New evidence for anthropic theory that fundamental physics constants underlie life-enabling universe

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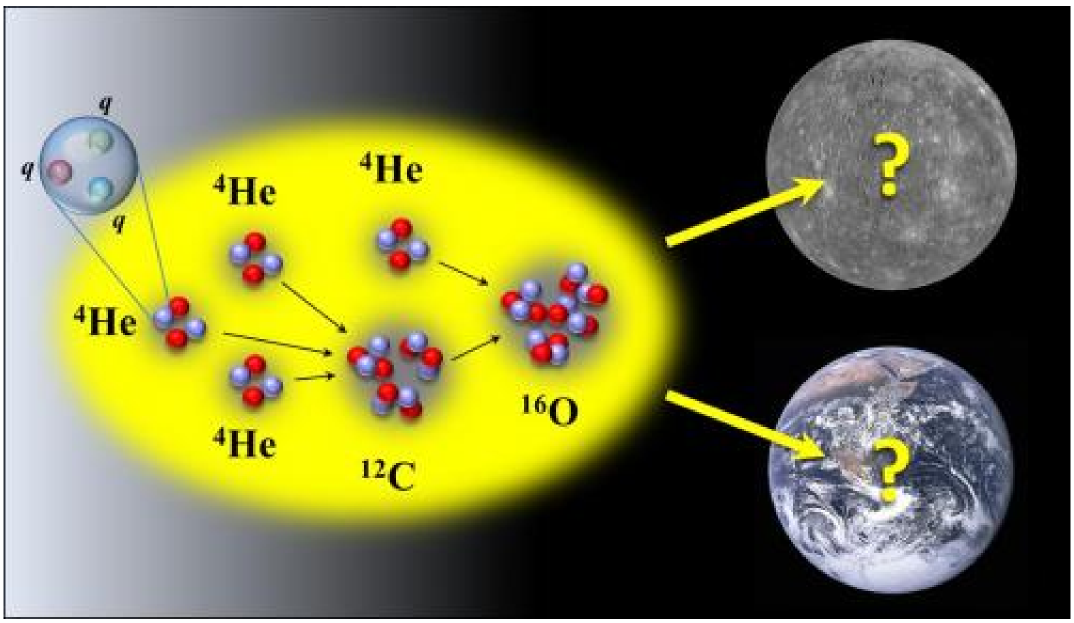

Graphical representation of the question of how fine-tuned life on Earth is under variations of the average light quark mass and α_{EM}. Image courtesy of Dean Lee. Credit: Science China Press

For nearly half a century, theoretical physicists have made a series of discoveries that certain constants in fundamental physics seem extraordinarily fine-tuned to allow for the emergence of a life-enabling universe. Constants that crisscross the Standard Model of Particle Physics guided the formation of hydrogen nuclei during the Big Bang, along with the carbon and oxygen atoms initially fused at the center of massive first-generation stars that exploded as supernovae; these processes in turn set the stage for solar systems and planets capable of supporting carbon-based life dependent on water and oxygen.

The theory that an Anthropic Principle guided the physics and evolution of the universe was initially proposed by Brandon Carter while he was a post-doctoral researcher in astrophysics at the University of Cambridge; this theory was later debated by Cambridge scholar Stephen Hawking and a widening web of physicists around the world.

German scholar Ulf-G Meißner, chair in theoretical nuclear physics at the Helmholtz Institute, University of Bonn, adds to a series of discoveries that support this Anthropic Principle.

In a new study titled "Anthropic considerations in nuclear physics" and published in the Beijing-based journal *Science Bulletin* (previously titled *Chinese Science Bulletin*), Professor Meißner provides an overview of the Anthropic Principle (AP) in astrophysics and particle physics and states: "One can indeed perform physics tests of this rather abstract [AP] statement for specific processes like element generation."

"This can be done with the help of high performance computers that allow us to simulate worlds in which the fundamental parameters underlying nuclear physics take values different from the ones in Nature," he explains.

"Specific physics problems we want to address, namely how sensitive the generation of the light elements in the Big Bang is to changes in the light quark mass m_q and also, how robust the resonance condition in the triple alpha process, i.e. the closeness of the so-called Hoyle state to the energy of 4He+8Be, is under variations in m_q and the electromagnetic fine structure constant α_{EM}," he adds.

Brandon Carter initially posited the theory: "The universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers within it at some stage."

Stephen Hawking, expert on the Big Bang and cosmic inflation, extended the dialogue on the Anthropic Principle in a series of papers and books. In "A Brief History of Time," he outlines an array of astrophysics phenomena and constants that seem to support the AP theory, and asks: "Why did the universe start out with so nearly the critical rate of expansion that separates models that recollapse from those that go on expanding forever, that even now, ten thousand million years later, it is still expanding at nearly the critical rate?"

"If the rate of expansion one second after the Big Bang had been smaller by even one part in a hundred thousand million million," he explains, "the universe would have recollapsed before it ever reached its present size."

Professor Ulf-G Meißner, in explaining his new groundbreaking study, states: "The Universe we live in is characterized by certain parameters that take specific values that appear to be remarkably fine-tuned to make life, including on Earth, possible. "

"For example, the age of the Universe must be large enough to allow for the formation of galaxies, stars and planets, and for second- and third-generation stars that incorporated the carbon and oxygen propagated by earlier exploding stars," he says.

"On more microscopic scales, he adds, "certain fundamental parameters of the Standard Model of light quark masses or the electromagnetic fine structure constant must take values that allow for the formation of neutrons, protons and atomic nuclei."

And while the Big Bang Nucleosynthesis gave rise to hydrogen nuclei and alpha particles (4He nuclei), elements widely regarded as essential to life including carbon and oxygen were only produced later, inside massive stars that burned bright and died quickly, some through a supernova explosion that spread these elements to later generations of star systems.

In one series of experiments involving intricate computer simulations on JUQUUEN at Forschungszentrum Jülich, Professor Meißner and his colleagues altered the values of light quark masses from those found in Nature to determine how great a variation would prevent the formation of carbon or oxygen inside massive stars. "Variations in the light quark masses of up to 2-3 percent are unlikely to be catastrophic to the formation of life-essential carbon and oxygen," he concludes. (please see Figure 1)

And earlier, during the Big Bang's generation of the nuclei of first two elements in the Periodic Table, he notes, "From the observed element abundances and the fact that the free neutron decays in about 882 seconds and the surviving neutrons are mostly captured in 4He, one finds a stringent bound on the light quark mass variations ... under the reasonable assumption that the masses of all quarks and leptons appearing in neutron β-decay scale with the Higgs vacuum expectation value."

"Thus," Professor Meißner states, "the Big Bang Nucleosynthesis sets indeed very tight limits on the variations of the light quark mass."

"Such extreme fine-tuning supports the anthropic view of our Universe," he adds.

"Clearly, one can think of many universes, the multiverse, in which various fundamental parameters take different values leading to environments very different from ours," Professor Meißner states.

Professor Stephen Hawking states that even slight alterations in the life-enabling constants of fundamental physics in this hypothesized multiverse could "give rise to universes that, although they might be very beautiful, would contain no one able to wonder at that beauty."

Professor Meißner agrees: "In that sense," he says, "our Universe has a preferred status, and this is the basis of the so-called Anthropic Principle."

More information: Meißner, U. "Anthropic considerations in nuclear physics" *Science Bulletin*, 2015, 60(1) : 43-54. link.springer.com/article/10.1007%2Fs11434-014-0670-2

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