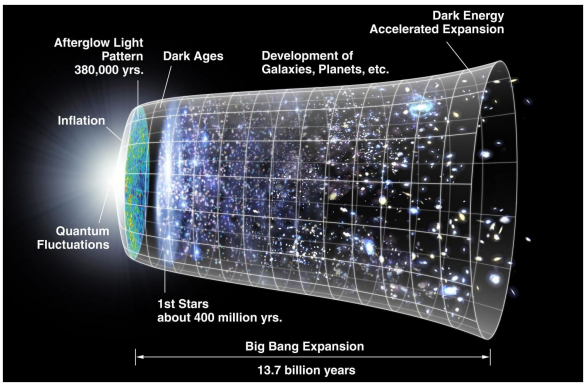
SEARCH FOR LIFE IN THE SOLAR SYSTEM AND BEYOND: A UNIFYING VISION FOR NASA SCIENCE THROUGH 2050. Heidi B. Hammel[1], Matt Mountain[1], and John M. Grunsfeld[2]. [1]AURA, 1331 Pennsylvania Avenue NW, Suite 1475, Washington, DC 20004; [2]NASA, emeritus.

Introduction. The frontiers of science today are intriguing and inspiring; grand discoveries await. We hold, today, a world-view that no generation has possessed before, whether we use it to explore the diverse array of worlds within our Solar System and beyond, to concentrate on the complexities of climate change, or to unravel the intricacies of life itself.

The Endless Frontier. We have arrived at this point in human history in no small part because of the vision set forth in 1946 by Vannevar Bush in "*Science, the Endless Frontier*" [1], and the subsequent commitment made by the United States to the scientific enterprise. As Vannevar Bush wrote, "without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world." His vision continues to resonate today with its prescience.

Because of decades of investment in America's portfolio of fundamental research, we now know the story of our Universe, and our evolution within it, to incredible detail. We know the Universe's age to better than 2%. We have measured the basic constituents of matter to unprecedented precision. We have seen the gravitational signature of two merging black holes with LIGO. And, through genetic analysis, we know that life likely emerged from a common singled-celled ancestor some 3.5 billion years ago.



Our generation revealed the remarkable story of our Universe across 13.7 billion years of cosmic history, from cosmic birth to our living Earth. Initial quantum fluctuations, through the growth of space and time, led to 100 billion galaxies. In one of those galaxies, on one small blue planet circling one of the 200 billion stars within that galaxy, RNA and DNA emerged. After a complex series of events, a species emerged that today looks out into this vast universe with unique tools and asks, "are we alone?"

Mystery Most Profound: Are We Alone? Yet the scientific frontier still holds many secrets, of which perhaps most profound for our species is: can we causally relate the Big Bang to the emergence of RNA and DNA? Can we tell the story of how life emerged, and whether that event was unique?

Today, we suspect that habitable environments may exist in many places within our own Solar System. And within our own galaxy alone, there are more than 200 billion stars with at least 100 billion planets. Yet we still have no way to calculate the probability whether life would emerge on all those worlds and their countless moons, or only one (ours). When the eminent evolutionary biologist E.O. Wilson was asked at a public lecture in 2012 what was "the most important experiment in evolutionary biology," he replied, "the search for extraterrestrial life." [2]

Plurality of Worlds and Plurality of Sciences. By 2050, the search to determine if we are alone within our Universe must take us to the surface of Mars and to the salty ocean under the icy crust of Jupiter's moon Europa. *In situ* explorations of Saturn's moon Titan will offer a glimpse of how the early pre-biotic Earth may have looked: what lurks in its hydrocarbon seas, fed by its methanological weather cycle?

To be comprehensive, our quest for life elsewhere must also include Saturn's moon Enceladus. We must explore Neptune's active moon Triton, the fresh ice floes on the distant double-planet Pluto-Charon, the salty spires on Ceres, and many other places in our Solar System. These explorations are the purview of NASA's Planetary Science Division.

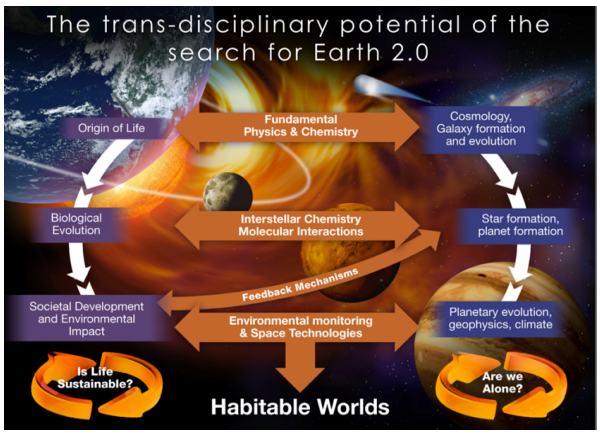
The search for life requires, as well, deep understanding of the influence of our star, the Sun, on our climate and on living ecosystems within our Solar System. It will require the careful assessment of the activity of our Sun and its impact not only now, but on the nascent Earth and other potentially habitable environments. This expertise is found in NASA's Heliophysics Division.

Our search for life elsewhere drives us to the remote sensing of planets around other stars. Just as we study our Sun to learn the story of life here, we will need to carefully assess the affects on habitability of other stellar classes. We must also assess Sun-like stars at other stages of life to assess the impact on the formation and evolution of our habitable environment. Evermore sophisticated telescopes and techniques will permit us to directly detect and evaluate the atmospheres and envi-

ronments on planets around other stars. This is the realm of NASA's Astrophysics Division.

Cross-Disciplinary Science is Key to Success. As we see, a true search for life elsewhere requires a multi-dimensional space where scientists, technologists, engineers, entrepreneurs and educators will jointly collaborate, explore, and innovate.

Such multi-dimensional exploration is the hallmark of the modern scientific endeavor, whether the effort to combat cancer, or the revolution sought by the Brain Initiative, or the creation of a societal response to climate change.



While this "search for life" endeavor provides a unifying theme across the NASA Science Division, we must acknowledge that this grand challenge is not limited to NASA. True expertise in the fundamentals of life lies in the arenas of biology, biophysics, fundamental chemistry, geodynamics, planetary physics, and many more fields.

The search for life beyond Earth links the central efforts of a manifold of Federal investments in science, including NASA, NSF, NOAA, USGS, DOE Office of Science, and NIH.

This is what a great society can do: we can craft common quests that propel us forward on the path across the endless frontier of science, including the great challenge of the search for life beyond Earth.

Finding life elsewhere defines a frontier that can only be traversed with sophisticated inquiry and unique observations. It requires an investment that only our federal government, in partnership with the international community, can plausibly make. It requires all facets of the NASA portfolio, from science to launch vehicles, to human spaceflight.

Summary. To return to where we started, with Vannevar Bush: "It has been basic United States policy that Government should foster the opening of new frontiers. It opened the seas to clipper ships and furnished land for pioneers. Although these frontiers have more or less disappeared, the frontier of science remains. It is in keeping with the American tradition - one which has made the United States great - that new frontiers shall be made accessible for development by all American citizens."

The search for life beyond the confines of Earth defines a frontier that our generation—for the first time in human history—can cross.

References: [1] Bush, V. (1945). https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm. [2] Wilson, E. O. (2012), question and answer period of "On the Shoulders of Giants: A special address by Edward O. Wilson," Saturday, June 2, 2012 NYU Global Center, New York, NY. *This abstract has been adapted from an earlier white paper entitled "The United States at the Frontier of Science: A Tipping Point in Human History" by J. M. Grunsfeld, H. B. Hammel, and M. Mountain.*