night sky can make the world feel both smaller and larger at once. Familiar worries shrink beneath it; the distances between stars make our own lives seem brief. We look up and encounter a strange combination of intimacy and indifference. The same atoms that form our bodies were forged through processes older than Earth. The same physical laws that shape a raindrop govern the motion of planets and galaxies. Yet, so far as we can establish, this world is the only place where the universe has become aware of itself.

I should say where I stand before we begin. I am a sceptic who would genuinely like to be proved wrong, and I would rather lose an argument to good evidence than win it with a good story.

That last statement is both astonishing and carefully limited. Earth is the only world on which life has been confirmed. It is not proof that Earth is the only living world. Nor is the existence of planets around other stars proof that life is common. Between those two positions lies one of the most important unanswered questions in science: how often does nature cross the threshold from chemistry to life, and how often does life develop the ability to ask where it came from?[1]

The Cosmic Succession Hypothesis begins with that gap between what is known and what remains possible. It asks whether life and intelligence may be recurring features of cosmic history rather than events that happened only once. It also asks whether these processes, if they occur elsewhere, might be connected by the movement of material, the exchange of information, or the rise and disappearance of technological societies. The questions belong together, but they are not identical. Evidence that microbes could travel between planets would not establish that intelligent civilisations exist. A possible atmospheric biosignature would not demonstrate that anyone had visited Earth. A puzzling monument would not become extraterrestrial simply because its builders remain impressive to us.

That distinction is the starting point of this book. Wonder is not the enemy of rigour. In fact, wonder becomes more powerful when it is allowed to survive contact with evidence. The goal is not to make every mystery fit one explanation. It is to examine what each mystery can reasonably tell us, what it cannot tell us, and what future discovery might change our minds.

Consider the chain of events that brought us here. Stars formed from clouds of gas. Within stars and in the violent events surrounding their deaths, elements

were created and dispersed. Those elements became part of later generations of stars and planets. On at least one planet, chemistry eventually gave rise to systems capable of maintaining themselves and evolving. Life altered the atmosphere, transformed landscapes and diversified through billions of years. One branch produced organisms that developed language, mathematics, telescopes and spacecraft. Those instruments now search for worlds that might have their own histories.

Nothing in that sequence guarantees that it has happened elsewhere. We know only one example of life, and one example cannot by itself tell us the cosmic frequency of the process. But the question is no longer purely philosophical. Astronomers discover planets around other stars; planetary scientists study ancient environments on Mars and hidden oceans beneath icy moons; chemists investigate organic molecules in space and in meteorites; and researchers develop methods for assessing possible biosignatures. Scientists also search for technosignatures: potential traces of technology that might be detectable across interstellar distances.

The challenge is immense. A planet can have liquid water and still be lifeless. Organic molecules can form without organisms. A gas in an atmosphere can have biological and non-biological explanations. A strange light in the sky can be real and still have an ordinary cause. Even a genuinely extraordinary observation may be too incomplete to support a confident conclusion. Discovery requires more than a compelling story: it requires reliable data, competing explanations, tests that can be repeated, and independent scrutiny.

This book will move between scales. It will look at the chemistry of life, worlds that may once have been habitable, planets orbiting other stars, the search for intelligence, the possibility of civilisations that leave traces, and the human tendency to interpret the unknown through stories. It will also examine ancient monuments and modern unidentified anomalous phenomena, not as shortcuts to an extraterrestrial conclusion, but as examples of how evidence can be weighed when the answer is uncertain.

The phrase *cosmic succession* is used here as a framework for asking whether life, intelligence and technology could recur through time and across worlds. It is not presented as a proven scientific law, and the broad idea has precedents in existing research on astrobiology and cosmic convergent evolution. The book's

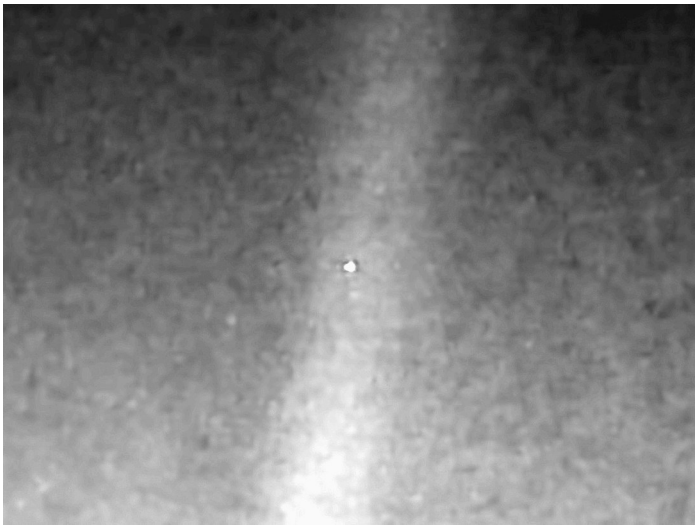
contribution therefore lies in the way it connects questions that are often discussed separately, while keeping their evidential boundaries visible.

There may be no single discovery that settles every part of the question. We might find independent microbial life and learn that biology is not unique to Earth. We might identify a convincing technosignature and learn that technology has emerged elsewhere. We might find nothing for decades, not because nothing exists, but because the distances are vast, the signals faint and the windows of detectability short. Or we might discover that the universe is stranger than our present categories allow.

The purpose of this journey is not to promise an answer before the evidence arrives. It is to prepare for the answer, whatever it may be. If Earth is one chapter in a much longer story, the first task is to learn how to read the clues without writing the ending in advance.

CHAPTER ONE

A Small World in a Vast Story



Earth, a speck less than a pixel wide, photographed by Voyager 1 from about six billion kilometres away in 1990.

NASA/JPL-Caltech

A perspective problem

There is a natural temptation to treat our own world as the centre of the story. For most of human history, the sky appeared to turn around us. The Sun crossed overhead, the stars wheeled through the night, and Earth felt stable beneath our feet. Modern astronomy did not make our world less remarkable; it changed the context in which we understand it. Earth is not the centre of the Solar System, the Sun is not the centre of the Milky Way, and the Milky Way is

one galaxy among an enormous population of galaxies in the observable universe.

I find the old line about humanity being repeatedly demoted a little too neat. Feeling small is easy. Staying curious while you feel small is the harder trick, and it is the one I am after in this book.

That sequence of discoveries is sometimes described as a series of humiliations. It can be understood differently. Each change widened the stage on which our existence could be understood. The discovery that Earth moves around the Sun did not make Earth less valuable. Learning that the Sun is one star among many did not erase the uniqueness of life as we know it. Instead, it revealed that the setting for our story is far larger than our ancestors could observe directly.

Scale, however, can mislead. The universe is vast, but vastness alone does not prove that life exists elsewhere. A huge number of opportunities may increase the chance of a rare event, yet the result depends on how rare the event is and on the conditions it requires. If the transition from non-living chemistry to life is extremely difficult, even an immense universe might contain fewer inhabited worlds than intuition suggests. If that transition occurs readily under suitable conditions, life could be widespread. We do not yet know the answer.

This distinction matters because the cosmic perspective can be used to support almost any conclusion if it is treated as a substitute for evidence. Some people argue that there must be countless civilisations because there are so many stars. Others argue that we are alone because no one has contacted us. Neither conclusion follows automatically. Both require assumptions about how often life begins, how often it develops intelligence, how long technological societies remain detectable, and whether our search methods are capable of finding them.

The universe we can observe

The observable universe is the region from which light has had time to reach us since the early universe. It is not necessarily the whole universe. Beyond the observable region, space may continue, but we cannot directly inspect it simply by pointing a telescope farther. This is an important limit: when we speak about cosmic scale, we should distinguish what observations allow us to measure from what cosmological models suggest may lie beyond our horizon.

The universe is estimated to be about 13.8 billion years old. Our Solar System formed roughly 4.6 billion years ago from material in a cloud enriched by earlier generations of cosmic processes. Earth formed from the debris surrounding the young Sun. Its subsequent history included intense impacts, the development of an atmosphere and oceans, and changes in the planet's surface and interior. The oldest evidence for life reaches deep into Earth's early history, although the exact timing and pathway of life's emergence remain subjects of research.[2]

These timescales are difficult to picture. Human recorded history occupies a tiny fraction of Earth's age; the age of our species is a sliver of that. Radio astronomy and spaceflight are newer still. Our technological ability to look for life beyond Earth has existed for only a brief moment compared with the age of the universe. A search that has lasted a few decades cannot be treated as though it has surveyed every world, every wavelength, every time period and every possible form of technology.

This is one reason the absence of a confirmed discovery must be interpreted cautiously. A search can fail because the target is absent, but it can also fail because the signal is weak, the instrument is not sensitive enough, the observation window is too short, or the target does not produce the kind of signal we expected. Non-detection is meaningful when we understand what was searched for and how completely it was searched. It is much less informative when the search space is enormous and the limits are poorly constrained.

Stars, planets and the ingredients of worlds

Stars are not merely lights in the sky. They are environments in which matter changes form, and they provide the energy that can sustain planetary climates. Planets form from the material left around young stars, and planetary systems can differ greatly from our own. Some worlds orbit very close to their stars; others follow longer paths. Some are rocky, some are gas-rich, and some occupy categories for which our Solar System offers no exact example.

The discovery of exoplanets, planets orbiting stars other than the Sun, has transformed the question of how common planets are. Astronomers have identified thousands of confirmed exoplanets, using methods including transits, radial-velocity measurements, direct imaging and gravitational microlensing. Each method has its own selection effects. A transit survey is more likely to find

planets whose orbits carry them across the face of their stars from our viewpoint. Radial-velocity surveys are sensitive to the gravitational pull a planet exerts on its star. The population we discover is therefore shaped not only by what exists but also by what our instruments can detect.[3]

That is a general lesson for the Cosmic Succession Hypothesis: the observed sample is not necessarily a complete sample. A catalogue of detected planets is a remarkable achievement, but it is not a direct census of every world in the galaxy. The same principle will later apply to possible biosignatures and technosignatures. Our knowledge is filtered through instruments, observing time, distance, background noise and the assumptions built into our search strategies.

The chemical ingredients associated with life are not confined to Earth. Organic molecules have been found in a variety of cosmic environments, and the chemistry of carbon is active in interstellar clouds, planetary atmospheres and small Solar System bodies. But the word organic can cause confusion. In chemistry, it generally refers to carbon-containing compounds; it does not mean that a substance was made by an organism. Nature can produce many organic molecules without biology. The presence of organic chemistry is a reason to investigate a world, not a declaration that it is alive.

Water is similarly important but not decisive. Life as we know it depends on liquid water, and researchers use water availability as one guide when assessing habitability. Yet a world with water is not automatically inhabited, and a world with a different environment may challenge assumptions drawn from Earth. The central scientific task is to identify environments where life could operate, determine what forms of life might leave detectable traces, and test whether those traces are actually present.

Habitability is not habitation

The distinction between habitability and habitation is one of the most important in astrobiology. A habitable environment is one in which certain conditions could support life as we understand it. An inhabited environment contains life. The first does not guarantee the second.

Imagine finding a sheltered valley with liquid water, useful chemical elements and a source of energy. Those conditions might make the valley an attractive place to search for organisms. But a geologist could establish the water history

and mineral composition without finding a single living cell. The same logic applies to Mars, icy moons and exoplanets. Evidence of ancient lakes on Mars supports the conclusion that some environments there once contained liquid water. It does not prove that life arose. A subsurface ocean on an icy moon may offer an environment worth investigating, but an ocean is not itself a biosignature.

A biosignature is a feature that may provide evidence of past or present life. It could be a fossil-like structure, a chemical pattern, an isotope ratio, or a combination of atmospheric gases that is difficult to explain without biological activity. The word 'may' matters. Potential biosignatures can have non-biological explanations, and biological traces can be altered or destroyed by geological processes. A strong claim therefore depends on context and multiple lines of evidence, not on one intriguing measurement.[4]

NASA's work on life detection explicitly treats this as a problem of interpretation as well as measurement. Researchers must understand how biological signatures form, how they persist, how they might be detected, and how non-biological processes could imitate them. A signal is only as useful as the explanation connecting it to the process that produced it. The more extraordinary the conclusion, the more carefully that chain must be tested.

This does not diminish the importance of possible discoveries. It protects them. If every ambiguous chemical signal is announced as life, public excitement may outrun the evidence and then collapse when a mundane explanation emerges. If researchers explain uncertainty clearly, a candidate signal can remain scientifically valuable even when it does not become a confirmed detection. It can sharpen instruments, improve models and identify the next observation needed to resolve the question.

One example is not a frequency

Earth is the only planet currently known to host life. That gives us a detailed case study, but it creates a statistical problem. If we want to estimate how often life begins, we would ideally compare many independent examples. At present, we have one confirmed biosphere and no confirmed second genesis. We can study the variety of life on Earth, the environments it occupies, and the chemical

and geological traces it leaves behind. We cannot yet calculate the frequency of life's origin across planets from a sample of one.

This uncertainty leaves room for very different possibilities. Perhaps life begins readily when the right ingredients and energy sources persist for long enough. Perhaps the transition requires a rare sequence of chemical events. Perhaps microbial life is relatively common but complex organisms are unusual. Perhaps intelligence capable of technology is a rare outcome, or perhaps it emerges more than once under certain evolutionary pressures. Each possibility would lead to different expectations, and each requires evidence that we do not yet possess.

The distinction between life and intelligence is especially important. On Earth, life existed for billions of years before modern humans appeared. Complex life, intelligence, language, industrial technology and detectable radio transmissions are not interchangeable milestones. A planet might host microbes for most of its history without ever developing a species that builds telescopes. Another might develop technology but remain detectable for only a short interval. A third might use technologies that produce few signals we know how to recognise.

This is where the idea of succession becomes useful as a question. Instead of treating 'life elsewhere' and 'aliens' as a single yes-or-no proposition, we can ask about stages: the emergence of life, the persistence of biospheres, the evolution of complexity, the appearance of intelligence, the development of technology and the duration of detectable traces. These stages may have different probabilities and different timescales. Evidence for one stage should not be silently promoted into evidence for the next.

Time is another kind of distance

Space is not the only barrier to contact. Time may be just as important. A technological society could emerge millions of years before another, or long after it. Even if two civilisations exist in the same galaxy, they may not overlap in time. Signals travel at finite speed, and the distances between stars are vast. A message sent from a world hundreds or thousands of light-years away would take hundreds or thousands of years to arrive. A reply would take at least as long to return.

Detectability also depends on choices and circumstances. Earth has emitted radio leakage for a little over a century, but not all of that leakage is equally powerful or easy to detect across interstellar distances. Some of our transmissions are narrow-beam communications aimed at particular receivers; others spread outward but become weaker with distance. A future civilisation might communicate using methods that do not leak strongly into space. It might also choose not to broadcast at all.

For these reasons, the absence of confirmed contact is not a simple verdict on whether others exist. It tells us that no confirmed signal has been established by the searches conducted so far. The interpretation depends on the targets, instruments, frequencies, time windows and detection thresholds involved. As searches improve, the range of possibilities constrained by non-detection may increase. But no finite search has yet examined every plausible signal from every possible source.

A similar problem arises when considering the traces of past societies. The longer the time interval, the more likely that surface structures will be eroded, buried, recycled or destroyed. Geological processes can erase evidence; they can also preserve unusual chemical or isotopic patterns. An ancient technological society, if one had existed, would not necessarily leave obvious cities intact for millions of years. But that observation is not evidence that such a society did exist. It simply identifies a problem researchers would face when asking what survives deep time.

A framework, not a verdict

The Cosmic Succession Hypothesis can now be stated more precisely. It asks whether life and intelligence may recur across cosmic time, whether their traces might be detectable, and whether material or information could connect separate worlds. The framework has three distinct parts.

The first is biological succession: life might originate independently on multiple worlds, or material relevant to life might move between them. The second is intelligence succession: intelligent and technological societies might arise more than once, with different lifetimes and different forms of detectability. The third is cosmic connection: natural processes or deliberate activity might move organ-

isms, materials or information between worlds. These ideas overlap, but none automatically proves another.

The framework must also remain open to disconfirmation or revision. If evidence shows that a proposed biosignature has a strong non-biological explanation, the biological claim should be weakened. If a supposed technosignature cannot be independently verified, it should remain unresolved rather than become proof of a civilisation. If a claimed archaeological anomaly is adequately explained by known human techniques and context, the extraterrestrial interpretation should be set aside. A hypothesis that cannot lose against evidence is not doing useful explanatory work.

It is also necessary to acknowledge earlier scholarship. Researchers have already explored cosmic convergent evolution, astrobiology and SETI. This book does not claim that the broad notion of recurring life or intelligence across the cosmos is entirely new. The physicist Lee Smolin, for example, proposed in 1992 that universes themselves might undergo a kind of natural selection, an idea he later set out for general readers in The Life of the Cosmos (1997). His proposal concerns the reproduction of universes, not the recurrence of life or civilisations, so it is a different claim from the one explored here; but it is an important earlier attempt to ask what a succession of cosmic histories could mean, and it deserves credit. Its purpose is to bring several strands of inquiry into one accessible discussion and apply a consistent method to the claims encountered along the way.

That method begins with a modest set of questions. What exactly was observed? How was it measured? What explanations could produce the same observation? What evidence would distinguish those explanations? Has the result been independently checked? What conclusion is justified, and what remains beyond the evidence? These questions can be applied to a molecule in a planetary atmosphere, a signal in a radio telescope, a geological formation on Mars, a monument on Earth or a report of an unusual object in the sky.

The scale of the universe invites bold imagination. The discipline of science asks us to make that imagination answerable to observation. The two impulses need not be enemies. A careful question can be more exciting than a premature answer because it leaves the door open to discoveries we have not yet learned to anticipate.

The view from here

We are living at a moment when the question of life beyond Earth can be investigated through several complementary approaches. Planetary missions examine the history and chemistry of nearby worlds. Telescopes study planets orbiting distant stars. Laboratory experiments explore how prebiotic chemistry might proceed. Researchers consider how life could alter a planet's atmosphere or surface, and how technological activity might create detectable traces. Each approach has limits, but together they are building a more disciplined search.

No single instrument will answer every question. A rover may investigate a local environment but cannot survey a whole planet. A telescope may measure an atmosphere but struggle to distinguish biological from geological chemistry. A radio survey may search a large area of sky but only within selected frequencies and time windows. Archaeological evidence is often local, incomplete and shaped by the preservation of materials. The strongest conclusions will come from matching the method to the question and being honest about what remains beyond reach.

The most important shift may be from asking whether the universe is 'full of aliens' to asking a sequence of more useful questions. How common are potentially habitable environments? How often does life emerge? How long can it persist? What kinds of biosignatures does it create? How often does intelligence evolve? Which technologies might be detectable, and for how long? What would count as convincing evidence that another world has its own biological history?

Those questions do not guarantee that we will find life. They do make the search clearer. A negative result can constrain a hypothesis. An ambiguous result can guide the next experiment. A confirmed discovery would change our understanding of biology and our place in the universe. The point is not to force the cosmos to answer on our schedule, but to improve the quality of the questions we ask.

For now, Earth remains our only confirmed living world. That fact is not a conclusion about the entire universe; it is the boundary of present knowledge. The chapters that follow explore how far we can push beyond that boundary while keeping a clear line between observation, interpretation and imagination.

The next question is more basic than whether intelligence exists elsewhere: what do we mean by life itself? Before looking for a second biosphere, we need to understand what counts as a living system, which signs might reveal one, and why even a promising chemical clue can have more than one explanation.